SERA
Seismology and Earthquake Engineering
Research Infrastructure Alliance for Europe

DELIVERABLE

D8.1 - Technical report on SERA Transnational Access activities TA1-TA10 (M12)

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Lead	EUCENTRE
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Summary

Within the EU funded Horizon 2020 Research and Innovation programme under grant agreement No.730900 - SERA, Transnational Access (TA) to the largest collection of high-class experimental facilities for earthquake engineering and engineering seismology in Europe – and worldwide – is offered to selected talented research groups.

Users are integrated in the scheduling of the infrastructure 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 infrastructure 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.

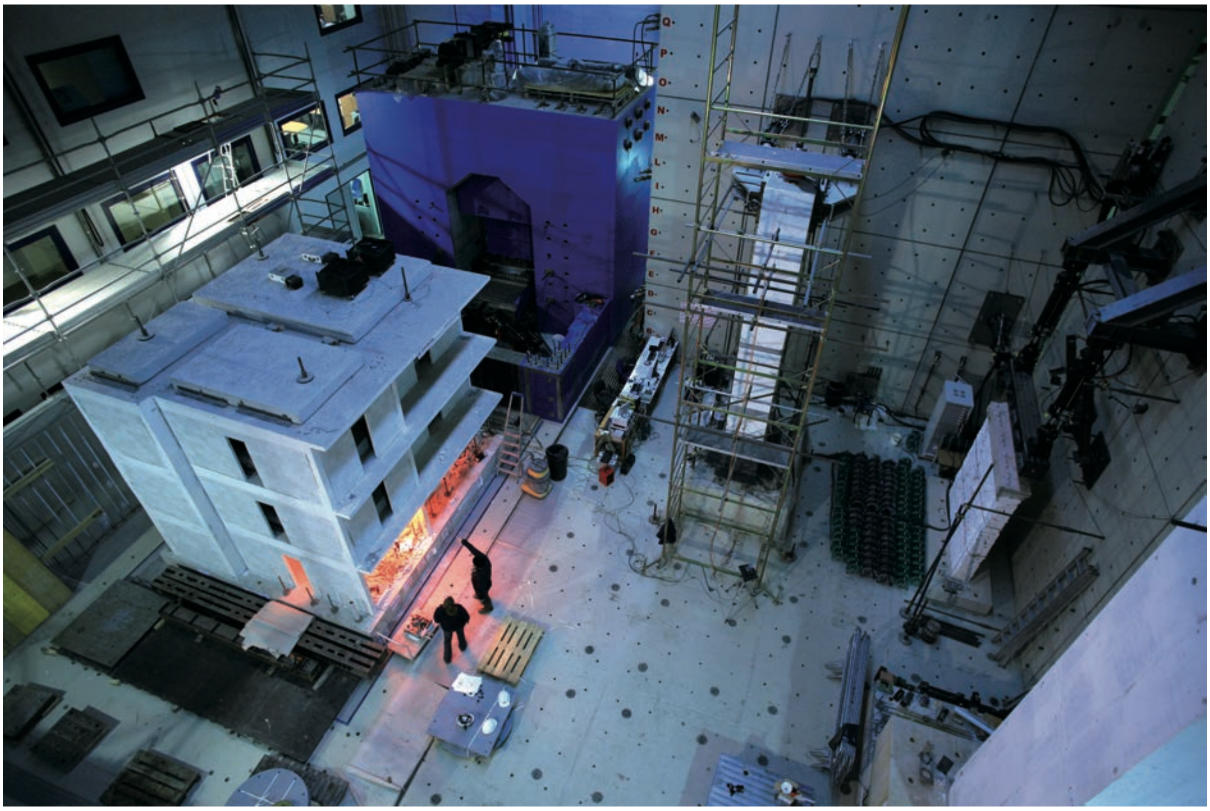


Figure 1 View of the EUCENTRE Shake Lab

Services that are provided to the users include among others:

- first-class technical and scientific support and collaboration from the staff of the infrastructure;
- support for analytical and numerical modeling;
- technical assistance in the definition and design of the test model and of the experimental setup, to adapt the testing program to the characteristics of the infrastructure;
- support for the fabrication of the test specimen(s), either in reduced or full scale;
- support in the definition of the instrumentation layout focused on the key objectives of the research;
- assistance in the choice of the input signals;

- support to data-processing, analysis and results interpretation;
- support to logistic, user hosting and meeting organization;
- travel accommodation subsistence.

A user team is eligible for TA support under the grant when the User Group Leader and most users work in EU member countries or EU associated countries, different from where the selected installation is located. Access for user groups with most users not working in a EU or associated country is limited to 20% of the available TA resources.

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)

At M12 of the SERA project, 2 calls for proposals have been already completed. Since an effective implementation of the experimental activities require, prior testing, extensive numerical simulation campaigns, the design of the test setup and instrumentation layout, the setup components and specimen manufacturing and the definition of a proper testing protocol, the calls have been issued at earliest stage, but compatibly with the time required for the User Groups to prepare the proposals.

The first 2 calls have been very successful; all Research Infrastructures received high-quality proposals, evaluated by TA Selection and Evaluation Panel (TA-SEP), and all of them are currently working on the first stages of different projects.

In the following tables, the awarded projects and the TA resources are illustrated.

PROJECTS SELECTED IN THE 1st CALL FOR PROPOSALS

Number of Project	Title of Project	Hosting Research Infrastructure
1	EQUFIRE – Multi-hazard performance assessment of structural and non-structural components subjected to seismic and fire following earthquake by means of geographically distributed testing	JRC
2	SLAB STRESS – SLAB STructural RESponse for Seismic European Design	JRC
3	Dynamic testing of variable friction seismic isolation devices and isolated systems	EUCENTRE
4	SE.RE.M.E. – SEismic REsilience of Museum contEnts	CEA
5	FUTURE – Full-scale experimental validation of steel moment frame with EU qualified joints and energy efficient claddings under near fault seismic scenarios	CEA
6	(Towards the) Ultimate Earthquake proof Building System: development and testing of integrated low-damage technologies for structural and non-structural elements	LNEC
7	Seismic Response of Masonry Cross Vaults: Shaking table tests and numerical validations	LNEC
8	ARISTA – Seismic Assessment of ReInforced Concrete frames with SmooTh bArs – Proposals for EC8-Part 3	STRULAB
9	ARCO – Effect of Axial Restraint on the Seismic Behaviour of Shear-Dominated COupling Beams	STRULAB
10	Seismic Response of Novel Integral Abutment-Bridges	University of Bristol
11	Statistical verification and validation of 3D seismic rocking motion models	University of Bristol
12	RE-BOND – REsponse of as-Built and strengthened three-leaf masONry walls by Dynamic tests	University of Bristol
13	Influence of the floor-to-wall interaction on the seismic response of coupled wall systems	IZIIS
14	Seismic behaviour of anchored Steel Sheet-Piling (SSP) retaining walls: experimental investigation, theoretical interpretation and guidelines for design	University of Cambridge
15	STILUS – Structure-Tunnel Interaction in LiqUefiable Sand	University of Cambridge
16	IMPEC – On the broadband synthetic sIgnals enhanceMent for 3D Physic based numerical analysis, the EUROSEISTEST Case study	EUROSEISTEST and EUROPROTEAS
17	Blind beamforming in array processing	NORSAR

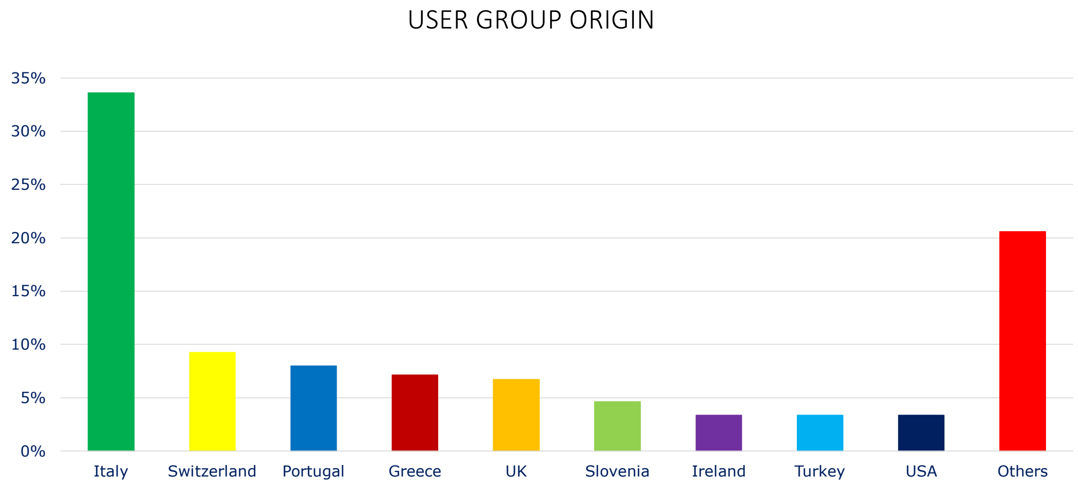
PROJECTS SELECTED IN THE 2nd CALL FOR PROPOSALS

Number of Project	Title of Project	Hosting Research Infrastructure
18	SEismic Response of Actual steel SILOS (SERA-SILOS)	EUCENTRE
19	Seismic Testing of Adjacent Interacting Masonry Structures (AIMS)	LNEC
20	HybrId Testing of an Existing Steel FRAme with Infills under Multiple EarthquakeS (HITFRAMES)	STRULAB
21	NSFuse: Ductile steel fuses for the protection of critical nonstructural components	University of Bristol
22	SEeismic BEhavior of Scaled MOdels of groin VAults made by 3D printers (SEBESMOVA3D)	University of Bristol
23	Investigation of Seismic Deformation Demand, Capacity and Control in a Novel Self-Centring Steel Braced Frame (SC-CBF)	IZIIS
24	Seismic Behaviour of Rigid Pile Inclusions	University of Cambridge
25	COSMO:Change Of Seismic MOtion due to pile-soil kinematic interaction	University of Cambridge
26	Dynamic Soil Structure Interaction: Three-dimensional Time-domain Analysis of Field Model Scale Experiments	EUROSEISTEST and EUROPROTEAS
27	"SISIFO"Seismic Impedance for Soil-structure Interaction From On-site tests	EUROSEISTEST and EUROPROTEAS
28	Ambient and forced vibration techniques for improving design and performance assessment of structures with consideration of soil-structure interaction	EUROSEISTEST and EUROPROTEAS
29	Seismic SITE effects in sedimentary basins from 3D physics-based numerical modeling (SITE3D)	EUROSEISTEST and EUROPROTEAS
30	Comparison of rocking on rigid and compliant base using the EUROPROTEAS real-scale facility	EUROSEISTEST and EUROPROTEAS
31	Seismic tremor detection in Greece using small aperture arrays	NORSAR
32	The velocity model up to 300 km deep using NORSAR array data (Baltic Shield) based on P and S receiver functions.	NORSAR
33	Joint processing of seismo-acoustic array data as tool to discriminate between man-made explosions and earthquakes	NORSAR

Distribution of projects per TA facility

Research Infrastructure	Facility	Total TA Projects (estimated)	Projects Assigned in the 1st call	Projects Assigned in the 2nd call	New Projects Availability
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	10	1	5	4
NORSAR	Array seismology	8	1	3	4
TOTAL		**45**	**17**	**16**	**12**

Proposals have been submitted by heterogeneous User Groups, composed either by universities and private companies often in joined applications, coming from 26 different countries. In the following tables, the percentages of the candidate User Groups for the involved countries and the testing technique/specimen considered are shown. Data refer to all received project, i.e. the sum of accepted, reserve and not accepted.



Others (<3%): Germany (2.52%), Bulgaria (2.10%), Netherlands (2.10%), Romania (2.10%), Belgium (1. 68%), France (1.68%), New Zealand (1.26%), Spain (1.26%), Cyprus (0.84%), Denmark (0.84%), Luxembourg (0.84%), Poland (0.84%), Russia (0.84%), Canada (0.42%), China (0.42%), Japan (0.42%), Norway (0.42%).

TESTING TECHNIQUE

Type	1st call	2nd call
Shaking Table	12	10
Reaction Wall	11	0
Numerical Simulation	2	7
Centrifuge	2	2
Hybrid	1	2
Bearing Tester System	1	0

TYPE OF SPECIMEN/ANALYSIS

Type	1st call	2nd call
Mixed	8	0
Reinforced Concrete	7	1
Steel	4	5
Masonry	4	5
Seismic Devices	3	2
Waves Propagation	2	3
Soil-Structure Interaction	1	7

In the following chapters, all Research Infrastructures provided their contribution in the description of each installation, the awarded projects, the ongoing and foreseen activities and the expected impact of the current research to the advances in earthquake engineering and engineering seismology fields. Since the TA-SEP decision on the projects of the 2nd call and the due date of this document are very close, almost any activity related to those projects has been carried out at the moment; therefore, only the projects awarded during the 1st call are considered hereafter.

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 and SLABSTRESS. These projects meet the full availability offered by the JRC ELSA Reaction Wall.

1.1 Multi-hazard performance assessment of structural and non-structural components subjected to seismic and fire following earthquake by means of geographically distributed testing – in progress (EQUFIRE)

1.1.1 Summary of the project

The proposed research aims to investigate the experimental response of structural and non-structural components of a steel building to Fire Following Earthquake (FFE), in view of improving existing design guidelines and future standards. The EQUFIRE proposal foresees an experimental campaign aimed at investigating the multi-hazard performance assessment, by means of geographically distributed testing. In particular, a representative case study of a concentrically reinforced steel frame is envisaged.

A geographically distributed hybrid simulation for seismic and fire tests will be used because there are currently no laboratories where combined seismic and fire tests can be performed at this scale, since full-scale tests require highly-specialised personnel and facilities.

In addition to making possible tests that have not been available up to now, this technique saves considerable resources, compared to equipping a laboratory with the missing facilities and expertise.

Up to now, most of the research regarding the behaviour of structures in fire has been carried out on single components or partial subassemblies subjected to standard heating curves. Although they offer significant information for the understanding of fire performance of specific structural elements, they do not provide insight on the interaction between the fire development and the whole structure. In order to overcome such limitations, Hybrid Simulation (HS), extensively investigated in the seismic domain, represents a tempting approach. The hybrid model of the prototype structural system combines numerical and physical substructures (NSs and PSs). The dynamic response of the hybrid model is predicted using a time-stepping response history analysis with reduced costs and effort.

The model reproduces the lower part of a six-storey steel concentrically braced frame, designed according to Eurocodes that will serve as a case study, as illustrated in Figure 2.

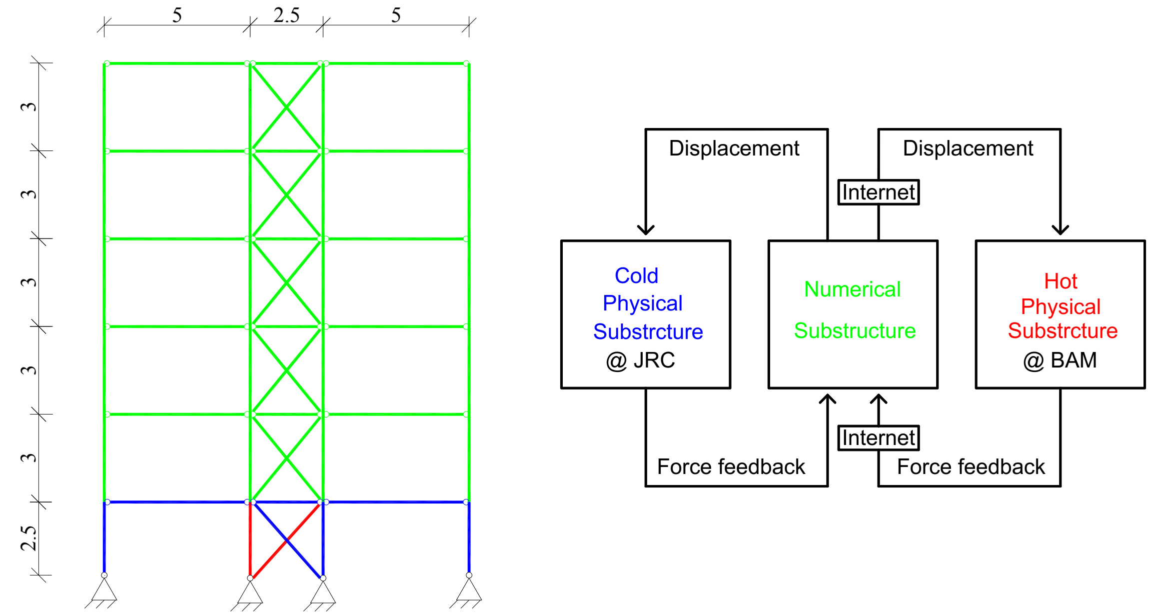


Figure 2: EQUFIRE steel braced frame (left) and framework for geographically-distributed hybrid simulation (right)

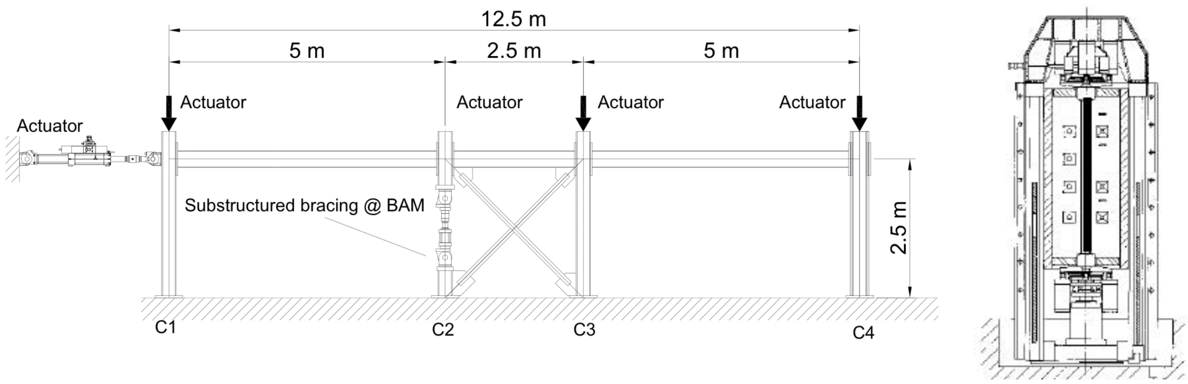


Figure 3: Experimental set-up at JRC Reaction Wall (left) and BAM (right) for test #1 and test #3

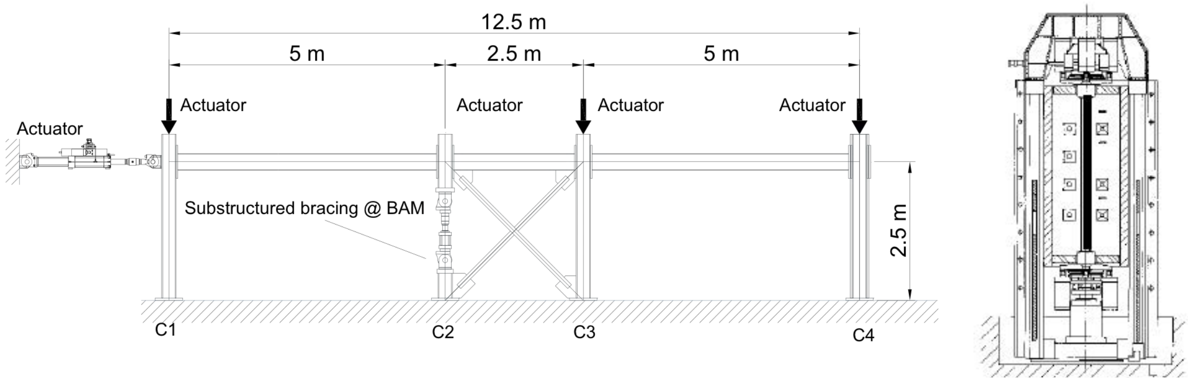


Figure 4: Experimental set-up at JRC Reaction Wall (left) and BAM (right) for test #2 and test #4

The building is an office building with a square plan (12.5 m x 12.5 m), located in Norcia (Central Apennines, Italy) in an area of high seismic activity. The height of the floors is 3 m except for the first floor, which is 3.6 meters high, are compatible to full-scale tests, both in Earthquake and Fire conditions. The lateral force resistance system is positioned on the perimeter of the building and it is assumed that the rest of the frames only support gravitational loads. The steel grade is S355 (EN 10025-2, 2005). The structural members have standard commercial metrics cross-sections.

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

The objectives of the research activity are the following:

1. Increasing the knowledge on the FFE behaviour of *structural* components.
   1.1. Application of the sub-structuring technique to investigate the response of an unprotected-*lowly-damaged column* of a concentrically steel braced frame under FFE (TEST #1).
   1.2. Application of the sub-structuring technique to investigate the response of an unprotected-*highly-damaged bracing component* of a concentrically steel braced frame under FFE (TEST #3).
   1.3. Reliability analysis of existing numerical models to simulate the performance of *structural* elements (i.e. columns and bracing) against fire following a seismic event.
   1.4. Establishing seismic fragility functions between engineering demand parameters (EDP) and damage measures (DM) for *structural* components.
2. Increasing the knowledge on the FFE behaviour of *non-structural* components: fire protection system.
   2.1. Application of the sub-structuring technique to investigate the response of fire protection system applied on a *lowly-damaged column* of a concentrically steel braced frame under FFE (TEST #2).
   2.2. Application of the sub-structuring technique to investigate the response of fire protection system applied on a *highly-damaged bracing component* of a concentrically steel braced frame under FFE (TEST #4).
   2.3. Application of the sub-structuring technique to investigate the response of a fire barrier wall under seismic loading (TEST #4).
   2.4. Reliability analysis of existing numerical models to simulate the performance of *non-structural* elements (i.e., fire walls and fire protection system) against fire following a seismic event.
   2.5. Establishing seismic fragility functions between EDP and DM for *non-structural* components.
3. Providing an effective framework for hybrid fire testing, geographically-distributed over the internet, which enables the interoperation of facilities with different expertise: seismic and fire testing, in this case.

1.1.3 Project status

The project is in progress. Following the selection by the SERA TA SEP, the User Group and the TA facility communicated via e-mail on the details of the project. A meeting took place at the JRC Ispra on the 20th of February 2018, where the following issues were discussed: final design of the specimen, testing sequence, instrumentation and developments on distributed testing. It was agreed to start the EQUFIRE project in January 2019. JRC and users will continue working on the project until then. 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. The Transnational Access User Agreement will be signed soon after.

1.1.4 Foreseen activities and schedule

MONTH 1	MONTH 2	MONTH 3	MONTH 4	MONTH 5	MONTH 6	MONTH 7	MONTH 8	MONTH 9	MONTH 10	MONTH 11	MONTH 12
STEP 1	Step 1	Step 1									
		Step 2	Step 2	Step 2	Step 2						
			Step 3	Step 3	Step 3	Step 3	Step 3				
							Step 4	Step 4	Step 4	Step 4	Step 4

- STEP 1 (3 months): Design of all the components and details of the case study. Design of the specimens and of the experimental setup.
- STEP 2 (4 months): Procurement of materials and devices, and construction of the specimens and for the experimental setup.
- STEP 3 (5 months): Tests of the common communication protocol between BAM and ELSA for the geographically-distributed test. Tests of the numerical method developed for hybrid fire testing.
- STEP 4 (5 months): Preliminary tests and tests of the specimens. Data elaboration.

1.1.5 User Group

	NAME	ORGANIZATION NAME	ORGANIZATION COUNTRY
USER GROUP LEADER	Manfred Korzen	Bundesanstalt für Materialforschung und -prüfung (BAM)	Germany
ADDITIONAL USERS	Elnaz Talebi	BAM	Germany
	Nicola Tondini	University of Trento (UNITN)	Italy
	Oreste S. Bursi	UNITN	Italy
	Luca Possidente	UNITN	Italy
	Giuseppe Abbiati	Eidgenössische Technische Hochschule (ETH) Zürich	Switzerland
	Božidar Stojadinović	ETH	Switzerland
	Laurentiu Danciu	ETH	Switzerland

1.2 SLAB STructural RESponse for Seismic European Design (SLABSTRESS)

1.2.1 Summary of the project

The main aim of this proposal is to study the seismic response of flat slab structures under combined gravity and lateral loads, to develop European Seismic Code regulations for these structures, mainly within the scope of the seismic response of reinforced concrete 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 seismic resistant system and can be designed as secondary systems supporting gravity loads at the design deformations, due to the compatibility with the primary system. In the structural analysis process, this leads 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.

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.

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.

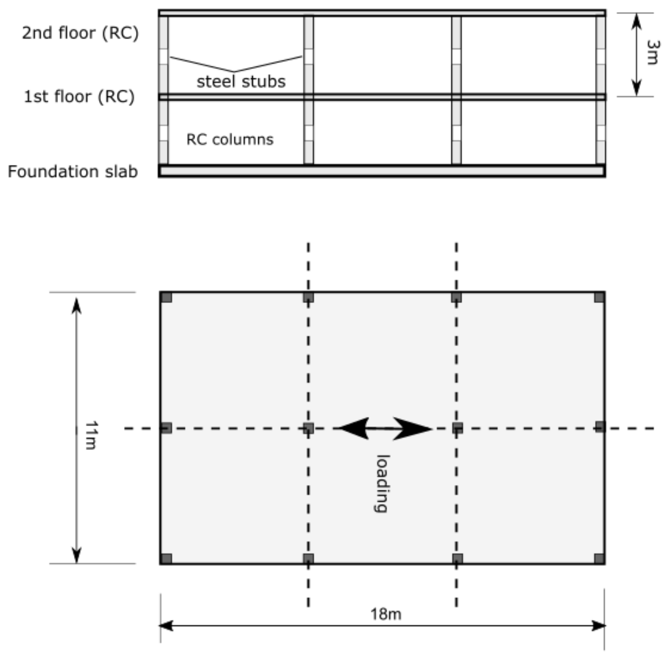


Figure 5: Side view and plan of the SLABSTRESS specimen

1.2.2 Main research objectives and expected contribution to the 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. Thick concrete slabs without voids are chosen for the research, as this is the most common system in the construction industry in Europe.

Technically, the definition of the ultimate deformation capacity of flat slab connections for given gravity shear ratios would simplify greatly the design process, avoiding in some cases structural analysis and strength verifications in correspondence to a limited design deformation demand imposed by the primary seismic resistant system.

1.2.3 Project status

The project is in progress. Following the selection by the SERA TA SEP, the User Group and the TA facility communicated via e-mail on the details of the project. A meeting took place at the JRC Ispra on the 23rd of February 2018, where the following issues were discussed: final design of the specimen, testing sequence, instrumentation and dissemination activities (the User Group proposed to invite students to attend the experiments and to organise a blind benchmark prediction competition among interested researchers). 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. The Transnational Access User Agreement will be signed soon after.

1.2.4 Foreseen activities and schedule

MONTH 1	MONTH 2	MONTH 3	MONTH 4	MONTH 5	MONTH 6	MONTH 7	MONTH 8	MONTH 9	MONTH 10	MONTH 11	MONTH 12
STEP 1	Step 1										
		Step 2	Step 2	Step 2							
					Step 3						
						Step 4					
							Break	Step 5			
									Step 6		
										Step 7	Step 7

Brief description of each step:

- STEP 1 (2 months): Design of the test specimen and experimental setup.
- STEP 2 (3 months): Construction of the models, material testing, and transportation of the specimen inside the lab. Numerical modelling in preparation for the hybrid tests.

- STEP 3 (1 month): Preparation of experimental setup.
- STEP 4 (1 month): Hybrid Testing (Test 1.1 and 1.2, Serviceability Limit State and Ultimate Limit State).
- STEP 5 (1 month): Observation of damage, processing of test results, repair of the first floor slab.
- STEP 6 (1 month): Cyclic tests to failure (Test 2.1 and 2.2) – final 'funeral' test.
- STEP 7 (2 months): Transportation outside the lab, final observations, dismantling.

1.2.5 User Group

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

2 EUCENTRE – Shaking Table and Bearing Tester System

The EUCENTRE Foundation, European Centre for Training and Research in Earthquake Engineering, based in Pavia (Italy), is a non-profit organisation that promotes, supports and sustains training and research in the field of seismic risk mitigation.

Part of EUCENTRE since 2005 is its experimental laboratory SHAKE Lab, since 2017 the new experimental installation 6D Lab and since 2018 the brand new MOBILE Lab. The experimental facilities have been specifically designed according to the most innovative technologies and thanks to their high performance equipment allow conducting both dynamic and static experimental research on full-scale prototypes. Four independent hydraulic systems provide oil flow to a uniaxial high-performance Shake Table 5.6 by 7 m, a multi-axial Shake Table 4.8 by 4.8 m, a Strong floor-reaction wall system, a Dynamic testing system for bearings and isolators, a Damper testing system, a Mobile laboratory and a Mobile unit for structural assessment.

Within SERA project, transnational access is provided to the uniaxial high-performance shake table and to the Bearing Testing System. 75 access days are foreseen, which will allow for the implementation of 3 complete experimental campaigns. In the first of the 3 calls for proposals foreseen, 1 project titled "Dynamic testing of variable friction seismic isolation devices and isolated systems" has been assigned to EUCENTRE. Such project effectively take advantage of the synergy between characterization tests of full-scale isolators on the Bearing Testing System and Shake Table tests on a real isolated structure.

2.1 Dynamic testing of variable friction seismic isolation devices and isolated systems

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. Within the scope of the SERA project, both component testing of the developed variable friction devices in the dynamic test press and shake table tests on a single story structural frame system with variable friction devices at the base will be conducted. The dynamic response of the isolated system under uniaxial seismic excitation as well as inherently varying axial loads on the variable friction devices 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

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, is currently working on developing variable friction devices in its R&D department by applying several treatment techniques on the stainless steel friction surfaces of friction pendulum isolators through a grant from the Turkish Research Council (TUBITAK). This project was completed in 2017, where sufficient progress has already been achieved. 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. The third and the lowest friction will be obtained by applying circular perforations to the advanced polished steel surface for increasing pressure underneath the slider pad, further reducing the friction. There is an inverse relation between interface pressure and the coefficient of friction.

Milano Polytechnic and TIS are currently working on the development of a new material with lower friction properties. Possible application of this material to the variable friction device will be investigated in the project for obtaining 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 center to the highest at the periphery. The lowest friction region at the centre is merely a circular hole with a calculated radius and the edges trimmed smoothly in order to prevent consumption of the friction material. Different friction materials for obtaining different sets of variable friction coefficients will be also developed. Such materials will be assessed by Milano Polytechnic University and material wear tests in combination with different steel surfaces will be conducted at their laboratories within the scope of the project. Pressure and velocity dependence relations for different friction materials and mating surfaces will be established at these tests and used for preliminary evaluation of the material combinations.

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 a simple single story steel frame with four columns will be constructed at the Eucentre Lab for the next testing phase. This frame will be isolated with the four variable friction pendulum devices. The isolated frame will be tested on the shake table under selected ground motions which represent return periods of 72, 475 and 2475 years at a high seismicity site in Turkey.

A typical prototype device that will be tested at the Eucentre Lab Bearing Tester is shown in Figure 6 . The preliminary design of the single story steel frame with four columns, isolated with variable friction devices is also shown in Figure 7. The dimensions of the devices and the frame fits to the dimension requirements of the Lab.

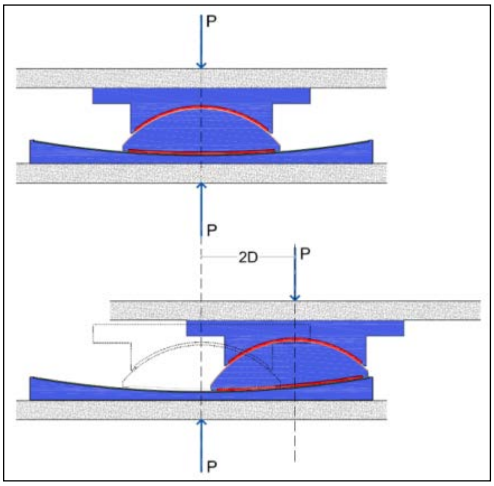


Figure 6 Prototype isolators

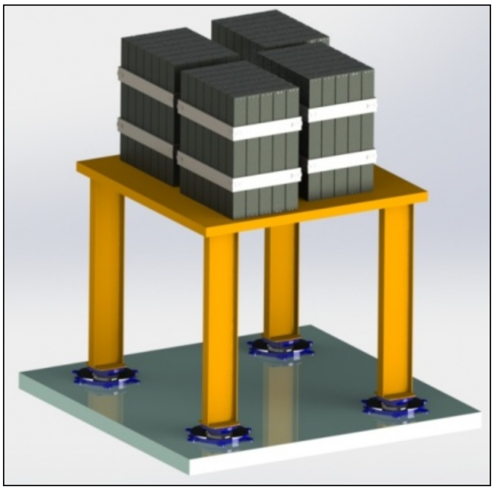


Figure 7: Single storey isolated frame

Upon completion of the experimental testing program, analytical models for the force-displacement behavior of variable friction devices under imposed displacement reversals that mimic seismic excitation will be refined. Analytical studies will be conducted at the University of Washington, the Middle East Technical University, and, partly at UCL (for uncertainty characterization of the developed analytical models). These models will then be calibrated with the test results for improving their prediction capability. Major response parameters for analytical prediction are the maximum displacement demand, residual displacement of the isolators and maximum base shear transmitted to the superstructure.

Due to the strongly non-linear constitutive behaviour typical of many isolation devices (as those developed here), the seismic response of base-isolated buildings is usually evaluated through non-linear dynamic analysis. In this type of analysis a suitable set of ground motions is needed for representing the earthquake loads and for exciting the structural model. Many methods can be found in the literature for defining the ground motions. When natural accelerograms are used, the methods mainly differ from each other based on the IMs used for scaling the records to the defined earthquake intensity level. Investigations have been carried out for evaluating the predictive capability of the intensity measures used in these methods. While many studies focused on ordinary buildings, only a very few are focused on base-isolated ones. Hence, a further objective of the proposed research is to evaluate the most commonly used IM, which are currently available in the literature, with respect to their capability to predict the seismic response of base-isolated buildings implementing the newly developed variable friction seismic isolation devices. Selected for the investigation will be a set of frame structures characterized by a different number of storeys and base-isolated with systems having different properties (e.g. uniform and variable friction). Different sets of accelerograms, consisting of ordinary and pulse-like near-fault records, will be used in the analyses and in the evaluation of the IMs. Modified versions of existing IMs will be proposed, with the intent of improving the correlations between the considered IMs and response quantities of interest, in a performance-based earthquake engineering (PBEE) framework.

The final phase of analytical studies is concerned with developing a design procedure under design earthquake excitation. An equivalent linear analysis procedure which conforms to the existing code procedures for isolator design will be established where the basic design parameters are equivalent stiffness and damping at the design displacement and the base shear force transmitted to the superstructure.

In summary, the expected outcome of the proposed project is a new seismic isolation device with more favorable 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 center 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 reduced recentring capacity 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 termination of ground excitation.

2.1.3 Research expected contribution to the 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. We will investigate how variable friction with circular bands can be formulated in a double pendulum device. If we can show that a stable, symmetrical response can be obtained, then we will extend the concept 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. We 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 waste steel 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.

In summary, the project can offer tremendous opportunities for broader impact on Society, Economy, Knowledge and People.

- Society: Findings from the project can contribute to increase society's seismic safety and resilience by
    - protecting critical structures/infrastructure, and allowing them to remain operational (e.g. hospitals, schools, etc.) or to “return to normal” as soon as possible;
    - increasing the safety of the population, particularly in the case of critical structures/infrastructure.
- Economy: Apart from the social risks, extreme loads result in enormous economic losses related to repair costs, loss of building occupation, business interruption, or building demolition due to irreparable damage. The project can eliminate these economic losses by avoiding (or significantly reducing) damage. More in general, the proposed research on variable friction seismic isolation devices and isolated systems will significantly contribute to the competitiveness of several European industries (e.g., engineering consultants, construction companies, etc.) and stakeholders with a characterized technology to increase their markets worldwide through new technologies offering higher performance and lower prices. The ultimate goal is to create a vibrant core of activities in which research is driven by genuine user priorities, and industry in turn benefits from access to state-of-the-art techniques and innovation assembled by world-leading experts.

- Knowledge & People: The project addresses major intellectual challenges by going beyond the state-of-the-art in the field of seismic isolation, seismic design, earthquake response assessment, and design of resilient and sustainable structural systems. Therefore, the project will raise major international interest, providing several stakeholders with an innovative, advanced, performance-based framework (and related computational tools) for designing isolated structures and infrastructure. The project will also provide training to postgraduate students (at MSc and PhD level) collaborating with the investigators involved in the different tasks at the different institutions and contribute to the Continued Professional Development of industrial partners.

2.1.4 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

2.1.5 Project status

The research group at UW has been investigating two types of Variable Friction Systems (VFSs). The first type is characterized by a sliding surface with coefficients of friction that have relatively smooth transitions between adjacent "rings". This bearing type will be addressed as VFS type A in this report. The force displacement curve of a type A VFS can be represented by a simplified bi-linear curve if appropriate radii and coefficients of friction are chosen. The side view of a type A VFS and some examples of the simplified bi-linear hysteresis of such systems are shown in Figure 8.

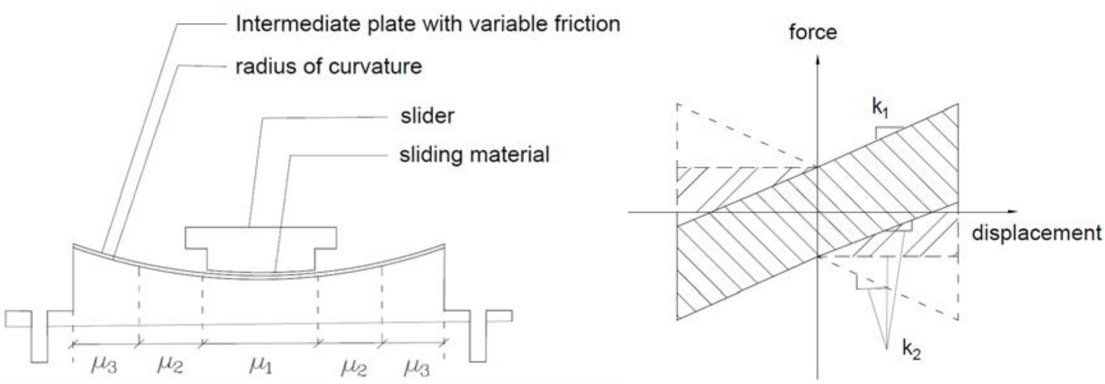


Figure 8: Side view and hysteretic behaviour of type A VFSs.

The other type of VFSs (type B) under investigation is characterized by a sliding surface with coefficients of friction that change somewhat abruptly between adjacent "rings". Instead of having a sliding surface arranged in three to four concentric rings with "smoothly" varying frictional properties, type B VFSs have only two rings. As shown in Figure 9, type B VFSs are essentially Friction Pendulum System (FPS) with an outer ring characterized by significantly higher friction coefficient (with respect to that of the inner ring). It is believed that such systems can be used as passive adaptive devices that are capable of achieving high performances for multiple earthquake intensities.

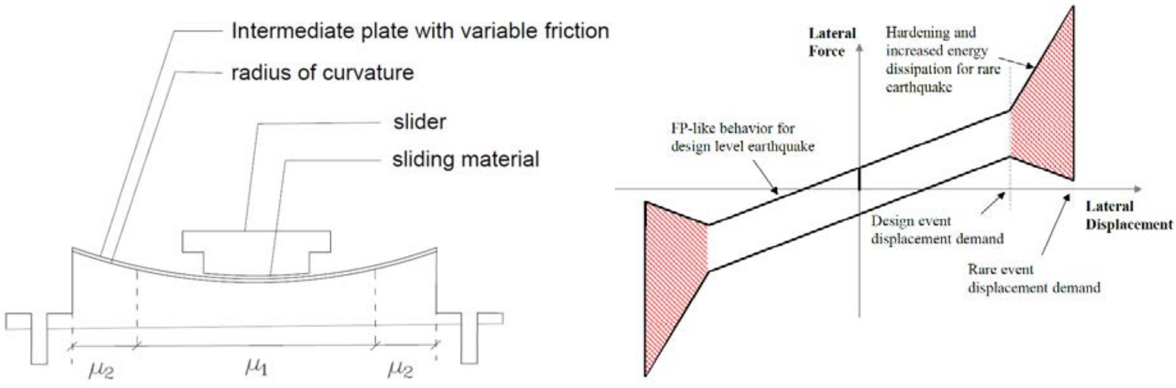


Figure 9: Side view and hysteretic behaviour of type B VFSs.

Most of the work conducted thus far is related to type A VFSs. Compared to a traditional FPS companion, type A VFSs exhibit higher energy dissipation capacity when reaching the same maximum displacement. A preliminary design process for type A VFSs has been developed and preliminarily validated. To this end, once the designer has selected the design parameters α and β (the design shear to activation shear ratio and the re-centering to post-activation stiffness ratio, respectively), the design of the optimal VFS can be completed following a Direct Displacement Based Design (DBDD) procedure. It should be noted that, within the design procedure, several relatively empirical parameters are employed. These parameters are the “Equivalent Viscous Damping” (EVD) of the base isolator and the associated displacement reduction factor, η, which are the keys in determining the displacement demand on the system. To this end, first principles, in combination with a large number of non-linear time history analyses (conducted in Matlab using a customized program developed by the research group), were used to calibrate suitable design equations. Close-form design equations that relate the EVD of a VFS to the design parameters α and β, capable of accounting for the asymmetry in the response of a VFS, were derived.

In order to further investigate the performance of VFSs and simulate the non-linear response of these bearings in the context of non-linear time history analyses of realistic case study structures, a 2-dimensional (horizontal-vertical coupling) non-linear spring element, which is capable to capture the true (expected) hysteretic behaviour of VFSs, was implemented in OpenSees software. The implementation allows researchers to include in the dynamic analysis the effects of multidirectional (horizontal-vertical) excitations, overturning, different friction models, and bearing uplift.

The simplified bi-linear model representing the approximate behaviour of type A VFSs was also implemented into OpenSees. The accuracy of using the simplified bi-linear model was evaluated by running NLTHA on a one-story-one-bay test structure with 30 pairs of spectrum compatible ground motions. The results show that the differences in maximum displacement and maximum base shear between using the two hysteretic models are all within 1.5% and have an average difference of 1%. Thus the simplified bi-linear model is (in most instances) considered sufficiently accurate to represent the true behaviour of VFSs when appropriate radii and friction values are chosen, especially preliminary design/analysis stages. Figure 10 shows the comparison between the two models of the theoretical hysteretic behaviour and the resulted hysteresis from one of the NLTHA conducted.

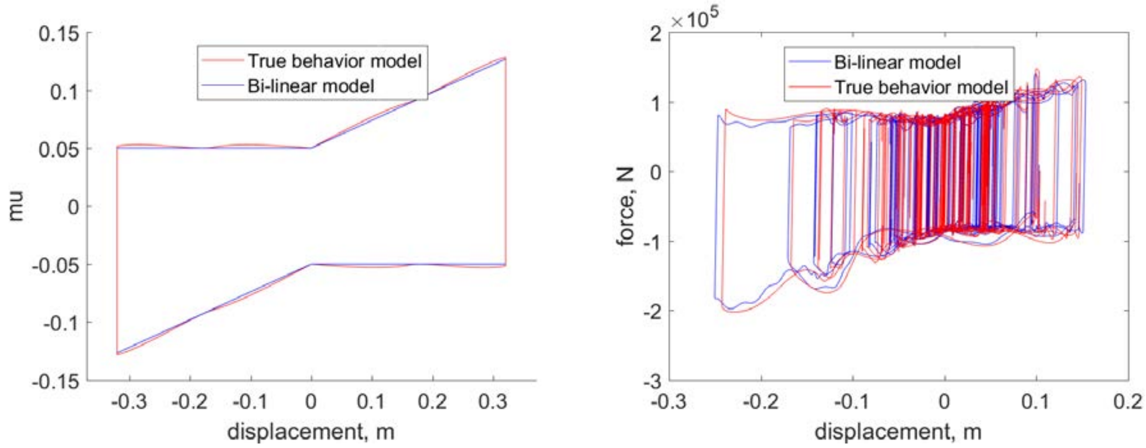


Figure 10: Comparison of the theoretical hysteresis and an example hysteresis from NHTLA between the true behaviour model and the simplified bi-linear model.

Preliminary parametric studies were performed on a one-story-one-bay steel structure and a three-story steel moment frame building. Both case study structures were designed using DDBD procedure and have realistic superstructure and bearing properties. More than 10 pairs of spectrum compatible ground motions were selected. For the sake of brevity, only the results of the one-story building are reported herein. However, both studies indicate that type A VFSs can reduce the maximum displacement and maximum base shear, with the potential (expected) drawback of increasing the residual displacement of the superstructure at the end of the ground motions. The preliminary study shows that VFSs with β equal to zero tend to achieve high overall performance. Thus, β equal to zero may possibly represent the optimal design value. To this end, further studies are obviously needed. As shown in Figure 11, for the four intensity levels considered, compared to the VFS with β = 1.0 (which represents an FPS), the mean maximum base shear value using a VFS with β = 0.0 decreased by 0.35%, 3.45%, 6.10%, and 7.55%. Concurrently, the mean maximum displacement value decreased by 1.85%, 5.98%, 7.18%, and 7.42%. These results show that the larger the intensity of the input ground motion, the more effective the VFSs appears at reducing the maximum displacement and base shear demand. It can also be observed that, with increasing intensity of the input ground motion, the displacement and base shear demands increase nonlinearly (i.e. more rapidly) for a traditional friction pendulum, while they have seemingly slower growth rate for a VFS with β = 0.0, which makes VFSs more attractive when dealing with large intensity earthquakes.

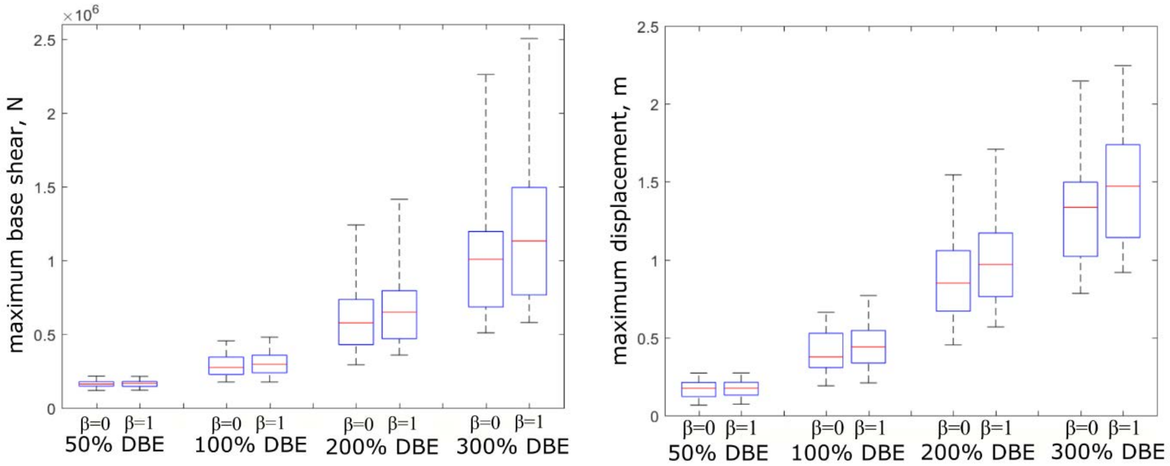


Figure 11: Comparison of the maximum base shear and maximum displacement between VFSs with β equals to 0 and β equals to 1 (i.e. FPS).

As for type B VFSs, the damping properties and the design procedure for utilizing VFSs as a passive adaptive device to meet several performance goals are currently being investigated.

Besides the numerical evaluations mentioned above, the research group also designed a series of small-scale bearing tests which are currently being conducted. These tests have three primary goals:

- Provide evidence of the feasibility of type A and type B VFSs.
- Provide realistic values of the friction coefficients that can be used in type A and type B VFSs.
- Calibrate the existing friction models for further analyses.

2.1.6 Foreseen activities

In parallel with the development of the variable-friction surfaces of the isolation devices and with the implementation of the non-linear numerical simulations, the experimental activities are being organized. The test setup of the Bearing Tester System characterization tests has been already designed; a modification of existing steel plates to connect the devices to the testing machine is in progress. Characterization tests following a EN15129 testing protocol will be performed on 4 specimens with different sliding surfaces, having the following main characteristics (while they differ from the friction transition within the sliding surface).

	SINGLE PENDULUM
EQUIVALENT RADIUS OF CURVATURE (MM)	4520
DISPLACEMENT CAPACITY (MM)	±300
MAXIMUM EXPECTED FRICTION COEFFICIENT AT 70T AXIAL LOAD	10%
HEIGHT OF DEVICE (MM)	137
DIAMETER OF THE BACKING PLATE (MM)	900

In addition, an advanced preliminary study of the shake table test structure layout has been carried out. A RC slab will serve as foundation of the 1-storey steel structure, which will be settled on 4 variable-friction isolation devices. 4 pairs of steel plates will be manufactured to realize the connection between the seismic devices, the RC slab and the EUCENTRE shake table. The steel structure features 4 HE 200B profiles with diagonal braces in the direction of motion. The total mass of the structure plus the live load will be about 70 tons, which is compliant with the shake table capacity. Since usual vertical loads on typical isolation devices are much higher, and generally not compatible with shake table systems, a scaled version of the isolators will be considered here, while BTS dynamic characterization tests will be performed on realistic full-scale devices.

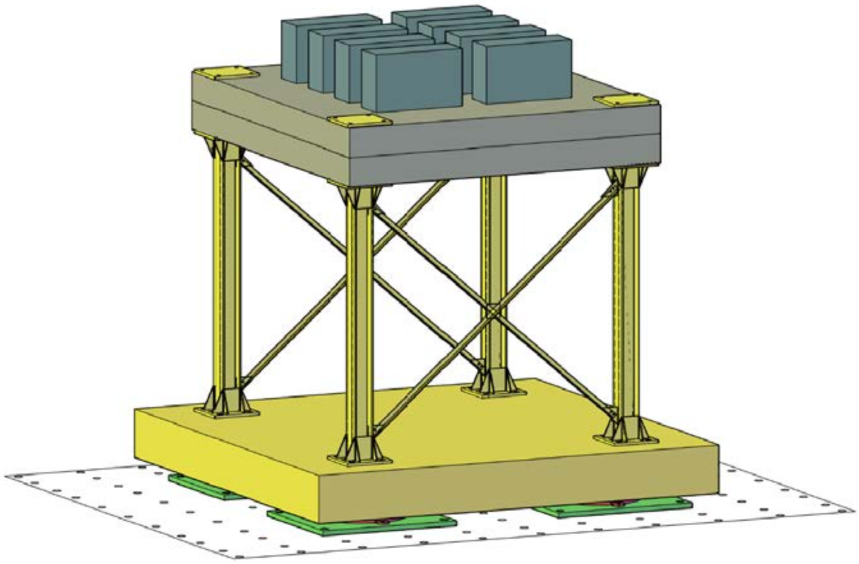


Figure 12: 1-storey isolated frame

The planned activities are shown in the following Gantt chart.

ACTIVITIES	SPR 2018	SUM 2018	FALL 2018	WIN 2019	SPR 2019	SUM 2019
Bearing tests and results analysis	-	-				
Type b vfss parametric study	-	-				
Shake table test and results analysis		-	-	-		
3d implementation of vfs into opensees		-	-	-	-	
Intensive parametric study on vfss using calibrated numerical model from shake table test				-	-	-
develop a design/modelling/analysis guidelines for vfss				-	-	-

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.

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

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 in its design phase. The University of Napoli Federico II is finalizing the dimensioning calculations and the plans of the model (Figure 13). All the plans will be provided to the CEA before the end of April 2018. The commercial consultation phase for the model and connectors manufacturing can then begin, in parallel with the selection of the seismic excitations.

An interlocking telephone meeting was held on October 25, 2017. Regarding the configurations to be tested, an approximate duration of 4 months for the tests was determined during these meetings. The tested configurations nevertheless remain to be confirmed according to the manufacturing costs of the model.

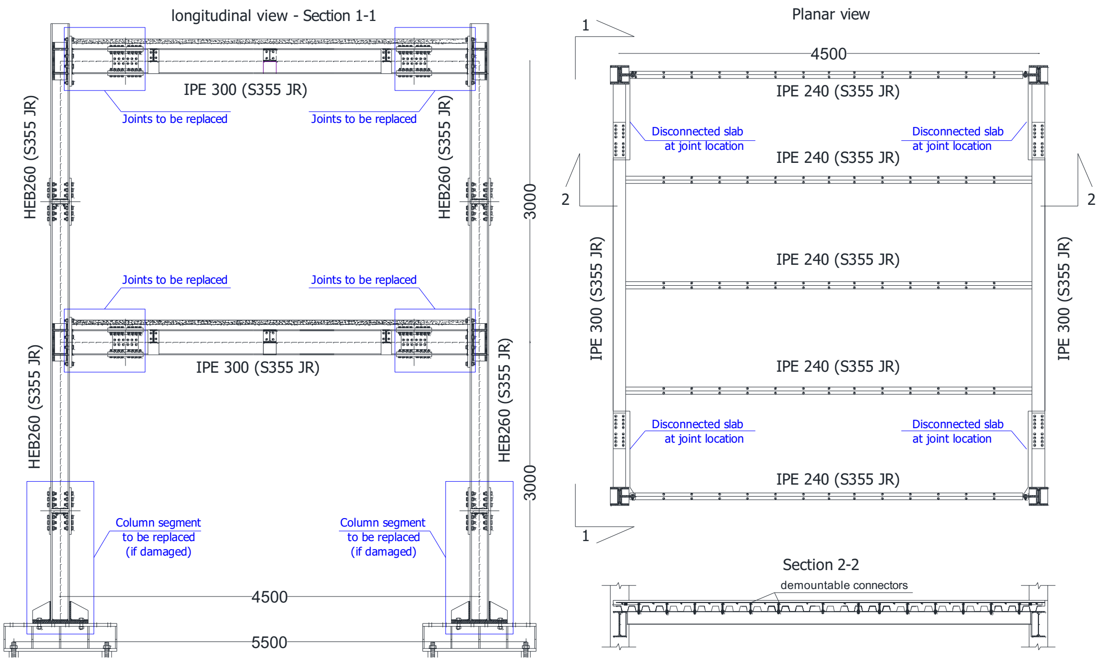


Figure 13: Structural layout of the mockup with detachable dissipative zones and detachable slab.

3.1.4 Foreseen activities and schedule

END OF APRIL 2018	Reception by the CEA of the manufacturing plans for the model and connectors.
MAY AND JUNE 2018	Verification and validation of the manufacturing plans, drafting of the manufacturing specifications for the call for tenders.
JULY - OCTOBER 2018	Call for tenders.
NOVEMBER 2018	Selection of the manufacturing company, order.
DECEMBER - JUNE 2019	Manufacturing of the model and connectors. Selection of excitations.
JULY 2019	Reception of the assembly elements.
AUG-NOVEMBER 2019	Assembly, instrumentation, tests.
DECEMBER - MAY 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 SEismic REsilience of Museum contEnts (SEREME)

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 14). 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 14: 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 15), 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.

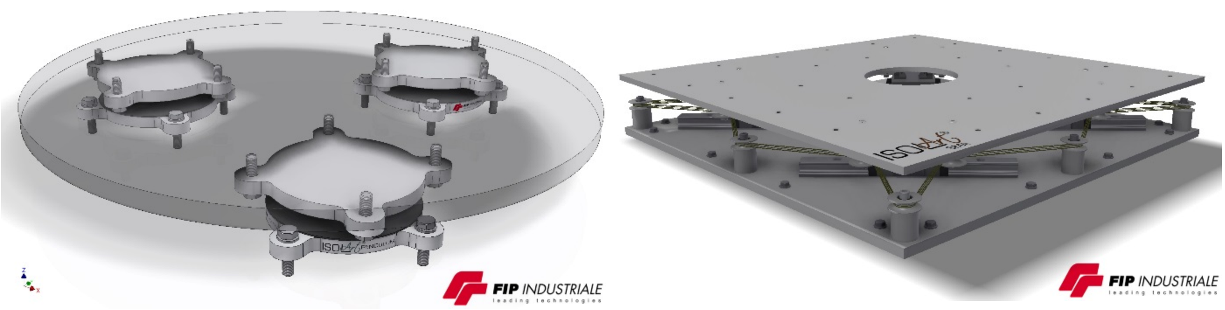


Figure 15: ISOLART® PENDULUM (left) and ISOLART® SMA (right)

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 invetigation 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 omited due to its high frequency content. Especially for designing suitable risk mitigation systems, the effect of the vertical component has to be studied experimentaly.

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.

Tests to verify the behaviour of the seismic isolators will first be carried out in early 2019 on the Vésuve single axial shaking table. For these tests, statues will be replaced by equivalent masses. The Azalée shaking table testing campaign will then be conducted over a period of approximately 4 weeks, starting in July 2019.

Two types of statues have already been selected and will be supplied to the CEA through a company specializing in this type of manufacture. Financial figures are in progress.

3.2.4 Foreseen activities and schedule

END OF MAY 2018	Choice of statues manufacturer, order.
FROM JUNE TO OCTOBER 2018	Manufacture of statues and shipment to the CEA.
FEBRUARY MARCH 2019	Testing of isolators on Vésuve.
JULY 2019	Tests on Azalée shaking table
AUGUST 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	Università del Sannio	Italy
	Anna Saetta	University of Venezia	Italy
	Ihsan Engin Bal	Hanze University of Applied Sciences Groningen	The Netherlands
	Maria Gabriella Castellano	FIP Industriale S.p.A.	Italy
	Tara C. Hutchinson	University of California, San Diego	USA
	Ugo Brancaccio	B5 engineering	Italy

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.

The LNEC-3D shake table (ST) has three independent translational degrees of freedom, with the rotational ones being passively restrained via a stiff torque tube system. The actuators allow for dynamic forces of 1000 kN in the vertical and 700 kN in the horizontal directions to be applied to the system, with peak velocities up to 0.7 m/s and peak displacements of ±0.2 m in all directions. At this moment, and as previously discussed with the User Groups (UGs) during the preparation of their applications, LNEC is upgrading the actuator system in one of the horizontal directions due to a reformulation of the shake table facility.

The control of the ST is fully digital, allowing input displacements of any form in a frequency range of 0-40 Hz. The digital control hardware and software was upgraded in 2011 into a more advanced and open platform, whereby the introduction of new control strategies or the implementation of new test strategies (e.g., hybrid simulations) is facilitated. The acquisition system allows a large number of physical variables (such as pressures, forces, accelerations, displacements, strains, etc.) to be monitored, using the extensive instrumentation available or specially developed instrumentation. The possibility of performing digital image processing for motion tracking using a set of synchronised fast megapixel cameras is under development.

The LNEC-3D ST was designed specifically for testing structures and components up to collapse or near-collapse conditions. It has a large capacity in terms of payload (max. weight of 40 tonnes), allowing tests on medium-sized structures or larger structures at reduced scale. A special feature of this installation is that the ST is surrounded by three stiff reaction walls, which can be used for different test setups.

During SERA, LNEC will host 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.

4.1 Seismic Response of Masonry Cross Vaults: shake table tests and numerical validations

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 will be 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 contents and displacement demands, 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.

In order to achieve these 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, will be considered (Figure 16). The height will be 1.12 m, with a total mass of the model of approximately 4.4 ton. The masonry pattern of a typical cross vault will be reproduced, while the overall geometry of the vault will be the same considered in the static tests performed on a scaled model at the Univ. of Genova in 2015.

Figure 16: Geometry of the vault model and masonry pattern.

Boundary conditions: The boundary conditions that represent standard configurations of vaults in historic churches, depicted in Figure 17, will be 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.

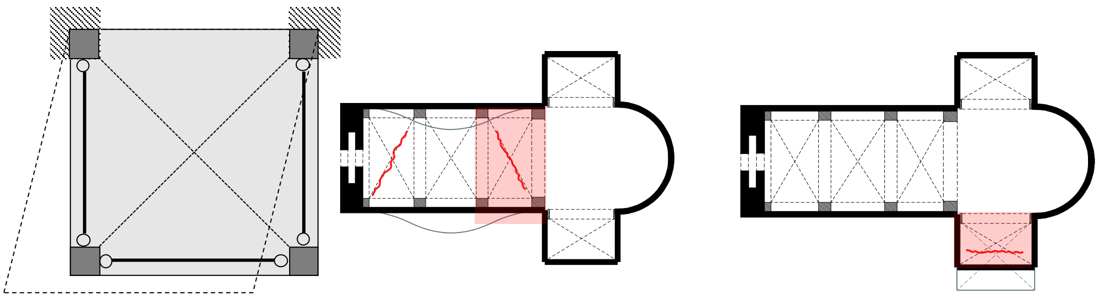


Figure 17: Boundary conditions considered in the tests.

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.

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).

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.

4.1.3 Project status

The project is currently ongoing. LNEC and the UG have been exchanging information and performing 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 possible contractors to build the real-scale model of a brick unreinforced masonry cross vault are underway.

4.1.4 Foreseen activities and schedule

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

MONTH 3	MONTH 6	MONTH 9	MONTH 12	MONTH 15	MONTH 18	MONTH 21	MONTH 24	MONTH 27
S1-T1	S1-T1							
S1-T2	S1-T2							
		S2-T1						
		S2-T2	S2-T2					
			S2-T3					
S3-T1	S3-T1	S3-T1						
	S3-T2	S3-T2						
					S3-T3	S3-T3	S3-T3	S3-T3
			S4-T1					
				S4-T2	S4-T2			
					S4-T3			
					S4-T4	S4-T4		
	S5-T1	S5-T1	S5-T1	S5-T1	S5-T1	S5-T1	S5-T1	S5-T1
						S5-T2	S5-T2	S5-T2
								S5-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

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 late 2018 and continue through the 1st semester of 2019.

4.1.5 User Group

	NAME	ORGANIZATION NAME	ORGANIZATION COUNTRY
USER GROUP LEADER	Chiara Calderini	University of Genova	Italy
ADDITIONAL USERS	Sergio Lagomarsino	University of Genova	Italy
	Michela Rossi	University of Genova	Italy
	Chiara Ferrero	University of Genova	Italy
	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 (Towards the) Ultimate Earthquake proof Building System: development and testing of integrated low-damage technologies for structural and non-structural elements

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 will be 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 will be 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 will be 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 will focus 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 expectation.

The overall research project will comprise analytical/numerical and experimental investigations focusing around the shake table tests of a 1:2 scale, or larger, 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 will give 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 aims to bring 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 will consist 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 will include 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).

Geometry and mass: The test specimen will consist on 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 current specimen 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 18.

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

Diaphragms: Concrete-timber floor system will be adopted as diaphragm, with mechanical (and possibly) dissipative 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.

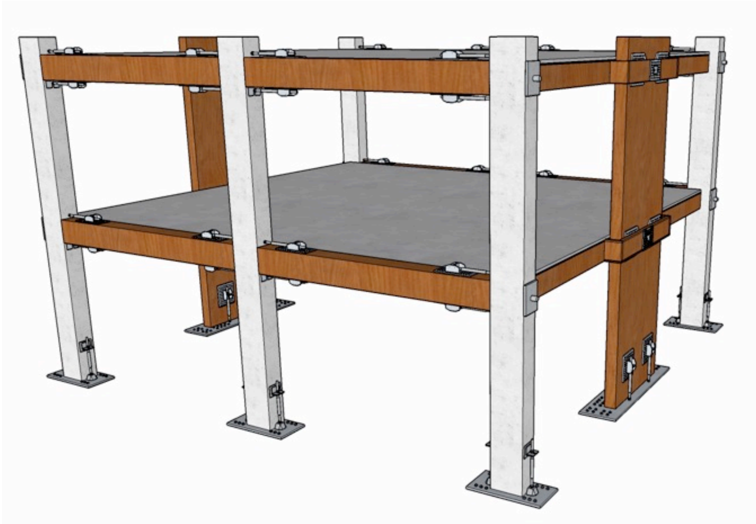


Figure 18: Full view of the test specimen.

Instrumentation and structural monitoring: An array of displacement transducers (wire/string or laser-type, LVDTs), load cells, strain gauges, optical cameras and accelerometers will be required to fully monitor the building dynamic performance. The key parameters to be measured will include, but not be 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' will be comprised of:

- - Facades – heavy concrete facades in the longitudinal directions and lighter curtain walls/glazing systems in the orthogonal ones (see Figure 19);
- - 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 will be adopted using either traditional or innovative dissipative/protecting systems;
- - Fastened NSE elements to concrete floors or walls using traditional or innovative anchors.

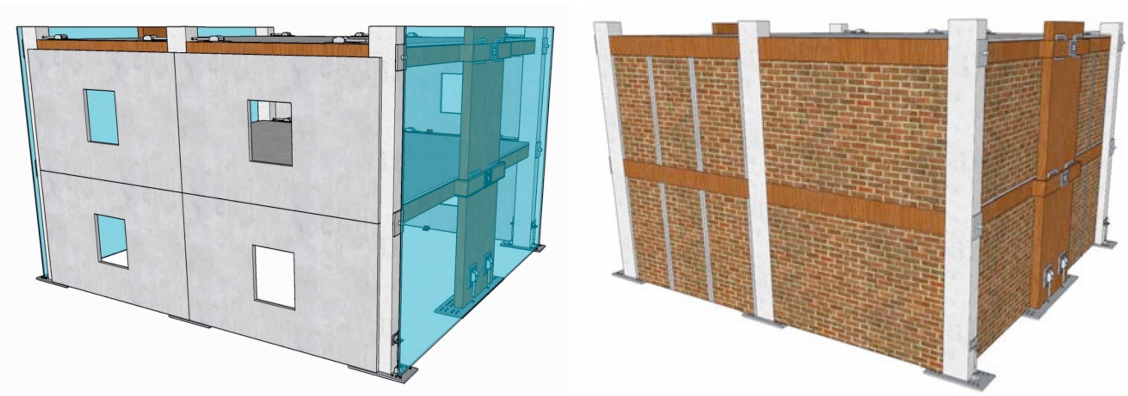


Figure 19: Proposed facades for test specimen: precast cladding panels and spider glazing system (left) and unreinforced clay brick infill walls (right).

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 up-take of low-damage building systems.

4.2.3 Project status

The project is currently ongoing. LNEC and the UG 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 production of the entire system in Italy, with posterior shipping and testing 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.

4.2.4 Foreseen activities and schedule

Two configurations are anticipated to be adopted for the non-structural elements, as shown in Figure 19. The bare skeleton will be tested initially, followed by the tests with the two non-structural envelopes.

The testing protocol will consist on the use of a suite 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. It is envisaged that the full sequence of tests can be completed within 2 days.

For the bare skeleton configuration, two levels of post-tensioning and contribution ratios between post-tensioning and dissipation (i.e. 100-0, post-tensioned only; 50-50 or ideal flag-shape) will be considered.

A one day allowance will be given to change/replace the dissipaters from hysteretic to viscous. Not all tests will need to be carried out, but in the upper limit 2days will be additionally needed.

Allowance for mounting of the non-structural components will be considered, 2-4 days. The same suite of records at the same number of intensities as previously done for the structural system will be tested, with only one (50-50) post-tensioned vs. dissipation configuration. Considering the need for a more regular checking to non-structural components, a much larger allowance will be given here.

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

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR
STEP 1	Step 1	Step 1												
		Step 2	Step 2	Step 2										
				Step 3	Step 3	Step 3	Step 3							
							Step 4	Step 4	Step 4					
									Step 5	Step 5				
										Step 6	Step 6			
												Step 7	Step 7	
													Step 8	Step 8
														Step 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
- STEP 5 – Lifting of specimen on the shaking table and experimental tests [Total step 5: 13-15 days]:
- 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 [11-12 days]
- STEP 9 – Removal of specimen off table. Disposals/relocation of material/specimen

The foreseen experimental tests are thus planned for October/November 2018 and February/March 2019.

4.2.5 User Group

	NAME	ORGANIZATION NAME	ORGANIZATION COUNTRY
USER GROUP LEADER	Stefano Pampanin	Sapienza University of Rome	Italy
ADDITIONAL USERS	André Filiatrault	IUSS Pavia	Italy
	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

5 STRULAB_Univeristy of Patras

The STRULAB facility of the Department of Civil Engineering of the University of Patras is a structural laboratory for the static and pseudodynamic testing of civil engineering structures. It employs two reaction walls and a reaction floor system, accompanied by a relocatable auxiliary wall.

A total of 3 projects can be accommodated through the TA component of the SERA project. The Lab attracted the interest of 5 research groups in the first call – two of the proposals were assigned to the Lab (ARISTA and ARCO).

5.1 Seismic Assessment of ReInforced Concrete frames with SmooTh bArs - Proposals for EC8-Part 3 (ARISTA)

5.1.1 Summary of the project

The Use Agreement between the lab providing access (STRULAB) and the 4-strong user group (represented by the Cyprus University of Technology) was signed on November 21st, 2017. The project, with a total duration of 8 months and estimated number of twenty-six (26) access days, is currently under execution and is on-schedule.

The proposed research focuses on the response of existing reinforced concrete (RC) structures designed with smooth bar reinforcement and without or limited seismic design provisions. It involves near-full-scale (1;1.5) 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. The 2D frames are involved in one-way frame action, due to in-plane seismic loading and response. They provide the opportunity to test columns with vertical smooth bars either lap-spliced at all three floor levels - as commonly done in practice -- or continuous from the foundation to the roof, in order to study the effects on the response. Moreover, the effect of FRP wrapping of the column end regions will be studied, by wrapping in FRP only the ends of one of the two outer columns in all three stories and subjecting the test structure to a loading history fully symmetric in the two directions of loading (positive and negative); a final test at significantly higher level of deformation will follow, to bring some of the columns to ultimate conditions and beyond.

The proposed test specimen involves two, three-story two-bay (i.e., three-column) 2D frames (Figure 20), 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.

The 2D frames will represent 1:1.5-scaled version of actual RC frames in existing structures (i.e. non-seismically designed) and will be involved in one-way frame action, due to in-plane cyclic loading and response. Thus, the two frames will be tested in unison: they will be connected at all floor levels through transverse beams and slabs into a stable 3D test structure, to be loaded in its long direction. The center-to-center distance between the 2m-high columns will be 3.30m (tentative dimension).

Each of the two parallel frames employes columns with lap-spliced or continuous column bars – the smooth, 12mm-diameter vertical bars, are:

- hook lap-spliced at all three floor levels (as commonly done in practice), for two of the diagonally opposite columns at the extremities of the pair frames and for the two intermediate columns of the frames,
- continuous from the foundation to the roof, for the other diagonally opposite pair of columns.

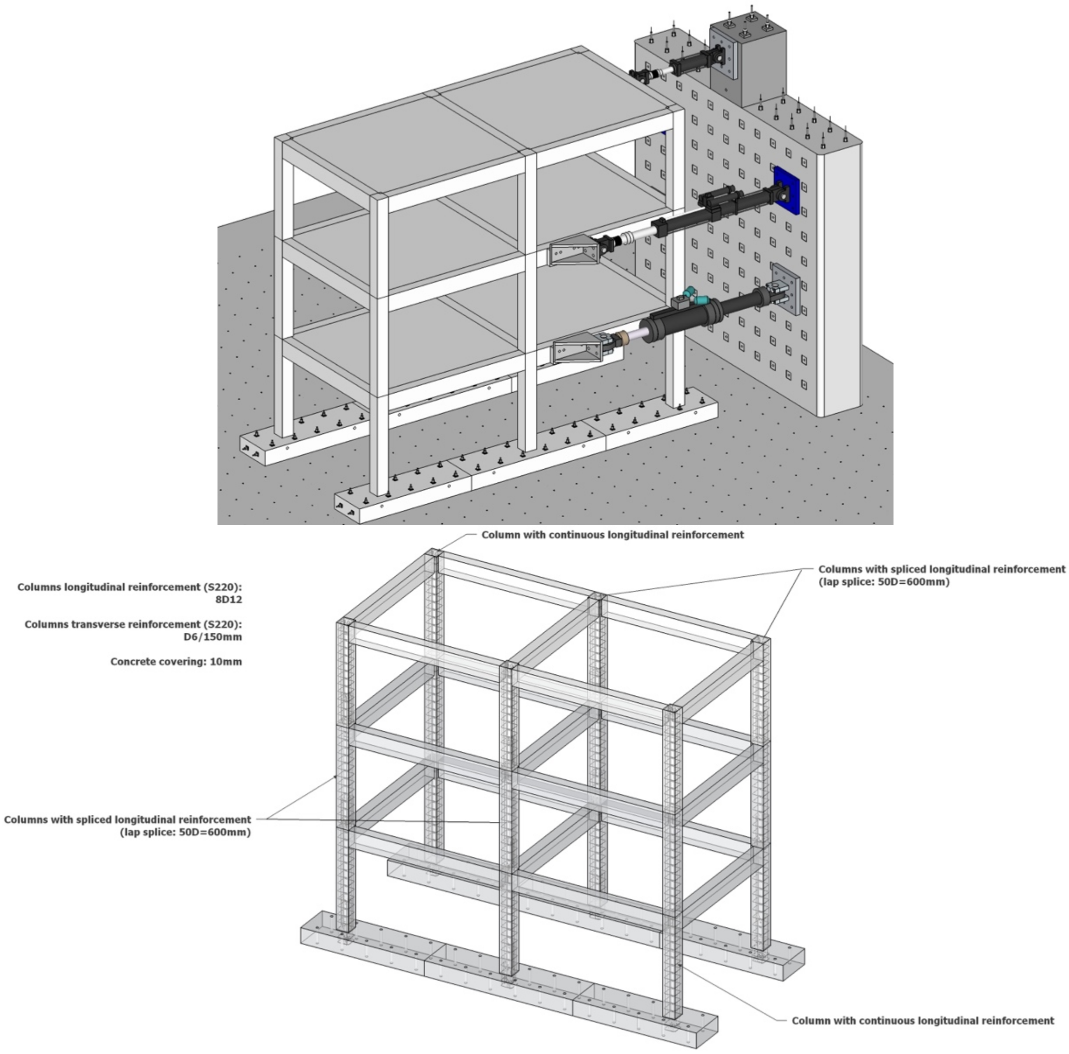


Figure 20: The ARISTA structure: schematic (top) and reinforcement layout (bottom)

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

The test results and the calibrated numerical models will provide information regarding the two most important properties of a concrete member (as-built/retrofitted) for the purposes of seismic assessment and retrofitting, i.e. its secant stiffness to the yield point and its ultimate chord rotation under cyclic loading and will facilitate the development of assessment equations to be introduced in European Standards such as EC8-Part 3.

5.1.3 Project status

The project is in progress. The 3-story specimen has been constructed as designed by the research team, the additional masses have been placed and secured and the first test (free vibration – snap-back test) has been completed.

Figure 21: ARISTA structure (as of March 16th, 2018)

Figure 22: ARISTA structure: snap-back test setup

5.1.4 Foreseen activities and schedule

The project comprises 5 phases, of total duration of 8 months (with some overlapping of tasks):

- **Phase 1**: Detailed design of test specimen – Non-linear analyses (duration: 2 month)
- **Phase 2**: Construction of specimen – instrumentation (duration approx. 3 months)
- **Phase 3**: Testing round #1, specimen retrofitting - Testing round #2 (duration 2 months)
- **Phase 4**: Testing round #3 – Testing to failure – Specimen demolition (duration 1 month)
- **Phase 5**: Data elaboration – Report (2 months)

As of March 16th, 2018 (almost 3 months after agreement signature), Phases 1 and (the most significant part of) Phase 2 (construction of specimen) have been completed. A small part of Phase 3 (snap-back test) has also been realized, along with all required material testing. The time efficiency was, to a large extent, a result of the preparedness of the research team to provide an elaborated design early enough at the beginning of the project.

Currently, instrumentation and actuators (Phase 3) are been installed.

5.1.5 User Group

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

5.2 Effect of Axial Restraint on the Seismic Behaviour of Shear-Dominated COupling Beams (ARCO)

5.2.1 Summary of the project

The project 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.

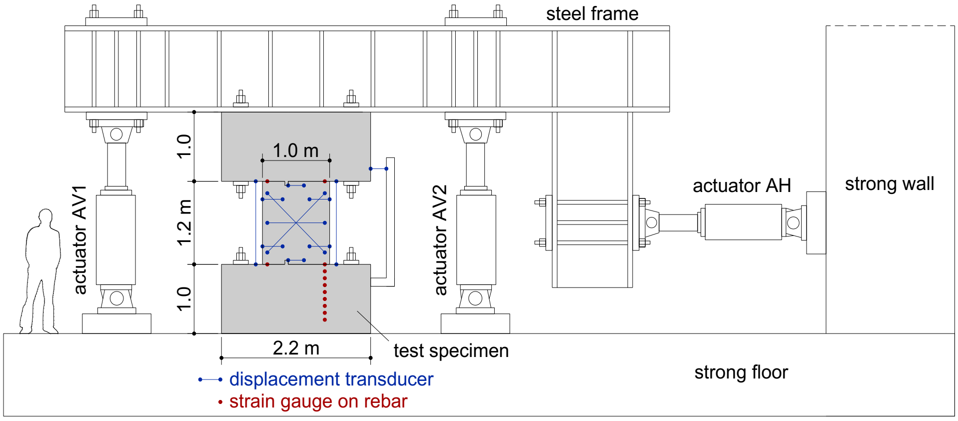


Figure 23: ARCO project – indicative test setup

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

Despite the identified fact that axial restraint of coupling beams in wall structures can have a detrimental effect on the behaviour of such critical structural members, this effect has not been considered in past experimental studies. For this reason, the first main objective of this research project is to perform a detailed experimental program which provides valuable evidence on the cyclic behaviour of short coupling beams under various levels of axial restraint. In order to aid the seismic evaluation and retrofit of critical structures built before the 1970s, the tests will be performed on three specimens with conventional orthogonal reinforcement which do not meet current design requirements. The second main objective of the project is to develop enhanced analytical models that are able to capture the effect of axial restraint on the backbone response of coupling beams, and to provide guidance for the application of these models in the performance-based seismic evaluation of coupled walls systems.

5.2.3 Project status

The User Agreement is under preparation.

5.2.4 Foreseen activities and schedule

Project activities comprise the following phases:

- Phase 1: Design of test specimens, FEM analysis of coupled walls
- Phase 2: Construction of test specimens and test setup
- Phase 3: Testing of the four coupling beams
- Phase 4: Analysis of test data

At the stage of the preparation of the User Agreement, the duration of each phase will be identified in a more detailed way.

It is expected that specimen preparation may commence in June-July, 2018.

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

6 University of Bristol Earthquake Laboratory

The Earthquake and Large Structures Laboratory (EQUALS) is part of the Bristol Laboratories for Advanced Dynamics Engineering (BLADE) in the Faculty of Engineering at the University of Bristol, UK. It houses a 15t capacity, 6 DoF earthquake shaking table surrounded by a strong floor and adjacent strong walls up to 15m high.

The shaking table consists of a stiff 3mx3m platform, weighing 3.8 tonnes, with a regular grid of M12 bolt holes for attaching to the platform body and for mounting of specimens. The platform can accelerate horizontally up to 3.6g with no payload and 1.6g with a 10t payload.

Corresponding vertical accelerations are 5.6g and 1.2g respectively. Peak velocities are 1m/s in all translational axes, with peak displacements of ±0.15 m.

The shaking table is accompanied by a set of 40 servo-hydraulic actuators that can be configured to operate in conjunction with the shaking table, strong floor and reaction walls, providing a highly adaptable dynamic test facility that can be used for a variety of earthquake and dynamic load tests.

Hydraulic power for the shaking table is provided by a set of six shared, variable volume hydraulic pumps, providing up to 900 lt/min at a working pressure of 205 bar. The maximum flow capacity can be increased to around 1200 lt/min for up to 16 seconds at times of peak demand with the addition of extra hydraulic accumulators.

A special feature of the EQUALS facility is its digital control system, with world leading features, including a 'hybrid test' capability (also known as 'dynamic sub-structuring') in which part of the structural system of interest can be emulated by a numerical model embedded in the digital control system, while only a sub-component need be tested physically. Extensive instrumentation is available, including 256 data acquisition channels.

The shaking table can be augmented by additional actuators, to enable multiple-support excitation or travelling wave effects to be explored.

Summary:

- Principal data of Bristol Lab: shaking table
- aluminium platform weight: 3.8t
- table dimensions: 3m x 3m
- degrees of freedom: 6 (via 8 hydraulic actuators)
- capacity: 15 tonnes, (3.6g with no payload, 1.6g with 10t payload)
- corresponding vertical accelerations (5.6g & 1.2g)
- peak horizontal velocity: 1m/sec (in all translational axes)
- peak-to-peak displacements: 300mm
- data acquisition channels: 256
- laminar box for the shaking table

6.1 Seismic Response of Novel Integral Abutment-Bridges (SERENA)

6.1.1 Summary of the project

The object of this project is to investigate seismic soil-structure interaction effects in complex structures involving Integral Abutment Bridges (IAB's), develop numerical and analytical solutions, for different configurations, while checking a number of innovative technological solutions, and produce provisional design guidelines.

The experimental campaign will be performed on the shaking table of the University of Bristol using the shear box available in the laboratory realising a specimen including the abutment and the foundation as shown in Figure 24.

The research team intends to conduct shaking table tests on Integral Abutment Bridges to assess the performance of different foundation and abutment schemes as related to earthquake response.

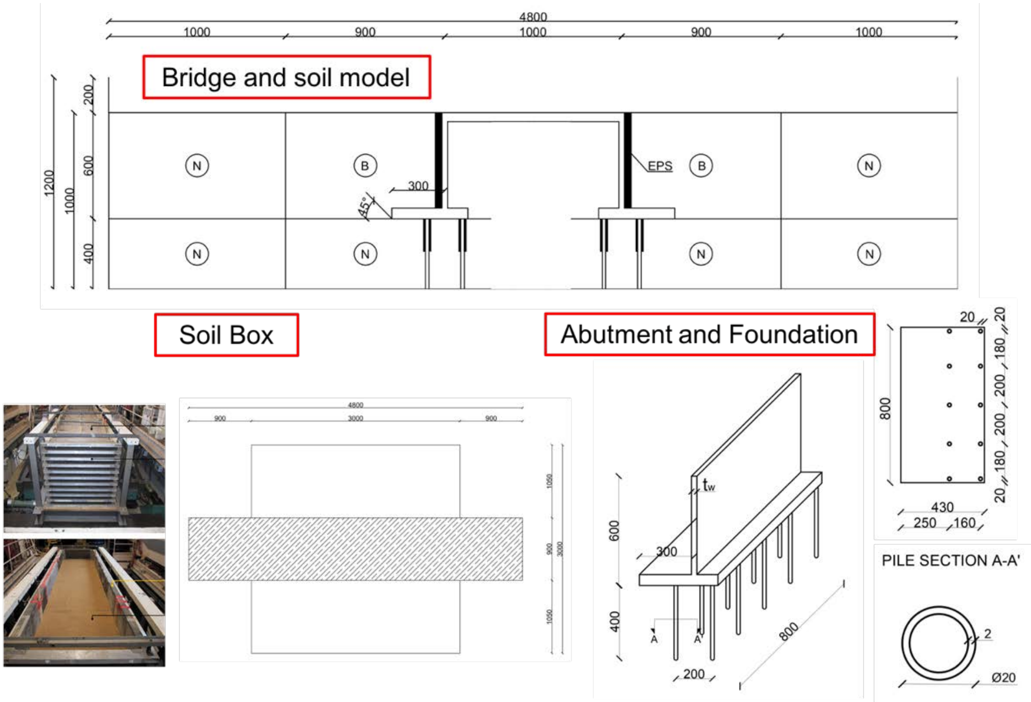


Figure 24: Experimental set up configuration and specimen.

Specifically, the following configurations will be explored:

- Pile-footing connection
  - Piles disconnected from the footing (cap) to allow sliding;
  - Piles monolithically connected to the footing.
- Backfill configurations
  - Piles disconnected from the footing (cap) to allow sliding;
  - Piles monolithically connected to the footing.

Numerical analyses using OpenSees and FLAC will be performed to interpret and validate the experimental results and to calibrate simplified design formulations to be included in code and guidelines for the design of integral abutments.

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

In the last few years the Integral Abutment Bridge (IAB) concept has generated considerable interest among bridge engineers, not only for the newly built bridges but also in the retrofit of existing ones because of the enormous benefits associated with the elimination of expansion joints and reduced installation and maintenance costs. Although not a new concept (the formulation dates back at least to the 1930s) it has been successfully employed to address long-standing structural problems frequently occurring in conventional bridge designs.

Regarding number of applications, United States has the widest experience on IABs and it is reported that more than 13,000 such bridges were built by the mid 2000's. Nevertheless, a meaningful number of bridges within this family can be found in central Europe, mainly in Germany, Switzerland, UK, Austria, Luxembourg and France. IABs have been considered and realized in many other countries, including Japan and Australia. In China, the first applications started at the end of the 1990s, but only in the recent years the Jointless Bridges are becoming more popular. In view of the large number of realizations worldwide, one would expect that a consolidated design practice and guidelines would be available. On the contrary, indications are missing even in modern codes, in particular for the specific aspect of seismic design. This can be attributed, to a good extent, to the fact that from an analysis and design view point the structural continuity existing between deck (see Figure 25), abutment wall and supporting piles makes essential a full consideration of soil–structure interaction (SSI) phenomena, an area which still requires specialized expertise and is not satisfactorily amenable to simplified procedures used in practice.

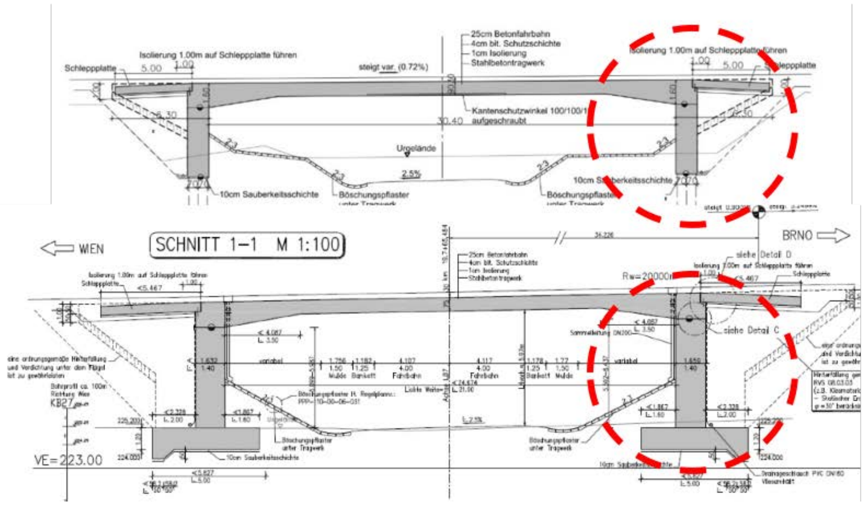


Figure 25: Typical integral bridge abutment schemes.

Consideration of SSI is essential for both seismic action and service loads. With respect to the latter, one aspect peculiar to this typology is that regardless of the presence of loads, the cyclic thermal excursions of the deck lead to a progressive build-up of earth pressures behind the abutments, which may reach very large levels at the occurrence of seismic actions. Furthermore, the relevance of SSI becomes dominant in case of elevated bridges, e.g., overpasses, due to the presence of the embankments at their ends. These components have a seismic response of their own that, in many cases, may govern the response of the whole system. Notably, the fact that embankment contribution is entirely neglected even in modern codes, such as Caltrans, ATC and Eurocode 8 part 2, confirms the lack of established methods. Nonetheless, studies on the analysis of these bridges are relatively abundant in the technical literature. A review of the methods, however, reveals the actual scarcity of comprehensive approaches, contrasting with the larger number of papers dealing with specific, partial aspects of the whole problem. Numerous analytical and experimental research studies have been conducted on the behaviour of IABs under thermal and live load effects, soil–structure interaction effects in IABs, as well as state of art and practice in IAB design. Many studies focused on the longitudinal response of IAB both in linear and non-linear regimes. The maximum deck length is a debated issue, but indications tend to agree on a limit between 400 and 500 m. Only recently comprehensive 3D models of an IAB are employed in inelastic time-history analyses. From these new advancements it has been observed that the embankment dynamic properties is fundamental in the response of IABs.

Regarding experimental studies, a wide variety of tests have been conducted to study the thermal load effects and influence of creep and shrinkage on IABs. The extent and type of the tests largely depended on the research goals.

Recently, a comprehensive joint research of several US universities (UNR, UCSD, UCB) devoted to seismic response of bridges with seat type abutments was completed. A series of collaborative tests and simulations were performed to consider their seismic response, including soil-structure interaction. For that purpose, facilities of the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) have been employed to perform shake table experiments. Large scale (One-quarter) two-span and four-span bridge models were tested at the University of Nevada at Reno at three shaking tables. In addition, investigation of the abutment contribution to the dynamic bridge response was conducted at the University of California in San Diego. It was concluded that the passive earth resistance and mobilized passive stresses at the large accelerations should be further investigated. Tests of whole bridges demonstrated that the seismic response of the bridge can be considerably influenced by the interaction between the structure and the abutments. Based on these experimental data adequate numerical models were developed.

The above brief overview shows that there is significant room for improvement in modelling of these structures, especially with the aim of devising models that capture the fundamental physical aspects and response characteristics of IABs, without resorting to tools that cannot be used in practice for design and can be regarded as high-ended even at research level. Further, even though in some cases parametric studies have been conducted on the effect of some system parameters, and some probabilistic approaches have been presented for static loads and seismic actions, proper consideration of the uncertainty affecting both system properties and the seismic excitation and strategy to reduce them should be further investigated.

Building upon this background, the object of this project is to investigate seismic soil-structure interaction effects in complex structures involving Integral Abutment Bridges (IAB's), and to develop numerical and analytical solutions, for different configurations, while checking a number of innovative technological solutions, and produce provisional design guidelines. To achieve this main aim, we identified several objectives:

1. Simulate earthquake response of IABs on a shaking table: the experimental facility in Bristol composed of the shaking table and of the shear box offer the optimal opportunity to study the problem in an empirical manner.
2. Development of a monitoring system: several parameters need to be monitored during analysis, such as the earth pressure on abutment and the deck accelerations.
3. Innovation for SSI of integral bridges: enhanced design based on industrially produced materials such as EPS Geofoam.
4. Explore different connection schemes: different combination of constraints/restraints and innovative solutions are considered.
    4.1. NOEPS, CP
    4.2. EPS, CP
    4.3. EPS, NOCP
    4.4. NOEPS, NOCP

where (a) EPS stands for geofoam between abutment wall and embankment and around piles, (b) NOEPS stands for absence of EPS between abutment and embankment and around piles, (c) CP stands for Fixed connection between foundation pier and piles, and (d) NOCP stands for vertical support only (piles disconnected from foundation). Figure 26-Figure 29 show the graphical representation of the 4 schemes above mentioned.

5. Simulations with finite element software packages (e.g. Opensees and FLAC): the experimental tests represent an unprecedented opportunity for the calibration of bespoke numerical models. Insight on the modelling will represent a step forward for both new design and assessment of existing bridges.
6. Development of simplified analysis methods (engineering provisions and Codes): empirical results and numerical analysis will be used to define simplified formulation and guidelines that will be at the base of the next generation of structural codes.
7. Dissemination of findings: at the end of the experimental activities findings will be disseminated either on the shape of refereed journal papers and international conferences proceedings, and as worked examples.

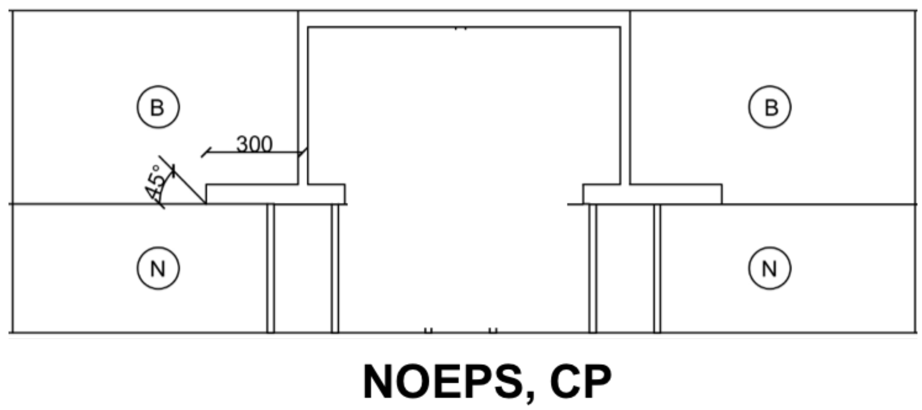


Figure 26: Configuration test 1 NOEPS, CP.

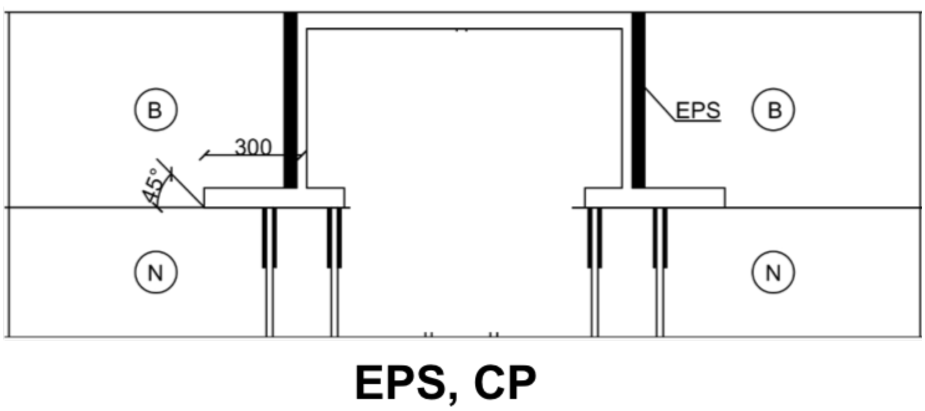


Figure 27: Configuration test 2 EPS, CP.

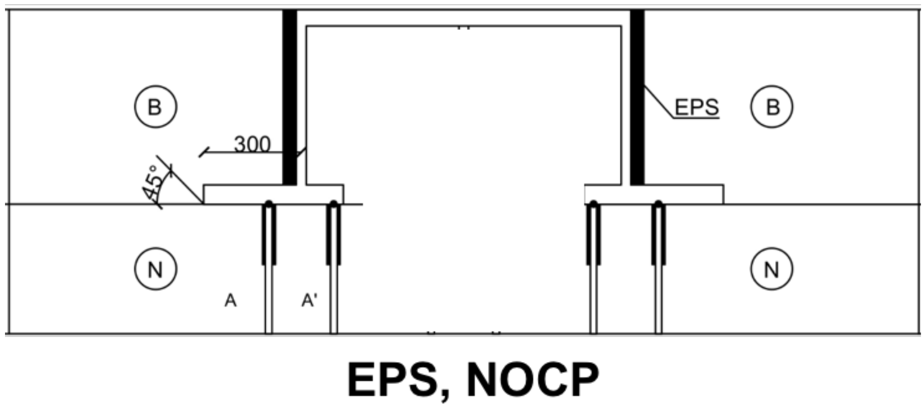


Figure 28: Configuration test 3 NOEPS, NOCP.

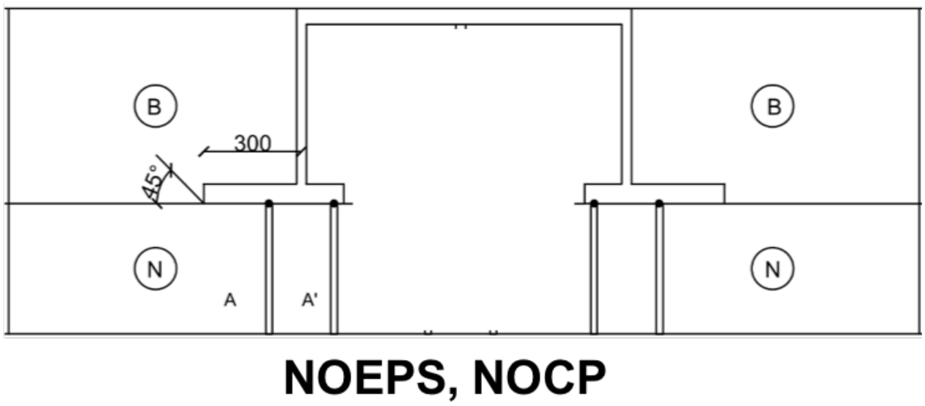


Figure 29: Configuration test 4 NOEPS, NOCP.

6.1.3 Project status

The current progress of the project is described herein. The first project meeting was held at the University of Bristol on February 20, 2018. In this occasion two representatives from Partner 1 (University Roma Tre, Italy) and one representative from Partner 5 (Fuzhou University, China) joined the host institution team at the University of Bristol to discuss the timeline of the project and to agree on the general principles for the design of the experimental campaign. Prof Camillo Nuti (Roma Tre), Dr Gabriele Fiorentino (Roma Tre) and Prof Bruno Briseghella (Fuzhou University) took part to the meeting.

In this first meeting the schedule of project activities was discussed and finalised as per section 1.1.4 of this report.

Given the logistic related to the setup of each specimen configuration (i.e., box filling time with soil, test preparation, test) the timetable slot time was agreed (i.e., 04/06/2018 – 13/07/2018) and the number of configurations to be tested was agreed to be four. The availability of instrumentation and the time necessary to prepare such instrumentation on each specimen was discussed.

- Preparation of test 1 on the table (time necessary 2 weeks)
- Test 1 - EPS, CP: Geofoam and connected piles (time necessary 1-2 days)
- After test 1 it is easy and fast to disconnect piles (time necessary 1 week)
- Test 2 - EPS, NOCP: Geofoam and disconnected piles (time necessary 1-2 days)

- After test 2 there is the need to remove the backfill and connect piles (time necessary 2 weeks)
- Test 3 - NOEPS, CP: Geofoam removed and connected piles (time necessary 1-2 days)
- After test 3 it is easy and quite fast to disconnect piles (time necessary 1 week)
- Test 4 - NOEPS; NOCP: No Geofoam and disconnected piles (time necessary 1-2 days).

The general scaling approach to be followed for the design of the specimen was discussed referring to the work by Veletsos and Young (1997). A preliminary dimensioning of the specimen was agreed, and it was referred to relevant experimental studies available in literature and real scale examples of integral bridge abutments.

Discussion on the accelerograms to be used for each test and general requirement to be compliant with the scaling laws for wave propagation in the shear box.

In the following weeks, the project leading institution (i.e., University Roma Tre) and the host institution (i.e., University of Bristol) have start to collaborate remotely on the finalisation of the geometry of the specimen. This activity is still ongoing at the date of submission of this report.

6.1.4 Foreseen activities and schedule

As a result of the first project meeting at the University of Bristol held on the 20th of February 2018, the following schedule was agreed on the basis of the condition that no maintenance is required for the shaking table in this period.

ACTIVITY DESCRIPTION	START DATE	END DATE
DESIGN SPECIMENS, SELECT ACCELEROGRAMS FOR TESTING	20/02/2018	15/05/2018
PREPARATION: BOX REFURBISHMENT, ORDER MATERIAL	15/05/2018	04/06/2018
SHAKING TABLE TESTS	04/06/2018	13/07/2018
ANALYSES OF RESULTS, NUMERICAL ANALYSES AND DISSEMINATION	13/07/2018	13/07/2019

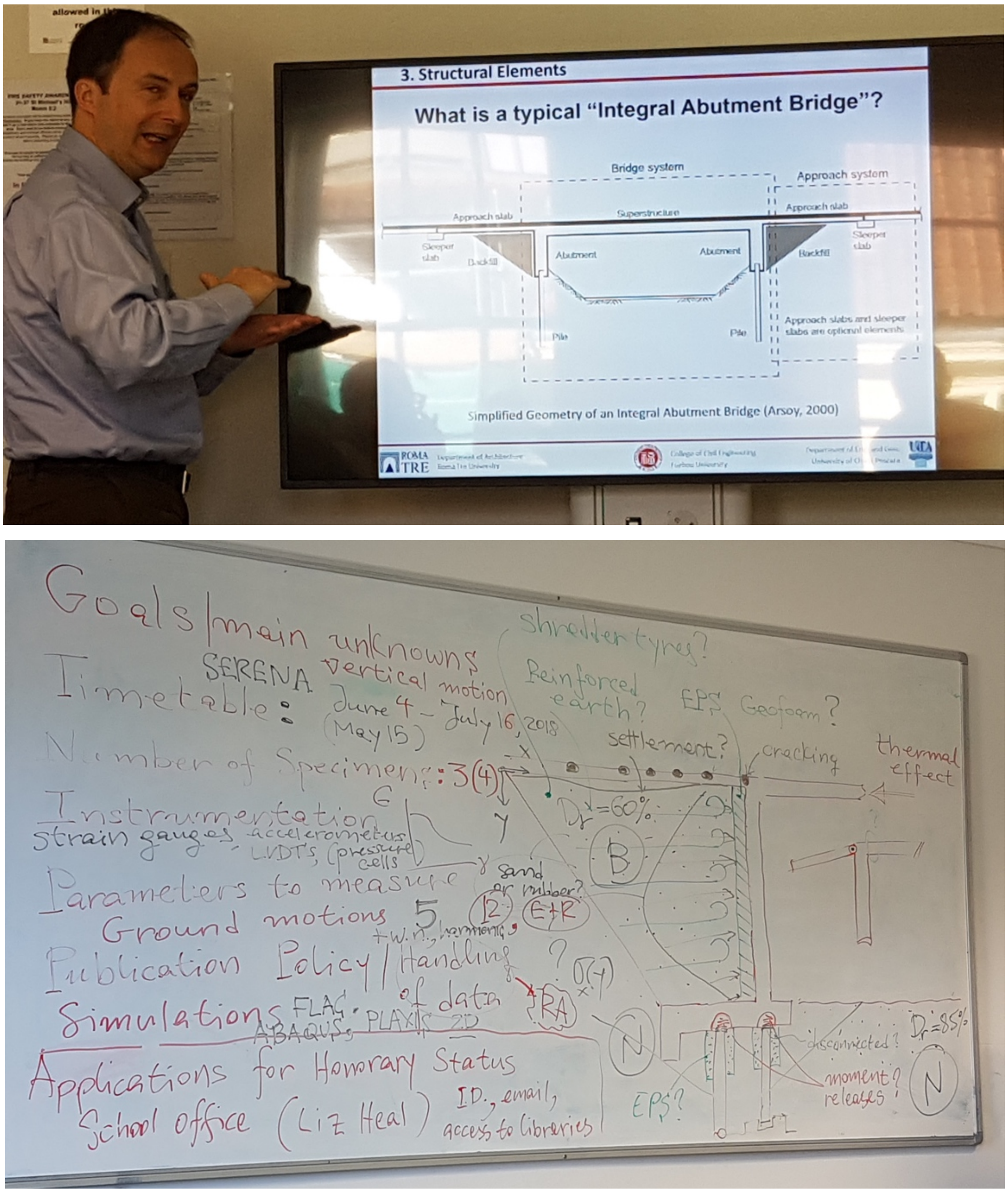


Figure 30: Project Meeting at the University of Bristol

6.1.5 User Group

	NAME	ORGANIZATION NAME	ORGANIZATION COUNTRY
USER GROUP LEADER	Prof Camillo Nuti	University Roma Tre	Italy
ADDITIONAL USERS	Prof Christos Vrettos	Technischen Universitat Kaiserslautern	Germany
	Dr António Topa Gomes	University of Porto	Portugal
	Prof Tatjana Isaković	University of Ljubljana	Slovenia
	Prof Bruno Briseghella	Fuzhou University	China

6.2 Statistical verification and validation of 3D seismic rocking motion models (3DROCK)

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.

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.

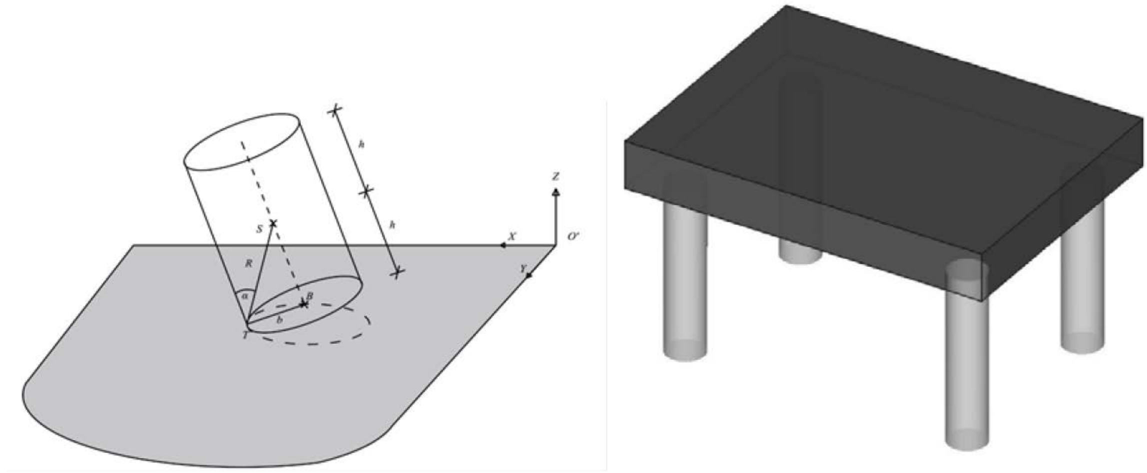


Figure 31: Left: Bounded wobbling model (Vassiliou et al. 2017). The cylinder is constrained to roll only above its initial position. Right: Sketch of a slab supported on wobbling columns

In summary, the project is broken down into the following work packages (implementation steps):

- Generation of the ground motions (4 weeks)
- Design, construction and measuring the properties of the specimens (4 weeks /1 lab day)
- Perform shake table tests of the free rocking specimens with steel surfaces and post process the results (2 weeks/ 7 lab days)
- Perform shaking table tests for the bounded rocking specimens (1 week / 3 lab days))
- Perform shake table tests of the free rocking specimens with concrete surfaces and post process the results (1 week/ 4 lab days)
- Numerical modeling of the response of the free rocking specimens with steel and concrete plates (2 weeks, each team)
- Compare numerical and experimental results of the free rocking specimens with steel and concrete plates (4 weeks, each team)
- Numerical modeling of the response of the bounded rocking specimen (1 week)
- Compare numerical and experimental results of the bounded rocking-specimen (2 weeks)
- Data Curration and Reporting (8 weeks)

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

To our knowledge no statistical validation of 3D rocking models has ever been performed. This is a major scientific gap, since a wide class of objects and structures can only be described by the rocking oscillator, while elastic spectra based methods are inadequate. Moreover, non-repeatability of tests has been reported that has led to numerical models generally not being trusted by practicing engineers. Many researchers thus focused on refining 1963 Housner model disregarding the huge uncertainty originating from the ground motion itself. Once this gap is bridged and the model is trusted, the next step would be to evaluate the influence of seismological parameters to the response of rocking oscillators, which is an open subject. If this project proves that the structural modeling uncertainty is not the dominant one, this will shift the interest of researchers working or rocking from structural modelling to ground motion induced uncertainty. It will also be an argument to be used on the debate on whether rocking can be used as a seismic response modification technique. The rocking oscillator, in addition to its academic and intrinsic theoretical interest, is useful in a number of applications ranging from seismic safety of nuclear facilities to bridge engineering, and stability of historical structures. More specifically (Figure 32):

- Nuclear waste is often stored in concrete/steel containers that are allowed to uplift and sustain rocking motion. The importance of quantifying the risk of a damage is beyond any doubt, and, in that sense, the project contributes to public safety and sustainable growth. Currently we lack both trustworthy models and an understanding of what seismological parameters correlate better to the rocking response. Since the project has applications on the nuclear industry, it contributes to the 5th objective of the EU cohesion policy (promoting climate change adaptation, risk prevention and management).
- It has been proposed that rocking be used as a means of seismic isolation. The uplift acts like a mechanical fuse and limits the forces transmitted to the structures, as well as the design forces of the foundation. Its effect on both the superstructure and the foundation has attracted the attention of both structural and geotechnical engineers, and hence rocking is related to both engineering fields. The bridge engineering community is reluctant to adopt rocking because the models have not been validated. Their validation would facilitate the adoption of a new design approach based on uplift that can lead to more resilient and economic structures (and therefore contribute to public safety and sustainable growth). Moreover, its bridge-related applications, make the project a contribution to the 7th objective of the EU cohesion policy (promoting sustainable transport and improving network infrastructures).
- Ancient Greco-Roman temples, as well as free standing statues and museum artifacts constitute an important part of the European cultural heritage. All the above behave as rocking oscillators and their protection is of major cultural importance. In the very recent July 2017 earthquake in Kos Island, Greece, the archeological museum suffered no damage, but many precious artifacts were heavily damaged (Figure 32). Better understanding the rocking motion can lead to a better evaluation of the seismic risk that museum artifacts and monuments face.
- Finally, as the complex dynamics of 3D rocking structures are not fully understood, there exists no code for rocking structures. The results of this study contribute to better understanding 3D rocking and thus are a contribution to European Standardization and therefore contributes to the European integration (through defining common norms).

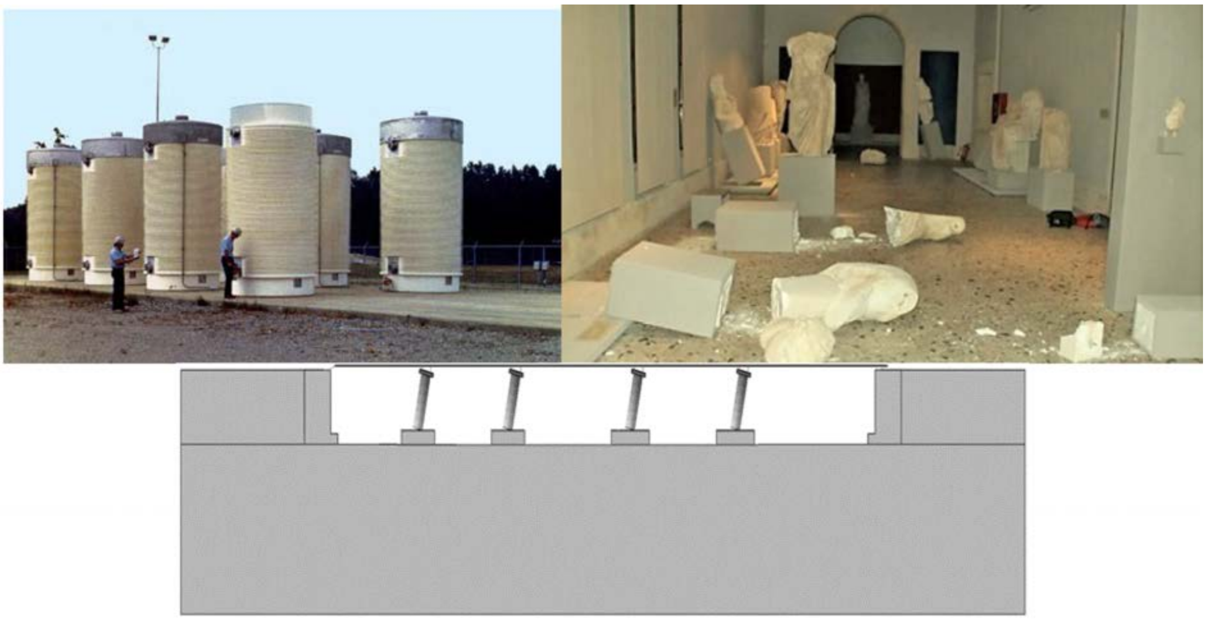


Figure 32: Top Left: Nuclear Waste Containers. Top Right: Kos Island Museum, July 2017 earthquake, Bottom: FEM Model of a bridge supported on rocking Piers.

6.2.3 Project status

The first project meeting took place at the University of Bristol on March 18th, 2018 with the participation of Professor Bozidar Stojadinovic and Dr. Michalis Vasiliou (ETH). Prof. Mylonakis and Assoc. Professors Anastasios Sextos and Nick Alexander were also present together with Laboratory personnel Dr. Matt Dietz and Dr. Luiza Dihoru. An outline of the project was first given by the user group followed by a detailed discussion mainly focusing on (Figure 33):

- The objectives of the project and the appropriate tasks and milestones needed for those to be met
- Specimen geometrical properties, material and mass that will permit rocking and wobbing in relation to the capacity and stroke of shaking table
- Specimen base configurations that can prevent sliding
- Protecting mechaniisms that can prevent damage to the shaking table and the specimen itself upon loss of stability
- Ground motion properties that will ensure unbiased probabilistic assessment of the 3D rocking response of rigid models
- Project timeframe, expenses and logistics

A decision was made that the experiments shall be scheduled in between the experimental campaigns of the other two SERA projects, namely SERENA (04/06/2018 – 13/07/2018) and REBOND (late October 2018). The sequence of tests is described below:

- Preparation of test 1 on the table (time necessary 2 weeks)
- Test 1 – Preliminary test of a single cylindrical free rocking specimens for validation and optimization purposes (time necessary 1-2 days)
- Validation of the experimental concept in terms of rocking properties, instantaneous frequencies, friction issues, overturning safety, statistical proxies etc (time necessary 1 week)
- Test 2 – Series of tests of a single cylindrical free rocking (steel and possibly concrete) specimen for statistical processing based on the sample of selected ground motions for various intensities and ground motion characteristics (time necessary 1 week)

- Clearance of the table after test 2 (time necessary 1 day)
- Test 3 – Series of tests for the slab supported on wobbling columns and the sample of the selected ground motions (time necessary 1 week)

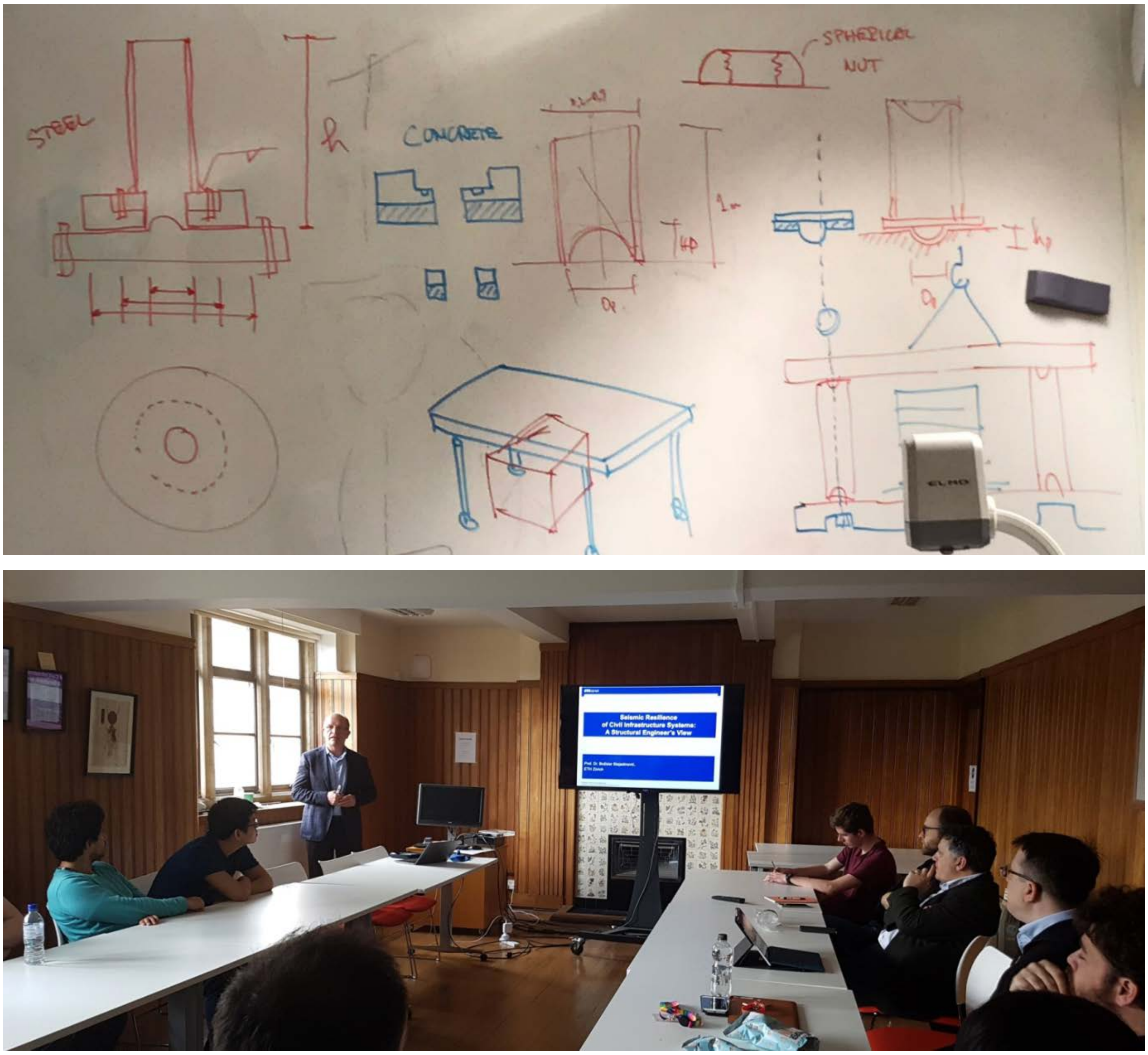


Figure 33: Project meeting and invited talk (18/03/2018)

In the following weeks, the user team (ETH/NTUA) and the hosting institution (UoB) offering TA will work closely on further clarifying the above experimental campaign and specifying the sub-tasks associated with preparation of the tests and post-processing of the results.

6.2.4 Foreseen activities and schedule

Based on the outcomes of the project meeting, the associated activities were scheduled as follows. It is noted that only minor deviations are made with respect to the initial brief.

ACTIVITY DESCRIPTION	START DATE	END DATE
GENERATION OF THE GROUND MOTIONS	01/08/2018	31/08/2018
DESIGN, CONSTRUCTION AND MEASURING THE PROPERTIES OF THE SPECIMENS	01/09/2018	30/09/2018

PERFORM SHAKE TABLE TESTS OF THE FREE ROCKING SPECIMENS WITH STEEL SURFACES AND POST PROCESS THE RESULTS	01/10/2018	15/10/2018
PERFORM SHAKING TABLE TESTS FOR THE BOUNDED ROCKING SPECIMENS	16/10/2018	23/10/2018
PERFORM SHAKE TABLE TESTS OF THE FREE ROCKING SPECIMENS WITH CONCRETE SURFACES AND POST PROCESS THE RESULTS*	24/10/2018	31/10/2018
NUMERICAL MODELING OF THE RESPONSE OF THE FREE ROCKING SPECIMENS WITH STEEL AND CONCRETE PLATES	01/11/2018	15/11/2018
COMPARE NUMERICAL AND EXPERIMENTAL RESULTS OF THE FREE ROCKING SPECIMENS WITH STEEL AND CONCRETE PLATES	16/11/2018	15/12/2018
NUMERICAL MODELING OF THE RESPONSE OF THE BOUNDED ROCKING SPECIMEN	07/01/2019	15/01/2019
COMPARE NUMERICAL AND EXPERIMENTAL RESULTS OF THE BOUNDED ROCKING-SPECIMEN	16/01/2019	31/01/2019
DATA CURRATION AND REPORTING	01/02/2019	31/03/2019

* Test possibly to be performed with NTUA or merged with that of the steel specimens depending on the preliminary validation tests

6.2.5 User Group

	NAME	ORGANIZATION NAME	ORGANIZATION COUNTRY
USER GROUP LEADER	Prof Bozidar Stojadinovic	ETH	Switzerland
ADDITIONAL USERS	Dr. Michalis Vasiliou	ETH	Switzerland
	Dr. Marco Broccardo	ETH	Switzerland
	Prof. Ioannis Psycharis	National Technical University of Athens	Greece

6.3 REsponse of as-Built and strengthened three-leaf masONry walls by Dynamic tests (REBOND)

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.

The considered specimens will be built 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.

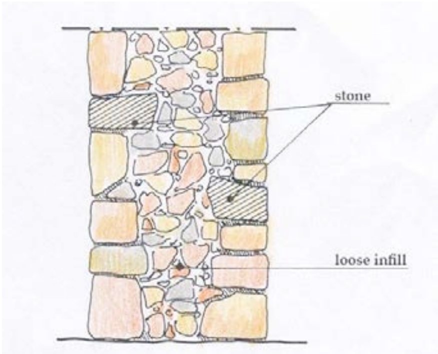


Figure 34: Typical transversal vertical section of a three-leaf "a sacco" masonry wall

Figure 35: Delamination of three-leaf masonry walls observed in Visso and Ussita after the 2016 Central Italy Earthquake

The main expected outcomes of the project are listed in the following:

1. Insight on the in-plane behaviour of as-built and strengthened three-leaf walls;
2. Assessment of the vertical ground motion component effects of the walls' behaviour, more specifically on its strength and failure mechanisms;
3. Assessment of the strength enhancement obtained with the proposed strengthening techniques, critical to evaluating whether buildings with three leaf walls may be seismically strengthened to sustain the design earthquake;
4. Assessment of the failure mechanisms of strengthened walls;
5. Formulation of enhanced design expressions for the strength of three-leaf walls, as-built and strengthened;
6. Creation of a database of experimental results for numerical simulations and development of new strength expressions and novel modelling tools.

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

The project involves shaking table experimental tests on full-scale single masonry walls, made of three-leaf masonry (two external leaves made of irregular stones plus loose infill) that will be carried out under different loading conditions. Tests are aimed at investigating:

1. The in-plane strength of the as-built walls;
2. The influence of the vertical ground motion component on the in-plane behaviour of the as built-walls;
3. The effectiveness of strengthening techniques that include: a) grout injections carried out with a compatible mortar; b) addition of through 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.

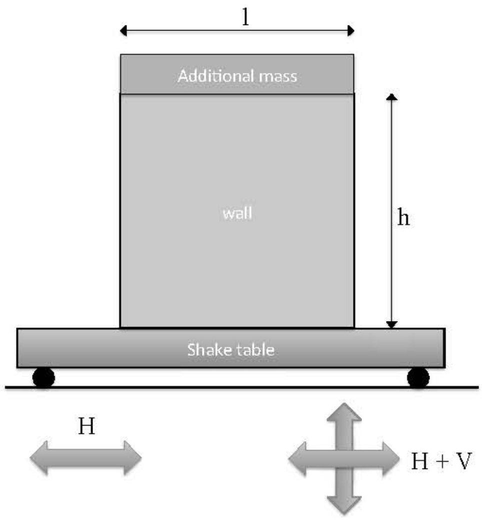


Figure 36: Schematic wall on shake table and ground motion directions

The experimental layout is schematically shown in Figure 36. Even though the actual test set-up will be finalized together with the host facility, it is now foreseen that each test will comprise a l=2m by h=2m three-leaf masonry panel having total thickness of approximately 0.7 m. The panel, representative of the base level of a two-storey structure, will be loaded at the top with a mass of approximately 5 tons to simulate the vertical load and dynamic mass of the second floor plus a light roof. The walls are intended to represent an external panel that runs parallel to the floor joists: this way, the floor applies little or no gravity loads on the wall. In this configuration the wall has a maximum compressive stress of approx. 0.1 MPa.

It is proposed that the tests be carried out on the shaking table of the EQUALS laboratory of Bristol, which includes the vertical degree of freedom necessary to apply the vertical ground motion component.

Three rectangular panels will be shaken in their horizontal, longitudinal direction (H) using three different grounds motions (EQ1, EQ2 and EQ3). Three ground motions will be selected to account for the statistical record-to-record variability. Three similar specimens will be tested later with the same horizontal ground motions, including the vertical component (H+V) in order to assess the effects of the particular ground motion component.

The selection of the ground motions is a key aspect, as ongoing work by the proposing team shows that only vertical ground motions characterized by short epicentral distance, medium/high moment magnitude and dip-slip faults drastically affect the walls' response. Three ground motions, selected according to specific characteristics (distance from the fault line, magnitude, fault type, frequency content of the vertical component with respect to the wall vertical frequency and energy ground motion parameters), will be applied. Each ground motion will be applied first scaling it down to a very low base acceleration and then repeating its application with an increased scale factor up to wall failure. Since it is expected that in the as–built configuration the walls will show very brittle behaviour, a total of three runs (low, moderate, high) is planned.

To obtain the modal characteristics of the walls, white noise dynamic tests will be run prior to each ground motion application.

Two types of specimens will be investigated: the first is a rectangular wall representative of a wall in the middle of an external façade and not connected to an orthogonal wall, the second is a T-wall representative of a wall in the middle of an external façade but connected with an orthogonal wall. In the second case, for the as built specimens the connection between the two perpendicular walls will reflect construction techniques observed in central Italy after the 2009 and 2016 earthquakes.

Given that one of the basic characteristics of a sustainable building is its static and dynamic strength, it is fundamental to test strengthening techniques if buildings made of three-leaf walls are to be used by future generations. For each specimen tested in the first phase of the test program, three types of strengthening techniques will be combined and applied in order to evaluate their effectiveness:

a) (MI): lime-based Mortar Injections (see Figure 37);

b) (TR): insertion of through-thickness reinforcing rods to connect the external leaves (see Figure 38);

c) (OC): insertion of reinforcing rods to enhance the Orthogonal Connection between the orthogonal T-walls (see Figure 39

Mortar and rods will be designed together with the Industry Partner that will also donate all strengthening materials. The through-thickness connectors will be either rods or fibre bundles, made of either stainless or galvanized steel. Similarly, the orthogonal connections will be made of stainless or galvanized steel rods appropriately anchored to the orthogonal walls.

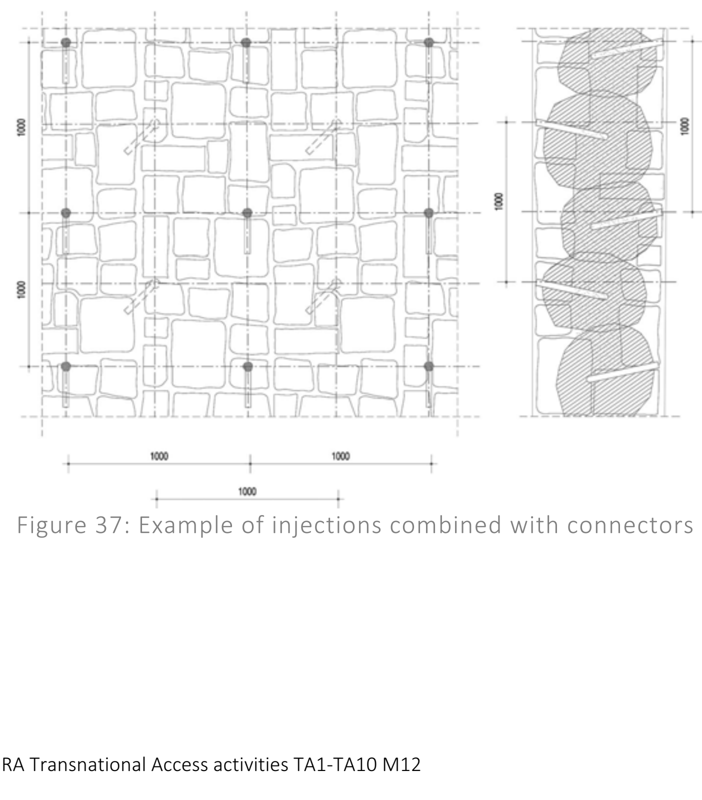


Figure 37: Example of injections combined with connectors

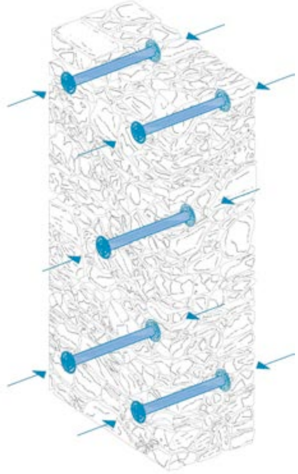


Figure 38: Example of through-thickness connectors

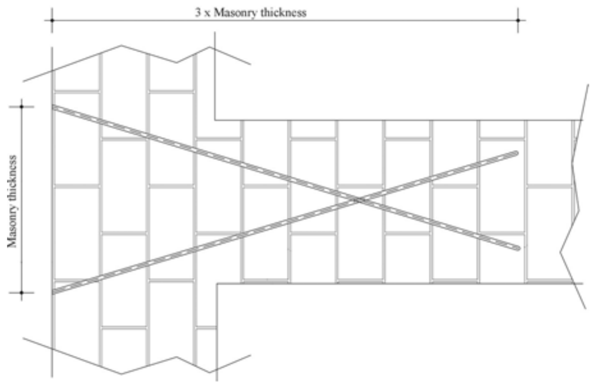


Figure 39: Example of connectors between two orthogonal walls

6.3.3 Project status

The current progress of the project is described herein. The first project meeting was held at the University of Bristol on February 22, 2018.

In this occasion three representatives from Partner 1 (University "G. d'Annunzio" of Chieti-Pescara, Italy) and two representatives from Partner 3 (Aristotle University, Greece) joined the host institution team at the University of Bristol to discuss the timeline of the project and to agree on the general principles for the design of the experimental campaign. Prof Enrico Spacone (University "G. d'Annunzio" of Chieti-Pescara), Prof Guido Camata (University "G. d'Annunzio" of Chieti-Pescara), Prof Giuseppe Brando (University "G. d'Annunzio" of Chieti-Pescara), Mr. Francesco Di Michele (University "G. d'Annunzio" of Chieti-Pescara), Prof George Manolis (Aristotle University) and Dr Konstantinos Katakalos (Aristotle University) took part to the meeting. University of Bristol was represented by Professor George Mylonakis, Dr Adam Crewe and Dr Anastasios (Tasos) Sextos.

In this first meeting the schedule of project activities was discussed and finalised as per section 1.1.4 of this report. The timetable slot time was agreed (01/10/2018 – 02/11/2018).

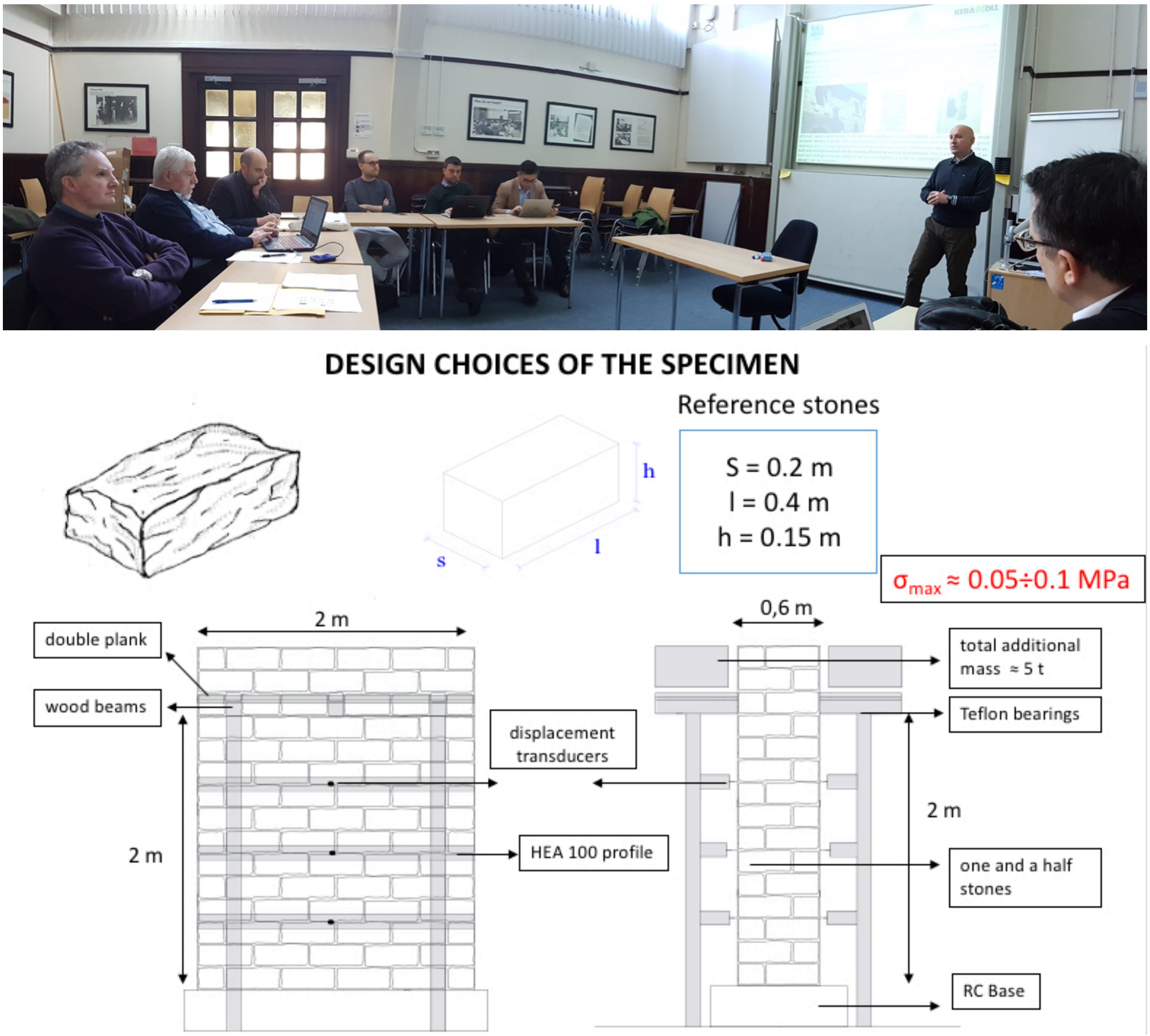


Figure 40: Project meeting at the University of Bristol and preliminary design of the tests

6.3.4 Foreseen activities and schedule

The overall testing program is summarized in Table 1. A total of twenty-four specimens are foreseen.

Table 1: Planned shaking – table tests:

TYPOLOGY	WALL TYPE	GROUND MOTION INPUT	GROUND MOTION COMPONENTS (different specimens)	STRENGTHENING TECNIQUE
Three-leaf rectangular wall	As-built	EQ1	H	-
			H+V	
		EQ2	H	-
			H+V	
		EQ3	H	-
			H+V	
	Strengthened	EQ1	H	MI+TR
			H+V	MI+TR
		EQ2	H	MI+TR
			H+V	MI+TR
		EQ3	H	MI+TR
			H+V	MI+TR
Three-leaf T-wall	As-built	EQ1	H	-
			H+V	
		EQ2	H	-
			H+V	
		EQ3	H	-
			H+V	
	Strengthened	EQ1	H	MI+TR+OC
			H+V	MI+TR+OC
		EQ2	H	MI+TR+OC
			H+V	MI+TR+OC
		EQ3	H	MI+TR+OC
			H+V	MI+TR+OC

The research activities related to the proposed experimental tests will be organised in

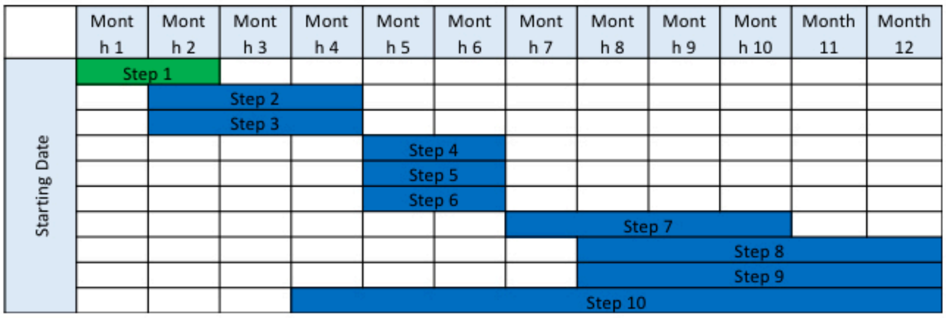
the following seven Working Packages (WP):

- WP1: State-of-the-art
  - Documentation on three-leaf walls found in seimic-prone Mediterranean countries;
  - Previous experimental tests on three-leaf walls;
  - Impact of previous earthquakes on three-leaf walls;
  - Previous studies on the effects of the vertical ground motion component.
- WP2: Walls' design and construction
- WP3: Record selection
  - Select three records based on specific characteristics (distance from the fault line, magnitude, fault type, frequency content of the vertical component with respect to the wall vertical frequency and energy ground motion parameters).
- WP4: Monitoring/Instrumentation
  - Design of monitoring/Instrumentation system.
  - Instrumentation will also include digital imaging (for the crack patterns) and optic fibers (for the reinforcing rods).
- WP5: Tests
- WP6: Modelling
  - Organize and publicize blind-test numerical contest

- Use results to calibrate models and to develop new modelling approaches.
- WP7: Interpretation and Dissemination
  - Analysis and interpretation of test results, using both experimental results and numerical prediction;
  - Use experimental results to formulate updated design code-expressions for capacity of three-leaf walls;
  - Use experimental results to propose design-code approach to consider vertical ground motion component effects in design process;
  - Results dissemination.
  - Some WPs, notably 2, 3, 4, 5, will be carried out in collaboration with the host facility.

The whole project will be developed according the following timetable:

STEP 1 – State-of-the Art on Three Leaf Masonry Walls.
STEP 2 – Wall design (with the support of preliminary FEM models, see Step 3)
STEP 3 – Set up of preliminary FE numerical model
STEP 4 – Fabrication of Test Specimens
STEP 5 – Organization of the Laboratory Activities
STEP 6 – Blind Test by FEM models
STEP 7 – Tests
STEP 8 – Reports on the Performed Tests
STEP 9 – Validation of the FEM model and Parametric analysis
STEP 10 – Dissemination



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	Faculty of Engineering of the University of Porto	Portugal
	GEORGE D. MANOLIS	Aristotle University, Thessaloniki	Greece
	PAOLO CASADEI	University of Bologna	Italy
	GIUSEPPE BRANDO	University “G. d’Annunzio” of Chieti-Pescara	Italy
	FRANCESCO DI MICHELLE	University “G. d’Annunzio” of Chieti-Pescara	Italy
	GUIDO CAMATA	University “G. d’Annunzio” of Chieti-Pescara	Italy
	KONSTANTINOS KATAKALOS	Aristotle University, Thessaloniki	Greece

7 Shaking Table at the Institute of Earthquake Engineering and Engineering Seismology (IZIIS) Dynlab

The shaking table that is offered to the users in this project represents a five–degrees-of-freedom MTS earthquake simulator. It is presently one of the most advanced shaking tables since it possesses a new state-of-the-art digital control system produced by MTS as the most renowned producer of these simulators. The main characteristics of this sophisticated shaking table are:

- Size of table: 5.0 x 5.0 m;
- Weight of table: 30 t;
- Payload: 40 t;
- 5 DOF, Two lateral and four vertical actuators;
- Type of excitation: random, harmonic or computer generated;
- Frequency range: 0.1-80Hz;
- Maximum stroke: horizontal ±125 mm and vertical ±50 mm;
- Maximum acceleration (bare table) horizontal 3.0 g and vertical 1.5g
- Maximum velocity, horizontal 1.0 m/s, vertical 0.5 m/s.

The IZIIS, 5 m x 5 m seismic shake table is a pre-stressed reinforced concrete plate. The table is supported by four vertical hydraulic actuators located at four corners at a distance of 3.5 m in both orthogonal directions. The table is controlled in the horizontal direction by two hydraulic actuators at a distance of 3.5 m with a total force capacity of 850 kN. The four vertical actuators have a total force capacity of 888 kN.

New equipment for data acquisition and measuring as well as sensors are available at DYNLAB too.

The maximum number of users/ projects in a course of the SERA duration is limited to 3. In a firs call there were four proposed projects, and two of them as a first priority. Only one project was assigned to the first call.

7.1 Influence of the floor-to wall interaction on the seismic response of coupled wall systems

7.1.1 Summary of the project

Buildings with RC walls have been one of the most frequently and successfully used structural systems to resist the 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.

Two 1:2 scale 3-story coupled walls will be tested (Figure 41), each with two T-shaped piers and a tributary floor system. Two levels of coupling will be analyzed to study the interaction between the floor system and wall piers: 1) In one specimen the piers will be coupled only by the slab; 2) In the second specimen, the level of coupling will be increased by means of coupling beams. The shape and the reinforcement of the piers will provide a realistic representation of the floor-pier interaction as well as realistic boundary conditions for the floor system. Following the frequent practice in many countries, the piers of the second specimen will be coupled by RC beams with diagonal reinforcement designed to provide resistance to the shear demand.

The improved numerical models and the findings of the experiments will be used to propose an adequate design procedure, which might be included in the future versions of seismic codes, in particular, Eurocodes.

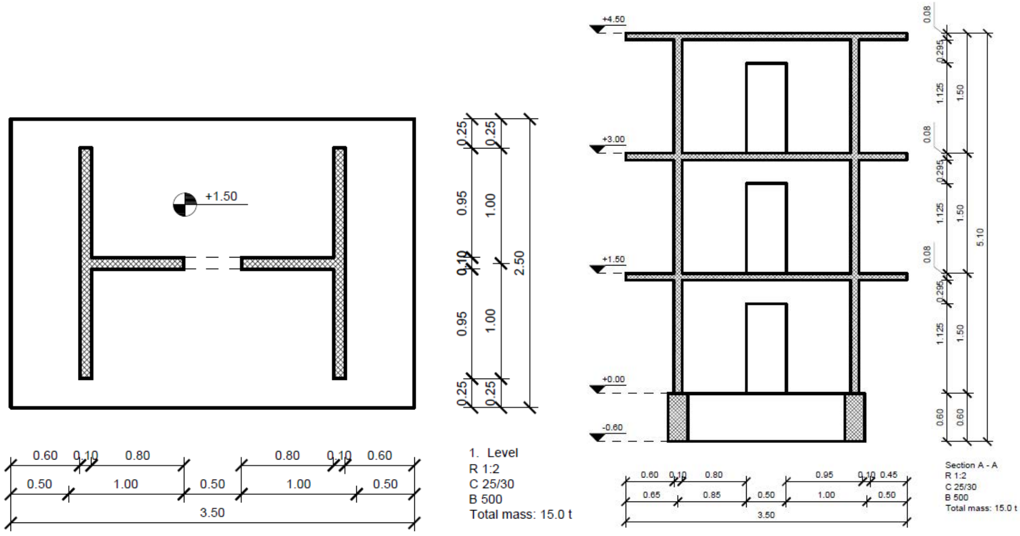


Figure 41: Drawings of the specimen with coupling beams (floor plan and cross- section)

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

The main objective of the project is to experimentally study the interaction between the piers and floors in RC coupled walls. However, the current understanding of mentioned floor-to-piers interaction effects is poor. Due to the excessive complexity of the problem, further and focused experiments are needed to reveal some of the basic mechanisms of the response of RC coupled walls.

To achieve the main objectives of the project, shake table experiments are needed in order to provide realistic simulation of the dynamic interaction between floors and piers. The specifics of the thin elements and reinforcement details call for a large-scale model as close to the prototype as possible.

In order to reveal the influence of slabs to the interaction between floors and piers, two specimens with different levels of coupling intensity will be tested. In one specimen, the coupling of the piers will be provided only by 8 cm thick slab. In the second specimen, a greater level of coupling will be provided by coupling beams.

The results of the project and related improvements of the codes will make possible to control the extent of damage more accurately. It will be possible to prevent the collapse of structures much more reliably and to prevent the undesirable types of damage, particularly the brittle ones. This will lead to safer and more economical structural solutions and prevent irreparable types of damage during strong earthquakes. Finally, it will also contribute to the key development goals of sustainability, energy conservation and carbon emission reduction.

The needs of the research, which will contribute to the improvements of the currently poor design practice of RC coupled walls, has been recognized all over the world. The project will contribute to coordinated worldwide activities (NSF SAVI Wall Institute) through the cooperation of the European and US researchers and it will further strengthen the joint regional research efforts of the University of Ljubljana and IZIIS.

7.1.3 Project status

The project is still in its initial phase. The proposer of the project is the University in Ljubljana, namely the Faculty of Civil and Geodetic Engineering. We permanently communicate with the lead user of the proposing team – Prof. Dr. Tatijana Isakovic and with the additional user – Prof. Dr. Matej Fishinger. After intensive negotiations, we agreed with the official start of the project to be on 15.02.2018. At the moment, the team from Ljubljana is intensively working on the design of the models. This team is permanently communicating with the colleague from KALTEK (Prof. Dr. John Wallace). In accordance with the plan, we are in the final phase of preparation of a tendering procedure to find out a contractor for the construction of the models to be tested. As planned, the preparations for the tendering procedure should have been finished by 25 03 2018. Around 26 03 2018, there will be an announcement of a call for bids in the electronic and printed media. Upon completion of the procedure for the selection of the most favorable bidder that is to last for a month and a half, the construction of the first model is to begin. The first model will be completed around the midst of May so that the instrumentation of the model and its testing on the seismic shaking table in DYNLAB can start as anticipated in the first brief report on the work in progress, i.e., around the midst of June.

In our communication with the user group in Ljubljana, we proposed to meet for the purpose of better coordination of the project at the first SERA annual meeting in Bucharest. The colleagues from Ljubljana apologized for not being able to come due to their commitments related to the teaching process.

7.1.4 Foreseen activities and schedule

As previously stated in the project status, the design of the three-storey model with reinforced concrete walls will have been completed around the midst of May so that the foreseen activities and the schedule would be the same as those given in the first brief report:

- 04 06 2018 – 10 06 2018 – Preparation of the model to be tested and its instrumentation and checking of the functioning of the installed sensors.
- 11 06 2018 –*Beginning of testing of the model*.
- 13 06 2018 – Completion of the tests on the first model.
- 25 07 2018 – 25 08 2018 – Beginning of construction and completion of the second model.
- 03 09 – 08 09 2018 – Instrumentation of the second model.
- 10 09 2018 – *Beginning of testing of the second model.*
- 11 09 2018 – Completion of tests on the second model.
    - 12 09 – 12 11 2018 – Processing of the results and preparation of the report on the tested second model
    - 13 11 2018 – 13 02 2019 – Numerical Analyses of the tested model
    - 14 02 2019 – Workshop and presentation of the results.
    - 15 02 2019 – END OF THE FIRST PROJECT
    - 16 02 2019 – 02 01 2020 – Preparation of papers and reporting of the results at conferences and in international journals.

However, in the last email sent by the leader of the group – Prof. Dr. Tatijana Isakovic, she asked the first experiment to be carried out in the second half of September, if possible, while the second experiment, namely, the testing of the second model to be done in November. At the moment, it has still not been decided whether the tests of the models will be postponed since there is a danger of overlapping of the activities of the first project with the activities of the project that would be selected after the second SERA call and would be possibly carried out at DYNLAB.

It should be noted that the resources provided for the travel and local costs of the members of the user group are insufficient, because for the three SERA projects a maximum allocated amount is 12 500 Eur. The estimation of the cost for the users of this project is minimum 5500 Eur.

7.1.5 User Group

	NAME	ORGANIZATION NAME	ORGANIZATION COUNTRY
USER GROUP LEADER	Tatijana Isakovic	University of Ljubljana, Faculty of Civil and Geodetic Engineering	Slovenia
ADDITIONAL USERS	Matej Fischinger Aleŝ Jamŝek	University of Ljubljana, Faculty of Civil and Geodetic Engineering	Slovenia
	John Wallace Kristijan Kolozvari	University of California, Los Angeles, Department of Civil Engineering	CA

8 Cambridge University

Cambridge University offers transnational access under the SERA project to the 10m diameter Turner beam centrifuge housed at the Schofield Centre for Geotechnical Process and Construction modelling. This large centrifuge allows small scale models to experience the same stresses and strains as full-size prototype structures and hence to show prototype behaviour even with the non-linear stress-strain behaviour of soils. The centrifuge can also carry earthquake shakers; either a Stored Angular Momentum shaker (SAM) which generates approximately sinusoidal motions or a more modern servo-hydraulic shaker allowing uni-directional shaking with a controllable waveform to be imparted on the model.

Cambridge University offered 49 access days under the SERA with the expectation that these would be split between 4 or 5 projects. In the first round of project allocations, two projects were approved, STILUS being allocated 14 days and SSP 15 days.

8.1 Structure-Tunnel Interaction in LiqUefiable Sand (STILUS)

8.1.1 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 proposed research intends to investigate this problem through a series of centrifuge tests. These will be carried out on a reduced scale model of a typical case of a cut-and-cover tunnel in urban environment. A rectangular model tunnel will be embedded in a liquefiable layer of sand. A model building will be founded close to it. Furthermore, a possible remedial technique to reduce both tunnel and building movements will be modelled in some tests, by mixing a nano-clay to a volume of sand, either beneath the tunnel or the building, thus lowering the potential of soil liquefaction.

The study will contribute to the wider topic of the resilience of urban environment to natural hazards, and to earthquake-induced soil liquefaction specifically.

8.1.2 Test specimen

The model will be 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 will consist of homogenous Hostun sand at a relative density of about 40%. This will be 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 will be deployed at the desired locations. Displacement transducers (LVDTs) will be used to measure the settlements at different locations.

During model preparation a model tunnel will be embedded in the sand layer (see the list of tests later on). The rectangular model tunnel will be made using an extruded section of aluminium alloy. Rough dimensions are provided in the sketches of figure 1. The rectangular tunnel will represent a section of a metro station tunnel that can accommodate two separate platforms. The soil cover above the tunnel corresponds to an embedment ratio $C/H_T = 0.5$.

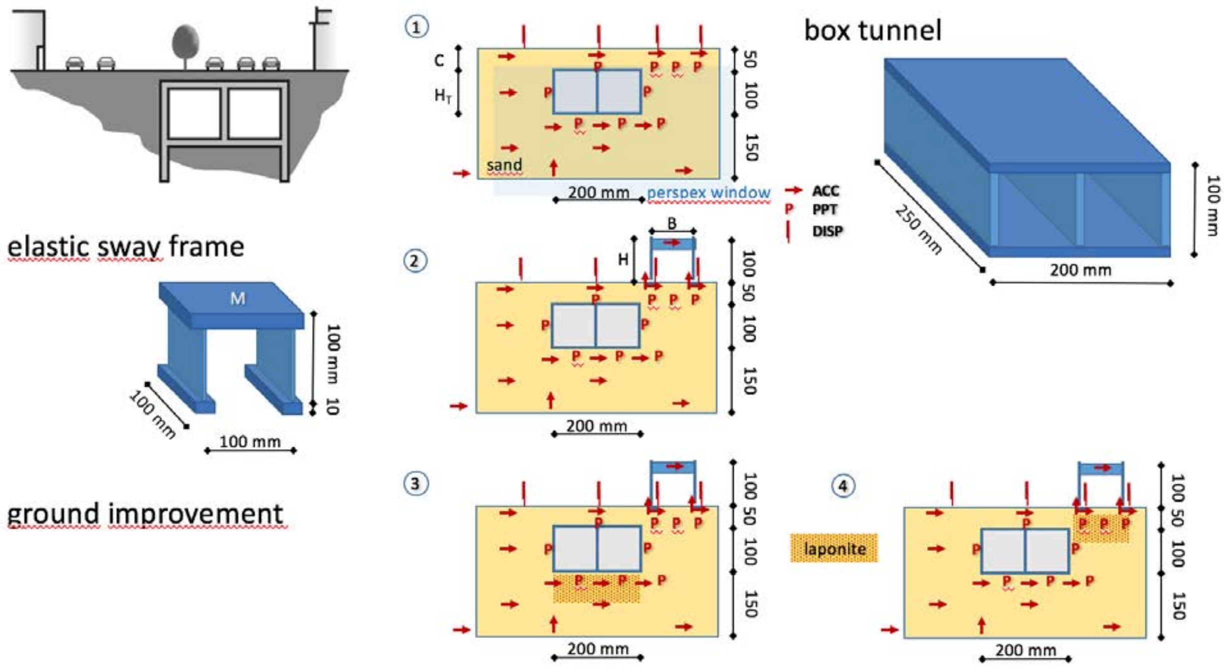


Figure 42

8.1.3 Testing program

In total 4 centrifuge models will be tested (Fig. 1), 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.

The stored angular momentum (SAM) earthquake actuator will be 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 will be 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) will be monitored.

In the test with the Perspex window box (#1), the displacement field around the tunnel will be monitored via photogrammetry. This will enable a deep insight on the triggering of uplift and the evolution of the mechanism. This test will be 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. Moreover, its influence on the dynamic response of the sway-frame before and after liquefaction will be captured. This is an interesting side results of the experiments.

The possibility to monitor also internal forces in the tunnel lining using strain gauges will be considered, although it is not essential within the scope of this project.

In model #3 a volume of sand below the tunnel will be improved by percolating a laponite/water suspension during model making. An amount of laponite corresponding to 1% of the dry weight of sand will be mixed to water in concentration equal to 3%. This suspension is able to keep a low viscosity (similar to pure water) for a time sufficient to percolate in the sand, before it increases to larger values, thus reducing the potential of liquefaction of the sand [15].

In model #4 a similar improved volume will be located beneath the foundation level of the sway frame. A comparison among results of tests #2, #3 and #4 will enable 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.

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

The proposal intends to investigate 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 will be 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 will be varied: either a layer of sand beneath the tunnel or a layer of sand beneath the building will be improved.

8.1.5 Project status

The user agreement was signed in February 2018. Preparation for testing is ongoing

8.1.6 Foreseen activities and schedule

The 3 testing weeks for this project are anticipated to commence in September 2018 with testing being completed by February 2019.

8.1.7 User Group

	NAME	ORGANIZATION NAME	ORGANIZATION COUNTRY
USER GROUP LEADER	Emilio Bilotta	University of Napoli Federico II	Italy

8.2 Seismic behaviour of anchored Steel Sheet-Piling retaining walls

8.2.1 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 seismic actions are introduced in accordance with EN1998-5, that is 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, including 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.

More rational design procedures, based on the application of the Newmark's sliding block method, have been recently proposed within the performance-based design framework for the seismic design of both gravity and cantilevered retaining structures. In this context, the critical (yield) acceleration is the key parameter controlling both the maximum internal forces in the wall and the permanent displacements induced by the design earthquake. 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 (usually a homogeneous layer) and the hydraulic and kinematic boundary conditions, and the dynamic input motion are controlled and well defined.

The main objective of this project is to provide 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 will be carried out at the University of Cambridge, considering different layouts and input earthquakes. The experimental results will allow 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 mechanism can affect the overall observed behaviour. Moreover, based on the experimental outcome, new theoretical methods will be explored for the seismic design of anchored SSP walls.

8.2.2 Test specimen

Four dynamic centrifuge tests will be carried out in the 10 m diameter Turner beam centrifuge of the University of Cambridge, all prepared using dry sand.

The tests will be carried out at a centrifugal acceleration of 60g, preparing the models within a dry medium dense sand layer (DR = 50%), in plane strain conditions.

A fine-grained siliceous Hostun sand will be used to form the models, whose mechanical behaviour under monotonic, cyclic and dynamic loading conditions is well characterized in the scientific literature. Both the retaining wall and the anchor plate will be modelled using aluminium alloy plates with a bending stiffness at prototype scale similar to that of an AZ25 steel sheet pile profile, while the anchor rods will be modelled by means of aluminium alloy rods hinged to both ends in order to do not transfer bending moment.

The models will be 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 will be included between the rigid end walls and the soil in order to prevent generation of P-waves and multiple wave reflection during shaking (absorbing boundary).

As far as the instrumentation is concerned, accelerations at different locations in the model will be measured using miniaturized piezoelectric accelerometers, while horizontal and vertical accelerations of the wall will be recorded using MEMS accelerometers, capable of measuring the dynamic acceleration as well as the static acceleration due to gravity and centrifuge swing up; displacements will be measured using LVDTs transducers; the axial load in the anchors will be measured using miniature load cells located in the mid-section of each rod, while strain gauges will be used to measure the bending moments of the wall; finally, a fast digital camera will be used for the PIV analysis.

The dynamic input will be provided by the Servo-Hydraulic earthquake actuator, capable of applying both trains of approximately sinusoidal waves with different nominal frequencies and amplitudes, and more realistic earthquake motions. The underlying idea is to identify first the main physical mechanisms occurring in the soil-anchor-wall system under a simplified dynamic loading, and then to extend the experimental observations to more realistic dynamic conditions.

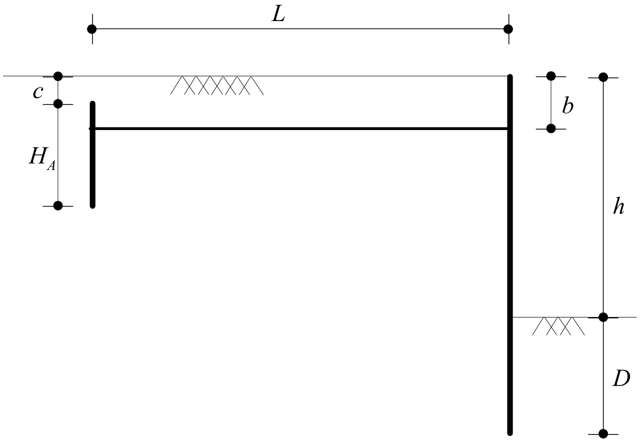


Figure 43: (a) Layout of the wall-anchor system in the centrifuge tests

Table 1: Main geometric parameters at prototype scale.

TEST	SSP1	SSP2	SSP3	SSP4
H [M]	8.00	8.00	8.00	8.00
B [M]	1.00	2.25	1.00	1.00

D [M]	3.75	3.75	5.25	3.75
C [M]	0.50	0.50	0.50	0.50
H_A [M]	3.50	3.50	3.50	5.00
L [M]	15.00	15.00	15.00	15.00
D_R [%]	40	40	40	40
ACTUATOR	SHyd	SHyd	SHyd	SHyd

8.2.3 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.

Define and validate theoretical methods for computing the critical acceleration of the wall, based on limit analysis and/or limit equilibrium approaches, taking into account possible global and local failure mechanisms (failure of the anchor system or full mobilization of the soil passive resistance in front of the wall).

In order to fulfil the first two objectives, four dynamic centrifuge tests will be carried out in the 10 m diameter Turner beam centrifuge of the University of Cambridge.

At a later stage during the project, 2D-FDM numerical simulations of the tests will be also performed to provide a more comprehensive understanding of the dynamic behaviour of SSP walls. The extensive experimental database, combined with a concurrent theoretical and numerical investigation, will allow defining new methods for computing the critical acceleration of anchored SSP walls, capable of taking into account the possible occurrence of both local and global failure mechanisms within the system.

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.

8.2.4 Project status

The user agreement was signed in February 2018. Preparation for testing is ongoing with the first test week commencing on 2nd April.

8.2.5 Foreseen activities and schedule

The first two testing weeks for this project have been scheduled for 2nd April and 14th May, with completion of testing being anticipated by September 2018.

8.2.6 User Group

	NAME	ORGANIZATION NAME	ORGANIZATION COUNTRY
USER GROUP LEADER	Riccardo Conti	Università di Roma Niccolò Cusano	Italy
ADDITIONAL USERS	Giorgio Caputo & Alessandro Fusco	Università di Roma Niccolò Cusano	Italy
	Cécile Prum & Perla El Boueiz	Arcelor Mittal	Luxembourg

9 EUROSEISTEST and EUROPROTEAS facility

This site constitutes the data dissemination portal of the EUROSEISTEST database. EUROSEISTEST is a multidisciplinary European experimental site for integrated studies in earthquake engineering, engineering seismology, seismology and soil dynamics. It is the longest running valley-instrumentation project worldwide and is located in Mygdonia valley (epicenter area of the 1978, M6.4 earthquake), about 30km to the NE of the city of Thessaloniki in northern Greece. It consists of a 3D strong motion array and an instrumented SDOF structure (EuroProteas) to perform free and forced tests.

All strong motion records that have been recorded by the EUROSEIS permanent network (network code: EG) since its establishment in 1993, are available for visualization and/or downloading (in sac, little-endian, or ascii format) through the "Database search" page. Information relative to the stations and metadata (V_S profiles, borehole data, dynamic properties of the soil etc) are also distributed (in ascii format, wherever possible) through the "Database search - Stations" page. The data of the "EuroProteas" tests are available upon request.

The database is updated each time a new event is being recorded. Check for "New Event Upload Notifications" in the "Announcements" section of this home page.

The EUROSEISTEST database web portal was greatly inspired by ITACA (http://itaca.mi.ingv.it/ItacaNet/).

9.1 On the broadband synthetic sIgnals enhanceMent for 3D Physic based numerical analysis, the EUROSEISTEST Case study (IMPEC)

9.1.1 Summary of the project

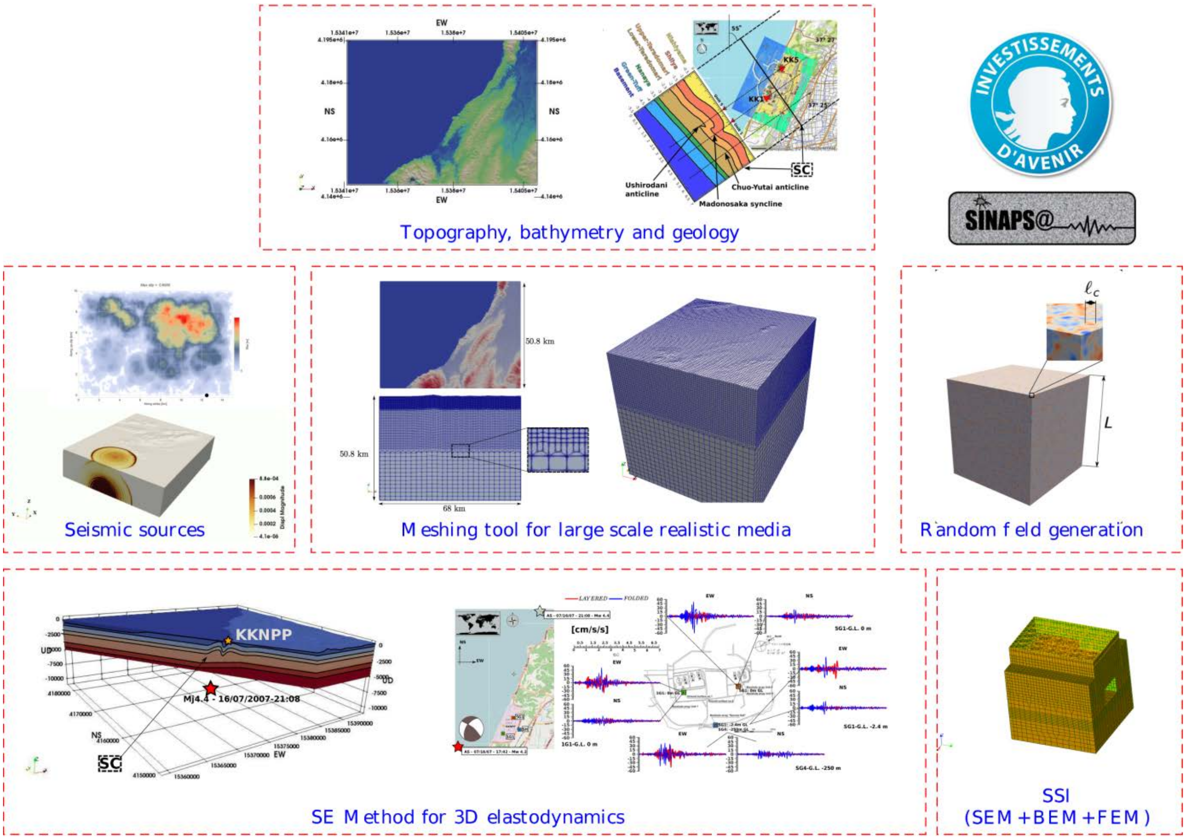
The “IMPEC - On the broadband synthetic signals enhancement for 3D Physic based numerical analysis, the EUROSEISTEST Case study” is currently ongoing. The Mygdonia valley represents a very appealing test site for the calibration and tuning of large scale numerical models of strong ground motion earthquake 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 multiscale 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 44), 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.



3D simulation of source-to-site earthquake scenario - SINAPS@ (ANR-11-RSNR-0022-04)

Figure 44: 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 (firstly introduced by Anderson and Hough, 1984). 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.

9.1.3 Project status

In the first stage of the IMPEC project, the effect of soft sediments on the dispersion of the earthquake ground motion is numerically investigated on a preliminary model of the Mygdonian basin, to assess the effects of:

- the 3-D geological interfaces
- the spatial fluctuations of the mechanical properties

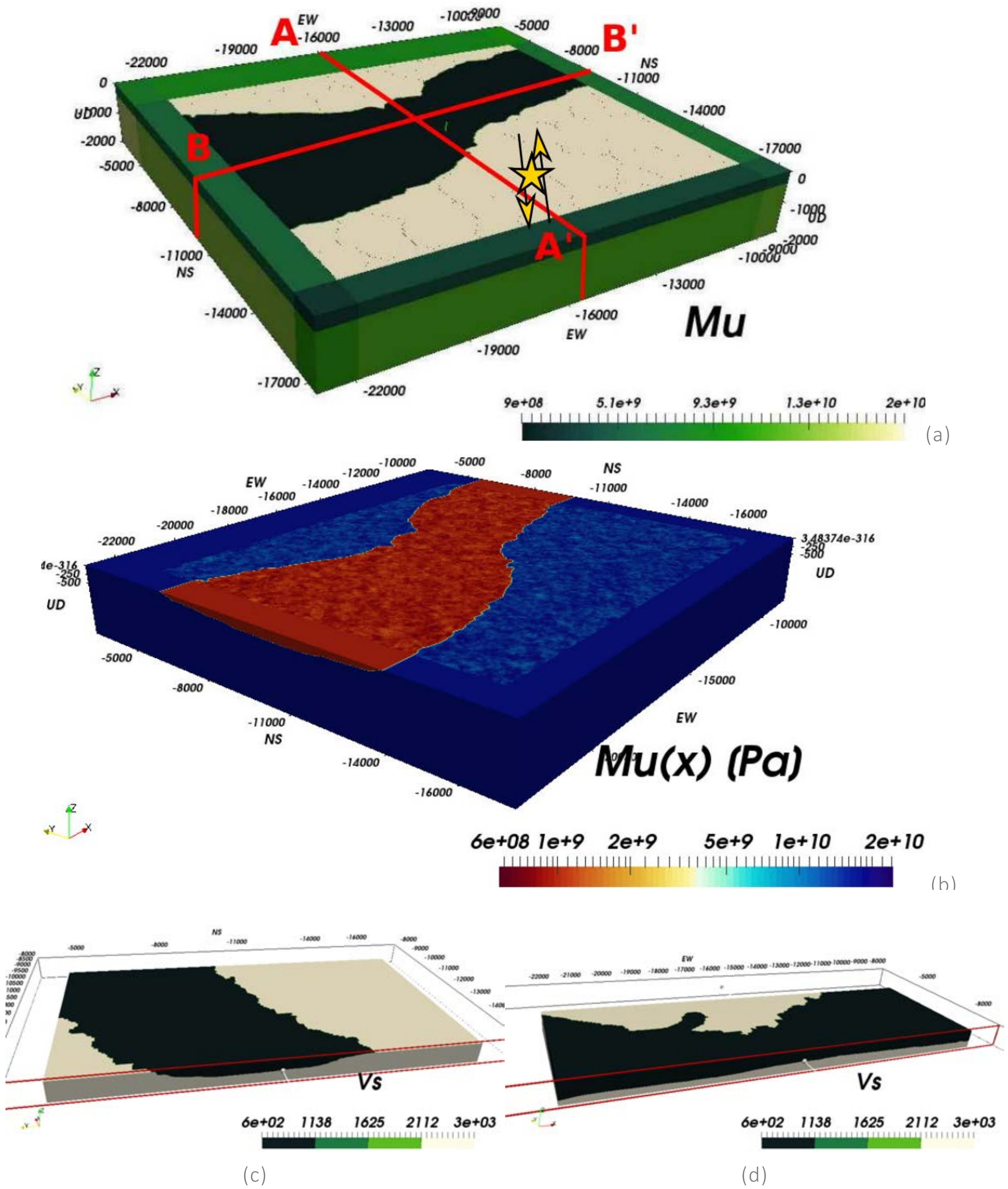
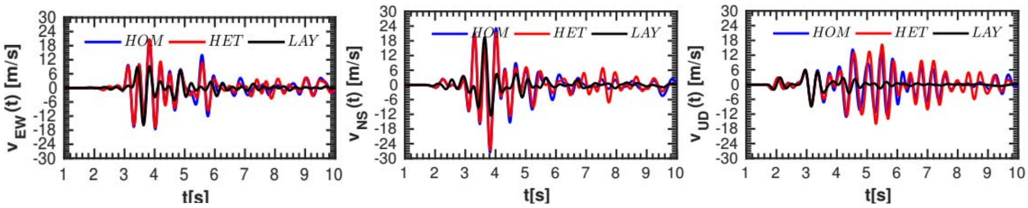


Figure 45: (a) Numerical model of the surroundings of the Mygdonian basin. (b) Example of the heterogeneous shear modulus field Mu(x). In red, the basin (average shear velocity Vs=650 m/s) and, in blue, the outcropping bedrock (average shear velocity Vs=26000 m/s. The yellow star indicates the epicenter with focal mechanism (arrows) (b) Section A-A' (EW=-16100 m, in Hatt coordinates) and B-B' (NS=-10400 m, in Hatt coordinates).

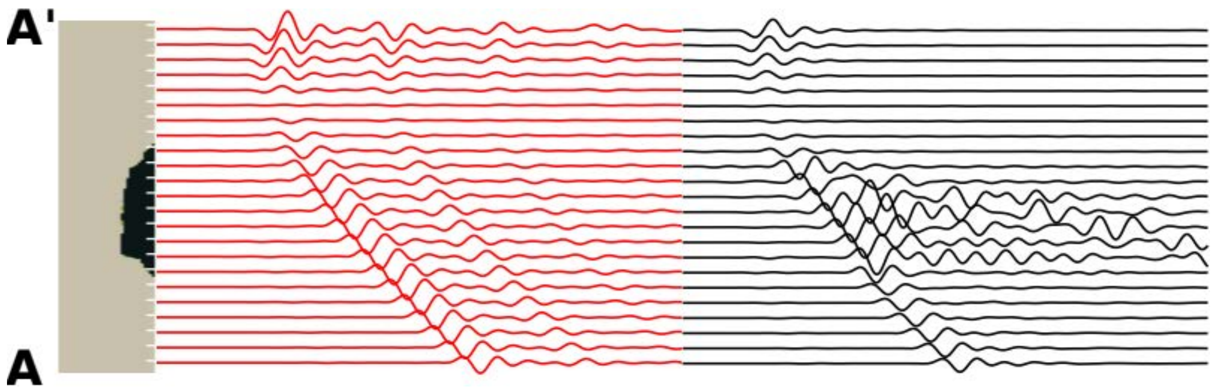
Based upon the works of Chaljub et al. 2015 and Maufroy et al. 2015 (EUROSEISTEST Verification and Validation Project, E2VP), who characterized the basin's seismic response, from an observational and numerical point of views, a source-to-site computational model was built-up (Figure 45 a). The model is configured as a 3-D soft basin embedded in outcropping bedrock and it was constructed upon the database of the EUROSEISTEST and EUROPROTEAS facility, consisting in the spatial description of the regional geological interfaces, fully characterized by Manakou et al. (2010). The available information includes the mechanical properties of three soft layers lying within the edges of the Mygdonian basin (Figure 45 c and d). The transient wave-field is accurately computed by means of SEM3D, a numerical code based on the spectral element method in elastodynamics and vectorized over large parallel supercomputers, for efficient scalability. Broad-band (0-7 Hz) earthquake simulations at regional scale (tens of kilometers) was performed, including the irregular edges of the basin and the spatial fluctuations of the mechanical properties (such as the shear modulus Mu(x), see Figure 45 b).

To integrate the complex 3-D geology into the computational grid, a not-honouring approach was employed, i.e. the geological interface was not directly meshed, but the heterogeneous mechanical properties were interpolated over the structured computational grid. No viscous dissipation was introduced at this stage. The spatial fluctuation of the shear modulus is integrated into the model as a multi-variate stationary random field, sampled at the computational nodes. An extensive comparison between three geological models of the Mygdonian basin area was outlined, namely (1) horizontally bi-layered half-space (LAY), (i.e. classical Green's function model), (2) homogeneous (HOM) 3-D basin embedded into outcropping bedrock and (3) heterogeneous (HET) 3-D basin embedded into outcropping bedrock. The effect of soil heterogeneity is compared to the homogeneous counterpart, both in terms of time histories simulated at the surface (see the velocigrams in Figure 46, the interferograms in Figure 47 and velocity contours in Figure 48) and in terms of wave motion coherency (Figure 49). The basin scatters the wave motion propagated from the point-wise source (double-couple seismic moment at 5000 m of depth, with focal mechanism Φ=22.5°, λ=0°, δ=90°), trapping the radiated energy due to the great basin-crust great impedance contrast. Moreover, the basin effect give rise to longer duration of vertical coda wave-motion at surface (Figure 46c).

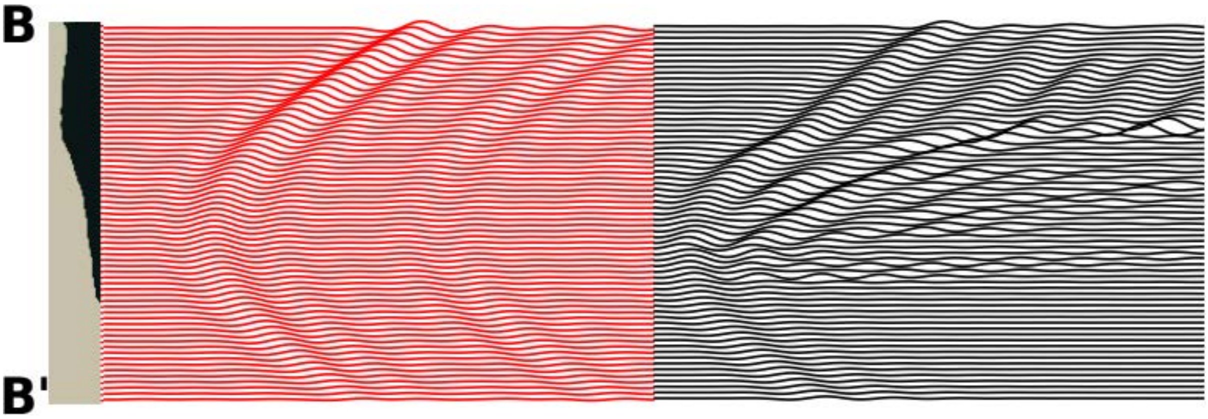


(a) (b) (c)

Figure 46: Synthetics velocigrams (filtered at 7 Hz) obtained for HOM (blue), HET (red) and LAY (black) respectively, at the intersection between sections A-A' and B-B' (EW=-16100 m, NS=-10400 m, in Hatt coordinates) correspond to EW direction (a), NS direction (b), UD direction (c) respectively.



(a)



(b)

Figure 47: Interferograms for section A-A’ (a) and section B-B’ (b). Red velocigrams refer to the layered test case; black velocigrams refer to the heterogeneous basin case.

The soil heterogeneity, on the other hand, acts at a smaller scale, inducing local scattering which however is poorly visible in this frequency range. Both the basin configuration and soil heterogeneity, however, cause a coherency drop in the wave motion at surface (Figure 49).

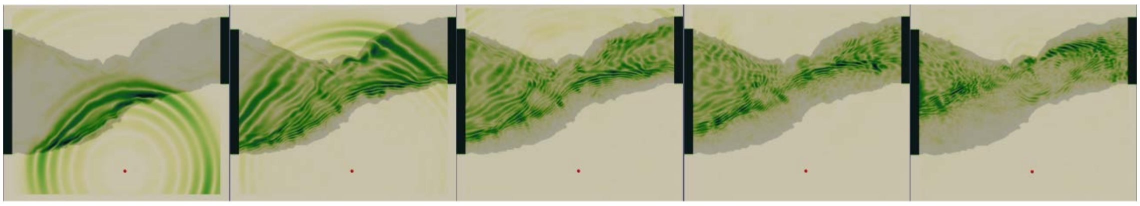


Figure 48: Horizontal velocity contours of the SEM3D simulation of the wave propagation throughout the Mygdonian basin (HET case).

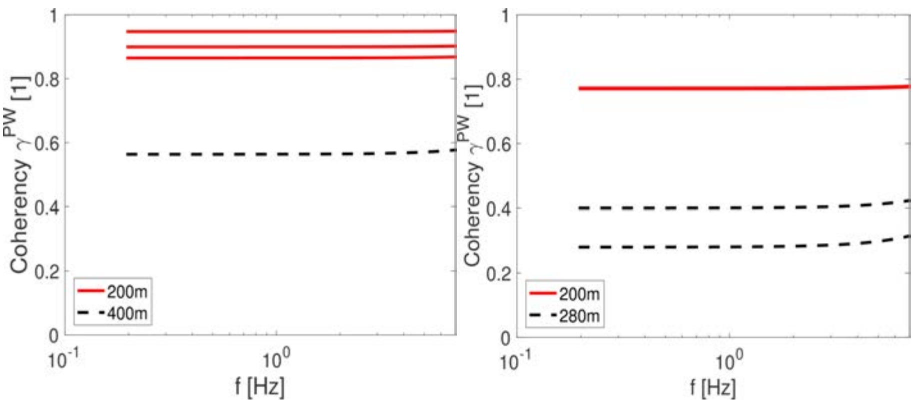


Figure 49: Plane-wave coherency curves obtained for the HET case at three stations: (a) aligned along the A-A’ section and (b) aligned along the 45◦ diagonal.

The computations were performed on the supercomputer cluster Fusion, held by the Université Paris Saclay. This first attempt to predict the seismic response of the Mygdonian basin via numerical approach was object of a conference paper, submitted at NUMGE2018 (9th European Conference on Numerical Methods in Geotechnical Engineering in Porto, Portugal, 25 - 27 June 2018).

9.1.4 Foreseen activities and schedule

As future developments, the softer basin layers will be included in the analysis, along with an increased frequency range to be able to follow the coherency drop broad-band and specify the role of the soil heterogeneity at higher frequencies. Moreover, we aim at extending the basin model so to enlarge the area of study and include the whole 3-D geological interfaces, i.e. the site is located at the center of the Mygdonian sedimentary basin between the Volvi and Lagada lakes, in the epicentral area of the magnitude 6.5 event that occurred in 1978 and damaged the city of Thessaloniki. The Mygdonian basin has been extensively investigated within the framework of various European projects (Pitilakis et al., 2009).

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9.1.5 User Group

	NAME	ORGANIZATION NAME	ORGANIZATION COUNTRY
USER GROUP LEADER	Fernando LOPEZ-CABALLERO	CentraleSupélec	France
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10 NORSAR

NORSAR is the premier operator of seismological arrays in Europe and a worldleader 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 a 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 one research visit. Three research visits are planned for 2018 and 2019 each and a last one for the beginning of 2020.

10.1 Blind beamforming in array processing

10.1.1 Summary of the project

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.

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

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.

10.1.3 Project status

The one-month long research visit was in November 2016 and is finished.

10.1.4 Foreseen activities and schedule

Wrapping up the results and present them at international conferences and prepare a publication.

10.1.5 User Group

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