Systemic Seismic Vulnerability and Risk Analysis for Buildings, Lifeline Networks and Infrastructures Safety Gain

Reporting

Project Information

SYNER-G

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ARISTOTELIO PANEPISTIMIO THESSALONIKIS
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Final Report Summary - SYNER-G (Systemic Seismic Vulnerability and Risk Analysis for Buildings, Lifeline Networks and Infrastructures Safety Gain)

Executive Summary:

SYNER-G is a European collaborative research project focusing on systemic seismic vulnerability and risk analysis of buildings, transportation and utility networks and critical facilities. The methodology is implemented in an open source software tool and it is applied and validated in selected case studies. SYNER-G is integrated across different disciplines with an internationally recognized partnership from Europe, USA and Japan. The 14 participants in the consortium represent a variety of organizations, from universities and academic institutions to research foundations and SMEs. The objectives and the deliverables are focused to the needs of the administration, local authorities, responsible for the

management of seismic risk, private and public services managing utility systems and infrastructures, insurance industry, as well as the needs of the construction, consulting and insurance industry.

SYNER-G developed an innovative methodological framework for the assessment of physical as well as socio-economic seismic vulnerability at urban and regional level. The built environment is modeled according to a detailed taxonomy into its component systems, grouped into the following categories: buildings, transportation and utility networks, and critical facilities. Each category may have several types of components. The framework encompasses in an integrated fashion all aspects in the chain, from regional hazard to fragility assessment of components to the socioeconomic impacts of an earthquake, accounting for relevant uncertainties within an efficient quantitative simulation scheme, and modeling interactions between the multiple component systems in the taxonomy. The prototype software (OOFIMS) which provides several pre and post-processing tools, is implemented in the SYNER-G platform. The methodology and software tools are applied and validated in selected sites and systems in urban and regional scale: the city of Thessaloniki (Greece), the city of Vienna (Austria), the harbour of Thessaloniki, the gas system of L'Aquila (Italy), the electric power network in Sicily, a roadway network in South Italy and a hospital facility again in Italy. Adequate guidelines and appropriate dissemination schemes for all products of the project at European and international level have been proposed, including among others seven European Reference Reports, synthetic documents and deliverables, high quality brochure and leaflet, three technical workshops, a special session in the 15WCEE, peer review publications in journal and conferences, and preparation of two books in Springer Editions.

The main features of the SYNER-G methodology are outlined in the following:

• Unified and harmonized typology and taxonomy definitions are proposed for almost all physical assets at risk in the European context.The physical elements are the built environment namely buildings, lifeline networks, transportation infrastructures, utilities and critical facilities. Social elements are fatalities, incuries and various social and economic losses, which are evacuate based on the availiable demographic and socio-economic data. It is essential to compile inventory databases of elements at risk and to make a classification on the basis of pre-defined typology definitions. Inventories are obtained from Census Data, Owner/Operators Data, and ground surveys or through remote sensing techniques.
• Fragility curves are proposed for all elements at risk based on SYNER-G taxonomy, using available data and developing new ones if needed. A Fragility Function Manager Tool is available for the storage, harmonization, utilization and comparison of all available fragility functions.
• The seismic hazard is defined based on SHARE EC/FP7. A stochastic simulation is performed for the generation of spatially correlated and cross-correlated fields for ground motion intensity measures (called "Shake-fields"). Site effects and various geotechnical hazards (liquefaction, fault crossing, landslide displacements) are also considered.
• A systemic analysis methodology and tool is developed for buildings, utilities and lifelines (electrical power, water, waste water, gas, transportation and harbor networks and health care facilities). The Object-Oriented Modeling paradigm is used (called here after OOFIMS), where the complex problem of several interacting systems is decomposed in a number of interacting objects. Each system is specified with its components, solving algorithms – interactions between components, performance indicators (PIs) and interactions with other systems.
• An advanced innovative systemic vulnerability assessment is carried out considering uncertainties based on Monte Carlo or importance samping simulation. Damages and losses for all assets are assessed

on Monte Carlo or importance sampling simulation. Damages and losses for all assets are assessed. Representative results are building damages, casualties (deaths, injuries, displaced people), connectivity or flow analysis-based performance indicators for networks and infrastructures and mean annual frequency of exceedance of the PIs. Distribution of estimated damages and losses for specific events is given through thematic maps.
• Socio-economic losses are assessed including shelter needs, health impact and accessibility models. A Multi-criteria Decision Analysis tool is applied, which provides decision makers with a dynamic decision-support platform to capture post-disaster emergency shelter demand decisions. Apart from building and utility losses, building usability, building habitability and social vulnerability of the affected population together with socio-economic indicators (Urban Audit/EUROSTAT) are considered in the analysis.

Project Context and Objectives:

Main objectives:

• Encompass all past and ongoing knowledge and know-how on this topic to develop new innovative and

powerful tools for seismic risk assessment.

Review of current state of the art, understanding of systemic vulnerability and risk of assets and urban systems (buildings, building aggregates, lifeline networks, utilities and infrastructures); development of a general methodology to assess vulnerability and losses including the inter and intra dependencies.

• Select and develop advanced fragility functions and methods to assess the physical and societal-economic vulnerability of all assets.

Appropriate fragility curves/functions are proposed for numerous elements at risk (buildings, building aggregates, utility and transportation components and critical facilities) according to the typological features of European construction and practice.

• Propose the most appropriate means of selecting seismic scenarios at system level.

Development of an enhanced seismic hazard model adequate for spatially distributed systems.

• Develop a unified methodology to assess vulnerability at a system level.

A general methodology is proposed, to evaluate and quantify vulnerability and losses considering systemic interdependencies, which is further specified for each particular network.

• Develop methodology and tools to assess the socio economic vulnerability and losses.

A methodology and tools to assess the socio-economic impacts due to seismic damages that influence preparedness and response activities in the context of short-term emergency relief and recovery (emergency shelter, health care facilities, transportation infrastructure, utility systems). Appropriate methodologies including indicator based systems for integrating socio-economic impacts with fragility functions and performance models

functions and performance models.

• Build an appropriate open-source software and tool to deal with systemic vulnerability.

An appropriate open source and unrestricted access software tool where the SYNER-G methodology and tools has been implemented.

• Apply and validate the effectiveness of the methodology and tools to specific and well selected case studies at city and regional scale.

Verification of the systemic vulnerability and risk assessment approaches developed in SYNER-G through numerous applications at selected case studies at city scale (Thessaloniki, Vienna), regional scale (a transportation network in South North-Eastern Italy, an electric power transmission network in Sicily and a gas pipeline network in Central Italy) and in complex systems (the harbor of Thessaloniki and a large hospital facility in Reggio di Calabria, Italy).

Propose guidelines and dissemination schemes for all products of the project.

Several reference reports were prepared to use in practice and appropriate dissemination schemes at European and International level were built for the entire community and administration entities as well as insurance industry.

Project context:

SYNER-G proposes an integrated general methodology and a comprehensive simulation framework for the vulnerability assessment and the evaluation of the physical and socio-economic impact and losses of an earthquake, allowing also for consideration of multiple interdependent systems within the infrastructure. The end result is implemented into an open, modular and expandable software package for effective seismic risk management.

The concept of SYNER-G is to focus on systemic vulnerability assessment and seismic risk analysis of spatially distributed systems and infrastructures considering their distinctive European features, their inter and intra dependencies and including socio economic vulnerability and losses. SYNER-G provides a unified European probabilistic/ quantitative method for systemic physical vulnerability evaluation for buildings, lifeline networks, critical facilities and infrastructures to earthquakes. The project meets the expected impact by increasing understanding of vulnerability of various societal elements at risk, addressing inter-element and intra-system synergies, establishing a seismic societal vulnerability framework and specifying systemic vulnerability. An enhanced seismic hazard model for spatially distributed systems is developed and appropriate fragility functions are proposed for all elements at risk respecting the distinctive European features. A large number of case studies are included in the project for the demonstration and test the applicability of the proposed methodology and tools. Various dissemination activities, including a web portal, 7 reference reports, 3 technical workshops, numerous publications and presentation in conferences, transfer the latest developments to End-Users as well as to the scientific community. In this way, a valuable, powerful and innovative toolbox is provided to the decision-makers to assist the development of mitigation measures, while their implementation in practice is encouraged

assist the development of mitigation measures, while their implementation in practice is encouraged, contributing to changing the perception and confidence in risk management.

In particular the following results have been achieved:

Development of the general methodology

Development of the scientific basis for inter and intra-dependences for the vulnerability and loss assessment of complex interacting systems. A general methodology for systemic vulnerability analysis, including various aleatory and epistemic uncertainties has been developed. Performance indicators (PI) for systemic risk analysis have been defined and categorized. The typology/taxonomy for all elements at risk defined in SYNER-G has been carefully defined and practical means of data integration have been proposed and implemented. A prototype software (OOFIMS) has been developed using Object-Oriented Matlab platform where the methodology has been implemented and tested.

Seismic hazard

Seismic scenarios generation adequate for multi-system infrastructure risk analysis. This includes characterization of spatial correlation of single ground motion intensity measures and spatial cross-correlation of multiple intensity measures. Extension of the seismic input generation methodology to include geotechnical factors, such as site amplification of strong shaking and permanent ground deformation of slope displacement and liquefaction.

Remote sensing for systemic vulnerability analysis

Remote sensing and GIS data generation to be used for building inventories. A clear understanding of the applicability and potential limitations to the application of both airborne and space borne remote sensing data for deriving information pertaining to urban infrastructure. This includes automated derivation of road networks and extraction of key parameters relating to the geometry and typology of buildings within a region of interest.

Fragility curves for all assets

Selection of adequate fragility curves and functions and development of new ones, if needed, for all elements at risk, describing the systems of interest. A powerful fragility function manager tool (open source) for buildings and bridges has been developed.

Socio economic vulnerability and losses

Definition of socio-economic fragility and coping capacity indicators, data harmonization and benchmarking, definition of socio-economic impact models for Shelter Needs and Health Impact. Elicitation of importance weights for the selected indicators proposed for the shelter model based on the results of the literature study, the elicitation of weights for the indicators through statistical methods and deriving weights for the indicators based on a validation case study (L'Aquila). Development of a multi-criteria methodology and software tool for implementing shelter and health impact models considering all

criteria methodology and software tool for implementing shelter and health impact models considering all innovative aspect of SYNER-G. Development of health impact model extending the earthquake casualty estimation methods and linking with hospital functionality models based on a multi-criteria-analysis.

Systemic vulnerability

Specification of interdependencies between components of different systems namely system structure, represented by UML class diagrams, analysis levels and performance indicators. Each system has also been described using the object-oriented framework and represented with UML class diagram.

Applications and validation studies

Application and validation of the developed methods and tools in selected test sites: in city/ urban scale (Thessaloniki, Vienna), in network/regional scale (a transportation network, an electric power transmission network and a gas pipeline network in Italy), and in case of complex systems (the harbor of Thessaloniki and a hospital facility in Italy). For each system, selected Performance Indicators (PIs) are calculated

based on the estimated damages and functionality losses of the different components. The overall performance of the network/infrastructure is expressed through the moving average μ and moving standard deviation σ (averaged over simulations), as well as the Mean Annual Frequency (MAF) of exceedance of the PIs. Maps with the distribution of estimated damages.

Prototype software

Fully functional open source software has been made freely available to the public. A comprehensive tutorial has been produced to allow handling and operation of the complex toolbox. The modular system contains input from all work packages and is held flexible enough to allow any future improvement. The software has been tested and its application successfully demonstrated.

Dissemination activities

Dissemination of SYNER-G results to the scientific community, civil engineering society, public authorities and stakeholders through appropriate dissemination schemes including: project web server, seven comprehensive European Reference Reports, synthetic documents and deliverables, high quality brochure and leaflet, three technical workshops, a special session in the 15WCEE, peer review publications in journal and conferences, preparation of two books in Springer Editions.

Project Results:

FOR THE MAIN S&T RESULTS/FOREGROUDNS SEE THE ATTACHED.pdf FILE

Potential Impact:

Socio-economic impact and wider societal implications:

The high seismic vulnerability of humans and built environment in Europe and the relative lack of

The high seismic vulnerability of humans and built environment in Europe and the relative lack of appropriate mitigation programs, together with the overall moderate to high or very high seismicity resulted to significant direct and indirect earthquake losses in the past 30 years in Europe with a rapidly growing tendency. The vulnerability assessment methodology and the tools proposed by SYNER-G will have considerable impact on the seismic risk assessment and mitigation in Europe. The vulnerability assessment considering system inter- and intra-dependencies is in general higher than individual vulnerability of the elements within each system or even at a system. This new and advanced approach and products will help to apply mitigation measures in an optimized way, which can make them more effective for the society and the economy. Besides the reduction of loss of life and fatalities, the economic and social losses are expected to be considerably reduced.

SYNER-G will have impact at the following levels:

o Technology: A unique advanced European approach has been created which is well advanced with respect to other approaches available in USA and Japan.
o Society: The protection and safety of the population will be considerably improved.

o Economy: The results will enable to improve European building environment, infrastructures and lifelines, thus avoiding excessive losses from earthquakes to come. It will also bring European know-how at a leading position in this field.
o Standards: A standard modular methodology has been created allowing a European approach to the subject and allowing application all over the continent and enabling the construction industry to improve the built infrastructure and the risk assessment of complex industrial facilities and infrastructures.
o ERA: The European Union will be enabled to implement greater economic integration with its neighbours and internationally who are also considerably in need of these new methodologies.
o International Collaboration: The results of the project will make collaboration with Europe more attractive in particular for the USA, Japan, China and India. Europe will be enabled to take the lead on this subject.
o Technology Transfer: Europe will be seen as enabling the rising problems of mega cities in earthquake prone areas.

In particular, the main results of SYNER-G will have the following impact:

o The proposed unified advanced methodology for the systemic vulnerability and loss assessment of buildings, utilities, transportation networks and critical facilities due to seismic hazard at a European level, will help policy-setters and decision makers to optimize urban development and infrastructure planning and the efficiency of seismic risk mitigation strategies.
o The advanced methods and software tools for systemic seismic vulnerability and loss assessment of buildings, lifelines and networks will provide an increased understanding of the combined vulnerability of various societal elements at risk, including the inter-element and intra-system dependencies, which generally increase vulnerability and losses. The efficiency and applicability of the tools have been tested through appropriate case studies at European level.
o The fragility functions for all elements at risk considered in SYNER-G are a key step for the whole methodology, considering the specific typological features of European elements at risk and systems.
o Production of seven comprehensive reference reports constitute a European reference world-wide. They will provide guidance to stakeholders on where to direct research and development efforts and to allocate resources where uncertainties need to be reduced or where cost-effectiveness can be increased.

resources where uncertainties need to be reduced or where cost-effectiveness can be increased.
o Reports and guidelines on innovative and state of the art methods and software produced within SYNER-G, will provide the roadmap beyond the state-of-the-art in lifeline earthquake engineering research, and a benchmark for future research in the field.
o The establishment of links and collaborative research between the engineering community (universities, research institutes and centres, private companies) and the insurance industry will lead to significant developments regarding the financial and social losses due to earthquakes, and facilitate direct output to interested stakeholders with an immediate impact for decision makers and policymakers.
o The various dissemination activities and the web portal, together with the reference and other reports have been the instruments to disseminate the latest developments in lifeline risk assessment and management and the proposed approaches and tools. In this way, a valuable toolbox is provided to the decision-makers to assist the development of mitigation measures, while their implementation in practice will be encouraged, thus again contributing to changing the perception and confidence in risk management.

Main dissemination activities:

The partners of the project disseminated the results of SYNER-G through a dedicated program established at the start of the project (D8.4) and updated all through its completion (D8.18). A graphical representation of all dissemination schemes is given in Fig. 26. The activities for dissemination are given in the following list:

o Publication of Seven Reference Reports (Fig. 27), documenting the methods, procedures, tools and applications developed in SYNER-G. The list of the Reference Reports, with its corresponding editors, reviewers and address audience, is given in Table 1.
o Development of a website platform for the project set up early in the project, providing general, non-confidential information to external users, such as key publications and deliverables, newsletters and announcement of meetings and workshops (Fig. 28). The address of the home page of the public website is www.syner-g.eu.
o Preparation of a Project Leaflet (Fig. 29) and a Project Presentation (Fig. 30), prepared at the beginning of the project.
o Issuing of three Newsletters, at month 3, 15 and 27 (Fig. 31)
o Organization of two Technical Workshops, the first in Thessaloniki (1/3/2013) (Fig. 32) and the second on Vienna (5/3/2013) (Fig. 33), presenting the case studies for these two cities.
o Organization of the Final Workshop in Milano (21-22/3/2013) (Fig. 34), with the participation of the International Advisory Committee and invited experts.
o Preparation of a demo explaining the use of the software tool (Fig. 35)
o Participation at key events and Conferences, in particular: i) 14th European Conference on Earthquake Engineering, held in Skopje, FYROM, from 30/8 to 3/9/2010; ii) 4th International Disaster and Risk Conference IDRC “Integrative Risk Management in a Changing World – Pathways to a resilient Society”, held on 26-30/08/2012 in Davos, and iii) 15th World Conference on Earthquake Engineering (15WCEE), held in Lisbon, Portugal, on 24-28/9/2012, with a special session organized on 24/9 describing the objectives and main outcomes of SYNER-G (Fig. 36).
o Publication of scientific results in peer reviewed journals, conferences proceedings and magazines, including an article on “Assessing earthquake protection” in the magazine Research Media Ltd

including an article on "Assessing earthquake protection" in the magazine Research Media Ltd (http://www.research-europe.com) (Fig. 37).
o Production of a 76 page High-Quality brochure describing the main project products and the key results of the applications to the European urban, infrastructure and network sites (Fig. 38).

Exploitation of results:

In the following are summarized the main issues and recommendations gathered from the various discussions and interventions at the Final Workshop of the project:

o The definition of the taxonomy of elements at risk was one of the main outcomes of the project. However, for several elements, especially those of complex networks (e.g. industrial facilities), it will be necessary to extent the taxonomy and define appropriate fragility curves. It was also suggested to start working towards the production of European guidelines on taxonomy, with a possible view for future standardization. It was suggested to seek interaction with the INSPIRE Directive.
o In Horizon 2020 the issue of seismic and single natural risk may have a reduced importance with respect

to FP7, with a shift towards multi-hazard risk and energy issues. It is important that the consortium and the scientific community as a whole explore ways on how to respond to the evolving needs of the society. The JRC proposed to combine seismic retrofit with energy upgrading, analysing the impact of different options in economic terms.
o To this end (Horizon 2020) the Strategic Research Agenda on Earthquake Risk should be updated with contributions from SYNER-G and other on-going EU projects, as well as from the seismologists' community.
o The consortium should improve the communication of results to stakeholders, shifting from the impact of an earthquake event to the impact of mitigation measures. It is important that the scientific community does not promise zero losses, but rather a reduction of risk through constructive suggestions and recommendations.
o The active participation of stakeholders in future applications is essential for the improvement of results and for more practical use of outputs. It is also important to make the results more accessible and easily understood to the wider community of potential end users. For example the use of average values over a large number of Monte Carlo runs was questioned, as it does not provide a physical quantity that can be communicated to stakeholders. The homogeneity and clarity of the various presentations of the results of the applications is necessary to this extend.
o The SYNER-G software and tools (pre and post processing) needs to be upgraded and further improved in order to be more "friendly" to end-users as well as to improve its computation performance.
o SYNER-G presented the state-of-the-art in systemic risk. It was questioned, however, that the method, as it is proposed, is far more detailed than the level of data available (elements at risk, fragility curves). Therefore, it is necessary to invest in data mining to refine the inventories of elements at risk we have today. It is also necessary to invest more to quantify better the effects of various uncertainties, including the available data, in the accuracy of the results.
o Other issues discussed: The SYNER-G webpage will run for the next two years under the NERA platform. Then a more permanent administration mechanism should be proposed. The SYNER-G DEMO will be prepared after the final reporting under the coordination of AUTH and VCE; JRC will contribute to its dissemination.

FOR A COMPLETE DESCRIPTION OF DISSEMINATION ACTIVITIES, WITH FIGURES, SEE THE ATTACHED PDF

List of Websites:

Project public website: www.syner-g.eu

Contact: Prof. Kyriazis Pitilakis, coordinator, email: kpitilak@civil.auth.gr

Address:

Aristotle University of Thessaloniki
P.O.Box 424
GR-54124 Thessaloniki - GREECE
Prof. Kyriazis Pitilakis

Geotechnical Engineering Division
Laboratory of Soil Mechanics, Foundations and Geotechnical Earthquake Engineering

Telephone: +30.2310.995693 / 995728
Fax: +30.2310.995619

Related documents

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