SERA

Seismology and Earthquake Engineering Research Infrastructure Alliance for Europe

Fact sheet 1 I Spring 2018

Introduction

Prof. Domenico Giardini, SERA Coordinator, ETH Zurich

Based on innovative research and development projects, the **Seismology and Earthquake Engineering Research Infrastructure Alliance for Europe (SERA)** aims to contribute significantly to the reduction of the risk posed by natural and anthropogenic earthquakes.

Knowing and understanding seismic hazard and risk in Europe is crucial for the development of efficient and successful precautionary measures. By promoting a strong collaboration between seismology and civil engineering, SERA enhances the impact of the knowledge and experiences acquired in those fields. SERA connects the numerous attempts in compiling, processing, and analysing data gathered in different communities. The facilitated access to infrastructures further allows conducting forefront experimental science. Building on those efforts, SERA will develop a revised European seismic hazard reference model and establish a first, comprehensive framework for seismic risk modelling at European scale.

To account substantially to a better understanding of seismic hazard and risk in Europe, several questions have to be answered. With our fact sheet series, we address key questions SERA is challenged with by explaining crucial terms and concepts as well as by presenting first results to an interested public. ■

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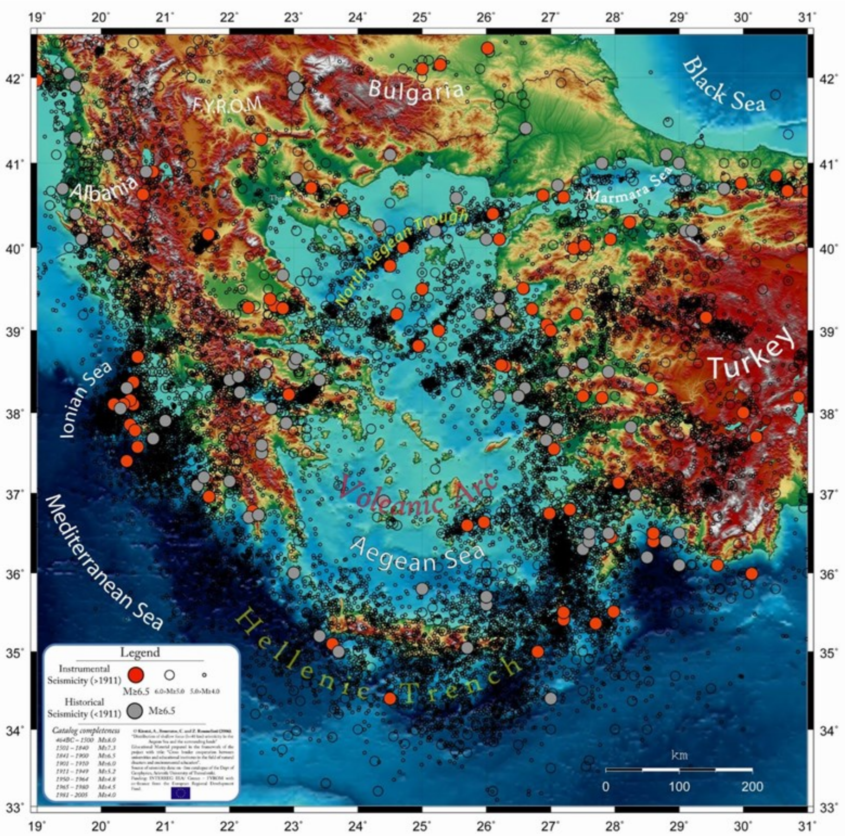
Why is it important to know the Seismic Hazard?

Prof. Kyriazis Pitilakis, Aristotle University, Thessaloniki, Greece

Seismic hazard is the probability of an earthquake occurring at a given location, within a given window of time, and with a ground motion intensity measure i.e. peak ground acceleration, exceeding a given threshold. The assessment of seismic hazard essentially comprises two steps, (a) the definition of the seismic action in the framework of European and National Seismic Codes and, (b) the evaluation of the seismic risk at local, regional or national scale. For evaluating the Seismic Risk (R) of physical and non-physical elements at risk, i.e. socio-economic features, one needs to combine the evaluation of Seismic Hazard (H) with the Exposure (E) of the elements and, most importantly, the Vulnerability (V) of each element.

$$R = H * V * E$$



Distribution of shallow focus (h≤40 km) seismicity in the Aegean Sea and the surrounding areas (Kiratzi et al. 2006)

Realistic seismic hazard assessment requires good knowledge of historical and recent seismicity (see figure above) and the neotectonic regime, namely the seismically active or seismogenic faults (see map of faults in the Euro-Mediterranean area). Such information will allow defining, along with other multidisciplinary data (e.g., geological, geodetic, satellite), those sources capable of producing damaging earthquakes. In addition, well calibrated/validated methods and models may be developed, with the aim to predict the intensity of a given ground motion measure at a specific site, from an earthquake of specific magnitude and distance from the site. Local site effects modifying the seismic actions could be also included in the seismic hazard assessment. Several seismic sources contribute to the seismic hazard in an area and their combined effect is mapped as probabilities in seismic hazard maps.

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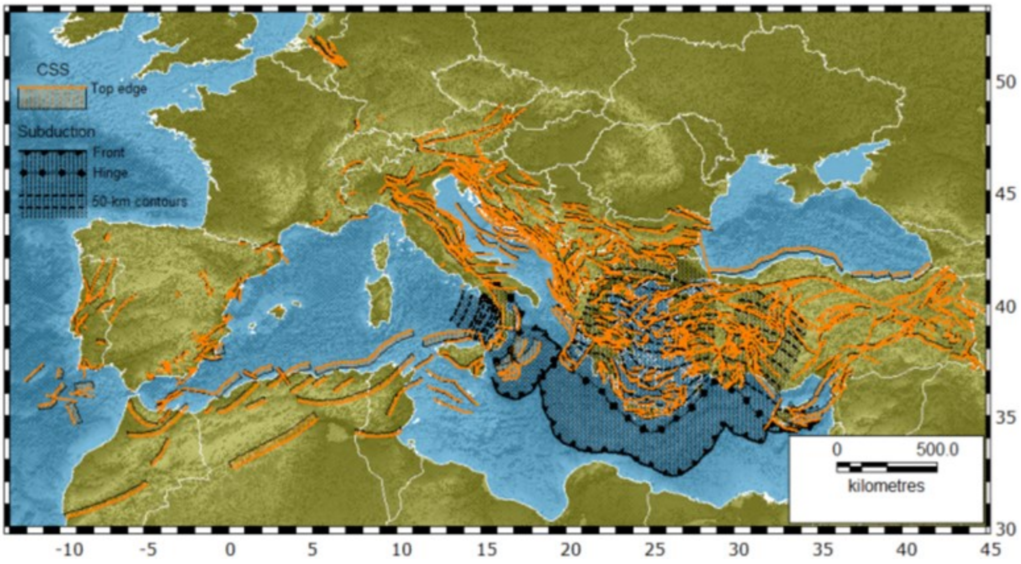
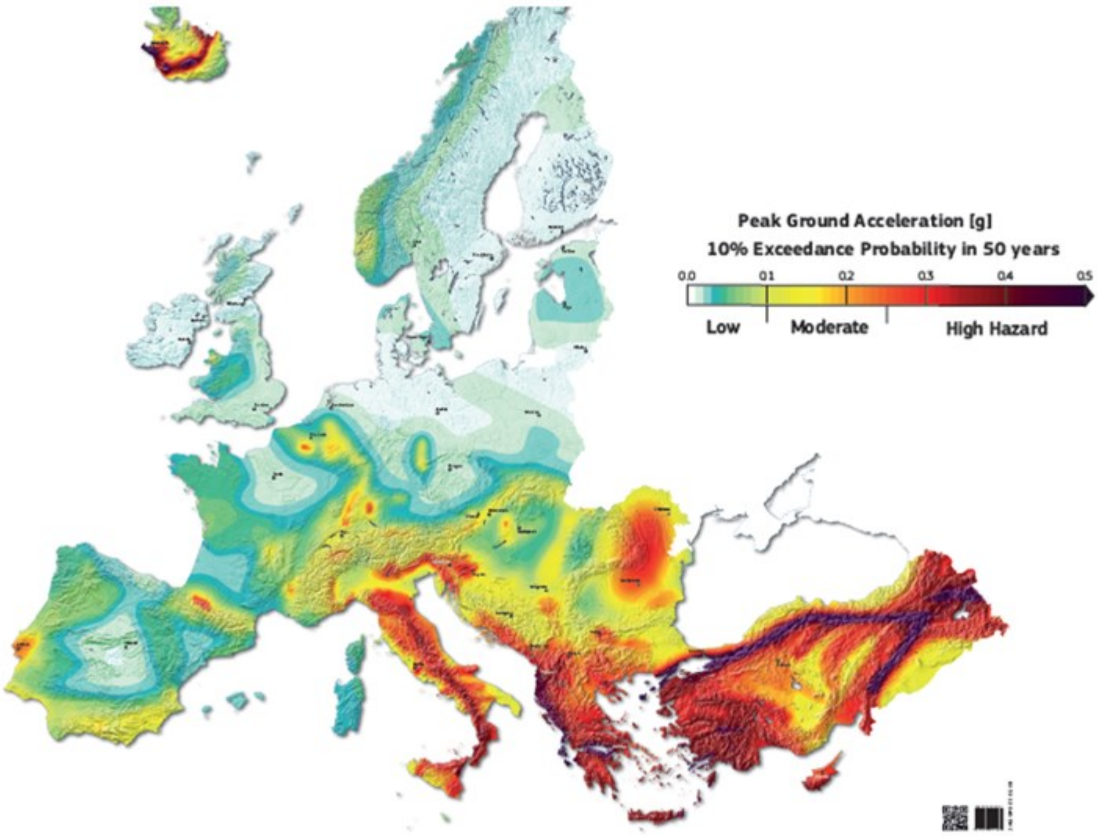


Seismogenic Faults capable of generating earthquakes of magnitude equal to or larger than 5.5 in the broader Euro-Mediterranean area (http://diss.rm.ingv.it/share-edsf/)

A European Seismic Hazard Map showing the 10%-probability of exceedance of peak ground acceleration in 50 years (mean return period 475 years – the basis for most seismic codes) is depicted below. ■



European Seismic Hazard Map showing the probability of peak ground acceleration exceedance of 10 % in 50 years. (SHARE Project, http://www.share-eu.org/)

What is seismic risk? Addressing European and global objectives for Disaster Risk Management

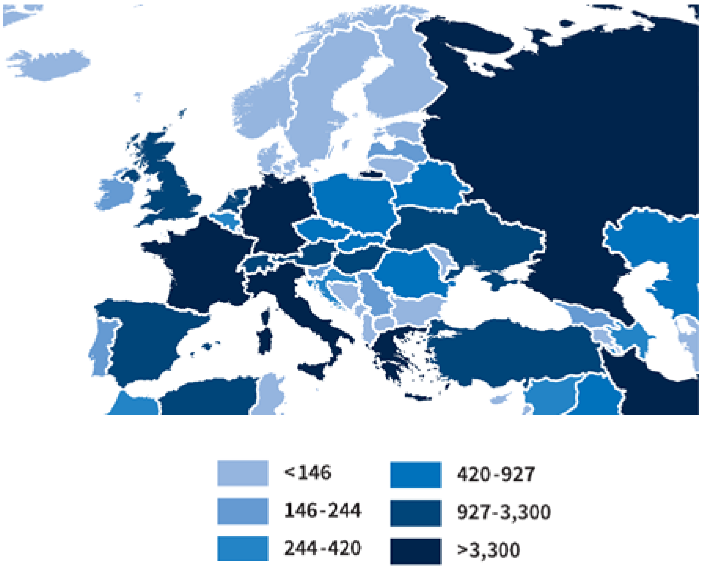
Georgios Tsionis, Maria Luísa Sousa, Artur Pinto, European Commission, JRC Ispra

Risk assessment is a key component of the complex disaster risk management activity, which comprises identification, evaluation, and prioritization of risks and should be understood in a multi-hazard/multi-risk perspective. It can be carried out at local, regional or country level by national authorities and/or governmental agencies according the corresponding policies and mandates.

European policies on disaster management aim at achieving a high level of mitigation to protect people, but also of the environment and property, including cultural heritage, against all kinds of natural and man-made disasters. This is achieved through cooperation and coordination among countries, together with regional and local authorities, on prevention, preparedness and response actions. Prevention is more cost-effective and can be even a driver for economic growth. It is therefore attracting more attention as part of the disaster management cycle.

The disaster management cycle

In the global context, the Sendai Framework aims to prevent new and substantially reduce existing disaster risk and losses, applying measures such as the reduction of vulnerability and exposure. Inclusive, safe, resilient and sustainable cities feature among the Sustainable Development Goals.



Multi-hazard (earthquake, flood, cyclone wind, storm surge and tsunami) average annual loss in million $, adapted from GAR (2015)

In the most recent national risk assessments prepared by the countries participating in the Union Civil Protection Mechanism, earthquakes are the fourth most common hazard assessed after flooding, extreme weather and forest fires. 19 countries (Austria, Bulgaria, Croatia, Cyprus, France, Germany, Greece, Hungary, Iceland, Italy, Malta, Norway, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain and Sweden) performed seismic risk assessment and in some cases considered cross-border risk and cascading effects such as tsunami, landslides, disruption of infrastructure and industrial accidents.

To understand the following, some definitions are appropriate. Disaster risk comprises three elements: *hazard*, *exposure* and *vulnerability*. *Hazard* is the dangerous phenomena, being the source of potential harm. *Exposure* refers to people, property, systems or other elements present in hazard-prone areas. *Vulnerability* represents the susceptibility of an element at risk of being adversely affected by natural phenomena.

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Disaster risk is the potential loss of life, injury, or destroyed or damaged assets which could occur to a system, society or a community in a specific period of time. Disaster risk assessment is the qualitative or quantitative approach to determine the nature and extent of disaster risk by analysing potential hazards and evaluating existing conditions of exposure and vulnerability that together could harm people, property, services, livelihoods and the environment. Finally, disaster risk management is the application of disaster risk reduction policies and strategies to prevent new disaster risk, reduce existing disaster risk and manage residual risk, contributing to the strengthening of resilience and reduction of disaster losses.

Seismic risk could be defined as the likelihood of damage from earthquakes to a building, system or the entire society taking into account social, economic and environmental consequences. It is normally obtained from the hazard of the site/region and from the vulnerability for the different types of buildings or constructions and quantified in terms of losses. Methods to assess and mitigate seismic risk are briefly described in the following.

Early warning systems rely on the difference of arrival times between warning messages and destructive shaking waves. The former are transmitted almost instantaneously when triggered by an earthquake, whereas the latter may take seconds to minutes to arrive at a location. People and automated systems may use this short time delay to activate measures to protect life and property.

Near real-time loss assessment systems provide rapid estimates of ground motion, damage and losses following a seismic event, once its magnitude, time of occurrence and location is known. PAGER is a well-known near real-time loss assessment system, which provides estimates of human and economic losses at a global scale.

Earthquake scenarios are used to elaborate seismic risk emergency plans, to model seismic losses, to evaluate the seismic actions needed for the design of civil engineering structures, etc. An example of an earthquake hazard scenario is the maximum probable or credible earthquake, i.e., the largest earthquake that is reasonable to be expected in a region. In the last decades several tools have been developed for the assessment of loss scenarios, or for the evaluation of earthquake impact on critical infrastructures, such as, HAZUS, CAPRA, AFAD – RED, EQIA, SELENA, GEM OpenQuake, RASOR, or Rapid-N.

Probabilistic seismic risk assessment takes into account all possible earthquakes that may affect a site and a probabilistic estimation of damage and losses, including relevant uncertainties. Results are obtained in terms of risk metrics, such as loss exceedance curves or averaged earthquake losses. Thus, seismic risk may be described, among others, by (i) the probability that various levels of loss will be exceeded, (ii) by average annualized earthquake losses, (iii) or by average annualized earthquake loss ratio (AELR). AELR is a useful metric to compare the relative risk across different regions, since it is normalized by the replacement value.

It is worth emphasising the importance of standards and building regulations in achieving more resilient and sustainable buildings. The EN Eurocodes that are a series of 10 European Standards, EN 1990 - EN 1999, providing a common approach for the design of buildings and civil engineering infrastructures, have proven to be a useful mechanism to mitigate seismic risk and to reduce losses in future earthquake events.

Partial collapse of a residential building after the 2009 L'Aquila earthquake

Among other activities, SERA provides access to the largest collection of high-class experimental facilities for earthquake engineering in Europe for researchers to test new technologies, methods and materials to reduce the vulnerability of the built environment and eventually increase the resilience of societies. ■

What happens to buildings in case of an earthquake?

Prof. Stathis Bousias, University of Patras, Greece

Earthquakes are one of the most hazardous natural threats to life and property – their effects are often causing high social, economic and environmental costs. The share of civil engineering structures in the earthquake–inflicted damage is large, justifying that "collapsing structures kill people, not earthquakes". Earthquake excitation is a very intricate loading condition as it:

- occurs unexpectedly in space and time;
- varies considerably in intensity even at short distances;
- is composed of randomly changing cycles of varying amplitude;
- may include vibration components in more than one direction;
- acts in tandem with (part of) the vertical loads;

When seismic waves reach the foundation of a structure, the latter follows soil displacement and due to the "cyclic" nature of the input waves, the whole structure starts vibrating in (generally) three directions.

Although concrete and masonry buildings are stiffer than their counterparts made of steel, they cannot be considered as rigid bodies – had that been so each point on it would move in the same amount as the ground. Concrete and masonry buildings indeed deform, displace and rotate due to their flexibility. Their behavior depends mainly on the fundamental period of vibration (function of the stiffness of the structural system, its mass, and its total height).

Structural geometry is very decisive for the type (mode) of vibration of a structure: while a simple, symmetric structural configuration results in a rather uniform action throughout the structure, structures of irregularly configured layout (T-shaped/L-shaped structures or structures with vertically offset floor levels) tend to concentrate deformation demands on few locations, thus lending members to higher damage. Therefore, the same seismic excitation affects buildings differently; for example, tall buildings tend to amplify the motions of longer period earthquake excitation components. Adjacent structures, vibrating at their own period, may also affect the vibrational response of a neighboring building via the additional deformations they impose through pounding.

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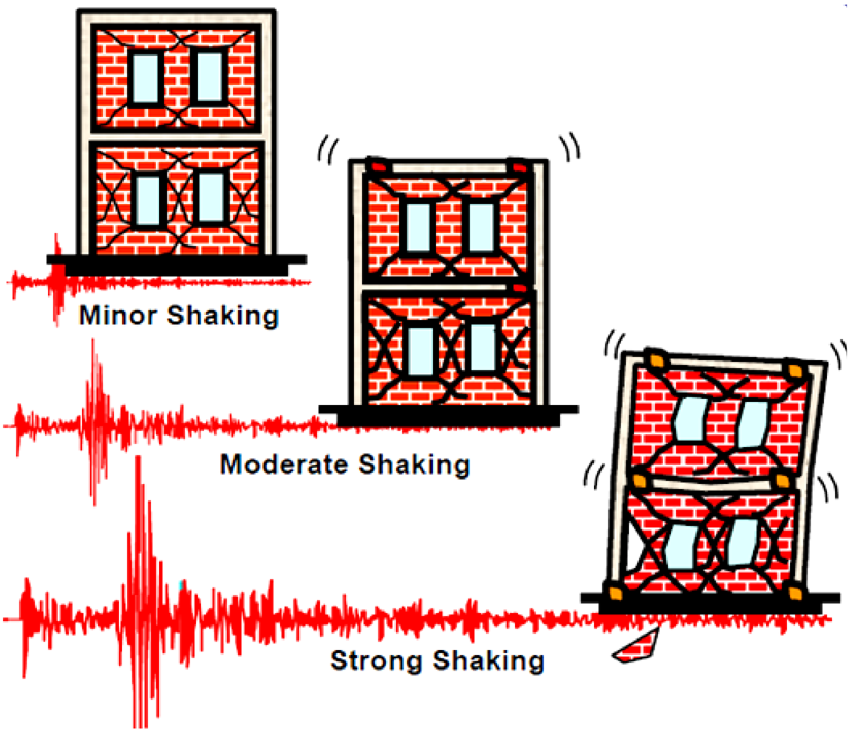


At low levels of excitation, structural members behave elastically: when the seismic motion stops, the structure returns to its initial position without any or with only minor damages to non-structural elements (e.g. partition walls). With increasing amplitudes of seismic motion, the deformation level of all building elements is enhanced as well. Structural members may accommodate the deformations exerted (displacements and rotations) as long as the deformation demand does not exceed the members' capacity in terms of relevant engineering properties (drift, strain, angle of rotation, etc.). When this threshold is surpassed, damage occurs.

Damage of load-bearing (structural) elements is a form of energy dissipation within the structure (more decisive than the inherent material/structural damping), but also the reason for a decrease in material strength. The cyclic nature of shaking is very detrimental for most common construction materials (i.e. concrete, masonry and steel), particularly when they are exposed to deformations of large amplitude. Among others, the following processes lead to degradation of material performance: opening or closing of cracks in concrete/masonry, yielding of steel, deformation of connections/nodes in steel structures, transition of reinforcing bars from compression to tensions and vice-versa, and lateral expansion of concrete under axial compression.

With increasing amplitude of motion, cracks propagate and reinforcement enters in its yielding (plastic) state. At this point, damage results in a continuous modification (reduction) of the stiffness and thus of the dynamic characteristics (vibration period of vibration) and deformation of the structure during shaking.

Even after the seismic motion ceases, structures (due to their kinetic energy) continue to vibrate. Due to the inherent structural damping and the energy consumption in the damaged areas (hysteretic damping) the amplitude of free-vibration motion continuously decreases, until the structure stops. With increasing extent and severity of damage, structures develop permanent deformations and, thus, do not attain their pre-earthquake geometry. The degree of damage, for the same seismic motion, varies from structure to structure. Structures built before the advent of modern design codes are particularly vulnerable ones. The damage that develops in a structure can be either contained within few elements (creating the conditions for possible collapse) or, may propagate to larger number of elements (allowing, thus, enough margin till the relevant member resistance). This observation is particularly useful and forms the underlying principle in regulatory documents.

After a seismic event, depending on the expected impact on the structural stability, the authorities conduct a screening procedure in order to characterize the damaged structures as useable, useable after repair or to be demolished.

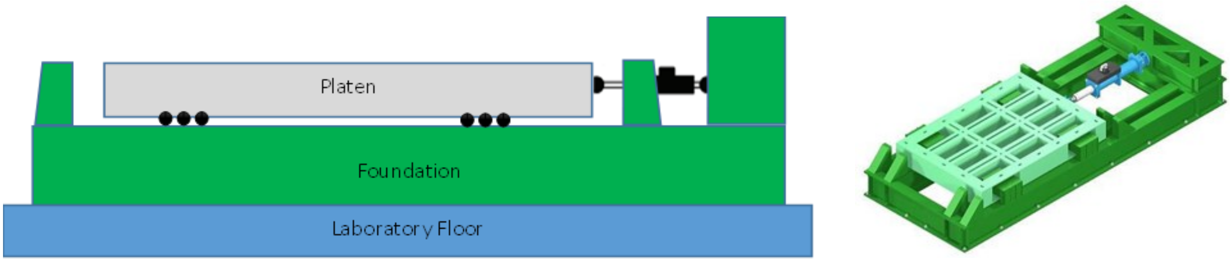
Modern codes of practice (e.g. Eurocodes) include appropriate approaches both for designing new structures and for assessing or retrofitting existing ones. Code provisions for new structures promote – as economically more viable – the design of flexible and strong structures. Their main target is to avoid structural collapse and, while they do allow some damage to develop, they strive to preclude uncontrollable or non-repairable damage. With this compromise, modern societies, maybe with the exception of critical structures, consent to some degree of acceptable risk, as they do in other areas. Nevertheless, users may opt for a no-damage approach and then modern technologies like seismic isolation or active control may be employed, certainly at much higher costs. ■

How does the testing of a building on a shake table works?

Dr. António A. Correia, Laboratório Nacional de Engenharia Civil (LNEC), Portugal

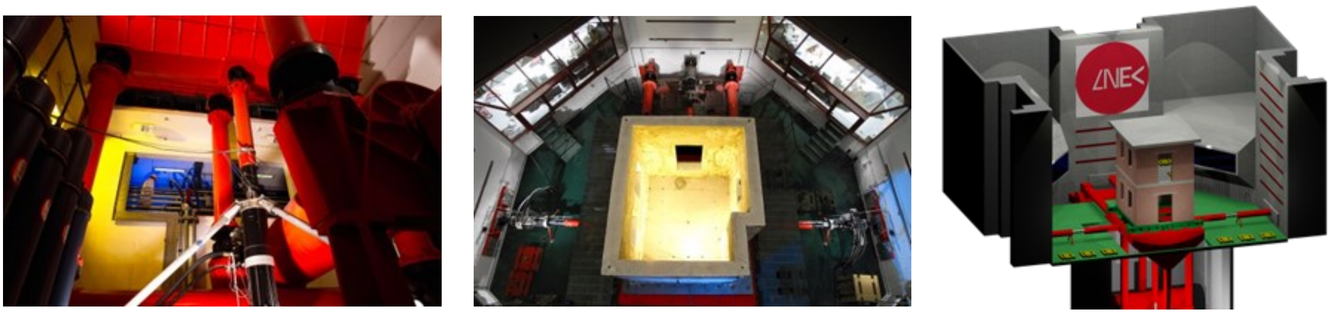
In order to study the effects of earthquake actions on a structure, performing shake table tests is the most realistic research approach. This article describes how the testing of a building structure on a shake table is performed and which are the outcomes and benefits of this type of experimental test.

A shake table system is composed of several components, comprising mainly the hydraulic pumping system, servo-valve controlled actuators, the shake table platform, and the digital control system. A simple uniaxial shake table platform and its components is depicted in the following picture.



Shake table components and idealised model.

In the pictures below a larger triaxial shake table system, surrounded by reaction walls, allows for a variety of test setups to be envisaged.



Triaxial shake table system with surrounding reaction walls and with an idealised test specimen

When planning a shake table test, one of the first decisions is related to the geometric scale of the model with respect to the prototype (real structure). When the capacity of the shake table system is not able to withstand the dimensions and weight of the real structure, a reduced scale model has to be used and dynamic similitude laws should be adopted based on the Cauchy and/or Froude numbers. The former relates the inertial forces to the elastic resisting ones, while the latter relates the inertial forces to the gravity ones. The scaling laws for a reduced scale specimen when both similitudes are respected (and for an example with a geometric scale of 1:1.5) are included in the Table.

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Cauchy-Froude similitude (elastic, inertia and gravity forces)

Physical quantity	Scaling law
Length, $\lambda = L_p/L_m$	$\lambda = 1.5$
Elastic modulus, E_p/E_m	1
Density, r_p/r_m	$1/\lambda = 0.67$
Mass, m_p/m_m	$\lambda^2 = 2.25$
Displ, Vel, Accel	$\lambda = 1.5$, $\lambda^{1/2} = 1.22$, 1
Weight, Force	$\lambda^2 = 2.25$
Moment	$\lambda^3 = 3.38$
Stress	1
Strain	1
Time, t_p/t_m	$\lambda^{1/2} = 1.22$

p – protoype (real structure), m – model (reduced scale specimen)

After defining the typology, geometry and materials of the model, the latter is usually built outside the shake table and then transported onto it, either by a moving crane or over roller supports. The model is then fixed on the table and instrumented (see figure).

Model transportation and instrumentation

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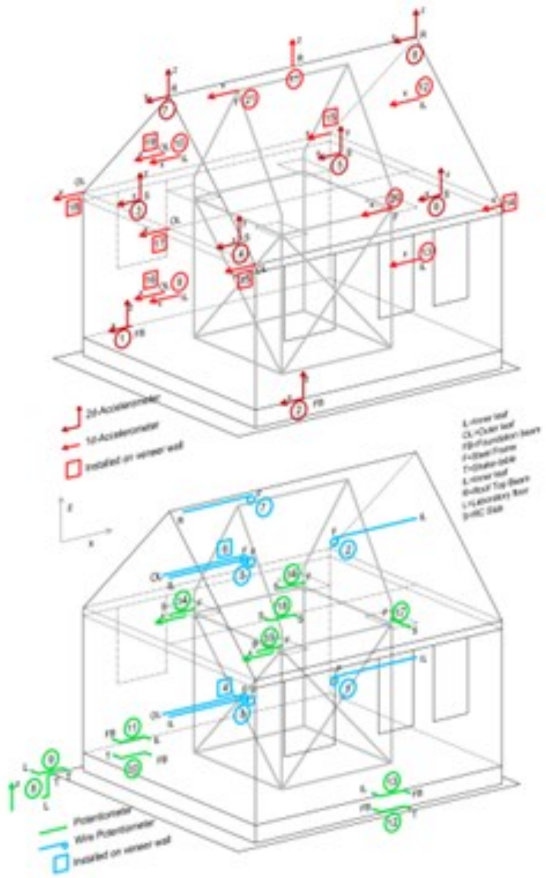
Given the plethora of phenomena intervening on the dynamic response of a structure, it is important to collect accurate and extensive sets of data during the shake table test. This implies adopting an instrumentation plan for measuring different physical quantities using available technology (displacement transducers, accelerometers, strain gauges, load cells, optical measurement de vices, etc.), and placed at the locations where significant response quantities are foreseen and where damage is expected to occur. Typically, in a shake table test, the sensing devices should be able to measure accurately at frequencies up to 100 Hz and should be sensitive enough to measure small values of the response quantities with a high signal-to-noise ratio, while being robust enough to measure up to the amplitude range of interest. A typical instrumentation layout for a specimen and its application is shown in the picture next.



Typical specimen instrumentation layout

In shake table tests one may also be interested in simulating the behaviour of non-structural elements, which often represent a significant portion of the economic losses due to seismic activity.

Shake testing of non-structural components

Shake table tests are performed in stages of increasing intensity of the seismic input, intertwined with dynamic identification stages for assessing the evolution of the dynamic properties of the specimen.

At each stage of seismic input, the shake table controller has the objective of achieving a target table motion by continuously correcting the motion of the actuators through feedback readings and real-time comparison between executed and target motions. Usually, the initial drive motion for a given seismic input stage is already the result of a previous tuning process using the shake table system with a dummy specimen. Such dummy specimen should represent the actual specimen’s mass, mass-distribution and (possibly) its stiffness with the aim of calibrating the actuators' input motions so that they match the required target input and incorporate the dynamics of the coupled shake table—specimen system. Nevertheless, the dummy specimen is often not capable of fully representing the real specimen's dynamics and its degradation due to damage. The real-time control is thus very important for ensuring a shake table input motion is close to the target one. Target and achieved shake table motions should closely match during all testing stages (as shown below in the pseudo-acceleration response spectrum and corresponding recorded acceleration histories).

The dynamic identification between test stages is very useful to quantify the degradation of the model in terms of the decreasing natural frequencies of vibration and increasing modal damping.

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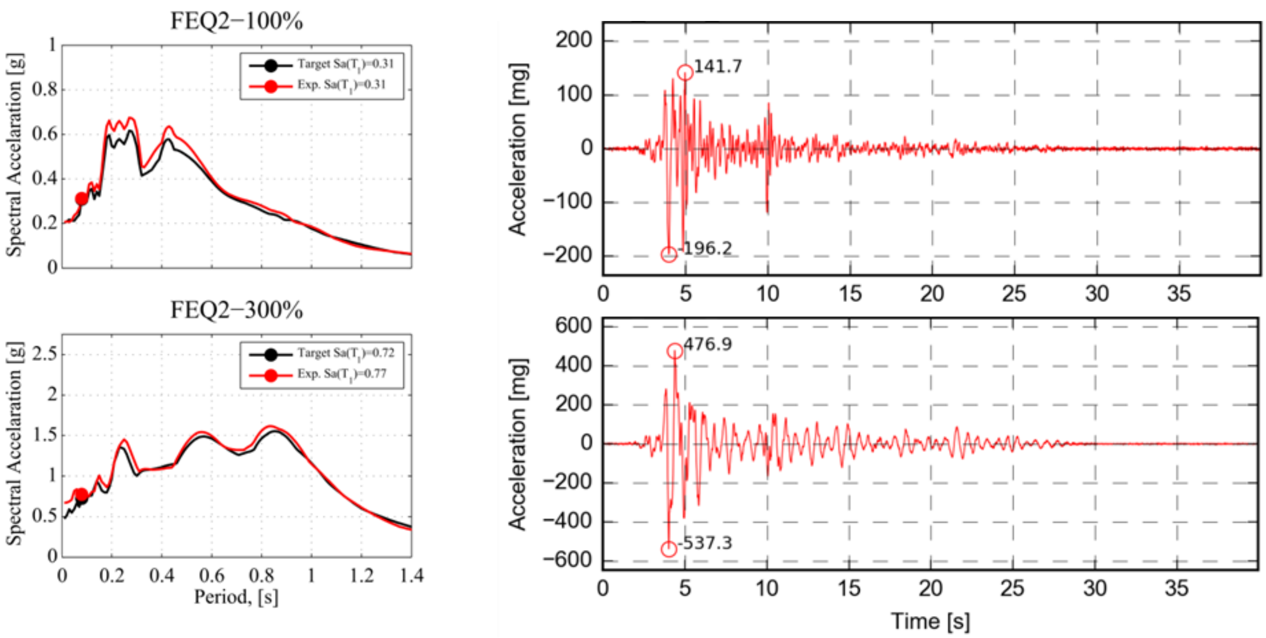

Pseudo-acceleration response spectra for two test stages and recorded acceleration histories

Upon cracking, yielding, and general damage phenomena, the structure becomes more flexible – decreasing its natural vibration frequencies and dissipates more energy during vibration due to friction and hysteretic behaviour. This results in larger equivalent damping and a shorter settling time after the ground motion input ends. The quantitative assessment is an important complement to the visual inspection of damage in the specimen. Damage assessment of a stone masonry model using both methods is shown next-note the decrease in modal frequencies for the first two modes of vibration and the crack pattern observed at the end of the test.

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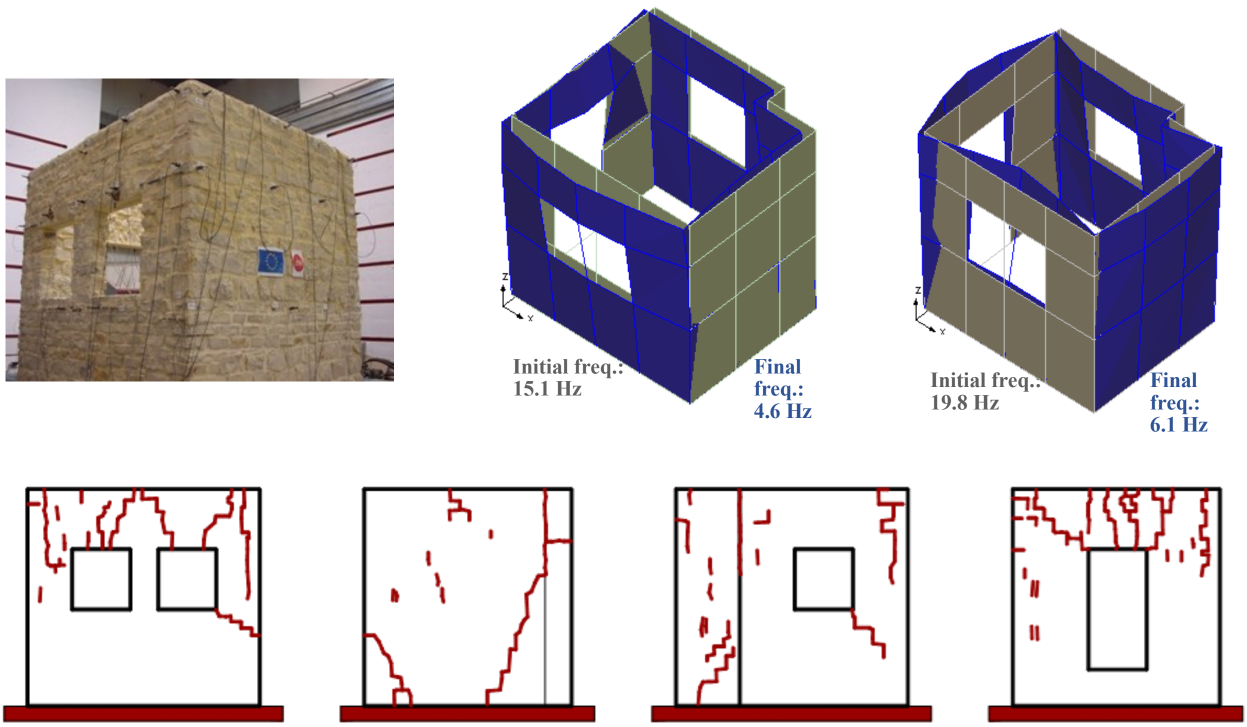
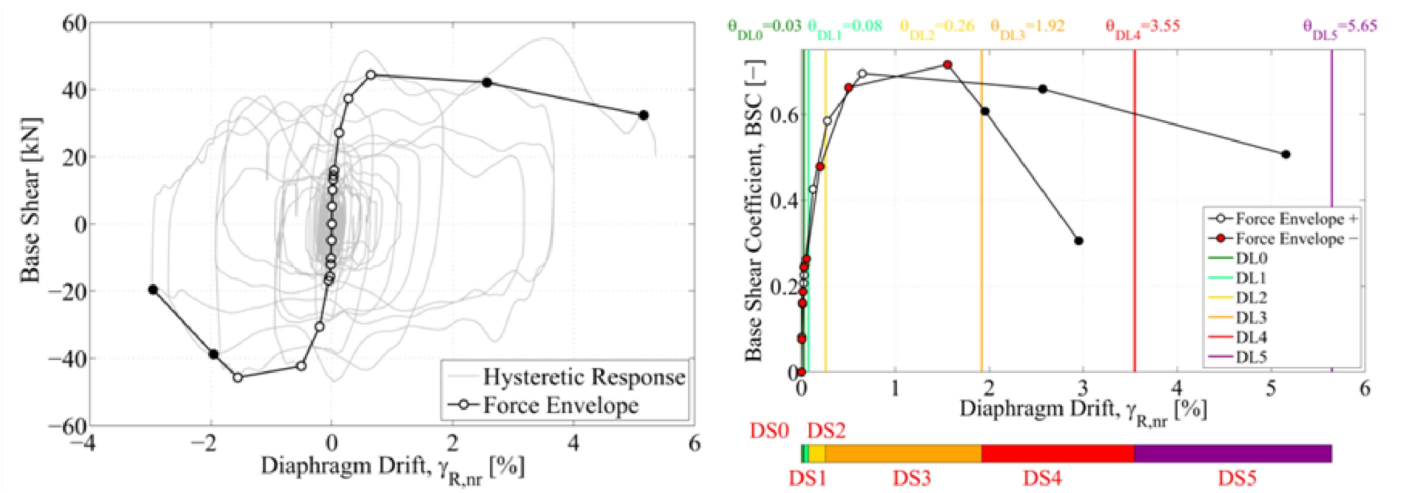


Assessment of damage in a masonry model through dynamic identification (top row) and crack pattern (bottom row) representation

The measurement of accelerations, forces and displacements, together with the abovementioned damage assessment procedures allows for the interpretation of the specimen's dynamic behaviour. For this, global force-displacement plots recorded during a shake table test for a given specimen, along with a summary of the damage limit states attained for each displacement demand, may be employed. During a shake table test, it is important to be able to characterise the full spectrum of damage limit states, from the initial cracking up to the collapse of the specimen.

This experimental technique has been very important in the past and continues to give important contributions to our understanding of the structural behaviour and seismic strengthening, while also accompanying the development of new technologies for testing and data acquisition. Furthermore, the seismic qualification of critical equipment and the development and calibration of numerical tools for simulating the dynamic response of structures, rely heavily on the results of shake table tests. Concluding, the development of seismic mitigation techniques, materials and devices have in shake table testing the ultimate proof of concept before being adopted in real structures. ■



Global force-displacement response and damage limit states' definition

Collapse state of reinforced concrete specimen with masonry infills

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