SERA
Seismology and Earthquake Engineering
Research Infrastructure Alliance for Europe

Deliverable

D9.1 - Technical report on SERA Transnational Access activities TA1-TA10 M24

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Summary

The SERA project, funded by the European Union within the Horizon 2020 Research and Innovation programme under grant agreement No.730900, involved in the Transnational Access (TA) activities at this stage 44 User Groups composed by 261 EU and extra-EU talented researchers out of more than 500 of them involved in the calls for proposals.

TA Users are integrated in the scheduling of the Research Infrastructure (RI) during the execution programme of each project, from the design and construction of the specimen, to instrumentation, experimental testing and interpretation of the experimental results, receiving from the staff of the RI all the support needed to carry out their project. A support team is allocated to each user on a daily basis, to develop and execute the test programme, including appropriate technicians for test model fabrication, instrumentation, etc. The infrastructure facilities are well prepared for hosting external researchers who, during their stay, are integrated with the permanent staff, from whom they receive technical and scientific assistance. After receiving the necessary training, users are able to fully participate in the test preparation, execution, data acquisition and results interpretation.

Figure 1: SLABSTRESS project @JRC Research Infrastructure

Figure 2: SERA-SILOS project @EUCENTRE Research Infrastructure

The 1st year of SERA, as reported last year in the previous report, has been characterized by several activities related to the Transnational Access (TA) framework, such as the implementation of the web portal for the proposal management, the definition, publication and advertising of 2 calls for proposals, the nomination of the TA Selection and Evaluation Panel (TA-SEP). A tight schedule was imposed both to the Research Infrastructures (RIs) and to the first born User Groups in order to have a sustainable activities calendar in the next phases of SERA TA. All projects within each call required, in fact, the constitution of a strong User Group, the definition and preparation of an innovative proposal, the evaluation and selection of the best projects and the real campaign implementation. The evaluation criteria considered to select the best proposals are listed here:

- Fundamental Scientific and Technical value and interest
- Originality and innovation
- Quality of proposing team
- Importance for public safety
- Importance for European standardisation
- Importance for European integration and cohesion
- Importance for sustainable growth
- Importance for European competitiveness
- Importance and relevance to TA facility's own scientific interest
- Synergies and complementarities with other TA tests
- Previous use of TA facility by any in the user team
- Cost and feasibility according to TA facility
- Availability of similar infrastructures in any of the users' countries

SERA TA FACILITIES
• ELSA Reaction Wall, JRC, Ispra (IT)
• Shake Lab Bearing Tester and Shake Table, EUCENTRE, Pavia (IT)
• AZALEE Shake Table TAMARIS/CEA, Paris (FR)
• LNEC-3D Shake Table LNEC, Lisbon (PT)
• STRULAB Reaction Wall, University of Patras, Patras (GR)
• EQUALS Shake Table, University of Bristol, Bristol (UK)
• DYNLAB Shake Table IZIIS, Skopje (MK)
• Centrifuge University of Cambridge, Cambridge (UK)
• EUROSEISTEST and EUROPROTEAS, Aristotle University, Thessaloniki (GR)
• Array Seismology NORSAR, Kjeller (NO)

Table 1: SERA TA Research Infrastructures

The work done in the 1st year settled strong basis for the 2nd year of SERA TA, which has been characterized by a considerable number of running and concluded projects, as highlighted in the next chapters. Moreover, a third call for proposals was activated on M17, leading to the official allocation of the TA remaining available resources (Table 2).

PROJECTS SELECTED IN THE 3rd CALL FOR PROPOSALS

Number of Project	Title of Project	Hosting Research Infrastructure
34	Seismic performance of multi-component systems in special risk industrial facilities	EUCENTRE
35	SHAking Table testing for Near Fault Effect Evaluation (SHATTENFEE)	University of Bristol
36	SSI-STEEL: Soil-Structures Interaction effects for STEEL structures	University of Bristol
37	INfills and MASonry structures protected by deformable POLyurethanes in seismic areas (INMASPOL)	IZIIS
38	Resonant metamaterial-based earthquake risk mitigation of large-scale structures and infrastructure systems: assessment of an innovative proof-of-concept via medium-size scale testing	EUROSEISTEST and EUROPROTEAS
39	“DYMOBRIS” Dynamic identification and Monitoring of scoured BRIdgeS under earthquake hazard	EUROSEISTEST and EUROPROTEAS
40	SOil Frame-Interaction Analysis through large-scale tests and advanced numerical finite element modeling (Acronym: SOFIA)	EUROSEISTEST and EUROPROTEAS

Number of Project	Title of Project	Hosting Research Infrastructure
41	Earthquake Spectral Provisions and Urban Fragility Evaluation	NORSAR
42	Beamforming of aftershock strong-motion time-histories recorded on the ICEARRAY for earthquake source studies	NORSAR
43	Investigation of (micro)seismicity of the Laptev Sea using a small-aperture array	NORSAR
44	Design, location and processing of a regional array in SW Portugal - Europe	NORSAR

Table 2: Projects selected within the 3rd call for proposals

Distribution of projects per TA facility					
Research Infrastructure	**Facility**	**Total TA Projects**	**Projects Assigned in the 1st call**	**Projects Assigned in the 2nd call**	**Projects Assigned in the 3nd call**
JRC	ELSA	2	2	0	0
EUCENTRE	SHAKE LAB	3	1	1	1
CEA	AZALEE	2	2	0	0
LNEC	LNEC-3D	3	2	1	0
University of Patras	STRULAB	3	2	1	0
University of Bristol	EQUALS	7	3	2	2
IZIIS	DYNLAB	3	1	1	1
University of Cambridge	Centrifuge	4	2	2	0
Aristotle University of Thessaloniki	Euroseistest & Europroteas	9	1	5	3
NORSAR	Array seismology	8	1	3	4
TOTAL		**44**	**17**	**16**	**11**

Table 3: Distribution of projects per TA facility

Proposals have been submitted by heterogeneous User Groups, composed by both universities and private companies often in joined applications, coming from 31 different countries. In the following graphs, the percentages of the candidate User Groups for the involved countries are shown. Data refer to all received projects, i.e. the sum of accepted, reserve and not accepted.

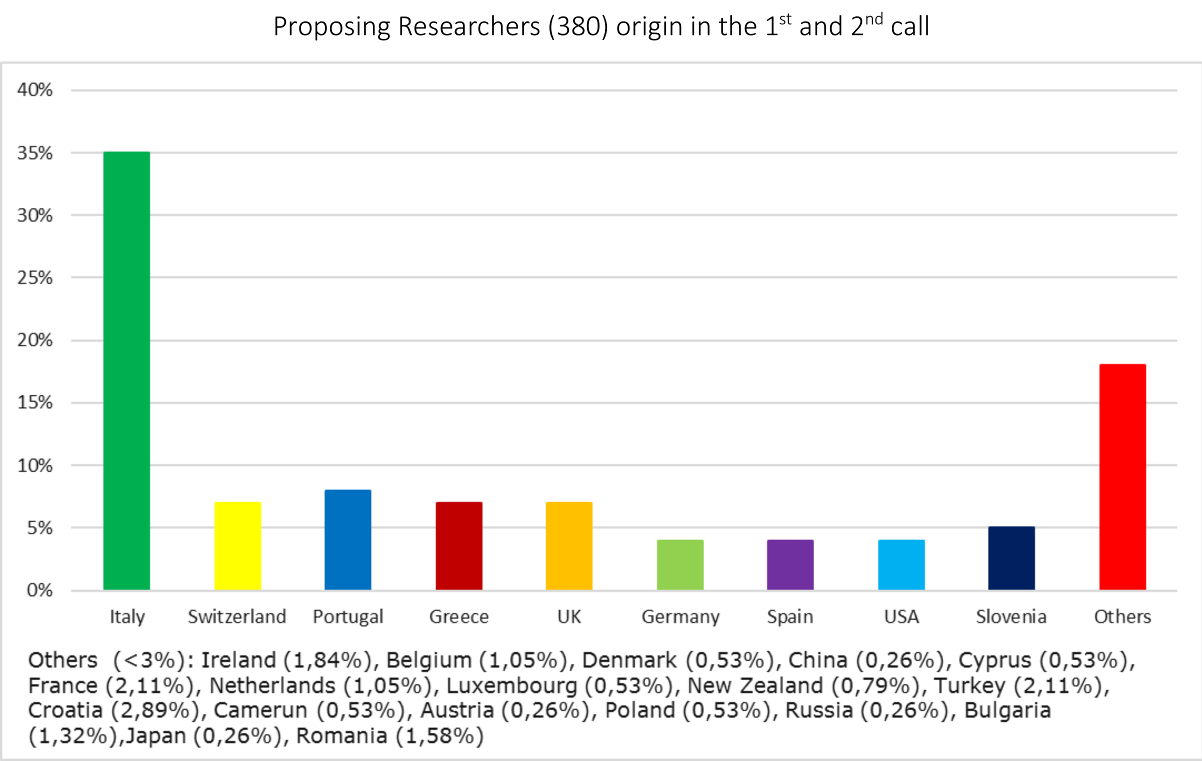


Figure 3: Proposing Researchers origin – 1st and 2nd call

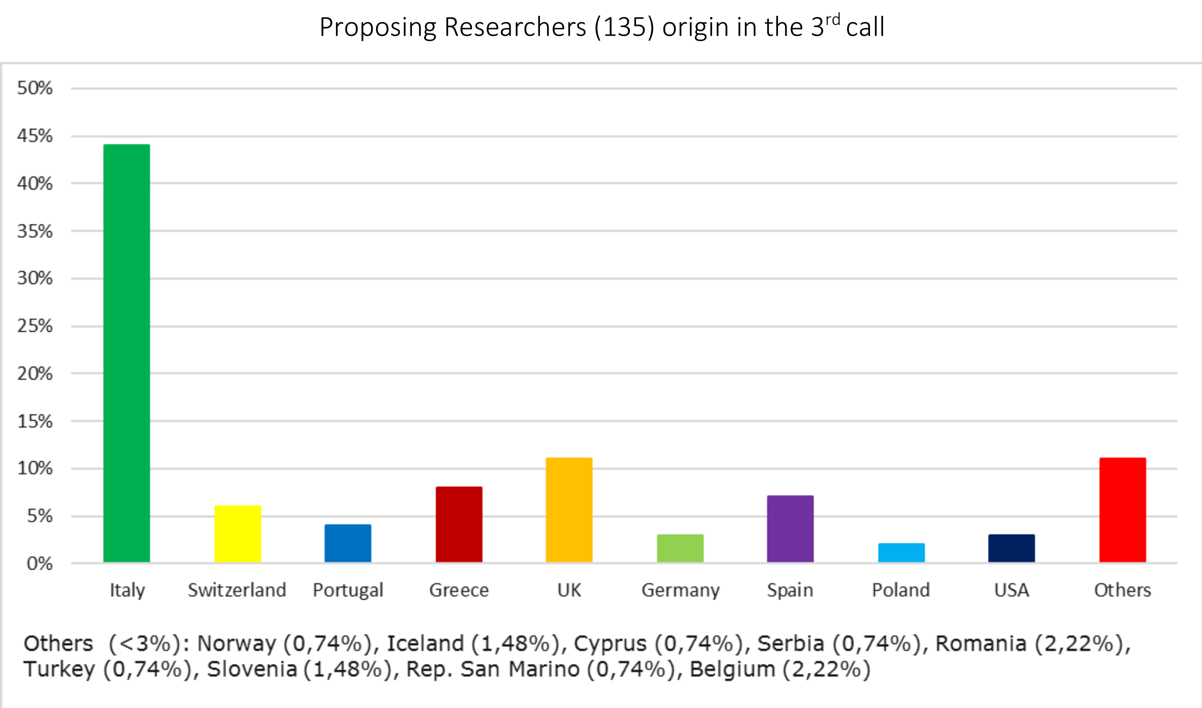


Figure 4: Proposing Researchers origin – 3rd call

In Table 4 and Table 5, all received proposals have been categorized by the testing technique meant to be used, and by type of specimen or analysis. While the testing technique is pretty related to the number of available facilities featuring a certain equipment and their foreseen access units, the type of specimen is very well balanced among 8 categories. All technologies are considered, ranging from existing structures to innovative proposed concepts, and non-structural elements too, in line with the progressively increasing attention of the last years.

TESTING TECHNIQUE

Type	1st call	2nd call	3rd call	Total
Shaking Table	15	9	9	33
Reaction Wall	12	1	0	13
Numerical Simulation	1	3	4	8
Centrifuge	2	3	0	5
Bearing Tester System	1	0	0	1
Field	1	7	3	11

Table 4: Received proposals organised by testing technique

TYPE OF SPECIMEN/ANALYSIS

Type	1st call	2nd call	3rd call	Total
Mixed	8	0	0	8
Reinforced Concrete	6	0	1	7
Steel	3	3	0	6
Masonry	5	2	1	8
Anti-Seismic Devices	2	2	2	6
Waves Propagation	3	4	6	13
Soil-Structure Interaction	2	9	3	14
Non-Structural	3	3	3	9

Table 5: Received proposals organised by type of specimen/analysis

In Table 6, the allocated and delivered access units (months for Norsar and days for the other RIs) are shown. Currently, an average of 42% among the facilities allocated resources has been already exploited. This result is considered in line with the expectation, since the actual usage of the access units is the one of the last phases of the experimental campaign process, while all preliminary steps (test and setup design, instrumentation typology and layout definition, testing protocol, specimen characterization, etc.) are not reflected in the access units.

Access Units status

Research Infrastructure	Delivered	Allocated	Total foreseen	Delivered %
JRC	0	10	10	0%
EUCENTRE	57	75	75	76%
CEA	6	47	47	13%
LNEC	9	75	75	12%
University of Patras	42	71	71	59%
University of Bristol	60	115	115	52%
IZIIS	23	65	65	35%
University of Cambridge	35	49	49	71%
Aristotle University of Thessaloniki	59	110	110	54%
NORSAR	4.23	8.2	8.2	52%

Table 6: Allocated and delivered Access Units

In the following chapters, each one of the ten SERA TA Research Infrastructures provided its contribution in the description of the awarded projects status, the ongoing and foreseen activities and the expected impact of the current research to the advances in earthquake engineering and engineering seismology fields.

1 JRC ELSA Reaction Wall

The European Laboratory for Structural Assessment (ELSA) is a research infrastructure of the European Commission's Joint Research Centre. The kernel of ELSA is the Reaction Wall. It consists of a reinforced concrete vertical wall and a horizontal floor rigidly connected together to test the vulnerability of buildings to earthquakes and other hazards. By means of computer-controlled hydraulic actuators it is possible to expose full-scale structures to loads of dynamic strong forces and control the resulting movements with high precision. The wall and the floor are designed to resist the forces, typically several MN, which are necessary to deform and seriously damage the full-scale test models of structures. The ELSA Reaction Wall is the largest facility of its kind in Europe and one of the largest in the World - only exceeded in Japan.

Following the first call for proposals, two projects were assigned: EQUFIRE (see details in section 1.1) and SLABSTRESS (see details in section 1.2). These projects cover the full availability for transnational access offered by the JRC ELSA Reaction Wall.

The work carried out until M12 of the SERA project included the provision of material for the SERA-TA website, the communication with the teams that were preparing proposals for Transnational Access to ELSA Reaction Wall, the review of the submitted proposals, the definition of the details of the EQUFIRE and SLABSTRESS projects, and the preparation of the Transnational Access User Agreements. Two meetings were held in February 2018 with the Users of the two projects. The meeting of the 2nd call SERA TA-SEP was hosted at JRC on the 21st of March 2018.

The activities carried out from M12 to M24 included the final design of the specimens for the EQUFIRE and SLABSTRESS projects, the preparation of the Transnational Access User Agreements, the definition of the testing sequence and the selection of input accelerograms, the selection of the type and location of instruments, the discussions with EQUFIRE partners about the testing method for hybrid simulation and distributed testing at JRC and BAM, the procurement, construction and transportation inside the lab of the full-scale SLABSTRESS specimen, and the preparatory work for the set up and instrumentation needed for the SLABSTRESS project.

In the period M25-M30 it is foreseen to complete the installation of the experimental setup for the SLABSTRESS project, perform tests A1 and A2, repair the floors as will be necessary, perform tests B1 and B2, and construct the specimens and install the experimental setup for the EQUFIRE project in the ELSA Reaction Wall and BAM facilities. In the period M31-36 it is foreseen to perform the tests for the EQUFIRE project.

1.1 Project #1 – EQUFIRE – [in progress]

1.1.1 Summary of the project

The research aims to investigate the experimental response of structural and non-structural components of a steel building to fire following earthquake, in view of improving existing design guidelines and future standards. In order to replicate the structural behaviour as close as possible to the actual case within a reasonable budget and to connect two different facilities by optimising the resources at disposal in terms of budget and skilled personnel, an advanced experimental testing method that integrates geographically distributed hybrid simulation for seismic and fire testing will be employed.

The test specimen is a concentrically braced frame with pinned connections (see Figure 5a). The ground floor of the frame will be tested at the JRC (cold physical substructure) and at the BAM facilities (hot physical substructure), as shown in Figure 5b. The remainder of the structure will be simulated numerically according to the finite element method and it will be kept at ambient temperature throughout the test. In particular, at the JRC the designated element will be tested against lateral seismic loading at ambient temperature, whilst it will be subjected to the fire at BAM, simulating the fire after earthquake loading.

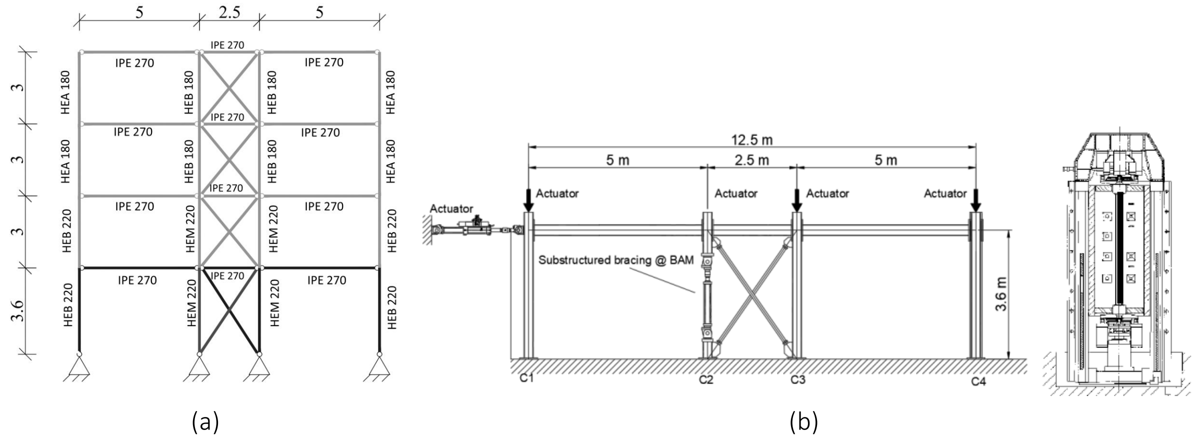


Figure 5: Dimensions of the EQUFIRE specimen (a) and setup for tests 1-4 at JRC and BAM (b)

The sequence of tests will be as follows:

- Preliminary tests to check the communication between JRC and BAM facilities.
- Test 1: structure without fire protection elements; seismic test followed by fire test.
- Test 2: structure with standard fire protection boards around one column and one brace; seismic test followed by fire test.
- Test 3: structure with 'seismic resistant' fire protection boards around one column and one brace; seismic test followed by fire test.
- Test 4: structure with sprayed vermiculite-type fire protection around one column and one brace; seismic test followed by fire test.
- Test 5: structure with fire barrier wall in one bay; seismic test only.

Fire tests will be performed on the column only.

1.1.2 Main research objectives and expected contribution to the seismology and earthquake engineering community

The objectives of the research activity are to:

- increase the knowledge on the fire following earthquake behaviour of structural and non-structural components of a concentrically braced steel frames by employing the substructuring technique: i) unprotected columns with low damage, ii) fire protection systems applied on a column with low damage, iii) fire barrier wall under seismic loading;
- provide an effective framework for hybrid fire testing geographically distributed over the internet, which enables the interoperation of facilities with different expertise (i.e. seismic and fire testing);
- analyse the reliability of existing numerical models to simulate the performance of structural (i.e., columns and braces) and non-structural elements (i.e., fire barrier walls and fire protection system) against fires ensuing the seismic event;
- establish seismic fragility functions for structural and non-structural components.

1.1.3 Project status

The project is in progress. A meeting took place at the JRC Ispra on the 4th and 5th of February 2019, where the following issues were discussed: final design of the specimen, sequence of tests, fire protection elements, instrumentation, test method, time table, establishment of software development station at BAM for controller software, network configuration for EQUFIRE experiments, communication type (socket, semaphore etc.), new necessary software.

Two industrial partners, Promat and Xella, have expressed their interest in joining the project and will offer the materials and installation of the fire protection elements that will be tested at the ELSA Reaction Wall and the BAM facilities.

1.1.4 Foreseen activities and schedule

The following time table was agreed at the meeting in February 2019.

DATE	ACTION	MAIN CONTRIBUTOR
15/03/2019	Final design of steel frame, including details for connection of actuators and secondary frame	UNITN, BAM, JRC
15/03/2019	Specifications, number (thermocouples, heating blankets, etc.) and proposed suppliers for the consumables needed at BAM	BAM
APRIL 2019	Final agreement with ETEX concerning time table for application of fire protection systems at BAM	
1/04/2019	Number and location of strain gauges and other instrumentation for the specimen at JRC	UNITN, JRC
15/04/2019	Final design of fire protection elements	ETEX, XELLA, UNITN
30/04/2019	Order consumables for BAM, including steel columns	JRC
JUNE 2019	Delivery of 5 steel columns with top and bottom plates to BAM	
15/07/19	Meeting on IT issues and communication between BAM and JRC	JRC, BAM
JULY 2019	Finish mounting of thermocouples to columns	BAM
JULY 2019	Finish application of fire protection system(s) including sprayed material to columns	ETEX at BAM
JULY 2019	Finish application of heating blankets to columns	BAM
16/09/2019	Start of preliminary tests	JRC, BAM, AU
16/09/2019	Installation of sprayed fire protection at JRC	ETEX, JRC
4/11/2019	Test 1	JRC, BAM, UNITN, AU

1.1.5 User Group

	NAME	ORGANIZATION NAME	ORGANIZATION COUNTRY
USER GROUP LEADER	Manfred Korzen	Bundesanstalt für Material-forschung und -prüfung (BAM)	Germany
ADDITIONAL USERS	Elnaz Talebi	Bundesanstalt für Material-forschung und -prüfung (BAM)	Germany
	Kai-Uwe Ziener	Bundesanstalt für Material-forschung und -prüfung (BAM)	Germany
	Sven Riemer	Bundesanstalt für Material-forschung und -prüfung (BAM)	Germany

	Nicola Tondini	University of Trento (UNITN)	Italy
	Oreste S. Bursi	University of Trento (UNITN)	Italy
	Patrick Covi	University of Trento (UNITN)	Italy
	Giuseppe Abbiati	Aarhus University (AU)	Denmark
	Božidar Stojadinović	ETH Zürich (ETH)	Switzerland
	Laurentiu Danciu	ETH Zürich (ETH)	Switzerland
	Marco Antonelli	Promat	Belgium
	Barbara Gilardi	Xella Italia S.r.l.	Italy

1.2 Project #2 – SLABSTRESS – [in progress]

1.2.1 Summary of the project

The main aim of this project is to study the seismic response of flat slab structures under combined gravity and lateral loads and to develop European seismic codes/regulations for these structures. The significance of the research is based on the lack of specific provisions in Eurocode 8 (EN 1998-1) and on the widespread and growing use of these structures in many European countries with moderate and high seismicity, following recent research and code developments.

Limited knowledge on the stiffness and non-linear deformations of these systems leads to difficulties in the design of flat slabs. On the basis of Eurocode 8, flat slabs cannot be considered to contribute to the primary system and can be designed as secondary systems that support gravity loads. In the structural analysis process, this leads to very high internal forces and moments, that do not correspond to the actual system behaviour and make member verifications and reinforcement detailing difficult and uneconomical.

The specimen is a full-scale reinforced concrete building with two reinforced concrete flat slab floors (Figure 6) that was designed according to the Italian Standard NTC08 (DM 14.01.2008). Thick concrete slabs without voids are chosen for the research, as this is the most common system in the construction industry in Europe. The seismic design was carried out for a system with primary ductile walls (q = 4) with a PGA = 2.5 m/s^2.

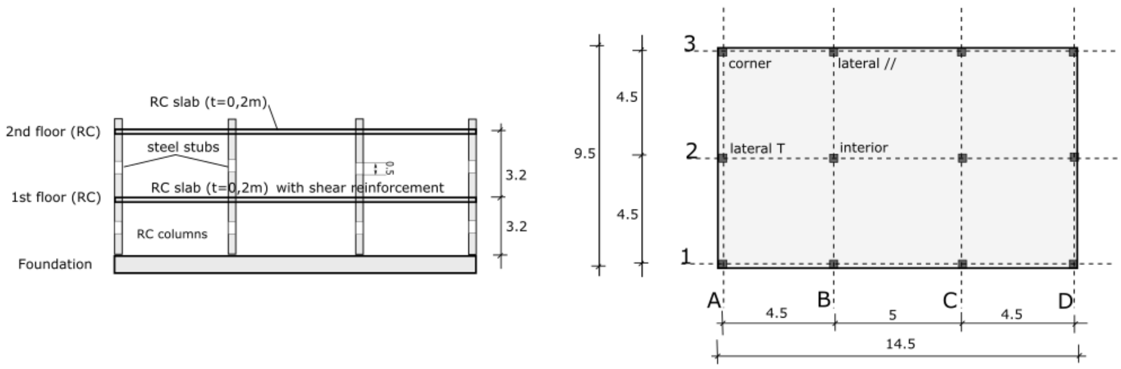


Figure 6: Side view and plan of the SLABSTRESS specimen

Hybrid tests will be carried out for the seismic loading using nonlinear sub-structuring to model the primary seismic resistant walls. Repair of the damaged connections will be carried out using post-installed transverse reinforcement, followed by a cyclic test to failure. Two groups of tests are foreseen:

- pseudo-dynamic tests with a maximum storey-drift selected in order to avoid large plastic deformations in the slab and punching of the slab-column connections at the Serviceability Limit State (test A1) and the Ultimate Limit State (test A2);
- cyclic test up to punching of the slab-column connections at the first floor (test B1) followed by repair of the slab and then a cyclic test until punching at the second floor and/or the first repaired floor (test B2).

A recorded acceleration time history will be used as input motion for tests A1 and A2. A scaling factor equal to 0.3 will be applied for test A1 to match the Serviceability Limit State design spectrum of the Italian code. A scaling factor equal to 0.87 will be applied for test A2 to match the Ultimate Limit State design spectrum of the Italian code. For tests B1 and B2 the loading scheme will follow a 2:1 ratio of imposed loads on the second and first floor.

1.2.2 Main research objectives and expected contribution to the seismology and earthquake engineering community

The use of flat slabs has been intensive in earthquake-prone European countries over the past decades, in the absence of specific design provisions. The cost-effectiveness of flat slab construction on the worksite encourages the use of this solution, and hence the development of the European codes. The European research in this field is lagging behind this design and construction activity. This research will contribute to advance the scientific and technical knowledge, giving continuity to studies developed in the past decade. The research is important both in the field of design of new buildings and for the assessment of existing buildings.

The definition of the ultimate deformation capacity of flat slab connections for given gravity shear ratios would greatly simplify the design process, possibly avoiding in some cases structural analysis and strength verifications for the deformation demand imposed by the primary system.

The testing of floors will complete the knowledge from previous experiments carried out by the proposing team on slab-column connections, giving information on the stiffness and deformation capacity of these structural systems.

1.2.3 Project status

The project is in progress. The Transnational Access User Agreement was signed on the 23rd of November 2018. Construction of the full-scale specimen was completed in December 2018 (see Figure 7a). At the time of submission of the deliverable the experimental setup (actuators, instrumentation, etc.) is being installed (see Figure 7b). The first set of tests (A1 and A2) is scheduled for June 2019. The project is scheduled to be completed with test B1 and B2 by the end of October 2019. A blind prediction competition, that will be completed after the end of the SERA project, is organised by the User Group.

(a) (b)

Figure 7: Full-scale SLABSTRESS specimen (a) and installation of experimental setup and instrumentation inside the ELSA Reaction Wall facility (b)

1.2.4 User Group

	NAME	ORGANIZATION NAME	ORGANIZATION COUNTRY
USER GROUP LEADER	Dario Coronelli	Politecnico di Milano	Italy
ADDITIONAL USERS	Aurelio Muttoni	École Polytechnique Fédérale de Lausanne	Switzerland
	Miguel Fernández Ruiz	École Polytechnique Fédérale de Lausanne	Switzerland
	João T. Simões	École Polytechnique Fédérale de Lausanne	Switzerland
	Antonio Manuel Pinho Ramos	Universidade Nova de Lisboa	Portugal
	Válter José da Guia Lúcio	Universidade Nova de Lisboa	Portugal
	Rui Pedro César Marreiros	Universidade Nova de Lisboa	Portugal
	Ion Radu Pascu	Universitatea Tehnică de Construcții, București	Romania
	Viorel Popa	Universitatea Tehnică de Construcții, București	Romania
	Eugen Lozinca	Universitatea Tehnică de Construcții, București	Romania
	Dragos-Constantin Coțofană- Jianu	Universitatea Tehnică de Construcții, București	Romania
	Luca Martinelli	Politecnico di Milano	Italy
	Patrick Bamonte	Politecnico di Milano	Italy
	Francesco Foti	Politecnico di Milano	Italy

2 EUCENTRE

Within SERA project, EUCENTRE provides transnational access to both the uniaxial high-performance shake table, featuring a 5.6m by 7m platen and PGA up to 1.8g with a 60 tons specimen, and to the 6-DOF Bearing Testing System, with force and displacement control capabilities, vertical load up to 50'000 kN, integrated with real-time dynamic hybrid testing capabilities.

In line with the expectations at the beginning of SERA project, the 2nd year of the TA activities has been particularly intense and characterized by more than a half of the total experimental activities foreseen (57 access days over 75).

From M1 to M12, the first acquired project, *Dynamic testing of variable friction seismic isolation devices and isolated systems*, was running at EUCENTRE. At M12, all preliminary phases prior testing were carried out. Such phases included:

- numerical simulations of the devices and the structure response, even trough the implementation of a novel FEM element by the User Group;
- devices and different sliding surfaces design and manufacture;
- test setup design and manufacture;
- definition of the testing phases, test conduct and potential variations possibly required based on the first characterization tests results.

The second acquired project, SERA-SILOS (SEismic Response of Actual steel SILOS) was assigned to EUCENTRE by the TA-SEP few weeks before the submission of the previous TA activities report, therefore it was not started yet.

From M13 to M24, the 3rd call for proposals was announced; on M20, the TA-SEP assigned to EUCENTRE the 3rd and last foreseen project *Seismic Performance of multi-component systems in special risk Industrial Facilities (SPIF)*. A preliminary online meeting has been already held to start planning the upcoming activities. Since this project is at very early stage, a detailed description will be included in the next TA report at M36.

Between M13 and M24, the experimental activities of the first two projects have been entirely carried out. Project #1 - *Dynamic testing of variable friction seismic isolation devices and isolated systems* – required some iterations and modifications to the initial plan to achieve satisfactory results on the isolation device prototype; the hybrid testing technique resulted very effective to maximize the trials and testing possibilities, leading to a perfectly successful testing campaign, as better described in § 2.1. Project #2 - *SERA-SILOS (SEismic Response of Actual steel SILOS)* – preliminary activities started at the very beginning of the 2nd year, and resulted in an excellent collaboration between EUCENTRE, the User Group and the external services supplier involved in the testing campaign. After the numerical simulation and test design phases, more than 200 shake table tests with random, earthquakes, sine and impulse signals have been performed both on fixed and base isolated Silo configurations.

The foreseen activities from M25 to M36 are basically related to both preliminary and main testing phases of Project #3 - *Seismic Performance of multi-component systems in special risk Industrial Facilities (SPIF)*. In addition, the data-processing, results interpretation and publication production will continue in cooperation between EUCENTRE and the User Groups of Project #1 and #2.

2.1 Project #1 – Dynamic testing of variable friction seismic isolation devices and isolated systems – [concluded]

2.1.1 Summary of the project

Seismic isolation is the prominent seismic protection technology for buildings, bridges and generally different kind of structures. It aims to significantly, or in many cases totally, reducing structural/non-structural seismic vulnerability under severe earthquake ground motions. Seismic isolation is implemented with isolation devices of two basic types: rubber bearings with lead core, and friction pendulum devices. Steel-based friction pendulum devices are gaining increasing popularity over rubber isolators and are being widely used in several applications worldwide. This is mainly due to the versatility in design and production, and their easier implementation in practice. The variability of the seismic demand is much less in friction pendulum devices. Moreover, torsional eccentricity imposed by the distribution of friction pendulum devices along the isolation interface is less significant compared to the rubber devices, hence their re-centering capacity is higher.

The main focus of the proposed project is to improve friction pendulum isolation devices by imposing variable friction properties along the sliding surfaces. Although there are several theoretical studies in literature on the theory and analysis of variable friction devices, there is no developed technology yet. The variable friction devices that will be developed within the scope of the proposed project will be designed and produced by the industrial partner TIS. The validation of the proposed concept will be performed trough characterization tests following an EN15129-like type testing protocol, then moving to seismic tests once satisfactory preliminary results are obtained. The dynamic response of the isolated system under uniaxial seismic excitation will be observed. An improved definition of ground motion intensity measures (IMs) will be developed, particularly in near-fault conditions, as well as the corresponding hazard-compatible record selection procedures for friction based isolation devices. Finally, non-linear numerical models will be implemented and calibrated through the experimental data for predicting the isolator and system response accurately, and then, based on a larger analytical study (i.e., simulation-based) propose design procedures for structures isolated with variable friction devices.

2.1.2 Main research objectives and expected contribution to the seismology and earthquake engineering community

The main objectives of the proposed research are:

- To develop variable friction seismic isolation devices;
- Conduct dynamic verification tests in a certified and qualified laboratory equipped with real-time seismic testing facilities;
- Develop analytical procedures for response prediction, and calibrate analytical models with the test results;
- Propose design procedures for buildings isolated with variable friction pendulum devices;
- Improve the definition of ground motion intensity measures (IMs) and corresponding hazard-compatible record selection procedures for friction based-isolated structures, with reference to design procedures, and assessment of displacement demand and expected residual displacement.

The industrial partner TIS, which is producing friction pendulum devices in Ankara, Turkey, recently worked on the development of variable friction devices in its R&D department by applying several treatment techniques on the stainless steel friction surfaces of friction pendulum isolators. Two different friction coefficients have been obtained by applying two different polishing techniques on the stainless steel sliding surfaces of the friction pendulum isolators. The friction coefficients obtained between the treated surfaces and the PTFE based friction material used by TIS are 4.5-5% with advanced polishing, and 6.5-7% with ordinary polishing, under a common vertical pressure of 45 MPa.

Milano Polytechnic and TIS worked on the development of a new material with lower friction properties. Possible application of this material to the variable friction device is meant to be investigated in the project to obtain another set of variable friction surfaces.

Variable friction surfaces will be implemented on the curved circular stainless steel sheets in concentric circular bands, from lowest friction at the centre to the highest at the periphery. Once the variable friction pendulum devices are designed for a selected superstructure weight, vibration period and design displacement, they will be produced by TIS at their factory in Ankara, and four devices will be shipped to EUCENTRE for seismic verification testing. The first set of tests on the new devices will be conducted on the Bearing Tester System (test press) by applying the EN 15129 testing protocol for friction pendulum prototypes. These tests will reveal the cyclic force-displacement characteristics and their stability under axisymmetric displacement reversals. Then, the devices will be subjected to real seismic tests within a simple structural context; a 1-storey isolated building will be considered.

A typical prototype device that will be tested at the EUCENTRE Lab Bearing Tester is shown in Figure 8

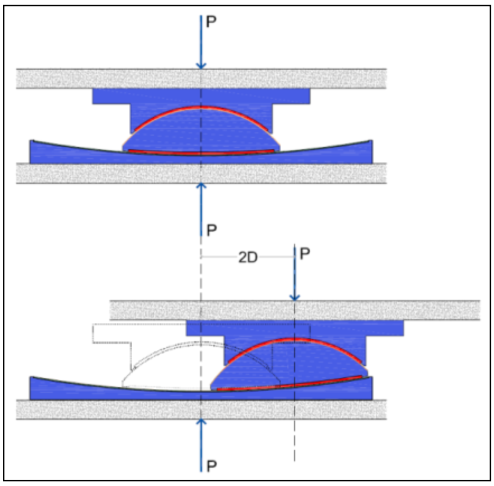


Figure 8: Prototype isolator

Upon completion of the experimental testing program, analytical models for the force-displacement behaviour of variable friction devices under imposed displacement reversals that mimic seismic excitation will be refined. Seismic isolation device with more favourable characteristics compared to the existing friction pendulum devices with uniform friction. Variable friction requires less curvature, hence larger radius of curvature for equivalent energy dissipation, and lower restoring force compared to the uniform friction device. This results in smaller devices for the same design displacement. Related savings in material leads to reduced cost of devices, which is essential for their wide spread public use in earthquake protection. Lower curvature also reduces the vertical accelerations resulting from pendulum motion. A low friction coefficient at the centre during activation of the isolation mode is a further advantage for reducing floor accelerations of the superstructure which is critical for protecting acceleration sensitive equipment. The only expected problem can be a reduced recentering capability due to higher friction and lower curvature of the sliding surface. An extensive analytical study will be carried out to investigate the effect of residual displacements at the end of the ground excitation.

The present research is expected to give a significant contribution to the seismology and earthquake engineering community. Modern earthquake engineering is a fairly young field of engineering science, not older than 80 years. The advances in engineering seismology and structural analysis methods had been remarkable during these decades which eventually lead to the development of modern earthquake resistant design procedures and the associated seismic design codes. Despite such significant progress, the ultimate performance objective of “no damage to structures under strong earthquakes” had never been achieved. This is indeed impossible with the conventional construction materials and techniques due to their limited capacities which are easily exceeded by the excessive demands produced by strong earthquakes. The only possibility for meeting this fundamental objective is introducing new technologies to earthquake resistant construction.

Seismic isolation is the only successful technology so far. Although it was developed almost 40 years ago, its implementation in practice had been very limited. One of the basic reasons for its limited use is the high cost of isolation devices. The basic motivation, originality and innovation of the proposed project comes from introducing variable friction to sliding surfaces of friction pendulum devices for developing smaller, hence cheaper devices for obtaining equivalent seismic performance. Variable friction is a simple idea, but not so easy to realize. It has not been developed and produced before, hence it is original. Analytical solution of isolator response with variable friction applied to a single pendulum device is available, but it is not yet available for double pendulum devices. It will be investigated how variable friction with circular bands can be formulated in a double pendulum device. Once a stable, symmetrical response is obtained, then the concept will be extended to double pendulum devices for further testing. Whether implemented to single or double pendulum devices, the proposed research is both original and innovative because this technology has not been developed before and produced as a new product by anybody else.

Imposing variable friction along the sliding surfaces does not add to the cost of devices, but increases the effectiveness of isolators significantly. The User Group will conduct a comprehensive cost-benefit analysis for variable friction devices in comparison to the uniform friction pendulum devices for proving their economic feasibility in earthquake protection. Broader impact of a new technology or invention can be proved if it can be easily used in practice. This depends on the robustness of its response, and the market price. The aim of the proposed research is to show that it is possible to obtain the desired robustness of seismic response and a significantly cheaper product can be obtained when variable friction is implemented. Lower curvature will reduce the steel waste remarkably, and higher restoring force will reduce the device radius due to lower displacement demand. The result of the combined benefit is a smaller isolation device with a reduced cost.

2.1.3 Project status

In a preliminary phase, small scale tests have been conducted to experimentally assess the effectiveness of the proposed concept. The research group has been investigating variable friction surfaces on a small scale model of a flat bearing, using a custom biaxial testing system.
The test piece consists of a flat pad of sliding material (diameter 50 mm) rubbing on a stainless steel sheet. The surface of the stainless steel sheet exhibits two areas with different roughness: a “smooth” area with Ra = 0,02 – 0,04 µm, and a “rough” area with Ra = 6 – 10 µm (Figure 9).

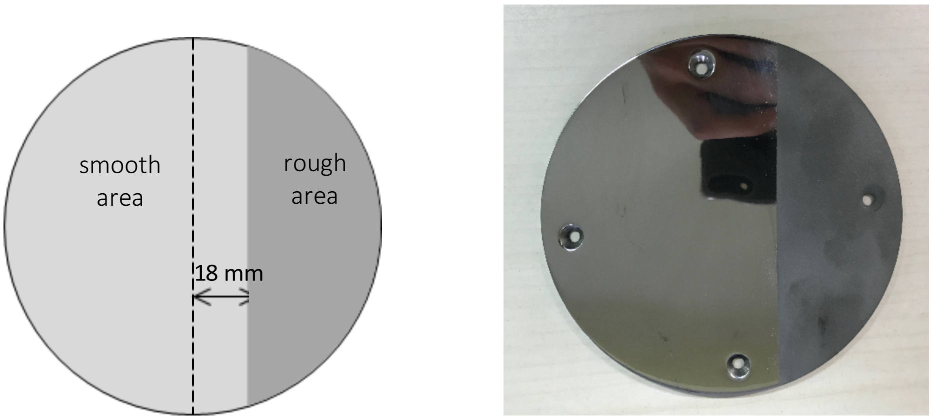


Figure 9: Dimensions of the test sample (left) and picture of the stainless steel plate (right).

Tests were performed at two levels of contact pressure on the pad surface, namely 22.5 MPa and 45 MPa. Each test consisted of 100 fully reversed cycles with total amplitude (peak-to-peak) of 30 mm at three different velocities: 1 mm/s, 50 mm/s and 100 mm/s.

Typical results are illustrated in Figure 10, in terms of ratio of horizontal to vertical force (i.e. the coefficient of friction versus displacement plots at two velocities. Only results at 22.5 MPa contact pressure are shown, but consistent results were obtained at either pressure level.

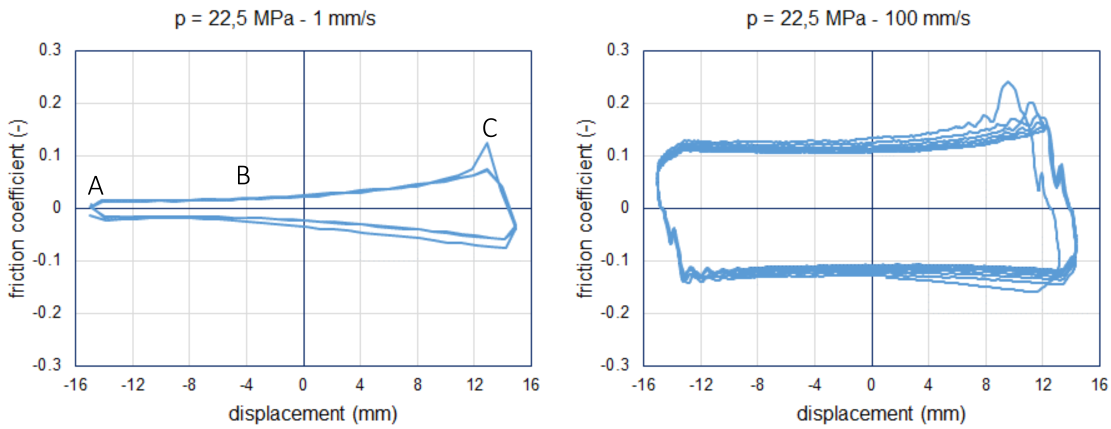


Figure 10: Friction – displacement plots at different velocities.

The test at very low velocity (1 mm/s) shows the expected behaviour of the variable friction bearing, with a steady and low coefficient of friction as far as the pad slides on the smooth surface (branch OA), and a stiffening response as the pad crosses the rough surface (branch AB). Depending on the pad position, the coefficient of friction increases from a minimum value of 1.3% to a maximum value of 12.5% at the first cycle and 7.4% at the subsequent cycles (six-folds increase).

By increasing the velocity, the change of the coefficient of friction with surface roughness is less pronounced, though still important: at 100 mm/s the coefficient of friction ranges from 12% to 23.8% at the first cycle and 22% at the subsequent cycles (two-folds increase). This behaviour is ascribed to the effect of heating of the sliding pad, which produces a most important decrease in the coefficient of friction over the rough area, where friction is higher, than over the smooth area. It is also worth noting that good stability of the friction plots over the duration of the test, corresponding to an accumulated slide path of 6000 mm.

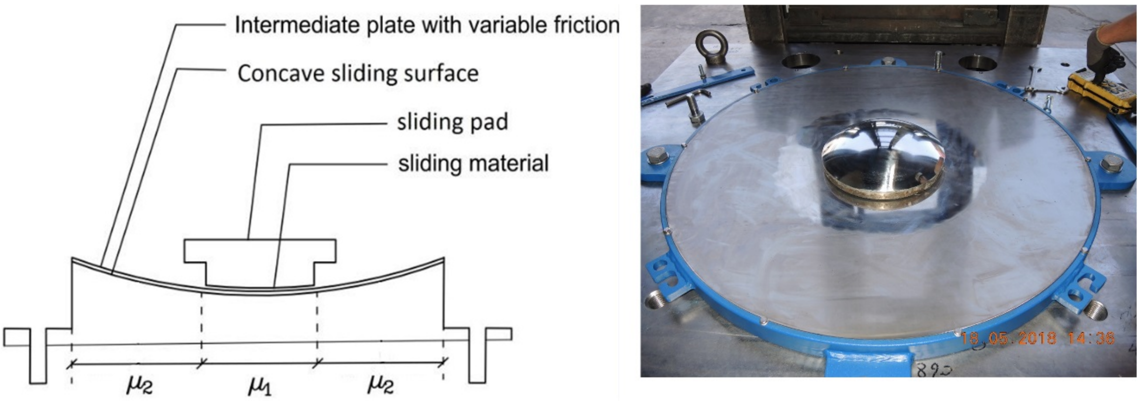
In conclusion, the small scale tests have provided an independent confirmation of the feasibility of manufacturing variable friction sliding bearings with stable and consistent behaviour even during sustained motion; further they have addressed to need of sliding material with a good stability of the coefficient of friction with temperature.

Afterwards, full-scale experiments were conducted on a total of six Single Variable Friction System (VFS) and two Double Curvature VFS prototypes at the experimental facilities of using the Bearing Tester System (BTS) shown in Figure 11.

Each prototype bearing of the first category consisted of a conventional single friction pendulum system with rigid slider, but the concave stainless steel sliding surface was treated using different polishing techniques to achieve spatially varying frictional properties. Namely, three areas (in some specimens only two), with different roughness were obtained: starting from the centre of the device, a low friction "polished" surface, a medium friction "unpolished" one, and a high friction "sandblasted" region. A schematic drawing and a plan view of one of the full-scale prototype VFS bearing with polished and unpolished treatment are shown in Figure 12.

(a) (b)

Figure 11: (a) The EUCENTRE BTS; (b) Elevation view of the bearing test setup.



(a) (b)

Figure 12: (a) Schematic drawing of a two-ring VFS bearing; (b) Plan view of the concave sliding surface and the slider of the prototype VFS bearing.

The main properties of one of the tested VFS prototypes are summarized in Table 7. The parameters reported in the table represent the radius of the sliding pad (r0), the radius of the low friction area (r1), the external radius of the medium friction area (r2), the coefficient of friction between the sliding pad and the low friction area (μ1), the coefficient of friction between the sliding pad and the medium friction area (μ2), and the radius of curvature of the sliding surface (R).

Prototype #	r_0 (m)	r_1 (m)	r_2 (m)	μ_1 (%)	μ_2 (%)	R
1	0.125	0.150	0.450	7.0	9.2	4.5

Table 7: Properties of one of the tested VFS prototypes

The dynamic coefficients of friction between the sliding pad and the sliding surface were equal to 7.0% and 9.2% for the smooth and the rough areas, respectively. These values have been obtained through friction characterization tests performed in the laboratory.
Following the friction characterization tests, the VFS prototypes were subjected to the testing program recommended by the European standard EN 15129. The program comprised a series of unidirectional harmonic displacement histories, with different displacement amplitudes and frequencies. A list of the tests conducted is summarized in Table 2. For brevity, only some of the main results are presented herein. For the presented tests, the displacement amplitude of the harmonic motion was 0.3 m, and the peak velocities were 500 mm/sec and 200 mm/sec.

Test name	Ampl. [m]	Max.vel. [m/s]	load shape	Vert.load [kN]	cycles
Frictional resistance	±0.006	0.0001	triangle	2000	1
Service	±0.060	0.005	sine	2000	20
Benchmark	±0.300	0.050	sine	2000	3
Dynamic 1	±0.075	0.500	sine	2000	3
Dynamic 2	±0.150	0.500	sine	2000	3
Dynamic 3	±0.300	0.500	sine	2000	3
Seismic	±0.300	0.500	sine	1000	3
Seismic	±0.300	0.500	sine	2500	3
Bidirectional	±0.300	0.500	sine	2000	3
Property verification	±0.300	0.500	sine	2000	3

Table 8: Testing program on Group 1 VFS prototypes

Both single and double VFS devices were then subjected to hybrid tests, simulating the response of a base isolated single-story structure. The stiffness of the superstructure (treated as a linear-elastic single-degree of freedom system) was selected to achieve different natural periods of vibration ranging from 0.4 to 1 second. The tests were performed under the application of recorded ground motions with different intensities. The peak velocity recorded during these tests reported was approximately 1 m/sec.

The horizontal force-displacement response characterizing the VFS prototypes is reported in Figure 13. The black lines represent the first-cycle response, while the grey lines refer to the second and third loading cycles. It can be seen that the first-cycle response differs quite significantly from that of the subsequent cycles. In particular, the effects of the variable friction are clearly visible in the first cycle, but they tend to disappear in later loops. This undesirable discrepancy was ascribed to the creation of a transfer film of the sliding material on the mating surface, which smoothed the surface and made the sliding behaviour more uniform over the two areas with different roughness. At the current stage, this still represents a major challenge and one of the main constraints limiting the possible frictional properties that can be selected for a VFS. Additionally, µ1 and µ2 are only marginally different in their initial values, thus the variability of the friction coefficient is low.

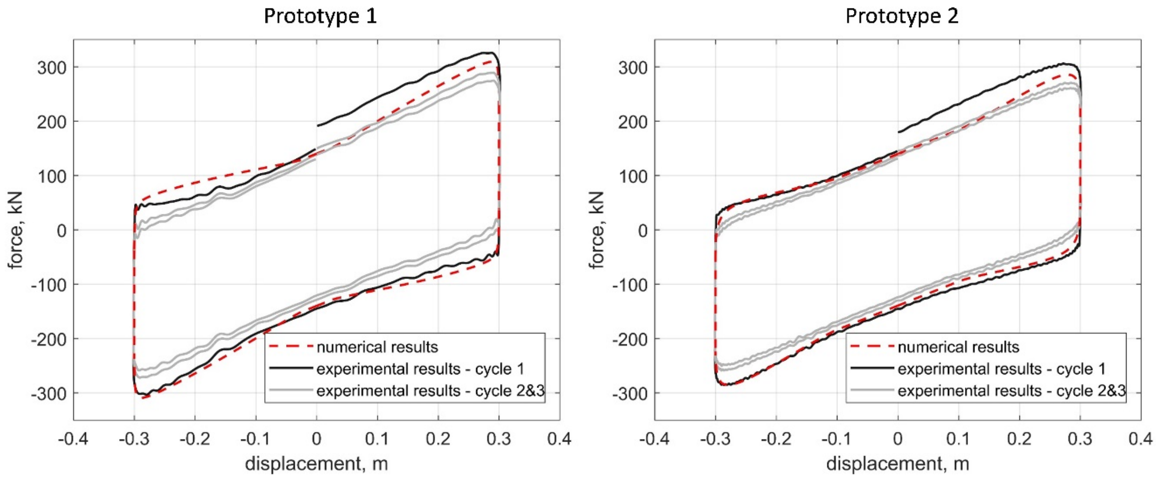


Figure 13: Comparison between the hysteretic curves from numerical model and experimental data for Group 1 VFS prototypes

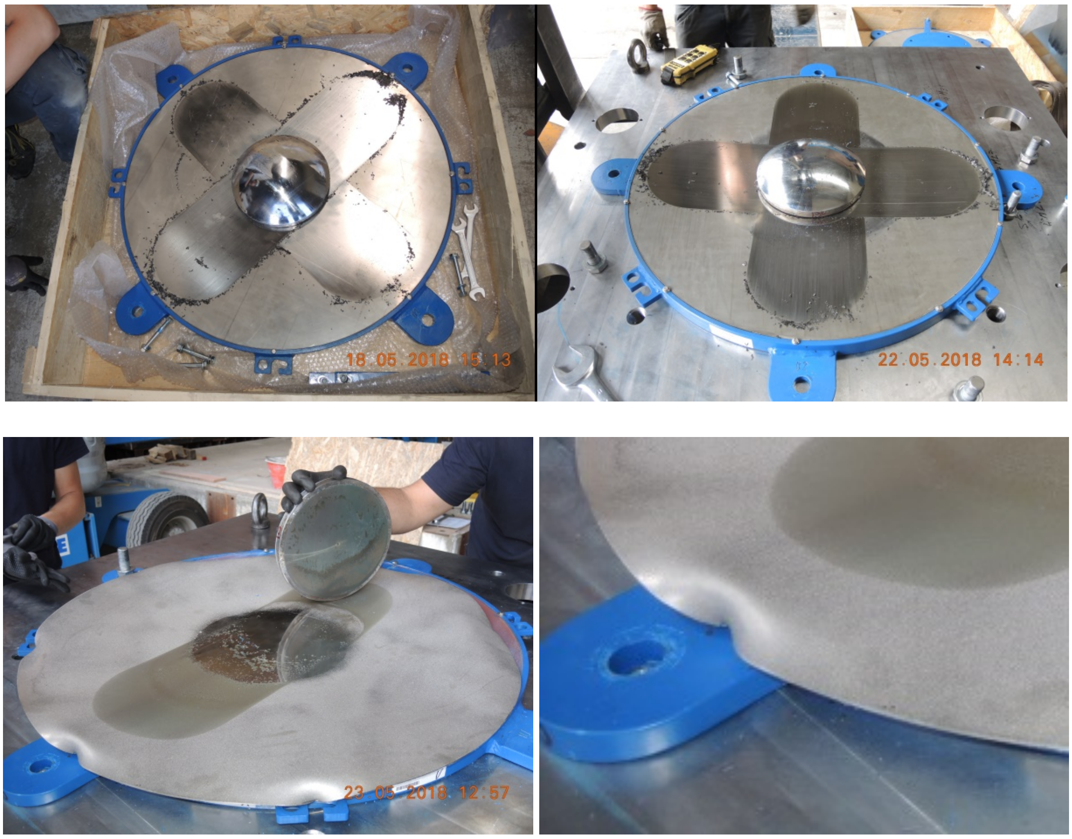


Figure 14: Test of VSP and failure of the high friction sliding surface

Since in the first specimens the transition between the regions with different friction was not that evident and further reduced in the subsequent cycles, a sliding surface with the lowest and highest friction was considered as well. This abrupt response modification gave some interesting preliminary results, while resulted in the failure of the specimen due to the loss of bonding of the surface with the bottom steel plate (Figure 14).

The undesired response obtained led the research team to opt reconsider the original plan, which involved shake table testing of a one-storey case-study structure, and opt for hybrid simulation (also referred as hybrid testing) to maximize the testing days and the different devices possible configurations (single and double CSS, different sliding materials, different sliding surface treatments). The hybrid testing technique consists in combining a numerical model of a portion of the structure to be tested, together with a physical portion, generally the one(s) difficult to model and/or under experimental investigation. These two systems interact with each other in real-time, in order to represent the experimental test of the whole structural system. In this case, the physical system was the isolation device prototype, while the numerical system was a 2-DOF structure, identical of the one initially foreseen (R,C. slab on the isolation system and a 1-storey frame structure on top of it). The whole system was subjected to real ground motions as the input of the hybrid testing. Since the physical devices have been tested on the Bearing Tester instead of the shake table, bigger and realistic slider dimensions have been considered (Figure 15).

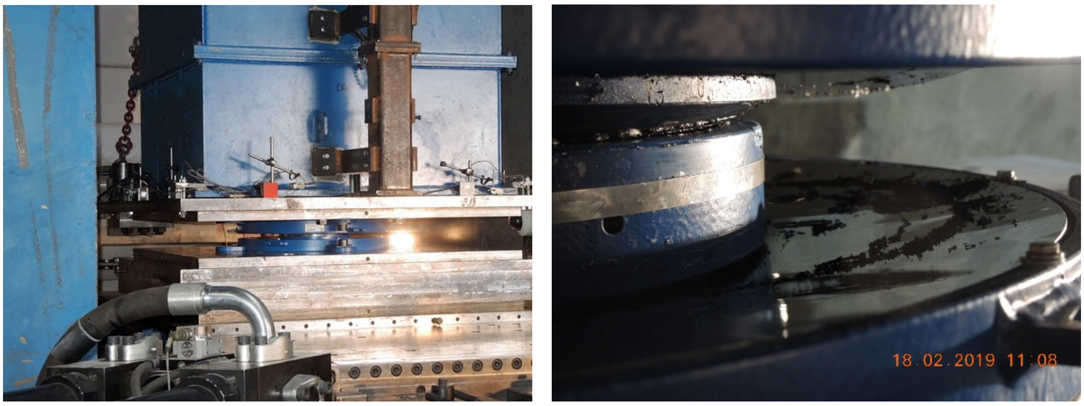


Figure 15: Test on the EUCENTRE Bearing Tester trough hybrid testing technique

The horizontal force-displacement responses characterizing the VFS prototype undergoing a realistic ground motion in the context of hybrid testing is shown in Figure 16. The black dashed lines represent the experimental results, while the grey solid lines represent the numerical predictions, obtained using the newly developed model described later.

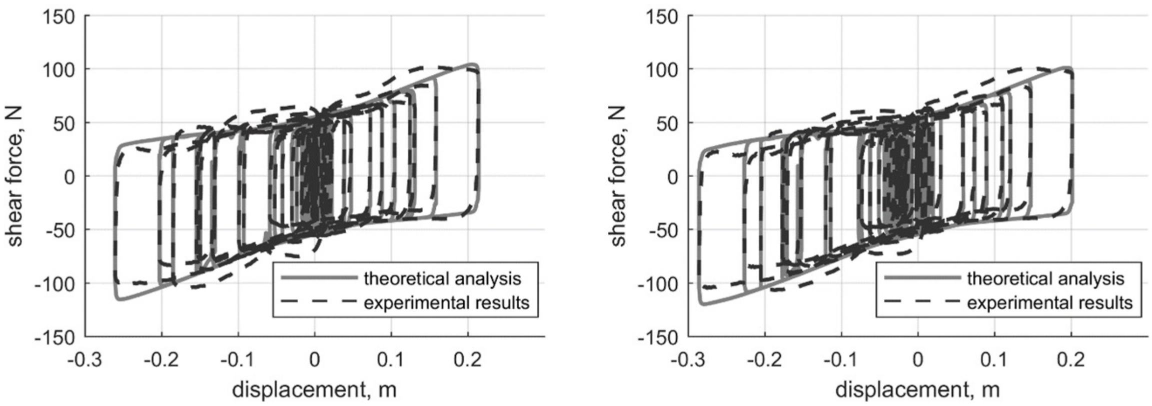


Figure 16: Comparison between the hysteretic curves from numerical model and experimental data for Group 2 VFS prototype.

The research activities related on numerical aspects can be summarized as follows:

1. Development of a 3D numerical model to simulate the response of VFS in the context of non-linear static and dynamic analysis (Figure 17);
2. Implementation of the 3D VFS model into OpenSees;
3. Partial processing of the experimental results and preliminary validation of the developed numerical model, using the results of the available experiments;
4. Development of a Direct Displacement-Based Design procedure for structures isolated via VFS;

5. Validation of the proposed design method via extensive parametric study conducted on Single- and Multi-degree of freedom (SDOF and MDOF) (involving > 1,000,000 non-linear time history analysis);
6. VFS performance evaluation via extensive parametric study conducted on Single- and Multi-degree of freedom (involving > 1,000,000 non-linear time history analysis);
7. Ongoing processing of the experimental results.

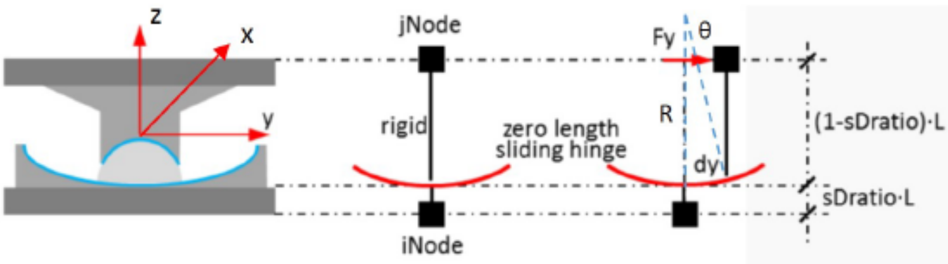


Figure 17: Schematic drawing of the Variable Friction Pendulum element in OpenSees.

Some of the key results of the analyses are illustrated in Figure 18. Performance comparisons between VFSs with different β values are provided in terms of maximum base shear, maximum displacement, and normalized residual displacement (with respect to the maximum displacement).

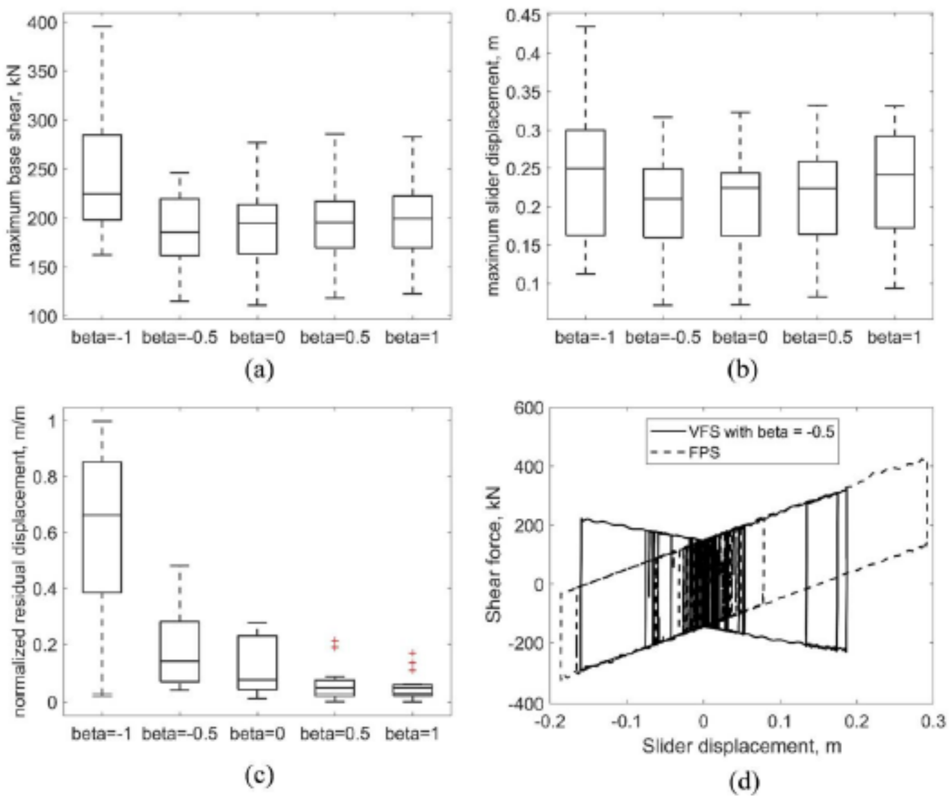


Figure 18: (a) Maximum base shear comparison; (b) maximum displacement comparison; (c) normalized residual displacement comparison; (d) example hysteresis.

The test results of the DCSS devices are still being processed, therefore the detailed results will be reported in the next TA activity report. For sake of completeness, some of the experimental results are reported hereafter.

In Figure 19, the VF-DCSS force and displacement response in hybrid test # HT8_116 (PGA = 2g) is shown. The increase of friction and simultaneous curved surface radius reduction can be clearly appreciated for relative displacements higher than 190 mm.

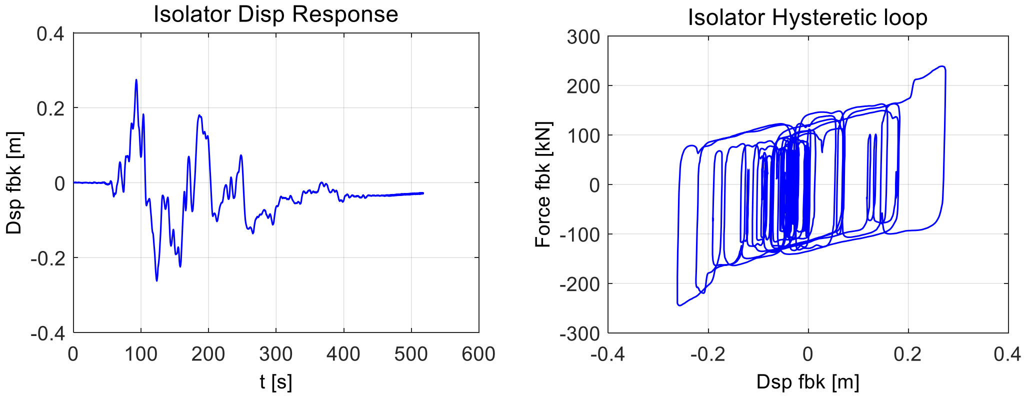


Figure 19: Variable-friction DCSS response in test HT8_116, PGA = 2g

While the concept is the same of the VFP, the achievement is done differently and the stability of the response turned out to be significantly higher. For these reasons, notwithstanding the higher complexity of the system, the last part of the experimental campaign was focused on the latter technology. A detailed analysis of the related results is being currently carried out and will be reported in the next TA activity report.

2.1.4 Foreseen activities and schedule

The experimental activities of this project have been successfully concluded delivering just 2 access days more than what initially foreseen. A considerable amount of testing has been carried out, such as 8 standard EN15129-like characterization protocols, and more than 100 seismic tests, taking advantage of the hybrid testing technique.

The User Group is currently working on the data processing and results interpretation of such amount of recorded data with the support of EUCENTRE. Publications and dissemination of the results will take place in the next months, as foreseen by the SERA project.

2.1.5 User Group

	NAME	ORGANIZATION NAME	ORGANIZATION COUNTRY
USER GROUP LEADER	Haluk Sucuoğlu	Middle East Technical University	Turkey
ADDITIONAL USERS	Uğurcan Özçamur	TİS Technological Isolation Systems	Turkey
	Carmine Galasso	University College London	UK
	Paolo M. Calvi	University of Washington	USA
	Virginio Quaglini	Politecnico di Milano	Italy

2.2 Project #2 – SEismic Response of Actual steel SILOS (SERA-SILOS) – [concluded]

2.2.1 Summary of the project

This research project aims at performing a series of shaking-table tests on a full-scale flat-bottom manufactured steel silo filled with a granular material to investigate the actions caused by the granular solid onto the silo wall under earthquake input. Two different base conditions will be investigated: (1) fully restrained and (2) seismically isolated.

Current seismic design recommendations for silo structures (e.g. EN 1998-4) are based on approximate quasi-static, and often overly conservative, assumptions as a consequence of the widespread lack of experimental investigations on the seismic response of real silos. Therefore, significant advancements in the knowledge of the structural behaviour of silo structures are still necessary.

Recently, researchers of the proposing team developed an analytical model for the estimation of the maximum horizontal pressures exerted by the ensiled material to a cylindrical element under earthquake excitation. The findings indicated that, in the case of squat silos characterized by low, but usual, height/diameter aspect ratios, the portion of the grain mass that interacts with the silo walls (e.g. the effective mass) turns out to be noticeably smaller than both the total mass of the grain in the silo and the effective mass suggested by EN 1998-4 for design purposes. This analytical model has so far been validated only on shaking-table tests conducted on small-scale Plexiglas cylindrical specimens, albeit with very encouraging results.

The main objectives of the tests are: (i) the identification of the basic dynamic properties (period of vibration, damping ratio, amplification) of the grain-silo system, (ii) the experimental verification of the analytical theory proposed by Silvestri et al. in 2012 on actual silos, for possible future implementation into structural design procedures, and (iii) the assessment of the benefits obtained introducing an isolation system at the base of the silo.

2.2.2 Main research objectives and expected contribution to the seismology and earthquake engineering community

The experimental shaking-table tests aim at investigating the dynamic and seismic response of full-scale flat-bottom actual steel silos in both fixed-based and seismically-isolated conditions.

The main objectives are:

- Dynamic behaviour: the basic dynamic properties (period of vibration, damping ratio, amplification) of the particle-silo system will be obtained using white-noise and sinusoidal input. In particular, it will be checked whether they depend on the input acceleration level;
- Seismic response: the actions (overturning moment and shear force) induced by granular solid at the base of the silo wall will be obtained to verify the analytical theory proposed by Silvestri et al. in 2012;
- To evaluate the benefits of introducing a seismic isolation system at the base of the silo.

THE SPECIMEN

A full-scale flat-bottom steel silo with two different base conditions will be tested under white noise, low-frequency sinusoidal, impulse and earthquake input on the EUCENTRE shaking-table:

(1) flat-bottom silo on fixed restraints;

(2) flat-bottom silo on seismic isolators.

The tests on configuration (1) will allow the basic dynamic properties of the flat-bottom silo to be established and will act as a validation of the analytical theory in the case of an actual manufactured steel silo (composed of corrugated sidewall sheets, external vertical "hat" stiffeners and roof structure) under earthquake acceleration input.

Configuration (2) has a twofold significance: first, to investigate the effects of the isolation system on the pressures exerted by the granular solid on the silo wall, since, as is well known, the particle-silo system dynamic response is significantly changed by the isolators; second, by comparison with configuration (1), to evaluate the benefits of the introduction of a base isolation system for possible reasoning on the feasibility and cost/benefit analysis of such an unexplored solution.

EXPECTED OUTCOMES

The expected outcome is the direct availability of experimental data on the actual seismic response of a full-scale flat-bottom steel silo containing granular solids, as well as the identification of the important key parameters (wall-particle friction, inter-particle friction, acceleration level, aspect ratio, effective mass, …) governing the seismic behaviour of silos.

Also, the development of the tests with and without base isolation gives immediate information on the benefits that can be achieved with seismic isolators.

SCIENTIFIC AND TECHNICAL VALUE AND INTEREST

The scientific value of the research lies in the experimental verification of the theory developed by Silvestri et al. in 2012 with reference to a full-scale manufactured corrugated steel silo under seismic acceleration. The research will also represent the first shaking-table test conducted on a seismically-isolated silo, which is a structural solution that could open new roads in the field of seismic isolation.

From a technical point of view, the outcome could be used for possible future improvement of structural design procedures (e.g. effective mass) and to propose hand methods for a robust evaluation of the forces acting on the silo walls. More specifically, the results of the experimental campaign will shed light on the following open issue: to what extent is the effective mass prescribed by EN 1998-4 over conservative.

2.2.3 Project status

A flat-bottom cylindrical silo has been tested in fixed-base and isolated-base configurations. It is the smallest actual silo manufactured by the Italian company AGI-FRAME. The height is H = 5.5 m and the radius is R = 1.82 m. The silo wall is realized by 5 stripes of horizontal corrugated sheets (ferrules) with thickness equal to 1 mm. Each strip is high 881 mm. The silo wall is supported by 8 vertical stiffeners characterised by a hat-shaped thin open cross-section which changes in thickness along the height (from the top to the bottom: 1.5, 2, and 3 mm). The stiffeners are connected to the silo wall by M10 7cm-spaced bolts. The silo roof is made by 16 inclined metal sheets. The silo is filled with soft wheat up to a 3.3 m height, in order to reproduce an aspect ratio H/2R roughly equal to 1 (stocky silo). The weight of the steel silo itself is around 12 kN, the amount of grain is around 285 kN, the 4.8mx4.8mx0.4m r.c. plate is 230 kN weigh. The isolators put between the table and the r.c. plate are Curved Surface Sliders friction pendulum devices expressly manufactured by the MAURER company (Germany – Switzerland) in order to obtain a 3 s period of vibration (radius = 2.2364 m, max allowable displacement = 20 cm).

Figure 20: Silos specimen global view and details

List of the conducted tests

TIME	N° TEST	SIGNAL	MAX ACC. (n° trials)
FILLING - 20/02/2019			
11:49	first 150 KN amount of grain		
12:47	second 100 KN amount of grain		
13:19			
13:53	third 35 KN amount of grain		
FIXED BASE - 25/02/2019			
13:48	1	RND	0.1g (1)
14:21	2	SIN 0.5 Hz	0.1g (8)
15:19	10	EQUAKE rs1	0.1g (4)
15:35	14	EQUAKE a1	0.1g (3)
15:57	17	EQUAKE rs3	0.15g (3)
18:02	20	RND	0.2g (2)
18:24	22	SIN 1 Hz	0.2g (5)
FIXED BASE – 26/02/2019			
10:27	27	SLOW	-
10:39	28	SLOW	-
11:08	29	EQUAKE rs1	0.2g (3)
11:21	32	EQUAKE a1	0.2g (3)
11:30	35	EQUAKE rs3	0.2g (4)
11:39	39	RND	0.2g
11:43	40	RND	0.2g
12:38	41	SIN 1 Hz	0.3g (5)
12:54	46	EQUAKE rs1	0.3g (3)
13:03	49	EQUAKE a1	0.3g (3)
13:12	52	EQUAKE rs3	0.3g (4)
.15:14	56	SIN 1 Hz	0.4g (4)
15:30	60	EQUAKE rs1	0.4g (3)
16:05	63	EQUAKE a1	0.4g (4)
16:16	67	EQUAKE rs3	0.4g (3)
16:49	70	STATIC	-
17:18	71	SIN 1 Hz	0.5g (6)
17:37	77	EQUAKE rs1	0.5g (4)
17:53	81	EQUAKE a1	0.5g (3)
18:02	84	EQUAKE rs3	0.5g (3)
FIXED BASE - 27/02/2019			
10:09	87	SLOW	-
10:48	88	RND	0.07g (2)
10:47	90	RND	0.15g (2)
11:04	92	RND	0.2g (2)
11:23	94	RND	0.25g (3)
11:56	97	SIN 0.5 Hz	0.1g (5)
12:07	102	SIN 1 Hz	0.2g (5)
12:16	107	SIN 1 Hz	0.3g (5)
13:12	112	SIN 1 Hz	0.4g (5)
13:21	117	SIN 1 Hz	0.5g (5)
15:01	122	EQUAKE rs3	0.6g
15:07	123	EQUAKE rs1	0.6g

TIME	N° TEST	SIGNAL	MAX ACC. (n° trials)
15:25	124	EQUAKE rs3	0.6g
15:37	125	EQUAKE a1	0.6g
16:01	126	SIN 5Hz	0.1g (4)
16.27	130	SIN 6 Hz	0.1g (5)
16:49	135	SIN 7 Hz	0.1g (5)
17:05	140	SIN 8 Hz	0.1g (6)
ISOLATED BASE – 01/03/2019			
11:19	146	SLOW	-
11:20	147	SLOW	-
11:57	148	RND	0.05g (17)
13:08	166	EQUAKE a1	0.1g (3)
13:22	169	RND	0.3g (2)
13:37	171	EQUAKE a1	0.1g (4)
13:47	175	EQUAKE a1	0.2g (5)
14:02	180	RND	0.4g (2)
14:16	182	RND	0.1g
14:27	183	EQUAKE a1	0.3g (5)
14:47	188	RND	0.2g
15:00	189	EQUAKE a1	0.4g (5)
15:48	194	EQUAKE a1	0.45g
16:02	195	EQUAKE a1	0.5g
16:30	196	EQUAKE a1	0.55g
ISOLATED BASE – 04/03/2019			
10:29	197	SLOW	-
10:41	198	RND	0.2g (3)
10:55	201	EQUAKE rs3	0.1g (5)
11:28	206	EQUAKE rs3	0.2g (5)
11:53	211	EQUAKE rs3	0.3g (5)
12:15	216	EQUAKE rs3	0.4g (5)
14:17	221	EQUAKE rs3	0.45g
14:33	222	EQUAKE rs3	0.5g
15:00	223	EQUAKE rs3	0.55g
15:15	224	EQUAKE rs1	0.1g (4)
15:37	228	EQUAKE rs1	0.2g (4)
16:08	232	EQUAKE rs1	0.2g
16:27	233	EQUAKE rs1	0.25g
16:41	234	EQUAKE rs1	0.3g
17:59	235	EQUAKE rs1	0.3g
18:13	236	EQUAKE rs1	0.35g
ISOLATED BASE – 05/03/2019			
10:08	237	SLOW	-
10:20	238	PULSE	0.1g (5)
10:30	243	PULSE	0.2g (5)
11:00	248	PULSE	0.3g
11:22	249	SIN 0.7 Hz	0.13g (5)
12:02	254	SIN 0.6 Hz	0.14g (3)
DISCHARGING – 06/03/2019			

Filling phase

During the filling of grain into the silo, data acquisition has been performed. Hereafter illustrative plots are reported which show the pressure values captured by the four load cells, specifically designed and realized by EUCENTRE for this project, and the strain values measured in three different points at the base (42 cm from the RC slab level) of one stiffener.

It can be noticed that the grain has been introduced from the top opening of the roof with a small eccentricity leading to a cell (n. 2) loading first than the one on the other side (n. 1).

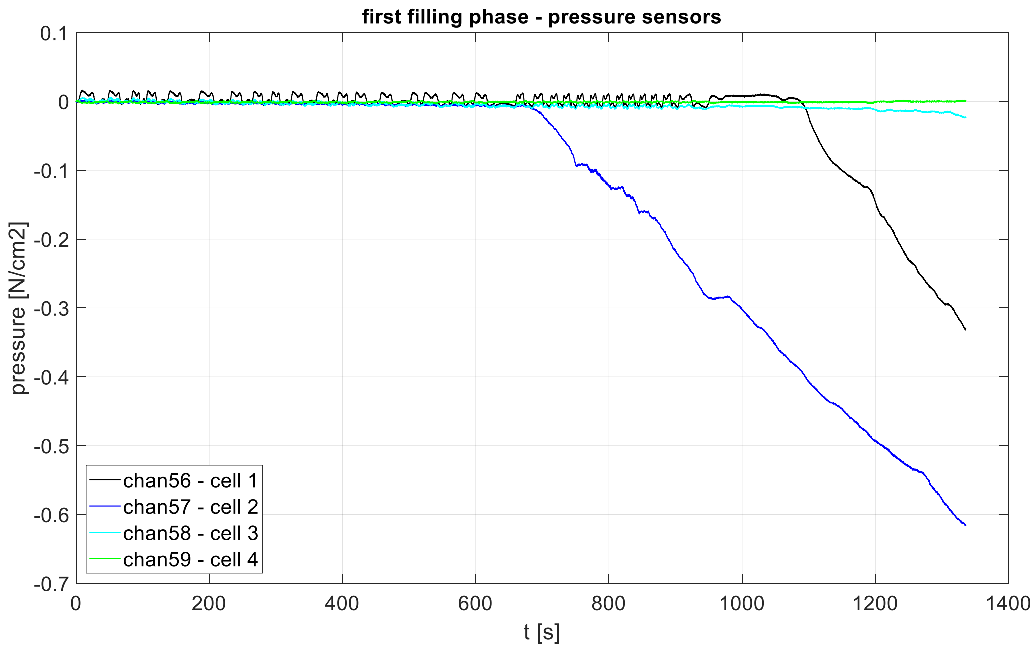


Figure 21: Internal pressure of the silo during the filling phase

First session of tests: fixed-base configuration

One of the objectives of the project regards the fundamental dynamic properties of the grain-silo system. Firstly, during the test design phase, the fundamental frequency has been estimated by means of different numerical models (coarse FEM model with plain isotropic ferrules, refined FEM model with corrugated isotropic ferrules and coarse FEM model with equivalent plain orthotropic ferrules), in which the grain has been considered either as an elastic material with Young modulus equal to 2.3 MPa (f = 7.1 Hz) or as distributed mass hung on the wall (f = 9.7 Hz assuming the Eurocode effective mass assumption, and f = 15.3 Hz assuming the effective mass provided by the analytical theory to be verified).

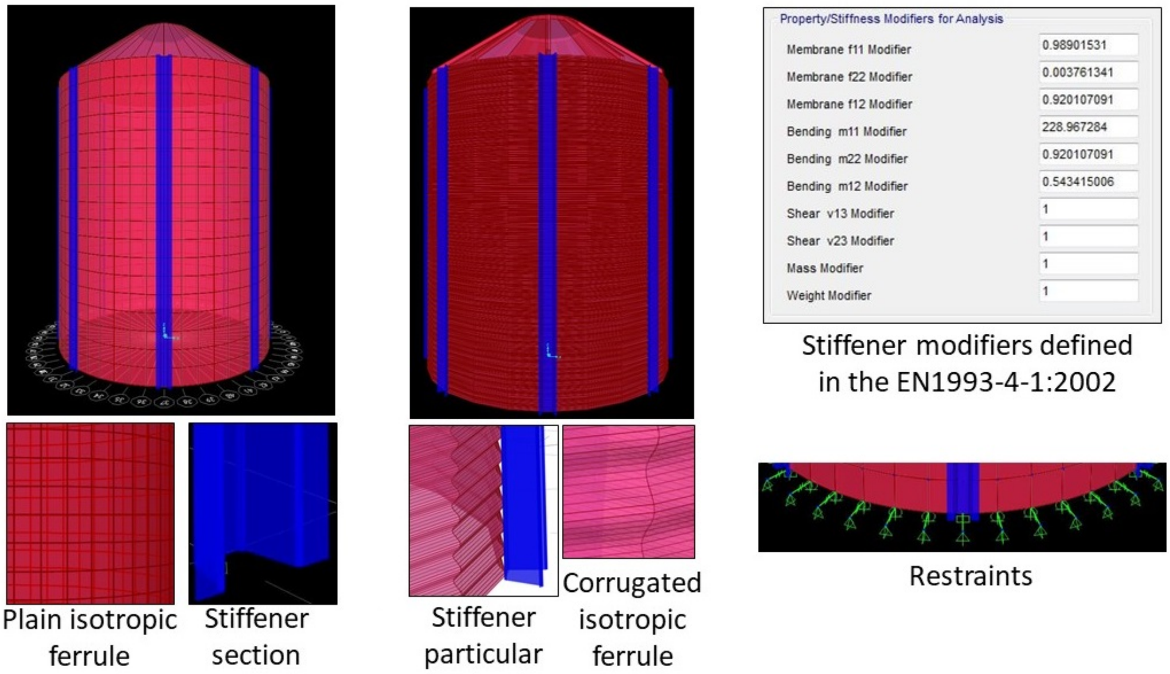


Figure 22: Silos FEM models

Secondly, the experimental frequencies have been obtained from the response of the silo as subjected to white-noise random (RND) signals for various table acceleration levels.

Signal	First set of tests before grain compaction		Second set of tests after grain compaction	
RND	Test	f (Hz)	Test	f (Hz)
0.07 g	1	10.8	88; 89	12.3
0.15 g	20; 21	9.6	90; 91	10.7
0.20 g	39; 40	9.3	92; 93	10.3
0.25 g	-	-	94; 95; 96	10.0

It can be noticed that the fundamental frequency of the structure depends both on the acceleration level and on the compaction level: it decreases with increasing acceleration (more effective mass) and it increases with increasing compaction (higher stiffness).

As far as the dynamic amplification of the grain-silo system is concerned, Figure 23 represents the response of the accelerometers placed at different heights of the silo wall for the 0.3g 1Hz sinusoidal input and for the 0.3g rs3 earthquake input.

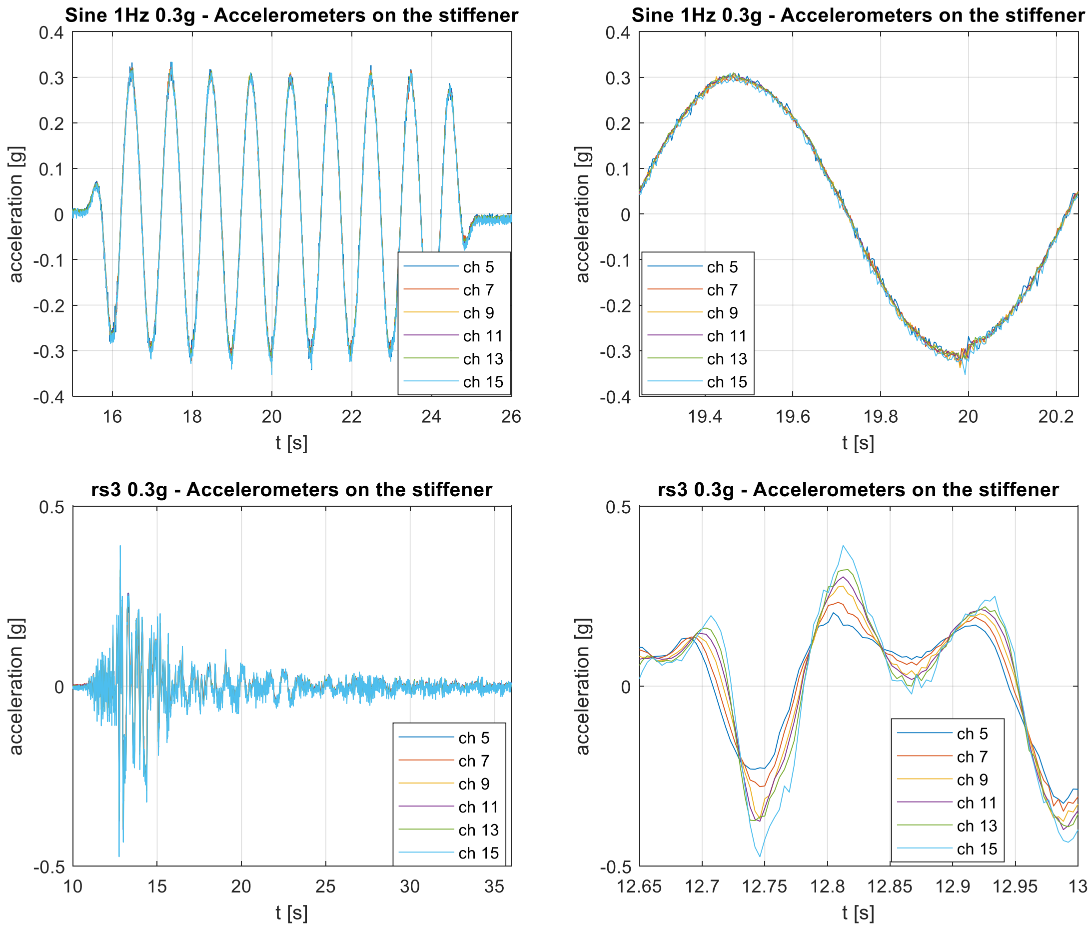


Figure 23: Silo dynamic amplification for low-frequency sine and earthquake input motions

The Figure 24 displays the so-called Peak Acceleration Profiles, as they collect the maximum accelerations measured at different heights of the silo wall, for the following 0.2g and 0.3g inputs: 1Hz sinusoidal, rs1 earthquake (real record of the Campano Lucano Italy 23/11/1980 earthquake, identified as a “far-from-resonance frequency content” input), a1 (artificial) earthquake, rs3 earthquake (real record of the Kalamata Greece 13/09/1986 earthquake, identified as a “close-to-resonance frequency content” input, namely a demanding one for the grain-silo system).

It can be noticed that the response of the grain-silo system is substantially not affected by dynamic amplification for the sinusoidal and the rs1 earthquake inputs, whilst a slight amplification (1.3 – 1.5) is observed for the artificial and the rs3 demanding earthquake.

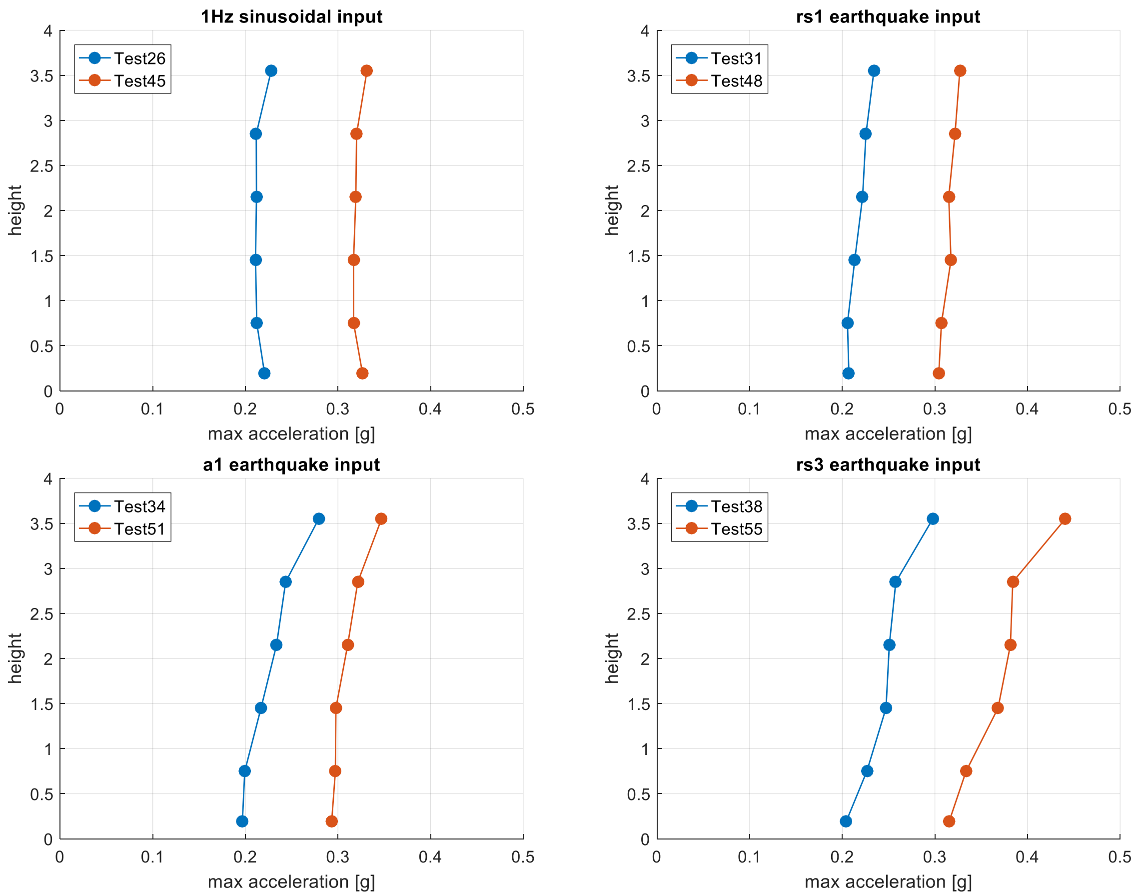
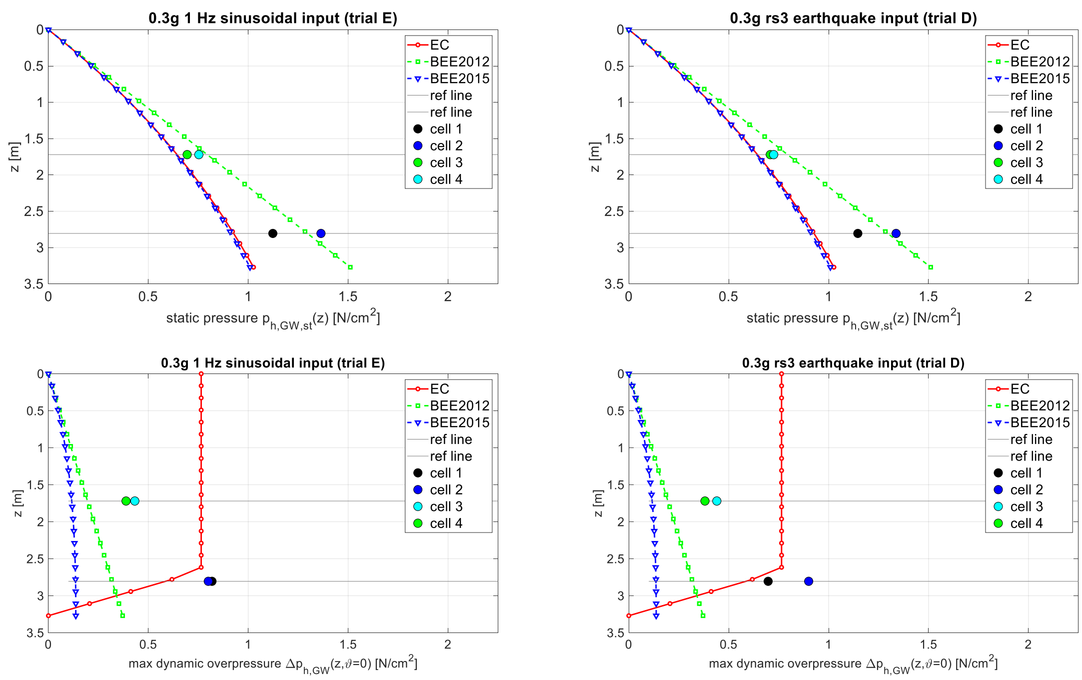


Figure 24: Maximum acceleration vs. height for sine and earthquake input

Figure 25 show the comparison between the maximum pressure values observed during two tests with the predictions provided by the EuroCode and the BEE2012 and BEE2015 analytical theories (to be verified).



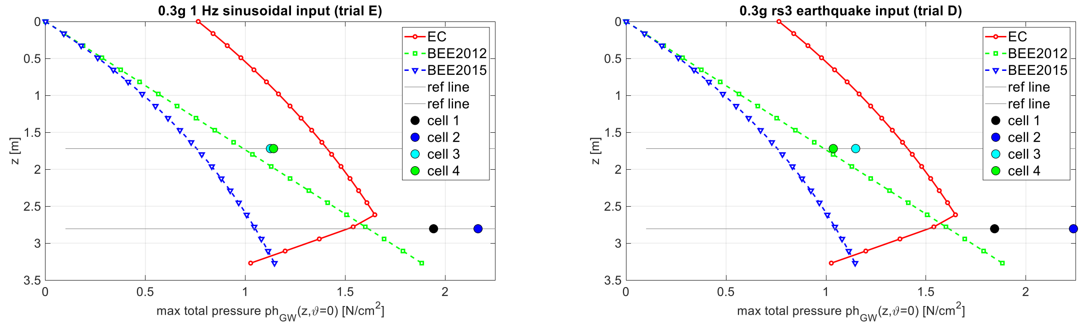


Figure 25: Experimental pressure values and code provisions

It can be noticed that the measured pressure values (both static and dynamic, and consequently the total ones) increase from the top to the bottom of the silo, somehow following a linear profile. This indicates that the EuroCode prediction of the dynamic pressures does not match the observed pressure profile. On the contrary, the predictions provided by the BEE2012 and BEE2015 analytical theories qualitatively match the observed pressure profile, even if a further calibration of the grain parameters (pressure ratio and grain-wall friction coefficient) is needed.

Second session of tests: isolated-base configuration

The silo has also been tested in isolated conditions, by removing the steel anchorages used to fix the RC slab to the table in the first fixed-base configuration.

The next figures display the relative displacement between the table and the superstructure (silo on the RC slab), i.e. the displacement experienced by the isolators, for the rs1 and rs3 earthquake inputs, both scaled at 0.3g. Two simple 2-dofs models have been prepared to predict this maximum relative displacement: one linear equivalent model with friction coefficient equal to 5%, and another non-linear model with friction coefficient equal to 8%.

It can be noticed that the non-linear model is capable of well capturing the measured displacement.

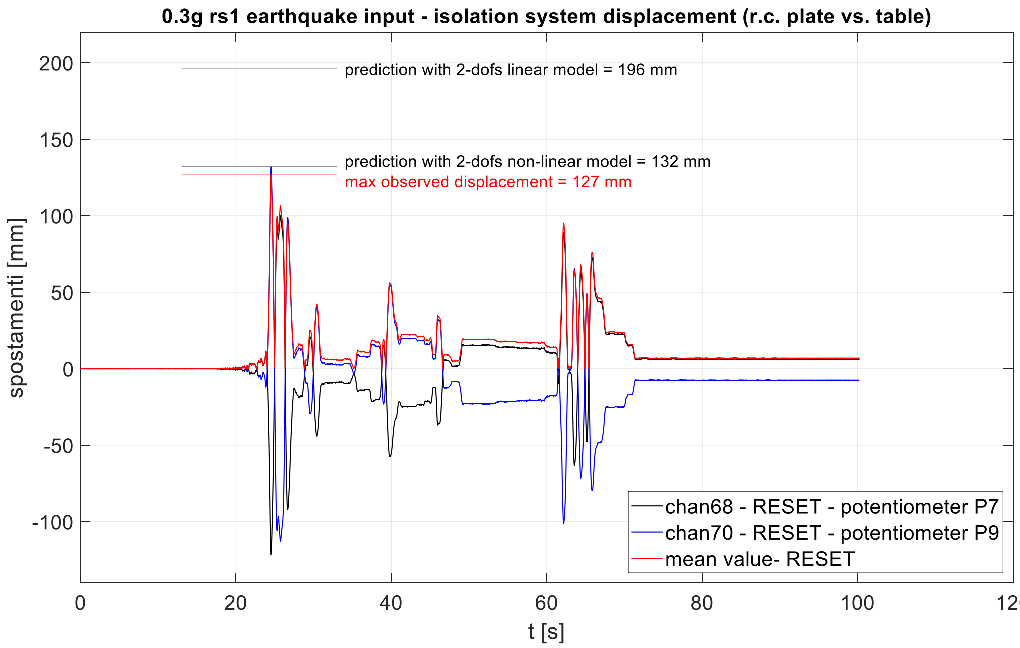


Figure 26: 0.3g rs1 earthquake input – isolation system displacement response

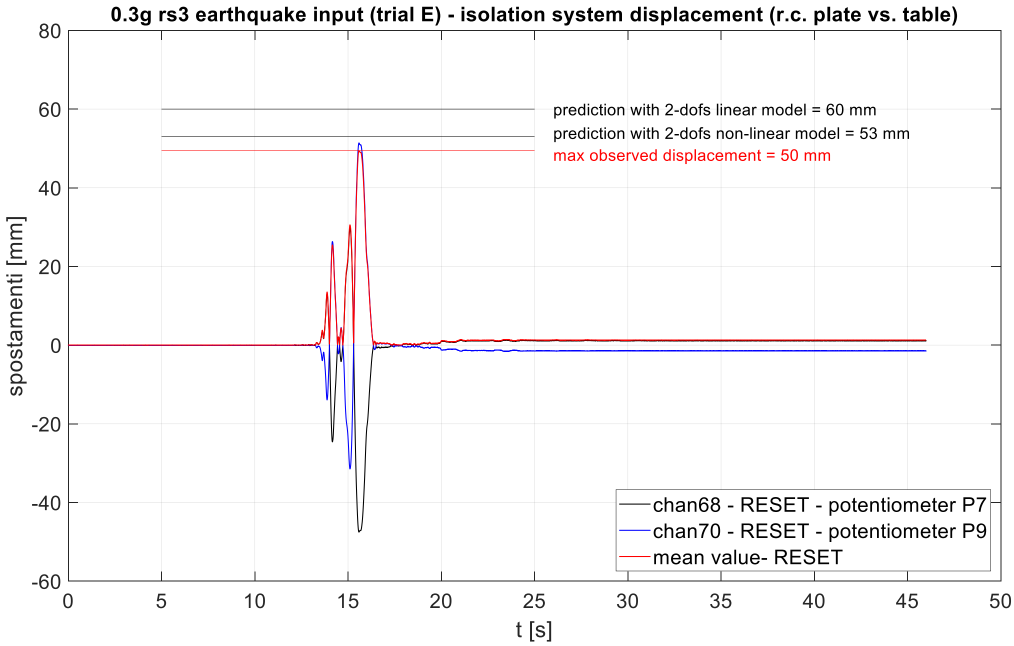


Figure 27: 0.3g rs3 earthquake input – isolation system displacement response

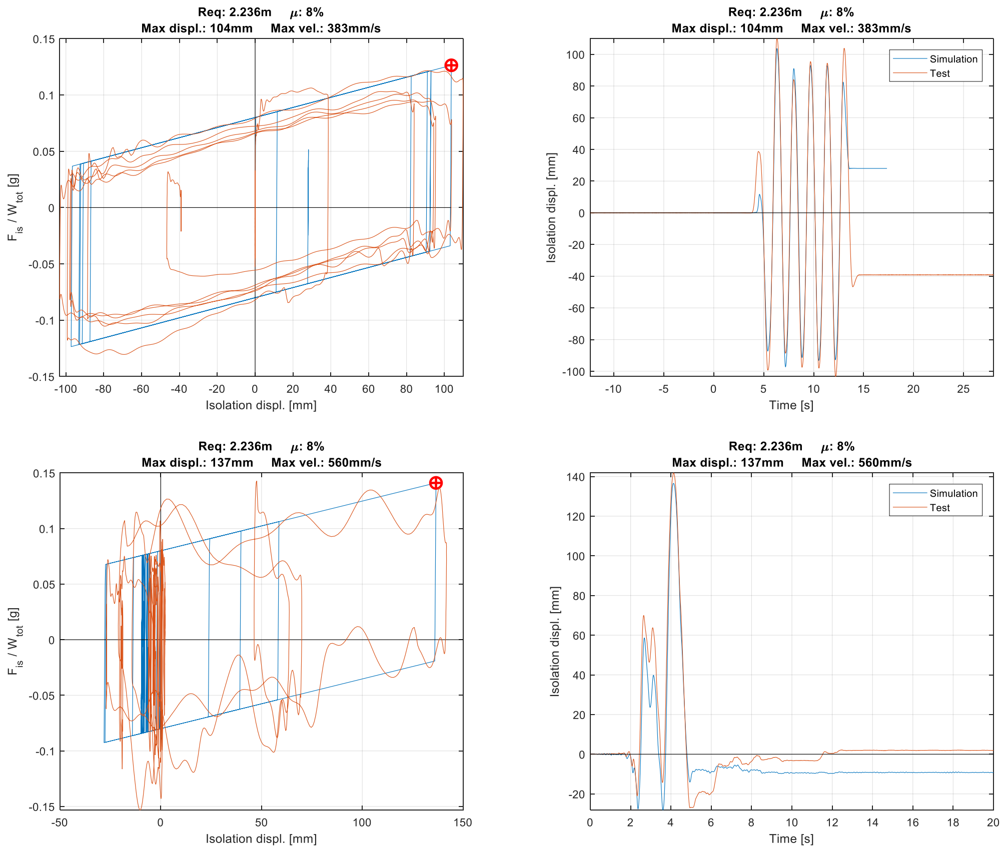


Figure 28: Hysteretic and displacement response of the isolation system (numerical prediction vs. experimental) to sine and earthquake inputs

2.2.4 Foreseen activities and schedule

Currently tests on material parameters, specifically on the grain pressure ratio and on the grain-steel friction coefficient, are under development by the researchers of the User Group.

A huge amount of experimental data has been collected during the 2-weeks of tests: more than 250 acquisition records will be analysed in the next months. In addition to what briefly presented in the previous section, measurements from the strain gauges on the stiffeners, from the markers glued on the silo, and from accelerometers positioned inside the silo within the grain will be analysed.

2.2.5 User Group

	NAME	ORGANIZATION NAME	ORGANIZATION COUNTRY
USER GROUP LEADER	Enrique Hernàndez-Montes	University of Granada	Spain
ADDITIONAL USERS	Stefano Silvestri	Università di Bologna	Italy
	Michele Palermo	Università di Bologna	Italy
	Adam Jan Sadowski	Imperial College	UK
	Johann Distl	Maurer Engineering GmbH	Germany
	Felix Weber	Maurer Engineering GmbH	Germany
	Tomoyo Taniguchi	Tottori University	Japan

3 CEA

The Work package 10 gives an access to the Azalée shaking table of the TAMARIS facility of the CEA (Saclay, France).

The TAMARIS infrastructure and its main shaking table AZALEE, to which access is offered, belong to CEA's Seismic Mechanics Study Laboratory (EMSI), who is leading the French SEISM Institute, is part of the Paris Saclay University regrouping about 19 academic partners and research institutes, and has international RTD collaborations with other facilities (EU, Japan, China, USA). The AZALEE shaking table, with 100t allowable model mass, is one of the largest shaking tables in Europe. To date, tests with masses up to 92t have been successfully performed. The shaking table is 6mx6m and 6 Degrees-of-Freedom (DoF), allowing testing specimens under independent excitations of various types: sinusoidal, random, shock and time-history with 0 to 100 Hz frequency ranges. Maximum accelerations of 1g and 2g in the horizontal and vertical directions, respectively, can be applied to specimens with the maximum payload of the table. The peak velocity of the shaking table is 1m/s, peak displacements are +/-0.125 m and +/-0.1 m in the horizontal and vertical directions, respectively.

The first Call for Proposals permitted to select the 2 projects FUTURE and SEREME for the CEA (WP10-TA3). This first selection made it possible to reach the number of access days allocated to the CEA, so the TAMARIS installation did not participate in the second selection call.

The University of Napoli Federico II made some dimensioning calculations of the FUTURE project till April 2018 and provided plans to the CEA in January 2019. The project is currently close to the call-for tender phase for the model and connectors manufacturing. The commercial consultation phase should begin by April 2019 and end in June 2019, in parallel with the selection of the seismic excitations. Then, the manufacturing phase will start and the reception of the mock up is expected in January 2020. Finally, test will be performed between January and April 2020. The test report will be written before September 2020.

The SEREME project was also accepted in the first call for proposals. At the beginning of the project, Two types of statues have been selected. They have been ordered by CEA and 4 statues and 5 busts were then delivered to CEA/Saclay at the end of February 2019 with their 3D scans. Design of the isolators (SMA and Pendulum) is currently under progression. The delivery of the isolators at CEA/Saclay is expected before end of May 2019. Order for the fabrication of the pedestals needed for the tests has been given and should also be delivered before the end of May. Layout of the tests, calculation of input seismic motions and the set-up of instrumentation are under process. They have to be definitely define before middle of April. Tests will be performed between July and September 2019 and the test report will be written before December 2019.

3.1 Project #1 - FUTURE – [in progress]

FUTURE: Full-scale experimental validation of steel moment frame with EU qualified joints and energy efficient claddings under near fault seismic scenarios.

Estimated access days: 30

3.1.1 Summary of the project

There is a great wealth of numerical and experimental research dealing with the seismic response assessment of new steel moment resisting frames (MRFs). Such research has shown that: (i) the seismic behaviour of MRFs is largely influenced by the behaviour of the joints; (ii) the loading protocol adopted to qualify/test beam-to-column joints are representative of the cumulative and maximum rotation demands imposed by far field natural records and (iii) the design of new steel MRFs according to EC8 is mostly influenced by the serviceability checks (i.e., damage limitation requirements).

It is worth noting that most of the existing studies conducted in the past focused mainly on sub-assemblage tests, without accounting for the response of the building as a whole. Additionally, the loading protocols used for qualifying the joints do not mimic actual earthquake demands at near-collapse conditions. This is also the case of Near Fault (NF) seismic input. Importantly, there is a lack of knowledge about the behaviour of steel joints when subjected to near fault seismic demand. Moreover, earthquake reconnaissance studies have shown that the ratio of vertical-to-horizontal peak ground acceleration can be larger in near-fault than far-fault seismic events. Near fault strong motions tend to increase the inelastic demand on structural steel members and joints. On the other hand, the use of special ductile energy efficient claddings can be beneficial to relax the drift limitations, thus allowing to optimize the structural design (i.e., reducing the design over-strength), reducing the material consumptions, the constructional costs and encouraging the use of more sustainable solutions. The use of such ductile non-structural components will also lower the earthquake-induced losses arising from the claddings.

The project FUTURE aims at investigating the seismic response of steel MRFs accounting for different types of pre-qualified beam-to-column joints as well as the role of ductile claddings under NF earthquakes. To this end, comprehensive shake table tests on specifically conceived mockup have been planned. The mockup consists of a 2 storey steel MRF (5.5m x 5.5m) sub-structured from a reference archetype building. The sample specimen is equipped with special energy efficient and extra-ductile façade cladding.

Three types of bolted beam-to-column joints will be tested, namely haunched, extended stiffened and dog-bone. The sample mockup is also designed to detach and to replace easily all plastic components, which correspond to the portions of the beams with plastic hinge and the corresponding end-plate connections. The joints will be designed considering strong column web panels, so that the column components remain elastic during the whole test campaign.

The experimental program consists of two phases, each of them repeated three times (i.e., one per examined type of beam-to-column joint). In the first phase, the entire mockup (i.e., frame + claddings) is subjected to base ground motion incrementally increased to cover Full Operation (FO), Damage Limitation (DL/ SLS) and Significant Damage (SD/ULS) earthquake intensity levels as defined in the new draft version of Eurocode 8. In the second phase, after the removal of the cladding and the substitution of the base columns (if damaged), the damaged joints are replaced without mounting new cladding and the acceleration is incrementally increased up to Near collapse (NC) earthquake intensity. The experimental campaign will be supported by comprehensive numerical analyses of the entire mockup and its components to simulate both the pre- and post-test conditions.

The project intends to develop design rules for the fully detachable dissipative zones (i.e. the beam segment containing the potential plastic hinge and EU pre-qualified end connection) and provide guidelines for the reliable evaluation of the earthquake response of steel structures, with the presence of ductile claddings.

3.1.2 Main research objectives and expected contribution to the seismology and earthquake engineering community

This project aims at investigating the response of steel moment resisting frames (MRFs) accounting for three different types of bolted beam-to-column joints (i.e., haunched, extended stiffened and dog-bone) as well as the role of energy efficient ductile claddings under near fault (NF) seismic scenarios. The main objectives of the proposal can be summarized as follows:

1. To provide design rules for steel frames under combined effects of horizontal and vertical components NF, which are yet not considered in the design standards for new and existing structures;
2. To validate the response of MRFs equipped with EU prequalified joints (i.e., haunched, extended stiffened and dog-bone) under NF earthquakes as well as to demonstrate the effectiveness of the new design rules for joints currently implemented in the draft of the amended EN1993:1-8;
3. To verify the efficiency of slab-to-beam and slab-to-joint details for the ductility of plastic hinge under NF earthquakes (i.e., to avoid the composite action at joint level but to ensure effective torsional restraints to the beams);
4. To demonstrate the efficiency of fully detachable dissipative beam-to-column joints, which allow easy replacement after seismic damage;
5. To contribute with new background data for the assessment and the repairing/retrofitting of steel frames (e.g. the use of bolted dog-bone joints is representative of potential retrofitting solution) in order to update the next version of EN1998-3;
6. To verify the revised requirements about P-Delta effects currently proposed by WG2 CEN-TC 250/SC8 and ECCS-TC13 for the amended version of EN1998-1;
7. To validate the use of special energy efficient and extra-ductile claddings for MRFs, characterized by drift limits at DL/SLS larger than 1.5% of the interstorey height.
8. To develop experimentally-based fragility relationships for such ductile non-structural components, which tend to minimize the earthquake losses due to claddings.

In order to achieve the above objectives, the planned activities are organized within 5 Work Packages (WPs), each subdivided in several tasks whose responsibility has been allocated to the partners having the best expertise in that field. Hereinafter the description of each WP.

3.1.3 Project status

The project is currently close to the call-for tender phase. The University of Napoli Federico II finalized the dimensioning calculations and the plans of the model by January 2019 (Figure 29 and Figure 30). CEA is preparing the call-for-tender for the model and connectors manufacturing. The commercial consultation phase is expected to begin by April 2019, in parallel with the selection of the seismic excitations.

Several interlocking telephone meetings were held on 2017 and 2018 in for discussing technical details of the experimental mockup and campaign. Mario D'Aniello (University of Naples Federico II, Italy) and Luigi Di Sarno (University of Sannio, Italy) visited CEA on July 2018.

User agreement was signed on December 18, 2018.

Regarding the configurations to be tested, an approximate duration of 4 months for the tests was determined during these meetings. The final tested configurations nevertheless remain to be confirmed according to the manufacturing costs of the mockup.

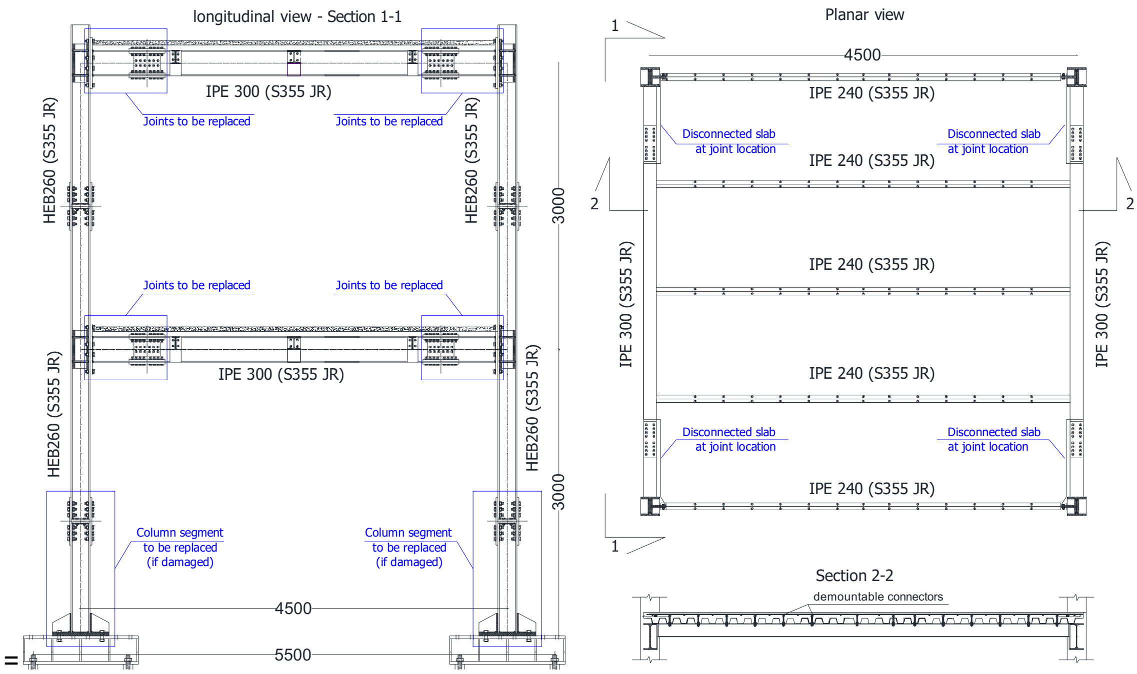


Figure 29: Structural layout of the mock-up with detachable dissipative zones and detachable slab.

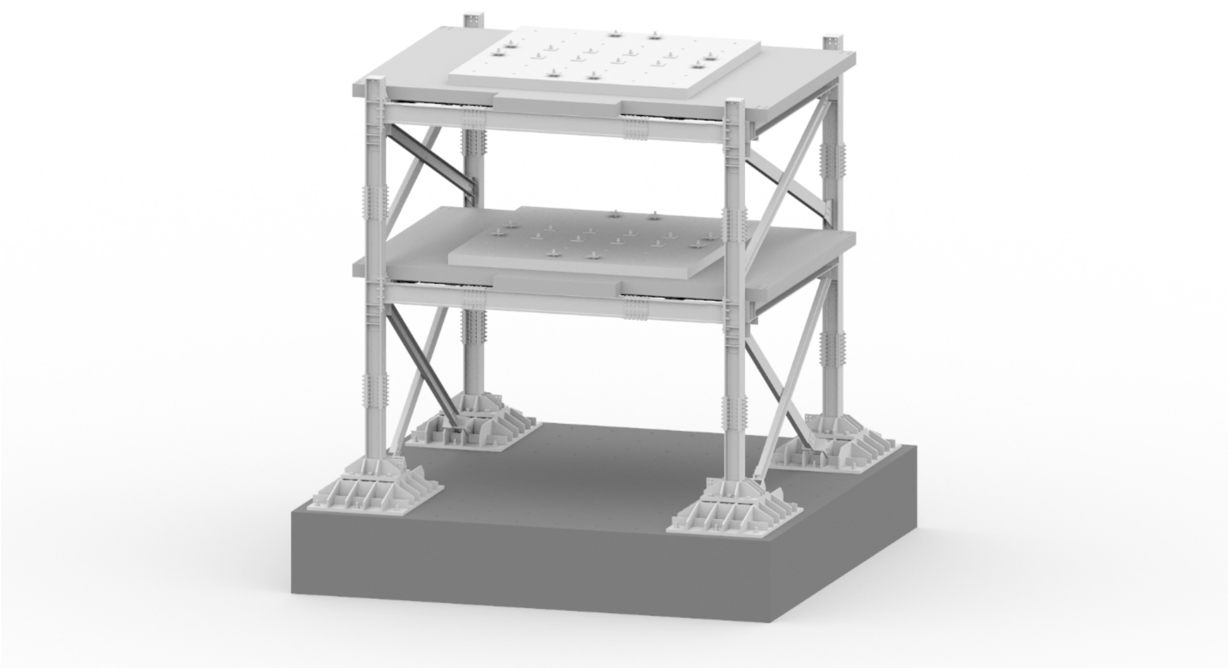


Figure 30: 3D view of the structure without panels.

3.1.4 Foreseen activities and schedule

April - June 2019	Call for tenders.
July 2019	Selection of the manufacturing company, order.
August – December 2019	Manufacturing of the mockup and connectors. Selection of excitations.
January 2020	Reception of the assembly elements.
January - April 2020	Assembly, instrumentation and tests.
May - December 2020	Analyses / Writing of the test report.

3.1.5 User Group

	NAME	ORGANIZATION NAME	ORGANIZATION COUNTRY
USER GROUP LEADER	Raffaele Landolfo	University of Naples Federico II	Italy
ADDITIONAL USERS	Dan Dubina	Universitatea Politehnica Timisoara	Romania
	Ahmed Elghazouli	Imperial College of Science Technology and Medicine	UK
	José Miguel Castro	University of Porto	Portugal
	Roberto Leon	Virginia Tech	USA
	Claudia Chiti	Knauf Italia	Italy

3.2 Project #2 - SEREME – [in progress]

SEREME: SEismic REsilience of Museum contEnts.

Estimated Access days: 17

3.2.1 Summary of the project

Earthquakes are a major threat to museums and their contents worldwide (Figure 31). However, European museums host a large portion of the most significant world cultural heritage. The protection of museums and their treasures against earthquakes is, therefore, a priority, particularly to assure community resiliency.

Figure 31: Seismic Damage on the statue collection of the Archaeological museum of Kos island on 21 July 2017

The SEREME project will study the seismic behaviour of museum assets and will propose novel and cost-effective risk mitigation schemes for improving the seismic resilience of European museums. In this regard, artefacts, mainly statues, of different sizes and configurations will be tested on the 6-dof shaking table at the Earthquake and Large Structures Laboratory (EQUALS) at the University of Bristol (UK).

Today most museums are located in historical buildings at the centres of European cities. The SEREME project will consider two case-study museums, a typical Italian museum building with a masonry structural system and a reinforced concrete museum building in Greece. Strong ground motion records of different amplitudes will be applied to numerical models of these structures and the acceleration response histories at different locations along the plan/height of the building will be calculated numerically and used as acceleration input for the shake table tests.

A Museum Virtual Exhibition Room (MVER) will be created on the 6-dof shaking table. The MVER will contain exhibits such as sculptures and artefacts of different sizes and geometries. The project will first examine the seismic behaviour of the test specimens absent seismic protection (in other words, their most common installation). The tests will be repeated using different seismic protective measures, emphasising the use of low-mass base isolation systems. Two new and highly efficient base isolation systems (Figure 32), tailored to art objects, will be extensively tested for the first time. The first isolator is a pendulum-based system, while the second utilises Shape Memory Alloy wires. These experiments will allow a direct comparison, in a controlled laboratory setting, of the resilience of the seismically protected artefacts with those artefacts that are not protected.

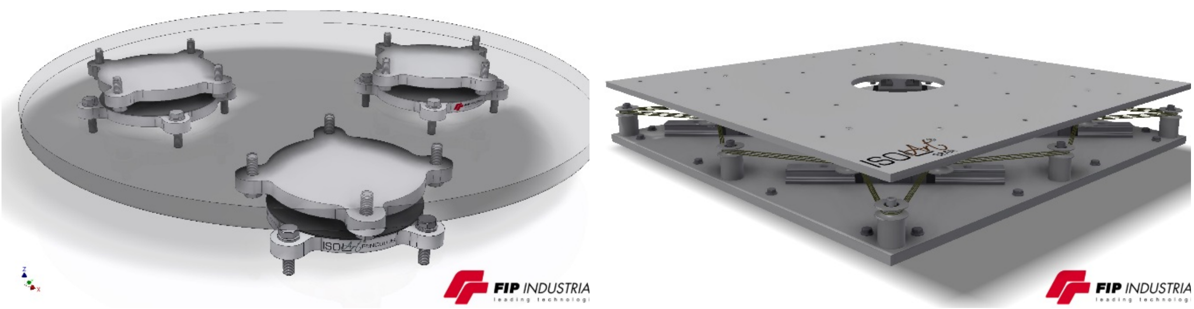


Figure 32: ISOLART® PENDULUM (left) and ISOLART® SMA (right)

The project will develop and calibrate novel numerical models for single- and two- block rocking systems, while experimental and numerical results will be combined in order to develop quick overturning assessment criteria. The final task of SEREME will combine the shaking table experimental outcomes with numerical results, obtained from calibrated models, in order to develop fragility curves for museum artefacts. Moreover, pre-normative guidelines for the seismic assessment and retrofitting of artefacts will also be proposed.

3.2.2 Main research objectives and expected contribution to the seismology and earthquake engineering community

The seismic response analysis of museum artefacts is of uttermost importance for European countries where thousands of museum buildings are located in earthquake prone regions. Existing recommendations for the seismic assessment and retrofitting of museum artefacts are primarily qualitative/descriptive. The main objectives of SEREME are:

1. Assess experimentally the seismic behaviour of museum artefacts and investigate the validity of rocking theory on slender, heavy unanchored objects with non-rectangular geometry, such as human-formed statues.
2. Perform shake table testing on two new base isolation systems, a pendulum-based and a Shape-Memory-Alloy-based system developed by FIP Industriale S.p.A.
3. Propose and calibrate simple numerical models of single- or two- block rocking systems.
4. Study the significance of the combination of vertical and horizontal seismic components on the response of museum artefacts, and in particular compare the isolated versus the non-isolated cases.
5. Develop criteria for the rapid fragility assessment of museum artefacts and for determining whether immediate protection measures need to be taken.
6. Examine the effect of the artefact's location within the building and also the importance of the type of the building structural system. Decide on possible modifications of the isolation systems depending on the location of the artefacts in the building.

SEREME project aims to investigate the seismic response of objects of small mass and small dimensions under three-directional earthquake action. Horizontal excitations, combined with strong vertical accelerations, may considerably reduce the gravity's stabilizing effect and affect the friction mechanism. This is worth of experimental investigation since field observations indicate that the combined effect of horizontal and vertical accelerations could be significant, although numerical research efforts [1] have shown that the vertical component often may be omitted due to its high frequency content. Especially for designing suitable risk mitigation systems, the effect of the vertical component has to be studied experimentally.

3.2.3 Project status

The project was accepted in the first call for proposals. A first start-up telephone meeting was held on October 13, 2017. A second meeting took place at CEA on January 23, 2018 in the presence of CEA managers and lead users.

User agreement was signed on 11/29/2018.

4 statues and 5 busts were delivered to CEA/Saclay on 02/26/2019 (Figure 30).

Figure 33: Statue and bust

Design of the isolators (SMA and Pendulum) is still under progression. The delivery of the isolators at CEA/Saclay is not expected before end of May.

Order for the fabrication of the pedestals needed for the tests has been given. Pedestals (Figure 34) will be delivered around middle of May.

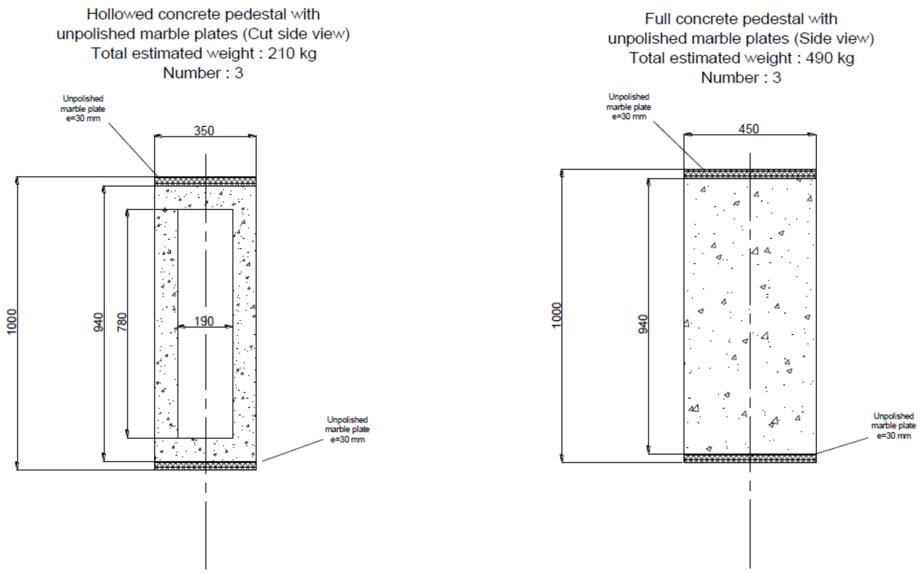


Figure 34: Drawing of pedestals

Layout of the tests and instrumentation set-up are under discussion. They have to be definitely define before middle of April. Input seismic motions are still not available. Calculations must be performed by users to provide the storey time histories to be used during the tests.

The Azalée shaking table testing campaign will then be conducted over a period of approximately 4 weeks, starting in July or september 2019.

3.2.4 Foreseen activities and schedule

End of May 2018	Choice of statues manufacturer, order.
From June 2018 to February 2019	3D scan of statues and busts, manufacture of statues/busts and shipment to the CEA.
End of May 2019	Manufacturing of the isolators
July 2019 or September 2019	Tests on Azalée shaking table
Septembre to December 2019	Analysis / Test report.

3.2.5 User Group

	NAME	ORGANIZATION NAME	ORGANIZATION COUNTRY
USER GROUP LEADER	Michalis Fragiadakis	National Technical University of Athens	Greece
ADDITIONAL USERS	Luigi Di Sarno	University of Sannio	Italy
	Anna Saetta	University of Venezia	Italy
	Maria Gabriella Castellano	FIP MEC S.r.l.	Italy
	Ihsan Engin Bal	Hanze University of Applied Sciences Groningen	Netherlands
	Tara C. Hutchinson	Department of Structural Engineering (UCSD)	USA

4 LNEC

The Earthquake Engineering and Structural Dynamics Unit of LNEC runs an infrastructure with a 5.6 m x 6.4 m 3D shake table (LNEC-3D), to which access is offered, located in a large testing hall with 10 m height and an overhead crane with 400 kN capacity, resulting in a versatile test facility that can be used for a variety of earthquake and dynamic load tests.

During SERA, LNEC is hosting 3 User Groups (UGs) and Projects, for a total of 75 access days. In the 1st call for TA Projects, 5 UGs applied to LNEC as the 1st choice as TA host and 3 UGs applied to LNEC as the 2nd choice for hosting institution. Two projects were selected:

- Seismic Response of Masonry Cross Vaults: shake table tests and numerical validations;
- (Towards the) Ultimate Earthquake proof Building System: development and testing of integrated low-damage technologies for structural and non-structural elements.
- In the 2nd call for TA projects, the 3rd UG was selected, among additional 8 applications from which 3 had LNEC as the 1st choice as TA host. The selected project is:
- Seismic Testing of Adjacent Interacting Masonry Structures.

Until M12, the User Agreements were established with the first two UGs and the design of the models to be tested was developed taking into account the constraints of the facility and the objectives of the UGs, as already reported in Deliverable D8.1.

The activities carried out during the second year of SERA for the first two UGs correspond to the final developments of the design of the specimens, tender launching for the construction and actual construction and partial testing of the specimens. The User Agreement was also established with the 3rd UG, which has been developing the design of the test specimen. Its construction and testing are foreseen for the upcoming 6 months. All testing activities for all UGs will be concluded until the end of January 2020.

4.1 Project #1 – Seismic Response of Masonry Cross Vaults: shake table tests and numerical validations – [in progress]

4.1.1 Summary of the project

Masonry vaults play a much relevant role in the seismic response of heritage masonry buildings, ranging from housing to the greatest cathedrals. Acting as both a ceiling and a structural horizontal diaphragm with significant mass, their mechanical behaviour affects the overall seismic response of buildings, in terms of strength, stiffness, and ductility. Moreover, local damage and collapse of vaults may produce significant losses in terms of cultural assets and casualties. In spite of the importance of this topic, the evaluation of the complex three-dimensional behaviour of vaults is still an important challenge for researchers. The main objectives of the present research project are:

1. To better understand the seismic behaviour of masonry cross vaults by means of shake table tests on both full-scale and small-scale models;
2. To assess the capability of different modelling/analysis approaches to predict the seismic response of these masonry structures.

In particular, three sets of shake table tests are planned and under preparation:

1. Tests on a 1:1 scale model of a brick unreinforced masonry cross vault: to investigate the behaviour of brick masonry cross vaults under different seismic inputs, in terms of damage, displacement capacity and peak acceleration;
2. Tests on a 1:1 scale model of a brick reinforced masonry cross vault: to evaluate the effectiveness of reinforcing techniques to repair the vaults previously tested;
3. Test on a 1:5 scale cross vault made of 3D-printed blocks assembled with dry joints: to validate the effectiveness of static tests on scale mock-ups, performed in earlier studies, to describe the seismic dynamic response of masonry vaults.

In addition to the experimental tests, numerical simulations are being performed to assess the efficacy of different modelling strategies and analysis techniques. The final aims are to improve the safety assessment procedures proposed for historic masonry buildings in Eurocode 8 and to provide better seismic assessment techniques and strengthening measures.

4.1.2 Main research objectives and expected contribution to the seismology and earthquake engineering community

The project comprises the following five main research objectives:

1. Improving the knowledge on the seismic response of masonry cross vaults, in terms of collapse modes, strength and displacements capacity.
   Motivation: masonry cross vaults are widespread in historic masonry buildings and are often decorated with frescos, wooden carving and paintings; their damage/collapse may produce severe injuries to occupants and unrecoverable cultural losses; they are very vulnerable structural elements; almost no experimental studies concern their seismic behaviour.
2. Stressing the role of the seismic input on the response of masonry vaults.
   Motivation: seismic input may be strongly variable in terms of PGA, duration, frequency content and displacement demand, etc.; the response of nonlinear structures, such as masonry ones, may be strongly affected by the “quality” of the seismic input; seismic analyses of masonry structures should take into account such interaction.
3. Assessing the effectiveness of innovative repair/strengthening techniques on masonry cross vaults.
   Motivation: being vulnerable structural elements, cross vaults often suffer severe seismic damage; if a vault is judged to be unsafe or is damaged by an earthquake, it should be strengthened/repaired; repair and strengthening techniques should be tested in order to assess their effectiveness and practical feasibility.
4. Assessing the reliability of static tests on scaled dry joints mock-ups in forecasting the dynamic behaviour of real masonry vaults.
   Motivation: static tests on masonry vaults are much easier to perform and economical than shake table tests; however, they provide a rough description of the reality; the reliability of such models should be assessed.
5. Assessing the reliability of numerical models to predict the seismic response of masonry vaults.
   Motivation: analytical and numerical models are the most economical way to predict the seismic behaviour of masonry structures; different modelling approaches and safety assessment procedures are proposed in the literature; the reliability of such approaches and procedures has never been assessed for 3D-curved masonry structures at full scale and in the dynamic field; finally, accurate parametric analyses will be possible in order to define simplified assessment and design procedures.

4.1.3 Project status

In order to achieve the mentioned objectives, the project comprises a set of research activities as described below:

Geometry of the cross vault: A reference cross vault, having a square base with a net span of approximately 3.1 m, and made up of typical bricks with lime-based mortar joints, is considered (Figure 35). The height is 1.12 m, with a total mass of the model of approximately 4.4 ton. The masonry pattern of a typical cross vault is reproduced, while the overall geometry of the vault being the same considered in the static tests performed on a scaled model at the Univ. of Genova in 2015.

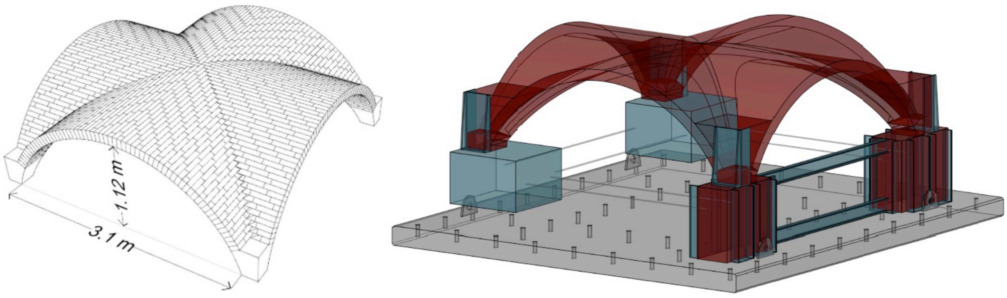


Figure 35: Geometry of the vault model.

Boundary conditions: The boundary conditions that represent standard configurations of vaults in historic churches, depicted in Figure 36, are considered. The vault's abutments will be placed on steel supports connected by tie-rods, whose stiffness are calibrated in order to reproduce the stiffness of constraining lateral walls or real tie-rods. Two abutments will be fixed, while the other two will be free.

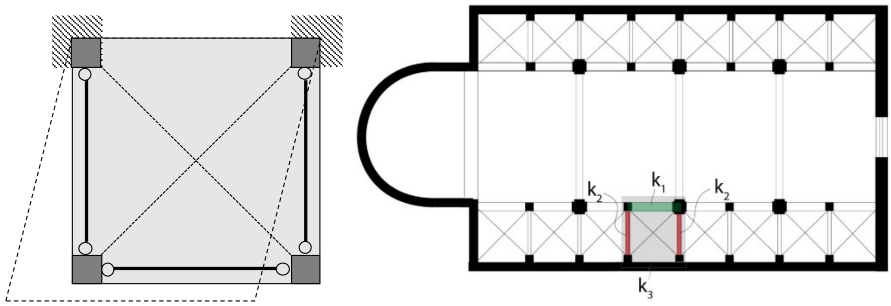


Figure 36: Boundary conditions.

Strengthening: After a first set of tests in undamaged and un-strengthened state, the vaults will be repaired/strengthened by GeoSteel Grid 200 by Kerakoll. This is a biaxial grid made of basalt fibres, balanced by micro wires of stainless steel (AISI 304) and fixed to the vault extrados surface by a natural lime mortar (GeoCalce® F Antisismico, class M15).

Building and calibration of the models: The full-scale models will be built in the testing hall of LNEC. For identification of material properties, tests on constituent materials (brick and mortar) and masonry specimens will be carried out in the preparatory phase. Moreover, ambient vibration tests will be performed to obtain the free vibration modes of the built model.

Type of tests: Incremental Dynamic Analyses will be carried out. Two different sets of real accelerograms (using the three components actually recorded), with different length, frequency contents, and displacement demands, will be used. They will be selected in order to represent a near-fault and a far-fault ground input, with the vertical component of the earthquakes expected to have a very important contribution in the near-fault scenario.

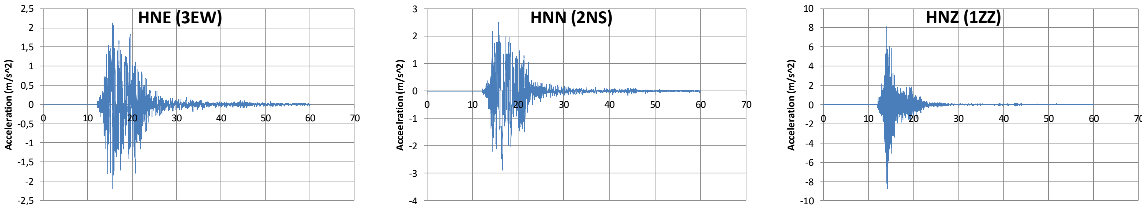


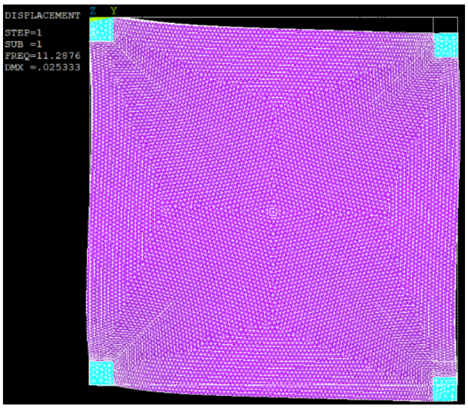
Figure 37: Sample input motions.

Planned tests: Tests on un-strengthened vaults subjected to two different accelerograms (objectives 1 and 2); tests on previously damaged and strengthened vaults (objective 3); tests on the reduced scale model (objective 4).

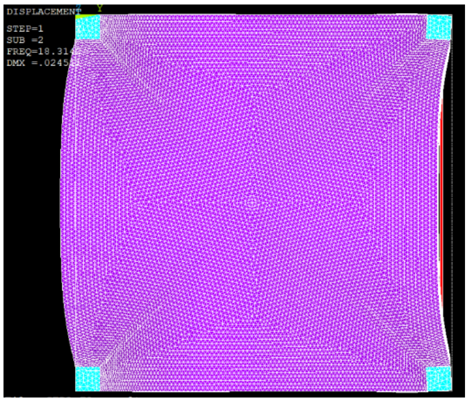
Measurements: During the tests, the accelerations of the shake table and of the vault specimen will be recorded by accelerometers. The displacement pattern will be monitored and tracked by optical cameras and displacement transducers. The stress in the tie-rods will also be monitored.

Numerical simulations: In the preparatory phase, linear elastic analyses will support the design and calibration of the model. Then, nonlinear dynamic analyses with both Finite Element and Discrete Element models, as well as Limit Analyses with incremental displacement patterns, will be carried out to predict the experimental response of the vaults. Different safety assessment procedures, based on both force and displacement approaches, will be evaluated (objective 5).

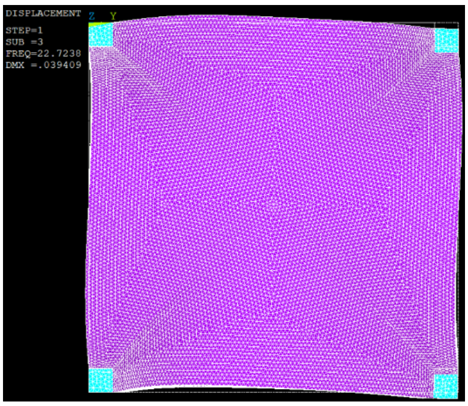
First mode – 11.29 Hz



Second mode – 18.31 Hz



Third mode – 22.72 Hz



Fourth mode – 24.21 Hz

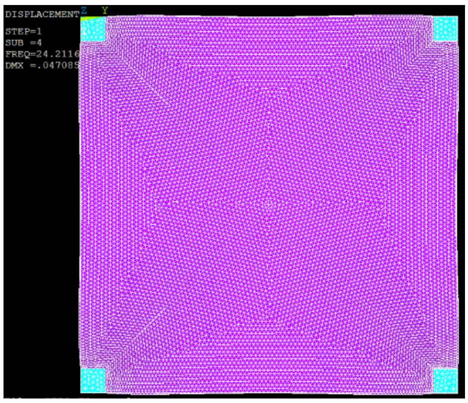


Figure 38: Modes of vibration of numerical model.

In the end, the expected project outcomes are: 1) evaluation of the maximum acceleration applicable to cross vaults; 2) evaluation of the diaphragm stiffness and ultimate displacement capacity of cross vaults; 3) identification of the damage modes; 4) evaluation of the role of seismic input on the dynamic response of these vaults; 5) estimation of the increased seismic capacity due to repair and strengthening interventions; 6) comparison between static and dynamic tests and evaluation of the influence of the test type; and 7) evaluation of the reliability of analytical/numerical models and safety assessment procedures.

The project is currently ongoing. LNEC and UG1 have been thoroughly exchanging information and performing teleconferences for finalizing the design of the structure and to prepare the construction of the specimens, the test setup, the test input and the instrumentation layout. Possible contractors to build the real-scale model of a brick unreinforced masonry cross vault were consulted and the tender process has been launched.

4.1.4 Foreseen activities and schedule

The whole project has been developed according to the following timetable, which starts at the 1st January 2018:

Steps		Month 3	Month 6	Month 9	Month 12	Month 15	Month 18	Month 21	Month 24	Month 27
S1	T1									
	T2									
S2	T1									
	T2									
	T3									
	T4									
	T5									
S3	T1									
	T2									
	T3									
S4	T1									
	T2									
	T3									
	T4									
S5	T1									
	T2									
	T3									

S1	Executive design of the setup
T1	Design of the masonry vault (choice of the materials and masonry pattern)
T2	Design of base supports/boundary conditions and design of operational phases (building and installation on the testing rig)

S2	Building of the model
T1	Building of the base supports and boundary conditions
T2	Building of the vault
T3	Curing
T4	Retrofitting of the vault
T5	Curing

S3	Numerical analyses
T1	Definition and design of numerical models
T2	Preliminary modal analyses to support the design of the test setup
T3	Numerical analyses

S4	Experimental tests
T1	Preliminary tests on the materials of full-scale masonry models (brick and mortar)
T2	Shake table tests on full scale masonry models
T3	Shake table tests on the reduced scale model
T4	Analysis and interpretations of the results

S5	Exploitation of the results
T1	Dissemination of tests
T2	Publication of the results
T3	Final seminar on the results

The foreseen experimental tests are thus planned to start in mid-2019 and finish in early 2020.

4.1.5 User Group

	NAME	ORGANIZATION NAME	ORGANIZATION COUNTRY
USER GROUP LEADER	Chiara Calderini	University of Genova	Italy
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	Michela Rossi	University of Genova	Italy
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	Paulo B. Lourenço	University of Minho	Portugal
	Nuno Mendes	University of Minho	Portugal
	Matthew DeJong	University of Cambridge	UK
	Eftychia Dichorou	University of Cambridge	UK
	Paolo Casadei	KERAKOLL Group	Italy
	Paolo Girardello	KERAKOLL Group	Italy

4.2 Project #2 – (Towards the) Ultimate Earthquake proof Building System: development and testing of integrated low-damage technologies for structural and non-structural elements – [in progress]

4.2.1 Summary of the project

Targeting life-safety is arguably not enough for our modern society and communities, with a paradigm shift being required towards a damage-control or low-damage design philosophy which should embrace the building system as a whole. This project intends to promote a catalyst research effort within the European environment for the development and wider industry/community uptake of an integrated low-damage building system, including skeleton and non-structural components for the next generation of buildings.

Attention is given to design methodologies and technical solutions for both the structural skeleton and the non-structural components (e.g. partitions, facades, ceilings, services). A ‘flexible and sustainable’ design approach is considered by employing modular demountable, replaceable and relocatable components to facilitate the rearrangement of internal spaces, layout and exterior “envelope/dress” of these building systems. This in turn would allow for potentially several changes of use during its (potentially extended) lifetime (e.g. residential vs. commercial/offices/retails and vice-versa) with also potential reusability and recyclability of obsolete or not anymore fit-for-purpose components. This would lead to an enhanced level of ‘sustainability – by design’.

The core role is given to the use of internationally emerging solutions based on self-centring and dissipative systems using prefabricated elements and unbonded post-tensioning techniques. This technology, originally developed for precast concrete from the 1990s (with the PRESSS-Program coordinated by Nigel Priestley at UCSD) has gone through substantial and comprehensive developments and refinements in the past 15 years, and was subsequently extended to steel and timber (engineered wood) solutions (Pres-Lam or prestressed laminated timber) with numerous on-site applications (and incorporations within code design provisions) in New Zealand and growing interest around the world.

The experimental programme within the SERA Project focuses on the needs and peculiarities of the European reality, developing specific ad-hoc solutions with reference to current design codes (Eurocode 8 as well as national codes, such as the Italian NTC08), construction practices and market expectations.

The overall research project comprises analytical/numerical and experimental investigations focusing around the shake table tests of a 1:2 scale super-assembly (two storeys-two bays building system) low-damage building system, comprising structural skeleton (frames in one direction and coupled walls in the other) and non-structural components/envelope/services.

The research team brings together a strong academic-industry group, with a unique mixture of research and design experience, covering the various key aspects of material, design approaches, modelling, building technology, and experimental testing. The SERA Project gives the unique opportunity to leverage on and further develop, the last 15-20 years of research, developments and best design practice experience of the key researchers in this field and carry out a (probably world-first) large scale shake-table test of a complete low-damage building systems, based on rocking-dissipating post-tensioned solutions (frames and walls, with mixed materials, concrete and timber) and low-damage non-structural elements. The outcome of the project will be widely disseminated through various channels (papers, seminars, presentations, courses, website, databases, guidelines) to the international technical and non-technical community to further raise the awareness on these latest low-damage technologies and further stimulate the interest of the wider industry, policy makers, and stakeholders for its wider embracing in the near future.

4.2.2 Main research objectives and expected contribution to the seismology and earthquake engineering community

This project brings around the table top and key players in the area of research and design of innovative technologies for both structural and non-structural components with the intention to build on the best know-how for the development and shake-table testing of an integrated low-damage building system, consisting on self-centring and dissipative structural systems (post-tensioned frames in one direction and coupled walls in the other) with mixed materials (concrete-based and timber based).

The overall project consists of experimental, numerical and analytical investigations, with the following main objectives:

1. Development, refinement and validation of the seismic response of 3D innovative low-damage structural systems based on post-tensioned rocking dissipative solutions for multi-storey and open-space post-tensioned buildings with hybrid (concrete-timber) materials and structural systems (frames and walls);
2. Investigation of alternative options for low-damage non-structural elements, including partitions, (facades, ceiling, glazing, services etc);
3. Research on the full interaction of structural and non-structural systems during simulated real-time seismic response under three directional components.

The latest includes a focus on displacement-incompatibility issues between frames, walls, floor systems and non-structural components; floor spectra and acceleration-displacement demand to non-structural components; validation and refinement of currently used nonlinear macro-models; calibration of interface/local behaviour by using FEM micromodels; calibration of 'elastic' damping and hysteretic models for design purposes; performance assessment of various components vs. predictions (limit states, fragility curves, structural and economical/losses).

Expected outcomes and outputs:

- Evidence-based scientific technical publications on the key findings;
- Wider dissemination through papers, presentations, workshops, courses;
- Preparation of test results for inclusion into international databases accessible to wider researcher community;
- Recommendations ("white paper"-style) for a wider uptake in the European and international environment of low-damage building system technologies with actions within various environments: regulatory (i.e. changes in codes/standard, financial incentives); university level education (undergraduate and graduate courses); professional continuum educations (seminars/courses to engineers and architects); construction industry; wider community (national/government publicity via media channels);
- Raising awareness within the European academic-industry community: as anticipated, this project intends to act as an initial catalyst for the development of a European research-industry network for a wider spread and uptake of low-damage building systems.

4.2.3 Project status

Geometry and mass: The test specimen consists of a two-storey, two bays, 1:2 scale fully prefabricated and dry-assembled system. The dimensions in plan, elevations, total mass, etc., have been selected and designed to conservatively respect the limits and capability of the shake table facilities at LNEC. The specimen under construction is approximately 5.5 m x 5.2 m in plan and 3.7 m in elevation (excluding foundation) for a total mass of approximately 42 tonnes (foundation included). It is represented in Figure 39.

Vertical structural systems: Post-tensioned frames in the longitudinal direction and coupled walls in the transverse direction. In the frame direction, a mixed configuration with concrete columns and timber beams is considered.

Diaphragms: A mixed concrete-timber floor system will be adopted as diaphragm, with mechanical connectors being used to transfer the diaphragm forces to the lateral seismic resisting systems.

Special detailing including unbonded length slots will be adopted to minimize the vertical (uplift) and horizontal (beam-elongation) displacement incompatibility between floors and walls and frames.

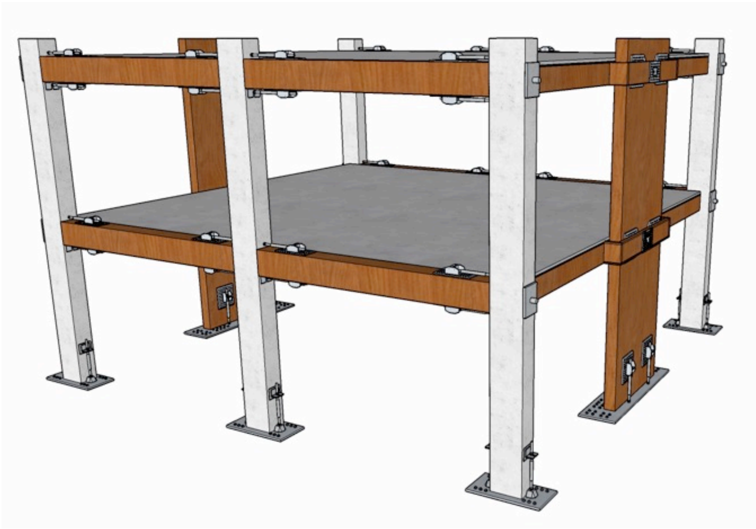

Figure 39: Full view of the test specimen.

Instrumentation and structural monitoring: An array of displacement transducers (wire/string or laser-type, LVDTs), load cells, strain gauges, optical cameras and accelerometers are required to fully monitor the building dynamic performance. The key parameters to be measured include, but are not limited to: interstorey displacements, connection rotations (beam-column, column-to-foundation, wall-to-foundation), relative wall-to-wall movement, U-shape Flexural plates and 'Plug&Play' Devices, strain and displacements neutral axis position, forces in the post-tensioning tendons/bars, relative displacements/movement between floors and lateral resisting systems, etc.

Non-Structural Elements: The NSE 'package' is comprised of:

- Facades – heavy concrete facades in the longitudinal directions and lighter curtain walls/glazing systems in the orthogonal ones (see Figure 40);
- Partitions – different interior (gib-board-type) partition solutions at the same floor level (e.g. the two different bays implementing two different options), representing both a traditional (ordinary damage) solutions and a low-damage version;
- Piping/Services – suspended piping services are adopted using either traditional or innovative dissipative/protecting systems;
- Fastened NSE elements to concrete floors or walls using traditional or innovative anchors.

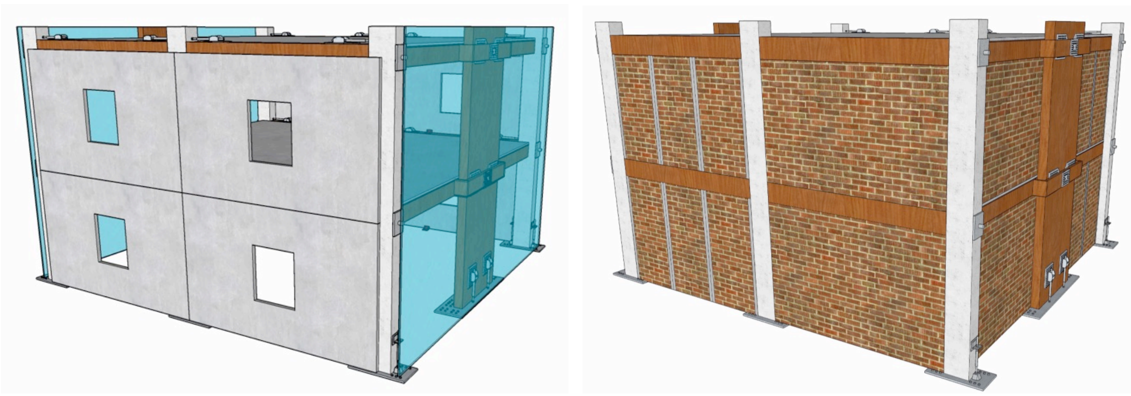

Figure 40: Proposed facades for test specimen: precast cladding panels and spider glazing system (left) and unreinforced clay brick infill walls (right).

The project is currently ongoing, with the construction of the specimen and the preparation of the test setup, as shown in Figure 41. The structural components were mostly built in Italy, with posterior shipping and assembling at LNEC. The test specimen will be sent back to Italy after testing, for reassembling and to be permanently monitored for durability purposes and as a showcase.

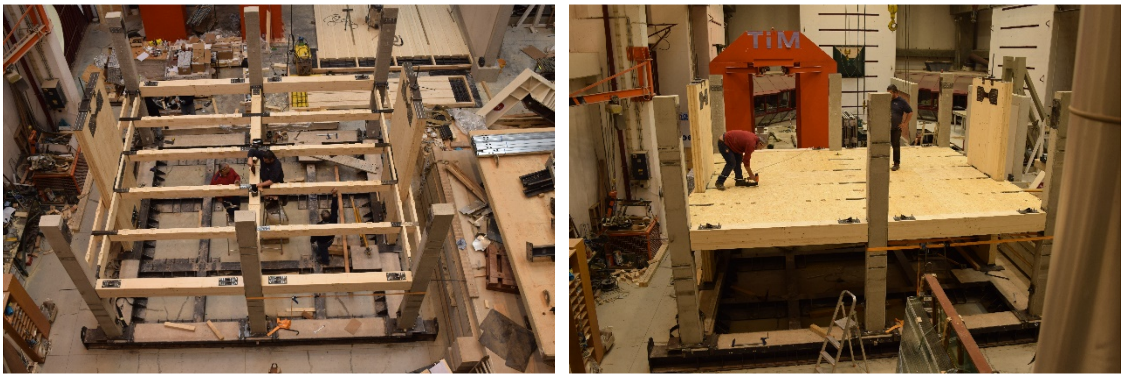

Figure 41: Construction of the specimen: skeleton of the structure (left) and mixed concrete-timber floor (right).

4.2.4 Foreseen activities and schedule

Two configurations are adopted for the non-structural elements, as shown in Figure 40. The bare skeleton will be tested initially, in a few weeks, followed by the tests with the two non-structural envelopes.

The testing protocol consists on the use of a set of far-field and near-field ground motion records with three components (X-Y-Z directions). For each suite of records three-to-five levels of intensities will be used corresponding to the annual probability of exceedance (return period) of code-based and performance limit states (e.g. 1/25, 1/50, 1/100, 1/250, 1/500, 1/2500). Not all records will be tested at the higher 1/500 or 1/2500 intensities.

Allowance for mounting of the non-structural components will be considered, with the same set of records at the same number of intensities as previously done for the structural system will be tested.

Following this phase, the specimen will be lifted from the table and modified to the second non-structural envelope solution. The whole project has been developed according to the following timetable, which starts at the 1st January 2018:

Steps	Month 3	Month 6	Month 9	Month 12	Month 15	Month 18	Month 21	Month 24	Month 27
1									
2									
3									
4									
5									
6									
7									
8									
9									

Brief description of each step:

STEP 1 – Preliminary and developed design of test specimen – analytical check

STEP 2 – Detailed design of test specimen, test setup and instrumentation – blind predictions

STEP 3 – Confirmation of shop-drawings, order of materials and procurement

STEP 4 – Construction of specimen: assembly of model + instrumentation (Option 1)

STEP 5 – Lifting of specimen on the shaking table and experimental tests

STEP 6 – Removal of specimen from the testing rig and partial de-mounting

STEP 7 – Assembly of model + instrumentation (Option 2)

STEP 8 – Lifting to table and testing

STEP 9 – Removal of specimen off table. Disposals/relocation of material/specimen

The foreseen experimental tests are thus planned for April/May 2019 and July 2019.

4.2.5 User Group

	NAME	ORGANIZATION NAME	ORGANIZATION COUNTRY
USER GROUP LEADER	Stefano Pampanin	Sapienza University of Rome	Italy
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	Daniele Perrone	IUSS Pavia	Italy
	Bozidar Stojadinovic	ETH Zurich	Switzerland
	Anastasios Tsiavos	ETH Zurich	Switzerland
	Damian Grant	Arup	UK
	Rachid Abu-Hassan	Arup	Netherlands
	Michele Palmieri	Arup	Netherlands
	Alessandro Palermo	University of Canterbury	New Zealand
	Giuseppe Loporcaro	University of Canterbury	New Zealand
	Gabriele Granello	University of Canterbury	New Zealand
	Jonathan Ciurlanti	Sapienza University of Rome	Italy
	Simona Bianchi	Sapienza University of Rome	Italy
	Murilo Mancini	Sapienza University of Rome	Italy

4.3 Project #3 – Seismic Testing of Adjacent Interacting Masonry Structures (AIMS) – [in progress]

4.3.1 Summary of the project

In many historical centres in Europe, stone masonry buildings are part of building aggregates, which developed when the layout of the city or village was densified. In these aggregates, adjacent buildings share structural walls to support floors and roofs. Meanwhile, the masonry walls of the façades of adjacent buildings are often connected by dry joints since adjacent buildings were constructed at different times. Observations after, for example, the recent Central Italy earthquakes showed that the dry joints between the building units were often the first elements to be damaged. As a result, the joints opened up leading to pounding between the building units and a complicated interaction at floor and roof beam supports.

Stone masonry buildings with timber floors are thus among the most vulnerable buildings when subjected to earthquake excitation. Key challenges of the seismic assessment of stone masonry buildings are related to (i) their flexible ceilings (timber floors), which largely prevent the transfer of forces between walls and favour local out-of-plane failure mechanisms, (ii) the largely unknown deformation capacity of stone masonry walls under in-plane loading, (iii) the sparse information on the response of spandrels, (iv) the interaction of in-plane and out-of-plane failure modes and (iv) the interaction between adjacent buildings in building aggregates.

The analysis of such building aggregates is very challenging and modelling guidelines are missing. Advances in the development of analysis methods have been impeded by the lack of experimental data on the seismic response of such aggregates. The objective of this project is to provide such experimental data by testing an aggregate of two buildings under two components of horizontal excitation. One building is a two-storey building, the other a one storey building. The buildings share one common wall while the façade walls are connected by dry joints. The floors are at different heights leading to a complex dynamic response of this smallest possible building aggregate. The results of the shake table test will allow (i) to investigate the behaviour of pounding masonry structures, (ii) to develop a rational method for the analysis of such aggregates using equivalent frame models, and (iii) to define performance limits for this type of aggregate structure.

4.3.2 Main research objectives and expected contribution to the seismology and earthquake engineering community

The objective of this study is to investigate the seismic response two adjacent stone masonry buildings, which are solely connected by a dry joint. In particular, the influence of the dry joint on the in-plane and out-of-plane response of the adjacent masonry walls will be studied under increasing levels of seismic excitation. It is expected that the building units will first respond as a unity and with increasing level of excitation, after damage to the joints, respond independently, which leads to pounding of the building units.

It is expected that the shake table tests of the proposed test unit will provide important insights and high-quality data on the following issues concerning the behaviour of stone masonry building aggregates:

- Information concerning performance limits of stone masonry aggregates;
- Data on the degradation of the dry joint between the units and the interaction (pounding) after the joint has been strongly degraded;
- Information on the energy dissipation resulting from pounding;
- Information on the interaction of in-plane and out-of-plane failure mechanisms of stone masonry buildings;
- Data for the validation of numerical models of stone masonry aggregates.

The character of many European historical centres is determined by aggregates of stone masonry buildings. Past earthquakes have highlighted the vulnerability of these structures. In order to assess the seismic performance of such buildings and to design effective retrofit interventions, it is important to understand the nonlinear dynamic response of such an aggregate. This includes in particular the effect of the damage to the joint between buildings on the dynamic response of the buildings including pounding effects and the effect of the joint damage on the in-plane and out-of-plane response of adjacent walls. One of the main objectives of this project is to generate the first experimental data that allows to validate models for the dynamic response of stone masonry building aggregates.

The test results will be used to gain insight into the dynamic behaviour of stone masonry building aggregates under seismic loading. It will yield in particular insights into (i) the behaviour of dry joints between building units and their degradation during earthquake excitation, (ii) the pounding between building units, (iii) the interaction of in-plane and out-of-plane failure modes. The data collected during the test will be carefully curated and made publicly available to the research community. The results can serve the research and engineering community for validating numerical and mechanical models of such building aggregates. It is assumed that the current lack of corresponding experimental data has impeded the development of such models and the results of this test might trigger the development of new and more advanced models. To foster the validation of models with regard to their capability to model the interaction in such building aggregates, a blind prediction will be organised. For this purpose, colleagues worldwide (participants of masonry conferences and mini-symposia at international conferences dedicated to modelling masonry structures) will be invited to predict the response a priori as well as to update their response posteriori. The results will be summarised in a publication. If sufficient entries are received, a special session at the WCEE in Japan or one of the annual masonry conferences will be considered.

Regarding the impact on the European standardization and design practice, the analysis of building aggregates is not treated by the current version of Eurocode 8 nor is it included in the 2nd generation under preparation. This is most likely due to the fact that, at present, established and validated analysis methods are missing. As a result, the seismic response of building units that are part of aggregates are often analysed without considering the interaction between units. The results of this test will allow to validate more accurate analysis techniques for such building aggregates.

The proposed test specimen is an aggregate consisting of one two-storey unit and one single-storey unit, as shown in Figure 42. The separating wall belongs to the two-storey unit but the beams of the single unit frame into this wall. The masonry buildings will be connected by a dry joint, as mentioned before. The objective was to design a test unit which is as simple as possible but allows to investigate the research objectives. For this purpose, it was decided to design a one-storey unit and a two-storey unit with floors at different heights. The proposed test unit is a near full-scale unit (1:1.25).

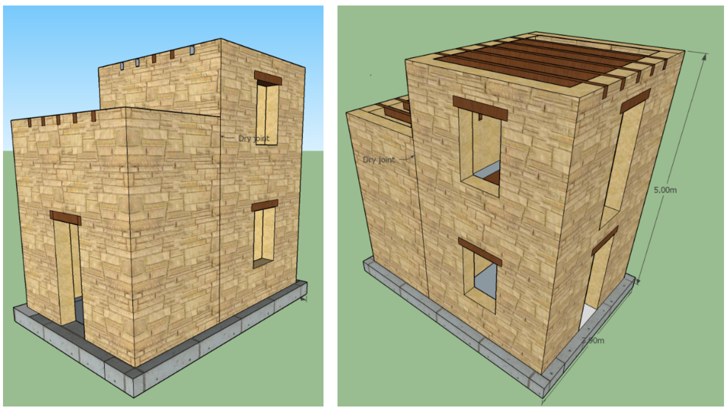

Figure 42: Proposed test specimen.

4.3.3 Project status

The floor area of the test unit is 4.10 m x 2.10 m. The stone masonry walls will be constructed using stone masonry of typology A-B. The corners of the units should be constructed with large square blocks, which provide good interlocking, in order to avoid a premature failure of the corners. The timber beams for the floors and the lintels above openings are spruce beams with cross sections of 8 x 12 cm. The floor boards are boards of 2.5 cm thickness. The walls will be plastered on the outside and painted white in order to easily identify cracks.

Regarding the construction of the test unit, a key element of the specimen is the dry joint between the two building units. In order to obtain a realistic response of this dry joint, the two buildings need to be constructed one after the other. The two-storey structure should be constructed first. Then, the roughness of the surface, which will become the dry joint connecting the two units, should be measured by laser scanning. Afterwards, the one-storey unit should be constructed. The joint surface should have a natural roughness but no mechanical connection should cross the surface.

The test unit will be subjected to a series of tests with increasing levels of intensity. Based on first analyses it was proposed to carry out five tests with PGAs between 0.05g and 0.40g (0.05g, 0.1 g, 0.2g, 0.3g, 0.4g). The PGA level of 0.4g corresponds to the estimated level of a near or partial collapse. Testing the structure up to this level would allow to cover a large range of performance levels. For each intensity level, it would be desirable to carry out three tests: First, in the longitudinal direction in order to increase the damage to the joint. Second, in the transverse direction to investigate the influence of the joint damage on the out-of-plane response of the long façade. Third, a bi-directional test to investigate the interaction of the in-plane and out-of-plane mechanisms. Between the tests, dynamic identification tests should be carried out in order to evaluate the shift in the natural frequencies.

The analyses will be repeated and refined once the design of the test unit is finalized. The ground motion will correspond to the two horizontal components of a real ground motion. This ground motion will be scaled to the pre-determined PGA-levels and must fit the velocity and displacement limits of the TA facility.

The project is currently ongoing. LNEC and UG3 have been exchanging information and performing face-to-face meetings and teleconferences for finalizing the design of the structure and to prepare the construction of the specimens, the test setup and the instrumentation layout. Contacts with contractors were successfully established for the construction of the specimen and the tender is expected to be finalised in June 2019.

4.3.4 Foreseen activities and schedule

The whole project has been developed according to the following timetable, which starts at the 1st January 2018:

Steps	Month 3	Month 6	Month 9	Month 12	Month 15	Month 18	Month 21	Month 24	Month 27
1									
2									
3									
4									
5									
6									

Brief description of each step:

STEP 1 – Detailed design of the test specimen and setup

STEP 2 – Record selection and finalization of test program; launching of blind-prediction competition

STEP 3 – Construction of the test unit, plastering and painting of outer wall surfaces (outside the laboratory), curing period

STEP 4 – Transportation of test unit onto shake table, installation of the instrumentation and test

STEP 5 – Material tests (compression tests on masonry wallettes, standard tests on masonry samples)

STEP 6 – Post-processing of the results; preparation of test report, preparation of data sets for open access, preparation of journal and conference articles

The foreseen experimental tests are thus planned for September/October 2019.

4.3.5 User Group

	NAME	ORGANIZATION NAME	ORGANIZATION COUNTRY
USER GROUP LEADER	Katrin Beyer	EPFL	Switzerland
ADDITIONAL USERS	Andrea Penna	Univ. Pavia	Italy
	Matthew DeJong	Cambridge Univ.	United Kingdom
	Christoph Butenweg	RWTH Aachen	Germany

5 University of Patras

The STRULAB of University of Patras attracted the interest of 5 research groups in the first call – two of the proposals were assigned to the Lab (ARISTA and ARCO) in the first Call, while a 3rd one was undertaken following the 2nd Call for Proposals. The three projects assigned, completed the available access days to be provided by the Lab in SERA.

Until M12, the first two Phases of project ARISTA were completed (i.e. design and construction of the specimen, instrumentation and free vibration testing). Twenty-seven access days were used for carrying out the ARISTA project

From M13 to M24, the project ARISTA was completed (test phases 3-5) and a paper comprising the test results was submitted (to the Bulletin of Earthquake Engineering). In the sequence, the Agreement with the user team of ARCO was signed and four specimens were designed and constructed for project ARCO. The special test setup required for this project was also designed and assembled. Testing of two of the ARCO specimens has been completed so far (M24). Finally, the Agreement with the project team HITFRAMES was signed.

For the period M25-M36, the remaining two specimens for ARCO will be tested and the HITFRAMES structure will be constructed and tested.

5.1 Project #1 – ARISTA - [concluded]

5.1.1 Summary of the project

The proposed research focused on the response of existing reinforced concrete (RC) structures designed with smooth bar reinforcement and without or limited, seismic design provisions. It involved near-full scale (2:3) two-bay 2D frames with three stories, in order to include a typical intermediate story (the middle one), the ground story with the connection to the foundation, and the top story with the column bars terminating at the level of the roof.

5.1.2 Main research objectives and expected contribution to the seismology and earthquake engineering community

The goal of the tests was to further our understanding of the seismic behavior of RC frame structures with plain bars and support the validation of existing models of the behavior or the development of new ones. A broader goal was to either confirm the conventional wisdom that structures with plain bars are inherently vulnerable to earthquakes or challenge it.

The results of the experiments and their numerical simulation by the proposers will allow calibration of models for the ultimate goal of the calculation of the its secant stiffness to the yield point and its ultimate chord rotation under cyclic loading - identified in a test with the point beyond which resistance cannot rise above 80% of its peak value during the test.

The calibration of these models will aid the assessment process of existing non-seismically designed RC frames and their retrofitting with FRP jacketing thus having a contribution to the public safety of people in the seismic regions and promote sustainable development, since existing buildings will be strengthened allowing for the sustainable use of resources through extending the life of the buildings.

5.1.3 Project status

The project has been completed. Column detailing, the testing program and instrumentation focused on the behavior of plain bars and its impact on local and global performance. Four of the six columns followed the standard old practice of lap-splicing the vertical bars at floor levels and at the connection to the foundation; for comparison, two diagonally opposite corner columns had continuous bars, from the footing to the roof. Moreover, after three half-cycles of inelastic deformation, the frame had both ends of three of its ground story columns wrapped in FRP jackets, before been subjected to larger amplitude cycles; the FRP-wrapped columns were compared to the unretrofitted columns of the ground story and those of the intermediate one, which were subjected to similar deformation demands as the columns of the ground story.

Figure 43: Test frame under construction (left), tested of as-built (middle) and after retrofitting (right)

Figure 44: ARISTA frame damage: initial structure (top row) and the retrofitted structure (bottom row)

The resulting shear-interstory drift loops were characterized by an inverted-S shape – typical of bond-slip loops – showing that the hysteretic behavior of all stories in the frame was governed by the bond along the column bars; nevertheless, cyclic strength decay, also typical of bond-slip loops, was not observed at story level or in the entire structure.

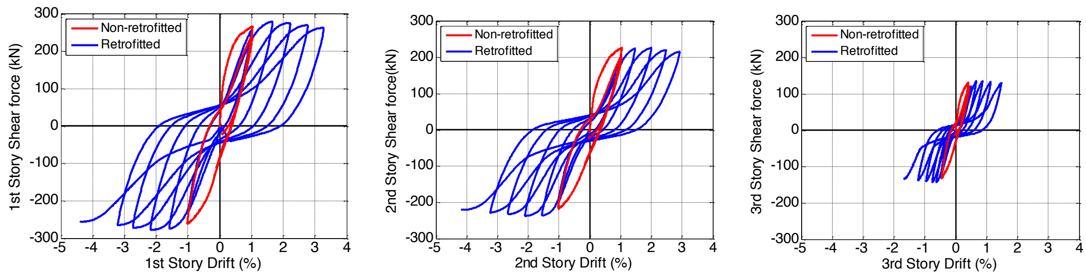

Figure 45: Test frame story shear-interstory drift for 1st (left), 2nd (middle) and 3rd (right) story, for the initial and the retrofitted structure

Chord rotation demands reached 0.055 rads and story drifts almost 5%, causing: a) debonding of FRP overlays applied on the exterior face of joints after their diagonal cracking early in the test, b) residual through-thickness cracks in slabs and torsional ones in transverse beams, as slabs worked as effective flanges of the beams and transferred them in-plane forces to the frame's joints by torsion in the transverse beams. Column deformations were concentrated at flexural cracks at the top and base sections, due to slippage of the plain bars. Hysteresis loops had a shape typical of bond-slip behavior, but without strength decay during load cycling. The dominant role of bar slippage in the response did not lead to transfer of bar tension to the hook at the bars' far end: the strains show that wherever the surrounding concrete was in compression, column bars were in compression as well. Lap splices at and/or FRP wrapping of column end regions did not have systematic effects on column behavior. Overall, no adverse effect of the use of plain bars was identified.

5.1.4 Foreseen activities and schedule

The test results have been elaborated by the Lab and user teams and a joint paper has been prepared: “Three-story, two-bay concrete frames with plain bars under cyclic lateral loading”, X. Palios, E. Strepelias, N. Stathas, M.N. Fardis, S. Bousias, C. Z. Chrysostomou, N. Kyriakides. The manuscript has been submitted for possible publication to a highly esteemed journal in the area of earthquake engineering, i.e. the Bulletin of Earthquake Engineering.

The STRULAB team is currently actively engaged in uploading the experimental data to the Data Access Portal it maintains.

5.1.5 User Group

	NAME	ORGANIZATION NAME	ORGANIZATION COUNTRY
USER GROUP LEADER	Prof. Christis Chrysostomou	Cyprus Univrsity of Technoilogy	Cyprus
ADDITIONAL USERS	Dr. Nicholas Kyriakidis	Cyprus Univrsity of Technoilogy	Cyprus
	Prof. Panagiotis Kotronis	Ecole Central de Nantes	France
	Dr. Sofia Grammatikou	DENCO Structural Engineering	Greece

5.2 Project #2 – ARCO - [in progress]

5.2.1 Summary of the project

Project ARCO: "Effect of Axial Restraint on the seismic behavior of shear-dominated COupling beams", will focus on testing to failure of coupling beams with various levels of axial restraint. As coupled-wall systems built before the 1970s are the most susceptible to brittle failures, the test specimens will feature conventional orthogonal reinforcement which does not meet the current design requirements. Three nominally identical coupling beams will be tested to failure under reversed cyclic loading and variable level of axial restraint to investigate the effect of the restraint on their seismic performance. Furthermore, while the first three specimens will be subjected to a conventional loading protocol with a gradually increasing displacement magnitude, a fourth beam will be tested under a large inelastic pulse in one direction followed by a push to failure in the opposite direction. Even though this loading scenario is realistic and can cause severe strength degradation, it has been neglected in experimental studies.

5.2.2 Main research objectives and expected contribution to the seismology and earthquake engineering community

Past studies regarding coupled wall systems neglected the restraining effect on the elongation (due to cracking and yielding) of the beams owing to the surrounding stiff walls and floor diaphragms – the restraint yields axial compression forces on the beams, influencing their deformation capacity. Exactly because past experimental studies have almost exclusively neglected this effect, the latter is not captured by current models for coupling beams and it is not included in code provisions such as EC8 Part 3 for the performance-based seismic evaluation of existing buildings.

The research project focuses in addressing the identified gap of knowledge, through testing coupling beams to failure, considering – for the first time – various levels of axial restraint. One of the most innovative aspects in the project is the evaluation of the components of shear resistance based on detailed deformation measurements. This new experimental evidence will have a significant impact, not only on the modelling of coupling beams, but a variety of critical regions and elements such as deep girders, short walls, short columns, beam-column joints. Finally, the original experimental study will be used to advance an innovative kinematics-based approach along with stress-field and plasticity models in order to capture the effect of axial restraint, and to integrate these models into the framework of EC8 Part 3 for the seismic evaluation of existing buildings.

5.2.3 Project status

The project is midway of being completed (2 out of 4 specimens completed). The test setup designed for the testing activities comprises a very stiff L-shaped steel beam, prestressed on the top block of each specimen. Two horizontal actuators are acting on the vertical leg of the L-beam, at the level of the specimen mid-height. This scheme results in applying constant shear force, with equal and of opposite sign moments acting on the top/bottom of the specimen, simulating double-fixity conditions. A pair of vertical actuators attached on the horizontal portion of the L-beam guarantee that no rotation develops at the top block, while also maintaining a certain level of axial force or specimen axial deformation (either zero or of predefined value).

Four specimens have been constructed for the purposes of the project.

Specimens RB1, RB2, RB3: all 3 are identical in terms of reinforcing pattern and loading (monotonic). The loading scheme for these specimen comprises application of a monotonically increasing horizontal force, while the vertical actuators may: (a) allow for free vertical deformation of the specimen (specimen RB1), (b) fully constrain member axial deformation (specimen RB2), and (c) apply a user-defined level of axial force such that the specimen can develop limited axial deformation (specimen RB3). The loading history was developed on the basis of non-linear fem analyses carried out by the users.

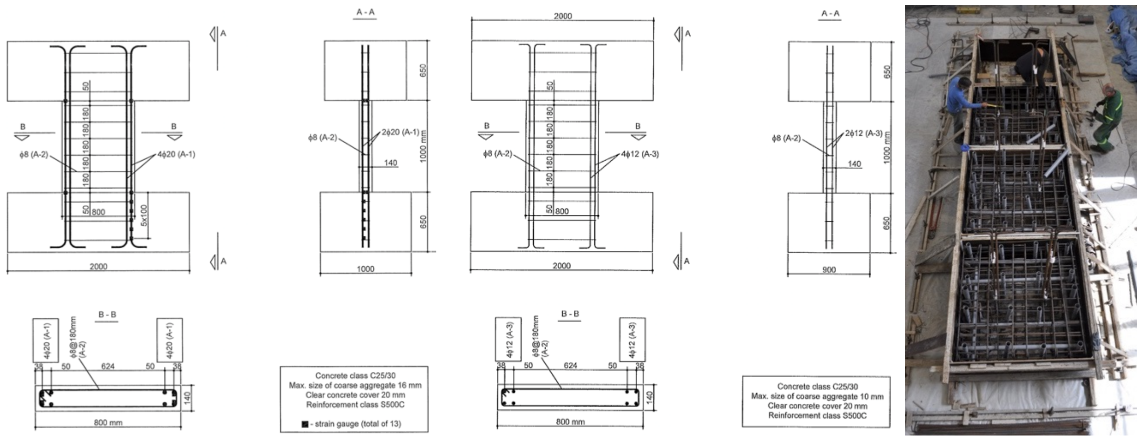

Figure 46: Dimensions and reinforcing pattern for specimens RB1-3 (left), RB4 (middle), specimen construction (right)

Specimen RB4: While tests RB1-3 are to be performed under a typical loading protocol with gradually increasing cyclic displacements, specimen RB4 has been tested under a different loading sequence. In the latter test, after applying several symmetrical cycles prior to the yielding of the flexural reinforcement, the specimen was subjected to a large inelastic displacement in the “positive” loading direction followed by a push to failure in the “negative” direction. Past studies have shown that gradual cyclic loading results in negligible reduction of peak resistance, but a significant reduction of ductility as compared to monotonic tests. It is expected however that the proposed loading protocol for the fourth test can be more severe, as it can also cause a significant strength reduction in the “negative” loading direction.

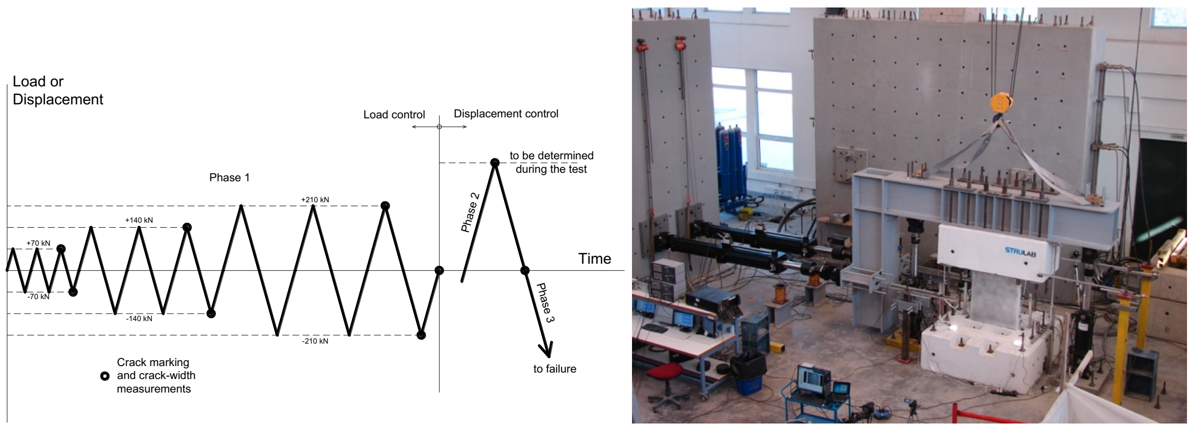

Figure 47: Loading scheme for specimen RB4 (left) and specimen setup for testing (right)

The specimens tested were strategically instrumented, while digital image correlation techniques were also employed for providing users the necessary data for their model calibration. To that end, a random black-white dots pattern of varying size was created at the front side of the specimen.

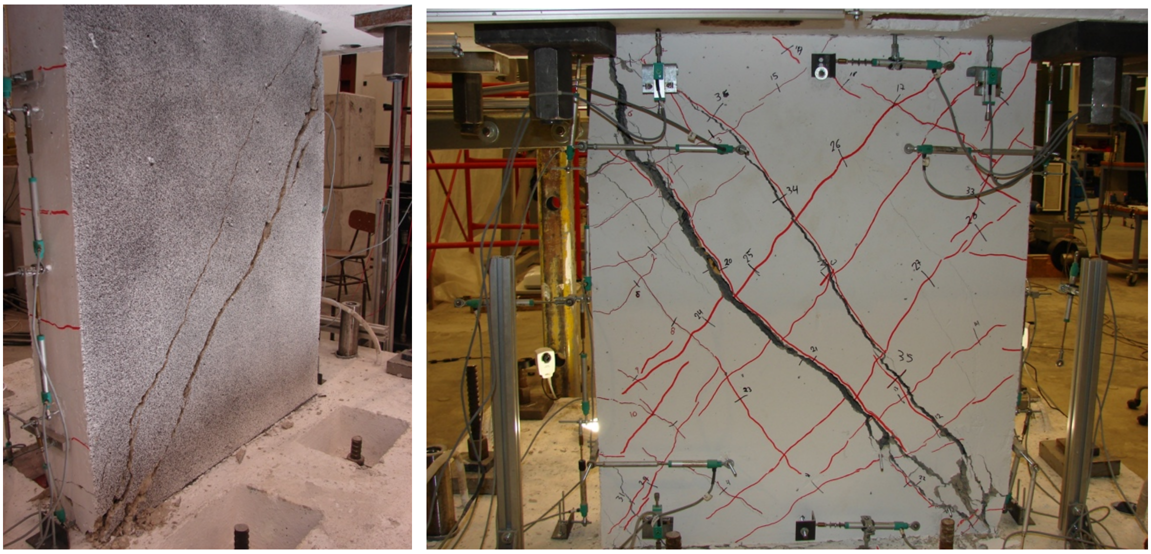

Figure 48: Specimen RB4 at (shear) failure: front side with DIC pattern (left), back side (right).

The specimen force-displacement response is depicted below.

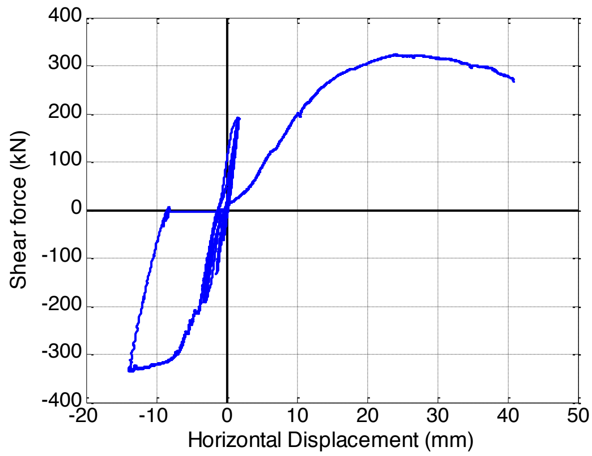

Figure 49: Specimen RB4 response: force-displacement response curve

5.2.4 Foreseen activities and schedule

The remaining two specimens are scheduled for testing in the next weeks. Data elaboration will follow, along with data uploading to the Data Access Portal.

5.2.5 User Group

	NAME	ORGANIZATION NAME	ORGANIZATION COUNTRY
USER GROUP LEADER	Prof. Boyan Mihaylov	University of Liege	Belgium
ADDITIONAL USERS	Prof. Joao Almeida	University of Lisbon	Portugal
	Miguel Ferreira	University of Lisbon	Portugal
	Prof. Lars German Hagsten	Aarhus University	Denmark

5.3 Project #3 – HITFRAMES - [in progress]

5.3.1 Summary of the project

Several existing steel multi-storey residential framed buildings were designed primarily for gravity loads; they exhibit low energy absorption and inadequate dissipation capacity under seismic loadings, as demonstrated by recent earthquakes occurred in the Mediterranean regions. The low lateral stiffness and strength of the steel framed structures and the slender masonry infills induce significant lateral drifts, buckling and/or facture of structural steel members. Additionally, the current provisions for the seismic performance assessment of existing steel structures are scarce and they do not account for the presence of the infills. It is therefore necessary to provide effective methods for the seismic assessment and retrofitting of existing non-compliant steel frames.

Another project innovation is the use of the hybrid simulation technique that will be employed in testing the structure at question.

The project comprises two distinct parts: in the first, a 3D substructure of the prototype steel building will be constructed and tested, with the rest structure represented numerically (hybrid simulation approach). The structure is a 3D steel frame with concrete slabs and masonry infilling (Figure 50).

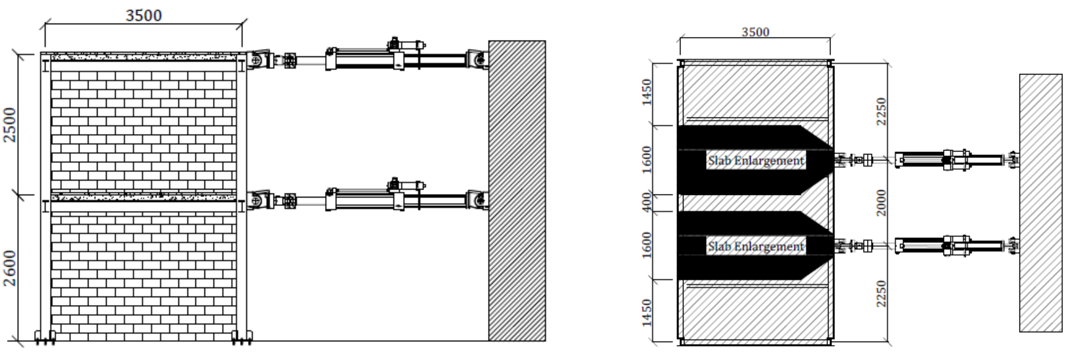

Figure 50: Scaled, 3D infilled frame: side view (left) and plan view (right)

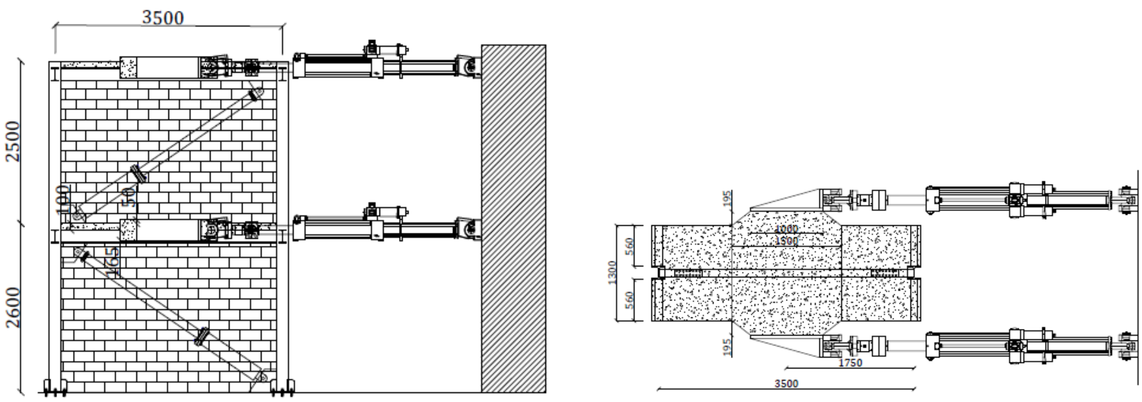

Figure 51: Scaled, 2D infilled frame, BRB retrofitted: side view (left) and plan view (right)

The testing program is summarized below:

		modal test	1st record - Amatrice sequcence	Sequence of 4 natural records registered at Amatrice
3D frame, 1x1 bays, 2 storey model	bare frame	1		
	infilled frame **(No BRB)**	2	3	4

			1st record of Amatrice sequcence	Sequence of 4 natural records registered at Amatrice
2 storey, 2D frame	bare frame	1		
	infilled frame (No BRB)	2		
	BRB retrofitted frame	3	4	5

(numbers indicate the testing sequence)

5.3.2 Main research objectives and expected contribution to the seismology and earthquake engineering community

The HITFRAMES project aims at:

1. Developing reliable methods for the seismic assessment of existing steel frames, especially under multiple earthquakes;
2. Developing design procedures for buckling restrained braces (BRBs), considering contribution of masonry infills in the lateral load resisting system;
3. Evaluating the effectiveness of BRBs, as seismic retrofitting measure;
4. Deriving fragility curves for existing steel frames with infills and systems retrofitted with BRBs and infills, considering also the effects of earthquake sequences.

The project will also facilitate the development of pre-normative documents for the seismic assessment and retrofitting of existing steel multi-storey buildings, which will be adopted as background documents for the on-going revision of steel section of EN1998-3.

The User Agreement for the project has been signed. The user team is currently elaborating on the design of the specimens. The final design is expected by the end of March.

5.3.3 Project status

The User Agreement has been signed. The project is currently at the initial phase of specimen final design and preparation for call for tenders.

5.3.4 Foreseen activities and schedule

Following the availability of the final design drawings, the Lab will proceed with a Call for tenders for specimen construction and delivery.

5.3.5 User Group

	NAME	ORGANIZATION NAME	ORGANIZATION COUNTRY
USER GROUP LEADER	Prof. Luigi di Sarno	University Liverpool University of Sannio	Belgium Italy
ADDITIONAL USERS	Prof. Raffaele Landolfo	University of Naples Federico II	Italy
	Prof Matjaz Dolsek	University of Ljubljana	Slovenia
	Prof. Fabio Freddi	University College London	UK
	Prof. Oh-Sung Kwon	University of Toronto	Canada
	Dr. Jamin Park	University of Toronto	Canada
	Dr Maria Gabriella Castellano	FIP Industriale	Italy

6 University of Bristol

The Earthquake and Large Structures (EQUALS) Laboratory at University of Bristol has been delivering sound research for many EU actions, including SERA. Within the context of the present EU H2020 SERA project, the 1st Call attracted the interest of 7 research groups – three of the proposals were assigned to the Lab (SERENA, 3DRock, RE-BOND). The 2nd Call of the project submissions attracted a total of 4 research groups – two of the proposals were assigned to the Lab (NSFuse and SEBESMOVA3D). The 3rd Call attracted the attention of 3 research groups and two more proposals were assigned to the Lab (SHATTENFEE and SSI-STEEL). The seven projects assigned completed the available access days to be provided by the Lab in SERA. Agreements for all projects have been signed.

Until M12, the first phases of projects SERENA and RE-Bond were completed (i.e. design of the experimental rig and the instrumentation). Also, some preliminary work was done on project 3DRock. No access days were used in carrying out the experimental campaigns.

From M13 to M24, two of the projects, namely, SERENA and 3DRock, have practically been finalized. Also, agreements for all seven projects were signed. A paper summarising the test results on SERENA was submitted to COMPDYN2019 Conference and a draft for a journal paper on the same project was put together and is currently under review. The experimental data from project 3DRock have been forwarded to the users for processing, and a first paper is under preparation. UBRI is currently actively engaged in uploading the experimental data of the first two projects to the Data Access Portal.

Significant work has been undertaken on the other three projects during the specific period and all projects have been granted shaking table access days. These projects are: RE-BOND, NSFuse and SEBESMOVA3D. Training of the shaking table for the RE-BOND and NSFuse projects has now been completed. The procurement of parts for RE-BOND and SEBESMOVA3D experimental rigs have also been finalized by large. The testing slots for these three projects have been allocated on the shaking table calendar and the progress of the preparatory work suggests that allocated testing slots will be taken up by these projects from M24 onwards.

With reference to the two projects added to the roster in the 3rd Call, namely SHATTENFEE and SSI-STEEL, following the ratification of the agreements by the Institutions, the kick off meetings have taken place and the rigs have been designed. Training for the shaking table is to be completed in April 2019 and the projects, are to be delivered in due course. Fifty percent of the total assigned access days were used during this period.

For the period M25-M36, the remaining five projects will be completed. Specifically, projects RE-BOND, NSFuse, and SEBESMOVA3D are scheduled to be completed in 2019, while projects SHATTENFEE and SSI-STEEL will be completed in 2020. All shaking table slots have been allocated and the remaining fifty percent of the total assigned access days will be used during that period.

6.1 Project #1 – SERENA – Seismic Response of Novel Integral Abutment Bridges – [in progress]

6.1.1 Summary of the Project

Summary and objectives of proposed research Integral abutment bridges under seismic action will be studied including soil-structure interaction. Integral Abutment Bridges are characterized by the elimination of support and joints. Therefore, are totally monolithic structures. Integral Abutment

Bridges (IAB's) is a classical design, dating back at least to the 1930's, which exhibits distinct advantages over conventional bridges with joints, especially with reference to simplicity of construction, maintenance and durability. In addition, use of prefabricated segments may accelerate construction and lower uncertainty, and reduce cost. Despite these merits, IAB's are known to possess a number of disadvantages associated mainly with development of stresses/cracking due to thermal, creep and concrete shrinkage effects, as well as settlements on the approach slabs. As a result, the behavior of the abutments controls the design of such structures. Important unknowns include: (1) the magnitude and distribution of soil pressures on abutment walls as function of the deck elongation/contraction due to temperature variation, (2) corresponding magnitude of shear forces and bending moments on piles under the abutment, and normal forces and bending moments on the monolithic connection between abutment and deck, (3) associated deformations in the superstructure and foundation, (4) best measures to minimize the above using compliant materials at soil-structure interfaces such as EPS geofoam. Additional concerns (5) come from earthquake response of such bridges, which is strongly dependent of abutment stiffness - thus on SSI - and may lead to significant stress/deformation demands on the structural elements. Therefore, one of the main concerns in this type of structures comes from the settlements in the backfill which are strongly demonstrated by the push and pull at the abutment due to temperature variation, while settlements often occur after earthquakes even of moderate intensity. The consequences in term of road safety and related maintenance costs are of paramount importance and impact. The proposed research effort focuses on the last item in the above list, with the aim of developing a basic understanding through shaking table testing and subsequent simulations on: (A) the earthquake response of such systems, and (B) ways of minimizing associated demands using pertinent design solutions such as disconnecting (C) the pile heads from the cap, and (D) the abutments from the backfill through a vertical coat of EPS geofoam, (E) settlement due to dynamic compaction effects in the backfill. To the best of the Co-I's knowledge, research on the above has been very limited. Findings from the proposed research may lead to the development of engineering provisions such as the Eurocodes. Photographs depicting the experimental setup mounted on the shaking table at University of Bristol is given in Figure 55.

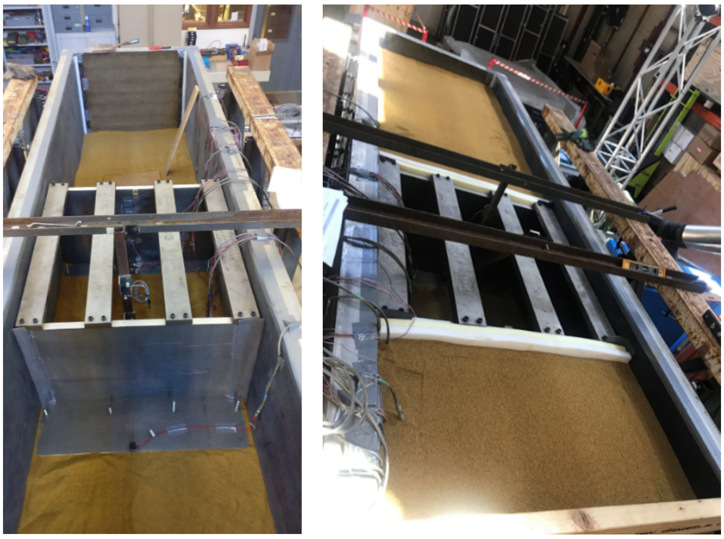

Figure 52: Experimental model on shaking table, (left) prior to the infill of backfill (right) backfilled model

6.1.2 Main research objectives and expected contribution to the seismology and earthquake engineering community

The objectives of the project are:

1. To explore response of Integral Bridge Abutments (IABs) on a shaking table
2. Explore different connection schemes between: (i) abutment and piles, (ii) abutment and backfill using a variety of materials such as gravel and EPS geofoam
3. Explore alternative/innovative materials for applications
4. Explore the influence of vertical components of the earthquake motions
5. Conduct numerical simulations using state of the art software

6.1.3 Project status

The experimental programme has been completed. 28 access days were allocated to this project. Currently analysis of the data is almost finished, and publications are being authored. A conference proceeding has been prepared for COMPDYN 2019 7th ECCOMAS Thematic Conference on Computational Methods in Structural Dynamics and Earthquake Engineering. The full paper of this contribution is added to this report in the addendum section.

6.1.4 Foreseen activities and schedule

Since the experimental programme has been completed in the summer of 2018, the direction of the research endeavour is towards rigorous analysis of the gathered data. Analysis of the data is undertaken to reveal some of the soil structure interaction SSI phenomena occurring in integral bridges. Currently the analysis effort is jointly pursued between the host facility and the transnational access users. A journal article is being prepared and a draft of the paper is now ready. The journal paper will be submitted to Earthquake Engineering and Structural Dynamics journal.

UBRI is currently actively engaged in uploading the experimental data to the Data Access Portal.

6.1.5 User Group

	NAME	ORGANIZATION NAME	ORGANIZATION COUNTRY
USER GROUP LEADER	Camillo Nuti	Rome Tre University	Italy
ADDITIONAL USERS	Christos Vrettos	Technische Universität Kaiserslautern	Germany
	Antonio Topa Gomes	University of Porto	Portugal
	Tatjana Isakovic	University of Ljubljana	Slovenia
	Bruno Briseghella	University of Fuzhou	China

6.2 Project #2 – Statistical Verification and Validation of 3D Seismic Rocking Motion Models – [in progress]

6.2.1 Summary of the project

This project aims to generate the data to statistically validate analytical and numerical models used to describe the motion of rocking structural systems excited by earthquakes. Even though rocking models have been used in practice to evaluate the seismic performance of structures and non-structural (but essential) equipment that uplifts and rocks, there is a consensus that these models are not validated: Rocking motion is very sensitive to the initial and boundary conditions, as well as the excitation, and is highly non-linear. To date, all of the attempts to deterministically match the numerical and experimentally measured time histories of the response of rocking blocks to earthquake excitations have failed.

Very recently the applicants showed that even though predicting the entire time history of the response of an object rocking in-plane is practically impossible, the well-known 1963 Housner model can predict the statistics of the response to an ensemble of specifically selected ground motions quite well. They argue that such statistical model validation is relevant to earthquake engineers, since the ground motion that is going to excite the prototype structure is now known a priori; what is known are the statistical descriptions of some of the properties of ensembles of such ground motions.

As the 3D rocking motion is even more sensitive than the planar one (experiments have been reported to be non-repeatable), the statistical validation of 3D rocking models is more challenging. Moreover, another challenge is the joint statistical characterization of the three orthogonal ground motion components and appropriate generation of the ground motion ensemble for the tests. This project aims to use the 6DOF shaking of table of University of Bristol to validate two classes of 3D rocking specimens: One related to essential equipment and one related to the recently suggested concept of rocking isolation of bridges. A photograph of the test setup for the first phase of the experiments is illustrated in Figure 56 for Statistical Verification and Validation of 3D Seismic Rocking Motion Models project.

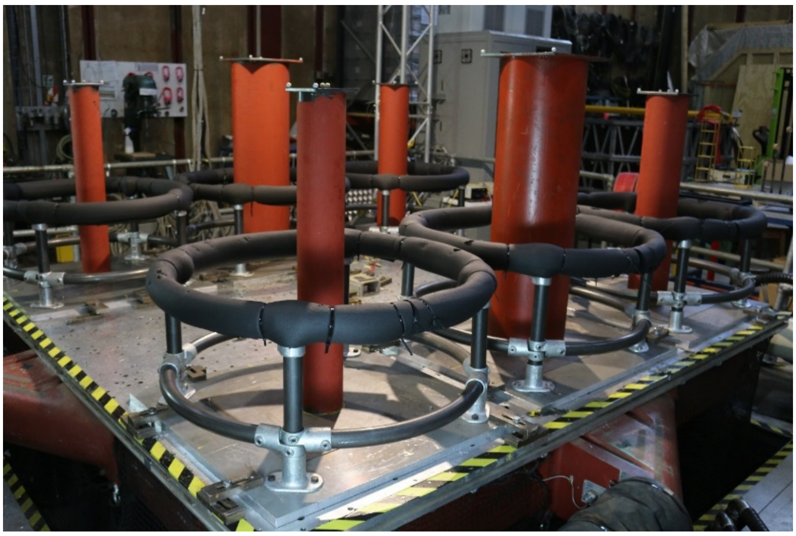

Figure 53: Individual columns (instrumented with Infrared Reflectors for motion capture) mounted on the shaking table

6.2.2 Main research objectives and expected contribution to the seismology and earthquake engineering community

The expected outcomes of this project are: generation of an experimental dataset to statistically validate a variety of 3D rocking models; validation and uncertainty quantification of a 3D extension of the 1963 Housner model; and conceptual development and implementation of a statistical validation and verification procedure appropriate for models of seismic response of structures.

6.2.3 Project status

The first phase of the project is completed in regards to experimental work. 20 days of TA access have been allocated. A second testing phase of the project is to be undertaken in M25-M36 period.

6.2.4 Foreseen activities and schedule

The second part of the experimental programme is scheduled to be conducted for two additional weeks in the beginning of May 2019. The users are currently processing the experimental data. Data uploading to the Data Access Portal will follow upon completion of the second testing phase in May 2019.

6.2.5 User Group

	NAME	ORGANIZATION NAME	ORGANIZATION COUNTRY
USER GROUP LEADER	Bozidar Stojadinovic	(ETH) Zurich	Switzerland
ADDITIONAL USERS	Michalis Vassiliou	(ETH) Zurich	Switzerland
	Marco Broccardo	(ETH) Zurich	Switzerland

6.3 Project #3 – RE-BOND – REsponse of as-Built and strengthened three-leaf masONry walls by Dynamic tests – [in progress]

6.3.1 Summary of the project

The present research proposes to test the dynamic behaviour of three–leaf masonry walls (two external leaves made of irregular stones poorly or not connected in the transversal direction separated by loose material infill in the centre) representative of a construction technique found throughout the seismic–prone Mediterranean countries. The proposed tests will also investigate the effects that the vertical component of the ground motion may have on the walls' behaviour.

Shake table tests under different loading conditions on single and T-shape masonry walls are planned, with the aim to investigate:

1. The in–plane behaviour up to failure of single isolated rectangular as–built walls;
2. The in–plane behaviour up to failure of single rectangular as–built walls connected to an orthogonal wall (T walls);

3. The influence of the vertical ground motion component on the behaviour and strength of the as built walls of points 1) and 2);
4. The effectiveness of strengthening techniques that include: a) grout injections carried out with a compatible mortar; b) addition of reinforcing devices (either steel rods or bundled steel fibers) to connect the outer stone leaves of the three-leaf walls; c) enhancement of the connections with the orthogonal wall for T walls using steel rods.

6.3.2 Main research objectives and expected contribution to the seismology and earthquake engineering community

The expected outcomes of this project are going to be the quantification of the seismic behavior of three-leaf masonry walls. The considered specimens will be built so as to reproduce a typical configuration used for three-leaf masonry walls throughout old Italian historic centres. Similar configurations are found in other Mediterranean and non-European seismic-prone countries.

6.3.3 Project Status

The shaking table at University of Bristol has been tuned to accommodate the heavy physical models required for this project. An equivalent dead weight is clamped on the shaking table platform to simulate the weight of the models and nonlinear tuning of the shaking table has been undertaken for a suite of ground motions. The design of the experiments has been completed. The delivery of the essential parts for the experimental program is on the way. The concrete slabs that are going to support the masonry walls are due to be constructed by the end of April 2019 (purchase requisitions for all materials have been approved and orders have been placed). The foreseen test slot for the experiments is in July 2019 for three weeks.

6.3.4 Foreseen activities and schedule

The delivery of the essential parts for the experimental program is on the way. The concrete slabs that are going to support the masonry walls are due to be constructed by the end of April 2019. The foreseen test slot for the experiments is in July 2019 for three weeks. Data elaboration will follow, along with data uploading to the Data Access Portal.

6.3.5 User Group

	NAME	ORGANIZATION NAME	ORGANIZATION COUNTRY
USER GROUP LEADER	Enrico Spacone	University “G. D’Annunzio” of Chieti-Pescara	Italy
ADDITIONAL USERS	Humberto Varum	University of Porto	Portugal
	George Manolis	Aristotle University of Thessaloniki	Greece
	Paolo Casadei	KERAKOLL Group	Italy

6.4 Project #4 – NSFuse: Ductile Steel Fuses for the Protection of Critical Non-Structural Components – [in progress]

6.4.1 Summary of the project

The testing and experimental/analytical verification of a controlled yielding fuse concept is proposed for the seismic protection of critical non-structural components. The objective is to offer a reliable and inexpensive solution for the protection of acceleration- and drift-sensitive equipment, such as mechanical components, HVAC units and medical devices that underpin the functionality of nearly all buildings. Recent events have showcased the vulnerability of non-structural components to even low- or moderate-intensity earthquakes that occur far more frequently that design-level events. Thus, critical facilities are often crippled for months despite having suffered little structural damage, clearly failing in the much-sought-after objective of resilience. The problem lies in the dynamics of narrowband excitations appearing at the floors (and ceilings) of buildings and the corresponding resonant response of many rigidly-connected components, introducing component accelerations that can exceed 5 times the (already amplified) peak floor response. In contrast, a controlled yielding anchor offers a reliable detuning effect that only requires a minor ductility of 1.5 – 2.0 to achieve reductions in acceleration and deformation demands by factors of 2 to 3. Still, an actual verification of this concept and a prototype design of such a fuse-like yielding element are yet to appear.

The kick-off meeting has taken place at University of Bristol. The shaking table tuning for the project is carried out. The input motions provided by transnational access users have been processed and a total of 14 time histories are programmed into the shaking table. The time histories programmed into the shaking table are actual floor recordings coming from various buildings that have suffered damages in Loma Prieta, Northridge and Ferndale earthquakes. The Ferndale recordings for example are the floor accelerations of the 4- story Eureka Hospital (depicted in Figure 57).

Figure 54: A photograph of the Eureka Hospital

6.4.2 Main research objectives and expected contribution to the seismology and earthquake engineering community

The proposed project aims to comprehensively fulfil this need by offering an innovative experimental campaign featuring an easily-modifiable specimen, replaceable sacrificial elements, and multiple input acceleration time histories from instrumented buildings to test the yielding fuse concept to satisfaction.

6.4.3 Project status

The project is currently in progress. The kick-off meeting with the transnational access users was held at the University of Bristol and a clear understanding of the research outcomes and research methodologies have been reached between the scientists. The shaking table has already been trained for 14 input motions. UBRI is currently waiting for the final/agreed blueprints of the experimental rig to be submitted by the users. Following the availability of the final design drawings, the Lab will proceed with a Call for tenders for specimen construction and delivery.

6.4.4 Foreseen activities and schedule

The second part of the experimental programme is scheduled to be conducted for three weeks (last week of October 2019 and first two weeks of November 2019). Data elaboration will follow, along with data uploading to the Data Access Portal.

6.4.5 User Group

	NAME	ORGANIZATION NAME	ORGANIZATION COUNTRY
USER GROUP LEADER	Dimitrios Vamvatsikos	National Technical University of Athens Heroon Polytechneiou	Greece
ADDITIONAL USERS	Athanasia Kazantzi	National Technical University of Athens Heroon Polytechneiou	Greece
	Dimitrios Lignos	École Polytechnique Fédérale de Lausanne	France
	Ahmed Elkady	École Polytechnique Fédérale de Lausanne	France
	Eduardo Miranda	Stanford University	USA

6.5 Project #5 – SEBESMOVA3D - SEeismic BEhavior of Scaled MOdels of groin VAults made by 3D printers – [in progress]

6.5.1 Summary of the project

This research proposal aims at developing a series of shaking-table tests on scaled models of groin vaults in different support conditions (springs either placed on fixed restraints or on typical supports like piers or walls) to analyse their behaviour under seismic excitation.

Vaults represent a very common typology of roofing structural elements in monumental buildings and, in particular, in historical masonry churches. The damages observed after recent Italian and Spanish earthquakes pointed out that vaults are among the most vulnerable elements. Thus, the understanding of their dynamic and seismic behavior represents a crucial issue for the seismic vulnerability assessment of such structures.

A vault under earthquake excitation is mainly subjected to two different phenomena: (i) response of the vault to differential horizontal displacement imposed at its springings by the excitation of the underlying structures (walls and piers), and (ii) dynamic response of the vault itself to acceleration imposed at its springings.

Experimental tests will be associated to numerical simulations, in both the design and the interpretation phases. The scaled vault will be designed and modelled not only by means of Finite Element Method (FEM), but also Distinct Element Method (DEM), using the commercial software 3DEC.

The scaled model of the groin vault will be designed as an assembly of distinct scaled “plastic-mortar” blocks: each block will be formed as a plastic skin (hollow section) and the inner core will be filled with mortar to acquire the corresponding mass for dynamic tests. The global geometry and the mass will be designed according to appropriate scaling methodologies (e.g., the Pi-Buckingham theorem). The formwork will be designed to allow the structure to be built and rebuilt after the tests at the lab facility without the need of specifically trained masons, minimising quality issues and time spent their technicians. The formwork and each scaled block of the model will be produced using a 3D printer.

The advantage of this procedure is the repeatability of the tests, as the “plastic-mortar” blocks can be reused many times after each test to quickly rebuild the scaled model and carry out new -tests. In this way the effects of different support conditions and different directions of the horizontal seismic action with respect to the geometry of the groin vault will be assessed.

6.5.2 Main research objectives and expected contribution to the seismology and earthquake engineering community

The main objective of this project is to evaluate the crack pattern and the collapse mechanism of groin vaults with two different support conditions: on four fixed points and on two columns and a wall. The information to be gained from the effect of the supporting structure is fundamental to correctly plan seismic strengthening intervention projects in vaults and will be useful to the professional engineers.

6.5.3 Project status

The project is currently in progress. The kick-off meeting with the transnational access users was held at University of Bristol and a clear understanding of the research outcomes and research methodologies have been reached between the scientists. The design of the experiments is agreed upon, all relevant materials have been ordered and the 3D printing of the groin vault bricks is about to start in Italy and shipped to Bristol in June 2019. Training of the shaking table is expected to be completed by the end of M24.

6.5.4 Foreseen activities and schedule

- 8-12 July 2019: filling the bricks with mortar.
- 29 July-2 August 2019: first assemblage of the vault model and preparation of the boundaries beside the table.

- 5-23 August 2019: tests and completion of TA access.

Data elaboration will follow, along with data uploading to the Data Access Portal.

6.5.5 User Group

	NAME	ORGANIZATION NAME	ORGANIZATION COUNTRY
USER GROUP LEADER	Dora Foti	Politecnico di Bari	Italy
ADDITIONAL USERS	Dimitris Theodossopoulos	Edinburgh College of Art (ECA)	United Kingdom
	Stefano Silvestri	DICAM– Università di Bologna	France
	Salvador Ivorra Chorro	University of Alicante	Spain

6.6 Project #6 – SHATTENFEE - SHAking Table TEsting for Near Fault Effect Evaluation– [in progress]

6.6.1 Summary of the project

Recent surveys conducted after destructive earthquakes demonstrated that, in near fault (NF) conditions, combined vertical and horizontal motions caused unusual and poorly understood damage to geotechnical and structural systems. In NF conditions, ground motions are influenced by the short distance from the fault, short time delay between P- and S-wave arrivals, and the seismic waves' incidence direction (generally not vertical). However, there is limited understanding of the effects of such NF motions on soil and superstructure response. Consequently, the existing codes of practice do not account for the combined effects of horizontal and vertical components in NF conditions and need urgent updating. Furthermore, little is understood about vertical motion effects on SSI systems, so this project will focus on this aspect as a key step in understanding the overall problem. The vertical dynamic behaviour of a typical soil deposit, with and without the presence of a foundation system and a simplified scaled oscillator as a representation of a building superstructure, will be explored experimentally on the 6-DoF shaking table at Bristol University, using a new soil container specifically designed for vertical wave propagation. The vertical dynamic response characteristics, e.g. the period of vertical vibration, damping coefficient, and effect of soil non-linearity and excitation characteristics (e.g., harmonic, impulse, seismic), will be investigated experimentally and numerically to provide fundamental insight and guide further research and code of practice development. If it proves feasible, additional insights will be gained from pilot experiments using combined horizontal and vertical motions using Bristol's existing laminar shear stacks, which were not designed for vertical motion inputs.

The principal scientific outcome will be the improved understanding of the fundamental mechanics of soil-structure interaction under vertical seismic excitation as a key step in improving knowledge on the effects of combined horizontal and vertical seismic actions in near-fault conditions. A further outcome will be a guidance route map for further research that will lead to improved code of practice provision for NF effects. Objectives: Empirical evidence will be collected from a shaking table test programme using a novel, versatile, cylindrical soil container that constrains the soil motion to the vertical direction.

Theoretical and numerical studies will complement the empirical evidence with the overall aim of obtaining a precise characterization of the mechanics of the experimental specimen, as a prototype in its own right, before mapping the characterization, through scaling logic, to representative prototype-scale SSI scenarios.

6.6.2 Main research objectives and expected contribution to the seismology and earthquake engineering community

The specific project objectives are:

- With Bristol colleagues, design and build a soil container that is suitable for vertical shaking and mitigates boundary effects, for studying the vertical wave propagation and assess the soil response;
- Assess the suitability of existing laminar boxes at Bristol (designed for horizontal motion input) for the soil response under vertical and combined horizontal and vertical components;
- Evaluate the effects of vertical strong motion on a simplified structure, (e.g. single- or two- degree-of-freedom) located at the top of a piled foundation, paying attention to NF motion characteristics;
- Build numerical parametric models, validated against the empirical evidence, to further investigate the problem;
- Clarify, and resolve where possible, epistemic uncertainty gaps that are barriers to developing new code of practice provision for NF situations, and set out a longer-term research route map for doing so. Experiment concept: Discussions with Bristol colleagues have explored the research need in detail, identified principal performance requirements of the experimental rig, and scoped out the nature and detailed objectives of the test programme.

6.6.3 Project Status

Prior discussions with the project partners have led to the design of experiments: a conceptual design of a new test rig (including instrumentation opportunities); an associated, high-level, experimental programme; and a complementary numerical study programme. The experiment concept is for a vertical, thick-walled, dynamically rigid, perspex cylindrical soil container up to 4m high and 1m in diameter.

The kick off meeting took place in Naples on 12th April 2019; details of the experimental rig were reviewed and agreed upon.

6.6.4 Foreseen activities and schedule

Tests are to be commenced in January 2020, for two weeks. As with the other projects, training of the shaking taking is expected to be completed by the end of M24. Data elaboration will follow, along with data uploading to the Data Access Portal.

6.6.5 User Group

	NAME	ORGANIZATION NAME	ORGANIZATION COUNTRY
USER GROUP LEADER	Armando Lucio Simonelli	Università del Sannio - Dipartimento di Ingegneria	Italy
	Luigi Di Sarno	Università del Sannio - Dipartimento di Ingegneria	Italy
ADDITIONAL USERS	Augusto Penna	Università del Sannio - Dipartimento di Ingegneria	Italy

	Maria Incoronata Fredella	Università del Sannio - Dipartimento di Ingegneria	Italy
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	Diletta Aliperti	Università del Sannio - Dipartimento di Ingegneria	Italy
	Carmine Lucadamo	Università del Sannio - Dipartimento di Ingegneria	Italy
	Michalis Fragiadakis	School of Civil Engineering National Technical University of Athens (NTUA)	Greece
	Ioannis Taflampas	School of Civil Engineering National Technical University of Athens (NTUA)	Greece
	Spyridon Diamantopoulos	School of Civil Engineering National Technical University of Athens (NTUA)	Greece
	Alessandro Gajo	ICAM University of Trento	Italy
	Farzaneh Ghalamzan Esfahani	ICAM University of Trento	Italy
	George Anoyatis	KU Leuven	Belgium

6.7 Project #7 – SSI-STEEL - Soil-Structures Interaction effects for STEEL structures – [in progress]

6.7.1 Summary of the project

The research project aims at investigating the behaviour of steel structures founded on different types of soil, with the final goal of evaluating the Soil-Structure Interaction (SSI) influence on the overall system response, in terms of stresses, displacements, failure modes/mechanisms, etc.

To this purpose, shake table tests will be carried out at the EQUALS Laboratory of the University of Bristol on scaled models founded on both rigid and flexible soil conditions. These tests will be executed under selected records that, considering predetermined soil-structure relative stiffnesses, will allow to emphasize the SSI effects. Then the experimental outcomes will be considered for validating numerical FE models that will be used in order to carry out parametric analyses. These parametric analyses will be addressed to the revision of the design parameters currently proposed by Codes and Guidelines. For example, the behaviour factors given for the most conventional structural types, in order to carry out linear analyses taking into account the structural ductility and dissipative resources, will be revised.

Four structural types will be dealt with in the project. Two of them are Concentrically Braces Frames (CBF) and Moment Resisting (MRF) Frames, which, although they are largely dealt with in the current European Codes, nonetheless, they are usually designed according to rules and formulations that have been indicated based on studies and researches of the past carried out under the assumption of rigid soil.

Also, a Dual Steel Frame (DSF) with new brace-type hybrid dampers will be taken into account. The new damper consists on tube-in-tube assemblage of two commonly available hollow structural sections with a central bar made of Shape Memory Alloys (SMA) material (NiTi).

Finally, the seismic response of offshore wind turbines (OWT) taking SSI into account will be dealt with considering different types of superstructures and foundations.

The research activity is articulated into four steps:

Step 1. Set up of preliminary numerical models;

Step 2. Shake Table Tests;

Step 3. Validation of the Numerical Simulation Procedure;

Step 4. Execution of Numerical Parametric Analyses.

The second step represents the core of the project and will be carried out under the synergetic collaboration of all the Users and the people of the Host TA facility.

However, before of that step, a strong preparation of the campaign is necessary aiming at selecting the most adequate scaled specimens (in terms of mechanical, structural and geothecnic features) in order to stress the development of SSI detrimental effects. To this aim, preliminary numerical models will be calibrated. These models will be carried out in the first five months of the project.

As for the CBF and MRF, numerical models validated on the basis of five shake table tests published in literature will be developed. The considered tests concern: a) soil in free field conditions (Durante et al., 2015); b) shallow foundation partially embedded in the subsoil (Massimino and Maugeri, 2013); c) foundation on piles (Durante et al., 2016); d) fixed base MRF frame (Tabatabaiefar et al., 2013); e) fixed base CBF frame (Goggins et al., 2013). These tests will be simulated by the Users from University of Patras and University of Chieti-Pescara.

As for the DSF with dampers, previous shake table test conducted by Users of the University of Madrid assuming rigid foundations will be used (Benavent-Climent et al, 2014). Indeed, these tests were conducted on reinforced concrete frames, but the results will be very useful to determine appropriate values for the strength and stiffness of the dampers for certain strengths and stiffnesses of the bare frame.

6.7.2 Main research objectives and expected contribution to the seismology and earthquake engineering community

The role of the team from ASDEA Software will be of fundamental importance. In fact, this company recently developed the STKO (Scientific ToolKit for OpenSees) software, an advanced pre and post processor for OpenSees, a research-oriented opensource FEM code, specialized in Earthquake engineering simulations.

The numerical models calibrated in “step 1” will be used in order to find, for all the tests developed in “step 2”, those set-ups that will allow to evidence the possible SSI detrimental effects. To this purpose, a preliminary parametric analysis will be carried out by varying the mechanical and geometrical features of the models and selecting the most suitable natural records that will be scaled during the tests in order to evidence the structures performance for several limit states.

Based on the results of the analyses, eleven shake table tests on scaled models will be carried out at the TA host facility. The scale of the specimens to be tested will be selected in order to realize systems with a maximum weight of 10 tons.

Three tests will be focused only on soil-foundation systems: (i) Soil in free condition, (ii) Soil and shallow foundation, (iii) Piles.

Six tests will concern the frames (MRF, CBF, DSF with dampers) on both conditions of rigid (structures directly connected to the shake table) and flexible soils-foundation system. For the MRF a shallow foundation embedded in the terrain will be adopted, whereas piles will be considered for CBF and DSF.

It is necessary to highlight that the number of specimens that will be used in the tests will be based on an initial MRF that will be subsequently transformed in the other frames by the removal/addition of structural components, by the replacement of the structural (dissipative) elements that will be damage during each test, as well as by the addition of piles under the initial shallow foundation. In this way the cost will be really contained below acceptable limits.

In the specific case of the OWT models, two tests will be carried out. The first consists in a tower founded on a group of three piles, and the latter concerns another tower configuration on a group of three buckets (tripod). The OWT specimens will be composed by standard aluminium tubes, plates, angles and sheets, being the upper structure (modelling the tower and rotor) common to both cases. The level of shaking will be limited and the tested structures will remain in the elastic range. As a consequence, no elements will need replacing due to damage. Thus, also for these two tests, the costs will remain contained under acceptable limits.

The foundation system consists in a laminar equivalent shear beam container, where the foundation system is embedded with the superstructure on the top. The equivalent shear beam consists of rectangular aluminium rings, which are stacked alternately with rubber sections to create a hollow flexible box.

In this step of the reseach, the group will benefit from the contribution given by the SARA Electronic Instruments s.r.l. The experts from SARA will consider the expected maximum excitation of the model and select a model of accelerometers or other transducers to perform the measurement with the highest signal-to-noise ratio. This will allow to record a dataset for a full waveform analysis from the strongest to the lowest injected signal and down to the test-site background noise.

Experimental results from laboratory tests will be used for validating the models conceived in the step 1 and used in the design phase of step 2. Then, these models will be used to carry out parametric analyses by changing the geotechnical/structural features (therefore the relative stiffness) of the whole system, also considering frames with different numbers of storeys and different bay spans. The aim is to understand how the main performance parameters can be influenced by the SSI effects. Moreover, the outcomes of the parametric analysis will be used in order to provide modification factors/functions to be applied to the current design parameters given by Code (mostly EC3/EC8).

6.7.3 Project Status

Agreement between Bristol and TA users has been signed. The kick-off meeting was held in Athens on 15th April 2019. The details of the experimental rig were largely reviewed and agreed upon. It was agreed that the structural part will be constructed in Italy and shipped to Bristol by early February 2020. The geotechnical component related to the soil contained and the foundation will be handled by the Bristol team.

6.7.4 Foreseen activities and schedule

As with the other projects, training of the shaking taking is expected to be completed by the end of M24. Following shipment of the structural models to Bristol early in 2020, tests are to be commenced in March 2020, for two weeks. Data elaboration will follow, along with data uploading to the Data Access Portal.

6.7.5 User Group

	NAME	ORGANIZATION NAME	ORGANIZATION COUNTRY
USER GROUP LEADER	Theodore L. Karavasilis	Department of Civil Engineering, University of Patras,	Greece
ADDITIONAL USERS	Giuseppe Brando	Department of Engineering and Geology, University “G. d’Annunzio”	Italy
	Alessandro Pagliaroli	Department of Engineering and Geology, University “G. d’Annunzio”	Italy
	Subhamoy Bhattacharya	University of Surrey	UK
	Amadeo Benavent-Climent	Technical University of Madrid	Spain
	Luis Alberto Padrón Hernández	University Institute of Intelligent Systems and Numerical Applications in Engineering (SIANI) University of Las Palmas de Gran Canaria	Spain
	Panos Kloukinas	Department of Engineering Science Faculty of Engineering and Science University of Greenwich	UK
	Guido Camata	ASDEA Software Start Up	Italy
	Mauro Mariotti	SARA electronic instruments	Italy

7 Institute of Earthquake Engineering and Engineering Seismology SS “Cyril and Methodius” (IZIIS) - University in Skopje

Activities covered in M12 of SERA project include only the initial phase of the PROJECT01 from the University of Ljubljana. In this stage permanent communication with the coordinator prof. Tatjana Isakovic was established with intensive negotiations for the designing procedure and shake table testing for the models.

In the second call, three projects were submitted, and based on the review process “Investigation of Seismic Deformation Demand, Capacity and Control in a Novel Self-Centering Steel Braced Frame (SC-CBF)” was chosen. The project is led by prof. Tatjana Isakovic.

The third call for TA projects was finished, and total nine projects were applied for IZIIS, where in six of them IZIIS was a chosen as a first choice. The projects were preliminary evaluated by the local user selection panel, at IZIIS, consisted of 5 professors on two days meetings where the advantages and disadvantages for all projects were discussed and were taken into account. The results have been sent to TA-SEP for further and final evaluation. Based on the review score “INfills and MASonry structures protected by deformable POLyurethanes in seismic areas (INMASPOL)” was accepted for realization, led by prof. Brian Broderick.

After the completion of the first, second and third call, three projects were selected for realization at IZIIS-DYNLAB. Closer communication with the Users’ groups for the three projects was established towards finalizing the model(s) to be tested, instrumentation set-ups, experimental programme (testing scenario), defining period for construction and shake table testing. It was announced a public procurement call for works and services for the first project for model construction, demolition, debris removal and transportation to depot. Also, User Agreement with University of Ljubljana for the first project was signed and one of the two planned models (MODEL01), has been already tested on the shake table.

During this period the user agreement for the second project, was signed with Trinity College Dublin, and the procedure for preparing the construction of the model and experimental testing was ongoing. The User Group and the TA facility communicated via e-mail on the details of the project. First initial skype meeting was held on 7th of December 2018. On the 1st of February 2019, meeting took place at the IZIIS, Skopje, where the following issues were discussed: final design of the specimen, manufacturing, experimental programme and instrumentation set up. At the time of submission of the deliverable, the User Group, in cooperation with the TA facility, is finalizing the design of the test specimen.

The User Group and the TA facility for the third project communicated via e-mail on the details of the project. An online meeting was held on the 19th of March 2019, where the issues concerning on the final design of the specimen, experimental programme and instrumentation set up of the model were discussed.

In the period from M24 to M36 it is expected all actions concerning the shake table testing of the three models to be finished and final reports submitted to the main office.

- For the first project: MODEL02 will be tested and all the results will be processed and used as agreed in the user agreement where in the last phase the numerical analysis of the experiments will be performed.

- For the second project a public procurement call for works and services for modelconstruction will be announced. All the details are confirmed and the shake table testing will be performed and finished within this period.
- For the third project also a public procurement call for works and services for model construction will be announced and it is expected total predicted experimental program to be realized during this period. It is foreseen the shake table testing to start at the end of September 2019.

7.1 Project #1 – Influence of the floor-to-wall interaction on the seismic response of coupled wall systems – [in progress]

7.1.1 Summary of the project

The main objective of the project is to experimentally study the interaction between piers and floors in RC coupled walls. The influence of slabs to this interaction and redistribution of demand between components at different seismic intensities, as well as numerical models, which can more reliably simulate the response will be studied.

Buildings with RC walls have been one of the most frequently and successfully used structural systems to resist seismic action. Nevertheless, in several cases (in particular during the recent earthquakes in Christchurch and Chile) some walls were heavily damaged, requiring high cost of repair or even demolition.

In a large number of such structures the damage was due to poor understanding of the complex interaction between the floor system and wall piers. This problem was therefore recognized as one of the priority research goals within the Virtual International Institute for Performance Assessment of Wall Systems (NSF SAVI Wall Institute) joining together most of the leading researchers in the field from all over the world.

However, the experimental studies of RC coupled walls, which could significantly contribute to the clarification of these response mechanisms, are very rare. Due to the specific geometry and high resistance of walls, experiments have required large and costly experimental facilities. This problem becomes particularly relevant when floor to walls system interaction is studied.

Two 1:2 scale 3-story specimens will be tested (MODEL01 and MODEL02). The shape and the reinforcement of the piers will provide realistic representation of the floor-pier interaction as well as realistic boundary conditions for the floor system.

The improved numerical models and the findings of the experiments will be used to propose adequate design procedure, which might be included into the future versions of seismic codes, in particular, Eurocodes. The proposed research is compatible with the work of the project partner UCLA, particularly in the frame of NSF SAVI Wall Institute, which has been established with the main goal to improve the design practice for RC walls and wall systems, and to develop the appropriate tools to achieve this goal. Through the partners of the Institute, the results of the project will be efficiently disseminated.

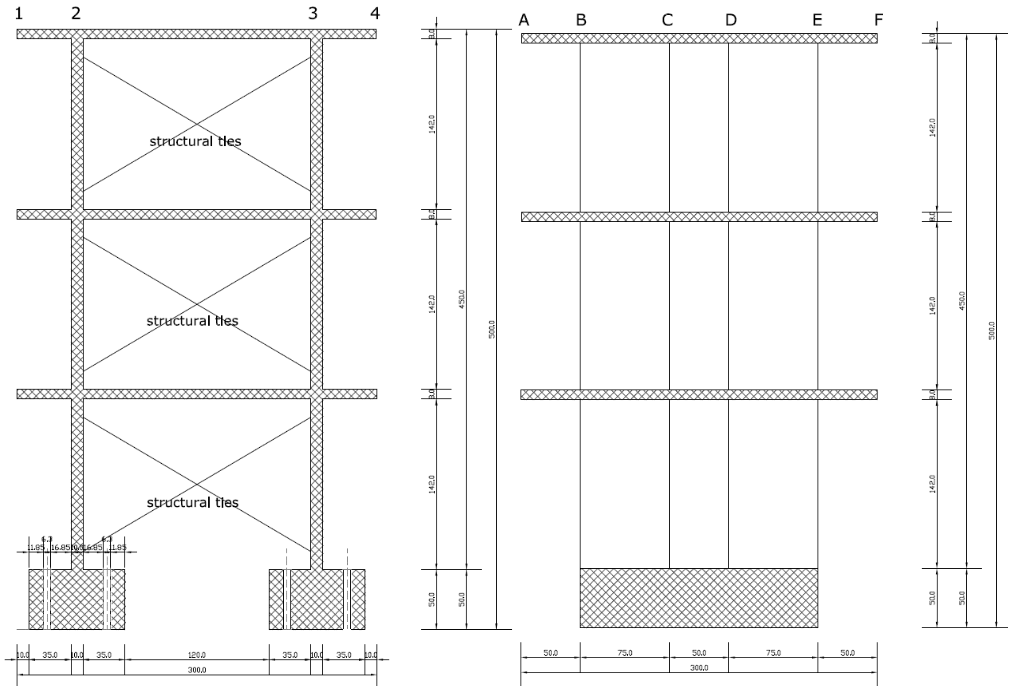


Figure 55: Schematic presentation of the MODEL01

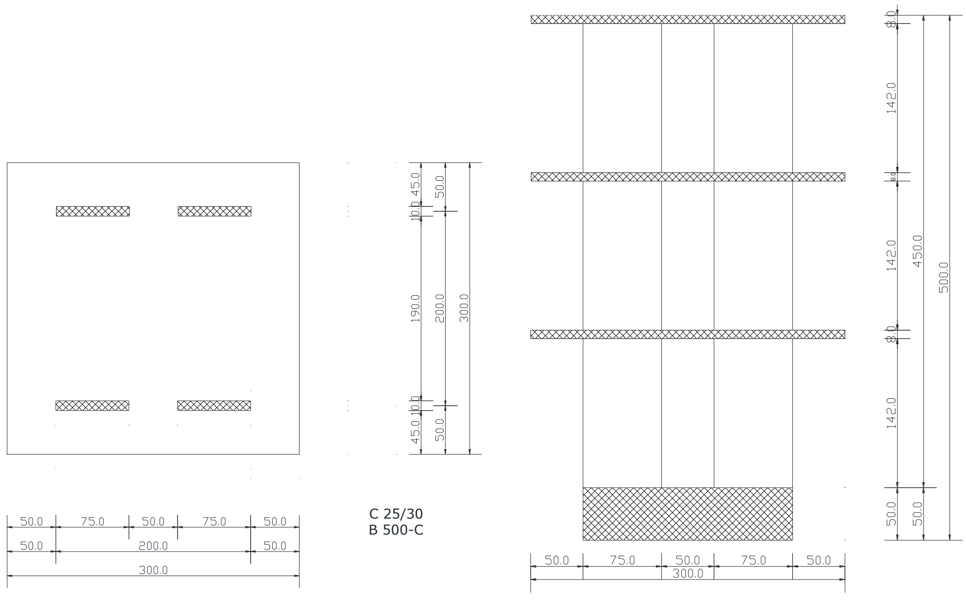


Figure 56: The geometry of the specimens with coupling beams a) typical floor plan, b) typical cross-section

7.1.2 Main research objectives and expected contribution to the seismology and earthquake engineering community

The main objective of the project is to experimentally study the interaction between piers and floors in RC coupled walls. The influence of slabs to this interaction and redistribution of demand between components at different seismic intensities, as well as numerical models, which can more reliably simulate the response will be studied.

7.1.3 Project status

In this stage of the PROJECT01, MODEL01 was tested and the results were processed and will be used for further procedure for the design and construction of MODEL02.

Figure 57: Instrumentation set up for tested MODEL01

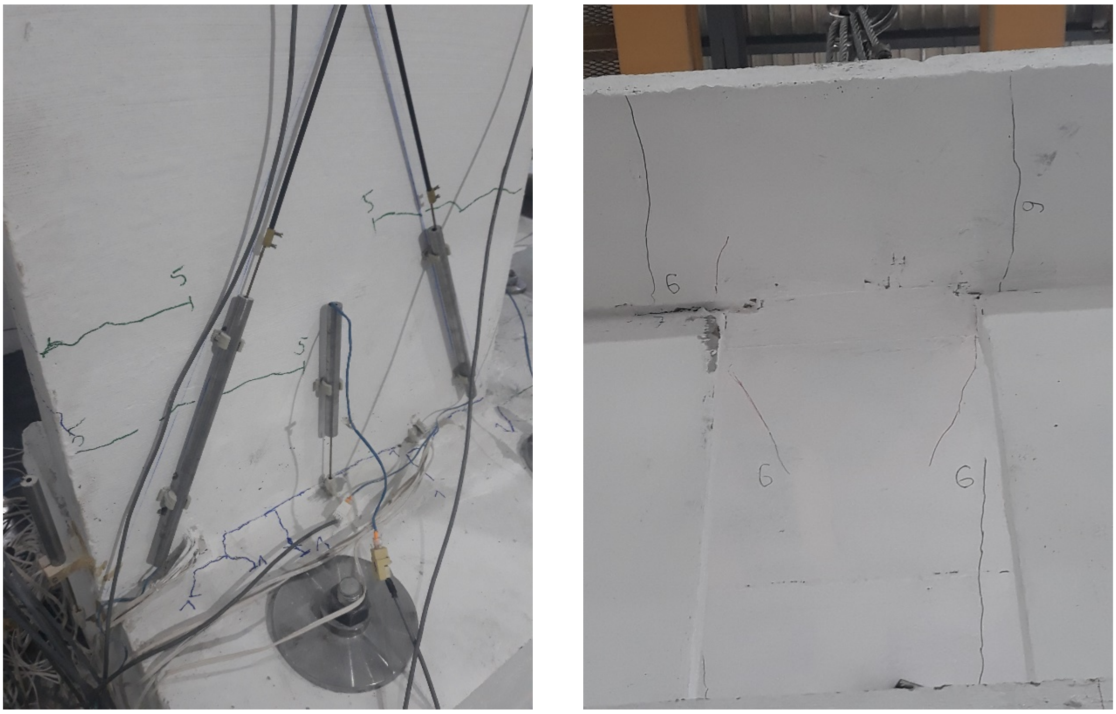


Figure 58: Cracks in MODEL01

7.1.4 Foreseen activities and schedule

The second specimen MODEL02, will be slightly changed according to the results of testing of the first specimen.

The second specimen will consist of two coupled walls, consisting of two rectangular piers each. The foreseen thickness of the walls in the model is 10 cm. The length of the single pier is 75 cm. The clear distance between piers is 50 cm. This corresponds to the typical door openings in walls (1.0m in the prototype). The total height of the piers is 4.5m. The height of the specimens and the number of stories have been selected considering the appropriate height-to-length ratio of piers, which is in the coupling direction larger than 4 (4.5 / 0.75 = 6.3). This will ensure the predominately flexural response of piers and reasonably realistic distribution of the bending moments. In the first specimen, the coupling of piers will be provided only by 8 cm thick slab.

Standard concrete C25/30 will be used for all structural components. The selected scale allows the use of the standard reinforcement.

To provide the realistic stresses and proper scaling of forces induced by the seismic excitation, it was decided to properly scale the accelerations and the time, rather than to add additional masses.

Total mass of the first specimen is estimated to 13 t (including the foundations). The additional masses, which are typically added in the scaled shake table tests to obtain the proper level of stresses, will be generally avoided. The only possible locations where additional masses can be installed are at the slabs, which would require increasing the floor area and substantially increase the cost of the experiments). As well, the thickness of the slabs would have to be considerably increased to be able to support the additional masses, which is unacceptable in these particular experiments, since one of the key objectives is to analyse the role of the slab in the interaction between the floors and piers.

To be able to get an insight into the complex interaction between components of tested RC coupled walls, the global as well local response quantities of all walls' components will be measured. The accelerometers will be used to measure horizontal as well as vertical accelerations at all floor levels (including the top of the footings) in order to obtain the information about the inertial forces. The vertical accelerations will give important information about the variation of axial forces in piers.

LVDTs will be used to measure the vertical and horizontal displacements at all floor levels. To obtain the information about the response of coupling elements, the relative deformation between piers and coupling elements in two horizontal and in the vertical direction are needed.

Strain gauges will be used to measure the deformations of reinforcement in piers and coupling elements at all critical locations (e.g. at the base of piers, at the connections of coupling elements and piers, etc.). This information combined with the measurements provided by the LVDTs will be used to analyse the variations of stiffness in different components of tested walls. The measurements of the reinforcement deformations will provide the information that will be used to define the (over)strength of the coupling elements and effective width of the slabs. For this purpose, a special attention will be devoted to the instrumentation and measurements of slab deformations, particularly near the piers.

Phases of the project

Next Phases:

1. First phase will be devoted to the design and testing of the second specimen.
2. In the second phase the results of the tests will be processed and the final report will be prepared

3. In the last (third) phase the numerical analysis of the experiments will be performed.

Testing program

At the shake table in IZIIS, the specimens can be excited in one horizontal direction. Thus, the uniaxial tests are primarily foreseen.

Specimen will be excited with the ground motion, generated based on the registered accelerogram selected from the European strong-motion database, and scaled to fit the Eurocode 8 acceleration spectrum. In the first experiment the maximum acceleration at the shake table will be gradually increased. Several tests are scheduled, presumably with the following acceleration intensities (at the shake table): 0.1g, 0.3g, 0.5g, 0.7g. The final numbers of excitations and the maximum acceleration applied to the shake table will be defined based on the observed response of the specimen during the test. Free vibration tests will be performed before and after each of these tests in order to estimate the periods of vibrations of the tested specimen.

The testing programme of the second specimen will be similar. The final testing programme for the second specimen will be defined after the analysis of the experiment performed on the first specimen.

Expected period for experimental testing of second model MODEL02 is the beginning of June.

7.1.5 User Group

	NAME	ORGANIZATION NAME	ORGANIZATION COUNTRY
USER GROUP LEADER	Prof. dr. Tatjana Isaković	University of Ljubljana, Faculty of Civil and Geodetic Engineering	Slovenia
ADDITIONAL USERS	Prof. dr. Matej Fischinger	University of Ljubljana, Faculty of Civil and Geodetic Engineering	Slovenia
	Assist.prof dr. Matija Gams	University of Ljubljana, Faculty of Civil and Geodetic Engineering	Slovenia
	Prof. dr. John Wallace	University of California, Los Angeles, Department of Civil Engineering	USA
	Dr. Kristijan Kolozvari	University of California, Los Angeles, Department of Civil Engineering	USA

7.2 Project #2 – Investigation of Seismic Deformation Demand, Capacity and Control in a Novel Self-Centring Steel Braced Frame (SC-CBF) – [in progress]

7.2.1 Summary of the project

Seismic design codes seek to limit structural displacements to minimise damage, however no explicit consideration is usually given to the state of the structure after the earthquake, which can be critical for re-occupancy, monetary losses and the speed that repairs and modifications can be carried out. This project will further the development of a novel system designed to control residual deformations in steel frames, creating more resilient structures.

An integrated experimental and numerical research programme will be completed, the central element of which will be a set of shake table experiments on single-storey self-centring concentrically braced frame (SC-CBF) models subjected to a variety of seismic actions. The aim of these tests will be to assess the effectiveness of a novel self-centring system in controlling global deformation demand in CBFs, including the sensitivity of the CBF response to ground motion characteristics. Correlative pre-test predictions and post-test simulations using pushover and time-history analysis will be carried out to support these experiments.

Brace member and connection details will be varied between experiments to investigate a range of structural properties suitable for European design practice. In each experiment, three separate tests will be performed with table excitations scaled to achieve performance levels corresponding to elastic response, brace buckling/yielding and brace fracture. The results will include residual frame and brace deformations, brace ductility demand and capacity; the influence of connection detailing on maximum and residual deformations; and measurements of effective stiffness and equivalent viscous damping in SC-CBFs. Numerical model validation will facilitate simulation of the seismic response of CBFs buildings with deformation control systems using a wider range of braces, connections and ground motions to support the evaluation and development of Eurocode 8 design guidance for CBFs.

7.2.2 Main research objectives and expected contribution to the seismology and earthquake engineering community

- - Experimentally investigate the variation of seismic deformation demands in CBFs with ground motion characteristics and CBF design parameters;
- - Advance the development of a novel self-centring method for damage control in CBFs (SC-CBF);
- - Obtain experimental data for the validation of numerical models.

Expected results: A unique set of data will be obtained on the seismic deformation demand and capacity of SC-CBFs with realistic brace members and connections subjected to a variety of ground motions. The processed results will include residual frame and brace deformations, brace ductility demand and capacity; the influence of connection detailing on maximum and residual deformations; and measurements of effective stiffness and equivalent viscous damping in SC-CBFs.

7.2.3 Project status

The project is in the early stage, user agreement was signed in February 2019, and the procedure for preparing the construction of the model and experimental testing is ongoing. The User Group and the TA facility communicated via e-mail on the details of the project. A meeting took place at the IZIIS, Skopje on the 1st of February 2019, where the following issues were discussed: final design of the specimen, manufacturing, experimental testing and instrumentation set up. At the time of submission of the deliverable, the User Group, in cooperation with the TA facility, is finalising the design of the test specimen.

7.2.4 Foreseen activities and schedule

Test specimen

The above objectives will be achieved through an experimental investigation of a full-scale single-storey SC-CBF model on a large capacity shake table facility. The model SC-CBF will include two nominally identical brace members whose properties will be varied between tests.

The novel self-centring system to be employed in the model SC-CBF is designed to eliminate residual deformations in CBF structures. This system employs an additional horizontal post-tensioning element at floor level that ensures that the structure self-centres following an earthquake. The next stage in the development of this novel technology is the use of full-scale shake table testing to prove the self-centring capability of the system to eliminate residual drifts after major seismic loading. The shake table tests will validate the performance of this system under dynamic earthquake loading at different intensities.

The test set-up will be similar to that successfully employed by the User Group at CEA Saclay in the 'BRACED' SERIES TA Project. The test model will comprise a single storey steel frame with a central SC-CBF containing the brace specimens and self-centring system, and two external non-braced gravity frames with very low lateral resistance (Figure 59, Figure 60 and Figure 61). These three frames will support a test mass of approximately 40 tonnes at a height of approximately 2.5m above the shake table. Uniaxial loading with peak table test accelerations up to 1g will be imposed. Measures to prevent frame collapse after brace fracture will be required.

Approximately twelve experiments will be completed, with a new pair of brace specimens inserted into the central SC-CBF for each test. Bolted connections between the brace and beam members will facilitate the easy exchange of the brace specimens between tests. The brace members will be fabricated from cold-formed tubular steel sections (S235/275). Cross-section dimensions will be selected to obtain normalised brace slenderness in the practical range while ensuring that the ultimate lateral resistance of the CBF remains comfortably below the capacity of the shake table. The test specimens will collectively capture the most important brace parameters known to affect seismic performance, i.e.

- *Brace section sizes*: various member and cross-section slenderness values;
- *Gusset plate design*: conventional design with standard linear clearance (SLC), and balanced design with elliptical clearance (EC).

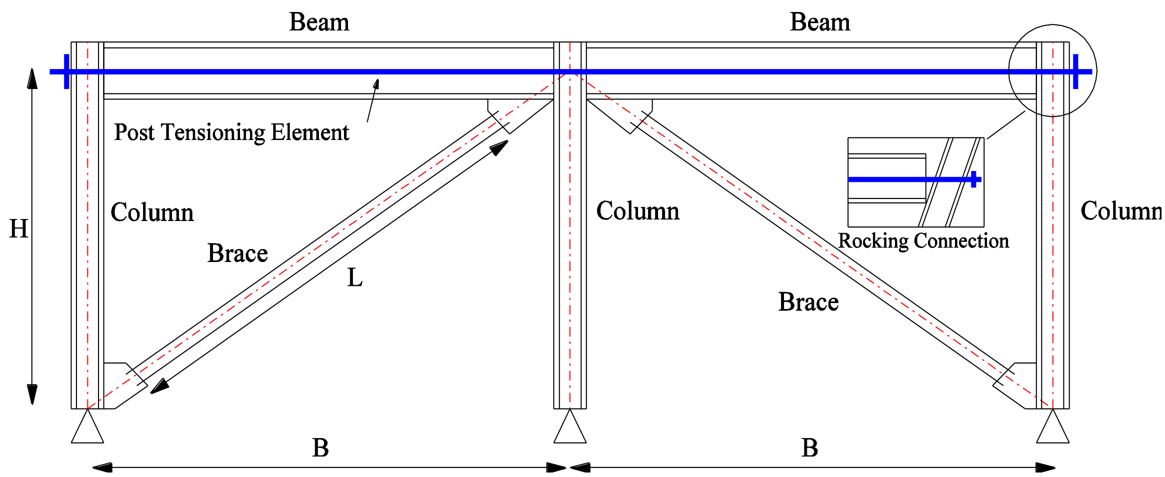


Figure 59: General arrangement of the SC-CBF system.

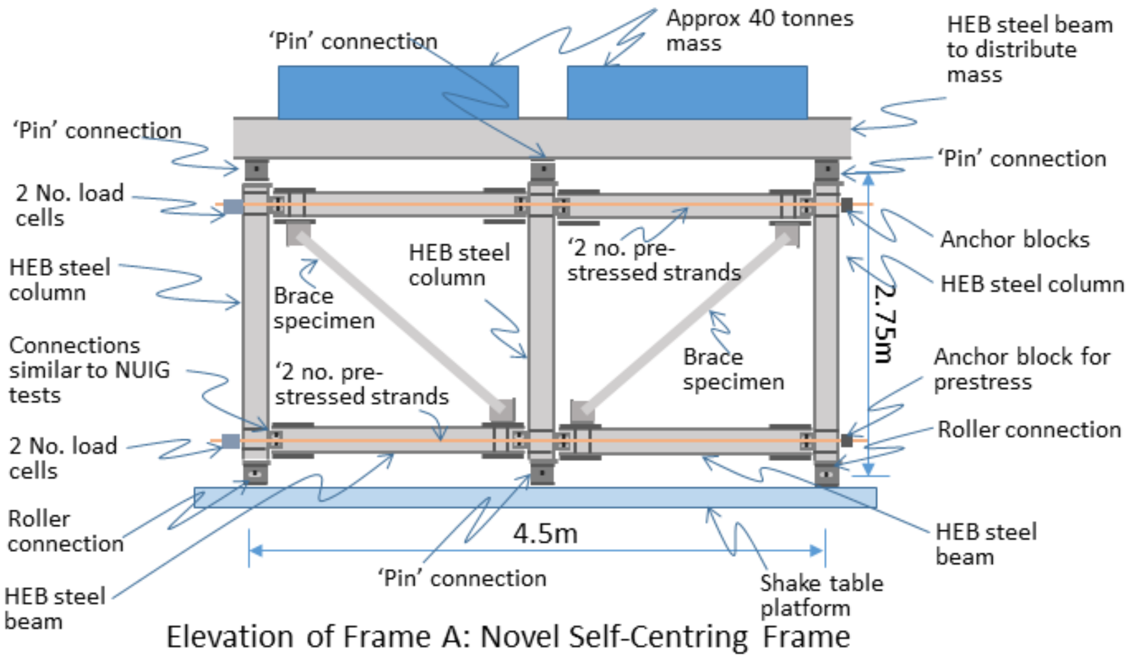


Figure 60: Proposed test set-up at DYNLAB-Seismic Shaking Table, IZIIS - elevation.

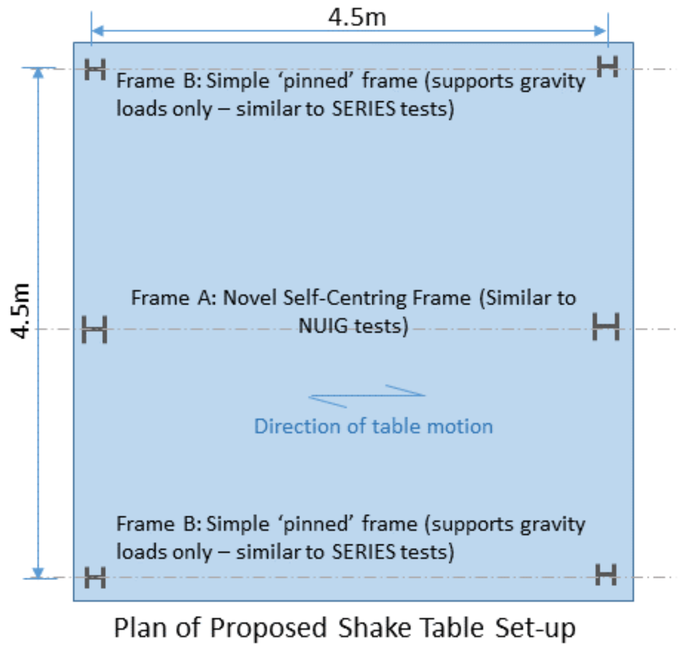


Figure 61: Proposed test set-up at DYNLAB-Seismic Shaking Table, IZIIS – plan

Response Measurement: The following quantities will be measured in each test: acceleration of table and mass (accelerometers); strain at critical points in brace members and on gusset plates; displacement of table and mass, brace elongation and lateral buckling deformation (wire displacement transducers) and video recordings of model response. The team could also bring a 3D laser scanner to capture the shape of the brace members before and after testing.

Phases of the project

STEP 1- preparation stage: duration 6 months:

Proposed Start: 1/11/2018

Month 1-2: Finalisation of experimental programme with Host Laboratory (overall dimensions of the two frame models, number of experiments/specimens, excitation)

Month 3: Pre-test numerical analyses of CBF models with damage control systems

Month 4: Detailed design of SC-CBF models and brace specimens with different connection types. Send engineering drawings to Host Laboratory.

Month 5-6: Steelwork fabrication (SC-CBF model and brace specimens)

STEP 2 – Laboratory Stage (2.5 months):

Week 1-2: Erection of test frame on shake table platform.

Week 3-4: Installation and checking of instrumentation

Week 5-9: Execution of experiments: 12 experiments x 2 days each (1 day set-up plus 1 day testing)

Week 10: Test frame dismantling and removal

STEP 3 - Post Test Stage (3 months)

Months 1-3 post laboratory stage: Post-processing of measurement data; extraction of frame and brace response quantities; post-test numerical analyses; completion of report

Testing program

Uniaxial earthquake excitations will be employed in all experiments. In each shake table experiment, a pair of brace specimens will be tested using three excitations of increasing amplitude, scaled to induce (i) elastic response, (ii) brace buckling or initial yield and (iii) brace fracture, respectively. Each experiment will take approximately one day to complete plus set-up time. A programme of 12 tests is envisaged, but a flexible plan will be followed to fit with the resources and constraints of the host laboratory. The final test programme will be agreed with the host laboratory, and a larger or smaller number of test specimen variables and excitations can easily be accommodated due to the efficient design of the model SC-CBF.

General Timeline

The project will be developed according the following timetable: (modify table and description as needed)

	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10	Month 11	Month 12
Starting Date	Step 1											
							Step 2					
									Step 3			

Step 1: Preparation stage – ON GOING

Step 2: Laboratory stage - beginning of June 2019

Step 3: Post-test stage

Experimental programme for the Project02 is planned to be realized in the beginning of the June 2019.

7.2.5 User Group

	NAME	ORGANIZATION NAME	ORGANIZATION COUNTRY
USER GROUP LEADER	Prof Brian Broderick	School of Engineering, Trinity College, Dublin 2	Ireland
ADDITIONAL USERS	Dr Jamie Goggins	National University of Ireland, Galway	Ireland
	Prof Ahmed Elghazouli	Imperial College London	UK
	Dr Primož Može	University of Ljubljana	Slovenia
	Dr Suhaib Salawdeh	National University of Ireland, Galway	Ireland
	John Hickey	Trinity College Dublin	Ireland
	Terence Ryan	Trinity College Dublin	Ireland
	Edward Fagan	National University of Ireland, Galway	Ireland

7.3 Project #3 – "Infills and Masonry structures protected by deformable Polyurethanes in seismic areas (INMASPOL)" – [in progress]

7.3.1 Summary of the project

The behaviour of RC frames with masonry wall infills is influenced a lot by the stiffness and yield displacement difference between the frame and the infill. The flexible frame is unable to carry high loads at low displacements and this can cause the infill to damage already at moderate seismic intensity. In case of aftershocks, the damaged infills can fail out-of-plane. On the other hand, if the stiff infill is too strong relative to the column, it may cause undesirable behaviour of the frame or even shear failure in the column. The response of structural system can be improved by using a flexible interface between the frame and the infill. This project proposes the testing of rc frames with a flexible joint made of polyurethane (PUFJ) with the masonry wall infills. The application of around 2 cm thick PUFJ reduces the stress concentrations at the contact and thereby reduces damage to infills and rc frames and improves the displacement capacity of the structural system. Furthermore, it offers a high amount of damping. Despite the flexibility of the polyurethane (PU), the bond between the PU and the other materials can transfer significant loads during in-plane and out-of-plane excitations. The PUFJ is versatile because different types of PU with very different stiffness, damping and strength characteristics can be used to manipulate the system dynamic behaviour. In case of premature out-of-plane flexural or in-plane diagonal tension infill failure, PUs can be used for bonding of various composite fibers to the weak masonry substrate to form Fiber Reinforced PU (FRPU) as well as for repair of damaged rc frames. The PU can cover emergency situations as it cures within hours and is easy to apply. The proposed project will assess the efficiency of the method through testing of full-scale infilled rc building on shaking table. The seismic tests will validate in-plane and out-of-plane infill performance when modified, repaired or strengthened with PUFJ and FRPU systems.

7.3.2 Main research objectives and expected contribution to the seismology and earthquake engineering community

The proposed project will assess the efficiency of the innovative intervention method through testing of full-scale infilled rc building on shaking table. The seismic tests will validate in-plane and out-of-plane infill performance when modified, repaired or strengthened with PUFJ and FRPU systems. The detailed objectives are further specified with respect to different testing phases.

7.3.3 Project status

The user agreement will be signed in the beginning of April 2019. The project is in the early stage and the preparation for design, construction of the model and testing is ongoing. The User Group and the TA facility communicated via e-mail on the details of the project. A skype meeting was held on the 19^{th} of March 2019, where the following issues were discussed: final design of the specimen, experimental testing and instrumentation set up of the model.

7.3.4 Foreseen activities and schedule

Test specimen

One fully symmetrical 3D frame of one storey with 4 RC columns, 4 beams, a slab and 4 infill masonry walls will be constructed, all designed according to current Eurocodes. The real scale building has plane dimensions of 3.8x3.8m and height of 3.18m (2.85m to the level of the diaphragm) based on the detailing of the anchoring system of the seismic table of IZIIS. It will be tested in 1 horizontal direction and the infill walls are subjected to in-plane and out-of-plane excitation simultaneously. Two of the infill walls are tested with 3 out of the four concrete-brick interfaces injected with PUFJ (infills 1 and 2 receiving modification of type B) and two with all 4 interfaces bonded prefabricated PUFJ laminates as frame-infill joints (infills 3 and 4, receiving modification of type C). The building is turned by 90 degrees on the seismic table to cover in-plane testing of both cases at serviceability limit states (SLS) damage for comparison. Both cases of infills receive emergency repair using FRPU, applied in various configurations, including modification of infill walls. The emergency interventions upgrade infill walls (1-4) against in-plane and out-of-plane testing at ultimate limit state (ULS). FRPU may be used also for rc damaged elements.

The tests include step by step exciting with gradual increase of scaled accelerograms to construct the different dynamic pushover curves and acquire the dynamic characteristics at each level of excitation for the different cases of infills (1,2 or 3,4) for the 3d building.

FRPU emergency strengthening RC frame and infill

Figure 62 and show in detail the design and construction of the reinforced concrete structure and the design of the flexible joints of type B and C by the accredited implementation team before the start of the testing procedure.

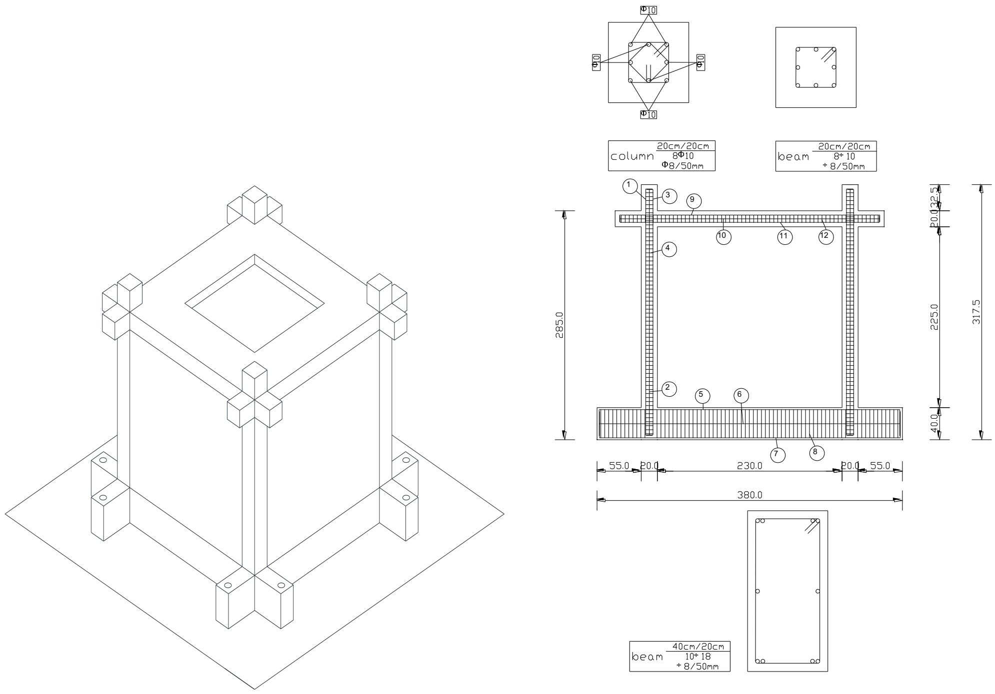


Figure 62: Design and reinforcement plan for the model

The preliminary analyses for 20KN axial load per column (slab and additional mass included), for C30 (fcm around 38MPa), B500C (fsy, fsu around 650 MPa) provides a base shear capacity around 80-90KN owed to the RC structure and around 50KN owed to the infills prior to FRPU repair/strengthening

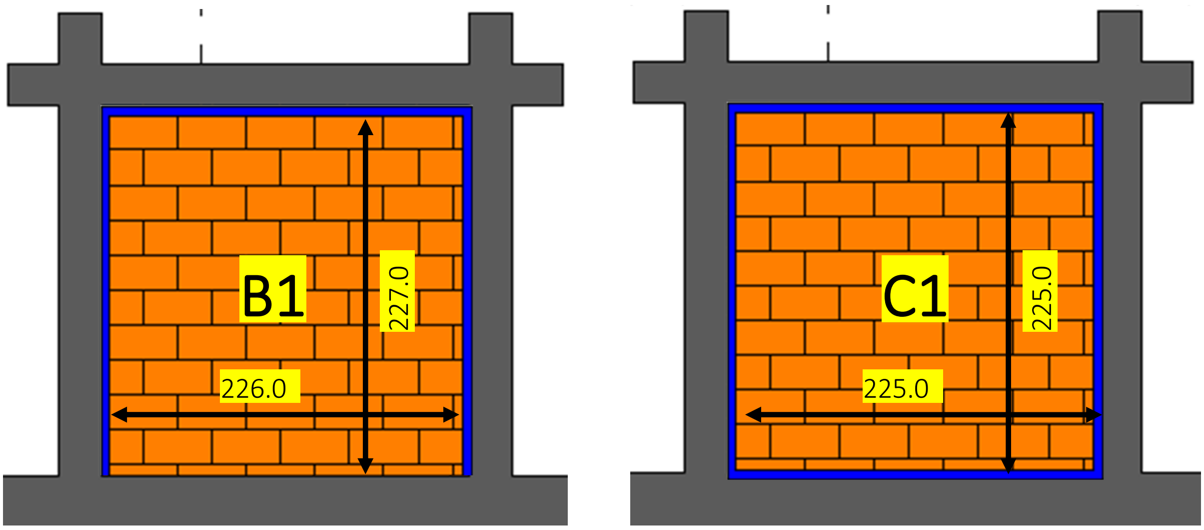


Figure 63: Injected PUFJ (B) and prefabricated PUFJ (C)

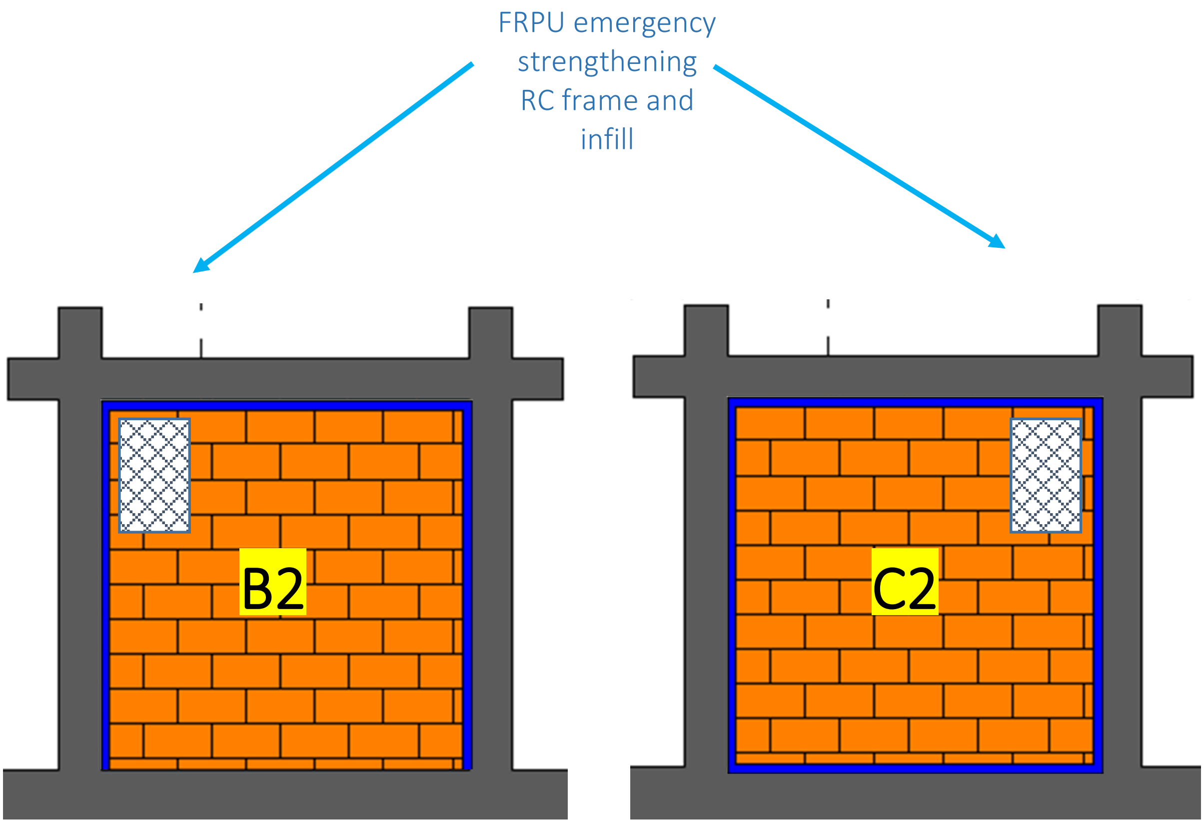


Figure 64: FRPU strengthening in both cases

Phases of the project

Testing phases and main objectives:

The excitations used for the seismic table tests are those from Kefallonia earthquake Chavriata3-2-2014_E-W_n115_excitation, considering a 4-level RC building with similar frame characteristics and the excitation at the upper node at the 4th floor (Figure 65). The excitations will be suitably scaled to the potential of the advanced IZIIS seismic table.

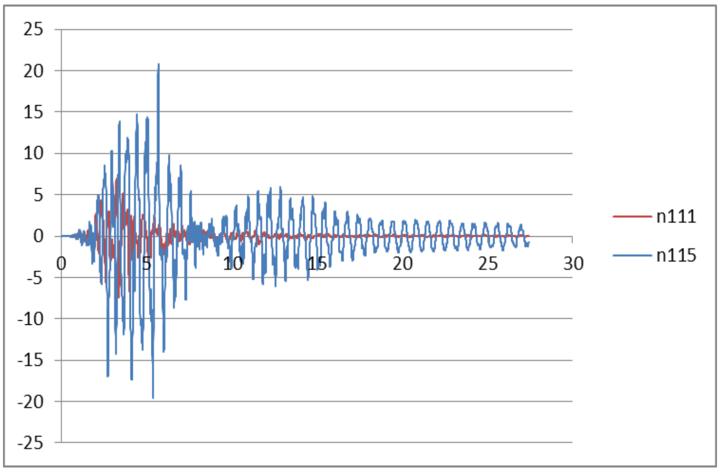


Figure 65: The excitation for ground level (n111) and top level (n115) in a(m/sec2) – t (sec) from Chavriata3-2-2014_E-W

The instrumentation of the specimen concerns 3 accelerometers at the top of the specimen to record 2 orthogonal translations and torsion as well as 4 accelerometers on the infills (1 at each infill) to measure out of plane excitation. Further, it concerns, 8 LVDTs (two LVDTs diagonally placed at each infill) and at least 4strain gauges on the bars of the columns (at least one at each corner bar to record steel yielding). All instruments will be provided by IZIIS. All strain gauges have to be installed during constructing of the rc frame.

Phase A.

(i) The building is excited gradually to the damage initiation level of the PUFJ modified infill walls 1&2 – type B through injection (up to 0.5% -0.7% lateral drift, lower than steel yielding) in plane. Simultaneously, PUFJ modified wall infills 3&4 – type C having received prefabricated laminates are tested out of plane. Both in plane infills 1&2 and out-of-plane infills 3&4 are not expected to be damaged at this stage. The rc frames suffer only concrete cracking.

(ii) Then, gradual increase of the same excitation is performed up to yielding initiation of the steel bars of concrete members (around 1% lateral drift). No damage initiation is expected for the infills 1&2 or infills 3&4 based on our preliminary analytical investigations. Phase A (ii) will prove and quantify out of plane performance of the prefabricated PUFJ modified infills 3&4 and in-plane performance of injected PUFJ modified infills 1&2 as well as the extension of SLS level of the whole rc building with infills when using PUFJ.

(iii) The building is excited gradually to the damage initiation level of the infills 1&2 - type B tested in-plane (up to 2% lateral drift). Simultaneously, infills 3&4 - type C tested out-of-plane are not expected to be damaged at this stage. Special care is taken to avoid damage of the infills 3&4 - type C. Phase A(iii) will prove and quantify out of plane performance of the prefabricated PUFJ modified infills 3&4 and in-plane performance of injected PUFJ modified infills 1&2 as well as of the whole rc building with infills when using PUFJ at the ULS (2% drift) level.

(iv) Then, the infills 1&2 (B1, B2) tested in-plane receive emergency FRPU repair while on the seismic table (Figure 64 shows the FRPU application), executed by the accredited implementation team. The infills 3&4 (C1&C2) are left without emergency FRPU repair.

(v) The building is excited gradually to the severe damage level of the infills 1&2 - type B tested in-plane (up to 3% lateral drift). Simultaneously, infills 3&4 - type C tested out-of-plane are not expected to be damaged at this stage. Special care is taken to avoid damage of the infills 3&4 - type C. Phase A(v) will prove and quantify out of plane performance of the prefabricated PUFJ modified infills 3&4 and in-plane performance of injected PUFJ modified infills 1 receiving also emergency FRPU repair as well as of the whole rc building with infills when using PUFJ beyond the ULS (3% drift) level. Dynamic response in the inertance domain of the main structure and of the infills will be controlled using modal hammer excitation after each testing step. (1 week on the seismic table).

Phase B.

(i) The building is rotated by 90 degrees on the seismic table. (ii) It is excited gradually under the same time-history as in phases A(i) and A(ii). It is expected that infills 3&4 – type C suffer no damage for in-plane testing (around 1% lateral drift) and similarly will repaired infills 1&2 – type B at out-of-plane loading. Phase B(ii) shows and quantifies differences in injected PUFJ modified infills 1&2 and prefabricated PUFJ modified infills 3&4 behaviour for in-plane loading. Also, injected PUFJ modified infills 1&2 of type B and prefabricated PUFJ modified infills 3&4 of type C for out-of-plane loading.

(iii) The building is excited gradually to the damage initiation level of the infills 3&4 - type C tested in-plane (up to 2% lateral drift). Simultaneously, FRPU repaired infills 1&2 - type B tested out-of-plane are not expected to be damaged at this stage. Phase B(iii) will prove and quantify in-plane performance of the prefabricated PUFJ modified infills 3&4 and out of plane performance of FRPU repaired infills 1&2 as well as of the whole rc building with infills when using PUFJ of different structural conditions, at the ULS (2% drift) level.

(iv) Then, the infills 3 & 4 C1,C2 tested in-plane receive emergency FRPU repair while on the seismic table (Figure 64 shows the FRPU application), executed by the accredited implementation team.

(v) The building is excited gradually to the advanced damage level of the infills 3&4 - type C tested in-plane (up to 3% lateral drift). Simultaneously, FRPU repaired infills 1&2 - type B tested out-of-plane are not expected to be damaged at this stage. Phase B(v) will prove and quantify in-plane performance of the prefabricated PUFJ modified infills 3&4 and out of plane performance of FRPU repaired infills 1&2 as well as of the whole rc building with infills when using PUFJ of different structural conditions, beyond the ULS (3% drift) level.

(vi) The building is excited gradually up to failure of the tested non-structural elements (infills) and then of structural elements (columns) – close to collapse. Phase B(vii) will prove and quantify in-plane and out of plane limit states (ultimate post-failure resistance) of the whole rc building and of the FRPU repaired infills when using PUFJ, far away beyond the ULS (>3% drift) level.

Phase B(vi) will also prove and quantify the ductile and safe performance of the suitably designed rc frames with ductile infills. Dynamic response in the inertance domain of the main structure and of the infills will be controlled using modal hammer excitation after each testing step. (1 week on the seismic table).

Testing program

STEP 1 – from 6/5/2019 or signature of this agreement to 31/8/2019

The group delivers with this agreement all necessary drawings and specifications to IZIIS required for STEP1 (design of the test specimen and setup). Step 1 will be extended from 6th of May 2019 to 31 of August 2019 to include potential preliminary elaborations of the testing procedure and feedback to be taken into account for the construction of emergency repairs, if necessary.

STEP 2 – from 1/6/2019 to 8/9/2019

The specimen will be constructed and cured by IZIIS during June 10th to July 21st. The construction has to consider the required materials for the brick infills and the flexible joints as well as the accredited application workers and detailed construction procedure etc. The construction of infills and PUFJs is planned in the 30th week of 2019, July 22nd to July 28th and the period of 31th-34th weeks of 2019, July 29th to August 25th is left for curing of the infills (summer vacation time in August). Installation of the main specimen with the infills on the shaking table is planned in the 35th week of 2019, August 26th to September 1st by IZIIS.

STEP 3 - from 2/9/2019 to 22/9/2019

Installation of instrumentation will be executed in 36th week of 2019, September 2nd to September 8th by IZIIS. Tests of the specimens on shaking table are planned in 37th-38th weeks of 2019, September 9th to September 22nd by IZIIS. IZIIS will also conduct required material testing for concrete, reinforcing steel bars, infill walls and FRPU.

The specimen will be ready for the experiments to start 9th of September 2019 for phase A(i).

Phases A(ii) and A(iii) will follow to be concluded up to 10th of September or earlier. Phases A(iv) will start 11th of September and then phase A(v) will follow to be concluded up to evening of 12th of September. Rest of the week is in reserve to cover unexpected delays and for rotation and re-instrumentation of the specimen, so that it is ready for testing 16th of September 2019.All the group members will contact elaborations during the preparation and execution of the tests based on the experimental results to achieve the goals of the testing program and prepare preliminary short reports.

The specimen is rotated so that it is ready for testing phase B(i) 16th of September 2019.

The specimen is excited according to phase B(ii) and B (iii) 16th of September 2019.

Phase B(iv): The specimen will be retrofitted with PUFJ and FRPU while on the seismic table by the accredited team on 17th of September during phase B(iv).

The specimen will be re-instrumented wherever suited and the excitations to failure of phase B(v) and B(vi) will be concluded 18th of September 2019.

The days 19th and 20th will be left as additional days in case of unexpected delays in order the tests are concluded during these two weeks of September 2019. Preliminary short reports will be prepared.

STEP 4 - 23/9/2019 – 31/12/2019

The elaborated experimental results of recorded acceleration – time, recorded displacement-time and recorded strain – time and actuator load-time for all different instruments and positions will be executed by IZIIS and delivered up to 10/10/2019.

The User Group will further elaborate the delivered primary experimental results to present in comparison to analytical predictions and for paper writing.

STEP 5 – 23/9/2019 – 31/12/2019

Writing of final reports by the User Group.

Vacation time in August 2019 will be during curing of the infills and is included in whole time.

General Timeline

Month	1	2	3	4	5	6	7	8	9	10	11	12

	Apr '19	May '19	Jun '19	Jul '19	Aug '19	Sep '19	Oct '19	Nov '19	Dec '19	Jan '20	Feb '20	Mar '20
Starting Date		Step 1										
			Step 2									
						Step 3						
						Step 4						
						Step 5						

7.3.5 User Group

	NAME	ORGANIZATION NAME	ORGANIZATION COUNTRY
USER GROUP LEADER	Assis. Prof. dr Theodoros Rousakis	Democritus University of Thrace,	Greece
ADDITIONAL USERS	Prof. dr. Alper Ilki	Istanbul Technical University, Turkey	Turkey
	Prof. dr. Arkadiusz Kwiecień	Cracow University of Technology (CUT), Poland	Poland
	Assoc. Prof. dr. Alberto Viskovic	G. D'Annunzio University of Chieti – Pescara, Italy	Italy
	Petra Triller	Slovenian National Building and Civil Engineering Institute (ZAG), Ljubljana, Slovenia	Slovenia
	Assis. Prof. dr. Bahman Ghiassi	University of Nottingham, UK, University Park Nottingham, UK	UK
	Prof. dr. Alper Ilki	Istanbul Technical University, Turkey	Turkey
	Prof.dr.Andrea Benedetti	Alma Mater Studiorum-Universita' di Bologna,Italy	Italy
	Maciej Karpała	SIKA Poland Sp. z.o.o., Cracow, Poland	Poland
	Kothalis Agis	KEBE SA, Head offices-Factory Nea Santa, Kilkis,	GREECE
	Bogusław Zając	FlexAndRobust Systems Ltd, Cracow, Poland	Poland
	Assis.prof.Matija Gams	University of Ljubljana (UL),Slovenia	Slovenia

8 University of Cambridge

The Schofield Centre at University of Cambridge houses the high gravity centrifuge and the earthquake simulation facilities that were offered as part of the TA activities with acronym UCAM. These facilities are used for soil-structure interaction problems and soil liquefaction problems widely. SERA provided an opportunity to the EU researchers to use the UCAM facilities to investigate interesting problems and there was high demand from the community for the access days.

From M1 to M12, two projects were selected to use the UCAM facilities, two under first call of SERA. We have carried out one centrifuge test for the research project on anchored Steel Sheet Pile (SSP) walls (Project #14) and started planning for the testing of the second project on tunnel-structure interaction (Project #15) called STILUS.

Two projects were selected under the second call of SERA. The first project (Project #24) was aimed at investigating the settlement and rotational behaviour of a raft foundation supported on dis-connected pile foundations. The second project (Project # 25) that was selected in this call was called COSMO and is aimed at understanding the filtering effects of piles on high frequency components of earthquake shaking.

There was no more availability of access days hence UCAM did not participate in the third call of SERA.

In the current period, M13-M24, the UCAM facilities have been very heavily used for the SERA-TA projects. Firstly, we completed the remaining three centrifuge tests for SSP project (Project#14). These tests have yielded very valuable data on the deformation mechanisms of the soil behind the retaining wall and also in front of the anchor. More detailed description of the results is presented in Sec. 8.1

In addition, we carried out three centrifuge tests for the STILUS project (Project#15) that looks at the uplift of rectangular tunnel in liquefiable soil and its effects on nearby structure. Again these centrifuge tests have yielded very interesting results as detailed in Sec. 8.2. There is still one more centrifuge test to be conducted under this project.

Finally, we have carried out the first centrifuge test under project COSMO (Project#25) that investigates the kinematic interaction between piles and soft clay. A second centrifuge test under this project is planned for July/August 2019. The details of the centrifuge test are presented in Sec. 8.3. This centrifuge test had two separate flights as detailed in Sec. 8.3. The data from these flights is currently being analysed.

From M25 to M36, we anticipate to complete the remaining centrifuge test for the STILUS project (Project#15) that will complete the experimental testing for this project. This centrifuge test is planned to happen in the next four weeks or so. We will also carry out the second centrifuge test for the COSMO (Project #25) by July/August 2019 to complete the experimental testing for that project.

Currently we are collaborating with concerned researchers on Project#24 that deals with raft foundation supported on dis-connected piles. These centrifuge tests are planned for summer of 2019 and we anticipate completion of all our experimental testing by October 2019.

We anticipate that results from all the centrifuge tests will be further analysed and further joint publications will follow, involving the researchers from each of the proposal and UCAM researchers.

8.1 Project #1 – Seismic behaviour of anchored Steel Sheet-Piling (SSP) retaining walls: experimental investigation, theoretical interpretation and guidelines for design – [concluded]

8.1.1 Summary of the project

Steel Sheet-Piling (SSP) walls are frequently adopted as retaining structures in quays and wharves, as they may be more economical with respect to concrete caissons or other types of retaining structures.

In current design practice, SSP retaining walls are usually designed using simple calculation tools, based on Sub Grade Reaction Models (SGRM) or Limit Equilibrium Methods (LEM). If the seismic action is introduced following a pseudo-static approach, then the same methods can be used, at least in principle, for the seismic design of SSP walls. However, depending on wall flexibility, contact properties at the soil-wall interface, strength properties of the system, and assumptions on both the seismic action (amplification/phase shift of accelerations within the soil) and the stress distribution into the soil, these methods can lead to highly over-conservative or un-conservative predictions. Numerical Finite Difference (FD) and Finite Element (FE) methods often provide more economical solutions than SGRM or LEM methods. However, numerical modelling of geotechnical systems under dynamic conditions is quite complex, requiring careful consideration of many factors (e.g.: the definition of the input motion and of suitable boundary conditions and, most of all, the choice of an adequate constitutive model for the soil), and not always readily accessible for the practicing engineer.

Following the Performance-Based Design methodology, in recent years a new design concept has started to be explored for the seismic design of retaining structures. This is based on the idea that the structure can experience permanent displacements during the design earthquake, provided that the related damage does not exceed some allowable threshold, defined on the basis of a given required performance level. Within this context, the attention has progressively moved from the computation of the maximum internal forces in the retaining structure under an equivalent system of pseudo-static forces, to the prediction of the permanent displacements experienced by the structure under a given acceleration time history (earthquake). To this end, the Newmark's sliding block procedure has been successfully applied to the evaluation of permanent displacements of both gravity and cantilevered walls, and the critical acceleration has been proved to control both the maximum internal forces in the structural members and the final permanent displacement.

A possible extension of these procedures to the seismic design of anchored SSP walls requires a better understanding of the dynamic behaviour of these systems to identify the main factors affecting their response under seismic actions. In this respect, centrifuge tests carried out on reduced-scale physical models provide a powerful tool to investigate the seismic response of geotechnical systems in idealised situations, in which the initial state of the soil, the hydraulic and kinematic boundary conditions and the dynamic input motion are controlled and well defined.

This project was aimed at providing a better insight into the seismic behaviour of anchored SSP walls, focusing on the main physical mechanisms affecting the distribution of earth pressures on the wall during the earthquake, the possible increase of internal forces in the structural members and the progressive accumulation of permanent displacements. To this end, four centrifuge tests were carried out at the Schofield Centre, University of Cambridge (UCAM), considering different layouts and input earthquakes. The experimental results allowed to understand how the critical acceleration of the soil-wall system governs the behaviour of SSP walls, both in terms of maximum internal forces and permanent displacements, and how the activation of different plastic mechanisms can affect the overall observed behaviour. Moreover, based on the experimental outcome, new theoretical methods have been explored for the seismic design of anchored SSP walls.

Following on from the initial tests reported in the deliverable D8.1, three more dynamic centrifuge tests were carried out in the period M12 to M24. The details of these tests are presented in this report, which led to identification of the two failure mechanisms for the anchored Steel Sheet Pile (SSP) walls. This project has now been completed and all the testing has concluded.

8.1.2 Main research objectives and expected contribution to the seismology and earthquake engineering community

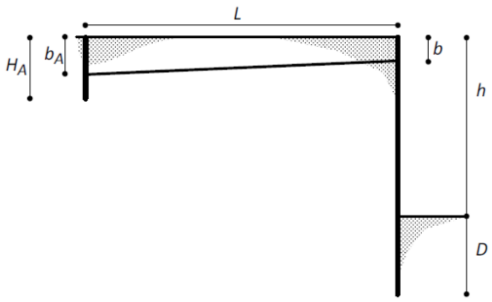
The main objective of this project is to provide a better understanding of the seismic behaviour of anchored SSP walls, focusing on the main physical mechanisms affecting the possible increase of internal forces in the structural members and the progressive accumulation of permanent displacements during the earthquake. Accordingly, the research project has three objectives:

- Identify the possible plastic mechanisms actually occurring in the soil-wall-anchor system, depending on the geometrical layout of the problem, and the critical acceleration associated to each mechanism.
- Understand if the maximum internal forces and displacements experienced by the wall during the earthquake are effectively controlled by the critical acceleration, as it is the case for gravity and cantilever walls. In other words, verify that the internal forces remain essentially constant when the critical acceleration of the system is attained and that permanent displacements are only accumulated when the soil acceleration exceeds the critical value.
- Validate the theoretical limit equilibrium method recently proposed by Caputo et al. (2018) for computing the critical acceleration of the wall, which takes into account all the possible global and local failure mechanisms (failure of the anchor system or full mobilization of the soil passive resistance in front of the wall).

The experimental results and theoretical findings coming from this project will have not only a clear scientific value, as a close combination of experimental and theoretical tools to the interpretation of the dynamic behaviour of anchored SSP walls has not been attempted so far in the scientific literature, but also a direct technical impact. As a matter of fact, based on these results, simple methods for the seismic design of SSP walls will be eventually developed, capable of extending also to these structures a more rational Performance-Based Design methodology.

8.1.3 Project status

Four dynamic centrifuge tests were carried out in the 10 m diameter Turner beam centrifuge of the University of Cambridge. Figure 66 shows the layout of the wall-anchor system in the four tests (dimensions at prototype scale). The main parameters that were varied are the position of the anchor rod with respect to the anchor plate (ba/Ha), the normalized embedment depth of the wall (D/h) and the normalised anchor length (L/h). As a matter of fact, very recent theoretical developments have shown that these three dimensionless parameters control the nature of the plastic mechanism effectively taking place during shaking, to be either local anchor failure or global failure of the whole system, and thus eventually affecting the expected value of the critical acceleration.



ID test	h [m]	D [m]	b [m]	b_a [m]	H_a [m]	L [m]	N
$\boldsymbol{AF01}$	proof test of the window box						80
$\boldsymbol{AF02}$	7	3	0.5	0.5	2	17	60
$\boldsymbol{AF03}$	8	2	0.5	0.5	2	17	60
$\boldsymbol{AF04}$	8	2	0.5	1.3	2	12	60
$\boldsymbol{AF05}$	8	2	0.5	0.5	2	12	60

(a) (b)

Figure 66: (a) Layout of the wall-anchor system in the centrifuge tests and (b) main geometrical quantities (at prototype scale)

The tests were carried out in plane strain conditions, at a centrifugal acceleration of 60g, preparing the models within a homogeneous dry medium-dense layer (DR = 50%) of fine-grained siliceous Hostun sand. Both the retaining wall and the anchor plate were modelled using aluminium alloy plates with a bending stiffness at prototype scale similar to that of an AZ28 steel sheet pile profile, while the tiebacks were modelled using four steel cables hinged to both ends.

The models were prepared within a rigid container with a Perspex viewing window, allowing soil deformations and wall displacements to be measured during the tests with a Particle Image Velocimetry (PIV) technique. A layer of DUXSEAL was included between the rigid end walls and the soil in order to prevent generation of P-waves and multiple wave reflection during shaking.

As far as the instrumentation is concerned (Figure 67), accelerations at different locations in the model were measured using miniaturized piezoelectric accelerometers, while accelerations of the wall were recorded using MEMS accelerometers; displacements were measured using LVDTs transducers; the axial load in the anchors was measured using miniature load cells, while strain gauges were used to measure the bending moments of the wall; finally, a fast digital camera was used for the PIV analysis.

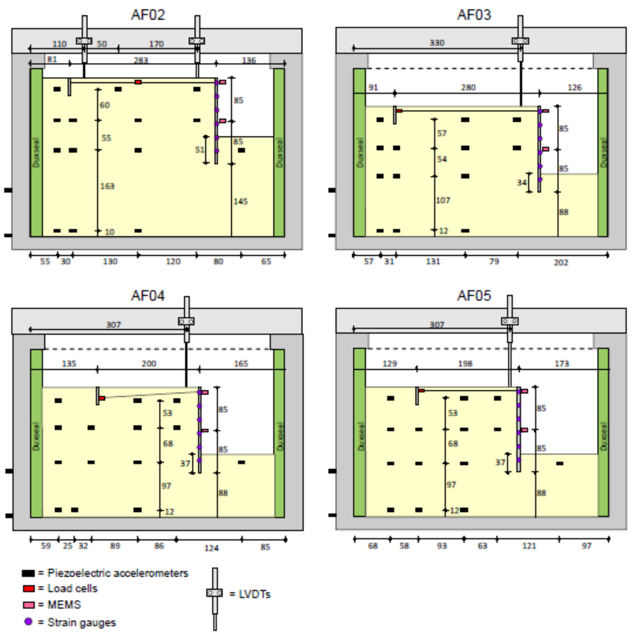
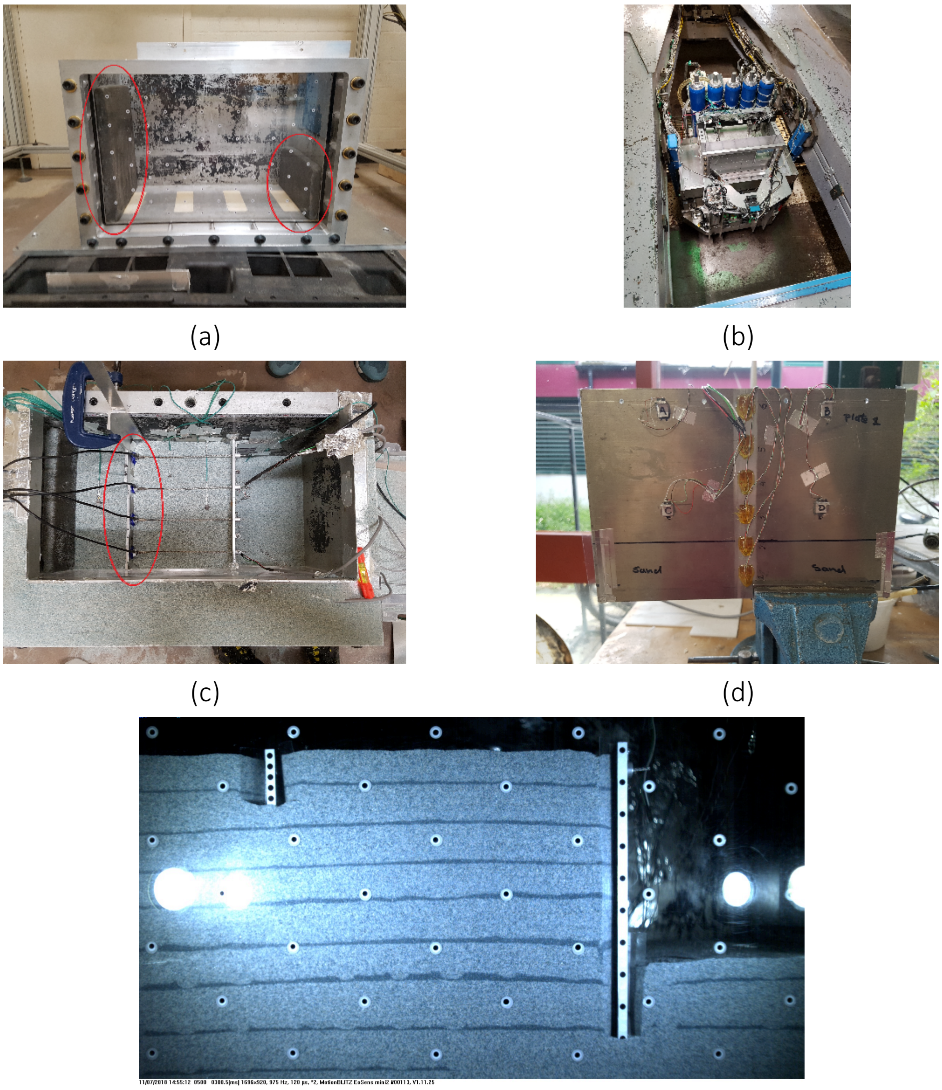


Figure 67: Position of the instrumentation used in each test

The dynamic input was provided by a Servo-Hydraulic earthquake actuator, capable of applying both trains of approximately sinusoidal waves and more realistic earthquake motions. Some details of the adopted instrumentation is shown in Figure 68.



(a) (b) (c) (d) (e)

Figure 68: (a) rigid container with a Perspex viewing window and Duxseal layers at the sides; (b) servo-shaker mounted on the centrifuge; (c) load cells in the tie-backs in the test AF04; (d) small-scale model of the retaining wall, with details of the instrumentation placed on it; (e) side view of the model in test AF04

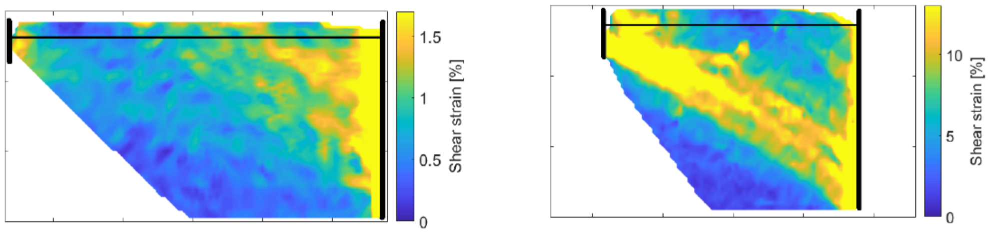
Table 9 reports, for each test, the critical acceleration and the expected failure mechanism according to the theoretical model proposed by Caputo et al. (2018), adopting two values for the soil peak friction angle, estimated using the empirical formula proposed by Bolton (1979). In the first two tests (AF02 and AF03) a local failure of the anchor system was expected, while a global failure mechanism was predicted for the last two tests (AF04 and AF05).

Table 9: Estimated critical acceleration and expected failure mechanism for each test

ID test	a_c [g] ($\varphi = 38°$)	a_c [g] ($\varphi = 39°$)	expected failure mechanism
***AF*02**	0.21	0.24	anchor failure
***AF*03**	0.12	0.16	anchor failure
***AF*04**	0.145	0.165	global failure
***AF*05**	0.095	0.11	global failure

From the analysis of the experimental data, it was possible to compute the evolution, during the applied earthquakes, of the internal forces in the structural members (axial force in the tieback and bending moment distribution in the wall) and of the displacements of the anchor plate and the main wall. Moreover, from a preliminary analysis of the experimental results, it was possible to highlight the role played by the critical acceleration on the maximum internal forces and the maximum displacements experienced by the system during the applied earthquake.

For the sake of brevity, only the experimental results obtained from the PIV analysis are presented in the following. Specifically, in order to identify the plastic mechanism effectively activated during the centrifuge tests, the shear strains developed into the soil between the anchor plate and the retaining wall were estimated from the displacements computed by the PIV analysis. As an example, Figure 69 shows the contours of shear strains computed during the strongest earthquake applied in test AF02 (earthquake EQ4) and AF05 (earthquake EQ3). In the first case (Figure 69a), shear strains are mostly clustered in a wedge behind the retaining structure and above dredge level, consistently with the development of a local anchor failure and the rotation of the retaining wall around the toe. In the second case (Figure 69b), instead, the shear strains mainly develop along a failure surface going from the bottom of the anchor wall to the toe of the retaining wall, suggesting a global failure mechanism of the whole anchor-soil-wall system. As shown in Figure 70, this observation is fully consistent with the theoretical log-spiral failure surface proposed by Caputo et al. (2018).



(a) (b)

Figure 69: Soil shear strains obtained from PIV analyses: (a) test AF02 and (b) test AF05

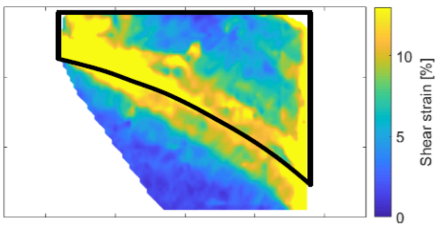


Figure 70: Test AF05 (Earthquake EQ3): comparison between soil shear strains obtained from PIV analyses and theoretical prediction of the global failure mechanism (black lines)

8.1.4 Foreseen activities and schedule

Even though the Project formally ended on December 2018, we are still working on the interpretation of the huge amount of experimental data coming from the four centrifuge tests carried out within the Project. Specifically, based on the experimental data and on advanced numerical dynamic analyses carried out so far, we are working on the definition of simple procedures for predicting the permanent displacements experienced by anchored SSP walls during the earthquake. This work will provide the basis for applying a performance-based design procedure also to the seismic design of these structures.

8.1.5 User Group

	NAME	ORGANIZATION NAME	ORGANIZATION COUNTRY
USER GROUP LEADER	Riccardo Conti	University of Rome Niccolò Cusano	Italy
ADDITIONAL USERS	Cécile Prum	ArcelorMittal	Luxembourg
	Giorgio Caputo	University of Rome Niccolò Cusano	Italy
	Alessandro Fusco	University of Cambridge	UK
	Perla El Boueiz	ArcelorMittal	Luxembourg

8.2 Project #2 – STILUS – [in progress]

8.2.1 Summary of the project

Relatively shallow and light underground structures, such as urban tunnels, may cross liquefiable sand deposits and liquefaction has induced floatation and large uplift to sewer pipes or open-cut tunnels in some recent strong earthquakes. It is worth noticing that in urban area shallow tunnels are likely close to the foundations of buildings and easily interact with them during earthquakes (i.e. Soil-Structure-Underground Structure-Interaction, SSUSI). Nevertheless, the reciprocal influence of a tunnel and an adjacent building in presence of soil liquefaction has not been investigated in the literature yet. This problem appears rather important considering the rapid extension of the built environment, both above- and underground, to areas that may be subjected to seismic-induced soil liquefaction.

The research investigates the problem of the dynamic interaction of an underground structure and a building founded in liquefiable sand. To this aim a series of centrifuge tests are carried out on a reduced scale model of a rectangular tunnel embedded in a liquefiable layer of sand, with and without a model building founded in proximity, as a typical case of a cut-and-cover tunnel in urban environment. Furthermore, tests will be carried out on models where the liquefiable ground is improved by adding nanomaterials (laponite) to increase locally the fine content. The position of the improved ground is varied in the models: either a layer of sand beneath the tunnel or a layer of sand beneath the building is improved.

The models are created at reduced scale and tested accordingly at N-times increased g-level in the Turner Beam Centrifuge at the Schofield Centre of the University of Cambridge.

The ground layer consists of homogenous Hostun sand at a relative density of about 45%-50%. This is dry pluviated in thin layers through an automatic hopper system. During the model preparation, arrays of miniature pore pressure transducers (PPTs), piezoelectric and MEMS accelerometers are deployed at the desired locations. Displacement transducers (LVDTs) are used to measure the settlements at different locations.

During model preparation a model tunnel is embedded in the sand layer (see the list of tests later on). The rectangular model tunnel is made using an extruded section of aluminium alloy. Rough dimensions are provided in the sketches of Figure 71. The rectangular tunnel represents a section of a metro station tunnel that can accommodate two separate platforms. The soil cover above the tunnel corresponds to an embedment ratio $C/H_T = 1$.

A linear-elastic sway frame (SDOF) made of aluminium is founded in the sand layer in most tests (see the list of tests later on). Rough dimensions are provided in the sketch in Figure 71. The figure shows the centrifuge models including the sway frame (i.e. the building), that is located beside the tunnel. The sway frame is fitted with accelerometers to capture its horizontal sway as well as rocking behaviour. Two vertical accelerometers are positioned on the base of the structure to enable measurement of rocking angles. A displacement transducer is located at the base of the frame to measure vertical settlement.

The sand layer needs to be saturated before testing. To avoid the incompatibility between the dynamic and diffusion time scaling laws, a high viscosity aqueous solution of hydroxypropyl methylcellulose (HPMC) is used to saturate the sand layer, with a viscosity N times larger than water.

Considering the need to study the displacement field around the tunnel, high speed photogrammetry is used in the tests. Hence stems the choice to use a transparent side container. A rigid container with a Perspex window is used. It is known that this type of model container may cause boundary effects affecting the response, particularly when liquefaction is reached. Therefore, a soft material called Duxseal® is used on the walls, to minimize the boundary effects: it has been showed that it can reduce the stress wave reflections by about two-thirds.

In total 4 centrifuge models are being tested (Figure 71), according to the following sequence:

1. Tunnel only, in window box;
2. Tunnel and adjacent building;
3. Tunnel and adjacent building, ground treatment below the tunnel floor;
4. Tunnel and adjacent building, ground treatment below the building.

A servo-hydraulic earthquake actuator is used to apply near-sinusoidal earthquake motions to the centrifuge model. The amplitude of the signal will be increased during the test, until soil liquefaction is achieved.

Time histories of acceleration and pore pressure in the ground are recorded during shaking, along vertical and horizontal arrays. Similarly, displacement time histories at a few points at ground surface (settlement) and on the sway frame (settlement, horizontal displacement and tilt) are monitored.

PIV Photogrammetry enables a deep insight on the triggering of uplift and the evolution of the mechanism. This is very useful for the calibration of a numerical model to simulate the centrifuge tests and to reliably extend later the study to different geometrical conditions.

Comparing the time histories measured in model #1 and #2 will enable to highlight the influence of tunnel-building interaction on the displacements field induced by soil liquefaction.

In model #3 a volume of sand below the tunnel is improved by pouring the sand in a laponite/water suspension during model making. An amount of laponite corresponding to 1% of the dry weight of sand is mixed to water in concentration equal to 5%.

In model #4 a similar improved volume is located beneath the foundation level of the sway frame. A comparison among results of tests #2, #3 and #4 enables to discuss the effectiveness of laponite injection in the ground to reduce the effects of sand liquefaction on both the underground structure and the building.

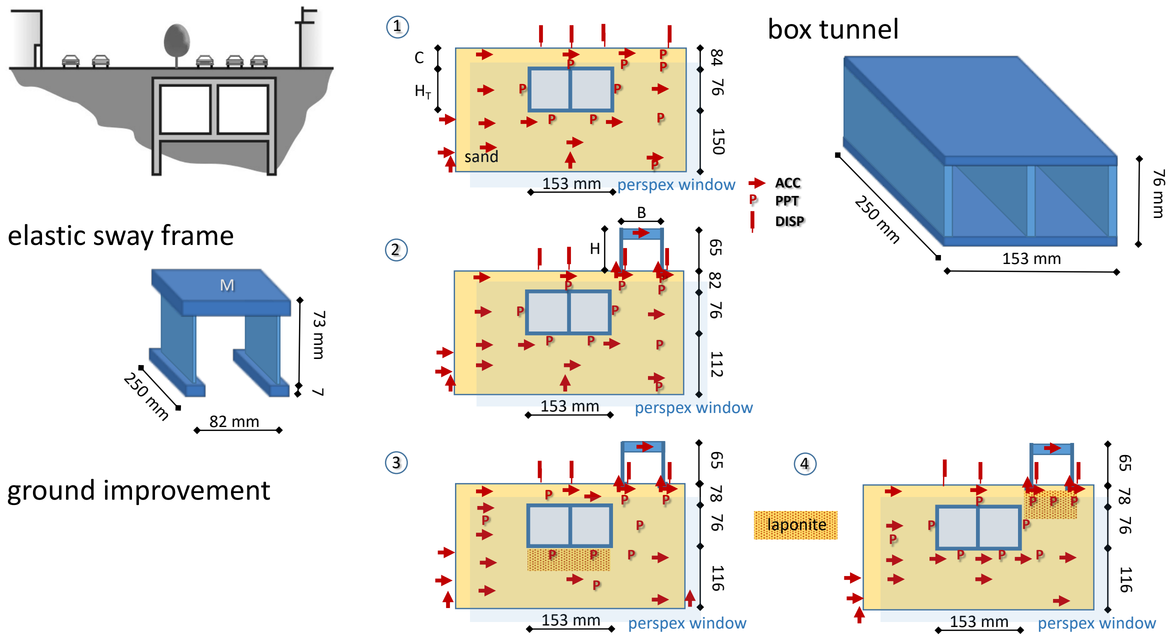


Figure 71: schematic draws of the four centrifuge models

8.2.2 Main research objectives and expected contribution to the seismology and earthquake engineering community

The mechanism of the uplift behaviour of underground structures, focusing on the influence of the degree of liquefaction, the external forces acting on the underground structure and the deformation of the liquefied ground, has been investigated in past studies with reference to free ground surface conditions.

However, recent centrifuge testing on the behaviour of buildings founded in liquefiable ground layers have shown that smaller net excess pore pressures are generated within the liquefiable layer under a structure by increasing the contact pressure and height/width ratio of the building. Other studies have shown reciprocal influence of adjacent buildings, affecting non-uniform settlement during liquefaction.

How the uplift mechanism of an adjacent underground facility is influenced by the presence of the building and how the development of a mechanism beside the building due to the floating of the underground structure can affect the tilt and settlement of the building are both aspects that have not been investigated in the literature.

This problem appears rather important for the earthquake engineering community considering the rapid extension of the built environment, both above- and underground, to areas that may be subjected to risk of liquefaction. Hence the study intends to contribute to the wider topic of the resilience of urban environment to natural hazards.

8.2.3 Project status

At the time being 3 out the 4 foreseen models have been tested, according to the layout 1 to 3 shown in Figure 71.

Figure 72 to Figure 74 show pictures of the models before testing.

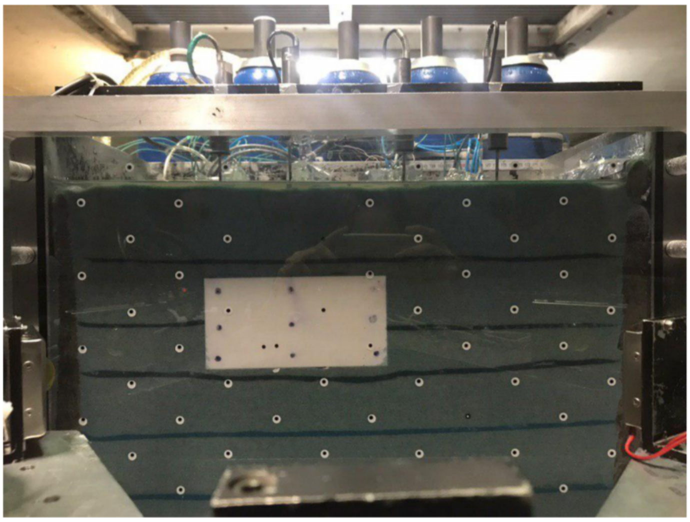


Figure 72: front picture of model #1 in Figure 71

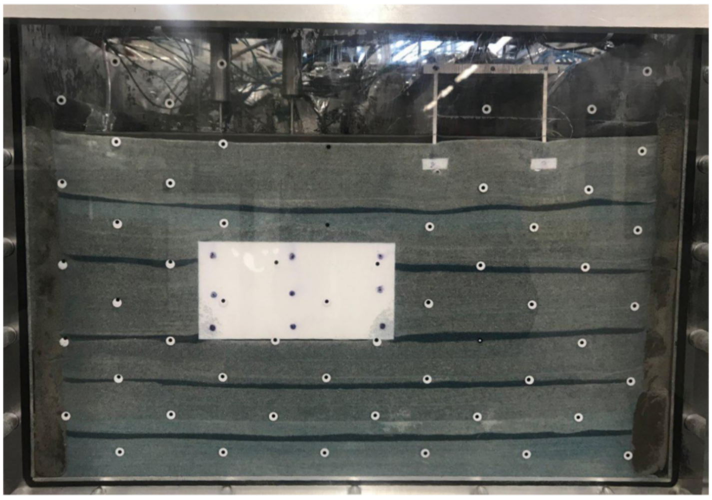


Figure 73: front picture of model #2 in Figure 71

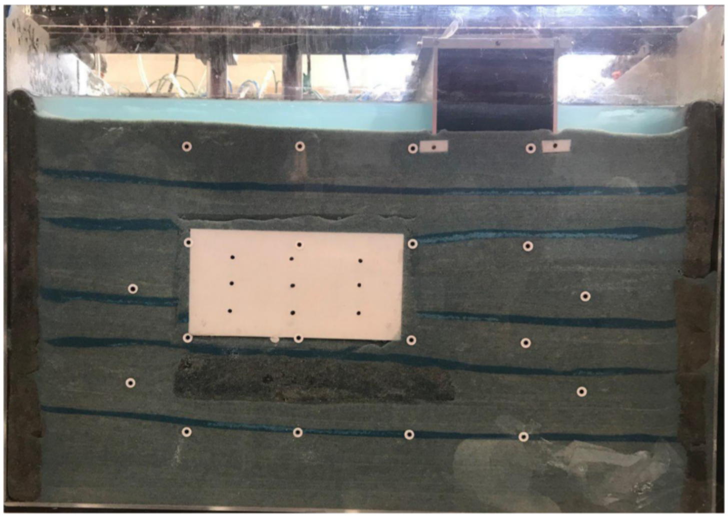


Figure 74: front picture of model #3 in Figure 71

The main characteristics of the shaking applied to the models 1 to 3 are shown in Table 10. The first shaking of each model is generally very weak ant it was applied to improve the homogeneity of the model prior to the following shakings. Shaking no.2 is generally able to provide information on the dynamic behaviour of the model without inducing liquefaction. From shaking 3 ongoing, significant liquefaction is expected to occur in the model. Most of the shakings were induce by pseudo-harmonic input signals, although on models 1 and 3 a final shaking was excited, that corresponds to the natural record of Kobe.

earthquake	frequency (Hz)	cycles	PGA (g)
model 1			
1	1	10	0.058
2	1	10	0.100
3	1	10	0.310
4	1	15	0.339
Kobe	-	-	0.167
model 2			
1	1	10	0.067
2	1	10	0.105
3	1	10	0.369
4	-	15	0.416
model 3			
1	1	10	0.054
2	1	10	0.097
3	1	10	0.390
4	1	15	0.390
5	1	15	0.440
Kobe	-	-	0.142

Table 10: input signals used in the tests

Figure 75 shows the contours of vertical displacements at the end of earthquake 3 and 4 in all the models tested until date. They were measured by using PIV. As a general comment, it should be noted that larger displacements occurred during earthquake 3 than during earthquake 4, although in the latter higher accelerations were applied. This indicates possible densification of the sand layer as a consequence of liquefaction occurred during earthquake 3.

Figure 76 to Figure 79 show the time histories of vertical displacement of selected target in the tunnel and on the structure (or in corresponding points in the free-field model) as they were obtained from PIV.

A comparison between “model 2 - earthquake 3” and “model 1 - earthquake 3” shows that lower upheaval of the tunnel is observed in model 2, due to the higher initial relative density (51% *vs.* 43%), despite the input PGA in model 2 is slightly higher than in model 1.

When comparing “model 3 - earthquake 3” and “model 1 - earthquake 3”, the upwards displacements of the soil around the tunnel (above it in particular) are similar in terms of magnitude, despite the PAG of earthquake 3 in model 3 is about 30% higher than the corresponding value in model 1, and the two models have comparable relative density (44% *vs.* 43%). This indicates that the layer of sand improved with laponite that has been created in model 3 beneath the tunnel is able to reduce the tunnel uplift.

Figure 79 shows a comparison of time histories of excess pore pressure. Excess pore pressure within the layer treated with laponite (7 and 8) are lower than outside the layer (5), indicating the effectiveness of laponite suspension to reduce excess pore pressure that produces the tunnel uplift.

Concerning the structure, a reciprocal influence between the tunnel and the structure movements can be detected by looking at the displacement patterns in Figure 75. Measurements seem to indicate that the improvement of sand with laponite beneath the tunnel as a limited effect on the structure. Numerical analyses are needed to verify this conclusion.

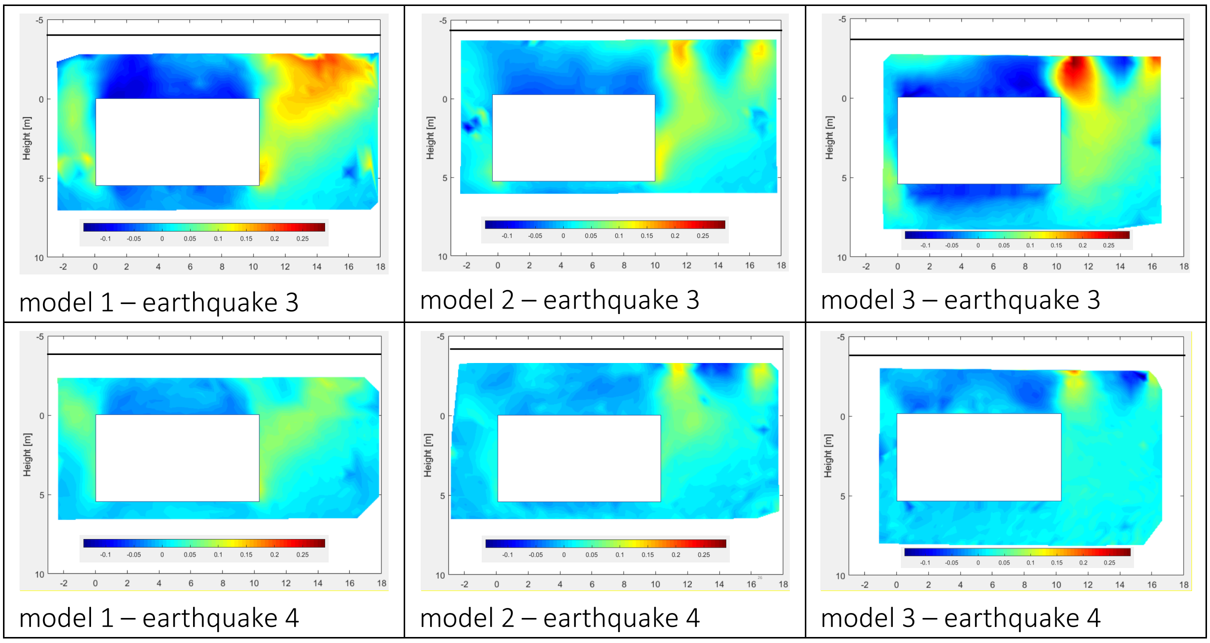


Figure 75: contours of vertical displacement from PIV at the end of earthquake 3 and 4 in models 1,2 & 3

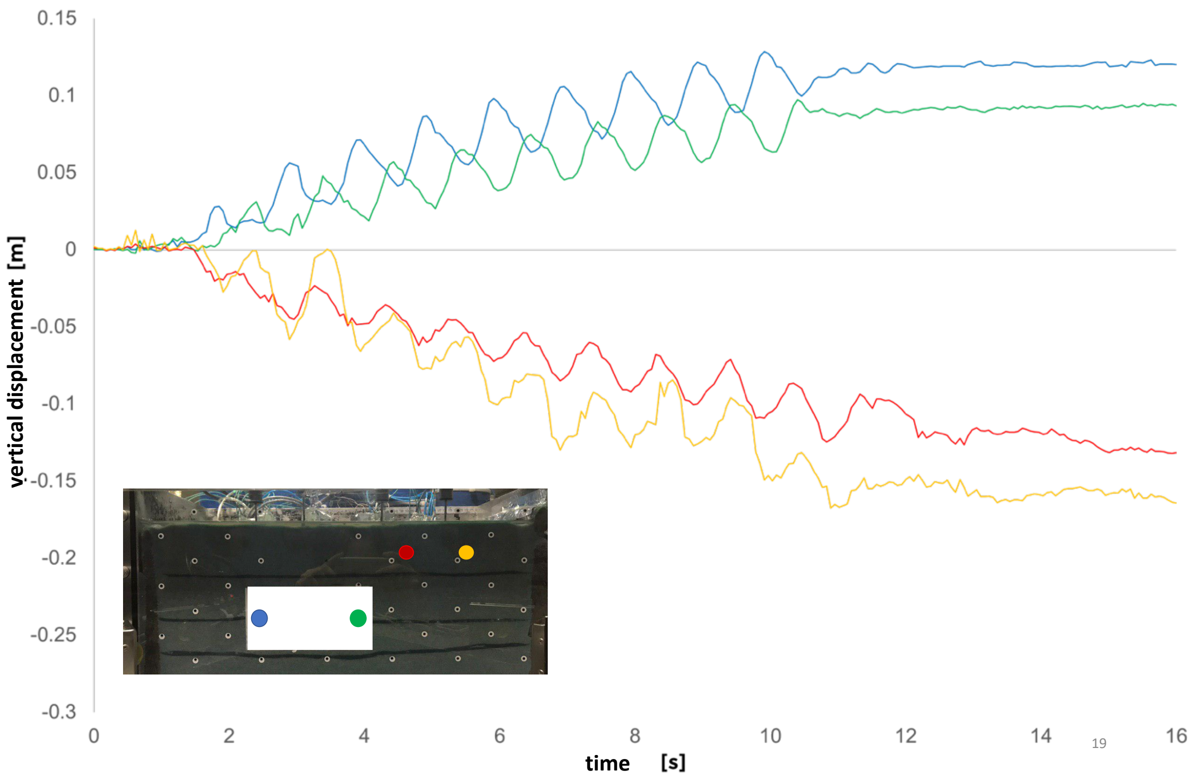


Figure 76: time history of vertical displacement from PIV: tunnel and free-field, model 1, earthquake 3

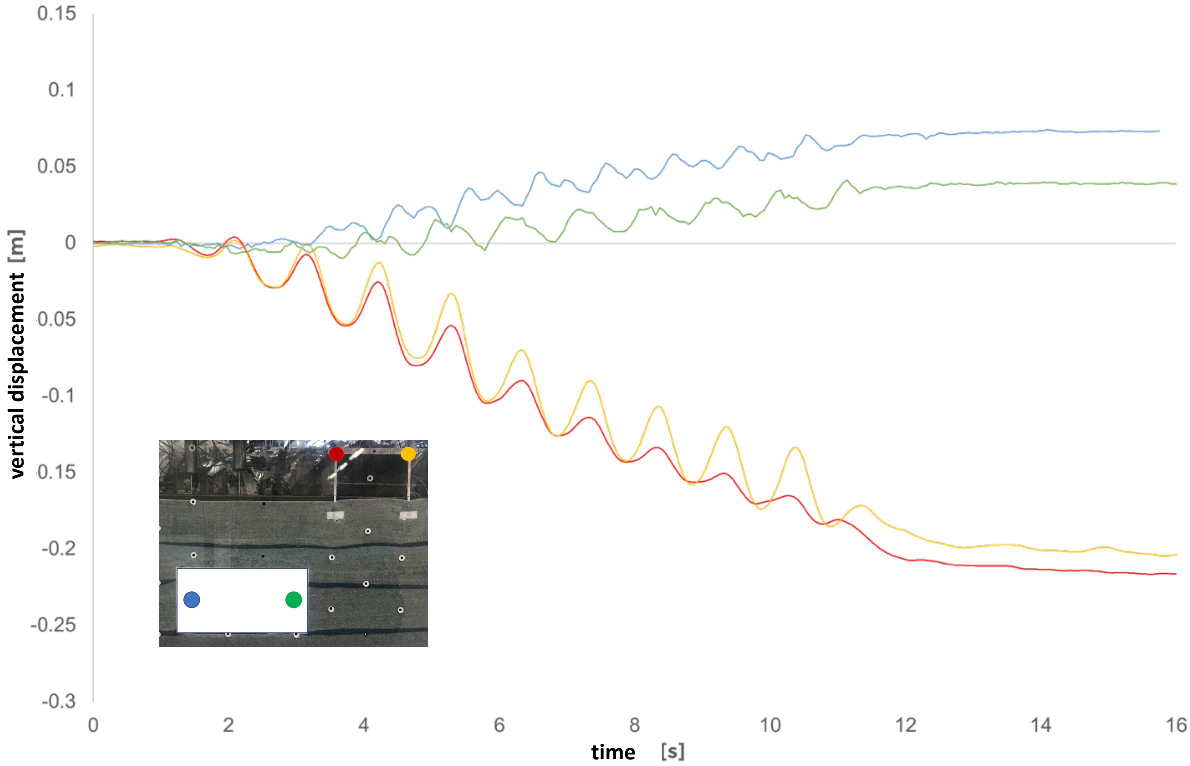


Figure 77: time history of vertical displacement from PIV: tunnel and building, model 2, earthquake 3

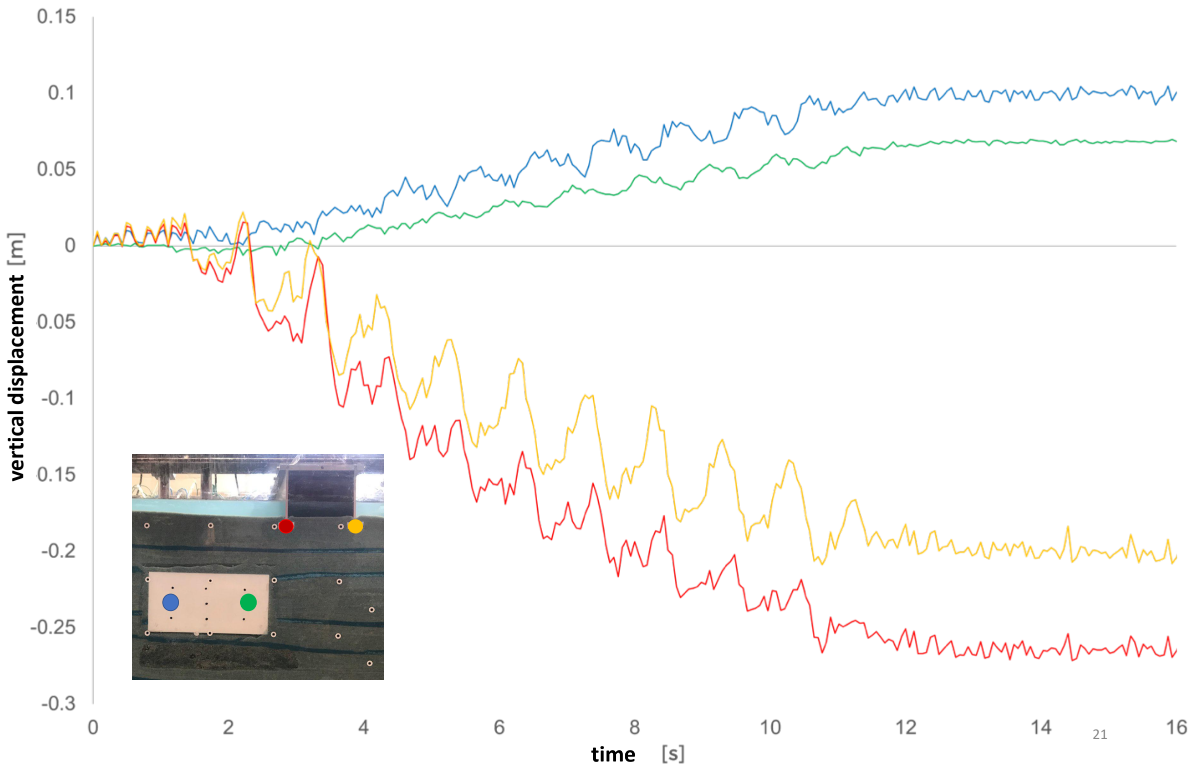


Figure 78: time history of vertical displacement from PIV: tunnel and building, model 3, earthquake 3

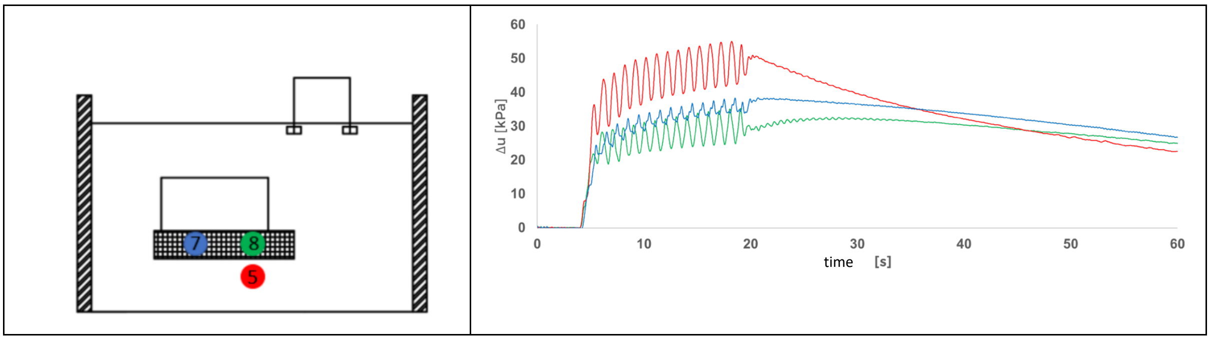


Figure 79: time history of excess pore pressure with (7,8) and outside (5) the treated layer (earthquake 3, model 3)

8.2.4 Foreseen activities and schedule

The fourth and last test of the series will be completed in the second week of April. This test will be carried out on model 4, where a layer of soil between the tunnel and the building foundations will be improved with a laponite suspension of the same characteristics adopted in model 3.

8.2.5 User Group

	NAME	ORGANIZATION NAME	ORGANIZATION COUNTRY
USER GROUP LEADER	Emilio Bilotta	University of Napoli Federico II	Italy
ADDITIONAL USERS	Valeria Nappa	University of Napoli Federico II	Italy
	Gaetano Miranda	University of Napoli Federico II	Italy

8.3 SERA TA Project #3 – COSMO: Change Of Seismic MOtion due to pile-soil kinematic interaction – [in progress]

8.3.1 Summary of the project

Seismic analysis of structures supported on piles is conventionally performed by considering the free-field motion as the base excitation. In this regard, possible piles-induced modification of the seismic motion due to the interplay between soil and piles, which is referred to as kinematic soil-pile interaction, is neglected. However, piles, depending on their stiffness, are not always able to follow motions with short wavelengths induced by the surrounding soil. As a result, piles may filter the high-frequency components of the free-field motion and may, thus, modify the input motion of a pile-supported structure. The above physical phenomenon which is referred to as “filtering effect” may be particularly pronounced for soft soils, where piles represent the most common design option. Experimental evidence on this filtering action of piles is still limited to some instrumented pile-supported buildings in Japan. These experimental data clearly indicate that piles filter out the high frequency component of the free-field motion. However, the above acceleration recordings at the foundation of these buildings include inherently the effect of the superstructure oscillation. Thus, there is a lack of experimental evidence on the alteration of seismic motion that can be attributed exclusively to piles.

COSMO research project aims to advance the present state-of-the-art on the above critical issue of piles-induced filtering effect. For this reason, a series of centrifuge tests are proposed on models of aluminium piles embedded in soft soils. The proposed model tests include both single piles and groups of three piles rigidly connected by a cap under harmonic excitations. The influence of diameter, soil-cap contact and cap-embedment on the alteration of seismic motion will be also investigated.

8.3.2 Main research objectives and expected contribution to the seismology and earthquake engineering community

The main objective of this experimental program is to provide well-documented experimental evidence on the critical issue of the change of seismic motion induced by pile-soil kinematic interaction. Moreover, the testing campaign within COSMO project will be complementary to a relevant series of centrifuge test already performed at the Schofield Centre of the University of Cambridge on models of aluminium piles rigidly connected by a cap (clear to the soil) and embedded in kaolin with variable pile spacing (under Reluis 2017 research project granted by the Italian Emergency Management Agency). The additional tests planned within COSMO project will investigate for the first time a set of critical parameters that are involved in the kinematic response of a piled foundation such as the cap-soil contact and the cap embedment. The proposed model tests will be also examined numerically by the use of a hysteretic non-linear model based on Ramberg-Osgood formulation, so as to reproduce in a realistic manner the degradation of the shear stiffness of soil, the increase of soil damping ratio generated by the passage of seismic waves and the occurrence of earthquake induced excess pore pressures. The experimental evidence supplied by the above projects will serve as a benchmark to assess the validity of the simplified methods of analysis aimed at the evaluation of the base excitation for pile-supported structures. The experimental assessment of the transfer functions for both pile groups and the isolated piles, will have a remarkable scientific, technical and economic impact. First, the results of this testing campaign will have a direct positive impact on the understanding of the physical problem under examination. Second, the experimental evidence supplied by this work will enhance the ability to predict the seismic input motion of pile-supported structures, thus allowing for a more rational allocation of resources in seismic risk mitigation strategies. Third, the investigation of the basic aspects of the mechanism governing the change of seismic motion by pile-soil kinematic interaction will provide guidance for the selection of physical model of pile groups to be tested in the future.

The originality and innovation of the proposed project lie within the following research advancements:

<u>Development of a new well-documented database of recordings for piles filtering effect.</u>

As outlined before, the available experimental evidence on the filtering effect exerted by piles is limited to published works that go back to the early 70s (Kawamura et al. 1977) and 80s (Otha et al. 1980, Gazetas 1984). The experimental data that will be acquired from the COSMO project will advance the database which is already available from project ReLUIS 2017, to provide a well-documented database on the alteration of seismic motion due to pile-soil kinematic interaction.

Validation of theoretical/numerical models and analysis tools: The Users Team of COSMO proposal has established a strong theoretical background on the issue of the filtering action of piles by means of pertinent analysis methods, as reflected in several publications of the research group Part of the above research has resulted in simple analytical expressions of pile-to-soil kinematic response ratios in the frequency domain. The above analytical expressions were obtained under the assumption of raft clear to the soil. Within COSMO project, predictions of the above models will be compared with the centrifuge tests results in order to check the applicability of the published formulae under circumstances where the raft is in contact with the soil or embedded and, eventually, develop ad hoc design oriented formulae for quantifying the filtering effect in the presence of a piled raft.

Contribution towards seismic design practice of piles.

Di Laora & de Sanctis (2013) observed that, in case of large diameter pile in soft soils, the filtering action may result in a reduction of the seismic demand up to 50% - 70% (for low-period structures). The reduction of spectral accelerations between pile-head and free-field may be even higher when piles are embedded in inhomogeneous soil (Rovithis et al. 2015, 2017). The above considerations will be validated accordingly by means of the experimental dataset produced by the COSMO project and may have a direct impact in future revisions of seismic codes with reference to the design of structures on piles. Under this perspective, piles in the future may be also viewed as 'seismic demand reducers' in the design of a structure.

In view of the fact that European researchers, practitioners and companies will be the beneficiaries of the outcome of this research, the following benefits are expected:

- Improvement of the accuracy of existing methods for seismic vulnerability assessment of buildings and infrastructures;
- Improvement of public safety, as current design practice will surely benefit from the results obtained;
- Improvement of European competitiveness, as the experimental evidence supplied by this research can be used by European companies and exported abroad to support innovative solutions for seismic risk mitigation strategies.

8.3.3 Project status

The first centrifuge experiment, PSKI-A, was carried out in March, during week 19-23. We examined the response of models of aluminium single piles and pile groups embedded in soft kaolin clay and excited by both earthquakes. The centrifuge experiment was performed at 50-g in the Equivalent Shear Beam (ESB) container (Brennan & Madabhushi, 2002) and included two flights. In the first flight (F1), the pile cap was made of Perspex and therefore considered as negligible, so as to minimize the effect of inertial interaction; in any case, the overall response of both the pile groups and the isolated piles unavoidably include the small inertial effect due to Perspex cap which is needed to install the measurement devices. In the second flight (F2), we added an elevated aluminium cap to each foundation model, in order to investigate essentially the response to inertial actions.

Experimental Set up.

Geotechnical centrifuge. The experiment was conducted in Turner beam centrifuge at Schofield Centre, Department of Engineering, University of Cambridge.

Seismic actions. They consisted of a sequence of 4 quasi-sinusoidal waves followed by 5 real earthquakes. Quasi-sinusoidal waves with different amplitude and predominant frequency were applied to simulate the motions generated by the earlier SAM actuator, while the subsequent real earthquakes throughout the servo-hydraulic shaker recently developed at the Schofield Centre.

Model Container. The physical models were installed in the equivalent shear beam (ESB) container (Schofield and Zeng, 1992), a rectangular box made of hollow aluminium rings of width 75 mm interbedded by rubber layers. The internal dimensions are 230 x 645 mm and the height is 400 mm. An aluminium ring of 200 mm in height was placed on the top of the container. In order to fix the location of instruments inside the box, five horizontal aluminium wires were settled in it.

Clay

Laboratory grade Speswhite kaolin, whose mechanical behaviour has been extensively studied (Take 2003, Lam 2010, Williamson 2014, Lau 2015) was used in this test.

Model pile foundations. Aluminium tubular model piles of lengths L_1 = 200 mm and L_2 = 190 mm, d = 15 mm in diameter and thickness t = 1 mm were used to simulate the behaviour of single piles and pile groups at prototype scale. The flexural stiffness of the prototype piles is equivalent to a 0.75 m diameter and high-strength concrete piles. The pile lengths of 10 and 9 meters at the prototype scale is large enough to consider the pile as 'long' from a mechanical viewpoint and therefore its response to dynamic loading represents also the response of any other longer pile. Pile spacing is constant and equal to s = 64 mm. All single and grouped piles were covered by hollow Perspex caps of different heights, D_1 = 20 mm (mass = 90 g) and D_2 = 40 mm (mass = 170 g), representing two different foundation embedments.

Figure 80 shows single and grouped piles along with their pile caps used in the first flight (dimensions are in model scale).

Model superstructures. Single degree of freedom systems were made by the mean of steel structures with a fundamental period of 0.2 s. This value was confirmed by tests on these (fixed base) structures subjected to an impulse, by measuring the acceleration through MEMS. Figure 81 shows single and grouped piles along with their pile caps and superstructures used in the second flight. Figure 82 shows a pile group with its superstructure used in the test (flight 2).

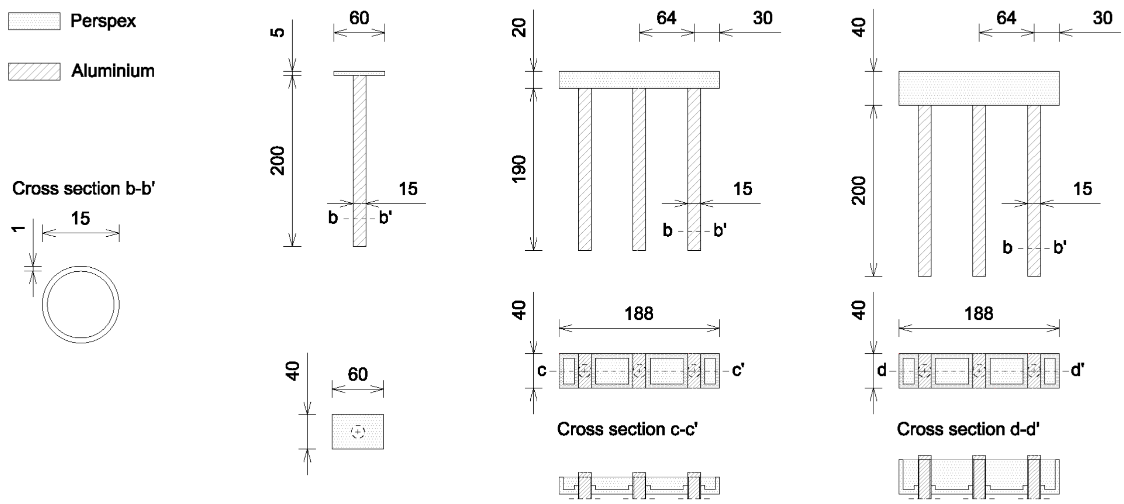


Figure 80: Model pile foundations used in this experiment in flight 1 (dimensions at model scale)

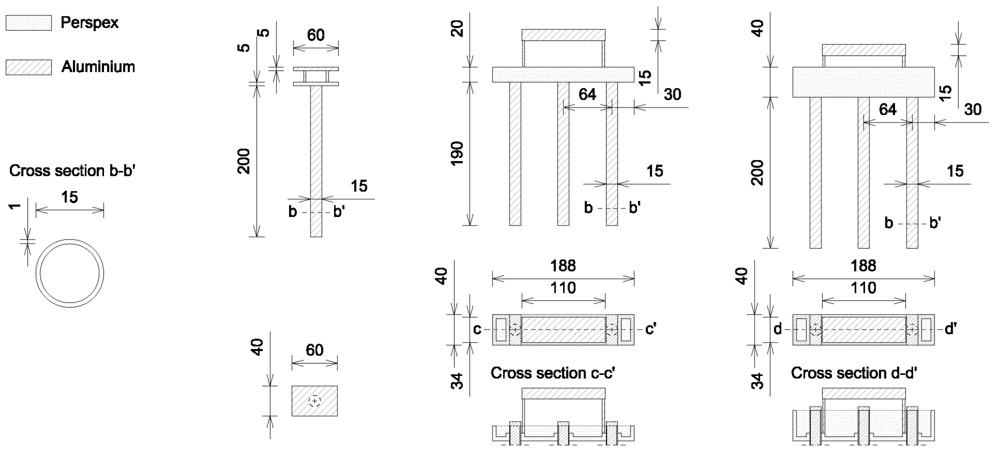


Figure 81: Model pile foundations and superstructures used in this experiment in flight 2 (dim at model scale)

Figure 82: Model pile foundations and superstructures used in this experiment in flight 2

Experimental Instrumentation. In order to capture the response of consolidated clay and pile foundations during the tests, different instruments are used, as listed below.

- 11 Piezo-electric Accelerometers (PA): to record the seismic accelerations developed in the clay.
- Before installing PA in clay sample, their surfaces were sealed with wax to avoid direct contact with water.
- 20 Micro-Electro-Mechanical System accelerometers (MEMS): to measure both horizontal and vertical accelerations of pile foundations.
- 4 Pore Pressure Transducers (PPT): to measure the pore pressure within the soil model.
- This is done by applying known water pressures and measuring the voltage output from the PPT.
- 6 Linearly Variable Differential Transformer (LVDT): to monitor the settlement of clay, single piles and pile groups at different phases of testing.

Calibration factors were determined before and after the test.

T-Bar Penetrometer Test. The strength of clay was determined using a T-bar penetrometer. It measures the resistance to penetration, by a load cell, as it advances trough a soft clay layer at constant speed. The theoretical basis for this empirical correlation was set by Randolph & Houlsby (1984). A driving actuator pushes the T-bar in to the clay and the depth of penetration is measured using the LVDT fixed next to the actuator.

Air Hammer Device. The stiffness of clay was evaluated using a miniature Air Hammer Device (AHD). It consists in a small brass tube containing a metal pellet within it that is made to accelerate by applying high-pressure air on alternative ends. Its striking the end of the tube induces a share wave at the base of the model which propagate upward towards the soil surface. Accelerometers placed at different but known locations record the arrival times, hence shear wave velocity, V_S between adjacent accelerometers can be computed ($V_S=\Delta s/\Delta t$, where Δs is the distance between the instruments and Δt is the lime lag between the signals), as well as the small strain shear modulus G_0 ($=\rho V_S^2$, where ρ is the density of the soil).

Experimental Procedure

The Speswhite kaolin clay powder was first mixed with de-aired water in 1:1.25 ratio under vacuum for two-three hours using the clay-mixer available in Schofield Centre. The bottom of ESB box was then covered with a thin layer of filter material and its inner surface was coated with silicone grease to minimize friction against the clay. In order to fix the location of instrument inside the box, five horizontal aluminium wires were settled in it. Clay slurry was then transferred into the ESB box, once the instruments were fixed with utmost care. The top surface of clay was covered with a filter material and top loading plate was placed over it. The clay slurry was allowed to consolidate on its self-weight for 24 hours. To obtain a soft clay profile with a given strength at the surface and then increasing strength with depth, a combination of consolidation under vertical stress and hydraulic consolidation by suction-induced seepage were used to consolidate the clay slurry. The ESB box was placed under a computer-controlled hydraulic press to consolidate under a vertical stress of 1 kN. Once the clay consolidated for the applied vertical stress, the sample was subjected to suction induced seepage consolidation by applying a suction pressure of -90 kPa at the bottom of ESB box in increments of -10 kPa. A vertical stress of 1 kN on top of clay was added and constantly maintained even during this suction induced seepage consolidation. Once the clay was consolidated, sample was unloaded and taken out from the consolidation chamber. Then, the clay top was slightly trimmed to obtain levelled surface. Clay samples were collected at different depths to measure the moisture content before the test. Piles were installed by gentle push in to the clay. Figure 83-Figure 86 show the schematic view of plan and section of the model and the instrument locations for both flights 1 and 2 (dimensions are in model scale). Figure 88 show the model in the centrifuge. The model was swung up to 50g and nine earthquakes (Table 11) were fired one after the other using the Servo-hydraulic earthquake actuator. The strength and stiffness of clay are evaluated using T-bar and an Air Hammer Device (AHD), respectively. T-bar tests were performed at 1g before centrifuge, at 50g and at 1g after centrifuge. Air Hammer tests were performed at 1g before centrifuge, at 50g, between each earthquake and the next and at 1g after centrifuge. The data from all the instruments were monitored using Dasy lab. After this, the model was swung down. Clay samples were collected at different depths to know the moisture content after the test.

n.	type	name	frequency [Hz]	cycles	peak base acceleration [g]
1	sinusoidal		30	12	0.07
2	sinusoidal		40	16	0.09
3	sinusoidal		60	24	0.18
4	sinusoidal		50	20	0.24
5	real earthquake	Kobe (mul. 0.25)			0.15
6	real earthquake	Imperial Valley (mul. 4)			0.13
7	sine sweep		30 up to 150		0.08
8	real earthquake	Kobe (mul. 4)			0.42
9	sinusoidal (CF=7g/V)			12	0.08

Table 11: Excitations used in this test

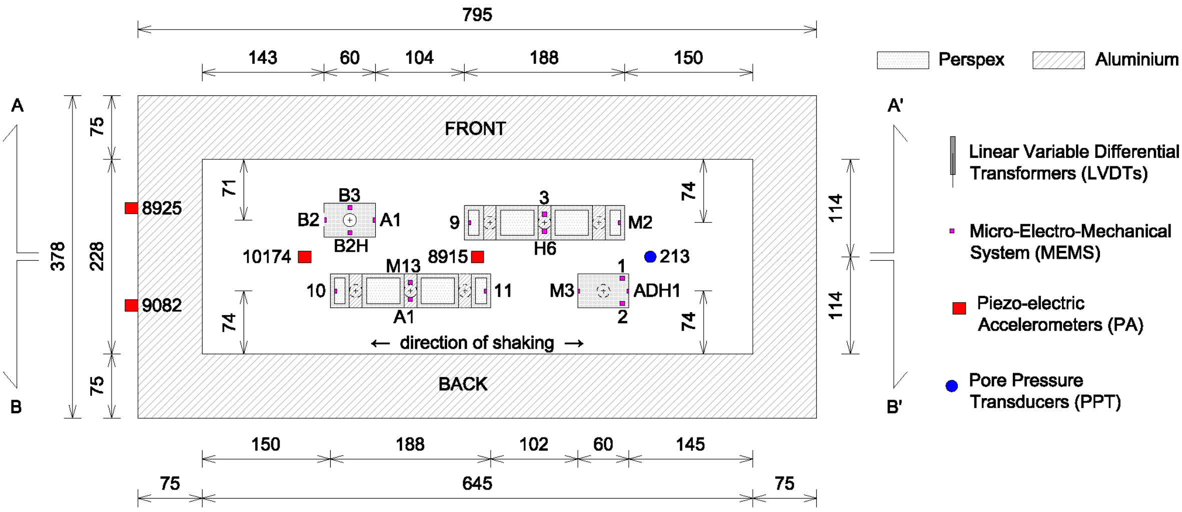
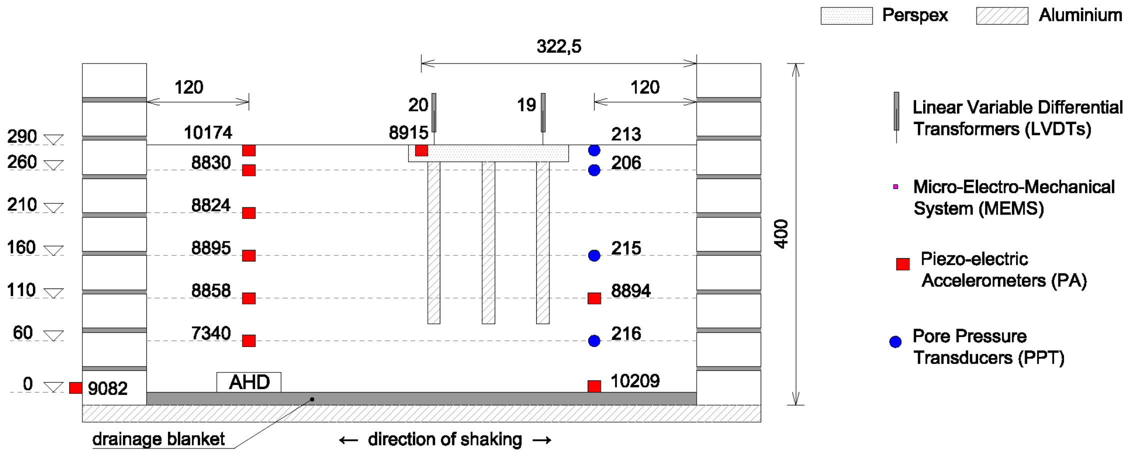


Figure 83: Plan view of the model used in this experiment in flight 1

Cross-section along the plane A-A'



Cross-section along the plane B-B'

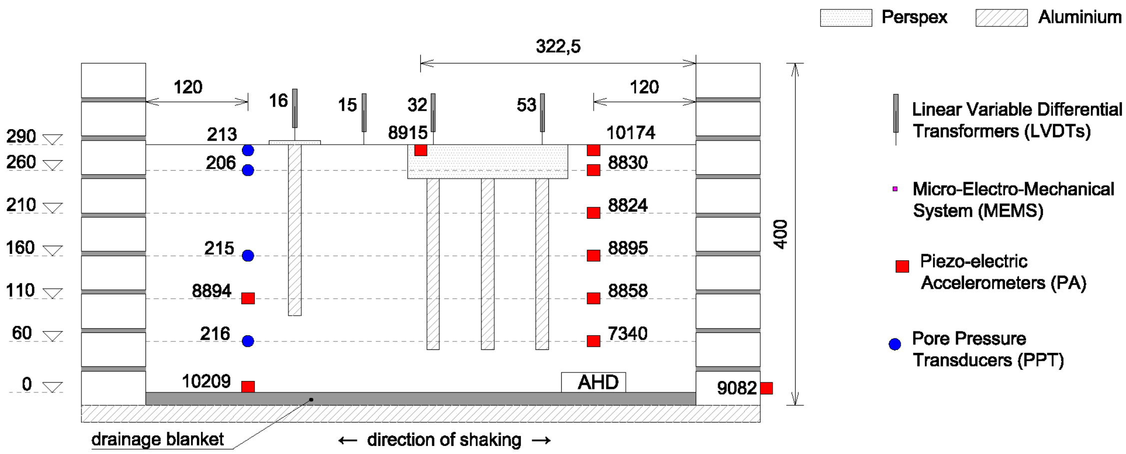


Figure 84: Cross section views of the model used in this experiment in flight 1

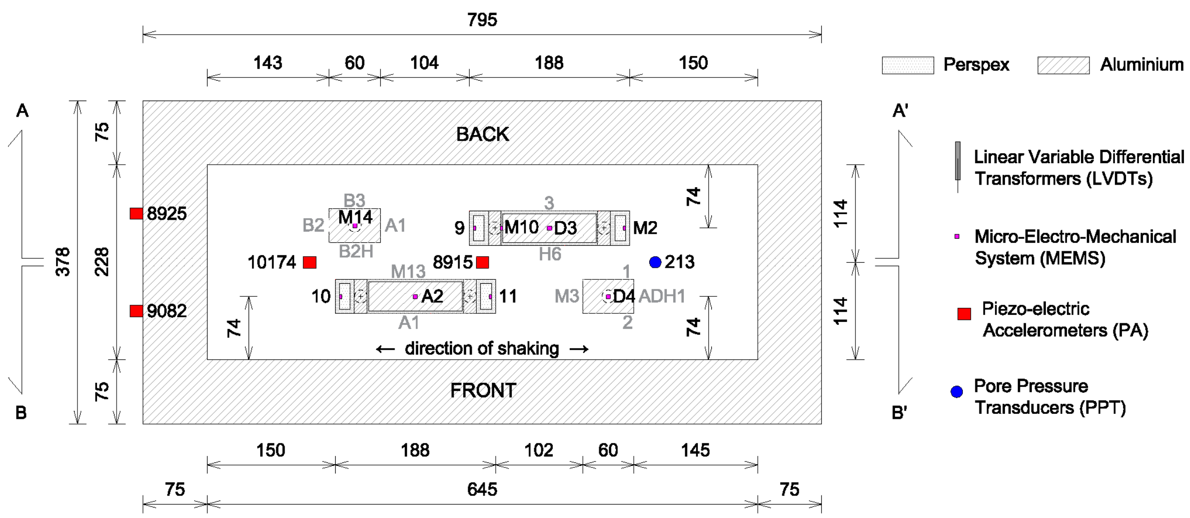


Figure 85: Plan view of the model used in this experiment in flight 2

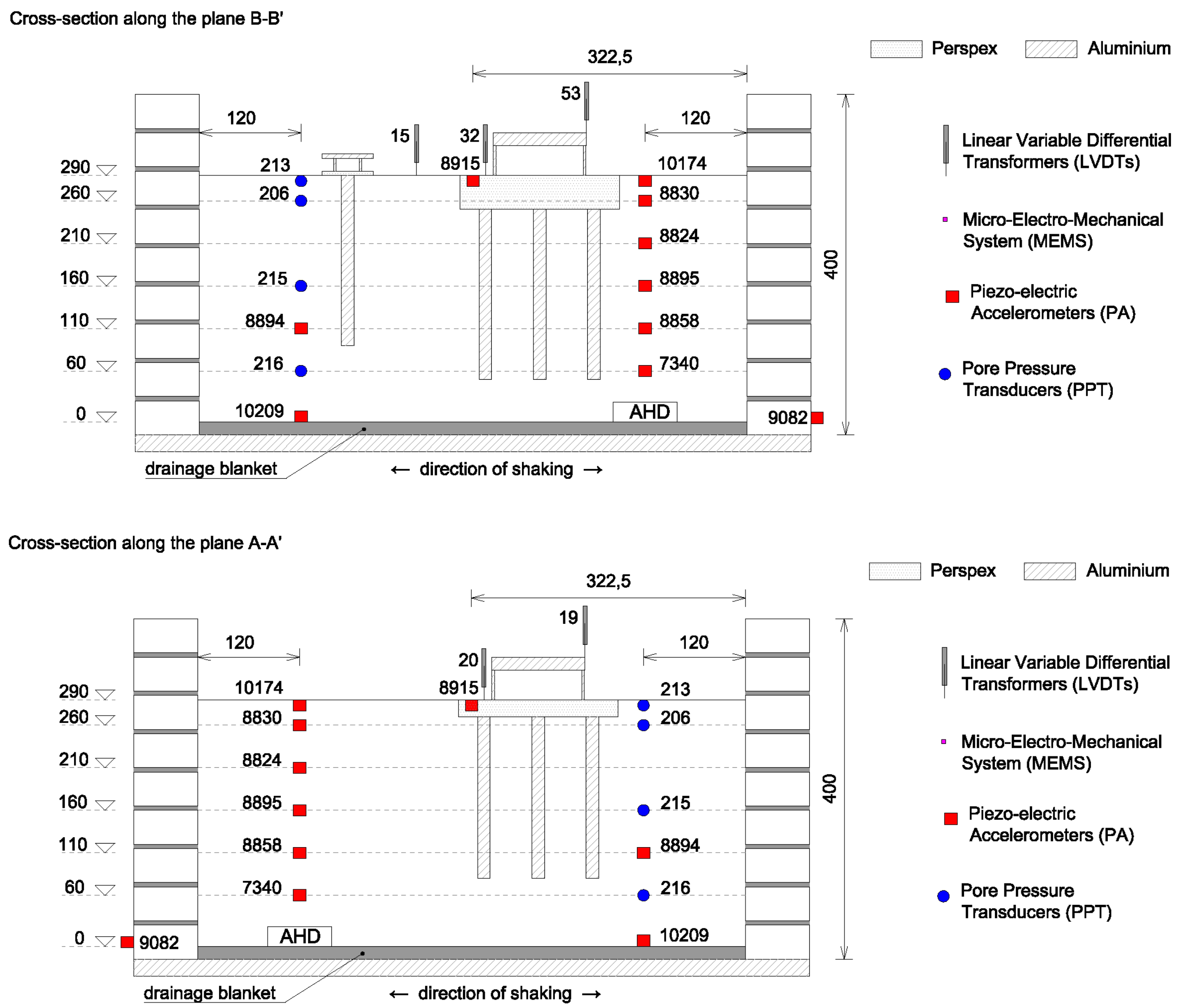


Figure 86: Cross section views of the model used in this experiment in flight 2

Figure 87: Model used in this experiment in flight 2

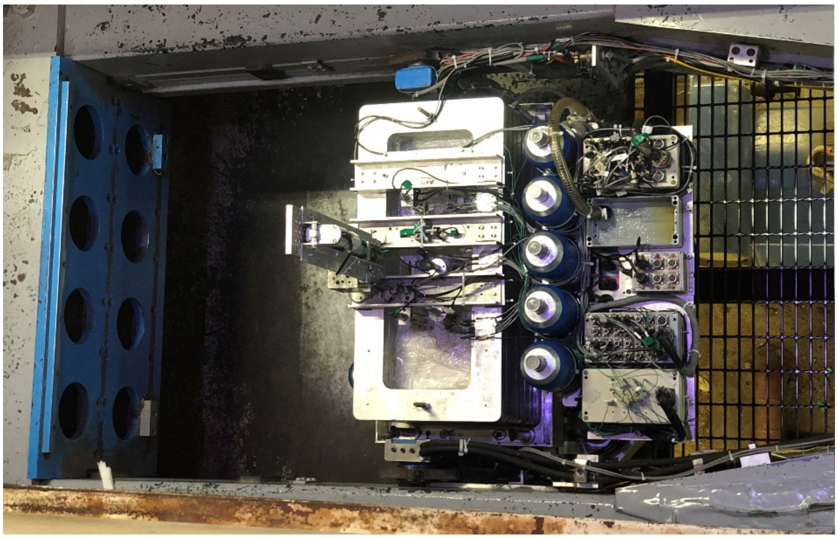


Figure 88: Model in the centrifuge

8.3.4 Foreseen activities and schedule

We have planned to perform the second experiment in July 2019. According to the timetable of the research proposal, we will focus in the following two months on the interpretation of the experimental data and on construction of the plots resuming the main results of the experimental work. Additionally, we also plan to use the data for at least two journal publications.

8.3.5 User Group

	NAME	ORGANIZATION NAME	ORGANIZATION COUNTRY
USER GROUP LEADER	Luca de Sanctis	University of Napoli Parthenope	Italy
ADDITIONAL USERS	Maria Iovino	University of Napoli Parthenope	Italy
	Emmanouil Rovithis	Earthquake Planning and Protection Organization EPPO - Research Unit ITSAK	Greece
	Raffaele Di Laora	University of Campania Vanvitelli	Italy
	Roberto Cairo	University of Calabria	Italy
	Enrico Conte	University of Calabria	Italy
	Luigi Di Sarno	University of Liverpool	UK

9 EUROSEISTEST and EUROPROTEAS

During the period till M12 the User Group of CentraleSupélec carried out part of the project "IMPEC - On the broadband synthetic signals enhancement for 3D Physic based numerical analysis, the EUROSEISTEST Case study". The main object of the project is to validate the multi-tool platform developed for 3-D physics-based analysis, to build-up a reliable earthquake strong ground motion scenario of the Mygdonia valley and to predict realistic time-histories at the site by simulating the source-to-site wave-propagation. The effect of soft sediments on the dispersion of the earthquake ground motion was numerically investigated on a preliminary model of the Mygdonian basin. The model was constructed based on the database of the EUROSEISTEST and EUROPROTEAS facility that the User Group had access.

The projects assigned in the 2nd call are the following:

1. **Title:** "SISIFO" - Seismic Impedance for Soil-structure Interaction From On-site tests
   User Group Leader: Francesco Silvestri
   Organization Name: University of Napoli Federico II
   Organization Country: Italy
2. **Title:** Ambient and forced vibration techniques for improving design and performance assessment of structures with consideration of soil-structure interaction
   User Group Leader: Matjaž Dolšek
   Organization Name: University of Ljubljana
   Organization Country: Slovenia
3. **Title:** Seismic site effects in sedimentary basins from 3D physics-based numerical modeling (SITE3D)
   User Group Leader: Chiara Smerzini
   Organization Name: Politecnico di Milano
   Organization Country: Italy
4. **Title:** Comparison of rocking on rigid and compliant base using the EUROPROTEAS real-scale facility
   User Group Leader: Ioannis Anastasopoulos
   Organization Name: ETH Zurich
   Organization Country: Switzerland
5. **Title:** Dynamic Soil Structure Interaction: Three-dimensional Time-domain Analysis of Field Model Scale Experiments
   User Group Leader: Stavroula Kontoe
   Organization Name: Imperial College
   Organization Country: United Kingdom

The projects assigned in the 3rd call are the following:

1. **Title:** Soil Frame-Interaction Analysis through large-scale tests and advanced numerical finite element modeling (Acronym: SOFIA)
   User Group Leader: Maria Rossella Massimino
   Organization Name: University of Catania
   Organization Country: Italy
2. **Title:** Resonant metamaterial-based earthquake risk mitigation of large-scale structures and infrastructure systems: assessment of an innovative proof-of-concept via medium-size scale testing
   User Group Leader: Alessandro Marzani
   Organization Name: University of Bologna
   Organization Country: Italy

3. **Title:** "DYMOBRIS" - DYnamic identification and MOnitoring of scoured BRIdgeS under earthquake hazard
   User Group Leader: Enrico Tubaldi
   Organization Name: University of Strathclyde
   Organization Country: United Kingdom

During the period between M13 to M24 the experimental programs concerning five projects were carried out. The detailed test programs along with some indicative results are presented in the present report. All the experimental data has been shared between the Host Facility Group and the corresponding User Groups. Technical support on the data exploitation is made available by the Host Facility Group. All the recordings have been used to update the current experimental database of the Host Facility Group.

Additionally, for the rest of the projects detailed descriptions of the desired experiments on the EUROPROTEAS and EUROSEISTEST Facility along with careful planning of the test programs have been carried out.

Within the next 12 months all the experiments described in the rest of the projects are going to be performed. All the experimental data will be shared between the Host Facility Group and the corresponding User Groups. Technical support on the data exploitation will be made available by the Host Facility Group. All the projects will be concluded as described in each User Group proposal.

9.1 Project #1 – IMPEC - On the broadband synthetic signals enhancement for 3D Physic based numerical analysis, the EUROSEISTEST Case study – [concluded]

9.1.1 Summary of the project

The "IMPEC - On the broadband synthetic signals enhancement for 3D Physic based numerical analysis, the EUROSEISTEST Case study" is concluded.

The Mygdonia valley represents a very appealing test site for the calibration and tuning of large scale numerical models of strong ground motion earthquake scenarios. A manifold objective is to employ the available data (specifically, the cluster of strong ground motion observations (i.e. Mw>5.5), recorded by the dense array network and geological/geotechnical data at a regional and site scale, such as VS profiles, borehole data and dynamic soil properties) to construct a 3-D physics-based numerical model of the site surroundings (approx. within a radius of 30-50 km) to reproduce the complex broadband (i.e. fmax>8 Hz) wave-field generated by the interaction between the seismic waves (radiated by the fault-offset along rupture discontinuities) with the heterogeneous sedimentary basin laying underneath the region of interest and its complex 3D configuration.

9.1.2 Main research objectives and expected contribution to the seismology and earthquake engineering community

In recent years, the physics-based numerical simulation of realistic earthquake strong ground motion scenarios has become the prominent type of seismic predictive analysis, aiming at effectively solve complex three-dimensional (3-D) source-to-site seismic wave propagation problems. This predictive approach bares on multi-tool high performance computational platforms (HPC) to construct multi-scale deterministic numerical models, embracing a holistic philosophy. Typically, the critical aspects of a reliable earthquake predictive model are

- the accurate description of the time-space rupture path and
- the modeling of the dispersion/attenuation/amplification phenomena, due to the wave-field passage across complex 3-D geological interfaces towards the surface, from harder bedrock to softer soil layers.

With this respect, the numerical investigation pays special attention to the description of the near-source wave-field, e.g. the reproduction of energetic velocity pulses, of the scattering due to the heterogeneous shallow soil layers and of the effect of the topographical conformation. The routinely employment of such forward simulation technique to assess structural vulnerability passes through a validation phase, where the Goodness of Fit (GoF) is computed, comparing the synthetics to the seismic records belonging to dense observation networks deployed at the site. Since 2014, our research group at CentraleSupelec is developing a multi-tool computational platform for the routine construction of physics-based earthquake ground motion scenarios at a regional scale, mainly to perform predictive vulnerability assessment of critical structures, along with regional risk assessment. The steering target is the capability to generate reliable broad-band synthetics (i.e. 0-10 Hz) to fill the gaps of available high-quality seismic databases. This objective may be systematically reached by designing a vast parametric analysis spanning the uncertainty related to the source (i.e. position, geometry, slip distribution and rupture) and on the impact of buried geomorphology and topographical surface (i.e. the typical dispersive site-effects induced by the incident wave-motion impinging softer sedimentary deposits embanked in rigid bedrock). From another point of view, those so-called stress-tests represent the methodological basis for the vulnerability assessment of critical and spatially extended structures, along with of large urban areas. The stronghold is represented by a solid multi-tool academic platform (Figure 89), tailored to create the computational incarnation of large 3-D earth's chunks (with an approximate characteristic dimension of 50-100 km) to solve the wave propagation problem by means of the Spectral Element Method, applied to viscoelastic heterogeneous soil sediments and bedrock layers. The solver kernel, the mesher and the heterogeneous random field generator have been effectively speeded-up, with high scalability performances.

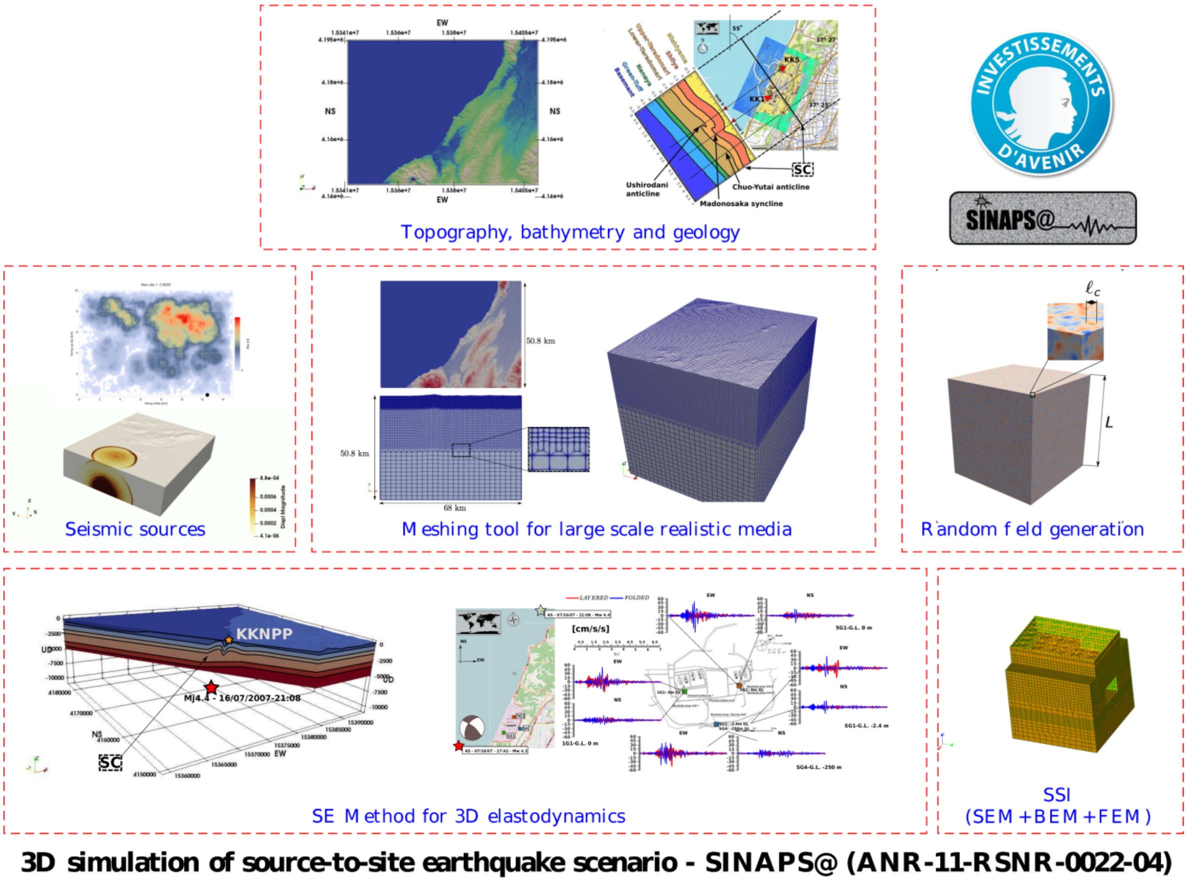


Figure 89: Conceptual scheme of the proposed strategy to study earthquake scenarios (SINAPS@).

With that being said, our major goal is to explore uncertainties associated to data, to the knowledge of the physical processes and methods that are used at each stage of the seismic risk assessment, from the seismic hazard to the vulnerability of structures, including the site-specific effects and the interaction between the seismic wave field, the soil and the structures). More precisely in this project, the main objective is to identify or quantify, potential seismic margins that result from assumptions or when choosing the seismic design level or the design method (i.e. taking into account uncertainties by conservative choice). The availability of the whole EUROSEISTEST database unlocks the possibility to improve the seismological model of the area already available. Enriching the high-frequency content of the simulated ground shaking scenario is undoubtedly a prominent goal of the analysis, to be able to shorten the traditional incompatibility between low-frequency seismological models (i.e. up to 1-2 Hz) and broader-band structural analyses (typical modal analyses spans a 0-30 Hz frequency range). Reliable synthetics in the engineering frequency band of interest could be generated and employed to feed more detailed (yet small-sized) Soil-Structure-Interaction models, serving as realistic input motions for parametric and stress analysis (eventually applying the Domain Reduction Method proposed by Bielak et al. 2003). The shortage of ad-hoc high-quality seismic records can be reduced by employing those earthquake scenarios opportunely calibrated. The latter statement applies specifically to risk and vulnerability analysis in geographical areas of lower-moderate seismicity, where poor strong ground motion databases are available. Another benefit resorted from frequency broadening is the possibility to constrain some seismological models that are still a matter of debate as, for instance, the high-frequency dispersion/attenuation controlled by the κ (kappa) coefficient. The latter is employed to correct local site conditions in ground motion prediction studies and it is still estimated with high uncertainty, especially when assessing the regional value, since it is affected by several mechanisms characterizing the along-path wave-propagation (dispersion, attenuation, non-linear site-effects) and eventually it depends on the seismic source itself. Specifically, the κ value is highly influenced by the anisotropic heterogeneity of the Earth's crust (correlation lengths and structure): in this sense, the data provided for the Mygdonia valley will allow to calibrate the physics-based model, whose outcome will integrate the available recordings so to perform an "host-to-target" analysis and estimate the ground motion response spectra along with the effect on the ground motion incoherence at free-field.

However, the foreseen effort to constrain the computational model with an accurate site-specific characterization will be useful to investigate and test the current traditional predictive methods, such as the GMPEs, in a low-frequency range. The distributions of the data over the predictor variable space necessarily influence the GMPE calibration, i.e. the lack of data at close distances for small earthquakes diminish their predictive performance, meaning that the near-source ground motions for small events will be less constrained by observations. In addition, there are many fewer small magnitude data for long periods than for short periods, which means that the small-earthquake magnitude scaling will be less well determined for long oscillator periods than for short oscillator periods (Boore et al. 2013). As a general statement, physics-based analyses will be employed to test the accuracy of the GMPE prediction based on a recordings-synthetics-GMPE comparison. Moreover, the impact of the source proximity to the site is usually widely recognized in the free-field recordings: high-energy impulsive velocigrams are likely to be observed, due to evident forward directivity effects. It happens that this long-period near-field impulsive ground motion can increase the structural demand if compared to ordinary records and they can entail unexpected damaging at structures designed with obsolete building codes, in areas of moderate seismicity. The use of nonlinear static procedures (specifically the displacement coefficient method) for performance-based seismic design (PBSD) and assessment is a well-established practice, which has found its way into modern codes for quite some time, but the distinct presence of pulse-like wavelets in the near-field strong ground motion recordings is progressively taken into account in probabilistic seismic hazard analysis (Baltzopoulos et al., 2015).

To sum up, the main goal of the proposal is to validate the multi-tool platform developed for 3-D physics-based analysis to build-up a reliable earthquake strong ground motion scenario of the Mygdonia valley and to predict realistic time-histories at the site by simulating the source-to-site wave-propagation. The simulations are intended to produce the broad-band synthetics (fmax > 8 Hz) to study the influence of the soil/crust heterogeneity on the high-frequency content of the site response along with the characteristic features of near-source ground motion (pulse-like records, directivity, spatial incoherence). The seismic response of the Mygdonian basin will be assessed to compare the effect of the softer shallow soil layers on the incident wave motion, generated by either small point-wise sources (aftershocks) and extended fault discontinuities. The outcome of this forward deterministic analysis will be employed to perform statistical analysis on the records and on their peak values to characterize their spatial distribution and correlation structure.

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Baltzopoulos G, Chioccarelli E, Iervolino I (2015). The displacement coefficient method in near-source conditions. Earthquake Engineering & Structural Dynamics, 44, 1015-1033.

9.1.3 Project status

The User Group was granted remote access on the EUROSEISTEST database containing seismological geotechnical and geological data.

A physics-based source-to-site computational model was built molded upon a classical yet explicative geological configuration: a 3-D multi-layered soil basin, embedded in the surrounding outcropping bedrock. Steered by a holistic modelling philosophy, the conceptual model spaned a few tens of kilometers, so to include the point-wise double-couple seismic source and thus to bypass the classical obstacle represented by the choice of suitable boundary conditions on fictitious cropping boundaries, to simulate the incident wave-motion.

The set of analysis was carried out by exploiting a 3-D Spectral ElementMethod code, SEM3D. SEM3D couples the high-order approximation of the spectral method applied to elastodynamics, together with a reduced computational burden, granted by an efficient vectorization, and with an improved scalability obtained by tailoring the code to run over multi-core parallel architectures. Compared to traditional numerical schemes (e.g. finite element and finite difference methods) SEM3D improves the limitations due to irregular geometries (such as the basin's edges). However, SEM3D was developed essentially to enlarge the frequency band of the generated synthetics, with reasonable additional computational costs.

The strategy adopted to model the heterogeneity of the Earth's crust consists into identify the heterogeneous mechanical property to a scalar stationary random field, sampled at the computational nodes, at which both mass matrix and internal force vectors are computed. Modelling soil heterogeneity in large scale domains implies however two extra computational efforts, besides the need to characterize the marginal distribution of the mechanical property. As a matter of fact, the computational grid must resolve the minimum wavelength and properly sample the field given a certain correlation length. This drawback was efficiently tackled by employing the dense computational grids of the Spectral Element Method. However, to cope with the scalability issue arisen when dealing with large computational domains, smaller-sized independent realizations were first generated and then recomposed into the large one, by granting a smooth transition from one to another sub-realization along overlapping zones.

Finally, the heterogeneity of the shallow soil layers is studied, by including a realistic 3-D basin-like geometry and the material along with the fluctuation of the mechanical properties observed in-situ. The effect of the basin is studied in terms of time histories recorded at the surface and in terms of wave motion coherency. The results were compared with the homogeneous counterpart under the classical sub-horizontally layered geological configuration. This permitted to assess the influence of the distance from the basin's edges, in terms of amplification of body waves and generation of surface ones.

9.1.4 Foreseen activities and schedule

The project is concluded. No foreseen activities are scheduled.

9.1.5 User Group

	NAME	ORGANIZATION NAME	ORGANIZATION COUNTRY
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ADDITIONAL USERS	Filippo GATTI	CentraleSupélec	France
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9.2 Project #2 – "SISIFO" - Seismic Impedance for Soil-structure Interaction From On-site tests – [in progress]

9.2.1 Summary of the project

The "SISIFO" - Seismic Impedance for Soil-structure Interaction From On-site tests" is currently ongoing.

Investigation on the soil-foundation-structure interaction (SFSI) through numerical interpretation of dynamic model and full-scale tests has been shown to be effective for improving the prediction of the seismic performance of buildings, especially those located on deformable soil.

Advances in the dynamic monitoring and signal processing techniques nowadays allow for characterizing the seismic behaviour of the soil-structure systems, to be identified through the interpretation of dynamic motion recorded on-site under random noise or forced vibration.

In simplified dynamic SFS models, it is required to introduce the dynamic compliance of the foundation-soil system by frequency-dependent impedance functions. The proposal SISIFO aims at investigating the reliability of different procedures for back-calculating the impedance functions of shallow foundations from the on-site tests. Random, forced and free vibration tests have been performed on the full-scale experimental facility of EuroProteas. Acceleration and velocity on several significant points of the structure and in an extended volume of the interacting soil have been recorded.

9.2.2 Main research objectives and expected contribution to the seismology and earthquake engineering community

<u>Objectives</u>

The proposed SISIFO project aims at investigating on the effectiveness of different procedures of experimental identification of the impedance functions at prototype scale. To this aim, random, forced and free vibration tests will be performed on the full-scale experimental facility of EuroProteas in the Euroseistest site located in the Mygdonian valley in Northern Greece.

The structure is a steel frame with removable X-bracings overtopped by two stacked reinforced concrete slabs, each one similar to the shallow foundation, which is placed on a very soft silty sand.

To record the dynamic response of the SFS system, the foundation and the roof slabs were instrumented with triaxial accelerometers. Velocimeters were placed on the soil surface along and across the loading direction. The instrumentation was integrated with down-hole arrays located at the center of the foundation and next to the foundation slab. The experimental layout monitored the response of a soil volume as large as three times the foundation width and as deep as four times the foundation width.

Three types of test were performed on the prototype:

1. random noise test (N), in which the structural response was recorded with no external excitation;
2. harmonic forced vibration tests (H), in which the frequency of the shaker force was held constant until the system achieved the steady state; the test was repeated changing the frequency of the excitation in the range 1-10Hz;
3. snap-back tests (S), in which the roof was slightly displaced and released to induce the free-vibration of the prototype. This test intended to emphasize the free vibration response, characterizing the impedance at the main vibration modes of the prototype.

The forced vibration tests were carried out placing the shaker on the roof (r) and on the foundation (f). The calculation of the impedance is complicated when the displacements induced in the structure are low, since they are affected by noise.

Expected Outcome

A fundamental outcome is the individuation of the experimental layout mostly appropriate to facilitate the experimental characterization of the impedance functions on similar prototypes. The effectiveness of the proposed experimental procedures will be weighted through the coherence of the impedance functions. The impedances are reliable in the frequency range in which the coherence is higher than 0.8 and approaches unity in the absence of noise. Consequently, the larger the frequency range with high coherence, the more reliable and effective the test procedure.

All the acceleration time histories recorded on the structure during each of the 8 programmed tests will be rated basing on their coherence. The final ranking will provide information on the best set-up, namely: 1) the most suitable excitation (test type N, H or S), 2) the best position of the shaker during the forced vibration tests (test type r or f), 3) the minimum number of instruments required and their most appropriate arrangement.

The ranking will be integrated with a cost estimation to provide an evaluation of the effectiveness and the sustainability of each test procedure.

Fundamental Scientific and Technical Value and Interest

Most experiences available in the literature on experimental assessment of impedance functions derive from forced vibration tests. The proposal should provide innovative chances to compare the experimental impedance functions obtained from the forced vibration tests with those back-figured from the random noise and free-vibration tests, highlighting possible improvements with respect to the traditional procedure.

The experimental impedance functions will be obtained as the complex ratios between the Fourier spectra of the forces and the displacements acting on the foundation-soil system. They will be compared to the analytical formulations developed for a rigid foundation resting on a homogeneous soil, assumed to be characterized by the mean VS of the soil volume involved in the foundation motion. The most difficult issues for the application of analytical formulations are the appropriate depth through which VS should be averaged and the modification of the free-field VS profile induced by the structural overburden. The large size of the soil volume monitored by the vertical and horizontal arrays will help to identify the depth of interest by comparing the signals recorded in the down-hole array vs the free-field records. Precious indications on the choice of an equivalent value of VS will be obtained by comparing the experimental impedances with the analytical solutions computed on both the free-field VS profile and that measured in the borehole below the foundation of the prototype.

9.2.3 Project status

A series of field tests were performed by AUTH in the EUROSEISTEST and EUROPROTEAS facility. Specifically, the experimental program of the SISIFO project was comprised of three sets of experiments:

- Two sets of forced vibration experiments, including 44 different intensity levels each one
- One set of free-vibration experiments, including 5 tests in total

A large number of instruments of various types were installed in every set in the foundation, the top of the structure and the surrounding soil to obtain a well instrumented 3D set of recordings of the response of the soil-structure system.

<u>Instrumentation</u>

The general instrumentation scheme was designed particularly to capture the response of the structure and the foundation in both in-plane and out-of-plane direction as well as the soil surface response in the same directions and also below the foundation. The instrumentation layout is presented in Figure 90. The instruments used are:

- 5 triaxial accelerometers GMG-5T (Guralp)
- 4 triaxial accelerometers CMG-5TCDE (Guralp)
- 1 borehole triaxial accelerometer CMG-5TB (Guralp)
- 7 digital broadband seismometers CMG-40T (Guralp)
- 1 12m long shape acceleration array (SAAR) (Measurand)

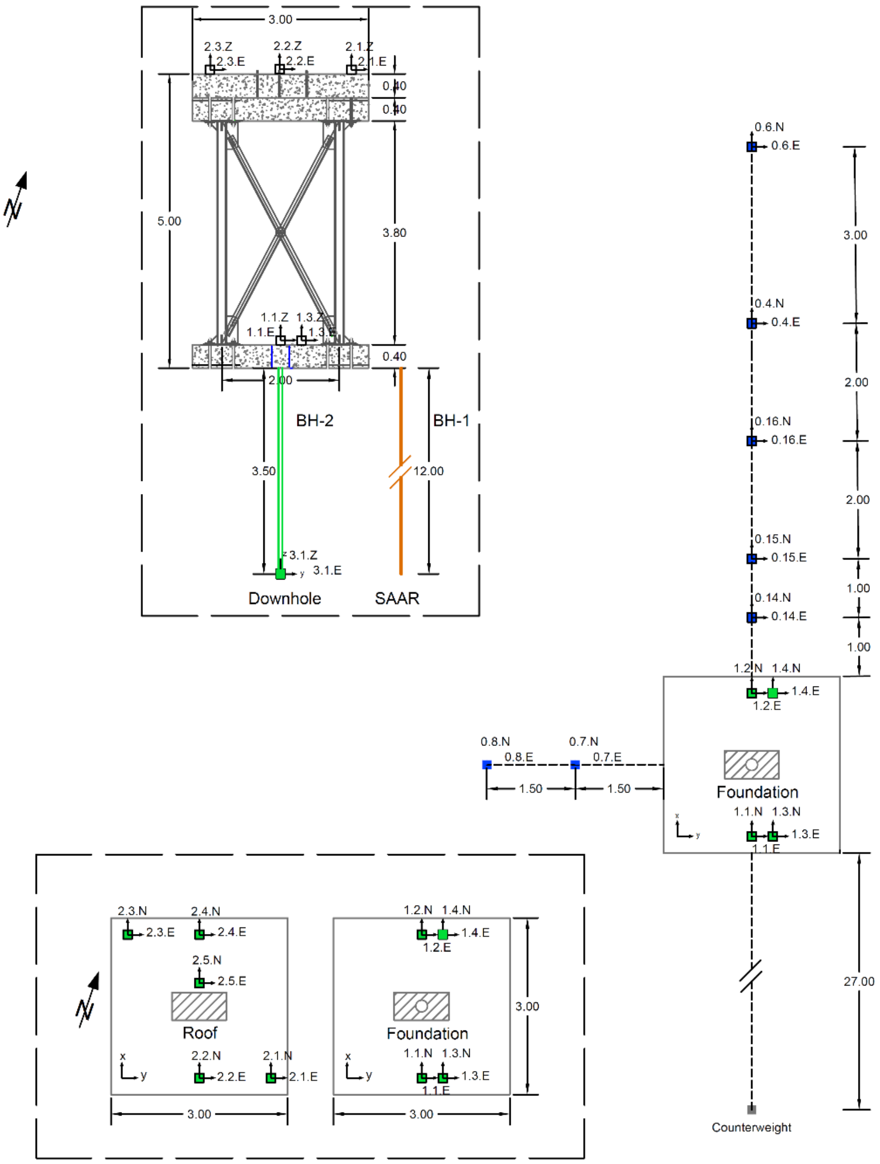


Figure 90: Instrumentation layout of the EUROPROTEAS facility in the SISIFO project

Five accelerometers (2.1 to 2.5 in Figure 89) were installed on the roof of the structure, three of them along the direction of loading and two of them in the two opposite corners to capture possible torsional response of the structure. Four accelerometers (1.1 to 1.4 in Figure 89) were mounted on the foundation along the direction of loading to capture possible translational and rocking response. One accelerometer (3.1 in Figure 89) was clamped inside the borehole BH-2 located at the geometrical center of the foundation at the depth of 3m.

Five seismometers (numbered 0.14 to 0.16, 0.4 and 0.6 in Figure 89) were placed on the soil surface along the direction of loading. This parallel to the loading direction array, which is denser close to the foundation, was able to record the soil response and wave emanation due to the oscillation of the structure. Additionally, two seismometers (0.7 and 0.8 in Figure 89) were placed on the soil surface in the out-of-plane direction. Finally, one shape acceleration array was installed in the borehole BH-1 adjacent to the foundation.

All the instruments were configured at a sampling frequency of 200 Hz and were connected to external global positioning system (GPS) antennas.

Forced-Vibration tests

The eccentric mass shaker MK-500U owned by the Institute of Engineering Seismology and Earthquake Engineering (ITSAK) was implemented as a source of harmonic excitation. It is a portable uniaxial dual counter-rotating shaker that can produce a maximum force amplitude of 5 tons in a frequency range between 0.1-20Hz (Fig. 2a). Eight mass plates in four different sizes (A, B, C and D) can be used in pairs to adjust the eccentricity of the shaker and hence the output force as shown in Figure 2b. The amplitude of the output force of the shaker is given by the equation

$$F = E(2\pi \mathrm{f})^2$$

where F is the shaker output force in Newtons, E is the total eccentricity of the shaker in kg-m and f is the rotational speed of the shaker in Hz. Table 12 lists the maximum force produced when adjusting the total eccentricity and the rotational speed of the shaker.

Table 12: MK-500U shaker total eccentricity and output force

Plate	Total Eccentricity (kg-m)	Maximum Frequency (Hz)	Force at Maximum Frequency (ton)
Rods only	0.15	20	0.24
A	1.85	20	2.97
A + B	3.93	17.8	5
A + B + C	6.93	13.4	5
A + B + C + D	11.31	10.48	5

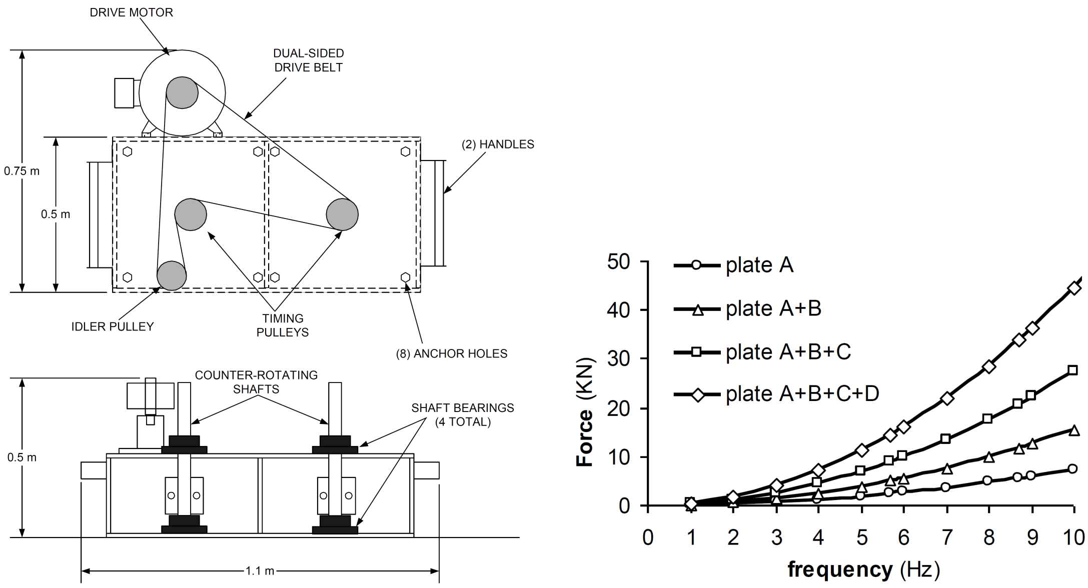


Figure 91: (a) MK-500U schematic and (b) Frequency – Force relationship of the shaker

In the two sets of experiments performed in the framework of SISIFO project, four levels of progressively increasing excitation force were applied by implementing mass pair of plates A, A+B, A+B+C and A+B+C+D.

In the first set of experiments the eccentric mass shaker was placed at the geometrical centre of the top roof slab of the structure and it was orientated to produce a force having a direction that formed an angle of 30 degrees with the magnetic North.

In the end of this set of experiments ambient noise was recorded for 4 minutes.

In Table 13 the first set of forced-vibration tests is summarized.

In the second set of experiments the eccentric mass shaker was placed at the geometrical centre of the foundation slab having the same orientation.

In Table 14 the second set of forced-vibration tests is summarized.

Experiment No.	Mass / Plates	Test No.	Shaker Frequency (Hz)	Duration (sec)
A	A	1	1	60
		2	2	60
		3	3	60
		4	3.5	60
		5	4	60
		6	4.5	60
		7	5	60
		8	6	60
		9	7	60
		10	8	60
		11	9	60
		12	10	60
B	A + B	13	1	60
		14	2	60
		15	2.5	60
		16	3	60
		17	3.5	60
		18	4	60
		19	5	60
		20	6	60
		21	7	60
		22	8	60
		23	9	60
		24	10	60
C	A + B + C	25	1	60
		26	2	60
		27	2.5	60
		28	3	60
		29	3.5	60
		30	4	60
		31	5	60
		32	6	60

		33	7	60
		34	8	60
D	A + B + C + D	35	1	60
		36	2	60
		37	2.5	60
		38	3	60
		39	3.5	60
		40	4	60
		41	5	60
		42	6	60
		43	7	60
		44	8	60

Table 13: Summary of the first set of experiments

Experiment No.	Mass / Plates	Test No.	Shaker Frequency (Hz)	Duration (sec)
A	A	1	1	60
		2	2	60
		3	3	60
		4	3.5	60
		5	4	60
		6	4.5	60
		7	5	60
		8	6	60
		9	7	60
		10	8	60
		11	9	60
		12	10	60
B	A + B	13	1	60
		14	2	60
		15	2.5	60
		16	3	60
		17	3.5	60
		18	4	60
		19	5	60
		20	6	60
		21	7	60
		22	8	60
		23	9	60
		24	10	60
C	A + B + C	25	1	60
		26	2	60
		27	2.5	60
		28	3	60
		29	3.5	60

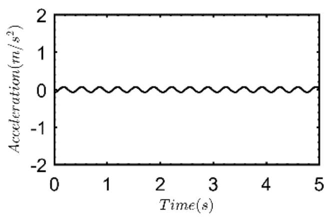
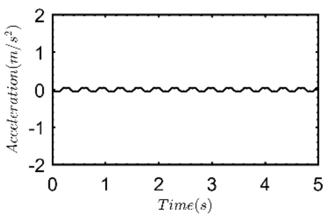
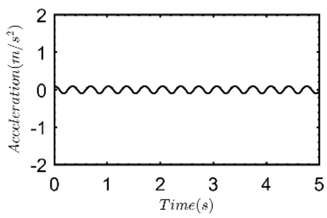
		30	4	60
		31	5	60
		32	6	60
		33	7	60
		34	8	60
		35	9	60
		36	10	60
D	A + B + C + D	37	1	60
		38	2	60
		39	2.5	60
		40	3	60
		41	3.5	60
		42	4	60
		43	5	60
		44	6	60
		45	7	60
		46	8	60

Table 14: Summary of the second set of experiments

Experimental Recordings of the Forced-Vibration tests

Selected recordings of the structure and soil response are presented in the following figures. The responses are presented in the in-plane (North-South, NS), out-of-plane (East-West, EW) and vertical (Vertical, Z) direction according to the direction of loading.

In Table 15 and Table 16 the recorded acceleration at the roof and foundation of the structure for the first set of experiments in the case of two pairs of mass plate and for excitation frequency of 2.5, 3 and 8Hz is presented. The corresponding velocity records on the soil surface are presented in Table 17 and Table 18.

	Experiment No.		B
	Mass / Plates		A + B
	Test No.		16
	Shaker Frequency (Hz)		3
Instrument	**NS component**	**EW component**	**Z component**
1.2			

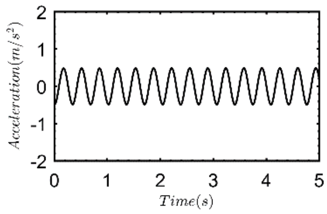
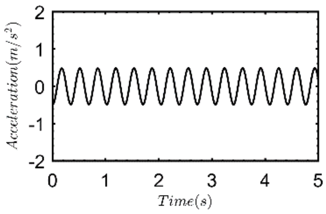
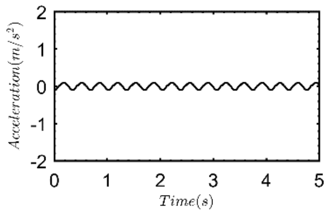
2.2			

Table 15: Recorded acceleration at the structure – Mass A+B – Shaker Frequency 3Hz – 1st set

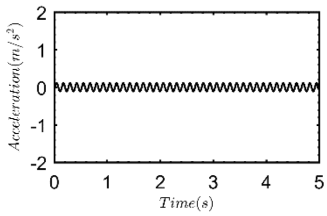
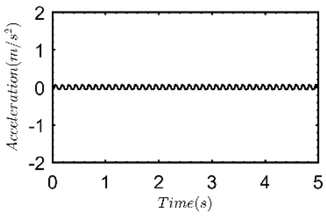
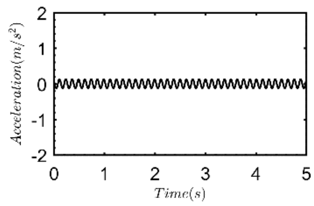
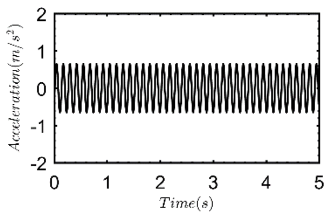
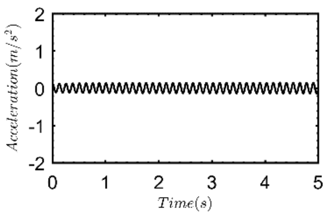
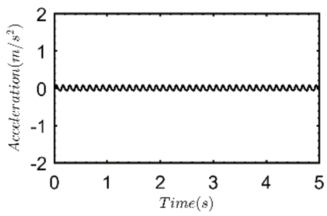
	Experiment No.		B
	Mass / Plates		A + B
	Test No.		22
	Shaker Frequency (Hz)		8
Instrument	NS component	EW component	Z component
1.2			
2.2			

Table 16: Recorded acceleration at the structure – Mass A + B – Shaker Frequency 8Hz – 1st set

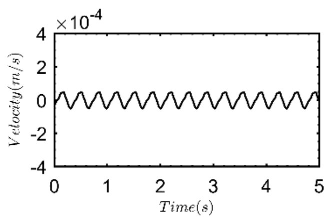
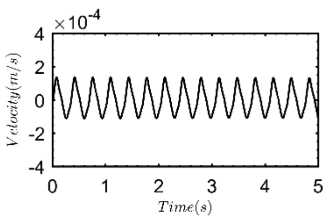
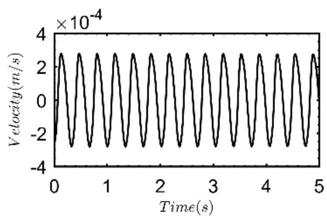
	Experiment No.		B
	Mass / Plates		A + B
	Test No.		16
	Shaker Frequency (Hz)		3
Instrument	NS component	EW component	Z component
0.14			

Table 17: Recorded acceleration on the soil surface – Mass A + B – Shaker Frequency 3Hz – 1st set

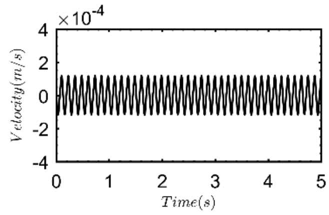
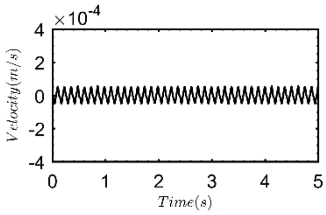
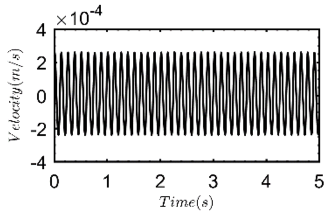
Experiment No.			B
Mass / Plates			A + B
Test No.			22
Shaker Frequency (Hz)			8
Instrument	**NS component**	**EW component**	**Z component**
0.14			

Table 18: Recorded acceleration on the soil surface – Mass A + B – Shaker Frequency 8Hz – 1st set

Free-Vibration tests

Pull-out forces were applied on the roof of the structure by a wire rope. A load cell, with which the applied tension force was measured, was attached to the roof slab and to the one end of the rope. The other end of the wire rope was attached to a wire rope pulling hoist having a working load limit of 32kN. The pulling hoist was clumped to a buried counterweight of 3 tons. The total length of the wire rope was 27m. In Table 19 the free-vibration tests performed are summarized.

Experiment No.	Force (kN)
A	1.18
B	2.14
C	2.65
D	3.25
E	4.77

Table 19: Free-vibration tests

Experimental Recordings of the Free-Vibration tests

Selected recordings of the structure and soil response are presented in the following figures. The responses are presented in the in-plane (North-South, NS), out-of-plane (East-West, EW) and vertical (Vertical, Z) direction according to the direction of loading.

In Table 20 the recorded acceleration at the roof and foundation of the structure is presented.

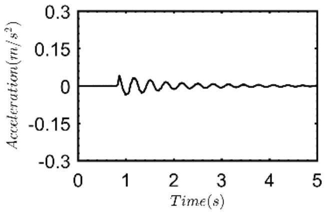
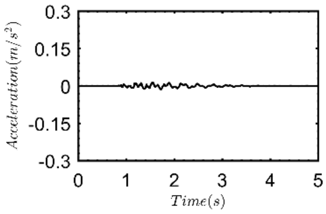
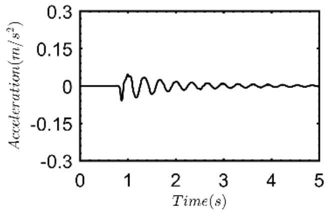
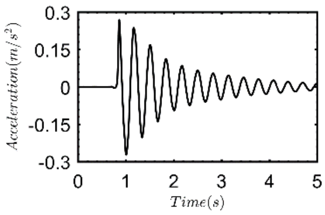
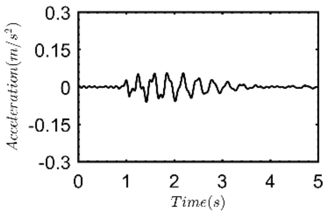
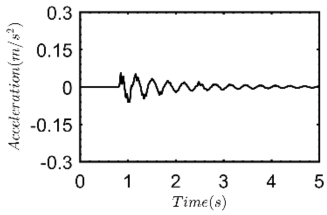
	Experiment No.		E
	Force (kN)		4.77
Instrument	**NS component**	**EW component**	**Z component**
1.2			
2.2			

Table 20: Recorded acceleration at the structure – Force 4.77kN

9.2.4 Foreseen activities and schedule

The next task is the back-calculation of the experimental impedance functions and their comparison to the analytical formulations developed for a rigid foundation resting on a homogeneous soil. The reliability of the proposed experimental procedures will be validated by calculating the coherence of the impedance functions which should approach unity. Another issue that will be investigated is the appropriate depth at which V_S should be averaged for the application of the analytical formulations and the modification of the free-field V_S profile induced by the structural overburden.

There is currently an open communication and exchange of ideas and opinions between the User Group and the Host Facility Group, while there is technical support by the Host User Group on the data exploitation as well, aiming at the proper analysis and processing of the recordings.

9.2.5 User Group

	NAME	ORGANIZATION NAME	ORGANIZATION COUNTRY
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	Filomena de Silva	University of Napoli Federico II	Italy
	Annachiara Piro	University of Napoli Federico II	Italy
	Chiara Amendola	University of Napoli Federico II	Italy

9.3 Project #3 – Ambient and forced vibration techniques for improving design and performance assessment of structures with consideration of soil-structure interaction – [in progress]

9.3.1 Summary of the project

The project "Ambient and forced vibration techniques for improving design and performance assessment of structures with consideration of soil-structure interaction" is currently ongoing.

Excessively simplified design of new buildings or performance assessment of existing buildings, without eliminating major sources of epistemic uncertainties, can lead to incorrect decision-making. Ongoing research is thus focused on the improvement of design and assessment procedures of structures without increasing their complexity. The objective of the proposed project is to support such research by investigating the usability of detailed measurement of soil-structure interaction based on ambient and forced vibrations of a simple structure. Two series of experiments will be performed at EuroProteas site:

a) Ambient-vibration measurements: the aim of experiment is non-destructive system identification using different methods

b) Forced-vibration measurements: the aim of experiment is the measurement of the response of the soil-interacting system to gradually increased forced vibrations in linear and nonlinear range.

The results of the first series of experiments will be used to validate different methods for system identification, and to study how these results can be used to reduce epistemic uncertainties involved in seismic assessment of existing buildings. The results of the second series of experiments will supplement the results of the first series of experiments and will be used to validate nonlinear models which will then be used in parametric studies in order to develop a simplified method for definition of design spectrum with consideration of soil structure interaction.

The proposed experimental campaign at EuroProteas will be in line with ongoing research at University of Ljubljana, which addresses the development of design response spectrum with approximate consideration of soil structure interaction and the usability of the non-destructive dynamic system identification techniques for the risk assessment of existing structures. The interest of the user group is also to acquire the knowledge to design and perform such experiments.

9.3.2 Main research objectives and expected contribution to the seismology and earthquake engineering community

<u>Objectives</u>

The main objectives of the proposed project are:

- to investigate the usability of detailed site measurement of ambient and forced vibrations for supporting development of a procedure for definition of design spectrum with approximate consideration of the effect of soil-structure interaction.
- to validate different methods for system identification and to investigate the usability of detailed measurement of soil-structure interaction of existing structure in order to improve nonlinear structural model which is used for seismic risk and loss estimation.

The research consists of experimental activities and numerical investigations with consideration of different experimental techniques and numerical models. The work has been organized in the following work packages:

WP1: Measurements of ambient and forced vibration for at EuroProteas site

Two large-scale experimental campaigns at the EuroProteas site have been performed in the first step:

a) The first experimental campaign consisted of ambient measurements of a simple soil-structure interacting system. Different non-destructive experimental techniques for the estimation of periods and vibration modes of the structure were used in order to investigate the dispersion of the results.

b) The second experimental campaign supplemented the results of the first campaign and consisted of a series of measurements of forced vibrations. The results of forced vibrations will be used to study the response of the soil-structure interacting system at different levels of nonlinearity and to evaluate the corresponding damping of the soil.

The experimental campaigns were carried out at the EuroProteas experimental facility. The advantage of EuroProteas site is that it is equipped with detailed instruments and a particularly simple stiff structure founded on soft soil, which was especially designed to mobilize strong soil-structure interaction taking into account the well-known foundation soil at site. The tests were performed in the frequency range between 1 and 10Hz, and up to forces of 20kN, which produced nonlinear response as already demonstrated by experiments performed at EuroProteas site.

WP2: Post processing of experimental results and simulation of experiments with mathematical modelling

The results of the experimental campaign (WP1) will be carefully post-processed using system-identification technics. The obtained results with different methods will be compared and critically assessed. Post-processing of experimental results will also be used in order to investigate if careful selection of instrumentation typology and location can be used to decouple the periods of vibration due to deformation of the structure and the surrounding soil. This result may be beneficial for the validation of numerical models.

Experiments performed in WP1 will be simulated by using different level of detail, and will be used to validate numerical models for simulation of soil-structure interaction. The most detailed model will be 2D nonlinear model developed in OpenSees or Plaxis 2D. In this case the special emphasis will be given on modelling of the soils in order to calibrate the boundary conditions with respect to the dimension of the soil used in the model. On the other hand, several models will also be developed in conventional software for structural analysis in order to investigate whether it is possible to simulate basic dynamic characteristic obtained from first experimental campaign.

The experimental results and results of parametric studies will be used to supplement ongoing research at University of Ljubljana, which aimed is to:

- develop a simple procedure for definition of design response spectrum with consideration of soil structure-interaction,
- develop guidelines for calibration of nonlinear models of existing buildings based on measurements of ambient vibration.

Fundamental Scientific and Technical value and interest

The measurement of ambient vibrations will be used to compare different methods for system identification and an attempt to identify which methods are the most appropriate. The obtained results will also be used to investigate to which extent the measurement of ambient vibrations can improve nonlinear models of structures by reducing the epistemic uncertainty in risk and loss assessment of existing buildings.

The measurements of forced vibrations will be used to study the nonlinear response of the soil-structure systems, and to calibrate the appropriate mathematical models for its simulation. The calibrated models will than used in parametric studies in order to develop a simplified method for definition of design spectrum with consideration of soil structure interaction. It is hoped that the development of a simplified method will facilitate the consideration of the effects of soil-structure in practice.

The interest of the user group is also to learn how to adequately perform ambient and forced-vibration measurements and how to post-process the results of such measurements.

9.3.3 Project status

A series of field tests were performed by AUTH in the EUROSEISTEST and EUROPROTEAS facility. Specifically, the experimental program was comprised of three sets of experiments:

- One set of forced vibration experiments, including 44 different intensity levels
- One set of free-vibration experiments, including 4 tests in total
- Ambient noise measurements

A large number of instruments of various types were installed in every set in the foundation, the top of the structure and the surrounding soil to obtain a well instrumented 3D set of recordings of the response of the soil-structure system.

The data recordings of the experiments were given to the USER group after the execution of the tests.

Instrumentation

The general instrumentation scheme was designed particularly to capture the response of the structure and the foundation in both in-plane and out-of-plane direction as well as the soil surface response in the same directions and also below the foundation. The instrumentation layout is presented in Figure 92. The instruments used are:

- 5 triaxial accelerometers GMG-5T (Guralp)
- 4 triaxial accelerometers CMG-5TCDE (Guralp)
- 1 borehole triaxial accelerometer CMG-5TB (Guralp)
- 7 digital broadband seismometers CMG-40T (Guralp)
- 1 12m long shape acceleration array (SAAR) (Measurand)

Five accelerometers (2.1 to 2.5 in Figure 92) were installed on the roof of the structure, three of them along the direction of loading and two of them in the two opposite corners to capture possible torsional response of the structure. Four accelerometers (1.1 to 1.2 and 1.5 to 1.6 in Figure 92) were mounted on the foundation to capture possible translational, rocking and out-of-plane response. One accelerometer (3.1 in Figure 92) was clamped inside the borehole BH-2 located at the geometrical center of the foundation at the depth of 3m.

Five seismometers (0.14 to 0.16, 0.4 and 0.6 in Figure 92) were placed on the soil surface along the direction of loading. This parallel to the loading direction array, which is denser close to the foundation, was able to record the soil response and wave emanation due to the oscillation of the structure. Additionally, two seismometers (0.7 and 0.8 in Figure 92) were placed on the soil surface in the out-of-plane direction. Finally, one shape acceleration array was installed in the borehole BH-1 adjacent to the foundation.

All the instruments were configured at a sampling frequency of 200 Hz and were connected to external global positioning system (GPS) antennas.

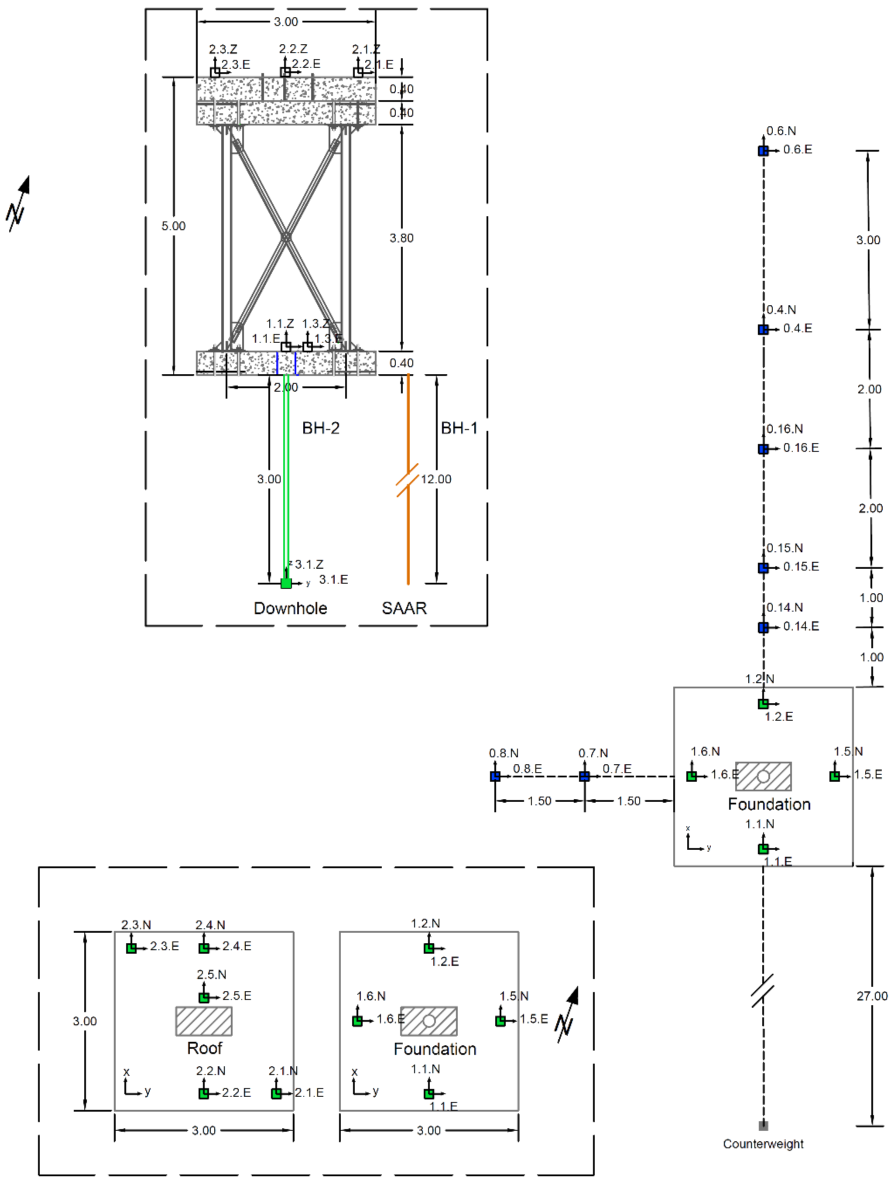


Figure 92: Instrumentation layout of the EUROPROTEAS facility in the current project

Forced-Vibration tests

The eccentric mass shaker MK-500U was implemented as a source of harmonic excitation. A detailed description of the shaker was presented in Section 9.1.3.

In the set of experiments performed, the shaker was placed at the geometrical centre of the top roof slab of the structure and it was orientated to produce a force having a direction that formed an angle of 30 degrees with the magnetic North. Four levels of progressively increasing excitation force were applied by implementing mass pair of plates A, A+B, A+B+C and A+B+C+D.

Experiment No.	Mass / Plates	Test No.	Shaker Frequency (Hz)	Duration (sec)
A	A	1	1	60
		2	2	60
		3	2.5	60
		4	3	60
		5	3.5	60
		6	4	60
		7	5	60
		8	6	60
		9	7	60
		10	8	60
		11	9	60
		12	10	60
B	A + B	13	1	60
		14	2	60
		15	2.5	60
		16	3	60
		17	3.5	60
		18	4	60
		19	5	60
		20	6	60
		21	7	60
		22	8	60
		23	9	60
		24	10	60
C	A + B + C	25	1	60
		26	2	60
		27	2.5	60
		28	3	60
		29	3.5	60
		30	4	60
		31	5	60
		32	6	60
		33	7	60
		34	8	60
D	A + B + C + D	35	1	60
		36	2	60
		37	2.5	60
		38	3	60

		39	3.5	60
		40	4	60
		41	5	60
		42	6	60
		43	7	60
		44	8	60

Table 21: Summary of the first set of experiments

In the beginning and the end of each experiment ambient noise was recorded for 1 minute.

<u>Experimental Recordings of the Forced-Vibration tests</u>

Selected recordings of the structure and soil response are presented in the following figures. The responses are presented in the in-plane (North-South, NS), out-of-plane (East-West, EW) and vertical (Vertical, Z) direction according to the direction of loading.

In Table 22 and Table 23 the recorded acceleration at the roof and foundation of the structure in the case of three pairs of mass plate and for excitation frequency of 3 and 3.5Hz is presented. The corresponding velocity records on the soil surface are presented in Table 24 and Table 25.

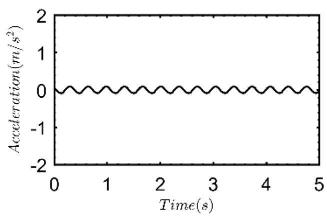
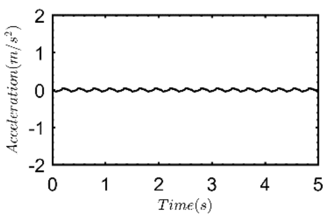
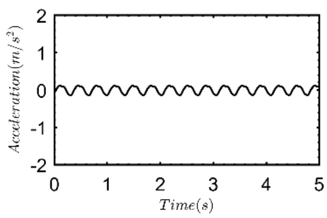
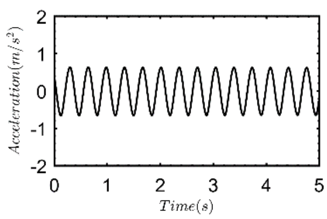
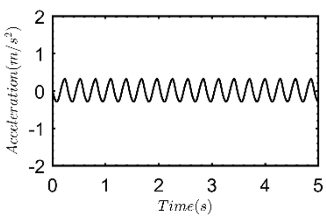
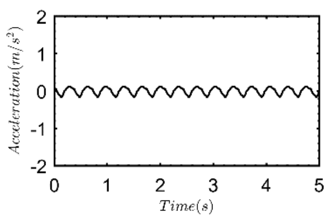
Experiment No.			C
Mass / Plates			A + B + C
Test No.			28
Shaker Frequency (Hz)			3
Instrument	**NS component**	**EW component**	**Z component**
1.2			
2.2			

Table 22: Recorded acceleration at the structure – Mass A + B + C – Shaker Frequency 3Hz

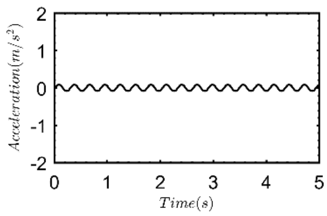
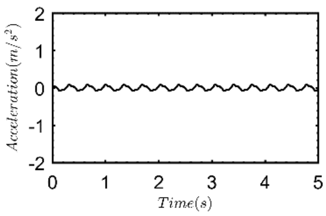
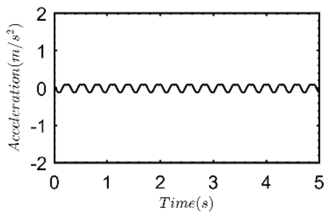
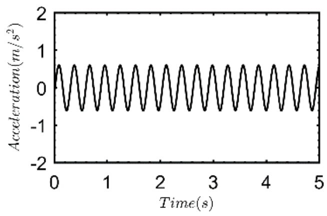
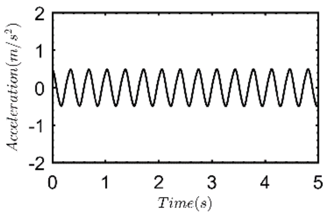
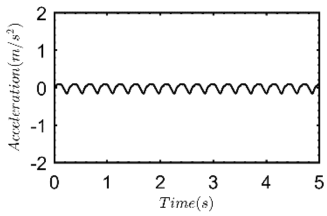
	Experiment No.		C
	Mass / Plates		A + B + C
	Test No.		29
	Shaker Frequency (Hz)		3.5
Instrument	NS component	EW component	Z component
1.2			
2.2			

Table 23: Recorded acceleration at the structure – Mass A + B – Shaker Frequency 3.5Hz

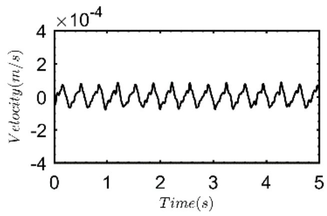
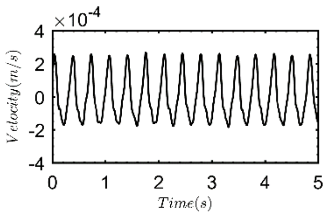
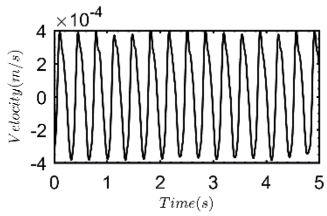
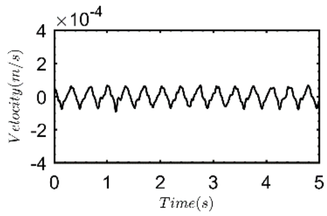
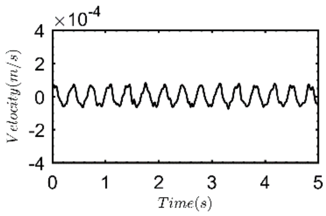
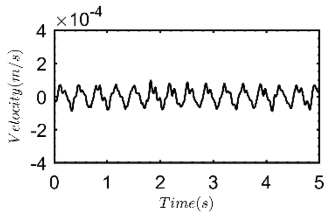
	Experiment No.		C
	Mass / Plates		A + B + C
	Test No.		28
	Shaker Frequency (Hz)		3
Instrument	NS component	EW component	Z component
0.14			
0.16			

Table 24: Recorded acceleration on the soil – Mass A + B + C – Shaker Frequency 3Hz

	Experiment No.	C
	Mass / Plates	A + B + C
	Test No.	29

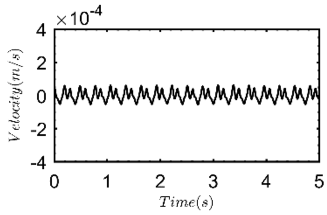
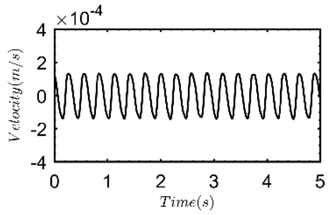
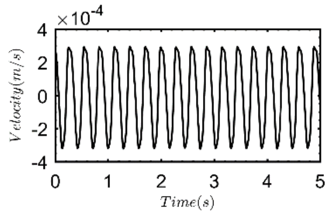
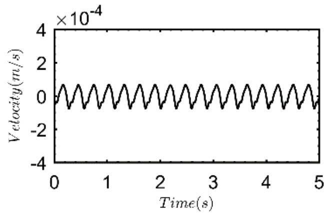
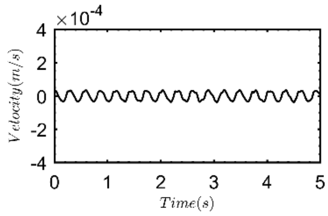
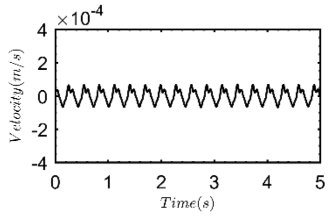
Shaker Frequency (Hz)			3.5
Instrument	**NS component**	**EW component**	**Z component**
0.14			
0.16			

Table 25: Recorded acceleration on the soil – Mass A + B + C – Shaker Frequency 3.5Hz

Free-Vibration tests

Pull-out forces were applied on the roof of the structure by a wire rope. A load cell, with which the applied tension force was measured, was attached to the roof slab and to the one end of the rope. The other end of the wire rope was attached to a wire rope pulling hoist having a working load limit of 32kN. The pulling hoist was clumped to a buried counterweight of 3 tons. The total length of the wire rope was 27m. In Table 26 the free-vibration tests performed are summarized.

Experiment No.	Force (kN)
A	6.83
B	4.32
C	10.58
D	16.14

Table 26: Free-vibration tests

Experimental Recordings of the Free-Vibration tests

Selected recordings of the structure and soil response are presented in the following figures. The responses are presented in the in-plane (North-South, NS), out-of-plane (East-West, EW) and vertical (Vertical, Z) direction according to the direction of loading.

In Table 27 the recorded acceleration at the roof and foundation of the structure is presented. The corresponding velocity records on the soil surface are presented in Table 28.

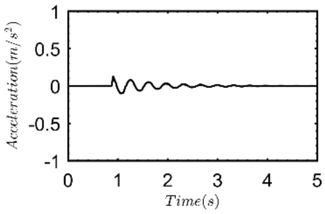
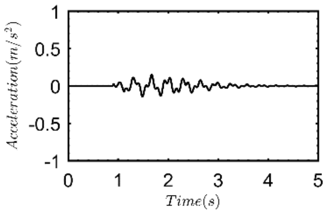
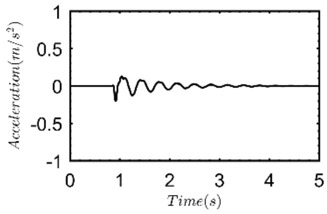
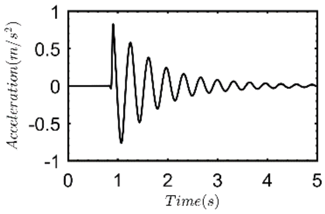
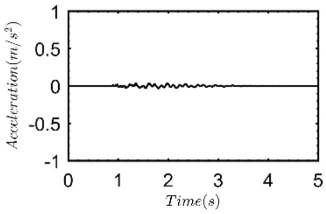
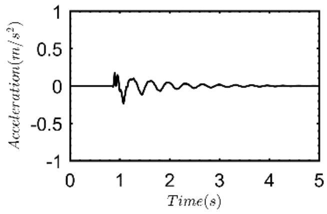
	Experiment No.		D
	Force (kN)		16.14
Instrument	NS component	EW component	Z component
1.2			
2.2			

Table 27: Recorded acceleration at the structure – Force 16.14kN

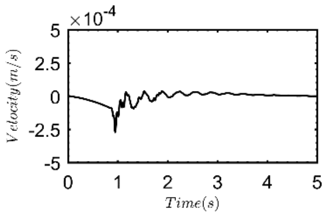
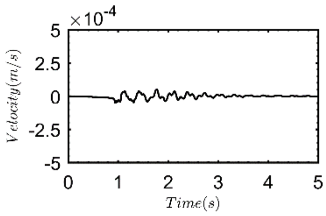
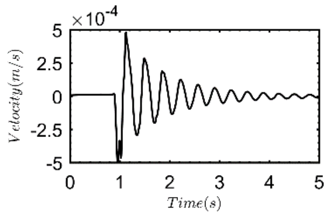
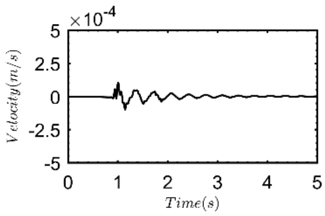
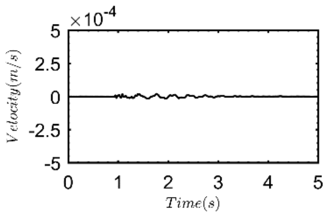
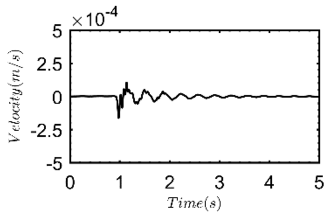
	Experiment No.		D
	Force (kN)		16.14
Instrument	NS component	EW component	Z component
0.14			
0.16			

Table 28: Recorded acceleration on the soil – Force 16.14kN

9.3.4 Foreseen activities and schedule

The post-processing of the experimental results is currently ongoing along with a comparison between different methods for system identification. The experiments will be simulated and will be used to validate numerical models for simulation of soil-structure interaction. Special emphasis will be given on modelling of the soils in order to calibrate the boundary conditions with respect to the dimension of the soil used in the model. On the other hand, several models will also be developed in conventional software for structural analysis in order to investigate whether it is possible to simulate basic dynamic characteristic obtained from first experimental campaign.

There is currently an open communication and exchange of ideas and opinions between the User Group and the Host Facility Group, while there is technical support by the Host User Group on the data exploitation as well, aiming at the proper analysis and processing of the recordings.

9.3.5 User Group

	NAME	ORGANIZATION NAME	ORGANIZATION COUNTRY
USER GROUP LEADER	Matjaž Dolšek	University of Ljubljana	Slovenia
ADDITIONAL USERS	Mirko Kosič	University of Ljubljana	Slovenia
	Jure Žižmond	University of Ljubljana	Slovenia
	Anže Babič	University of Ljubljana	Slovenia

9.4 Project #4 – Seismic site effects in sedimentary basins from 3D physics-based numerical modeling (SITE3D) – [in progress]

9.4.1 Summary of the project

An accurate prediction of earthquake ground motion amplification in complex geological structures and its incorporation in the definition of seismic action in building codes is of paramount importance for engineering research, as many densely populated urban areas and strategic extended structures are built on soft sedimentary basins. Standard tools for this purpose rely typically on one-dimensional numerical approaches, under the assumption of horizontally layered soil structure and vertical propagation of seismic waves. However, such approaches may provide unsafe estimates, because they do not take into account the complex, 3D morphology of the basin, including resonance effects and basin-edge surface waves, and its coupling with seismic rupture propagation effects, such as source directivity, polarization of motion, which may be relevant in near-source conditions. In this context, the Mygdonian basin (EUROSEISTEST and EUROPROTEAS facility), located about 30 km NorthEast of the city of Thessaloniki (Northern Greece), represents an ideal case study to test and validate different approaches for site effects estimation. The availability of detailed 1D, 2D and 3D soil models for the Mygdonian valley basin together with the information regarding site response from earthquake and noise recordings allows us to achieve the following key objectives: (i) 3D numerical modelling of seismic response of Mygdonian basin including the extended seismic source responsible of the historical 1978 earthquake; (ii) evaluation of 3D site amplification functions within the basin and comparison with the experimental ones; (iii) comparison between 3D, 2D and 1D approaches for estimation of site effects in the basin; (iv) definition of suitable 2D/3D aggravation factors to incorporate complex site effects in a design elastic spectrum.

9.4.2 Main research objectives and expected contribution to the seismology and earthquake engineering community

Objectives of the Project

The main objective of the proposed project is to evaluate seismic site effects at the EUROSEISTEST site, based on 3D physics-based numerical simulations of seismic wave propagation from the seismic fault rupture up to the complex geological irregularity of interest. Within the general scope of the project SITE3D, the following specific objectives can be identified:

- 3D numerical modelling of EUROSEISTEST broader area, encompassing the active seismic sources located around the valley as well as the 3D morphology of the valley;
- Quantification of long period 3D site effects and of their spatial variability within the basin;
- Validation of the simulated 3D site amplification functions by comparison with the available site response information and experimental results, coming from the EUROSEIS permanent accelerometric network (http://euroseisdb.civil.auth.gr);
- Assessment of the uncertainties related to the use of different numerical approaches (3D vs 2D vs 1D) for predicting earthquake ground motion in sedimentary basins for near-source earthquake scenarios;
- Determination of 2D/3D aggravation factors to quantify the additional effect of 2D/3D response of the basin in a format suitable for incorporation in a design elastic spectrum.

Methods

In recent years, stimulated by the increase of computational resources, physics-based 3D numerical simulations of seismic ground motion have emerged as a promising tool to give an accurate assessment of earthquake ground motion and of its spatial variability during real and realistic earthquakes. Based on the numerical solution of the seismic wave propagation equation, such an approach has the advantage of encompassing all the physical factors that affect ground shaking at the engineering site, from the fault rupture to the propagation path and to the complex site amplification effects owing to near-surface geology. In the framework of this project, both 2D and 3D numerical modeling of the Mygdonian valley will be carried out through the high-performance open-source spectral element code SPEED - SPectral Elements in Elastodynamics with Discontinuous Galerkin (http://speed.mox.polimi.it/). The code SPEED is the result of a ten-year research activity involving the Department of Civil and Environmental Engineering and the Department of Mathematics at Politecnico di Milano, and its development has been supported in the framework of several international research projects funded by both public and private institutions.

Tasks and Expected Results

The project SITE3D is intended to produce the following main results:

- Construction of a large-scale “source-to-site” 3D spectral element model of the EUROSEISTEST area, including the entire Mygdonian basin and the extended kinematic seismic source (calibrated on the basis of GreDaSS database, see http://gredass.unife.it/). Approximate size of the model is 50 km x 50 km x 15 km with a maximum frequency of about 3 Hz;
- 3D physics-based numerical simulations of ground motion in the Mygdonian basin by SPEED, accounting for a representative set of fault rupture scenarios along the Gerakarou/Langadhas faults. Results will be processed to get maps of peak ground motion values and response spectral ordinates, ground motion time histories at selected soft sites in the basin and movies of seismic wavefield. All results will be published on the SPEED website;
- Evaluation of site effects from 3D physics-based numerical simulations by computing the ratio of Fourier spectrum at the surface of the basin sediments with respect to the one simulated on outcropping bedrock (i.e. by performing a simulation without the 3D basin);

- Comparison of site amplification functions computed at previous point (3) with the ones obtained from the analysis of strong-motion recordings in terms of: (i) Standard Spectral Ratios (SSR), i.e., ratios of Fourier spectrum at soft site with respect to the one at a reference site on competent rock; (ii) Horizontal-to-Vertical Spectral Ratios (HVSR), i.e., ratios of Fourier spectrum of vertical component of ground motion at a given site over that of corresponding horizontal components. Information on site response features, already available in the EUROSEISTEST database, will be used as well;
- Construction of a 2D spectral element model of the Profitis-Stivos cross section of the Mygdonian basin under both vertical and oblique plane-wave propagation, using, as input, the output of the 3D simulation at outcropping bedrock;
- Generation of 1D soil column models at selected sites in the basin under vertical plane-wave propagation, using the same input as for the 2D model (see point 5);
- Definition of 2D/3D aggravation factors as ratios of response spectral acceleration at selected sites within the basin with respect to the corresponding 1D response of "equivalent" soil columns.

Scientific and Technical Impact

We envisage the following as major scientific impacts of the project:

- Develop and promote state-of-the-art numerical methods for the prediction of earthquake ground motion, including a realistic description of the seismic fault rupture and its interaction with complex geological structures;
- Produce certified 3D ground shaking scenarios, apt to represent specific features of earthquake ground motion of interest for engineering aims (e.g. near-fault effects and local site amplification);
- Evaluate quantitatively the impact of 3D site effects in local seismic response of sedimentary basins;
- Assess the performance of different numerical approaches, passing from the standard simplified 1D tools adopted in engineering practice up to advanced 2D/3D models of seismic wave propagation, in predicting local site effects;
- Provide insights into the incorporation of complex site effects into building codes, by definition of specific 2D/3D site aggravation factors to be applied to design elastic spectra.

9.4.3 Project status

The User Group was granted remote access on the EUROSEISTEST database containing seismological geotechnical and geological data. More specifically, the following data was provided to the User Group: 3D geological-geotechnical model of the Mygdonian basin, 2D geological-geotechnical model, Crustal model for deep rock materials, Ground motion data, Seismological parameters. This data was used for the development and validation of a 3D numerical model of the EUROSEISTEST broader area. In this model the active seismic sources located around the valley as well as a detailed 3D morphology of the valley are included. A representative set of fault rupture scenarios along the faults was performed in order to estimate the impact of 3D site effects in local seismic response of sedimentary basins. Then, the site amplification functions computed were compared to those obtained from the analysis of strong-motion recordings.

9.4.4 Foreseen activities and schedule

Numerical modelling of representative 2D cross-section and 1D soil columns will be developed within the next months. In the end a comparison of 3D vs 2D vs 1D site amplification functions will provide and assessment of the performance of different numerical approaches. The complex site effects will be defined by the estimation of 3D/2D site aggravation factors.

9.4.5 User Group

	NAME	ORGANIZATION NAME	ORGANIZATION COUNTRY
USER GROUP LEADER	Chiara Smerzini	Politecnico di Milano	Italy
ADDITIONAL USERS	Maria Infantino	Politecnico di Milano	Italy

9.5 Project #5 – Dynamic Soil Structure Interaction: Three-dimensional Time-domain Analysis of Field Model Scale Experiments – [in progress]

9.5.1 Summary of the project

The proposed project involves a series of carefully planned field tests at the EUROPROTEAS prototype aiming to i) establish fundamental aspects of dynamic soil-structure response and ii) fully validate the numerical procedures which are employed in direct, time-domain soil-structure-interaction (SSI) simulations with integrated modelling of the structure and the soil domain.

A series of free-vibration and forced vibration tests will establish the response of the framed structure for a wide range of frequencies and for a wide range of shear strains induced in the founding soil. The research will benefit from the available site characterisation information at the EUROPROTEAS site and the available seismic records which will enable a rigorous calibration of the constitutive models and a reliable simulation of the free-field conditions at the site. For the numerical modelling, the state-of-the-art features of the bespoke finite element code ICFEP will be employed to study the impact of soil nonlinearity on the foundation and structural response, the use of boundary conditions in three-dimensional (3D) analysis and the comparison with simpler 2D analysis.

In engineering practice SSI problems are usually simplified, employing a single-degree-of-freedom system to represent a structure founded in a visco-elastic soil, which is represented by a dashpot and a spring. Such simplified models will also be employed to simulate the EUROPROTEAS response and will be contrasted to the numerical analysis predictions. The aim of this part of the project is to provide specific guidance on the applicability of such models, as it is expected that due to the assumption of visco-elasticity their applicability will be limited to a narrow strain range. Finally the project will provide an insight on the impact of structural rocking and on the use and range of applicability of simplified SDOF-spring-dashpots models in dynamic SSI.

9.5.2 Main research objectives and expected contribution to the seismology and earthquake engineering community

The research group at Imperial College develops and maintains the in-house Finite Element software ICFEP (Imperial College Finite Element Program) (Potts and Zdravkovic 1999) which has been specifically developed to tackle geotechnical SSI problems. Over the last 15 years considerable effort has been placed on the dynamic analysis module of the program, implementing state-of-the-art time integration schemes (Kontoe et al 2008a), a domain reduction methodology Kontoe et al 2009, advanced boundary conditions (Kontoe et al 2008b) and a range of constitutive models which can simulate rigorously the soil behaviour under dynamic, cyclic and seismic loading (Grammatikopoulou et al 2006, Taborda et al 2014, Taborda et al 2016). The state-of-the-art dynamic capabilities of the program compliment a range of versatile other features (e.g. extensive library of structural elements, coupled consolidation formulation, Fourier Series Aided FE analyses, just to mention only few features potentially relevant to this project) which have been extensively used in static applications in Geotechnics over the last 40 years. The dynamic analysis features of ICFEP have been widely used in applications related to geotechnical earthquake engineering, for example on the dynamic analysis of tunnels (Kontoe et al 2008, Kontoe et al 2011, Kontoe et al 2014), of earthfill and rockfill dams (Pelecanos et al 2015, Han et al 2016) and to rigorously model of soil liquefaction (Tsaparli et al 2016 and Tsaparli et al 2017), just to mention few examples. In the proposed project the aim is to use recorded experimental data of the EUROPROTEAS testing facility to fully validate the numerical procedures which are employed in direct SSI simulations, giving emphasis on:

- modelling nonlinear soil behaviour and assessing its impact on the foundation and structural response
- the use of boundary conditions in three-dimensional (3D) analysis and the comparison with simpler 2D analysis
- comparison with simplified robust analytical methods, commonly employed in SSI problems.

The field testing programme was carefully designed to ensure a thorough validation of the numerical procedures to study wave propagation in the soil due to the vibration of the structure. Free and forced vibration tests of varying intensity and frequency will be used to assess the performance of the employed soil constitutive models for a range of shear strain levels, giving detailed guidance on their relative merits. The free-vibration tests involved uniaxial pull-out forces ranging between 0.1kN and 15kN and covered an important range of shear strain levels developing in the soil. This set of tests intends to characterise the response of the prototype at resonance and therefore to inform the development of the impedance functions associated with its main vibration modes. In addition in the forced-vibration tests, excitation frequencies between 1Hz and 10Hz and force amplitude between 1kN and 20kN are considered to cover a larger range of developing strains in the soil.

The soil characterisation for the EUROPROTEAS site is extensive from past research (Pitilakis et al., 1999, Raptakis et al., 2000), allowing a rigorous calibration of the employed constitutive models based on laboratory and field testing data. The available seismic records at various depths at the site from the Euroseistest database (euroseisdb.civil.auth.gr) will be also used for a preliminary assessment of the constitutive models under free-field conditions using 3D site response analysis.

The modelling of the structure will be carefully considered capitalising on the extensive library of structural elements in ICFEP. In that respect, interface elements will be employed at the soil-structure interface which will allow to study closely the rocking response of the structure. EUROPROTEAS is currently resting on the ground surface; as part of this project it is proposed that a series of tests will be undertaken for a shallow embedment case to further explore the impact of rocking. The aspect ratio of EuroProteas (height over width) is 3.3, implying that strong rocking of the structure due to SSI is expected.

The validation phase will also include an extensive investigation of 3D boundary conditions for dynamic analysis, including the widely used standard viscous boundary, cone boundary and tied degrees of freedom methods. The aim of this investigation will be to provide clear guidance on the optimum use of boundary conditions for dynamic 3D SSI problems, as there are several misconceptions in the literature (Kontoe et al 2007, Zdravkovic & Kontoe 2008). Furthermore, a series of analyses will be undertaken in 2D plane strain conditions using as a benchmark the fully validated 3D model. This series of analyses will allow to assess the importance of the 3D modelling and to examine whether a relationship between the 2D and 3D response can be established.

Due to the high computational cost of the direct approach, in engineering practice SSI problems are usually simplified employing a single-degree-of-freedom system to represent a structure founded in a visco-elastic soil which is represented by a dashpot and a spring. Such simplified models will also be employed to simulate the EUROPROTEAS response and will be contrasted to the numerical analysis predictions. The aim of this part of the project is to provide specific guidance on the applicability of such models, as it is expected that due to the assumption of visco-elasticity their applicability will be limited to a narrow strain range.

In summary a carefully planned set of experiments at EUROPROTEAS will be tailored to thoroughly validate advanced 3D FE modelling procedures. The validation will consider several important aspects of time domain numerical modelling aiming to provide specific guidance on the performance of different constitutive models, the use of boundary conditions in 3D models and the adequacy of 2D plane strain approximation. It is worth to mention that, according to the Users knowledge, no thorough validation of 3D finite element methodologies has been performed against purpose designed, field-scale SSI experiments, accounting for realistic nonlinear soil behaviour. In addition to these, the project will provide an insight on the impact of structural rocking and on the use and range of applicability of simplified SDOF-spring-dashpots models in dynamic SSI.

9.5.3 Project status

A series of field tests were performed by AUTH in the EUROSEISTEST and EUROPROTEAS facility. Specifically, project was comprised of:

- 8 sets of forced vibration experiments
- Two set of free-vibration experiments

In some sets of experiments, the two X-braces of the structure were removed.

A large number of instruments of various types were installed in every set in the foundation, the top of the structure and the surrounding soil to obtain a well instrumented 3D set of recordings of the response of the soil-structure system.

<u>Instrumentation</u>

The general instrumentation scheme was designed particularly to capture the response of the structure and the foundation in both in-plane and out-of-plane direction as well as the soil surface response in the same directions and also below the foundation. The instruments used are:

- 5 triaxial accelerometers GMG-5T (Guralp)
- 4 triaxial accelerometers CMG-5TCDE (Guralp)
- 1 borehole triaxial accelerometer CMG-5TB (Guralp)
- 6 digital broadband seismometers CMG-40T (Guralp)
- 6 digital broadband seismometers CMG-6TD (Guralp)
- 1 3m long shape acceleration array (SAAR) (Measurand)

Four accelerometers were installed on the roof of the structure, two of them along the direction of loading and two of them in the two opposite corners to capture possible torsional response of the structure. Five accelerometers were mounted on the foundation along the direction of loading to capture possible translational, rocking and out-of-plane response. One accelerometer was clamped inside the borehole BH-2 located at the geometrical center of the foundation at various depths.

Three different instrumentation configurations of the soil were implemented in the experiments as shown in Figure 93. Instrumentation configuration (a) aimed to record the motion near the corners of the foundation slab where large strains were anticipated to be induced. Configuration (b) aimed to examine the validity of plane strain approximation and to evaluate the potential applicability of the axis of symmetry in a future numerical model. Finally, configuration (c) aimed to assess the energy dissipation and damping (decay) with distance along both in and out of plane directions. Additionally, records form the instruments of this configuration will be used to examine the soil non-linearity in both directions for different applied forces and frequencies. For these three configurations, the downhole accelerometer was placed at the centre of the foundation slab at different depths. Those depths correspond to the B/2 (0.75m), B (1.5m) and 2B (3m) and it is hoped that this configuration will allow to approximate the developed pressure bulbs and the damping rate, as a function of depth, of the induced vertically propagated waves. For the same purpose a 3m SAAR sensors was placed vertically for the (b) and (c) configurations.

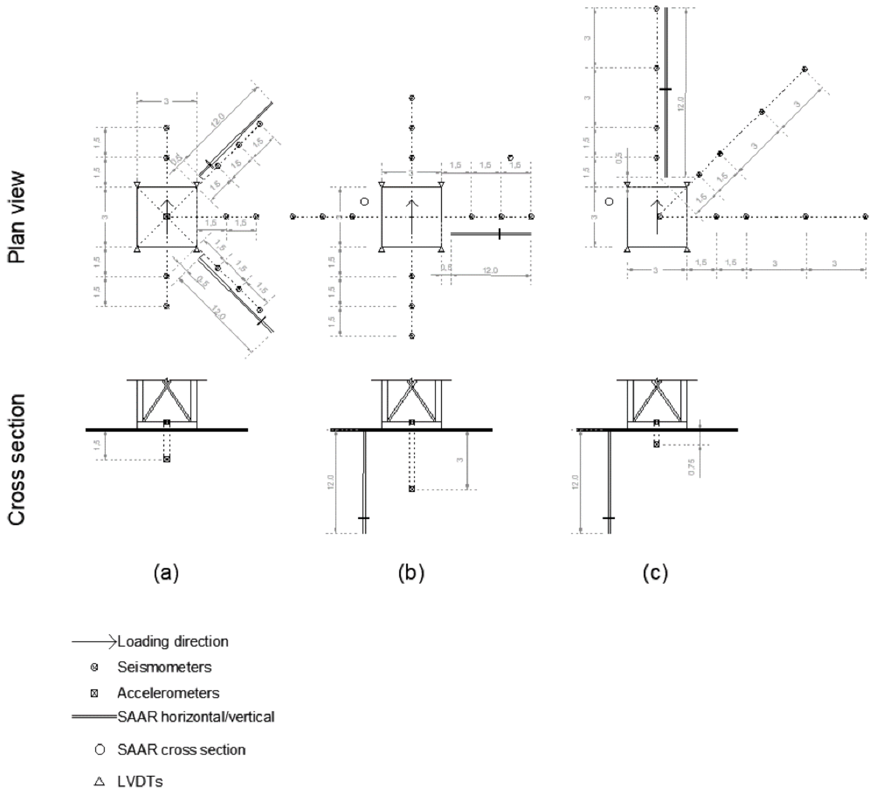


Figure 93: Instrumentation layout of the EUROPROTEAS facility in the current project

Figure 94 shows the configuration of instruments mounted on the structure.

An accelerometer was placed at the centre of the foundation and its recordings are going to be used as the representative recording of the motion of the slab and to calculate the impedance functions for forced vibration tests. The recordings of the pairs of accelerometers at the locations 0.1 and 0.3, and 0.4 and 0.5 will be used to calculate the rocking angle of the foundation slab and the corresponding rocking induced motion at the two axis of the top slab.

The recordings captured by accelerometer 1.2, mounted close to the centre of the roof, will be used as the representative recording for the motion of the slab. Moreover, the recordings of accelerometers

1.2 and 1.4 will be used to calculate the system's damping and the system's predominant frequencies. The latter will be established through transfer functions of the pull-out tests and by identifying the frequency which results to the maximum roof response for the forced-vibration tests. The impact of the force intensity and frequency on the response will be also evaluated.

Additionally, the recordings of accelerometers 1.1 and 1.3 will be used to establish the torsional oscillation mode of the structure.

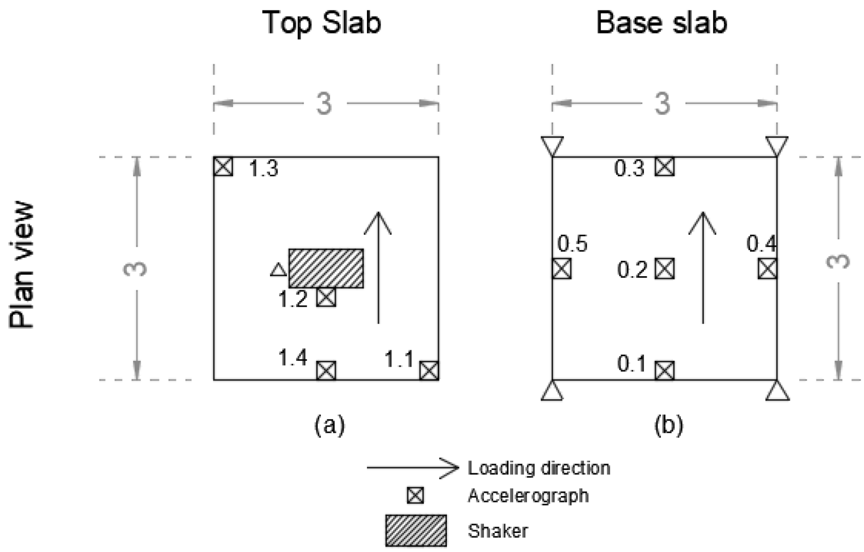


Figure 94: Configuration of instruments on the structure

Forced-Vibration tests

The eccentric mass shaker MK-500U owned by the Institute of Engineering Seismology and Earthquake Engineering (ITSAK) was implemented as a source of harmonic excitation. A detailed description of the shaker was presented in Section 9.1.3.

In the set of experiments performed, the eccentric mass shaker was placed at the geometrical centre of the top roof slab of the structure and for some set of experiments it was orientated to produce a force having a direction that formed an angle of 30 degrees with the magnetic North, while in other sets it was oriented in the perpendicular direction. Four levels of progressively increasing excitation force were applied by implementing mass pair of plates A, A+B, A+B+C and A+B+C+D.

Close to the observed in previous experiments natural frequency of the soil-structure system the frequency step of the loading was refined.

In the first sets of forced-vibration experiments the structure configuration included the X-braces in all the planes of the structure, while for the last sets of experiments the X-braces at the out of plane direction of loading were removed. In some sets of experiments the direction of the loading produced by the eccentric mass shaker was changed by an angle of 90degrees.

Free-Vibration tests

Pull-out forces were applied on the roof of the structure by a wire rope. A load cell, with which the applied tension force was measured, was attached to the roof slab and to the one end of the rope. The other end of the wire rope was attached to a wire rope pulling hoist having a working load limit of 32kN. The pulling hoist was clumped to a buried counterweight of 3 tons. The highest force can be applied on the structure was approximately 16KN. The total length of the wire rope was 27m.

In the first sets of forced-vibration experiments the structure configuration included the X-braces in all the planes of the structure, while for the last sets of experiments the X-braces at the out of plane direction of loading were removed.

9.5.4 Foreseen activities and schedule

All the available recordings are now under an extraction process from the Host Facility Group in order to be shared with the User Group. There is currently an open communication and exchange of ideas and opinions between the User Group and the Host Facility Group, while there is technical support by the Host User Group on the data exploitation as well, aiming at the proper analysis and processing of the recordings.

The next step is the modelling of the structure considering the extensive library of structural elements in ICFEP. The aim of this investigation will be to provide clear guidance on the optimum use of boundary conditions for dynamic 3D SSI problems.

9.5.5 User Group

	NAME	ORGANIZATION NAME	ORGANIZATION COUNTRY
USER GROUP LEADER	Stavroula Kontoe	Imperial College	United Kingdom
ADDITIONAL USERS	Lidija Zdravkovic	Imperial College	United Kingdom
	Julia Katharina Moeller	Imperial College	United Kingdom
	Marios Koronides	Imperial College	United Kingdom

9.6 Project #6 – Comparison of rocking on rigid and compliant base using the EUROPROTEAS real-scale facility – [in progress]

9.6.1 Summary of the project

Rocking of structures with surface foundations has been observed to have a beneficial effect on the event of an earthquake, a phenomenon referred to as “rocking-isolation”. Since the identification of this phenomenon in the sixties, much research has been performed and rocking-isolation has been proposed as a method for the seismic protection of structures. Different schemes of rocking isolation exist, with the two most major being rocking of a foundation on a rigid base, and rocking of a smaller than typically designed foundation on the underlying soil. Most research employs analytical or numerical tools to study these problems. In terms of experimental results, shaking table tests are rather common but suffer from unavoidable size effects and from incorrect scaling of soil properties. Such issues can be circumvented with real-scale testing. Here, it is proposed to perform real-scale experiments of rocking structures, using the EuroProteas facility. The concepts of rocking on a rigid base and rocking on soil will be examined, their effectiveness as seismic protection techniques assessed and compared. Moreover, the wealth of data obtained from EuroProteas will serve as an invaluable database for researchers in geotechnical engineering, useful for the validation of a plethora of analytical and numerical tools. To perform the proposed testing series, only small modifications will be required to the existing infrastructure of EuroProteas. Most notably, a smaller base plate will have to be attached under the existing one, to guarantee a rocking response while using the existing excitation mechanism. These experiments are expected to be of particular interest for the geotechnical engineering community and to provide significant insight on the use of rocking isolation as a low cost technique that can increase resilience by shielding structures from extreme seismic phenomena.

9.6.2 Main research objectives and expected contribution to the seismology and earthquake engineering community

It is proposed to use the EuroProteas facility in order to conduct experiments investigating the response of a real-scale, “rocking-isolated” structure subjected to dynamic loading. Two concepts of “rocking isolation” will be examined. The first refers to rocking of a structure onto a rigid base while the second promotes rocking of the structure on the underlying soil.

While such concepts have been studied in literature, most studies are analytical or numerical. Experimental examinations have been carried out, mostly using shaking tables. Such experiments can be problematic when examining the rocking of structures, because the size of the structures examined is too small and also because in the case of rocking on soil, the stiffness of the soil is not correctly modelling that at prototype scale. Experiments in geotechnical centrifuges can tackle these challenges and yield more accurate results but are rarer and often cannot offer the wealth of data that comes from a real-scale experiment. The use of the EuroProteas facility for the proposed experiments is expected to yield novel results that could significantly further knowledge regarding rocking isolation. Moreover, they would produce valuable data for the validation of analytical and numerical tools.

The two proposed concepts of rocking isolation can be examined with only small modifications of the already existing infrastructure of EuroProteas. It is proposed to centrally attach a slab of steel-reinforced concrete beneath the existing base slab of the EuroProteas structure. The dimensions of the proposed square slab according to preliminary calculations should be 3 m by 0.8 m, with a thickness of 0.40 m. This additional slab is small enough that should allow the existing structure to rock, albeit at small rotations, with the available configuration for imposing dynamic excitations. At the same time, it is thick enough to guarantee that the existing base slab will not reach the soil while the structure rotates, even for the experiments where the structure will be placed on the soil and settlements will occur. The existing EuroProteas structure is proposed to be loaded on the top with one of the two available top slabs of thickness 0.40 m. With one top slab and with the addition of the proposed base slab, the resulting weight and aspect ratio are such that rocking can be expected for the force available with the existing excitation mechanism.

When examining the first concept of rocking isolation, according to which the structure rocks on a rigid base an additional concrete slab must serve as the “rigid” base. This slab will not need substantial reinforcement and will thus be of limited cost.

To examine the second concept of rocking isolation, according to which the structure rocks on the underlying soil, the same structure configuration that was described above can be used. This time, the structure is proposed to be placed directly on the soil, without the addition of the “rigid” base.

Loading is proposed to be applied with the existing actuator system. Loading will start at lower forces and increase with additional tests. The static limit force for the proposed structure corresponds to 2 tons and is thus low enough to guarantee rocking occurs with higher excitation forces. It is aimed to obtain a rocking response at low rotational amplitudes. However, if a rotation of 0.2 rad takes place, the existing base plate will touch the "rigid" base or the soil, increasing the static limit force to more than 5 tons, which is the maximum the actuator can impose. As a result there will never be a danger of overturning. However, during the design phase finite element analyses will be performed to ascertain the safety of the configuration and decide on the levels of imposed excitations.

Overall, two series of experiments will be required, one for each concept of rocking-isolation. It is proposed to begin with the concept of rocking on a rigid base. As mentioned above, experiments will start with excitations of low amplitude, which will increase gradually and will be repeated at different frequencies. The loading will be uniaxial, parallel to one of the major axes of the structure, as already implemented for EuroProteas. If possible, free-vibration experiments could be added at the end of the test series. A time gap will be required before the second series, examining rocking on soil, can start. During this gap, the slab used as the "rigid" base will be removed. The configuration of the structure will remain unaltered. Subsequently, the second series of experiments will begin, following the same testing schedule as for the first series.

The existing instrumentation capabilities of EuroProteas, as reported in relevant publications, are considered sufficient for the requirements of the proposed experiments. The instrumentation of the structure with accelerometers covering all directions is essential, to monitor in-plane and possible out-of-plane vibrations, as well as possible torsional modes. Acceleration arrays attached to the steel columns allow the structural response to be fully captured. On top of the existing instrumentation for the structure, it is proposed to also use a camera to analyse its response using digital image correlation (DIC). This would be possible with the addition of optical markers on the structure, which are of trivial cost, and the use of a camera. Additional data could thus be produced for displacements, providing redundancy for the displacement estimations made using accelerometers. In the soil, the already existing seismometers, downhole array, and acceleration array can provide data for the second series of tests, where the structure will be placed directly on the soil. These data would be particularly valuable for the validation of numerical tools.

Results from the proposed experiments are expected to be particularly valuable in drawing conclusions regarding the effectiveness of each of the two rocking-isolation concepts examined. Comparison between the concepts is of particular interest. Moreover, the wealth of data produce from this real-scale experiment will be invaluable for the validation of analytical and numerical tools.

9.6.3 Project status

A careful design of the experiments that are going to be conducted within the month has been already made after an extensive collaboration between the Host Facility Group and the User Group. The User Group has developed a preliminary Finite Element Model and produced numerical analyses of the rocking EuroProteas structure under the envisaged forced vibration experiments, and accordingly AUTH has proceeded to the design of the tests.

Specifically, a preliminary FE model of the soil-structure was developed to primary estimate the response of the system after adding the additional base plate with dimensions 3x0.8x0.3m that was requested by the User Group.

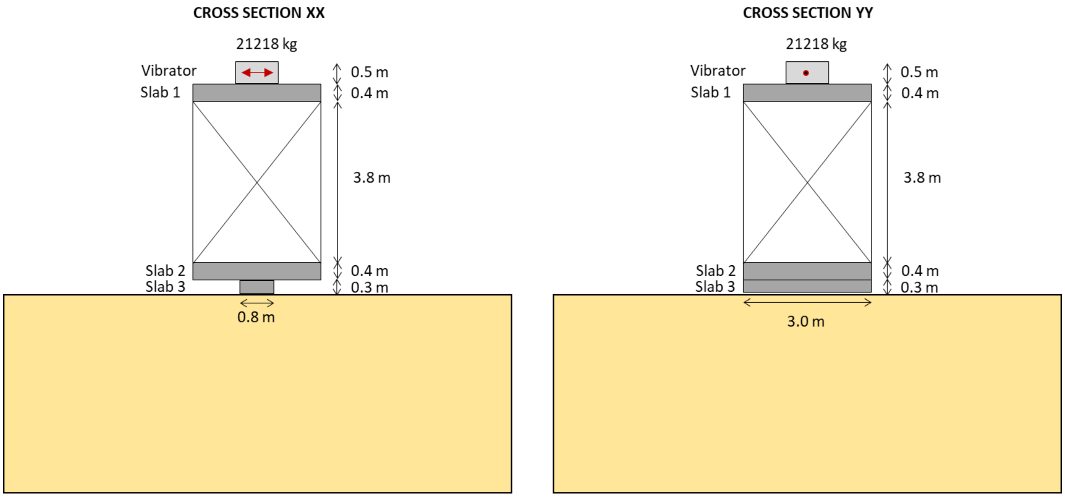


Figure 95: Cross sections of the FE model developed by the User Group for preliminary assessment of the forced-vibration experiments

STRUCTURE					
	Length (m)	Width (m)	Thickness (m)	Mass (kg)	Weight (kN)
Slab 1	3	3	0.4	9000	88.29
Slab 2	3	3	0.4	9000	88.29
Slab 3	0.8	3	0.3	1800	17.66
Columns				663.9	6.51
Xiasti				604.032	5.93
Vibrator				150	1.47
				21218.0	208.1

Table 29: Dimensions and Mass of the structure with the additional base plate.

The model was analyzed for a set of harmonic excitations that will be produced by the eccentric mass shaker.

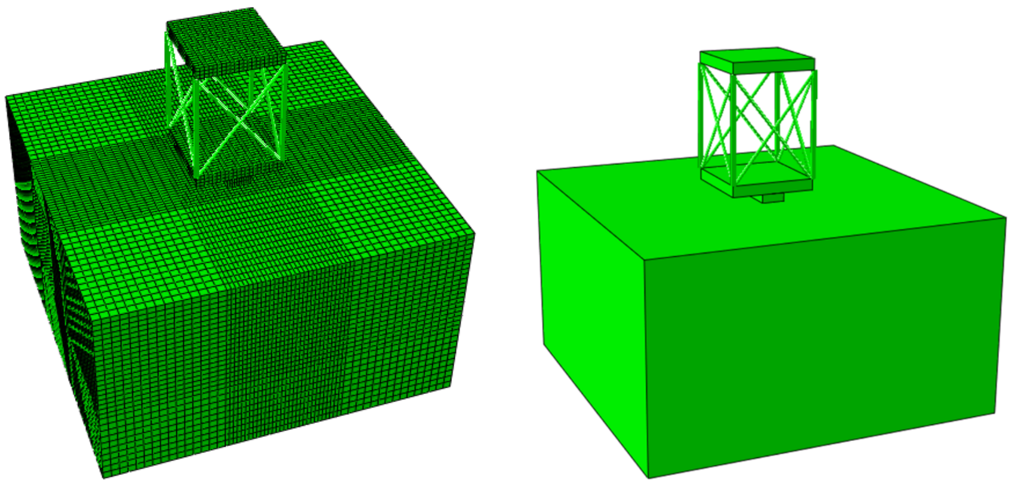


Figure 96: Soil – structure model of the EuroProteas with the additional base slab.

Some indicative results for different loading frequencies are presented below in Figures 9 and 10.

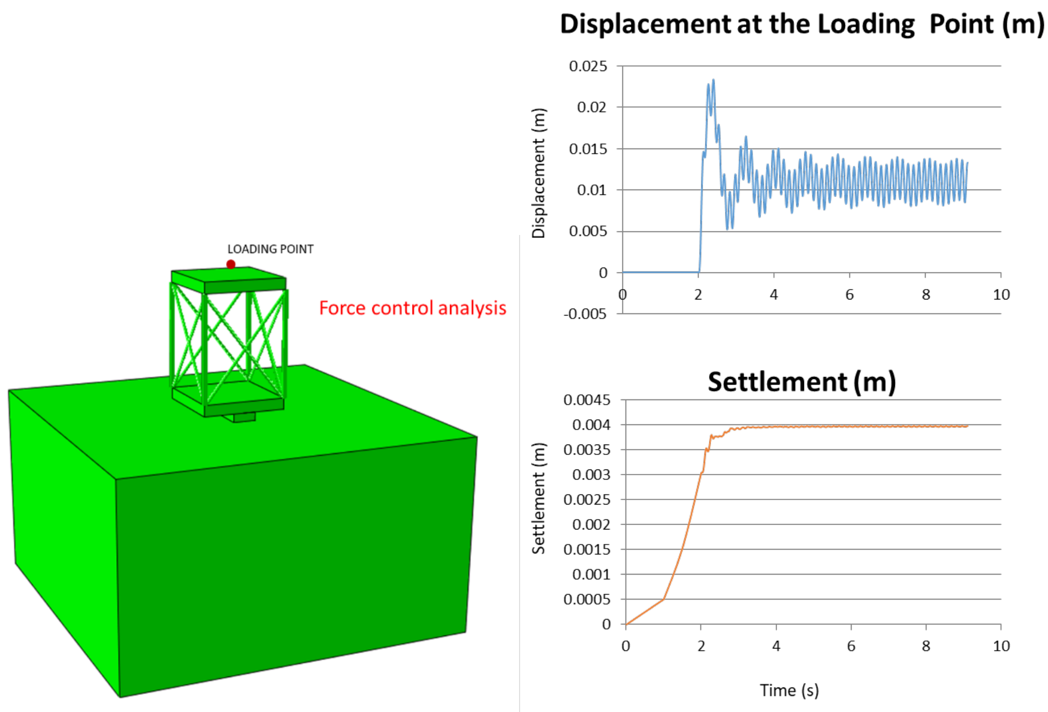


Figure 97: Displacement time history and settlement time history for shaker frequency of 7Hz

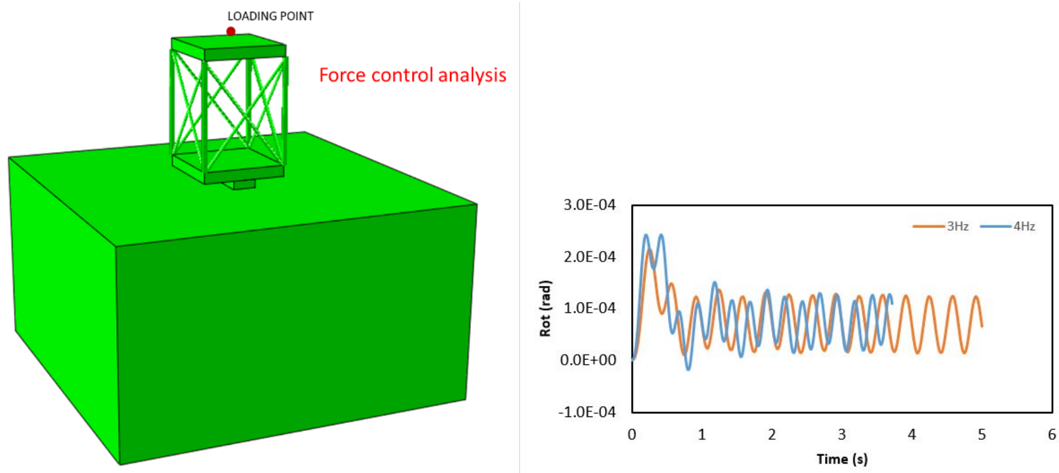


Figure 98: Rotation at the top of the structure for shaker frequency of 3Hz and 4Hz.

The results of the analysis of the FE model showed that the estimated rotation of the structure is within the safety limits of the structures. According to these results the Host Facility Group proceeded to the construction of the additional base plate.

9.6.4 Foreseen activities and schedule

The experiments will be performed within the next weeks and the results will be shared with the User Group.

9.6.5 User Group

	NAME	ORGANIZATION NAME	ORGANIZATION COUNTRY
USER GROUP LEADER	Ioannis Anastasopoulos	ETH Zurich	Switzerland
ADDITIONAL USERS	Orestis Adamidis	ETH Zurich	Switzerland
	Max Sieber	ETH Zurich	Switzerland
	Konstantinos Kassas	ETH Zurich	Switzerland

9.7 Project #7 – Soil Frame-Interaction Analysis through large-scale tests and advanced numerical finite element modeling (Acronym: SOFIA) – [in progress]

9.7.1 Summary of the project

The proposed research deals with experimental and numerical investigations of the Dynamic Soil-Structure Interaction (DSSI) concerning the existing EuroProteas structure in the Euroseistest site. New large-scale tests will be performed and then simulated by full-coupled FEM models. The main goals are: investigating the material and radiation damping of the wave field emanating from the foundation; studying the wave propagation away from the structure; examining the effects of soil non-linearity on the soil and structure responses; investigating the influence of rubberized foundation soil on the response of the structure; validating advanced FEM modeling of DSSI.

As for the experimental phase, forced-vibration tests will be performed at different excitation amplitude and frequency. The input will be given at the top of the structure. Moreover, sand-rubber mixtures will be placed beneath the footing in order to know their influence as a novel way of isolating structures. Additional accelerometers will be positioned on the structure, below it and along the soil surface, in order to investigate the dynamic response of the full-coupled system.

As for the FEM modeling phase, the structure will be modeled by a linear visco-elastic constitutive model; the soil non-linearity will be modeled both by an equivalent linear visco-elastic constitutive model (updating G and D according to the achieved shear strain level) and by a recently developed visco-elasto-plastic model with kinematic hardening. The dynamic response of the system will be analyzed in terms of: maxima accelerations and displacements; acceleration time-histories; Fourier spectra; amplification functions and ratios.

9.7.2 Main research objectives and expected contribution to the seismology and earthquake engineering community

The proposed research deals with the implementation of new large-scale tests on DSSI using the existing EuroProteas structure in the Euroseistest site, as well as their FEM modelling by full-coupled advanced models. The aim of the proposed research is to investigate on: i) soil-foundation interface behaviour, which influences the signal transmission from the structure to the soil, causing often important dissipation phenomena; as well as material and radiation damping of the wave field emanating from the foundation; ii) influence of rubberized soil, placed beneath the footing, on the dynamic response of the structure in order to see its influence as a novel way of isolating structures and its performance in real scale conditions; iii) validating advanced FEM modelling for DSSI.

Forced-vibration tests have been performed at different excitation amplitude and frequency, adopting a range of 1-10 Hz input frequencies. The input will be given at the top of the structure. Finally, further tests will be performed by placing sand-rubber mixtures beneath the footing as a novel way of isolating structures.

FEM modelling of tests performed on the above-mentioned EuroProteas structure has been recently developed by the researchers involved in this proposed research. Aim of the current research is to perform new tests for investigating in detail both the soil-foundation interface behavior, considering also advanced isolation measurements, and the wave propagation through the structure and away from it. As for the constitutive modelling, the structure will be modelled by means of linear visco-elastic constitutive model. In a first phase of the modelling, soil non-linearity will be taken into account by an equivalent linear visco-elastic constitutive model, updating shear modulus G and damping ratio D according to the achieved shear strain level; in a second phase, soil non-linearity will be taken into account by the advanced "Severn-Trent" model implemented into the FEM ADINA code.

The following experimental and numerical quantities will be detected and compared: maxima accelerations as well as acceleration time-histories concerning the structure and the soil; Fourier spectra and amplification functions in the structure and in the soil surface; acceleration amplification ratios from the top to the base of the structure, through the soil-foundation interface and along the ground surface.

The investigated quantities have a fundamental scientific and technical value and interest because concern a full-coupled large-scale soil-structure system, rarely investigated. The particular attention devoted to the effects caused by sliding and/or uplifting at the soil-foundation interface, to the effects of a new advanced way of isolating structures (sand-rubber mixtures), to the natural vibration periods of full-coupled soil-structure systems, to the material and radiation damping, to the wave propagation, to the effects of foundation embedment, to the soil non-linearity will offer interesting ideas for less expensive seismic designs.

9.7.3 Project status

The first experimental phase was performed by AUTH in the EUROSEISTEST and EUROPROTEAS facility including forced vibration tests of the prototype structure resting on the natural soil.

A large number of instruments of various types were installed in every set in the foundation, the top of the structure and the surrounding soil to obtain a well instrumented 3D set of recordings of the response of the soil-structure system.

<u>Instrumentation</u>

The general instrumentation scheme was designed particularly to capture the response of the structure and the foundation in both in-plane and out-of-plane direction as well as the soil surface response in the same directions and also below the foundation. The instruments used are:

- 5 triaxial accelerometers GMG-5T (Guralp)
- 4 triaxial accelerometers CMG-5TCDE (Guralp)
- 1 borehole triaxial accelerometer CMG-5TB (Guralp)
- 6 digital broadband seismometers CMG-40T (Guralp)
- 6 digital broadband seismometers CMG-6TD (Guralp)
- 1 3m long shape acceleration array (SAAR) (Measurand)

Four accelerometers were installed on the roof of the structure, two of them along the direction of loading and two of them in the two opposite corners to capture possible torsional response of the structure. Five accelerometers were mounted on the foundation along the direction of loading to capture possible translational, rocking and out-of-plane response. One accelerometer was clamped inside the borehole located at the geometrical center of the foundation at various depths.

Forced-Vibration tests

The eccentric mass shaker MK-500U owned by the Institute of Engineering Seismology and Earthquake Engineering (ITSAK) was implemented as a source of harmonic excitation. A detailed description of the shaker was presented in Section 9.1.3.

In the set of experiments performed, the eccentric mass shaker was placed at the geometrical centre of the top roof slab of the structure and for some set of experiments it was orientated to produce a force having a direction that formed an angle of 30 degrees with the magnetic North, while in other sets it was oriented in the perpendicular direction. Four levels of progressively increasing excitation force were applied by implementing mass pair of plates A, A+B, A+B+C and A+B+C+D.

Close to the observed in previous experiments natural frequency of the soil-structure system the frequency step of the loading was refined.

Sand-rubber mixtures underneath the foundation

A preliminary design of the soil-structure system was conducted with the placement of sand-rubber mixtures (two different mixtures 1 and 2) beneath the footing as shown in Figure 99.

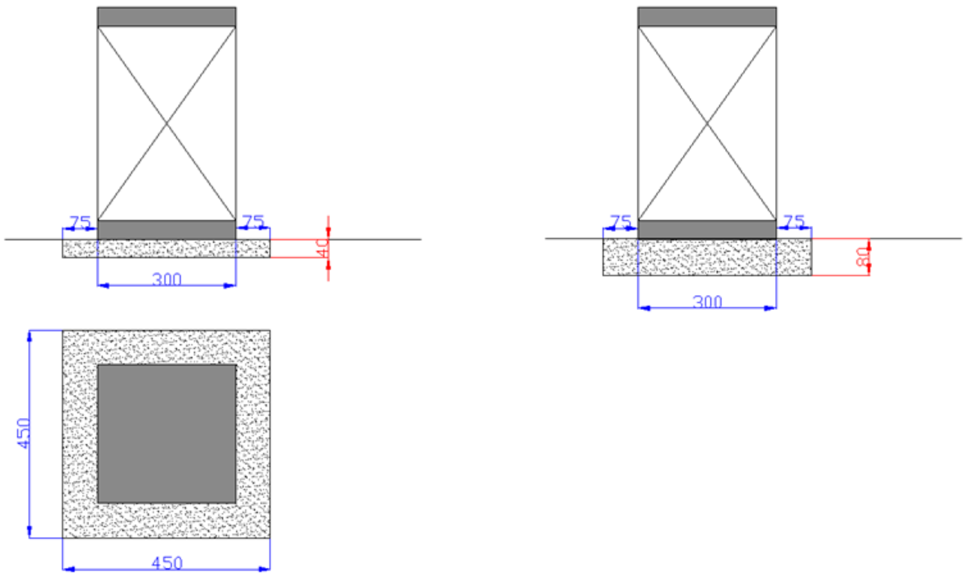


Figure 99: Placement of the sand-rubber mixtures: section (a) and plan view (b) of the two models.

The aim of these experiments will be the investigation of the response of the sand-rubber mixture and their influence as a novel way of isolating structures. In order to use the sand-rubber mixtures underneath the foundation, it is necessary to remove the existing soil down to the depth d = 40 cm for the first groups of tests and down to the depth d = 80 cm for the second groups of tests, i.e. the sand-rubber mixtures will be embedded firstly down to a depth of 40 cm below the ground surface and secondly down to a depth of 80 cm below the ground surface. So, the area in which to place the two mixtures will be 4.5 x 4.5 m2 as shown in Figure 99.

The mixtures will be compacted to an almost perfectly horizontal surface for the placement of the foundation slab, in order to assure the highest contact level between the bottom of the slab and the soil surface.

9.7.4 Foreseen activities and schedule

All the available recordings are now under an extraction process from the Host Facility Group in order to be shared with the User Group. There is currently an open communication and exchange of ideas and opinions between the User Group and the Host Facility Group, while there is technical support by the Host User Group on the data exploitation as well, aiming at the proper analysis and processing of the recordings.

The next step is to finalize the design and to perform of a new series of experiments in the EUROPROTEAS facility after placing soil-rubber mixtures bellow the foundation of the prototype structure.

9.7.5 User Group

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	Giovanni Tranchina	University of Catania	Italy

9.8 Project #8 – Resonant metamaterial-based earthquake risk mitigation of large-scale structures and infrastructure systems: assessment of an innovative proof-of-concept via medium-size scale testing – [in progress]

9.8.1 Summary of the project

Metamaterials inspired solutions for the protection of large-scale structures and infrastructures from earthquakes and other sources of low-frequency noise have been recently conceived.

The most known solution is the so-called Metafoundation, i.e. a foundation endowed with the capability to isolate the superstructure from incoming bulk waves. It can be tailored to attenuate vertical ground motions, for which no efficient protection measures currently exist, but it can hardly be used to retrofit existing structures and infrastructures.

More recently, the idea of a resonant Metabarrier placed within the ground around the structure, or a cluster of structures, to be protected, has been proposed. The metabarrier is purposely designed to reduce the incoming seismic Rayleigh surface waves energy. It has the ability to retrofit and shield existing vulnerable structures and infrastructures including historical buildings and cultural heritage sites. Additionaly, it can be tailored to operate in specific frequencies ranges, for instance at the resonant frequencies of the structure to protect, or to achieve broadband performance, thus giving high flexibility to its use in different applicative contexts.

While the metabarrier concept has been validated numerically and at small-scale laboratory tests, it still misses an on-field validation considering the true characteristics of ground, bearings and structural components.

The objective of this proposal is thus to demonstrate for the first time the effectiveness of the metabarrier at a medium-size scale by ad-hoc (i) designed experiments, (ii) data collection and (iii) data processing.

9.8.2 Main research objectives and expected contribution to the seismology and earthquake engineering community

Objectives

In this proposal, we aim at proving for the first time the effectiveness of the resonant metabarrier at a medium-size scale, within a 50-100 Hz frequency range, taking into account the inevitable variability in stiffness and strength of the soil and the resonators components. Although the fundamental functionalities of the metabarrier have been numerically verified, its experimental validation is still limited to small-scale laboratory samples. Thus, this proposal can result in a significant milestone, paving the way for future reale scale (1:1 scale) testing.

A modular metabarrier and a testing campaign designed to take place at the Euroseistest TA facility is envisaged. Several resonators will be designed and constructed, according to the in-situ soil properties and the operative frequency range of the measuring equipment. The resonators will be buried below the soil surface in an array fashion constituting the metabarrier. Next, equipment for the Multichannel Analysis of Surface Waves (MASW) will be used to excite the soil and to measure the soil response in the presence of the metabarrier or without it. The test setup is expected to confirm an attenuation of the ground motion in the presence of the metabarrier. The final design of the experimental test, to be discussed and developed within the SERA framework, will be supported by accurate finite element simulations.

Expected Outcomes

a. prove that buried resonant elements in soil are capable of interacting with Rayleigh waves;

b. demonstrate that an array of resonant elements with sub-wavelength dimensions can generate surface to shear wave conversion;

c. prove that resonators can be purposely tuned to exploit the rainbow trapping concept;

d. draw guidelines/indications for real scale testing for metabarrier seismic metamaterials.

Fundamental Scientific and Technical value

The key element of the metabarrier is the resonator. A very preliminary design of the resonator considers a homogeneous soil with shear bulk speed of 150 m/s and a mass density of 1500 kg/m3. The resonator consists of a PVC pipe (diameter 400 mm and height 600 mm), a 10 mm thick circular steel plate of 380 mm diameter, 4 linear elastic springs, and a circular steel plate with diameter 300 mm and thickness 10 mm. The resonators will be buried below the soil surface (their base placed at 600 mm depth) and arranged in a regular square grid of 5 x 10 spaced apart 0.5 meters. The mass of the resonator can be varied by adding circular concrete disks of approximately 16 kg each. This preliminary design should provide a surface wave attenuation within 50 and 55 Hz, well above the frequencies of the seismic action, with a limited overall experimental cost. In addition, higher frequencies involve smaller Rayleigh wavelengths and thus reduce the risk of having a soil stiffness variability on the considered layer.

The modular resonator design allows realizing metabarriers with different resonant frequencies (even once the resonators are in place). The resonant frequency of each resonator, once buried in the ground, will be evaluated to account also for the soil-structure-interaction (SSI) which should slightly lower the nominal resonant frequency. To this purpose, an operator can simply activate the resonator mass with a soft hammer stroke and record its motion with a single axis (vertical) accelerometer positioned on the top of the mass. Adjustments of the resonator frequency are achievable by varying the compaction of the soil below the resonator base, or varying the number/stiffness of some/all springs.

The modular design of the resonator is also meant to allow building metabarriers characterized by lines of resonators with different resonant frequencies. This, in alignment with the rainbow trapping concept, could open larger band gaps.

9.8.3 Project status

The Host Facility Group is currently in communication with the User Group for the proper design of the experiments that will take place within the next months. A detailed description of the desired experiments is made available by the User Group and there is a communication with a contractor for the construction of the resonators. A preliminary design of the resonators as developed by the User Group is presented in Figure 100.

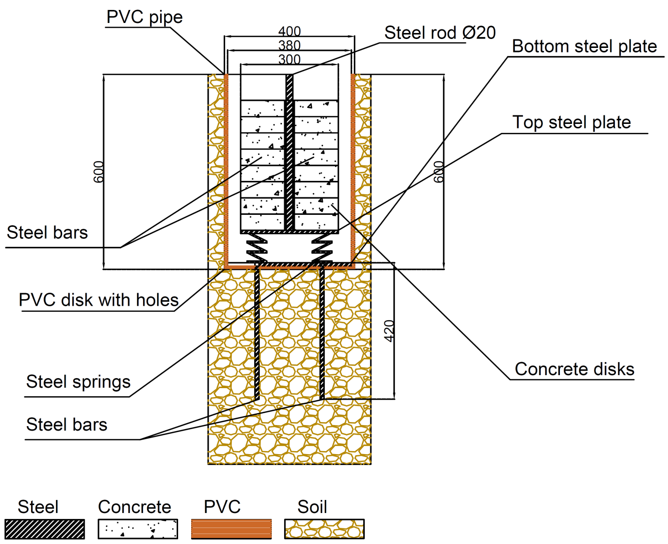

Figure 100: Schematic of the resonator as designed by the User Group.

Additionally, preliminary analysis of the experiment is currently being carried out by the User Group in order to define the desired frequency bandwidth of the excitation forces and the metabarrier resonators.

A detailed test program is being developed. The test program comprises T0-T4 phases whose definition will be supported by accurate finite element simulations:

T0: MASW tests will be performed in selected area outside of the array of resonators (soil in pristine condition). The test responses at the geophones will be recorded and the output analysed with the purpose of tuning the impact force (with or without the strike plate), the number of geophones, the best spacing of the geophones, the best source offset and the frequency range where Rayleigh waves are not dispersive.

T1: MASW tests will be performed across the 5x10 grid of holes (the PVC pipes are embedded in the soil without the resonators). The setting condition of T1 will be adopted and eventually modified.

T2: MASW tests will be performed across the metabarrier (5x10 resonators) with identical setting condition of T1. Different orientations of the seismic cable will be considered to test different resonators arrangments. For each test the responses at the geophones will be recorded and the output signals analysed.

T3: MASW tests will be performed across different lengths of metabarriers (arrays of 5x4, 5x6 and 5x8 resonators) obtained by simply removing lines or resonators. The setting condition of T2 will be always considered and the results for the 5x10 case will be used as a benchmark.

T4: MASW tests will be performed across different metabarriers (always 5x10 resonators) obtained by varying the masses of the resonators for the different lines. The setting condition of T2 will always be considered.

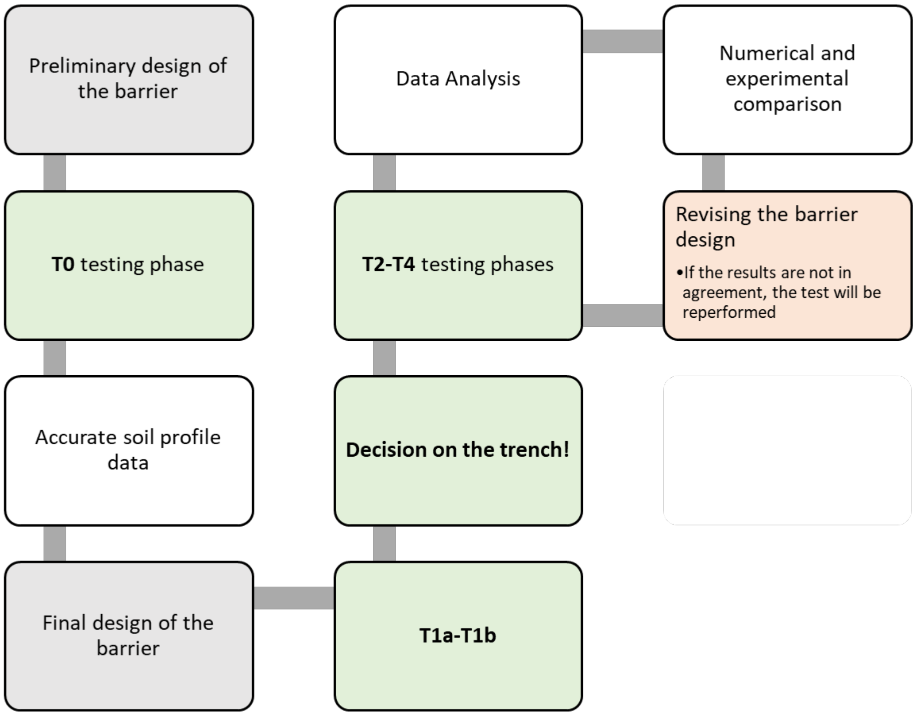

Figure 101: Flow chart of the testing programme

9.8.4 Foreseen activities and schedule

The experimental programme provided by the User Group is now being improved and enriched by the Host Facility Group.

Specifically, there is communication between the User Group and the Host Facility Group in order to arrange the last details of the experiments and deal with practical issues concerning the realization of the tests, such as the source of harmonic excitation and the space that will be available at the Facility for the performance of the experiments. A preliminary plan view as realized by both groups and being under discussion is shown in Figure 102.

Finally, the last arrangements are made for the construction of the resonators.

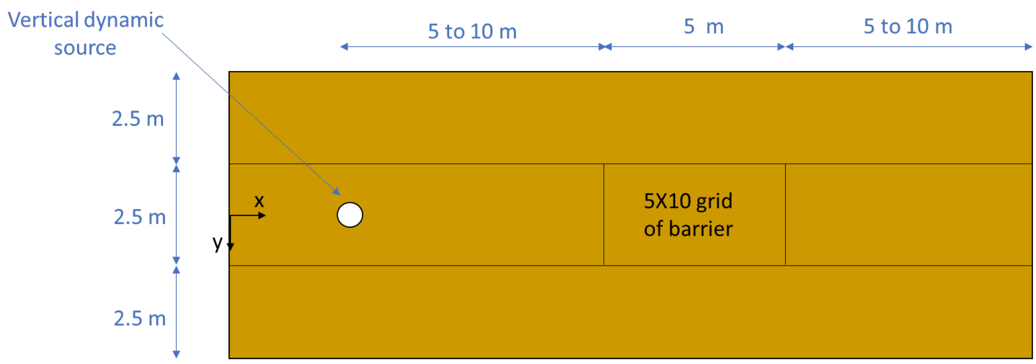

Figure 102: Plan view of the field test in EUROPROTEAS

9.8.5 User Group

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	Vasilis K. Dertimanis	ETH Zürich	Switzerland
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	Simon Hoffmann	Mageba sa - engineering connections	Switzerland

	Giulio Dal Forno	Envia Studio Associato	Italy
	Giacomo Mazzoni	Envia Studio Associato	Italy

9.9 Project #9 – "DYMOBRIS" DYnamic identification and MOnitoring of scoured BRIdgeS under earthquake hazard – [in progress]

9.9.1 Summary of the project

Earthquakes and foundation scour are the major causes of bridge failure, resulting in substantial direct and indirect losses in Europe and worldwide. Many bridges in earthquake-prone countries have shallow foundations, whose stability and seismic vulnerability can be significantly undermined by flood-induced scour. Despite the relevance of this problem, very few experimental and numerical studies have focused on shallow foundations, with the majority of researches addressing deep foundations.

The project aims i) to develop a methodology for non-invasive detection of scour in bridges with shallow foundations based on vibration monitoring, and ii) to quantify the effects of scour on the seismic vulnerability of these soil-foundation-structure (SFS) systems. For this purpose, an extensive experimental and numerical campaign is proposed, by exploiting the facilities available at Euroseistest. The EuroProteas prototype will be tuned to represent a bridge pier resting on a shallow foundation, and various realistic scour conditions will be reproduced by excavating the foundation soil. Ambient, free, and forced-vibration tests will be performed, providing information on how scour can be detected by monitoring the changes in the dynamic response of the SFS system. The experimental modal properties obtained for the different scour conditions will then be used to develop, calibrate, and validate analytical and numerical models for simulating scour effects on systems with shallow foundations. The validated numerical models, accounting for SFS interaction and radiation phenomena, among others, will be extended to other scour and soil scenarios, and will be used to predict the ultimate scour depth and the seismic performance of systems with scoured foundations.

These results will provide a unique benchmark for informing both the design and assessment of bridges and other marine structures subjected to a sequence of scour and earthquake effects.

9.9.2 Main research objectives and expected contribution to the seismology and earthquake engineering community

Objectives

This research aims to shed light on the effects of foundation scour on the dynamic and seismic behaviour of structural systems. The focus is on structures with shallow foundations rather than deep ones. This is because many bridges and other type of structures exposed to scour (e.g. offshore wind turbines) have superficial foundations and are very sensitive to the effects of scour and the resulting modification of support conditions and bearing capacity reduction. Moreover, research efforts have mainly considered only the case of deep foundations, while very few studies have studied shallow foundations.

The measurable objectives (OBJs) of the project are the following:

- OBJ 1. To assess the effects of scour on the dynamic properties of the SFS system.

- OBJ 2. To quantify the changes of the soil-foundation dynamic impedance function due to scour.
- OBJ 3. To identify the optimal sensing strategy and develop a vibration-based monitoring technique to enable indirect evaluations of the extent of scour around the foundation of a structure.
- OBJ 4. To validate analytical techniques and numerical models against experimental data of SFS interaction systems subjected to scour and earthquake actions.
- OBJ 5. To evaluate the influence of scour on the seismic vulnerability of the SFS system at hand.

Methodology and Outcomes

To achieve the project objectives, a series of tests will be carried out on the EUROPROTEAS SFS system. Different scour configurations will be simulated, by removing the soil underneath the foundation slab. For each scour-hole geometry, three types of tests will be performed, namely 1) ambient vibration (AV) tests, 2) snap-back (SB) tests, with the top slab slightly displaced and released to induce free-vibrations, and 3) forced vibration (FV) tests, with the shaker placed on the roof or at foundation level. For FV tests, harmonic excitations with frequencies in the range 1-15Hz will be applied, waiting each time to reach stationary conditions. Both the unbraced (U) and braced (B) frame configurations will be considered, to investigate two different structure's stiffness scenarios. Preliminary analyses employing simplified numerical models will be carried out to define the excitation amplitudes and the different scour configurations to be investigated. These conditions will be chosen in such a way that: 1) the effects can be monitored by the deployed instruments while maintaining the system within the elastic range, 2) realistic scour hole geometries are simulated, 3) changes in dynamic properties due to scour can be effectively identified, 4) potential safety risks are minimized by keeping the system far from irreversible limit state conditions (e.g., system overturning, loss of foundation bearing capacity, structure yielding, etc.). The response of the components of the SFS system will be recorded through accelerometers, LVDTs, strain-gauges, and the array of seismometers placed on the ground.

For OBJ1, the results collected from the tests will be utilised to calculate the modal characteristics, including changes in the frequency of the structure, alterations in damping capacities and displacements (i.e. drifts) following standard procedures and methods. Results for each scour condition will be compared against the baseline Europroteas specimen.

The same test results will be post-processed to back-calculate the foundation impedance functions (OBJ2), representing the frequency-dependent stiffness and damping characteristics of foundation-soil interaction. These impedances will then be utilised to inform the numerical models for the evaluation of the system seismic performance in presence of scour.

The tests results will also be used to assess the effectiveness of vibration-based, non-intrusive strategies for monitoring structures exposed to scour (OBJ3), overcoming the limitations of current approaches which are mostly based on expensive and potentially inaccurate underwater inspections and instrumentation. In particular, the optimal type and placement of sensors that maximize the information on scour depth and extent will be identified.

For OBJ4, the impedance functions for the different scour conditions will also be employed to develop, calibrate, and verify analytical and numerical models for describing soil-structure interaction in SFS systems, also accounting for scour. In addition to the analytical models already available in the literature (e.g., [5]), finite element numerical techniques will be tested and verified. Modification-factors to be applied to the analytical and numerical models disregarding scour will also be proposed to account for scour effects in a simplified way. In order to achieve OBJ5, numerical analyses will be carried out under different seismic records to evaluate the influence of scour on the seismic vulnerability of bridges with shallow foundations, by investigating different soil and scour scenarios.

It is worth to note that through the EUROPROTEAS testbed it is not possible to exactly reproduce the conditions of a bridge pier with underwater shallow foundations under scour (soil not under water, ratio of top slab to foundation slab mass different than ratio of deck mass to foundation slab mass, etc.). Nevertheless, the outcomes of the project will be of high scientific and technical value, as they will provide validated numerical and analytical models that can be used to perform SFS interaction of bridges subjected to local pier scour.

9.9.3 Project status

The Host Facility Group is currently in communication with the User Group for the proper design of the experiments that will take place within the next months.

A detailed description of the desired experiments is made available by the User Group and preliminary analysis of the experiment are currently being carried out. More specifically, a two-dimensional finite element model has been created. The nodes at the base of the foundation slab have been initially assumed as fixed. Modal analysis of the frame has been carried out on the fixed-base system, resulting in a vibration frequency of 9.27Hz, which is very close to the one provided in the literature.

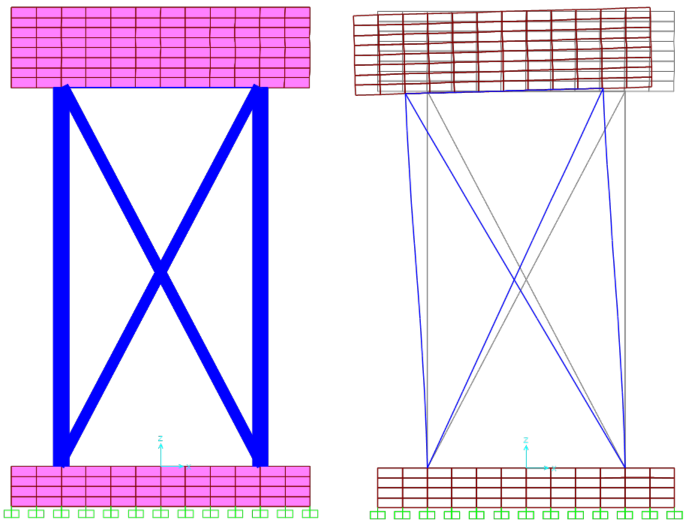

Figure 103: Model 1: fix

In order to simulate in a simplified way the SSI effects, the fixed-based model has been modified by replacing the fixed boundary conditions at the base of the slab with springs.

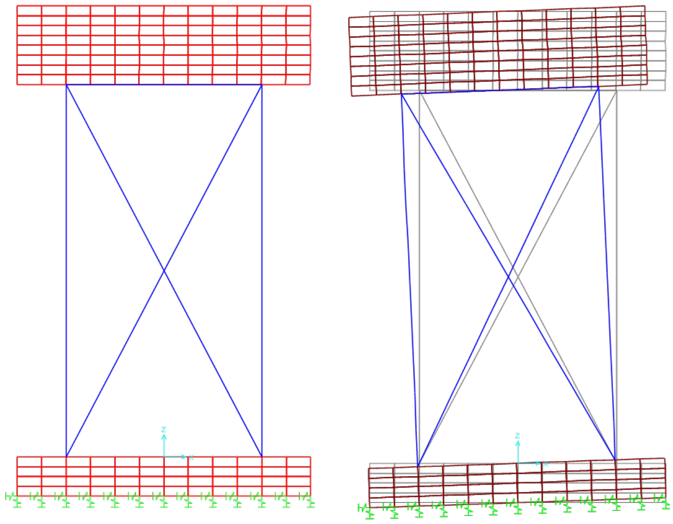

Figure 104: Model 2: springs

Finally, a possible scour scenario is simulated by removing the first three springs on the right of the model. This corresponds to a scour hole extending for 1.5m below the foundation slab.

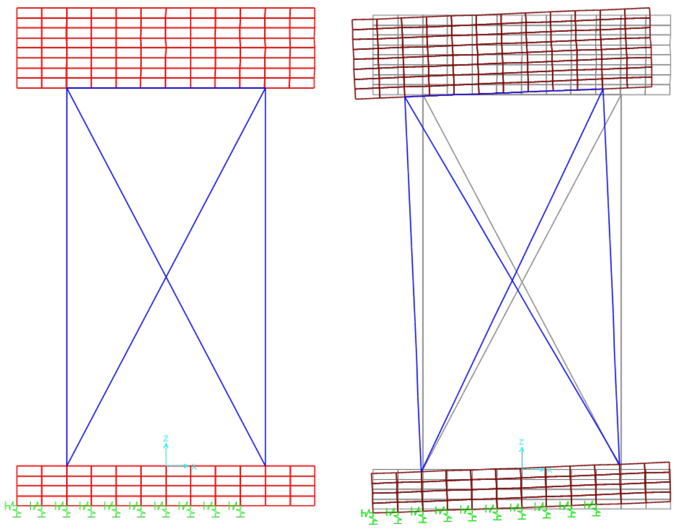

Figure 105: Model 2: springs + free ends

9.9.4 Foreseen activities and schedule

A detailed test program is being developed. Attention will be paid during the excavation, employing temporary propping and standard measures to avoid cave-in and other hazards. Nevertheless, the scour depth below the bottom edge of the footing will be adequately small, thus allowing the system to find a new, safe equilibrium condition should large displacements occur.

9.9.5 User Group

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	Andrea Maroni	University of Strathclyde	United Kingdom
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	Sandro Carbonari	Polytechnic University of Marche	Italy

10 NORSAR

NORSAR is the premier operator of seismological arrays in Europe and a world leader in array seismology. The infrastructure at NORSAR consists primarily of a data centre and field installations on Norwegian territory and the European Arctic, comprising four different seismic arrays (with apertures ranging from 1 to 60 km equipped with 1C or 3C short-period or broadband sensors) and three single 3C broadband stations. NORSAR is an active partner in the Norwegian National Seismic Network, operates an other international institutions operating seismic arrays and stations in Northern Europe and the European Arctic. NORSAR provides access to its unique digital database of seismic recordings from all its installations reaching back to April 1971. NORSAR has a group of scientists and engineers, which captures 40 years of experience and produces world renowned research in array seismology and automatic analysis of seismic data streams. By offering access to its infrastructure, NORSAR will contribute its knowledge on 1) array seismology, 2) automatic on-line data processing, 3) near real-time seismic monitoring in various scales from regional seismicity, aftershock sequences and mining-induced seismicity to microearthquakes associated with ground instabilities or hydrothermal activities, and 4) seismic hazard and risk assessment as well as earthquake engineering. Thereby, NORSAR will disseminate further developments in these research topics and promote their application in Europe and the rest of the world.

NORSAR had until now four research visits. The first research visit was during M1 and M12. The other three research visits were assigned in the 2nd call and were all finalized in 2018.

The other four of the eight planned research visits were all assigned in the 3rd call and three are already scheduled for 2019 (one in May, one in September and one in November). The last research visit is not yet scheduled but planned for the end of 2019 or beginning of 2020.

10.1 Project #1 – Blind beamforming in array processing – [concluded]

10.1.1 Summary of the project

The main goal of the proposal is twofold. On the one hand, the visit at one of the most renowned institutes of its kind, will offer the proposing researcher the opportunity to familiarize himself with state-of-the-art array processing techniques as well as gain insight on modern array applications. On the other hand, helped by the expertise of the personnel at the hosting facility, as well as the availability of real array data, a preliminary investigation of the potential use of blind beamforming in array processing, will take place.

Contrary to the conventional model-based beamforming, blind beamforming operates directly on the available signals, without making any assumptions regarding the mechanism(s) that generated them. In other words, blind beamforming stands for data-driven instead of model-driven beamforming Apart from its superior enhancement capabilities, the direct estimation of the time delays enables a more natural formulation of the signal detection and parameter estimation problems that truly captures the advantage of seismic arrays over conventional networks. In particular, the use of a recently developed, high-performance blind beamforming technique, based on Semi-Definite Programming (SDP-BB), is going to be investigated.

10.1.2 Main research objectives and expected contribution to the seismology and earthquake engineering community

The visit had two main objectives. The first one was to offer the visiting researcher the opportunity to familiarize himself with state-of-the-art array processing techniques as well as gain insight on modern array applications, through the collaboration with the experienced researchers at the hosting institute. The second objective of the visit was the realization of a preliminary investigation concerning the use of blind beamforming for the solution of the signal detection and parameter estimation problems in seismic arrays. Regarding signal detection, the main idea was to formulate the detection problem as a hypothesis testing problem, discriminating between the hypotheses of structured vs random time delays. With this goal in mind, one of the objectives of the visit was the examination of time-delay sets from real array data, with the purpose of determining the statistical properties of the obtained delays under the scenarios of “pure noise” and “signal”. On the other hand, regarding the parameter estimation problem, the goal was to formulate an inverse problem based on the obtained delay-estimates, for the estimation of the back-azimuth and apparent velocity parameters of the incoming wave. For this purpose, the objective was to analyze several cases of seismic phases with known wave parameters, recorded at the hosting institute.

10.1.3 Project status

The one-month long research visit was in November 2017 and is finished.

From the user’s point of view the visit can be characterized as a very successful endeavor, leading to very fruitful collaborations and exchange of ideas between the visiting researcher and the staff at the hosting institute. The objectives of the visit were fulfilled to a very satisfactory level. More specifically, with the guidance of NORSAR researchers, the user was able to establish a deeper understanding regarding the particularities of seismic array signals and array processing techniques. On the other hand, through numerous discussions as well as a formal presentation, the visitor was able to convey and refine his ideas regarding the incorporation of blind beamforming in seismic array methodology. The most graspable result of the visit was the formulation and initial evaluation of a new, delay-based technique for the joint detection and estimation of plane waves in seismic arrays. The preliminary results of the technique, using real array data, were very promising. The technique is still under development and both a conference presentation and subsequently a full paper submission are planned for the near future. Ideas for other interesting collaborative projects were also established during the visit. In conclusion, the outcome of the visit has provided the visiting researcher with a significant first step towards his goal of developing new array processing methodologies based on the use of blind beamforming.

10.1.4 Foreseen activities and schedule

Publication of results.

10.1.5 User Group

	NAME	ORGANIZATION NAME	ORGANIZATION COUNTRY
USER GROUP LEADER	Erion Pikoulis	University of Patras	Greece
ADDITIONAL USERS	–		

10.2 Project #2 – The new velocity model up to 300 km deep based on NORES array data (Baltic Shield) based on receiver function data – [concluded]

10.2.1 Summary of the project

The main goal of the proposed research is to construct a P- and S-wave seismic velocity of the crust and uppermost mantle of the southern part of Norway (Fennoscandian shield) by combining P-wave receiver-function data and S-wave receiver-function data of the NORSAR / NORES seismic arrays. For this purpose, we are going to use well known method of the receiver-function analysis, developed by the Institute of Physics of the Earth of Russian Academy of Sciences, along with classical array techniques. The model will include: a) P-wave velocity model; b) S-wave velocity model; c) position of the major seismic interfaces in the crust and upper mantle. In particular, we are going to investigate basic mantle boundaries such as LAB and Lehmann along with the transition zone 410-660 km. The model will be combined with the P- and S-wave velocity models of the crust and upper mantle obtained by the NORSAR local event studies.

10.2.2 Main research objectives and expected contribution to the seismology and earthquake engineering community

To investigate the velocity structure of the crust and uppermost mantle of the southern part of Norway using NORSAR data along with all the broadband seismic data for the region that could be obtained. Another goal of our attempts is to look on the mantle transition zone in 410-660 km to see whether any topography of this boundaries exists. The final goal is to get an accurate velocity model of the investigated area. To successfully obtain these goals the receiver function method has been chosen.

10.2.3 Project status

The one-month long research visit was in August/September 2018 and is finished.

For each seismic station we created thee catalogues, one for each phase of interest (P, S, SKS) of the events that are suitable to calculate the receiver function. The catalogues contain events since 1961 based on Harvard and ISC bulletins. For each NORSAR broadband seismic station along with the MAGNUS project and for several closed by seismic station like KUNO, HFC etc. each appropriate event has been processed into individual P-to-S receiver function (PRF). The total amount of PRF is more about 5000. We stacked PRF for each seismic station and for the total dataset. Times of onsets form the 410-km and 660-km discontinuities are a little smaller than they expected to be according to the average model and the time delay between these phases is also smaller. All of this could be an argument supporting that we have a weak rift on the investigated area that affects at least 410-km discontinuity. Another result is that 410-km discontinuity seems to be much more gradient than the 660-km. We presume that based on our work with different types of sensors that was installed on NORSAR in different time periods and working with different filtrations. All this should be proved and to do so we are working on creating the map of discontinuities of the boundaries of 410-km and 660-km discontinuities. Also, we are planning to synthetically reconstruct the structure of the boundaries. Finally, we will model the velocity structure up to 300 km deep using P, S and SKS phases for all seismic stations we have with respect to the azimuth to try to get an accurate 3D model.

10.2.4 Foreseen activities and schedule

Wrapping up the results and preparing publications.

10.2.5 User Group

	NAME	ORGANIZATION NAME	ORGANIZATION COUNTRY
USER GROUP LEADER	Andrey Goev	Russian Academy of Sciences, Moscow	Russian Federation
ADDITIONAL USERS	–		

10.3 Project #3 – Seismic tremor detection in Greece using small aperture arrays – [concluded]

10.3.1 Summary of the project

The main objective of this research proposal is to detect tremors of tectonic origin in Greece using seismic arrays and array data processing techniques. This type of signal is usually associated with slow-slip events, which have been mostly observed in several subduction zones worldwide. In Greece no such tremor recordings have ever been documented. There are, however, two candidate zones where they could possibly occur: the Hellenic Arc subduction zone, where the observed strain is mostly accommodated aseismically, and the western Corinth Rift. In the latter case, a strain transient associated with a slow-slip event was observed in December 2002, while there is evidence of creeping that occurs on a developing detachment within the brittle-ductile transition zone.

In the proposed research, an array that consists of 7 broadband seismometers, installed near the town of Magoula, at the western margin of the Corinth Rift, will be employed to detect tremors that may have occurred in the region using beamforming techniques. Candidate signals will be evaluated using a conventional method, such as envelope cross-correlation, at the stations of the local Corinth Rift Laboratory (CRL) network. The developed methodology will be also applied to another seismic array, composed of 9 stations, that is installed in Pylos, South Peloponnese, in collaboration with the National Observatory of Athens. This could target the SW portion of the Hellenic Arc, where tectonic tremors are more likely to be observed, but may be more difficult to evaluate due to the sparse distribution of stations of the regional Hellenic Unified Seismological Network (HUSN). The detection of tectonic tremors in Greece could reveal sites where slow-slip occurs, explaining part of the aseismically accommodated strain and could have implications on the seismic hazard assessment.

10.3.2 Main research objectives and expected contribution to the seismology and earthquake engineering community

The main objective of the SERA-TA visit with number TA10-3 was the development of array processing tools for the detection and location of tectonic tremors in the region of Greece. Prior to the visit at NORSAR, data had been collected from two arrays in Greece; one located in Pylos, S. Peloponnese, close to the interface between overriding and subducting plates of the Hellenic Arc, which is considered as a possible zone where tectonic tremors might occur; the other array is located in Magoula, in the W. Corinth Gulf, a region characterized by intense microseismic activity, where at least one slow slip event has been recorded as a strain transient signal by a dilatometer in December 2002. A data-sample of about one month was to be processed during the TA-visit at NORSAR. A "training dataset" of recorded tremors in Cascadia was also available to test the various array-processing techniques for their tremor-detecting capability. The latter appear as emergent, noise-like, coherent signals, mainly within the 2-8 Hz band, which may persist for several minutes to hours, days or even weeks. Their source is expected to be sustained for a long time in the same fault patch or gradually migrate over time. The source location can be determined using back-projection techniques, preferably using observations from multiple arrays, or other constraints such as a fixed depth. The detection and location of such events may provide information on aseismic slip that could possibly accelerate the occurrence of significant earthquakes in the area of study.

10.3.3 Project status

The one-month long research visit was in October 2018 and is finished.

During the SERA-TA visit with number TA10-3, several methods were examined for their capability to detect tectonic tremors on a "training dataset" from the SOOKE array in Cascadia. Scripts (macros) were written in the environment of the NORSAR proprietary software "EP". The implemented techniques included the following: Classic FK analysis on each available component; Average correlation coefficient between traces aligned at the maximum FK-power time-delays; Time-domain delay-and-sum beamforming; Cross-correlation beamforming. Other methods, e.g. FK analysis on envelopes or STA/LTA triggering using the "DP" software, did not yield usable results. The most efficient method was classical FK, averaging measurements from all components with a correlation threshold of about 0.7, as it provided results close to those expected for the "training dataset". Tests showed that a 60sec window-length achieves balance between adequate temporal resolution and low scattering of observations during tremors. Almost 2-years of recordings from Greece were processed on various bands using the preferred recipe, largely exceeding the original plan of a 1-month-long sample to be processed during the visit at NORSAR. The results were post-processed and candidate signals were visualized for evaluation. Many of the observations were associated with earthquakes, possible microseisms, noise of anthropogenic origin or even seismics (e.g., repeated airgun shots) in the W. Corinth Gulf. So far, no observations were associated with tremor on either site. However, the developed tools are now available for the processing of the rest of the data from the arrays and will be used for further monitoring of tremors in Greece.

10.3.4 Foreseen activities and schedule

Publication of results.

10.3.5 User Group

	NAME	ORGANIZATION NAME	ORGANIZATION COUNTRY
USER GROUP LEADER	Vasileios Kapetanidis	University of Athens	Greece
ADDITIONAL USERS			

10.4 Project #4 – Joint processing of seismo-acoustic array data as tool to discriminate between man-made explosions and earthquakes – [concluded]

10.4.1 Summary of the project

The proposed research is aimed to monitoring geophysical man-made hazard, i.e. controlled explosions, by jointly using data well-recorded with the Romanian seismic and infrasonic arrays, focusing on the Plostina seismo-acoustic site (PLOR and IPLOR stations). Recently, a constant increasing of interest in analyzing the infrasound data to include them in interdisciplinary domains as physics and geoscience have been observed at the global scale. The worldwide infrasound monitoring stations have proven capable to detect and locate atmospheric explosions as well as other natural phenomena generating infrasound signals.

During the project, infrasound and seismic array data recorded by Romanian stations will be processed and analyzed in order to discriminate between tectonic sources (earthquakes) and artificial events (quarry blasts and mine explosions). The examination of the infrasound propagation changes over time and distance is essential to understand the differences between real propagation through atmospheric layers and a hypothetical propagation along the earth's surface. The capability of the Romanian dense seismic network to detect and locate small events led to an undesirable side-effect as including of many man-made blasts and explosions in the Romanian earthquake catalogue ROMPLUS (Oncescu et al., 1999).

10.4.2 Main research objectives and expected contribution to the seismology and earthquake engineering community

To monitor man-made hazards by jointly using data well-recorded with the Romanian seismic and infrasonic arrays, focusing on the Plostina seismo-acoustic site (PLOR and IPLOR stations) by building an efficient tool to discriminate between man-made explosions and earthquakes, followed by seismic *catalogue* decontamination

Activities to follow:

- selection of natural and artificial reference events for the seismo-acoustic analysis and the stations (seismic and infrasound) where they were detected
- analysis of the infrasound data using standard processing methods to extract the waveform characteristics (direction of arrival - *backazimuth*, phase apparent velocity, frequency, amplitude, SNR)
- analysis of IPLOR infrasound station detection capacity to observe the diurnal and seasonal variations and identification of the causes which produce these variations
- analysis of seismic data from reference events in order to extract the characteristics of their seismic signature, such as waveform, frequency, amplitude, particle motion for determining the direction of arrival of the energy at the measuring sensor
- association of the infrasound detections obtained (*backazimuth* and arrival time measured with the IPLOR array) with the seismic events in the *analyzed* set (theoretical *backazimuth* and arrival time), considering the effect of the dynamics of atmospheric propagation
- inspection of the recorded seismic waveforms for events identified as acoustic sources based on their association with infrasonic detections (aspect, frequency content, radiated energy) for their validation as quarry bursts

- creation of the templates of the seismo-acoustic signals generated by the man-made explosions in order to compare them with the other recorded waveforms

10.4.3 Project status

The one-month long research visit was in November/December 2018 and is finished.

In order to accomplish the user-objectives, the following activities were done:

- selection of the promising events recorded on PLOR and BURAR from the earthquake catalog in order to analyze the recorded data at seismic and infrasound stations
- analysis of the infrasound recordings at IPLOR and BURARI stations using NORSAR processing software ep in order to extract the waveform characteristics (direction of arrival - backazimuth, phase apparent velocity, frequency, amplitude, SNR)
- analysis of the seismic recordings at PLOR and BURAR stations with NORSAR processing software ep in order to extract the characteristics of the seismic signatures
- association of the infrasound data with the seismic data obtained after the processing, considering the effect of atmospheric propagation
- scripts creation for seismo-acoustic signals in order to process and check the infrasound recordings at IPLOR and BURARI stations

10.4.4 Foreseen activities and schedule

Wrapping up the results and preparation of presentations at international conferences and publication of results.

10.4.5 User Group

	NAME	ORGANIZATION NAME	ORGANIZATION COUNTRY
USER GROUP LEADER	Raluca Dinescu	National Institute for Earth Physics	Romania
ADDITIONAL USERS	_		

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