Research Unit of Geotechnical Earthquake Engineering and Soil Dynamics

Director: Prof. Kyriazis Pitilakis

Research Projects
2009 - 2013
Research activities

Soil Dynamics & Geotechnical Earthquake Engineering

- Microzonation & site effect studies
- In situ & laboratory tests
- Protection of monuments against natural hazards
- Monitoring of structures
- Strong ground motion - engineering seismology
- Numerical & stochastic methods
- Soil-foundation-structure interaction (surface & deep)
- Seismic design
- Vulnerability & risk assessment of lifelines
- Ground improvements
- Underground structures & infrastructures
- Vulnerability of buildings
### Major Research Projects (on going & recently completed)

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<th>P: Major partner</th>
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SYNER-G: Systemic Seismic Vulnerability and Risk Analysis for Buildings, Lifeline Networks and Infrastructures Safety Gain

Duration: 2009-2013
Total Budget: 3.500.000 €
URL: www.syner-g.eu

Main goals

- To elaborate appropriate, in the European context, fragility relationships for the vulnerability analysis and loss estimation of all elements at risk
- To develop social and economic vulnerability relationships for quantifying the impact of earthquakes
- To develop a unified methodology, and tools, for systemic vulnerability assessment accounting for all components exposed to seismic hazard, considering interdependencies within a system unit and between systems
- To validate the methodology and the proposed fragility functions in selected sites and systems and to implement in an appropriate open source access software tools

Partners

Aristotle University of Thessaloniki (Coordinator)
Vienna Consulting Engineers
Bureau de Recherches Geologiques et Minieres
Commission of the EC - Joint Research Centre
Norwegian Geotechnical Institute
University of Pavia
University of Roma “La Sapienza”
Middle East Technical University
Analysis and Monitoring of Environmental Risks, University of Naples Federico II
Karlsruhe Institute of Technology
University of Patras
Willis Group Holdings
Mid-America Earthquake Center, University of Illinois
Kobe University

- > 80 deliverables
- Pilot studies
- Software tools
- Dissemination (publications, 2 Books)
- 7 Reference reports
- 2 technical workshops
- Final international workshop
SYNER-G: Systemic Seismic Vulnerability and Risk Analysis for Buildings, Lifeline Networks and Infrastructures Safety Gain

Layout of SYNER-G Methodology & Software tools

1. Hazard Definition & Seismic Intensity Measures (IM)
2. Inventory Selection
3. Fragility Models
4. Systemic Analysis
5. Damage & Loss Prediction
6. Decision Support

OOFIMS: Object Oriented Framework for Infrastructure Modeling and Simulation
SYNER-G: Systemic Seismic Vulnerability and Risk Analysis for Buildings, Lifeline Networks and Infrastructures Safety Gain

Earthquake scenarios for spatially distributed systems (Shake-fields).

Unified and harmonized typology and taxonomy definitions for the European physical assets at risk. Inventory databases.

Fragility curves based on SYNER-G taxonomy for all elements at risk. Fragility Function Manager Tool.

Systemic analysis methodology and tools for buildings, utilities and lifelines. Performance indicators and interactions between components and other systems.

Damages and losses for all assets.

Socio-economic losses: shelter needs, health impact and accessibility models. Decision Support tools.
**E2VP-2**: Evaluation, Verification, and Validation Project – Phase 2, subproject of the **CASHIMA Project**, CEA – France

**Duration**: 2009-2013

**Total Budget**: 1,465,000 €

**Main goals**

- To extend the 3D geological/geotechnical model of the EUROSEISTEST array area by incorporating a larger number of available geological, geophysical and geotechnical data
- To validate numerical simulation codes of strong ground motion using the EUROSEISTEST database

**Partners**

- CEA, France
- ISTerre of the Joseph Fourier University of Grenoble
- Comenius University, Bratislava
- Aristotle University of Thessaloniki
- OASP-ITSAK Thessaloniki
- Institut Laue-Langevin, Grenoble
E2VP-2: Evaluation, Verification, and Validation Project – Phase 2

Accomplishments:
- 3D Geological/Geotechnical Model of the EUROSEISTEST area
- Web Portal for the dissemination of EUROSEISTEST data
- Research publications on seismic wave propagation and site effects issues (4 peer-reviewed publications in the last 3 years)

Snapshots from the EUROSEISTEST web portal
(http://euroseisdb.civil.auth.gr)
SERIES: Seismic Engineering Research Infrastructures for European Synergies

University of Patras (Coordinator)
Aristotle University of Thessaloniki
Commissariat a l Energie Atomique et aux Energies Alternatives
Centro Europeo di Formazione e Ricerca in Ingegneria Sismica
Geodynamique et Structure
Technical University of Istanbul
Institute of Earthquake Engineering and Engineering Seismology
Commission of the EC - Joint Research Centre
Bogazici University
IFSTTAR
Laboratório Nacional de Engenharia Civil
Middle East Technical University
National Technical University of Athens
P&P LMC Srl
Technical University ‘Gheorghe Asachi’ of Iasi
University of Cambridge
Univerza V Ljubljani
Universita degli Studi di Napoli Federico II
Universität Kassel
Università degli Studi di Trento
University of Bristol
University of Oxford

Duration: 2009-2013
Total Budget: 8.700.000 €
URL: www.series.upatras.gr

Main goals

- > 40 deliverables
- 6 training courses on experimental testing techniques
- Dissemination (publications, 3 Books)
- 2 joint brochures
- 3 technical workshops
- 4 international workshop

- Enable networking activities and cooperation among all European research infrastructures and teams active in earthquake engineering
- Coordinate Transnational Access of Users to a world class portfolio combining:
  - EU’s four largest earthquake Shaking Tables, each one with diverse capabilities (TAMARIS; EUCENTRE; LNEC; Bristol University)
  - EU’s largest Reaction Wall and Pseudodynamic testing facility (ELSA)
  - Unique Centrifuge Test facilities (IFSTTAR; Cambridge University)
- Enable joint innovative research in the areas of new generation electro-dynamic actuators, instrumentation and sensor techniques and techniques for experimental study of soil-structure-interaction and seismic wave propagation
**SERIES:** Seismic Engineering Research Infrastructures for European Synergies

**EuroProteas**
- Full-scale experimental facility (EuroProteas) designed to study soil-foundation-structure interaction and wave propagation
- Free-vibration tests for various levels of pull-out loading
- Forced-vibration tests with an actuator on the roof or the foundation slab
- Large number (>80) of various types of recording instruments in 3D array to monitor the structural, foundation and soil response
- 2D / 3D numerical analyses during design, construction and simulation of experimental campaigns

**Rectangular Tunnels**
- Dynamic centrifuge tests to evaluate the seismic response of rectangular tunnels in soft soils
- Tests at centrifuge facilities of IFSTTAR and of the University of Cambridge
- Large number of instruments to monitor soil and tunnel response
- Study of crucial parameters controlling the response (e.g. soil-structure relative flexibility and interface characteristics)
- Experimental evidence of rocking
- Numerical simulations and calibration of existing design methodologies
SHARE: Seismic Hazard Harmonization in Europe

Partners
Swiss Seismological Service, ETHZ Zurich
GeoForschungsZentrum Potsdam
Istituto Nazionale di Geofisica e Vulcanologia
Laboratoire de Géophysique Interne et Tectonophysique, Université Joseph Fourier
Università degli Studi di Pavia
Aristotle University of Thessaloniki
Bureau de Recherches en Géologiques et Minières
Centre de Recherche en Astronomie, Astrophysique et Géophysique
Instituto Superior Técnico
Kandilli Observatory and Earthquake Research Institute Bogazici University
Laboratório Nacional de Engenharia Civil
Middle East Technical University
Montenegro Seismological Observatory
Natural Environment Research Council /British Geological Survey
National Institute for Earth Physics
Seismological Laboratory, University of Athens
NORSAR / International Centre for Geohazards
Observatoire Royal de Belgique

Duration: 2009-2012
Total Budget: 4.100.000 €
URL: www.share-eu.org
www.efehr.org

Main goals
- To build a framework for integration across disciplines and national borders, to homogeneously compile earthquake data and assess seismic hazard without the burden of political constraints and administrative boundaries.
- To pursue best practices and high standards in all aspects of seismic hazard assessment, from data collection to the computational framework.
- To cover the whole Euro-Mediterranean area
- To form a basis for longevity and continuous improvement of a dynamic model ready to incorporate the most recent developments from science and engineering.
- To maintain a direct connection to the Eurocode 8 applications and the definition of the Nationally Determined Parameters
- To produce direct outputs for risk assessment
- To focus on the effective dissemination of hazard tools and results.

- 37 deliverables
- > 60 time-independent European Seismic Hazard Maps
- Dissemination (web portal of the European Facility for Earthquake Hazard and Risk EFEHR)
New soil factors for Eurocode 8 soil classes

<table>
<thead>
<tr>
<th>Soil class</th>
<th>Type 2 (M ≤ 5.5) Proposed</th>
<th>Type 2 (M ≤ 5.5) EC8</th>
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<tbody>
<tr>
<td>B</td>
<td>1.40</td>
<td>1.35</td>
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<tr>
<td>C</td>
<td>2.10</td>
<td>1.50</td>
</tr>
<tr>
<td>D</td>
<td>1.80&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.80</td>
</tr>
<tr>
<td>E</td>
<td>1.60&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.60</td>
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<sup>a</sup> site-specific ground response analysis required

New soil classification scheme

<table>
<thead>
<tr>
<th>Soil Class</th>
<th>Description</th>
<th>T&lt;sub&gt;63&lt;/sub&gt;</th>
<th>Remarks</th>
</tr>
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<tbody>
<tr>
<td>D1</td>
<td>Recent soil deposits of silty thickness (up to 10 m) with high plasticity index (PI &gt; 40); liquefiable soil; very stiff or stiff clay</td>
<td>2.0</td>
<td>V&lt;sub&gt;pc&lt;/sub&gt; ≥ 300 m/s; PSFT ≤ 25; ( \phi_s ) ≥ 70° LPA</td>
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<tr>
<td>D2</td>
<td>Recent soil deposits of silty thickness (up to 10 m) with high plasticity index (PI &gt; 40); liquefiable soil; very stiff or stiff clay</td>
<td>2.0</td>
<td>V&lt;sub&gt;pc&lt;/sub&gt; ≥ 300 m/s; PSFT ≤ 25</td>
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New elastic response spectra

Pitilakis et al. (2012)

Pitilakis et al. (2013)
NERA: Network of European Research Infrastructures for Earthquake Risk Assessment and Mitigation

Duration: 2010-2014
Total Budget: 12,000,000 €
URL: www.nera-eu.org

Main goals
✓ To integrate the key research infrastructures in Europe to monitor, assess and prevent earthquake hazards
✓ To cover analytical vulnerability assessment tools and mobile facilities for site characterization of constructions
✓ To develop instruments, hazard and risk assessment, data processing and data dissemination
✓ To support the reduction of vulnerability of European citizens and constructions to earthquakes
✓ To foster international collaboration activities and further integration of the research field
Cardinal points: Network of European Research Infrastructures for Earthquake Risk Assessment and Mitigation

Waveform modeling and site coefficients for basin response

- Extensive parametric numerical elastic analyses on 2D trapezoidal models with varying mechanical and geometrical characteristics, and incoming wavefields
- 96 models with 10 input motions = 960 analyses
- Non-linear analyses for selected cases
- Target results: period-dependent aggravation factors AGF

Target results:
- $AGF_{w=2500, h=250}$
- $AGF_{w=2500, h=250}$
- $AGF_{w=500, h=250}$
- $AGF_{w=500, h=250}$

Non-linear analyses for selected cases:
- $a_1=20^\circ$
- $a_2=65^\circ$

Graphs showing period-dependent aggravation factors for different scenarios.
**REAKT:** Strategies and Tools for Real Time Earthquake Risk Reduction

### Partners

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### Duration:
2011-2014

### Total Budget:
10.100.000 €

### URL:
www.reaktproject.eu

### Main goals

- To improve the efficiency of real-time earthquake risk mitigation methods and their capability of protecting structures, infrastructures and populations.
- To develop methodologies that will enhance the quality of information provided by earthquake forecasting, early warning and real-time vulnerability systems.
- To establish best practices for how to use all of this information in a unified manner.
- To combine such information into a fully probabilistic framework, including realistic estimates of the uncertainties involved, that is suitable for decision making in real time.
REAKT: Strategies and Tools for Real Time Earthquake Risk Reduction

Layout of REAKT

- WP3
- WP2
- WP4
- WP3

Time scales of interest in real-time risk reduction

- Long-term Hazard Mapping
- Long-Term Forecasting
- Short-Term Forecasting
- Early Warning
- ShakeMaps & Rapid Loss
- Aftershock Forecasting

Decades → Years → Days → Minutes → Seconds → Minutes to Hours
Main Accomplishments:

- Derivation of time-dependent fragility functions for RC MRF buildings designed according to different seismic code levels and height classes considering aging effects and soil-structure interaction.
- Methodology for real-time vulnerability assessment of RC buildings from field monitoring data taking into account material strength degradation and potential existing structural damage.
- Implementation of an early earthquake warning system for the AHEPA hospital and the Thessaloniki port.
- Earthquake early warning and rapid post-earthquake assessment of damage in monitored buildings in Thessaloniki: the example of the AHEPA hospital.
**reakt**: Strategies and Tools for **Real Time EArthquake RisK ReducTion**

Framework of the implementation of the EEW and rapid post-earthquake assessment of damage in monitored buildings

- Rapid post-earthquake assessment of buildings based on field monitoring data
  - Finite element modeling (FEM)
  - Operational model analysis (OMA)
  - Early Earthquake Warning: Earthquake alert
  - Evaluation of MAC values: Comparison between numerical and experimental models
  - Finite element model updating
  - Sensitivity in structural materials
  - Selection of the "best" FE model
  - Derivation of "real-time" fragility curves
  - Computation of probability of damage
  - Intensity parameter PGA

Permanent real-time ANERA hospital network

Potential real-time ANERA hospital network

- Joint between the buildings
- Structural joint
- Temporary array for ambient noise experiments
SAFELAND: Living with Landslide Risk in Europe: Assessment, effects of global change, and Risk Management strategies

Duration: 2009-2012
Total Budget: 8.700.000 €
URL: www.safeland-fp7.eu

Main goals

✓ Develop quantitative risk assessment (QRA) methodologies by improving and adapting existing knowledge on landslide hazard and risk for different spatial scales, looking into uncertainties, vulnerability, landslide susceptibility and landslide frequency
✓ Provide improved harmonized framework and methodology for the assessment and quantification of landslide risk in Europe's regions
✓ Evaluate the changes in risk pattern caused by climate change, human activity and policy change scenarios
✓ Develop monitoring technology, especially early warning systems and remote sensing techniques
✓ Provide guidelines for choosing the most appropriate risk management strategies, including risk mitigation and prevention measures
**SAFELAND:** Living with Landslide Risk in Europe: Assessment, effects of global change, and Risk Management strategies

**Main Accomplishments:**

- **Physical vulnerability** of elements at risk to different landslide hazards: Methodologies for evaluation, fragility curves and damage states for buildings and lifelines.

- Application to case studies of structural impact of landslides

- Methodology for predicting the **evolution of landslide vulnerability** due to environmental deterioration of RC structures.

- **Mitigation measures** through reduction of structure’s vulnerability to different landslide hazards.

Framework of the analytical method for assessing vulnerability of RC buildings to slides – Fragility curves

Application to case studies of structural impact of landslides

Evolution of building vulnerability over time: derivation of fragility surfaces
PERPETUATE: Performance-based approach to earthquake protection of cultural heritage in European and Mediterranean countries

Duration: 2010-2013
Total Budget: 2.863.000 €
URL: www.perpetuate.eu

Main goals
✓ Develop European Guidelines for the evaluation and mitigation of seismic risk to cultural heritage assets, with innovative techniques for the seismic strengthening of historical buildings and the preservation of unmovable artworks.
✓ Face the problem both for architectonic assets (historic buildings; macroelements, which are architectonic elements that may be analyzed independently from the rest of the building) and artistic assets (frescos, stucco-works, statues, pinnacles, battlements, banisters, balconies …).
✓ Two different scales are considered:
  • assessment of a single cultural heritage asset.
  • assessment at the territorial scale.
✓ The main outcome of the project will be a document providing European Guidelines for safety and conservation measures and the overall methodology.

Partners
University of Genoa - Coordinator, Italy
ENEA - Italian National Agency for the new technologies, the energy and the sustainable economic Development, Italy
BRGM - Bureau de Recherches Géologiques et Minières, France
Aristotle University of Thessaloniki, Greece
National Technical University of Athens, Greece
University of Ljubljana, Slovenia
University of Bath United Kingdom
University of Science and Technology Houari Boumediene Algeria
Building and Civil Engineering Institute, Slovenia
II Cenacolo Srl, Italy
Proind Srl, Italy

- > 40 deliverables
- Case studies (Rhodes, Algiers, Italy, Slovenia)
- Dissemination (publications, 1 special issue)
- 3 technical workshops
PERPETUATE: Performance-based approach to earthquake protection of cultural heritage in European and Mediterranean countries

Accomplishments:
- Proposal of impedance functions for flexible masonry foundations (surface – embedded, horizontal – vertical – rotational modes)
- Field measurements for the estimation of the soil profile of the Medieval City of Rhodes as well as the seismic hazard
- Application of the proposed methodology to case studies (Hassan Bey’s Mansion, Neoclassical School, Arsenal De Milly)
- Research publications on the above-mentioned issues (7 peer-reviewed publications in the last 3 years)
**STREST:** Harmonized approach to stress tests for critical infrastructure (CI) against natural hazards

**Partners**
Eidgenoessische Technische Hochschule Zurich
Ecole Polytechnique Federale de Lausanne
Basler & Hofmann
European Centre for Training and Research in Earthquake Engineering, EUCENTRE
Analysis and Monitoring of Environmental Risks, University of Naples Federico II
Istituto Nazionale Di Geofisica E Vulcanologia
Toegepast Natuurwenschappelijk Onderzoek
Universite Joseph Fourier Grenoble 1
Aristotle University of Thessaloniki
Kandilli Observatory and Earthquake Research Institute
University of Ljubljana
Commission of the EC - Joint Research Centre

**Duration:** 2013-2016

**Total Budget:** 3.975.000 €

**Main goals**
- Establish a common and consistent taxonomy of CIs, their risk profiles and their interdependencies, with respect to resilience to natural hazard events;
- Develop a rigorous common methodology and a consistent modeling approach to hazard, vulnerability, risk and resilience assessment of LP-HC CI events used to define stress tests;
- Design a stress test framework and apply it to assess the vulnerability and resilience of individual CIs as well as to address the first level of interdependencies among CIs from local and regional perspectives;
- Work with key European CIs, to apply and test the developed stress test framework and models to specific real CIs;
- Develop standardized protocols and operational guidelines for stress tests, disseminate the findings of STREST, and facilitate their implementation in practice;
Research Group

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Publications

More than **400** papers in:
- scientific journals
- conference proceedings
- special issues
- book contributions