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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 D9.14

Periodic Progress Report 6

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List of Partners

Participant	Name	Country
ARU (Coordinator)	Anglia Ruskin University Higher Education Corporation	United Kingdom
UNIPV - Eucentre	Università degli Studi di Pavia European Centre for Training and Research in Earthquake Engineering	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 University-Cerrahpasa	Turkey

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. In the 20th century earthquakes were responsible for 1.87 million deaths and approximately $2.935 trillion (adjusted to 2012) total economic losses. Between 1980 and 2009 earthquakes affected approximately 61.5 million people worldwide, resulting in approximately 400,000 fatalities and leaving at least 16 million people homeless. Between 1998 and 2009 earthquake events resulted in approximately 19,000 fatalities and direct economic losses of approximately €29 billion across Europe. While structural remediation/rehabilitation of the built environment against earthquakes is a widely studied subject, the knowledge on foundation improvement to mitigate the effects of earthquakes on buildings and critical infrastructure is limited, with existing remediation techniques being very invasive and costly. This is particularly true when the earthquake results in liquefaction of the soil. Earthquake induced liquefaction occurs when soil strength and stiffness decrease as a result of increased pore water pressure in saturated cohesionless materials during seismic ground motion. Because of liquefaction soil behaves like a liquid and not a solid, resulting in large deformations at the ground surface that causes buildings and lifelines to sink, settle or fall (overturn).

Over the past 42 months, the LIQUEFACT project has studied the potential impacts that an earthquake induced liquefaction event could have on Europe and produced technical guidance on how to quantify the risks at a local (micro-zonation) or site specific scale. LIQUEFACT has compiled a database of past liquefaction occurrences and integrated this with a macro-zonation map that shows the level of risk of earthquake induced liquefaction across Europe. LIQUEFACT has also developed new techniques for modelling the damage caused by an earthquake induced liquefaction event on structures and infrastructures and evaluated three ground mitigation interventions (horizontal drains, vertical drains, and induced partial saturation) to improve soil performance. LIQUEFACT has integrated all the above into a Resilience Assessment and Improvement Framework (RAIF) and software solution (the LRG) for evaluating potential mitigation interventions to improve structure/infrastructure and community resilience. Together the

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, in some cases, 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: Validate the LRG software and produce guideline recommendations enabling the EU Structural EUROCODE standards revision task groups to produce new technical standards.

2. Progress on Objectives to date

This report provides details of the work carried out by the LIQUEFACT partners during the reporting period from 1st April 2019 to the 31st October 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.

During the reporting period work has principally been carried out on Objectives 1-7.

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

The final version of the RAIF was developed along with final versions of its supporting tools.

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

The final version of a GIS-based catalogue of historical Liquefaction occurrences in Europe and novel European empirical correlations to predict the Liquefaction occurrence starting from the main seismological information was developed. This version of the GIS platform included data for Liquefaction hazard and risk assessment at a continental scale in Europe. It also includes procedures for the macrozonation of the European territory and its application to produce maps for the earthquake-induced Liquefaction susceptibility, hazard and risk, respectively. A general methodology for the microzonation of a territory at an urban scale for earthquake-induced Liquefaction hazard and its application to four European testing areas located Emilia region (Italy), in Marmara region (Turkey), Ljubljana area (Slovenia), and Lisbon area (Portugal), respectively was completed.

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 was also completed. The development of design guidelines for soil characterisation and risk assessment was completed.

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

Centrifuge modelling tests were completed in the previous reporting period. Full-scale field trials of vertical drains, horizontal drains, and partial induced saturation mitigation techniques were completed in the previous reporting period. Numerical analysis to complement the physical and conceptual models and provide input into the development of design guidance was completed in this reporting period.

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

Final Versions of the community and critical infrastructure resilience tools were 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 was developed.

2.1.6 Objective 6: Develop LRG Software.

The final version of the LRG software was developed and tested. 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.

2.1.7 Objective 7: Validate the LRG software and Develop design guidance.

The LRG software was validated against Italian, Turkish, New Zealand and Japanese data sets. The results from the LIQUEFACT project have been presented to the drafting committee for EUROCODE 8.

3. Expected Potential Impact

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. The final version of the RAIF and all its supporting tools provides the input into the built asset management planning framework which forms the basis of critical infrastructure and community resilience assessments for EILD events. All of these tools are now complete.

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. During a meeting with the committee drafting the new version of EUROCODE 8 held at Eucentre Foundation (Pavia) on October 16th 2019, one hour was dedicated to a presentation of the LIQUEFACT project. The committee members found the presentation and the subsequent discussion very instructive and interesting. Based on the content of the presentation and on the recommendations of the LIQUEFACT project various amendments have been implemented in the final draft of EUROCODE 8 (Part 5 particular). Although the LIQUEFACT project is now complete

discussions will continue between the EUROCODE 8 drafting committee and key researchers from the LIQUEFACT project.

3.3 European Added Value – The need for a transnational approach

During the Reporting Period LIQUEFACT has presented its findings to the 7th ICEGE Conference 17-20 June 2019 (both as part of the normal conference proceedings and in a special half day workshop on the results from the LIQUEFACT project) and to the New Zealand QuakeCoRE annual workshop and meeting 2-5 September 2019. A joint one day workshop on earthquake induced liquefaction was held in conjunction with QuakeCoRE and a keynote presentation was given by representatives of LIQUEFACT to the annual meeting.

4. Explanation of the work carried out by the beneficiaries and overview of progress in this reporting period

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

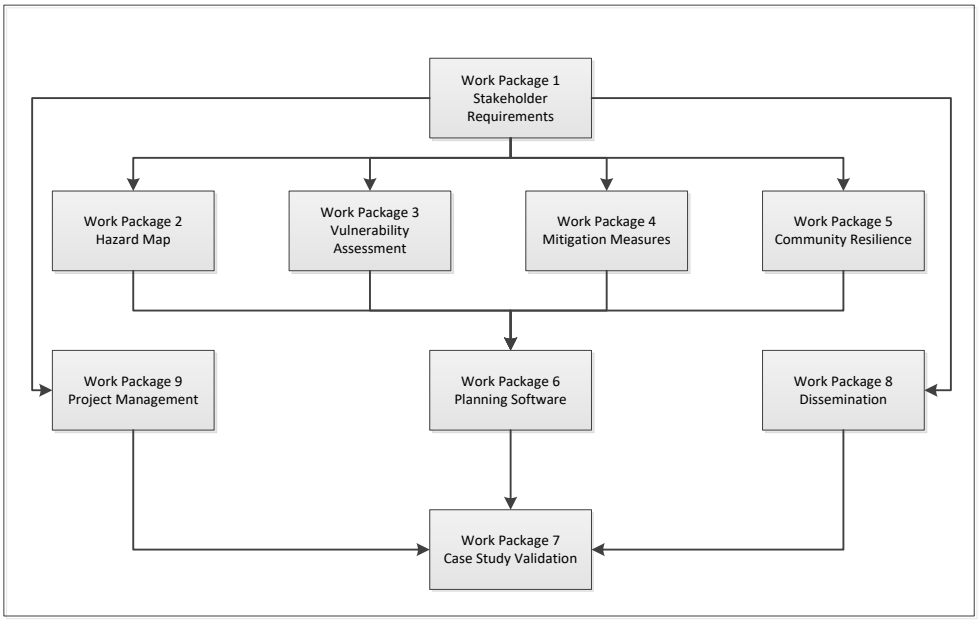

Figure 1: *LIQUEFACT Work Packages*

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. No activity in this reporting period.

4.2. Work Package 2: European LIQUEFACTion Hazard Map (Macrozonation) and Methodology for Localized Assessment of LIQUEFACTion Potential (Microzonation)

(UNIPV- Eucentre – Leader. Istan-Uni, ULJ, UPORTO – Participants)

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.

All outstanding tasks were completed in this reporting period including:

- Deliverable 2.6: Report to describe the adopted procedure for the development of the European Liquefaction hazard map.
- Deliverable 2.7: Methodology for assessment of earthquake-induced risk of soil Liquefaction at the four European testing sites (microzonation).

One of the main goal of the WP2 of LIQUEFACT project is to set-up a methodology for localized assessment of Liquefaction potential (microzonation) within Task 2.6. Microzonation of a territory for Liquefaction risk is the subdivision of the territory in areas characterized by the same probability of Liquefaction manifestation, under free-field conditions, in case of an earthquake of specified severity. Microzonation for Liquefaction risk is hereinafter considered as the subdivision of a territory at a municipal or submunicipal scale. The Liquefaction risk at a site depends on the severity of expected ground shaking and thus on the seismic hazard and the susceptibility to Liquefaction of that site. This in turn depends on geological, geomorphological, hydrogeological and geotechnical factors. Thus, Liquefaction risk implies the existence of areas characterized by a moderate to high seismic hazard in the sense of intensity of ground shaking.

The four areas under investigation are located in Marmara region (Turkey), Ljubljana area (Slovenia), Lisbon area (Portugal) and Emilia region (Italy). The four testing sites were selected on the basis of the following criteria: availability of geological and geotechnical data, presence of liquefiable soil deposits, documented cases of Liquefaction manifestations occurred in past earthquakes, representativeness of different geological setting, density of population in selected areas. The microzonation, objective of Task 2.6, is based on the results obtained from ground characterization carried out at each of the four selected areas in Task 2.1 (Deliverable 2.1, 2017).

It is worth noting that UNIPV and Eucentre drafted the "Guidelines on the methodology for localized assessment of Earthquake Induced Soil Liquefaction potential at the four European testing sites (Microzonation)" (v1.0 July 15, 2017) with the aim of establishing a shared framework among the partners involved in this task in order to deliver at the four selected areas compatible and to a certain degree homogeneous microzonation maps for Liquafaction risk. They are recommendations aimed to guarantee an acceptable degree of compatibility among the maps that will be produced at the four testing sites. LIQUEFACT is a research project and as such each partner should have the freedom to carry out their activities according to its own strategies and ideas. Finally, this document represents the base for the preparation of the Deliverable 2.7, in which the microzonation studies at the above four testing areas are fully illustrated.

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 was 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 focused on 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 has involved both geotechnical and structural engineers that have worked 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 were pursued to develop:

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

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

Although all the Deliverables associated with WP3 were uploaded before the start of this reporting period work did continue to ensure that the content of these Deliverables was effectively integrated into the work of WP6 and WP7 and informed the wider dissemination of the LIQUEFACT outputs in WP8. Work Package 3 in complete.

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.).

During this period, UNIPV-EUCENTRE has continued the activities of validation of the SD constitutive model by Cubrinovski and Ishihara, 1998[1] which was implemented in 2018 into the library of the commercial software FLAC2D (Itasca Inc.) for performing advanced geotechnical numerical analyses in liquefiable soils. The work of implementation has been performed using fundings from the LIQUEFACT project. This validation task is currently performed jointly with the research group of Prof. Misko Cubrinovski from the University of Canterbury in Christchurch, New Zealand.

All outstanding tasks were completed in this reporting period including:

- Task 4.1. This Task ended within RP1 (however, in accordance with the grant agreement D4.1 was submitted at M36 – 30 April 2019)
- *Task 4.5*. This Task involved the development of guidelines and implementation manual for the standard use of remediation technology against Liquefaction in the European building codes and standards. This task is complete and Deliverable 4.5 was uploaded on 3 May 2019.

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] Cubrinovski M. and Ishihara K. (1998). "Modelling of Sand Behaviour Based on State Concept". Soils & Foundations, Vol. 38, No. 3, pp. 115-127.

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)

Tasks 5.1, 5.2 and 5.3 were completed in the last reporting period.

Task 5.4 was completed in this reporting period:

- Task 5.4 which involved the development of a whole life-cycle built asset management planning tool for EILD events. This task also involved developing the final version of the RAIF to reflect the emerging LRG software tools being developed in WP6. This Task was completed following a joint meeting between key researchers from WP5 and WP 6 in April 2019. Following this workshop final versions of the Critical Infrastructure Resilience Tool; the customised UNDRR Disaster Resilience Scorecard for Cities; and the cost-benefit model for use in the built asset management framework and LRG software were also developed. Deliverable 5.4 was uploaded on 7 June 2019.

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 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. The basic for the development of the LRG software consists in integrating the knowledge (methodologies, procedures and models) from WP2, WP3, WP4 and WP5.

All outstanding Tasks were completed in this reporting period including:

- Task 6.2 Integration of procedure for the development of the European Liquefaction hazard with the use of outputs/deliverables from WP2. Algorithms for ground shaking and Liquefaction hazard simulation have been developed and integrated into the LRG software. 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 have been integrated into the LRG software. Deliverable 6.2 was uploaded on 08 November 2019.

- 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. Algorithms for the 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 have been and integrated in the LRG software. Deliverable 6.3 was uploaded on 9 July 2019.

- 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. This related Task was completed and Deliverable 6.4 was uploaded on 29 July 2019.

- *Task 6.5* Development and integration of procedures of LIQUEFACTion mitigation measures with the use of outputs/deliverables from WP4. This task involved the 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 task was completed and Deliverable 6.5 was uploaded on 22 November 2019.

- Task 6.6 Economic and societal consequences with the use of outputs/deliverables from WP5. The LRG has been integrated into the built asset management planning (D5.4). This task was completed. There was no specific deliverable associated with this task.

- Task 6.7 Development of technical manual with the use of outputs/deliverables from WP2, WP3, WP4 and WP5. This task is completed and Deliverable 6.6 was uploaded on 22 November 2019.

- Task 6.8 Training and plan of actions for leaders and decision-makers with contributions from all partners in WP2, WP3, WP4 and WP5. Training in the application of the LRG has been given to three groups of external stakeholders in Turkey and Italy. This task was completed. There was no specific Deliverable associated with this task.

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 28-42

The Work Package 7 aims to validate the risk assessment methodology defined in the project with the retrospective analysis of four past events, in this way providing a feedback for the correct implementation of the different components of the LIQUEFACT software toolbox, contributing to a more effective creation of databases and, finally, synthesizing the learnt lesson into guidelines that assist technicians and stakeholders to undertake Liquefaction risk assessment and mitigation, primarily the institutions of the European Commission in charge for the preparation of technical standards. The action has thus been focused on two complementary targets, i.e. identify the risk on a territorial scale to prioritize mitigation works and standardize the use of mitigation technologies.

All outstanding tasks are complete including:

- T7.1 – Definition of the database for risk assessment. This task has been carried out in cooperation with ARU, UNIPV, UPORTO, ULJ and Istan-Uni and NORSAR, and has defined the databases for Liquefaction risk assessment. This task was completed and Deliverable 7.1 was uploaded on 30 April 2019.

- T7.2 – Validation of the software for risk assessment. This task has been carried out in cooperation with ARU, Istan-Uni and NORSAR and with the advisory Institutions (Univ. of Canterbury, Univ. of Tokyo, Regione Emilia Romagna) and has defined the databases for Liquefaction risk assessment. This task was completed and Deliverable D7.2 was uploaded on 5 November 2019.

- T7.3 – Risk analysis for the selected sample areas and standardization of procedure. This task ran in parallel with Task 7.2, this task has been carried out in cooperation with ARU, Istan-Uni and NORSAR and with the advisory Institutions (Univ. of Canterbury, Univ. of Tokyo, Regione Emilia Romagna) and is aimed at defining the databases for Liquefaction risk assessment. This task was completed and Deliverable 7.3 was uploaded on 5 November 2019.

- 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). This task has been carried out in cooperation with UNIPV, UNINA, ISMGEO, TREVI and NORSAR. This task was completed and Deliverable 7.4 was uploaded on 5 November 2019.

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.

All outstanding Tasks are complete including:

- T8.3 – Dissemination of knowledge. Dissemination of knowledge has been continuously carried out by each partner publishing the outcomes of the work carried out in top journals and conference proceedings. At the end of the project 73 scientific journal and/or conference papers had been published and made available in open access. This task was completed and Deliverable 8.2 was uploaded on the 8 October 2019.

- T8.4 – Development of case studies and marketing material. Seven cases studies' dissemination material were collected thanks to the support many partners, UPORTO, UNICAS, ULJ, UNIPV and ISTANBUL UNIVERSITY-CERRAHPASA. Selected case studies were located in Brezice (Slovenia), Canakkale (Turkey), Cavezzo (Italy), Christchurch (New Zealand), Lisbon (Portugal), Terre del Reno (Italy) and Urayasu (Japan). This Task was completed and Deliverable 8.3 was uploaded on 29 October 2019.
- T8.5 – Business models for exploitation. An overview on available risk assessment programmes and software that are used for seismic risk studies is carried out in conjunction with NORSAR. This Task was completed and Deliverable 8.4 and Deliverable 8.5 were uploaded on 22 November 2019.
- T8.6 – Impact assessment. An end of project summary of the routes to impact for all the LIQUEFACT deliverables was completed and Deliverable 8.6 was uploaded on 29 October 2019.

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 complete. Deliverable 9.12 was uploaded on 2 April 2019; Deliverable 9.13 was uploaded on 10 May 2019; Deliverable 9.15 was uploaded on 22 November 2019; Deliverable 9.19 was uploaded on 5 November 2019. The final Deliverable 9.14 (this report) was uploaded on 29 November 2019.

4.10. Tasks completed in Reporting Period

ALL LIQUEFACT Tasks are complete.

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 prototypes and limitations of the models.	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.
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,	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

	WP9.	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

No additional risks were identified in this reporting period.

6. Deliverables

All Deliverables have been uploaded to the Portal.

7. Dissemination and exploitation

Publications, conference papers and journals submitted during reporting Period

UNIPV-Eucentre submitted a proposal of a Special Issue of the Bulletin of Earthquake Engineering of the LIQUEFACT Project. The major achievements of the project relevant for the earthquake engineering community have been included in the proposal, share with all the partners before the submission.

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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	5	2	1	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	0	0	0
SLP	0	2	0	2
ISMGEO	1	1	2	4
Istan-Uni	2	9	1	1
Istan-Uni CERRAHPASA	1	6	1	3
Total	**29**	**50**	**19**	**37**

9. References

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