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LIQUEFACT

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

H2020-DRA-2015

GA no. 700748

Deliverable D9.8

Periodic Progress Report 3

v. 1.0

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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
CA	Consortium Agreement
CH	Cross Hole
CI	Critical Infrastructure
CPT	Core Penetration Test
CRR	Cyclic Resistance Ratio
CSR	Cyclic Shear Ratio
CSS	Cyclic Simple Shear
CSV	Comma Separated Values
CTI	Compound Topographic Index
CTX	Cyclic Triaxial
D	Deliverable
DEM	Digital Elevation Model
DoA	Description of Action
EC	European Commission
ECEE	European Conference on Earthquake Engineering
EEAB	External Expert Advisory Board
EILD	Earthquake Induced Liquefaction Disaster
ENMC	Portuguese Authority for Fuel Market
ESA	European Space Agency
ESB	Equivalent Shear Beam
EU	European Union
FCUL	Faculty of Science of the University of Lisbon
GA	Grant Agreement
GIS	Geographic Information System
IAB	International Advisory Board
INGV	Italian Institute of Geophysics & Volcanology
IPL	Liquefaction Potential Index
kPa	Kilopascal
LNEC	Portuguese National Laboratory for Civil Engineering
LPI	Liquefaction Potential Index
LSI	Liquefaction Severity Index
LSN	Liquefaction severity Number
MASW	Multichannel Analysis of Surface Waves
NGO	Non-Governmental Organisation
PGA	Peak Ground Acceleration
QGIS	Quantum Geographic Information System
RAIF	Resilience Assessment and Improvement Framework

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Acronym	Description
RC	Reinforced Concrete
RFQ	Request for Quotation
SFSI	Solid Foundation Structure Interaction
SPT	Standard Penetration Test
SRTM	Shuttle Radar Topography Mission
UBC	Universally Defined Continuum
UBCSAND	Universally Defined Sand Continuum
UNISDR	United Nations International Strategy for Disaster Reduction
Vs	Velocity
WP	Work Package

Contents

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1. Summary for publication

1 Introduction

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

1.1 Earthquake Induced Liquefaction Disasters

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

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

1.2 Aim and Objectives of LIQUEFACT

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

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

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

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

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

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

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

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

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

2. Progress to date

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

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

Whilst the principles supporting the RAIF were developed in WP 1, work refining the RAIF and integrating it into the built asset management process formed a major area of work for WP5 (ARU) during the reporting period. In addition, other WP's continued to develop the specific tools required to operationalise the RAIF (WP2 – macrozonation and microzonation maps and GIS database; WP3 - fragility curves and generic methodology for the assessment of built asset vulnerability and resilience; WP4 – analysis of alternate mitigation techniques). Finally the integration of the tools being developed by the other WP's with the RAIF, and the ability to integrate the RAIF with the SELENA-LRG software being developed in WP6 were tested through a one-day workshop in Rome. Following this workshop version 2 of the RAIF is currently being developed in WP5. Work on achieving objective 1 is on target.

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

Work continues (mainly in WP2) to develop macrozonation and microzonation maps and to develop version 2 of the GIS based catalogue of historical liquefaction occurrences in Europe. This work was supported by colleagues from UPorto (Portuguese Case Study), Istan-Uni (Marmara Case Study) and ULJ/SLP (Slovenian Case Study). Work for achieving objective 2 is on target.

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

Work continues (mainly in WP3) to develop new simplified methodologies for the vulnerability assessment of structures and infrastructure to EILD event. During this reporting period UPorto has continued its review of existing modelling strategies and are developing new approaches which better model the soil-structure interface. This work was supported by colleagues from UNICAS/ISMGEO (settlement and angular distortion of buildings on liquefiable soil, estimation of soil impedance of liquefiable deposits); ULJ (the influence of differential settlement demands on the seismic response of buildings, fragility curves); and UNINA (fragility curves and loss estimation). Work for achieving objective 3 is on target.

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

Work continues (mainly in WP4) to assess liquefaction mitigation techniques using centrifuge modelling (centrifuge tests have taken place at ISMGEO) and full scale field tests (field work has commenced at Pieve de Cento, undertaken by TREVI). UNINA continue to undertake laboratory tests and perform numerical modelling in support of the centrifuge tests and field tests. This work is ongoing. Work for achieving objective 4 is on target.

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

Work continues (mainly in WP5) to develop a range of metrics which can be used by the RAIF to support the cost/benefit evaluation of alternative mitigation strategies to improve community and critical infrastructure resilience to EILD events. During this reporting period ARU began refining the UNISDR Scorecard to reflect the potential impact of EILD events on community resilience and continued to develop the critical infrastructure resilience tool. This work was supported by NORSAR (integration of the RAIF into SELENA-LRG) and all the partners who attended the Rome workshop. ARU also began development of a cost/benefit tool which will be used to evaluate alternative mitigation strategies. This work is ongoing. Work for achieving objective 5 is on target.

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

Work began (mainly in WP6) to develop the SELENA-LRG software tool. During this reporting period NORSAR developed the framework for SELENA-LRG and engaged in detailed discussions with representatives from WP2, WP3, WP4 and WP5 to explore how the outputs from these WPs could be best integrated into the SELENA-LRG tool (this formed part of the Rome workshop reported earlier). NORSAR have also began designing protocols for the development of the SELENA-LRG software (due to be reported in D6.1 in month 24). This work is ongoing. Work for achieving objective 6 is on target.

3. Expected Potential Impact

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

3.1 Impact of risk/resilience assessment and improvement on stakeholders

A broad variety of stakeholder groups would be interested in the prediction of the likely consequences of an EILD event. These range from individual infrastructure managers to regional government,

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insurance and civil protection organizations. The RAIF provides the stakeholders with the tools to assess their susceptibility, vulnerability and risks to an EILD event as well as the business modelling tools to evaluate the potential of mitigation options to improve their resilience.

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

3.2 Impact of seismic building codes

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

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

Goal: **This document aims to provide a summary description of activities and progress of all LIQUEFACT project partners between Months 15 and 21 (July 2017 – January 2018), highlighting completed deliverables and milestones.**

3.3 Work performed in months 15 - 21 July 2017 – January 2018

3.3.1. Anglia Ruskin University (ARU)

1st July 2017 – 31st January 2018

The activity of ARU in the period from July 1st 2017 – January 31st 2018 is described with reference to the objectives declared in the different work packages where ARU is involved.

WP5 June 2017-January 2018

Progress Report for Work Package 5: Community Resilience and Built Asset Management Planning

Introduction

Work on WP5 continues to progress well. Following the completion of Deliverables D5.1 (Report on individual stakeholder and urban community performance metrics) and D5.2 (Data toolkit for

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community resilience case studies) research attention has moved to Task 5.3 (cost/benefit modelling of liquefaction mitigation for (improved) community resilience) and Task 5.4 (whole lifecycle built asset management planning for EILD events). To support this work the research team at ARU has been enhanced with the appointment of a full time Research Fellow (Dr Mariantonietta Morga) to replace Dr Andrea Bartolucci (who left to take up a position elsewhere) and the addition of Dr Federica Pascale (who will focus on community resilience and support Professor Jones in the development of the Built Asset Management Planning Tool). Dr Wanigarathna continues to work on the development of the liquefaction cost/benefit model whilst Professor Jones continues to provide academic oversight to the whole of WP5.

Details of Work

Deliverable 1.3 outlines the Resilience Assessment and Improvement Framework (RAIF) to be used as the basis for developing the Built Asset Management Planning Tool being developed in Task 5.4. Deliverables 5.1 and 5.2 provide the community and critical infrastructure metrics that will be used by the Built Asset Management Planning Tool to assess the potential impact of mitigation interventions on community resilience to EILD events. Over the past 6 months researchers at ARU have been integrating the outputs from Deliverables 5.1 and 5.2 into the RAIF developed in Deliverable 1.3 and testing the inter-relationships between the Built Asset Management Planning Tool and other LIQUEFACT Work Packages. The following tasks have been performed.

1. Customising the generic UNISDR Disaster Resilience Scorecard for Cities to model the effects of EILD events on community resilience. This involved reviewing the application of the generic UNISDR Disaster Resilience Scorecard to disaster events and developing a series of data collection activities that will be used to focus the UNISDR Disaster Resilience for Cities Scorecard on modelling the impact of EILD events on community resilience. The data collection activities will take place over the next 9 months as part of WP5 and WP7. The first of these activities will be a one day workshop between LIQUEFACT partners to assess the relevance of each of the UNISDR Disaster Resilience for Cities Scorecard metrics (known as **items** in the Scorecard) to an EILD event. This workshop will be followed by community stakeholder workshops in Emilia Romagna (Italy) and Marmara (Turkey) to validate the customised UNISDR Disaster Resilience Scorecard for Cities.

2. Developing organisational specific metrics to customise the LIQUEFACT Critical Infrastructure Tool to model the effects of EILD events. This involved developing a series of data collection activities that will be used to focus the Critical Infrastructure Tool to the specific requirements of critical infrastructure providers. The data collection activities will take place over the next 9 months as part of WP5 and WP7. The first of these activities will be a one day workshop between Liquefact partners to assess to the relevance of each of the metrics to an EILD event. This workshop will be followed by interviews with critical infrastructure stakeholders' in Emilia Romagna (Italy) and Marmara (Turkey) to validate the Critical Infrastructure Tool.

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3. At the suggestion of the Liquefact Advisory Board meeting held in Naples (5th October 2017) a one-day 'sprint test' workshop was organised to test the robustness of data inter-actions between the various LIQUEFACT work packages to support the RAIF (WP5) and to provide appropriate metrics for inclusion in the SELENA-LRG software being developed as part of WP6. Researchers at ARU, in conjunction with colleagues from NORSAR, developed the workshop programme and facilitated the workshop event. The workshop was held in Rome at the headquarters of the Associazione Geotecnica Italiana (AGI), Viale dell'Università 11, Rome on the 17th November 2017.

The aims of the workshop were to review the ability of the RAIF and SELENA-LRG to support a facility manager/operational engineer assess:

- The antecedent vulnerability and resilience of their infrastructure assets to an EILD event; and
- Assess the relative improvement in vulnerability and resilience that could be achieved through the use of a range of mitigation interventions.

The workshop used a hypothetical (simulation) healthcare system (detailed in Deliverable D1.4 as a typical scenario as this would:

- Allow for scale – from assets dispersed across a region to a localised asset located on a site to test the RAIF and SELENA-LRG; and
- Primarily be comprised of modern assets which should have been designed to resist ground shaking and as such it will allow us to isolate the liquefaction impacts (suggestion of the LIQUEFACT Advisory Board).

The workshop examined the scenario at each stage of the RAIF to test the logic and data needs of the RAIF and its suitability for inclusion in the SELENA-LRG software tool.

- Identify what data (performance indicators, metrics and variables) are needed by the RAIF and SELENA-LRG at each stage of the assessment process.

The workshop programme was designed around a series of breakout sessions. The detailed programme is given below.

Time	Activity
9.30 – 9.45	Aims and objectives of the workshop (KJ)
9.45-10.15	Overview of the RAIF (KJ) and SELENA-LRG (AM)
10.15-10.45	Presentation and discussion of D1.4 (KJ)
10.45-11.00	Coffee
11.00-11.30	Breakout session: Stage 1 – Antecedent Condition Analysis (KJ)
11.30-12.00	Breakout session: Stage 2 – Impact Assessment (KJ)
12.00-12.30	Breakout session: Stage 3 – Community Impact Scenarios (KJ)
12.30-13.30	Lunch

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13.00-14.00	Breakout session: Stage 4 – Mitigation Options (KJ)
14.00-14.30	Breakout session: Stage 5 – Improvement Framework (KJ)
14.30-15.00	Breakout session: Stage 6 – Built Asset management Planning (KJ)
15.00-15.30	Coffee
15.30-16.30	Review of the day and next steps (AM/KJ)

During each breakout session attendees:

- Reviewed the requirements of the RAIF and SELENA-LRG
- Identified what indicators, metrics and variables are needed to support that stage of the RAIF?
  - Existing indicators, metrics, variables; and/or
  - New indicators, metrics, variables

The workshop established which LIQUEFACT work package was responsible for identifying and/or developing each indicator, metric and/or variable, including producing a specification that:

- Describes the aim of the indicator, metric or variable;
- Details the data type/format (qualitative, quantitative or mixed; empirical or theoretical; measured or derived from expert opinion, etc.) of each indicator, metric or variable; and
- Identifies the limitations of the indicator, metric or variable.

The output from the workshop will be a report that details how the RAIF and SELENA-LRG will use the indicators, metrics and/or variables to assess critical infrastructure and community resilience to an EILD event. This will then be the basis for an updated version of the RAIF and the validation tests to be performed in the case studies. The detailed report and updated version of the RAIF are still being prepared as part of WP5.

The workshop was attended by: Abdelghani Meslem (NORSAR), Alessandro Flora (UNINA), Antonio Viana da Fonseca (UPORTO), Carlo Giovanni Lai (UNIPV), Daniel Burman, Keith Jones and Mariantonietta Morga (ARU), Francesca Bozzoni (EUCENTRE), Janko Logar (ULJ), Luca Pingue (TREVI), Rose Line Spacagna (UNICAS) and Sadik Oztoprak (Istan-Uni).

4. Other Activities

After a careful review of the methods so far applied in literature to model the community and infrastructure resilience to disasters the Analytic Network Process was identified as the most appropriate modelling approach for this kind of application. Hence the collaborators of WP5 decided to use it for implementing the resilience toolkits in the RAIF. This is consistent with the approach presented in the original LIQUEFACT proposal.
The new Postdoctoral Research Fellow (Dr Mariantonietta Morga) spent time familiarising herself with the LIQUEFACT project and in particular with the RAIF and community and critical infrastructure toolkits. She was involved in customizing the UNISDR scorecard to assess the

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community resilience to EILD events. She will work on developing the indicators and metrics of the critical infrastructure tool and the data collection for the community resilience tool. Moreover she reviewed and is updating the glossaries proposed in other project Deliverables in order to produce the final project glossary that will become an appendix of D5.4. Finally she was involved in meetings with UNICAS in Emilia Romagna region for the collection of data to apply metrics and indices identified as critical for the infrastructure resilience tool.

Dr Wanigarathna continued to review alternative approaches to disaster cost/benefit analyses and in particular to modelling approaches that could be used to prioritise EILD impact mitigation options to improve community resilience. Existing research on cost benefit analysis for seismic design interventions focuses on four key areas of analysis: hazard; structural performance of buildings and components; fragility of buildings and components to various hazard intensities; and resultant loss and damages. LIQUEFACT research will contribute to this knowledge by investigating alternative approaches to estimate implications of non-engineering disaster resilience measures on loss and damage.

This work will continue over the next 6 months.

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3.3.2. Universita degli Studi di Pavia (UNIPV) & Eucentre

1st July 2017 – 31st January 2018

The activity of UNIPV-Eucentre in the period from July 1st 2017 – January 31st 2018 is described with reference to the objectives declared in the different work packages where UNIPV-Eucentre is involved.

In the period of reference, UNIPV-Eucentre team was mainly involved in the activities of **WP2 *European Liquefaction Hazard Map (Macrozonation) and Methodology for Localized Assessment of Liquefaction Potential (Microzonation)***.

Within Task 2.2 *Collection of geological and seismological data for Europe within a GIS framework*, a new European DEM (Digital Elevation Model) prepared by the ESA (*European Space* Agency) Copernicus programme and characterized by a 30m spatial resolution was acquired. This DEM was compared with the 90m DEM from SRTM (Shuttle Radar Topography Mission) for the European territory to identify the most suitable model for elaborations that will be carried in Task 2.5 (*Development of a European liquefaction hazard map – Macrozonation*). A bibliographic research about the VS30 maps obtained from topographic data was conducted. Finally, starting from the digital elevation model, geo-processing elaboration allowed us to extract additional data useful in the subsequent analysis that will be conducted in Task 2.5. In particular, those data are slope, Compound Topographic Index (CTI), Euclidean distance from stream network.

Within Task 2.3 *Construction of a GIS-based catalogue of historical liquefaction occurrences in Europe*, the first version of the GIS-based catalogue has been compiled by UNIPV-Eucentre. The catalogue includes two main type 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. A thorough literature review has been carried out to identify on scientific publications, reports and seismic bulletins reporting information on manifestations of liquefaction occurrences in European countries. Now, the GIS-based catalogue includes 939 liquefaction cases induced by 188 earthquakes. It is important to point out that liquefaction phenomena mainly occurred in countries in Europe characterized by moderate to large seismic hazard. Moreover, for 20 cases epicentral distance was not retrieved (i.e. geographical coordinates of earthquake or of liquefaction occurrences are not available) and for 103 cases geographical coordinates of liquefaction occurrences are not available, but at least epicentral distance was retrieved. With specific reference to Italy, an updated version of the catalogue of liquefaction occurrences has been constructed in GIS environment by UNIPV-Eucentre by merging the following sources: the catalogue by Galli (2000), which includes liquefaction cases starting from 1117 updated by Martino et al. (2014) who developed CEDIT, integrated by UNIPV-Eucentre with the detailed catalogue by Perrotta et al. (2007) for Eastern Sicily and a preliminary selection of liquefaction occurrences induced by 2012 Emilia quakes. It is worth noting that the Emilia-Romagna Region provided to UNIPV-Eucentre a GIS-database of the Emilia liquefaction cases, which includes thousand of liquefaction cases.

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Within Task 2.4 *Calculation of European regressions to predict liquefaction occurrence starting from the main seismological information of an earthquake*, a bibliographic review was carried out to identify worldwide studies to derive relationships between magnitude and distance for liquefaction. It is worth noting that no relationship is available for Europe. A first attempt to derive Italian relationships between magnitude and distance for liquefaction has been carried out by UNIPV-Eucentre by using the previously mentioned updated GIS-based catalogue for Italy. A general model from literature has been assumed and a nonlinear least-squares solver has been adopted to compute preliminary regression for Italy. The relationship between magnitude and distance for liquefaction computed by UNIPV-Eucentre has been also compared to the relationship proposed for Italy by Galli (2000) as shown in Figure 1. Attempts to derive European relationships between magnitude and distance for liquefaction are currently ongoing.

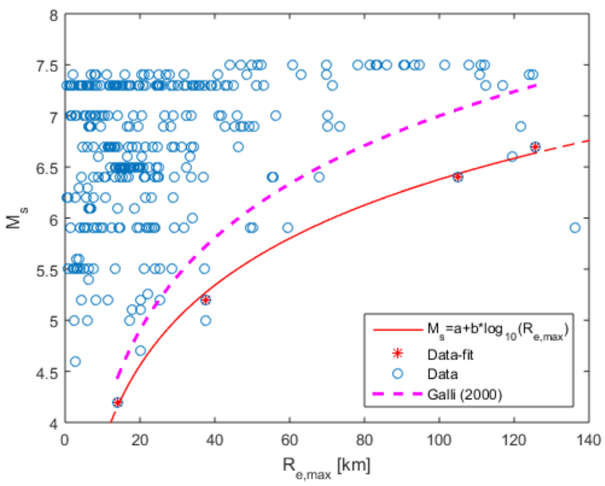

Figure 1. Comparison of the first attempt carried out by UNIPV-Eucentre to compute Italian relationship (red line) between magnitude and epicentral distance for liquefaction by using data from the updated GIS-based catalogue of liquefaction occurrences in Italy (blue circles) and comparison with the relationship proposed by Galli (2000) for Italy (dashed pink line).

In the first stage of the Task 2.5 an in-depth literature review of previous related research on liquefaction susceptibility and hazard assessment at a regional scale for ground shaking has been carried out to define a methodology for the assessment of liquefaction hazard at the European scale. Two different approaches have been highlighted:

- Data-driven methods: based on observational data;
- Knowledge-driven methods: based on experts' opinion.

The controlling factors ("predisposing", namely liquefaction susceptibility, and "triggering", namely severity of ground motion) at the European scale collected within Task 2.2 will be used as starting point for the applications of the methodologies.

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Within the data-driven approach framework, the logistic regression model proposed by Zhu et al. (2015) has been applied to the Italian area, as a first attempt. The proxies required for the model are the peak ground acceleration (PGA), the CTI and the Vs30. The output is a map in which every pixel is characterized by a probability of liquefaction.

Task 2.6 *Validation of the European liquefaction hazard map by detailed analysis at the four testing areas – Microzonation*, based on the GANTT chart of Grant Agreement, this task has just started (21st month). However, in July 2017 guidelines for microzonation of liquefaction potential at the four testing sites were set up by UNIPV-Eucentre and shared with all the main partners involved in this task. The scope of these guidelines is to establish a shared framework among partners performing microzonation for liquefaction potential so to deliver homogeneous and harmonized outcomes. Concerning the Italian site, i.e. the Municipality of Cavezzo, under the responsibility of UNIPV-Eucentre, a large number of in situ tests performed during post-earthquake reconstruction after 2012 quakes, were collected at the headquarter of Emilia Romagna Region in Bologna in July 2017. These data are currently digitized and processed jointly with the data described in Deliverable 2.1 in order to define a geological model for the area under investigation. Moreover, an inter-institutional agreement for microzonation study at Municipality of Cavezzo was signed in July 2017. The involved institutions are: UNIPV, Eucentre, Emilia-Romagna Region, Modena Province and the Municipality of Cavezzo. In this framework, local authorities funded a further investigation campaign in Cavezzo including in situ and laboratory tests performed in December and January 2017. By using the remaining amount of money set aside by UNIPV-Eucentre in Task 2.1 (Deliverable 2.1, completed on 30/01/2017) from the budget allocated for complementary ground investigation at the Italian testing area, a complementary geophysical campaign was carried out in Cavezzo by the Italian Institute of Geophysics and Volcanology (INGV) in October-November 2017.

Within WP4 ***Comparative Analysis of State of the Art Liquefaction Mitigation Measures***, shake table motions were define by UNIPV-Eucentre. Geotechnical and geophysical data from past investigation campaigns were acquired for the trial site in Pieve di Cento by UNIPV-Eucentre from the Administration of the Emilia-Romagna Region and from the literature. Proper interpretation of the acquired data led to the definition of a suitable soil geotechnical model to be used for ground response analyses. 21 different bedrock level motions purposely selected by UNIPV-Eucentre (i.e. 3 set of 7 natural spectrum-compatible rock outcrop ground motions for 3 different hazard levels, 475, 975, and 2475 years) were propagated to 15 meters depth, which represents the maximum depth of the physical model box at prototype scale. Analyses were done by using Pieve di Cento profile defined on the bases of the soil geotechnical model. In the corresponding analyses, the effect of the superficial and liquefiable layer between 2-6 meters on the motion at depth 15 meters was investigated using three different constitutive models: linear viscoelastic model, nonlinear hysteretic model, and an effective stress based model with loosely-coupled formulation. It was found that the motion at 15 meters is not strongly affected by the response of the superficial layer under consideration. Shake table motions were provided from the results of the nonlinear hysteretic model. Finally, obtained motions were properly scaled to keep the similitude between small- and large-scale models under

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consideration. Selecting the critical ground motion for the upcoming centrifuge tests has been completed as a support role for the ISMGEO partner. Moreover, a comparison among results from numerical simulations obtained by UNIPV-Eucentre and by UNINA was carried out. On this subject, a paper for the European Conference on Earthquake Engineering has been jointly prepared by UNINA and UNIPV-Eucentre and then submitted on December 2017. Calibration of an effective stress based advance constitutive model is still an ongoing activity.

Finally UNIPV-Eucentre were active in ***WP9 Consortium/Project Management*** and also in ***WP8 Dissemination/Exploitation***.

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3.3.3. Universidade do Porto (UPORTO)

1st July 2017 – 31st January 2018

The activity of UPORTO in the period from July 1st 2017 – January 31st 2018 is described with reference to the objectives declared in the different work packages where UPORTO is involved.

3.1 Objectives (List the specific objectives for the project as described in section 1.1 of the DoA and describe the work carried out during the reporting period towards the achievement of each listed objective. Provide clear and measurable details).

PO2: Develop a European liquefaction hazard geographical information system (GIS) map (macrozonation) framework and methodology for performing localized assessment of liquefaction potential (microzonation), which can subsequently be used to update the macrozonation framework. This methodology will be implemented within 4 case study sites in 4 different European regions (Italy, Portugal, Slovenia and Turkey) in order to validate the microzonation methodology and optimise the macrozonation mapping framework.

PO3: Closely linked to PO2, is to develop new simplified methodologies for the vulnerability assessment of structures and infrastructures to EILDs by establishing guidelines for the application of soil characterization and liquefaction risk assessment protocols and performing liquefaction fragility analysis of interacting earthquake-soil-structure system. The case study site characterisations performed in PO2 in the four European regions (Italy, Portugal, Slovenia and Turkey) of known liquefaction vulnerability will be used to establish these protocols, which would then be applicable in assessing the liquefaction vulnerability of structures and infrastructures in other regions.

During the reporting period, UPORTO team efforts focused on LIQUEFACT objectives PO2 and PO3. For the achievement of these objectives, the following work was carried out:

PO2: In order to prepare a European liquefaction hazard geographical information system (GIS) map, it was necessary to initiate the work by performing localized assessment of liquefaction potential in specific locations. As planned in the project's proposal, one of the case study sites is in Portugal, in the Greater Lisbon region. After the extensive field geotechnical and geophysical characterisation in the Portuguese pilot site, an additional high-quality sampling campaign was carried out, making use of a recently developed gel-push sampler. Subsequently, the work has focused on the laboratory characterisation of the undisturbed samples (using Mazier and gel-push equipments). The laboratory work comprised not only the physical characterisation for definition of the typical soil profiles, but also mechanical characterisation, through static and cyclic triaxial, and cyclic simple shear testing, complemented with seismic wave velocity measurements. In parallel, the preliminary liquefaction susceptibility analysis has been refined and geo-referenced for the purpose of microzonation mapping.

PO3: In order to develop methodologies and tools for the vulnerability assessment of structures to EILDs within the four regions, located in Italy, Portugal, Slovenia and Turkey, Uporto has targeted until

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now low-rise structures (residential and public like governmental offices, health facilities like hospital, fire stations, 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 working together to define a framework procedure to be used by city planning civil engineers and decision makers to evaluate their infrastructures.

In this sense, and in accordance to the proposal, Uporto has pursued the following specific objectives:

- Evaluation of existing numerical modelling strategies to simulate liquefaction-induced structural damage (T3.1);
- Develop an efficient probabilistic framework for liquefaction vulnerability analysis of critical structures and infrastructures (T3.2);
- Definition of guidelines to WP6/WP7, taking into account the results obtained for the selected sites, analysed in terms of liquefaction potential (e.g., LPI), to check if it can or not fully explain the great diffusion and extension of the liquefaction effects during the ground shakings. The calibration on physical modelling, and the numerical analyses under the modelling approaches (performed in WP4), will help to simulate the expected damaging deformations.

Meetings/Workshops of the consortium to workout

In **October 2017**, during the **consortium meeting in Naples, organized by UNINA**, UPorto has presented an overview of the different approaches to quantifying performance, based on mechanisms and phenomenon (analysis of soil-foundation-structure interaction with Liquefaction). The direct approach (model the all system), the mechanism approach (quantify individual mechanisms to obtain overall response) and an independent approach (which includes structural and liquefaction mechanisms separately, ignoring interaction).

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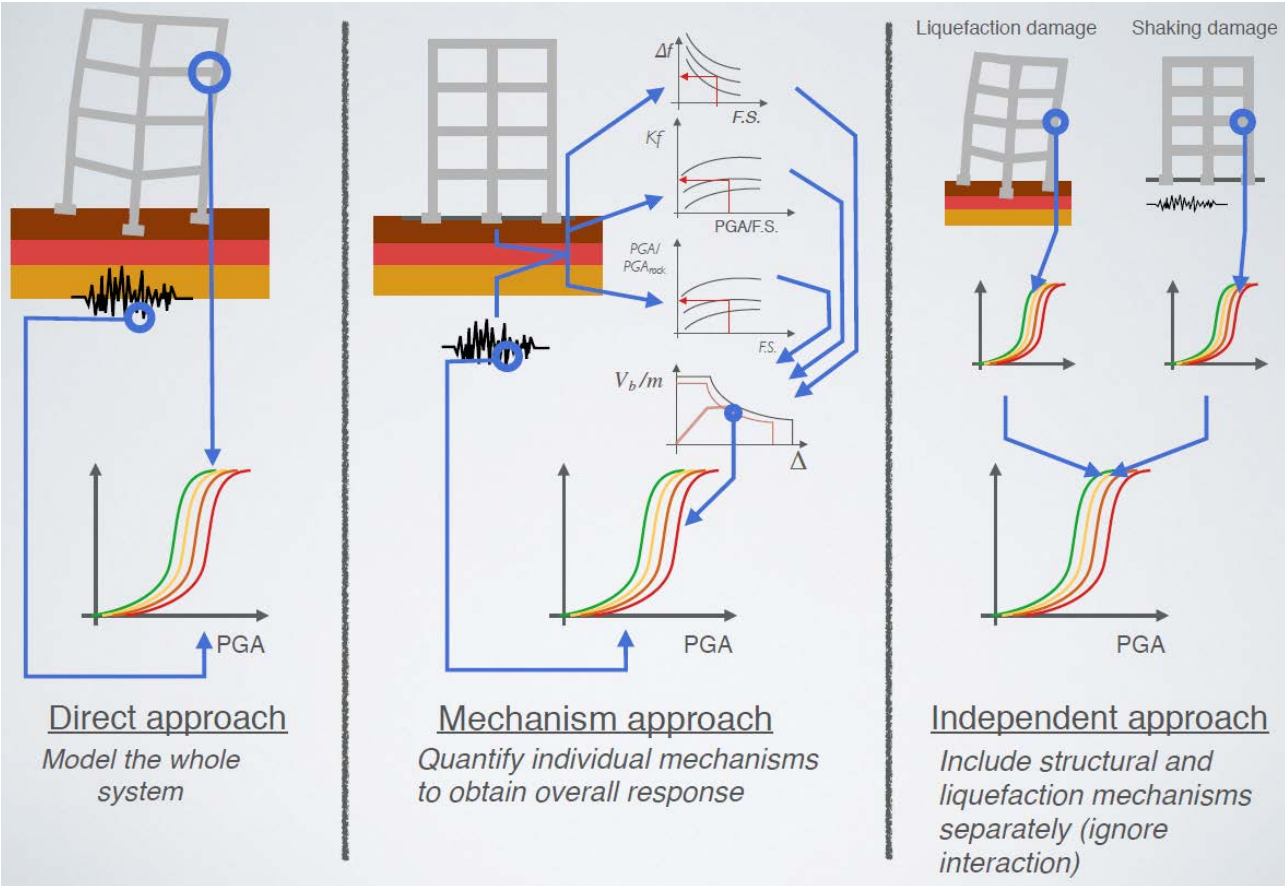

The later would aloe to adapt to different soil-structure types, incorporate multiple method, provide insight into largest uncertainties and minimise technical requirements of software.

A discussion was made how to deal with uncertainty and bias, with the introduction of a conceptual mechanism approach, considering 3 major effects: permanent deformations (reduced capacity due to settlement curvatures), foundation impedance (increased displacement due to reduced foundation stiffness) and ground motions (modified spectra due to liquefaction).

A mechanism-based procedure to develop fragility curves including liquefaction, was described and research task were identified:

1. Influence of liquefaction on nonlinear foundation impedance (already ongoing at UPorto)
2. Influence of soil variability on structural demands (already ongoing at UPorto)
3. Developing equivalent soil profiles from LSN maps (already ongoing at UPorto)
4. Influence of liquefaction on shaking demand (already ongoing at UPorto)
5. Estimation of permanent deformations (planned future research led by UPorto)
6. Soil residual strength (planned future research led by UPorto)

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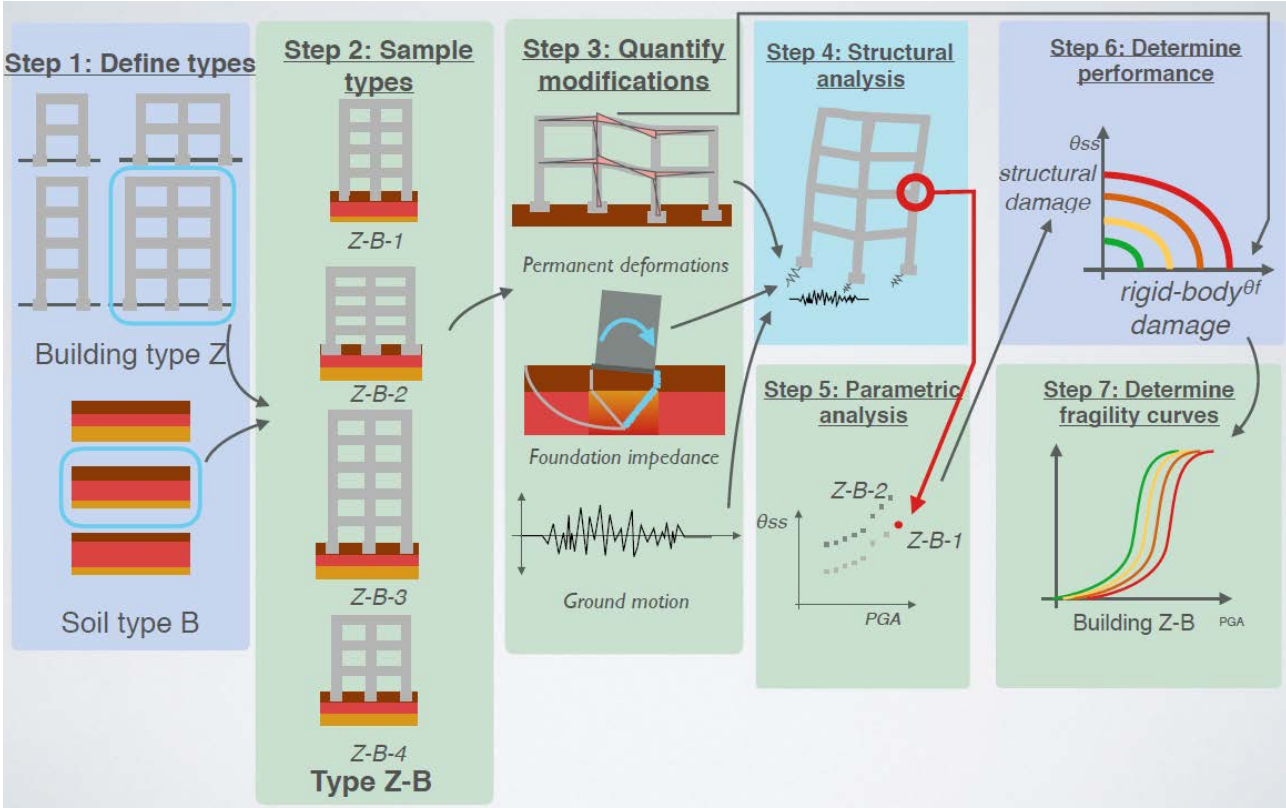
7. Structural response to liquefied ground motions (planned future research led by UPorto)
8. Quantify structural damage (planned future research led by UPorto)



Research gaps were identified, like foundation type distribution and combining differential and rigid body (transient and permanent) deformations, that should be discussed in the following months.

On 17th November 2017 a workshop was held in Rome to review the ability of the RAIF and SELENA-LRG to support a facility manager/operational engineer assess. Working through each step of the 6 stage assessment process (as defined in the Detailed user requirements and research output protocols for the LIQUEFACT Reference Guide – deliverable D1.4) to test the logic behind the Resilience Assessment and Improvement Framework (RAIF) and Norsar Software Toolbox for Liquefaction Mitigation Planning and Decision Support (SELENA-LRG), data (performance indicators, metrics and variables) needed by the RAIF and SELENA-LRG at each stage of the assessment process, was identified.

In the session associated to WP3, a specification was outlined to describe the aim of the indicator (metric or variable and existing or new), the data type/format (qualitative, quantitative or mixed; empirical or theoretical; measured or derived from expert opinion, etc.) and their limitations. In the following paragraph the work methodology will be presented.

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3.2 Explanation of the work carried per WP (Explain separately the work carried out in each WP during the reporting period giving details of the work carried out by each beneficiary involved).

During this reporting period, UPORTO team members were involved in activities associated with different WPs, as detailed below:

WP2:

With regard to Task 2.1, after the extensive ground characterisation activities in the 1st period of the project, a large number of high-quality samples was obtained by means of the gel-push sampler. This sampler was recently developed in Japan and has demonstrated very good performance in sampling loose to medium-dense sandy and silty sand soils. From these high-quality samples, more than 120 laboratory specimens have been prepared. Subsequently, the laboratory work involved physical and mechanical characterisation. Physical characterisation, comprising grain-size distribution and consistency limits, provides the basis for the definition of the typical soil profiles of the pilot site (provisionally, three distinct soil profiles will be established). Mechanical characterisation includes oedometer, cyclic simple shear, static and cyclic triaxial testing with shear wave velocity measurements. A considerable number of undisturbed samples, as well as reconstituted specimens, have been tested in the different testing apparatuses. Clear evidence of liquefaction has been observed in the laboratory specimens, despite the reduction in natural void ratio induced by sampling. The results show that the thick sandy or silty sand deposits of the pilot site are liquefiable for the design seismic conditions in that location. The combination of soil type characteristics with their mechanical behaviour will be later implemented in the numerical models.

Complementarily, additional geophysical surface wave campaigns, namely microtremor measurements and MASW (Multichannel Analysis of Surface Waves) have been performed to aid in the definition of the seismic site response. The microtremor measurements provided estimates of the fundamental frequency and corresponding local amplification factor, using the Nakamura method. For the MASW, four types of recordings were used, namely active and passive linear measurements, passive circular measurements and passive three-component single-station measurements. The accuracy of the results was verified by comparing the velocity models obtained through the joint inversion process with Cross-Hole and Seismic Dilatometer profiles. This work was carried out in collaboration with Prof. Rui Carrilho Gomes (IST) and Prof. Paula Teves-Costa (FCUL, University of Lisbon).

With regard to Task 2.2, the collection of geological and seismological data relative to Portugal has continued, with contributions from different stakeholders and researchers on this topic. The geological chart for the pilot site has been acquired. The results of this data collection was initially implemented in Google Earth, but the migration to QGIS software has been initiated.

In terms of Task 2.3, the historical liquefaction occurrences in Portugal have been investigated, particularly with the help of Dr. Celeste Jorge from the Portuguese National Laboratory for Civil Engineering (LNEC), who published the first (and only) catalogue of liquefaction occurrences in this

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country. These data, as well as specific seismological features of the region, has been geo-referenced, for the construction of the GIS-based catalogue.

Finally, the bases for the macro and microzonation tasks (Tasks 2.5 and 2.6, respectively) are currently being created. The existing data (from the data collection task) is being analysed and integrated with the geological, geophysical and geotechnical information from the site investigation campaign (from Task 2.1), in a geo-referenced database.

In addition, a large volume of existing geophysical data, mostly from seismic wave refraction tests, was obtained with the help and collaboration of ENMC (Portuguese Authority for Fuel Market). These vintage data is being reanalysed based on the most recent approaches to seismic refraction processing, supported by the expertise of Dr. Claudio Strobbia. The preliminary reprocessing analyses of such dataset provided reliable information regarding subsurface geometry and velocity.

WP3: Task 3.1

The Task 3.1 was concluded in October 2017 with the deliverable "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"-

That was developed by the following researchers from the partners:

- UPorto (Leader of WP3): António Viana da Fonseca, Maxim Millen, Fernando Gómez-Martinez, Xavier Romão, Julieth Quintero, Fausto Gómez, Pedro Costa, Sara Rios
- UNLj: Mirko Kosič, Matjaž Dolšek, Janko Logar, Sadik Oztoprak
- IstanUni: Ilknur Bozbey, Kubilay Kelesoglu, Ferhat Ozcep
- Unina: Alessandro Flora
- UNICAS: Alessandro Rasulo, Giuseppe Modoni, Paolo Croce

presenting a thorough description of liquefiable soil behaviour (the phenomena, the manifestation of liquefaction in free-field conditions and the soil constitutive models, towards future research opportunities), liquefaction-induced permanent deformations in buildings (manifestation of liquefaction in the presence of buildings, settlements, differential settlements, tilting, towards future research opportunities), liquefaction-induced modification of the dynamic response of buildings (ground motion modification, soil-foundation-structure impedance modification, structural modelling considerations, towards future research opportunities), liquefaction effects on other critical infrastructure (embankments, pipelines), assessing performance (performance levels, loss models) and conclusions.

This report discussed the importance of understanding liquefaction damage in relation to previous earthquake events. The phenomena involved with soil liquefaction and methods to estimate its occurrence and impacts were presented. Numerous procedures to estimate liquefaction induced permanent deformations and the response of buildings and other infrastructure were reviewed and several areas requiring future research were identified. Current procedures for quantifying loss were discussed, especially in relation to the propagation of uncertainty and limitations of modelling

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techniques for assessment liquefaction induced damage. The main limitations of current modelling techniques is that they are either focused on the geotechnical aspects or the structural aspects, whereas this problem requires a true multidisciplinary approach. The approaches for fragility analysis of buildings, which include a nonlinear model of the structure, focus only on the simulation of damage related to permanent ground deformations. These approaches do not involve coupled soil-structure interaction analysis, and as such are not capable of simulating the damage related to ground shaking. On the other hand there are numerous loss models for structures that do not account for liquefaction or any soil-structure interaction. The suitable combination of these two different disciplines to account for both ground deformation damage and shaking damage would represent an enhanced treatment of the problem, which is beyond the current state-of-the-art.

WP3: Task 3.2

With regard to Task 3.2 a complex detailed numerical modelling approach able to represent the damage and the complex behaviour of interacting structure-soil systems with liquefaction susceptibility has been conceived (details below). In the next months this will downgraded to fine tune a simplified model with an adequate balance between complexity and accuracy specifically suited for probabilistic analysis.

Regarding the specific modelling of soil-structure interaction effects, as it was proposed, the advantages and drawbacks of different types of approaches are being analysed in an attempt to find the most efficient modelling approach for probabilistic analyses. Substructuring techniques are being tested in order to use suitable modelling strategies for the structures and for the ground where liquefaction effects can develop. Adequate modelling of the more relevant sources of uncertainty for the vulnerability analysis problem are starting, first identifying those sources using suitable statistical techniques and sensitivity analyses. Probabilistic models of the factors associated to those sources of uncertainty hopefully will be established overlapping these uncertainties to the structural damage measures used in the vulnerability analyses.

A simple preliminary procedure for estimating the performance of a building on liquefiable soil is being developed in UPorto in order to propose a simplified approach that can be used by the responsible in the large universe of stakeholders that deal with the resilience of the populations affected by EILD. This will be an alternative methodology to complex and demanding calculations. The procedure directly accounts for damage related to ground shaking and in-directly accounts for ground movements (settlements and, eventually, lateral spreading).

The important factor of the changing in shaking demand and the natural vibration modes of the systems where liquefaction may take place, even partially, is considered and is being quantified by transfer functions that, hopefully, will have a simple parametrical solution.

This proposed procedure makes use of a displacement-based assessment procedure that considers nonlinear soil-foundation-structure interaction and extends it to include the effects of liquefaction. The procedure allows the consideration of soil-foundation-structure interaction (SFSI) through the use of effective stiffness properties of the structure and the soil and through displacement reduction

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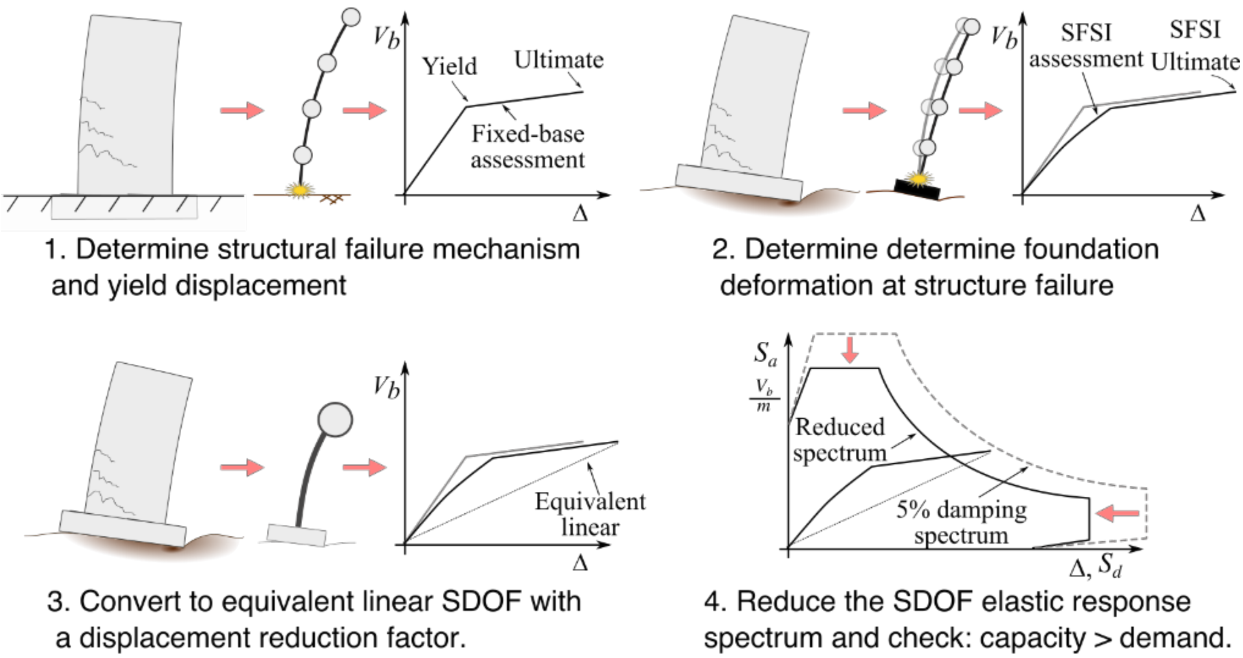
factors (or equivalent viscous damping) to capture energy loss through hysteretic and radiation damping in the foundation.



Displacement-based Assessment with SFSI

This method is described in a recent paper accepted to be presented in the 16th European Conference on Earthquake Engineering, to be held in Thessaloniki in June, 18-21, this year (Millen et al. 2018).

To account for liquefaction in this procedure, the influence of liquefaction compared to a conventional SFSI problem can be considered through three effects: (i) changes in the ground shaking hazard (modify the displacement spectrum and displacement reduction factors); (ii) changes in the soil-foundation-structure system (modification to the effective stiffness properties of the soil-foundation interface); and, (iii) increases in the soil-foundation permanent deformations (modification to local damage and the structural yield and ultimate displacements due to differential settlement, changes in overall performance due to rigid body tilt and settlement).

The additional stresses in the superstructure result in an earlier onset of yielding failure of members. The level of shear demand on the beams due to the complete loss of bearing under one footing compared to the demands of seismic action were estimated in the work developed in UPorto. This was presented in a recent paper accepted to be also presented in the 16th European Conference on Earthquake Engineering, to be held in Thessaloniki in June, 18-21, this year (Gomez et al. 2018).

The extensions of the displacement-based assessment procedure rely on several assumptions about the behaviour of the soil, site response and the structure, which require an extensive research to improve the robustness of the assessment. These will highlight the current deficiencies in the procedure and to examine the magnitude of their influence. To achieve this initial extension several broad assumptions have been applied as outlined below, and can be considered as areas of further research.

The preliminary procedure outlined here has highlighted the relative contributions of soil-foundation-structure-interaction, site effects and differential settlements. The major benefits of this procedure are:

1. Direct consideration of SFSI
2. Intuitive step-by-step procedure that highlights the relative contributions of individual mechanisms (e.g. direct calculation of expected foundation rotation)
3. Extends the well-established displacement-based assessment procedure
4. Updatable - new expressions to quantify site effects, SFSI and settlements/tilt can easily be incorporated
5. Easily extensible to include other liquefaction effects such as lateral spreading
6. Procedure can be applied at to individual buildings and in regional loss modelling as does not required detailed data of the soil and building properties
7. Can be used to assess the expected success of soil and structural mitigation techniques

Being the procedure, as it stands, limited by the introduction of the unfounded assumptions identified as follows:

1. Two separate assessments will be conducted: the first represents the loads and the system prior to liquefaction, and the second represents the system after liquefaction
2. The spectral demand of the pre-liquefaction analysis will be 90% of the demand for a non-liquefiable site, to reflect that the peak response often occurs in the earlier part of shaking and may occur before the onset of liquefaction
3. The pre-liquefaction analysis would be conducted with no reduction in the initial foundation impedances and no effects of differential settlement
4. The post-liquefaction analysis would use a 20% increase in the corner spectral period and a reduction to 30% of the non-liquefied spectral corner acceleration to capture the change in the site response of the liquefied soil deposit
5. The post-liquefaction analysis will assume the small strain foundation rotational stiffness has reduced to 60% of the original value and the friction angle has reduced to 70% to represent a reduction in foundation impedance and bearing capacity due to the build-up of pore pressure
6. The post-liquefaction analysis will assume the development of differential settlements results in no change to the yield displacement but in a 10% reduction in ultimate displacement capacity
7. The performance of the building will be considered as the envelope of the member responses from the pre- and post-liquefaction analyses

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8. Uniform displacements (rigid-body settlement and rigid body tilting) have been ignored in the study of the building performance

an accurate quantification of these relationships is needed before the procedure could be applied for practical benefit.

For this several mini-projects have been outlined:

Development of equivalent soil profiles AND Estimation of surface shaking on liquefiable deposits.

Develop and extension to the soil site class to include severity of liquefaction as a subclass and validate a procedure to develop equivalent 3-layered soil profiles.

The procedure to develop soil profile will congregate the values from risk indexes, such as LSN, and the CPT normalized data, including the influence of geology on likely representative soil profile (e.g. river deposit are more likely to have a thin permeable crust).

The performance of equivalent soil profile versus realistic soil profile are due to satisfy similarity of at least two factors:

- surface ground motions
- foundation settlements

The former factor - the influence of liquefaction on the response of buildings – is a consequence of the ground motion response being different for liquefied deposits and affects buildings differently. Timing of liquefaction, the inelastic spectra for liquefied deposits and for the soil-structure systems, as well as the EVD for liquefied deposits, will be evaluated, in view of determining inelastic spectra.

A case study will demonstrate the influence on wall or frame structure

Leading and taskforce: UPorto

Contributors: UNICAS

SETTLEMENT AND ANGULAR DISTORTION OF BUILDINGS ON LIQUEFIABLE DEPOSITS

Identification of the different settlement mechanisms, by review of centrifuge data (one liquefied and one non-liquefied); interpretation of different literature approaches to estimating settlements and differential settlements; and, development of new analytical approach.

Numerical FLAC studies are being developed to find equations for estimating each mechanism. Models were validated for a single footing, without and with structures (flexible: structural inertia can increase settlement). A comparison was made with applied load to the structure - removing the effect of soil inertia to investigate only settlement from structural inertia, without and with pore-water flow. Additionally, comparison of long shaking versus short shaking was undertaken, varying the soil profile

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(the thickness of the crust and density of the liquefied layer, as well as other soil parameters can modify the amount of settlement. Comparisons with total stress analysis, with simple assumptions of soil strength are pursued and the evaluation of the accuracy of using simple soil total stress models to obtain the same results.

Numerical study of the behaviour of close independent footings (footing spacing are determinant in the change in settlement, being that also important for quantifying tilt):

- Benchmark model, extends single footing benchmark, with three footings at 5m spacing
- Different spacing (As footings get closer their stress bulbs overlap, but also the pore water flow is affected)
- Different number of footings (More footings means it is harder to develop a failure mechanism, also soil is stressed to deeper levels (group effect), and pore water flow is affected)
- Normalisation of results

Numerical study of the behaviour of footing attached by frames but widely spaced so no soil interaction (influence of structural stiffness, soil variability, applied moment):

- Benchmark model, extending to single footing benchmark, with three footings at 5m spacing and stiff shear beam (10 times stiffer than soil impedance)
- Variation in structural stiffness (Change ratio of $EI_{1,2}$ and EIc, and ratio of EI_1 to EI_2) (The load redistribution from differential settlement is directly related to the stiffness of the structure)
- Variation in soil stiffness
- Asymmetric applied loads (N1 not equal to N2 or N3)
- Normalisation of results

Single footing under cyclic vertical load (Frame action effects):

- Highlight numerical to analytical and other literature models, especially under extreme cases where other settlement models are failing
- Implications and shortfalls of the proposed method

Leading and taskforce: UPorto

Contributors: ULJ

The influence of differential settlement demands the seismic response of buildings

It has been realized that differential settlements will make on minor changes to the dynamic behaviour in terms of peak response for a given shaking level. However, local damage near the differential settlement will increase and potential cause failure of the structure at lower drifts.

The assessment of vulnerability of buildings subjected to earthquake-induced liquefaction requires the definition of an integrated damage scale accounting both for ground motion damage and ground permanent movements, which cause rigid-body settlement and tilt of the building but also flexural demand on members due to differential settlement of pad footings. Nevertheless, most of the existing procedures for the estimation of differential settlements rely only in soil characteristics, thus neglecting the influence of building stiffness on the soil-structure interaction.

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Presently, studies are being developed based on simplified modelling of soil-structure variability and on preliminary assumption of force distributions, representative values of members' demand due to differential settlement are proposed. A simple approach relying on the structure-to-soil stiffness ratio and the equivalent soil degradation extent under pad footings is adopted.

The methodology is satisfactorily calibrated by means of a parametric linear analysis for a set of planar frames. Relative flexural demand due to differential settlements normalised to the seismic flexural demand are obtained. Results show that their relevance may not be very severe, thus damage assessment of differential settlements could be likely accounted separately from flexural and rigid-body demand.

The goal of the proposal rely on its simplicity and its ability to account in a simple manner for the soil-structure interaction. The procedure estimates the relative shear force demand on the first storey beams (chosen as a proxy) as a fraction of the maximum potential value corresponding to the full degradation of the soil below each pad footing settling individually, through an estimation of the structure-to-soil stiffness ratio and the equivalent soil degradation extent according to probabilistic estimation of soil variability.

Results show that, in most cases, the relevance of the potential increment of the demand on members due to differential settlements may not be very severe, thus leading to some alternatives for damage assessment in which differential settlements could be accounted separately from flexural and rigid-body demand, to some extent. The proposed tool should be carefully understood only as a preliminary, linear estimation; further research, including nonlinear analyses, is required.
Further analyses are under developments with some necessary simplified assumptions of force distribution.

Leading and taskforce: UPorto (with the collaboration fo Fernando Gomex., former Post-Doc in Liquefact, presently in University of Valencia, in Spain)

Contributors: UNICAS

Estimation of soil impedance of liquefiable deposits

It is expected that the change in soil-foundation interface stiffness will result in a change in the dynamic response of the structure especially for tall narrow structures. The change in stiffness that occurs during shaking could result in large peak and residual foundation rotations.

In this activity a "Novel" two spring model for capture foundation rotation will be implemented, modelling liquefaction with calibrated time dependent low-strain stiffness.

The quantification of the influence of changing foundation stiffness due to liquefaction in terms of peak rotation, residual rotation, peak structural response and residual structural response is an objective of this work. This implies an evaluation of the importance of the increase in residual rotation,

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to the flag-shaped hysteretic response (the reduction in foundation stiffness may causes a shift in the moment distribution within the structure).

Numerical models are being developed based on two-springs approaches, validated by push-over results from PLAXIS finite-element soil model on report for non-liquefied SDOF case (Deng experiments); for non-liquefied frame case (Mason experiments), with the aim of explain the calibrated time dependent soil spring mode.

Key characteristics of the response in comparison to a constant soil spring model to discuss how peak and residual structural displacement, peak and residual foundation rotation and peak structural acceleration, are affected by liquefaction.

Parametric studies are being undertaken with different ground motions and key parameters, like: beam depth, column depth, number of storeys, bay length, number of bays, differential settlement and hysteresis model.

Leading and taskforce: UPorto

Contributors: UNINA, ULJ

Development of fragility curves for the seismic performance of buildings on liquefied soils:

Loss estimation of buildings in liquefiable deposits

This activity is being developed to enable a simple procedure for estimating liquefaction damage at any scale, through a physics-based approach; rigid-body and differential movements will be combined for overall performance

Damage from foundation deformations is being combined with shaking damage, looking a the overall seismic loss from equivalent soil profiles from LSN.

There will be a quantification of liquefaction effects in terms of ground motions, impedance and permanent deformations, based on simple non-linear push over analysis with liquefaction and combining rigid-body and differential movements for overall performance. Empirical results will be compared with the results obtained as described before in some case studies.

Leading and taskforce: UPorto

Contributors: ULJ, IstanUni

Task 3.3 has not been addressed, but it is expected to intensify in the next months. This will be focused specifically in the two field trial tests at the two pilot sites, considering the parameters deduced from the characterization tests conducted after the application of the ground improving techniques that were applied in the pilot testing sites (WP4).

3.3 Impact (Include in this section whether the information on section 2.1 of the DoA (how your project will contribute to the expected impacts) is still relevant or needs to be updated).

WP2:

Conference papers related to WP2:

- A. Viana da Fonseca, C. Ferreira, S. Saldanha, C. Ramos, C. Rodrigues (2018). Comparative analysis of liquefaction susceptibility assessment by CPTu and SPT tests. CPT'18: 4th International Symposium on Cone Penetration Testing, 21 to 22 June 2018, Delft, The Netherlands (accepted for publication).
- C. Ferreira, A. Viana da Fonseca, S. Saldanha, C. Ramos, S. Amoroso, L. Minarelli (2018). Estimated versus measured V_S profiles and V_{S30} at a pilot site in the Lower Tagus Valley, Portugal. 16ECEE: 16th European Conference on Earthquake Engineering, 18 to 21 June 2018, Thessaloniki, Greece (accepted for publication).
- A. Ramos, R. Gomes, A. Viana da Fonseca (2018). Assessment of seismic site response based on microtremor measurements. 16ECEE: 16th European Conference on Earthquake Engineering, 18 to 21 June 2018, Thessaloniki, Greece (accepted for publication).
- C. Ramos, A. Viana da Fonseca, A. Oblak (2018). Cyclic Simple Shear and Cyclic Triaxial tests for liquefaction study in Lisbon sands. 5th Geotechnical Earthquake Engineering and Soil Dynamics, 10 to 13 June 2018, Austin, Texas, US, (accepted for publication).
- A. Viana da Fonseca, C. Ramos, C. Ferreira, A.S. Saldanha (2018). LIQUEFACT pilot site at the Greater Lisbon area: preliminary microzonation of liquefaction susceptibility. 16CNG: National Portuguese Geotechnical Congress, 27 to 30 May 2018, Ponta Delgada, Azores, Portugal (accepted, in Portuguese).

Journal papers related to WP2:

- A.S. Saldanha, A. Viana da Fonseca, C. Ferreira (2018). Microzonation of the liquefaction susceptibility: case study in the Lower Tagus Valley. Geotecnia, Portuguese Geotechnical Society journal (accepted, in Portuguese).
- A. Viana da Fonseca, C. Ferreira, A.S. Saldanha, C. Ramos, S. Amoroso, C. Rodrigues. Liquefaction susceptibility assessment based on in situ geotechnical and geophysical characterisation of a pilot site in the greater Lisbon area. Bulletin of Earthquake Engineering (submitted).

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

WP3:

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, 18 to 21 June 2018, Thessaloniki, Greece (accepted for publication).
- 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, 18 to 21 June 2018, Thessaloniki, Greece (accepted for publication).
- J. Quintero, S. Saldanha, M. Millen, A. Viana da Fonseca, S. Sargin, S. Oztoprak, M. K. Kelesoglu (2018). Numerical modelling of post-liquefaction displacement in liquefiable soils in free-field and shallow foundation buildings. 5th Geotechnical Earthquake Engineering and Soil Dynamics, 10 to 13 June 2018, Austin, Texas, US, (accepted).

Journal papers related to WP3:

- 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 (accepted to be published).

MSC thesis:

- Pedro Melchior Marques de Aguiar Barata de Tovar (2018). Numerical simulation of the effects of liquefaction in shallow foundation. MSc Thesis, Univesity 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.

UPORTO were active in ***WP9 Consortium/Project Management.***

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

3.3.4. Universita degli Studi di Napoli Federico II. (UNINA)

1st July 2017 – 31st January 2018

The activity of UNINA in the period from July 1st 2017 – January 31st 2018 is described with reference to the objectives declared in the different work packages where UNINA is involved.

UNINA were active in ***WP9 Consortium/Project Management.***

Please see appendix 2 for a description of UNINA's activity during this reporting period.

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

3.3.5. Trevi Societa per Azioni (TREVI)

1st July 2017 – 31st January 2018

The activity of TREVI in the period from July 1st 2017 – January 31st 2018 is described with reference to the objectives declared in the different work packages where TREVI is involved.

23/01/2018 Project Progress Update

<u>WP4</u>

By the end of September all preliminary in-situ investigations, both physical and geo-physical, have been completed. Core boxes and all soil samples collected have been sent to the Geotechnical Laboratory of the University of Naples.

A report reassuming all activities carried out and the main preliminary results has been written and will be included into deliverable D4.3 "Report on Demonstration of retrofitting techniques".

Since October 2017 the Job site in Pieve di Cento has no activity on going. The second main set of activities on site is supposed to start next spring in order to provide installation of Horizontal Drainage Pipes and Induced Partial Saturation pipes into the ground. In a Third jobsite phase these two liquefaction mitigation technologies will be tested.

This is why since November 2017 our effort for this Work Package mainly moved from site to a desk: several meetings/phone call have been done with the WP4 leader in order to move steps forward with the jobsite layout drawing (on the basis on the new information collected) and allow us to ask for all the RFQ (request for quotation) we do need. Main topics are the choice of pipe diameters and finalize their number together with the kind of Pore Pressure Transducers that will fit our necessity the best. These choices are strictly linked to other tasks of WP4 (centrifuge, lab tests ecc.)

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WP8

Dissemination and Exploitation activities have been brought up to speed. There is strong interactivity and a continuous share of information, ideas and know-how between TREVI-FIN Communication Department and UNICAS.

Using socials (Twitter, Facebook and LinkedIn) a brilliant prominence to the Consortium Meeting hold in Naples last October has been given. This activity started two weeks ahead the event and finished one week later the end of the consortium meeting, in this way we believe did our best to keep maximum the attention of our stakeholders through all the process.

During last Consortium Meeting it was agreed to start to send a LIQUEFACT NEWSLETTER to our stakeholders on a four months basis. TREVI-FIN Communication department first of all built a mailing list of all stakeholders improving the existing list coming from the Workshop of Bologna with several other addresses. The stakeholders mailing list today has 545 mail addresses.

All material coming from each Working Package Leader has been collected, reviewed and sent using MAILCHIMP software: the first NEWSLETTER has been sent on September the 10th. We are currently working in order to collect material for the second NEWSLETTER.

Another important topic for WP8 is to follow, give advices and, at the end, make a film able to promote Consortium activities going through each Working Package. This activity just started together with UNICAS.

It deserves to be mentioned also the activity of maintenance and improvement of Liquefact website carried out by us during this period.

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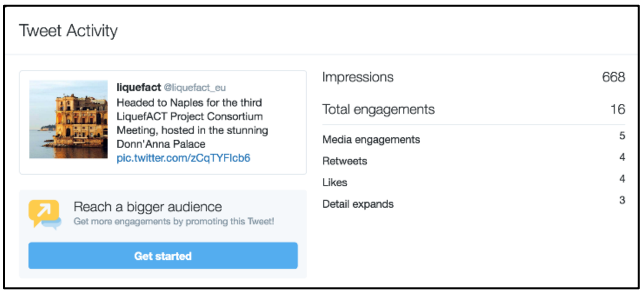

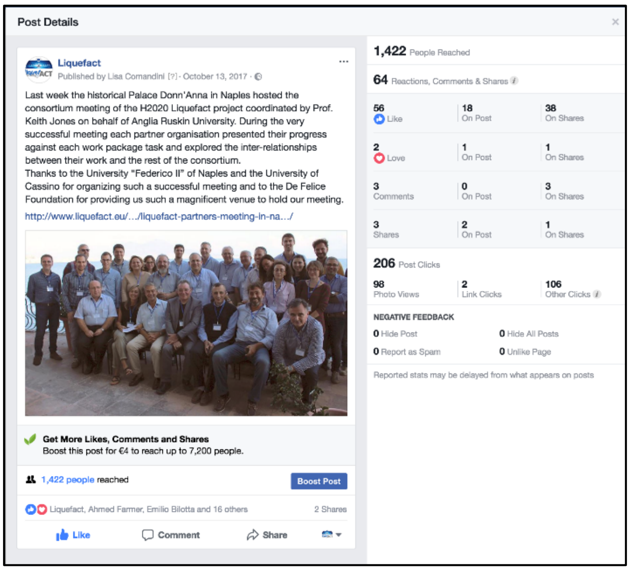

WP9

Project management activities during this period have been mostly linked to the Consortium Meeting hold in Naples. TREVI handled two presentations one for WP4 and another for WP8 in order to show and keep up to date all partners on the activities carried out in these two WPs were we are involved the most.

TREVI were active in ***WP9 Consortium/Project Management.***

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

3.3.6. Stiftelsen Norsar (NORSAR)

1st July 2017 – 31st January 2018

The activity of NORSAR in the period from July 1st 2017 – January 31st 2018 is described with reference to the objectives declared in the different work packages where NORSAR is involved.

Liquefact Project Progress Report - NORSAR Activity Summary

The activity undertaken by NORSAR for the period of July 1, 2018 – January 31, 2018 covered two main parts: the first part was about continuing in following and reviewing the deliverables from WP2, WP3, WP4 and WP5 and getting familiar with the various methodologies and procedures that have been developed and suggested by the WPs partners, and in the second part, the activity undertaken covered preparation and drafting strategies for the development of protocols were the various outputs from the LIQUEFACT consortium partners can be integrated and to software toolbox that will provide civil engineers and relevant stakeholders guidance in making informed assessments on the feasibility and cost-benefit of applying certain liquefaction mitigation techniques for a given earthquake-induced liquefaction threat (Figure 1).

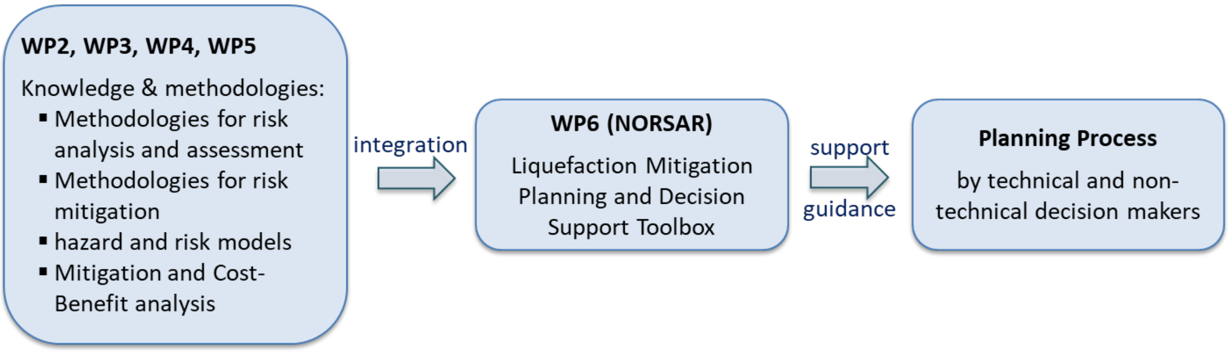

Figure 1: Framework for Liquefaction Mitigation Planning and Decision Support

<u>1- Reviewing and getting familiar with outcomes from WP2, WP3, WP4 and WP5</u>

Started earlier in 2017, NORSAR team has continued in reviewing and getting familiar with the various methodologies and procedures that have been developed by the LIQUEFACT consortium partners in WP2, WP3. This part of activity has also included the examination of various potential challenges and issues in integrating the methodologies and procedures into a software toolbox. This activity has allowed in getting a clear image and identify the expected protocols to be developed, including:

- Protocols related to liquefaction susceptibility modelling and computation of Liquefaction Severity Number (LSN) for a given ground shaking level.
- Protocols related to liquefaction demand and damage ratio computation for a given Liquefaction Severity Number.

With respect to WP4 and WP5, NORSAR team are also undertaking activities that would lead to the development of Protocols that can be associated to the different mitigation options and cost-given certain conditions benefit analysis related to the characteristics of site and structure, environmental

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conditions and community resilience …etc. A report containing the various outcomes of the literature review and protocols development associated to WP4 and WP5 is under development and will be later shared with the partners involved in WP4.

2- Designing protocols for software development perspective

Starting from October 1, 2017, NORSAR has initiated the works on WP6 through the implementation of Task 6.1 which is dealing with the development of the LRG software toolbox for liquefaction mitigation planning and decision support. The LRG toolbox will have two different options with respect to the scale and resolution of the analysis, i.e. dealing on an individual level (single building or infrastructure facility located on an individual site) and on a city/region level (building and infrastructure typologies located within a certain geographical unit) with procedures for additionally calculating socio-economic impacts and proposing risk reduction and resilience improvement strategies. Considering the extensive experience of NORSAR in research and development of advanced software tools, the envisaged LRG software toolbox will be designed in a way that the amount of efforts and time required to learn how to be use will be minimized through an easily understandable design. The software will be structured to provide outputs that can easily be understood by non-technical decision makers during the planning process for design and assessment. Deliverable report D6.1 "*Software toolbox for liquefaction mitigation planning and decision support*" is under development and will be delivered in M24. The report will contain information on the functionality of the various protocols and modules as well as the methodologies/procedures to be integrated, the different…etc.

3- LIQUEFACT consortium partners face-to-face meetings

The NORSAR team has attended the consortium partners face-to-face meetings in Naples on October 3 – 6, 2017, where several issues and challenges have been discussed in order to get clear directions on how the various work packages should be developed. Moreover, the NORSAR team has attended a one-day face-to-face meeting in Rome on November 17, 2017. The agenda of the meeting was to exercise applications on the various steps to be conducted by a future End-user (an engineer and decision-maker) for liquefaction mitigation planning, starting from defining hazard, evaluation of risk, and mitigation action based on cost-benefit analysis. The one-day meeting has allowed establishing a common working practice to ensure that activities undertaken in various work packages produce outputs that are directly useable for an effective and successful LRG software development.

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4- Presentation of LIQUEFACT project results

The NORSAR team has presented a poster on the LIQUEFACT project during a recent symposium on geohazards in Oslo on October 19, 2017.

Blum, C., Meslem, A., and Lang, D.H. (2017). The LIQUEFACT Project: Developing a more comprehensive understanding of Liquefaction Events in Europe, Abstract and Poster Presentation at Geofaredagen, Norwegian Geotechnical Institute (NGI), Oslo, Norway, October 19, 2017.

NORSAR were active in ***WP9 Consortium/Project Management.***

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3.3.7. Univerza v Ljubljani (ULJ) and 9. SLP Specializirano Podjetje za Temeljenje Objektov, D.O.O, Ljubljana (SLP)

1st July 2017 – 31st January 2018

The activity of ULJ and SLP in the period from July 1st 2017 – January 31st 2018 is described with reference to the objectives declared in the different work packages where ULJ & SLP are involved.

Summary of activities on Liquefact project by University of Ljubljana and SLP

In this period, the work continued predominantly on WP2 and WP3. Activities for WP4 were planned for January 2018 but are currently foreseen for February 2018.

WP2:

A draft paper has been prepared from the data collected at Lake Bohinj with the aim to solve the question whether or not Bohinj lake shore slid into the lake during 1998 earthquake due to liquefaction. In-situ investigations and later numerical work confirmed that the cause of this particular slide was not liquefaction (unfortunate for the project) but earthquake induced landslide of loose gravel. The paper will be submitted for publication in Slovenian journal Geologija.

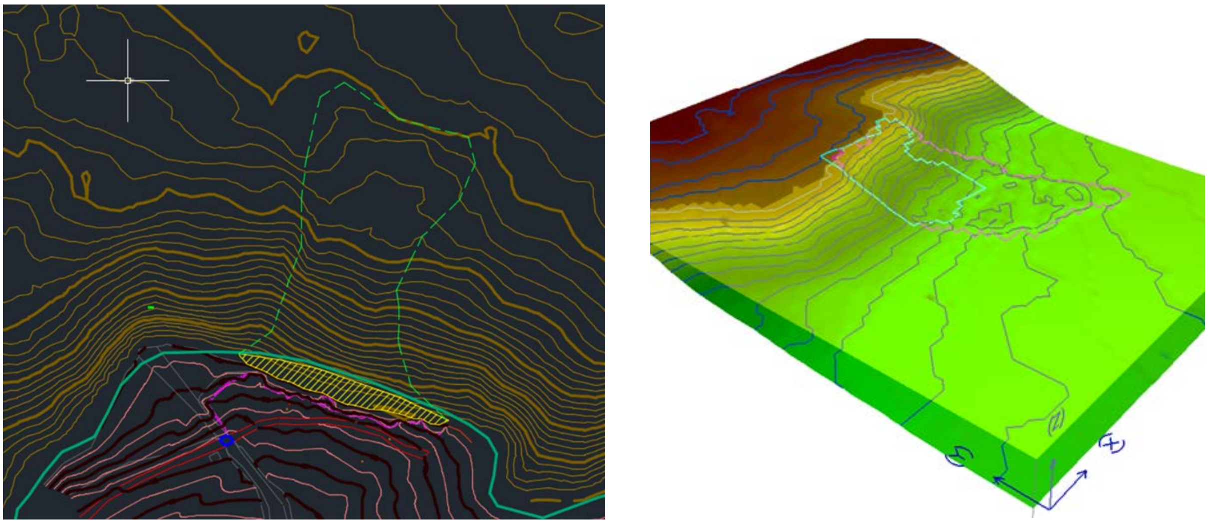

Figure 1: Comparison of observed extent of slide area from bathymetric measurements (left) and calculated by LS-Rapid software (right)

The preparations have been made for the task 2.6 on microzonation of our main test site at hydropower plant Brežice. Our test site has been visited in order to perform some additional testing

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as planned but due to the ongoing works around hydropower plant the situation has changed and the decision was taken that additional works will only be carried out if necessary for the task 2.6.

WP3:

In this period, we have cooperated closely with Porto University for the detailed definition of all necessary steps and details to calculate fragility curves for buildings.

During the consortium meeting in Naples (2nd – 6th October 2017) it was decided that all numerical liquefaction analyses will be performed using FLAC software since it is the only widely available software that allows for the pore pressure dissipation during dynamic loading. Since our group planned to work with another code, we had to purchase FLAC and start with training. In order to speed-up this process, Aleš Oblak went to Porto University in January 2018 for 2 weeks. In Naples meeting, the decision has been adopted that our group will deal with the development of fragility curves for embankments as a common element of infrastructural facilities. Nevertheless, the structural group of University of Ljubljana is in constant close contact with structural group from Porto University. We will continue to work on fragility of structures as well and we will ask for the change in distribution of person-months shortly. The proposal in under preparation.

WP4:

Matej Maček planned a visit in the laboratory of Naples in January 2018 to study their procedures to test the influence of partial saturation on the liquefaction susceptibility. Due to the planned work progress in Naples the visit is postponed for February 2018.

Events:

We have attended the consortium meetings in Brussels on 11th and 12th September 2017 (presentation of 1st periodic report of the project), Naples from 3rd to 6th October 2017 and in Rome on 17th December 2017.

Janko Logar attended the International Conference on Soil Mechanics and Geotechnical Engineering in Seoul, South Korea in September 2017 where liquefaction was one of the main topics.

Aleš Oblak visited research group at Porto University from 8th to 19th January to work together on the tasks for WP3.

ULJ and SLP were active in ***WP9 Consortium/Project Management.***

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

1st July 2017 – 31st January 2018

The activity of UNICAS in the period from July 1st 2017 – January 31st 2018 is described with reference to the objectives declared in the different work packages where UNICAS is involved.

Please see appendix 3 for a description of UNICAS' activity during this reporting period.

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

1st July 2017 – 31st January 2018

The activity of SLP in the period from July 1st 2017 – January 31st 2018 is described in the joint report submitted with Univerza v Ljubljani (ULJ) as detailed in section 7.

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3.3.10. Istituto Sperimentale Modelli Geotecnici Societa a Responsabilita Limitata (ISMGEO)

1st July 2017 – 31st January 2018

The activity of ISMGEO in the period from July 1st 2017 – January 31st 2018 is described with reference to the objectives declared in the different work packages where ISMGEO is involved.

Please see appendix 4 for a description of ISMGEO's activity during this reporting period.

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3.3.11. Istanbul Universitesi (Istan-Uni)

1st July 2017 – 31st January 2018

The activity of Istan-Uni in the period from July 1st 2017 – January 31st 2018 is described with reference to the objectives declared in the different work packages where Istan-Uni is involved.

Liquefaction studies

During this period, an intensive study was carried out regarding liquefaction calculations. A detailed literature study was performed and case studies where liquefaction occurred were selected. The case studies that were performed by Sancio (2003) in Adapazari were given more emphasis. Analyses were then carried out on these case studies. The analyses can be classified in two parts; analytical and numerical studies.

Data from Sancio (2003) covers Adapazari liquefaction data for some selected sites, where liquefaction settlements were observed.

- Among those, Site A was studied numerically using Plaxis 2D and analytically using the methods in the literature. The settlements that were calculated were compared with the data given by Sancio (2003). These studies are going on.
- Site F and Site C Sancio (2003) were also modelled by Plaxis 2D. The calculations have been completed for site F and the calculations are now going on for Site C. A centrifuge test which was tested in a laboratory was also modelled in Plaxis 2D.
- A monotonic triaxial test in Sancio (2003) which was carried on Adapazari silts from Site F was modelled by Plaxis 2D. The modelling studies are being continued for CDSS and CTX tests.
- Another modelling of CDSS laboratory test given in Onalp and Arel (2009) was also performed. The test was carried on in order to determine the engineering properties of Adapazari silts. This modelling was carried out in order to obtain the f_{achard} and f_{acpost} parameters which will be used in UBC sand model. A parametric study was carried out to obtain the best fitting parameters for Adapazari silts. This model was also studied with FLAC3D V6 but the application was not successful since the data that was needed for the liquefaction analyses were found to be very hard to determine. Therefore the analyses were not continued.

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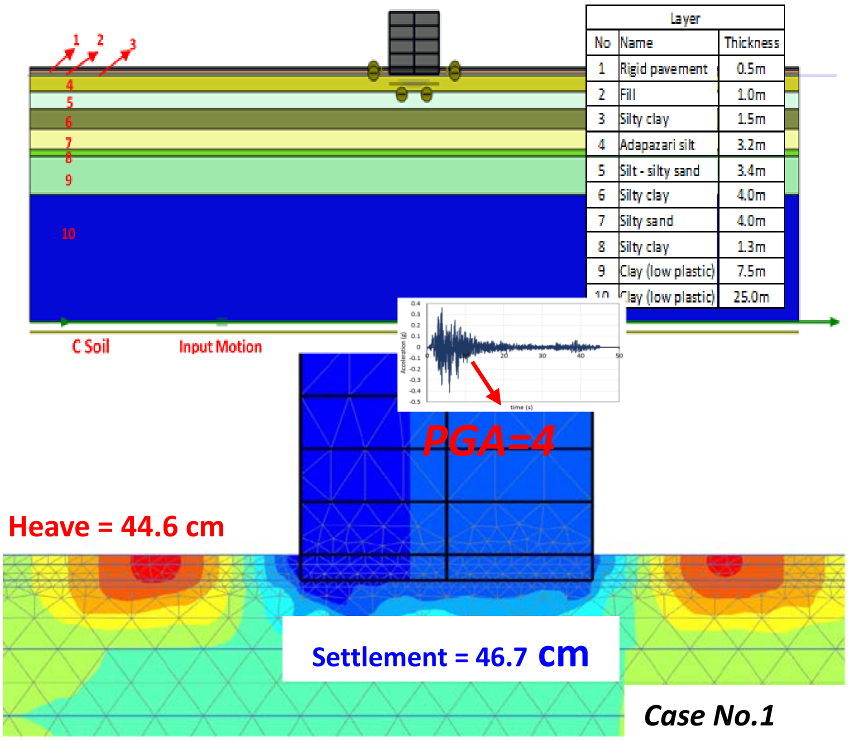
- Through the preceding period of the Project, soil models constituted for the liquefaction analyses were investigated. Particularly, Pm4Sand model, embedded in the Flac2D finite difference software was investigated among various existing models i.e. UBCSAND, PM4Sand, Wang, NTUA-Sand. Some of these models are fully coupled effective stress type of constitutive models. The parameters required to run such advanced soil models are difficult to estimate, thus the calibration of the soil model requires serious efforts with the centrifuge tests available in the literature. Ziotopoulou and Montgomery (2017) studied the centrifuge test carried out by Dashti et al. (2010) in order to validate the earthquake induced liquefaction effects on shallow foundations by using Pm4Sand. The results of these tests will form the basis to validate our liquefaction model. These studies are going on.

Some figures obtained within these studies are presented below as Figure 1.



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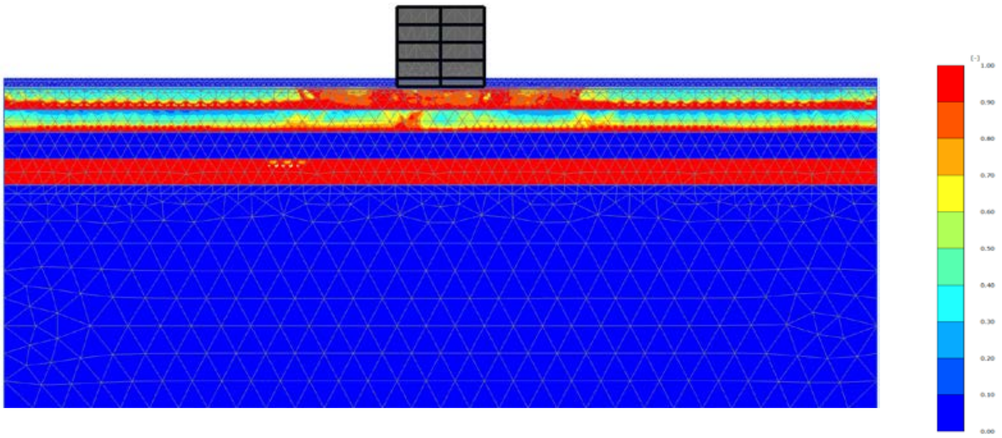

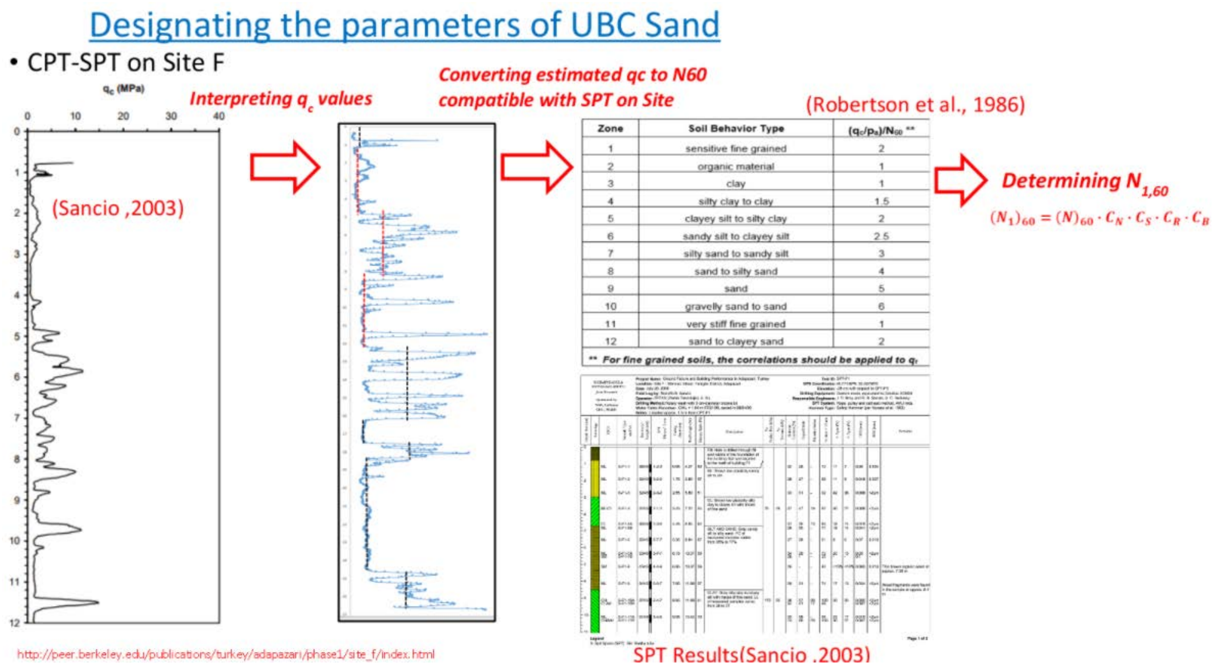

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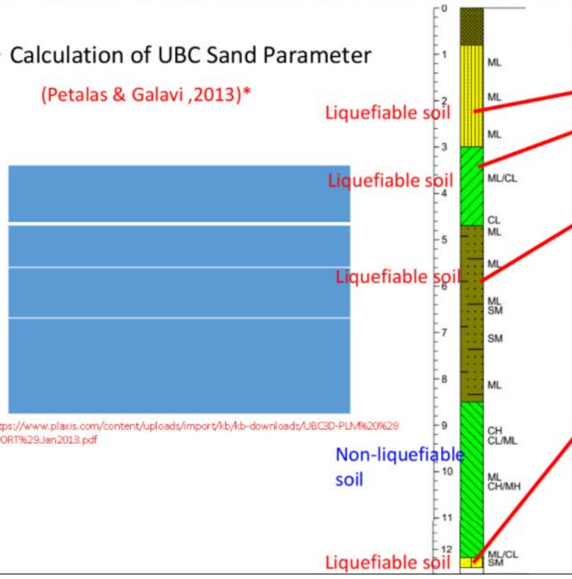
Designating liquefiable parameters of UBC Sand

- Calculation of UBC Sand Parameter

(Petalas & Galavi ,2013)*



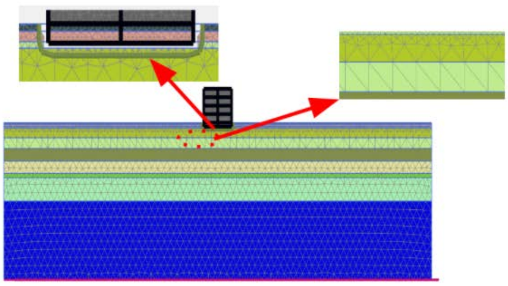
*https://www.plaxis.com/content/uploads/import/kb/kb-downloads/UBC3D-PLM%20%28REPORT%29.Jan2013.pdf

Table 3 - Input parameters of the UBC3D-PLM model in PLAXIS

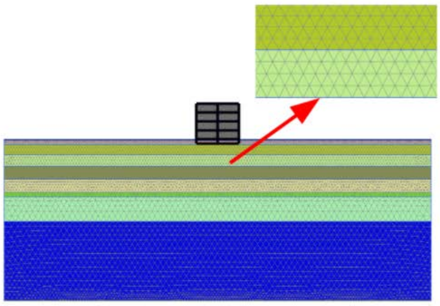
	Parameter	Unit	Adapazari Silt (4) [Best Inp.]	Silt-Silty Sand (5)	Silty Sand (7)	Adapazari Silt (4) [lower]	Adapazari Silt (4) [upper]
UBC Sand Input Parameters	Constant volume friction angle (φ_{cv})	(°)	30	30	30	30	30
	Peak friction angle (φ_p)	(°)	31	31	30	30.4	31.6
	Cohesion (c)	kPa	-	-	-	-	-
	Elastic shear modulus (K^e_G)	-	872.1	1162	1049	688.7	945
	Elastic plastic modulus (K^p_G)	-	123.[illegible]	448.5	301.4	108.3	125.5
	Elastic bulk modulus (K^e_B)	-	[illegible]10.5	213.3	734.3	482.1	661.5
	Elastic shear modulus index (ne)	-	0.5	0.5	0.5	0.5	0.5
	Elastic bulk modulus index (me)	-	0.5	0.5	0.5	0.5	0.5
	Plastic shear modulus index (np)	-	0.4	0.4	0.4	0.4	0.4
	Failure ratio (R_f)	-	0.933	0.779	0.805	0.991	0.864
	Atmospheric pressure (PA)	kPa	100	100	100	100	100
	Tension cut off (σ_t)	kPa	0	0	0	0	0
	Densification factor (fac_{hard})	-	1	1	1	1	1
	SPT value $(N_1)_{60}$	-	3	10	8	2	5
	Postliquefaction factor (fac_{post})	-	1	1	1	1	1
Interface properties	Oedometer modulus of soil (E^{ref}_{oed})	kPa	6569	44830	53090	6569	6569
	Cohesion at references stress (c'_{ref})	kPa	1	1	1	1	1
	Internal friction angle (φ')	(°)	30	31	30	30	30
	Dilation angle (ψ)	(°)	0	1	0	0	0

Inaccurate inputs for previous analyses

2. Before re-running the new analyse, finite element mesh was refined and interface elements omitted



Previously Model View



Modified Model View

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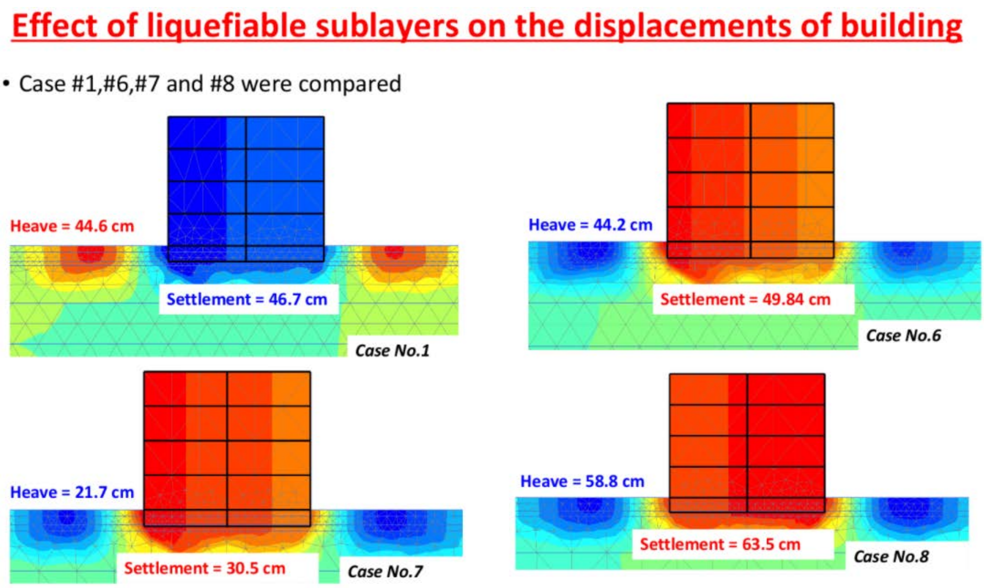

Figure 1. Example outputs and screenshots from the analyses

- A paper was written together with Porto University for the GEESD V 2018 conference which will be organized by ASCE. The paper is under review.
- A conference paper regarding our contribution in Work Package 2.1. was presented to 16th European Conference on Earthquake Engineering.The paper is under review.
- A paper was presented in 9th Congress of Balkan Geophysical Society which was organized in Antalya, Turkey regarding our contribution in Work Package 2.1.
- A poster was presented in AGU Fall Meeting in New Orleans, USA.

Microzonation studies

Another contribution to the project was made by our team member from Geological Department. The work carried out is within the context of Work Package 2.6 As a preliminary work, we obtained the maps of geology maps, shear wave velocity (Vs) maps and ground water level maps for Marmara Region, in which our test site was selected. Using this data, we then prepared microzonation maps for liquefiable and non-liquefiable sites. In the further stage, we need to verify these maps using boreholes, laboratory tests and SPT (if any) and/or CPT tests, which have been carried out in these areas. Therefore we contacted some municipalities and Ministry of Hazards to obtain the field tests

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and microzonation reports/maps. It should be recalled that many cities have implemented microzonation studies in Turkey, beginning from 1999 Adapazari Earthquake. After piling up all the data, we are planning to synthesis and interpret them using UNIPV's microzonation documents. Below is a figure (Figure 2) created within the context of this study. It should be noted that this a preliminary map and may be subject to change in the further stage.

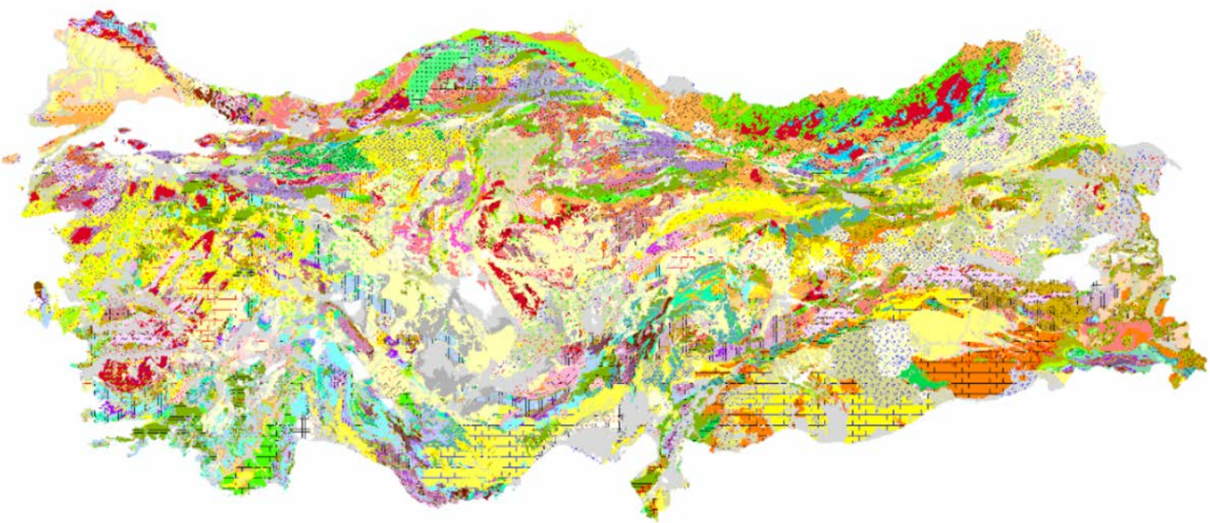

Figure 2. A preliminary map prepared within Work Package 2.6.

References:

K. Ziotopoulou, J. Montgomery (2017), "Numerical Modelling Of Earthquake-Induced Lıquefactıon Effects On Shallow Foundations" 16th World Conference on Earthquake Engineering, 16WCEE 2017, Santiago Chile

Dashti, S, Bray JD, Pestana, JM, Riemer, MR, Wilson D. (2010). "Mechanisms of Seismically-Induced Settlement of Buildings with Shallow Foundations on Liquefiable Soil". Journal of Geotechnical and Geoenvironmental Engineering, ASCE, 136 (1), 151-164.

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

Sancio, R.B. (2003), "Ground Failure and Building Performance In Adapazari, Turkey", Ph.D. Thesis, University of California, Berkeley.

Arel, E., Onalp, A. (2012), "Geotechnical Properties of Adapazari Silts", Bulletin of Engineering Geology and Environment, Springer, 71(4), 709-720.

Istan-Uni were active in ***WP9 Consortium/Project Management.***

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4. Deliverables

Del No	Deliverable name	WP No	Lead Beneficiary	Type	Dissemination Level	Del. Date (annex I)	Actual Delivery Date	Status	Comments
D34	LIQUEFACT project website	8	UNICAS	Website	PU	31/05/16	20/06/16	Approved	
D1	A report on the challenges to improve community resilience to EILD events.	1	ARU	Report	PU	31/07/16	30/07/16	Approved	
D40	Project Management Plan	9	ARU	Report	CO	31/07/16	27/07/16	Approved	
D41	Quality Procedures Manual	9	ARU	Report	PU	31/07/16	27/07/16	Approved	
D2	Proceedings of the first stakeholder/end-user workshop: including the workshop presentations.	1	UNICAS	Other	CO	31/08/16	31/10/16	Approved	
D3	Report outlining a risk based assessment and resilience improvement framework	1	ARU	Report	PU	31/10/16	31/10/16	Approved	
D42	Project Board Management Report 1	9	ARU	Report	CO	31/10/16	31/10/16	Approved	
D55	Data Management Plan v1	9	ARU	ORDP	PU	31/10/16	31/10/16	Approved	
D4	Detailed user requirements and research output protocols for the LIQUEFACT Reference Guide; in line with second workshop outcome	1	ARU	Report	PU	30/11/16	30/11/16	Approved	
D43	Periodic Project Progress Report 1	9	ARU	Report	PU	30/11/16	30/11/16	Approved	
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	2	UNIPV	Report	CO	31/01/17	30/01/17	Approved	

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

D6	GIS platform including data for liquefaction hazard assessment in Europe (version 1)	2	UNIPV	Other	CO	30/04/17	28/04/17	Approved	
D20	Report on individual stakeholder and urban community performance metrics	5	ARU	Report	PU	30/04/17	19/05/17	Approved	
D21	Data collection toolkit for community resilience case studies (for WP6/7)	5	ARU	Other	PU	30/04/17	22/05/17	Approved	
D44	Project Board Management Report 2	9	ARU	Report	CO	30/04/17	28/04/17	Approved	
D45	Periodic Project Progress Report 2	9	ARU	Report	PU	30/06/17	25/09/17	Approved	
D56	Data Management Plan v2	9	ARU	Other	PU	30/06/17	23/06/17	Approved	

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5. Milestones

Milest. no.	Milestone title	Related WP(s) no.	Lead beneficiary	Delivery date from Annex 1	Means of verification	Achieved	Comments
1	Comprehensive project scoping complete	WP1, WP8, WP9	ARU	01/11/2016	D34 D1 D40 D41 D2 D3 D42 D55 D4 D43	*YES*	
2	Case study sites prepared and analysed		UNIPV	01/02/2017	D5	*YES*	
3	European liquefaction hazard GIS map platform established		UNIPV	01/05/2017	D6	*YES*	

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6. Critical implementation risks and mitigation actions

6.1 Foreseen Risks

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

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4	Possible technical or legal obstacles to produce dynamic actions on site to check 'directly' the effectiveness of the soil liquefaction mitigation techniques under study	4	The technologies that we are thinking to produce dynamic actions have been already used elsewhere, provided that local restrictions have been respected. The effectiveness of liquefaction mitigation techniques can be correctly checked also by indirect methods (laboratory and in-situ testing) without risk of failure.

6.2 Unforeseen Risks

The following table lists the Risks identified in Annex 1. The table is read-only and it is provided as a reference for the State of Play table below. **Risk Number**	**Description of Risk**	**Work Packages Concerned**	**Proposed risk-mitigation measures**
U1	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.	4	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

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	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.		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.
U2	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.	9	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 2 3) All beneficiaries will take part in quarterly budget meetings
U3	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.	2, 3, 4, 5, 6, 7, 8, 9	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

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			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
U4	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.	2, 3, 4, 5, 6, 7, 8, 9	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.
U5	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,	6, 9	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

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	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.		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.
U6	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.	2, 3, 4, 5, 6, 7, 8, 9	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

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7. Dissemination and exploitation of results

No scientific publications to date

7.1 Dissemination and communication activities

Type of dissemination and communication activities	**Number**
Organisation of a Conference	1 Consortium Meeting, Italy
Organisation of a Workshop	1 Sprint Test, Italy
Press release	-
Non-scientific and non-peer reviewed publications (popularised publications)	-
Exhibition	-
Flyers	-
Training	1 Intranet training
Social media	5 (Facebook, YouTube, LinkedIn, Twitter, Google+)
Website	1 internet, 1 intranet
Communication campaign (e.g. radio, TV)	http://www.lepida.tv/
Participation to a conference	1
Participation to a workshop	-
Participation to an event other than a conference or workshop	4
Video/film	1
Brokerage event	-
Pitch event	-
Trade fair	-
Participation in activities organised jointly with other H2020 project(s)	-
Other	-
Total funding amount	

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

8. Gender

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

Gender dimension in the project

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

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Appendices

Appendix 1

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

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

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

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

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Appendix 2

REPORT Period 01.07.17 – 31.01.18

UNINA

Index

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T4.2 Small scale centrifuge modelling (leader ISMGEO)

T4.2.1 DESIGN OF THE MODEL STRUCTURE FOR CENTRIFUGE TESTS

As a part of support activity of UNINA to T4.2, the design of a model structure to be used in centrifuge tests has been carried out, as described in the followings.

T4.2.1.1 Design of model structure

Some tests in the centrifuge consider the percent of the structure model on the top of the ground. The sizing and the design of this model was carried out assuming as a target natural period that of two-story masonry buildings.

Figure *T4.2.1* shows the final drafts of the model that has been designed.

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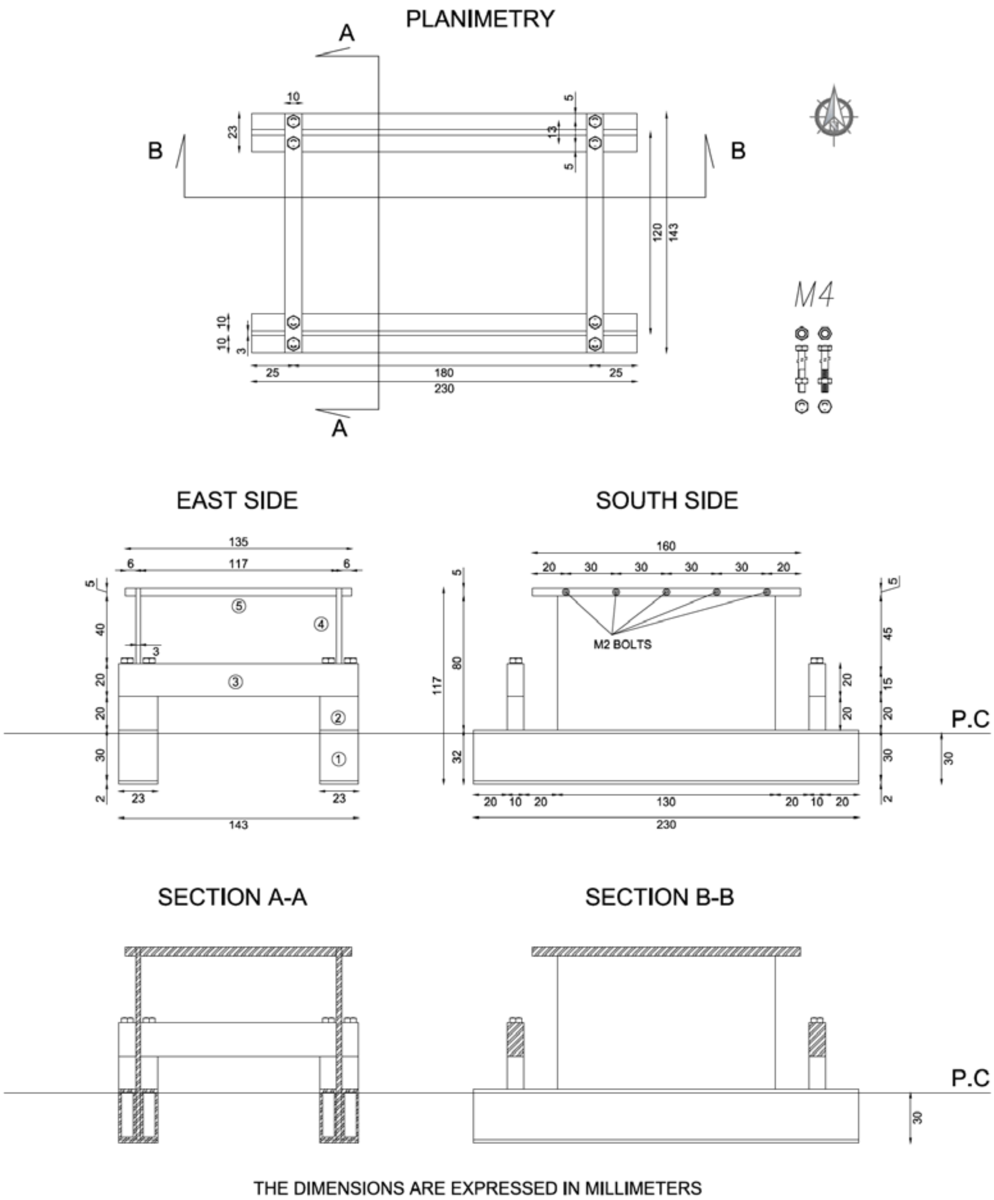

Figure T4.2.1: Model of structure for tests in the centrifuge.

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T4.3 Field trials at the selected case study pilot testing site (leader TREVI)

T4.3.1 SUPERVISION OF FIELD ACTIVITIES

In its roles within T4.3, UNINA was in charge of planning the field trial (Pieve di Cento - BO) and interpreting the results. UNINA supports TREVI during the months from July to September 2017 with the aim to supervise the in situ geotechnical and geophysical investigation, the soil sampling by the traditional Osterberg sampler and the new Gel-Pusher sampler, for laboratory characterization.

The geotechnical characterization of the soils prior the treatment is indispensable to have a reference "zero" condition.

TREVI did the following geotechnical and geophysical in situ tests (Fig.T4.3.1 and Fig. T4.3.2):

- Boreholes with continuous soil sampling (CH1, CH1bis, CH2, Ch3, CH4, CH5)
- Undisturbed sampling (Osterberg and Gel Pusher samplers)
- Piezocone penetration tests (CPTU1, CPTU2, CPTU3, CPTU4, CPTU5)
- Seismic Cross hole and Tomographic electrical survey (Technical Report by Trevi Spa, Oct. 2017).

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Figure *T4.3.1.* . Photos of the in situ investigation in Pieve di Cento (BO, Italy)

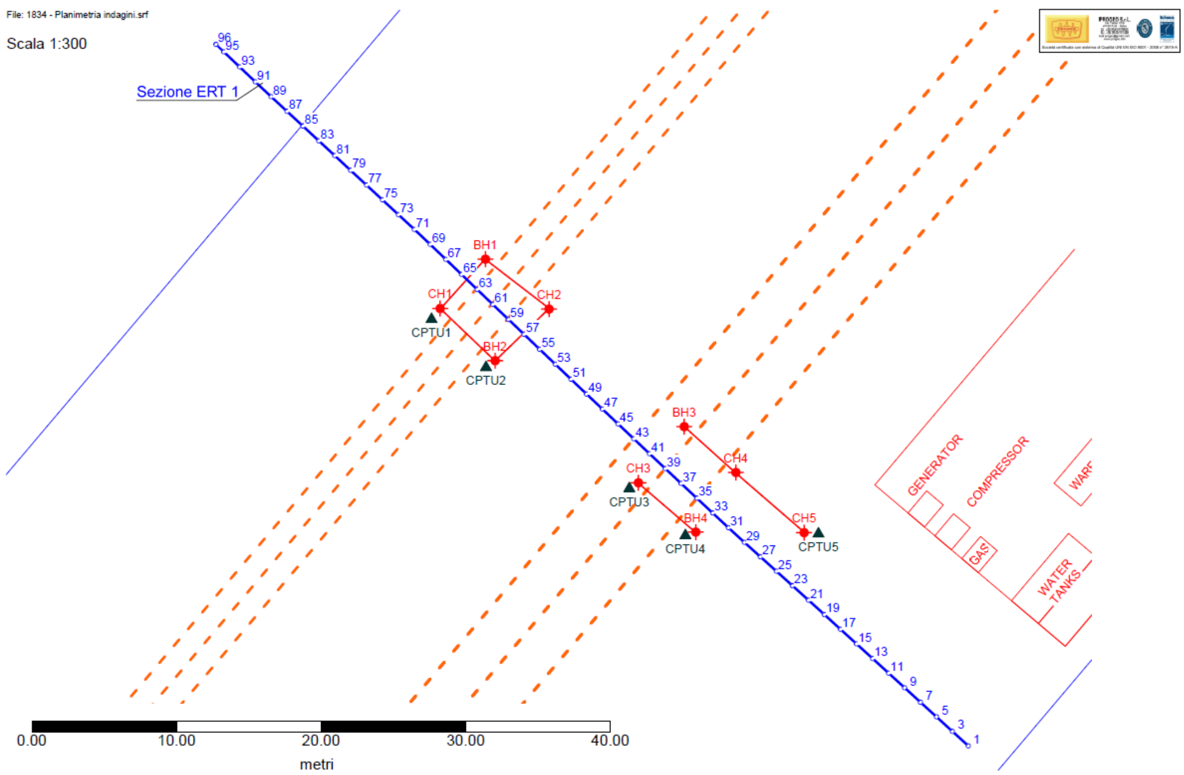

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Figure T4.3.2. Plan view of the trial field

Boreholes	date	Osterberg (m)	Gel Push (m)
CH1	04/09/2017		
CH1 BIS	08/09/2017	2,0-2,5	2,5-3,5
		3,5-4,0	
CH2	06/09/2017	3,0-3,5	4,5-5,5
		4,0-4,5	
CH3	06/09/2017	2,50-3,00	3,5-4,5
		4,50-5,00	
CH4	07/09/2017	2,00-2,50	5,0-6,0
		4,50-5,00	
CH5	11/09/2017	2,0-2,5	2,00-3,00
		3,5-4,0	

Figure T4.3.3. Undisturbed samples retrieved in the trial field

T4.3.2 PROCESSING OF THE IN SITU DATA

T4.3.2.1 CPTU tests

The CPTU tests results (Fig. T4.3.4) have been processed in order to obtain:

- Soil behavior type index Ic (Fig. T4.3.5) that highlighted that at a depth of 6 m from the ground level, there is a layer of clayey non liquefiable soil: this is confirmed also by the boreholes sampling and by the pore pressure measured during the CPT tests. Furthermore a thin layer (30-50 cm) of clayey soil is located at a depth of 4.5 m from the ground level.
- Peak friction angle φ and relative density Dr (Fig. T4.3.6) of sandy soils ($0<z<4.5$; $5<z<6$ m).
- Small Strain Shear modulus G_0 (Fig. T4.3.7).
- Normalized cone penetration resistance q_{c1N} (Fig. T4.3.8a) and clean-sand equivalent normalized cone penetration resistance q_{c1NS} (Fig. T4.3.8b).

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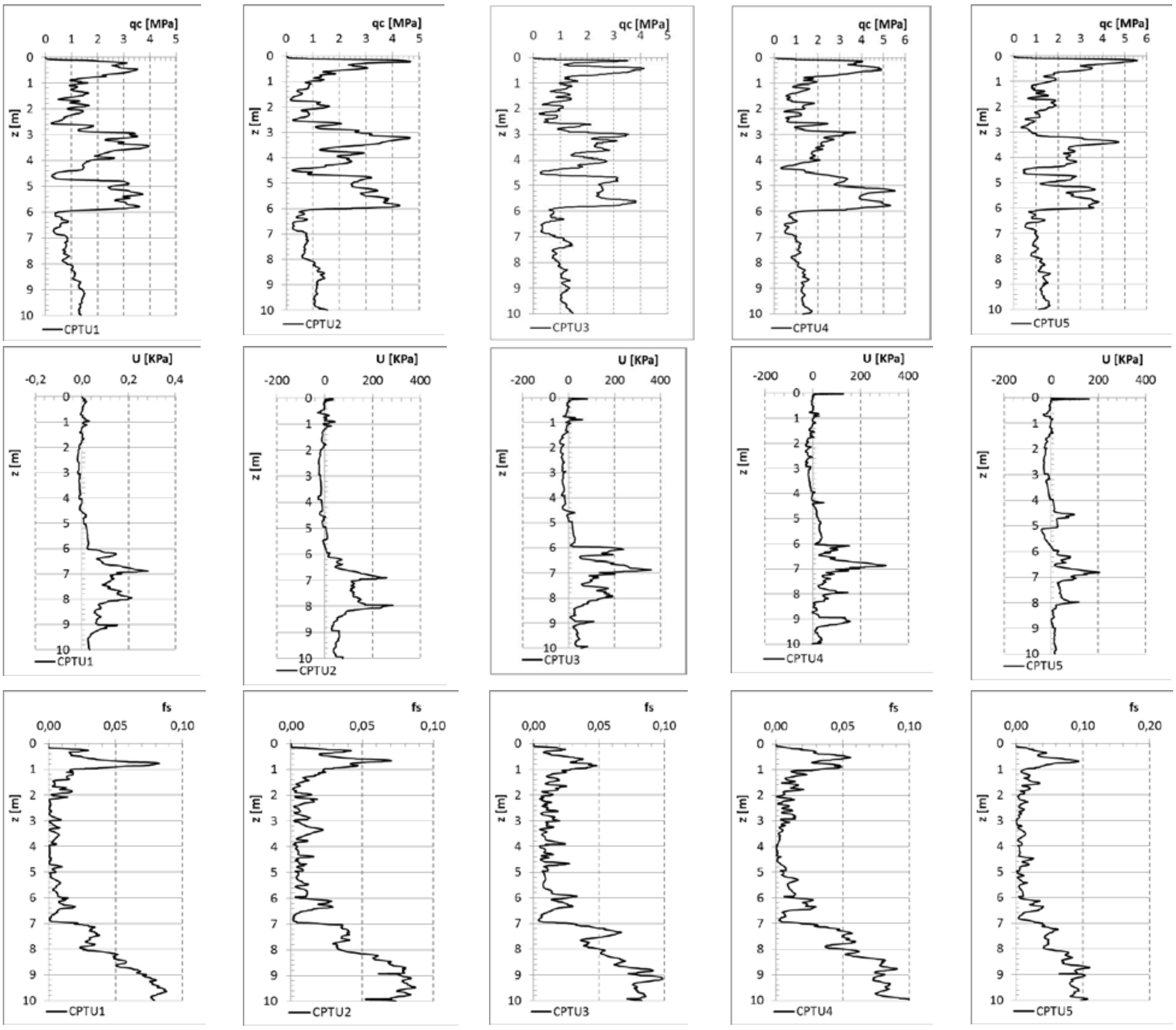

Figure T4.3.4. Piezocone penetration tests results: cone resistance qc, pore pressure u and sleeve friction fs.

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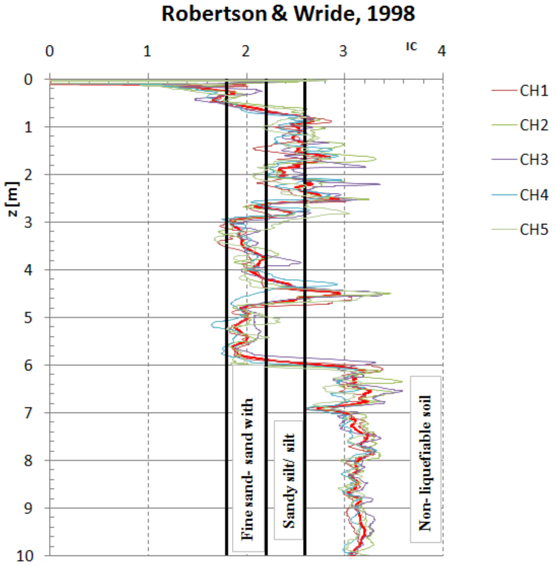


Soil behaviour type	I_c
Fine sand - sand with silt	1.8 – 2.2
Sandy silt / silt	2.2 – 2.6
Non-liquefiable soil[1]	> 2.6

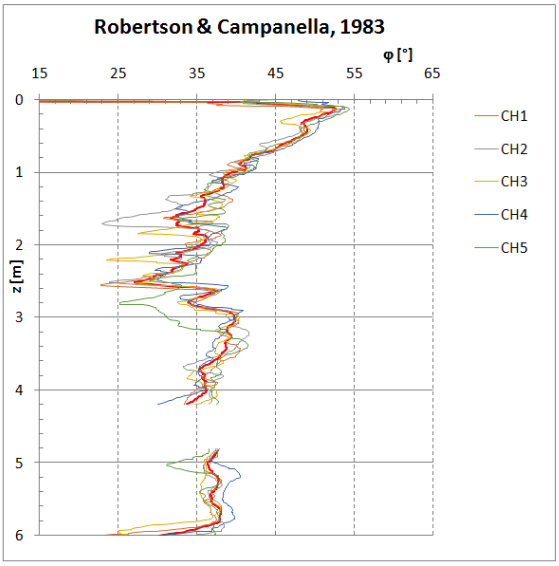
[1]Plastic silt or clayey soil

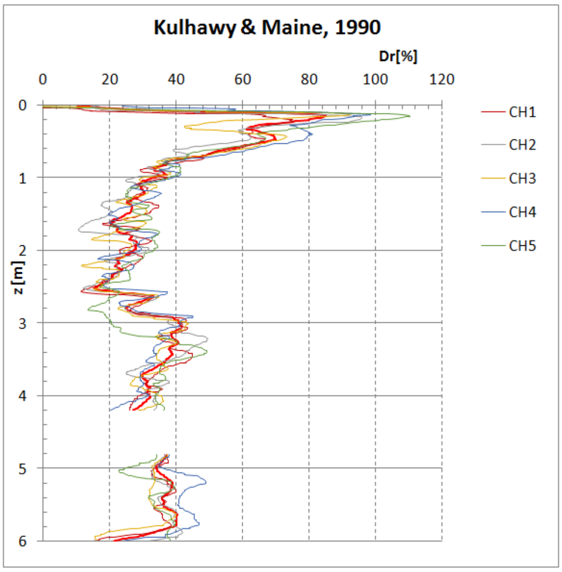
$$I_c = \left[\left(3.47 - \log(Q)\right)^2 + \left(1.22 + \log(F)\right)^2\right]^{0.5}$$

$$Q = \left(\frac{q_c - \sigma_{vc}}{P_a}\right)\left(\frac{P_a}{\sigma'_{vc}}\right)^n$$

$$F = \left(\frac{f_s}{q_c - \sigma_{vc}}\right) \cdot 100\%$$

Figure T4.3.5. Soil behavior type Ic (Robertson & Wride, 1998).





$$\phi' = \arctan\left[0.1 + 0.38 \cdot \ln\left(\frac{q_c}{\sigma'_{v0}}\right)\right]$$

$$D_r = \left[\frac{q_{c1}}{305}\right]^{0,5}$$

(a) (b)

Figure T4.3.6. Geotechnical characterization: peak friction angle φ (a) and relative density Dr (b)

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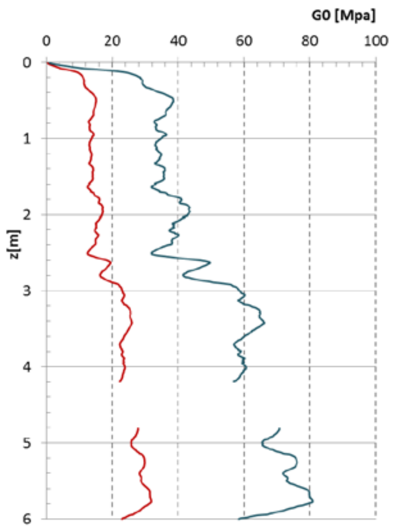
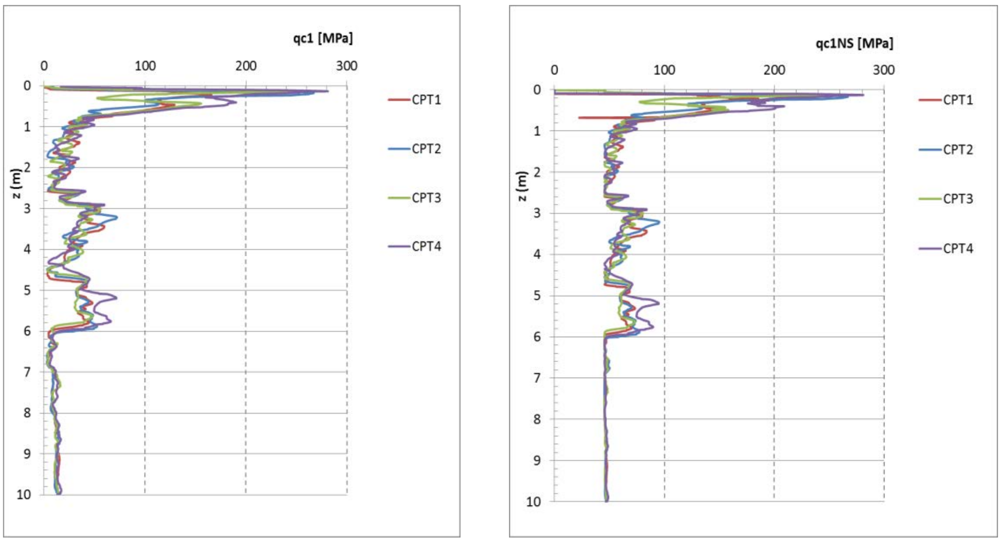


$$G_0 = 280\sqrt[3]{q_c \sigma'_v p_a} \quad \text{lower bound : cemented}$$
$$\text{upper bound : uncemented}$$
$$G_0 = 110\sqrt[3]{q_c \sigma'_v p_a} \quad \text{lower bound uncemented}$$

Figure T4.3.7. Small strain shear modulus G0 (Schnaid et al. 2004)



$$(q_{c1N})_{cs} = K_c q_{c1N}$$

$$q_{c1N} = \frac{q_c}{p_a} \cdot \left(\frac{p_a}{\sigma'_{vo}} \right)^{0.5}$$

$$K = 1 \qquad \text{for } I_c < 1.64 \qquad (4a)$$
$$= 1 + 80.06(I_c - 1.64)(q_{c1N})^{-1.2194} \quad \text{for } 1.64 \le I_c \le 2.38 \qquad (4b)$$
$$= 1 + 59.24(q_{c1N})^{-1.2194} \qquad \text{for } I_c > 2.38 \qquad (4c)$$

(a) (b)

Figure T4.3.8. Normalized cone penetration resistance qc1 (a) and modified cone penetration resistance qc1NS (b, Robertson & Wride, 1998)

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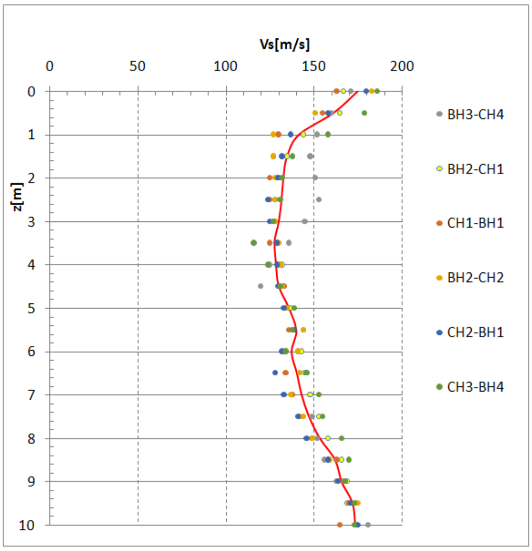
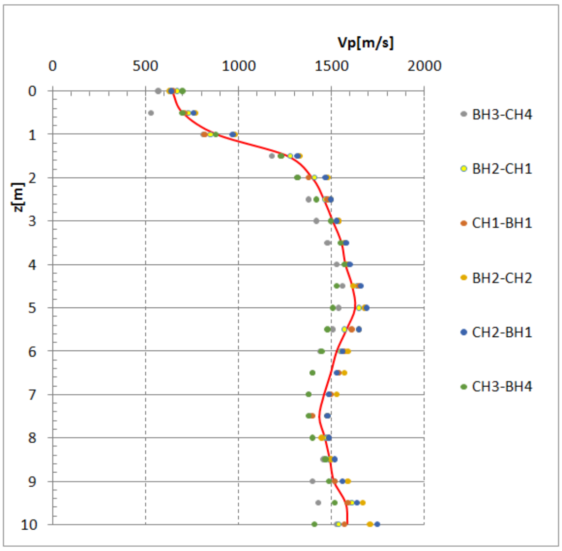
T4.3.2.2 Cross hole tests

The Cross hole tests results (Fig. T4.3.9) have been processed in order to obtain:

- Soil Shear Modulus al small strain levels G_0 (Fig. T4.3.10a).
- Soil porosity n (Fig. T4.3.10b).



(a)



(b)

Figure T4.3.9. Shear and compression wave velocities V_s (a) and V_p (b) measured in the cross hole tests.

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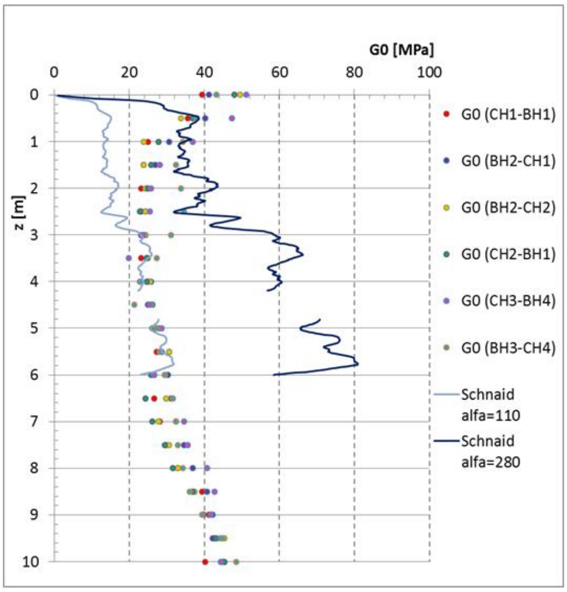
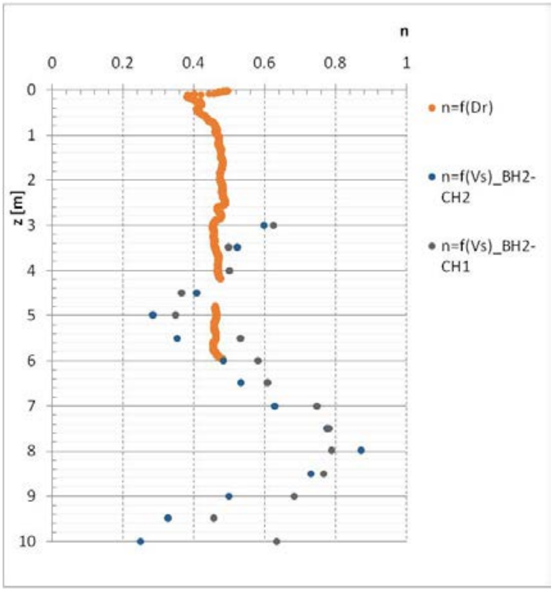


$$G_0 = \rho_s \times V_S^2$$



$$n = \frac{\rho_s - \left[\rho_s^2 - \frac{4(\rho_s - \rho_f)B_f}{V_p^2 - 2\left(\frac{1-\nu_s}{1-2\nu_s}\right)V_s^2}\right]}{2(\rho_s - \rho_f)}$$

(a) (b)

Figure T4.3.10. Small strain shear modulus G0 (a) and soil porosity n (b, Foti et al., 2016).

T4.3.2.3 Simplified geotechnical model

The in situ testing results have been processed in order to define a simplified geotechnical model of the subsoil, briefly described in Figure T4.3.11. Six different layers have been identified:

- SL1 (0<z<1): sandy silt - dried crust
- SL2 (1<z<2.8): sandy silt
- SDL1 (2.8<z<4.2): sand
- LA1 (4.2<z<4.8): no liquefiable soil - clayey soil
- SDL2 (4.8<z<6.0): sand
- LA2 (6.0<z<10.0): no liquefiable soil - clayey soil

The water table is located at a depth of 1.8 m from the ground level: its position changes during the winter season, reaching higher levels.

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Z (m)	Stratigraphy	H(m)	Z_G (m)	Ic	Soil Type	qc (Mpa)	Dr (%)	φ (°)	su (Mpa)	Vs (m/s)	K0	G0 (Mpa)	qc1ns (Mpa)
0 1	SL1	1	0.5	1.8<Ic<2.1	sandy silt	**2.5 - 3**	50	42	-	164	0.33	**40**	80
zw=1.8m 2.8	SL2	1.8	1.9	2.1<Ic<2.6	sandy silt	**0.8-1**	25	35	-	130	0.43	**25**	50
4.2	SDL1	1.4	3.5	1.8<Ic<2.1	sand	**2.3-3**	35	35	-	130	0.43	**25**	70
4.8	LA1	0.6	4.5	>2.6	no liquef. soil	**0.7**	-	-	0.041	97.3	-	**14**	48
6	SDL2	1.2	5.4	1.8<Ic<2.1	sand	**2.3-3**	35	35	-	138	0.43	**28**	70
10	LA2	4	8	>2.6	no liquef. soil	**0.8-1.2**	-	-	0.047–0.074	160		**Go (z) = 6.5 z -15.6**	48

Figure T4.3.11. Soil stratigraphy and geotechnical parameters of the six soil layers.

T4.3.2.4 Cyclic resistance ratio CRR

The cyclic resistance ratio CRR (for magnitude M=7.5) has been computed using the CPTU results with the two equations given by Roberson & Wride (1997) and Chen et al. (2008): the results are plotted in Fig. T4.3.12 for the CPTU 1, CPTU 4 and CPTU 5 tests.

Robertson & Wride, 1997	Chen et al, 2008
if $50 \le (q_{c1N})_{cs} < 160$, $\mathrm{CRR} = 93\left[\frac{(q_{c1N})_{cs}}{1000}\right]^3 + 0.08$ [8b] if $(q_{c1N})_{cs} < 50$, $\mathrm{CRR} = 0.833\left[\frac{(q_{c1N})_{cs}}{1000}\right]^3 + 0.05$	$\mathrm{CRR} = 0.05 + \exp\left[A + B \times (q_{t1N}/100)^C\right]$ $A = I_c \cdot (q_{t1N}/100) - 10.455$ $B = 0.669 \cdot I_c^3 - 5.55 \cdot I_c + 12.993$ $C = 0.284 - 0.0214 \cdot I_c^2$

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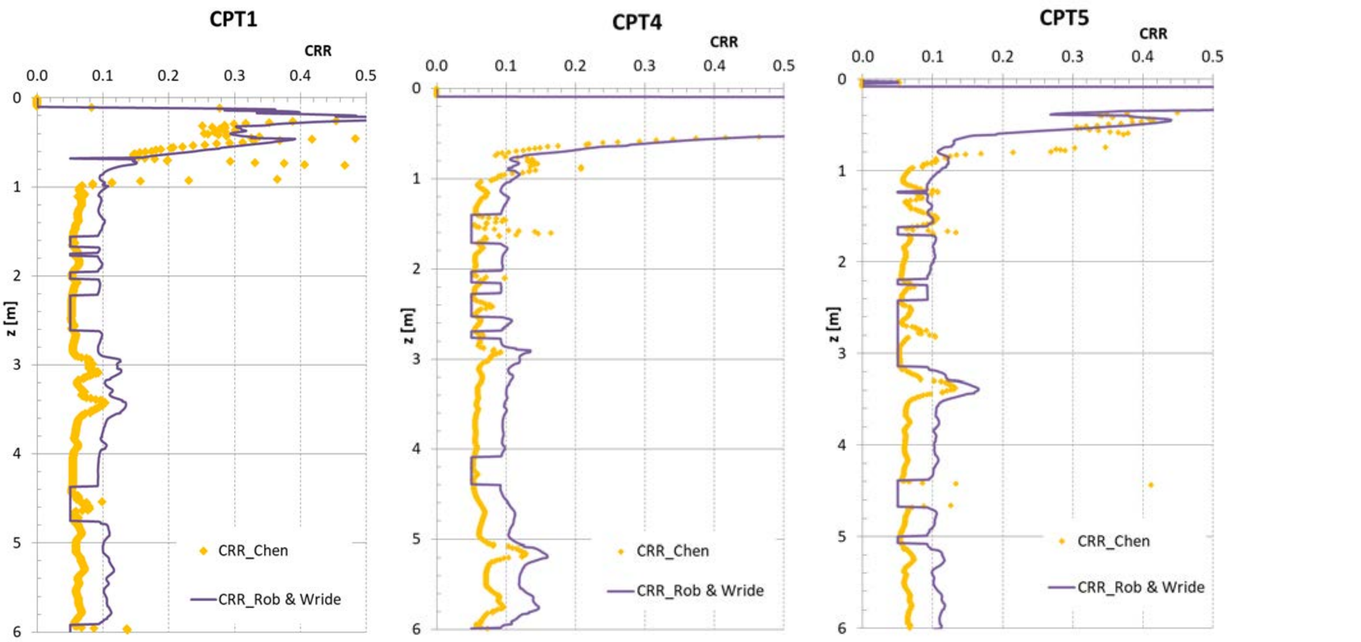

Figure T4.3.12. Cyclic resistance ratio with depth given by Roberton and Wride (1997) and Chen et al. (2004).

T4.3.2.5 Cyclic stress ratio CSR

The cyclic stress ratio CSR generated by the earthquake shaking, at a given depth z, is usually expressed via the equation suggested by Seed & Idriss (1971) for a moment magnitude M_w=7.5:

$$(CSR)_{M=7.5} = 0.65 \frac{a_{max}}{g} * \frac{\sigma_v}{\sigma'_v} * rd$$

with the stress reduction coefficient r_d=1.0-0.00765 z (for z<9.15 m).

To adjust CSR to magnitudes other that 7.5, the calculated $CSR_{7.5}$ must be divided by an appropriate magnitude scaling factor MSF.

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The adopted Magnitude Scaling Factor MSF is the one suggested by Boulanger & Idriss (2014,2015) that takes into account the values of the clean-sand equivalent normalized cone penetration resistance q_{c1NS} (Fig. T4.3.8b), variable along the depth:

$$\mathrm{MSF} = 1 + (\mathrm{MSF}_{\max} - 1)\left[8.64 \exp\left(\frac{-M}{4}\right) - 1.325\right]$$

where $\mathrm{MSF}_{\max}$ was related to q_{c1Ncs} values as

$$\mathrm{MSF}_{\max} = 1.09 + \left(\frac{q_{c1Ncs}}{180}\right)^3 \leq 2.2$$

The CSR values are plotted in Fig. T4.3.13, using the data of three CPTu tests.

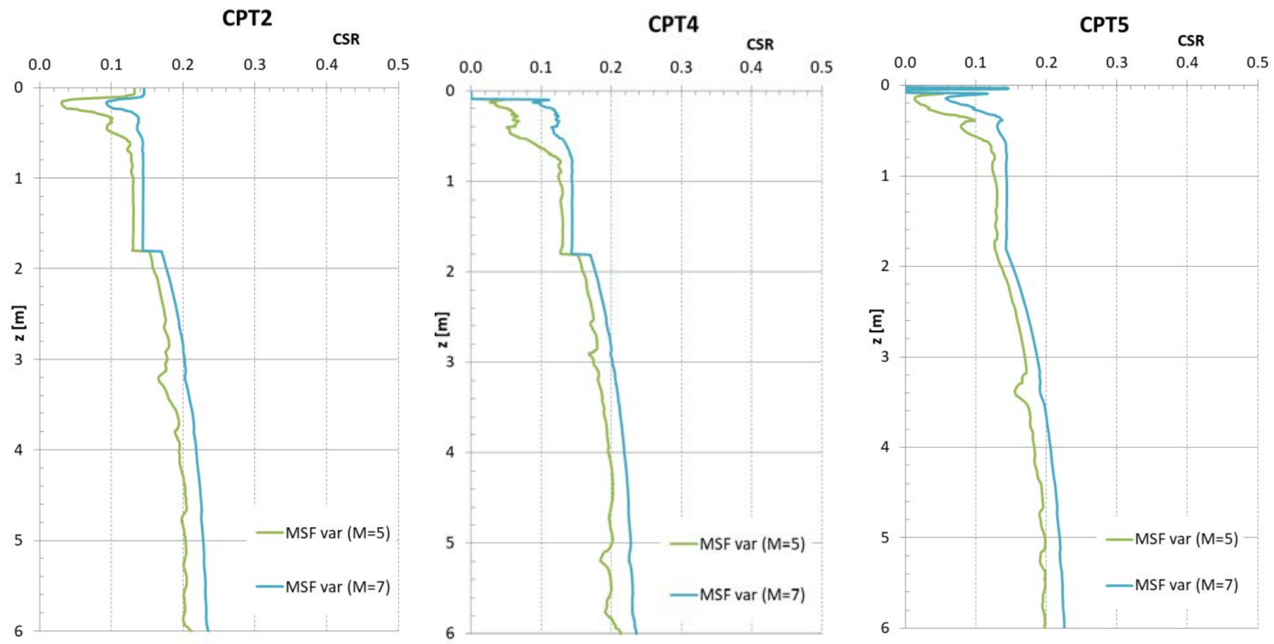

Figure T4.3.13. Cyclic stress ratio CSR with a magnitude scaling factor MSF variable along the depth (Boulanger & Idriss, 2015).

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T4.3.2.6 Liquefaction susceptibility

The capacity of the soil to resist liquefaction - expressed in terms of CRR - has been compared to the seismic demand on a soil layer - expressed in terms of CSR - via the safety factor FS:

$$FS = \frac{CRR}{CSR}$$

Four safety factors have been plotted (Fig. 14):

- FS1 as ratio between CRR with Robertson & Wride equation and CSR for M=5;
- FS2 as ratio between CRR with Robertson & Wride equation and CSR for M=7;
- FS3 as ratio between CRR with Chen et al. equation and CSR for M=5;
- FS4 as ratio between CRR with Chen et al. equation and CSR for M=7.

It can be noted that, regardless the adopted magnitudes (M=5,7) and equations, below the depth of 1 m from the ground level, the safety factor FS is always less than one.

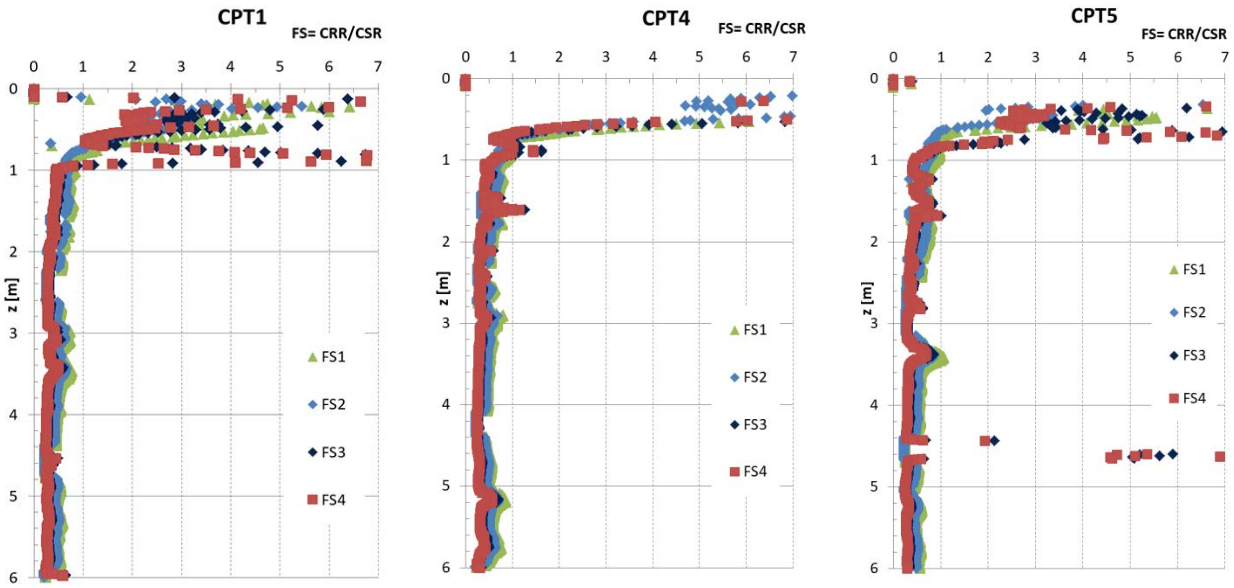

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Figure T4.3.14. Safety factor FS for CPTU1, CPTU4 and CPTU5.

Three different liquefaction index have been calculated:

- Liquefaction Potential Index IPL (Iwasaki et al., 1982).
- Liquefaction Severity Number LSN (Tonkin e Taylor, 2013);
- Liquefaction Severity Index LSI (Juang et al, 2003).

All of that reveal a high/ very high liquefaction risk of the soils located in the trial field.

LIQUEFACTION INDEX	CPTU1	CPTU2	CPTU3	CPTU4	CPTU5	MEAN VALUE
IPL (M=5)	27.29	24.25	24.22	26.78	23.97	**25.30**
IPL (M=7)	29.03	26.11	26.15	26.15	26.15	**26.72**
LSN	34.49	35.69	34.08	34.74	33.83	**34.57**
LSI (M=5)	42.76	39.64	39.90	43.91	40.49	**41.34**
LSI (M=7)	43.52	40.77	41.17	45.02	41.51	**42.40**

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T4.3.3 LABORATORY TESTING

T4.3.3.1 Tests on reconstituted samples

UNINA was in charge of carrying out laboratory tests on Pieve di Cento sand. In the reference period oedometer, cyclic triaxial (CTX) and cyclic simple shear (CSS) tests were performed.

An oedometer test was carried out on Pieve di Cento sand with a relative density of 15.4% (e=0.964). the curve in the compression plane is reported in Figure T4.3.15.

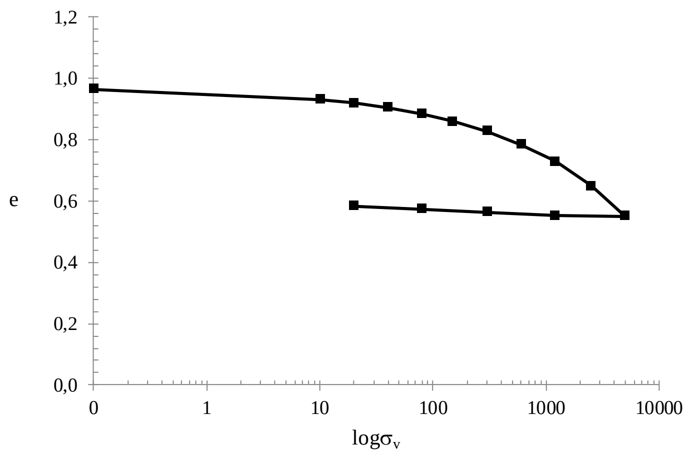

Figure T4.3.25. Oedometer curve in compression plane.

The cyclic triaxial tests were carried out in a Bishop&Wesley triaxial cell on specimens having an average relative density (Dr) of 47%, while the average value of Dr is 45% for the specimens of the cyclic simple shear apparatus (Tab.1). The consolidation was isotropic in CTX with a confining pressure of 50 kPa, while in CSS a K0-consolidation was run, with a vertical effective stress of 50 kPa.

The results in term of CRR-N_{liq} were plotted in Figure T4.3.16, where the correction of Castro was applied for cyclic triaxial results (Castro, 1975):

$$CRR_{ss} = c_r \cdot CRR_{tx} \qquad (1)$$

The eq. (1) allows to compare the cyclic resistance curves of CTX tests with those of CSS tests, transforming the CRR of a CTX test (CRR_{tx}) in a CRR_{ss} (simple shear) through a constant (c_r), whose equation is reported below:

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$$c_r = \frac{2 \cdot (1 + 2K_0)}{3\sqrt{3}} \qquad (2)$$

Where k_0 is the coefficient of earth pressure at rest, evaluated by Jacky's formula:

$$K_0 = 1 - \sin \varphi \qquad (3)$$

Where the peak friction angle was considered (35°).

In table T4.3.1 the CRR_{ss} is reported. The attainment of liquefaction is reached when the pore pressure ratio (Ru) is 0.9, where Ru is defined as the ratio between Δu and σ'_v.

Table T4.3.1: Cyclic tests on Pieve di Cento sand.

Test	Consolidation	σ'_v (kPa)	Dr (%)	e	CRR_{ss}	N_{liq} (Ru=0.9)
CTX_1	Isotropic	50	47	0.808	0.150	4
CTX_2	Isotropic	50	55	0.769	0.128	12
CTX_3	Isotropic	50	43	0.828	0.114	33
CTX_4	Isotropic	50	42	0.828	0.093	No
CSS_1	K0	50	45	0.818	0.154	6
CSS_2	K0	50	45	0.818	0.140	16
CSS_3	K0	50	45	0.819	0.154	21

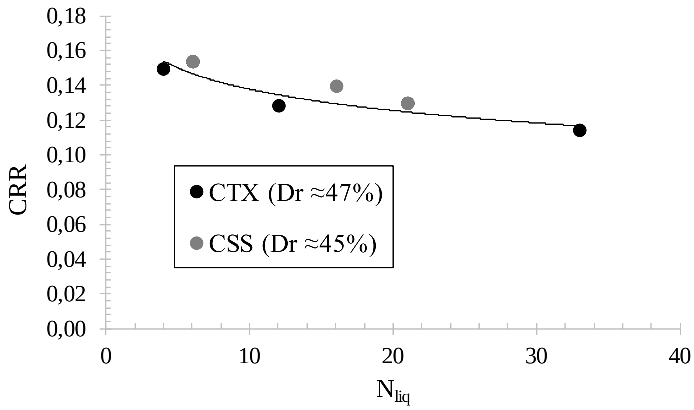

Figure T4.3.16 Cyclic resistance curve of Pieve di Cento sand.

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The figure 2 shows that there is a unique cyclic resistance curve for all experimental data, verifying the correlation of Castro (eq.(1)).

T4.3.3.2 Tests on indisturbed samples

Osterberg and Gel-Pusher samplers (Fig. T4.3.17) were used for the laboratory characterization.

In the reference period, two soil sampling tubes were opened:

- Gel-Pusher sampler (CH2); z= (4.5-5.5) m;
- Osterberg sampler (CH1 BIS); z= (3.5-4.0) m.

The extrusion of Gel-Pusher and Osterberg samples was made by an extruder.

Figure T4.3.17. Ostreberg and Gel-Pusher samplers

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From the Gel-Pusher sampler (CH2) a specimen was retrieved at a depth of 5.0 m and an oedometer test was carried out. The result in the compression plane was plotted in Figure T4.3.18, along with the oedometer test of reconstituted specimen retrieved in the first 2 meters and used in centrifuge tests.

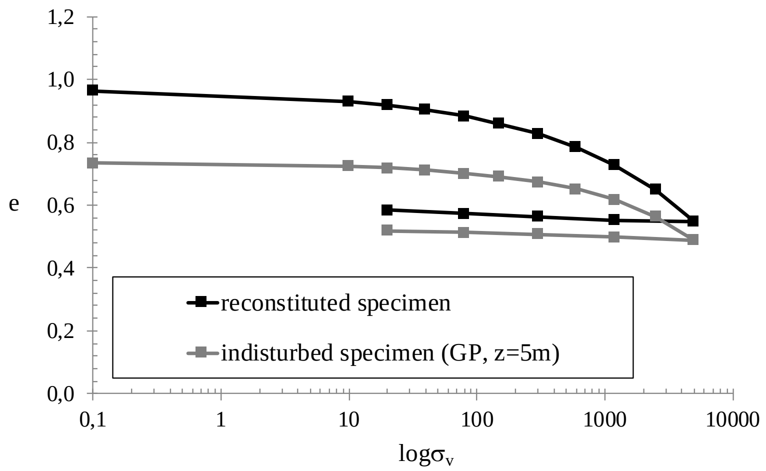

Figure T4.3.18. Oedometer curves in compression plane.

The initial void ratio (e_0) for undisturbed specimen is 0.734, higher than the reconstituted one. In figure 7 the grain size distribution curve of the oedometer specimen was plotted.

From Osterberg sampler (CH1 BIS) a specimen was retrieved at a depth of 3.6 m and a cyclic simple shear test was carried out on it (Fig. T4.3.19).

An effective vertical stress of 50 kPa was applied during a K0-consolidation.

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Figure T4.3.19. Osterberg sample for a cyclic simple shear test.

The result in the plane CRR-N_{liq} is reported in Figure T4.3.20.

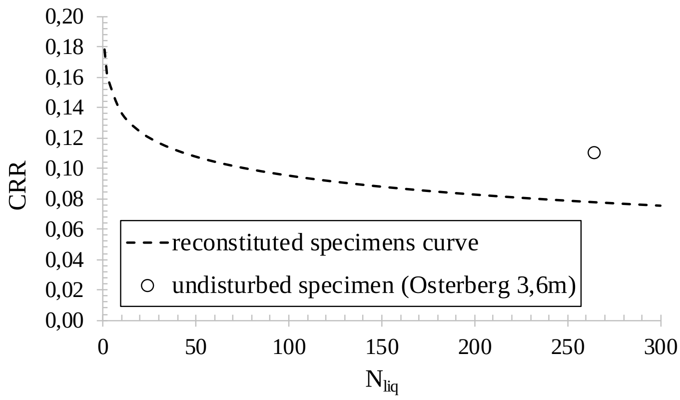

Figure T4.3.20. Result of undisturbed specimen in plane CRR-Nliq.

The cyclic resistance for the undisturbed specimen is higher than reconstituted specimens with an average Dr of 45%, the main reason can be the value of void ratio, which is 0.737 for Osterberg specimen, so it is denser than the reconstituted ones.

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In figure T4.3.21 the grain size distribution curve of undisturbed sample is plotted along with the curve of Pieve di Cento sand retrieved in the first 2 meters and used in centrifuge tests.

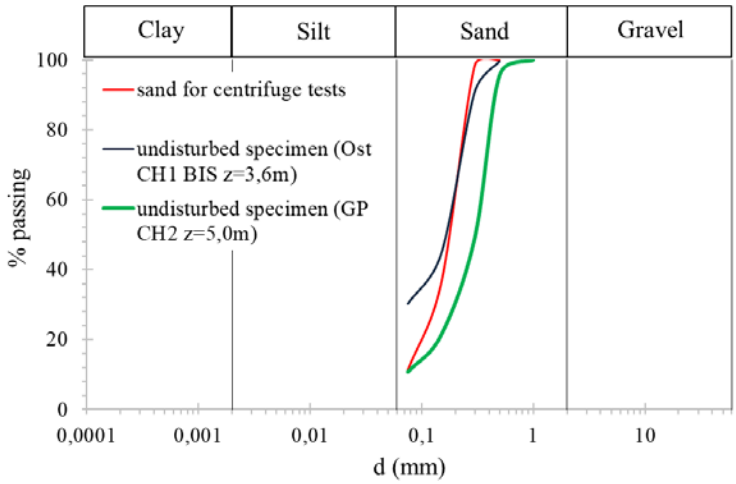

Figure T4.3.21. Grain size curves of reconstituted and undisturbed specimens.

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T4.4 Numerical modelling (leader UNINA)

Within T4.4, UNINA was in charge of carrying out numerical simulation of the tests in the centrifuge (T4.2) and of the field trial (T4.3).

T4.4.1 NUMERICAL MODELLING OF CENTRIFUGE TESTS

The numerical simulation of centrifuge tests is carried out through Dafalias-Manzari model (Dafalias & Manzari, 2004) that is implemented in FLAC 3D. In the following, one of the simulations is illustrated.

T4.4.1.1 Simulation of the static and cyclic triaxial tests

The simulation concerns of the M1S3GM17 test, it requires in a first phase the calibration on the laboratory tests. The chosen tests are the monotonic triaxial tests (Table T4.4.1) and cyclic triaxial tests (T4.4.2), in the following figures are reported the simulation of these tests:

Table T4.4.1: Static tests on Pieve di Cento sand.

Test	Consolidation	σ'_v (kPa)	Dr (%)	e
TX-CIU 05/09/2017	Isotropic	100	52	0.784
TX-CIU 08/09/2017	Isotropic	200	54	0.778
TX-CIU 12/09/2017	Isotropic	50	56	0.765

Table T4.4.2: Cyclic tests on Pieve di Cento sand.

Test	Consolidation	σ'_c (kPa)	Dr (%)	e	CRR_{tx}	N_{liq} (Ru=0.9)
CTX-CIU 26/09/2017	Isotropic	50	47.5	0.805	0.225	3
CTX-CIU 29/11/2017	Isotropic	50	55	0.769	0.175	11

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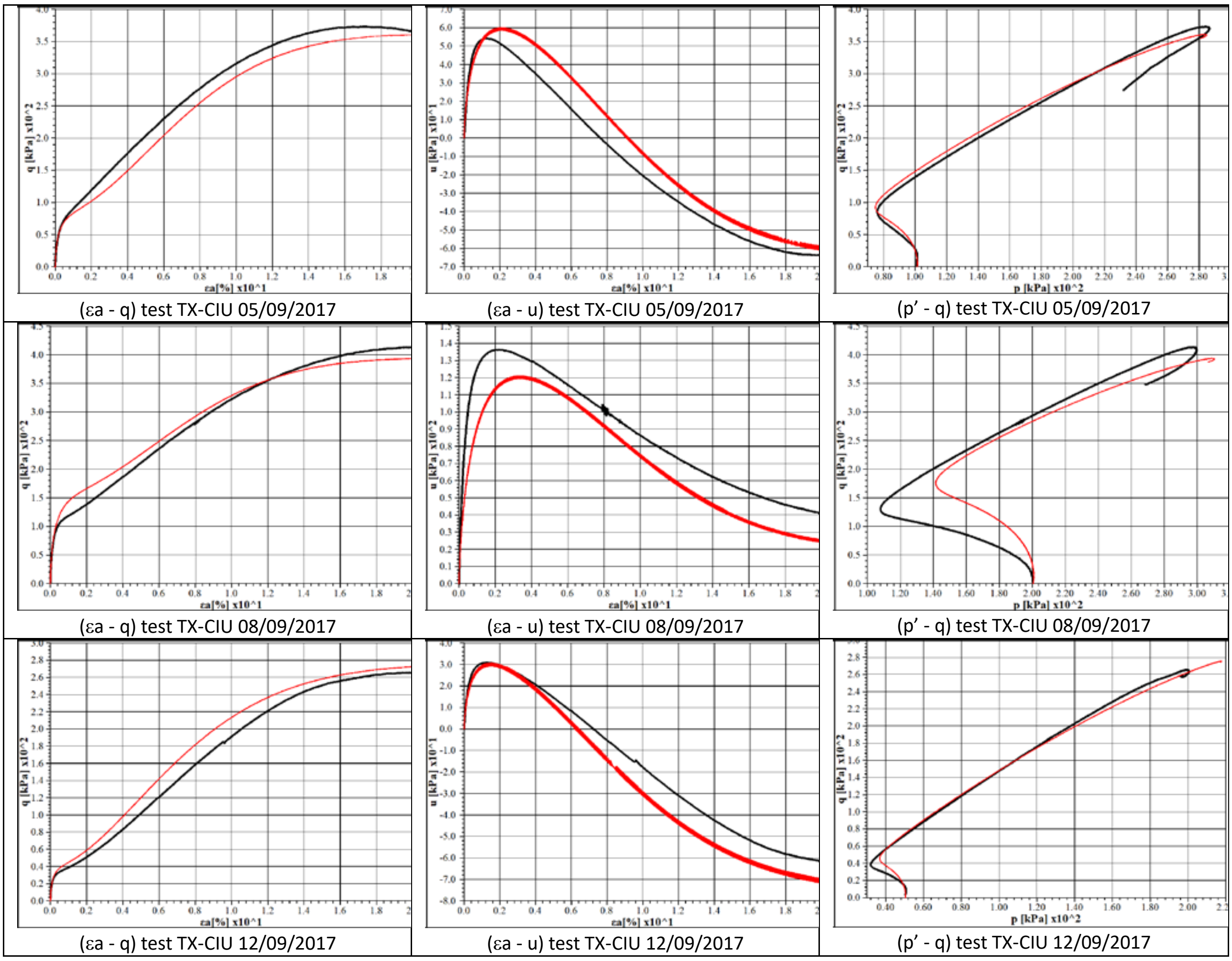
In the following, the plots of the laboratory tests (black lines) and the simulation of the tests (red lines) are represented (Fig. T4.4.1).



(εa - q) test TX-CIU 05/09/2017 | (εa - u) test TX-CIU 05/09/2017 | (p' - q) test TX-CIU 05/09/2017

(εa - q) test TX-CIU 08/09/2017 | (εa - u) test TX-CIU 08/09/2017 | (p' - q) test TX-CIU 08/09/2017

(εa - q) test TX-CIU 12/09/2017 | (εa - u) test TX-CIU 12/09/2017 | (p' - q) test TX-CIU 12/09/2017

Figure T4.4.1: Monotonic triaxial test curves of Pieve di Cento sand.

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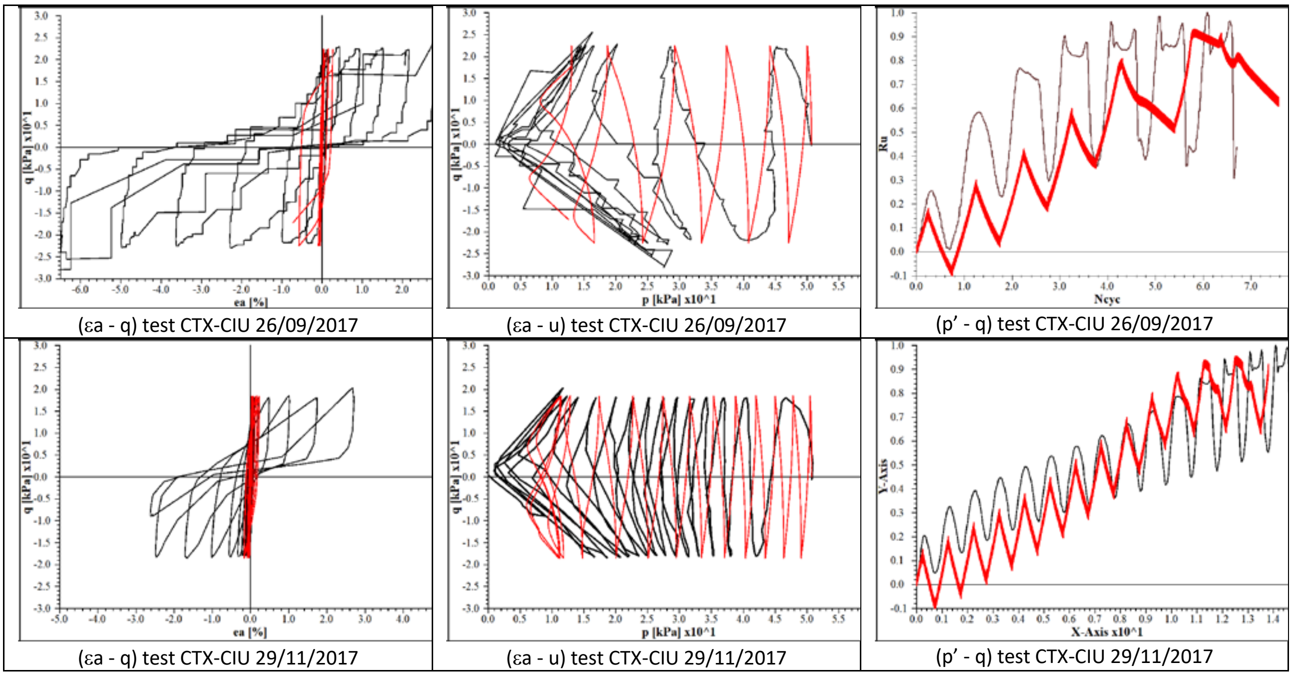

(εa - q) test CTX-CIU 26/09/2017 | (εa - u) test CTX-CIU 26/09/2017 | (p' - q) test CTX-CIU 26/09/2017

(εa - q) test CTX-CIU 29/11/2017 | (εa - u) test CTX-CIU 29/11/2017 | (p' - q) test CTX-CIU 29/11/2017

Figure T4.4.2: Cyclic triaxial test curves of Pieve di Cento sand.

T4.4.1.2 Simulation of tests in the centrifuge

Centrifuge tests are carried out on model layers in an Equivalent Shear Beam (EBS) that is represented in Fig. T4.3.4.

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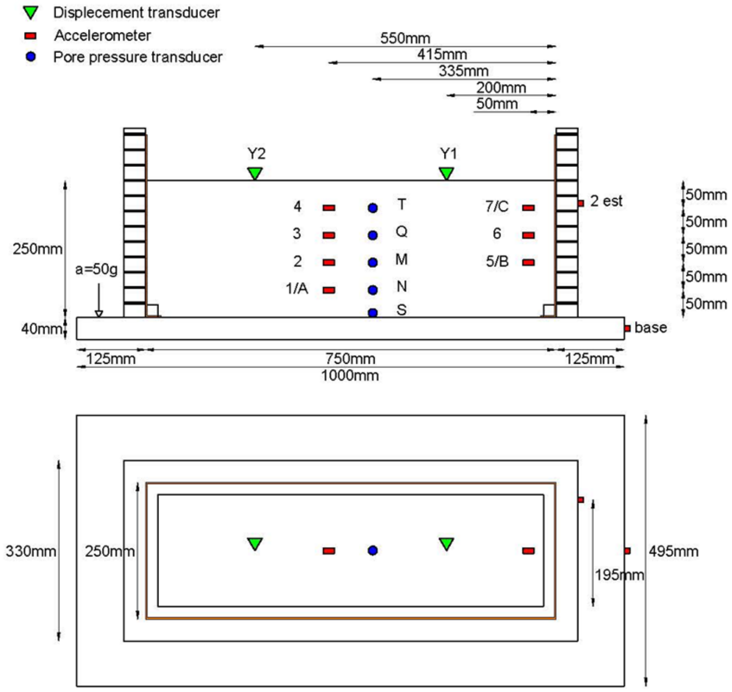

Figure T4.4.3: Configuration of test in centrifuge (test M1S3GM17)

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In order to model the boundary conditions applied in centrifuge, a preliminary work was aimed at modelling and comparing the free-field conditions (Figs. T4.4.5, T4.4.6) with those achieved in the ESB (Figs. T4.4.7, T4.4.8) used in centrifuge. In the followings the numerical models and the results, in terms of Ru, are shown and compared (Fig. T4.4.9).

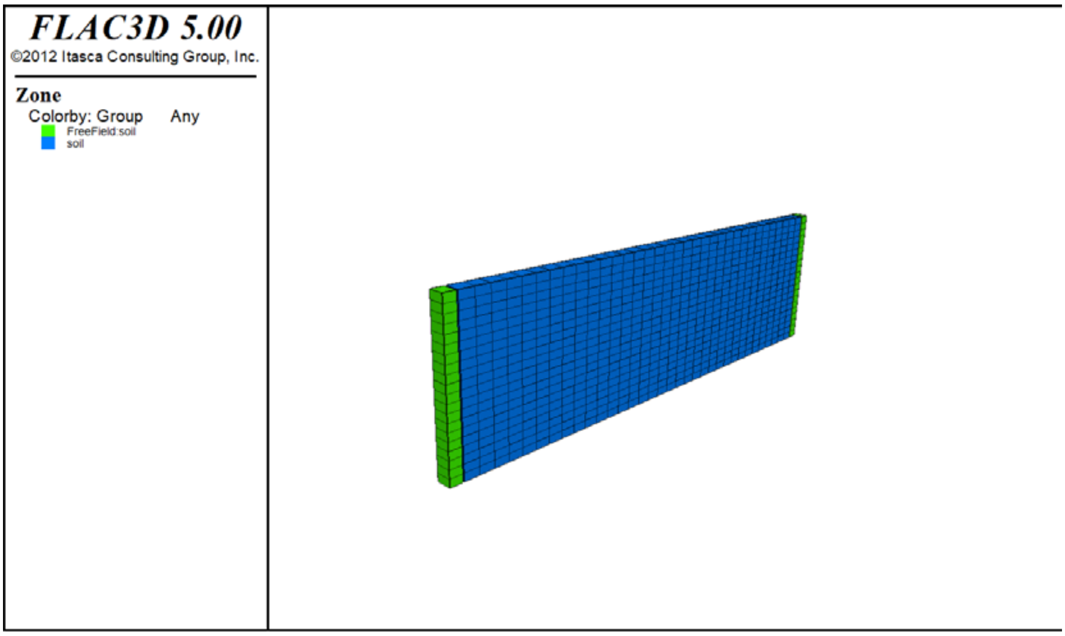

Figure T4.4.5: M1S3GM17 test in the centrifuge on Pieve di Cento sand (Free-Field model)

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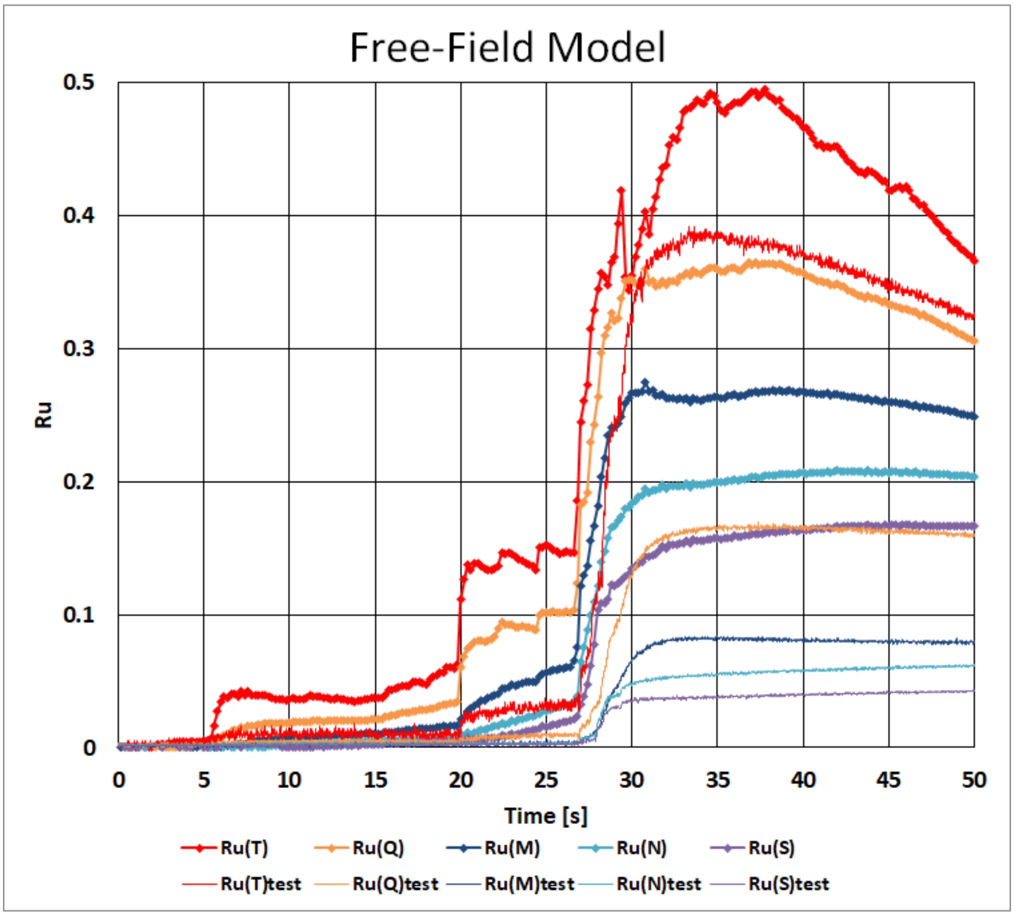

Figure T4.4.6: Results of simulation of M1S3GM17 test (Free-Field Ru curves)

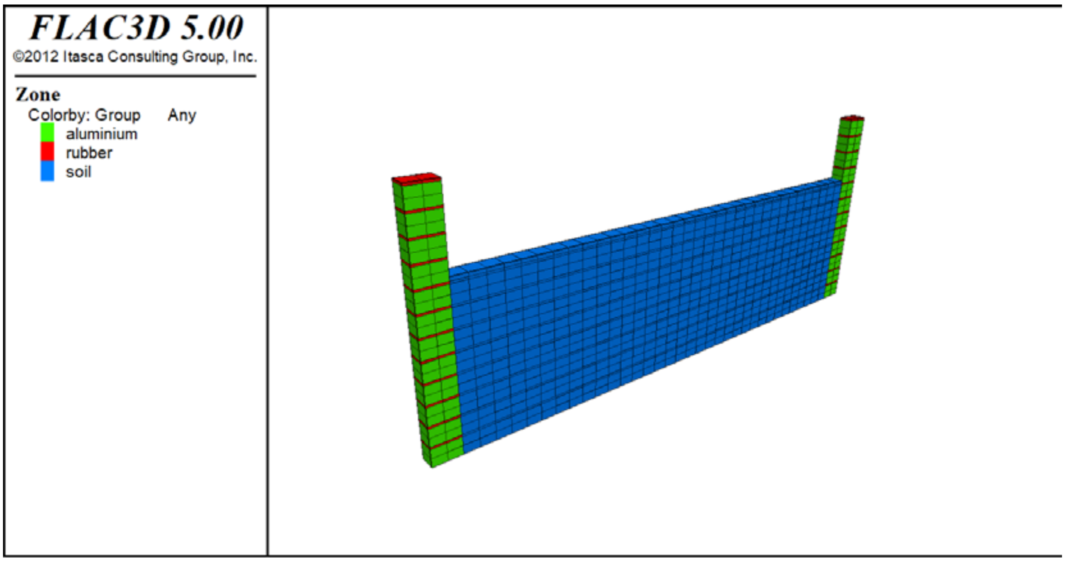

Figure T4.4.7: M1S3GM17 test in the centrifuge on Pieve di Cento sand (Equivalent Shear-Beam model)

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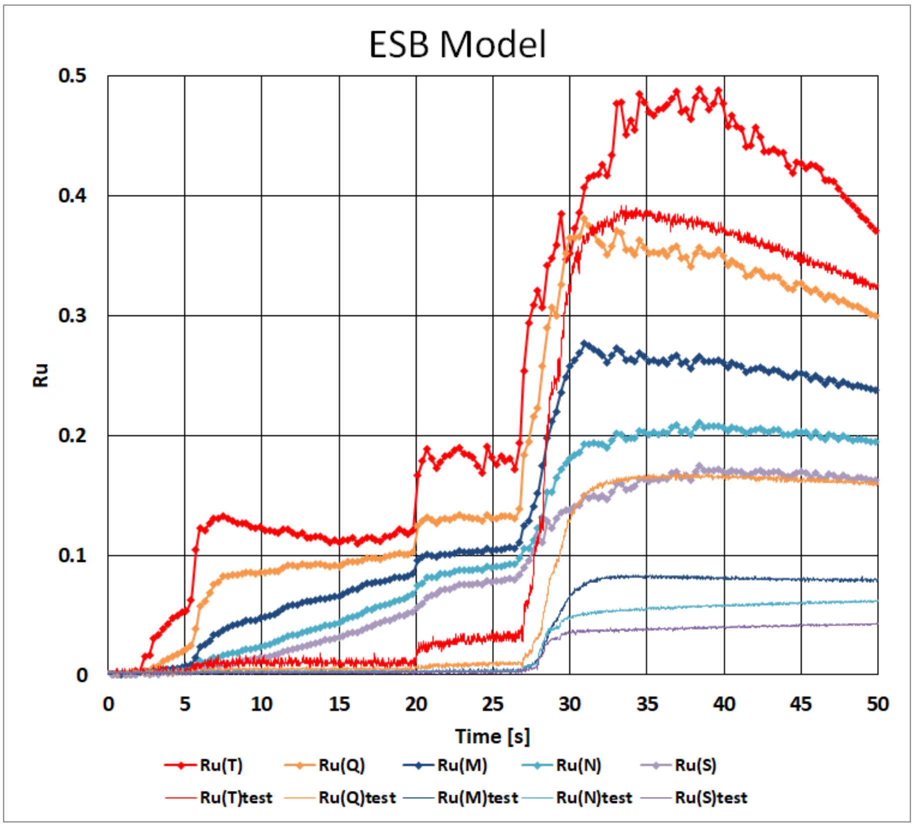

Figure T4.4.8: Results of simulation of M1S3GM17 test (Equivalent Shear-Beam Ru curves)

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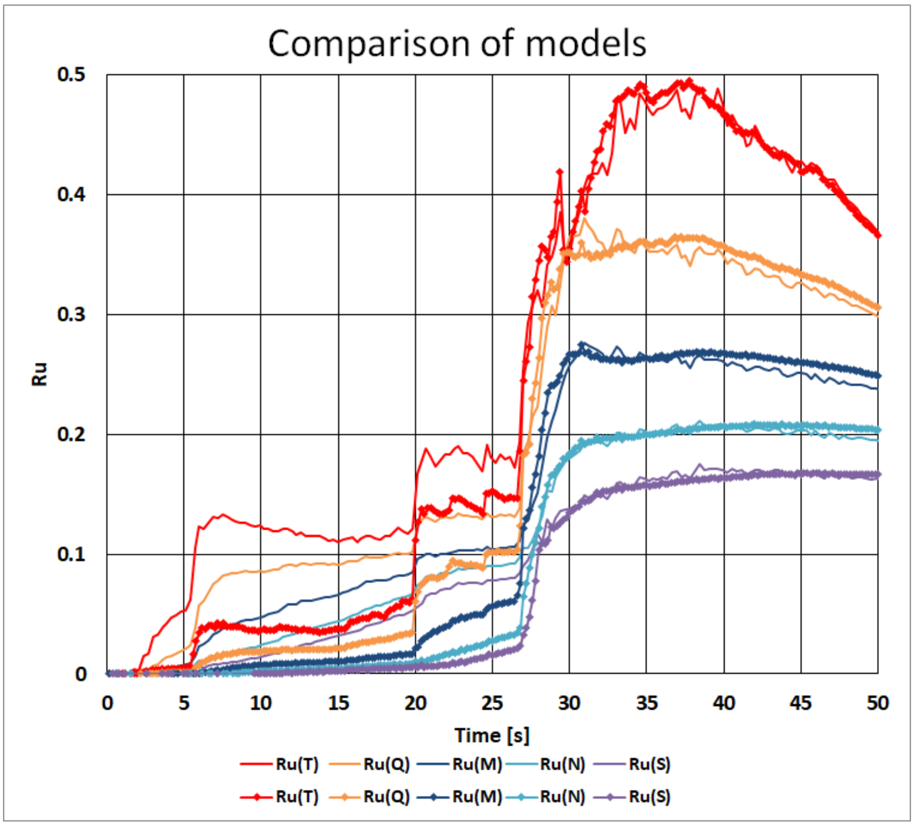

Figure T4.4.9: Comparison of both models (Free-field model and ESB model)

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T4.4.2 NUMERICAL ANALYSIS OF THE SEISMIC RESPONSE OF THE TEST SITE

The UNINA task on numerical modelling is working on the simulation of the seismic soil response of the test site. This site, located in the Pieve di Cento (Bologna) municipality at the boundary with the Sant'Agostino (Ferrara) municipality (Figure T4.4.10), experienced widespread liquefaction manifestations after the mainshock of the 2012 seismic sequence. Preliminary dynamic analyses have been carried out in order to reproduce the observed liquefaction triggering after the 2012 main event.

Figure T4.4.10. Fault projection and epicenter of the 20.V.2012 seismic event

T4.4.2.1 Geotechnical model

The soil deposits at the testing site in Pieve di Cento have been characterized on the basis of the first outcomes from the in situ geotechnical and geophysical investigation of the test site (see T4.3.2), whose results were integrated with geological and geotechnical data retrieved from the literature and from previous investigation campaigns (Chiaradonna et al., 2018).

The soil column consists of a sequence of silty-clay and sandy soil deposits, divided into several geological units, called subsystems (Minarelli et al., 2016). Shear wave velocity and thickness were assigned to every subsystem based on the DH presented by Minarelli et al. (2016) and on retrieved geological sections. Dynamic material curves were generated by considering Darendeli (2001) framework, in which the plasticity index is selected as 0 and 30 for 0-6 and 6-220 meters, respectively. Apart from the main influencing parameters (mean effective confining stress and plasticity index), the other required parameters were assumed as: over-consolidation ratio OCR=1, excitation frequency 1 Hz and number of cycles N=10. Figure T4.4.11a shows the soil layering and the related VS profile obtained by interpreting all the available information.

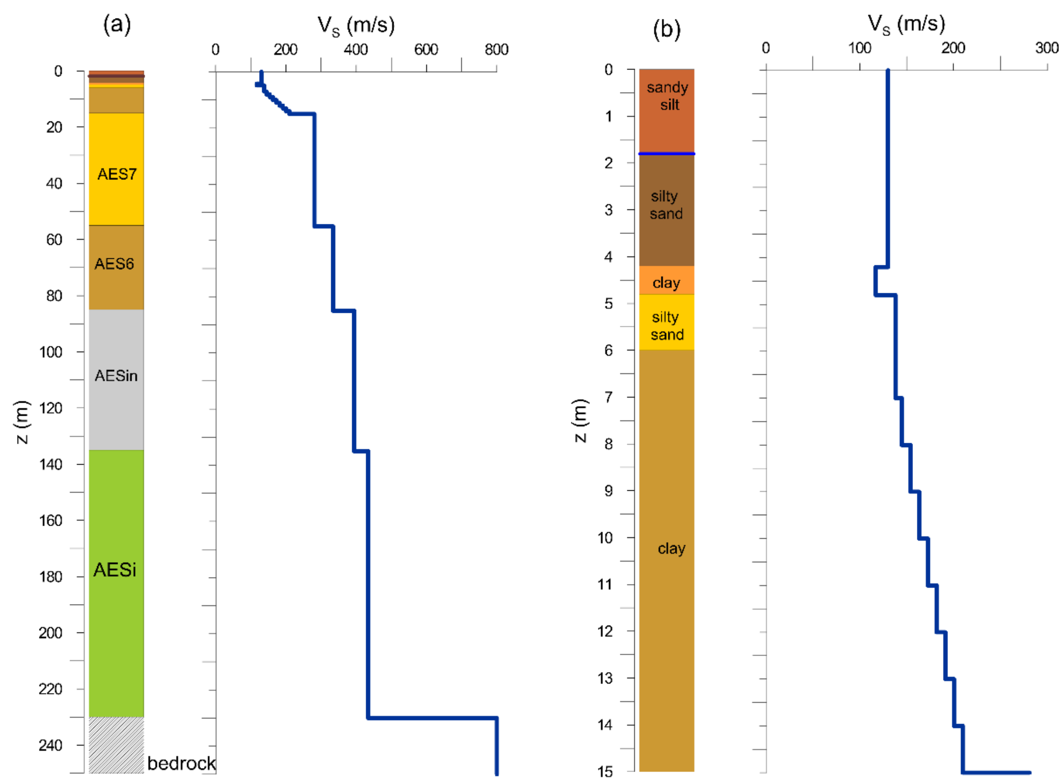

Figure T4.4.11. Shear wave velocity profile used for Pieve di Cento site. (a): in larger depth range, (b): in smaller depth range

Figure T4.4.11b focuses on the shallow layering and the shear wave velocity profile as identified from a borehole and a Cross-Hole test carried out at the site. The soil column consists of a sandy silt layer overlaying a silty sand layer that is supposed to be the liquefiable layer. In the considered borehole, a thin clayey layer is identified in the silty sand deposits between 4.2 and 4.8 m depth. The same formation is in the soil profile beyond 6 m depth from the ground surface, as shown by combining the data from the 10 m borehole and pre-existing Cone Penetration Tests. The shear wave velocity profile was defined from the interpretation of the results of the Cross-Hole test, shown in Figure 2b. A linear trend has been identified in the clay layer; it has been adopted for the whole clay formation and the interbedded thin clay layer, which was not revealed by the Cross-Hole test.

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Since site-specific laboratory tests are currently in progress, the non-linear soil properties have been modelled assuming shear modulus reduction and damping curves of the soil deposits at Scortichino (Figure T4.4.10), where resonant column tests were performed (Tonni et al., 2015). At this site, 20 km far from the test-site, sandy and clayey layers have the same geological background and a grain size distribution similar to those in Pieve di Cento.

T4.4.2.2 Input motion

The adopted input motion aims to reproduce the seismic demand induced at the reference test site by the mainshock of the 2012 Emilia seismic sequence, using the recorded acceleration time histories.

The mainshock of the Emilia 2012 earthquake sequence occurred on May 20, 2012 at 02:03:53 UTC time. The MRN station of the Italian strong-motion network (RAN), located in Mirandola town, is the closest to the epicenter (Figure T4.4.10) and recorded a peak ground acceleration, PGA, as high as 0.273g (Chiaradonna et al., 2018).

This record cannot be used directly as a reference input motion in a seismic site response analysis, because the station is located on a deep layer of soft ground, with an equivalent shear wave velocity VS,30 = 208 m/s, i.e. a Class C site according to Eurocode 8 (EC8). Indeed, the 2012 seismic sequence affected an alluvial plain with a significant depth of the seismic bedrock, hence the closest stations located on a rock outcrop lie too far from the epicenter. To overcome this problem, the deconvolved outcrop motion at MRN station was adopted (Chiaradonna et al., 2018) and the motion was scaled down to account for the epicentral distance of the test site.

In the end, the deconvolved motion was propagated from the assumed bedrock (230 m deep) up to 15 m depth (Figure T4.4.11a). The obtained ground motion at 15 m is shown in Figure T4.4.12 in terms of acceleration time history (Figure T4.4.12a) with the correspondent acceleration response spectrum (Figure T4.4.13b).

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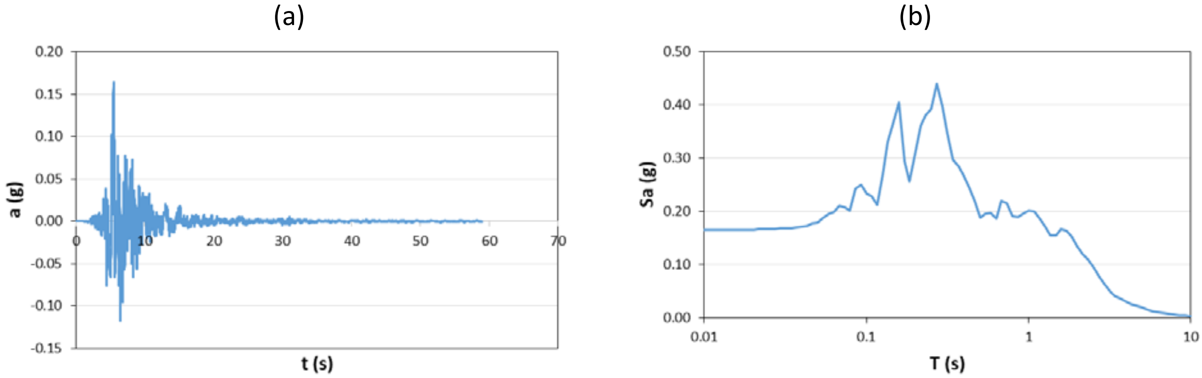

Figure T4.4.12. Deconvolved input motion at 15 m (a): acceleration time history, (b): acceleration response spectrum

T4.4.2.3 Non-linear 1D analysis

Dynamic analyses on the shallow soil profile were carried out in effective stresses according to a loosely coupled approach. The adopted geotechnical model has been described in §T4.4.2.2 (Figure T4.4.11b). The depth of the ground water table has been assumed at 1.8 m below the ground level as shown by the in-situ investigations and a pore-water pressure model has been assigned to the silty sand layers based on the laboratory test results (see Fig. T4.3.16)

The excess pore water pressure build-up in the saturated soils has been calculated using a simplified model based on the accumulation of shear stress (Chiaradonna et al., 2018b), which is implemented in the 1D computer code SCOSSA (Tropeano et al., 2016). Figure T4.4.13 reports the results of simulation in terms of maximum profile of acceleration and excess pore pressure ratio, r_u, defined as the ratio between the excess pore pressure and the initial effective vertical stress.

The acceleration profile is characterized by reduced values above the liquefiable silty sand soils, caused by the sharp reduction in shear wave velocity in the liquefied/degraded soil layer that works as an isolator. Excess pore water pressure ratio profile shows that the model is able to predict the occurrence of the observed liquefaction, as it was observed at the site during the event.

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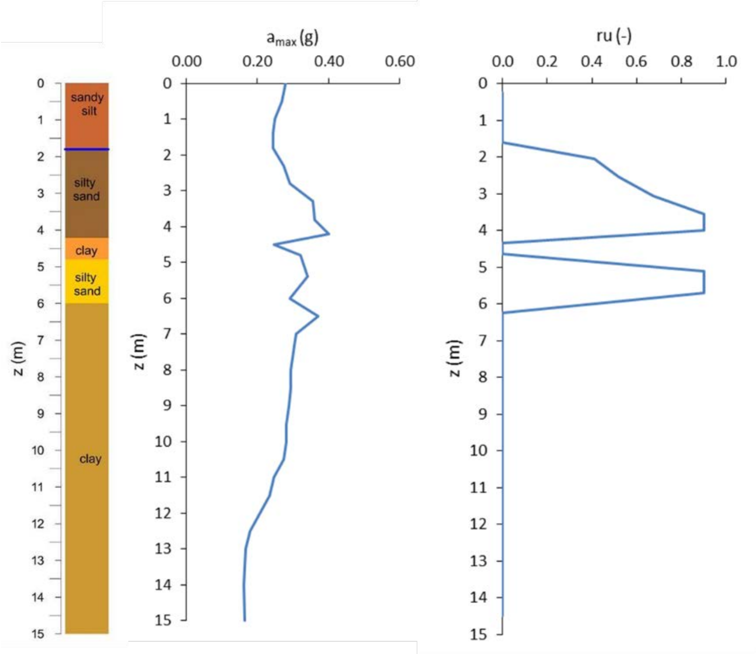

Figure T4.4.13. Effective stress analysis results: subsoil profile; maximum acceleration and maximum pore pressure ratio

T4.4.3 NUMERICAL ANALYSIS OF THE MITIGATION TECHNIQUES ADOPTED IN THE FIELD TRIAL

For this task the numerical analysis has the goal to establish dimensioning criteria. For this reason, several analyses are performed, each of them with a different layout for drains. This activity is still ongoing.

In Figure T4.4.14, one of the models that have been adopted is shown

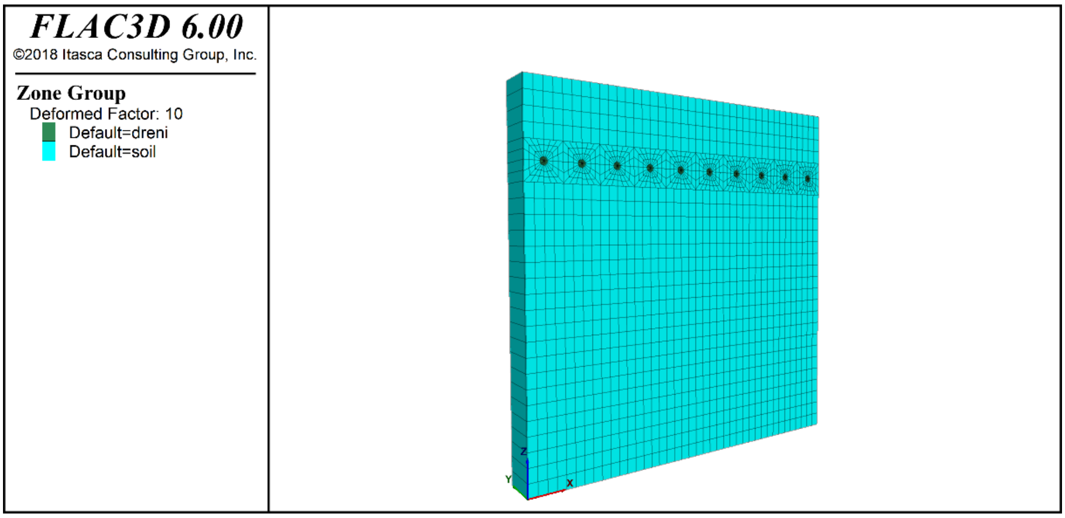

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Figure T4.4.14. example of mesh for analyzing the horizontal drainage as a mitigation technique

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Appendix 3

Project Number: 700748

Project Acronym: LIQUEFACT

Project title: Assessment and mitigation of liquefaction potential across Europe: a holistic approach to protect structures / infrastructures for improved resilience to earthquake-induced liquefaction disasters — LIQUEFACT

UNICAS Periodic Technical Report

Period covered by the report: from 01/07/2017 to 31/01/2018

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

1.1 Summary of the context and overall objectives of the project

During the reference period, from 01.08.2017 to 31.01.2018 the group of UNICAS has participated at the different activities of the project, being involved in each Work Package with the effort described by the following table:

Work Package	WP1	WP2	WP3	WP4	WP5	WP6	WP7	WP8	WP9
Involvement (Months*Persons)	-	0.40	0.5	-	0.40	-	2.50	0.30	0.30

Regarding the overall objectives of the project, the contribution of UNICAS has mainly consisted in the validation of the procedures adopted in WP2, 3, 4, 5 and 6. The researchers of UNICAS have assisted all phases of the implementation (micro-zonation, resilience and vulnerability assessment, preparation of the toolkit for risk assessment etc.) and have worked at preparing the databases necessary to compare the predictions with the effects observed in a number of relevant case studies. In addition, UNICAS has assisted significantly the management of the project, contributing at the organization of the periodic meeting in Napoli, and at a variety of dissemination activities like the creation and management of an external and of an intranet website, the future participation at conferences, workshops etc. and the preparation of a dissemination video.

1.2 Work performed in the period covered by the report and main results achieved so far

The personnel of UNICAS involved in the period of reference is:

Ph.D. Giuseppe Modoni (Coordinator)

Ph.D. Alessandro Rasulo

Ph.D. Michele Saroli

M.Sc. Prof. Paolo Croce

Ph.D. Rose Lune Spacagna (Post doc)

M.SC Luca Paolella (PhD student)

With reference to the different work packages, the contribution provided in the reference period is described as follows.

WP1 - Event though the time for this work package has expired, the communication with stakeholders has continued incessantly to better identify their requirements and the industry-research gaps. In particular, prof. Modoni has been involved in the organization of the session Geosismica of the next REMTECH Expo (http://www.remtechexpo.com/index.php/it/programmi-congressuali/comitati-scientifici), to be held in Ferrara next September 2018, and has been appointed for the organization of a workshop where the researchers of LIQUEFACT will share their outcomes and receive a feedback with different operators (factories, construction companies, professionals governmental institutions etc.) of environmental remediation technologies.

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Other contacts have been officially established with governmental institutions (e.g. "Servizio Geologico" and "Agenzia per la Ricostruzione" of the Emilia Romagna Regiona) and with industrial partners (BASF chemical) to understand their specific instances with reference to the theme of liquefaction.

WP2 - With regard to this work package, the contribution of UNICAS has mainly consisted in the collection of data and the creation of databases useful to improve the knowledge of the liquefaction hazard at different geographical scales. Thanks to an agreement established between UNICAS and the Emilia Romagna Region (annex 1), data regarding seismicity, subsoil investigation, building stocks and observed damage, position and characteristics of infrastructures etc. are available for the territory hit by the 2012 earthquakes.

WP3 - On the theme of vulnerability, UNICAS has assisted UPORTO providing data and performing calculation aimed at computing liquefaction fragility curves for different types of civil and industrial constructions and of infrastructures. With specific regard to the infrastructures, the group of UNICAS has assisted UPORTO for the preparation of the state of the art on the vulnerability of pipelines. With regard to the assessment of the effects of liquefaction on buildings, UNICAS has identified a specific case study in the fraction of San Carlo (Municipality of Sant'Agostino – Emilia Romagna) and collected data on the seismic excitation, subsoil properties from in situ and laboratory tests, structural characteristics and damages of a masonry building that will be used to validate the procedure implemented to build the fragility curves. Iterative calculations are also being performed with numerical code (FLAC 2D and 3D versions) specifically purchased for this and other tasks of the project, to formulate a criterium that frames complex subsoil stratigraphy into simpler schemes. Finally, UNICAS is performing iterative structural calculation with an different source software (e.g. Opensees) to investigate the interaction between differential settlements and shaking on framed buildings.

WP4 - The personnel of UNICAS is only indirectly involved on the theme of mitigation, as one of the activities of the work package 7 leaded by UNICAS is the preparation of guidelines to future Eurocode recommendation to mitigate the liquefaction risk on critical infrastructures. Nevertheless, UNICAS is sharing its competences with the group of UNINA, leader of WP4, for the experimental and theoretical activities and is testing in its laboratory the validity of a mitigation technique based on the injection of nanosilicate grout. The results of this study will be made available to the consortium.

WP5 - The contribution of UNICAS for this work package consists in assisting the other participants, particularly the WP leader ARU, on the particularization of the UNISDR Disaster Resilience Scorecard for Cities to the specific theme of liquefaction and on the application of the implemented methodology to specific case studies. In details, in November 2017 the personnel of UNICAS and ARU have participated at two meetings, with representatives of respectively Emilia Romagna Region and Municipality of Terre del Reno, to activate a preliminary exchange of information, prepare the basis for the application of the resilience toolkit to a specific case study and collect the necessary information on critical infrastructures. An official agreement has been established between UNICAS and Emilia Romagna Regional Government to officialise the collaboration and exchange of competences and information on the specific theme of Liquefact.

WP6 - Despite an involvement of UNICAS in this work packages is not officially prescribed, the stron intersection between WP6 and WP7, leaded by UNICAS, has led to define a common strategy. With

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this purpose, a meeting of the two groups has been held in September 2017 at the University of Cassino to share competences and information for the preparation of the toolkit for risk assessment and for its application to real case studies. From January, a member of UNICAS (dr. Luca Paolella) has been hosted at NORSAR to assist the preparation of the toolkit with a continuous feedback on two of the case studies presently analysed at UNICAS (Emilia Romagna and Christchurch).

WP7 - This is the core activity of UNICAS in the LIQUEFACT project. The purpose of this WP is to validate with different case studies the procedures implemented in the previous work packages and to prepare the guidelines for the application of risk assessment and mitigation for the future Eurocode recommendation. With this aim, agreements have been established with the Emilia Romagna region (see annex 1), or are being established with the University of Canterbury at Chrustchurch (New Zealand) and the University of Tokyo (Japan).

After the agreement with the Emilia Romagna Region, a large number of data have been made available on the seismicity of the area, on the geotechnical investigations, on the characteristics of buildings and infrastructures and on the recorded damages over the area hit by the 2012 earthquake and subjected to severe liquefaction. These data are being processed and framed into databases ready to be used as input of the risk assessment toolkit and for validation.
With regard to the case study of Christchurch, data concerning the geology of the subsoil, the stratigraphic and geotechnical properties of the subsoil, the seismicity of the area have been already collected. The next step is to add information on the seismic response of buildings and infrastructures. With this purpose, two meetings have been held with prof. Misko Cubrinovski (September 2017, during the periodic meeting of Napoli) and dr. Gabriele Chiaro (December 2017, University of Cassino), both from the University of Canterbury, to define the terms of a cooperation. The University of Canterbury will be subcontracted by Liquefact to assist the consortium in the application of the risk assessment toolkit to the case study of Christchurch and back analyse the effects occurred during the 2011-2012.
An agreement has been also prepared to subcontract the University of Tokyo and define the terms of a cooperation aimed at assisting the LIQUEFACT consortium in the application of the risk assessment toolkit to the case study of the 2011 Tohoku Oki earthquake.
In November a meeting has been held at the University of Cassino with Prof. Sadik Oztoprak of the University of Istanbul to explore the possibility to extend the validation to the case study of 1999 Adazapari earthquake (Turkey).

WP8 - Dissemination is continuously carried out by the personnel of UNICAS. The main activities carried out in the reference period are the management of the website (www.liquefact.eu), the organization of a workshop foreseen in September within the Geosismica session of Remtech Expo (Ferrara-Italy), the organization of a workshop at the XVI European Conference on Earthquake Engineering (16 ECEE) in Thessaloniki (Greece). Finally, a dissemination video is being prepared under the guidance of UNICAS to demonstrate the different activities of Liquefact. The shooting of video has started at the geotechnical laboratory of the University of Napoli Federico II.

WP9 - With regard to the management, the personnel of UNICAS has assisted the WP leader ARU in the preparation of all documents (periodic scientific and financial reports, timesheets, etc.), has attended all the meetings (Official meeting with the EU officer held in September 2017 in Brussels, Periodic meeting held in October 2017 in October, thematic meeting held in November in Rome), has completed the preparation of the intranet network http://intranet.liquefact.eu/, has promoted all the activities of the consortium at the institutional partners.

As a general conclusion, the work done so far by the personnel of UNICAS both with the leading of WP7 or with the assistance to the other WPs, forms the basis for the achievement of the prescribed goals. Noticeable results are particularly expected from the analysis of the data coming from the case studies selected for the validation of the implemented procedures.

Publications

Salvatore, E., Modoni, G., Mascolo, M.C., Grassi, D., Traldi, D., Proia, R., Croce, P. Low pressure grouting with nanosilicates to reduce the liquefaction susceptibility of sand, Proc. of the XVI European Conference of Earthquake Engineering, June 18-21, Thessaloniki (Greece).

Spacagna, R.L., Paolella, L., Rasulo, A., Modoni, G., Spatial variability of CPT data for liquefaction assessment, Proc. of the XVI European Conference of Earthquake Engineering, June 18-21, Thessaloniki (Greece).

Organization of future Workshops:

- LIQUEFACT Workshop planned at the next REMTECH EXPO exhibition, September 19-21 2018 – Ferrara Fiere.
- EARTHQUAKE INDUCED LIQUEFACTION RISK: HOLISTIC ASSESSMENT AND MITIGATION – Workshop at the 16 Conference of Earthquake Engineering (ECEE), June 18-21 2018 in Thessaloniki (Greece) -

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ANNEX 1: Official agreement between UNICAS and Emilia Romagna

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ACCORDO DI COLLABORAZIONE ISTITUZIONALE TRA REGIONE EMILIA-ROMAGNA E L'UNIVERSITÀ DEGLI STUDI DI CASSINO E DEL LAZIO MERIDIONALE - DIPARTIMENTO DI INGEGNERIA CIVILE E MECCANICA, PER L'ACQUISIZIONE E L'ANALISI DI DATI PER LA VALUTAZIONE DELLA VULNERABILITÀ A LIQUEFAZIONE E DEI DANNI INDOTTI AD INFRASTRUTTURE E STRUTTURE E PER LO SVILUPPO DI APPROCCI METODOLOGICI FINALIZZATI AL MIGLIORAMENTO DELLA RESILIENZA

Con la presente scrittura privata, da valere ad ogni effetto di Legge,

tra

Regione Emilia-Romagna (di seguito Regione), codice fiscale 80062590379, Direzione Generale Cura del Territorio e dell'Ambiente, Servizio Geologico, sismico e dei suoli, nella persona dell'ing. Bartolini Gabriele, Responsabile del Servizio Geologico, sismico e dei suoli, domiciliato per la carica presso Viale della Fiera n.8, Bologna, autorizzato alla stipulazione del presente atto con deliberazione di Giunta della Regione Emilia-Romagna n. 2077 del 20 dicembre 2017;

e

Università degli Studi di Cassino e del Lazio Meridionale - Dipartimento di Ingegneria Civile e Meccanica (di seguito UniCAS-DICeM), codice fiscale 81006500607 e partita I.V.A. 01730470604, con sede in Cassino (FR), Via Gaetano Di Biasio n. 43, nella persona del direttore del DICeM, Prof. Marco Dell'Isola, autorizzato alla sottoscrizione del presente atto con decreto Rettorale n. 539 del 30.07.2014;

(di seguito, congiuntamente, per brevità "Parti" e ciascuna, singolarmente, anche "Parte")

PREMESSO CHE:

- la Regione nell'espletamento dei propri compiti istituzionali promuove e favorisce la ricerca scientifica nel settore delle scienze geologiche, della geotecnica e dell'ingegneria anche ai fini della prevenzione e mitigazione del rischio sismico;

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- UniCAS-DICeM tra rispettivi compiti istituzionali ha quello di promuovere e sviluppare la ricerca e la formazione in particolare nei campi dell'ingegneria geotecnica, della sismologia applicata e della riduzione del rischio sismico;
- la Commissione Europea, nell'ambito del programma Horizon 2020 – EU.3.7, ha approvato il progetto LIQUEFACT *"Assessment and mitigation of liquefaction potential across Europe: a holistic approach to protect structures/ infrastructures for improved resilience to earthquake-induced liquefaction disasters"*; tale progetto, iniziato nel maggio 2016, terminerà nell'ottobre 2019 ed ha come obiettivi l'individuazione delle condizioni predisponenti e scatenanti il fenomeno della liquefazione in Europa, la verifica delle procedure per la valutazione del rischio e l'individuazione di tecniche efficaci di mitigazione degli effetti di tale fenomeno sulle costruzioni;
- per raggiungere gli obiettivi di cui al punto precedente sono previsti studi pilota anche nel territorio italiano e il gruppo di coordinamento delle attività di LIQUEFACT ha individuato come zona d'interesse dove validare le metodologie di valutazione del rischio proposte alcune porzioni dell'area emiliana interessata dai fenomeni di liquefazione del suolo verificatisi durante la sequenza sismica del maggio-giugno 2012;
- la Regione si è dichiarata interessata agli sviluppi e alle conclusioni del progetto (comunicazione del Responsabile del Servizio Geologico, Sismico e dei Suoli PG.2016.580876 del 18/8/2016), nonché disponibile a collaborare per l'individuazione del territorio dove condurre lo studio di microzonazione sismica per il rischio liquefazione in Emilia-Romagna;
- le Parti hanno individuato i territori dove effettuare gli approfondimenti oggetto di questo accordo nei centri abitati maggiormente interessati da fenomeni di liquefazione verificatisi durante la sequenza sismica di maggio-giugno 2012;
- UniCAS-DICeM ha le competenze necessarie per effettuare tali attività nell'ambito del progetto;

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- la Regione dispone di numerosi rilievi, studi e progetti effettuati per la ricostruzione post-sisma 2012, depositati e archiviati presso il Servizio Geologico, Sismico e dei Suoli;
- le Parti sono accomunate dall'interesse, per quanto possibile, di verificare la vulnerabilità delle costruzioni prima del sisma e analizzare i danni indotti alle infrastrutture e strutture dal fenomeno della liquefazione nonché definire approcci metodologici finalizzati ad incrementare la resilienza e ridurre il rischio sismico.

Tutto ciò premesso, a valere quale parte integrante e sostanziale del presente accordo, tra le Parti, come sopra rappresentate;

SI CONVIENE E SI STIPULA QUANTO SEGUE:

ART.1 - SOGGETTI E SCOPI DELL'ACCORDO

La collaborazione tra le Parti ha come scopo l'analisi della vulnerabilità a liquefazione e del danno indotto ad infrastrutture e strutture nonché di approcci metodologici finalizzati ad incrementarne la resilienza.

UniCAS-DICeM metterà a disposizione le risorse strumentali e umane in possesso delle competenze necessarie, nella misura che riterrà opportuna, per indagini e analisi di approfondimento da effettuare nei territori individuati.

La Regione metterà a disposizione propri dati, competenze, strutture e risorse, nella misura che riterrà opportuna, ai fini dell'individuazione delle aree oggetto degli approfondimenti e il raggiungimento delle finalità sopra indicate.

Alla fine delle attività di concerto sarà prodotto un documento d'indirizzo per la mitigazione dei rischi da liquefazione.

ART.2 - MODALITÀ DI ESECUZIONE

Per l'esecuzione delle attività sopra indicate Regione e UniCAS-DICeM si avvarranno delle competenze del personale da ciascuna Parte rispettivamente impegnato nelle attività.

Per il raggiungimento degli scopi sopra indicati:

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- UniCAS-DICeM analizzerà i dati resi disponibili dalla Regione, in particolare quelli relativi alle indagini geotecniche sulle aree interessate dai fenomeni di liquefazione, sulle caratteristiche strutturali degli edifici e delle infrastrutture critiche presenti su tali aree, sull'agibilità a seguito del sisma e più in generale sulle manifestazioni al suolo degli effetti della liquefazione.
- la Regione renderà disponibili i dati archiviati nelle proprie banche dati, in particolare quelli disponibili presso il Servizio Geologico, Sismico e dei Suoli relativamente agli effetti di liquefazione connessi al sisma dell'Emilia del 2012 e fornirà il necessario supporto tecnico-scientifico per l'interpretazione degli stessi e favorire le attività di UniCAS-DICeM.

L'attività di ricerca prevede la possibilità di affiancare, ai dati relativi alla valutazione dell'agibilità, i dati derivanti dall'analisi dei progetti di riparazione e rafforzamento o miglioramento sismico nonché i costi degli interventi; ciò attraverso l'estrazione di un dataset relativo a un campione significativo e selezionato di progetti di riparazione e rinforzo sismico di edifici localizzati nel territorio emiliano che hanno manifestato effetti indotti da liquefazione dei terreni di fondazione.

I territori d'interesse in cui concentrare le attività sopra indicate saranno individuati dalle parti nei Comuni della Provincia di Ferrara interessati da fenomeni di liquefazione a seguito dei terremoti del 20 e 29 maggio 2012.

Alla fine delle attività le Parti produrranno di concerto un rapporto delle attività contenente la descrizione dei dati, delle procedure di analisi e dei risultati e un documento d'indirizzo per la mitigazione dei rischi da liquefazione.

ART.3 – STRUTTURE COINVOLTE E RESPONSABILI SCIENTIFICI DELLE ATTIVITÀ

All'attività di ricerca oggetto della collaborazione partecipano quale Unità di Ricerca Coordinatrice, il Dipartimento di Ingegneria Civile e Meccanica dell'Università di Cassino e del Lazio Meridionale; per la Regione la struttura individuata per tale attività è il Servizio Geologico, sismico e dei suoli della Direzione Generale Cura del Territorio e dell'Ambiente.

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La responsabilità tecnico-scientifica delle attività regolate dal presente accordo è affidata:

- per la Regione, al dott. Luca Martelli funzionario del Servizio Geologico, sismico e dei suoli;
- per UniCAS-DICeM, al prof. ing. Giuseppe Modoni

ART.4 - DURATA

Il presente accordo avrà la durata di dodici mesi a decorrere dalla data dell'ultima sottoscrizione digitale, ex art. 15, comma 2-bis, della L. 241/90.

ART. 5 - SPECIFICHE INIZIATIVE

Le Parti potranno stipulare, ove necessario, appositi atti integrativi che, ferme restando le disposizioni previste dal presente accordo, regolamenteranno iniziative specifiche, definendone più opportunamente modalità di realizzazione ed eventuali risorse da destinare.

ART.6 - COSTI

L'attuazione del presente accordo di collaborazione istituzionale non comporta per le Parti, l'assunzione di oneri aggiuntivi rispetto a quelli derivanti dall'esecuzione degli impegni assunti da ciascuna con la sottoscrizione dello stesso. Tali oneri resteranno a carico esclusivo della Parte che li ha sostenuti, fatto salvo quanto diversamente concordato tra le Parti stesse negli eventuali atti integrativi di cui all'art.5.

ART.7 - RESPONSABILITÀ

Ciascuna Parte provvede alle coperture assicurative per responsabilità civile e per infortuni del personale rispettivamente impegnato nell'esecuzione delle attività previste dal presente accordo.

Ogni Parte, pertanto, fatti salvi i casi di dolo o colpa grave, nonché quelli imputabili alla responsabilità civile di ciascuna, solleva e tiene indenne le altre Parti da ogni altra responsabilità per qualsiasi evento dannoso che possa accadere al personale delle altre Parti durante la permanenza presso le sedi di esecuzione delle attività.

In caso di infortunio del personale delle Parti durante lo svolgimento delle attività di cui al presente accordo, condotte nelle sedi di svolgimento delle stesse ed *in itinere*, la Parte interessata deve procedere, nei modi e nei tempi previsti dalla normativa vigente,

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per la denuncia dell'infortunio all'INAIL territorialmente competente, comunicando tempestivamente l'accaduto alla Parte interessata.

ART.8 - DEFINIZIONE DELLE CONTROVERSIE

Per eventuali controversie che dovessero insorgere fra i contraenti circa l'esecuzione del presente accordo, sarà competente esclusivamente il Foro di Bologna.

ART.9 - TRATTAMENTO DATI PERSONALI

Ai sensi del D. Lgs. n.196/2003 e ss.mm., le parti contraenti consentono il trattamento dei dati personali contenuti nel presente accordo per le finalità strettamente connesse all'attività prevista nello stesso.

ART.10 - REGISTRAZIONE

Il presente accordo sarà registrato solo in caso d'uso ai sensi dell'art. 5 del D.P.R. n. 131/86, con onere a carico della parte richiedente la registrazione.

Il presente atto, previa lettura e conferma, viene sottoscritto digitalmente dalla Parti nei modi e nelle forme di legge in segno di piena accettazione.

Luogo e data della sottoscrizione digitale

Regione Emilia-Romagna	Università degli Studi di Cassino e del Lazio Meridionale
Il Responsabile del Servizio Geologico, sismico e dei suoli	Il Direttore del Dipartimento di Ingegneria Civile e Meccanica
Ing. Gabriele Bartolini	Prof. Ing. Marco Dell'Isola

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Appendix 4

LIQUEFACT - Periodic Project Progress Report from 1st August 2017 to 31st January 2018.

ISMGEO has been involved in the following activities:

Work Package 4:

The experimental activity carried out by ISMGEO during this period has been focused on two main objectives: i) complete the first series of tests necessary to find the best combination of soil and ground motion useful to correctly reproduce liquefaction phenomena in centrifuge models, ii) testing different drainage patterns of the sand massif, that is among the remediation techniques proposed in the project.

To achieve the first target new ground motions have been prepared and tested with the shaking table on physical models composed by different combinations of soil columns. In this phase the interaction with the other partners of the Work Package 4 has been fundamental in order to define a new ground motion whose seismic characteristics are well suited on the case history of 2012 Emilia earthquake. The new models have shown clear liquefaction evidences, thus representing a good benchmark to evaluate the effectiveness of remediation techniques that will be tested in the following experiments. The results have been compared with the results issued from previous models, experimental data have been deeply discussed with the other partners leading to common decisions on the setup for the following tests.

The second target of the tests concerns the second series of tests reported in the Grant Agreement about the remediation technique by soil drainage. To this aim the first element that has been prepared are the reduced scale models of drains. Drains are composed by silicon pipes with an external diameter of 6 mm and internal diameter of 4 mm. Those value correspond to 30 cm and 20 cm respectively at prototype scale and are consistent with a generalized diameter for drains. Each drain is provided with two holes each 5 mm (25 cm at prototype scale) and this condition assures the efficiency of the drain, the viscous fluid used in the models can flow inside and outside the drain just by gravity without any additional pressure. As a consequence the excess pore pressure developed in the soil during the simulated earthquake can be dissipated by this type of drains.

The disposition and spacing of drains in soil models has been object of a shared decision with the partners of WP4: a square pattern has been decided for vertical drains, a triangular pattern for horizontal drains. Spacing conditions to be tested for both vertical and horizontal drains corresponds to 5 times and 10 times the diameter. Vertical drains have been driven in the model at the end of its setup phase, the soil was preventively instrumented and saturated. Specific supports have been manufactured to guarantee the correct pattern for drains. Horizontal drains, instead, have been installed during the model setup at specific design depths. In this case vertical square pipes are installed on the sides of the model and acts as manifolds. Test results show clearly the benefic effect of soil drainage and also give interesting insights on the improved effect given by the spacing configurations adopted.

Table 1 reports a summary of tests carried out in the reporting period 01/08/2017–31/01/2018.

test #	model type	soil/drain	ground motion	test name
12	2 (two layers:3+clay)	3	34	M2_S3_GM34
13	2 (two layers: 1+clay)	1	34	M2_S1_GM34
14	1 (ticino sand)	1	31	M1_S1_GM31
15	ticino sand + clay	1	31	M2_S1_GM31
16	1 (homogeneous)	V	i1	M1_S1_VD1_GM31
17	1	V	i2	M1_S1_VD2_GM31
18	1	H	i1	M1_S1_HD1_GM31
19	1	H	i2	M1_S1_HD2_GM31
20	2 (two layers)	V	i1	M2_S1_VD1_GM31
21	2	V	i2	M2_S1_VD2_GM31
22	2	H	i1	M2_S1_HD1_GM31
23	2	H	i2	M2_S1_HD2_GM31

Table 1. Tests performed from 01/08/2017 to 31/01/2018

Work Package 9:

Two activities are ascribable to this work package. First, the participation to the general Meeting held in Naples in the first week of October. Second, a scientific/experimental meeting has been organized in Seriate on 14/11/2017. Participants were from Anglia Ruskin University, University of Naples, Eucentre, Porto University and Ismgeo.

A busy working schedule has accompanied this meeting. A synoptic comparative of results of the first series of tests has been proposed at first. Then all the participants had the occasion to assist to a centrifuge test that was preliminary prepared. Some preliminary results have been discussed on real time. Finally, on the basis of the analysis of previous tests and on the results obtained in real time, experimental choices concerning the setup for following tests have been decided. Considered parameters concerned: sand type, ground motion, drains dimensions and pattern, depth, volume of soil submitted to remediation technique.