

# Preliminary Report to ESFRI roadmap for the new Research Infrastructure EFAST

*EFAST project (Design Study of a European Facility for Advanced Seismic Testing)*

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# TABLE OF CONTENTS

<b>Abstract</b> .....	3
<b>Introduction</b> .....	3
<b>Seismic risk in Europe and Earthquake Engineering research needs</b> ....	5
Synthesis from “Earthquake Engineering – Vision - Strategic Research Agenda report” .....	6
Synthesis from EFAST Workshop conclusions about needs .....	9
Synthesis from EFAST Inquiry about Nuclear, Chemical and Construction Industries .....	11
<b>Technology for Seismic Testing in EU and Worldwide</b> .....	13
Synthesis from EFAST Workshop conclusions about technology .....	13
Synthesis from EFAST Inquiry about laboratories .....	14
Current and future facilities .....	16
<i>Main shaking tables in U.S.A.</i> .....	16
<i>Main shaking tables in Japan</i> .....	17
<i>Main shaking tables in Korea</i> .....	17
<i>Main shaking tables in Europe</i> .....	17
<i>Reaction walls</i> .....	18
<b>Proposed concept and strategic value of EFAST</b> .....	18
Strategic value .....	18
Conceptual and technical design studies .....	20
Integration with the existing EU e-infrastructure .....	20
Maturity of the project .....	21
<b>Expected socio-economic impacts of EFAST</b> .....	22
<b>Conclusions</b> .....	23
<b>References</b> .....	24

## ABSTRACT

The present report provides information useful for the preparation of the application of the new Research Infrastructure EFAST to the ESFRI roadmap.

A brief introduction about the EFAST project and the ESFRI open the document. Two sections follow: the first one is devoted to identify the main need in Earthquake Engineering, the second one deals with the current and future testing technologies all around the world. The proposed concept of the EFAST testing facility is then described and the main strategic values are illustrated. Economic aspects about its realisation and the positive fall down on European economy are also discussed. A section dedicated to the impact of EFAST on the scientific community and, more generally, on the whole society conclude the report.

## INTRODUCTION

EFAST (Design Study of a European Facility for Advanced Seismic Testing) is a joint project financed by the European Commission that foresees the study of all the aspects regarding the design of a major testing facility in Europe that would complement and collaborate with the existing ones. This study aims at identifying the current and future needs in the field, and proposes the concept of a facility using the best available testing technologies.

Five organisations in Europe are involved in this design study, coordinated by CEA:

- CEA (Commissariat à l'Énergie Atomique - French Atomic Energy Commission) (France)
- “Gh. Asachi” Technical University of Iasi (Romania)
- Eucentre (European Centre for Training and Research in Earthquake Engineering) (Italy)
- Kassel University (Germany)
- JRC (Joint Research Centre of the European Commission) (EC).

The above organizations have a wide experience in Earthquake Engineering, in operation of testing laboratories (JRC operates the largest reaction wall in Europe, CEA uses the largest payload shaking table) and in RTD related to seismic and dynamic testing. They are all involved in National, European or International R&D programs.

The work plan to ensure a vision of the new European large research infrastructure in earthquake engineering comprises several work packages, from which the technical ones are summarised here:

1. **Assessment of infrastructure characteristics** in order to properly design the new research infrastructure EFAST. An inquiry has been launched focused on available technologies and future needs in order to obtain a broad consensus of the scientific community in the field of earthquake engineering. A dedicated workshop was organised on the 2<sup>nd</sup> and 3<sup>rd</sup> of March 2009 at JRC in Ispra where invited attendants discussed about testing needs and methods for earthquake engineering tests. A second workshop for final assessment will be held in 2011.
2. **Testing and Simulation.** This task deeply analyses and validates advanced testing methods envisaged for this new level of infrastructure including the use of multiple

shaking tables, combination of them with reaction walls and fast hybrid and distributed tests.

3. **Technology.** This task is dedicated to enter whole definition and technical details of the European Facility for Advanced Seismic Testing.

The project has started on the 1<sup>st</sup> of September 2009 and will last for three years until the 31<sup>st</sup> of August 2011. For further information see also the EFAST website at the address <http://efast.eknowrisk.eu/EFAST/>.

This foreseen EFAST new Research Infrastructure (RI) on earthquake engineering perfectly fits into the ESFRI roadmap purposes. ESFRI, the European Strategy Forum on Research Infrastructures, is a strategic instrument to develop the scientific integration of Europe and to strengthen its international outreach. The competitive and open access to high quality Research Infrastructures supports and benchmarks the quality of the activities of European scientists, and attracts the best researchers from around the world. The mission of ESFRI is to support a coherent and strategy-led approach to policy-making on research infrastructures in Europe, and to facilitate multilateral initiatives leading to the better use and development of research infrastructures, at EU and international level.

The ESFRI Roadmap identifies new RI of pan-European interest corresponding to the long term needs of the European research communities, covering all scientific areas, regardless of possible location. Potential new RI (or major upgrade) identified are likely to be realized in the next 10 to 20 years. Therefore they may have different degrees of maturity but it should be noted that they are supported by a relevant European partnership or intergovernmental research organisation.

Project descriptions highlight the manner in which they would impact on science and technology development at international level, how they would support new ways of doing science in Europe, and how they would contribute to the enhancement of the European Research Area.

The ESFRI roadmap is an on-going process; therefore the roadmap will be periodically updated and its subsequent revisions will be considered by the different Member states as well as by the European Commission to better define priority projects to be supported at national and Community level. The process leading to the first update of the roadmap already started early 2007. For further information about ESFRI see <http://cordis.europa.eu/esfri/home.html>.

This report inserts into this stream. The EFAST project is now entering into its second year. Since the definitive design study will be ready only at the end of the project, this preliminary report does not contain yet the technical specifications.

This RI concerns the realisation of a new advanced European class shaking table laboratory together with the interfaces needed to network it to the other facilities within Europe or all around the world. The RI answers to the needs for physical tests of a broad scientific community in earthquake and structural dynamic engineering.

# SEISMIC RISK IN EUROPE AND EARTHQUAKE ENGINEERING RESEARCH NEEDS

Europe and the neighbouring countries are far from being outside the earthquake risk; the number of victims and the overall economic losses are important compared to Japan and United States. Modern society is increasingly vulnerable to external hazards. It is readily apparent that, in developed countries, although the numbers of victims of major earthquakes is tending to drop, the costs of the consequences are constantly rising. The costs of the consequences, resulting in significant damage and widespread disorganization in the area, are constantly rising. Considering damage to plants, loss of data and drops in productivity, are extremely costly. It is therefore indispensable for Europe to intensify the research and development in this field [1].

The recent seismic event in Italy (L'Aquila, 2009) has shown the high level of risk in existing built infrastructures, not only in modern cities but also in small and medium size historical urban sites, where the coexistence of old constructions with new ones, some of them being not really seismically designed, is leading to a more critical situations for human lives and economical assets.

The costs of the consequences, resulting in significant damage and widespread of losses in the area including panic and other social consequences are constantly rising. The damage to residential areas, industrial plants, lifelines and drops of productivity are extremely costly. In a new IT based environment the loss of database and other information can cause also other destructive effects on normal society functioning.

Under these circumstances, the vulnerability of whole infrastructure in urban large size cities but as well as in small and medium size urban locations, related to buildings and a whole range of industrial, transportation, including lifelines facilities, is becoming more and more a highly-important political, technical and economic issue.

In the recent decades, considerable progress in Earthquake Engineering (EE) research has been done, and the application of modern earthquake resistant design codes and procedures by engineering companies and builders, has become an effective way of avoiding major construction damage when earthquakes occur. Even though much research progress has been done, there are still research needs. As an illustration, after the recent earthquake in Italy of April 2009, many structures, including old historical monuments along with new public structures of great importance, such as hospitals and schools, after the event have encountered severe damages at levels difficult to be predicted.

Much research progress still needs to be made. Main topics of the research and development aim to improve the capability of prediction of the behaviour of new or existing structures and equipment, define reliable and economic ways of retrofit, better understand and quantify the interaction between soil and structures, organize the result of research in databases, in order to disseminate them, optimize their use, and for information feeding on risk oriented approaches. This research requires a large amount of analytical and experimental studies.

The capability of performing advanced testing techniques (such as hybrid and distributed testing) is a key innovative step of EFAST. The new RI answers to the needs of a broad scientific community in earthquake and structural dynamic engineering by gathering a large expression of the scientific community. The definition of EFAST ensures flexibility and complementarities with the existing infrastructures criteria. EFAST will become the most advanced European shaking-table infrastructure, within the European consortium of testing and simulation/computational dedicated laboratories, linked by a high-speed network as GEANT and allowing distributed tests. The upgrade/network improvement of other existing facilities will give considerable additional value to the new RI.

The EE community recognizes that the availability of high level experimental facilities is essential to meet the objectives of earthquake risk mitigation worldwide, and, to progress towards the performance based seismic design, based on recent methods for the assessment of buildings and civil infrastructures. The recent event organized within EFAST project, namely the 1<sup>st</sup> International Workshop on needs for advanced research based on modern testing platform demonstrates clearly that more progress is needed and a new platform for seismic testing in Europe is not only useful but also a real need for this purpose. Such facility will allow studying a large variety of structures and systems, being an indispensable tool to calibrate and validate the new conceptual approaches in modelling and simulations developed for performance based analysis and design and redesign of safe structures Europe wide. In order to increase world wide the European competitiveness and to fulfil the wish of building the knowledge based Europe in the field of EE, building a new modern and advanced infrastructure for research is again an urgent need.

## Synthesis from “Earthquake Engineering – Vision - Strategic Research Agenda report”

This document [1] reports an overview of the state and needs of Earthquake Engineering research in relation to Europe.

Earthquakes were the cause of more than 1.5 million deaths worldwide during the 20th century. A number of the most deadly earthquakes have occurred in Europe. Earthquakes have also caused huge economic losses which recent experience has shown are increasingly unacceptable in developed countries.

Earthquakes remain a serious threat in many parts of the EU and its regions and have continued to cause major loss of life and destruction in recent years. Moreover, earthquakes can no longer be regarded as natural disasters, since the main cause of damage —the inadequate seismic resistance of the building stock, lifelines and industry— is well understood and could be avoided.

The number of casualties which a society suffers when an earthquake occurs depends to a great extent on the state of preparedness of that society. Europe is poorly prepared as table 1, based on figures compiled by the UN, shows [3].

Disaster Risk for Earthquakes 1980-2000						
Country	Average number of events per year (event/year)	Number of people killed per year	Average number of people killed per million inhabitants	Average physical exposure per year (people/year)	Physical exposure in percentage of population (%)	Relative risk (killed/million exposed)
ITALY	0.52	225.71	3.98	1 288 265	2.27	<b>175.21</b>
TURKEY	0.76	949.86	15.58	2 745 757	4.5	<b>345.94</b>
EUROPE	2.24	1187.6	2.97	7.187.388	5.2	<b>75.89</b>
JAPAN	1.14	281.29	2.31	30 855 862	25.39	<b>9.12</b>
USA	0.48	6.52	0.03	6.745.799	2.61	<b>0.97</b>

Table 1: Earthquake events and risks per region

Note: these include events equal or greater than a magnitude 5.5 of the Richter scale.

(From: Reducing Disaster Risk, UNDP, Statistical Annex, page 143)

Based on these figures the risk of being killed by an Earthquake in Europe (including Turkey) is 8 times higher than in Japan and 80 times higher than in the United States. One of the main reasons for this difference is the major investment into earthquake research in these countries. Their budgets are 10 times bigger than the European budget (figure 1).

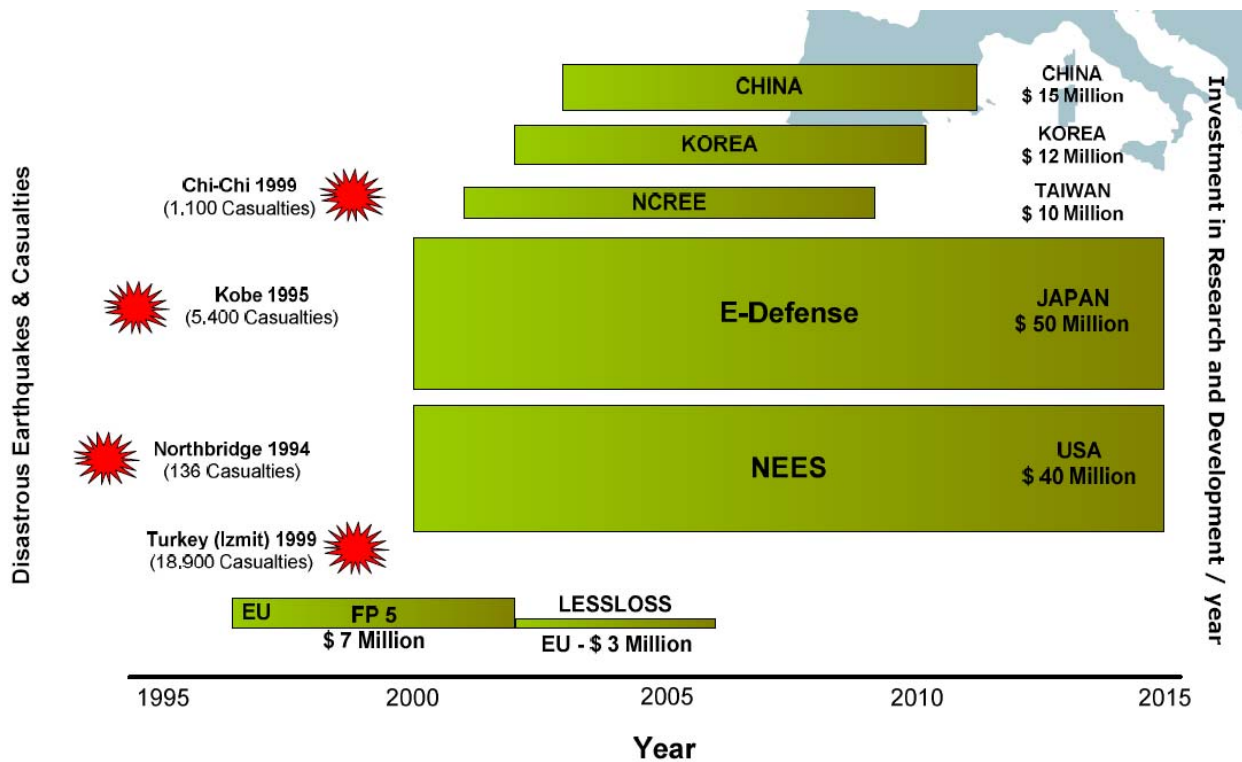


Figure 1: Annual Budget for Earthquake Engineering Research per Region (Source: VCE)

The SESAME Project [4] earthquake hazard map (figure 2) shows clearly the uneven distribution of earthquake hazard across Europe.

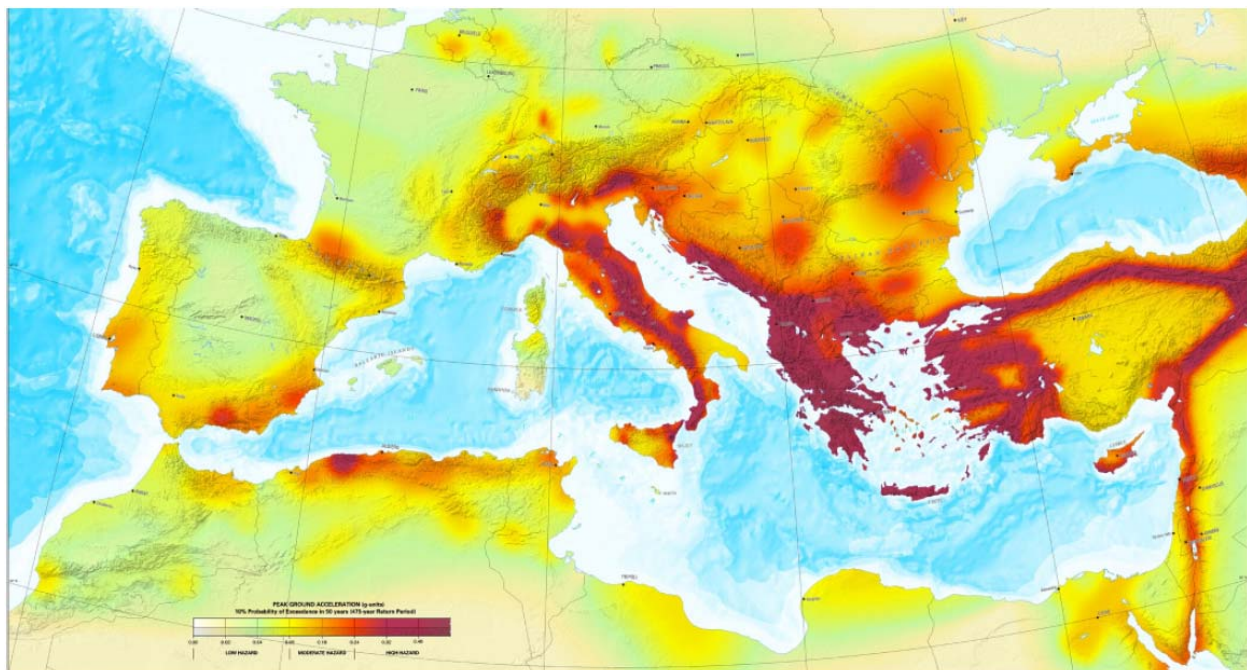


Figure 2: The 2003 SESAME Project Map of Seismic Hazard in Southern Europe and the Mediterranean. Shading shows the peak ground acceleration with a 10% exceedance probability within 500 years

Within today's EU, large parts of Italy and Greece, Slovenia, Romania and Bulgaria experience the highest seismicity, while smaller parts of Portugal, Spain, France, Germany, Austria and the Czech Republic also have significant risk. Areas of equally high and even higher risks are identifiable in some of the bordering (accession) countries, notably Turkey, which is already a part of the European Research Area. And most of the rest of the EU experiences some degree of seismic risk.

EUROCODES constitute today a coherent set of 57 standards, based on a unified philosophy of safety. In particular, the structural checks are carried out at limit states which should not be exceeded. In the set of EUROCODES, EUROCODE 8 – Design of Structures for Earthquake Resistance - plays a particular role, since it brings additional provisions to other EUROCODES to ensure the resistance and the limitation of damage in seismic situations. EUROCODE 8 covers on a rational basis a large variety of civil works conceived with the great types of structural materials covered by the other EUROCODES.

The Earthquake Engineering community widely recognizes that the availability of experimental facilities is essential to meet the objectives of earthquake risk mitigation worldwide and progress towards the performance based seismic design and assessment of buildings and civil infrastructures. Such facilities allow studying a large variety of structures and systems, and constitute an indispensable tool to calibrate the numerical models developed for analysis and design. In particular, some of these facilities, which fall into the category of large scale infrastructures, allow handling near to full-scale models of complex structures, helping to improve the understanding of the global response of building and bridge structures, and the effects of real phenomena such as soil-structure interaction.

In order to significantly improve their capacities, testing infrastructures should also allow the combination of physical testing with numerical simulation, online and offline, in a sort of “real-virtual testing environment”, where local and global, point and field measuring/visualization systems and corresponding processing can provide detailed information on demands and performance.

Among the different types of testing facilities it is possible to classify them in the following groups: shaking tables, reaction walls and centrifuges, as well laboratories in structural mechanics and field testing. All these facilities have provided so far support to the understanding and progress in earthquake resistant design and practice.

Shaking tables are used for the study and verification of the dynamic behaviour of structural elements and reduced scale models of structures, allowing the reproduction and simulation of vibration phenomena, like those induced by earthquakes. Reaction walls, on the other hand, are used to test large and real-size structures quasi-statically, whereby the earthquake effects are represented pseudo-dynamically. Centrifuges generate artificial gravitational fields with high accelerations acting on specimens fixed on a rotating arm and are mainly used, in parallel with shear stack facilities, for studies on soil-structure interaction on reduced scale models. Shaking tables, reaction walls and centrifuges are all complementary, and are used to study the earthquake behaviour of the structure and of its interaction with the soil. Figure 3 shows how these large scale infrastructures are distributed all around Europe.

Shaking Tables Labs	Reaction Walls Labs	Centrifuges Labs
<b>1</b> CEA, Saclay (France)	<b>1</b> EERC, Bristol (United Kingdom)	<b>1</b> CESTA, Le Barp (France)
<b>2</b> CEDEX, Madrid (Spain)	<b>2</b> EMPA, Duebendorf (Switzerland)	<b>2</b> Delft Geo, Delft (The Netherlands)
<b>3</b> CESI-ISMES, Seriate (Italy)	<b>3</b> ETH, Zurich (Switzerland)	<b>3</b> ETH, Zurich (Switzerland)
<b>4</b> CKTI, Saint Petersburg (Russia)	<b>4</b> EUCENTRE, Pavia (Italy)	<b>4</b> ISMES-GEO, Seriate (Italy)
<b>5</b> EERC, Bristol (United Kingdom)	<b>5</b> JRC-ELSA, Ispra (EC - Italy)	<b>5</b> LCPC, Bouguenais (France)
<b>6</b> ENEA-DIN, Rome (Italy)	<b>6</b> Univ. of Basilicata, Potenza (Italy)	<b>6</b> RU, Bochum (Germany)
<b>7</b> ESA-ESTEC, Noordwijk (The Netherlands)	<b>7</b> Univ. of Patras (Greece)	<b>7</b> UMIST, Manchester (United Kingdom)
<b>8</b> EUCENTRE / Univ. Pavia, Pavia (Italy)	<b>8</b> Univ. of Trento (Italy)	<b>8</b> Univ. of Cambridge (United Kingdom)
<b>9</b> INCERC, Iasi (Romania)		
<b>10</b> ITAM, Prague (Czech Republic)	<b>14</b> NTUA, Athens (Greece)	
<b>11</b> IZIIS-DYNLAB, Skopje (Republic of Macedonia)	<b>15</b> SP, Borås (Sweden)	
<b>12</b> KOERI, Istanbul (Turkey)	<b>16</b> TsNIISK, Moscow (Russia)	
<b>13</b> LNEC, Lisbon (Portugal)	<b>17</b> USTARCH SAV, Bratislava (Slovakia)	

Figure 3: Large-scale EE testing facilities (shaking tables, reaction walls and centrifuges) in Europe

Concerning large scale infrastructures at a global scale, there is quite a balanced distribution of shaking table and reaction wall facilities between American, Asian and European continents, which would indicate that the research communities are backed by a suitable set of such facilities, providing support to the progress on understanding and advancing earthquake resistant design and practice, training and education worldwide. However, it is known that most of these infrastructures are essentially concentrated in a small number of countries, namely USA, Japan and Italy, and that a large part of the earthquake research community does not have access to these facilities.

Moreover, the recent initiatives in the USA (NEES), Taiwan (NCREE) and Japan (E-Defense) for the upgrading and construction of new facilities are shifting the geographical balance on research infrastructures in favour of these countries. Regarding reaction walls, the ELSA of the JRC of the EC in Italy is at the forefront of capacities and technology in the world, while regarding shaking tables, Europe is missing a facility with the capacities and technology at the level of the most important ones in North America and Asia.

## Synthesis from EFAST Workshop conclusions about needs

The integral document about the 1<sup>st</sup> EFAST Workshop that was held in Ispra (Italy) on the 2<sup>nd</sup> and 3<sup>rd</sup> of March 2009 is available on the web [2]. The final section reports the emerged considerations about the testing needs inside the Earthquake Engineering community.

The emerged needs not necessary imply that the actual testing capabilities in Europe are insufficient to give a proper answer. They simply suggest what should be investigated in the field of experimental earthquake engineering. However, as a matter of fact, some of the proposed tests require a new and powerful experimental installation.

The main needs areas are:

- **Eurocodes.** National-defined parameters need a stronger validation and closer harmonization. This is a short term need in the sense that it should be fulfilled in the following years, so probably with the existing testing facilities. Nevertheless, to achieve these goals, further studies regarding assessment and retrofitting of buildings are needed. Full scale and multiple-support tests are also requested. Most of the tests on large-scale specimens are needed for demonstrative purposes and are more feasible pseudo-dynamically because of the difficulties and cost of dynamic tests on huge specimens.

In particular for **Eurocode8**, a very important issue are masonry & masonry infill structures with more than 2 storeys. These structures can be tested with the pseudodynamic method, but, because of their distributed masses, the best choice is probably to test them on a shaking table if it can be done in real size. Several tests should be conducted because of the variability of construction techniques and materials.

- **Cultural heritage** protection. There is a need to test structures retrofitted with innovative techniques. The purpose of these tests is double: on one side to test innovative materials and methods, on the other one to demonstrate their effectiveness to an enlarged community including all the actors in the field of cultural heritage protection.
- **Soil-(Foundation)-Structure Interaction (S(F)SI)** must be deeply studied. Tests must be as close as possible to real size in order to avoid scaling effects; this means using large boxes (for example: height 4 m, length 8 m, depth to be specified) + the specimen. Even with such large boxes, it is unlikely that pile tests will be feasible on a shaking table. In some cases the pseudo-dynamic method can be used or even tests can be done, with a dynamic shaker or outdoors, on a real soil to provide suitable results for calibration of numerical models. However this type of tests cannot deal with the full interaction problem since the input is imposed to the structure thus disregarding the kinematic interaction.
- **Nuclear industry.** There is a need to test structural components & equipment & processes (both for demonstrative full scale aspects and for a better understanding of the behaviour in the non-linear range). Vertical acceleration and floor amplification are very important. Due to floor amplification, components must be tested with high acceleration (4g) in the frequency range from 0.1 Hz to 50 Hz. Vertical excitation must often be taken into consideration (3D tests). The behaviour of tanks, vessels with fluids, complex connected slender structures as well as S(F)SI are some key points for nuclear industry.
- **Secondary structures** have some specific important aspects (sensitive equipments “integrated engineering systems”, high value equipment) that must be addressed. These complex structures are characterised by having multiple supports, this fact affects the overturning moment and payload.
- **Meaningful probability risk assessment.** Available actual safety margins of the structures have to be estimated. To this end, tests with high excitation level up to collapse or resulting in a relevant significant damage level must be carried out. This implies that the new facility should have the capability to reproduce high intensity excitations (high acceleration, velocity and displacement).
- **Qualification of protection devices.** This is becoming increasingly important. There are only a few high capacity demanding tests required by codes. The remaining, less demanding tests, are already carried out either by the manufacturers themselves or in the existing facilities. However Europe should get the capacity for doing also these large scale tests in the future.
- **Cooperation with emerging countries.** There is a need for these countries to have access to the facility with low cost; they should be facilitated in using European testing facilities in general.

Some needs regards the techniques and technologies associated to experimental testing activities:

- It is important to assign larger importance to pre-test, post-test and between tests **computation** in order to improve the test (design of the specimen and the set-up, analyse final but also intermediate results, assess the quality of measurement and detect probable improper function of sensors etc.). This work may be done in the experimental facility itself (if there is sufficient computational capability) or by networking in cooperation with specific centres or laboratories. This stresses the importance of networking & complementarity.
- It is very important to have a proper **acquisition system** and a proper **network of sensors**. New measurement technologies should be **also considered** that allow **field measurements** (optical measurements, but not only).
- The research community asks for **more exhaustive** and reliable results and needs to maximize the **impact of research**. To easily share the data, new “Informatics Technologies” (IT) should be adopted.
- Last but not least, a better use of **existing facilities** and **integration** with EFAST should be foreseen. Once more, the importance of networking and cooperation is pointed out.

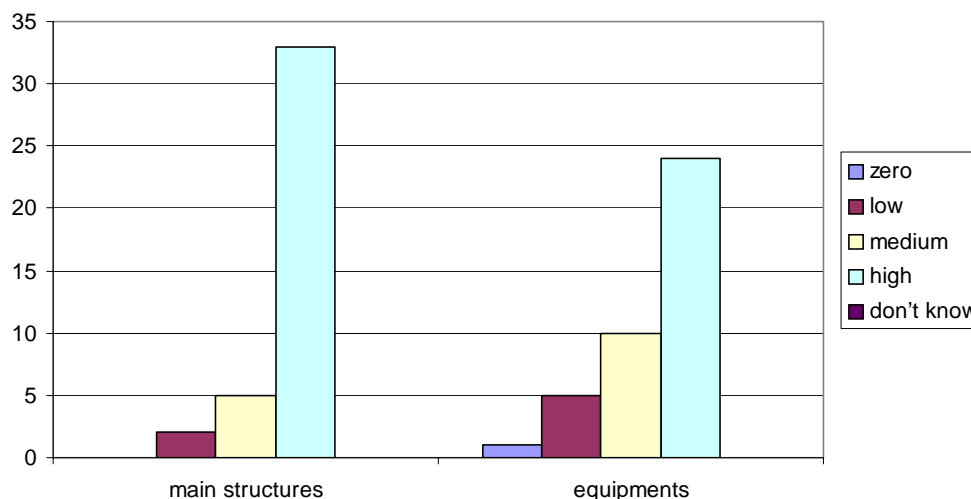
## Synthesis from EFAST Inquiry about Nuclear, Chemical and Construction Industries

The two sections of the EFAST Inquiry related to Nuclear, Chemical and Construction Companies can be found within the integral document about the EFAST Inquiry [5].

The main conclusions about the testing needs that can be summarised from the obtained answers are the following:

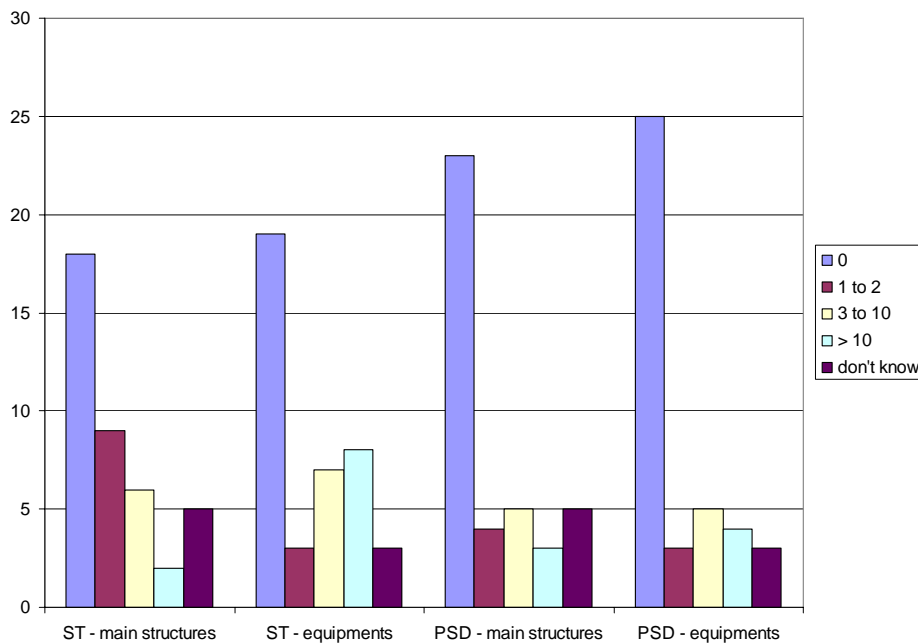
- Seismic risk is very important for most of the respondents, probably also because most of the interviewed are directly involved in seismic activities. They are both interested into main structures tests and in equipment tests (see figure below).

What is your company interest on analysing thoroughly the earthquake response of structures and equipments respectively?



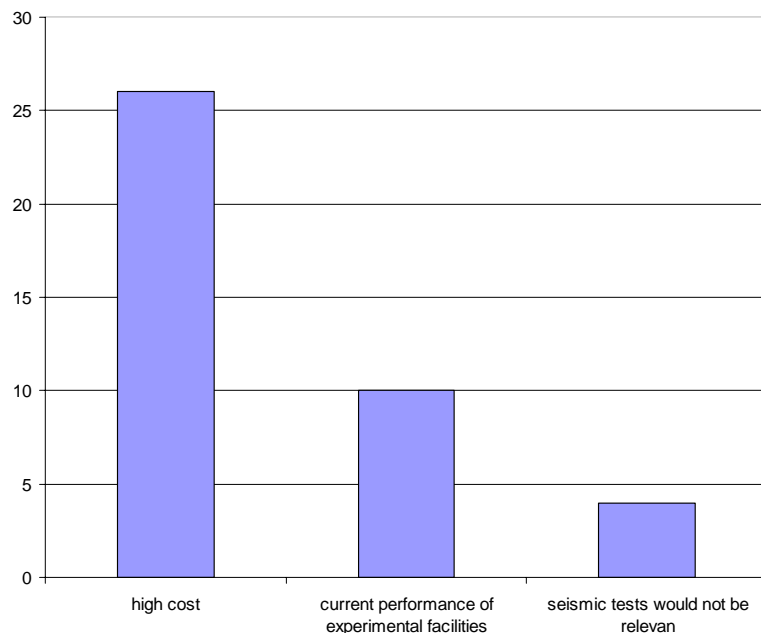
- There is a high demand for tests, but only a few ones were performed in the last years (see figure below). ST is more used for equipments than for main structures.

**How many test campaigns did your company perform by itself or fund in the last 15 years?**



- The main problem is cost (see figure), but also the lack in the current capability of the testing facilities is a reason why seismic testing is not used more often. Maybe there is also a lack of accessibility.

**What is the main reason your company does not use seismic testing facilities more often?**



- Surely there is a high demand for large-scale tests, both for main structures and for equipments (but most of potential users have no clear idea about the desired masses and maximum accelerations).
- These tests have the dual role of improving the research and to serve as demonstrative projects.

# TECHNOLOGY FOR SEISMIC TESTING IN EU AND WORLDWIDE

In this section the general perspective about the available technology for seismic testing facilities is given with especial emphasis on shaking table technology, which the proposed main testing device for EFAST.

## Synthesis from EFAST Workshop conclusions about technology

The integral document about the 1<sup>st</sup> EFAST Workshop that has been held in Ispra (Italy) on the 2<sup>nd</sup> and 3<sup>rd</sup> of March 2009 is available on the web [2]. The final section reports the emerged considerations about the available technologies for seismic testing.

The main conclusions about the needed technology are:

- **Versatility** is surely a key feature of the future testing facility: wide working space, adequate room for construction, an outside demolition area, possibility to extend the laboratory accordingly to future needs, capability for applying **multi-axial loading** and for **substructuring** testing. The initial design of the facility must **enable future extensions and improvements**. The possibility of some **outdoors** tests should also be investigated.
- Uni-axial, bi-axial, tri-axial and **6-DOFs** shaking table facilities are needed for different kind of tests, but for Nuclear Industry qualification tests a rigid 6-DOFs shaking table is compulsory.
- The **spurious pitching** (and other input errors) of the shaking tables must be minimized at the best today attainable level for qualification tests. It must be bounded between reasonable values for other tests and in any case it should be always measured and reported.
- The reaction wall could be conceived as composed by **modular** and **light** elements so that to enable modification of its configuration depending on the requirements for different tests.
- Besides the main testing facility, some **dedicated Testing Facilities** —such as MATS— (Multi-Axial Testing System) or testing systems for non structural components— should be considered. If the aforementioned machines are not constructed from the beginning, the design of the facility must be thought so that they could be integrated in a second phase.
- Even if fast and real-time **substructuring** (hybrid) techniques are still under development and yet impossible in practice for degrading specimens, the new testing facility must be designed taking them into account, so having the required hardware capacity to do it.

Besides these “physical” aspects, there are also some very important associated requests:

- It is important to have a strong coupling between the experimental and the **numerical** aspects. Software **harmonization** should be promoted among different laboratories in Europe.

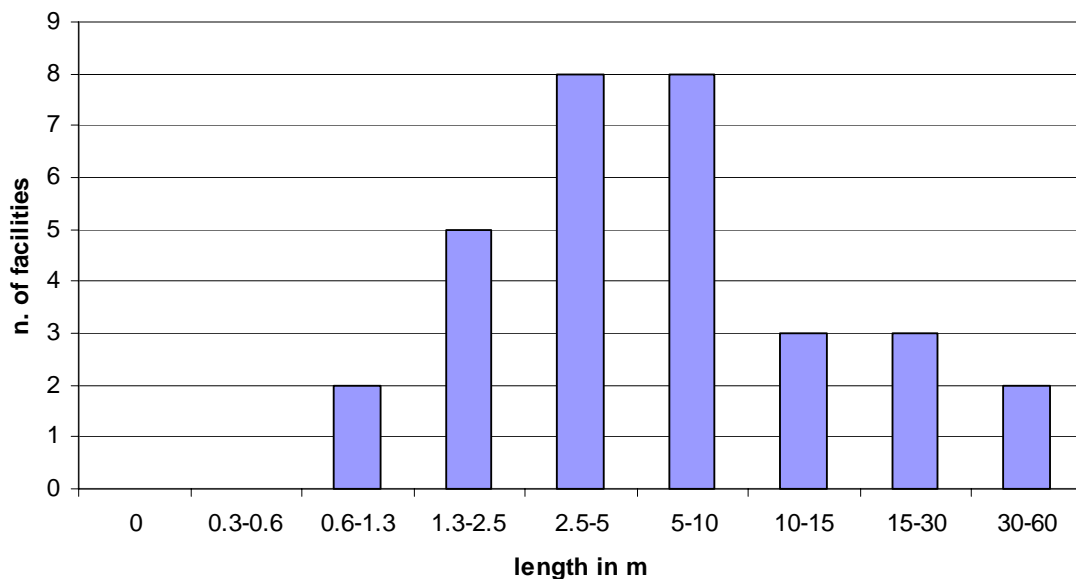
- Information, **dissemination** and **collaboration** must be stressed. During the design phase of the new testing facility, **networking** should be considered.
- **Instrumentation** issues should be studied jointly with the design of the testing part of the facility in order to have a proper calibration hardware and software: some certified elements, some partially certificated elements, optical hardware and methods for field measurements.
- A special care must be devoted on the estimation and quantification of the **construction costs** and of the **maintenance costs** (all aspects must be considered: infrastructures, operation costs, the numerical and IT tools and teams etc.)

## Synthesis from EFAST Inquiry about laboratories

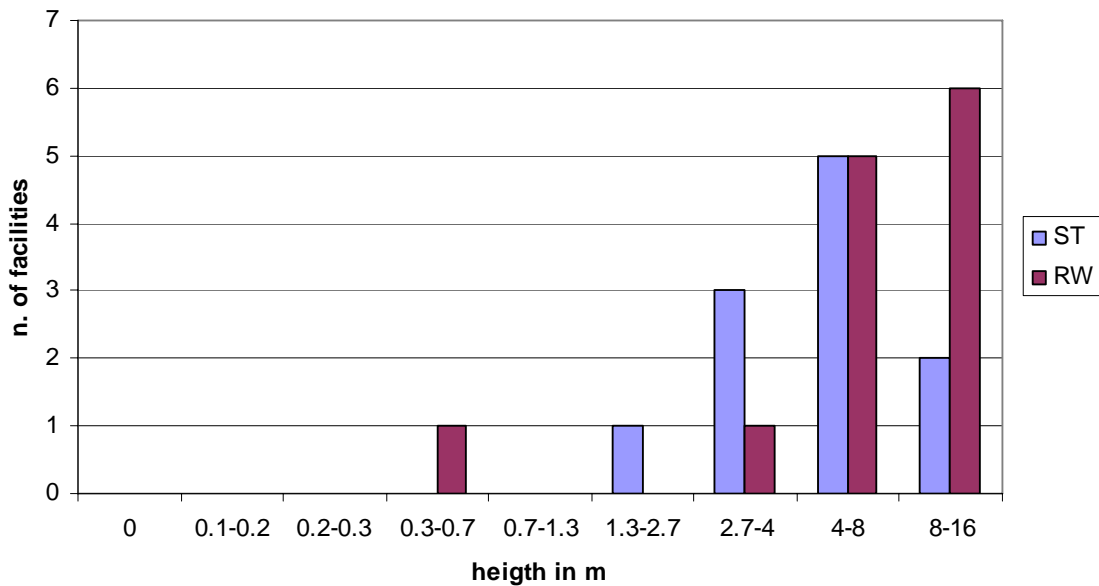
The section of the EFAST Inquiry related to the laboratories can be found within the integral document about the EFAST Inquiry [5].

The main conclusions coming from an analysis of the obtained answers from 35 laboratories from the entire world are:

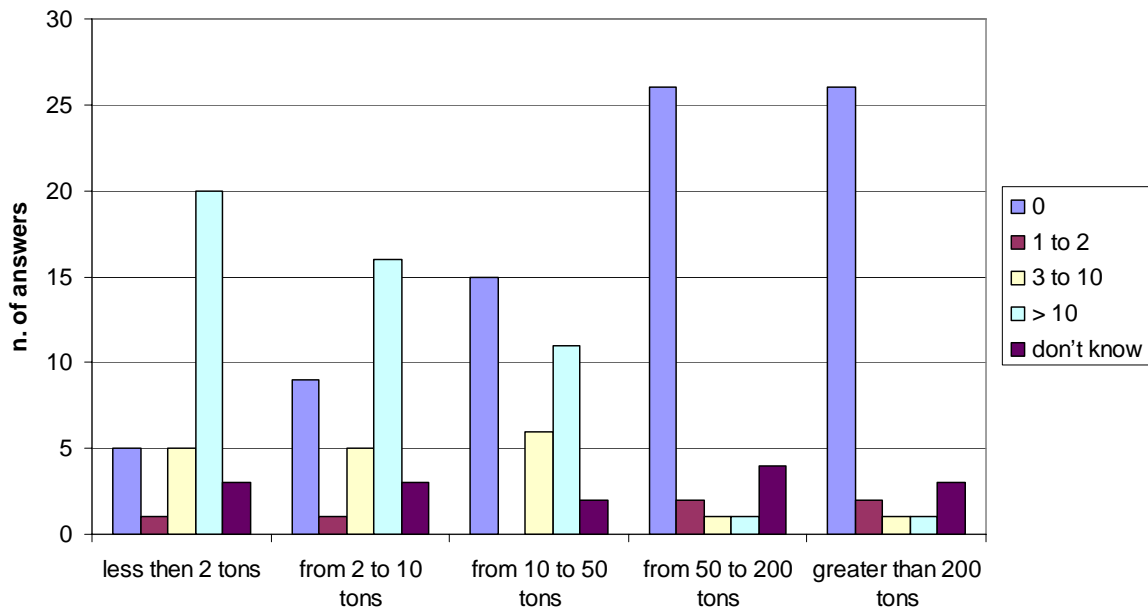
- The available maximum weight, length, width, height and displacement for each facility are usually distributed over a wide spectrum of values. The following figure shows the distribution of maximum length which applies to specimens to be tested within the interviewed laboratories.



- Regarding the maximum weight, length, width and height (see figure below), often the upper values are for Reaction Walls (RW) facilities, the lower values are for Shaking Tables (ST) facilities.

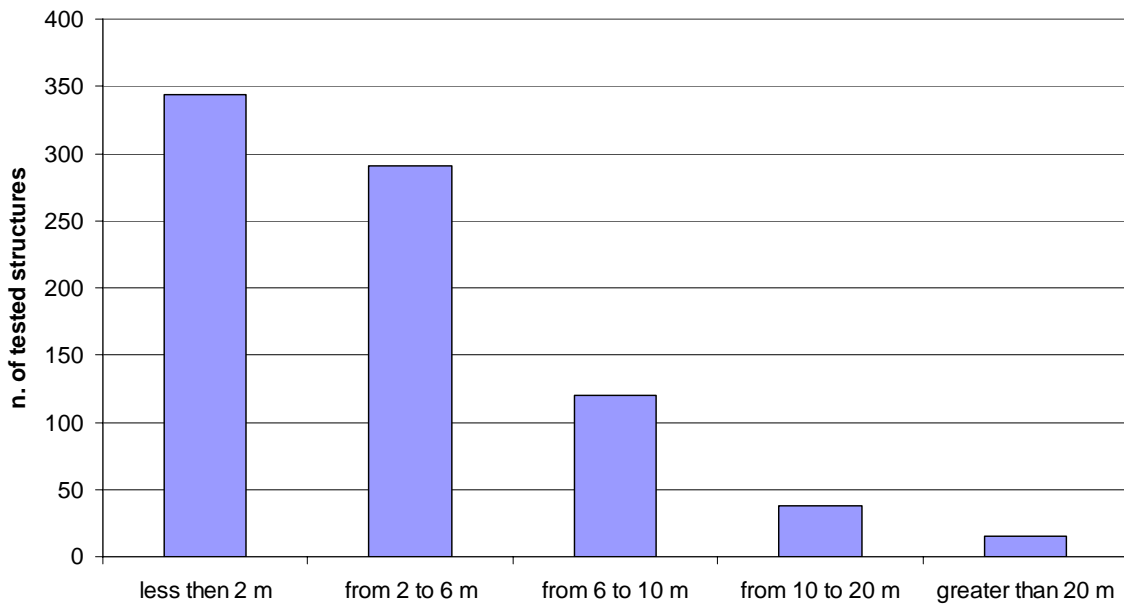


- Regarding the maximum displacement that the testing facility can realize, it is interesting to notice that some facilities cannot perform tests in the transversal and the vertical direction.
- Most of the times the tested specimens are light, small in length and height. The following figure, as an example, shows that a significant number of tests is performed only with small specimens. Heavy (and, a consequence, large scale) specimens are seldom tested.



- Only a few structures were tested in transversal or vertical direction. In fact the total number of tested structure in longitudinal direction was around 750, in the transversal direction it was around 400 and in the vertical direction only 340.
- There is a wide possibility for multi-axial tests, but only a few tests were performed in the past with vertical or lateral displacements. On the one hand, this is probably a problem of cost. On the other hand, a question arises: are multi-axial tests really a needed?
- The following figure shows that more than 40% of the tested specimens have a height smaller than 2 meters. These specimens are often tested with small displacements (the

47% of tested structures were subject to maximum 12.5 cm of longitudinal displacement).



- Presently, there is a prevalence of unidirectional excitation tests even if several multidirectional excitation tests were also performed.
- Rigid-base excitation is strongly the most common choice while asynchronous multiple-support excitation tests are very rare.
- Tests are usually performed without substructuring, sometimes with pseudo-dynamic (in slow time scale) substructuring and only in very few cases with real-time (or fast time scale) substructuring.
- Telepresence is sometimes used, but the majority of the conducted tests were without telepresence.
- Tests with inter-facility distributed testing are very rare, the almost totality of the performed tests being without inter-facility distributed characteristics.
- The used database type is usually localised in one site (67% of the answers) and only a few ones have multiple site centralise or distributed database.

## Current and future facilities

### Main shaking tables in U.S.A.

U.S.A. has three main shaking tables with different capabilities.

The NEES Equipment Site at the **University of Nevada at Reno** [6] is a biaxial, multiple-shake-table facility (with three identical biaxial shake-tables) that is suitable for conducting research on long, spatially distributed, structural and geotechnical systems. The facility is also capable of testing conventional structural and non-structural systems by using the tables in large-table-mode operating them as a single unit. Each table is 4.3 m x 4.5 m and has a maximum payload of 45 tons. The maximum stroke is +/-300 mm, the maximum velocity is +/-1270 mm/sec and the maximum acceleration is 1 g in the frequency range of 0-50 Hz.

The NEES Equipment Site at the **State University of New York at Buffalo** [7] is a set of two high-performance, six degrees-of-freedom shake tables, which can be rapidly repositioned from

directly adjacent to one another to positions up to 30 meter apart (centre to centre). Together, the tables can host specimens of up to 100 tons and as long as 35 meters, and subject them to fully in-phase or totally uncorrelated dynamic excitations. Each table is 3.6 m x 3.6 m, but they can be extended to 7 m x 7 m. They have a maximum payload of 50 tons each. The maximum stroke is +/-150 mm (+/-75 mm in vertical direction), the maximum velocity is +/-1250 mm/sec (+/-500 mm/sec in vertical direction) and the maximum acceleration is 1.15 g in the frequency range of 0-50 Hz.

The NEES Equipment Site at the **University of California at San Diego** [8] is the world's first outdoor shake table and the largest shake table in the U.S.A. It is said to be able to test structures weighing up to 2200 tons and as tall as 30 meters. The facility consists in a 7.6 m wide by 12.2 m long single degree of freedom (DOF) system with the capability of upgrading to 6-DOFs. The maximum stroke is +/-750 mm, the maximum velocity is +/-1800 mm/sec and the maximum acceleration is 1 g in the frequency range of 0-20 Hz.

### Main shaking tables in Japan

The largest Japanese earthquake-testing facility **E-Defense** [9] came on function in January 2005 on the 10<sup>th</sup> anniversary of the Kobe earthquake. It is placed **in the city of Miki**, to the north of Kobe and it is the largest shaking table in the world. E-Defense allows testing structures subjected to simulated high-intensity earthquakes. The massive 6-DOFs shaking table platform measures 20 m x 15 m and can accommodate a four-story building weighing 1200 tons. The maximum stroke is +/-1000 mm (+/-500 mm in vertical direction), the maximum velocity is +/-2000 mm/sec (+/-700 mm/sec in vertical direction) and the maximum acceleration is 1 g (1.5 g in vertical direction) in the frequency range of 0-50 Hz.

### Main shaking tables in China

**Tongji University in Shanghai** [2] is constructing the largest shaking table array in China. The system will consist of 4 tables that can be moved inside trenches to be positioned in different configurations. The tables will have 3-DOFs and will measure 4 m x 6 m each. The maximum stroke will be +/-500 mm, the maximum velocity will be +/-1000 mm/sec and the maximum acceleration will be 1.5 g in the frequency range of 0-50 Hz. They will have different payloads: two tables will support 30 ton specimens, two others tables will support 70 ton specimens.

### Main shaking tables in Korea

The **Korean government** has launched the project of building 12 large scale testing facilities at the major universities in the country [10]. These laboratories will be interconnected by using a high performance information network. In particular one of them will be a multi-platform seismic simulation facility with one fixed shaking table 2-DOFs with size 5 m x 5 m and two moveable shaking tables 2-DOFs with size 3 m x 3 m each.

### Main shaking tables in Europe

The main shaking table installations in Europe [11] are located in France (**CEA**), Italy (**Eucentre**) and Portugal (**LNEC**) (see also [12] for a comprehensive and updated list of the shaking table installations in Europe and all around the world, even if the information reported there must be checked following the links to the official website of each installation). Their capabilities are sensibly lower than the main ones already available or under construction in the rest of the world.

## Reaction walls

With its reaction wall of 16 m high and 20 m long, provided with two reaction platforms of pre-stressed cellular construction with a total surface of 760 m<sup>2</sup> that allow for testing of real scale structural models on both sides of the wall, **ELSA laboratory** of the JRC of the EC in Italy [13] is the biggest laboratory in Europe and one of the main seismic testing facilities in the world. The test models can be built outside the laboratory and then transported inside a climate controlled shed through large door openings. The laboratory is equipped with more than 20 actuators with capacities comprised between 0.5 and 3 MN and strokes ranging between +/-0.25 and +/-1.0 m. The hydraulic equipment is capable of delivering a flow of 1500 l/min at a pressure of 210 bars.

## PROPOSED CONCEPT AND STRATEGIC VALUE OF EFAST

### Strategic value

The strong R&D need in earthquake engineering [2] is satisfied by the new RI characteristics:

1. high performances in terms of testing capabilities (payload, velocities, displacement, acceleration, control);
2. single-site integrated facilities coupling shaking tables with reaction walls;
3. modularity, flexibility and versatility;
4. operating easiness;
5. complementarity to existing research infrastructures in Europe;
6. networking with other European laboratories (which imply possible upgrade of existing testing facilities to meet new requirements to perform distributed tests) and capability of performing distributed testing, where different parts of the model are tested and/or simulated on different facilities, with a coupled response;
7. coupling of numerical tools for simulation and advanced test methodology;
8. interdependency of testing and simulation, so hybrid testing will be one key element of the future facility;
9. improved access and knowledge dissemination with telepresence.

With EFAST advanced testing capabilities will be possible to obtain:

- Simulation up to collapse, with assessment of the performance at different input level. Collapse is often associated with very large displacements which will become achievable with EFAST.
- Fragility curve of components is a key point of SPSA (Seismic Probabilistic Safety Assessment). The experimental determination and the validation of fragility curves require high level excitation with accurate control that will become achievable with EFAST.
- Simulation at large scale of significant parts of structures. Coupling physical tests and simulation is a key element of the EFAST facility.
- Representation of real failure mode, that is due to inertial forces on relative displacement thanks to the multiple shaking tables capabilities of EFAST.

- The prediction of the dynamic response of soil-structure interaction will be permitted by EFAST using a laminar box for performing testing and validate computational methods in the non linear field.
- Development of simple, reliable, market oriented and easy to use ways of retrofitting structures.

EFAST main testing facility will consist in a high performance shaking table system. This is partially motivated by the fact that a reaction wall of world class is already present in Europe (ELSA, at JRC in Ispra (VA – Italy)). This is not the case for shaking tables. This new RI will allow answering to the unsatisfied needs emerged in these last years and reported in [5].

The realisation of this new RI is motivated also by the fact that extra European countries (U.S.A., China, Japan, Taiwan, Korea) are investing considerable resources in terms of human and material resources to improve their testing capabilities [1]. Some ambitious projects are presently under construction or operating in extra European countries. The most important existing high performance facilities are University of California San Diego, E-Defense in Japan; the main projects or facilities under construction are located in China, Korea and Japan.

Moreover, new experimental techniques such as hybrid simulation, distributed testing and real-time substructuring are now developing and arising and Europe should be ready to full exploit them.

Two shaking tables that can work together will be constructed from the beginning, but the main floor or trenches will be ready to accept more shaking tables flexibly allocated. Besides this main testing facility, a modular reaction wall with flexible location will also be constructed allowing hybrid and substructuring tests. Some dedicated Testing Facilities (MATS - Multi-Axial Testing System, testing of non structural components) that may be added in future enlargements will also be considered regarding the required space and capacity of the installations: the aforementioned machines will not be constructed from the beginning, but the design of the facility had thought so that they could be integrated in a second phase.

The EFAST research instrument will enable to increase the knowledge in fields, such as soil structure interaction, realization of complex hybrid testing, studying complex structures, tracing fragility curves of components and safety margins for structures, testing buildings on isolators or other devices.

EFAST and EU capabilities, by means of distributed tests and computations, will allow the researcher to increase the size of the specimens of interest, delivering much better results to study nonlinear behaviour and failure mechanisms. The focus of EFAST linked to EU capabilities is to achieve always more accurate tests by increasing the size of the specimen and increasing the degrees of freedom and realism of the simulated earthquake excitation. The EFAST capabilities will allow earthquake resistant structural design researchers to conduct large specimen complex nonlinear tests with better, more accurate and realistic results.

Coupling reaction wall in the vicinity of shaking tables, allow new 3D dynamic hybrid testing (6-DOFs), in real time control, including reproduction of strain rate effects, viscous damping, and inertial effect of structures.

## Conceptual and technical design studies

The structure and the operational form of future test facilities needed to meet the requirements of the European and international scientific community is a subject which is discussed in different parts of the world, since about ten years:

- The need of facilities with high performances in terms of payload, velocities, displacement, acceleration and control. The objective is to be able to represent any significant input signal, to conduct tests until failure, to simulate all the possible failure modes (caused by inertial forces and/or relative displacements);
- The capacity to have a great flexibility and versatility for testing. This imply optimized layout around shaking tables, possibility of constructing specimen, handling mock-up, consideration of multiple tables;
- Testing and simulation are interdependent. Hybrid testing is one key element of the future facility; a “real” part of a structure is shaken on tables and a “virtual” part of a structure is replaced by actuators. Control of these actuators, including finite element calculation in the loop, permits to simulate the behaviour of the virtual part, in general the less complex one. The next key step is distributed testing, where different parts of the model are tested and/or simulated on different facilities, with a coupled response;
- The strong integration of different facilities within networks; this will allow sharing of data, distributed testing, optimization of test programs, and enhanced cooperation between partners;
- Improved access and knowledge dissemination, either for physical presence at the facility or with telepresence. Access of third countries or small laboratories will be facilitated.

## Integration with the existing EU e-infrastructure

The new RI will be linked with the existing ones by a high-speed network as GEANT and allowing distributed tests. A fundamental aspect of EFAST infrastructure will be the networking development in order to optimize exchange between researchers, distributed testing, remote participation, education and training.

## Maturity of the project

Many informal communications between partners and the earthquake engineering community confirms that there is a strong interest in the new RI EFAST. The list of Universities, Institutions and Companies that have formally demonstrated interest into the EFAST infrastructure by answering to the inquiry is the following:

### Inquiry for Seismic Testing Laboratories

Tongji University	China
CEA - Commissariat a l'Energie Atomique	France
Sopemea	France
Universität Kassel	Germany
National Technical University of Athens	Greece
University of Patras	Greece
Indian Institute of Technology	India
CESI ricerca spa	Italy
ENEA - Ente per le Nuove Tecnologie, l'Energia e l'Ambiente	Italy
Joint Research Centre	Italy
P&P Consulting Engineers	Italy
Università degli Studi della Basilicata	Italy
Università degli Studi di Trento	Italy
Central Research Institute of Electric Power Industry	Japan
Public Works Research Institute	Japan
Seoul National University	Korea
Laboratório Nacional de Engenharia Civil	Portugal
University of Azores	Portugal
Technical University 'Gheorghe Asachi'	Romania
SP Technical Research Institute of Sweden	Sweden
Empa - Swiss Federal Laboratories for Materials Testing and Research	Switzerland
Geotechnical Drum Centrifuge	Switzerland
National Center for Research in Earthquake Engineering	Taiwan
Deltares	The Netherlands
The Kandilli Observatory and Earthquake Research Institute	Turkey
University of Cambridge	U.K.
Purdue University	U.S.A.
The State University of New York	U.S.A.
U.S. Army Corps of Engineers	U.S.A.
University of California at Davis	U.S.A.
University of California at Los Angeles	U.S.A.
University of California at San Diego	U.S.A.
University of Colorado at Boulder	U.S.A.
University of Illinois at Urbana Champaign	U.S.A.
University of Texas at Austin	U.S.A.

### Inquiry for Nuclear Energy and Chemical Industry Activities:

AIEA	Austria
NRG	Belgium
NPP-Kozloduy	Bulgaria
AECL (Atomic Energy of Canada)	Canada
State Nuclear Power Technology Cooperation	China
ASN (Autorité de Sûreté Nucléaire)	France
CEA	France
GDF SUEZ	France
AREVA NP	France

VGB Power Tech e. V.	Germany
GRS	Germany
Nuclear Power Corporation of India Limited	India
Bhabha Atomic Research Centre	India
TERI	India
Atomic Energy Regulatory Board	India
Indira Gandhi Centre for Atomic Research	India
ENEL	Italy
Tokyo Electric Power Company	Japan
NSC Netherlands	Netherlands
European Commission	Netherlands
PAEC (Pakistan Atomic Energy Commission)	Pakistan
Ingenieria IDOM Internacional	Spain
Basler & Hofmann	Switzerland
Swiss Federal Nuclear Safety Inspectorate	Switzerland
Swissnuclear	Switzerland
State Nuclear Regulatory Commit.	Ukraine
NRC (Nuclear Regulatory Commission)	U.S.A.
Westinghouse Electric Company	U.S.A.
EPRI (Electric Power Research Institute)	U.S.A.

*Inquiry for Construction Companies:*

Géodynamique & Structure	France
Paver	Italy
Agom International srl	Italy
Fischer Italia srl	Italy
Boviar	Italy
C&P Costruzioni Isotex	Italy
Alga spa	Italy
Galileian srl.	Italy
Emmedue	Italy
Freissynet	France
Fip Industriale spa	Italy
Solgeo srl	Italy
Diagnosis srl	Italy

## EXPECTED SOCIO-ECONOMIC IMPACTS OF EFAST

By offering unique research services (access, networking, distributed testing...) to users from different countries, by attracting young people to science and through networking of facilities, research infrastructures help structuring the scientific community and play therefore a key role in the construction of an efficient research and innovation environment. Because of their ability to assemble a ‘critical mass’ of people and investment, they contribute to national, regional and European economic development. The new RI EFAST can and should play a catalysing and leveraging role by helping to ensure wider and more efficient access to potential users in the different Member States. Strong networking will contribute to the structuring of European and world scientific community together with operators of infrastructures.

EFAST will significantly contribute to the development of high level European research capacities in order to support industry to strengthen its base of technological knowledge and

develop a new generation of European standards and codes. These tools are essential for the industries in Europe and abroad.

More precisely, the EFAST research infrastructure benefits for the EU citizens and the scientific community are expected in various aspects:

- Increased protection of citizens by use of advanced codes and standards by engineering and building companies; EUROCODES, especially EC8, devoted to seismic design, must be reviewed, taking into account progress in seismic behaviour and with the idea of moving towards Performance Based Design.
- Establishing excellence centre in earthquake engineering, with high scientific level, based on simulation and test results, EFAST will be very attractive for young European researchers, as a centre of knowledge, education and innovation.
- EFAST will create strong capabilities of networking, by direct access or remote participation for scientists and practitioners engineers from all around the world, with an emphasis on third countries. Contacts and connexions to world networks in the same field of activity (as NEES in USA) will be facilitated.
- Education and dissemination of results is an important aspect of EFAST. Large scale test results play an important role in public awareness to the seismic risk.

## CONCLUSIONS

Because of the research and regulation investments in countries such as USA and Japan, their seismic risk is nowadays lower than the one in Europe, even though they have a larger natural seismic hazard. In fact, the current level of risk in Europe is not justified and should be reduced in a similar manner to those countries by similar adequate improvement of investment.

As demanded by the Scientific Community and the Industry, seismic testing of large-size specimens with large testing capacities and by advanced testing methods is a very effective mean to increase our knowledge in this field.

When looking at the research infrastructures for seismic testing in Europe, and in comparison with the rest of the world, a large capacity shaking table facility, such as the proposed EFAST, is missing. The role of EFAST would be strengthen our research production in this field, so that Europe can better develop its standards and contribute to the innovation of our structures and their safety against earthquakes.

The proposed concept of network facility for EFAST in cooperation with the existing facilities will produce a synergetic effect by which the quality of the produced research in the whole network will be increased through extension of the testing techniques and capabilities as well as the improved exchange of information.

## REFERENCES

- [1] Helmut Wenzel (prepared by), European Strategic Research Agenda, “Earthquake Engineering – Vision - Strategic Research Agenda - Roadmap for Implementation”, July 2007, European Association for Earthquake Engineering, [www.eaee.boun.edu.tr/earthquake-research-agenda-V9-August\\_Part%2012.pdf](http://www.eaee.boun.edu.tr/earthquake-research-agenda-V9-August_Part%2012.pdf).
- [2] Francesco Marazzi and Javier Molina, “1<sup>st</sup> EFAST Workshop - Challenges, Needs and Open Questions”, 2009, JRC Scientific and Technical Reports, JRC 51632, EUR 23822 EN, ISSN 1018-559, [http://efast.eknowrisk.eu/EFAST/images/JRC\\_SR\\_1EFASTWS.pdf](http://efast.eknowrisk.eu/EFAST/images/JRC_SR_1EFASTWS.pdf).
- [3] UNDP, 2006. Reducing Disaster Risk.
- [4] University of Grenoble, 2005. The SESAME Project Site EffectS assessment using Ambient Excitations, <http://sesame-fp5.obs.ujf-grenoble.fr/index.htm>.
- [5] Francesco Marazzi and Javier Molina, “EFAST Inquiry - Seismic Testing Laboratories, Nuclear Energy and Chemical Industry Activities, Construction Companies”, 2009, JRC Scientific and Technical Reports, JRC xxxxx, EUR xxxxx EN, ISSN xxxx-xxx.
- [6] <http://nees.unr.edu/>
- [7] <http://nees.buffalo.edu/>
- [8] <http://nees.ucsd.edu/>
- [9] <http://www.bosai.go.jp/hyogo/ehyogo/>
- [10] “Hybrid Simulation: Theory, Implementation and Applications”, editors: Victor Saouma, Mettupalayam V. Sivaselvan, 2008, Taylor & Francis/Balkema, ISBN 978-0-415-46568-7.
- [11] Fabio Taucer and Giorgio Franchioni, “Directory of European facilities for seismic and dynamic tests in support of industry”, CASCADE Series Report No. 6, Published by LNEC, Lisbon, Portugal (ISBN 972-49-1970-6).
- [12] [http://en.wikipedia.org/wiki/Earthquake\\_shaking\\_table](http://en.wikipedia.org/wiki/Earthquake_shaking_table)
- [13] <http://elsa.jrc.ec.europa.eu/>

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**Abstract**

The present report provides information useful for the preparation of the application of the new Research Infrastructure EFAST to the ESFRI roadmap.

A brief introduction about the EFAST project and the ESFRI open the document. Two sections follow: the first one is devoted to identify the main need in Earthquake Engineering, the second one deals with the current and future testing technologies all around the world. The proposed concept of the EFAST testing facility is then described and the main strategic values are illustrated. Economic aspects about its realisation and the positive fall down on European economy are also discussed. A section dedicated to the impact of EFAST on the scientific community and, more generally, on the whole society conclude the report.

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