Surface liquefaction effects detected and measured by DInSAR: 2012 Emilia (Italy) earthquake

Marco Chini¹, Matteo Albano², Michele Saroli³, Luca Pulvirenti⁴, Marco Moro², Christian Bignami², Emanuela Falcucci², Stefano Gori², Giuseppe Modoni³, Nazzareno Pierdicca⁵, Salvatore Stramondo⁵.

¹Luxembourg Institute of Science and Technology, Belvaux, Luxembourg
²Istituto Nazionale di Geofisica e Vulcanologia, Rome, Italy
³DiCEM – Department of Civil and Mechanical Engineering, University of Cassino and Southern Lazio, Cassino, Italy
⁴CIMA Research Foundation, Savona, Italy
⁵Department of Information Engineering, Electronics and Telecommunications, Sapienza University of Rome, Rome, Italy.
Presentation outline

• The Emilia 2012 earthquake
• The liquefaction phenomenon
• Available dataset
• Methods
• Results & back analysis
The seismic event(s)

- A seismic sequence occurred in Emilia region in the timeframe between May and June 2012
- Two major events took place on May 20 and May 29, magnitude 5.9 and 5.8, respectively
- 5 aftershocks recorded 5.1 < ML < 5.3, and more than 2000 minor events
- More than 50 km², elongated in the WNW–ESE direction
Liquefactions

Induced differential compaction by expulsion of water and fine-gross sand

Variation of topographic level
Liquefactions evidences in epicentral area

- numerous sand boils and water leaks at the ground surface with a diffused pattern of ground settlements, randomly distributed
- cracks not randomly distributed but located along preferential alignments → with small vertical throws
- openings of few centimetres wide occasionally reached 40–50 cm.
- in some areas (San Carlo and Sant’Agostino villages), ruptures were accompanied by significant vertical offsets → more than 50 cm reached
- fine sand outcropping of more than ten meters in length, in Bondeno and San Carlo, with extensions from few to many hundreds m² → depending on the amount of ejected water
- localized subsidence with ponding that caused damages to many buildings, roads, fenced walls, and lifelines
COSMO-SkyMed dataset

• Two pre-seismic and two post-seismic images
• April 1, May 19, May 23, and June 5, 2012
• Stripmap Himage mode (3x3 m per pixel SLC), HH polarization, right looking, incidence angle 29°, descending orbits
• 6 interferograms computed (pre- co- and post-seismic)
• Standard DinSAR applied: 2x2 multi-look, SRTM-DEM topo removal, Goldstein phase noise filtering, MCF unwrap
SAR derived features

• Displacement maps (DinSAR)
• Complex Coherence (CC) maps
• Intensity Correlation (IC) maps:
  ✓ Pearson coefficient derived by multi-looked data

• CC and IC bring different information about surface changes:
  ✓ CC mostly influenced by the phase difference in radar returns particularly related to the spatial arrangement of scatterers within the pixel and thus to their possible random displacements
  ✓ IC more related to change in the statistics of magnitude of the radar returns

\[ \rho_I = \frac{E(I_1I_2)}{\sqrt{E(I_1^2)E(I_2^2)}} \]
Results: urban areas

[A] RGB SAR coherence images → R: pre-seismic(April1–May19,2012); G=B: co-seismic(May19–May23,2012)
[B] RGB SAR intensity correlation images → R: pre-seismic; G=B: co-seismic
Results: built-up

- For damaged structures both CC and IC decrease in co-seismic SAR pair
Results: agricultural areas

- cyan colour prevails in the CC maps: co-seismic CC > pre-seismic CC
- low pre-seismic values due to the large temporal baseline (nearly 2 months)
- black “snake-shaped” pixels are evidence of a paleo-channel not previously mapped, where liquefactions occurred
Results: deformation map

co-seismic

Bn= 366 m

post-seismic

Bn= 1311 m
Results: deformation map

- Compaction induced by liquefaction
- Confirmed by Liquefaction Susceptibility analysis
Back-analysis

- geotechnical surveys carried on near the epicentral areas were used
  - Boreholes (SC), drilling (SD), water wells (PA), mechanical and electrical cone penetrometer test (CPT/CPTE)
  - at variable depths: from a few to more than 50 metres
- presence of deposits and flood fans in the first 10–15m from surface
- strata composed of alternations of sands, sandy silts and clays
Back-analysis: soil composition

- Profiles of the classification index ($I_c$, by Robertson, 1990) from 13 CPTE show the presence of a fine to medium sandy layer at depths between 9 and 13 m, below surface

- Layer is always submerged: water table between 2 and 6 m below the surface - by piezometric measurements
Back-analysis: Safety Factor

- From CPTE profiles the Safety Factor (SF) can be calculated

- \( SF = f(a, Mw, \text{soil, depth}) \): \( Mw = 5.9 \), \( a = 0.22g \)

- SF is systematically lower than 1 for the sandy saturated layer

the soil is susceptible to liquefaction
Back-analysis

- From CPTE data and previous analysis the volumetric strains induced by liquefaction at different depths could be computed with the empirical procedure proposed by Zhang et al. (2002)

- Large areal extension and limited thickness of the liquefied soil layer the volumetric strains are assumed equivalent to the vertical strains

- A ground subsidence ranging between 10 and 16 cm for the zones A and B, and equal to 3 cm in the zone C are estimated

- CPTE only in zone C
Conclusions

• Surface displacement field due to the earthquake sequence that hit the Emilia region using DInSAR technique with COSMO-SkyMed data were performed

- The VHR capability and X-band data allows detection of different surface effects caused by soil liquefactions:
  - Agricultural areas: evidenced previously unrecognized paleo channels and subsiding areas confirmed by ground surveys (punctual features interested by liquefactions/cracks observed)
  - Urban areas: SAR coherence & SAR Intensity Correlation changes allowed identification of differential soil compaction in hit area

• Back analysis on CPTE allowed the identification of the soil responsible for the liquefaction

• Back analysis on CPTE shows a qualitative consistency between calculation and measurements


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THANKS!