MACRO- AND MICRO-ZONATION OF A TERRITORY FOR EARTHQUAKE-INDUCED LIQUEFACTION

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Legend

- key-staff
- staff involved in specific activities
- students
ABOUT SPATIAL SCALES....

- **macro-zonation**
- **meso-zonation**
- **micro-zonation**

Emilia

![Soil profile](image)

Chareyre et al. (2018)

- **soil profile**
  - Silt and fine sand
  - Clay
  - Fine and medium sand
  - Coarse sand
  - Clay
  - Coarse sand
  - Fine and medium sand
  - Clay
  - Coarse sand
  - Silt and sand with some alpine gravel
  - Pliocene bedrock
  - Sand and marine pebbles

- **soil grains**

liquefaction
EARTHQUAKE-INDUCED LIQUEFACTION HAZARD OR RISK?

SYSTEM

Soil + Structure

SOIL

saturated, loose sand (VULNERABILITY)

seismic shaking (HAZARD)

RISK OF DAMAGE FROM EARTH-QUAKES

CONVOLUTION OF:

• HAZARD
• VULNERABILITY
• EXPOSURE

RISK = H * V * E

PROBABILISTIC FRAMEWORK

RISK of (DAMAGE-STRU)

CASCADING EFFECT!

HAZARD

STRUCTURE

(http://nisee.berkeley.edu/equiis.html)
MACRO-ZONATION OF EUROPEAN TERRITORY FOR LIQUEFACTION RISK
MACRO-ZONATION — INPUT DATA

CATALOGUE OF HISTORICAL LIQUEFACTION OCCURRENCES IN EUROPE
(Task 2.3)

Map showing the distribution of liquefaction manifestations included in the catalogue across Europe. The color of the circles is proportional to the event moment magnitude.
MACRO-ZONATION – INPUT DATA

- PGA – Extracted from SHARE project
- PGAm (PGAxMWF)*
- CTI – derived from DEM
- Vs30 – derived from DEM
- River distance - derived from DEM
- Coast distance
- Waterbody distance (i.e. distance from the nearest river/coast/lake)
- TPI (Topographic Position Index) - derived from DEM
- TRI (Terrain Roughness Index) - derived from DEM

*Magnitude-Weighting Factor: $MWF = \frac{M^{2.56}}{10^{2.24}}$

The data listed are all collected as raster maps at European extension
Harmonized in a GIS environment:
✓ Same spatial resolution (cells dimension) of 900x900m
✓ Perfectly overlapped (i.e. the edges of the cells of each raster are snapped to those of the other rasters)
MACRO-ZONATION – DATASET DEVELOPMENT

Build a dataset containing for each record:
- One value for each explanatory variable (extracted from the rasters cells)
- A binary outcome (1/0) indicating whether liquefaction was detected in that cell or not

The seismological data in the database must refer to the specific earthquake event that triggered or did not trigger liquefaction

4 events selected:
- Emilia earthquake 2012
- Cephalonia earthquake 2014
- L’Aquila earthquake 2009
- Parma 2008

The final model need to be trained on both positive (occurrence of liquefaction) and negative (non occurrence of liquefaction) data

Potentially there could be a huge number of 0 cells, given the spatial extension of the shakemaps data

Unbalanced dataset: classes (0, major class and 1, minor class) are not represented equally.

From shakemaps, not from SHARE
SHARE data will be used later for hazard maps

Dataset layout example

<table>
<thead>
<tr>
<th>ID</th>
<th>Vs30 (m/s)</th>
<th>CTI</th>
<th>PGA (g)</th>
<th>...</th>
<th>Y/N</th>
</tr>
</thead>
<tbody>
<tr>
<td>XXXX</td>
<td>150</td>
<td>25</td>
<td>0.2</td>
<td>...</td>
<td>1</td>
</tr>
<tr>
<td>YYYY</td>
<td>700</td>
<td>15</td>
<td>0.18</td>
<td>...</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>...</td>
<td></td>
</tr>
</tbody>
</table>
MACRO-ZONATION — HAZARD MAPS

Validation with the liquefaction catalogue events characterized by a RT = 475 years

Non-susceptible soils and area characterized by a PGA lower than 0.10g are excluded from the analysis and a 0 value is assigned a priori.

The optimal threshold reported in the previous table is employed to distinguish liquefaction - no liquefaction in the right image.
Non-susceptible soils and area characterized by a PGA lower than 0.1g are excluded from the analysis and a 0 value is assigned a priori.

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MACRO-ZONATION – HAZARD MAPS

Validation with the liquefaction catalogue events characterized by a RT = 475 years

Non-susceptible soils and area characterized by a PGA lower than 0.1g are excluded from the analysis and a 0 value is assigned a priori.

The optimal threshold reported in the previous table is employed to distinguish liquefaction - no liquefaction in the right image.
MACRO-ZONATION — EXPOSURE

EXPOSURE MODEL (Sousa et al., 2017)

- Divided in 5 classes (1 low exposure, 5 high exposure) based on population density
- Areas extracted from Corine Land Cover with low population density but considered at high exposure (port and airport areas, railways) was assigned to class 5
Each pixel of the final map has a rank, assigned with the AHP procedure.
The higher the rank, the higher the risk.
SEISMIC MICRO-ZONATION
(URBAN SCALE)
European Testing Sites

EMILIA REGION, ITALY CAVEZZO MUNICIPALITY
UNIPV-EUCENTRE

LISBON AREA IN PORTUGAL
UPORTO

LJUBLJANA AREA IN SLOVENIA
ULJ

MARMARA REGION IN TURKEY
Istan-Uni
INTER-INSTITUTIONAL AGREEMENT
FOR MICRO-ZONATION STUDY AT CAVEZZO

Liquefaction in Cavezzo
May, 29 2012 M6 EQ
PROCEDURE FOR MICRO-ZONING LIQUEFACTION RISK AT URBAN SCALE: 
THE CASE-STUDY OF CAVEZZO

1. Definition of **geological and seismo-tectonic setting** associated to case study
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6. Micro-zoning territory of Cavezzo for liquefaction risk
PROCEDURE FOR MICRO-ZONING LIQUEFACTION RISK AT URBAN SCALE: THE CASE-STUDY OF CAVEZZO

1. Geological, geo-morphological and hydro-geological framework

2. Investigation campaigns for geotechnical characterization

3. Definition of geotechnical & seismo-stratigraphic model

4. Definition of reference seismic Input
   - Set of 7 real sismo- and spectrum-compatible accelerograms

5. Ground Response Analyses
   - 475, 975, 2475 yrs return periods
   - Ground response analysis

6. Micro-zoning territory of Cavezzo for liquefaction risk
Map showing existing data available for the territory of Cavezzo before LIQUEFACT project started in 2016 (left) and (right) data acquired by March 2018 for geotechnical characterization.

Black dots show liquefaction manifestations occurred during May-June 2012 sequence.
LITHO-STRATIGRAPHIC 3D GEOLOGICAL MODEL

- IDW interpolation with cross-sections guide
- 30 Horizon
- Cell size resolution: 100 m
- Vertical resolution 0.5 m
- 30-40 m max. depth
PSEUDO-STOCHASTIC 1D GROUND RESPONSE ANALYSES

For about 3000 points →

\[ F^l = \sum_{j=1}^{7} w_{acc} \sum_{k=1}^{11} w_{mod} F^i_{jk} \]

wacc = 1/7 → (same weight for 7 accelerograms)
wmod = 0.05 for 10 models INGV; 0.5 for OGS model

- 5% acceleration response spectra
- 9 amplification factors (\( F_{PGA}, F_{H0.1-0.5s}, F_{H0.5-1s}, F_{H0.5-1.5s}, F_{H0.7-1.1s}, F_{A0.1-0.5s}, F_{A0.5-1s}, F_{A0.5-1.5s}, F_{A0.4-0.8s} \))
MICRO-ZONING THE TERRITORY FOR EXPECTED GROUND MOTION

Map of (horizontal) PGA computed at free surface by 1D linear-equivalent ground response analyses assuming an input motion of 475 years return period

Calibration of reduction curves using Darendeli (2001) model based on laboratory tests (i.e. RC, DSS test)
LIQUEFACTION VULNERABILITY BY IN-SITU TESTS METHODS TAKING INTO ACCOUNT THE EPISTEMIC UNCERTAINTY

CPR from ~ 450 CPT/CPTU

Empirical or semi-empirical correlations

Robertson (2009)

Boulanger and Idriss (2016)

Moss et al. (2006)

25% 50% 50%

Critical state-based methods

Giretti and Fioravante (2017)

Jefferies and Been (2015)

70% 50%

CPTe-based

CPTm-based

Boulanger and Idriss (2016) corrected by Facciorusso et al. (2017)

V_s-based

Kayen et al. (2013; 2014)

MAP OF LIQUEFACTION POTENTIAL INDEX (LPI)

Legend
- ▲ 2012 liquefaction events

LPI (Somnez, 2003)
- LPI = 0
- 0 < LPI ≤ 2
- 2 < LPI ≤ 5
- 5 < LPI ≤ 15
- LPI > 15

LPI (Somnez, 2003) - IDW
- LPI = 0
- 0 < LPI ≤ 2
- 2 < LPI ≤ 5
- 5 < LPI ≤ 15
- LPI > 15

Spatial interpolation using different algorithms (e.g. IDW, kriging)

Return Period: 475 years

Black dots: 2012 liquefaction manifestations

from Monte Carlo simulations
MAP OF LIQUEFACTION-INDUCED SETTLEMENTS

Legend
- 2012 liquefaction events

S (Zhang, 2002)
- 0cm < S ≤ 2cm
- 2cm < S ≤ 5cm
- 5cm < S ≤ 8cm
- 8cm < S ≤ 15cm
- S > 15cm

S (Zhang, 2002) - IDW

Legend
- 0cm < S ≤ 2cm
- 2cm < S ≤ 5cm
- 5cm < S ≤ 8cm
- 8cm < S ≤ 15cm
- S > 15cm

from Monte Carlo simulations

CPT-based methods

Return Period: 475 years

Black dots: 2012 liquefaction manifestations
THANK YOU FOR YOUR ATTENTION!
Earthquake *geotechnical*– versus *structural*– induced building collapse

(http://nisee.berkeley.edu/eqiis.html)