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

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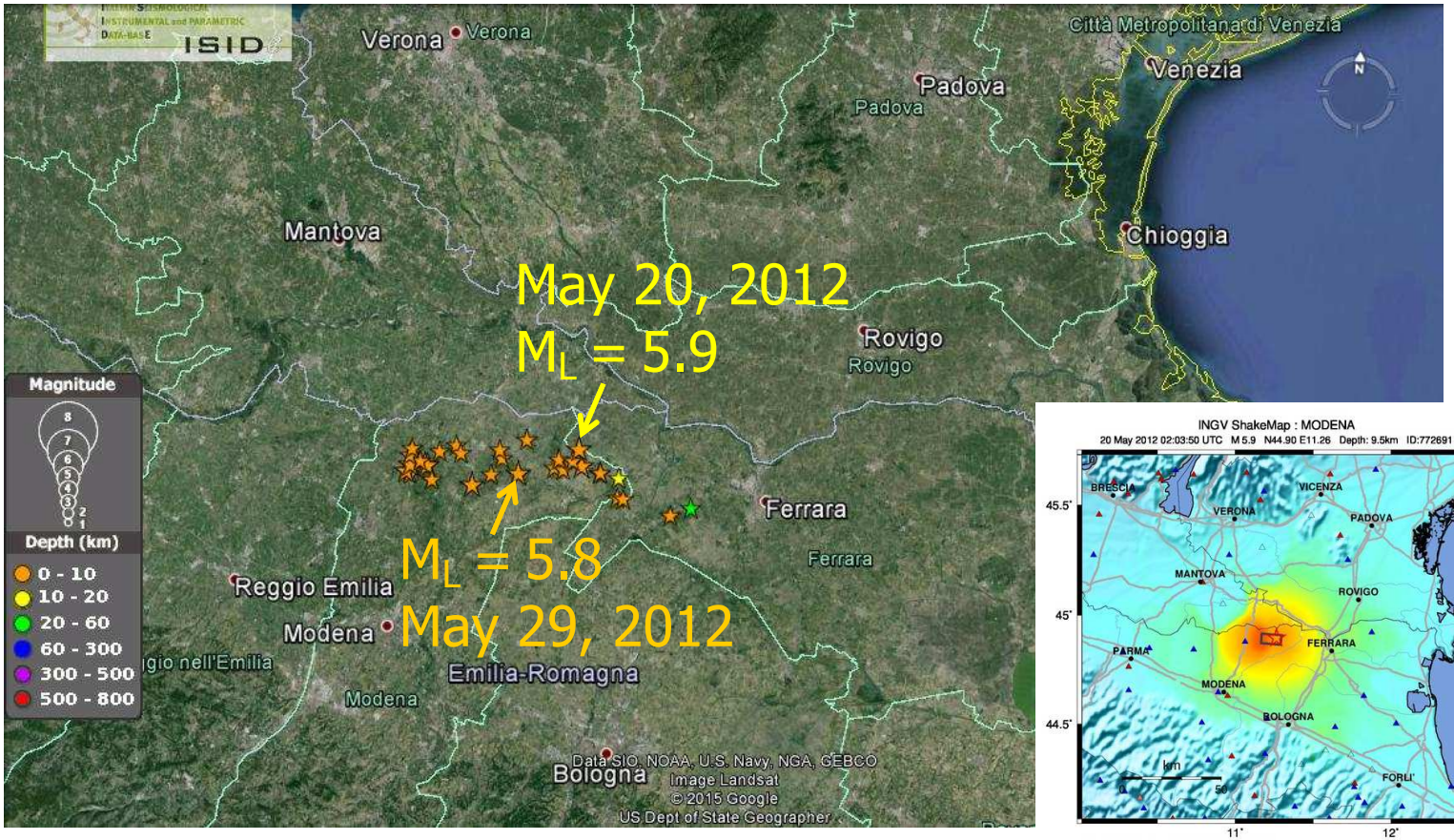
The 2012 Emilia seismic sequence



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.05	0.3	2.8	6.2	12	22	40	75	>139
PEAK VEL.(cm/s)	*<0.02*	*0.1*	*1.4*	*4.7*	*9.6*	*20*	*41*	*86*	*>178*
INSTRUMENTAL INTENSITY	I	II–III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Worden et al. (2012)

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)

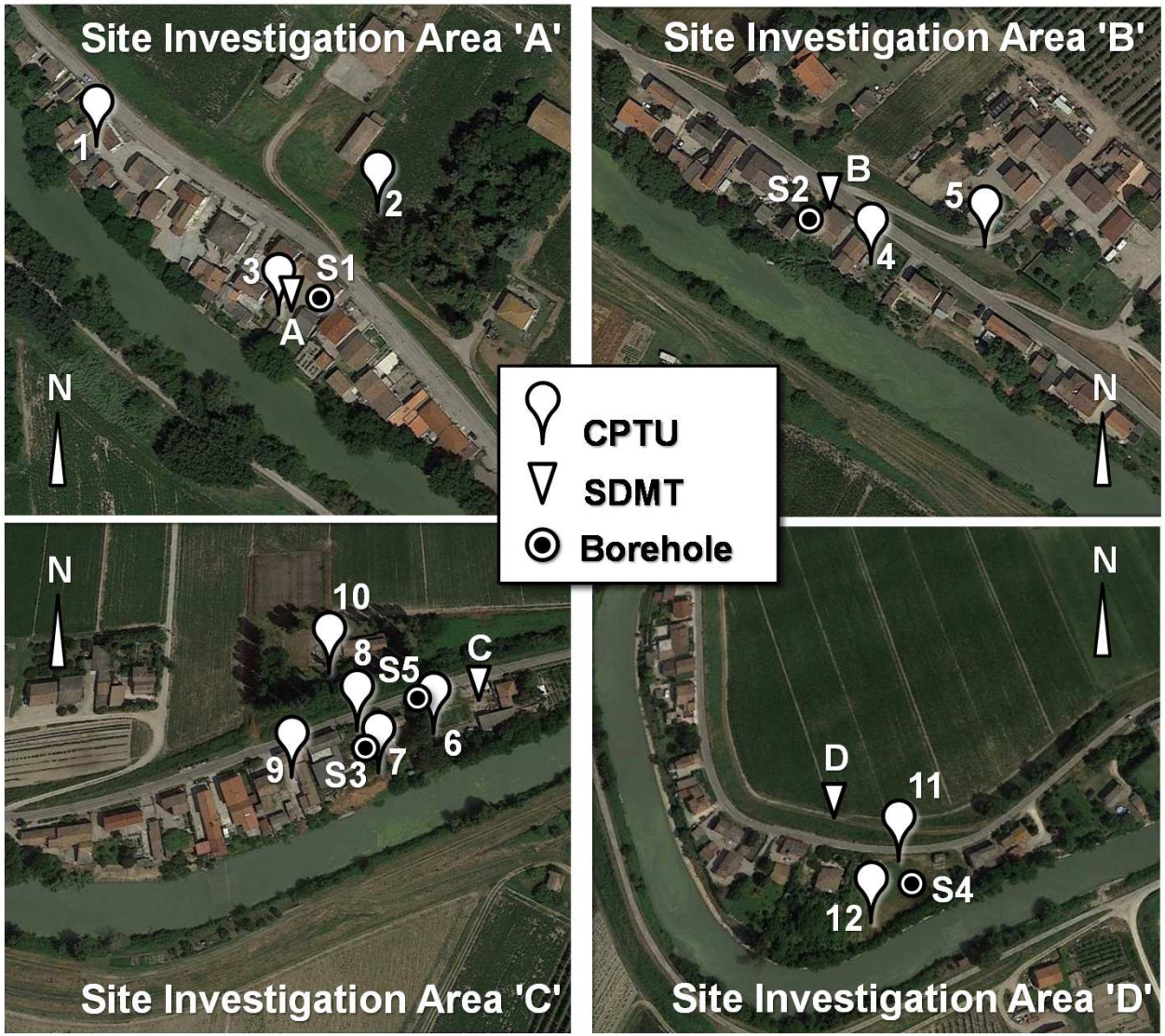
"Gruppo di Lavoro Argini"

- **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**

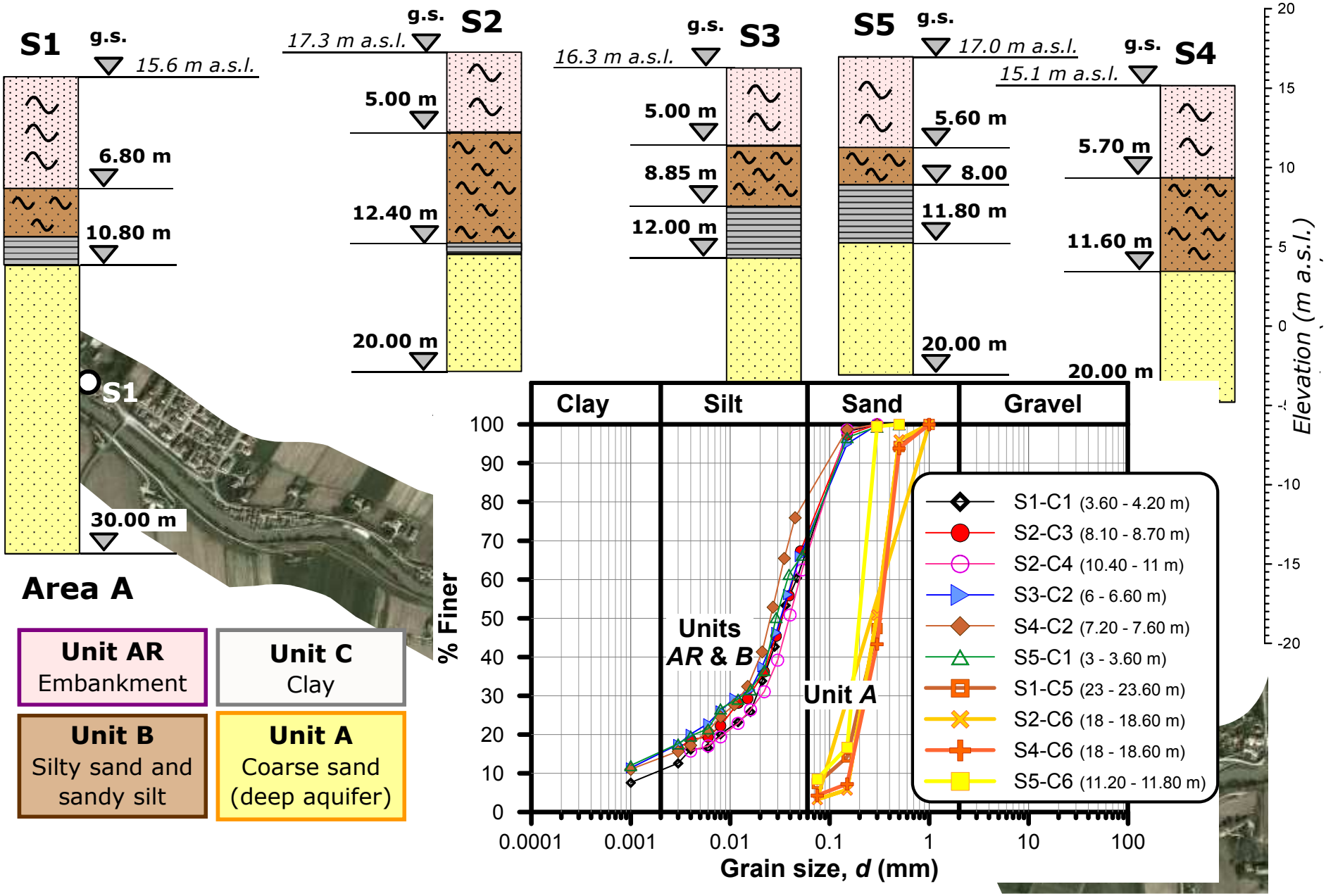
Scortichino canal levee

Selected investigated areas

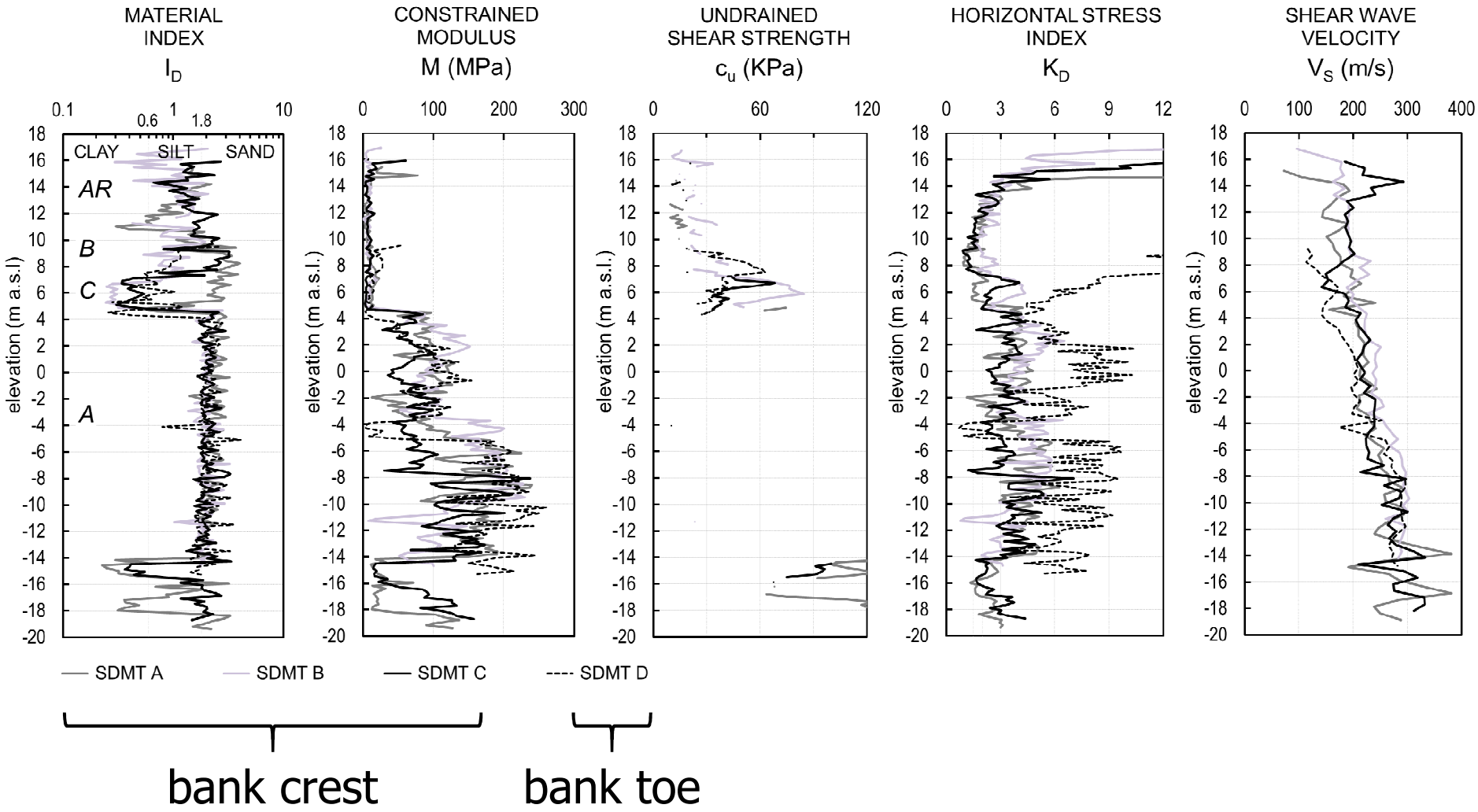
Location of SDMT and other in situ tests in the four selected areas



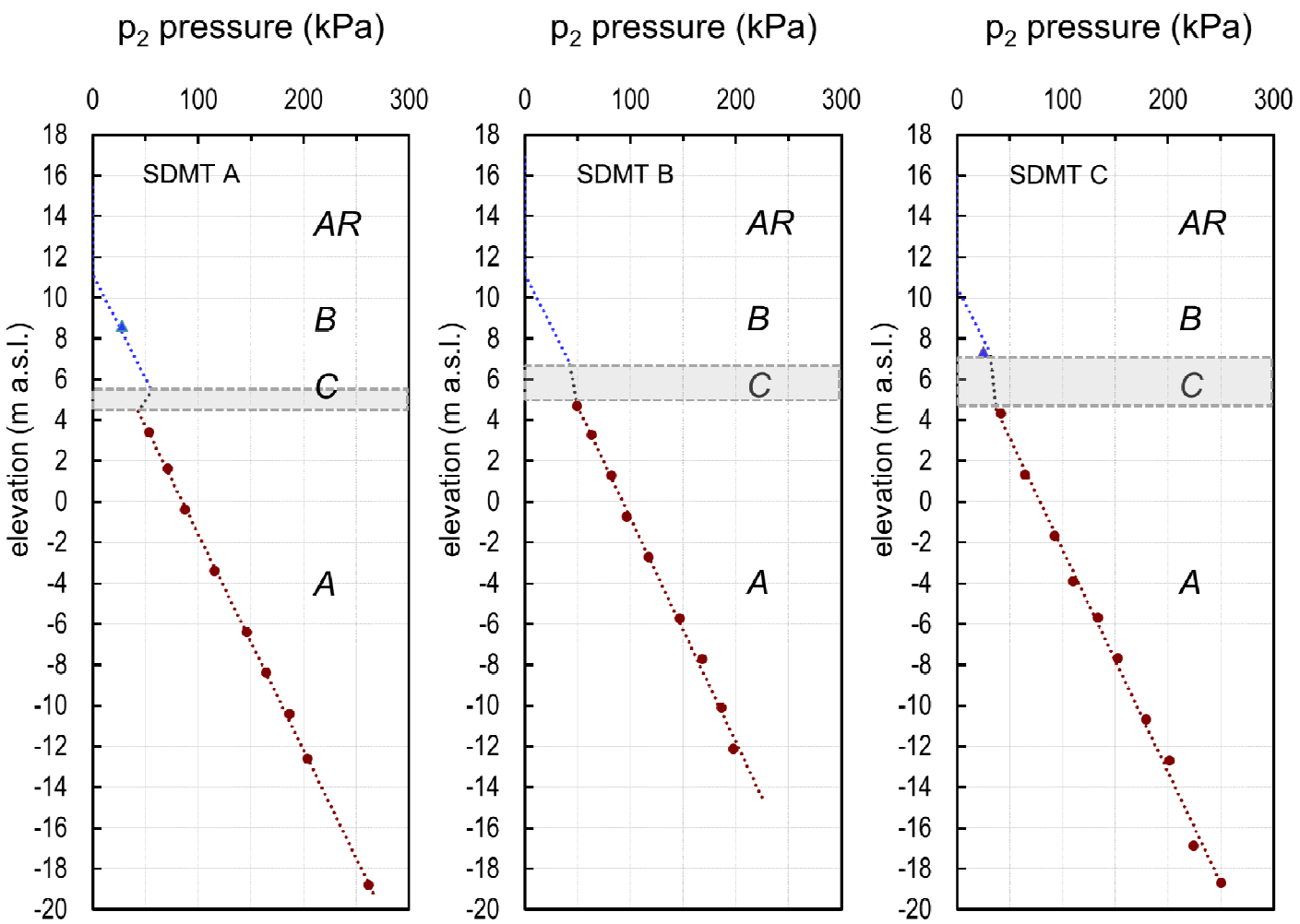
Soil stratigraphy from boreholes



SDMT results



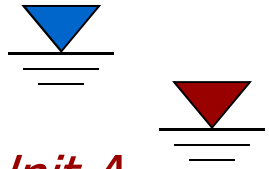
p_2 pressure measured in sandy-silty layers and inferred u distribution



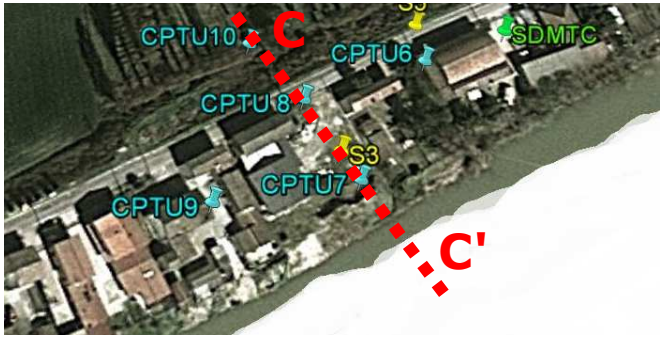
▲ measured p_2 and ····· presumed u distribution in the upper sandy-silty layers (AR+B)

● measured p_2 and ····· presumed u distribution in the lower sandy layer (A)

Units AR + B
GWT ≡ canal water level 11.16 m a.s.l.



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



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

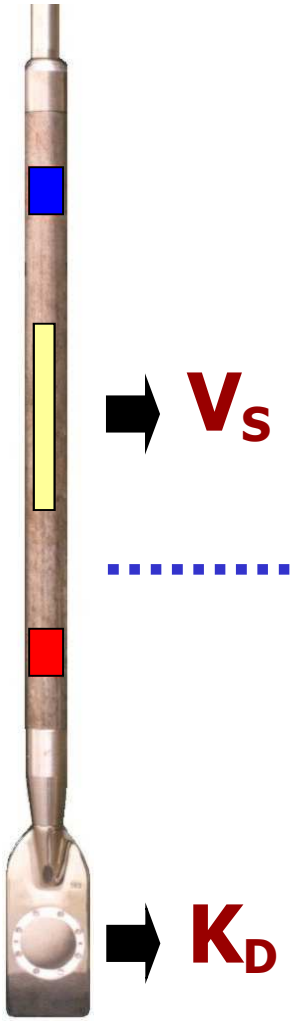
- Triggering earthquake: May 20, 2012 main shock (04:03 local time), moment magnitude M_w = 6.1, epicentral distance R_{epi} = 7.5 km
- CSR from 1D (EERA) ground seismic response analysis *(WG activity – Gottardi et al. 2014, Tonni et al. 2015)*

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

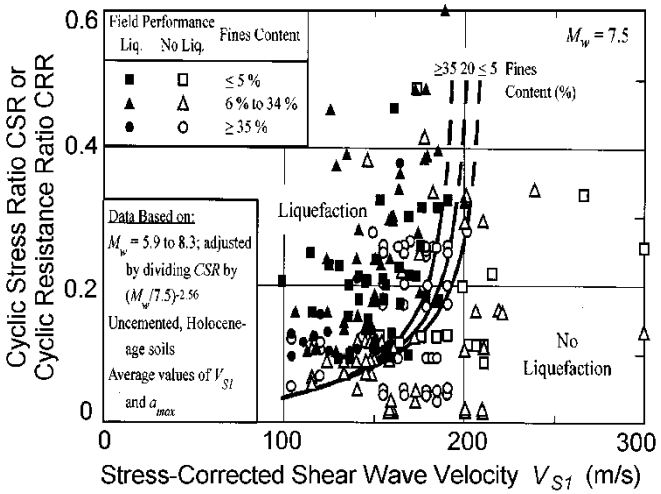
τ_{max} calculated using different accelerograms selected in Italian earthquake database (M_w = 5.5-6.5, R_{epi} = 5-10 km …), scaled to PGA = 0.183 g *(no ground motion recordings available in this area)*

SDMT-based liquefaction analyses

CRR from V_S & K_D



➡ **V_S**

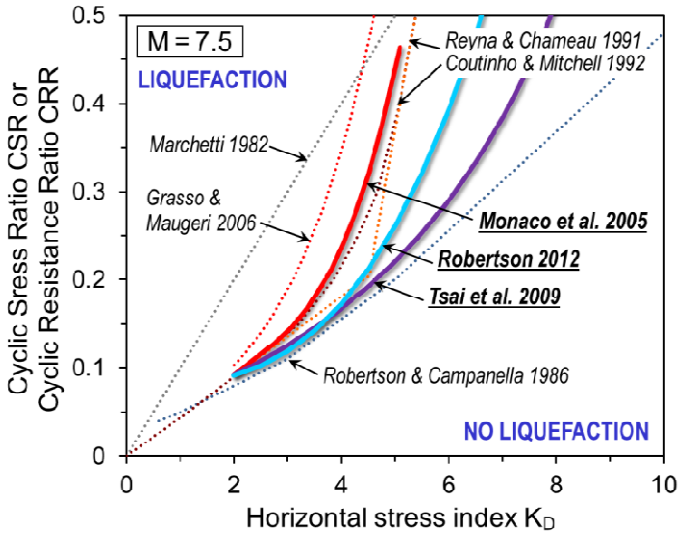


$CRR_{M=7.5}$ from **V_S**

Andrus & Stokoe (2000)
Kayen et al. (2013)

FC

➡ **K_D**

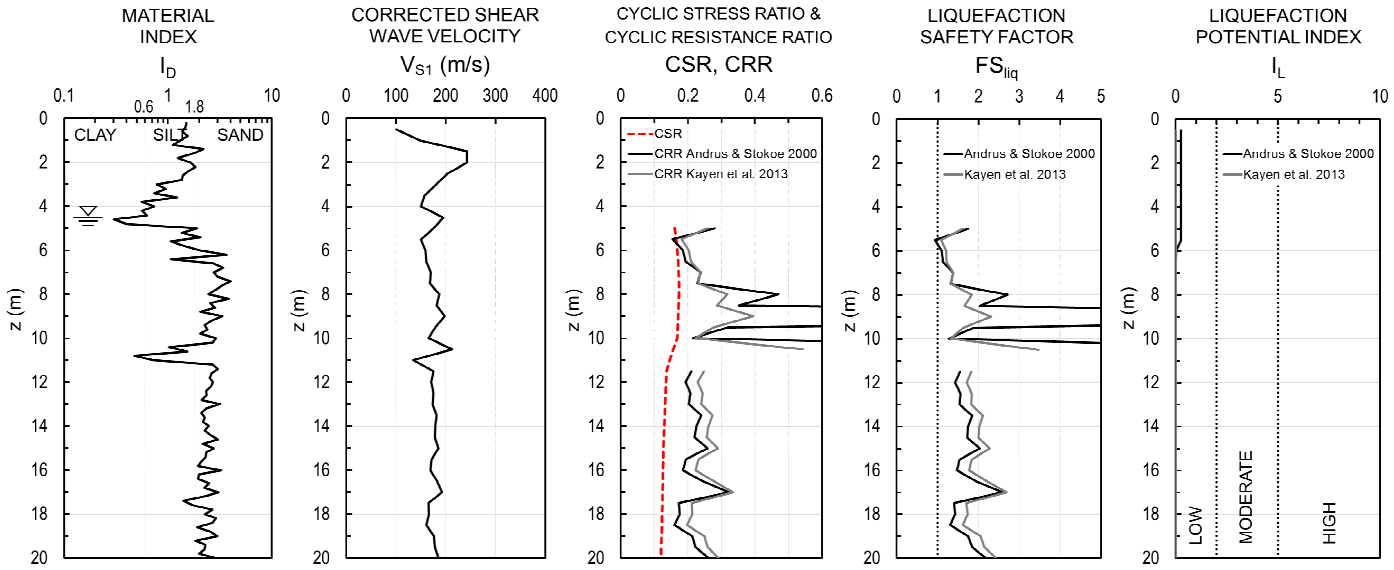


$CRR_{M=7.5}$ from **K_D**

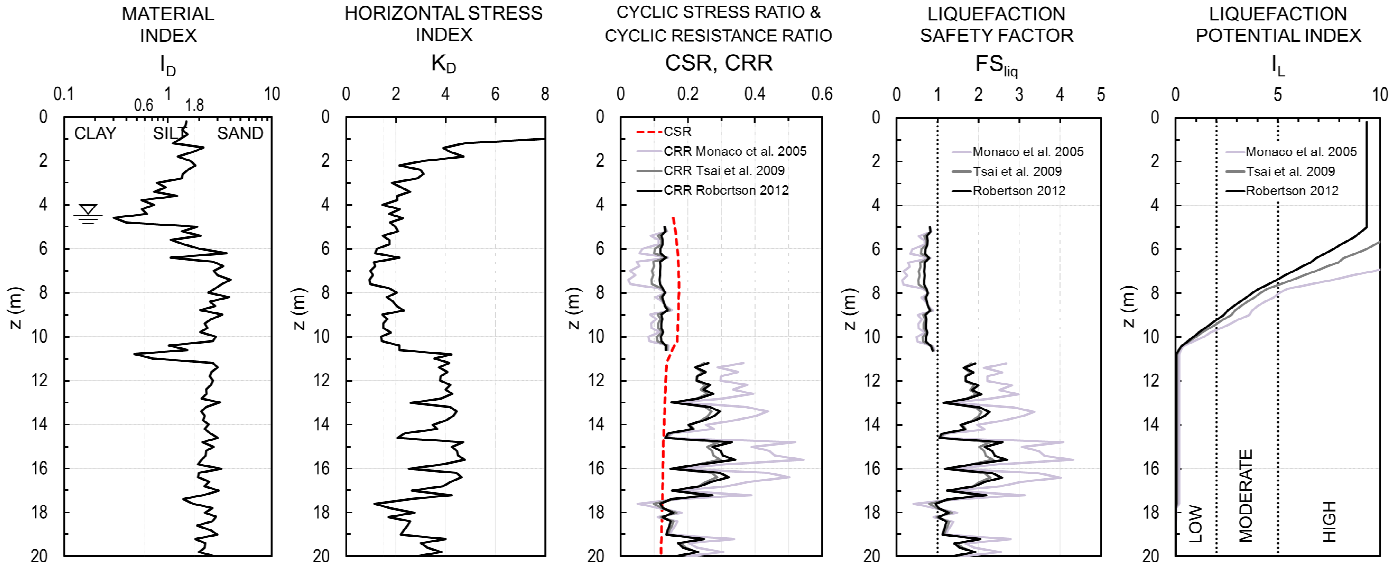
Monaco et al. (2005)
Tsai et al. (2009)
Robertson (2012)

Clean Sand

SDMT A – Results of liquefaction analysis based on V_S & K_D

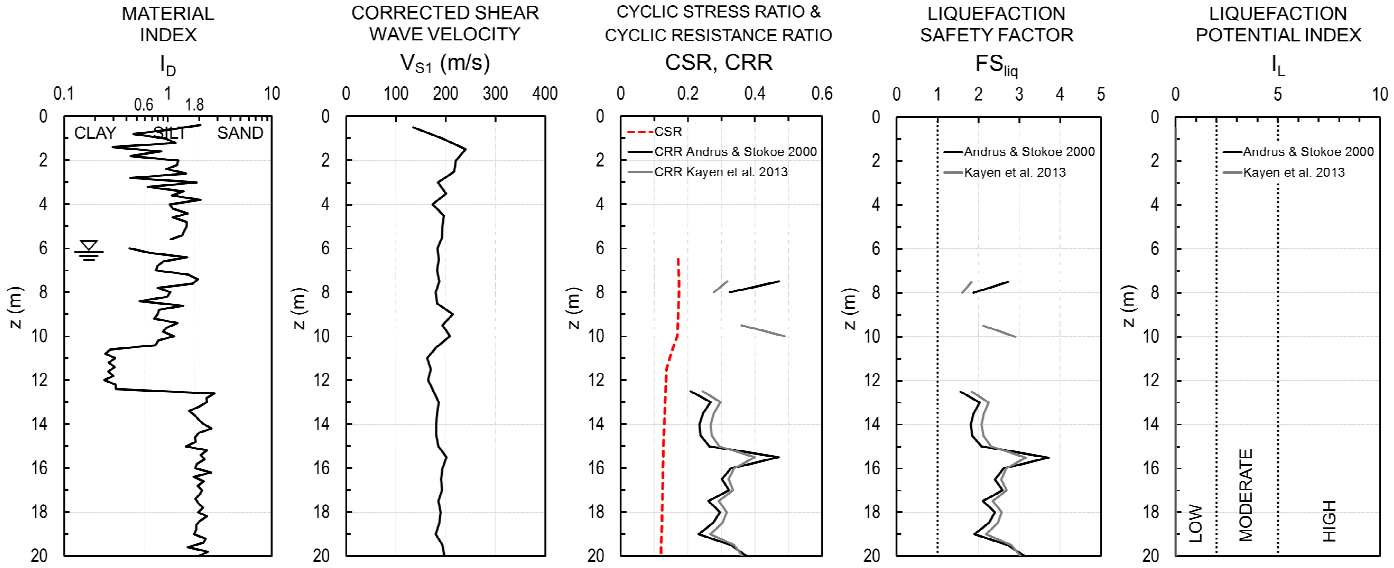


CRR-V_S

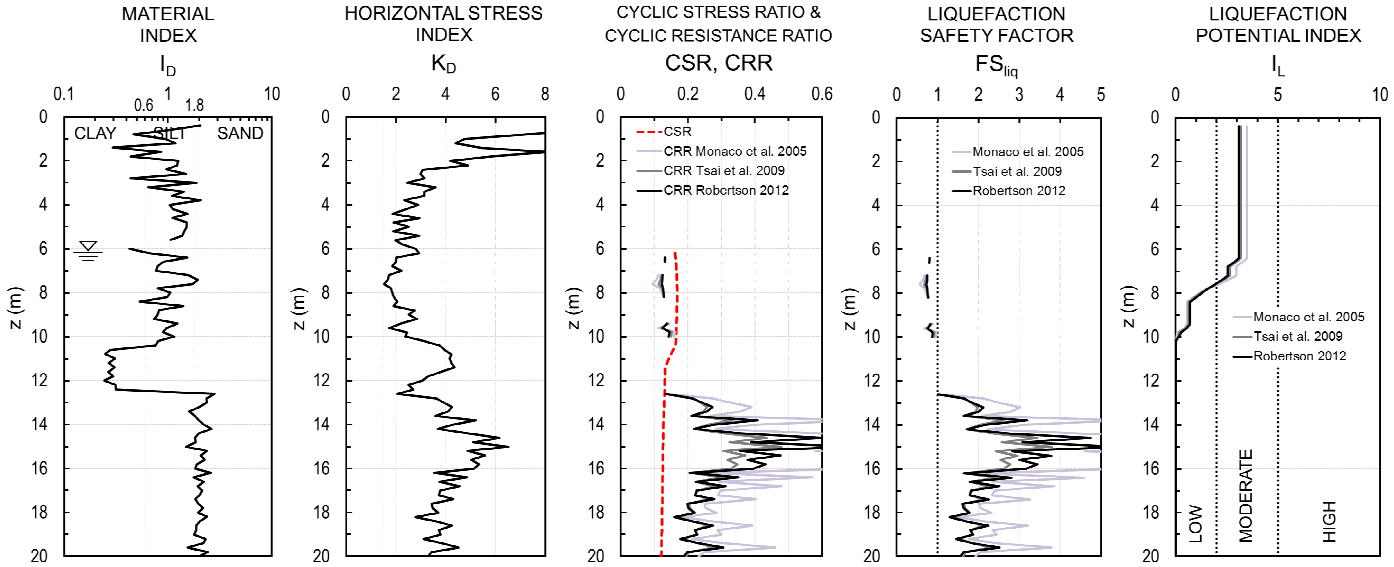


CRR-K_D

SDMT B – Results of liquefaction analysis based on V_S & K_D

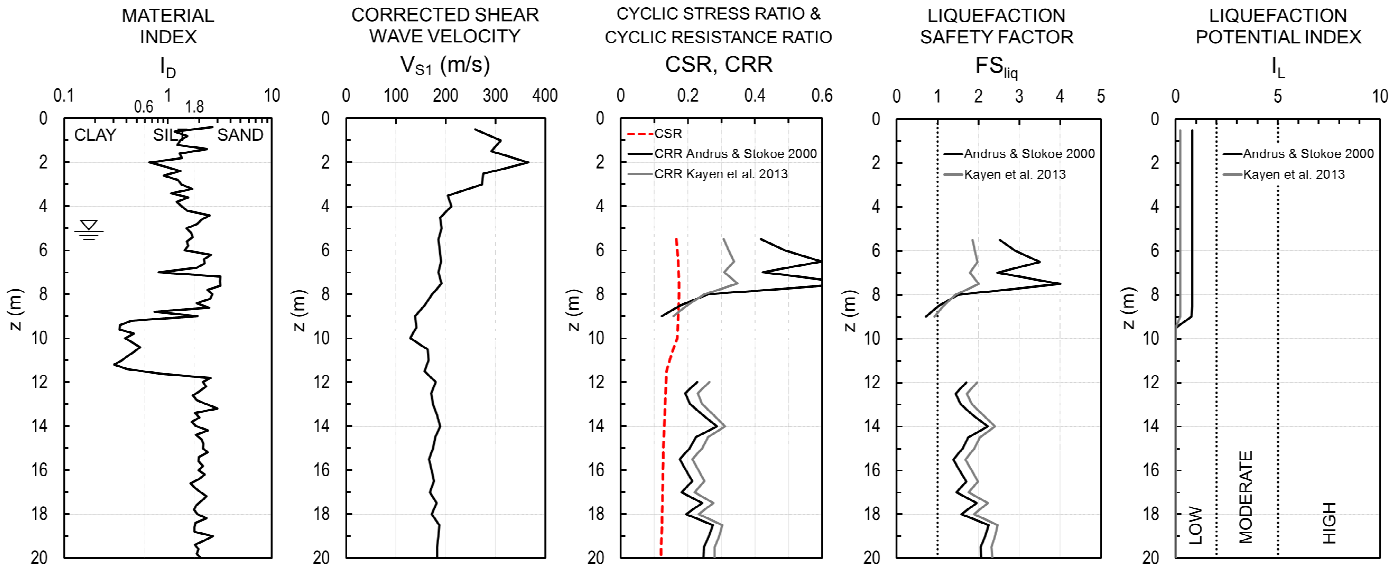


CRR-V_S

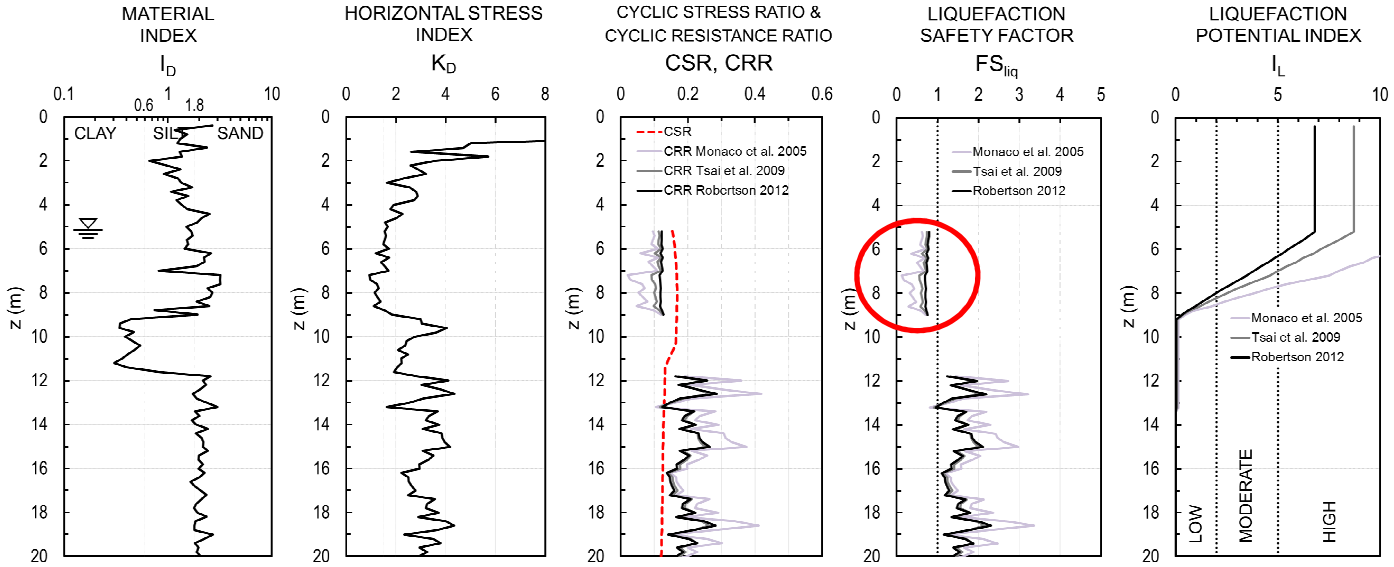


CRR-K_D

SDMT C – Results of liquefaction analysis based on V_S & K_D



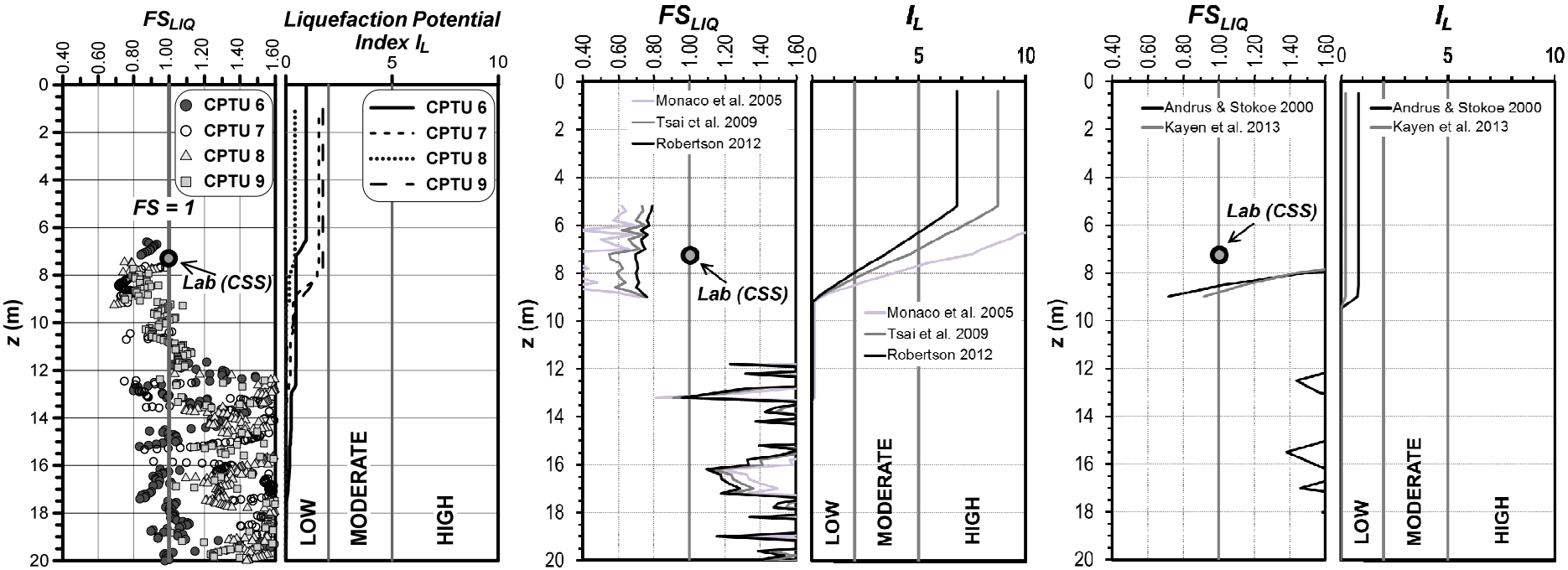
CRR-V_S



CRR-K_D

Results of liquefaction analysis based on CPTU (q_t) – SDMT (V_S & K_D) – Lab

Area C



CRR-q_t **CRR-K_D** **CRR-V_S**

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