Seismic Engineering Research Infrastructures for European Synergies (SERIES)

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SUMMARY:
Through the 4-year project SERIES (Seismic Engineering Research Infrastructures for European Synergies) of the 7th Framework Programme for Research (2007-2013), the European Community brought together Europe's research infrastructures in structural and geotechnical earthquake engineering into a seamless and sustainable platform of co-operation and outreach to Europe’s community of science, technology and practice in earthquake engineering to share their experimental capabilities and the fruits of their research. It also helps them to enhance their potential, by jointly developing novel seismic testing systems and techniques, e.g., a novel hybrid actuation system in which a high capacity electric actuator improves the high-frequency fidelity of a servo-hydraulic one; novel instrumentation, data processing and modelling to support of seismic testing and advanced experimental techniques for soil Soil-Structure-Interaction studies, including Fast Hybrid Testing.

Keywords: European seismic research, Framework Programme 7, Research Infrastructures, Seismic testing

1. INTRODUCTION AND OVERVIEW

Despite large investments over the past decades, European seismic engineering research suffers from extreme fragmentation of Research Infrastructures (RI) between countries and limited access to them by the scientific earthquake engineering community, especially that of Europe's most seismic regions. There is no hub for seismic engineering research, because individually none of Europe's research infrastructures has the critical mass of people and the broad range of experimental capability or expertise needed for major breakthroughs in the state-of-the-art. The European Community (EC) aims to bolster the efficiency of research facilities and human capital in earthquake engineering through sharing of infrastructures and resources across Europe in the framework of the four-year project SERIES (Seismic Engineering Research Infrastructures for European Synergies) of its 7th Framework Programme for Research (2007-2013).

The SERIES project addresses the fragmentation, inefficiency and sub-optimal use of European research infrastructures by creating a 23-strong partnership of the major European players in earthquake engineering and opening up the major research infrastructures to the wider European earthquake engineering research community. SERIES integrates that community via a portfolio of:

- Networking Activities (NA): a large distributed database of test results; telepresence in testing; standards, protocols and criteria for qualification of seismic research infrastructures; training of users of these infrastructures; ability for geographically distributed concurrent testing; collaboration with national and international initiatives; dissemination through four international workshops, etc.
- Free-of-charge Transnational Access (TA) and support to European researchers to carry out experimental research at EU's four largest shaking tables, EU's largest reaction wall and pseudodynamic (PsD) testing facility and two unique centrifuge test facilities.
- Joint Research Activities (JRA) toward new fundamental technologies and techniques for efficient and joint use of seismic research infrastructures, in areas where the consortium excels at world level: new-generation electro-dynamic actuators (including coupling with hydraulic ones) for high-

performance, enhanced-quality real-time testing; new instrumentation and sensors for improved sensing and test control; dedicated software for data collection, processing and communication, serving current needs for model calibration and interpretation of structural response; data assimilation and model updating for virtual models of equipment-specimen systems; use of recent advances in control, to reduce calibration pre-tests, optimise instrumentation and improve the quality of results; new capabilities and techniques for experimental study of soil-structure-interaction and seismic wave propagation phenomena.

2. THE CONSORTIUM

The Consortium (see Table 2.1) comprises essentially all experimental research infrastructures in Europe in the fields of structural or geotechnical earthquake engineering. Its 20 laboratories cover in a complementary way the full range of seismic testing techniques and capabilities:

- Pseudo-dynamic testing at eight Reaction Wall facilities, including EU's largest at ELSA/JRC;
- Shaking Table testing at 10 facilities with diverse capabilities and technical characteristics, some of them of world-class.
- Centrifuge Testing at two world-class, pioneering geotechnical laboratories;
- a dedicated Testing System for Seismic Bearings and Isolation/Dissipation Devices;
- an Experimental Test Site for site effects and wave propagation.

In addition, the Consortium includes three private industrial partners (two design and consulting firms and a consultancy and laboratory firm), with large experience and expertise in seismic applications.

Table 2.1. Composition of the Consortium

University of Patras *	GR
Aristotle University of Thessaloniki	GR
Commissariat Énergie Atomique (CEA) ‡	FR
Centro Europeo di Formazione e Ricerca in Ingegneria Sismica (EUCENTRE) ‡	IT
Géodynamique et Structure (GDS)	FR
Technical University of Istanbul (ITU)	TR
Institute of Earthquake Engineering and Engineering Seismology (IZIIS)	MK
ELSA, JRC (Ispra) ‡	EC/IT
Bogazici University - Kandilli Observatory and Earthquake Research Institute (KOERI)	TR
Institut Francais des Sciences et Technologies des Transports, de L'Amenagement et des Reseaux (IFSTTAR - formerly LCPC) ‡	FR
Laboratório Nacional de Engenharia Civil (LNEC) ‡	PT
Middle East Technical University (METU)	TR
National Technical University of Athens (NTUA)	GR
P&P LMC Srl	IT
Technical University 'Gheorghe Asachi' of Iasi	RO
University of Cambridge ‡	UK
University of Ljubljana	SI
Universita degli Studi di Napoli Federico II	IT
Universität Kassel	GE
Universitá degli Studi di Trento	IT
University of Bristol ‡	UK
University of Oxford ‡	UK
VCE Holding GmbH (VCE)	AT

* Co-ordinator
‡ Facility offering Transnational Access (TA) to Users

3. OVERVIEW OF NETWORKING ACTIVITIES (NA)

The networking activities of the project have a two-pronged strategy, aiming at:

- reaching out to Europe's widest possible community of science, technology and practice in

earthquake engineering, to spread the outcomes of the research infrastructures, increase awareness of their capabilities and attract users to benefit from them during and after the project; and
- establishing a seamless and sustainable platform of co-operation between the European research infrastructures in earthquake engineering, developing synergies and complementarities between them and fostering their joint development in terms of performance and access, and

The outreach to the European scientific, technical and professional earthquake engineering community is pursued through:
- the European Association of Earthquake Engineering (EAEE);
- the European bodies in charge of drafting and maintaining Eurocode 8;
- the European Earthquake Protection Initiative (EEPI);
- the international federation for structural concrete, *fib*;
- the project's four international open Workshops, organised in Iasi (RO) in 2009, in Ohrid (MK) in 2010 - in conjunction with the 14th European Conference on Earthquake Engineering - in Istanbul in 2012 and at the JRC in Ispra (IT) in 2013, the latter being a joint effort with US-NEEs.
- liaison with relevant national networks, such as ReLUIS in Italy and UK-NEES.

The platform of co-operation between the research infrastructures comprises:
- A corporate web-portal (www.series.upatras.gr) as the central contact point for SERIES and main reference point for research infrastructures in earthquake engineering in Europe, during the project and afterwards. It provides education and dissemination material, information on transnational access, workshop details, telepresence in experimental activities, repository of scientific knowledge (including that generated during SERIES), information on the qualification of research infrastructures, etc., and, most important, access to the distributed database highlighted below.
- A distributed database of experimental information, whereby the data stay at the individual facility and a communication protocol ensures their transfer to the end user in a common language and format. It will contain experimental data and all supporting documentation: data generated by the research infrastructures during SERIES (TA projects included), past data from the very research infrastructures and from literature, and new data uploaded in the future. It aspires to become the world's largest source of experimental information in earthquake engineering. It will provide real-time access to data generated during experimental campaigns and on-line access and interaction through telepresence and distributed testing. Details about the progress till early 2012 in the construction and operation of the database and in telepresence are given in (Bosi at al, 2012).
- Capability for geographically distributed concurrent testing at several research infrastructures, enlarging their individual capabilities and profiting from their complementarities (see Bosi at al, 2012, for details). It will encompass research infrastructures possessing Reaction Walls and PsD testing capabilities, large or small. Compounded with training of beneficiaries' technical and research personnel on advances in testing and good practice in operation of research infrastructures, it will pave the way for up-and-coming ones to develop further in the framework of a dynamic map of research infrastructures in Europe.
- A common protocol for qualification of earthquake engineering research infrastructures in Europe.

Since (Bosi at al, 2012) deal in detail with the second and most of the third bullet point above, the rest of this Section highlights the efforts and the progress towards qualification of earthquake engineering research infrastructures in Europe. These efforts are guided by the pursuit of reliability of testing, via repeatability (i.e., the principle that experimental activities repeated on the same specimen in the same laboratory lead to the same results) and reproducibility (i.e., the principle that experimental activities repeated on the same specimen in different laboratories lead to the same results). Besides establishing the general reliability of structural testing in Europe, a common platform for qualification will significantly enhance the expertise of testing facilities, as a result of the continuous benchmarking of similar laboratories.

The efforts within SERIES towards qualification of earthquake engineering research infrastructures addressed first the assessment criteria for their technical competence, in order to develop the basis for their mutual accreditation. Data were collected on the testing procedures used for seismic experimentation and the laboratory use and management of instrumentation to support it (Zola and Taylor, 2011, Kurç et al, 2011). Questionnaires were established to this end on the basis of the EN ISO/IEC 17025 Standard, one for each of the four different types of seismic testing facilities; they were widely diffused to large testing research facilities, national accreditation or standardization bodies, industrial organizations involved in the seismic qualification of products and in seismic research activities, collected and processed. A Workshop was held on the "Qualification of Research Infrastructures" in the framework of the International SERIES Workshop: "Role of Seismic Testing Facilities in Performance-based Earthquake Engineering" (Fardis and Rakicevic, 2012), which reached the following conclusions:

- The only applicable standards for certification/accreditation are ISO 9001 and EN ISO/IEC 17025.
- Industry needs:
  - Qualified testing facilities per ISO 9001 and EN ISO/IEC 17025;
  - Standardized test methods and estimates of measurement uncertainty.
- As reference for accreditation may serve the European cooperation for Accreditation (which manages a peer evaluation system among national accreditation bodies from the EU Member States and other European countries) and national accreditation bodies (nb. the International Laboratory Accreditation Cooperation, together with the International Accreditation Forum, manage the mutual agreements at international level).
- The European seismic testing facilities lack official certification but have a Quality Management System and meet most accreditation requirements per EN ISO/IEC 17025
- Specific standards for qualification of seismic research (testing) facilities need to be developed.
- Some standards for seismic testing of certain types of structural components exist. However, more are needed, especially for structural systems.
- A Common Protocol for the qualification of seismic research testing facilities is a proper step towards the ultimate goal of their official accreditation, according to standards to be developed.

Other important points emerging from the Workshop are (Zola and Taylor, 2011):

- To qualify a laboratory requires demonstrating its competence to conduct testing; for international recognition, the demonstration should be done by an "accredited Third Party".
- Basic methods for the determination of repeatability and reproducibility are given by international standards. To enable high repeatability and reproducibility, common standard test methods should be used. Nevertheless, this is only one of the requirements for the qualification.
- For the management of testing equipment, common standard procedures are not required; each laboratory may adopt its own procedures.
- REGULATION (EC) No 765/2008 gives the rules for product certification, but neither it nor the CE marking do pertain to research activities.
- The qualification of a laboratory could be performed on the base of a specific agreement with each client; however, this procedure does not guarantee the mutual international recognition of the research laboratories qualification.
- Inter-laboratory comparison is a suitable tool to validate internal testing methods and assess measurements traceability; however, it is only one of the requirements for the qualification.
- Proficiency testing requires time and money, which will contribute to the increase of the management costs of the laboratories. This is against the demand from industry for low test pricing.
- The cost of the initial accreditation is about 50,000 €; the maintenance of the accreditation may cost about 10,000 €/year.
- University Laboratories offering services to industry, also require a third party certification.
- Current standardized test methods tend to impose a generic set of requirements, not necessarily relevant to the particular test specimen in question; thus, unnecessary tests might be conducted, posing unnecessary costs and demands on the specimen. Standardized test programmes do not always test the specimen under the seismic conditions it might actually be exposed to in service. Performance based approaches in earthquake engineering may be used to tailor the test programme to achieved performance outcomes that are explicitly defined for the particular test specimen. The standardization would be in the generic process that establishes and justifies the performance outcomes and the test programme that achieves them; the test programme could still default to existing standards if appropriate, but this would be come about as the result of an explicit, rational

decision. A performance-based approach opens the door to cost efficiencies and better focused test programmes. However, these concepts are still novel and require detailed development and evaluation before they can be promoted and adopted as an alternative to the current standardized approaches. They would also involve wider training in performance-based thinking and approaches amongst clients, consultants and test engineers.

With the above baseline, a draft Common Protocol has been produced for the qualification of research infrastructures in earthquake engineering. It gives in detail the technical rules and the quality assurance approach to be adopted as a condition for mutual accreditation of a seismic testing engineering laboratory. It is supplemented by the necessary technical guidance and recommendations, in the form of five Technical Annexes. SERIES research infrastructures have started implementing the protocol in their laboratories, on a voluntary and pilot basis, to identify potential difficulties in its application. On the basis of the lessons learned, the draft protocol will be revised into a final Common Protocol for the qualification of research infrastructures in earthquake engineering.

4. TRANSNATIONAL ACCESS (TA)

TA opportunities in SERIES were publicized from the outset via: a) direct circular emailing from the co-ordinator to over 500 potential TA Users throughout Europe, b) the websites of the project and of the seven research infrastructures offering TA, c) the international Workshop "Opportunities for users to access European research infrastructures in earthquake engineering" in Iasi (RO) in July 2009, and d) the European Association of Earthquake Engineering (EAEE). The calls are open to international teams of researchers established in a European country, who count not as representatives of their Organisation but as individuals. The team is represented to SERIES by its "Lead User", who, although is not a PI (Principal Investigator), cannot be established in the same country as the TA facility. Five calls for proposals have been made. Right after a call's deadline, the full proposals are sent to the members of a 11-strong User Selection Panel (USP), comprising the co-ordinator, one representative from each of the seven TA facilities and three high-level external experts. Few days after, the USP meets to discuss and debate each individual proposal. After each discussion, every USP member present grades secretly the proposal according to a set of 13 weighted criteria. In addition to the proposal's scientific merit and originality, the proposing team's quality, size and internationality, these criteria consider - negatively - the use of the TA facility by anyone in the user group in the past (even before SERIES) and the availability of similar research infrastructures in any of the users' countries (both). If the USP-average in a single criterion is below 6 out of 10, the proposal is rejected. Non-rejected proposals are accepted, unless the TA facility exceeds the limit of "access days" it can provide to TA Users according to the EC Grant Agreement (during an "access day" the main equipment to be used for testing - the shaking table, the bucket of the centrifuge, the PsD actuators and control system, etc. - is exclusively occupied by the specific TA project, normally with the structural control and the data acquisition systems hooked up to the loading system and the instrumentation, respectively). The "Lead User" of a successful proposal is called to conclude with the TA facility a TA Contract Agreement, delineating the tasks and responsibilities of the two sides and the technical details of the project to be carried out, etc. It is via this Agreement that the general terms of the SERIES EC Grant Agreement are extended from the TA facility to the team of TA Users.

Free-of-charge services offered to the TA Users include:
- technical assistance for definition and design of the test model and set-up and of the input signals;
- fabrication of the test models and preliminary tests for material properties, as relevant;
- technical assistance in the design, calibration and implementation of the instrumentation;
- data acquisition systems, visual records of the model before, during and after testing;
- use of analytical tools for the design of the model and the test campaign and for pre-test analysis;
- data processing, analysis and repository system accessed via Internet, interpretation of test results;
- training specific to the Users' interest and the TA project, as relevant to the TA facility;
- a test report co-authored by the Users;
- travel and subsistence for short stays.

Table 4.1. Transnational Access (TA) projects (as of September 2012)

Project	**Lead User**	**TA facility**	**Testing**	**Status**
Seismic retrofitting of RC frames with RC infilling (SERFIN)	C.Chrysostomou, Cyprus Un. Tech. (CY)	ELSA/JRC	Reaction wall –PsD	Tests completed
Seismic vulnerability of old RC viaduct with frame piers - Effectiveness of isolation systems	F. Paolacci, Un. Roma Tre (IT)	ELSA/JRC	Reaction wall –PsD	Tests to start 09/12
Full-scale experimental validation of dual eccentrically braced frame with removable links	D.Dubina, Tech. Un. Timisoara (RO)	ELSA/JRC	Reaction wall –PsD	Tests to start 09/12
Polyfunctional technical textiles for protection & monitoring of masonry structures in earthquakes	L.Stempniewsky Un. Karlsruhe (GE)	EUCENTRE	Shake table	Tests completed
Seismic behaviour of structural systems composed of cast-in-situ concrete walls	S.Ivorra, Un. Alicante (ES)	EUCENTRE	Shake table	Tests completed
Seismic behaviour of mixed reinforced concrete-unreinforced masonry wall structures	K.Beyer, EPFL (CH)	EUCENTRE	Shake table	Tests completed
Experimental and numerical study of shear wall RC buildings under torsional effects	A.Yakut, METU (TR)	CEA	Shake table	Tests to start 01/13
Seismic strengthening of deficient RC buildings with ductile post-tensioned metal strips	K.Pilakoutas, Un. Sheffield (UK)	CEA	Shake table	Tests completed
Improved European design and assessment methods for concentrically-braced frames	B.Broderick, Trinity College Dublin (IR)	CEA	Shake table	Tests to start 09/12
Experimental investigation of dynamic behaviour of cantilever retaining walls	A.Evangelista - Un. Napoli (IT)	EQUALS Un. Bristol	Shear stack, Shake table	Tests completed
High-performance composite-reinforced earthquake resistant buildings with self-aligning capabilities	B. Kasal, ITAM (CZ)	EQUALS Un. Bristol	Shake table	Tests completed
Dynamic behaviour of soils reinforced with long inclusions (piles)	C.Boutin, ENTPE (FR)	EQUALS Un. Bristol	Shear stack, Shake table	Tests completed
Seismic behaviour of L- and T-shaped unreinforced masonry walls including acoustic insulation devices	H.Degee, Un. de Liège (BE)	EQUALS Un. Bristol	Shake table	Tests completed
Soil-Pile-Structure Seismic Interaction	A.L.Simonelli, Un. Sannio (IT)	EQUALS Un. Bristol	Shear stack, Shake table	Tests completed
Assessment of the seismic behaviour of flat-bottom silos containing grain-like materials	D. Foti, Un. Bari (IT)	EQUALS Un. Bristol	Shake table	Tests ongoing
Study of multi-building interactions and site-city effect through an idealized experimental model	P.Y.Bard, Un. Grenoble (FR)	EQUALS Un. Bristol	Shake table	Tests completed
Seismic performance of multi-storey timber buildings	M.Piazza & R.Tomasi, Un. Trento (IT)	LNEC	Shake table	Tests ongoing
Tests of historic architecture retrofitted with energy dissipators	D.D'Ayala, Un. Bath (UK)	LNEC	Shake table	Tests ongoing
Full scale testing of modern unreinforced thermal insulation clay block masonry houses	S.Lu, Wienerberger AG (AT)	LNEC	Shake table	Tests to start 10/12
Assessment of innovative solutions for non-load bearing masonry enclosures	E.Vintzileou, NTUA (GR)	LNEC	Shake table	Tests to start 11/12
Centrifuge modeling of dynamic behaviour of box shaped underground structures in sand	Y.Özkan, METU (TR)	IFSTTAR	Centrifuge	Tests completed
Studies of nonlinearity in soils using advanced laboratory-scaled models	G.Scarascia, Un. di Roma Sapienza (IT)	IFSTTAR	Centrifuge	Tests to start 01/13
Investigation of the seismic behaviour of shallow rectangular underground structures in soft soils	E.Rovithis, ITSAK (GR)	IFSTTAR	Centrifuge	Tests to start 01/13
Experimental verification of shallow foundation performance under earthquake-induced liquefaction	G.Bouckovalas, NTUA (GR)	Cambridge Un.	Centrifuge	Tests completed
Shallow foundations exposed to seismic liquefaction: Study of the level, mitigation of effects	P.A.Coelho, Un. Coimbra (PT)	Cambridge Un.	Centrifuge	Tests completed
Centrifuge study of seismic performance of propped flexible retaining walls embedded in saturated sand	G.Viggiani, Un. Roma Tor Vergata (IT)	Cambridge Un.	Centrifuge	Tests ongoing
Investigation of seismic behavior of shallow rectangular underground structures in soft soils	K.Pitilakis, Un. Thessaloniki (GR)	Cambridge Un.	Centrifuge	Tests ongoing

After five rounds of calls for proposals, open competitions and peer-reviewed evaluations, the seven TA facilities undertook to carry out the 27 TA projects listed in Table 4.1. The first three in the list are described in some detail by (Bosi at al, 2012) and those carried out at the EQUALS laboratory of the University of Bristol by (Taylor et al, 2012). Figures 4.1(a) and (b) shows views of the 4-storey full-scale test building of the first TA project in Table 4.1, and (c) and (d) scale models from the 4th and 5th TA projects in the list.

Figure 4.1. Views of TA test structures: (a) and (b) SERFIN; (c) "Polyfunctional ..masonry structures" (Peloso et al, 2011); (d) "Seismic ... systems composed of cast-in-situ concrete walls" (Ivorra et al, 2012)

5. OVERVIEW OF JOINT RESEARCH ACTIVITIES (JRA)

5.1. JRA1: Novel Actuation Systems for Real-Time Control

JRA1 concerns itself with the appraisal of alternatives to servo-hydraulic actuation for seismic testing, to improve fidelity and extend the scope. The performance requirements of common earthquake engineering actuation devices have been surveyed and the need for high-force electrical actuators that provide both capacity and precision has been identified. Future high-performance actuation systems may see electrical actuators as direct replacements for servo-hydraulic ones or as subcomponents in hybrid actuation systems that employ both types of actuators. Alternative actuator technologies that satisfy the performance requirements and improve the range of operation frequencies have been identified, classified and evaluated technically, alongside the problems associated with combining different technologies. Proposed improvements to servo-hydraulic test systems include:

- a novel dual manifold servovalve, combining a high-flow servovalve with a high-speed, low-flow one for an overall performance where high-frequency, small-amplitude motions can be superimposed on large amplitude, lower-frequency motions;
- a novel asymmetric tandem actuator with less energy demand for fatigue testing;
- Reichert's directly controlled piezo-servovalve with many desirable features, but needing further testing to assess its suitability for seismic structural testing; and
- a novel design hybrid actuator with piezo-actuators inside the cylinder of a servo-hydraulic one to impose small, high-frequency changes on the oil volume to improve the high frequency response;

As an alternative to servo-hydraulic systems, two types of electrical actuators have been investigated experimentally. The first one is electro-mechanical, consisting of a screw mechanism driven by an electric motor through a reduction gearbox. The second type is electro-magnetic, with the actuator piston driven directly by control of high-capacity rare-earth electro-magnets. In both cases, the load capacity of commercially available systems is limited to around 10 kN, at the bottom end of the useful range for structural testing. They are both usable with careful filtering to deal with electrical noise in instrumentation, with the electro-mechanical ones being more versatile, compact and easy to control. Finally, a high capacity electric actuator has been specified, with static and dynamic load capacities of 200 kN and 130 kN, respecively, and is being fabricated for assembly into a novel prototype hybrid actuation system in which the electric actuator improves the high-frequency fidelity of a servo-hydraulic actuator. Details of the achievements of JRA1 are given in (Taylor et al 2012).

5.2. JRA2: Advanced Sensing, Data Processing and Modelling

In short, the objectives of JRA2 are:

1. Implementation and application of new types of sensors for improved sensing and control: new types of instrumentation (wireless, fibre optics, 3D visualization tools) and techniques for measuring structural and foundation response are explored; the new instrumentation and techniques are to calibrated/validated through tests at different levels of complexity.
2. Numerical tools for processing data from experiments on structures and foundations, suitable for model calibration or specimen simulation and assessment of the uncertain propagation of random or systematic errors in computer models owing to experimental measurements; compatibility with data formats of the distributed database developed in the NAs is ensured.
3. Use of recent advances in model updating to develop complete virtual models of the test equipment-specimen-instrumentation system and use, alongside the latest advances in control, to reduce the number of calibration pre-tests and improve the quality of results.

Task 1 started with in-depth analysis of integration methods, adaptive control strategies for real-time substructuring tests, optimized PID control, internal model control, model predictive control, combined inverse-dynamics, adaptive control for instrumentation control, optical sensors for displacement measurement, wireless sensors for strain or acceleration measurements and error assessment. Control techniques were tested in real-time tests on a testing bench comprising four electro-magnetic actuators controlling four-DoF linear/non-linear systems with or without substructuring (both with monolithic and partitioned time integration algorithms using optimized PID and Internal Model Controllers), as well as on a a base-isolated structure with spherical sliding bearing, and a shaking table with substructuring. The performance of optical fibres based on FBG technique was assessed on concrete tunnel linings substructures; those of wireless MEMS for measuring strains and accelerations on one-storey, one-bay concrete structure. Measurement systems using lasers, gyroscopic sensors and vision systems were designed and used to capture displacement fields on specimens shaken on shaking tables. Vision systems, either texture- or target-tracking are employed with four cameras to measure displacements, rotations and deformations on a bridge model PsD-tested in a TA project. A vision-based displacement measurement system was developed for a medium size structural laboratory, based on a single camera system for measurement of displacements in a plane with resolution of 0.1 mm in a 0.50 m-square monitored area.

Software developed so far for data processing (Task 2) includes:
- a portable data processing tool in the LabView platform (2004) for dynamic tests;
- software for modal parameter extraction and identification of modal properties and damping from dynamic response of components and structural systems;
- a Performance-based Earthquake Engineering toolbox in Matlab, in combination with the FE-based OpenSees software, that enables identification of errors in structural models by the post-processing results of pseudo-dynamic tests;
- software for structural health monitoring of structures in situ, in order to track changes in their dynamic characteristics and detect damage with simple web tools and techniques for real-time data analysis and interpretation.
- Software for parametric or non-parametric identification of hysteretic systems, for 3D animation of modal shapes from OpenSees outputs and of real-time tests.

Progress so far for the integration of modelling tools with test equipment and for virtual model development (Task 3 above) includes:
- experimental transfer functions to identify the dynamics of shake table systems;
- an offline tuning approach of shaking tables through simplified FE models of specimens developed within the OpenSees environment.
- nonlinear identification techniques of hysteretic restoring forces for statically indeterminate building systems under earthquake excitations, verified on a four-storey concrete structure subjected to pseudo-dynamic testing.

5.3. JRA3: Testing techniques for Soil Structure Interaction (SSI) and wave propagation

This JRA3 focuses on the development of new capabilities and techniques for experimental studies of wave propagation and SSI phenomena for surface and embedded structures, beyond what is current practice of experimental research. The work pertains to the use of reaction wall and shaking table facilities in conjunction with centrifuges and field testing for assessment and calibration purposes. Strong ground motion estimates as appropriate input motion for SSI studies is part of the work.

More specific objectives include:
1. Calibration of field techniques, including permanent and temporary arrays for studying wave propagation in complex media, with emphasis on the wave field generated by the structure vibration (surface or embedded) and the study of spatial variability of ground motion.
2. Calibration of SSI test techniques through centrifuge testing.
3. Calibration of SSI test techniques by means of Pseudo-dynamic (PsD) tests.
4. Calibration of SSI test techniques by means of shaking table and fault-rupture box testing.
5. Calibration of field testing techniques to assess SSI.

All these tasks have as prerequisite a good site characterization of soil or site conditions; this task has not been individualized, but is common to all of them.

For Task 1 (wave propagation), field testing techniques have been developed to estimate shear wave velocity and shear modulus in soil formations, with emphasis on geophysical techniques and inverse analysis, including methods for estimation of wave fields propagating underneath and around oscillating structures. These techniques have been calibrated on the basis of data from centrifuge or shaking table testing and numerical modeling. Ongoing is the global validation and assessment of the efficiency of the proposed monitoring system for SSI wave fields, with quantification of the importance of various system parameters.

For Task 2 (centrifuge testing for SSI), calibration tests were carried out on single-degree-of-freedom lumped mass structures or sway-frames on dry sand of different relative densities at the two centrifuge centres, focusing on repeatability; besides, the quality of input acceleration signals in centrifuge tests, the response of the foundation soil and the super-structure and the instrumentation used were assessed and better insights into the effect of structural surcharge and soil density were gained. Ongoing is the integration of foundation response from centrifuge tests into shake table and PsD testing.

For Task 3 (PsD tests of SSI), the behaviour of shallow foundations under cyclic loading in PsD tests performed in the past at ELSA/JRC or elsewhere has been studied, with emphasis given on the identification of the non-linear mechanisms leading to the development of permanent settlements and tilt of the foundation. Further, a nonlinear macroelement has been developed for SSI in shallow foundations, capable of reproducing the observed foundation settlements and tilts in cohesive or frictional soils and of account for dynamic phenomena, like radiation damping, frequency-dependence of foundation impedance, effect of soil inertia forces, etc. The model has been validated on the basis of SSI tests carried out in a centrifuge, on a shake table or and in the field and used to formulate recommendations for a test protocol for PsD testing including SSI.

For Task 4 (shaking table and fault-rupture box testing for SSI), the impact of the stiffness and inertia of the laminates and of boundary reflections in 1g laminar boxes has been studied and a simplified methodology for their numerical simulation developed, among others, to help isolate boundary reflections effects. The Fast Hybrid Testing (FHT) technique was applied with novelties to a SSI problem in two shake table laboratories, modeling the soil numerically and the superstructure as a physical model on the shaking table. Fault rupture propagation and the interaction with foundation-structure systems were studied in a fault-rupture box and a simplified methodology was developed on the basis of numerical analyses of the interacting soil-caisson systems, to compute the faulting-induced stressing on foundation and structures. Ongoing is the study of FHT techniques using a laminar shear stack on a shaking table for the response of the soil and modeling the superstructure numerically, as well as of the need for automatic gain controllers in the adaptation process, or for systematic specimen identification to include time-varying and nonlinear (physical/numerical) sub-structures, or to investigate the control of numerical substructures with multiple degrees of freedom

For Task 5 (field testing for SSI), SSI effects on the structural response of model structures have been studied in real-scale using monitoring systems developed and validated in JRA2. The field monitoring system was further assessed under shock excitation on the basis of numerical simulation results. Real-scale field test results are compared with reduced-scale ones from centrifuge and shake table tests and numerical simulation results, for cross-assessment of the performance of these techniques.

The outcome of all the above Tasks of JRA3 will be synthesised, the capabilities and limitations of the various approaches will be examined and synergies between them will be sought to balance the limitations and recommendations will be made on how to better incorporate SSI into seismic testing.

6. CONCLUSIONS

SERIES establishes a seamless, sustainable platform of cooperation among all research infrastructures and teams in European earthquake engineering, increasing its visibility as a world leader, optimising resources and fostering integration. It is reaching out to Europe's widest possible community in earthquake engineering, to spread the outcomes of the research infrastructures, increase awareness of their capabilities and attract users to benefit from them during and after the project. It's database of seismic test results will become one of the world's top sources of information on experimental earthquake engineering, providing real-time access to data obtained in tests.

ACKNOWLEDGEMENT
This work receives funding from the European Community's 7th Framework Programme (FP7/2007-2013) under grant agreement n° 227887. The author expresses his gratitude to all partners of the SERIES Consortium for their precious contributions and excellent co-operation. Special thanks are due to O. Bursi, A. Pecker, P. Pegon, C.A. Taylor and M. Zola for a very efficient and fruitful leadership of key parts of the work and to Dr. D. Biskinis and Ms V. Vayenas for their invaluable support for the co-ordination of this challenging project.

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