# LIQUEFACT

Assessment and mitigation of liquefaction potential across Europe: a holistic approach to protect structures/ infrastructure for improved resilience to earthquake-induced liquefaction disasters.

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## Deliverable D9.6

## Periodic Progress Report 2

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## List of Partners

| Participant | Name | Country |
|---|---|---|
| ARU (Coordinator) | Anglia Ruskin University Higher Education Corporation | United Kingdom |
| UNIPV | Universita degli Studi di Pavia | Italy |
| UPORTO | Universidade do Porto | Portugal |
| UNINA | Universita degli Studi di Napoli Federico II. | Italy |
| TREVI | Trevi Societa per Azioni | Italy |
| NORSAR | Stiftelsen Norsar | Norway |
| ULJ | Univerza v Ljubljani | Slovenia |
| UNICAS | Universita degli Studi di Cassino e del Lazio Meridionale | Italy |
| SLP | SLP Specializirano Podjetje za Temeljenje Objektov, D.O.O, Ljubljana | Slovenia |
| ISMGEO | Istituto Sperimentale Modelli Geotecnici Societa a Responsabilita Limitata | Italy |
| Istan-Uni | Istanbul Universitesi | Turkey |

## Glossary

| Acronym | Description |
|---|---|
| CA | Consortium Agreement |
| DoW | Description of Work |
| EC | European Commission |
| EEAB | External Expert Advisory Board |
| EILD | Earthquake Induced Liquefaction Disaster |
| GA | Grant Agreement |

| | |
|---|---|
| PM | Project Manager |
| PC | Project Coordinator |
| PO | Project Officer |
| WP | Work Package |
| WPL | Work Package Lead |

# Contents

# Summary for publication

# 1 Introduction

Earthquakes are one of the most destructive natural phenomena. Over the past decade, earthquakes proved to be the deadliest of all European disasters, with almost 19,000 fatalities and economic losses of around €29 billion. While structural remediation of the built environment against earthquakes has been widely studied, the knowledge about foundation improvement to mitigate the effect of earthquakes is limited and remediation techniques can be very invasive and costly. The most critical effect of the earthquake on foundations and other geotechnical structures is the liquefaction of the soil.

## 1.1 Earthquake Induced Liquefaction Disasters

Liquefaction is the phenomenon whereby, under seismic loading, a soil loses strength and can no longer support structures founded on it. Further damage can be caused from the resulting settlements.

Recent events have demonstrated that Earthquake Induced Liquefaction Disasters (EILDs) are responsible for significant structural damage and human casualties with, in some cases, EILDs accounting for half of the economic loss caused by earthquakes. The causes of liquefaction are largely acknowledged so the LIQUEFACT project sets out to recognise the factors that contribute to its occurrence, estimate the impacts of EILD hazards and identify and implement the most appropriate mitigation strategies that improve both infrastructure and community resilience to an EILD event.

## 1.2 Aim and Objectives of LIQUEFACT

The primary aim of the LIQUEFACT project is to develop a more comprehensive understanding of EILDs and the application of mitigation techniques to safeguard small to medium sized critical infrastructures from its effects.

In order to achieve this aim the project identified seven specific research objectives:

**Objective 1:** Establish an EILD Risk/Resilience Assessment and Improvement Framework (RAIF) to identify vulnerability in terms of physical, social, economic and environmental factors and appropriate mitigation strategies.

**Objective 2:** Develop a European liquefaction hazard geographical information system (GIS) map framework and methodology for performing localized assessment of liquefaction potential.

**Objective 3:** Develop new simplified methodologies to assess the vulnerability of infrastructure to EILDs.

**Objective 4**: Analyse, using geotechnical seismic centrifuge testing and full scale field testing, state of the art liquefaction mitigation techniques suitable for critical infrastructures.

**Objective 5**: Identify the most appropriate vulnerability, resistance, resilience and adaptive capacity models for Europe and develop a range of performance metrics through which they can be assessed.

**Objective 6**: Integrate the acquired knowledge and methodologies into a LIQUEFACT Reference Guide (LRG), an easy-to-use software application toolbox, which can be used to make informed assessments on the feasibility and cost-benefit of applying mitigation techniques.

**Objective 7**: Produce guideline recommendations enabling the EU Structural Eurocodes standards revision task groups to produce new technical standards.

# 2 Progress to date

During the reporting period work has principally been carried out on Objectives 1-5.

### 2.1.1 Objective 1: Establish an EILD Risk/Resilience Assessment and Improvement Framework (RAIF)

A workshop was held in Bologna to present the LIQUEFACT project to stakeholders in the Emilia Romagna region, Italy. It attracted 205 delegates drawn from engineers, geologists, architects, civil protection and politicians. A questionnaire survey was undertaken to inform the initial development of the RAIF which will be further developed and integrated into a software tool.

### 2.1.2 Objective 2: Develop a European liquefaction hazard geographical information system (GIS) map.

For the European liquefaction hazard map, the first version of a GIS framework has been developed. In addition, a literature review has been started to construct a catalogue of European historical liquefaction occurrences.

To validate the localised assessment methodology, the ground characterisation at four European testing sites (Emilia Romagna in Italy, Lisbon in Portugal, Ljubljana in Slovenia and the Marmara region in Turkey) has been completed and the results reported.

### 2.1.3 Objective 3: Development of new simplified methodologies for the vulnerability assessment of structures and infrastructure to EILDs.

Evaluation has started of the existing numerical modelling strategies to simulate liquefaction induced structural damage and to analyse the liquefaction vulnerability of interacting soil-structure systems in the field trials at the pilot testing sites.

### 2.1.4 Objective 4: Assess liquefaction mitigation techniques using centrifuge modelling and full scale field testing.

This objective involves the testing of soil before and after the application of liquefaction mitigation techniques. A series of small scale centrifuge tests and full scale field tests have been planned to assess the effects of densification, addition of fines and low-desaturation.

### 2.1.5 Objective 5: Develop a range of European performance metrics to assess vulnerability, resistance and resilience to an EILD event.

A community resilience tool to assess the antecedent and post mitigation EILD resilience of a community and a critical infrastructure resilience tool to assess the impact that such an event would have on the ability of the system to deliver its core services have been developed.

A cost/benefit model of liquefaction mitigation for community resilience will be developed next.

# 3 Expected Potential Impact

The current building standards do not fully address the issue of liquefaction and LIQUEFACT will tackle this shortcoming by providing research and demonstration to develop new simplified methodologies and tools. LIQUEFACT's impact on the innovation capacity will be two-fold.

## 3.1 Impact of risk/resilience assessment and improvement on stakeholders

A broad variety of stakeholder groups would be interested in the prediction of the likely consequences of an EILD event. These range from individual infrastructure managers to regional government, insurance and civil protection organizations. The RAIF provides the stakeholders with the tools to assess their susceptibility, vulnerability and risks to an EILD event as well as the business modelling tools to evaluate the potential of mitigation options to improve their resilience.

Ultimately the RAIF will be incorporated into the SELENA-LRG software toolbox which will be made available as open source.

## 3.2 Impact of seismic building codes

Seismic building regulations are strongly connected to earthquake risk assessment. It is important, however, to distinguish between new and existing construction. For new construction, hazard mitigation is embedded in the process of earthquake-resistant design. The current design codes primarily apply to new construction and typically do not include recommendations for the strengthening and rehabilitation of existing structures. The lack of consideration of existing structures in seismic building codes would therefore have a dramatic effect on expected losses during a future seismic event. However, in many parts of the developing world the availability of a proper design code is of greater importance.

LIQUEFACT aims at consolidating the varying knowledge around liquefaction mitigation and here contribute to the convergence of building design codes and the ongoing revision process of the Structural Eurocode.

Goal: **This document aims to provide a summary description of activities and progress of all LIQUEFACT project partners between Months 1 and 14 (May 2016 – June 2017), highlighting completed deliverables and milestones.**

## 3.3 Work performed from project commencement in May 2016 – June 2017

### Anglia Ruskin University (ARU)

**WP1** - Review of literature and theory; Development and hosting of 1st partner workshop; Development of the RAIF; Coordination of the lexicon of terminology; Coordination of the development of protocols for research design; Contributions to workshops and virtual meetings.

**WP2** - Contribution to the coordination of partners involved in WP2 and to the formal submission of the deliverables. Contribution to links between the outputs from WP2 and the RAIF being developed in WP5

**WP3** - Contribution to partner coordination and to links between the outputs from WP3 and the RAIF being developed in WP5.

**WP4** - Contribution to partner coordination and to links between the outputs from WP4 and the RAIF being developed in WP5.

**WP5** - Review of existing community and critical infrastructure resilience models; development of the community and critical infrastructure resilience models; development of data collection toolkits;

**WP8** - Presentation of Liquefact to European Facilities Management Conference (https://www.youtube.com/watch?v=ZPN2vNM8bRU)

## Universita degli Studi di Pavia (UNIPV)

**WP1** - Contribution to the development of the RAIF; Contribution to the development of the lexicon of terminology; contribution to the development of protocols for research design; contribution to workshops and virtual meetings. Contribution to the development of Stakeholder and End-User Group.

**WP2** - Guidelines for ground characterization within Task 2.1. Ground characterization of the Emilia, Italian site. Contribution to D2.1 and preparation of the final deliverable merging the reports from the other partners (i.e. UPORTO, ULJ-SLP, and Istan-Uni). Preparation of the first version of the GIS platform and D2.2. Preliminary activities in the construction of GIS-based catalogue of historical liquefaction, calculation of European regressions to predict liquefaction and development of a European liquefaction hazard map (macrozonation). Preparation of the draft of guidelines for localized assessment of liquefaction potential at the four European testing sites (microzonation).

**WP4** - Selection of input signal for centrifuge tests that are representative of hazard in the selected field trial site. Participation in the definition of the programme of the small scale physical tests.

**WP8 –** Academic publication

## Universidade do Porto (UPORTO)

**WP1** - Contribution to the development of the RAIF; Contribution to the development of the lexicon of terminology; contribution to the development of protocols for research design; contribution to workshops and virtual meetings.

**WP2** - Ground characterization of the Lisbon, Portugal site. Contribution to D2.1.

**WP3** - Extensive review of the available numerical modelling strategies to simulate liquefaction-induced structural damage, taking into account uncertain factors which affect the behaviour of liquefiable soils and of interacting soil-structure systems. Based on the information gathered from the referred literature review, an efficient numerical modelling procedure for the probabilistic analysis of liquefaction-induced structural damage has been pursued.

Numerical modelling of specific site conditions, based on the fundamental parameters from the tests conducted in one of the experimental sites of WP2, the Adaparazi region, in Turkey. Different ways to deal with instability were considered: the SANISAND model, UBC3D-PLM in Plaxis® and the PM4SAND in Flac®.

Development of parametric studies for defining the factors that condition the construction of the fragility laws to be considered into the vulnerability analyses, starting with inelastic soil-structure interaction, formation of damage in the structure, as well as the analysis of different building typologies.

**WP4** - Literature review on the existing liquefaction mitigation measures; definition of experimental plan to test the desaturation effect at lab scale by performing cyclic triaxial tests in sand specimens with degree of saturation of around 98%; adaptation of a triaxial apparatus with capacity for imposing desaturation with axis translation technique (high air pressure porous ceramic plates); selection of soil to perform these tests.

**WP8** – Academic publication

## Universita degli Studi di Napoli Federico II (UNINA)

**WP1** - Contribution to the development of the RAIF; Contribution to the development of the lexicon of terminology; contribution to the development of protocols for research design; contribution to workshops and virtual meetings.

**WP2** - Contribution to T2.1, in the analysis of the existing in-situ geotechnical data coming from past investigation campaigns in the site chosen in Emilia-Romagna Region (Cavezzo, Italy) and analysis of existing maps identifying the presence of liquefiable soil deposits in Emilia sites.

**WP3** - Contribution in the tasks T3.1, by reviewing and analysing available numerical modelling strategies to simulate liquefaction-induced structural damage (soil-structures interaction). Contribution in the development of the methodology for the liquefaction fragility analysis of critical structures and infrastructures.

**WP4** - Laboratory tests for characterization of the treated and untreated soil and review of the results. Preliminary analysis for centrifuge modelling and desk study on centrifuge testing.

**WP8** - Contribution to the tasks T8.1, disseminating the preliminary results of the project to the academic and professional communities, by means of publication of peer-reviewed papers (Proc. of XXVI Italian Geotechnical Conference, 20th - 22nd June, Rome), floor presentation at a national conference (XXVI Italian Geotechnical Conference) and in workshops (LIQUEFACT 1st stakeholder/end-user workshop, Bologna, Italy October, 2016; Master in Geotechnical Design, Cassino, Italy, May, 2017).

## Trevi Societa per Azioni (TREVI)

**WP1** - Direct involvement in the organisation of the stakeholder workshop in Bologna including both academic presentations and logistical coordination; Contribution to the development of the RAIF; Contribution to the development of the lexicon of terminology; contribution to the development of protocols for research design; contribution to workshops and virtual meetings.

**WP4** - Inspection of the case study field test site; preliminary jobsite layout for the test site including an assessment of the suitability of the site for the testing potential mitigation technologies; development of specifications and detailed negotiations for the use of specialised testing equipment (ground shaker) for use on the test site; development of a legal contract for access to and use of the test site; liaising with Pieve di Centro municipality for access to the test site.

**WP8** - Development of the Liquefact website; management and maintenance of the LIQUEFACT website; monitoring and evaluation of the LIQUEFACT website; development and promotion of information to stakeholders; coordination of dissemination activities; production of periodic newsletters; production of promotional leaflets; contribution to the development of the intranet.

## Stiftelsen Norsar (NORSAR)

**WP1** - Review of literature and theory; Contribution to the development of the RAIF; Contribution to the development of the lexicon of terminology; contribution to the development of protocols for research design; contribution to workshops and virtual meetings.

**WP2** - Contribution to create links between WP2 and WP6.

**WP3** - Literature review on the current state-of-the-art procedures/techniques, regarding the estimation of liquefaction demand under a building and combination of ground shaking-induced damage with liquefaction ground deformation-induced damage, for software development perspective. This investigation also aimed in developing WP3-related software protocols and identifying the various barriers and challenges that can be encountered. Reports containing the various outcomes of the literature review and protocols development have been produced and shared with the partners involved in WP3. The NORSAR team has attended the WP3 first face-to-face meetings (in Porto), where several issues and challenges have been discussed. The meeting has allowed establishing a common understanding and get clear directions on how the various Work Tasks should be developed.

**WP4** - The activities undertaken in WP4 were followed up in order to establish a common understanding and get clear directions on how the WP4 outcomes (knowledge and methodologies) can be directly used and implemented for an effective and successful LRG software development.

**WP5** - Contribution to the review of community and critical infrastructure resilience models; contribution to the development of the community and critical infrastructure resilience models.

## Univerza v Ljubljani (ULJ)

**WP1** - Contribution to the development of the RAIF; Contribution to the development of the lexicon of terminology; contribution to the development of protocols for research design; contribution to workshops and virtual meetings.

**WP2** - Ground characterization of the Ljubljana, Slovenia site. Contribution to D2.1.

**WP3** - Contribution to the evaluation of existing numerical modelling strategies to simulate liquefaction-induced structural damage. Special attention was given to research, which addressed numerical modelling of soil-structure interaction and fragility analysis of structures on liquefiable soils. Preliminary work on a methodology for efficient liquefaction fragility analysis of critical structures and infrastructures. Development of a preliminary framework for derivation of fragility curves with consideration of liquefaction. The framework takes into account all relevant aspects of the soil-structure interaction problem, i.e. the seismic response of the liquefiable soil, the interaction between the soil and the structure, and the induced damage in the structure.

**WP4** - On the Lower Sava river test site (Hydro power plant Brežice) some possible mitigation measures for the prevention of liquefaction had been studied within the scope of the HPP design. The relevant documents were obtained and an interview with the designer was made in order to understand the reasoning behind the final decision.

## Universita degli Studi di Cassino e del Lazio Meridionale (UNICAS)

**WP1** - Contribution to the development of the RAIF; Contribution to the development of the lexicon of terminology; contribution to the development of protocols for research design; contribution to workshops and virtual meetings.

**WP2** - Preparation of the reports to illustrate the methodology to perform localised liquefaction analysis within the framework of the European liquefaction hazard map. Here the contribution of UNICAS has consisted in reviewing the results of the ground characterization carried out at the four European testing sites by the other groups to maximize the impact of this activity on the WP7, where the manual for risk assessment will be developed. In parallel, the UNICAS group has analysed different additional sites affected by earthquake induced liquefaction damage, collecting data and performing analyses. This activity will serve to analyse the toolkit to be developed in the other work packages.

**WP3** - Review the updates of WP3 to define a reliable methodology to perform localised liquefaction analysis within the framework of the European liquefaction hazard map and to prepare the guidelines for the application of soil characterization and liquefaction risk assessment protocols. UNICAS is contributing to develop a procedure to evaluate the liquefaction-induced damage in critical infrastructures by proposing an approach based on the observation of liquefaction occurrence in large territories. This activity, subsidiary to the numerical modelling carried out by other groups, aims to derive a general strategy that, starting from the subsoil properties, enables public authorities to give the input to users and owners of critical infrastructures to increase their resilience.

**WP5** - Data collection for community resilience case studies, and preparation of the community resilience and cost/benefit modelling framework (socio-technical-economic impact on stakeholder and wider community). UNICAS is assisting ARU in collecting data from stakeholders and urban communities to develop performance metrics and for identifying community resilience case studies (for WP6/7).

**WP8** - Responsible for the updating of the website created in the first months of the projects and this goal has been periodically accomplished adding new information, links to other projects, and linking the website with other communication tools. In particular, a web site has been created (www.liquefact.eu) with 5739 readers, 3078 visitors (from 19th September, 2016 to April, 2017), with an average number of 300 visitors per month, together with an intranet (www.intranet.liquefact.eu) open to all partners to speed up the exchange of information. Dissemination has been also promoted via social networks (Facebook, YouTube, LinkedIn, twitter, google +). Additionally, an overall report on the project has been published in the TREVI group journal.

Also, the external website www.liquefact.eu has been coupled with an internal website where partners can collect and share information (literature, deliverables, outcomes, etc.), communicate with forums, etc. The members of UNICAS have also organized a number of events like short courses, seminars, in Italy and abroad aimed at disseminating the scope and results of the research carried out in the project. A communication strategy has also been implemented with the Work Package leader (Trevi) for disseminating results with periodical newsletters.

### SLP Specializirano Podjetje za Temeljenje Objektov, D.O.O, Ljubljana (SLP)

**WP1** - Contribution to the development of the RAIF; Contribution to the development of the lexicon of terminology; contribution to the development of protocols for research design; contribution to workshops and virtual meetings.

**WP2** - Coordination and execution of lab tests on samples for the Ljubljana, Slovenia site.

### Istituto Sperimentale Modelli Geotecnici Societa a Responsabilita Limitata (ISMGEO)

**WP1** - Contribution to the development of the RAIF; Contribution to the development of the lexicon of terminology; contribution to the development of protocols for research design; contribution to workshops and virtual meetings.

**WP2** - Contribution to the definition of tests to be performed for the ground characterization of the Emilia, Italy site. Contribution to the involvement of Italian local authorities.

**WP4** - Design of a Model Pore Fluid (MPF), design and construction of a special Laminar Box, execution of some Centrifuge Proof Tests.

**WP8** - Contribution to academic publications.

### Istanbul Universitesi (Istan-Uni)

**WP1** - Contribution to the development of the RAIF; Contribution to the development of the lexicon of terminology; contribution to the development of protocols for research design; contribution to workshops and virtual meetings.

**WP2** - Ground characterization of the Marmara, Turkey site. Contribution to D2.1.

**WP3** - Simulation studies using UBC Sand model for PLAXIS and UBC Sand model and Sani sand model for FLAC. Identification of the capabilities, limitations and performance of these models for liquefaction. Literature review and identification of the main factors, which affect soil-structure interaction.

Gathering of field data from Adapazari, Turkey, including a field trip to the city by the Istanbul University team.

Preparation of the reinterpretation of the available data for sites where earthquake damage was observed due to liquefaction, for a more correct and rigorous database.

**WP5** - Contribution to the review community and critical infrastructure resilience models; contribution to the development of the community and critical infrastructure resilience models

## 4. Explanation of the work carried out in each work package

The LIQUEFACT project comprises nine Work Packages, seven of which have been active during this reporting period. Following section summarises the work undertaken by each Work Package in this reporting period.

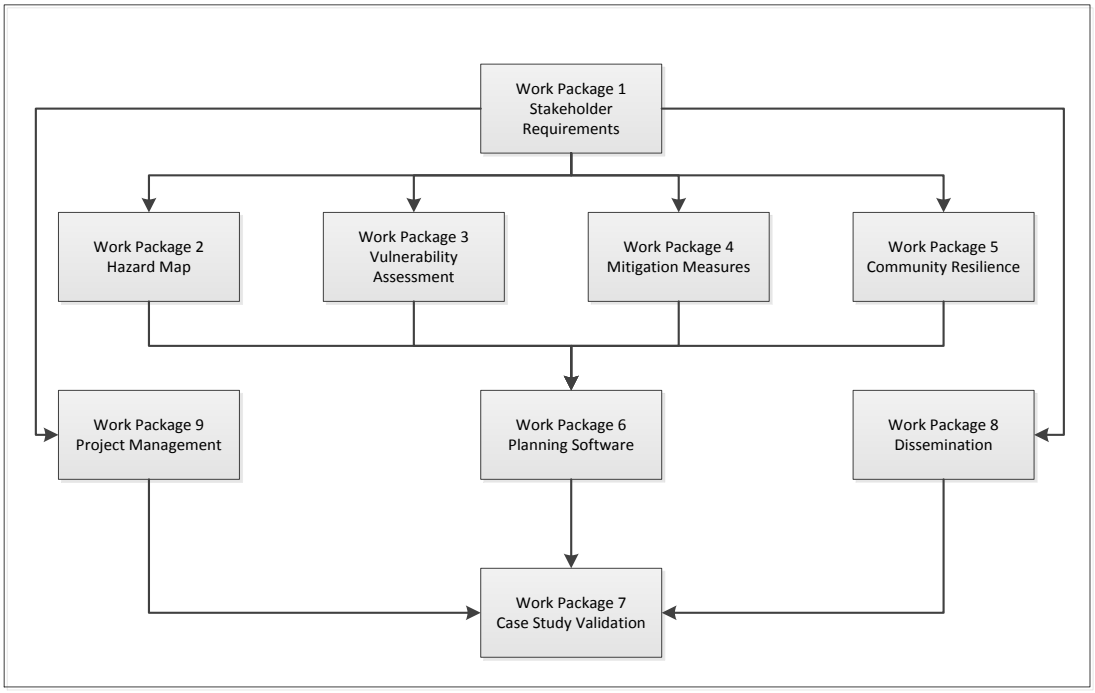



Figure 2: LIQUEFACT Work Packages

## Work Package 1: Stakeholder Requirements and Industry/Research Gaps

**(ARU – Leader. All partners involved)**

The aim of this Work Package was to establish a common understanding amongst the project team and stakeholders of the factors that affect vulnerability, resilience and adaptive capacity of an urban community to EILD events and of the inter-relationships between stakeholders that enhance or inhibit the recovery process. The Work Package's objectives were:

1. Identify an over-arching theory of urban community resilience to EILD events in Europe.
2. Develop an outline decision making framework for improving urban communities' resilience to EILDs.
3. Establish a common working practice to ensure that activities undertaken in the other Work Packages produce outputs that are directly useable in the decision making framework including:
    - develop a common understanding of stakeholder and end-user requirements (design code requirements; decision making metrics; cost/benefit protocols etc.) for all Work Package outputs
    - establish common criteria for the selection and analysis of the chosen case study examples
    - develop a common reporting framework for sharing data and outputs between Work Packages, including standard protocols for the integration of outputs into the liquefaction mitigation planning and decision support software toolbox (WP6)
    - develop a common approach to dissemination of outputs across Work Packages
    - develop a common understanding of the potential routes to impact and set common protocols for Work Package outputs that ensure that they support these routes to impact.

4. Establish working protocols to ensure the efficient sharing of data and outputs between Work Package research teams (technical operational procedures, not overall consortium / project management).
5. Coordinate the integration of findings from all other Work Packages into a final overarching theory for improved urban community resilience to EILDs through whole-life resilience planning.

This Work Package is complete and all of the above objectives have been met. In addition, one academic paper has been written and presented to the European Facilities Management Conference. The paper was on the challenges to Facilities Managers in improving the resilience of critical infrastructure to disaster events (Jones et al, 2017)[1].

## Details of Activities in Work Package 1

*T1.1 – Review of theory of disaster resilience (Task Leader: ARU)*

- The first project partner workshop took place at Anglia Ruskin University on the 25th and 26th May, 2016. The aim of the meeting was to establish operating procedures and guidelines to ensure the smooth running of the project and to explore the issues pertinent to improving the resilience of communities and critical infrastructure to EILD events. Each Work Package lead presented an overview of their Work Package and drew attention to issues that would affect their work and their Work Packages relationship to other Work Packages. In particular, each Work Package lead outlined the methodological approach that they intended to use to address their specific Work Package objectives and explored the interconnectivity between their Work Package objectives and other parts of the LIQUEFACT project. Each presentation was followed by a detailed discussion amongst the project partners of the issues that had been raised and specific actions were identified for resolution prior to the second workshop. Following the workshop all the presentations were shared amongst the project partners as were detailed notes, transcribed from audio recordings.
- A review of the theory of disaster resilience was undertaken by Anglia Ruskin University. The review examined the background and context of the LIQUEFACT project and explored the definitions of vulnerability, resilience and adaptive capacity as they affected community resilience to natural and man-made disaster events. The review also identified the factors from literature that affected community resilience and identified a range of frameworks and toolkits, including the Sendai Framework for Disaster Risk Reduction, that were publicly available to measure community resilience. The results of the review were published in Deliverable 1.1 (27th July, 2016) and presented to the rest of the LIQUEFACT partners for discussion and debate at the second project partner workshop.
- The second project partner workshop was held at the University of Ferrara, Italy between 4th and 5th October, 2016. The aim of this meeting was to review the background theory underpinning the LIQUEFACT project and establish a common understanding amongst project partners of the key issues that would affect community and critical infrastructure resilience

[1] Keith Jones, Andrea Bartolucci and Katie Hiscock (2017) 'The role of FM in disaster resilience: Integrating the Sendai Framework into disaster risk management' Research papers for EUROFM 16th research symposium EFMC 2017, 25-28 April 2017, Madrid, Spain pp 203-213.

to an EILD event. Representatives from each Work Package presented details of the theoretical basis to their particular work and, through a series of group discussions, project partners identified potential problems that needed to be addressed before detailed work on identifying mitigation options could begin. In particular, the need to establish a common lexicon of agreed terminology was identified and work began to compile the lexicon. Over the two months following the workshop researchers from the project partners contributed to the lexicon which was published as part of Deliverable 1.4. A summary of the factors that affect community resilience are given in Table 1. Full details of each factor can be found in Deliverable 1.1.

Table 1: Summary of factors identified in literature that affect community resilience to disaster events.

| Resilience Factor / Characteristic | Indicator / Expectations |
|---|---|
| Robustness | Damage avoidance in lifelines and CI (transportation networks, residential housing stock, healthcare facilities, communication networks, commercial and manufacturing establishments etc.); Continuity of service provision; Continuity of functional systems performance; Avoidance of casualties; Avoidance / minimisation of economic losses. |
| Redundancy | Backup and/or duplicate systems; Backup or access to alternate resources to sustain operations (insurance, alternative sites, robust supply chains etc.); Alternative community logistics (food, water, power etc.); Untapped resources/contingency budgets. |
| Resourcefulness | Access to money; Information; Technology; Human resources; Household emergency plans; Business continuity plans; Diagnostic and damage detection systems; Contingency plans across stakeholder groups. |
| Rapidity | Disaster preparedness (Organisational capacities, Early warning systems, Contingency planning, Emergency response planning, etc.); Reduced time of recovery to return systems as close as possible to business as normal. |
| Personal Factors | Critical awareness; Self-efficacy; Sense of community; Outcome expectancy (positive or negative); Action coping and resource availability; Education and training; Psychological preparedness; Empowerment; Social norms; Trust; Personal responsibility; Social responsibility; Experience; Resources; Adaptive capacity; Cultural attitudes and motivations; Social networks; Property values; Livelihoods; Participation in recovery; Volunteering. |
| Community Factors | Collective efficacy; Participation; Commitment; Information exchange; Social support; Decision making; Resource availability; Engagement; Leadership; Demographics; Sense of community; Community values-cohesion; Collective efficacy; Place attachment; Adaptive capacity; Local understanding of risk (Hazard assessment, Vulnerability assessment, Impact assessment, Resource management, Mitigation); Counselling services; Health and well-being services; Community organisations (e.g. faith based etc.); Employment; |
| Institutional Factors | Empowerment; Trust; Resources; Mechanisms for community problem solving, Adaptive capacity, Participation in hazard reduction programmes; Hazard mitigation plans; Zoning and building standards; Emergency response plans; Interoperable communications; Continuity planning; Municipal finance/revenues. |
| Governance Factors | Policy & Planning; Legal and regulatory systems; Integration across time and scale; Leadership; Partnerships; Accountability. |

*T1.2 – Development of a Stakeholder and End-User Group (Task Leader: UNICAS)*

- The first stakeholder workshop took place in Bologna on 3rd October, 2016. The workshop was organized under the auspices of the "Associazione Geotecnica Italiana", of the "Ordine degli Ingegneri della Provincia di Bologna" and of the "Ordine dei Geologi della Regione Emilia Romagna". The aim of the workshop was to bring together an internationally diverse group of major stakeholders and end-users to: discuss the specific industry and research gaps with regards to the susceptibility assessment and mitigation implementations to EILD events; identify how assessments and implementations are currently addressed; illustrate the content of the project to the stakeholders/end users group and get their feedback; disseminate the project objectives; and initiate a framework for communication and collaboration during the lifetime of the project.
- More than a hundred invitation letters were sent out with 205 participants attending the workshop. The participants were drawn from: engineers and geologists representative of municipalities, local authorities, governmental institutions; academic staff and researchers; consultant firms; and practitioners.
- The workshop was divided into three sessions. The first session sort to contextualise the problem of EILD events from the end-user stakeholder's perspective. The second session examined the state of the art in mitigation to liquefaction. The third session presented the LIQUEFACT project and outlined each of the LIQUEFACT Work Packages. As part of this session the participants were asked to identify which factors they believed affected the Emilia Romagna region's resilience to liquefaction events and to weight the relative importance of each factor to overall community resilience.
- The event was recorded and transmitted via streaming television on the internet http://videocenter.lepida.it/videos/video/2509/?live=true. One hundred and twenty nine attendees were recorded for the morning session, 176 for the afternoon session. The videos with full presentations can be viewed at https://www.youtube.com/c/LiquefactEu and on the LIQUEFACT website www.liquefact.eu.
- Full details of the workshop are presented in Deliverable 1.2.

*T1.3 – EILD Risk / Resilience Assessment and Improvement Framework (Task Leader: ARU)*

- The RAIF is a decision support tool that can be used by built asset owners and/or managers to assess the antecedent vulnerability, resilience and adaptive capacity of their built assets to EILD events. The RAIF relates directly to the work to be carried out in Work Packages 2-6. The RAIF provides the over-arching structure for the considerations that needs to be taken into account when making improvement decisions from identifying location susceptibility (WP2) and assessing infrastructure vulnerability and resilience within the region (WP3). The RAIF also considers appropriate mitigation options (WP4) and the wider socio-economic impact/implication of these if they are implemented or not (WP5). All these considerations will then be packaged within a liquefaction mitigation planning software toolbox (WP6). As such all the partners were involved in the development of the RAIF.
- Initial discussions, both face-to-face and through virtual meetings (using Adobe connect or Skype), sought to identify the factors and interrelationships that affect community and critical infrastructure vulnerability, risk and resilience to EILD events. These discussions led directly to the development of version 1 of the RAIF tool (Deliverable 1.3). This version of the RAIF

tool was reviewed by all the partners at the Ferrara workshop where detailed discussions identified enhancements that would be required in order for the RAIF tool to effectively assess the potential benefits that mitigation intervention would have on community and critical infrastructure resilience. Version 2 of the RAIF tool was developed as part of T1.4.

*T1.4 – Establish user requirements for the RAIF (Task Leader: ARU)*

- During the Ferrara workshop all the partners reviewed version 1 of the RAIF and identified the need for a common lexicon of terminology to support the RAIF. Following the workshop, all the partners contributed to the development of this common lexicon which was reported in Deliverable 1.4.
- The Ferrara workshop also identified the need to establish common research protocols to allow data to be shared between the different Work Packages and integrated into the RAIF and SELENA-LRG tools. The protocols for developing common research methods were carried out through face-to-face and virtual discussions with all partners and these are presented in Deliverable 1.4.
- Version 2 of the RAIF was developed after the Ferrara workshop to accommodate the results of the common lexicon of terminology and research protocols. Version 2 of the RAIF is shown in Figure 3 and full details of its development are given in Deliverable 1.4.

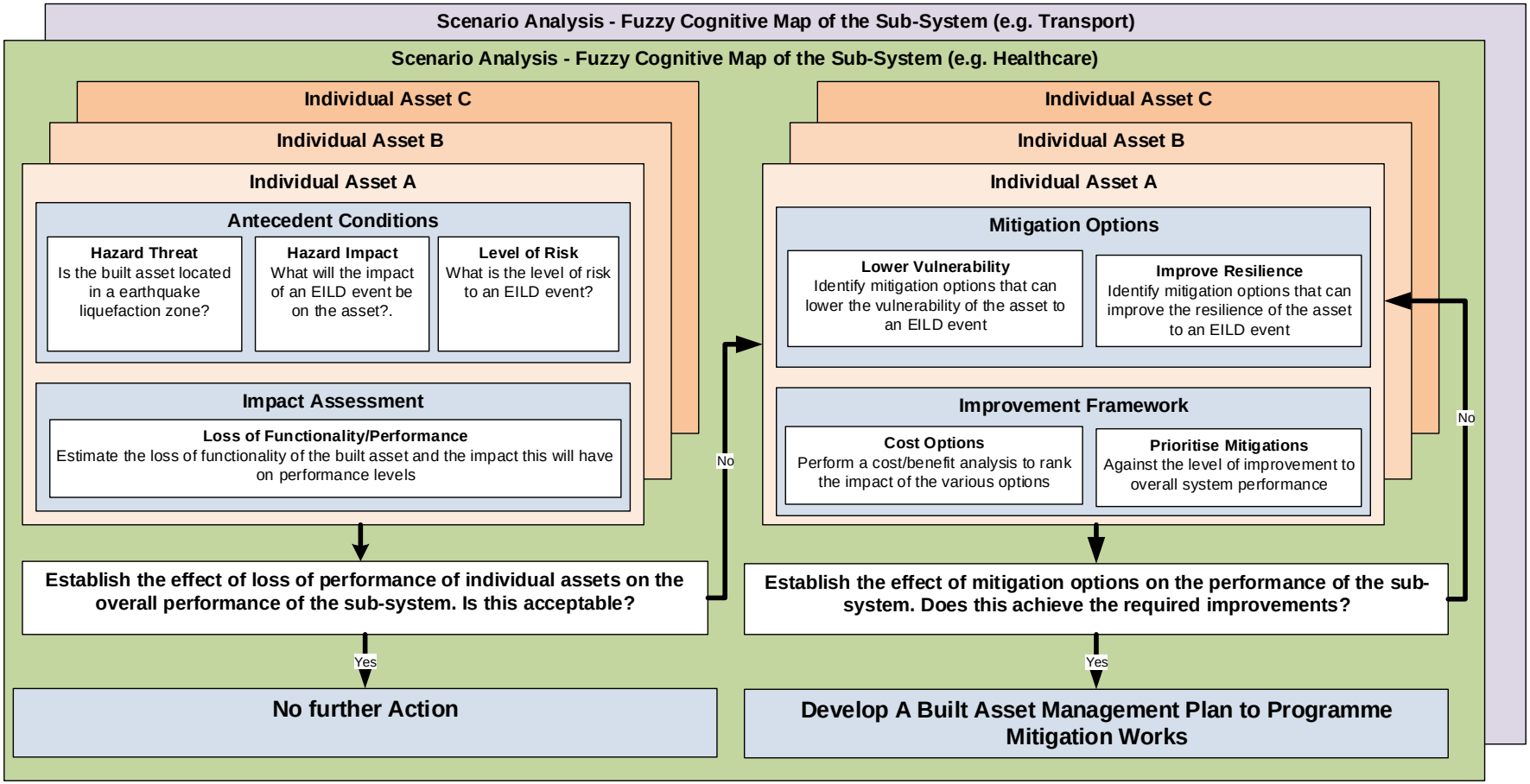



Figure 3: Version 2 of the RAIF

## Work Package 2: European Liquefaction Hazard Map (Macrozonation) and Methodology for Localized Assessment of Liquefaction Potential (Microzonation)

**(UNIPV – Leader. ARU, UPORTO, UNINA, NORSAR, ULJ, UNICAS, SLP, ISMGEO, Istan-Uni Participants)**

The main objective of this Work Package is the development of tools to be used for localised regional assessment of liquefaction hazard in Europe and, thus, to establish a European liquefaction hazard mapping framework. Starting from existing European research projects (such as SHARE), the aim is to narrow down existing seismic hazard maps to areas that have high risk of liquefaction. A database will be set up to provide information regarding past liquefaction occurrences in Europe, helping delineate areas prone to liquefaction. A broad and roughly estimated liquefaction hazard map for Europe based on historical data, combined with available geological and seismological data, will be initially generated and will then be validated and/or optimised by performing specific localised analysis in four regions. The Work Package will have the following objectives:

1. Construction of a GIS-based catalogue of European liquefaction occurrence and, on the basis of this database, development of simplified tools to predict the liquefaction occurrence starting from the main seismological information of an earthquake;
2. Establishment of a European liquefaction hazard GIS map, which can distinguish, at large scale, areas that may be susceptible to damaging liquefaction from areas where damaging liquefaction is unlikely;
3. Definition of a framework to perform localised liquefaction analysis where the results can be used to update (validate and/or optimise) the European liquefaction hazard GIS map
4. Application of the developed framework to perform localised liquefaction analysis to four case-study sites in varying regions with varying geotechnical topologies.
5. Ground characterization of soil deposits at the four selected sites by performing geotechnical and geophysical investigation campaigns using in situ and laboratory tests. At one of the four sites, selected as case study pilot sites (see WP4), after ground characterization, ground treatment will also be carried out to mitigate the liquefaction potential.

At the end of the project, data access to the GIS platform implemented in this Work Package will be guaranteed through purpose developed web services set-up in WP6. Since the outcomes from the ground characterization at the selected testing sites will be used, as input data, within various Work Packages, mainly in WP2, but also in WP3 and WP4, this activity will start at the beginning of the project.

This Work Package is ongoing.

### Details of Activities in Work Package 2

*T2.1 – Ground characterization at the four European testing sites (Task Leader: UNIPV)*

- The activities around this task began in May, 2016 after the kick off meeting (Chelmsford-UK, 25th – 26th May, 2016). UNIPV and Eucentre set up the "Guidelines for geological-geotechnical characterization of liquefiable ground at the four European testing sites". These guidelines were shared with the other partners involved in this task with the aim to establish a shared framework to deliver homogeneous and harmonized outcomes to be used as input in the microzonation studies of Task 2.6.

- Concurrently, UNIPV and Eucentre's efforts were focused on the choice of the Italian testing site. The Municipality of Cavezzo in the Emilia-Romagna Region was chosen as the Italian case study after a series of meetings with Italian local authorities. This is a municipality located about 45 kilometres northwest of Bologna and about 20 kilometres northeast of Modena, with an area of 26.8 square kilometres. It is known that in this area liquefaction occurred during the 2012 seismic sequence. Geological information and existing geotechnical data of this area were collected and stored in a GIS database. A complementary investigation campaign, including in situ geotechnical and geophysical tests, was planned and performed between December, 2016 and January, 2017. The acquired data was integrated with existing data gathered from previous investigations carried out in collaboration with local authorities.
- Similar activities were performed by the other main partners involved in this task. The University of Ljubljana, together with SLP, selected two test sites in Slovenia. One site is near the Brežice hydropower plant, on the lower Sava River, where some previous data exists. The other is on the shores of Lake Bohinj in the Alps, where during 1998 earthquake a failure along the shoreline was observed and some authors conjectured that this was a consequence of ground liquefaction. No previous data on the ground conditions exists for this site. The test field near the Brežice hydropower plant (HPP) had been geotechnically investigated during the design phase of the HPP. In-situ tests (Cone penetrometer (CPT), seismic dilatometer test (SMDT) and dynamic probing (DP)) were carried out and laboratory investigations (index properties, soil water content, density and cyclic simple shear tests) were performed. The ground conditions in this area are extremely interesting; the loose silty-sand layer was historically unsaturated but will become saturated as the HPP reservoir is filled to capacity. On both test sites, permissions were obtained for the implementation of site investigation programs and the in-situ tests were completed during the winter (November, 2016 – January, 2017). Laboratory tests were carried out simultaneously some in collaboration with the University of Porto when in May, 2017 the University of Ljubljana hosted a researcher from UPORTO for three weeks to perform cyclic simple shear tests on samples from Portugal. The University in Ljubljana has also investigated evidence to suggest the occurrence of past liquefaction events in Slovenia and its vicinity. The research has revealed no clear evidence of liquefaction in Slovenia, but liquefaction events have been documented further down the River Sava (25 km from Brežice) around Zagreb in Croatia. Data was also used from the Albanian site in Porto Romano.
- The University of Porto, after a preliminary analysis performed on two possible sites, selected as the testing site an area located in the Lezíria Grande, Municipality of Vila Franca de Xira, in the metropolitan region of Lisbon. This area has been affected throughout its history by severe earthquakes causing serious damage and many casualties. The seismicity of the area is evidenced by a number of past events, such as the 1755 earthquake generated at the Eurasia-Nubia plate boundary zone, and numerous magnitude 6 - 7 local intraplate earthquakes in 1344, 1531, and 1909. Pre-existing geological and geotechnical information in the Lower Tagus River (LTV) area was gathered through collaboration with public institutions, governmental agencies and private companies. A total of 95 geotechnical reports were collected, giving a total of more than 350 test results. Complementary site characterization included geophysical and geotechnical in situ testing, namely SPT, CPTu, SDMT, Cross-Hole, SASW, seismic refraction and noise measurements (HVSR). A number of undisturbed samples were collected with the Mazier sampler, on which a series of laboratory tests were carried

out, comprising of classification (grading and consistency limits) and mechanical tests (oedometer, cyclic simple shear, static and cyclic triaxial with shear wave velocity measurements).

- Istanbul University selected six testing sites in Canakkale city centre. The area was chosen for the following reasons: Canakkale is prone to earthquakes with high peak ground accelerations; soil conditions are suitable for liquefaction with a high groundwater table; a sufficient amount of reliable geological and geotechnical data was available. Pre-existing studies for the test sites were compiled and evaluated and then a schedule for a complementary study was produced. Pre-existing data showed that there are lithological units of Quaternary (Holocene) soil deposits. Complementary tests (SPT, CPTU, SCPT, DMT and several geophysical tests) were carried out and dynamic soil properties which had not been measured in previous studies were investigated. Dynamic soil properties were measured using resonant column and cyclic direct shear tests.
- Data acquired in this Task was published in Deliverable 2.1 (submitted 30th January, 2017). Special efforts were dedicated by UNIPV and Eucentre to prepare the deliverable (D2.1) merging all the contributions from the partners involved in Task 2.1.

*T2.2 – Collection of geological and seismological data for Europe within a GIS framework (Task Leader: UNIPV)*

- The liquefaction macrozonation study at the European scale (aim of Task 2.5) has been initiated with the identification of the controlling factors (liquefaction susceptibility and triggering severity of expected ground motion). Data available for Europe were collected within a GIS framework. The main features of version 1 of the GIS platform was presented in Deliverable 2.2 (submitted on time on 30th April, 2017).
- Geological, hydrogeological and seismological data were included in version 1 of the GIS platform. In particular, the following data were selected: Geological Map of Europe; Hydrogeological maps; Digital Elevation Data (SRTM and ASTER DEM) and derived parameters; Global Vs30; European Earthquake catalogue; Catalogue of Italian earthquakes (CPTI15); Seismogenic faults in the Euro-Mediterranean region; Seismogenic zones for Europe; Probabilistic seismic hazard maps for the Euro-Mediterranean region. Seismological data was mainly obtained from the deliverable of the SHARE European research project. Full details are given in Deliverable 2.2.
- The acquired data is being combined in a GIS environment. The first version of the European liquefaction hazard assessment GIS platform (V1.0) involved the creation of the preliminary structure of the database, as reported in the Deliverable 2.2. This version of the current GIS platform is the first of three and a further two versions will be delivered as D2.3 (Version 2) and D2.5 (Version 3), due by the end of April, 2018 and by the end of October, 2018, respectively.

*T2.3 – Construction of a GIS-based catalogue of historical liquefaction occurrences in Europe (Task Leader: UNIPV)*

- A thorough literature review to construct the catalogue of historical liquefaction occurrences is underway. The search focuses on scientific publications, reports and seismic bulletins reporting information on manifestations of liquefaction occurrences in European countries characterized by a moderate to large seismic hazard.
- UNIPV-Eucentre has started to integrate the acquired data under a GIS environment to create a homogeneous, composite GIS-based catalogue of liquefaction occurrence in Europe. The GIS-based catalogue includes two pieces of information: main seismological features of the seismic events (date, geographic coordinates, magnitude, etc.) and liquefaction site parameters (epicentral distance, type of failure, etc.).

*T2.4 – Calculation of European regressions to predict liquefaction occurrence starting from the main seismological information of an earthquake (Task Leader: UNIPV)*

- On the basis of the European liquefaction occurrences catalogue, compiled in Task 2.3, empirical correlations to predict liquefaction potential using the main seismological information of an earthquake will be determined in Task 2.4. UNIPV-Eucentre has started a bibliographic review to relate earthquake magnitude and distance with liquefaction occurrence.

*T2.5 – Development of a European liquefaction hazard map – Macrozonation (Task Leader: UNIPV)*

- An in-depth literature review of previous related research on liquefaction susceptibility and hazard assessment at a regional scale for ground shaking has been carried out to define a methodology for the assessment of liquefaction hazard at the European scale. The objective is to develop a liquefaction hazard map that will allow identifying territories that are expected to experience severe liquefaction in case of strong ground shaking. Two different methods are currently under consideration: Logistic regression (data-driven method), based on the model proposed by Zhu et al. (2014); and Analytical Hierarchy Process (AHP).
- Within the logistic regression framework, a preliminary application of the model proposed by Zhu et al. (2014) has been carried out. The input data (from Task 2.2) required for the model are the peak ground acceleration (PGA), the compound topographic index (CTI) and the Vs30 model (proposed for Europe by USGS). The output is a map in which every pixel is characterized by a probability of liquefaction (i.e. a value between 0 and 1). This model has been calibrated by the authors on the 1995 Kobe and the 2011 Christchurch earthquakes, where the presence/absence of liquefaction has been mapped, and then has been validated on the data from the 2010 Haiti earthquake. The output map has a 30 arc-sec resolution (900m). It is important to point out that in June, 2017, an updated version of the logistic regression model, based on different proxies, has been published by the authors.
- A first attempt to apply the Analytical Hierarchy Process (AHP) methodology has been carried out. AHP is a knowledge-driven method, based on a subjective assignment of a liquefaction susceptibility factor rated by experience (based on the knowledge of past liquefaction occurrences and their causal factors within a given area, an expert assigns weights to certain combinations of factors). The first step is the classification of the proxies based on their

influence on liquefaction hazard (the highest rank is assigned to the factor that most influences liquefaction). The methodology then assigns to every layer a weight through a comparison matrix. The output is a map obtained by a weighted sum-overlay operation, in which every pixel has a "score", based on the above-mentioned factors affecting the pixel: the higher the score, the higher the liquefaction hazard. As for the logistic regression map, the output map of AHP methodology has a 30 arc-sec resolution (900m).

*T2.6 – Validation of the European liquefaction hazard map by detailed analysis at the four testing areas – Microzonation (Task Leader: UNIPV)*

- Although in the GANTT chart of the Grant Agreement this task will start from the 21st month of the project, each partner involved in this task has started some preliminary activities.
- A literature review has been initiated to identify guidelines for seismic microzonation at international, national and regional level to be used as starting point in Task 2.6.
- UNIPV and Eucentre drafted the "Guidelines on the methodology for localized assessment of Earthquake Induced Soil Liquefaction potential at the four European testing sites (Microzonation)". The scope of these guidelines is to establish a shared framework among partners performing microzonation for liquefaction potential to deliver homogeneous and harmonized outcomes.
- Concerning the Italian testing site under the responsibility of UNIPV-Eucentre, a preliminary 3D geological model of the municipality of Cavezzo has been created by exploiting the stratigraphic profile obtained from the boreholes and by interpreting the CPT tests for the soil profile reconstruction. A preliminary analysis of the suitable accelerograms recorded on rock outcrop conditions that could be used as seismic input for subsequent ground response analyses has been carried out.
- From February to May, 2017 the preliminary work of the University of Ljubljana has been devoted to instigate a comparison of the prediction of liquefaction susceptibility based on in-situ test results by numerous methods proposed by the literature. In general, test results collected within the LIQUEFACT project were used, but some others were also included. The results of these preliminary studies have been reported in a master's thesis. Moreover the University of Ljubljana has started working on the implementation of all collected results in GIS.
- A comprehensive assessment of the liquefaction susceptibility of the soils in the Portuguese pilot site, based on in situ test results, has been started by UPorto. Conventional as well as more recent approaches to liquefaction assessment were applied to inform the progress of the microzonation.
- IstanUni compiled the pre-existing studies for the test site and evaluated these rigorously. The framework of the complementary study was then created and a macrozonation study was completed. Then corresponding information was established for the microzonation studies.

## Work Package 3: Structural Liquefaction Resilience & Vulnerability Assessment Methodologies

**(UPORTO – Leader. ARU, UNIPV, UNINA, NORSAR, ULJ, UNICAS, Istan-Uni – Participants)**

The aim of this Work Package is the development of methodologies and tools for the vulnerability assessment of structures to EILDs within the four regions, located in Italy, Portugal, Slovenia and Turkey. The target is small to medium sized 'critical' infrastructures such as "lifelines" (waste and sludge drain lines, electricity cables, gas and petrol pipelines, road networks) and low-rise structures (residential and also public like governmental offices, transport stations, terminals), which could have aggregated impacts of greater significance than initially perceived during an EILD event. This Work Package will involve both geotechnical and structural engineers that will work together to define a framework procedure to be used by city planning civil engineers and decision makers to evaluate their infrastructures. In this sense, the following specific objectives will be pursued:

1. Develop an efficient numerical procedure for the simulation of liquefaction-induced damage in critical structures and infrastructures.
2. Develop an efficient probabilistic framework for liquefaction vulnerability analysis of critical structures and infrastructures.

General framework procedure for, in view of subsoil properties, the public authorities to give the necessary approaches for users and owners of critical infrastructures to increase their resilience.

This Work Package is ongoing.

### Details of Activities in Work Package 3

*T3.1 – Evaluation of existing numerical modelling strategies to simulate liquefaction-induced structural damage (Task Leader: UPORTO)*

UPORTO has carried out an extensive review of the available numerical modelling strategies to simulate liquefaction-induced structural damage, taking into account uncertain factors which effect the behaviour of liquefiable soils and the soil-structure interaction. Based on the information gathered from the literature review, an efficient numerical modelling procedure for the probabilistic analysis of liquefaction-induced structural damage has been pursued. The analysis of the most recent approaches to define a reliable and representative model evidenced the need to simulate the complex process of excess pore water pressure generation contributing to complete or partial liquefaction, with simultaneous flow to the drainage borders of the liquefiable layers. This process requires the use of fully coupled dynamic analyses, in order to simulate the settlements and lateral spreading response of shallow foundations and other structural elements of lifelines on liquefiable soil deposits. Current work associated with WP3 is as follows:

- Reproduction of existing literature case studies using Plaxis software, in order to compare previous results with the obtained modelling results. This activity allowed for a clear understanding of the software operation and associated tools.
- Development of a finite element model under free-field conditions using data from in-situ test results in the greater Lisbon study area.
- "Soil Test" module was explored to simulate laboratory tests in Plaxis and to identify the influence of UBC3D-PLM parameters in soil behaviour simulation.

- Calibration of the parameters of UBC3D-PLM constitutive model, using the numerical tool "Soil test" and results from static triaxial tests.
- Development of a finite element model of a cyclic triaxial test to calibrate the dynamic parameters of UBC3D-PLM constitutive model.
- Development of a finite element model for a case study in Adapazari, Turkey. This model analyses liquefaction effects under free-field conditions for multiple ground motions including a parametric study of the benchmark model and analysis of the settlements as a function of the ground profile properties and ground motion intensity.

Some of the available and more frequently used constitutive models, such as UBC3D-PLM and PM4SAND, have been tested to assess the capability of the numerical tools to simulate correctly the post-liquefaction reconsolidation settlements in free-field conditions and considering soil-structure interaction. The aspects of a fully coupled dynamic analysis were verified in codes such as Plaxis® and Flac® and the differences in simulation results were compared with well-documented case histories of damages in buildings with shallow foundations on liquefiable soil deposits. The results from cyclic triaxial and cyclic direct shear tests on undisturbed and reconstituted specimens were employed to calibrate the parameters of these constitutive models. It is generally recognised that this type of simulation can be misleading or not conveniently interpreted, since these elemental tests cannot by themselves represent a multifactor problem. Most of the total footing settlements generated during strong motion shaking are due to deviatoric settlement, with a comparatively smaller portion of the settlement due to post-liquefaction reconsolidation volumetric strains. The deviatoric strains are likely to be caused by both loss of strength due to partial bearing failure and the accumulation of settlements consequence of soil-structure-interaction (ratcheting), as recently discussed by several authors, and this is being checked by numerical analyses.

In order to coordinate all the involved partners in the tasks of this work package, a meeting was held at FEUP (Faculty of Engineering of UPorto) on May 8$^{th}$ with ARU, UNINA, NORSAR, ULJ, UNICAS and Istan-Uni, those directly involved in WP3. This one-day meeting enabled constructive discussion on the strategies to be followed in the coming months, enhancing working relationships and increasing productivity. The discussion topics included the methodologies for evaluation of liquefaction vulnerability of soil-structure interactions, as well as the most efficient numerical procedure for the simulation of liquefaction-induced damage in critical structures and infrastructure, specifically for low-rise buildings with shallow foundations.

*T3.2 – Liquefaction vulnerability analysis of interacting structure-soil systems in the field trials at the two pilot testing sites (Task leader: UPORTO)*

UPORTO carried out numerical modelling of specific site conditions, based on the fundamental parameters deduced from the tests conducted at one of the experimental sites of the four liquefiable zones identified in WP2, in this case the Adaparazi region, affected by the 1999 Kocaeli earthquake, in Turkey. Distinct approaches to deal with instability were compared.

For that purpose, the following constitutive models have been used: SANISAND from Dafalias-UPC (following a collaboration with Prof. Jean Vaunat from UPC, Barcelona), UBC3D-PLM version implemented in Plaxis® in finite elements, and PM4SAND in Flac®, a tool based on finite differences and therefore an explicit resolution algorithm. These simulations had the aim of assessing the ability of numerical tools to estimate correctly post-liquefaction reconsolidation settlements in free-field conditions and with structural interaction. Fully coupled dynamic analysis were evaluated, and it

was decided to carry out subsequent analyses with Flac® using PM4SAND, a model developed by Prof. Ross Boulanger and his group at the University of California at Davis (UCD). A complex and comprehensive set of numerical analyses will be developed and used to establish reference solutions to validate the simplified model approach. To increase the work capacities of the UPORTO team, advanced hardware facilities were created and implemented in the department, this required buying new equipment for optimizing the computational processes.

*T3.3 – Guidelines to be provided to WP6/WP7 (Task Leader: UPORTO)*

The studies carried out led to important conclusions that have implications in the decisions for the following studies in WP3:

- Centrifuge models in free-field conditions should be numerically simulated using model parameters identified through cyclic triaxial or simple shear testing (CTx or CSST) programmes. These will have to be adjusted to represent centrifuge experimental data. A set of purely undrained and drained tests needs to be carried out, to solve the identified inconsistencies with the calibration.
- The free-field deformations should be *a priori* reproduced by models that make use of parameters derived from elemental laboratory tests (CTx or CSST) and in situ test results (CPTu). These have to be checked against well controlled centrifuge tests in sandy loose soil during and after seismic loading. Clarification of the behaviour of the free-field will improve the understanding of the performance of structures built on liquefiable ground.
- The numerical prediction of footing settlements due to the seismic loading is inevitably affected by the inability to replicate the free-field settlement. It is proposed that this causes a considerable underestimation of the footing settlement;
- The major difference occurs during the earthquake, as the post-earthquake settlement progresses similarly in the numerical and centrifuge models.

It is expected that by adding the free-field settlements, the numerical prediction will closely match the experimental observations, suggesting that the numerical model will have to be readdressed. The process will be closed when these uncertainties are resolved, that is when a protocol for calibration of the two scenarios of during- and post-earthquake deformations are conveniently reproduced.

Parametric studies will be then developed in a code that will allow the defining factors that condition the construction of the fragility laws to be considered into the vulnerability analyses, starting with inelastic soil-structure interaction, formation of damage in the structure, as well as the analysis of different building typologies.

## Work Package 4: Comparative Analysis of State of the Art Liquefaction Mitigation Measures

**UNINA – Leader. ARU, UNIPV, UPORTO, TREVI, NORSAR, ULJ, ISMEGO – Participants)**

The objectives of this Work Package are to establish and comparatively analyse the state of the art measures of liquefaction mitigation for protection/resilience of small to medium sized 'critical' infrastructures and low-rise structures (also residential). The attention will be especially focused on the infrastructures and structures whose functioning during and after an earthquake is essential within urban communities (e.g. installations for energy, transport, water, ICT, hospitals, etc.).

This Work Package is ongoing.

### Details of Activities in Work Package 4

*T4.1 – Treated soil characterization (Task leader: UNINA)*

The activities carried out in T4.1 covered laboratory tests on different soils (Sant'Agostino Sand and Leighton Buzzard Sand) treated with different liquefaction mitigation techniques: densification, addition of fines and low-desaturation. The effectiveness of these techniques has been analysed by means of triaxial tests carried out on natural and treated specimens by applying various static and cyclic stress paths. Soil density has been investigated by obtaining three different initial densities by means of wet tamping techniques. Fines were added to soil in the form of a synthetic silicate nanoparticle (laponite) and different suspensions have been studied (by means of preliminary rheological and permeability tests).

The most interesting results, in terms of improvement of soil liquefaction resistance, have been obtained in the tests performed on specimens treated with the induced partial saturation technique. The results highlighted that a significant increase in liquefaction resistance can be obtained with a very small decrease of the degree of saturation: more tests will be carried out in the near future to analyse in detail some other important issues connected with this technique (longevity of air bubbles, modification of the induced degree of saturation over time). This new liquefaction mitigation technique seems to be the most interesting because combines the greatest effectiveness with the least environmental and economic impact.

*T4.2 – Small scale centrifuge modelling (Task leader: ISMGEO)*

The activities carried out in T4.2 include the design of a Model Pore Fluid (MPF), the design and construction of a special Laminar Box, and the execution of some Centrifuge Proof Tests. A special additive (hydroxypropylmethylcellulose) to be mixed with water has been selected and tested (viscometer measurements, permeation tests in triaxial cell, cyclic triaxial tests), in order to obtain a fluid with a viscosity and density that fulfil the requirements of dynamic centrifuge test scaling laws. An equivalent laminar shear box to be used for the dynamic test has been designed and constructed. The designed container is able to deform with the soil during base shaking and at the same time allows minimization of the boundary effects which are more critical in dynamic centrifuge modelling. Some centrifuge proof tests - using a rigid boundary container - have been carried out in order to define and verify the procedure to be adopted to reconstitute and saturate the centrifuge model with the MPF.

The programme of small scale physical tests on re-constructed soil models, subjected to appropriate time regimes, were planned with the other partners (Unina, UniPavia) in order to clarify the mechanical and hydraulic behaviour during earthquakes of soils treated with the techniques under study and to validate theoretical and numerical models useful in design practice. This programme

was defined during the meeting held at ISMGEO in Seriate on the 13th April 2017. The meeting was attended by ISMGEO, UNINA, and UNIPV.

*T4.3 – Field trials at the selected case study pilot testing site (Task leader: TREVI)*
The activities at the selected testing site (Pieve di Cento, Italy) will start at the beginning of July, 2017. The choice of the testing site required preliminary activities. These included the assessment of the suitability of the site for the testing of mitigation technologies; retrieving the material for the centrifuge laboratory (ISMGEO) and for the mechanical laboratory (Unina), definition of the preliminary and post-treatment in situ investigation, choice of technologies for undisturbed sampling.

Once UNINA and UNIPV had chosen the potential location for the field trials on the north-east boundary of Pieve di Cento Municipality, TREVI was invited to the jobsite inspection carried out on 27th February, 2017.

After the visit, TREVI analysed the feasibility of the site from a logistical and geometrical point of view.

A preliminary scheme of works was prepared for the site, approximately 6500 m², where, according to the Geological Survey service of the Emilia Romagna Region, liquefaction occurred after the earthquake of the 20th May, 2012. The preliminary scheme proposes to implement at least two of the potential mitigation methods, from the various technologies tested in the small scale centrifuge modelling, as described in the Grant Agreement.

A meeting called by UNINA was arranged by TREVI in Rome 21st April, 2017 to finalize type and number of tests and technologies to be carried out in the field trials. The meeting was attended by TREVI, UNINA, UNIPV and ISMGEO. TREVI proposed the use of advanced drilling technologies and innovative materials particularly for drainage systems.

To assess the selected liquefaction mitigation technologies a highly specialized piece of equipment, a ground shaker, has been sourced as requested by the WP4 lead.

On 5th May, 2017, TREVI signed a contract of lease with the owner of the land where the selected mitigation technologies will be tested. The field will be available for the trials for two years, from 01/06/2017 to 30/06/2019. Geological, geotechnical and geophysical characterization of the site will be the first activities scheduled for July, 2017.

*T4.4 – Numerical modelling (Task leader: UNINA)*
The task will start at the beginning of July, 2017. Some numerical analyses were carried out for the back analysis of preliminary centrifuge tests (T. 4.2) and laboratory tests (T.4.1). Preliminary desk study on available numerical models have been carried out. The constitutive models used for the soil were calibrated on the basis of the results of the laboratory tests carried out on natural and treated specimens.

*T4.5 – Guidelines to be provided to WP6/WP7 (Task leader: UNINA)*
This task has not yet started.

## Work Package 5: Community Resilience and Built Asset Management Planning Framework

**(ARU – Leader. NORSAR, ULJ, UNICAS, Istan-Uni – Participants)**

This Work Package will explore the factors that enhance or inhibit the resilience of communities to EILDs. The Work Package will identify the most appropriate vulnerability, resilience and adaptive capacity models for different parts of Europe and develop a range of performance metrics through which inherent vulnerability, resilience and adaptive capacity can be assessed. The Work Package will also identify the effect on resilience of inter-relationships between the various community stakeholders, national agencies, Governments and the EU and identify how each of these might better prepare themselves to support the recovery of a community following a disaster event. The Work Package will have the following objectives:

1. To review evidence from EILD events and develop a series of community performance metrics to assess the antecedent vulnerability, resilience and adaptive capacity of individual stakeholders and overall communities to EILD events and evaluate the potential reduction in vulnerability and improvements in resilience and adaptive capacity that could result from the uptake of the technical mitigation measures evaluated in WP3 and WP4.
2. Investigate the inter-relationship between the various stakeholders and its effect on each stakeholder's vulnerability, resilience and adaptive capacity to respond to and recover from an EILD event
3. Integrate the metrics into the decision making framework (task 1.3) and develop a multi-criteria assessment methodology (Analytical Network Process Model) to evaluate the cost/benefit of the various mitigation interventions (WP4) relating to improvements in community resilience to EILDs.
4. Develop and test a series of decision support models that enable mitigation actions to be integrated into the built asset management (BAM) life cycle.
5. Develop data collection protocols to apply the framework across the EU high risk regions (protocols will be used in WP6)

This Work Package is ongoing.

### Details of Activities in Work Package

*T5.1 – Develop stakeholder and urban community performance metrics and inter-relationship (Task Leader: ARU)*

- This task is built directly on the outputs from WP1, in particular Deliverables 1.1, 1.3 and 1.4.
- The review of the background theory underpinning the RAIF was extended to include a detailed analysis of six current EU funded projects (RESILENS, IMPROVER, SmartReslience, DARWIN, RESIN and EU-CIRCLE) that are developing toolkits and frameworks for assessing critical infrastructure (and community) resilience to natural and man-made disaster events. Each of these projects was analysed to identify the theoretical basis underpinning their approach to resilience modelling and the range of factors/metrics that they were proposing to use to score community and critical infrastructure resilience to disaster events. The generic approaches and range of metrics being suggested by these projects are consistent with the approach outlined by LIQUEFACT in the original proposal and as such the research team are

confident that the theory underpinning the RAIF is consistent with the current state-of-the-art.

- Whilst the generic approach being adopted by other EU funded projects is consistent with that being developed by LIQUEFACT, none of the current critical infrastructure resilience tools provide the level of detail that would support cost benefit analysis and options appraisal required by the RAIF. As such, an enhanced critical infrastructure resilience tool will be developed that considers not only the direct impacts of a disaster event on an organisation's physical assets but also considers the indirect impact that the event will have on service delivery and service performance. The RAIF addresses this problem and as such the final version of the RAIF will go beyond the current state of the art.
- The review of community resilience tools was based upon the UNISDR Disaster Resilience Scorecard for Cities which was developed to support the Sendai Framework for Disaster Risk Reduction. The Disaster Resilience Scorecard for Cities provides a comprehensive approach to assessing the 10 'Essentials' that taken together describe the antecedent resilience of a city or region to a disaster event. Each 'Essential' comprises a subject/issue, an item to be measured, indicative measurements, a 0-5 indicative measurement scale, and comments that contextualise the measurement. The scorecard represents the current state-of-the-art and as such will be used as the basis for assessing community resilience to EILD events.
- The results of the review of individual stakeholder and urban community performance metrics are given in Table 2 and the community and critical infrastructure resilience framework in Figure 4. Full background to both the metrics and the framework are given in Deliverable 5.1. This task is complete.

Table 2: Summary of the subject/issues addressed in the UNISDR Disaster Resilience Scorecard for Cities that will form the basis for the assessment of community resilience to EILD events (Source: UNISDR, 2015)

| Essential Element | Subject/Issue | Number of Items Measured |
|---|---|---|
| Organise for Disaster Resilience | Organization and Coordination | 5 |
| | Integration of disaster resilience with other initiatives | 1 |
| | Capturer, publication and sharing of data | 2 |
| Identify, Understand and Use Current and Future Risk Scenarios | Risk Assessment | 4 |
| | Update process | 1 |
| Strengthen Financial Capacity for Resilience | Financial plan and budget | 3 |
| | Contingency funds | 1 |
| | Incentives and financing for business, community organizations and citizens | 5 |
| | Financing of resilience expenditures | 1 |
| Pursue Resilient Urban Development | Land use - effectiveness of zoning to prevent exposure build–up | 3 |
| | Building codes | 3 |
| | New developments | 2 |
| Safeguard Natural Buffers to Enhance Protective Functions Offered by Natural Ecosystems | Ecosystem services | 3 |
| Strengthen Institutional capacity | Skills and experience | 1 |
| | Public education and awareness | 2 |
| | Training delivery | 1 |
| | Languages | 1 |
| | Learning from others | 1 |
| Increase Societal and Cultural Resilience | Grass roots organizations | 4 |
| | Private sector / employees | 2 |
| | Systems of engagement | 1 |
| Increase Infrastructure Resilience | Protective infrastructure | 2 |
| | Communications | 3 |
| | Electricity | 3 |

| | | |
|---|---|---|
| | Water and sanitation | 3 |
| | Gas | 4 |
| | Transportation | 6 |
| | Law and order, First responders | 2 |
| | Education | 3 |
| | Healthcare | 3 |
| | Administrative operations | 1 |
| | Computer systems and data | 2 |
| Ensure Effective Disaster Response | Early warning | 1 |
| | Event management plans | 1 |
| | Staffing / responder needs | 2 |
| | Equipment and relief supplies | 1 |
| | Food, shelter, staple goods, and fuel supply | 4 |
| | Interoperability and inter-agency compatibility | 2 |
| | Drills | 2 |
| Expedite Recovery and Build Back Better | Post event recovery planning | 3 |

*T5.2 – Community resilience model (Task Leader: ARU)*

- This task builds on the review of the resilience models undertaken in WP1 and the report on individual stakeholder and urban community performance metrics undertaken in T5.1.
- Two data collection tools were required to support the application of the community and critical infrastructure resilience models developed in T5.1 to the Emilia Romagna region as part of WP7.
- A data collection tool was developed to allow bespoke assessments of the resilience of critical infrastructure in the Emilia Romagna region. The data collection tool contains a critical infrastructure framework of generic factors (grouped by organisation and management, technical systems, operational systems) and sub factors (grouped by finance, coordination, business planning, physical assets, asset infrastructure, service design, service delivery) that were identified from literature as affecting the resilience of critical infrastructure systems to disaster events. Each sub factor is in turn divided into a range of indicators and these will be used during semi-structured interviews with representatives from critical infrastructure providers to identify the importance of each indicator to the organisation's resilience against a 'most severe 'and 'most probable' EILD event scenario. The data collection tool will also define specific metrics and measurement scales for each indicator and allow for weightings to be provided to each indicator for use in a multi-criteria decision making framework. An extract from the critical infrastructure data collection tool is given in Figure 5 with the full details underpinning the tool presented in Deliverable 5.2.

- A data collection tool was developed to contextualise the UNISDR Disaster Resilience Scorecard for Cities to an EILD disaster event. The data collection tool will be used during semi-structured interviews with stakeholder representatives from the Emilia Romagna region to identify the relevance and importance of each item to an EIA event and to identify the impact that an EILD event would have on the community. An extract from the community resilience data collection tool is given in Figure 6 with the full details underpinning the tool presented in Deliverable 5.2.
- Both the community and critical infrastructure resilience data collection tools will be tested in WP7 where the underlying community and critical resilience models will be reviewed in the light of the case study findings. Final versions of both the community and critical resilience models and their associated data collection tools will be included in the SELENA-LRG software tool to be developed in WP6.

*T5.3 – Cost/benefit model of liquefaction mitigation for community resilience (Task Leader: ARU)*

- Task 5.3, cost/benefit model of liquefaction mitigation for community resilience, has been started but is not due to report until 31st July, 2018.
- Progress against the objective is on schedule and there are currently no issues that suggest that it will not be successfully completed.

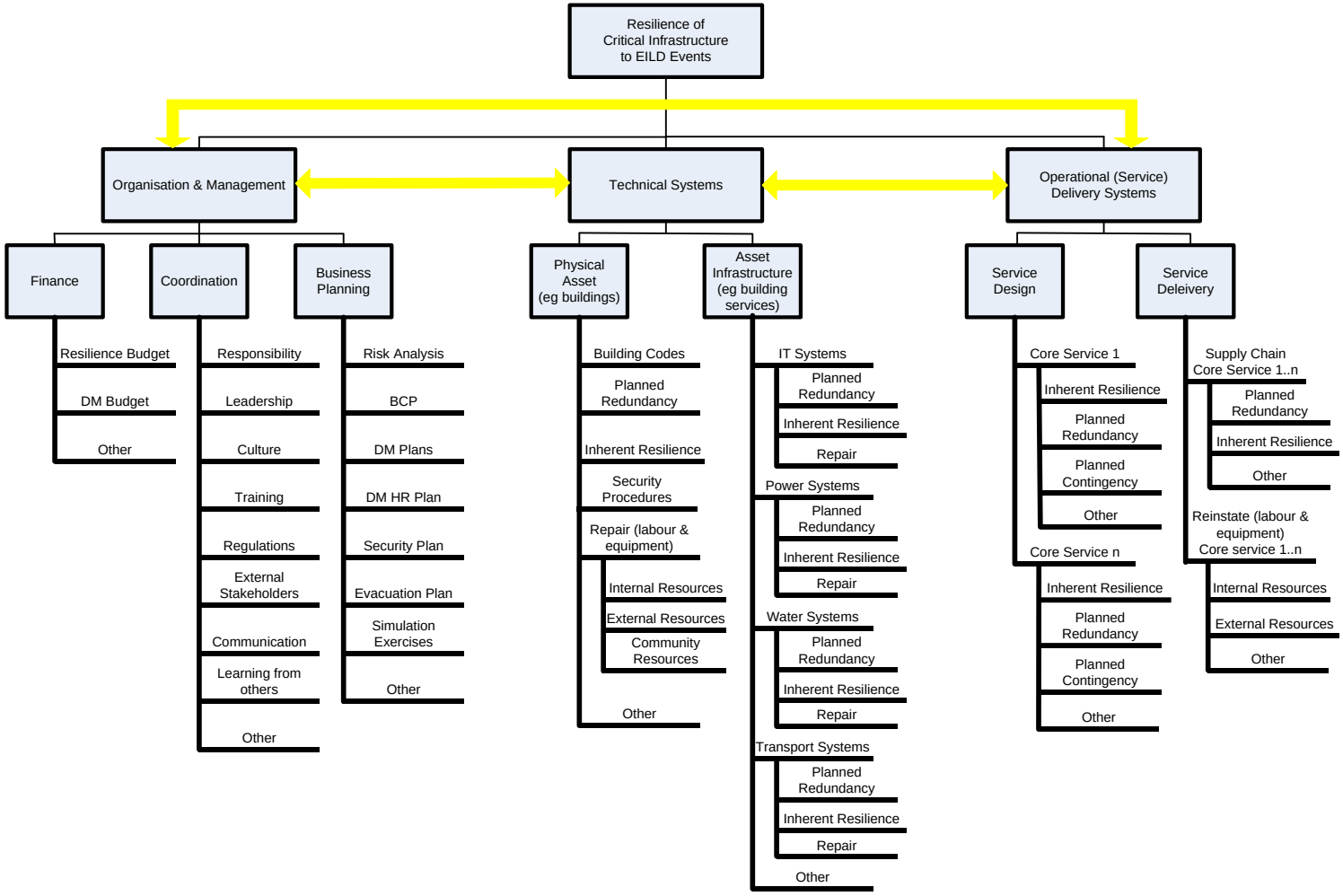
*T5.4 – Whole Lifecycle Built Asset Management Planning for EILD Events (Task Leader: ARU)*

This task has not yet started

*T5.5 – Develop field data collection tools for use in the case studies (Task Leader: ARU)*

This task has not yet started

Figure 4:




Diagrammatic representation of the Framework that will be used to assess the resilience of critical infrastructure systems to EILD events.

| Sub-Factor | Indicator | Metric (Indicative measurement) | Indicative measurement scale | Comments |
|---|---|---|---|---|
| **Finance** | **Specific budget for resilience measure** | *To be developed in consultation with the specific CI system stakeholders* | *5 –*<br>*4 –*<br>*3 –*<br>*2 –*<br>*1 –*<br>*0 –* | *To be developed in consultation with the specific CI system stakeholders* |
| | **Specific budget for disaster management** | *To be developed in consultation with the specific CI system stakeholders* | *5 –*<br>*4 –*<br>*3 –*<br>*2 –*<br>*1 –*<br>*0 –* | *To be developed in consultation with the specific CI system stakeholders* |
| | **Other indicators** | *To be developed in consultation with the specific CI system stakeholders* | *5 –*<br>*4 –*<br>*3 –*<br>*2 –*<br>*1 –*<br>*0 –* | *To be developed in consultation with the specific CI system stakeholders* |

| Sub-Factor | Indicator | Metric (Indicative measurement) | Indicative measurement scale | Comments |
|---|---|---|---|---|
| **Coordination** | **Single point of responsibility** | *To be developed in consultation with the specific CI system stakeholders* | *5 –*<br>*4 –*<br>*3 –*<br>*2 –*<br>*1 –*<br>*0 –* | *To be developed in consultation with the specific CI system stakeholders* |

Figure 5: Example of data collection tool that will be used to customise the critical infrastructure framework for EILD events

| Item | Item Measured | Indicative Measurement | Relevance in the context of an EILD event | Importance in the context of an EILD event | Impact that an EILD event would have on the item<br>(Tick all that apply). | Reasons for choices |
|---|---|---|---|---|---|---|
| 1.1 Organization and coordination | 1.1.1 Co-ordination of all relevant pre-event planning and preparation activities exists for the city's area, with clarity of roles and accountability across all relevant organizations. | Presence of organizational chart documenting structure and role definitions at each relevant agency to achieve a single overall point of co-ordination.<br>Structure agreed and preferably signed off by all participants via MOU or similar. | [ ] Yes<br>[ ] No<br>[ ] Don't Know | [ ] High<br>[ ] Medium High<br>[ ] Medium<br>[ ] Medium Low<br>[ ] Low | [ ] Organizational/Managerial<br>[ ] Technical/Physical<br>[ ] Operational/Service delivery | |
| | 1.1.2 Co-ordination of all relevant event response activities in the city's area, with clarity of roles and accountability across all relevant organizations. | Presence of organizational chart documenting structure and role definitions at each relevant Agency to achieve a single overall point of co-ordination.<br>Structure agreed and preferably signed off by all participants via MOU or similar. | [ ] Yes<br>[ ] No<br>[ ] Don't Know | [ ] High<br>[ ] Medium High<br>[ ] Medium<br>[ ] Medium Low<br>[ ] Low | [ ] Organizational/Managerial<br>[ ] Technical/Physical<br>[ ] Operational/Service delivery | |
| | 1.1.3 Participation and coordination of all relevant organizations in the structure(s) defined. | Level of participation and coordination achieved (see right) | [ ] Yes<br>[ ] No<br>[ ] Don't Know | [ ] High<br>[ ] Medium High<br>[ ] Medium<br>[ ] Medium Low<br>[ ] Low | [ ] Organizational/Managerial<br>[ ] Technical/Physical<br>[ ] Operational/Service delivery | |

| Item | Item Measured | Indicative Measurement | Relevance in the context of an EILD event | Importance in the context of an EILD event | Impact that an EILD event would have on the item<br>(Tick all that apply). | Reasons for choices |
|---|---|---|---|---|---|---|
| | 1.1.4 Co-option of physical contributions by both public and private sectors. | Identification of physical contributions for each major organization. | [ ] Yes<br>[ ] No<br>[ ] Don't Know | [ ] High<br>[ ] Medium High<br>[ ] Medium<br>[ ] Medium Low<br>[ ] Low | [ ] Organizational/Managerial<br>[ ] Technical/Physical<br>[ ] Operational/Service delivery | |

Figure 6: Example of data collection tool that will be used to customise the UNISDR Scorecard for EILD events.

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### Work Package 6: Liquefaction Mitigation Planning Software – Integrated Knowledge and Methodologies from WP2, 3, 4 and 5

**(NORSAR – Leader. ARU, ULJ Participants)**

This Work Package has not yet started.

### Work Package 7: Case Study Validation and Future Eurocode Recommendations

**(UNICAS – Leader. All partners are Participants)**

This Work Package has not yet started. In the grant agreement (Table 1.3.1) WP7 was planned to start in month 30 and complete in month 42. The coordinator negotiated with the Commission and WP7 will start at the end of November, 2017 (after month 18). Therefore, no activity has so far been initiated with reference to WP7.

However the fulfilment of WP7 requires a significant interaction with the activities of other work packages, particularly WP2 (European Liquefaction Hazard Map – Macrozonation – and Methodology for Localized Assessment of Liquefaction Potential - Microzonation), WP3 (Structural Liquefaction Resilience & Vulnerability Assessment Methodologies) and WP5 (Community Resilience and Built Asset Management Planning Framework). In addition, the collection of results from selected case studies where EILDs have occurred has been already started ready for the future involvement.

### Work Package 8: Dissemination and Exploitation

**(TREVI – Leader. All partners are participants)**

This Work Package will make the results of the LIQUEFACT project widely known amongst all relevant stakeholders within the seismic and earthquake engineering industry and research community.

1. To create awareness of the project results within the Civil Protection administrations and the Security organizations in the EU and abroad.
2. Perform a critical assessment of the potential post-project impact of the project results.
3. Engage the general public with the LIQUEFACT project and the wider challenges/impacts of EILDs.
4. Disseminate the existence and result of the project to the academic and professional communities, including public Security and Safety Agencies and NGOs, major building owners, companies offering structural consultancy services, companies in building construction, companies in building management, insurers, standardization bodies and the public at large.
5. Presentation of findings to the seismic and earthquake engineering industry representatives, the general public and global media.
6. Develop case studies and marketing material for further roll-out of the LIQUEFACT software toolbox (including any Eurocode standard recommendation) after the project.

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7. Research, evaluate and model the potential socio-economic and commercial benefits (and route to achieving it) of the LIQUEFACT Reference Guide (software and standards recommendation)
8. Develop the strategic exploitation approach; includes defining/elaborating the appropriate business/market model which can support the prospective exploitation of the project results.

This Work Package is ongoing.

### Details of Activities in Work Package

*T8.1 – Collaboration with other projects and initiatives (Task Leader: UNICAS)*

Projects on similar or related subjects have been identified and contact has been established with the coordinators. The main advantage of this type of collaboration comes from a faster and more effective definition of procedures, mostly related to risk assessment, vulnerability and resilience. It is planned to invite some participants of these projects to the next stakeholder/end-user group meeting. A list of the projects identified is published on the LIQUEFACT website. (http://www.liquefact.eu/related-projects/).

*T8.2 – Stakeholder and public engagement (Task Leader: UNICAS)*

Within the general scope of the project this task is aimed at developing a stakeholder and end-user group. The implementation of methodologies for mitigating the effects of EILD events within the EU requires that vulnerable regions are identified and the resilience of the structural types and overall urban community within these regions is strengthen. Planning and implementation is advantaged significantly by the interaction of the research group with a number of stakeholder and user communities, normally involved with the management of communities and territories. Governmental organizations at municipal, regional and national levels, civil protection agencies and owners of critical buildings and infrastructure, non-profit relief organizations, including NGOs have been contacted together with boards of civil engineering companies, organizations involved in the development of GIS maps and insurance companies. So far an internationally diverse and functionally proficient group of major stakeholders and end-users has been assembled in order to gather an internationally applicable requirement list and thus increase the chances of a successful development and post-project impact. A workshop was organized on 3rd October, 2016 at the Emilia Romagna Region Municipality in Bologna (Italy) to discuss the specific industry and research gaps with regards to the susceptibility assessment and mitigation implementations to EILD events, identify how assessments and implementations are currently addressed, illustrate the content of the project to the stakeholders/end-users group and get their feedback, disseminate the project objectives, initiate a framework for communication and collaboration during the lifetime of the project.

To organize this meeting a number of preparatory activities were carried out, including the invitation of eminent persons as speakers and attendees, the divulgation to the scientific and technical community and the arrangement of the location and communication facilities.

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Many prominent experts and community leaders were invited to the Bologna workshop from various public and private institutions. More than a hundred invitation letters were sent, receiving positive answers from 37 representatives of numerous institutions, who showed noticeable interest in the activities of LIQUEFACT. Many of them attended and actively took part in the workshop.

205 participants were registered at the conference and were subdivided in the following categories:

- engineers and geologist representative of municipalities, local authorities, governmental institutions
- university staff
- consultant firms
- practitioners

In conclusion, many positive outcomes can be drawn from the workshop. As a first comment, the theme of the workshop attracted a large number of experts coming from different public and private institutions involved in the design and management of the territory, together with researchers from academic or public institutions and private consultant engineers, all interested in the results of the project. This substantiates the concern that the technical world has in relation to the research problem and highlights the need to deliver an innovative strategy.

The morning session was given over to presenting the state of the art on liquefaction and the experience of other countries like New Zealand, which have recently been severely affected by this problem.

In the afternoon session an overview was given of the project and feedback received from the participants. The interest and expectations of the attendees is of primary importance for an efficient development of the research and for the creation of workgroups involving partners and stakeholders/end users.

In the afternoon session, a questionnaire was given to the attendees. The group of respondents consisted of engineers (47%), geologists (22%) and architects (5%); the remaining 26% were politicians, researchers and freelancers. The questionnaire concerned the interest of attendees on the different work packages and their future involvement in the activities of LIQUEFACT. One hundred people answered the questionnaire and the results showed that there is a significant interest in the technical aspects of the project but less in the more social aspects dealt with in WP5. This result is probably indicative of the large presence in of technicians (engineers, geologists and architects). However, the importance of considering the social issues induced by EILDs clearly emerged during the open discussion in the afternoon.

In general, a good level of satisfaction and interest was reported, both during and after the event, from many attendees to members of the Municipality of Emilia Romagna Region who took part in the organization of the event.

The group of stakeholders/end-users formed in the first four months of the project has been expanded to include a number of partners involved with the activities of the four test sites in order

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to improve the understanding of the specific needs regarding susceptibility, resilience and mitigation strategies. Additionally, the UNICAS group has participated in a number periodic meetings with the other partners, personally or via internet, to develop a common understanding on the technical and societal issues of the project. In particular, the contribution of UNICAS has consisted of the creation of common protocols to share information, data and outputs between the different work package leads and to develop a common approach to the dissemination of outputs across work packages.

*T8.3 – Dissemination of knowledge (Task Leader: UNICAS)*

The dissemination of knowledge has been promoted through the following events in which members of LIQUEFACT have participated with presentations on specific themes from the project:

- Stakeholder/end-users group meeting held at Bologna 3rd October, 2016 (No. of attendees 205 – policy makers, technicians, civil society, scientific community – No. of contacts via web (Lepida TV) 305 (129 morning, 176 afternoon session)
- "Rischio sismico nel Lazio Meridionale: nuove conoscenze e azioni di mitigazione", (workshop held at the University of Cassino – 7th October, 2016) No of attendees 250 (engineers and geologists)
- "Il Terremoto, cause, effetti e misure di protezione", (workshop held at the University of Cassino – 24th November, 2016), No. of attendees 480 (students from the school)
- "UNICITTA' Il terremoto dalla consapevolezza alla mitigazione" (workshop held at the municipality of Cassino – No. of attendees 100 – politicians, journalists)
- "Miglioramento e Rinforzo dei Terreni", workshop held at the University of Cassino – 4th – 5th May , 2016 No. of attendees about 200 (engineers and students)
- "Liquefaction Assessment: Protocols, Experimental Approaches and Indices", "The LIQUEFACT Project: Earthquake Liquefaction Assessment", "Potential, Vulnerability and Mitigation; Low Taggus River, Hollocenic Soils Characterization for EILD Microzonation", Seminar in UNAM 3rd February, 2017 (António Viana da Fonseca, UPorto).
- "Seguridad sísmica de presas de materiales sueltos: comparación entre experiencias italianas y argentinas", workshop held at the University of Mendoza (Argentina) on 26th April, 2017, organized by the Scuola di Studi Superiori in Scienze e Tecnologie (TECS) of CUIA (Consorzio Interuniversitario Italiano per l'Argentina, www.cuia.net). (No. of attendants 50).

The activity of LIQUEFACT has been so far disseminated with the following papers, published in Journals and Conferences by the members of the consortium

- Borozan, J., Alves Costa, P., Romão, X., Quintero, J., Viana da Fonseca, A. (2017). "Numerical modelling of the dynamic response of liquefiable deposits in the presence of small scale buildings". Paper accepted to 6th ECCOMAS Thematic Conference on Computational Methods in Structural Dynamics and Earthquake Engineering (COMPDYN 2017), Paper ID: C18447 presented orally in Rhodes Island 15th - 17th June, 2017.

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- Fioravante, V., Giretti, D., Unidirectional cyclic resistance of Ticino and Toyoura sands from centrifuge cone penetration tests, Acta Geotechnica, August, 2016, Volume 11, Issue 4, pp 953–968.
- Giretti, D., Fioravante, V., A correlation to evaluate cyclic resistance from CPT applied to a case history, Bulletin of Earthquake Engineering, May, 2017, Volume 15, Issue 5, pp 1965–1989.
- Chiaradonna, A., Tropeano, G., d'Onofrio A., Silvestri, F. (2017) A simplified model for pore pressure build-up prediction in 1D seismic response analysis. EASEC-15 Oct- 11-13, Xi'an, China
- Paolella L., Spacagna R.L., Chiaro G. Previsione degli effetti da liquefazione su scala urbana, VII IAGIG INCONTRO ANNUALE GIOVANI INGEGNERI GEOTECNICI, Catania (Italy), 20th May, 2017.
- Chiaradonna A., Tropeano G., Fasano G. Confronto tra codici di calcolo per analisi di risposta sismica locale nell'ipotesi di comportamento visco-elastico lineare del terreno, VII IAGIG INCONTRO ANNUALE GIOVANI INGEGNERI GEOTECNICI, Catania (Italy), 20th May, 2017.
- Jones, , K., Bartolucci , A. and Hiscock, K. (2017) 'The role of FM in disaster resilience: Integrating the Sendai Framework into disaster risk management' Research papers for EUROFM 16th research symposium EFMC 2017, 25-28 April 2017, Madrid, Spain pp 203-213.


The activities of LIQUEFACT have also resulted in the following Master's theses:

- Tovar, P. M. de (2017). Numerical simulation of the effects of Liquefaction in Soil-Structure Interaction, Master Degree thesis in Civil Engineering, Faculty of Engineering, University of Porto
- Azerêdo, C. M. (2017). Amplificação sísmica de maciços estratificados com areias liquidificáveis: agravamento dos assentamentos e deslocamentos laterais à superfície, Master Degree thesis in Civil Engineering, Faculty of Engineering, University of Porto
- Vozza, A. (2017). Numerical analyses of sand liquefaction susceptibility with an advanced constitutive model (in Italian), Master Degree thesis in Environmental Civil Engineering, University of Napoli Federico II.
- Paolella L., (2016), Liquefaction risk assessment: the 2010-2011 Christchurch Earthquake sequence, Master Degree thesis in Civil Engineering, Department of Civil and Mechanical Engineering, University of Cassino and Southern Lazio.
- Cennamo G. (2017), Back analysis dei fenomeni osservati durante il terremoto del 2012 in Emilia Romagna Master Degree thesis in Civil Engineering, Department of Civil and Mechanical Engineering, University of Cassino and Southern Lazio (in Italian).

*T8.4 – Development of case studies and marketing material (Task Leader: TREVI)*

Tasks 8.4 is linked to WP6 and will start in month 18, no activity has been carried out yet with respect to this task.

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*T8.5 – Business models for exploitation (Task Leader: TREVI)*
Tasks 8.5 is linked to WP6 and will start in month 18, no activity has been carried out yet with respect to this task.

*T8.6 – Impact assessment (Task Leader: ARU)*
This task has not yet started.

## Work Package 9: Consortium / Project Management

**(ARU – Leader. All other partners are Participants)**

This Work Package will provide the central management of the whole project, ensuring that activities throughout the other Work Packages and across all partners are fully coordinated. Furthermore it will provide a focal point for communication with the EC and for all administrative and financial aspects of the project. The Work Package will have the following objectives:

1. Legal, contractual, ethical, financial, research/technical and administrative management of the project, the grant and consortium
2. Coordination of knowledge management, deliverables, milestone reports and cost statements
3. Organisation of consortium meetings and collaboration activities
4. Ensure that liaison with the EC is carried out in an appropriate and timely manner

This Work Package is ongoing.

### Details of Activities in Work Package

*T9.1 – Maintaining the consortium agreement (Task Leader: ARU)*
The consortium agreement was finalised before the start of the project and is regularly monitored by ARU and the other partners. Although not yet actioned a change to the consortium agreement is required to accommodate a change to TREVI's legal status. Discussions are ongoing with the Project Officer over this matter.

*T9.2 – Project Management Meetings (Task Leader: ARU)*
Three project management meetings have been held to date. These meetings are formerly chaired by the project coordinator and the minutes taken at the meeting form part of the regular project management reporting process. The next project management meeting is due to be held in October, 2017. There will also be the first meeting of the Expert Advisory Panel in October, 2017.

*T9.3 – Communication strategy (Task Leader: ARU)*
A communication strategy was developed during the first six months of the project and this formed part of the data management plan that was uploaded to the portal on 31st October, 2016.

*T9.4 – Communication with the European Commission (Task Leader: ARU)*

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The project coordinator and project manager are in regular communication by email with the project officer. Unfortunately it has not been possible to arrange a face-to-face meeting although such a meeting would be welcomed.

*T9.5 – Collation of deliverables and progress reports (Task Leader: ARU)*
All the deliverables that were expected during this reporting period have been uploaded to Portal.

*T9.6 – Coordination of payments (Task Leader: ARU)*
The pre-financing payments have been distributed to all partners.

*T9.7 – Quality management (Task Leader: ARU)*
A quality management report was developed early in the project and distributed to all partners. A copy of the report was uploaded to the portal 27th July, 2016.

*T9.8 – Management of issues of legal, ethical, security related or classified nature (Task Leader: ARU)*
An ethics reporting procedure was established early in the project and this was communicated to all project partners.

## 4.1 Progress beyond the state of the art, expected results until the end of the project and potential impacts (including the socio-economic impact and the wider societal implications of the project so far)

# 5. Deliverables

| Del. no. | Deliverable name | WP no. | Lead beneficiary | Type | Dissemin. level | Delivery date from Annex 1 | Actual delivery date | Status | Comments |
|---|---|---|---|---|---|---|---|---|---|
| D34 | LIQUEFACT project website | WP8 | UNICAS | *WEB* | *PU* | 1 | 2 | Not assessed yet | |
| D1 | A report on the challenges to improve community resilience to EILD events | WP1 | ARU | *REPORT* | *PU* | 3 | 3 | Not assessed yet | |
| D40 | Project Management Plan | WP9 | ARU | *REPORT* | *CO* | 3 | 3 | Not assessed yet | |
| D41 | Quality Procedures Manual | WP9 | ARU | *REPORT* | *PU* | 3 | 3 | Not assessed yet | |

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| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| D2 | Proceedings of the first stakeholder/end-user workshop: including workshop presentations | WP1 | UNICAS | *OTHER* | *CO* | 4 | 6 | Not assessed yet | Deliverable delay agreed by PO via email due to stakeholder meeting held October 2016 |
| D3 | Report Outlining a risk based assessment and resilience improvement framework | WP1 | ARU | *REPORT* | *PU* | 6 | 6 | Not assessed yet | |
| D42 | Project Board Management Report 1 | WP1 | ARU | *REPORT* | *CO* | 6 | 6 | Not assessed yet | |
| D55 | Data Management Plan v1 | WP9 | ARU | *REPORT* | *PU* | 6 | 6 | Not assessed yet | |
| D4 | Detailed user requirements and research output protocols for the LIQUEFACT Reference Guide | WP1 | ARU | *REPORT* | *PU* | 7 | 7 | Not assessed yet | |
| D43 | Periodic Project Progress Report 1 | WP9 | ARU | *REPORT* | *PU* | 7 | 7 | Not assessed yet | |
| D5 | Report on ground characterization of the four areas selected as testing sites by using novel techniques and advanced methodologies to perform | WP2 | UNIPV | *REPORT* | *CO* | 9 | 9 | Not assessed yet | |

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| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | in situ and laboratory tests | | | | | | | | |
| D6 | GIS platform including data for liquefaction hazard assessment in Europe (version 1) | WP2 | UNIPV | *OTHER* | *CO* | 12 | 12 | Not assessed yet | |
| D20 | Report on individual stakeholder and urban community performance metrics | WP5 | ARU | *REPORT* | *PU* | 12 | 12 | Not assessed yet | |
| D21 | Data collection toolkit for community resilience case studies (for WP6/7) | WP5 | ARU | *OTHER* | *PU* | 12 | 12 | Not assessed yet | |
| D44 | Project Board Management Report 2 | WP9 | ARU | *REPORT* | *CO* | 12 | 12 | Not assessed yet | |

## 6. Milestones

| **Milest. no.** | **Milestone title** | **Related WP(s) no.** | **Lead beneficiary** | **Delivery date from Annex 1** | **Means of verification** | **Achieved** | **Comments** |
|---|---|---|---|---|---|---|---|
| 1 | Comprehensive project scoping complete | WP1, WP2 WP5 WP8, WP9 | ARU | 01/11/2016 | D34 D1 D40 D41 D2 D3 D42 D55 D4 | *YES* | |

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|---|---|---|---|---|---|---|---|
| | | | | | D43<br>D5<br>D6<br>D20<br>D21<br>D44 | | |

# 7. Critical implementation risks and mitigation actions

## 7.1 Foreseen Risks

| The following table lists the Risks identified in Annex 1. The table is read-only and it is provided as a reference for the State of Play table below. **Risk Number** | **Description of Risk** | **Work Packages Concerned** | **Proposed risk-mitigation measures** |
|---|---|---|---|
| 1 | Insufficient participation of external experts and end users with technical assistance and transfer of knowhow of actual industry needs | 1, 7 | Specialized meetings with comprehensive involvement and elicitation of national and thematic experts |
| 2 | Lack of data in the selected case studies to perform full validation of the project | 2, 7 | Any problem with the quality or non-availability of data will be detected in the early stage of the project to proceed to alternative sites/case studies with a plan for each strategic application worked out at kick off meeting |
| 3 | The dynamic numerical analyses on foundations in critical infrastructures and pipelines, tunnelling and underground stations, may not be possible to calibrate by the pilot tests (WP4), due to high complexity of implementation of the field prototypes and limitations of the models. | 3 | The calibration will be focusing in the simplest structures available from the field pilot tests and a more extensive attention will be made to the centrifuge physical models. |
| 4 | Possible technical or legal obstacles to produce dynamic actions on site to | 4 | The technologies that we are thinking to produce dynamic actions have |

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| | check 'directly' the effectiveness of the soil liquefaction mitigation techniques under study | | been already used elsewhere, provided that local restrictions have been respected. The effectiveness of liquefaction mitigation techniques can be correctly checked also by indirect methods (laboratory and in-situ testing) without risk of failure. |

## 7.2 Unforeseen Risks

There are no unforeseen critical risks

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## 8. Dissemination and exploitation of results

| No. | Type | Title | Authors | Title of the Journal/Proc./Book | Number, date or freq. of the Journal/Proc./Book |
|---|---|---|---|---|---|
| 1 | Publication in Conference proceedings/Workshop | Numerical modelling of the dynamic response of liquefiable deposits in the presence of small scale buildings | Borozan, J., Alves Costa, P., Romão, X., Quintero, J., Viana da Fonseca, A. | 6th ECCOMAS Thematic Conference on Computational Methods in Structural Dynamics and Earthquake Engineering (COMPDYN 2017) | 15th - 17th June, 2017. |
| 2 | Article in Journal | Unidirectional cyclic resistance of Ticino and Toyoura sands from centrifuge cone penetration tests | Fioravante, V., Giretti, D. | Acta Geotechnica | Volume 11 Issue 4 |
| 3 | Article in Journal | A correlation to evaluate cyclic resistance from CPT applied to a case history | Giretti, D., Fioravante, V. | Bulletin of Earthquake Engineering | Volume 15 Issue 5 |
| 4 | Publication in Conference proceedings/Workshop | Previsione degli effetti da liquefazione su scala urbana | Paolella L., Spacagna R.L., Chiaro G | VII IAGIG INCONTRO ANNUALE GIOVANI INGEGNERI GEOTECNICI | 2017 |

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|---|---|---|---|---|---|
| 5 | Publication in Conference proceedings/Workshop | Confronto tra codici di calcolo per analisi di risposta sismica locale nell'ipotesi di comportamento visco-elastico lineare del terreno | Chiaradonna A., Tropeano G., Fasano G. | VII IAGIG INCONTRO ANNUALE GIOVANI INGEGNERI GEOTECNICI | 2017 |
| 6 | Publication in Conference proceedings/Workshop | The role of FM in disaster resilience: Integrating the Sendai Framework into disaster risk management | Jones, , K., Bartolucci , A. and Hiscock, K. | Research papers for EUROFM 16th research symposium EFMC 2017 | 25-28 April 2017 |

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## 8.1 Dissemination and communication activities

| **Type of dissemination and communication activities** | **Number** |
|---|---|
| Organisation of a Conference | 1 x 2 day Kick Off Meeting, UK |
| Organisation of a Workshop | 1 Bologna, 3rd October 2016 |
| Press release | - |
| Non-scientific and non-peer reviewed publications (popularised publications) | - |
| Exhibition | - |
| Flyers | 1 flyer (300 copies)<br>4 posters (6 copies) |
| Training | 1 SELENA consortium training, 6th October 2016 |
| Social media | 5 (Facebook, YouTube, LinkedIn, Twitter, Google +) |
| Website | 1 internet and 1 intranet website |
| Communication campaign (e.g. radio, TV) | http://www.lepida.tv/ |
| Participation to a conference | - |
| Participation to a workshop | University of Cassino, Oct. 7th 2016 |
| Participation to an event other than a conference or workshop | - |
| Video/film | http://videocenter.lepida.it/videos/video/2508/?live=true |
| Brokerage event | - |
| Pitch event | - |
| Trade fair | - |
| Participation in activities organised jointly with other H2020 project(s) | - |
| Other | - |
| **Total funding amount** | Approximately 8.000,00 € |

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| **Type of audience reached**<br>**In the context of all dissemination & communication activities** | **Estimated Number of persons reached** |
|---|---|
| Board of professional (Engineers, Geologists, Architects),<br><br>Expertise Association (AGI) | Approximately 800 |

## 9. Gender

| Gender of researchers and other workforce involved in the project **Beneficiaries** | **Number Women researchers (all levels, incl. postdocs and PhD students)** | **Number Men researchers (all levels, incl. postdocs and PhD students)** | **Number Women in the workforce other than researchers** | **Number Men in the workforce other than researchers** |
|---|---|---|---|---|
| ARU | 2 | 3 | 3 | 1 |
| UNIPV | 2 | 1 | 2 | - |
| UPORTO | 1 | 3 | 1 | 4 |
| UNINA | 1 | 2 | 3 | 2 |
| TREVI | - | 2 | 2 | 6 |
| NORSAR | - | 2 | - | 1 |
| ULJ | - | 2 | - | 2 |
| UNICAS | 1 | 1 | - | 2 |
| SLP | - | 1 | - | 3 |
| ISMGEO | - | 1 | - | 1 |
| Istan-Uni | - | 3 | 6 | - |

Gender dimension in the project

Does the project include a gender dimension in research content? *No*

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# Appendix

**Table 1.** Stakeholder and end-user List of Istanbul University (ISTAN-UNI)

| **Stakeholder /end user** | | **Contact person** | **Email** |
|---|---|---|---|
| **Name** | **Type (*)** | | |
| (Lawmaker of CHP, 25th Period, Grand National Assembly of Turkey) | Politician | Prof. Dr. Haluk Eyidogan | eyidoganh@gmail.com |
| Chamber of Geophysical Engineers of Turkey | Non-profit relief organizations, including NGOs | Erdal Sahan | erdal.sahan@gmail.com |
| Kadıkoy-Istanbul Municipality | Governmental organizations at the municipal levels | Menekşe Perdi | meneksetekin@yahoo.com |
| Zetaş A.Ş. | Specialty geotechnical construction companies | Prof. Dr. Turan Durgunoglu | durgunoglut@zetas.com.tr |
| Belirti A.Ş. | Specialty geotechnical construction companies | Taner Teoman | taner@belirti.com |
| AKUT<br>Search and Rescue Association | Civil protection agencies | Çağlar Akgüngör | caglarakgungor@akut.org.tr |
| ISKI (Istanbul Water and Sewerage Administration ) | Owners of critical buildings and infrastructure | Erkan Öztürk | erkanozturk1903@yahoo.com.tr |
| Tekirdağ Büyükşehir Municipality | Governmental organizations at regional levels | Sevim Avcı | sevimavci@gmail.com |
| Nilüfer – Bursa Municipality | Governmental organizations at the municipal level | Güngör Armutlu | gungorarmutlu@nilufer.bel.tr |

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| | | | |
|---|---|---|---|
| Earth Sciences Research Department<br>Ministry of Environment and Urbanisation | Governmental organizations at the country level | Cahit Kocaman<br>(Head of Department) | cahit.kocaman@csb.gov.tr |
| Earth Sciences Research Department<br>Ministry of Environment and Urbanisation | Governmental organizations at the country level | Esra Ezgi Baksi | esraezgi.baksi@csb.gov.tr |
| Earth Sciences Research Department<br>Ministry of Environment and Urbanisation | Governmental organizations at the country level | Selcan Melike Öztürk | smelike.ozturk@csb.gov.tr |
| Çanakkale<br>Municipality | Governmental organizations at the municipal level | İbrahim Çoban | cbnibrhm@gmail.com |
| Kepez (Çanakkale)<br>Municipality | Politician, Member of Municipal Council | Ali Aygün | yerbilim@hotmail.com |
| Yalova<br>Municipality | Politician, Ex-Member of Municipal Council | Murat Uzun | Uzameryalova@hotmail.com |
| GEOgrup İnşaat A.Ş. (Turkish Representative of Plaxis Software) | Specialty geotechnical construction companies | Müge İnanır | info@geogrup.com.tr |
| Soil Mechanics and Geotechnical Engineering Society of Turkey | Non-profit relief organizations, including NGOs | Prof. Dr. Feyza Çinicioğlu | feyzac@istanbul.edu.tr<br>info@zmgm.org.tr |
| Earthquake Engineering Association of Turkey | Non-profit relief organizations, including NGOs | Assoc. Prof. Dr. Mustafa Kerem Kockar | mkockar@gazi.edu.tr |

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| | | | |
|---|---|---|---|
| Sumet Yerbilimleri | Specialty geotechnical construction companies | Erhan İçöz | erhanicoz47@gmail.com |

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**Photo 1.** Stakeholder meeting Bologna

**Photo 2.** Test site D2.1