SDMT-based site characterization and liquefaction analysis of canal levees damaged by the 2012 Emilia (Italy) seismic sequence

Laura Tonni, Guido Gottardi, Michela Marchi
*University of Bologna, Italy*

Luca Martelli
*Regione Emilia-Romagna, Bologna, Italy*

Paola Monaco, Lucia Simeoni
*University of L’Aquila, Italy*

Sara Amoroso
*Istituto Nazionale di Geofisica e Vulcanologia, L’Aquila, Italy*
The 2012 Emilia seismic sequence

Map of epicentres of earthquakes of magnitude $M_L \geq 4$ in the period 20 May – 30 June 2012

(ISIDE – Italian Seismological Instrumental and Parametric Data-Base
http://iside.rm.ingv.it)
Ground fractures and damage to structures on riverbanks (Scortichino)
"Gruppo di Lavoro Argini"

- **Working Group** (various Italian universities + Geological, Seismic & Soil Survey Regional Dept) promoted by Municipality of Bondeno, Emilia-Romagna Regional Authority in cooperation with Italian Geotechnical Society (AGI)

- **Task**: investigate causes of earthquake-induced damage, analyze seismic response of embankment, assess post-earthquake stability conditions, propose remedial measures => comprehensive site investigation program, including several in situ and laboratory tests (summary of WG results & activity: Gottardi et al. 2014, Tonni et al. 2015)

- This paper: focus on **use of SDMT results** for site characterization & liquefaction analyses
Scortichino canal levee
Selected investigated areas
Location of SDMT and other in situ tests in the four selected areas
Soil stratigraphy from boreholes

Area A

Unit AR
Embarkment

Unit C
Clay

Unit B
Silty sand and sandy silt

Unit A
Coarse sand (deep aquifer)
SDMT results

- **Material Index** ($I_D$)
- **Constrained Modulus** ($M$ (MPa))
- **Undrained Shear Strength** ($c_u$ (KPa))
- **Horizontal Stress Index** ($K_D$)
- **Shear Wave Velocity** ($V_s$ (m/s))

The diagrams show the variations of these properties with depth, marked by different layers (CLAY, SILT, SAND) and locations (AR, B, C) from the bank crest to the bank toe.
$p_2$ pressure measured in sandy-silty layers and inferred $u$ distribution

Units AR + B
GWT $\equiv$ canal water level
11.16 m a.s.l.

Unit A
"Acquifero padano" GWT 7.8 m a.s.l.

Triangles: measured $p_2$
Dashed line: presumed $u$ distribution in the upper sandy-silty layers (AR+B)

Circles: measured $p_2$
Dotted line: presumed $u$ distribution in the lower sandy layer (A)
Stratigraphic model
Area C
(cross-section c-c')
SDMT-based liquefaction analyses

Procedure

- Simplified dynamic approach
- Liquefaction safety factor $FS_{liq}$
  $$FS_{liq} = \frac{CRR}{CSR} = \frac{CRR_{M=7.5} \cdot MSF}{CSR}$$
- Cyclic stress ratio $CSR$ by ground seismic response analysis
- Cyclic resistance ratio $CRR_{M=7.5}$ from $V_S$ and $K_D$ by SDMT (this paper) + CPTU + Lab (CSS)
- Liquefaction potential index $I_L$ (Iwasaki et al. 1982 + Sonmez 2003)
  $$I_L = \int_{z=0}^{z_{crit}=20m} F(z) \cdot w(z) \, dz$$
**SDMT-based liquefaction analyses**

**Seismic input data**

- **Triggering earthquake:** May 20, 2012 main shock (04:03 local time), moment magnitude $M_w = 6.1$, epicentral distance $R_{epi} = 7.5$ km
- **CSR from 1D (EERA) ground seismic response analysis** *(WG activity – Gottardi et al. 2014, Tonni et al. 2015)*

$$CSR = \frac{\tau_{av}}{\sigma'_{v0}} = \frac{0.65 \tau_{max}}{\sigma'_{v0}}$$

$\tau_{max}$ calculated using different accelerograms selected in Italian earthquake database ($M_w = 5.5-6.5$, $R_{epi} = 5-10$ km ...), scaled to PGA = 0.183 g *(no ground motion recordings available in this area)*
SDMT-based liquefaction analyses

CRR from $V_S$ & $K_D$

**CRR$_{M=7.5}$ from $V_S$**
- Andrus & Stokoe (2000)
- Kayen et al. (2013)

**Clean Sand**

**CRR$_{M=7.5}$ from $K_D$**
- Monaco et al. (2005)
- Tsai et al. (2009)
- Robertson (2012)
SDMT A – Results of liquefaction analysis based on $V_s$ & $K_D$
SDMT B – Results of liquefaction analysis based on $V_S$ & $K_D$

CRR-$V_S$

CRR-$K_D$
SDMT C – Results of liquefaction analysis based on $V_S$ & $K_D$
Results of liquefaction analysis based on CPTU ($q_t$) – SDMT ($V_s$ & $K_D$) – Lab Area C

Idriss & Boulanger (2004)

Gottardi et al. (2014), Tonni et al. (2015)
Conclusions

- Liquefaction analyses by simplified methods based on $K_D$ (SDMT), in agreement with CPTU + Lab cyclic tests, suggest that local liquefaction phenomena may have been induced by May 20, 2012 earthquake in the sandy-silty soils below the Scortichino canal levee, while methods based on $V_S$ (SDMT) indicate no or minor liquefaction.

- Liquefaction, facilitated by groundwater in embankment core (in hydraulic connection with nearby canal), may have originated observed ground surface deformations and lateral spreading.