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Project Number: 700748

Project Acronym: LIQUEFACT

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

Deliverable D9.12

Periodic Progress Report 5

V1.0

Author(s)	Keith Jones
Responsible Partner	Anglia Ruskin University (ARU)
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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

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Glossary

Acronym	Description
BAM	Built Asset Management
B/C	Benefit to Cost Ratio
CBA	Cost Benefit Analysis
CCC	Christchurch City Council
CERA	Canterbury Earthquake Recovery Authority
CPT	Cone Penetration Test
CoRE	Centre of Research Excellence
CSF	Critical Success Factors
EEAB	External Expert Advisory Board
EILD	Earthquake Induced Liquefaction Disasters
ESP	Equivalent Soil Profiles
FLAC	Finite Difference Code
FM	Facilities Manager
GD	Ground Deformation
GIS	Geographic Information System
GMPE	Ground-Motion Prediction Equation
GS	Ground Settlement
GUI	Graphical User Interface
HD	Horizontal Drains
IM	Intensity Measures
IPS	Induced Partial Saturation
KPI	Key Performance Indicator
LA	Liquefaction Hazard Analysis
LP	Liquefaction Probability
LPI	Liquefaction Potential Index
LRG	Liquefact Reference Guide
LS	Liquefied Soil
LSN	Liquefaction Severity Number
MA	Mitigation Analysis
PGA	Peak Ground Acceleration
RA	Risk Analysis
RAIF	Resilience Assessment Improvement Framework
SLSFI	Soil Liquefaction Foundation Structure Interaction
SPT	Standard Penetration Test
WP	Work Package

Contents

1. Summary for publication

1.1 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.

1.2 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 is caused from the resulting settlements.

Recent events have shown 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 acknowledged so the LIQUEFACT project sets out to recognise the factors that contribute to its occurrence, estimate the impacts of EILD hazards and identify the most appropriate mitigation strategies that improve both infrastructure and community resilience to an EILD event.

1.3 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 infrastructures.

Objective 5: Identify the most appropriate vulnerability, 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) that 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 Eurocode standards revision task groups to produce new technical standards.

2. Progress on Objectives to date

During the reporting period work has principally been carried out on Objectives 1-6.

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

Version 2 of the RAIF has been developed along with versions three of the: EILD customised UNISDR Disaster Resilience for Cities scorecard; the Critical Infrastructure Resilience tool; and version 1 of the whole life cycle built asset management planning tool. These tools have been modified to reflect the outputs from other liquifact work packages and the LRG software.

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

Version 2 of the European Liquefaction hazard map has been developed. A literature review has informed the construction of a GIS catalogue of European historical Liquefaction occurrences. Alternative approaches to predict Liquefaction starting from seismological information has been undertaken.

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

Evaluation of existing numerical modelling strategies to simulate Liquefaction induced structural damage and to analyse the Liquefaction vulnerability of interacting soil-structure systems has been completed. Fragility curves for use in the LRG is well advanced. The development of design guidelines for soil characterisation and risk assessment is progressing.

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

Thirty-seven small-scale centrifuge tests have been completed to assess the effectiveness of vertical/horizontal drains and soil densification as Liquefaction mitigation interventions. The test site for a series full-scale field tests on the mitigation techniques has been prepared.

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

Versions 3 of the community and critical infrastructure resilience tools have been developed and integrated into a cost/benefit model of Liquefaction mitigation interventions for community and critical infrastructure resilience. A 10 step implementation tool for the application of the cost/benefit model has been developed for use by buy asset managers.

2.1.6 Objective 6: Develop LRG Software.

Version 0.9 Beta of the LRG software has been developed. The software includes end-user driven algorithms for Liquefaction hazard prediction and fragility analysis of critical infrastructure assets. The LRG user-interface is designed for use by a range of end-user stakeholders.

3. Expected Potential Impact

The current building standards do not fully address the issue of Liquefaction and Liquefact will provide research and demonstration to develop new simplified methodologies and tools. Liquefact's impact on the innovation capacity will be three-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/LRG 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.

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. However, current design codes 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 has begun to consolidate the varying knowledge around Liquefaction mitigation and explore how best to contribute to the convergence of building design codes and the ongoing revision process of the Structural Eurocode. Liquefact is affiliated with the QuakeCoRE initiative.

3.3 Explanation of the work carried out by the beneficiaries and overview of the progress

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. With the causes of Liquefaction being largely acknowledged, it is important to recognise the factors that contribute to its occurrence; to estimate the impacts of EILD hazards; and to identify and implement the most appropriate mitigation strategies that improve both building/critical infrastructure and community resilience to an EILD event. The Liquefact project adopts a holistic approach to address the mitigation of risks to EILD events. The Liquefact project aims to:

- achieve a more comprehensive understanding of the impacts that EILD events have on the resilience of communities and buildings/critical infrastructure on which they rely;
- achieve a more comprehensive understanding of the range of mitigation techniques (technical, operational, managerial and organizational) that can be implemented to improve the resilience of communities and building/critical infrastructure to EILD events;
- develop more appropriate mitigation techniques (technical, operational, organizational and managerial), for both European and worldwide situations;
- develop a Resilience Assessment and Improvement Framework (RAIF) to allow community and building/critical infrastructure stakeholders to make the business case for mitigation interventions.

This report provides details of the work carried out by the Liquefact partners during the reporting period from 1st September 2018 to the 31st March 2019. The report summarises progress against the objectives listed in annex one of the Liquefact grant agreement and provides details of the Deliverables submitted during the reporting period. The report also summarises progress against the milestones in the Grant Agreement.

The main priority during this reporting period was to finalise the range of tools needed for the Liquefact LRG toolbox. This activity is largely complete with only minor modifications required before the LRG is tested in WP7.

Information from previous reporting period

WP2 has:

- Developed the second version of the GIS platform has been developed by UNIPV-Eucentre (Deliverable D2.3).
- Developed the first version of the GIS-based catalogue has been compiled by UNIPV-Eucentre. The catalogue includes two main types of information: Liquefaction site information (geographic coordinates, epicentral distance, type of

failure, etc.) and seismological features of seismic events (date, geographic coordinates, magnitude, etc.) that induced each Liquefaction phenomenon.

- Calculated European regressions to predict Liquefaction occurrence starting from the main seismological information of an earthquake.
- Made a first attempt to derive Italian and European relationships between magnitude and distance for Liquefaction has been carried out by UNIPV-Eucentre.
- Undertaken a state of the art review has been carried out by UNIPV-Eucentre, first of all, to review methods available in literature for Liquefaction hazard and risk assessment at large scale and hence to define a methodology for macrozoning the European territory for Liquefaction risk.
- Begun the validation of the European Liquefaction hazard map (microzonation) at the four testing areas in Italy, Portugal, Slovenia and Turkey.

WP3 has:

- Undertaken and submitted a "State of the art review of numerical modelling strategies to simulate Liquefaction-induced structural damage and of uncertain/random factors on the behaviour of liquefiable soils": Deliverable D3.1.
- Developed a complex detailed numerical modelling approach able to represent the damage and the complex behaviour of interacting structure-soil systems with Liquefaction susceptibility.
- Developed a simplified modelling approach with an adequate balance between complexity and accuracy specifically suited for probabilistic analysis.
- Begun the calibration of the models against the Italian test site.
- Developed a procedure to estimate loss to buildings on liquefiable soil for inclusion in the LRG software (WP6).

WP4 has:

- Performed 37 centrifuge tests (ISMGEO), organized in three series: the first series aimed at investigating the Liquefaction triggering conditions, the second and third ones devoted at analysing the effectiveness of three selected Liquefaction remediation techniques (vertical drains, horizontal drains and induced partial saturation. In some tests a simple structure founded on a shallow foundation was included in the models. The structure scaled model was designed by UNINA
- Carried out laboratory tests on Ticino sand which was been used in centrifuge tests.
- Planned (UNINA) and carried out (TREVI) field trials at the selected case study pilot testing site.

- Carried out laboratory tests on the undisturbed samples collected from the case study testing site (UNINA).
- Prepared the case study pilot testing site for earthquake simulation (scheduled for October 2018) using the MERTZ M13S/609 S-WAVE servo-hydraulic vibrator.
- Undertaken numerical modelling (UNINA) of the centrifuge tests and field trails.
- Begun to develop guidelines to be implemented in the LRG (WP6) and to be recommended for implementation in the European building codes and standards (WP7).

WP5 has:

- Developed a 10-step Liquefaction built assessment toolkit for identifying appropriate ground mitigation measures to improve built asset resilience.
- Developed version 3 of the Liquefaction community resilience scorecard based on a customised (for an EILD event) version of the UNISDR Disaster Resilience Scorecard for Cities.
- Developed version 3 of the critical infrastructure resilience scorecard.
- Developed version 2 of the Resilience Assessment and Improvement Framework (RAIF).
- Begun the development of generic Business Continuity and Resilience Plans and Disaster Management Plans.

WP6 has:

- Developed version 0.9 Beta of the LRG software which is now ready to be used and tested (Deliverable D6.1, submitted in M24).
- Begun to develop algorithms for ground shaking and Liquefaction hazard simulation from the outputs provided by WP2.
- Begun to develop algorithms to be used for simulation and evaluation of seismic performance and vulnerability (physical damage and loss) of an asset (e.g. individual building/CI asset, portfolio of buildings/distributed infrastructure assets, etc.) given a level of Liquefaction threat (output from the protocol LA) from the outputs provided by WP3.
- Begun to develop algorithms where end-users can define the structural typology of the asset (structure/infrastructure) and assign the associated vulnerability model (fragility curves, loss models) from the outputs provided by WP3.

- Begun to develop algorithms where the vulnerability models can be stocked and presented as a library of pre-defined models that can be directly used by the end-users for their risk studies from outputs provided by WP3.
- Begun to develop algorithms allowing end-users to manually modify the vulnerability models and input their own customized models from outputs provided by WP3.
- Begun to develop procedures to integrate Liquefaction mitigation measures developed by WP4 into the LRG

WP7 has:

- Begun the development of a standard protocol for the creation of databases for Liquefaction risk assessment to be implemented in the LRG.
- Begun the validation of the LRG at 4 sample sites by the collection, homogenization and organization of all data into geographical information systems.
- Begun the development of guidelines for the standard use of remediation technology against Liquefaction.

WP8 has:

- Made contact with a number of projects and organisations working on similar or related subjects to pro-actively promote the Liquefact project.
- Cooperation agreements have been signed with a number of stakeholders to share information and data necessary to accomplish the goals of the project.
- Had more than 20 conference or journal papers accepted for publication or currently in press.
- Presented invited lectures around the world.
- Produced version 1 of a Liquefact video.
- Maintained and managed all the communication media promoting the project to the general public and business communities.

WP9 has:

- Maintained the consortium agreement
- Processed amendment for TREVI introducing new 3rd Party Beneficiary
- Monitored budgets and processed payments to partners
- Processed Change Management Requests
- Updated Risk Register

- Processed Subcontracts

1.1 Impact

The generic impacts identified in the Grant Agreement were:

- More effective building standards and design methodologies for infrastructures and households located in EILD vulnerable areas.
- Enhanced security of citizens and assets in such areas.
- Reduced socio-economic impact of natural catastrophes.
- Proactively target the needs and requirements of public bodies.

These expected impacts have not changed.

The specific impacts identified in section 2.1 of the Grant Agreements are:

1.1.1 Enhancing the innovation capacity and integration of new knowledge

The civil construction sector and built environment is characteristically conservative and slow in adopting innovation. The adoption of research and innovation in the construction industry and related professions is consistently regulated and hence, adequate regulation of standards can help the development of strong framework conditions for the sector. This is even more so for construction in seismic regions, particularly areas that are prone to Liquefaction. The current standards do not fully address the issue even though there have been significant amounts of research and innovation on Liquefaction potential assessment and mitigation. However, they have not yet made their way into regulation. Liquefact will address this shortcoming by providing research scoping and demonstration at an unprecedented scale in order to consolidate existing research knowledge and develop new simplified methodologies and tools that will be easier to apply by stakeholders for implementing Liquefaction mitigation strategies within an urban community context. Liquefact's impact on the innovation capacity will hence be two-fold:

1. Results generated within Liquefact will have a set path into the ongoing revision process of the Structural Eurocode. This will be achieved through some of the project's consortium partners (Paolo Croce and Alessandro Flora), who are members of the TC250/SC7 (Geotechnical Design Eurocode).
2. Also, the resulting LRG software toolbox will be made available as open source, with a possible business model for selling add-on professional services.

Whilst the above impact is yet to be realised, all the work undertaken to date supports the development of this impact. Indeed, the pathways to impact has formed a fundamental part of the discussions between project partners started in Work Package 1 and continued at the Project Management and International Advisory Board meetings held over the past 28 months. The outputs from all of the work packages to date have been tested against the needs of the RAIF and LRG tools through a 'Sprint Test' and they have been found to be consistent with the original objectives outlined in the Liquefact DOA and with the needs of the project stakeholders. The development of specific pathways to impact, including commercialisation routes for the LRG software forms part of WP8 and is due for completion during Reporting Period 3.

1.1.2 Impact of risk/resilience assessment and improvement on the various stakeholders and end-users

Depending on the scale and resolution of the EILD risk / resilience assessment, a broad variety of stakeholder / user groups would be interested in the prediction of the likely consequences of an EILD event. These range from individual structure/infrastructure owners/facility managers to regional government, (re)insurance and civil protection organizations. The RAIF provide 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. Whilst this impact is yet to be realised the principles underpinning the RAIF have been presented to European Facilities Manager practitioners at the 2017 EFMC conference. Discussions amongst the Liquefact project partners, external stakeholders and the International Advisory Board identified the benefits that could be derived by developing specific use-cases that would demonstrate how the RAIF and LRG could be used by different stakeholders and end-users to assess their level of risk/resilience to EILD events. Four use-cases (individual households, SME's, critical infrastructure providers, and local/regional authorities) that describe how each stakeholder end-user group can use the outputs from Liquefact are being developed as part of D5.4 and as part of the pathways to impact in WP8.

1.1.3 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. This is simply because existing structures generally represent the large majority of a building stock likely to undergo a seismic event in a certain period and most urban building stock only changes slowly over the course of time. However, in many parts of the developing world, especially where the urban population is growing inexorably along with a boom in the development of new construction, the availability of a proper design code is of greater importance. Worldwide the construction industry is forecast to be worth €12 trillion by 2020. Of this, residential corresponds to 40% of the total market. Global growth of residential construction is expected to be 4.4% between 2015 and 2020. The growth is expected to be somewhat slower in Europe, especially in the Western bloc. The residential sector currently corresponds to approximately 43% of the total construction output in Europe. According to estimates, up to 60% of the construction output came from renovation activity in 2013 alone. This trend has been constantly increasing, particularly in the centre of old European cities where space for new construction is rare. Any building code, not only those which are related to the seismic safety of buildings, is a technical rule which aims to ensure the fulfilment of requirements relating to the "quality, strength, effectiveness, fire resistance, durability and safety" of construction. In doing so, codes should reflect recognized practices current at the time of issue, without, however, preventing the progress of knowledge. Especially in the case of seismic building codes, experiences from past earthquakes lead to improvements and further development of the provisions, thus steadily increasing their quality and reliability. Modern seismic building design codes of various countries tend to converge on issues of design methodology and the state-of-the-art. However, significant differences exist in some of the provisions of various codes. Liquefact aims at consolidating the varying knowledge around Liquefaction mitigation and here contribute to the convergence of building design codes.

1.1.4 European Added Value – The need for a transnational approach

There are several reasons, though, why the proposed research should be conducted at a transnational EU level.

First, the problem of risk / resilience assessment and mitigation of EILD is significant to most Southern and Eastern European countries. However, in the goal of Europeanisation, crisis and disasters are not bound to national borders. Moreover, there are facilities, e.g., bridges, and electricity power lines that extend in more than one country. In addition, this project will strengthen the global competitiveness of the European construction industries as well as contribute to new European Structural Eurocode standards. There is the need to build on past EC sponsored research that will benefit this project and hence the need for the inclusion of common partners with these projects, which are spread across Europe. Also, bringing the best expertise across Europe will thus improve the quality of research. Another reason why Liquefact has to be carried out on a European level is the necessity of knowledge exchange and transfer. This project will ensure knowledge transfer through a large number of dissemination events (see WP8). The EU market as well as the world market is being targeted for the project results. It is thus useful to have eleven reputable partners from six different European countries, several of which are active in numerous European countries and abroad (for instance, NORSAR and TREVI).

During Reporting Period Liquefact has become an affiliate of the New Zealand QuakeCoRE Centre. QuakeCoRE aims to transform the earthquake resilience of communities and societies, through innovative world-class research, human capability development, and deep national and international collaborations. QuakeCoRE are a Centre of Research Excellence (CoRE) funded by the New Zealand Tertiary Education Commission to which the Liquefact project is now affiliated. QuakeCoRE gives the Liquefact project a truly global audience that will ensure our research findings and end-user tools have reach far beyond the initial scope identified in the DOA, Further details of QuakeCoRE can be found at http://www.quakecore.nz/

The remainder of this technical report provides details of the activities that have contributed to progress to date.

4. Explanation of work carried out in each Work Package

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

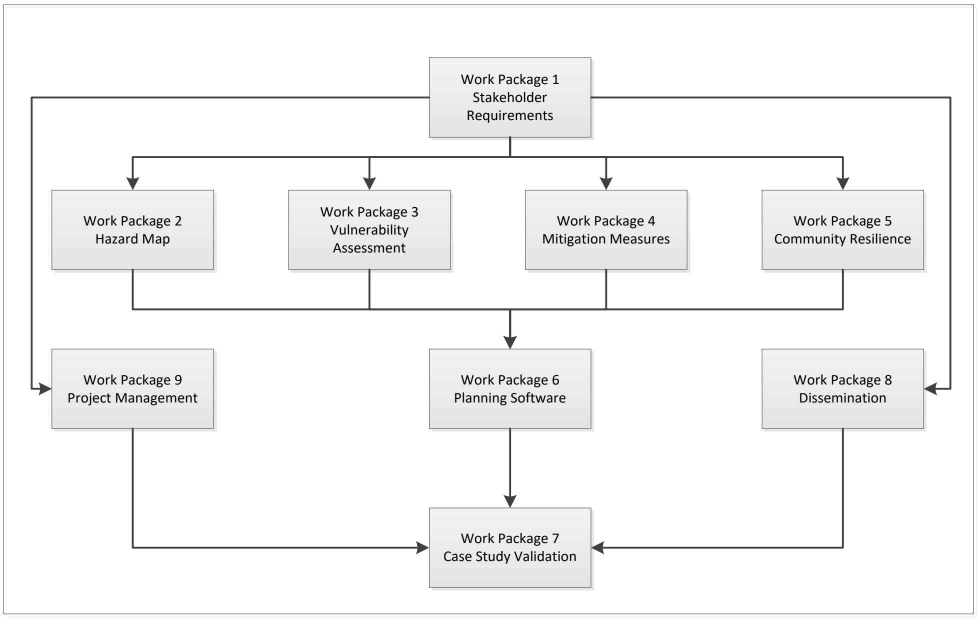

Figure 1: Liquefact Work Packages

4.1. Work Package 1: Stakeholder Requirements and Industry / Research Gaps

(ARU – Leader. All partners involved)

This Work package was completed in Reporting Period 1. However, as this Work Package provided the context for all the other Work Packages a brief review of the main outputs is presented here.

The aim of Work Package 1 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. To this end the Work Package:

1. Developed over-arching theory of urban community resilience to EILD events in Europe.
2. Developed an outline decision-making framework for improving urban communities' resilience to EILDs.
3. Established a common working practice to ensure that activities undertaken in the other Work Packages produced outputs that were directly useable in the decision making framework
4. Coordinated 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.

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Results from Work Package 1

A detailed review of literature, supported by project partner workshops and group discussions identified the factors that affected community resilience. These are summarised in Table 1. Full details of each factor can be found in Deliverable 1.1.

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.

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

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Following the identification of the factors that affect community resilience to EILD events a Risk / Resilience Assessment and Improvement Framework (RAIF) was developed. The RAIF (Figure 2) is a decision support tool for built asset owners and/or managers to assess the antecedent vulnerability, resilience and adaptive capacity of their built assets to EILD events and to evaluate alternative adaptation and mitigation options to either reduce vulnerability or improve resilience.

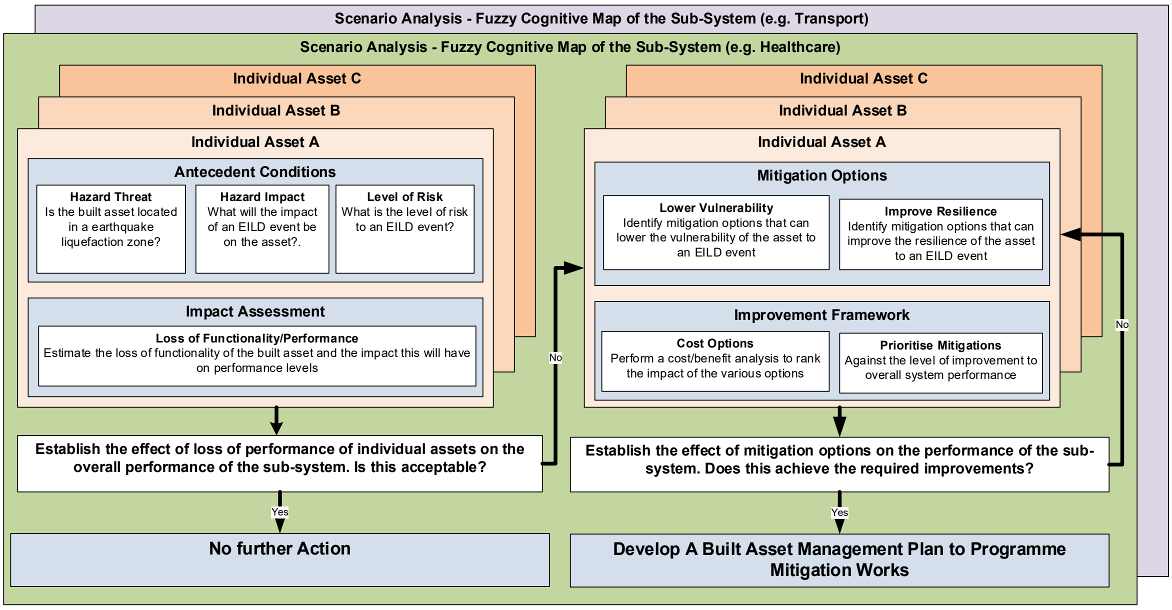

Figure 2: The Liquefact RAIF

The RAIF relates directly to the work carried out in Work Packages 2-6. Full details of its development are given in Deliverable 1.4.

4.2. Summary of Activities in Work Package 2 completed in Reporting Period:

The University of Pavia and EUCENTRE lead Work Package 2, which deals with the zonation of a territory for Liquefaction hazard at both continental and municipal/submunicipal scale. Indeed, the goal of WP2 is the definition of a European Liquefaction hazard map (*macrozonation*) as well as the development of a methodology for the assessment of the Liquefaction potential at an urban scale (*microzonation*). In a map of Liquefaction hazard, the territory is subdivided into an appropriate number of homogeneous zones where the likelihood of earthquake-induced soil Liquefaction is displaced according to a specified chromatic scale.

Task 2.2 focuses on building the GIS platform to manage data for Liquefaction hazard and risk assessment at the European scale. Geological, hydrogeological and geomorphological information and seismological data were collected at the European scale and then harmonized in the GIS platform. Proxy data of exposure available in Europe were also included in the GIS platform.

The first version of the GIS platform was delivered as D2.2 (*GIS platform including data for Liquefaction hazard assessment in Europe – Version 1*) at the end of April 2017. The updated version of the GIS platform was delivered as D2.3 (*GIS platform including data for Liquefaction hazard assessment in*

Europe - Version 2), at the end of April 2018. The third and last version of the GIS platform was delivered on time at the end of December 2018, as *D2.5 "GIS platform including data for Liquefaction hazard assessment in Europe - Version 3"*. The third version of GIS platform represents a refinement of the architecture of the preliminary database delivered as D2.2 and D2.3. It is organised in four different folders as follows:

1) Data: containing the input data and the geo-processed files
2) Layer files: containing the symbology of each original and processed files
3) Mxd: where the GIS projects (compatible with the ArcGIS version 10.4.1) are saved
4) Maps: visualization of data in pdf format

The third version of the GIS database is fully accessible via web in the Zenodo platform (https://zenodo.org/).

Within WP2, aim of **Task 2.3** is the construction of a GIS-based catalogue of historical Liquefaction occurrences in Europe. In this framework, a database containing historical information regarding the Liquefaction-related phenomena occurred in Europe, including sand ejects and boils, soil settlements and lateral spreading, ground and structural failures, was developed. To build the catalogue of Liquefaction manifestations, a critical bibliographic review was carried out to identify the most suitable sources to be used, such as existing databases for specific areas (e.g. for Italy), studies, reports and tales concerning earthquakes, chronicles and diaries, archival documentation and seismic bulletins. In this research, one of the most important starting points is represented by the earthquake catalogue set up for the European territory within recent research projects (i.e. SHARE "*Seismic Hazard Harmonization in Europe*"). Descriptions of Liquefaction manifestations triggered by earthquakes, including, if possible, photos and figures, were gathered from the collected references and used to construct a European database under a GIS environment. Thus, the GIS-based catalogue includes two pieces of information: main seismological features of the seismic events (date, geographic coordinates, magnitude, focal mechanism if known, etc.) and Liquefaction site parameters (epicentral distance, type of failure, etc.).

Based on the European Liquefaction occurrences catalogue, calculation of European regressions to predict Liquefaction occurrence was carried out starting from the main seismological information of an earthquake within **Task 2.4** of WP2. In particular, new empirical European relationships between earthquake magnitude and distance for Liquefaction was computed. The dataset was used to identify, on the basis of statistical analyses, magnitude-distance couple threshold below which Liquefaction is unlikely to occur, regardless of the geological site conditions. The new correlations was compared to those obtained from the studies available in literature. In setting up the novel empirical models, an effort was made to take into account the influence of both aleatory and epistemic (i.e. model-based) uncertainty. Furthermore, an attempt to define a peak acceleration threshold for soil Liquefaction for Europe was undertaken. The focus is on another single Liquefaction triggering factor, the peak ground acceleration (PGA) at the site surface. In fact, if the maximum acceleration at the site is lower than the acceleration limit, Liquefaction should not occur, or is very unlikely, regardless of other seismological and geotechnical conditions.

The activities carried out within Task 2.3 and Task 2.4 are fully illustrated in a report, called D2.4 "*GIS database of the historical Liquefaction occurrences in Europe and European empirical correlations to predict the Liquefaction occurrence starting from the main seismological information*", delivered on time on October 31, 2018.

Macrozonation of Liquefaction risk of the European territory is currently addressed within **Task 2.5** of Liquefact project. More specifically, the University of Pavia and EUCENTRE spend efforts in constructing geo-referenced European earthquake-induced soil Liquefaction risk maps for various return periods. They are built using available datasets at a continental scale on the expected seismic hazard and on the geological, geomorphological, hydrogeological, shallow lithology and digital terrain information. Two different types of algorithms are used to calculate the risk: *data-driven methods* like the logistic regression and *knowledge-driven methods* like the analytical hierarchy process. A validation of this work has been carried out by superimposing on the calculated macrozonation maps of Liquefaction risk, the GIS-based catalogue of Liquefaction manifestations occurred in Europe and well-documented in historical earthquakes. This catalogue was constructed in Task 2.3. The final Liquefaction risk maps of Europe are computed by convolving soil susceptibility to Liquefaction, expected severity of ground motion and exposure, the latter being alternatively described by either the European population density or the land use of the European territory.

WP2 of Liquefact project also addresses zonation of a territory at an urban scale for earthquake-induced Liquefaction risk (*microzonation*) within **Task 2.6**. Microzonation of a town consists in subdividing the territory of that town in homogeneous zones characterized by the same probability of Liquefaction occurrence, under free-field conditions, induced by an earthquake of a specified intensity. In Liquefact, four European testbed territories were selected as case studies where to construct microzonation maps for earthquake-induced Liquefaction risk. They are located in Emilia-Romagna region (Northern Italy), Lisbon metropolitan area (Portugal), Ljubljana area (Slovenia) and in Marmara region (Turkey).

A procedure was applied for the microzonation of the territories under investigation, based on the implementation of the following steps:

- Definition of the geological and seismo-tectonic setting associated to the case study;
- Collection of documented cases of Liquefaction manifestations in historical earthquakes;
- Definition of a subsoil model of the urban centre by merging information from local geology, geomorphology, hydrogeology, geophysical and geotechnical data;
- Execution of a complementary geotechnical and geophysical investigation campaign to integrate existing soil data;
- Definition of the reference seismic input;
- Microzoning the territory under investigation for the expected ground motion;
- Microzoning the territory under investigation for Liquefaction risk using state of the art methods.

4.3. 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 in Reporting Period

Summary of Activities in Work Package 3 completed in Reporting Period

Task 3.2 – Liquefaction vulnerability analysis of interacting structure-soil systems in the field trials at the two pilot testing sites

The objective of this task 3.2 is to develop an efficient probabilistic numerical procedure for the simulation of Liquefaction-induced damage and fragility analysis of critical structures and infrastructures. Different modelling strategies to simulate Liquefaction-induced structural damage including uncertain/random factors with relevant effects on the behaviour of liquefiable soils and of interacting structure-soil systems, were developed and existing techniques were evaluated. The key factors that contribute to the occurrence of Liquefaction and its impacts on critical structures and infrastructures were identified in the deliverable 3.2, to enable the development, evaluation and implementation of the most appropriate mitigation strategies to improve community resilience to against Earthquake Induced Liquefaction Damage (EILD) event.

The complexity of soil-Liquefaction-foundation-structure interaction (SLFSI) is a challenge for both geotechnical and structural engineers. To cope with this complexity, both analytical and empirical approaches were taken to develop practical models for different asset types that had an adequate balance between complexity and accuracy specifically suited to probabilistic vulnerability analysis. The vulnerability analysis forms a key step of the loss assessment procedure developed in the deliverable 3.3 of this Liquefact work package.

To adequately demonstrate the developed procedures, each approach was demonstrated on two different asset types (point/individual assets and distributed assets). Figure below illustrates the asset types and approaches covered in this report: (a) two analytical models, one for an individual asset (reinforced concrete building) and another for distributed asset (a road embankment); while, (b) two empirical database models were used, one for an individual asset (masonry structure building) and another for distributed asset (a road embankment).

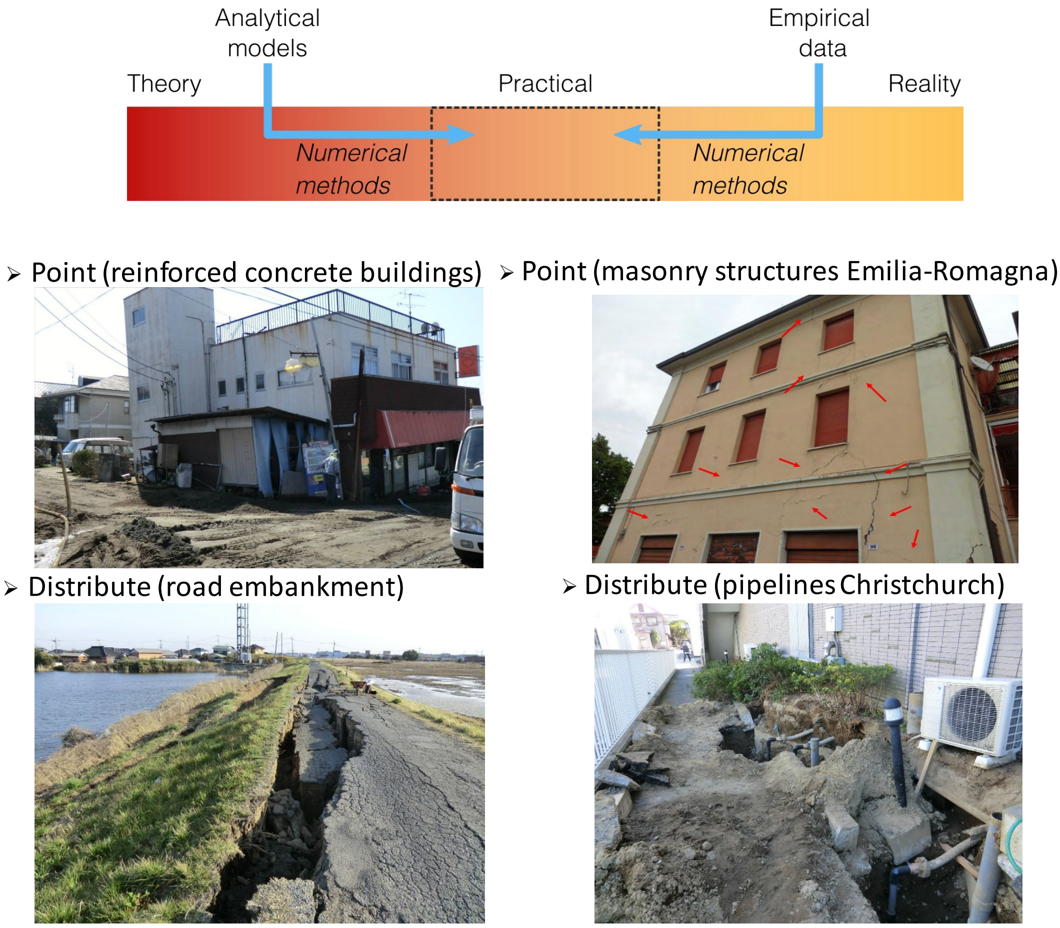

Figure 3: Type of critical structures and infrastructures modelled during this work package: (a) analytical approaches with calibrated numerical simulations: (b) empirical approaches.

Task 3.3 – Guidelines to be provided to WP6 / WP7:

This task has produced a report (deliverable 3.3) providing an overview of the key steps for assessing the risk of infrastructures that are exposed to Liquefaction and discusses key aspects related to the definition of exposure models (for infrastructures and soil deposits), seismic hazard, vulnerability assessment and expected loss quantification. Each topic is discussed in the context of Liquefaction-induced ground deformations and their effect on the performance of buildings, highlighting the necessary requirements as well as the existing approaches and their limitations. Particular focus is given to features developed in Liquefact. Among these, reference is made to the equivalent soil profile scheme for classifying Liquefaction susceptibility for loss assessment and that should be combined with existing infrastructure taxonomies for the purpose of developing a combined exposure model accounting for Liquefaction susceptibility. Likewise, reference is also made to a novel procedure presented for the calculation of losses accounting for Liquefaction-induced ground deformations that is based on a state-of-the-art approach for calculating probabilistic losses from a seismic vulnerability assessment considering building, foundation and system damage states.

Task 3.2 – Liquefaction vulnerability analysis of interacting structure-soil systems in the field trials at the two pilot testing sites (Task leader: UPORTO)

Task 3.3 – Guidelines to be provided to WP6/WP7 (Task Leader: UPORTO)

Submitted in the first week of January. We contributed, as planned in the deliverable T4.4 (led by UNINA), which deliverable was also submitted in January19.

We are still working in the application of our methodology in close collaboration with NORSAR (Abdel was in Porto for week, learning it to implement in "LRG Software Toolbox for Liquefaction Mitigation Planning and Decision Support"). We will be contribution to deliverable:

D6.3	Software toolbox development – Part2: Integration of procedure for Liquefaction vulnerability analysis	WP6	P	RE	M36

Still, this can be associated to our activities in WP1+WP7, as these works are associated to T7.4 – preparation of the guidelines for the standard use of remediation technology against Liquefaction (to be carried out in parallel with the other tasks)

And, of course we are working intensely in WP2 - Task2.6, for the microzonation of the pilot site in Portugal.

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

(UNINA – Leader. ARU, UNIPV, UPORTO, TREVI, NORSAR, ULJ, ISMGEO – Participants)

The objectives of this Work Package are to establish and comparatively analyze the state of the art measures of Liquefaction mitigation for protection/resilience of small to medium sized ‘critical’ infrastructures and low-rise structures (including 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.

Summary of Activities in Work Package 4 in Reporting Period

Task 4.1. This Task ended within RP1 (however, according to the grant agreement D4.1 will be submitted at M36)

Task 4.2. This Task ended within RP2 (D4.2 submitted at M25)

Task 4.3. This Task is active within RP3. (D4.5 will be submitted at M37)

Task 4.4. This Task ended within RP3 (D4.4 submitted at M32). It saw advanced constitutive models to be calibrated on soil lab tests, back-analysis of centrifuge tests, back analysis of field prototype experiments, extrapolation to different geometrical layouts and parametrical study. The activities of this Task were ancillary to T4.2, T4.3 and T4.4 as specified later in more details.

Task 4.5. This Task is active within RP3 (D4.5 will be submitted at M36). Reference guidelines are currently being developed within this task as input to WP6, to implement a manual in the software toolbox and as input to WP7, for the implementation of guidelines for the standard use of remediation technology against Liquefaction in the European building codes and standards.

Details of Activities in Work Package 4 in Reporting Period

Task 4.1 - treated soil characterisation (task Leader- UNINA)

This Task ended within RP1

Task 4.2 - small scale centrifuge modelling (task Leader: ISMGEO)

This Task ended within RP2

T*ask 4.3 – Field trials at the selected case study pilot testing site (Task leader: TREVI)*

The Liquefact test field carried out in Pieve di Cento Municipality on October 22 and 23, 2018 was the large-scale experimental "heart" of WP4. A Mega-Shaker, capable of generating a scaled local earthquake, was used on site to test the effectiveness of two innovative liquefaction mitigation techniques: Horizontal Drains (HD) and Induced Partial Saturation (IPS).

The test site, deeply investigated from a geological and geophysical point of view, showed a shallow liquefiable layer at a depth between 3 and 4 m, where innovative well screens made of micropored polyethylene offering a uniformly distributed porosity were installed.

The THDD technique was necessary in order to install well screens horizontally: this is an important technical detail in case these technologies have to be adopted in real liquefaction mitigation jobsites, consolidating the soil below existing structures (see figure 4).

Reamers with a diameter exceeding pipes' diameter by no more than 15% were used for both HD and IPS, and a low-viscosity natural biodegradable polymer slurry was adopted as drilling fluid to reduce soil disturbance to a minimum. Thanks to these specific measures and to the skill of the workers, no settlement was observed at ground level during installation.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 700748

FIGURE4: THDD application below existing structure

A total number of 12 tests on four footprints (one for the Virgin Soil, two for Horizontal Drains and one for the Induced Partial Saturation) were performed varying frequency and shake's duration. A huge amount of data was recorded during each test: pore pressure measurements, horizontal and vertical velocities measured with 2D geophones at different depths and accelerometers data. Data were also real-time shown on two screens available in the jobsite-office, to allow the decision makers to be fully in control of the ongoing tests. Showing results of the carried-out tests is not included in the scope of this report; however, effectiveness of the adopted liquefaction mitigation techniques was clearly inferred by the fact that a local liquefaction phenomenon, probably from the shallowest layer, occurred only in correspondence of the VS (unconsolidated area). Deliverable 4.3 "Report on demonstration of retrofitting techniques" is going to be submitted by the end of march 2019.

Task 4.4 – Numerical modelling (Task leader: UNINA)

This task focused on numerical analyses, carried out on a number of numerical models, considering the case of virgin soil (no ground improvement technique), that of the use of Horizontal Drains (HD), and that related to the use of Induced Partial Saturation (IPS), with the final goal to gain evidences of the pros and cons of the two selected Liquefaction risk mitigation techniques.

As a first step, the activity started by the definition of the seismic input motions at the field trial test site (Pieve di Cento, Italy). This activity was carried out at UPAVIA. Such motions were used as inputs in the centrifuge tests carried out at ISMGEO (Task 4.2), as reported in *Deliverable D4.2* (*Report on validation of retrofitting techniques from small-scale models*).

Support to T4.2

Since Liquefaction is a very complex, coupled mechanism, the constitutive models to be adopted in the simulations are much more complex than the ones usually adopted for static simulations of geotechnical problems. Therefore, in the task a number of advanced constitutive models were used in the numerical simulations (UNINA and UPAVIA), with different numerical codes (FLAC 2D and 3D, PLAXIS 2D, OpenSEES). Suitable calibration procedures were followed to simulate the different experiments (in the centrifuge or at the test site).

The results of physical centrifuge modelling reported in the previously mentioned *Deliverable D4.2,* for the cases of both virgin soil and mitigation techniques, were used as benchmarks to validate numerical modelling. Hence, a deeper insight on the mechanisms was achieved via a parametric analysis of the effectiveness of the considered mitigation technologies.

Support to T4.3

A number of numerical simulations was carried out (UNINA and UPAVIA), aiming to reproduce the results obtained at a real scale in the field trial (in which ground shaking was applied via a mega shaker placed at ground level above a deeply instrumented subsoil). The experimental activity carried out at the field trials test site is described in *Deliverable D4.3* (*Report on demonstration of retrofitting techniques*).

Additional parametric analyses were carried out to show the performance of some r.c. framed structures using the stratigraphy of the field trials test site (UPORTO).

Task 4.5 – Guidelines to be provided to WP6/WP7 (Task leader: UNINA)

A document including a short summary of currently adopted ground improvement techniques that may be adopted for Liquefaction mitigation has been completed within this task to be used as input for WP6. Such activities were carried out in close cooperation with NORSAR.

Further activities are currently carried out within the task in order to summarize the main results of previous tasks T4.1, T4.2, T4.3 and T4.4 within a single framework. Such a work is aimed to define a design approach to the innovative mitigation techniques on which this WP has put its focus. They are Horizontal drains and Induced Partial Saturation. In fact, among other considered, those techniques both showed promising results in their experimental and numerical validation. The results of this part of the task will be part of D4.5, to be used as a guide and input for WP7.

4.5. 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.

Summary of Activities in Work Package 5 in Reporting Period

Task 5.1 was completed before the start of this reporting period. Task 5.1 saw the development of version 1 of the stakeholder and urban community performance metrics and an assessment of the inter-relationship between them. The theory underpinning the RAIF was extended to include a detailed analysis of EU funded projects that were developing toolkits and frameworks for assessing critical infrastructure (and community) resilience to natural and man-made disaster events. The generic approaches and range of metrics identified in these projects were 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. However, whilst the generic approach being adopted by other EU funded projects is consistent with that being developed by Liquefact, none of the critical infrastructure resilience tools provide the level of detail that would allow them to be directly integrated into UNISDR Disaster resilience Scorecard for Cities or support cost benefit analysis and options appraisal required by the RAIF. As such, an enhanced critical infrastructure resilience tool is being developed as part of the built asset management (BAM) planning deliverable (D5.4) in this reporting period.

Task 5.2 was completed before the start of this reporting period. Task 5.2 saw the development of two data collection tools to support the application of the community and critical infrastructure resilience models developed in Task 5.1. A data collection tool was developed to allow bespoke assessments of the resilience of critical infrastructure. The data collection tool comprised 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. A second data collection tool was developed to contextualise the UNISDR Disaster Resilience Scorecard for Cities to an EILD disaster event. These data collection tool will be used during semi-structured interviews with stakeholder representatives from the Emilia Romagna region of Italy and the Marmara region of Turkey to identify the relevance and importance of each item to an EILD event and to identify the impact that an EILD event would have on the community in (WP7). Whilst these tasks are complete version 2 of the tools have been as part of the ongoing work of Task 5.4 to reflect the emerging requirements of the whole life-cycle BAM process.

Task 5.3 – was completed before the start of this reporting period. Task 5.3 saw the development of a cost-benefit analysis (CBA) model for use as part of Task 5.4. Two approaches to cost-benefit modelling for comparing the costs and resultant benefits of alternative development/mitigation options to reduce the vulnerability/improve the resilience of buildings and communities to EILD were developed. The forward-looking CBA framework (risk-based approach) combines data on hazard and vulnerability to assess antecedent risk and reduced risk after mitigation. Whilst this approach is mathematically rigorous, its application can be problematic in situations where data and resources available to undertake the assessment are limited (as is the case with EILD events). The approach is also less applicable to areas that are subject to multiple hazards or characterized by a large number of individual assets that have different vulnerabilities (as is the case with EILD events). In these situations it may be more pragmatic to use a backward-looking framework (impact based-approach) where past damage to assets is used to assess the risks associated with the disaster event and quantify potential future damage states that history suggests would exist should such an event occur again. Both of these approaches are compatible with the needs of the RAIF developed as part of the Liquefact project. Both of these models are being integrated into the BAM planning tool being developed as part of Task 5.4.

Details of Activities in Work Package 5 in Reporting Period

Task 5.4 - is ongoing and involves the development of a whole life-cycle built asset management planning tool for EILD events.

The role of built assets is to support the primary function of an organisation (its core business) in the most effective and efficient way. Built asset management is the process by which the performance (effectiveness and efficiency) of built assets to support 'core' business are specified, measured and managed Figure 5.

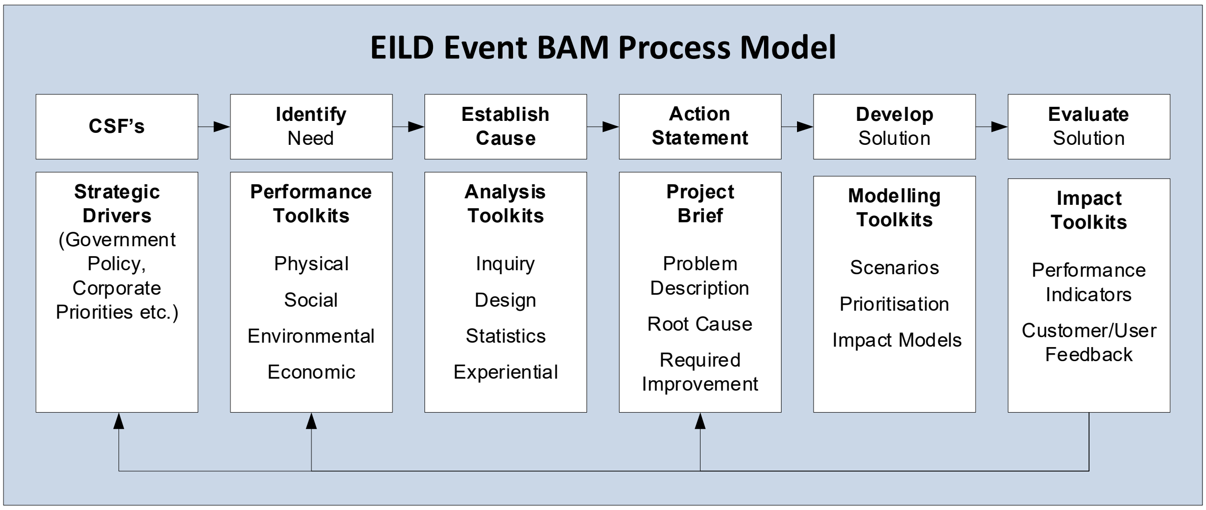

Figure 5: Strategic Built Asset Management Process Model

Built asset performance is measured against the organisation's CSF through a range of key performance indicators (KPI's) expressed as quantitative or qualitative metrics. The metrics cover: economic (€/service unit delivered); Social (impact on society); Environmental (energy, waste etc.); and Physical performance states. Although from a strategic perspective we consider built assets as holistic entities in reality all buildings comprise a complex arrangement of components (structural and non-structural) and sub-systems (Core Business; FM Services; HR Services etc.) that work together to deliver the organisation's primary function. As such, performance has to be considered from three different perspectives:

- Organisation/Management perspective;
- Technical Systems perspective; and an
- Operational (Service) Delivery perspective.

Key Performance Indicators and Benchmarks need to be established that describe how performance will be measured and set the tolerable range within which the KPIs needs to sit. These include developing KPI metric specifications (description and measurement scale) and setting benchmark ranges that reflect desired, acceptable and unacceptable levels of performance. Any underperformance identified is addressed through mitigation actions that seek to reduce the underperformance and/or adaptation actions that seek to modify the system to cope with the underperformance. However, for both mitigation and adaption to be successful it is first necessary to fully understand the cause of any underperformance. Establishing the root cause of underperformance relies on a process of:

- Inquiry (empirical analysis of system performance)
- Design (systemic analysis/modelling of product/service design)
- Statistics (comparative analysis system performance)
- Experiential (case study analysis of system performance)

Once the root cause of underperformance is established an Action Statement is written that describes the root cause of the problem and details the required improvement in performance in terms of the desired post intervention KPI score. At this point alternative mitigation and adaption solutions are identified and evaluated against a range of technical and business scenarios. Cost/Benefit analyses are performed to rank the effectiveness of the mitigations/adaptations and impact analyses consider the implications (to the organisation and external stakeholders) of any delay in instigating the mitigation or adaptation interventions. Although the above process has been described at a single point in time; in reality all built assets operate within their 'life-cycle' Figure 6. Prioritisation models are developed that sequence the adaptation or mitigations actions into the built asset life cycle. After implementation the success (or lack of) is assessed against the desired improvement in KPI's (through the use of disaster scenarios or against real disaster events) and the results fed back into the BAM planning model.

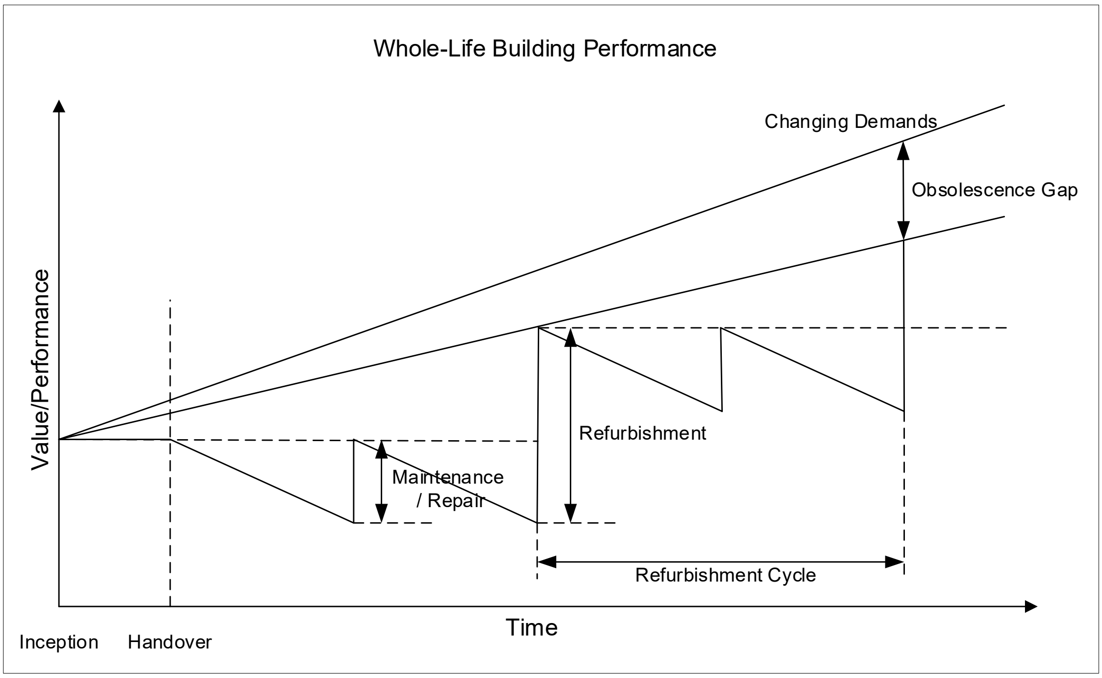

Figure 6: Typical built asset life cycle

Built asset maintenance is viewed by most organisations as a cost burden in which demand for action, identified via an assessment of the condition of the building, invariably exceeds the funds available, As such buildings fail to be kept to their optimum operating capacity and functional performance and an obsolescence gap develops in which the building is unable to meet all the demands placed on it. This obsolescence gap, and in particular the impact that it has on the performance of the activities that take place within the building, is what is critical to building owners/users, and not the condition of the building per se.

Most built environment maintenance texts define maintenance as any actions required to retain an item in, or restore it to, an acceptable condition. Similarly, they define refurbishment as work undertaken to improve every facility, its services and surrounds to a currently acceptable standard and to sustain the utility and value of the facility. Over the past six months Task 5.4 has reviewed both the BAM process model in the context of a typical built asset life-cycle and developed a 10 step BAM life cycle process model (that will be reported in Deliverable 5.4) that would allow an organisation to develop a strategic planning framework to better prepare it for the impact that an EILD event would have on its ability to deliver its key services immediately following the event and to allow it to recover as quickly as possible following the event. In developing the BAM life cycle process model researchers have considered what constitutes value/performance of a range of built assets to an EILD event; in particular exploring the impact that the principles underpinning the Sendai Framework for disaster risk reduction and the UNISDR Disaster Resilience Scorecard for Cities) have on changing demands (in terms of organisational and community expectations of service level delivery) over time. In addition, researchers have also explored the degree to which physical (ground improvement) mitigation interventions represent refurbishment actions that could be incorporated into the built asset management process over the built asset life-cycle (Figure 7).

The specific activities undertaken as part of the work of WP5 (Task 5.4) over the past 6 months include:

- Developed version 3 of the RAIF to reflect the emerging LRG software tools being developed in WP6. This has involved the development of hypothetical case study scenarios that are testing the logic in the RAIF and exploring the interactions between the RAIF and the LRG. This work is ongoing and a joint meeting between key researchers from WP5 and WP 6 is planned for April 2019.
- Developed version 3 of the Critical Infrastructure Resilience Tool that considers the interaction between this tool; the modified UNISDR Disaster Resilience Scorecard for Cities and the EILD risk framework being developed in WP7. A number of meeting (virtual and face-to-face) between key researchers from WP5 and WP7 have been held to explore the interactions between the three tools and the RAIF. This work is ongoing and further meetings between WP5 and WP7 will take place in April and then again throughout the case study period (see WP7).
- Continued the development of version 3 of the UNISDR Disaster Resilience Scorecard for Cities following a series of interviews and focus group meetings with Liquefact partners and external stakeholders in Italy and Turkey. The analysis is ongoing but early results suggest that it will be possible to develop a version of the scorecard that is uniquely customised to reflect the resilience of a city to an EILD event. Results also suggest that the process of customisation could provide the basis of a customisation methodology that could be applied to other (non-earthquake related) disaster scenarios.
- Developed the first version of the whole life-cycle built asset management planning tool for EILD events (Figure 8). This tool integrates all the previous Liquefact deliverables (tools developed by all of the technical work packages) into a single decision making framework (Table 2) that built asset managers can use to evaluate the antecedent vulnerability and resilience of their built assets to an EILD event.
- Begun the integration of the decision making framework into Business Continuity Resilience Plans (BCRP) and Disaster Management Plans (DMP) to help organisations prepare for, survive and recover from an EILD event. The BCRP's and DMP's will provide operational tools that will allow individual organisation's examine the impacts that an EILD event would have of their ability to continue to deliver their core activity (e.g. housing, business, critical services, heritage, community support etc.) during, and immediately following an EILD event.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 700748

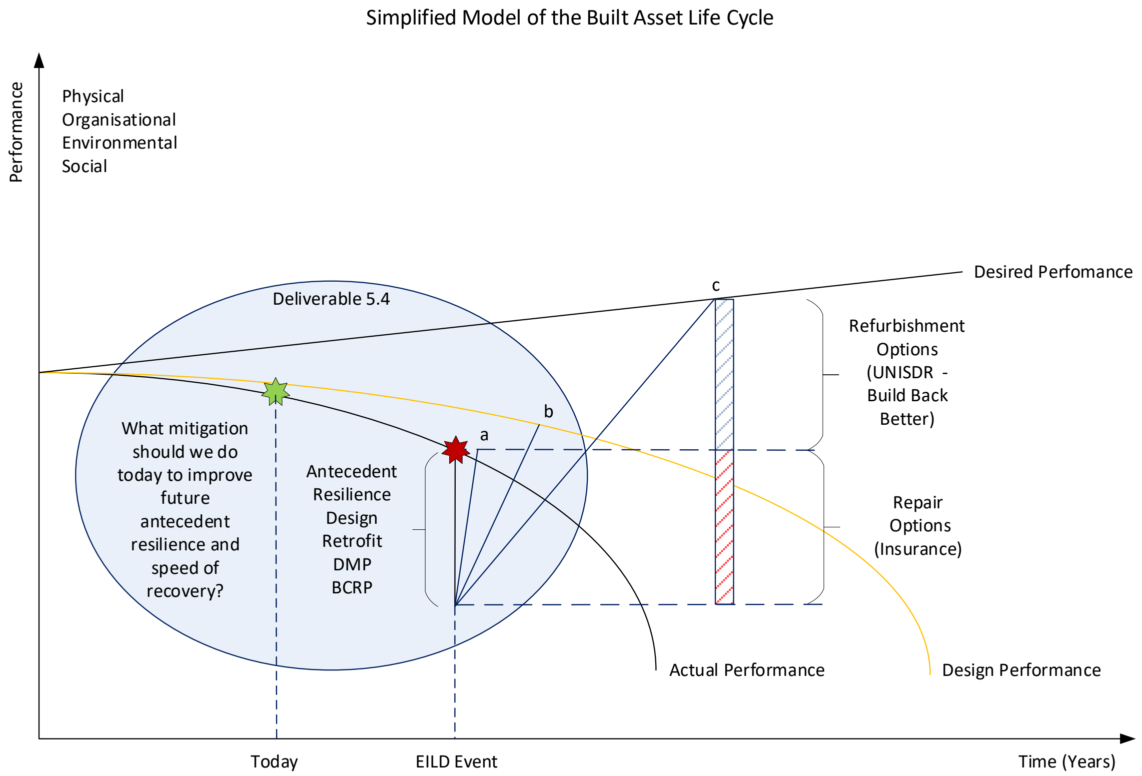

Figure 7: Modified version of the built asset life-cycle reflecting the impact of an EILD event.

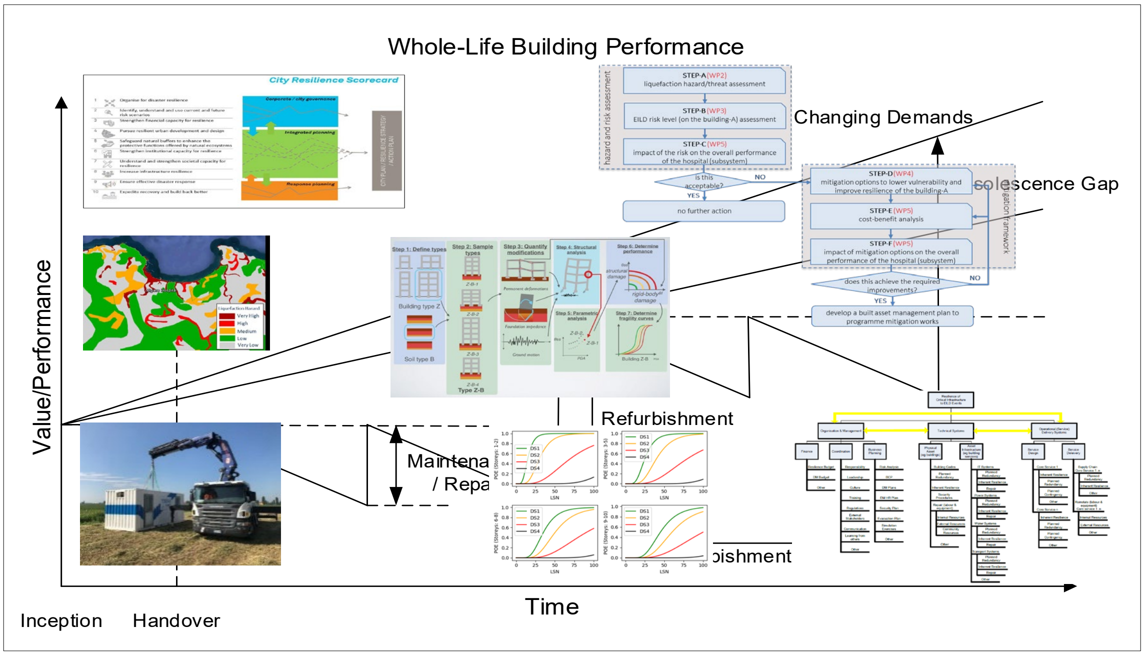

Figure 8: Theoretical model of the whole life-cycle BAM planning tool

Step	Activity	Data Source
1	Define the geographical area under investigation. This could be a site, town, city or region. Define the key objectives (in terms of resilience improvements) required from the study. This could be at the organisation, town, city or regional level and could involve specific operational improvements or more general community resilience improvements.	The key stakeholder commissioning the study.
2	Identify the general susceptibility of foundation soil of critical buildings/assets located in the region under investigation to EILD events. This will involve the use of macrozonation and microzonation analyses.	European macrozonation map and microzonation guidelines and microzonation studies for Liquefact WP2 case studies are available from WP2. The macrozonation map and the guidelines for microzonation studies will be given in the final version of the LRG.
3	For each critical infrastructure and building/asset relevant to the community and located in area susceptible to soil Liquefaction commission a detailed geotechnical investigations (site investigations, physical modelling, computer modelling etc.) to further understand the potential susceptibility of the site to earthquake induced Liquefaction.	Guidelines for commissioning a detailed geotechnical investigation at the site level are being developed in WP4 and will be available in the LRG.

4	For those sites where the detailed geotechnical investigations confirm their susceptibility to earthquake induced Liquefaction, identify the specific impacts (in terms of vulnerability and fragility) that a Liquefaction event would have on the buildings/infrastructure on the site.	Fragility curves for a range of typical buildings/infrastructure are being developed in WP3 and the potential impacts of soil Liquefaction on buildings/infrastructure is being developed in WP4. The outputs from WP3 and WP4 will be available through the LRG.
5	For those buildings at risk of physical damage as a result of soil Liquefaction assess the effect that such damage would have on the performance of the buildings/assets (in terms of the impact that loss or reduced functionality at the serviceability and ultimate limit states) has a potential impact on the society. The loss of functionality (performance) will be made on a case by case basis using the expert knowledge of the facilities manager and building users to interpret the impact that any given level of risk (a qualitative score ranging from very high to very low) will have on service functionality and performance.	A combination of the outputs from WP2, WP3 and WP4 will be used to categorise the level of risk. The BCRP and DMP developed in WP5 will provide the guidelines for linking damage to buildings to loss of performance. All of the above will be available through the LRG. The community resilience model to be developed following the case study analyses (in WP7) will be used to assess the potential impact that a loss of performance of individual buildings and assets will have on overall community resilience.

6	A range of mitigation actions will be identified (both physical and operational) for each building/asset identified as at high risk and whose impact has an adverse effect on community resilience. Two types of mitigation actions will be considered: those that seek to reduce a building/infrastructure assets vulnerability/increase its resilience; and those that seek to reduce the hazard level. The former are likely to be building level interventions; the latter are likely to be ground level interventions.	A combination of the outputs from WP3 and WP4 will be used to identify a range of technical building and ground level mitigations. Operational mitigations will be developed in WP5 as part of the BCRP and DMP. The mitigation options will provide sufficient detail on reduced physical impact to allow post mitigation service level performance to be assessed.
7	Once the mitigation options have been identified a CBA will be performed for each specific sub-system component. The cost/benefit analysis will consider both direct and indirect costs (e.g. physical, loss of revenue during refurbishment period, etc.) and benefits (e.g. to the organisation, community, etc.) and extend the analysis across geographical and temporal scales (e.g. consider the inter-relationships between multiple similar assets, consider the implications of delaying refurbishment until later in a building/infrastructure life cycle). A hybrid version of the forward-looking-and backward-looking frameworks developed by Mechler (2005) and customised for EILD events will be used.	CBA analysis will be available through the LRG.
8	The cost (capital and operating) of implementing each mitigation option will be derived from building cost databases (for rebuild and repair) and where necessary supplemented from historic accounts and contractor's estimates. The cost of operational mitigations will be derived through discussions with the building/asset owners/FM.	National cost databases, historic records, contractor's estimates, and the building/asset owners/Facility Manager (FM).

9	The benefits in terms of avoided losses without mitigation at the organisation level will consider both tangible and intangible losses. Tangible losses include: repair and rebuilding of buildings/assets; replacement of fixtures and fittings; clean-up and decontamination; loss of business; loss of income. Intangible losses include: loss of reputation; loss of market share; disruption to the supply chain, including additional costs associated with substitute services; etc. additional operating costs; additional human resources costs, including disruption to the workforce and availability of skilled labour; increased insurance costs; etc. The additional intangible losses without mitigation at the community level additionally include: increased mortality and morbidity rates; costs of temporary substitute services; loss of wages; increased poverty; increased levels of stress; reduce standards of living; economic stability; destruction of habitat/biodiversity; etc.	The total tangible costs will be calculated against a range EILD scenarios. Tangible direct losses will be derived from cost databases, historic records, contractor's estimates, and the building/asset owners/FM. Direct intangible losses will be derived from discussions with the organisation owners/FM and the use of the Liquefact CI Resilience Scorecard. The additional intangible losses at the community level will be calculated with reference to historic datasets, discussions with community level representatives and the use of the Liquefact Community Resilience Scorecard. The CI Resilience Tool and the customised Disaster Resilience Scorecard for Cities will be available in the LRG.
10	Compare the economic (quantitative) and social (quantitative) performance of each mitigation interventions against the business needs of the organisation and prioritise their inclusion into the Built Asset Management life-cycle. Mitigation interventions would be programmed to occur at some future point in the remaining service life of the asset. The timing of future mitigation interventions will depend on the remaining residual value of the asset and on where the asset currently sits in terms of the organisations maintenance and refurbishment cycle.	The LRG will provide a generic built asset management plan for the programming of EILD event mitigation interventions.

Table 2: 10 step BAM Planning Tool.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 700748

Task 5.5 – Develop field data collection tools for use in the case studies (Task Leader: ARU)

This task was completed in Reporting Period 1.

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

(NORSAR – Leader. ARU, ULJ Participants)

The aim of this work package, which has started in M18 and it will last until the end of the project in M42, is to develop an easy-to-use software (LRG software) that can provide civil engineers and relevant stakeholders with guidance in making informed assessments on the feasibility and the cost-benefit relationships of certain mitigation techniques for a given earthquake-induced Liquefaction threat (Figure 9). The basic for the development of the LRG software consists in integrating the knowledge (methodologies, procedures and models) from WP2, WP3, WP4 and WP5.

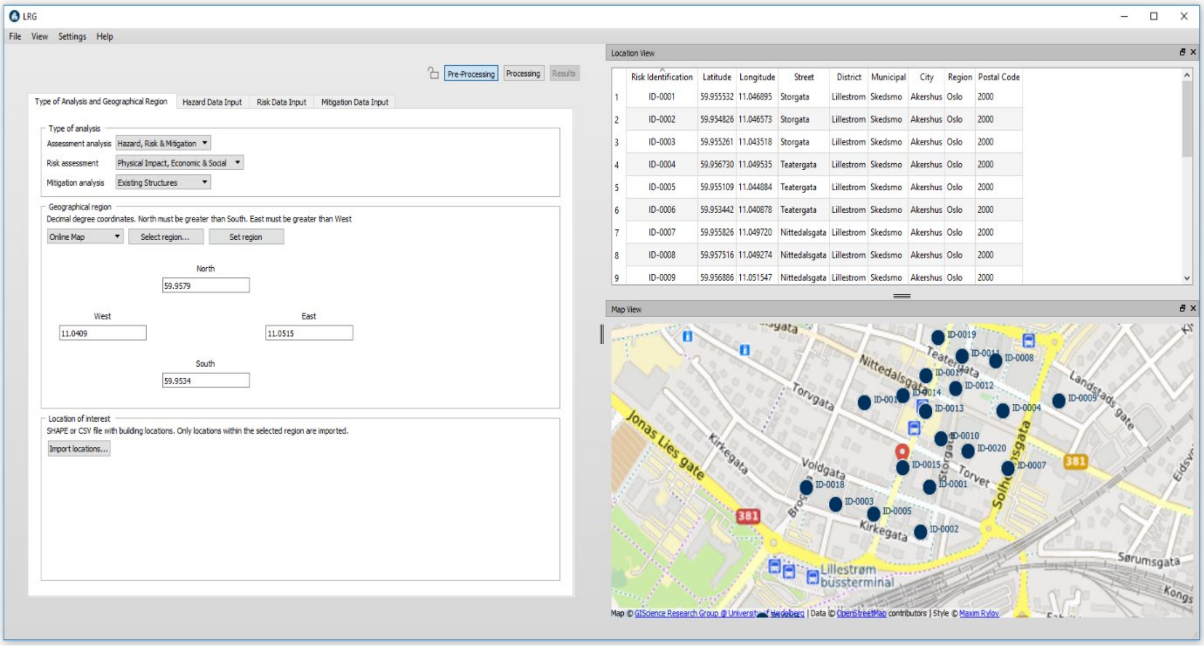

Figure 9. LRG Software

Summary of Activities in Work Package 6 Reporting Period

This Work Package had no activity in reporting Period.

Details of Activities in Work Package 6 in Reporting Period

The activities that have been undertaken during Period have included the development of the LRG software with its different protocols and modules where the various outputs from the consortium partners (WP2, WP3, WP4 and WP5) will be integrated (Task 6.1, Task 6.2, Task 6.3 and Task 6.4)

Task 6.1 - Development of software Toolbox for Liquefaction mitigation planning and decision support (Task Leader: NORSAR)

In this first task, which started in M18 and lasted until M24, the conducted activities were aimed to develop the LRG software. The process and activities had two main phases of development and integration:

Technological phase which involved the development and integration of number of tools to create an easy-to-use graphical user interface (GUI), ensure a better flexibility in data flow and management system, plotting curves and graphs, GIS visual view and interactive mapping system, development and integration of control system for tracking changes and coordinating work (Table 3).

Tools	Description
C++ and QML	code written in C++ 11 and QML (Qt 5.10) for Windows
Qt 5.10	used for the development of the User Interface
Qt and Qwt	used for plotting curves and graphs.
Git and Bitbucket	development of control system for Tracking changes and coordinating Work
OpenStreetMaps (embedded in Qt)	GIS visual view and interactive mapping system
Help and Manual	online help system and user manual
NSIS	easy installation with NSIS (Nullsoft Scriptable Install System) installer
FlexNet	Using FlexNet licensing system (www.flexera.com). Host name locked free license.

Table 3: LRG software development tools

The second phase consisted in designing and developing protocols and modules were the various outputs from WP2, WP3, WP4 and WP5 will be integrated. Earthquake-induced Liquefaction damage assessment is a multi-process analysis that requires different types and forms of input data related to geology and seismology of the site, geotechnical data, and structure-foundation system characteristics of the asset under risk. To this end, the LRG software has been designed in a way that EILD assessment is conducted at three independent protocol of analysis to provide more flexibility to the end-user's requirements with respect to the level of analysis to be implemented and type of input data that are available (Figure 10, Table 4). The three-independent protocol of analysis implemented in the LRG software are: Protocol for Liquefaction Hazard Analysis (LA), Protocol for Risk Analysis (RA), and Protocol for Mitigation Analysis (MA).

Version 0.9 Beta of the software has been made ready to be used and tested. Technical details of this version are provided in the Deliverable D6.1, submitted in M24.

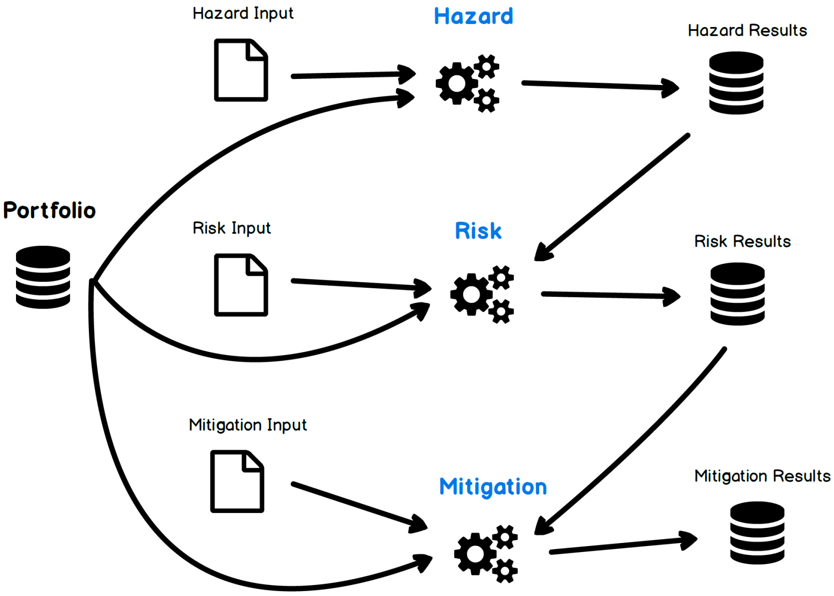

Figure 10. Protocol analysis processes in the LRG software

Type of Analysis	Data Requirement
hazard analysis – Liquefaction susceptibility (qualitative analysis)	Liquefaction hazard/susceptibility map
hazard analysis – probability and ground deformation (quantitative analysis)	geological and geotechnical data
EILD risk impact on the asset	structural characteristics-related data and vulnerability models
mitigation and cost-benefit analysis	library of Liquefaction mitigation measures and cost-benefit data

Table 4. LRG software Concept with respect to the type of analysis and level of data requirement

Task 6.2 Integration of procedure for the development of the European Liquefaction hazard with the use of outputs/deliverables from WP2 (Task Leader: NORSAR)

Task 6.2 has started in M24 and it will last until M40, and it involves the development of algorithms for ground shaking and Liquefaction hazard simulation to be integrated in the LA protocol. For ground shaking simulation, three types of ground shaking analysis are being integrated in the LA protocol: scenario-based analysis, predefined-based analysis (SHARE map are being integrated in the LA protocol), and User-defined based simulation. At the stage of Liquefaction hazard, two levels of Liquefaction analysis are being integrated (Figure 11): a) integration of procedures for qualitative analysis allowing end-users to identify how likely an asset (e.g. individual building/CI asset, portfolio of buildings/distributed infrastructure assets, etc.) is susceptible to Liquefaction; b) integration of procedures for quantitative analysis for Liquefaction potential allowing end-users to evaluate quantitatively the level of the threat. End-users will be able to provide different type of inputs data for Liquefaction assessment (CPT, SPT, Vs30 profile data).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 700748

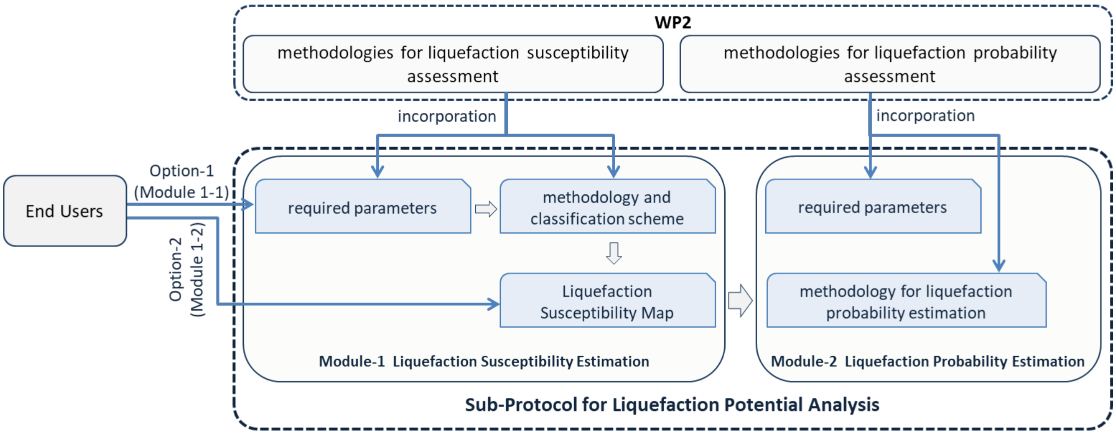

Figure 11. Protocol for Liquefaction potential analysis

Task 6.3 Development and integration of procedures for the Liquefaction risk analysis of critical structures and infrastructures with the use of outputs/deliverables from WP3 (Task Leader: NORSAR)

Task 6.3 has started in M24 and it will last until M35, and it involves the development of algorithms to be used for simulation and evaluation of seismic performance and vulnerability (physical damage and loss) of an asset (e.g. individual building/CI asset, portfolio of buildings/distributed infrastructure assets, etc.) given a level of Liquefaction threat (output from the protocol LA). These algorithms for the risk analysis are being developed and integrated in the RA protocol. The concept consists of: a) algorithm for reading end-user input of vulnerability model, b) algorithm for risk analysis by combining vulnerability model with Liquefaction threat level (output from LA protocol), c) and algorithm for output of the results in terms of various parameters (damage and performance, loss) presented in tables/maps (Figure 12).

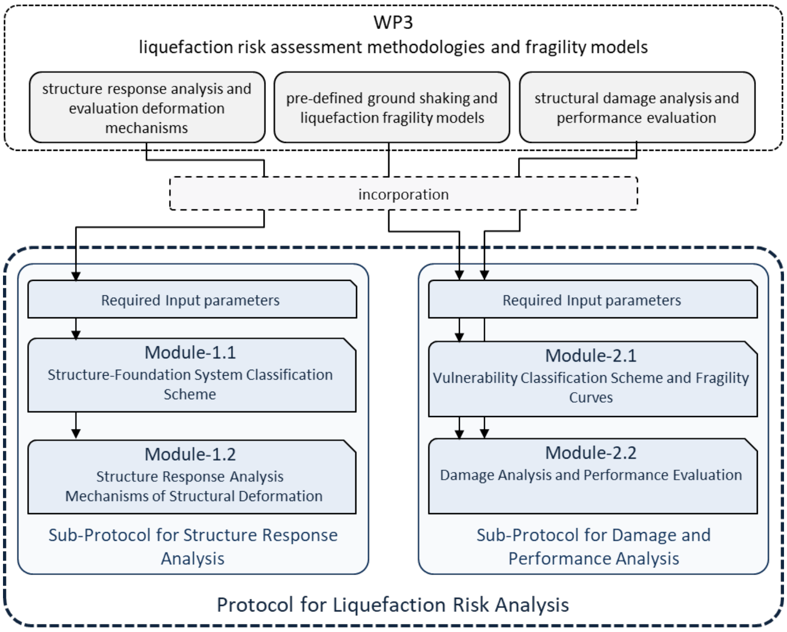

Figure 12. Protocol for Liquefaction risk analysis

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 700748

Task 6.4 Built-in Liquefaction vulnerability models: development and integration of Liquefaction vulnerability functions for critical structures and infrastructures with the use of outputs/deliverables from WP3 (Task Leader: NORSAR)

This task has started in M24 and it will last until M35. The related activities consist in developing and integration of: a) algorithms where end-users can define the structural typology of the asset (structure/infrastructure) and assign the associated vulnerability model (fragility curves, loss models); b) algorithms where the vulnerability models can be stocked and presented as a library of pre-defined models that can be directly used by the end-users for their risk studies; c) algorithms allowing end-users to manually modify the vulnerability models and input their own customized models (Figure 13).

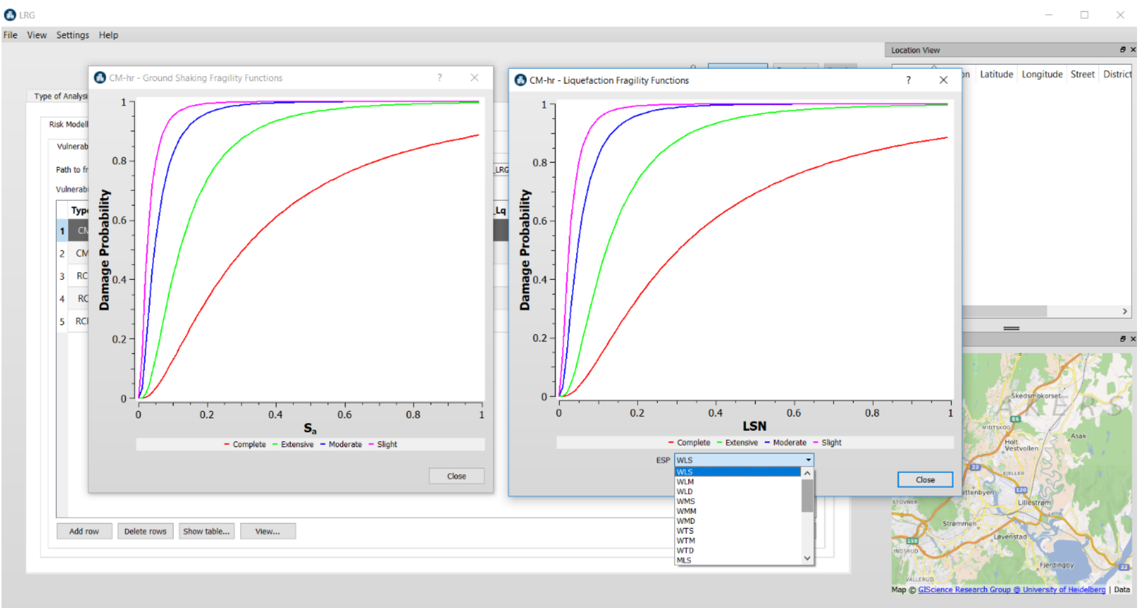

Figure 13. Built-in ground shaking and Liquefaction fragility/vulnerability models

Task 6.5 Development and integration of procedures of Liquefaction mitigation measures with the use of outputs/deliverables from WP4 (Task Leader: NORSAR)

This task has started in M24 and it will last until M39. The related activities consist in the followings:

Development of logical sequence framework for selection of a customized Liquefaction mitigation solution that end-users can establish based on the outcomes from the Liquefaction Risk Analysis. This development was a result of detailed review and evaluation of the current state-of-the-art technologies for soil improvement and Liquefaction mitigation. Table 5 shows the developed Logical Sequence where end-users can identify the condition related to the investigated asset (structure/infrastructure characteristics), the condition related to the site (soil profile characteristics), and the condition related to the environment. Based on the outcome of this logical sequence end-users can then obtain options of Liquefaction mitigation solutions that can be implemented for their case studies. Table 6 lists the various Liquefaction mitigation technologies that have been reviewed and investigated.

Development of algorithms where the Logical Sequence framework can be integrated with the different mitigation techniques that can presented as a library of pre-defined mitigation solution models.

Development of algorithms where end-users can establish a customized mitigation strategy/solution based on inputs (that follow the Logical Sequence framework) that can be provided manually or automatically (from result of Liquefaction Risk Analysis).

Questions / Steps	Input	Type of Input
Primary condition of the site?	• Free field • Existing buildings	manually
Types of failure do you want to prevent?	• Flow failure • Lateral spreading • Vertical settlement • Flow failure; Lateral spreading • Flow failure; Vertical settlement • Lateral spreading; Vertical settlement • Flow failure; Lateral spreading; Vertical settlement	automatically from risk Analysis Protocol
Project constraints (e.g., construction influences/damage to the adjacent structures, site access, traffic patterns, mobilization, sensitive equipment)?	• Low overhead clearance • Adjacent structures • Existing utilities • Low overhead clearance; Adjacent structures • Low overhead clearance; Existing utilities • Adjacent structures; Existing utilities • Low overhead clearance; Adjacent structures; Existing utilities	manually
Depth of groundwater table?	• 0-3 m • 3-6 m • 6-12 m • >12 m	manually
Treated soil type?	• Gravel soils (more than half of coarse fraction is larger than 4.75 mm) • Sandy soils (more than half of coarse fraction is smaller than 4.75 mm) • Inorganic silts, clays silts of low to medium plasticity	manually

presence of any subsurface obstructions?	• Yes • No	manually
Depth of the treatment zone based on case histories	• <3 m • 3-12 m • 12-18 m • 18-25 m • 25-40 m • >40 m	manually
Size of area to be improved	• Small (area smaller than 1000 m2) • Medium (area between 1000 m2 and 5000 m2) • High (area larger than 5000 m2)	manually
Select the improved foundation type	• Shallow foundations • Deep foundations	manually
Any environmental issues that may affect the project?	• Yes • No	manually

Table 5: Logical Sequence for Liquefaction mitigation technology/solution selection

Different technologies for soil improvement	Earthquake drains
	Deep Dynamic Compaction
	Vibro Compaction
	Blasting Compaction
	Vibro replacements
	Compaction Grouting
	Jet Grouting
	Deep soil mixing

Table 6: List of reviewed and evaluated technologies for Liquefaction mitigation solutions

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 700748

Task 6.6 Economic and societal consequences with the use of outputs/deliverables from WP5 (task Leader: NORSAR)

This task has not yet started

Task 6.7 Development of technical manual with the use of outputs/deliverables from WP2, WP3, WP4 and WP5 (task Leader: NORSAR)

This task has not yet started

Task 6.8 Training and plan of actions for leaders and decision-makers with contributions from all partners in WP2, WP3, WP4 and WP5 (task Leader: NORSAR)

This task has not yet started

4.7. Work Package 7: Case Study Validation and Future Eurocode Recommendations

(UNICAS – Leader. All partners are Participants)

Summary of Activities in Work Package 7 in Reporting Period Months 28-35

The Work Package 7 is aimed at validating the proposed methodology for risk assessment with the retrospective analysis of past events and to synthesize the learnt lesson into guidelines enabling EU to produce technical standards. The action is thus focused on two complementary targets, i.e. identify the risk on a territorial scale to prioritize mitigation works, standardize the use of remediation technologies. For this reason, starting of Work Package 7 has been anticipated from month 30 to month 18 together with the corresponding tasks and thus activities are ongoing. In summary, the activities carried out in the reporting period between months 28 and 35 regard the creation of databases for validation on three case past EILD events (Christchurch, Emilia Romagna and Tohoku Oki) and the definition of strategies and protocols for risk assessment and mitigation to be introduced into guidelines. In addition to the above three, a fourth case study has been implemented by the group of Istan-UNI concerning the city of Adazapari (Turkey) struck by the IZMIT earthquake in 1999. In summary, the activities carried out in this reference period consisted in the definition of the goals of the work package together with the involved partners, in the collection of results concerning case studies and in establishing a working methodology. To this aim several collegial and bilateral meetings have been held.

Details of Activities in Work Package 7 in Reporting Period Months 28-35

T7.1 – Definition of the database for risk assessment (Task Leader: UNICAS) (month 32)

This work package carried out in cooperation with UNIPV, UPORTO, ULJ and Istan-Uni and NORSAR, is aimed at defining the databases for Liquefaction risk assessment. Together with the activities singularly carried out by the different partners, the following meetings have been held to agree joint activities and share results:

- Meeting with the Liquefact group of partners in Oslo (October 1st – 5th, 2018) and in Brussels (November 6th -7th , 2018) to define protocols suitable for risk assessment and applicable on all case studies;

- Meetings of members of UNICAS with prof. Misko Cubrinovski of the University of Canterbury in Oslo (October 1st – 5th, 2018) to exchange data for the back-analysis of Liquefaction in the 2011 earthquake in Christchurch (New Zealand) and agree the procedure for cataloguing;
- Meeting between members of UNICAS and NORSAR in Oslo (October 8th-14th 2018) to standardize the implementation of LRG;
- Meetings of members of UNICAS with prof. Junichi Koseki of the University of Tokyo in Oslo (October 1st – 5th, 2018) to exchange data for the back-analysis of Liquefaction in Urayasu (Tokyo) during the 2011 earthquake in Tohoku-Oki (Japan) and agree the procedure the procedure for cataloguing;
- Meeting UNICAS-ARU in Cassino (January 20th- 23th, 2019) to agree a protocol for risk assessment of individual buildings or infrastructures;
- Meeting with members of the Emilia Romagna Region in Bologna and Ferrara (September 20th -21st, 2018) to agree the exchange data for the back-analysis of Liquefaction in the 2012 earthquake in Terre del Reno (Italy) and agree the procedure for cataloguing.

In details, the activity concerning this task have consisted in:

- Performing an overview of the risk assessment procedures defined in the international standards (Hazus, 2003 for risk assessment; Share, 2013 for seismic hazard; Syner-G, 2013 for vulnerability and loss estimate);
- Identify aims and limitation of risk assessment relating the level of the study to the following stakeholders:
    - Urban and territory planners
    - Owner/manager of lifelines /services
    - Emergency planners
    - Investors/Owners of building assets
    - Insurance Companies
    - Designers

- Standardize the creation of input database (GEODATABASE), processing of data (GEOPROCESSING) and provision of output (GEOVISUALIZATION) in Geographical Information Systems based on International, European and National standards (e.g. INSPIRE, https://inspire.ec.europa.eu/);
- Define seismic input, subsoil characteristics (geological model, geotechnical characterisation identification of the water table), vulnerability of structures, loss estimate model;
- Perform risk assessment on reference case studies and render output;
- Plan mitigation;
- Create a procedure to identify critical infrastructures and estimate losses;
- Frame all the above components into a guideline for risk assessment.

T7.2 – Validation of the software for risk assessment (Task Leader: UNICAS) (month 36 postponed at month 42 with amendment)

- According to the DOA, the applicability of the software toolbox for risk assessment is tested in a representative range of situations, focusing the analysis to selected sample cases representative of the European landscape, i.e. a large and a small urban district, a lifeline and some small to medium size buildings of different characteristics. Three sample sites have been thus selected in regions with proven evidences of damages originated by

Liquefaction (e.g. Emilia, northern Italy (2012) – Urayasu are in Tokyo, Japan (2011) – Christchurch, New Zealand (2011) to validate the calculation tool by the back analysis of past critical events. With this purpose, researchers form other partners of the consortium or from external institutions (University of Tokyo JP and University of Canterbury at Christchurch NZ) have been involved within specific agreements. In addition to the previous three, a fourth case study has been added concerning the city of Adazapari (Turkey) struck by the 1999 Izmit earthquake (M 7.6). Validation is being carried out at different scales, from large city and network infrastructures to single structures comparing the prediction made with simplified methodologies with observation and with more complete mechanical analyses performed with a Finite Difference Code (FLAC) specifically acquired for the project.

- The activities carried out in the reference period (months 28-35) have continued from the previous period and have consisted in the collection, homogenization and organization of all data into geographical information systems regarding the following case studies:

- Christchurch (New Zealand): the reference seismic input for this analysis are the two earthquakes of September 4th 2010 (M7.1 in Darfield) and February 22th 2011 (M6.2 in Christchurch) are considered for the present analysis; the number of subsoil investigations (5000 boreholes, 18000 CPT tests, groundwater level surveys) have been collected from the New Zealand Geotechnical Database https://www.nzgd.org.nz/ and elaborated in order to create a unique standard format necessary for the automatic processing; data concerning the characteristics and damage of buildings and infrastructures (clean water and wastewater distribution networks) have been collected from reports of the Christchurch City Council (CCC) and of the Canterbury Earthquake Recovery Authority (CERA) and catalogued according to the above defined standards. During a meeting of the members of UNICAS with prof. Misko Cubrinovski of the University of Canterbury in Oslo (October 1st – 5th, 2018) the procedure has been defined for the GEOPROCESSING of data and GEOVISUALIZATION of the risk assessment;

- Emilia Romagna: the reference seismic input is the May 22th 2012 earthquake (Mw 5.9 Mirandola). The analysis is here focused on the newly established municipality of Terre del Reno including the two previous municipalities of Sant'Agostino (with its district of San Carlo) and Mirabello; the analysis has regarded the collection and processing into a unique standard format of subsoil investigations (863 boreholes, CPT tests, cross and down holes profiles) partly taken from the Geographical Data Catalogue of the Emilia Romagna Region, partly from the documents reporting the survey of damage on private (MUDE database), public (FENICE database), and industrial (SFINGE database) buildings, all operated by the Emilia Romagna Region. The same databases have been studied to derive the structural characterisation and the quantification of damage induced by Liquefaction on buildings. To this aim, a specific agreement has been established between the University of Cassino and the Emilia Romagna Regional Government (RPI/2018/9 del 10/01/2018); in the reference period (months 28-35), members of UNICAS has visited several times (September 23rd-25th 2018) the Department of Emilia Romagna Region (Servizio Geologico e dei Suoli) to complete the collection of data and to establish the best procedures for GEOPROCESSING and GEOVISUALISATION. The data on building characteristics and damage in the same Municipality have been processed singularly and a database has been created to form the benchmark for validation. Furthermore, in the reference period (months 28-35) data have been also acquired on the potable water distribution system and on the road network in the area of Terre del Reno;

- Tohoku Oki (Japan). This analysis concerns the earthquake of March 11th 2011 (Mw9 Tohoku and Kanto region) and the analysis is focused on the district of Urayasu (Tokyo). The activity so far carried out in cooperation with the University of Tokyo consists in the collection of literature publications (journal and conference papers, survey reports) and data available from public databases concerning the geological setting, the geotechnical characterisation of the subsoil, the seismicity of the area and the survey of buildings characteristic and damage. In the reference period, a contract has been signed between the Liquefact consortium and the University of Tokyo for the exchange of data concerning the back-analysis of Liquefaction in Urayasu during the 2011 earthquake in Tohoku-Oki (Japan). The exchange has been planned in details during a meeting held in Oslo (October 1st – 5th, 2018) between members of UNICAS and Prof. Junichi Koseki of Tokyo University. In the reference period (months 28-35) the University of Tokyo has provided access to Japanese national databases concerning seismic input, geotechnical data, infrastructures and damage; UNICAS is processing these data in analogy with the other case studies creating databases and setting the conditions to validate the software toolbox;

- Izmit (Turkey) This analysis concerns the earthquake of August 17th 1999 (Mw 7.6 Izmit) and the analysis is focused on the district of Adazapari. The details of this activity have been harmonised with the other case studies in some bilateral meetings held by the members of ISTAN-UNI and UNICAS in Oslo (October 1st-5th). The activity carried out in the reference period (month 28-35) by the University of Istanbul has consisted in the collection of literature publications (journal and conference papers, survey reports) and data available from public databases concerning the geological setting, the geotechnical characterisation of the subsoil, the seismicity of the area and the survey of buildings characteristic and damage. Data have been analysed to preliminarily validate the vulnerability procedure implemented by UPORTO on the damage observed in the different part of Adazapari.

- T7.3 – Risk analysis for the selected sample areas and standardization of procedure (Task Leader: UNICAS) (month 42)

- All the material necessary for this analysis is being collected as described in task 7.2, and this activity is being performed in parallel with LGR toolbox implementation. During the reference period (months 28-35) a continuous feedback has been established between the different groups UPORTO, ISTAN-UNI, UNICAS and NORSAR to contribute with the experimental observations at defining the components of the software toolbox and, more generally, at the setup of the code. Within this activity, a member of UNICAS has spent one week in OSLO (October 8th-14th 2018) to work closely with the personnel of NORSAR, supporting with formatted available data the standardized implementation of LRG; meanwhile, a continuous communication exists between NORSAR and other partners (UNICAS, ARU, ISTAN-UNI, UPORTO) to provide continuously updated versions of the code that are being tested on the reference case studies.

- T7.4 – Preparation of the guidelines for the standard use of remediation technology against Liquefaction (to be carried out in parallel with the other tasks) (Task Leader: UNICAS) (month 42)

In the reference period (months 28-35), the review of the international panorama on the theme of foundation engineering and ground improvement with the specific focus of Liquefaction mitigation has proceeded with the contribution of all partners.

The activity details have been planned in a meeting held last December 3rd 2018 in Rome (see attachment), where representatives of UNICAS, UNINA and UNIPV have defined the structure of Deliverable 7.4 “GUIDELINES FOR USE OF G.I. TECHNOLOGIES TO MITIGATE THE LIQUEFACTION RISK ON CRITICAL INFRASTRUCTURES”.

The preparation of deliverable 7.4 is going on regularly with the identification of the principles for ground improvement and with the definition of the criteria to design execute and control the different techniques.


Operative Meeting – Rome - December 3rd 2018

ASSESSMENT AND MITIGATION OF LIQUEFACTION POTENTIAL ACROSS EUROPE
A holistic approach to protect structures / infrastructures for improved resilience to earthquake-induced liquefaction disasters

T.7.4 STANDARD USE OF REMEDIATION TECHNOLOGY AGAINST LIQUEFACTION

Giuseppe Modoni	
Carlo Lai	
Francesca Bozzoni	
Paolo Croce	
Roberta Proia	
Emilio Bilotta	
Gianluca Fasano	
Alessandro Flora	

Figure 14

In the reference period, a review of literature and international standards has been continued defining the common protocols. The members of UNICAS, UNINA and UNIPV have also participated at the meetings of the Working Groups of CEN TC250 for the updating of Eurocodes 7 and 8 in Napoli (November 29th 2018) and of the Italian Mirror group for the preparation of Eurocode 7 and 8 in Rome (January 17th 2019). During these meetings a connection has been established between the Liquefact group with the corresponding members of CEN T250 to contribute at the preparation of EC8 PART 5, Chapter 7: Siting (Liquefaction).

4.8. 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.
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.

Pursuing the above goals, this Work Package is making the results of the LIQUEFACT project known amongst relevant stakeholders within the seismic engineering industry and research community. Links are thus being continuously created with Civil Protection administrations, security organizations, manager of infrastructures, private companies and academic institutions in the EU and abroad to interact and increase the potential impact of the project, to engage the most general public with the LIQUEFACT project, to disseminate results of the project. This Work Package is ongoing.

This Work Package is making the results of the Liquefact project known amongst relevant stakeholders and in the community of researchers operating in the field of seismic engineering. Links are continuously created with public institutions, emergency organizations, manager of infrastructures, private companies and academic institutions in the EU and abroad to interact and increase the potential impact of the project, to engage the most public with the Liquefact project, to disseminate results of the project. This Work Package is ongoing.

Summary of Activities in Work Package 8 in Reporting Period 2

In the reporting period between months 28 and 35, new activities have been undertaken to spread the findings of the project to the representatives of the seismic and earthquake engineering world, but also to the general public and global media. The activities related to the case studies (e.g. WP2 and WP7) have consisted in organizing events where the researchers of the Liquefact consortium have presented their results to local and regional institutions (e.g. Emilia Romagna Region and other municipalities in Italy, Portugal, Slovenia and Turkey). In addition, contacts have been established the Quake Core, a New Zealand centre of earthquake resilience to organize a meeting to be held at Christchurch in September 2019. Among others, the researchers od UNICAS have had a paramount role in the scientific committee of Geo-Sismica a section of the Remtech Expo, that has led to organize a workshop held on September 20th during the exhibition of 2018. The workshop has been attended by more than 60 people exponent of the world of different private and public institutions.

The organization of the Liquefact workshop in the VII Int. Conf. on Earthquake Geotechnical Engineering to be held in Rome next June 2019 is continuing. Finally, a dissemination video has been prepared and is going to be issued in the next Liquefact consortium meeting. Thereafter the video will serve to spread within the non-expert community (websites, TV, social media etc.) summarizing relevance, technical goals, scientific activities and outcomes of the project.

Details of Activities in Work Package 8 in Reporting Period 2

Task 8.1 – Collaboration with other projects and initiatives (Task Leader: UNICAS)

A number of projects on similar or related subjects have been identified in the previous periods http://www.Liquefact.eu/related-projects/) and contacts have been established with the coordinators. Following the meeting held last June 20th 2018 at the XVI European Conference of Earthquake Engineering in Thessaloniki during a special thematic session devoted to Liquefact (http://www.Liquefact.eu/event/16ecee/) an intensive exchange of information has been promoted to implement the Liquefaction risk assessment procedures. Other relevant initiatives ((http://www.Liquefact.eu/events/) have been organised during the Liquefact workshop held at Ferrara last September 20th at the RemTech expo (September 19-21 2018 http://www.Liquefact.eu/2018/09/21/Liquefact-at-remtech-expo-2018/). or at the IABSE conference (http://www.Liquefact.eu/event/iabse-symposium-guimaraes-2019/) to enlarge the cooperation with other national and international projects. A strong effort is also being spent by the Consortium to organize a Liquefact special session in the next VII Int. Conf. on Earthquake Geotechnical Engineering to be held in Rome next June 2019. Apart from these initiatives involving groups altogether, each group is in contact with representatives of other projects to exchange information and experience on specific issues related with the tasks and work packages.

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

In the reporting period between months 28 and 35 the progress of Liquefact have been communicated to the stakeholder list and spread to the community through a periodic newsletter or through periodic information on social media. The relevance of risk assessment for EILDs and the implementation of methodologies for mitigating the effects is still taking significant advantage from the interaction of the research groups with stakeholders and user communities. With some of them (the Municipality of

Cavezzo, the Emilia Romagna Region, ……) normally involved with the management of seismic risk for communities and territories, specific cooperation agreements have been signed to share information and data necessary to accomplish the goals of the project and to share objectives of the research. A specific event has been organized with the cooperation of the Pieve di Cento Municipality to organize a public conference dedicated to Liquefact Project. The conference has been attended by about 80 students from the junior and high schools of the territory and by a number of teachers to inform the population about the risk caused by seismic Liquefaction and to inform them on the relevance of the project, including the experiment that was going on at the same time in their town.

The cooperation with public institutions is ongoing with periodic meetings and exchange of reports to inform them about the progress and outcomes of the work. The members of UNICAS, UNINA and UNIPV hold periodic meetings with the Servizio Geologico and the Agenzia per la Ricostruzione of the Emilia Romagna Region. A connection has been also established with European companies (e.g. BASF or CRM) producers of material and equipment for ground improvement, interested in the research for what concerns mitigation of risk.

In order to enlarge the plethora of stakeholder (an international exhibition on Remediation Technologies annually collecting more than 300 exhibitors and visited by more than 6000 attendees), a Liquefact workshop has been promoted within the Remtech edition of 2018 a workshop will be specifically held (http://www.Liquefact.eu/2018/09/21/Liquefact-at-remtech-expo-2018/) to show the results of Liquefact project. Additionally a stand in the exhibition has been held and managed by the Liquefact Consortium to introduce possible new stakeholders to the theme of EILD, assessment and mitigation of the risk. The contact with the organizers of RemtechExpo is continuing and some member of the Liquefact consortium are participating at the organization of the 2019 exhibition

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

The dissemination of knowledge is continuously carried out by each partner publishing the outcomes of the work carried out on top journals and conference proceedings. So far, 30 papers have been sent, accepted or published by the partners with the acknowledgement to Liquefact.

Apart from dissemination that each partner has carried out participating at local and national conferences and to the participation of the whole consortium to the special thematic session devoted to Liquefact (http://www.Liquefact.eu/event/16ecee/) held last June 20th 2018 at the XVI European Conference of Earthquake Engineering in Thessaloniki. Other initiatives ((http://www.Liquefact.eu/events/) have been held in the reporting period between month28 and 35, like the organization of a workshop at the RemTech expo (September 19-21 2018 http://www.Liquefact.eu/event/remtech-expo-2018/) or at the IABSE conference (http://www.Liquefact.eu/event/iabse-symposium-guimaraes-2019/). Together with the above more classical scientific dissemination activities, another project has been complete to disseminate the outcomes of research to a non-expert public, a video showing relevance, goals and results of the project. So far, the video has been completed with the contribution of all partners and its first form will be issued next April 2019.

In addition to the above initiatives, there is a continuous ongoing activity, managed by TREVI and UNICAS, consisting in updating all the communication media such as the Liquefact website (www.Liquefact.eu), the Liquefact pages on the social media and the preparation of the periodic newsletter sent to all stakeholders and published in the above media.

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

The implementation of these tasks follows the development of the software LRG: target schedule for the first revision of the software is March 2019. Therefore, this activity will be developed as soon as the software will be tested on the 4 case study site regions (Lisbon Area / Emilia Romagna Region / Ljubljana Region / Marmara Region) and the three international case study validation scenarios.

T8.5 – Business models for exploitation (Task Leader: TREVI)

This task will start once the various approaches and methodologies integrated in the LRG software have been validated through the case studies (WP7). The business models for exploitation will be established based on the following steps:

Define a group of customers or a specially selected focus group to collect feedbacks, by exposing the prototype or alpha version of the LRG software. This step will allow us to confirm if our product satisfy the needs of the costumers and provide innovative services (new services and quality of the solutions) beyond what already exist in the market.

Size the value of the product by matching with potential competitor prices and market demographics. From the focus group, the product will be tested (test costs, quality and pricing) in all elements of our pricing, marketing, distribution and maintenance.

The consortium network will be used to get feedback that is need from people with experience in the domain, as well as setting-up connections to talk to industry experts and potential investors.

Define the target audience that the LRG software will be used by. This step would lead to consider two different approaches: business-to-business approach (i.e., selling the software directly to other businesses) or the business-to-consumer approach (i.e. selling the software to a consumer).

T8.6 – Impact assessment (Task Leader: ARU)

This task has not yet begun.

4.9. 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 9 in Reporting Period

The Liquefact project has had a very successful second period with all of the activities identified above being successfully completed and all of the associated Deliverables being uploaded to the Participant Portal. In addition, Milestones MS4 (approaches for simulating Liquefaction-induced structural damage) and MS5 (small-scale centrifuge test models) have also been achieved. Phase 2 of the project has successfully laid the foundation for phase 3, where the output/results will be integrated into the Liquefact LRG and validated through the case studies. The results obtained from applying the LRG in the case studies will be disseminated through academic conference and journal papers, through industry conferences and workshops and through the Liquefact website. The recommendation guidelines will be fed into future Structural Eurocode revisions.

In order to facilitate phase 3 of the project, four changes to the Liquefact Project Gantt chart has been agreed with the Project Officer.

1. The due date for deliverable D5.4 has been put back to Month 34 to coincide with the end of Work Package 5 allowing a greater period to evaluate and modify the built asset management tools being developed in the Work Package.
2. The due date for deliverable D7.2 has been put back to Month 30 to allow for a more efficient timing of activities.
3. The due date for deliverable D4.4 has been put back to Month 32 to allow a greater period to evaluate the results of the numerical modelling.
4. There has been a request to extend the submission date of deliverables D2.6 and D2.7 to month 39 to allow for more in-depth result testing.

These changes had no financial implications for the project. The revised Gantt chart is shown in Figure 15.

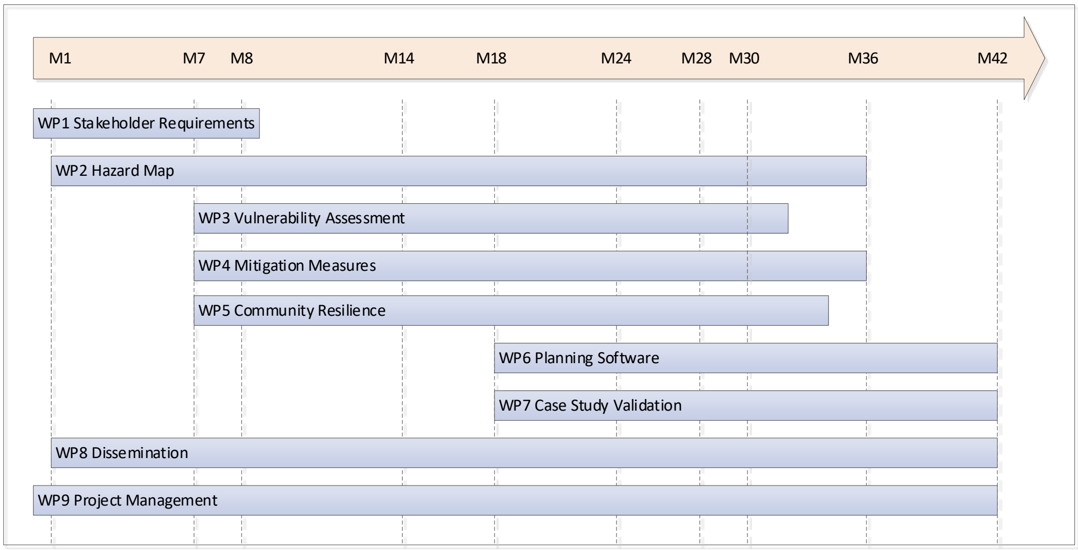

Figure 15: Revised project Gantt chart

Task T9.7 (D46) – ***Project Board Management Report 3***

Covering the Liquefact Periodic Review Strategy Meeting, reviewing all work undertaken by partners in the first 14 months of the Liquefact Project and forward planning months 15 – 28, performing checks and balances against the GANTT and highlighting potential issues, identifying mitigations and reaching consortium wide agreement on our approach.

Project Review meeting Brussels, assessing the degree to which the work plan had been carried out and whether all deliverables were completed. Assessing relevance of objectives against desire for scientific or industrial breakthrough potential. Planning and use of resources in relation to progress achieved and management procedures and methods.

Consortium Meeting, reporting progress against assigned tasks and work packages, sharing of results and assessing future critical risks, mitigations and impacts.

Independent Advisory Board Meeting, to seek feedback from independent experts in Liquefaction, resilience and vulnerability, specific advice on outputs and inputs between Work Packages and future opportunities and next steps.

Task T9.8 (D47) – ***Periodic Progress Report 3***

Reporting on progress achieved between Liquefact Partners, sharing achievements, impact, outputs and interrelations between Partners.

Task D9.9 (D48) – ***Project Board Management Report 4***

Covering the Sprint Test conducted after specific advice from the Independent Advisory Board, looking specifically at integration of multiple outputs from Liquefact Partners and individual Work Packages into Work Package 6.

Adaptation of the UN Scorecard for calculating risk and resilience in EILD's

Community Resilience, agreeing an action plan for the implementation of the results of WP5 into WP 7, sharing and discussion of survey results regarding damage to structures in the Emilia Romagna region in the municipality "Terre del Reno" as a result if the Emilia Romagna earthquake 2012.

Subcontracts for Professors Cubrinovski and Koseki

Amendment request and informal fortnightly Adobe Connect meetings

Task D9.18 (D57) – *Data Management Plan 3*

Updated to reflect the impact of GDPR

Partners' Roles:

Partner	Brief summary of activities
ARU	Appointment of a dedicated project manager; Coordination and management of all project management activities. Attendance at Project Management meetings.
UNIPV & Eucentre	Attendance at Project Management meetings.
UPORTO	Attendance at Project Management meetings.
UNINA	Attendance at Project Management meetings.
TREVI & TREVI-FIN	22nd May 2018 inclusion of a linked third party known as TREVI-FIN. Attendance at Project Management meetings.
NORSAR	Attendance at Project Management meetings.
ULJ	Attendance at Project Management meetings.
UNICAS	Attendance at Project Management meetings.
SLP	Attendance at Project Management meetings.
ISMGEO	Attendance at Project Management meetings.
Istan-Uni & Istanbul University-Cerrahpasa	May 2018 Amendment to beneficiary Istanbul University-Cerrahpasa (IUC) Attendance at Project Management meetings.

Access provisions to research infrastructures

Not Applicable.

Update of the plan for exploitation and dissemination of results

Details of the dissemination plan and activities over the past 14 months are set out in Section 1.2.8 Work Package 8: Dissemination and Exploitation.

4.10. Tasks completed in Reporting Period

Details of the work undertaken in each task to date is given in section 1.2. Table 11 shows the status of all the tasks that are either complete or currently in progress. All completed tasks have submitted all their Deliverables and there are no issues currently identified that should affect the ability of all ongoing tasks to successfully complete and submit their Deliverables.

Table 11

Tasks	Status	Outcomes
Task 1.1, 1.2, 1.3 and 1.4	Complete	All Deliverables completed in previous periodic report.
Task 2.1, 2.2 and 2.3	Complete	Deliverable 2.1, 2.2 and 2.3 completed in previous periodic report.
Task 2.4 and 2.5	Complete	Deliverable 2.4 and 2.5 completed in the reporting period.
Task 2.6 and 2.7	Ongoing	Deliverables not due until next reporting period.
Task 3.1, 3.2 and 3.3	Complete	All Deliverables completed in reporting period.
Task 4.2 Task 4.3, 4.4	Complete	Deliverable 4.2 completed in previous periodic report. Deliverables 4.3 and Deliverable 4.4 completed in the reporting period.
Task 4.1, 4.5	Ongoing	Deliverable 4.1 and 4.5 on going.
Task 5.1, 5.2 and 5.5	Complete	Deliverable 5.1, 5.2 and 5.5 completed in previous periodic report.
Task 5.3 and 5.4	Ongoing	Deliverable 5.3 completed in previous periodic report. Deliverable 5.4 on going.
Task 6.1	Complete	Deliverable 6.1 completed in previous periodic report.
Task 6.2, 6.3, 6.4, 6.5, 6.6, 6.7 and 6.8	Ongoing	Deliverables 6.2, 6.3, 6.4, 6.5, 6.6, 6.7 and 6.8 on going.

Task 7.1, 7.2, 7.3, and 7.4	Ongoing	No deliverables due in reporting Period.
Task 8.1	Complete	Deliverable 8.1 completed in reporting Period.
Task 8.2, 8.3, 8.4, 8.5, 8.6	Ongoing	Deliverables ongoing.
Task 9.1, 9.2, 9.3, 9.4, 9.5, 9.6, 9.7, 9.8, 9.9, 9.10, 9.11, 9.17, 9.18 Task 9.12	Complete	Deliverables 9.1, 9.2, 9.3, 9.5 and 9.6, 9.7, 9.8, 9.9, 9.10, 9.11, 9.17, 9.18 completed during previous periodic report. Deliverable completed in reporting period.
Task 9.13, 9.14, 9.19	Ongoing	Tasks to be completed by reporting period 3.
		All RP2 payments distributed to partners

All ongoing tasks are on schedule and no changes are envisaged to any of the tasks that have yet to commence.

5. Critical implementation risks and mitigation actions

5.1 Foreseen risks

Table of risks (from Grant Agreement)

Description of risk	**WP involved**	**Proposed mitigation measures**
Insufficient participation of external experts and end users with technical assistance and transfer of knowhow of actual industry needs	WP1, WP7	Specialized meetings with comprehensive involvement and elicitation of national and thematic experts
Lack of data in the selected case studies to perform full validation of the project	WP2, WP7	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
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	WP3	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.

prototypes and limitations of the models.		
Possible technical or legal obstacles to produce dynamic actions on site to check 'directly' the effectiveness of the soil Liquefaction mitigation techniques under study	WP4	The technologies that we are thinking to produce dynamic actions have been already used elsewhere, if 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.

5.2 Unforeseen risks

Description of risk	WP	Description of risk
Risk on task 4.2 Small scale centrifuge modelling The original detailed program of tests needs to be modified in order to account for the new aspects the tests evidence causing a delay of test execution and subsequent scheduled deliverable fixed at the end of March 2018. This event could cause delay in the field trials (task 4.3) and numerical modelling (task 4.4) which are the main experimental part of the research project.	WP4	Split the deliverable in two parts: The first deliverable would be submitted at the end of March 2018, it would contain test results in free field conditions, and the remediation measures (vertical and horizontal drains, de-saturation) would be tested, to provide all information necessary to the field trial, this will be not affect the original schedule on any other Work Package. The second deliverable would be submitted at the end of September 2018 and would contain the results of the tests with foundation models and the final report consolidating all results.
Risk: A partner runs out of money One of the main beneficiaries runs out of funds before the end of the project affecting their ability to complete their allocated tasks.	WP9	1) Consortium lead will assist partners to conduct a financial health check at the midway point (Month 21) identifying potential issues. 2) No beneficiary will be given more than 80% of their total budget before the end of Reporting Period

		3) All beneficiaries will take part in quarterly budget meetings
Risk: A partner is unable to complete their allocated task or work package/s One of the beneficiaries is unable to complete task or work packages assigned to them.	WP2, WP3, WP4, WP5, WP6, WP7, WP8, WP9.	1) Will hold fortnightly project management meetings via Adobe Connect and instigate face to face meetings where appropriate to ensure all partners are reporting on progress towards assigned task and work packages on a regular basis. 2) Will ensure all partners contribute to the 6 monthly project progress report and 6 monthly project management reports 3) Develop and implement a standardised internal report on project progress for monthly submission
Risk: Communication Identified by the External Expert Advisory Board (EEAB). Under communication between partners could represent the easiest point of failure, particularly with partners spread across Europe.	WP2, WP3, WP4, WP5, WP6, WP7, WP8, WP9.	Additional face to face meetings with partners to bolster the communication through Adobe Connect. EEAB suggest meeting quarterly at a minimum. Not all partners may need to attend all meetings but would be an opportunity to discuss the actions, tasks and work packages of the moment.
Risk: Poor understanding of common goals Identified by the External Expert Advisory Board (EEAB). Poor understanding of common goals resulting in the failure of the project, particularly linked to the start of Work Package 6 which sees the integration of a number of separate Work Packages into the SELENA-LRG software package.	WP6, WP9.	Specific advice from the EEAB Conduct a "Sprint Test" taking an imagined scenario and each work package lead demonstrating their results and feeding these into the SELENA-LRG production to ensure that the system is robust, and all outputs from Work Packages are able to be integrated. Suggest this is done in a face to face meeting to enable partners to discuss results and make real time changes to research outputs. This should be conducted within 1 month.

Risk: Loss of a Key member of staff A key member of staff at any of the Liquefact Partners becomes unavailable without notice, resulting in loss of vital information, knowledge or skills.	WP2, WP3, WP4, WP5, WP6, WP7, WP8, WP9.	1) Fortnightly Adobe Connect Calls within the Consortium with sharing of vital information 2) Central password database ensuring all work remains accessible 3) Increase frequency of face to face Consortium Meetings 4) Develop and implement a handover protocol and succession plan for Key staff 5) All key staff to keep detailed list of current tasks and pertinent actions

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 700748

6. Deliverables

Deliverables, Ethics, DMP, Other Reports								
WP No	Del Rel. No	Del No	Title	Lead Beneficiary	Nature	Dissemination Level	Est. Del. Date (annex I)	Status
WP8	D8.1	D34	Liquefact project website	UNICAS	Website	PU	31 May 2016	Approved
WP1	D1.1	D1	A report on the challenges to improve community resilience to EILD events.	ARU	Report	PU	31 Jul 2016	Approved
WP9	D9.1	D40	Project Management Plan	ARU	Report	CO	31 Jul 2016	Approved
WP9	D9.2	D41	Quality Procedures Manual	ARU	Report	PU	31 Jul 2016	Approved
WP1	D1.2	D2	Proceedings of the first stakeholder/end-user workshop: including the workshop presentations.	UNICAS	Other	CO	31 Aug 2016	Approved
WP1	D1.3	D3	Report outlining a risk based assessment and resilience improvement framework	ARU	Report	PU	31 Oct 2016	Approved
WP9	D9.3	D42	Project Board Management Report 1	ARU	Report	CO	31 Oct 2016	Approved
WP9	D9.16	D55	Data Management Plan v1	ARU	ORDP	PU	31 Oct 2016	Approved
WP1	D1.4	D4	Detailed user requirements and research output protocols for the Liquefact Reference Guide; in line with second workshop outcome	ARU	Report	PU	30 Nov 2016	Approved
WP9	D9.4	D43	Periodic Project Progress Report 1	ARU	Report	PU	30 Nov 2016	Approved
WP2	D2.1	D5	Report on ground characterization of the four areas selected as testing sites by using novel techniques and advanced methodologies to perform in situ and laboratory tests	UNIPV	Report	CO	31 Jan 2017	Approved
WP2	D2.2	D6	GIS platform including data for Liquefaction hazard assessment in Europe (version 1)	UNIPV	Other	CO	30 Apr 2017	Approved

WP5	D5.1	D20	Report on individual stakeholder and urban community performance metrics	ARU	Report	PU	30 Apr 2017	Approved
WP5	D5.2	D21	Data collection toolkit for community resilience case studies (for WP6/7)	ARU	Other	PU	30 Apr 2017	Approved
WP9	D9.5	D44	Project Board Management Report 2	ARU	Report	CO	30 Apr 2017	Approved
WP9	D9.6	D45	Periodic Project Progress Report 2	ARU	Report	PU	30 Jun 2017	Approved
WP9	D9.17	D56	Data Management Plan v2	ARU	Other	PU	30 Jun 2017	Approved
WP3	D3.1	D12	State of the art review of numerical modelling strategies to simulate Liquefaction-induced structural damage and of uncertain/random factors on the behaviour of liquefiable soils	UPORTO	Report	PU	30 Sep 2017	Approved
WP9	D9.7	D46	Project Board Management Report 3	ARU	Report	CO	31 Oct 2017	Approved
WP9	D9.8	D47	Periodic Project Progress Report 3	ARU	Report	PU	31 Jan 2018	Approved
WP2	D2.3	D7	GIS platform including data for Liquefaction hazard assessment in Europe (version 2)	UNIPV	Other	CO	30 Apr 2018	Approved
WP4	D4.2	D16	Report on validation of retrofitting techniques from small scale models	ISMGEO	Demonstrator	PU	30 Apr 2018	Approved
WP6	D6.1	D24	Software toolbox for Liquefaction mitigation planning and decision support	NORSAR	Demonstrator	CO	30 Apr 2018	Approved
WP9	D9.9	D48	Project Board Management Report 4	ARU	Report	CO	30 Apr 2018	Approved
WP5	D5.3	D22	Community resilience and cost/benefit modelling framework (socio-technical-economic impact on stakeholder and wider community)	ARU	Report	PU	31 Jul 2018	Approved
WP9	D9.10	D49	Periodic Project Progress Report 4	ARU	Report	PU	31 Aug 2018	Approved
WP9	D9.18	D57	Data Management Plan v3	ARU	Other	PU	31 Aug 2018	Approved
WP9	D9.11	D.50	Project Board Management Report 5	ARU	Report	CO	31 Oct 2018	Submitted
WP2	D2.4	D8	GIS database of the historical Liquefaction occurrences in Europe and European empirical	UNIPV	Other	PU	31 Oct 2018	Submitted

			correlations to predict the Liquefaction occurrence starting from the main seismological information					
WP3	D3.2	D13	Methodology for the Liquefaction fragility analysis of critical structures and infrastructures: Description and Case Studies	UPORTO	Report	PU	31 Oct 2018	Submitted
WP3	D3.3	D14	Design guidelines for the application of soil characterization and Liquefaction risk assessment protocols	UPORTO	Report	PU	31 Oct 2018	Submitted
WP4	D4.4	D18	Database of calibrated numerical modelling results	UNINA	Other	PU	31 Oct 2018	Submitted
WP5	D5.4	D23	Whole life built asset management modelling framework	ARU	Report	PU	31 Oct 2018	Pending
WP2	D2.5	D9	GIS platform including data for Liquefaction hazard assessment in Europe (version 3)	UNIPV	Other	CO	31 Dec 2018	Submitted
WP4	D4.3	D17	Report on demonstration of retrofitting techniques	TREVI	Demonstrator	PU	28 Feb 19	Pending
WP9	D9.12	D51	Periodic Project Progress Report 5	ARU	Report	CO	31 Mar 19	Pending

7. Dissemination and exploitation

Publications, conference papers and journals submitted during reporting Period

NORSAR

Conference in 2017

Blum, C.C., Meslem, A. and Lang, D.H. (2017) The Liquefact Project: Developing a More Comprehensive Understanding of Liquefaction Events in Europe. Geofaredagen 2017, October 19, Oslo.

2 Full papers submitted for international conferences to be held in 2019:

Meslem, A., Iversen, H., Kaschwich, T. and Drange, L.S. (2019) A High-Performance Computational Platform to Assess Liquefaction-Induced Damage at Critical Structures and Infrastructures. 7th International Conference on Earthquake Geotechnical Engineering, 17 - 20 June 2019 Roma, Italy

Meslem, A., Iversen, H., Lang, D.H., Kaschwich, T. and Drange, L.S. (2019) The LRG Software for Liquefaction mitigation planning and decision support. Guimaraes IABSE Symposium: Toward a Resilient Built Environment – Risk and Asset Management. 27-29 March 2019, Portugal.

UPORTO

Conference papers related to WP3:

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". Comunicação apresentada à 6th ECCOMAS Thematic Conference on Computational Methods in Structural Dynamics and Earthquake Engineering (**COMPDYN 2017**), Paper ID: C18447.

M. Millen, A. Viana da Fonseca, X. Romão (2018). Preliminary displacement-based assessment procedure for buildings on liquefied soil. **16ECEE**: 16th European Conference on Earthquake Engineering, Thessaloniki, Greece, http://www.16ecee.org/ (paper n. 10410)

F. Gómez-Martínez, M. Millen, P. Alves Costa, X. Romão, A. Viana da Fonseca (2018). Potential relevance of differential settlements in earthquake-induced Liquefaction damage assessment. **16ECEE**: 16th European Conference on Earthquake Engineering, Thessaloniki, Greece, http://www.16ecee.org/ (paper n. 11645)

J. Quintero, S. Saldanha, M. Millen, A. Viana da Fonseca, S. Sargin, S. Oztoprak, M. K. Kelesoglu (2018). Investigation into the settlement of a case study building on liquefiable soil in Adapazari, Turkey. Proc. **GESD V, Geotechnical Earthquake Engineering and Soil Dynamics V**, Austin, Texas. Geotechnical Earthquake Engineering and Soil Dynamics V ASCE Getechnical Special Publication, GSP 290, pp. 321-336.

Journal papers:

F. Gouveia, A. Viana da Fonseca, R. Carrilho Gomes,, P. Teves-Costa. Deeper Vs profile constraining the dispersion curve with the ellipticity curve: a case study in Lower Tagus Valley, Portugal**. Soil Dynamics and Earthquake Engineering**. Vol. 101,188-198. https://doi.org/10.1016/j.soildyn.2018.03.010.

MSC thesis:

Pedro Melchior Marques de Aguiar Barata de Tovar (2018). Numerical simulation of the effects of Liquefaction in shallow foundation. MSc Thesis, University of Porto (FEUP), sup. A. Viana da Fonseca, Ole Hededal, COWI/A/S.

Carlos Maria Blanco de Brito e Cunha de Azeredo (2018). Amplificação sísmica de maciços estratificados com areias liquidificáveis: Agravamento dos assentamentos e deslocamentos laterais à superfície. MSc Thesis, Univesity of Porto (FEUP), sup. A. Viana da Fonseca, R. Carrilho Gomes – UTLisbon.

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UNIPV-Eucentre

CONFERENCE PAPERS

Title: Numerical simulation of soil Liquefaction during the 20 May 2012 M6.1 Emilia Earthquake in Northern Italy: the case study of Pieve di Cento

DOI: --

ISBN: --

Authors: Chiaradonna, A., Ozcebe, A.G., Bozzoni, F., Fama, A., Zuccolo, E., Lai, C.G., Flora, A., Cosentini, R.M., d'Onofrio, A., Bilotta, E., Silvestri, F.

Publisher: Proceedings, 16th European Conference on Earthquake Engineering, 16ECEE, Thessaloniki, Greece, 18-21, June, 2018

Place: Thessaloniki, Greece

Year: 2018 (June)

Pages: 12

Public & private publication: Public

Peer Review: No

Title: Stima della suscettibilità a liquefazione sismica di aggregati urbani con metodi semplificati

DOI: --

ISBN: --

Authors: Spacagna, R.L., Paolella, L., Bozzoni, F., Rasulo, A., Modoni, G., Lai, C.G.

Publisher: Incontro Annuale dei Ricercatori di Geotecnica, IARG 2017, Matera, Italy, July 5-7, 2017

Place: Matera, Italy

Year: 2017 (July)

Pages: 12

Public & private publication: Public

Peer Review: No

THESES

Title: Modelli empirici previsionali sulla manifestazione del fenomeno co-sismico di liquefazione dei terreni in Europa

DOI: --

ISBN: --

Authors: De Marco, M. (Advisors: Lai, C.G., Bozzoni, F.)

Publisher: Master thesis - Department of Civil Engineering and Architecture - University of Pavia.

Place: Pavia, Italy

Year: 2018 (July)

Pages: 137

Public & private publication: Public

Peer Review: No

Title: Criteri per la valutazione a scala europea del rischio di liquefazione sismo-indotta

DOI: --

ISBN: --

Authors: Bandera, S. (Advisors: Lai, C.G., Bozzoni, F.)

Publisher: Master thesis - Department of Civil Engineering and Architecture - University of Pavia.

Place: Pavia, Italy

Year: 2017 (July)

Pages: 177

Public & private publication: Public

Peer Review: No

Lai C.G., Bozzoni F., Poggi V., Zuccolo E., Meisina C., Famà A., Conca D., Bonì R., Cosentini R., Martelli L., Özcebe A.G. (2018). "Seismic Microzonation for Liquefaction Risk". Proceedings, XXV Conference of Geotechnics of Torino (CGT 2018) entitled "Analyses and Design of Geotechnical Systems in Seismic Areas". Torino, Italy, November 8-9, 2018 (in Italian).

Massa, M., Mascandola, C., Lovati, S., Carannante, S., Morasca, P., d'Alema, E., Franceschina, G., Gomez, A., Poggi, V., Martelli, L., Lai, C. (2018). "Seismic and Geological Bedrock Depth Estimation at Cavezzo Site (Po Plain, Northern Italy): Example of Passive Geophysical Survey in the Assessment of Soil Liquefaction Potential". Geophysical Research Abstracts, European Geosciences Union General Assembly 2018, EGU 2018, April 8-13, 2018. Vienna, Austria. EGU2018-7882

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UNICAS

D'Apuzzo. M., Esposito. A., Evangelisti. A., Spacagna. RL., Luca P., Modoni. G,. STRATEGIES FOR THE ASSESSMENT OF RISK INDUCED BY SEISMIC LIQUEFACTION ON ROAD NETWORKS. 29th European Safety and Reliability Conference Hannover, Germany, 22 - 26 September 2019

Modoni. G., Croce. P., Proia. R., Spacagna. RL., GUIDELINES AND CODES FOR LIQUEFACTION MITIGATION BY GROUND IMPROVEMENT. Towards a resilient built environment risk and asset management, Guimaraes Portugal, March 27-29, 2019

Morga. M., Pascale. F., Spacagna. RL., Paolella. L., Modoni. G., Jones. K., Natural risk analysis of the built environment: understanding strengths and weaknesses of both quantitative and qualitative methodologies 8TH INTERNATIONAL CONFERENCE ON BUILDING RESILIENCE Risk and Resilience in practice: Vulnerabilities, Displaced People, Local Communities and Heritages November 14-16, 2018 I Lisbon, Portugal

SALVATORE. E., MODONI. G, MASCOLO. MC., GRASSI. D., TRALDI. D., PROIA. R., CROCE. P., LOW PRESSURE GROUTING WITH NANOSILICATES TO REDUCE THE LIQUEFACTION SUSCEPTIBILITY OF SAND -- 16th European Conference on Earthquake Engineering (16ECEE), organized this year here in Thessaloniki, Greece, in June 18-21, 2018.

ARU

Organised a special session at the Guimarães IABSE Symposium 2019; Towards a Resilient Built Environment. Risks and Asset Management (7: MARCH 28) where researchers from the Liquefact project presented six papers based on their work.

M. Morga; K. Jones. ‘Toolkit for resilience assessment of critical infrastructures to earthquake-induced soil Liquefaction disasters’

K. Jones; M. Morga; N. Wanigarathna; F. Pascale; L. Yarovaya. ‘Cost-benefit analysis of Liquefaction mitigation strategies’

C.G. Lai; D. Conca; C. Meisina; R. Bonì; F. Bozzoni. ‘Earthquake-induced soil Liquefaction risk: Macrozonation of the European territory taking into account exposure’

G. Modoni; P. Croce; R. Proia; R.L. Spacagna. ‘Guidelines and codes for Liquefaction mitigation by ground improvement’

A. Meslem; H. Iversen; D. Lang; T. Kaschwich; S.L. Drange; K. Jones. ‘The LRG Software for Liquefaction mitigation planning and decision support’

E. Bilotta; A. Chiaradonna; G. Fasano; A. Flora; L. Mele; V. Nappa; S. Lirer; V. Fioravante. ‘Experimental evidences of the effectiveness of some Liquefaction mitigation measures’

8. Gender

Beneficiary	Number of female researchers	Number of male researchers	Number of females in the workforce other than researchers	Number of males in the workforce other than researchers
ARU	4	2	2	1
UNIPV inc EUCentre	4	5	3	2
UPORTO	3	7	2	0
UNINA	4	4	4	4
TREVI inc TREVFIN	0	6	2	16
NORSAR	4	4	0	3
ULJ	0	4	3	1
UNICAS	5	4	0	0
SLP	0	2	0	2
ISMGEO	1	1	2	4
Istan-Uni	1	6	1	3
Total	**26**	**45**	**19**	**36**

9. References

1 Smyth, A.W., Altay, G., Deodatis, G., Erdik, M., Franco, G., GÜLkan, P., Kunreuther, H., Luş, H., Mete, E. and Seeber, N., 2004. Probabilistic benefit-cost analysis for earthquake damage mitigation: Evaluating measures for apartment houses in Turkey. Earthquake Spectra, 20(1), pp. 171-203.

1 Mechler, R., Czajkowski, J., Kunreuther, H., Michel-Kerjan, E., Botzen, W., Keating, A., Mcquistan, C., Cooper, N. and O'Donnell, I., 2014. *Making communities more flood resilient: the role of cost benefit analysis and other decision-support tools in disaster risk reduction.*