



# COMUNE DI CERVIA

Provincia di Ravenna

Settore Programmazione e Gestione del Territorio



Il Sindaco

**Dott. Luca Coffari**

L'Assessore all'Urbanistica

**Arch. Natalino Giambi**

Il Dirigente del Settore

**Ing. Daniele Capitani**

Il Servizio Urbanistica

Geom. Gianluca Magnani

Ing. Annalena Arfelli

Geom. Elena Taffagi

Arch. M. Laura Callegati

Nadia Nicolini



Quadro Conoscitivo



Oggetto

Verifiche di liquefacibilità Fascia costiera

Scala

Elaborato

**H2**



## **DIRIGENTE DEL SETTORE PROGRAMMAZIONE E GESTIONE DEL TERRITORIO**

Ing. Daniele Capitani

## **SERVIZIO URBANISTICA**

Geom. Gianluca Magnani

Ing. Annalena Arfelli

Arch. M. Laura Callegati

Geom. Elena Taffagli

Ing. Caterina Girelli

Nadia Nicolini

## **GRUPPO DI LAVORO:**

ATI composta da: Tecnicoop soc. coop.va; Arch. Carla Ferrari; Arch. Giuseppe Campos Venuti (QUADRO CONOSCITIVO ANNO 2013)

Arch. Carlo Lazzari (INDAGINE STORICA)

TEM - Territorio e Mercati - Arch. Sandra Vecchietti (SQUEA)

Ing. Simona Savini (SQUEA)

Dott. Geol. Fabbri Fabio (RISCHIO IDRAULICO)

Dott. Geol. Carlo Copioli (ZONAZIONE SISMICA ARENILE)

Dott. Geol. Samuel Sangiorgi (ZONAZIONE SISMICA)

Dott. Loris Venturini (CLASSIFICAZIONE ACUSTICA)

Ing. Chiara Semprini (VALSAT ARENILE)

Arch. Margherita Bastoni

## **APPORTI SPECIALISTICI SERVIZI COMUNALI**

Edilizia Privata, Progettazione Infrastrutture e Mobilità Sostenibile, Viabilità e Manutenzione Infrastrutture, Progettazione e Manutenzione Fabbricati, Sviluppo Economico - Parco della Salina, Ambiente, SUAP, Protezione civile, Verde, Demografici, Demanio e Porto, Patrimonio, Turismo, Servizi alla persona, Servizi alla comunità, Progettazione culturale, Politiche educative, Tributi, Polizia municipale

## **ENTI E SOCIETA' DI SERVIZI**

ANAS, Agenzia delle entrate - Ufficio territorio di Ravenna, ARPAE, ATERSIR, Autorità di Bacino del fiume Po, AUSL, CER, Consorzio di Bonifica della Romagna, ENEL, FF.SS., HERA Ravenna, Provincia di Ravenna, Regione Emilia Romagna, Romagna Acque, SNAM, TERNA, Soprintendenza archeologia, belle arti e paesaggio, Parco del Delta del Po



# COMUNE DI CERVIA

## PROVINCIA DI RAVENNA

STUDIO GEOLOGICO E DI MICROZONIZZAZIONE SISMICA DI III LIVELLO  
DI APPROFONDIMENTO PER L'ADEGUAMENTO DEL PIANO  
DELL'ARENILE DEL COMUNE DI CERVIA ALLA L.R. 9/2002 E ALLE  
DISPOSIZIONI DELLA DELIBERA DELLA REGIONE  
EMILIA-ROMAGNA N. 468/2003



## RELAZIONE GEOLOGICA

### ELABORATO 2 - VERIFICHE DI LIQUEFACIBILITA'

Dott. Geol. Carlo Copioli

Collaboratore: Dott. Geol. Fabio Vannoni



GEOPROGET

Studio di Geologia  
via Ceccarini, 171 - Palazzo La Viola  
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E-MAIL [vannoni.fabio1960@libero.it](mailto:vannoni.fabio1960@libero.it)  
[copiolicarlo@libero.it](mailto:copiolicarlo@libero.it)

Rif.2198 - Maggio 2016

## **ALLEGATO N.1**

**"VERIFICHE DI CALCOLO DEL POTENZIALE DI LIQUEFACIBILITÀ CON  
MAGNITUDO MW = 5,50 "**



**GEOPROGET**

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[copioicarlo@libero.it](mailto:copioicarlo@libero.it)

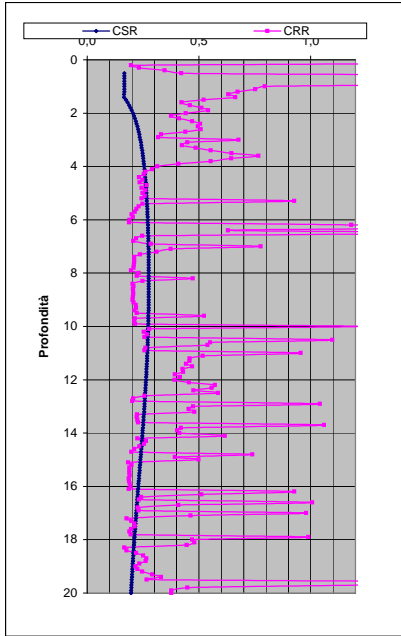
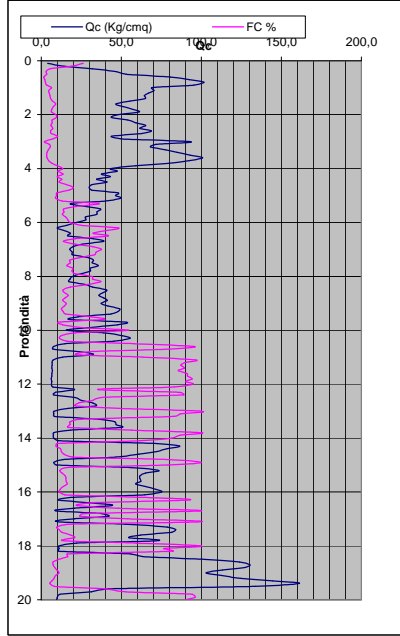
CPT-based liquefaction triggering analysis for a single sounding

Environmental parameters: Soil Classification, Zone No., Range of CPT Index Values, Behaviours, Sand-like=SC, Computer constants: alpha (N) = 1.0, Patm = 101.32, Probabilità e potenziale di liquefazione, Probabilità e suscettibilità di liquefazione, PL Overall Probability, Risk lev., IPL, PL, Roberton & Wride, agg. 2009, PROVA "CPT E 1", Displacements Parameters, Potential flow failure, No flow liquefaction.

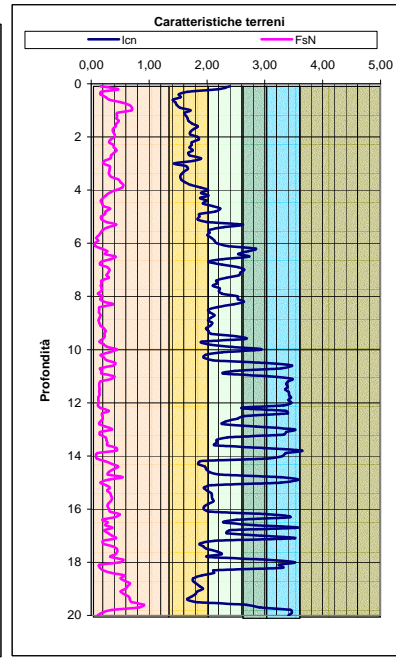
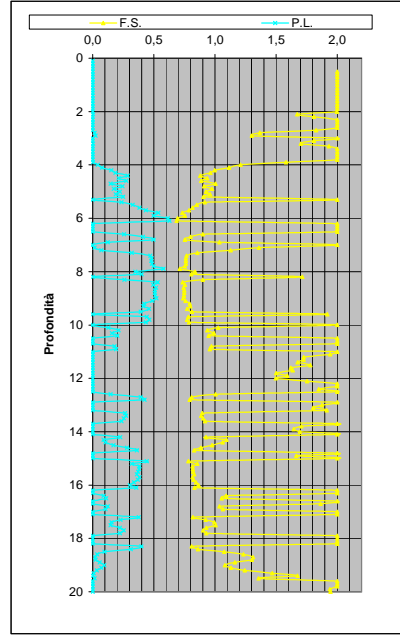
Table with columns: Depth (m), q (kPa), qc (kPa), F, Ic, N1(60), n, Kc, Layer, Flag, FC, Kh, Interpretation, CSR, Ks, xi, Kc, rrr, CRR, Factor of Safety FS, MSF SAND & CLAY, Limiting shear strain, Parameter, Fc, Delta H, ALDI, Vertical recons. Strain, ASI, Pmax PL, JUNG, F, IPI, IPI, Au/0', Au/0', Ru, Au/0', Dr, S, Ruc, Su/0'vc, OCR, qc1N, Sr, Su/0'vc, LSN, LSN Expression.

Main data table with 30 columns and 100 rows of numerical data for each sounding depth, including soil properties, stress ratios, and liquefaction resistance values.

DIAGRAMMI DI RIFERIMENTO VERIFICA LIQUEFAZIONE - METODO R. & W. , 2009



PROVA CPT E 1



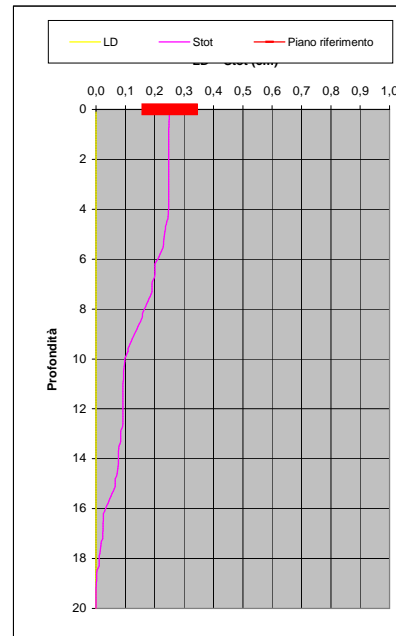
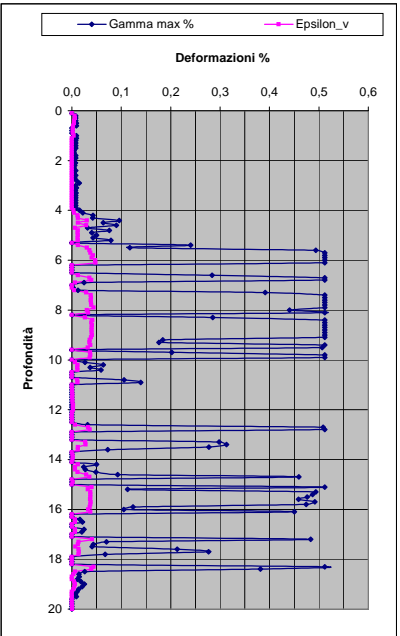
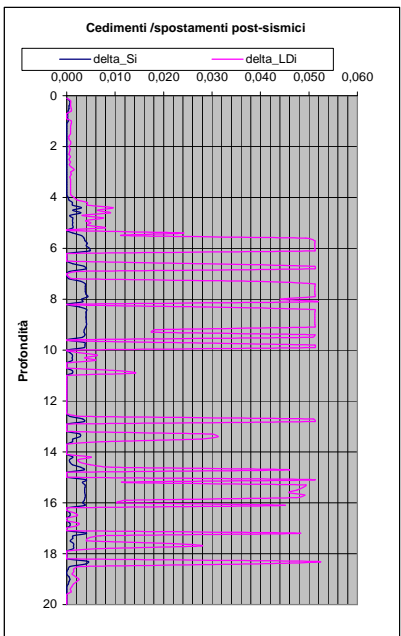
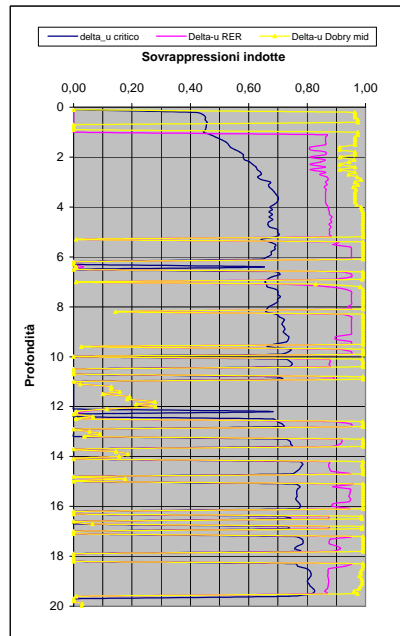
Soil Classification	Zone No.*	Range of CPT Index $I_c$ Values
Organic Clay Soils	2	$I_c > 3.60$
Clays	3	$2.95 < I_c < 3.60$
Silt Mixtures	4	$2.60 < I_c < 2.95$
Sand Mixtures	5	$2.05 < I_c < 2.60$
Sands	6	$1.31 < I_c < 2.05$
Gravelly Sands	7	$I_c < 1.31$

After Robertson and Wride (1998).  
\*Note: Zone number per Robertson SBT (1990).

- Argille - terreni organici
- Argille - argilla/argilla limosa
- Miscela di limi - limo argilloso/argilla limosa
- Miscela di sabbie - sabbia limosa/limo sabbioso
- Sabbie - sabbie pulite/sabbie limose
- sabbie ghiaiose / sabbie dense

LEGENDA

- Qc** = Res. alla penetraz. (Kg/cmq)
- FC** = Fine content - passante 0.074 mm (%)
- FsN** = Attrito laterale (Kg/cmq)
- F** = rapporto di frizione
- Qtn** = parametro di resist. alla punta normal.
- Icn** = Soil behaviour index normalized (ad)
- qc1N-cs** = Resist. alla pentrez. corretta all'FC e normalizzata
- $\xi$  = parametro di stato
- KH** = fatt. correttivo per spessore strato (ad)
- Rd** = stress reduction coefficient (ad)
- CN** = fattore di normalizzazione per carico litostatico (ad)
- K $\sigma$**  = fatt. correttivo per sovraccarico-profondità (ad)
- K $\alpha$**  = fatt. correttivo per sforzi di taglio (ad)
- MSF** = magnitudo scaling factor (ad)
- F.S.** = Fattore di sicurezza (CRR/CSR con correzioni) (ad)
- CSR** = Cyclic Stress ratio (ad)
- CRR** = Cyclic Resistance Ratio (ad)
- P.L.** = Probabilità di liquefazione (ad)
- IPL** = Indice del potenziale di liquefazione (ad)
- $\gamma_{max}$**  = deformazione di taglio massima indotta dal sisma (%)
- ev** = vertical reconsolidation strain
- $\Delta s_i$**  = cedimento i-esimo dello strato (mt)
- Su** =  $S_u / \sigma'_{vc}$  resistenza totale non drenata - strati coesivi (ad)
- Sur** =  $S_{ur} / \sigma'_{vc}$  resistenza totale residua non drenata - strati coesivi (ad)
- qc1N-sr** = Resist. alla pentrez. corretta all'FC e normalizzata
- Sr** =  $S_r / \sigma'_{vc}$  resistenza residua - strati incoerenti (ad)
- Ruc** =  $\Delta u / \sigma'_{vc}$  critico - stima sogliadi innesco fenomeni di instabilità/liquefazione
- $\Delta u$  RER =  $\Delta u / \sigma'_{vc}$  sovrappressioni circ. 112/2007 - tabella 2 R.E.R.
- $\Delta u$  Dobry M. =  $\Delta u / \sigma'_{vc}$  Dobry et al. 1984 "mean" x sabbie-Robertson '09 x argille
- $\Delta u$  Dobry L. =  $\Delta u / \sigma'_{vc}$  Dobry et al. 1984 "lower bound" x sabbie-Robertson '09 x argille
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- Stot** = Cedimento post-sismico totale (mt)
- LDI** = Lateral Displacement Index (mt)
- Dr** = Densità relativa (ad)
- $\theta$  = angolo di attrito interno (deg)
- OCR** = rapporto di sovraconsolidazione (sabbie e argille) (ad)
- St** = coefficiente di sensitività delle argille (ad)
- LSN** = Liquefaction Severity Number (ad)



IPL = 6,35      PL = 15,33      LDI = 2,679      Stot = 0,251 (mt)      LD = 0,00 (mt)      SLiq = 8,00 (mt)      LSN = 27,66      PG = 0,45

LSN Range	Expected ground surface damage
0-10	Little to no expression of liquefaction, minor effects
10-20	Minor expression of liquefaction, some sand boils
20-30	Moderate expression of liquefaction, with some sand boils and structural damage
30-40	Moderate to severe expression of liquefaction, settlement can cause structural damage
40-50	Major expression of liquefaction, undulations and damage to ground surface, severe total and differential settlements of structures
>50	Severe damage, extensive evidence of liquefaction at surface, severe total and differential settlements affecting structures, damage to services.

\* Table based on Table 13.1 from I&T report: Liquefaction Vulnerability Study

Probability	Description of the risk of liquefaction-induced ground failure
$0.9 < P_G$	extremely high to absolutely certain
$0.7 < P_G \leq 0.9$	high
$0.3 < P_G \leq 0.7$	medium
$0.1 < P_G \leq 0.3$	low
$P_G \leq 0.1$	extremely low to none



CPT-based liquefaction triggering analysis for a single sounding

Enviromenti: C Hill-H Plain-P Coast-C  
Behaviours: E Sand like-S

Computer constants: no. n: 1.70  
MSF NCEER: 0.0337  
Carico Kpa: 210  
K0: 0.45  
L(m): 10  
Cst(Kpa): 98

Probabilità e potenziale di liquefazione

Probabilità e suscettibilità di liquefazione

PL Overall Probability

Robertson & Wride, agg. 2009

PROVA "CPTE 2"



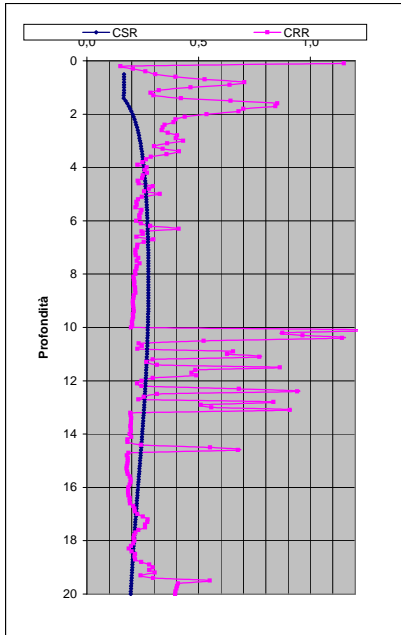
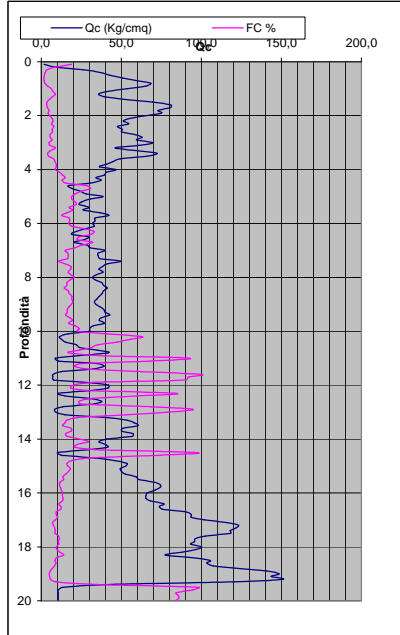
Potential flow failure if (N1) < 100-cv+10 and (q1) < 100-cv+50  
No flow liquefaction if (q1) < 65

Table with columns for input parameters (Peak ground accel, Earthquake magnitude, Water table depth, etc.), soil classification, and various geotechnical parameters (Q1, Qtn, F, Ic, etc.).

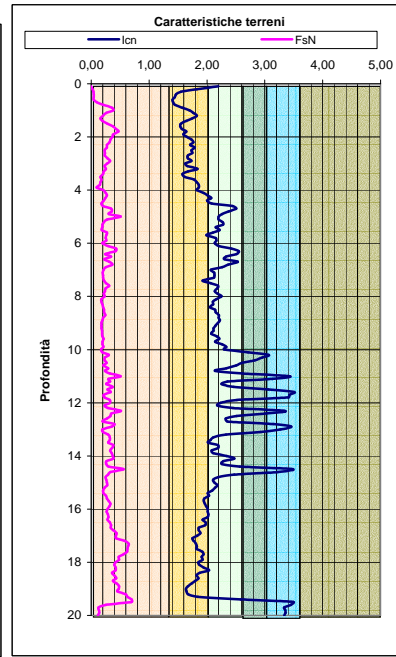
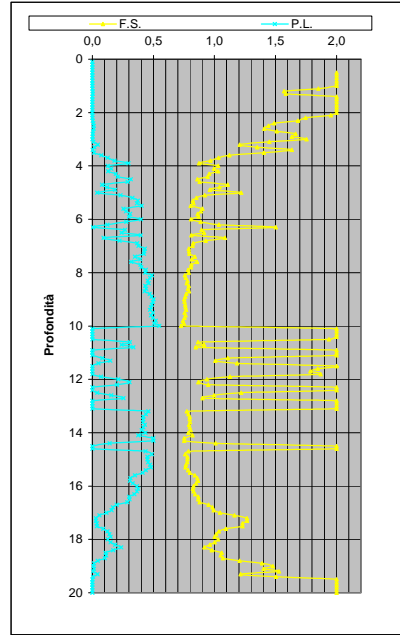
PROFONDITA' DI CALCOLO (mt da p.c.): 0,0 LDI = 3,884 Stot = 0,343 (mt) IPL = 7,92 PL = 20,34 LD = 0,00 (mt) PG = 0,71 SLiq = 10,1 (mt) LSN = 36,2

Main data table with columns for Depth (m), Soil Type, and various geotechnical parameters (Q1, Qtn, F, Ic, etc.) for each sounding depth from 1.1 to 10.1 meters.

DIAGRAMMI DI RIFERIMENTO VERIFICA LIQUEFAZIONE - METODO R. & W. , 2009



PROVA CPT2



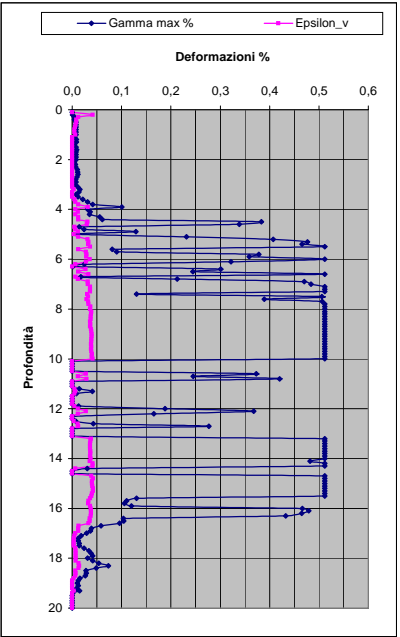
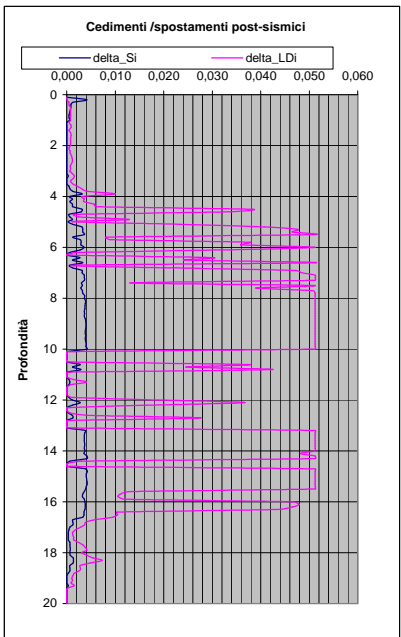
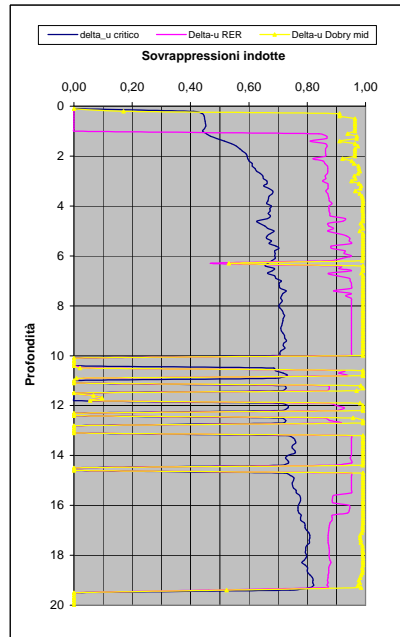
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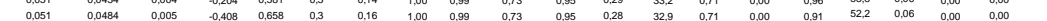
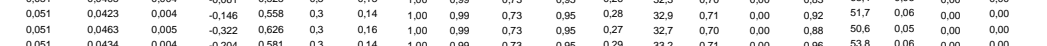
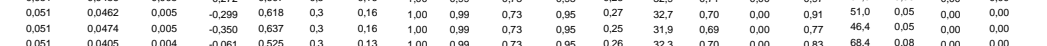
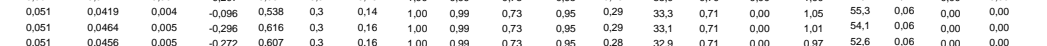
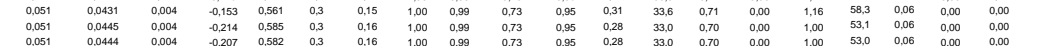
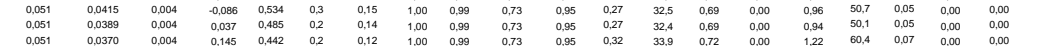
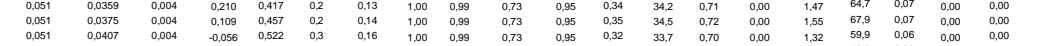
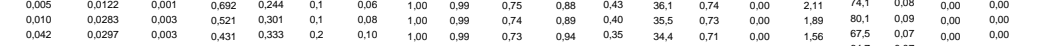
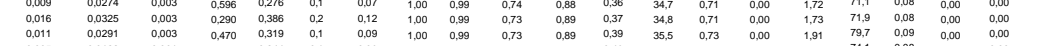
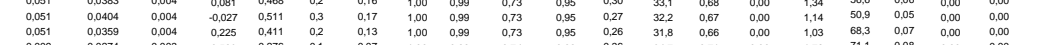
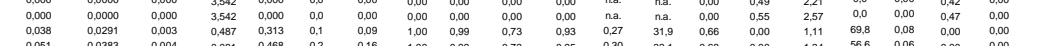
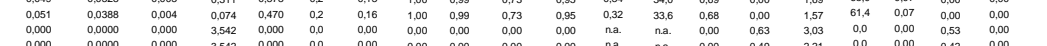
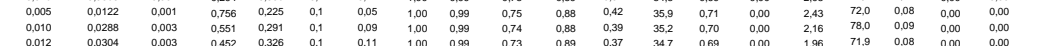
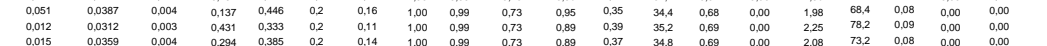
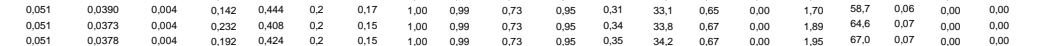
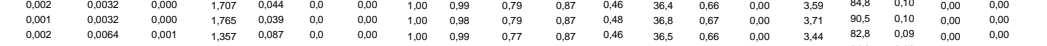
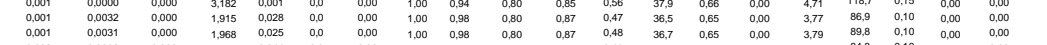
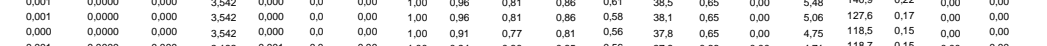
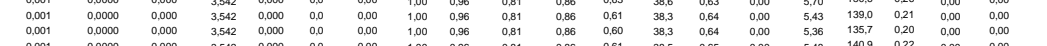
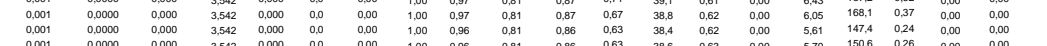
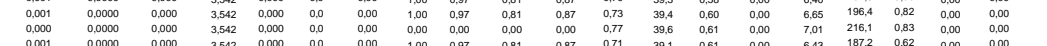
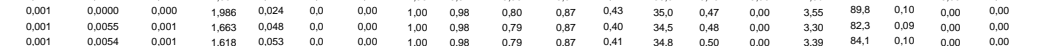
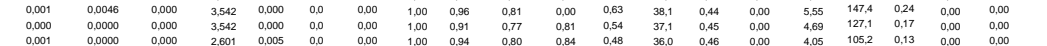
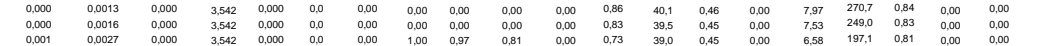
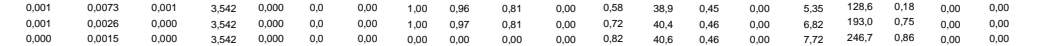
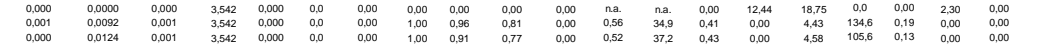
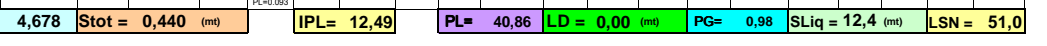
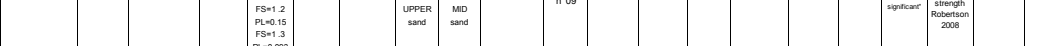
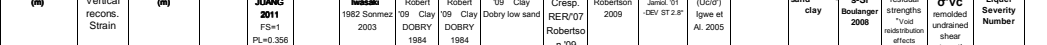
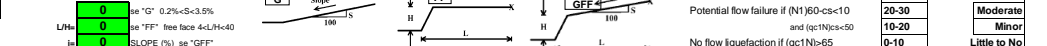
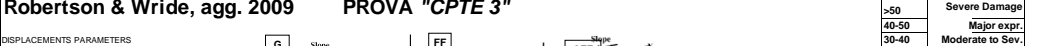
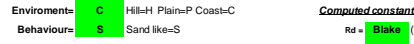
\* Table based on Table 13.1 from I&T report: Liquefaction Vulnerability Study

Probability	Description of the risk of liquefaction-induced ground failure
$0.9 < P_G$	extremely high to absolutely certain
$0.7 < P_G \leq 0.9$	high
$0.3 < P_G \leq 0.7$	medium
$0.1 < P_G \leq 0.3$	low
$P_G \leq 0.1$	extremely low to none

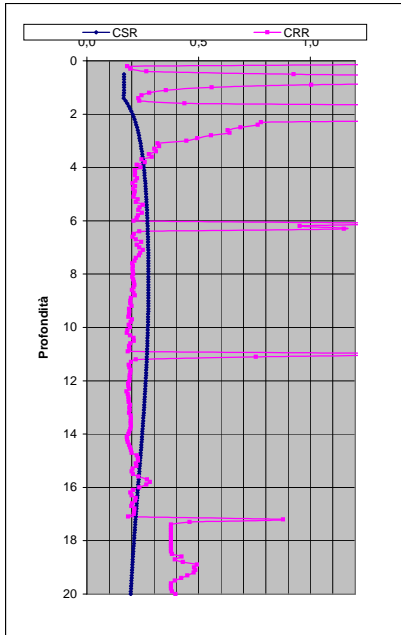
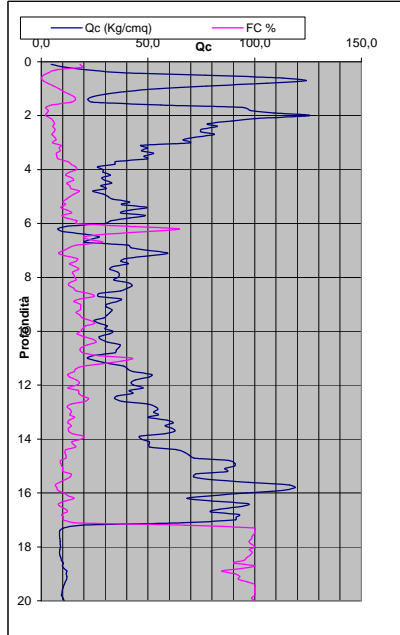
IPL = 7,92      PL = 20,34      LDI = 3,884      Stot = 0,343 (mt)      LD = 0,00 (mt)      SLiq = 10,10 (mt)      LSN = 36,17      PG = 0,71

CPT-based liquefaction triggering analysis for a single sounding

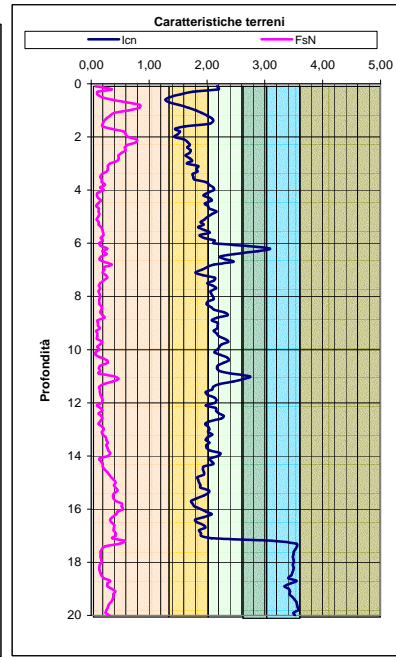
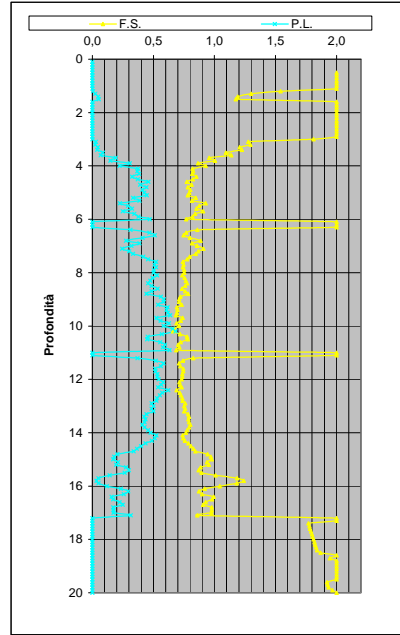
Main data table with columns for soil classification, CPT parameters, and various geotechnical indices. Includes a diagram of the CPT probe and a table of LsN values.



DIAGRAMMI DI RIFERIMENTO VERIFICA LIQUEFAZIONE - METODO R. & W. , 2009



PROVA CPTE 3



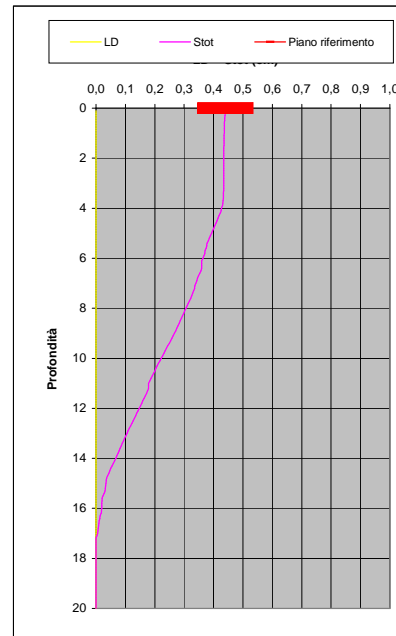
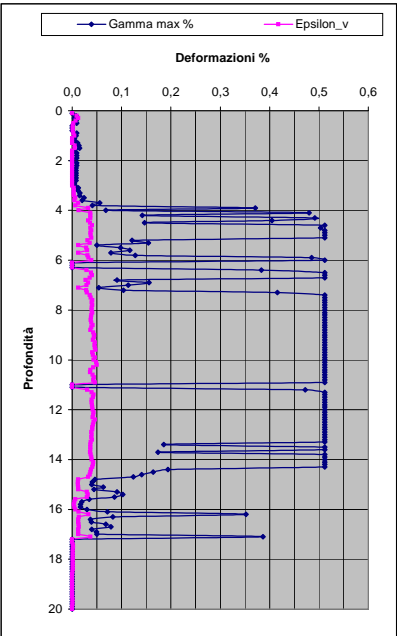
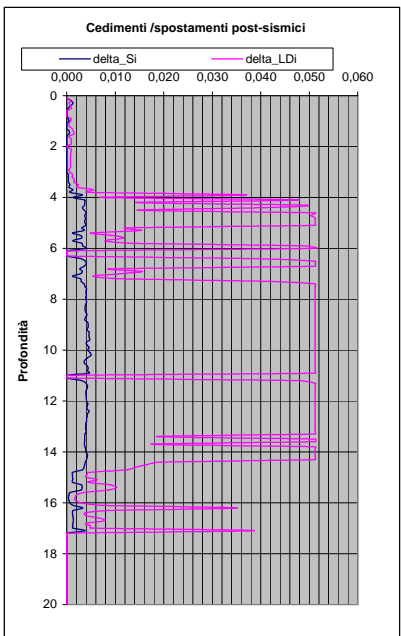
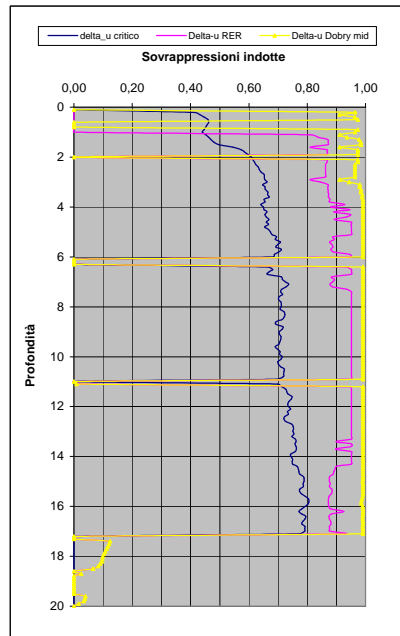
Soil Classification	Zone No.*	Range of CPT Index $I_c$ Values
Organic Clay Soils	2	$I_c > 3.60$
Clays	3	$2.95 < I_c < 3.60$
Silt Mixtures	4	$2.60 < I_c < 2.95$
Sand Mixtures	5	$2.05 < I_c < 2.60$
Sands	6	$1.31 < I_c < 2.05$
Gravelly Sands	7	$I_c < 1.31$

After Robertson and Wride (1998).  
\*Note: Zone number per Robertson SBT (1990).

- Argille - terreni organici
- Argille - argilla/argilla limosa
- Miscela di limi - limo argilloso/argilla limosa
- Miscela di sabbie - sabbia limosa/limo sabbioso
- Sabbie - sabbie pulite/sabbie limose
- sabbie ghiaiose / sabbie dense

LEGENDA

- Qc** = Res. alla penetraz. (Kg/cmq)
- FC** = Fine content - passante 0.074 mm (%)
- FsN** = Attrito laterale (Kg/cmq)
- F** = rapporto di frizione
- Qtn** = parametro di resist. alla punta normal.
- Icn** = Soil behaviour index normalized (ad)
- qc1N-cs** = Resist. alla pentrez. corretta all'FC e normalizzata
- $\xi$  = parametro di stato
- KH** = fatt. correttivo per spessore strato (ad)
- Rd** = stress reduction coefficient (ad)
- CN** = fattore di normalizzazione per carico litostatico (ad)
- K $\sigma$**  = fatt. correttivo per sovraccarico-profondità (ad)
- K $\alpha$**  = fatt. correttivo per sforzi di taglio (ad)
- MSF** = magnitudo scaling factor (ad)
- F.S.** = Fattore di sicurezza (CRR/CSR con correzioni) (ad)
- CSR** = Cyclic Stress ratio (ad)
- CRR** = Cyclic Resistance Ratio (ad)
- P.L.** = Probabilità di liquefazione (ad)
- IPL** = Indice del potenziale di liquefazione (ad)
- $\gamma_{max}$**  = deformazione di taglio massima indotta dal sisma (%)
- ev** = vertical reconsolidation strain
- $\Delta s_i$**  = cedimento -esimo dello strato (mt)
- Su** =  $S_u / \sigma'_{vc}$  resistenza totale non drenata - strati coesivi (ad)
- Sur** =  $S_{ur} / \sigma'_{vc}$  resistenza totale residua non drenata - strati coesivi (ad)
- qc1N-sr** = Resist. alla pentrez. corretta all'FC e normalizzata
- Sr** =  $S_r / \sigma'_{vc}$  resistenza residua - strati incoerenti (ad)
- Ruc** =  $\Delta u / \sigma'_{vc}$  critico - stima sogliadi innesco fenomeni di instabilità/liquefazione
- $\Delta u$  RER =  $\Delta u / \sigma'_{vc}$  sovrappressioni circ. 112/2007 - tabella 2 R.E.R.
- $\Delta u$  Dobry M. =  $\Delta u / \sigma'_{vc}$  Dobry et al. 1984 "mean" x sabbie-Robertson '09 x argille
- $\Delta u$  Dobry L. =  $\Delta u / \sigma'_{vc}$  Dobry et al. 1984 "lower bound" x sabbie-Robertson '09 x argille
- $\Delta u$  Dobry U. =  $\Delta u / \sigma'_{vc}$  Dobry et al. 1984 "Upper bound" x sabbie-Robertson '09 x argille
- Stot** = Cedimento post-sismico totale (mt)
- LDI** = Lateral Displacement Index (mt)
- Dr** = Densità relativa (ad)
- $\theta$  = angolo di attrito interno (deg)
- OCR** = rapporto di sovraconsolidazione (sabbie e argille) (ad)
- St** = coefficiente di sensitività delle argille (ad)
- LSN** = Liquefaction Severity Number (ad)



LSN Range	Expected ground surface damage
0-10	Little to no expression of liquefaction, minor effects
10-20	Minor expression of liquefaction, some sand boils
20-30	Moderate expression of liquefaction, with some sand boils and structural damage
30-40	Moderate to severe expression of liquefaction, settlement can cause structural damage
40-50	Major expression of liquefaction, undulations and damage to ground surface, severe total and differential settlements of structures
>50	Severe damage, extensive evidence of liquefaction at surface, severe total and differential settlements affecting structures, damage to services.

\* Table based on Table 13.1 from I&T report: Liquefaction Vulnerability Study

Probability	Description of the risk of liquefaction-induced ground failure
$0.9 < P_G$	extremely high to absolutely certain
$0.7 < P_G \leq 0.9$	high
$0.3 < P_G \leq 0.7$	medium
$0.1 < P_G \leq 0.3$	low
$P_G \leq 0.1$	extremely low to none

IPL= 12,49

PL= 40,86

LDI = 4,678 Stot = 0,440 (mt)

LD = 0,00 (mt)

SLiq = 12,40 (mt)

LSN = 51,02 PG= 0,98

CPT-based liquefaction triggering analysis for a single sounding

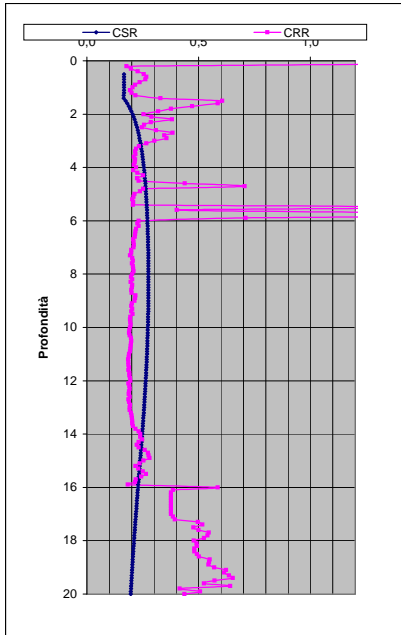
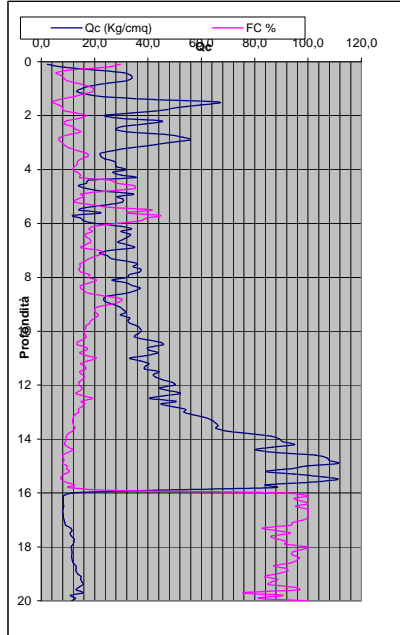
Environmental parameters, soil classification, and various probability and potentiality charts for liquefaction analysis.

Table with columns for Depth (m), Soil Classification, and various parameters like q<sub>v</sub>, q<sub>u</sub>, F, I<sub>c</sub>, etc.

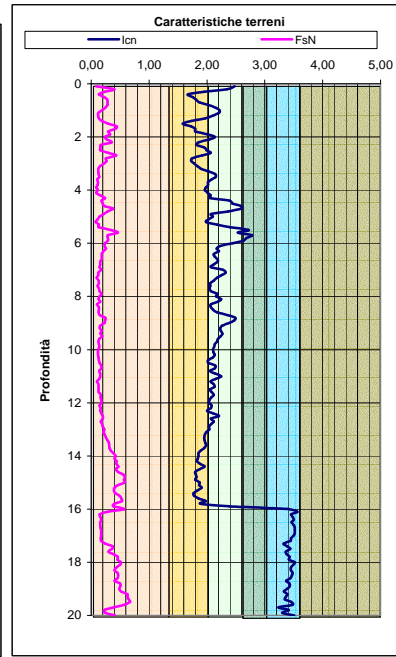
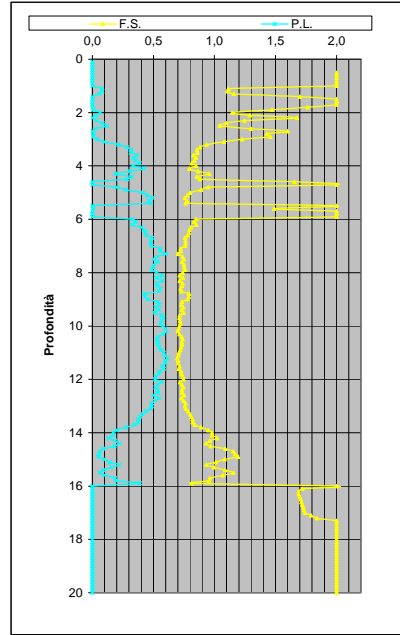
Main data table with columns for Depth (m), Soil Classification, and various parameters like q<sub>v</sub>, q<sub>u</sub>, F, I<sub>c</sub>, etc. Includes a large red vertical bar on the right side.

Summary table with columns for L<sub>SN</sub>, L<sub>SN</sub> Expression, and other summary metrics.

DIAGRAMMI DI RIFERIMENTO VERIFICA LIQUEFAZIONE - METODO R. & W. , 2009



PROVA CPTE 4



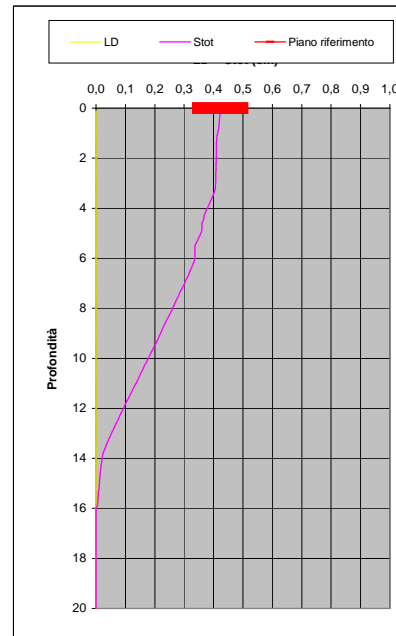
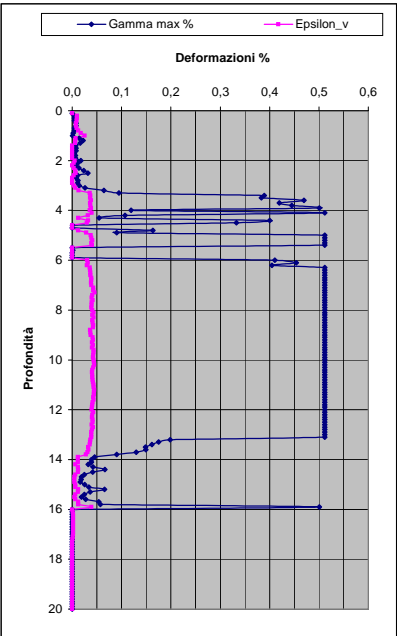
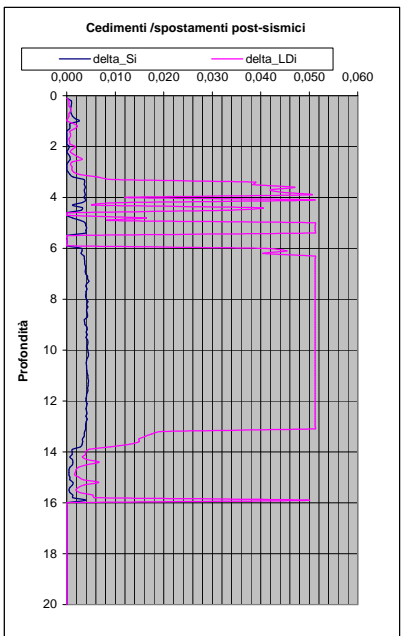
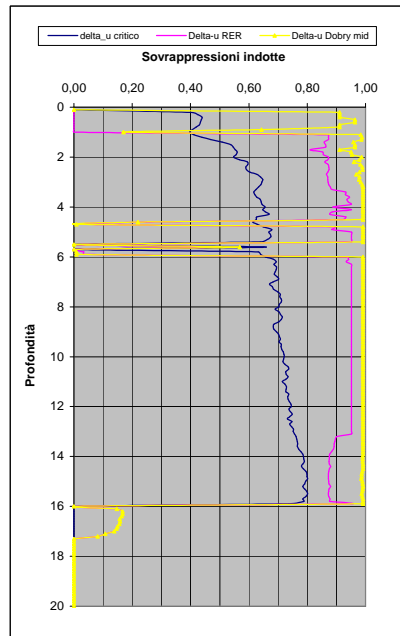
Soil Classification	Zone No.*	Range of CPT Index $I_v$ Values
Organic Clay Soils	2	$I_v > 3.60$
Clays	3	$2.95 < I_v < 3.60$
Silt Mixtures	4	$2.60 < I_v < 2.95$
Sand Mixtures	5	$2.05 < I_v < 2.60$
Sands	6	$1.31 < I_v < 2.05$
Gravelly Sands	7	$I_v < 1.31$

After Robertson and Wride (1998).  
\*Note: Zone number per Robertson SBT (1990).

- Argille - terreni organici
- Argille - argilla/argilla limosa
- Miscela di limi - limo argilloso/argilla limosa
- Miscela di sabbie - sabbia limosa/limo sabbioso
- Sabbie - sabbie pulite/sabbie limose
- sabbie ghiaiose / sabbie dense

LEGENDA

- Qc** = Res. alla penetraz. (Kg/cmq)
- FC** = Fine content - passante 0.074 mm (%)
- FsN** = Attrito laterale (Kg/cmq)
- F** = rapporto di frizione
- Qtn** = parametro di resist. alla punta normal.
- ln** = Soil behaviour index normalized (ad)
- qc1N-cs** = Resist. alla pentrez. corretta all'FC e normalizzata
- $\xi$  = parametro di stato
- KH** = fatt. correttivo per spessore strato (ad)
- Rd** = stress reduction coefficient (ad)
- CN** = fattore di normalizzazione per carico litostatico (ad)
- K $\sigma$**  = fatt. correttivo per sovraccarico-profondità (ad)
- K $\alpha$**  = fatt. correttivo per sforzi di taglio (ad)
- MSF** = magnitudo scaling factor (ad)
- F.S.** = Fattore di sicurezza (CRR/CSR con correzioni) (ad)
- CSR** = Cyclic Stress ratio (ad)
- CRR** = Cyclic Resistance Ratio (ad)
- P.L.** = Probabilità di liquefazione (ad)
- IPL** = Indice del potenziale di liquefazione (ad)
- $\gamma_{max}$**  = deformazione di taglio massima indotta dal sisma (%)
- ev** = vertical reconsolidation strain
- $\Delta s_i$**  = cedimento -esimo dello strato (mt)
- Su** =  $S_u / \sigma'_{vc}$  resistenza totale non drenata - strati coesivi (ad)
- Sur** =  $S_{ur} / \sigma'_{vc}$  resistenza totale residua non drenata - strati coesivi (ad)
- qc1N-sr** = Resist. alla pentrez. corretta all'FC e normalizzata
- Sr** =  $S_r / \sigma'_{vc}$  resistenza residua - strati incoerenti (ad)
- Ruc** =  $\Delta u / \sigma'_{vc}$  critico - stima sogliadi innesco fenomeni di instabilità/liquefazione
- $\Delta u$  RER =  $\Delta u / \sigma'_{vc}$  sovrappressioni circ. 112/2007 - tabella 2 R.E.R.
- $\Delta u$  Dobry M. =  $\Delta u / \sigma'_{vc}$  Dobry et al. 1984 "mean" x sabbie-Robertson '09 x argille
- $\Delta u$  Dobry L. =  $\Delta u / \sigma'_{vc}$  Dobry et al. 1984 "lower bound" x sabbie-Robertson '09 x argille
- $\Delta u$  Dobry U. =  $\Delta u / \sigma'_{vc}$  Dobry et al. 1984 "Upper bound" x sabbie-Robertson '09 x argille
- Stot** = Cedimento post-sismico totale (mt)
- LDI** = Lateral Displacement Index (mt)
- Dr** = Densità relativa (ad)
- $\theta$  = angolo di attrito interno (deg)
- OCR** = rapporto di sovraconsolidazione (sabbie e argille) (ad)
- St** = coefficiente di sensitività delle argille (ad)
- LSN** = Liquefaction Severity Number (ad)



IPL= 12,70

PL= 42,00

LDI = 4,630 Stot = 0,423 (mt)

LD = 0,00 (mt)

SLiq = 11,10 (mt)

LSN = 54,77 PG= 0,99

LSN Range	Expected ground surface damage
0-10	Little to no expression of liquefaction, minor effects
10-20	Minor expression of liquefaction, some sand boils
20-30	Moderate expression of liquefaction, with some sand boils and structural damage
30-40	Moderate to severe expression of liquefaction, settlement can cause structural damage
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\* Table based on Table 13.1 from I&T report: Liquefaction Vulnerability Study

Probability	Description of the risk of liquefaction-induced ground failure
$0.9 < P_G$	extremely high to absolutely certain
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$0.3 < P_G \leq 0.7$	medium
$0.1 < P_G \leq 0.3$	low
$P_G \leq 0.1$	extremely low to none

CPT-based liquefaction triggering analysis for a single sounding

Environmental and Behavioral parameters including Soil Classification, Zone No., Range of CPT Index Values, and various geotechnical parameters like q<sub>tip</sub>, q<sub>s</sub>, and CPT indices.

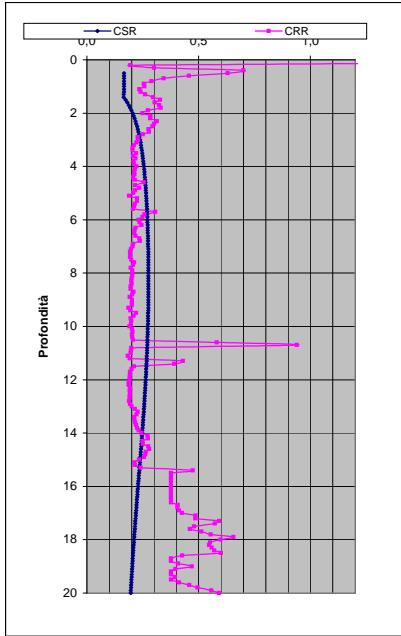
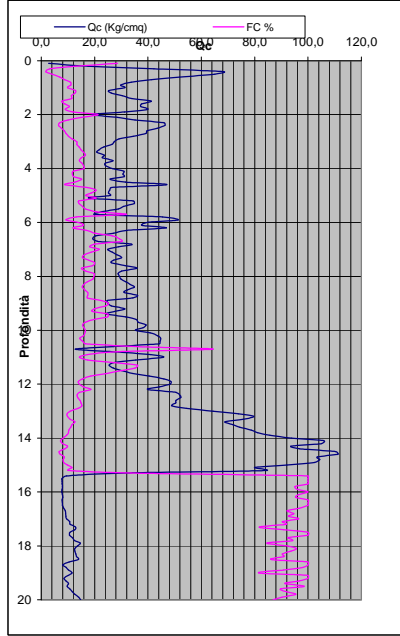
Computer constants section containing various coefficients and parameters for the liquefaction analysis, such as α, β, γ, δ, and e.

Probability and potential of liquefaction section, detailing different risk levels and their corresponding parameters.

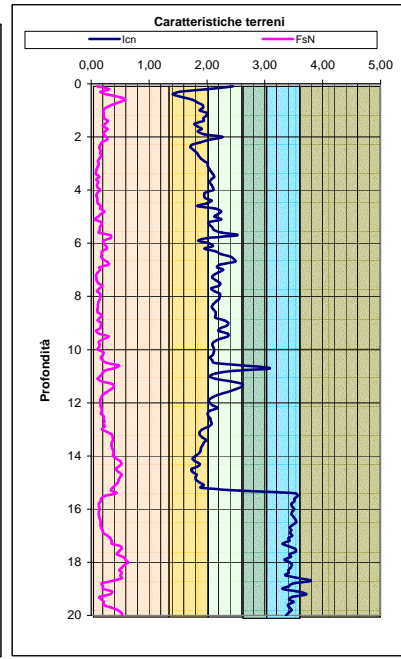
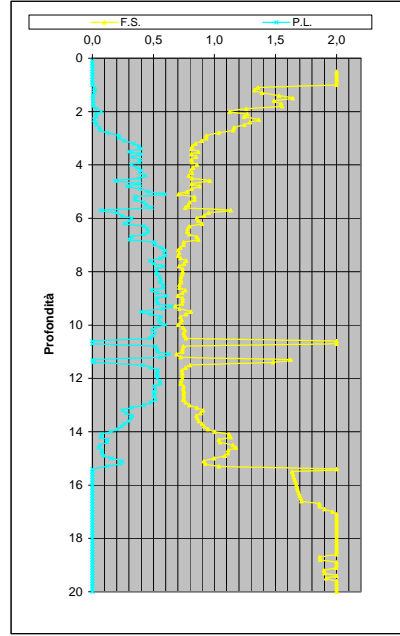
Robertson & Wride, agg. 2009 section, including the PROVA "CPTE 5" diagram and associated parameters for liquefaction potential.

Main data table with columns for Depth (m), Soil State, CPT indices, and various geotechnical parameters. The table is color-coded (green, yellow, red) to indicate different soil states and risk levels.

DIAGRAMMI DI RIFERIMENTO VERIFICA LIQUEFAZIONE - METODO R. & W. , 2009



PROVA CPTE 5



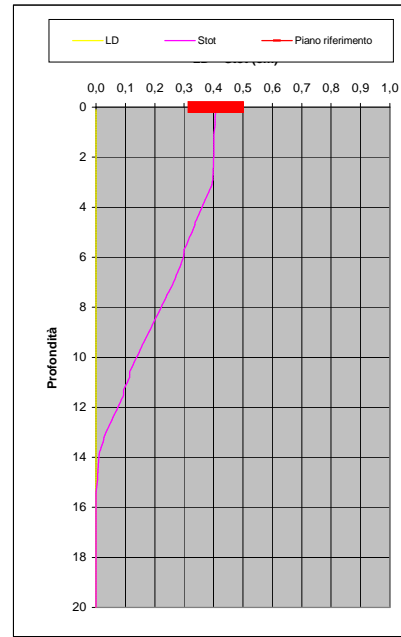
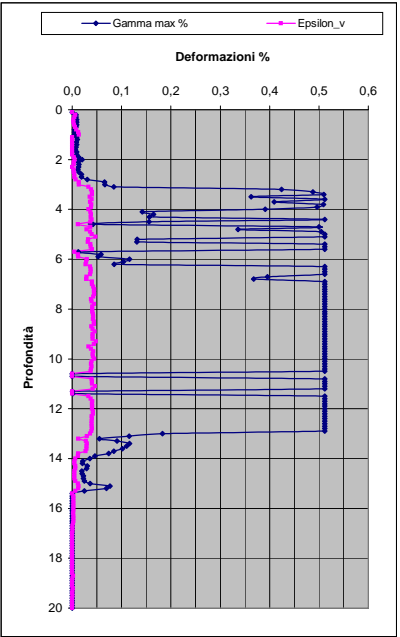
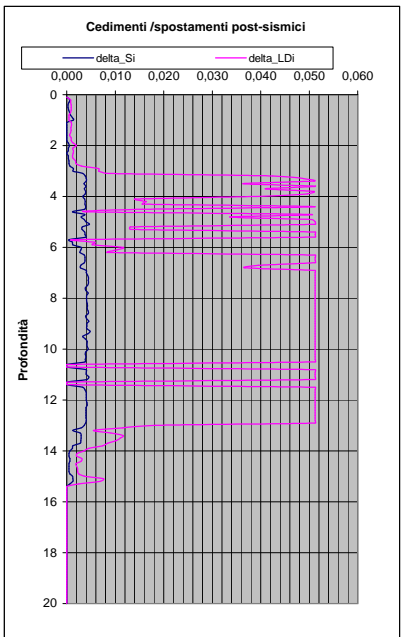
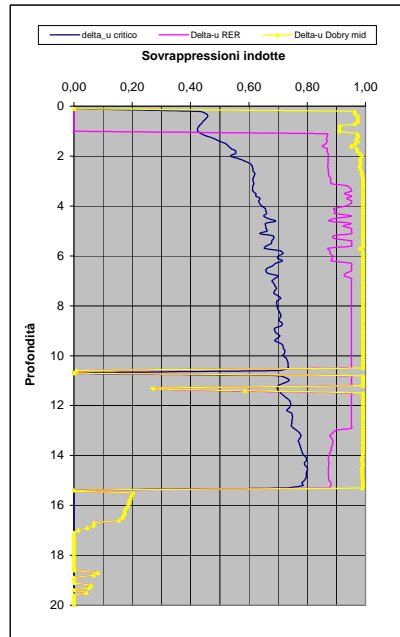
Soil Classification	Zone No.*	Range of CPT Index $I_c$ Values
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Sands	6	$1.31 < I_c < 2.05$
Gravelly Sands	7	$I_c < 1.31$

After Robertson and Wride (1998).  
\*Note: Zone number per Robertson SBT (1990).

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- Argille - argilla/argilla limosa
- Miscela di limi - limo argilloso/argilla limosa
- Miscela di sabbie - sabbia limosa/limo sabbioso
- Sabbie - sabbie pulite/sabbie limose
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LEGENDA

- Qc** = Res. alla penetraz. (Kg/cmq)
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- K $\alpha$**  = fatt. correttivo per sforzi di taglio (ad)
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- $\Delta u$  Dobry U. =  $\Delta u / \sigma'_{vc}$  Dobry et al. 1984 "Upper bound" x sabbie-Robertson '09 x argille
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- LDI** = Lateral Displacement Index (mt)
- Dr** = Densità relativa (ad)
- $\phi$  = angolo di attrito interno (deg)
- OCR** = rapporto di sovraconsolidazione (sabbie e argille) (ad)
- St** = coefficiente di sensitività delle argille (ad)
- LSN** = Liquefaction Severity Number (ad)



LSN Range	Expected ground surface damage
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>50	Severe damage, extensive evidence of liquefaction at surface, severe total and differential settlements affecting structures, damage to services.

Probability	Description of the risk of liquefaction-induced ground failure
$0.9 < P_G$	extremely high to absolutely certain
$0.7 < P_G \leq 0.9$	high
$0.3 < P_G \leq 0.7$	medium
$0.1 < P_G \leq 0.3$	low
$P_G \leq 0.1$	extremely low to none

IPL= 12,98

PL= 43,47

LDI = 4,381 Stot = 0,407 (mt)

LD = 0,00 (mt)

SLiq = 10,90 (mt)

LSN = 57,24 PG= 0,99



CPT-based liquefaction triggering analysis for a single sounding

Enviromenti: C Hill-H Plain-P Coast-C Behaviours: Sand like-S

Computer constants: no. n=350 (B' 2007 - Cefin' 2004 - NCEER - Blake) alpha (N) = 1.0

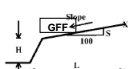
Probabilità e potenziale di liquefazione

Probabilità e suscettibilità di liquefazione

PL Overall Probability

Robertson & Wride, agg. 2009

PROVA "CPTE 6"



Potential flow failure if (N) ID<C<10 and (q) N<50 and No flow liquefaction if (q) N<65

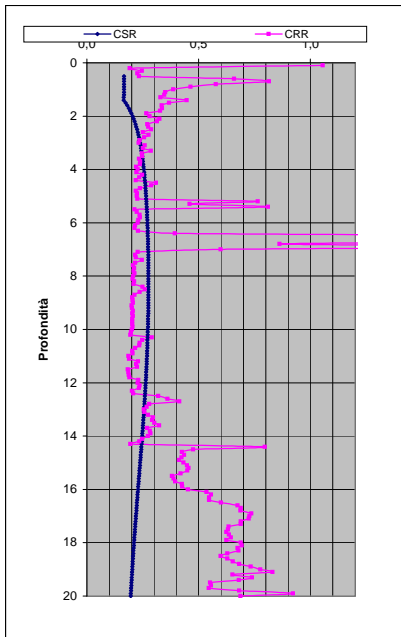
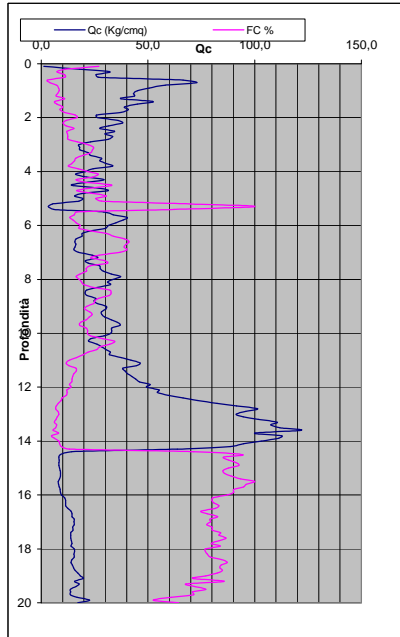
Summary table with columns for input parameters (Peak ground accel, Earthquake magnitude, etc.), computer constants, and various probability and liquefaction indices.

Main data table with columns for Depth (m), Soil Classification, and various geotechnical parameters like qc, q, F, Ic, N1(60), etc.

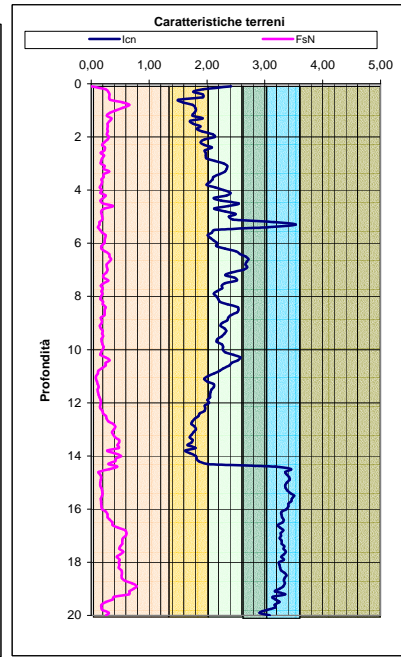
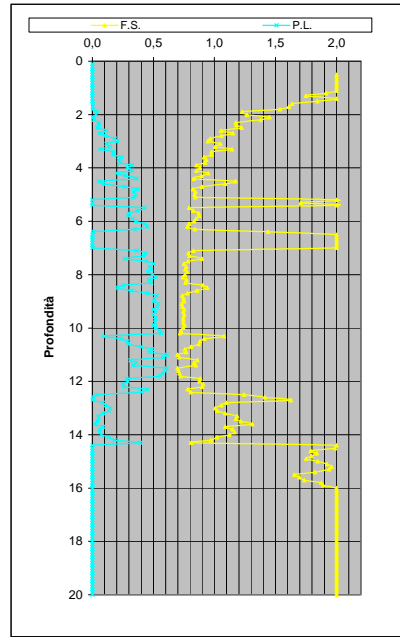
PROFONDITA' DI CALCOLO (mt da p.c.): 0,0 LDI = 3,142 Stot = 0,281 (mt) IPL = 8,48 PL = 22,39 LD = 0,00 (mt) PG = 0,79 SLiq = 8,2 (mt) LSN = 38,1

Main data table containing 101 rows of soil sounding data, including depth, soil type, and various geotechnical parameters.

DIAGRAMMI DI RIFERIMENTO VERIFICA LIQUEFAZIONE - METODO R. & W. , 2009



PROVA CPTE 6



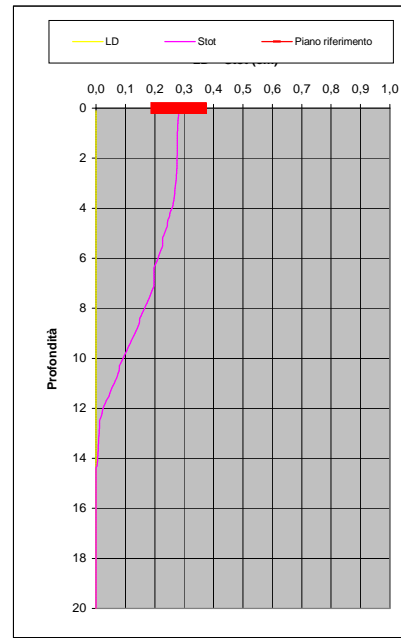
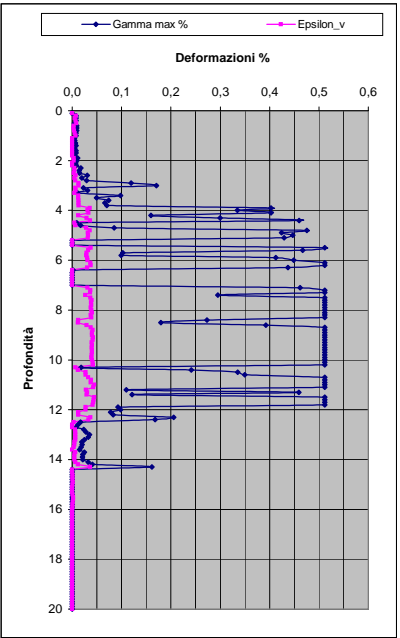
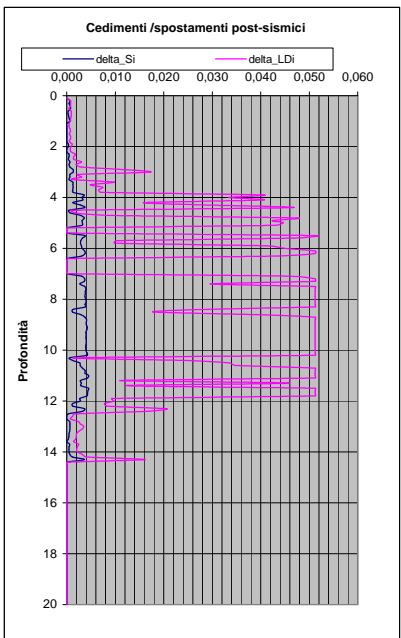
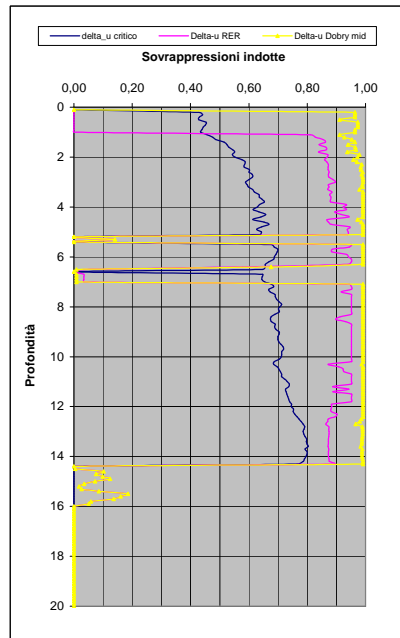
Soil Classification	Zone No.*	Range of CPT Index $I_c$ Values
Organic Clay Soils	2	$I_c > 3.60$
Clays	3	$2.95 < I_c < 3.60$
Silt Mixtures	4	$2.60 < I_c < 2.95$
Sand Mixtures	5	$2.05 < I_c < 2.60$
Sands	6	$1.31 < I_c < 2.05$
Gravelly Sands	7	$I_c < 1.31$

After Robertson and Wride (1998).  
\*Note: Zone number per Robertson SBT (1990).

- Argille - terreni organici
- Argille - argilla/argilla limosa
- Miscela di limi - limo argilloso/argilla limosa
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- Sabbie - sabbie pulite/sabbie limose
- sabbie ghiaiose / sabbie dense

LEGENDA

- Qc** = Res. alla penetraz. (Kg/cmq)
- FC** = Fine content - passante 0.074 mm (%)
- FsN** = Attrito laterale (Kg/cmq)
- F** = rapporto di frizione
- Qtn** = parametro di resist. alla punta normal.
- Icn** = Soil behaviour index normalized (ad)
- qc1N-cs** = Resist. alla pentrez. corretta all'FC e normalizzata
- $\xi$  = parametro di stato
- KH** = fatt. correttivo per spessore strato (ad)
- Rd** = stress reduction coefficient (ad)
- CN** = fattore di normalizzazione per carico litostatico (ad)
- K $\sigma$**  = fatt. correttivo per sovraccarico-profondità (ad)
- K $\alpha$**  = fatt. correttivo per sforzi di taglio (ad)
- MSF** = magnitudo scaling factor (ad)
- F.S.** = Fattore di sicurezza (CRR/CSR con correzioni) (ad)
- CSR** = Cyclic Stress ratio (ad)
- CRR** = Cyclic Resistance Ratio (ad)
- P.L.** = Probabilità di liquefazione (ad)
- IPL** = Indice del potenziale di liquefazione (ad)
- $\gamma_{max}$**  = deformazione di taglio massima indotta dal sisma (%)
- ev** = vertical reconsolidation strain
- $\Delta s_i$**  = cedimento -esimo dello strato (mt)
- Su** =  $S_u / \sigma'_{vc}$  resistenza totale non drenata - strati coesivi (ad)
- Sur** =  $S_{ur} / \sigma'_{vc}$  resistenza totale residua non drenata - strati coesivi (ad)
- qc1N-sr** = Resist. alla pentrez. corretta all'FC e normalizzata
- Sr** =  $S_r / \sigma'_{vc}$  resistenza residua - strati incoerenti (ad)
- Ruc** =  $\Delta u / \sigma'_{vc}$  critico - stima sogliadi innesco fenomeni di instabilità/liquefazione
- $\Delta u$  RER =  $\Delta u / \sigma'_{vc}$  sovrappressioni circ. 112/2007 - tabella 2 R.E.R.
- $\Delta u$  Dobry M. =  $\Delta u / \sigma'_{vc}$  Dobry et al. 1984 "mean" x sabbie-Robertson '09 x argille
- $\Delta u$  Dobry L. =  $\Delta u / \sigma'_{vc}$  Dobry et al. 1984 "lower bound" x sabbie-Robertson '09 x argille
- $\Delta u$  Dobry U. =  $\Delta u / \sigma'_{vc}$  Dobry et al. 1984 "Upper bound" x sabbie-Robertson '09 x argille
- Stot** = Cedimento post-sismico totale (mt)
- LDI** = Lateral Displacement Index (mt)
- Dr** = Densità relativa (ad)
- $\phi$  = angolo di attrito interno (deg)
- OCR** = rapporto di sovraconsolidazione (sabbie e argille) (ad)
- St** = coefficiente di sensitività delle argille (ad)
- LSN** = Liquefaction Severity Number (ad)



LSN Range	Expected ground surface damage
0-10	Little to no expression of liquefaction, minor effects
10-20	Minor expression of liquefaction, some sand boils
20-30	Moderate expression of liquefaction, with some sand boils and structural damage
30-40	Moderate to severe expression of liquefaction, settlement can cause structural damage
40-50	Major expression of liquefaction, undulations and damage to ground surface, severe total and differential settlements of structures
>50	Severe damage, extensive evidence of liquefaction as surface, severe total and differential settlements affecting structures, damage to services.

\* Table based on Table 13.1 from I&T report: Liquefaction Vulnerability Study

Probability	Description of the risk of liquefaction-induced ground failure
$0.9 < P_G$	extremely high to absolutely certain
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$0.3 < P_G \leq 0.7$	medium
$0.1 < P_G \leq 0.3$	low
$P_G \leq 0.1$	extremely low to none

IPL = 8,48      PL = 22,39      LDI = 3,142      Stot = 0,281 (mt)      LD = 0,00 (mt)      SLiq = 8,20 (mt)      LSN = 38,13      PG = 0,79

CPT-based liquefaction triggering analysis for a single sounding

Input parameters table including Peak ground accel (g), Earthquake magnitude (M), Water table depth (m), Average above water table (N60)30, Average below water table (N60)30, and Equipment (CPT-CPT1).

Environments: Hill-H Plain-P Coast-C

Behaviours table with columns for Soil Classification, Zone No., Range of CPT Index / Values, and Soil Name.

Computer constants:

Computer constants table with parameters like alpha (N) = 0.35, beta = 0.0357, and various soil strength parameters.

Probabilità e potenziale di liquefazione

Table showing Probabilità and Potenziale di liquefazione with columns for PL Overall Probability, Risk lev., and IPL.

Probabilità e suscettibilità di liquefazione

Table showing Probabilità e suscettibilità di liquefazione with columns for PL Overall Probability, Risk lev., and IPL.

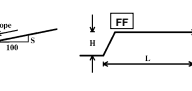
PL Overall Probability

Table showing PL Overall Probability with columns for Risk lev., IPL, and PL.

Robertson & Wride, agg. 2009

Table showing Robertson & Wride parameters with columns for PL Overall Probability, Risk lev., and IPL.

PROVA "CPTE 7"

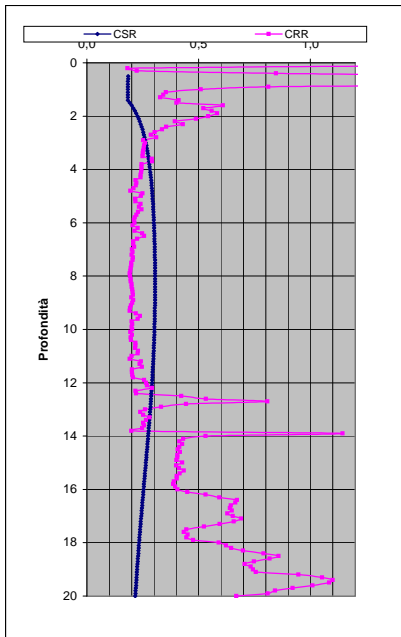
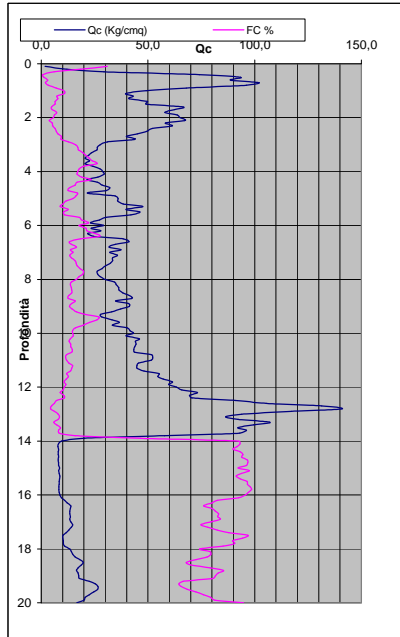


Main data table header with columns for Depth (m), q (kPa), qc (kPa), fs (kPa), and various soil strength and liquefaction parameters.

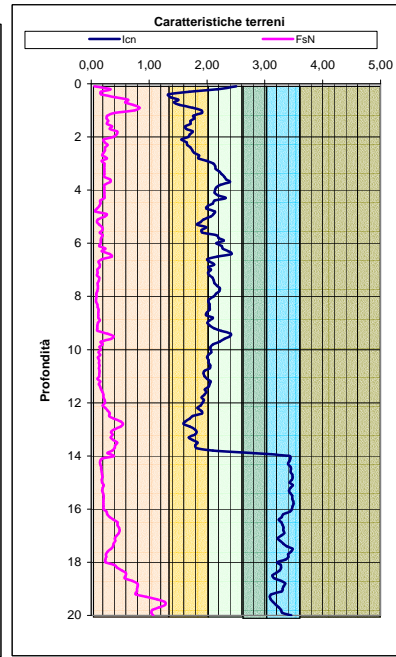
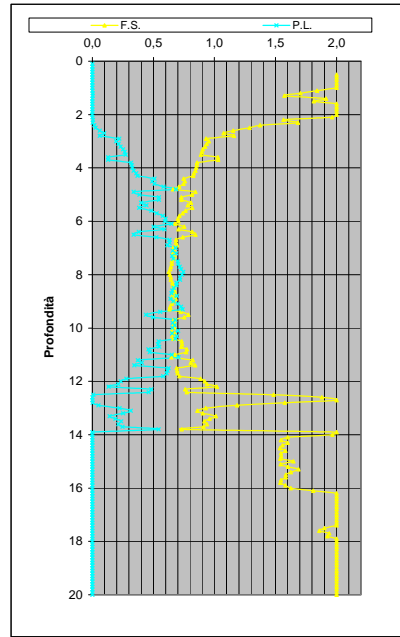
PROFONDITA' DI CALCOLO (mt da p.c.): 0,0 | LDI = 3,725 | Stot = 0,342 (mt) | IPL = 14,81 | PL = 53,41 | LD = 0,00 (mt) | PG = 1,00 | SLiq = 10,1 (mt) | LSN = 48,0

Main data table body containing 101 rows of soil test data, including depth, cone resistance, sleeve friction, and calculated liquefaction parameters.

DIAGRAMMI DI RIFERIMENTO VERIFICA LIQUEFAZIONE - METODO R. & W. , 2009



PROVA CPTE 7



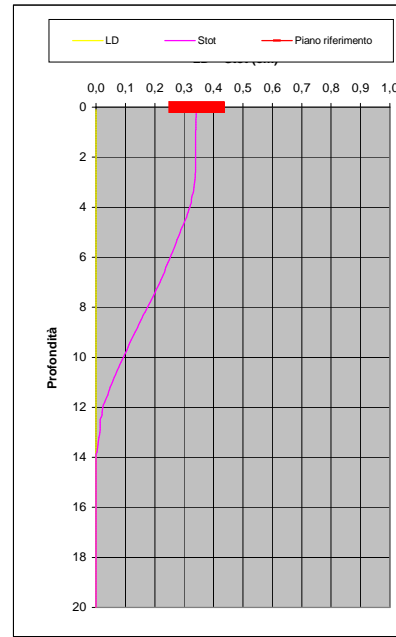
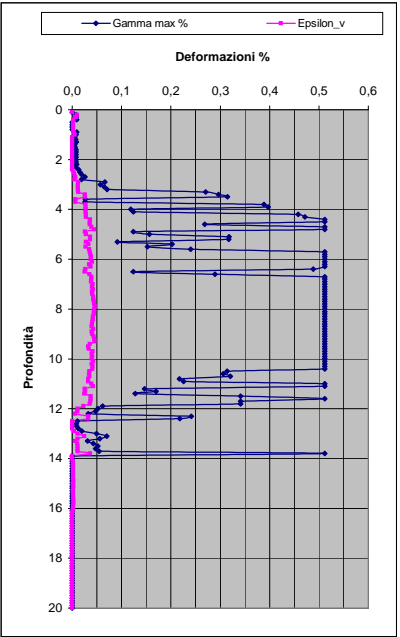
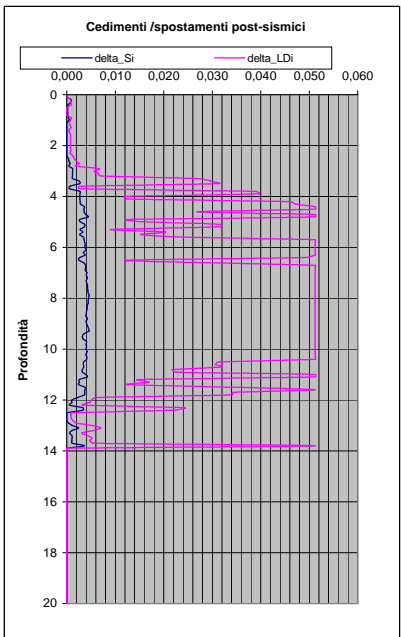
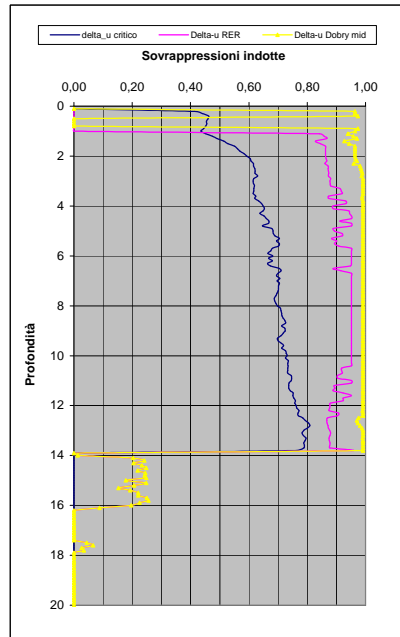
Soil Classification	Zone No.*	Range of CPT Index $I_c$ Values
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Clays	3	$2.95 < I_c < 3.60$
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Gravelly Sands	7	$I_c < 1.31$

After Robertson and Wride (1998).  
\*Note: Zone number per Robertson SBT (1990).

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\* Table based on Table 13.1 from I&T report: Liquefaction Vulnerability Study

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$P_G \leq 0.1$	extremely low to none

IPL= 14,81

PL= 53,41

LDI = 3,725 Stot = 0,342 (mt)

LD = 0,00 (mt)

SLiq = 10,10 (mt)

LSN = 47,97 PG= 1,00

CPT-based liquefaction triggering analysis for a single sounding

Environmental parameters, soil classification, and various probability and potentiality charts for liquefaction analysis.

Table with columns for Depth (m), Soil Type, and various geotechnical parameters like qc, N, and stress ratios.

Main data table containing liquefaction triggering analysis results for each depth, including parameters like LDI, Stot, and LSN.

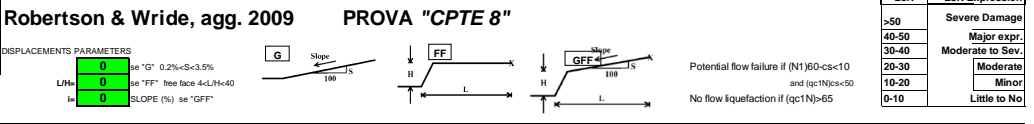
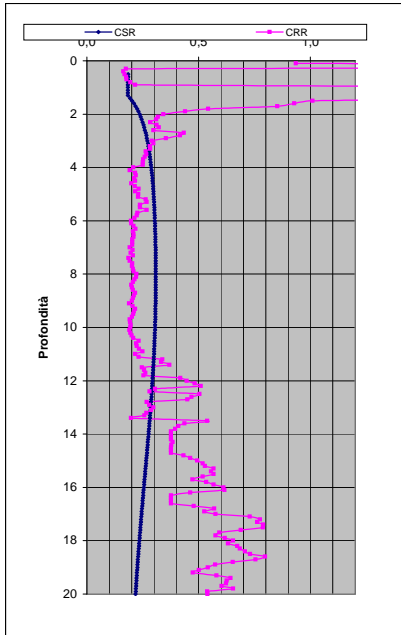
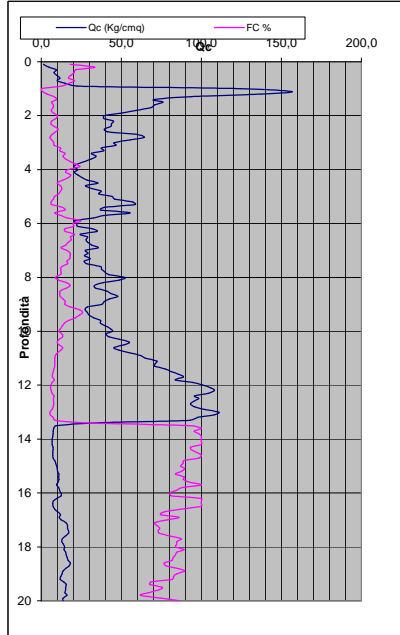
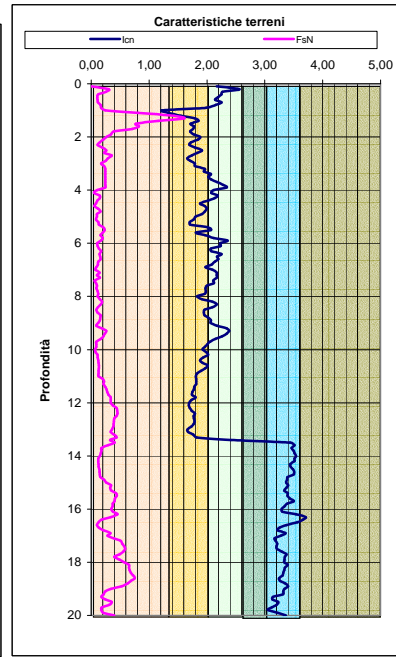
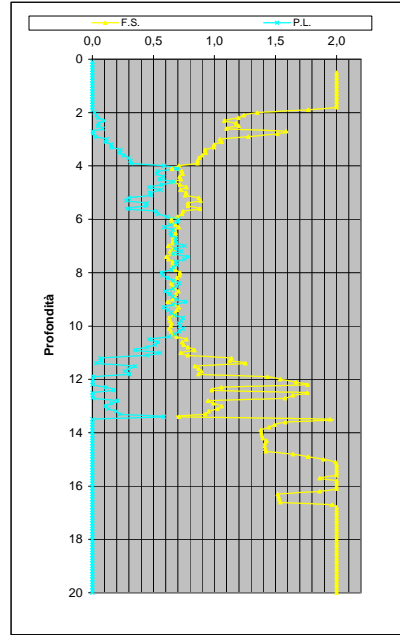


Table with columns for LSN and LSN Expression, showing the relationship between soil strength and liquefaction potential.

DIAGRAMMI DI RIFERIMENTO VERIFICA LIQUEFAZIONE - METODO R. & W. , 2009



PROVA CPTE 8



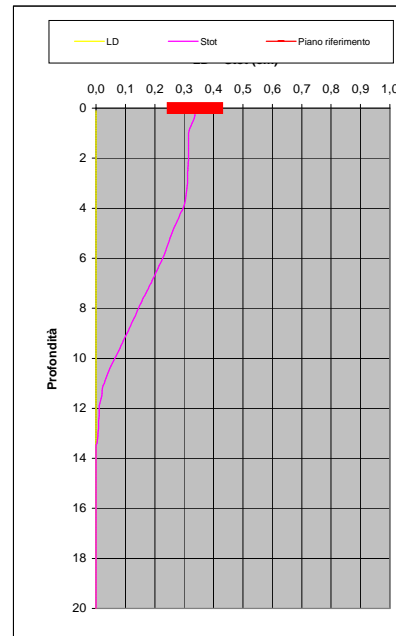
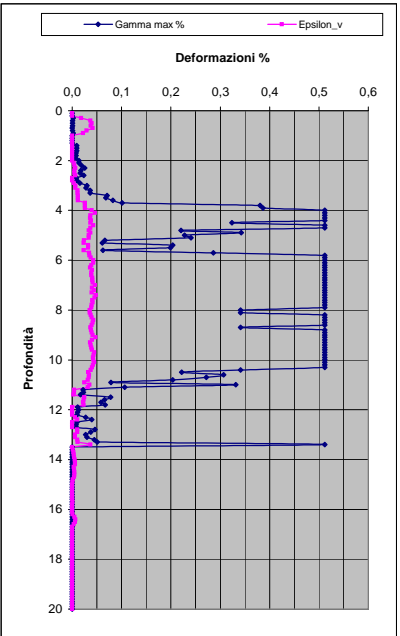
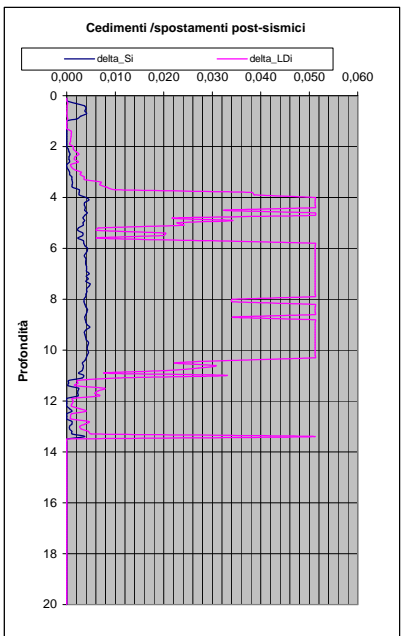
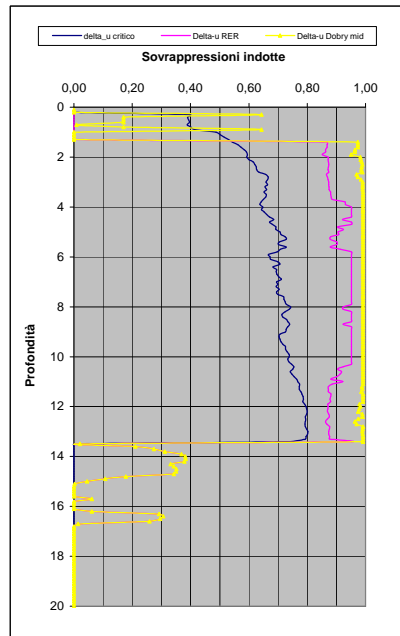
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After Robertson and Wride (1998).  
\*Note: Zone number per Robertson SBT (1990).

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LEGENDA

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- $\Delta u$  Dobry M. =  $\Delta u / \sigma'_{vc}$  Dobry et al. 1984 "mean" x sabbie-Robertson '09 x argille
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- Dr** = Densità relativa (ad)
- $\theta$  = angolo di attrito interno (deg)
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$0.1 < P_G \leq 0.3$	low
$P_G \leq 0.1$	extremely low to none

IPL= 14,40

PL= 51,17

LDI = 3,337 Stot = 0,337 (mt)

LD = 0,00 (mt)

SLiq = 9,00 (mt)

LSN = 46,57 PG= 1,00

CPT-based liquefaction triggering analysis for a single sounding

Main data table with columns for Depth (m), Soil Classification, Soil Parameters (qc, N, etc.), and Liquefaction Parameters (FS, CSR, etc.). Includes a detailed header section with various classification codes and calculation parameters.

Environments: Hill-H Plain-P Coast-C

Behaviours: Sand-like-S

Soil Classification: Sand-Clay-SC

Building (Y/N): Sedimentary environment

Equipment: CPT-CPT-1

Computer constants: alpha (N) = 1.0

Building (Y/N): Sedimentary environment

Equipment: CPT-CPT-1

Probabilità e potenziale di liquefazione

Probabilità e suscettibilità di liquefazione

PL Overall Probability

Robertson & Wride, agg. 2009

PROVA "CPTE 9"

DISPLACEMENT PARAMETERS

LsN and LsN Expression

Severe Damage, Moderate to Severe, Minor, Little to No

Potential flow failure (N) 60<=c<10 and (q/N) 60<=c<10

No flow liquefaction if (qc/N)>=65

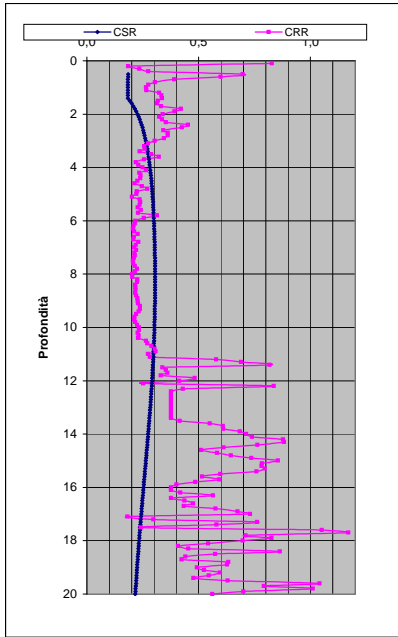
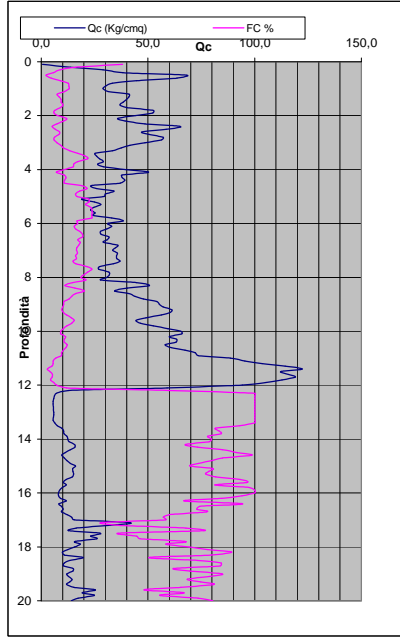
PROFONDITA' DI CALCOLO (mt da p.c.): 0,0

LDI = 2,808 Stot = 0,258 (mt) IPL = 11,20

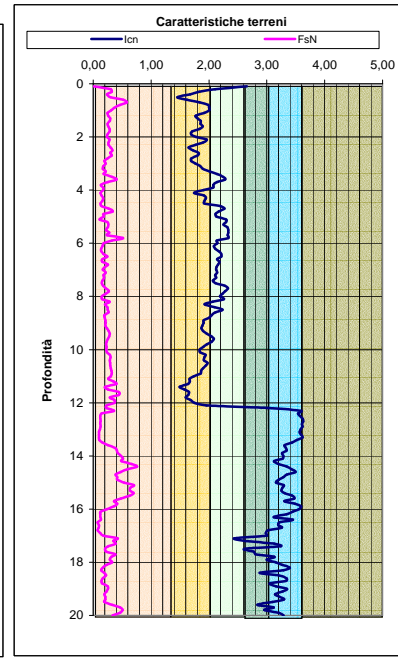
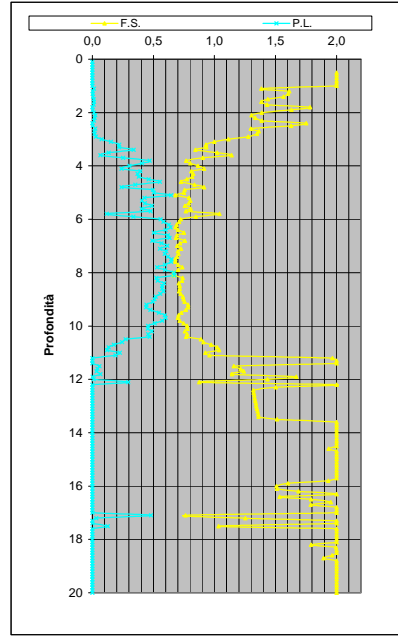
PL = 34,28 LD = 0,00 (mt) PG = 0,96 SLiq = 7,8 (mt) LSN = 38,0

Main data table with columns for Depth (m), Soil Classification, Soil Parameters (qc, N, etc.), and Liquefaction Parameters (FS, CSR, etc.).

DIAGRAMMI DI RIFERIMENTO VERIFICA LIQUEFAZIONE - METODO R. & W. , 2009



PROVA CPTE 9



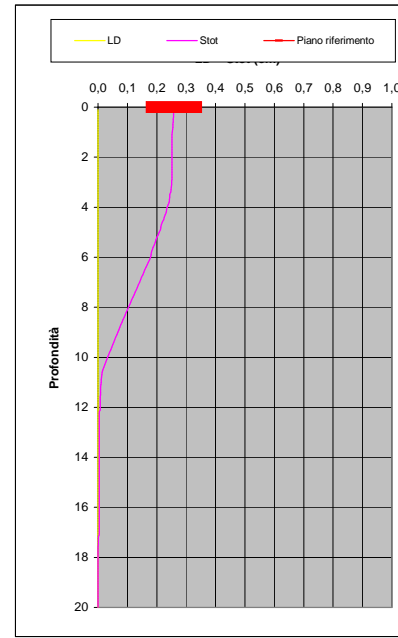
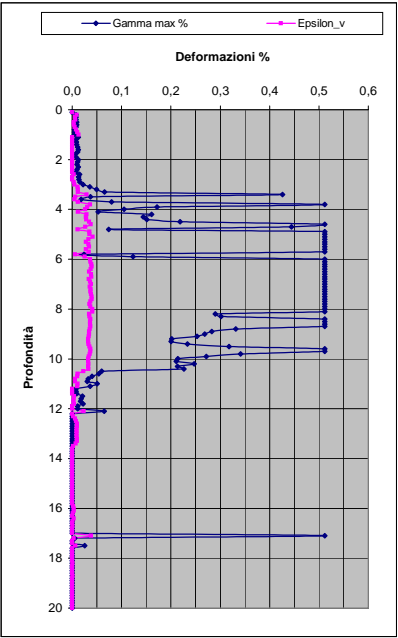
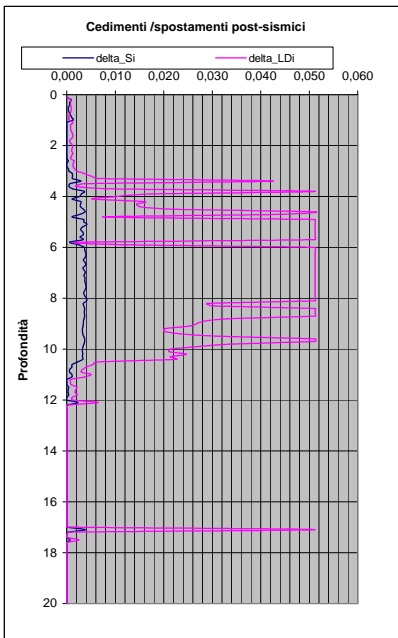
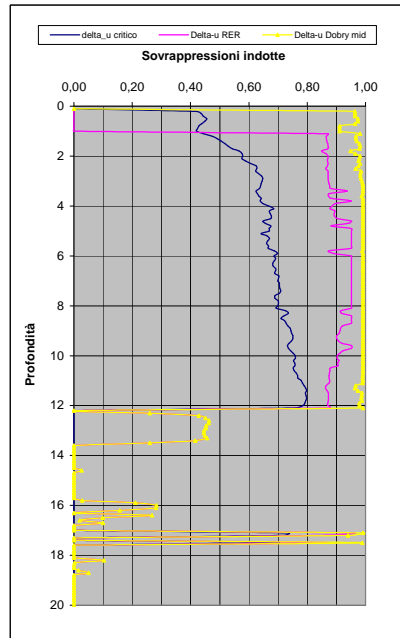
Soil Classification	Zone No.*	Range of CPT Index $I_c$ Values
Organic Clay Soils	2	$I_c > 3.60$
Clays	3	$2.95 < I_c < 3.60$
Silt Mixtures	4	$2.60 < I_c < 2.95$
Sand Mixtures	5	$2.05 < I_c < 2.60$
Sands	6	$1.31 < I_c < 2.05$
Gravelly Sands	7	$I_c < 1.31$

After Robertson and Wride (1998).  
\*Note: Zone number per Robertson SBT (1990).

- Argille - terreni organici
- Argille - argilla/argilla limosa
- Miscela di limi - limo argilloso/argilla limosa
- Miscela di sabbie - sabbia limosa/limo sabbioso
- Sabbie - sabbie pulite/sabbie limose
- sabbie ghiaiose / sabbie dense

LEGENDA

- Qc** = Res. alla penetraz. (Kg/cmq)
- FC** = Fine content - passante 0.074 mm (%)
- FsN** = Attrito laterale (Kg/cmq)
- F** = rapporto di frizione
- Qtn** = parametro di resist. alla punta normal.
- Icn** = Soil behaviour index normalized (ad)
- qc1N-cs** = Resist. alla pentrez. corretta all'FC e normalizzata
- $\xi$  = parametro di stato
- KH** = fatt. correttivo per spessore strato (ad)
- Rd** = stress reduction coefficient (ad)
- CN** = fattore di normalizzazione per carico litostatico (ad)
- K $\sigma$**  = fatt. correttivo per sovraccarico-profondità (ad)
- K $\alpha$**  = fatt. correttivo per sforzi di taglio (ad)
- MSF** = magnitudo scaling factor (ad)
- F.S.** = Fattore di sicurezza (CRR/CSR con correzioni) (ad)
- CSR** = Cyclic Stress ratio (ad)
- CRR** = Cyclic Resistance Ratio (ad)
- P.L.** = Probabilità di liquefazione (ad)
- IPL** = Indice del potenziale di liquefazione (ad)
- $\gamma_{max}$**  = deformazione di taglio massima indotta dal sisma (%)
- ev** = vertical reconsolidation strain
- $\Delta s_i$**  = cedimento i-esimo dello strato (mt)
- Su** =  $S_u / \sigma'_{vc}$  resistenza totale non drenata - strati coesivi (ad)
- Sur** =  $S_{ur} / \sigma'_{vc}$  resistenza totale residua non drenata - strati coesivi (ad)
- qc1N-sr** = Resist. alla pentrez. corretta all'FC e normalizzata
- Sr** =  $S_r / \sigma'_{vc}$  resistenza residua - strati incoerenti (ad)
- Ruc** =  $\Delta u / \sigma'_{vc}$  critico - stima sogliadi innesco fenomeni di instabilità/liquefazione
- $\Delta u$  RER =  $\Delta u / \sigma'_{vc}$  sovrappressioni circ. 112/2007 - tabella 2 R.E.R.
- $\Delta u$  Dobry M. =  $\Delta u / \sigma'_{vc}$  Dobry et al. 1984 "mean" x sabbie-Robertson '09 x argille
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- Stot** = Cedimento post-sismico totale (mt)
- LDI** = Lateral Displacement Index (mt)
- Dr** = Densità relativa (ad)
- $\theta$  = angolo di attrito interno (deg)
- OCR** = rapporto di sovraconsolidazione (sabbie e argille) (ad)
- St** = coefficiente di sensitività delle argille (ad)
- LSN** = Liquefaction Severity Number (ad)



LSN Range	Expected ground surface damage
0-10	Little to no expression of liquefaction, minor effects
10-20	Minor expression of liquefaction, some sand boils
20-30	Moderate expression of liquefaction, with some sand boils and structural damage
30-40	Moderate to severe expression of liquefaction, settlement can cause structural damage
40-50	Major expression of liquefaction, undulations and damage to ground surface, severe total and differential settlements of structures
>50	Severe damage, extensive evidence of liquefaction as surface, severe total and differential settlements affecting structures, damage to services.

\* Table based on Table 13.1 from I&T report: Liquefaction Vulnerability Study

Probability	Description of the risk of liquefaction-induced ground failure
$0.9 < P_G$	extremely high to absolutely certain
$0.7 < P_G \leq 0.9$	high
$0.3 < P_G \leq 0.7$	medium
$0.1 < P_G \leq 0.3$	low
$P_G \leq 0.1$	extremely low to none

IPL = 11,20

PL = 34,28

LDI = 2,808 Stot = 0,258 (mt)

LD = 0,00 (mt)

SLiq = 7,80 (mt)

LSN = 38,00 PG = 0,96



CPT-based liquefaction triggering analysis for a single sounding

Environment: Hill-H Plain-P Coast-C  
Behaviours: Sand like-S

Computer constants: α (N) = 1.0, N = 101.32, MSF NCEER = 0.8

Soil Classification: Sand-Clay-SC, Building (Y/N): Sedimentary environment

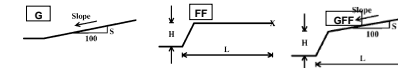
Probabilità e potenziale di liquefazione: Probabilità: 0.943, Pot di Liq: IPL-15

Probabilità e suscettibilità di liquefazione: Probabilità: 0.943, Suscettibilità: Quasi certa

PL Overall Probability: Risk lev. Very High, IPL: IPL-15

Robertson & Wride, agg. 2009

PROVA "CPTe 10"



Potential flow failure if (N) < 60-cv<10 and (q) < 100-cv<20  
No flow liquefaction if (q) < 100-cv<65

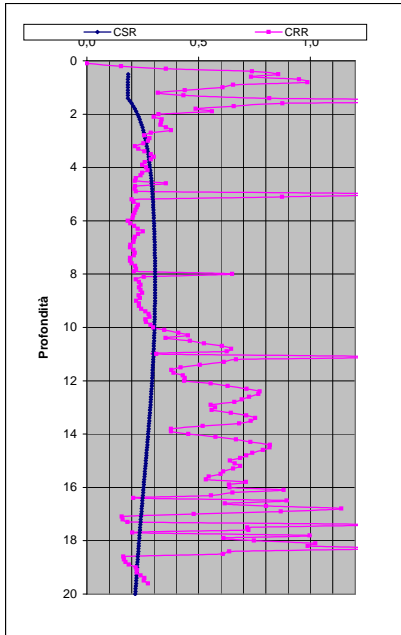
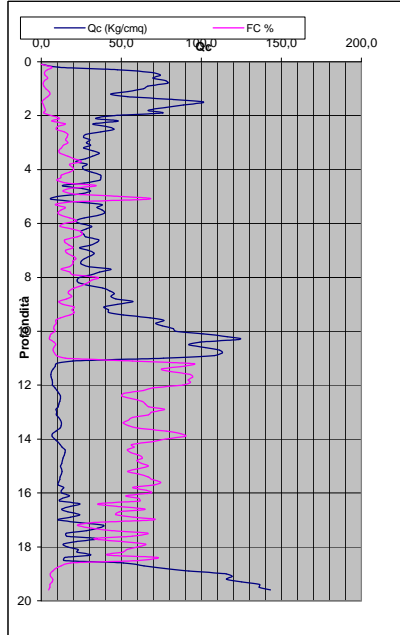
Table with 2 columns: LsN, LsN Expression. Values range from >50 to 0-10.

Table with 20 columns: Depth (m), qc(N)/kPa, fs(N)/kPa, etc. Includes data for various soil layers and parameters.

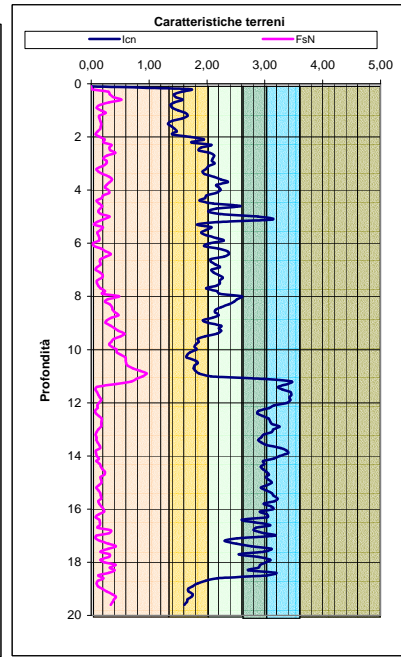
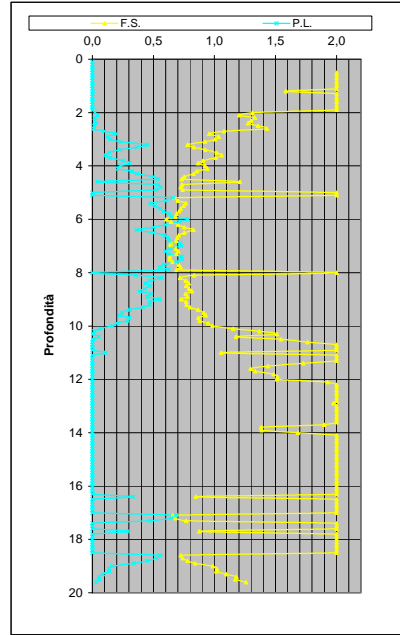
PROFONDITA' DI CALCOLO (mt da p.c.): 0,0 | LDI = 2,742 | Stot = 0,256 (mt) | IPL = 10,04 | PL = 28,82 | LD = 0,00 (mt) | PG = #NUM | SLiq = 7,4 (mt) | LSN = 36,8

Main data table with 20 columns: Depth (m), qc(N)/kPa, fs(N)/kPa, etc. Contains detailed soil test data for each depth interval.

DIAGRAMMI DI RIFERIMENTO VERIFICA LIQUEFAZIONE - METODO R. & W. , 2009



PROVA CPT E 10



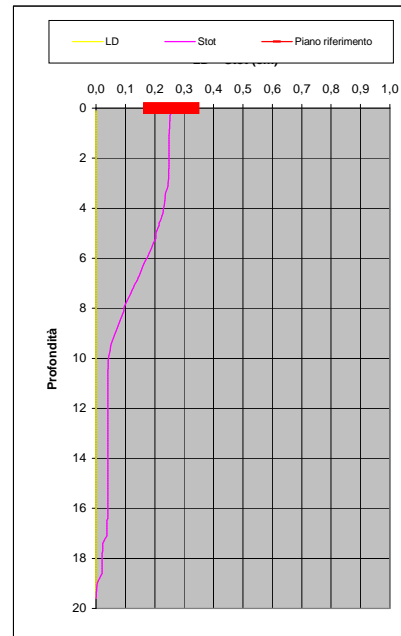
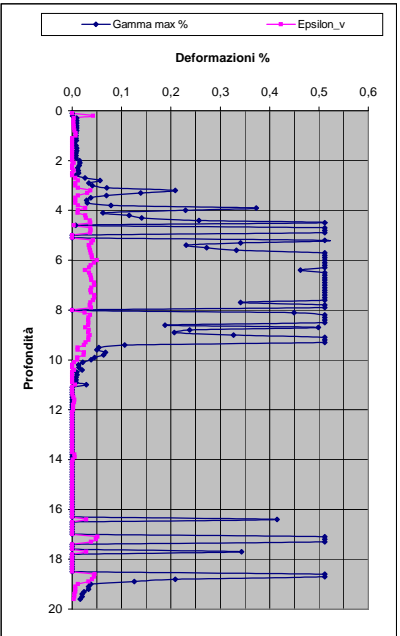
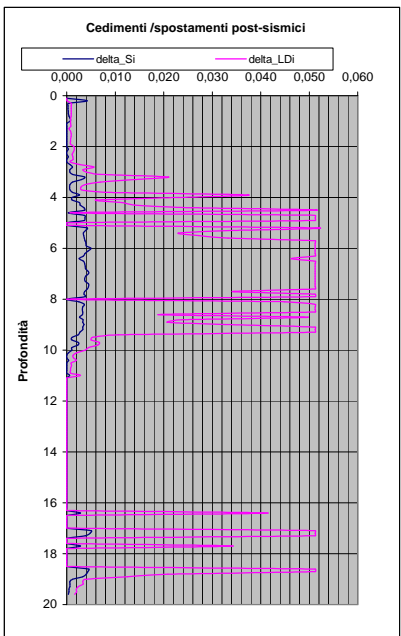
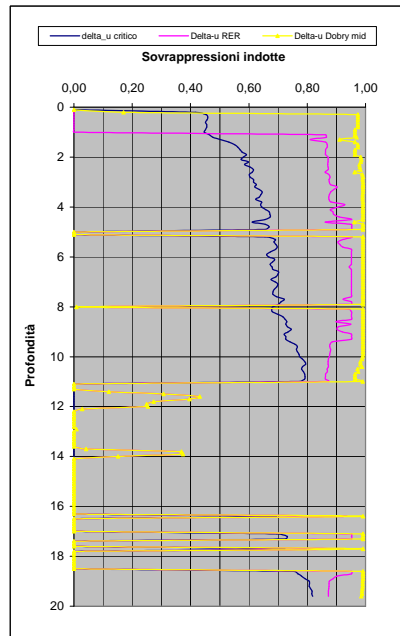
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After Robertson and Wride (1998).  
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- St** = coefficiente di sensitività delle argille (ad)
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LSN Range	Expected ground surface damage
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$0.1 < P_G \leq 0.3$	low
$P_G \leq 0.1$	extremely low to none

IPL= 10,04      PL= 28,82      LDI = 2,742      Stot = 0,256 (mt)      LD = 0,00 (mt)      SLiq = 7,40 (mt)      LSN = 36,77      PG= #NUM!

CPT-based liquefaction triggering analysis for a single sounding

Input parameters table including Peak ground accel (g), Earthquake magnitude (Mw), Water table depth (m), etc.

Soil Classification table with columns for Soil Classification, Zone No., Range of CPT Index / Values, etc.

Computer constants table including alpha (N) = 101.32, Patm = 101.32, etc.

Probabilità e potenziale di liquefazione table with columns for Probabilità, Potenzialità, etc.

Probabilità e suscettibilità di liquefazione table with columns for Probabilità, Suscettibilità, etc.

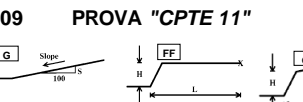
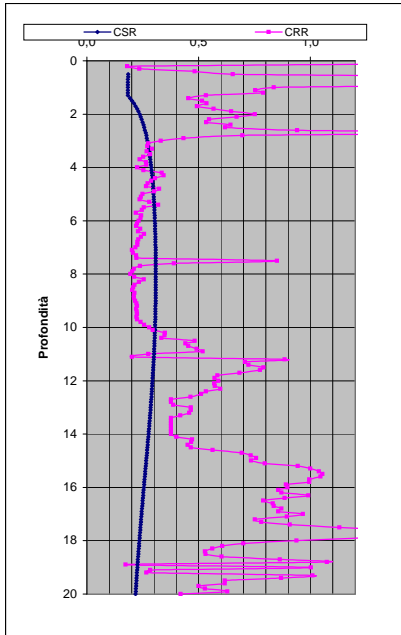
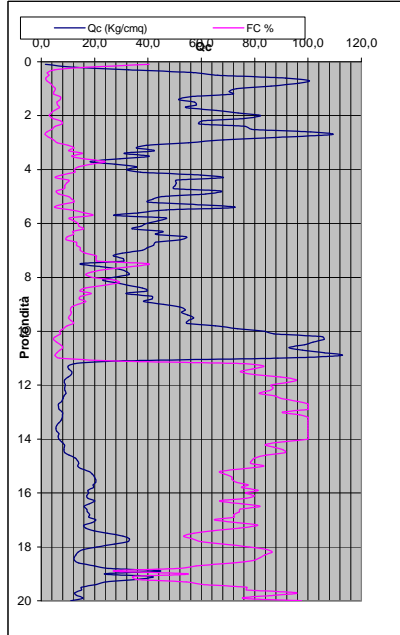


Table for Liquefaction Severity (LSN) with columns for LSN, LSN Expression, etc.

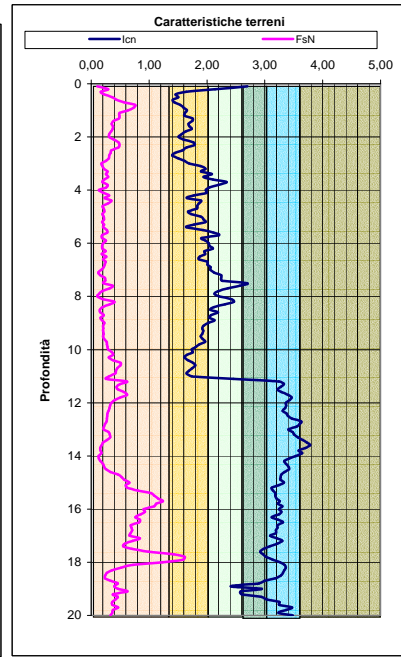
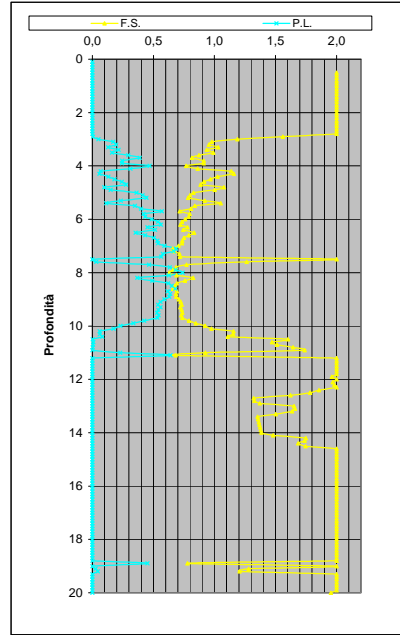
Main calculation table with columns for Depth (m), q (kPa), N60, etc., and a summary row at the bottom: PROFONDITA' DI CALCOLO (mt da p.c.): 0,0; LDI = 1,967; Stot = 0,203 (mt); IPL = 8,78; PL = 23,55; LD = 0,00 (mt); PG = 0,82; SLiq = 6,5 (mt); LSN = 29,8

Main data table with 100 rows of sounding data, columns including Depth (m), q (kPa), N60, etc.

DIAGRAMMI DI RIFERIMENTO VERIFICA LIQUEFAZIONE - METODO R. & W. , 2009



PROVA CPT E 11



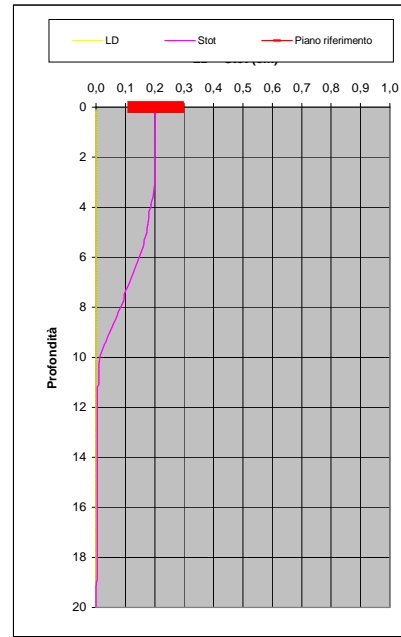
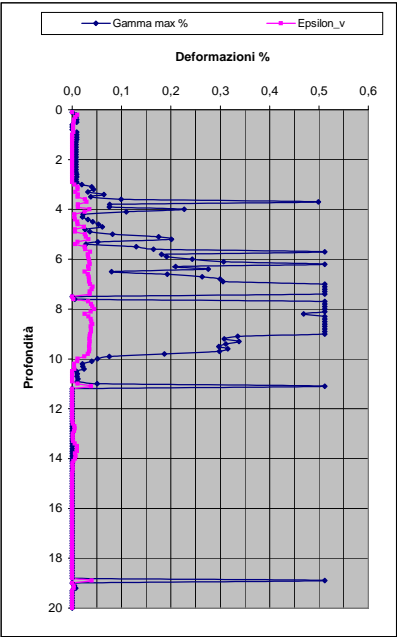
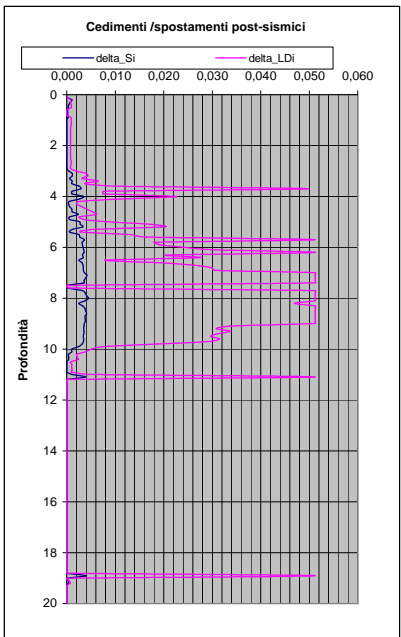
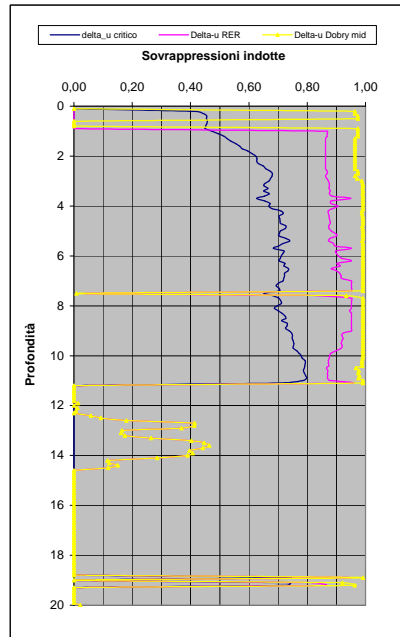
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After Robertson and Wride (1998).  
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LEGENDA

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- $\phi$  = angolo di attrito interno (deg)
- OCR** = rapporto di sovraconsolidazione (sabbie e argille) (ad)
- St** = coefficiente di sensitività delle argille (ad)
- LSN** = Liquefaction Severity Number (ad)



IPL = 8,78

PL = 23,55

LDI = 1,967 Stot = 0,203 (mt)

LD = 0,00 (mt)

SLiq = 6,50 (mt)

LSN = 29,78 PG = 0,82

LSN Range	Expected ground surface damage
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$0.3 < P_G \leq 0.7$	medium
$0.1 < P_G \leq 0.3$	low
$P_G \leq 0.1$	extremely low to none

CPT-based liquefaction triggering analysis for a single sounding

Enviroments: C Hill-H Plain-P Coast-C Behaviours: E Sand like-S

Computer constants: no. n: 10, 101.32; MSF NCEER: 0.6; Patm: 101.32; cov: 0.35-0.5; K: 1.2; IP COR: 1.2

Probabilità e potenziale di liquefazione

Probabilità e suscettibilità di liquefazione

PL Overall Probability

Robertson & Wride, agg. 2009

PROVA "CPTe 12"



Potential flow failure if (N1)60<cs<10 and (q1)N60>50 No flow liquefaction if (q1)N60<50

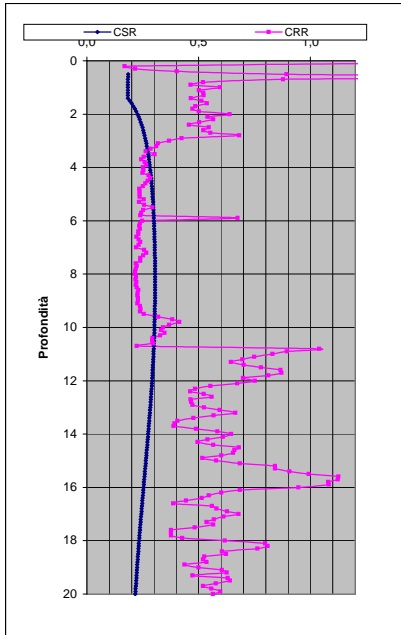
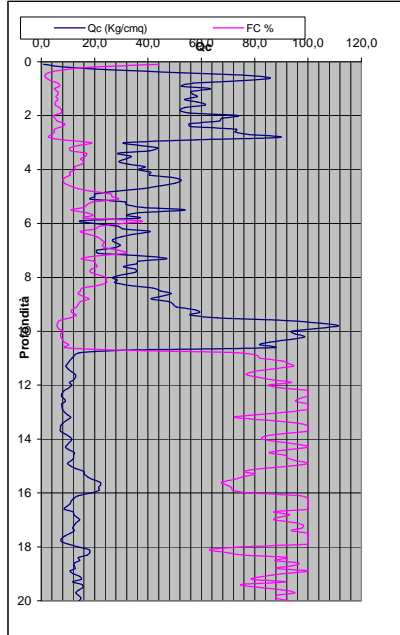
Table with columns for input parameters (Peak ground accel, Earthquake magnitude, etc.), soil classification, and various probability and liquefaction indices.

Table with columns for depth (m), soil type, and various geotechnical parameters (qc, q, F, Ic, etc.) and liquefaction indices (FS, MSF, etc.).

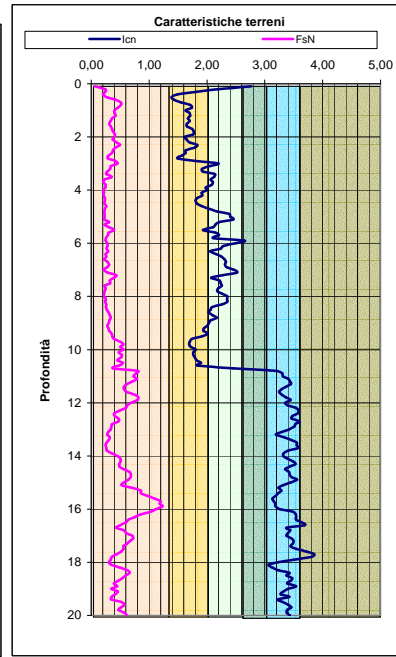
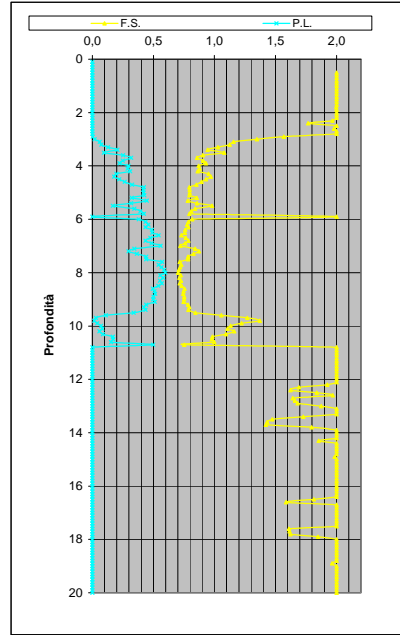
PROFONDITA' DI CALCOLO (mt da p.c.): 0,0 LDI = 2,109 Stot = 0,190 (mt) IPL = 7,79 PL = 19,89 LD = 0,00 (mt) PG = 0,69 SLiq = 6,4 (mt) LSN = 28,8

Main data table with 100 rows and 40+ columns, providing detailed soil test results and liquefaction analysis for each depth interval.

DIAGRAMMI DI RIFERIMENTO VERIFICA LIQUEFAZIONE - METODO R. & W. , 2009



PROVA CPT E 12



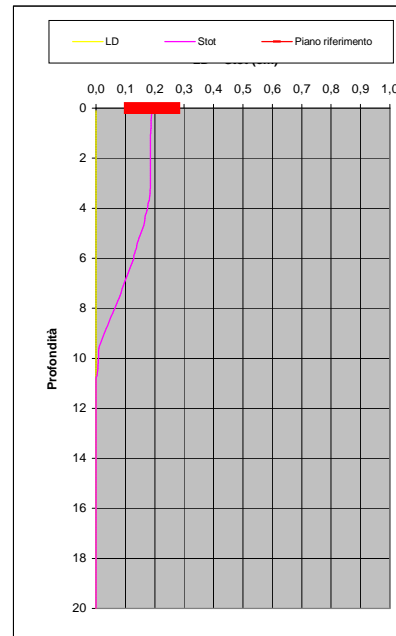
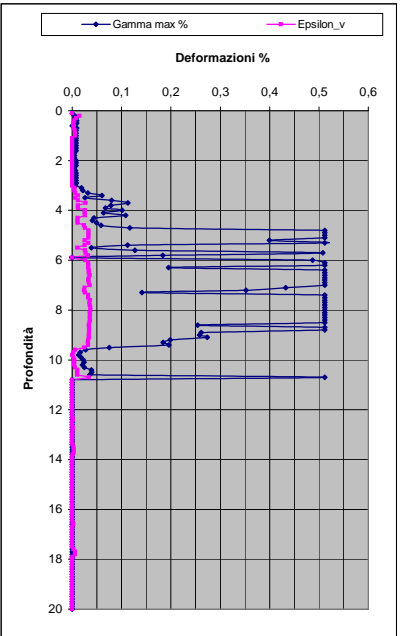
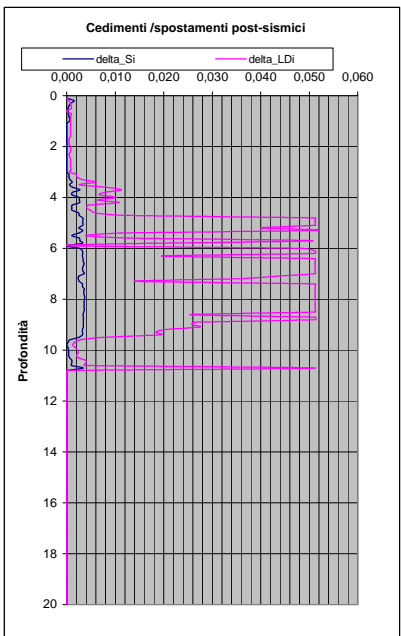
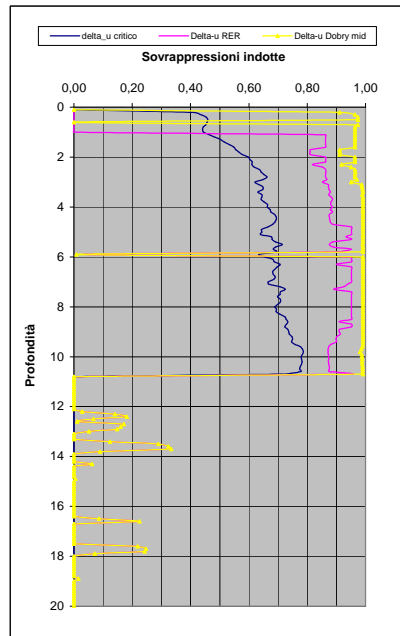
Soil Classification	Zone No.*	Range of CPT Index $I_c$ Values
Organic Clay Soils	2	$I_c > 3.60$
Clays	3	$2.95 < I_c < 3.60$
Silt Mixtures	4	$2.60 < I_c < 2.95$
Sand Mixtures	5	$2.05 < I_c < 2.60$
Sands	6	$1.31 < I_c < 2.05$
Gravelly Sands	7	$I_c < 1.31$

After Robertson and Wride (1998).  
\*Note: Zone number per Robertson SBT (1990).

- Argille - terreni organici
- Argille - argilla/argilla limosa
- Miscela di limi - limo argilloso/argilla limosa
- Miscela di sabbie - sabbia limosa/limo sabbioso
- Sabbie - sabbie pulite/sabbie limose
- sabbie ghiaiose / sabbie dense

LEGENDA

- Qc** = Res. alla penetraz. (Kg/cmq)
- FC** = Fine content - passante 0.074 mm (%)
- Fsn** = Attrito laterale (Kg/cmq)
- F** = rapporto di frizione
- Qtn** = parametro di resist. alla punta normal.
- Icn** = Soil behaviour index normalized (ad)
- qc1N-cs** = Resist. alla pentrez. corretta all'FC e normalizzata
- $\xi$  = parametro di stato
- KH** = fatt. correttivo per spessore strato (ad)
- Rd** = stress reduction coefficient (ad)
- CN** = fattore di normalizzazione per carico litostatico (ad)
- K $\sigma$**  = fatt. correttivo per sovraccarico-profondità (ad)
- K $\alpha$**  = fatt. correttivo per sforzi di taglio (ad)
- MSF** = magnitudo scaling factor (ad)
- F.S.** = Fattore di sicurezza (CRR/CSR con correzioni) (ad)
- CSR** = Cyclic Stress ratio (ad)
- CRR** = Cyclic Resistance Ratio (ad)
- P.L.** = Probabilità di liquefazione (ad)
- IPL** = Indice del potenziale di liquefazione (ad)
- Ymax** = deformazione di taglio massima indotta dal sisma (%)
- ev** = vertical reconsolidation strain
- $\Delta$ si** = cedimento i-esimo dello strato (mt)
- Su** =  $S_u / \sigma'_{vc}$  resistenza totale non drenata - strati coesivi (ad)
- Sur** =  $S_{ur} / \sigma'_{vc}$  resistenza totale residua non drenata - strati coesivi (ad)
- qc1N-sr** = Resist. alla pentrez. corretta all'FC e normalizzata
- Sr** =  $S_r / \sigma'_{vc}$  resistenza residua - strati incoerenti (ad)
- Ruc** =  $\Delta u / \sigma'_{vc}$  critico - stima sogliadi innesco fenomeni di instabilità/liquefazione
- $\Delta u$  RER =  $\Delta u / \sigma'_{vc}$  sovrappressioni circ. 112/2007 - tabella 2 R.E.R.
- $\Delta u$  Dobry M. =  $\Delta u / \sigma'_{vc}$  Dobry et al. 1984 "mean" x sabbie-Robertson '09 x argille
- $\Delta u$  Dobry L. =  $\Delta u / \sigma'_{vc}$  Dobry et al. 1984 "lower bound" x sabbie-Robertson '09 x argille
- $\Delta u$  Dobry U. =  $\Delta u / \sigma'_{vc}$  Dobry et al. 1984 "Upper bound" x sabbie-Robertson '09 x argille
- Stot** = Cedimento post-sismico totale (mt)
- LDI** = Lateral Displacement Index (mt)
- Dr** = Densità relativa (ad)
- $\phi$  = angolo di attrito interno (deg)
- OCR** = rapporto di sovraconsolidazione (sabbie e argille) (ad)
- St** = coefficiente di sensitività delle argille (ad)
- LSN** = Liquefaction Severity Number (ad)



LSN Range	Expected ground surface damage
0-10	Little to no expression of liquefaction, minor effects
10-20	Minor expression of liquefaction, some sand boils
20-30	Moderate expression of liquefaction, with some sand boils and structural damage
30-40	Moderate to severe expression of liquefaction, settlement can cause structural damage
40-50	Major expression of liquefaction, undulations and damage to ground surface, severe total and differential settlements of structures
>50	Severe damage, extensive evidence of liquefaction at surface, severe total and differential settlements affecting structures, damage to services.

\* Table based on Table 13.1 from I&T report: Liquefaction Vulnerability Study

Probability	Description of the risk of liquefaction-induced ground failure
$0.9 < P_G$	extremely high to absolutely certain
$0.7 < P_G \leq 0.9$	high
$0.3 < P_G \leq 0.7$	medium
$0.1 < P_G \leq 0.3$	low
$P_G \leq 0.1$	extremely low to none

IPL = 7,79      PL = 19,89      LDI = 2,109      Stot = 0,190 (mt)      LD = 0,00 (mt)      SLiq = 6,40 (mt)      LSN = 28,83      PG = 0,69

CPT-based liquefaction triggering analysis for a single sounding

Environments: Hill-H Plain-P Coast-C Behaviours: Sand like-S

Computer constants: no. of Blows (N) = 10.32 (MSF NCEER)

Probabilità e potenziale di liquefazione

Probabilità e suscettibilità di liquefazione

PL Overall Probability

Robertson & Wride, agg. 2009

PROVA "CPTU 1" - Colonia Montecatini

Table with 2 columns: LSN, LSN Expression. Values range from >50 to <0.

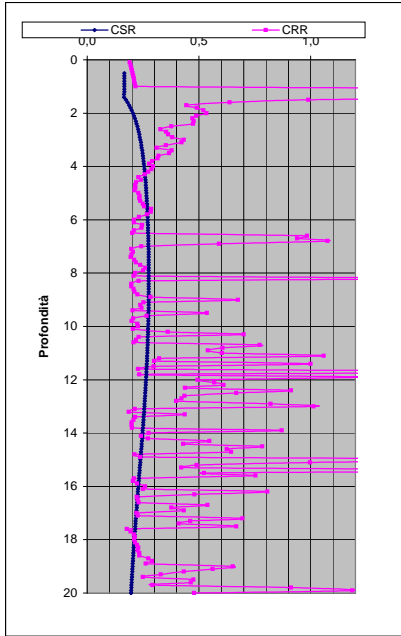
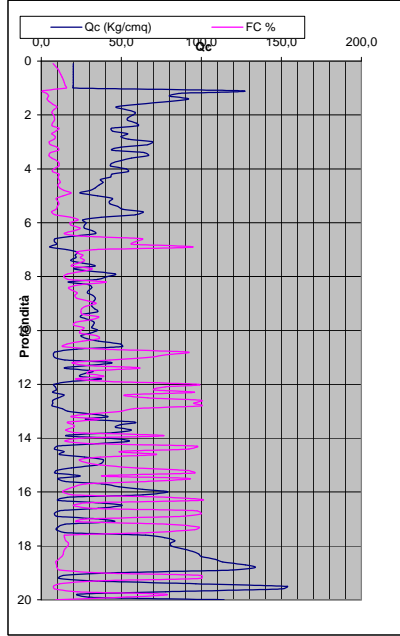
Input parameters table including Peak ground accel (g), Earthquake magnitude (M), Water table depth (m), Average above water table (N60)30, Average below water table (N60)30, Equipment (CPT-CPT1).

Table with 30 columns: Depth (m), q (kPa), qc (kPa), fs (kPa), etc. Includes various soil parameters and calculated values.

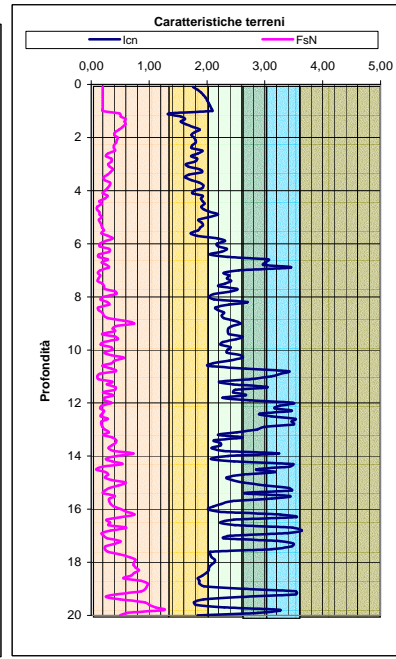
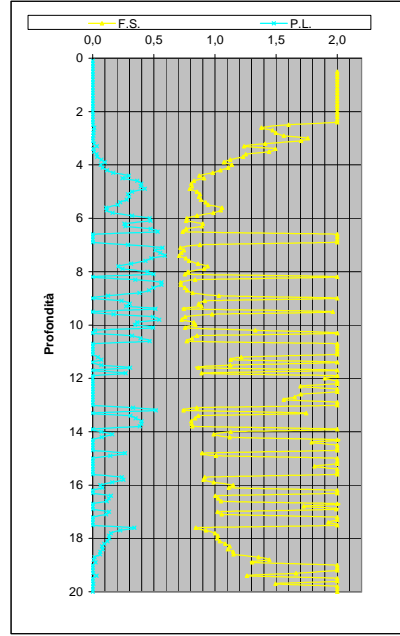
PROFONDITA' DI CALCOLO (mt da p.c.): 0,0 LDI = 2,495 Stot = 0,237 (mt) IPL = 6,30 PL = 15,20 LD = 0,00 (mt) PG = 0,44 SLiq = 6,8 (mt) LSN = 28,3

Main data table with 30 columns: Depth (m), q (kPa), qc (kPa), fs (kPa), etc. Contains 100 rows of data with highlighted values in red.

DIAGRAMMI DI RIFERIMENTO VERIFICA LIQUEFAZIONE - METODO R. & W. , 2009



PROVA CPTU 1 - Colonia Montecatini



Soil Classification	Zone No.*	Range of CPT Index $I_c$ Values
Organic Clay Soils	2	$I_c > 3.60$
Clays	3	$2.95 < I_c < 3.60$
Silt Mixtures	4	$2.60 < I_c < 2.95$
Sand Mixtures	5	$2.05 < I_c < 2.60$
Sands	6	$1.31 < I_c < 2.05$
Gravelly Sands	7	$I_c < 1.31$

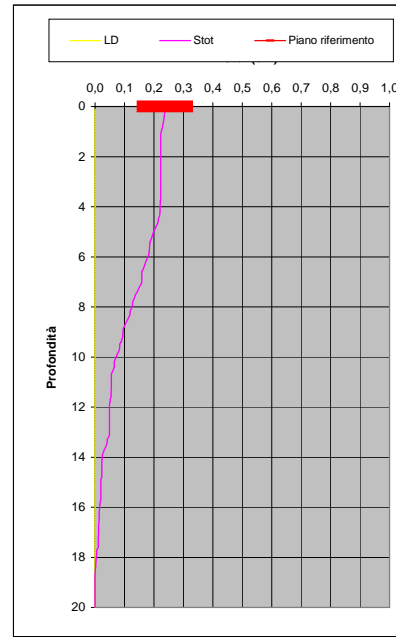
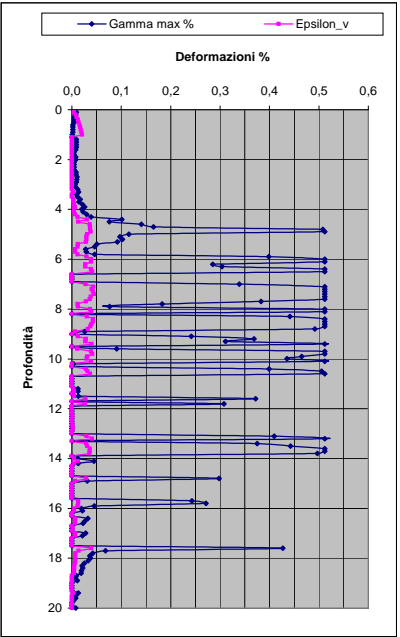
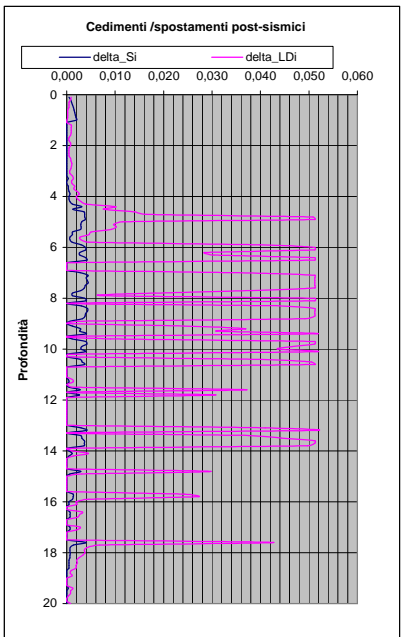
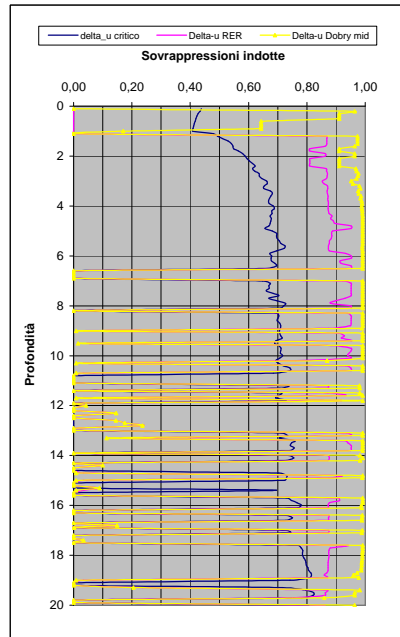
After Robertson and Wride (1998).

\*Note: Zone number per Robertson SBT (1990).

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- Argille - argilla/argilla limosa
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LEGENDA

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- FC** = Fine content - passante 0.074 mm (%)
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- F** = rapporto di frizione
- Qtn** = parametro di resist. alla punta normal.
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- $\xi$  = parametro di stato
- KH** = fatt. correttivo per spessore strato (ad)
- Rd** = stress reduction coefficient (ad)
- CN** = fattore di normalizzazione per carico litostatico (ad)
- K $\sigma$**  = fatt. correttivo per sovraccarico-profondità (ad)
- K $\alpha$**  = fatt. correttivo per sforzi di taglio (ad)
- MSF** = magnitudo scaling factor (ad)
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- P.L.** = Probabilità di liquefazione (ad)
- IPL** = Indice del potenziale di liquefazione (ad)
- $\gamma_{max}$**  = deformazione di taglio massima indotta dal sisma (%)
- ev** = vertical reconsolidation strain
- $\Delta s_i$**  = cedimento i-esimo dello strato (mt)
- Su** =  $S_u / \sigma'_{vc}$  resistenza totale non drenata - strati coesivi (ad)
- Sur** =  $S_{ur} / \sigma'_{vc}$  resistenza totale residua non drenata - strati coesivi (ad)
- qc1N-sr** = Resist. alla pentrez. corretta all'FC e normalizzata
- Sr** =  $S_r / \sigma'_{vc}$  resistenza residua - strati incoerenti (ad)
- Ruc** =  $\Delta u / \sigma'_{vc}$  critico - stima sogliadi innesco fenomeni di instabilità/liquefazione
- $\Delta u$  RER =  $\Delta u / \sigma'_{vc}$  sovrappressioni circ. 112/2007 - tabella 2 R.E.R.
- $\Delta u$  Dobry M. =  $\Delta u / \sigma'_{vc}$  Dobry et al. 1984 "mean" x sabbie-Robertson '09 x argille
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- Dr** = Densità relativa (ad)
- $\phi$  = angolo di attrito interno (deg)
- OCR** = rapporto di sovraconsolidazione (sabbie e argille) (ad)
- St** = coefficiente di sensitività delle argille (ad)
- LSN** = Liquefaction Severity Number (ad)



IPL = 6,30      PL = 15,20      LDI = 2,495      Stot = 0,237 (mt)      LD = 0,00 (mt)      SLiq = 6,80 (mt)      LSN = 28,33      PG = 0,44

LSN Range	Expected ground surface damage
0-10	Little to no expression of liquefaction, minor effects
10-20	Minor expression of liquefaction, some sand boils
20-30	Moderate expression of liquefaction, with some sand boils and structural damage
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\* Table based on Table 13.1 from I&T report: Liquefaction Vulnerability Study

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$0.9 < P_G$	extremely high to absolutely certain
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$0.3 < P_G \leq 0.7$	medium
$0.1 < P_G \leq 0.3$	low
$P_G \leq 0.1$	extremely low to none



CPT-based liquefaction triggering analysis for a single sounding

Enviroments: C Hill-H Plain-P Coast-C Behaviours: Sand like-S

Computer constants: no. 10,32 (B' 2007 - Cefin' 2004 - NCEER - Blake) MSF NCEER

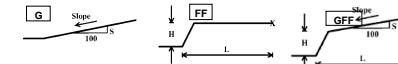
Probabilità e potenziale di liquefazione

Probabilità e suscettibilità di liquefazione

PL Overall Probability

Robertson & Wride, agg. 2009

PROVA "CPTU 2 II Canalino"



Potential flow failure if (N1)60-cs<10 and (q1)10>50 and No flow liquefaction if (q1)10<65

Table with 2 columns: LsN, LsN Expression. Rows show ranges for Severe Damage, Major expr., Moderate to Sev., Moderate, Mild, Little to No.

Table with 24 columns: Depth (m), q (kPa), qc (kPa), q1 (kPa), F, Ic, Icn2, N1 (blows/30cm), n, Kc, Layer, FC, Kh, Interpretation, CSR, Ks, Ks, CRR, FS, MSF, Limiting shear strain, PL, Risk lev., IPL, PL, Displacements Parameters, JWC, F, I, Au, Au, Ru, Au, Dr, Ruc, Su, Ocr, q1, Sr, Su, LsN.

PROFONDITA' DI CALCOLO (mt da p.c.): 0,0

LDI = 3,839 Stot = 0,356 (mt)

IPL = 9,73

PL = 27,46

LD = 0,00 (mt)

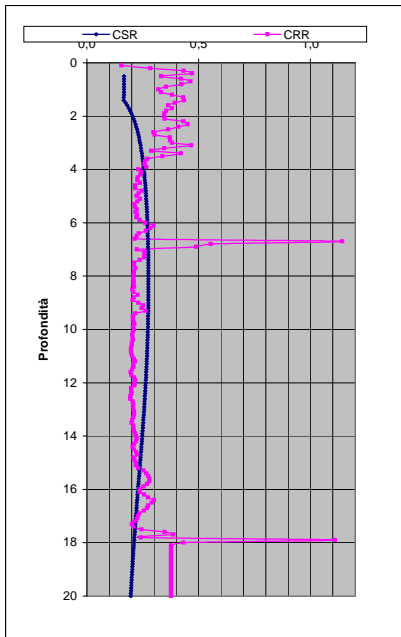
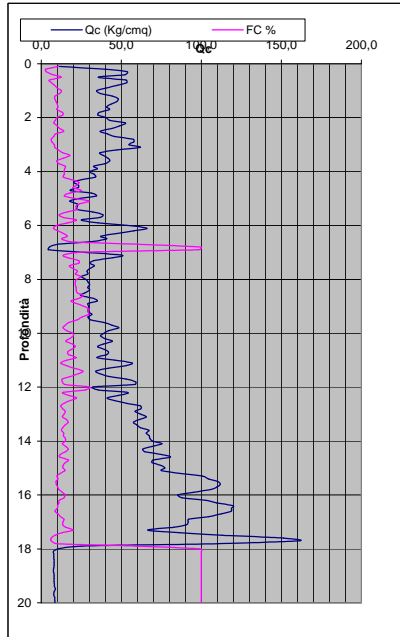
PG = 0,90

SLiq = 11,0 (mt)

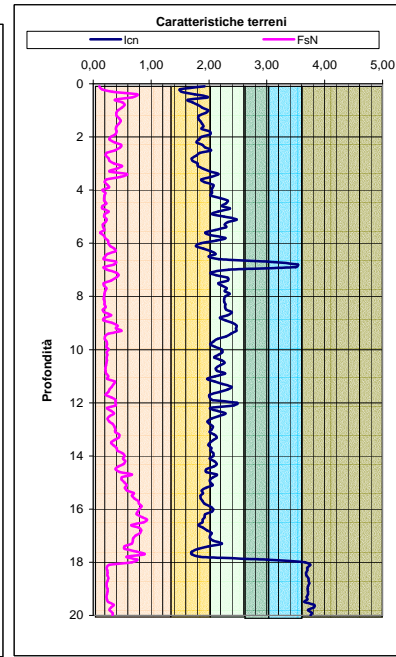
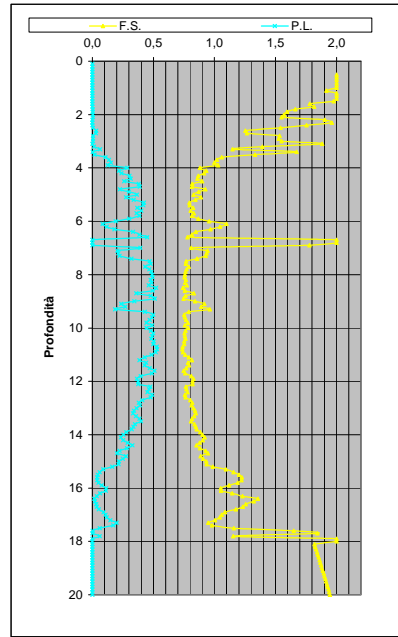
LSN = 41,1

Main data table with 24 columns and 100 rows of numerical data corresponding to the parameters in the header table above.

DIAGRAMMI DI RIFERIMENTO VERIFICA LIQUEFAZIONE - METODO R. & W. , 2009



PROVA CPTU 2 - Il Canalino



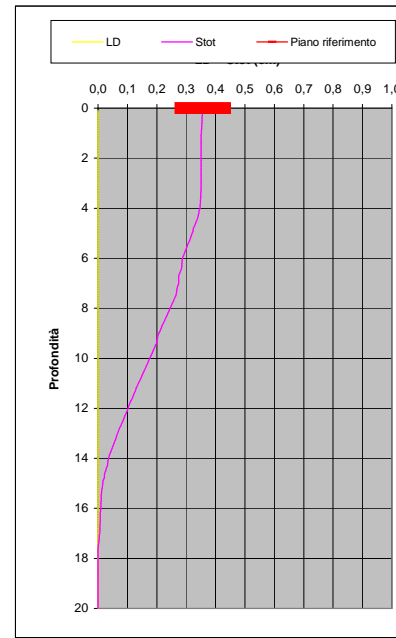
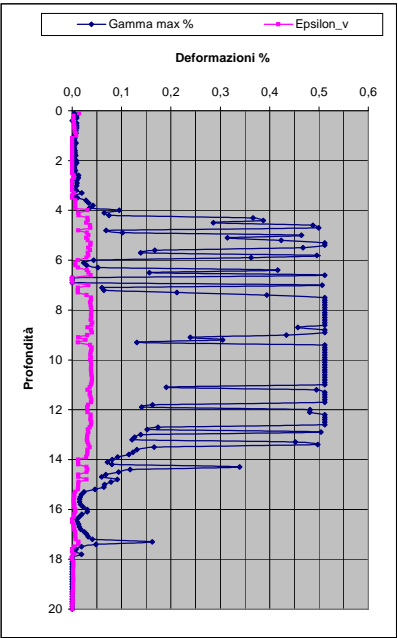
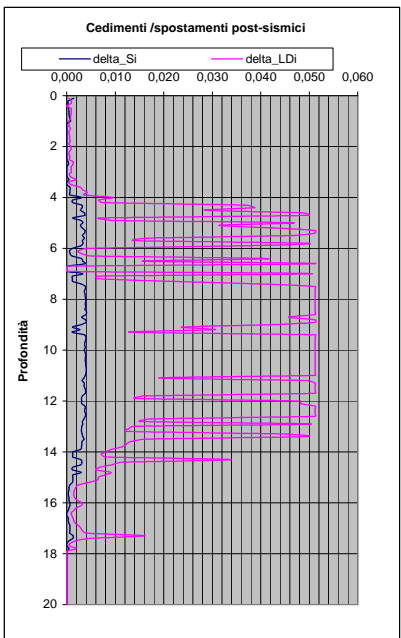
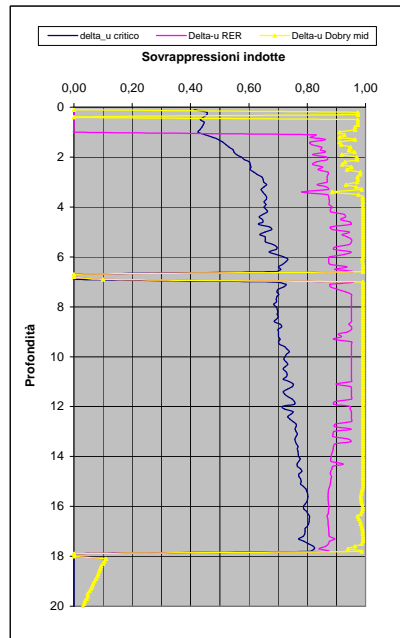
Soil Classification	Zone No.*	Range of CPT Index $I_c$ Values
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Gravelly Sands	7	$I_c < 1.31$

After Robertson and Wride (1998).  
\*Note: Zone number per Robertson SBT (1990).

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LEGENDA

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- K $\alpha$  = fatt. correttivo per sforzi di taglio (ad)
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- CRR = Cyclic Resistance Ratio (ad)
- P.L. = Probabilità di liquefazione (ad)
- IPL = Indice del potenziale di liquefazione (ad)
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- ev = vertical reconsolidation strain
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- Sr =  $S_r / \sigma'_{vc}$  resistenza residua - strati incoerenti (ad)
- Ruc =  $\Delta u / \sigma'_{vc}$  critico - stima sogliadi innesco fenomeni di instabilità/liquefazione
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- LDI = Lateral Displacement Index (mt)
- Dr = Densità relativa (ad)
- $\theta$  = angolo di attrito interno (deg)
- OCR = rapporto di sovraconsolidazione (sabbie e argille) (ad)
- St = coefficiente di sensitività delle argille (ad)
- LSN = Liquefaction Severity Number (ad)



IPL = 9,73

PL = 27,46

LDI = 3,839 Stot = 0,356 (mt)

LD = 0,00 (mt)

SLiq = 11,00 (mt)

LSN = 41,13 PG = 0,90

LSN Range	Expected ground surface damage
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\* Table based on Table 13.1 from I&T report: Liquefaction Vulnerability Study

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$0.1 < P_G \leq 0.3$	low
$P_G \leq 0.1$	extremely low to none

## **ALLEGATO N.2**

**"VERIFICHE DI CALCOLO DEL POTENZIALE DI LIQUEFACIBILITÀ CON  
MAGNITUDO MW = 6,14 "**



**GEOPROGET**

Studio di Geologia

via Ceccarini, 171 - Palazzo La Viola  
Riccione - 47838 - (RN) Tel/Fax 0541/606464

E-MAIL [vannoni.fabio1960@libero.it](mailto:vannoni.fabio1960@libero.it)  
[copicicarlo@libero.it](mailto:copicicarlo@libero.it)

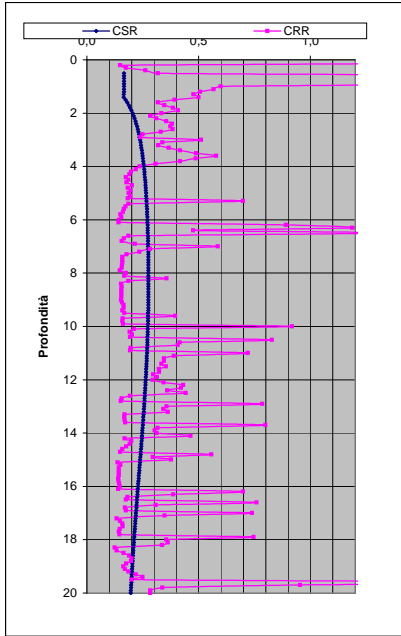
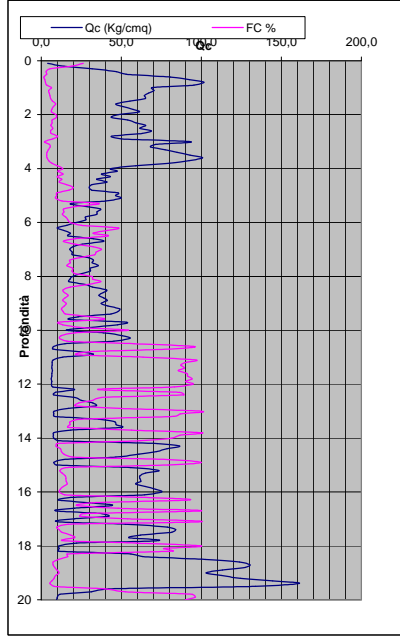
CPT-based liquefaction triggering analysis for a single sounding

Environmental parameters, soil classification, and various probability and susceptibility charts for liquefaction analysis.

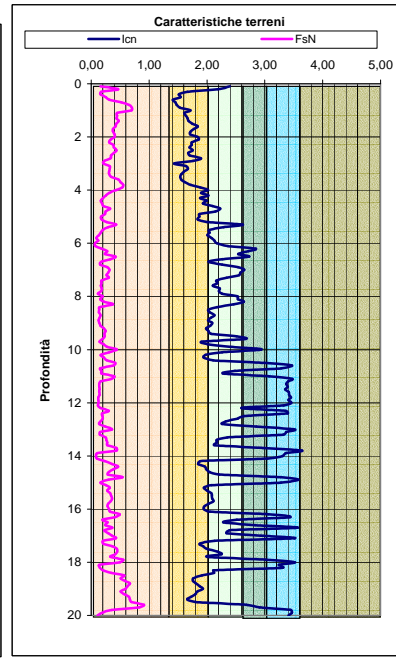
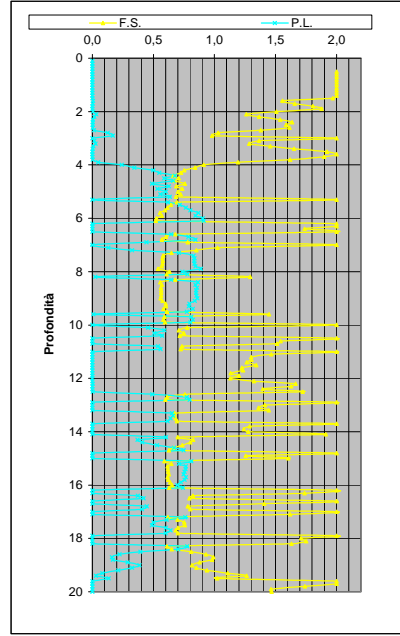
Table with columns for Depth (m), Soil Classification, and various geotechnical parameters like qc, q, F, Ic, etc.

Main data table containing 100 rows of sounding data with columns for depth, soil type, and various geotechnical and liquefaction parameters.

DIAGRAMMI DI RIFERIMENTO VERIFICA LIQUEFAZIONE - METODO R. & W. , 2009



PROVA CPT E 1



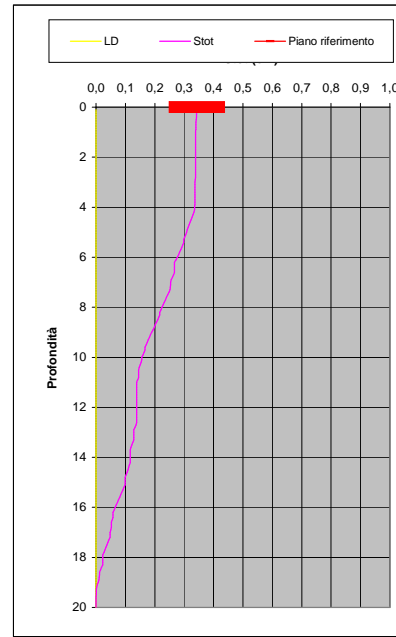
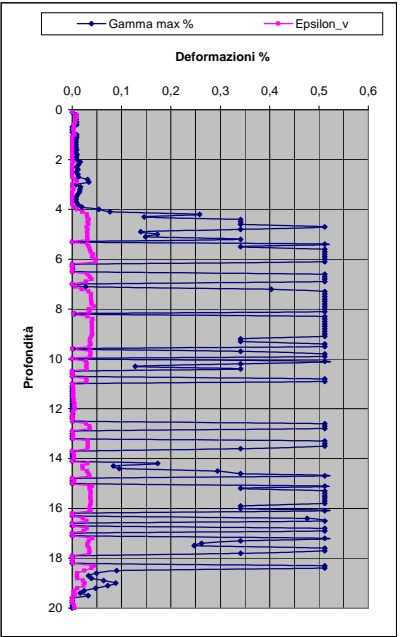
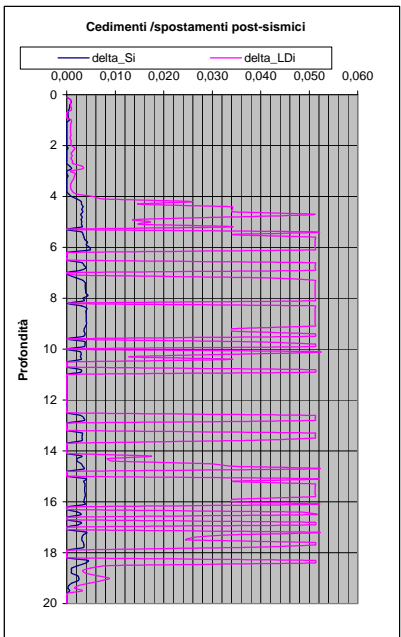
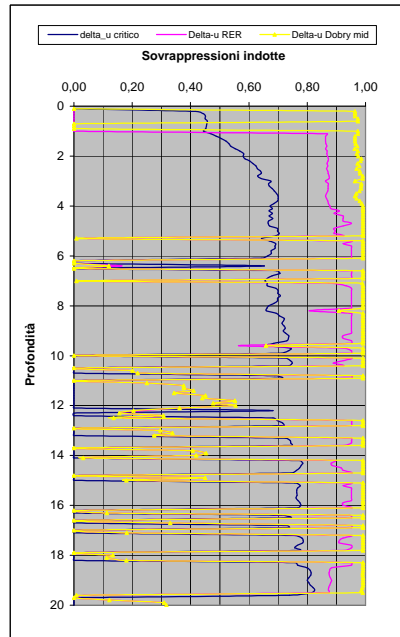
Soil Classification	Zone No.*	Range of CPT Index $I_c$ Values
Organic Clay Soils	2	$I_c > 3.60$
Clays	3	$2.95 < I_c < 3.60$
Silt Mixtures	4	$2.60 < I_c < 2.95$
Sand Mixtures	5	$2.05 < I_c < 2.60$
Sands	6	$1.31 < I_c < 2.05$
Gravelly Sands	7	$I_c < 1.31$

After Robertson and Wride (1998).  
\*Note: Zone number per Robertson SBT (1990).

- Argille - terreni organici
- Argille - argilla/argilla limosa
- Miscela di limi - limo argilloso/argilla limosa
- Miscela di sabbie - sabbia limosa/limo sabbioso
- Sabbie - sabbie pulite/sabbie limose
- sabbie ghiaiose / sabbie dense

LEGENDA

- Qc** = Res. alla penetraz. (Kg/cmq)
- FC** = Fine content - passante 0.074 mm (%)
- FsN** = Attrito laterale (Kg/cmq)
- F** = rapporto di frizione
- Qtn** = parametro di resist. alla punta normal.
- Icn** = Soil behaviour index normalized (ad)
- qc1N-cs** = Resist. alla pentrez. corretta all'FC e normalizzata
- $\xi$  = parametro di stato
- KH** = fatt. correttivo per spessore strato (ad)
- Rd** = stress reduction coefficient (ad)
- CN** = fattore di normalizzazione per carico litostatico (ad)
- K $\sigma$**  = fatt. correttivo per sovraccarico-profondità (ad)
- K $\alpha$**  = fatt. correttivo per sforzi di taglio (ad)
- MSF** = magnitudo scaling factor (ad)
- F.S.** = Fattore di sicurezza (CRR/CSR con correzioni) (ad)
- CSR** = Cyclic Stress ratio (ad)
- CRR** = Cyclic Resistance Ratio (ad)
- P.L.** = Probabilità di liquefazione (ad)
- IPL** = Indice del potenziale di liquefazione (ad)
- $\gamma_{max}$**  = deformazione di taglio massima indotta dal sisma (%)
- ev** = vertical reconsolidation strain
- $\Delta s_i$**  = cedimento i-esimo dello strato (mt)
- Su** =  $S_u / \sigma'_{vc}$  resistenza totale non drenata - strati coesivi (ad)
- Sur** =  $S_{ur} / \sigma'_{vc}$  resistenza totale residua non drenata - strati coesivi (ad)
- qc1N-sr** = Resist. alla pentrez. corretta all'FC e normalizzata
- Sr** =  $S_r / \sigma'_{vc}$  resistenza residua - strati incoerenti (ad)
- Ruc** =  $\Delta u / \sigma'_{vc}$  critico - stima sogliadi innesco fenomeni di instabilità/liquefazione
- $\Delta u$  RER =  $\Delta u / \sigma'_{vc}$  sovrappressioni circ. 112/2007 - tabella 2 R.E.R.
- $\Delta u$  Dobry M. =  $\Delta u / \sigma'_{vc}$  Dobry et al. 1984 "mean" x sabbie-Robertson '09 x argille
- $\Delta u$  Dobry L. =  $\Delta u / \sigma'_{vc}$  Dobry et al. 1984 "lower bound" x sabbie-Robertson '09 x argille
- $\Delta u$  Dobry U. =  $\Delta u / \sigma'_{vc}$  Dobry et al. 1984 "Upper bound" x sabbie-Robertson '09 x argille
- Stot** = Cedimento post-sismico totale (mt)
- LDI** = Lateral Displacement Index (mt)
- Dr** = Densità relativa (ad)
- $\theta$  = angolo di attrito interno (deg)
- OCR** = rapporto di sovraconsolidazione (sabbie e argille) (ad)
- St** = coefficiente di sensitività delle argille (ad)
- LSN** = Liquefaction Severity Number (ad)



LSN Range	Expected ground surface damage
0-10	Little to no expression of liquefaction, minor effects
10-20	Minor expression of liquefaction, some sand boils
20-30	Moderate expression of liquefaction, with some sand boils and structural damage
30-40	Moderate to severe expression of liquefaction, settlement can cause structural damage
40-50	Major expression of liquefaction, undulations and damage to ground surface, severe total and differential settlements of structures
>50	Severe damage, extensive evidence of liquefaction as surface, severe total and differential settlements affecting structures, damage to services.

\* Table based on Table 13.1 from I&T report: Liquefaction Vulnerability Study

Probability	Description of the risk of liquefaction-induced ground failure
$0.9 < P_G$	extremely high to absolutely certain
$0.7 < P_G \leq 0.9$	high
$0.3 < P_G \leq 0.7$	medium
$0.1 < P_G \leq 0.3$	low
$P_G \leq 0.1$	extremely low to none

IPL= 15,35

PL= 56,30

LDI = 4,101 Stot = 0,343 (mt)

LD = 0,00 (mt)

SLiq = 10,30 (mt)

LSN = 38,42 PG= 1,00

CPT-based liquefaction triggering analysis for a single sounding

Enviromenti: C Hill-H Plain-P Coast-C  
Behaviours: E Sand like-S

Computer constants:

ns: 2.0 (B\* 2007 - "Cefin" 2004 - "NCEER" - "Blake")  
msf: 0.0535 NCEER  
msf: 0.0535 NCEER  
msf: 0.0535 NCEER

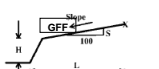
Probabilità e potenziale di liquefazione

Probabilità e suscettibilità di liquefazione

PL Overall Probability

Robertson & Wride, agg. 2009

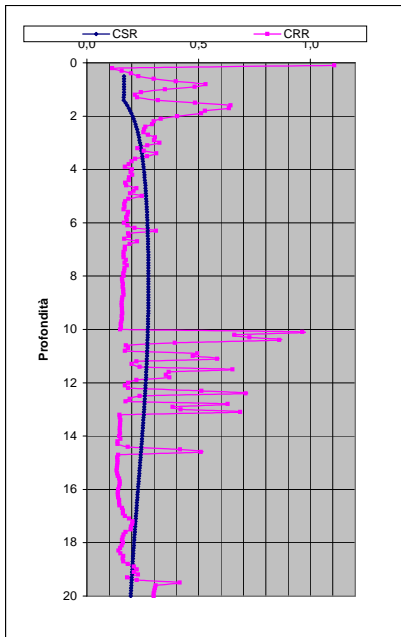
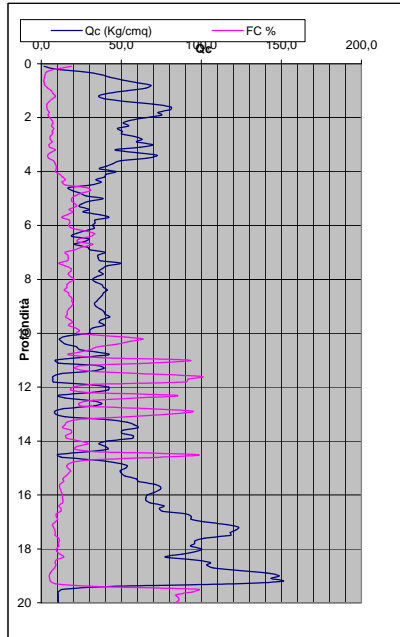
PROVA "CPTE 2"



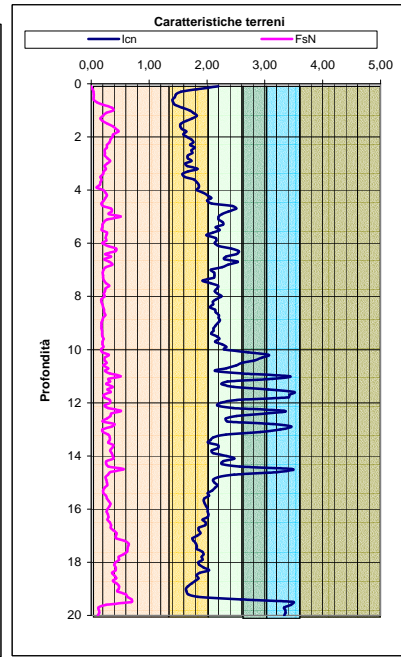
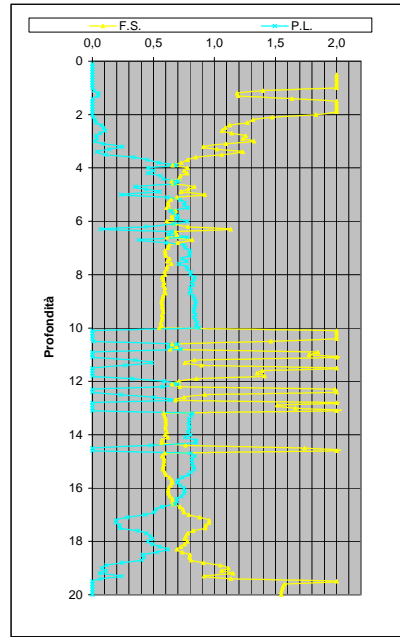
Potential flow failure if (N1) < 100 kPa and (q1/N) > 50  
No flow liquefaction if (q1/N) < 65

Main data table with columns for Depth (m), q1 (kPa), q1/N, q1/c, F, Ic, Ic/N, N1(60), n, Kc, Layer, Soil Type, and various probability and liquefaction parameters. The table includes a summary row at the top right with values like LDI = 5,441, Stot = 0,457, IPL = 19,61, PL = 76,54, LD = 0,00, PG = 1,00, SLiq = 13,4, LSN = 51,2.

DIAGRAMMI DI RIFERIMENTO VERIFICA LIQUEFAZIONE - METODO R. & W. , 2009



PROVA CPT2



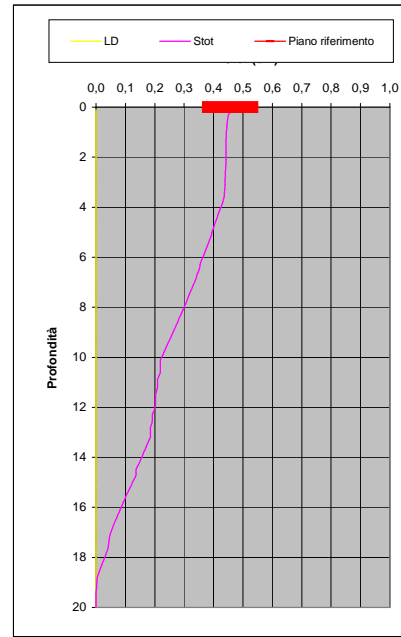
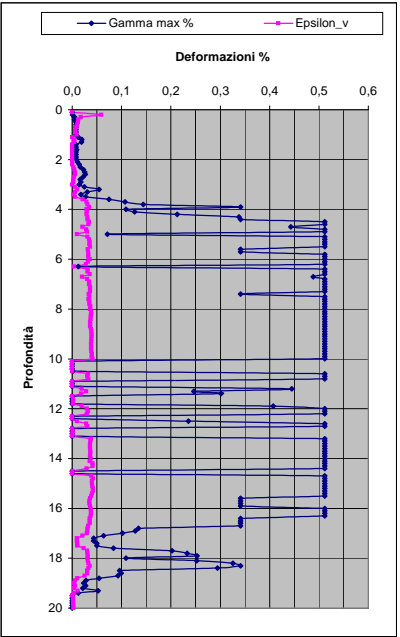
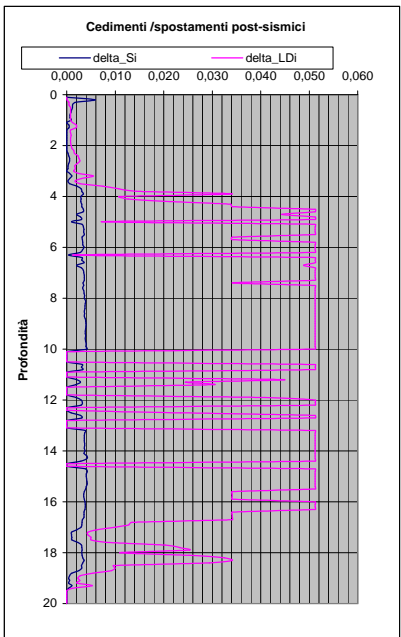
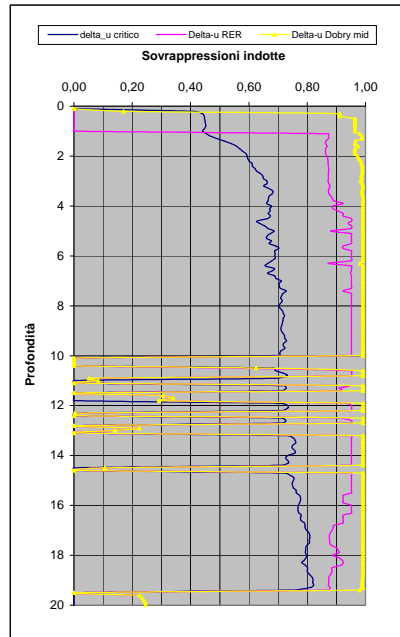
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- Ruc** =  $\Delta u / \sigma'_{vc}$  critico - stima sogliadi innesco fenomeni di instabilità/liquefazione
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$P_G \leq 0.1$	extremely low to none

IPL= 19,61

PL= 76,54

LDI = 5,441 Stot = 0,457 (mt)

LD = 0,00 (mt)

SLiq = 13,40 (mt)

LSN = 51,16 PG= 1,00

CPT-based liquefaction triggering analysis for a single sounding

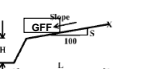
Enviroments: C Hill-H Plain-P Coast-C Behaviours: Sand like-S

Computer constants: no. n: 10, 32; MSF NEER: 1; Patm: 101,32; alpha (N): 0,35; beta: 0,35; gamma: 0,35; delta: 0,35; epsilon: 0,35; zeta: 0,35; eta: 0,35; theta: 0,35; iota: 0,35; kappa: 0,35; lambda: 0,35; mu: 0,35; nu: 0,35; xi: 0,35; omicron: 0,35; pi: 0,35; rho: 0,35; sigma: 0,35; tau: 0,35; upsilon: 0,35; phi: 0,35; chi: 0,35; psi: 0,35; omega: 0,35; A: 0,35; B: 0,35; C: 0,35; D: 0,35; E: 0,35; F: 0,35; G: 0,35; H: 0,35; I: 0,35; J: 0,35; K: 0,35; L: 0,35; M: 0,35; N: 0,35; O: 0,35; P: 0,35; Q: 0,35; R: 0,35; S: 0,35; T: 0,35; U: 0,35; V: 0,35; W: 0,35; X: 0,35; Y: 0,35; Z: 0,35; AA: 0,35; AB: 0,35; AC: 0,35; AD: 0,35; AE: 0,35; AF: 0,35; AG: 0,35; AH: 0,35; AI: 0,35; AJ: 0,35; AK: 0,35; AL: 0,35; AM: 0,35; AN: 0,35; AO: 0,35; AP: 0,35; AQ: 0,35; AR: 0,35; AS: 0,35; AT: 0,35; AU: 0,35; AV: 0,35; AW: 0,35; AX: 0,35; AY: 0,35; AZ: 0,35; BA: 0,35; BB: 0,35; BC: 0,35; BD: 0,35; BE: 0,35; BF: 0,35; BG: 0,35; BH: 0,35; BI: 0,35; BJ: 0,35; BK: 0,35; BL: 0,35; BM: 0,35; BN: 0,35; BO: 0,35; BP: 0,35; BQ: 0,35; BR: 0,35; BS: 0,35; BT: 0,35; BU: 0,35; BV: 0,35; BW: 0,35; BX: 0,35; BY: 0,35; BZ: 0,35; CA: 0,35; CB: 0,35; CC: 0,35; CD: 0,35; CE: 0,35; CF: 0,35; CG: 0,35; CH: 0,35; CI: 0,35; CJ: 0,35; CK: 0,35; CL: 0,35; CM: 0,35; CN: 0,35; CO: 0,35; CP: 0,35; CQ: 0,35; CR: 0,35; CS: 0,35; CT: 0,35; CU: 0,35; CV: 0,35; CW: 0,35; CX: 0,35; CY: 0,35; CZ: 0,35; DA: 0,35; DB: 0,35; DC: 0,35; DD: 0,35; DE: 0,35; DF: 0,35; DG: 0,35; DH: 0,35; DI: 0,35; DJ: 0,35; DK: 0,35; DL: 0,35; DM: 0,35; DN: 0,35; DO: 0,35; DP: 0,35; DQ: 0,35; DR: 0,35; DS: 0,35; DT: 0,35; DU: 0,35; DV: 0,35; DW: 0,35; DX: 0,35; DY: 0,35; DZ: 0,35; EA: 0,35; EB: 0,35; EC: 0,35; ED: 0,35; EE: 0,35; EF: 0,35; EG: 0,35; EH: 0,35; EI: 0,35; EJ: 0,35; EK: 0,35; EL: 0,35; EM: 0,35; EN: 0,35; EO: 0,35; EP: 0,35; EQ: 0,35; ER: 0,35; ES: 0,35; ET: 0,35; EU: 0,35; EV: 0,35; EW: 0,35; EX: 0,35; EY: 0,35; EZ: 0,35; FA: 0,35; FB: 0,35; FC: 0,35; FD: 0,35; FE: 0,35; FF: 0,35; FG: 0,35; FH: 0,35; FI: 0,35; FJ: 0,35; FK: 0,35; FL: 0,35; FM: 0,35; FN: 0,35; FO: 0,35; FP: 0,35; FQ: 0,35; FR: 0,35; FS: 0,35; FT: 0,35; FU: 0,35; FV: 0,35; FW: 0,35; FX: 0,35; FY: 0,35; FZ: 0,35; GA: 0,35; GB: 0,35; GC: 0,35; GD: 0,35; GE: 0,35; GF: 0,35; GG: 0,35; GH: 0,35; GI: 0,35; GJ: 0,35; GK: 0,35; GL: 0,35; GM: 0,35; GN: 0,35; GO: 0,35; GP: 0,35; GQ: 0,35; GR: 0,35; GS: 0,35; GT: 0,35; GU: 0,35; GV: 0,35; GW: 0,35; GX: 0,35; GY: 0,35; GZ: 0,35; HA: 0,35; HB: 0,35; HC: 0,35; HD: 0,35; HE: 0,35; HF: 0,35; HG: 0,35; HH: 0,35; HI: 0,35; HJ: 0,35; HK: 0,35; HL: 0,35; HM: 0,35; HN: 0,35; HO: 0,35; HP: 0,35; HQ: 0,35; HR: 0,35; HS: 0,35; HT: 0,35; HU: 0,35; HV: 0,35; HW: 0,35; HX: 0,35; HY: 0,35; HZ: 0,35; IA: 0,35; IB: 0,35; IC: 0,35; ID: 0,35; IE: 0,35; IF: 0,35; IG: 0,35; IH: 0,35; II: 0,35; IJ: 0,35; IK: 0,35; IL: 0,35; IM: 0,35; IN: 0,35; IO: 0,35; IP: 0,35; IQ: 0,35; IR: 0,35; IS: 0,35; IT: 0,35; IU: 0,35; IV: 0,35; IW: 0,35; IX: 0,35; IY: 0,35; IZ: 0,35; JA: 0,35; JB: 0,35; JC: 0,35; JD: 0,35; JE: 0,35; JF: 0,35; JG: 0,35; JH: 0,35; JI: 0,35; JJ: 0,35; JK: 0,35; JL: 0,35; JM: 0,35; JN: 0,35; JO: 0,35; JP: 0,35; JQ: 0,35; JR: 0,35; JS: 0,35; JT: 0,35; JU: 0,35; JV: 0,35; JW: 0,35; JX: 0,35; JY: 0,35; JZ: 0,35; KA: 0,35; KB: 0,35; KC: 0,35; KD: 0,35; KE: 0,35; KF: 0,35; KG: 0,35; KH: 0,35; KI: 0,35; KJ: 0,35; KK: 0,35; KL: 0,35; KM: 0,35; KN: 0,35; KO: 0,35; KP: 0,35; KQ: 0,35; KR: 0,35; KS: 0,35; KT: 0,35; KU: 0,35; KV: 0,35; KW: 0,35; KX: 0,35; KY: 0,35; KZ: 0,35; LA: 0,35; LB: 0,35; LC: 0,35; LD: 0,35; LE: 0,35; LF: 0,35; LG: 0,35; LH: 0,35; LI: 0,35; LJ: 0,35; LK: 0,35; LL: 0,35; LM: 0,35; LN: 0,35; LO: 0,35; LP: 0,35; LQ: 0,35; LR: 0,35; LS: 0,35; LT: 0,35; LU: 0,35; LV: 0,35; LW: 0,35; LX: 0,35; LY: 0,35; LZ: 0,35; MA: 0,35; MB: 0,35; MC: 0,35; MD: 0,35; ME: 0,35; MF: 0,35; MG: 0,35; MH: 0,35; MI: 0,35; MJ: 0,35; MK: 0,35; ML: 0,35; MN: 0,35; MO: 0,35; MP: 0,35; MQ: 0,35; MR: 0,35; MS: 0,35; MT: 0,35; MU: 0,35; MV: 0,35; MW: 0,35; MX: 0,35; MY: 0,35; MZ: 0,35; NA: 0,35; NB: 0,35; NC: 0,35; ND: 0,35; 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UY: 0,35; UZ: 0,35; VA: 0,35; VB: 0,35; VC: 0,35; VD: 0,35; VE: 0,35; VF: 0,35; VG: 0,35; VH: 0,35; VI: 0,35; VJ: 0,35; VK: 0,35; VL: 0,35; VM: 0,35; VN: 0,35; VO: 0,35; VP: 0,35; VQ: 0,35; VR: 0,35; VS: 0,35; VT: 0,35; VU: 0,35; VV: 0,35; VW: 0,35; VX: 0,35; VY: 0,35; VZ: 0,35; WA: 0,35; WB: 0,35; WC: 0,35; WD: 0,35; WE: 0,35; WF: 0,35; WG: 0,35; WH: 0,35; WI: 0,35; WJ: 0,35; WK: 0,35; WL: 0,35; WM: 0,35; WN: 0,35; WO: 0,35; WP: 0,35; WQ: 0,35; WR: 0,35; WS: 0,35; WT: 0,35; WU: 0,35; WV: 0,35; WW: 0,35; WX: 0,35; WY: 0,35; WZ: 0,35; XA: 0,35; XB: 0,35; XC: 0,35; XD: 0,35; XE: 0,35; XF: 0,35; XG: 0,35; XH: 0,35; XI: 0,35; XJ: 0,35; XK: 0,35; XL: 0,35; XM: 0,35; XN: 0,35; XO: 0,35; XP: 0,35; XQ: 0,35; XR: 0,35; XS: 0,35; XT: 0,35; XU: 0,35; XV: 0,35; XW: 0,35; XX: 0,35; XY: 0,35; XZ: 0,35; YA: 0,35; YB: 0,35; YC: 0,35; YD: 0,35; YE: 0,35; YF: 0,35; YG: 0,35; YH: 0,35; YI: 0,35; YJ: 0,35; YK: 0,35; YL: 0,35; YM: 0,35; YN: 0,35; YO: 0,35; YP: 0,35; YQ: 0,35; YR: 0,35; YS: 0,35; YT: 0,35; 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Probabilità e potenziale di liquefazione: Probabilità: 0,943; Pot di Liq: IPL-15; IPL: 15,62; Probabilità e suscettibilità di liquefazione: Probabilità: 0,943; Suscettibilità: Quasi certa; IPL: 15,62; FS=1,2

Robertson & Wride, agg. 2009

PROVA "CPTE 3"



Potential flow failure if (N) < 100-cv<10 and (q) < 100-cv<50. No flow liquefaction if (q) < 100-cv<65.

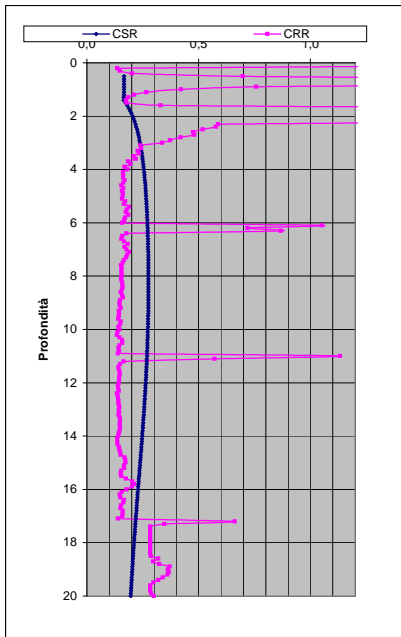
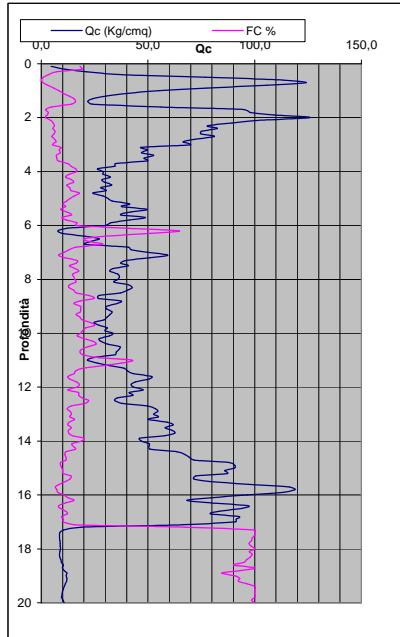
Table with 2 columns: L&N, L&N Expression. Values range from >50 to <10.

Main data table with columns: Depth (m), q (kPa), qc (kPa), F, Ic, N60, n, Kc, Layer, etc. Includes a summary row at the bottom: PROFONDITA' DI CALCOLO (mt da p.c.): 0,0; LDI = 5,638; Stot = 0,508; IPL = 25,15; PL = 91,62; LD = 0,00; PG = 1,00; SLiq = 13,9 (mt); LSN = 63,1.

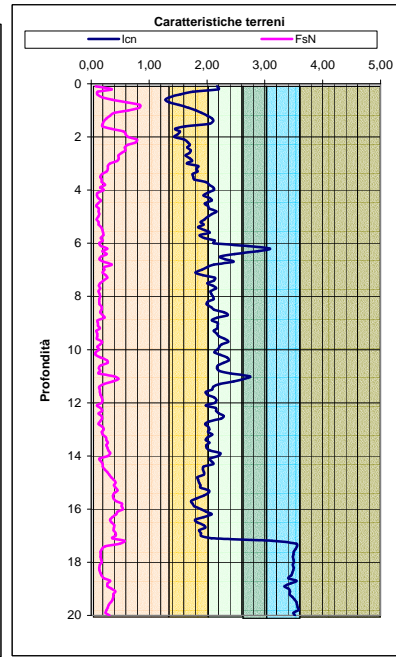
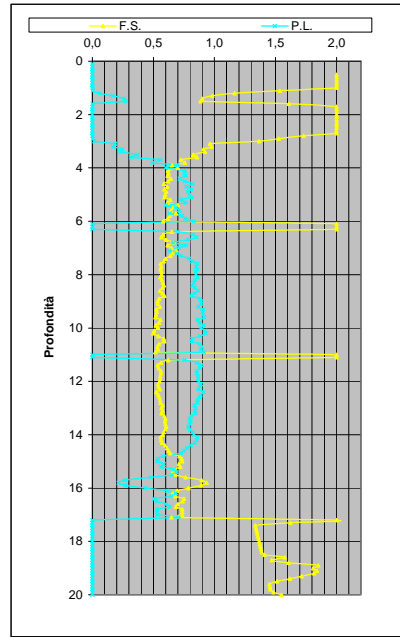
Main data table with columns: Depth (m), q (kPa), qc (kPa), F, Ic, N60, n, Kc, Layer, etc. This is the largest table containing the primary data for each depth interval.



DIAGRAMMI DI RIFERIMENTO VERIFICA LIQUEFAZIONE - METODO R. & W. , 2009



PROVA CPTE 3



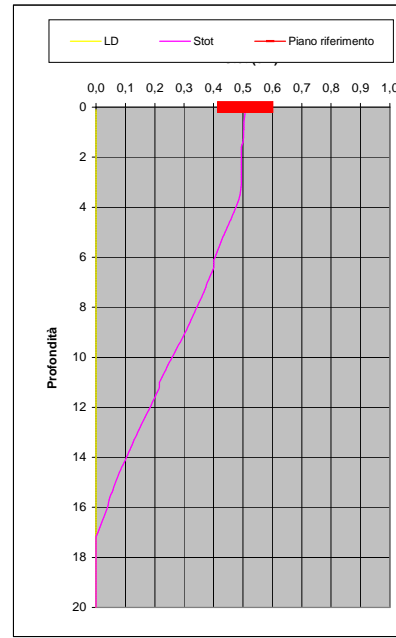
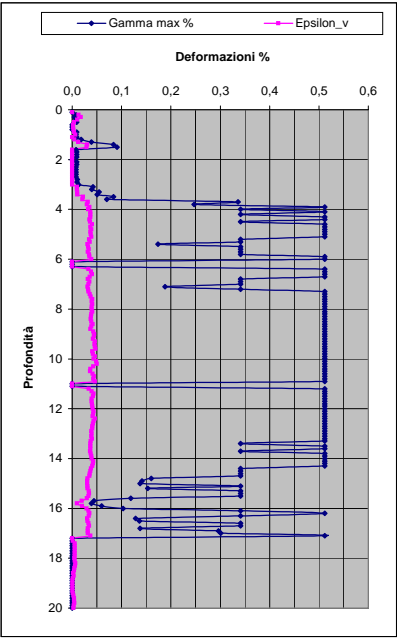
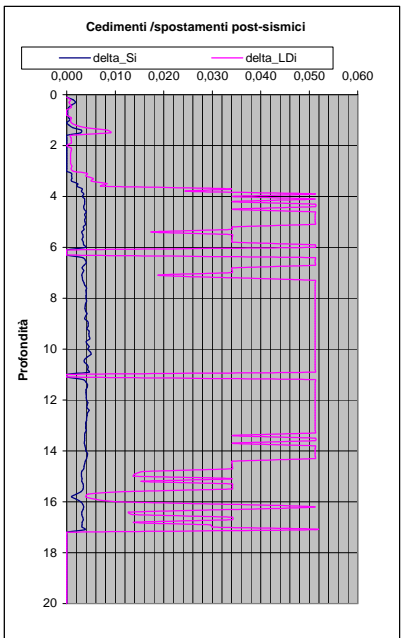
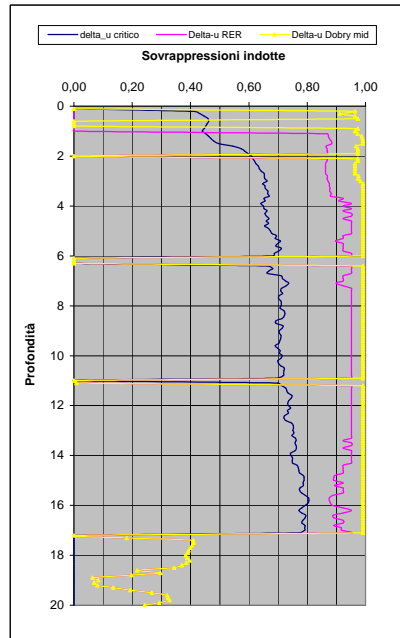
Soil Classification	Zone No.*	Range of CPT Index $I_c$ Values
Organic Clay Soils	2	$I_c > 3.60$
Clays	3	$2.95 < I_c < 3.60$
Silt Mixtures	4	$2.60 < I_c < 2.95$
Sand Mixtures	5	$2.05 < I_c < 2.60$
Sands	6	$1.31 < I_c < 2.05$
Gravelly Sands	7	$I_c < 1.31$

After Robertson and Wride (1998).  
\*Note: Zone number per Robertson SBT (1990).

- Argille - terreni organici
- Argille - argilla/argilla limosa
- Miscela di limi - limo argilloso/argilla limosa
- Miscela di sabbie - sabbia limosa/limo sabbioso
- Sabbie - sabbie pulite/sabbie limose
- sabbie ghiaiose / sabbie dense

LEGENDA

- Qc** = Res. alla penetraz. (Kg/cmq)
- FC** = Fine content - passante 0.074 mm (%)
- FsN** = Attrito laterale (Kg/cmq)
- F** = rapporto di frizione
- Qtn** = parametro di resist. alla punta normal.
- Icn** = Soil behaviour index normalized (ad)
- qc1N-cs** = Resist. alla pentrez. corretta all'FC e normalizzata
- $\xi$  = parametro di stato
- KH** = fatt. correttivo per spessore strato (ad)
- Rd** = stress reduction coefficient (ad)
- CN** = fattore di normalizzazione per carico litostatico (ad)
- K $\sigma$**  = fatt. correttivo per sovraccarico-profondità (ad)
- K $\alpha$**  = fatt. correttivo per sforzi di taglio (ad)
- MSF** = magnitudo scaling factor (ad)
- F.S.** = Fattore di sicurezza (CRR/CSR con correzioni) (ad)
- CSR** = Cyclic Stress ratio (ad)
- CRR** = Cyclic Resistance Ratio (ad)
- P.L.** = Probabilità di liquefazione (ad)
- IPL** = Indice del potenziale di liquefazione (ad)
- $\gamma_{max}$**  = deformazione di taglio massima indotta dal sisma (%)
- ev** = vertical reconsolidation strain
- $\Delta s_i$**  = cedimento i-esimo dello strato (mt)
- Su** =  $S_u / \sigma'_{vc}$  resistenza totale non drenata - strati coesivi (ad)
- Sur** =  $S_{ur} / \sigma'_{vc}$  resistenza totale residua non drenata - strati coesivi (ad)
- qc1N-sr** = Resist. alla pentrez. corretta all'FC e normalizzata
- Sr** =  $S_r / \sigma'_{vc}$  resistenza residua - strati incoerenti (ad)
- Ruc** =  $\Delta u / \sigma'_{vc}$  critico - stima sogliadi innesco fenomeni di instabilità/liquefazione
- $\Delta u$  RER =  $\Delta u / \sigma'_{vc}$  sovrappressioni circ. 112/2007 - tabella 2 R.E.R.
- $\Delta u$  Dobry M. =  $\Delta u / \sigma'_{vc}$  Dobry et al. 1984 "mean" x sabbie-Robertson '09 x argille
- $\Delta u$  Dobry L. =  $\Delta u / \sigma'_{vc}$  Dobry et al. 1984 "lower bound" x sabbie-Robertson '09 x argille
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- LDI** = Lateral Displacement Index (mt)
- Dr** = Densità relativa (ad)
- $\theta$  = angolo di attrito interno (deg)
- OCR** = rapporto di sovraconsolidazione (sabbie e argille) (ad)
- St** = coefficiente di sensitività delle argille (ad)
- LSN** = Liquefaction Severity Number (ad)



LSN Range	Expected ground surface damage
0-10	Little to no expression of liquefaction, minor effects
10-20	Minor expression of liquefaction, some sand boils
20-30	Moderate expression of liquefaction, with some sand boils and structural damage
30-40	Moderate to severe expression of liquefaction, settlement can cause structural damage
40-50	Major expression of liquefaction, undulations and damage to ground surface, severe total and differential settlements of structures
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\* Table based on Table 13.1 from I&T report: Liquefaction Vulnerability Study

Probability	Description of the risk of liquefaction-induced ground failure
$0.9 < P_G$	extremely high to absolutely certain
$0.7 < P_G \leq 0.9$	high
$0.3 < P_G \leq 0.7$	medium
$0.1 < P_G \leq 0.3$	low
$P_G \leq 0.1$	extremely low to none

IPL = 25,15      PL = 91,62

LDI = 5,638      Stot = 0,508 (mt)

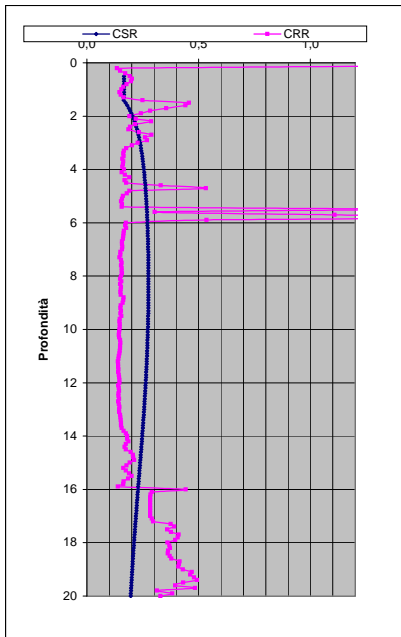
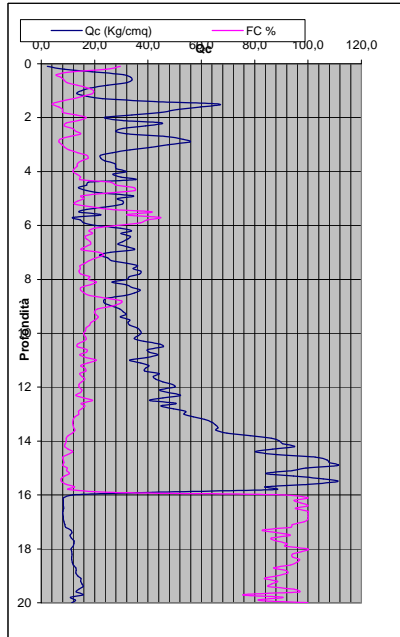
LD = 0,00 (mt)

SLiq = 13,90 (mt)

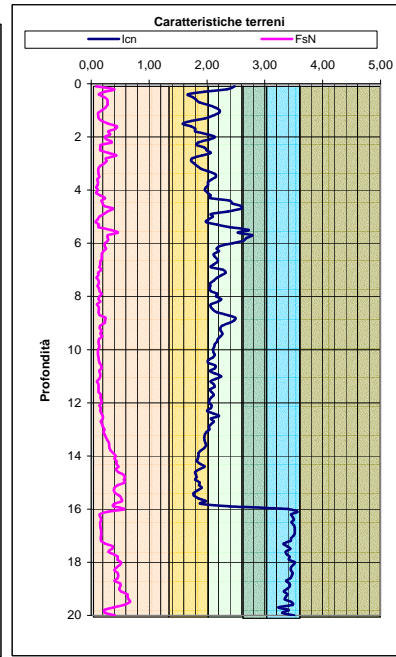
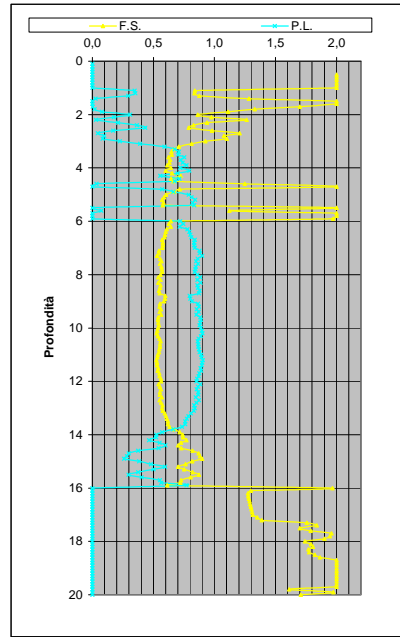
LSN = 63,12      PG = 1,00



DIAGRAMMI DI RIFERIMENTO VERIFICA LIQUEFAZIONE - METODO R. & W. , 2009



PROVA CPTE 4



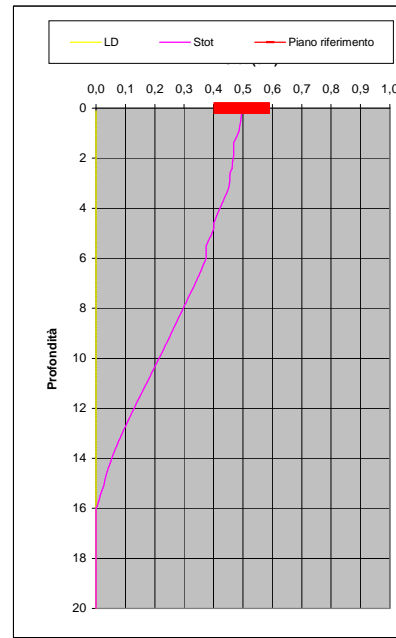
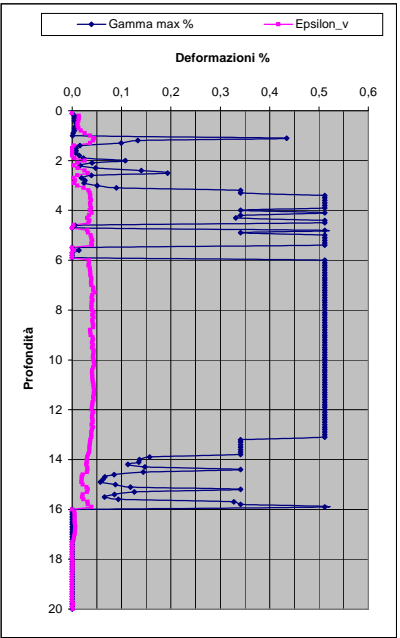
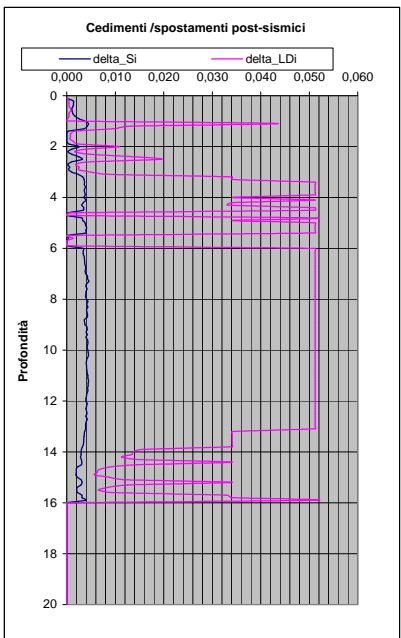
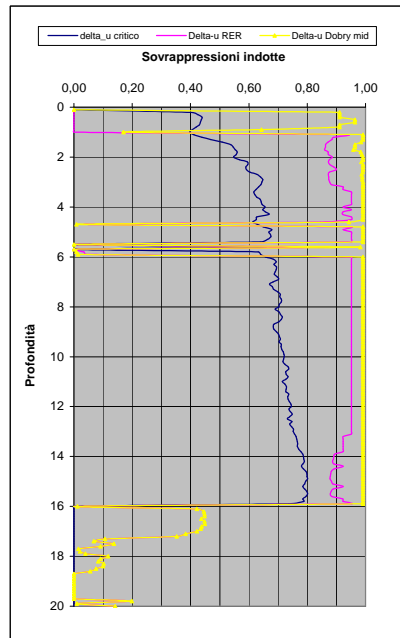
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After Robertson and Wride (1998).  
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$0.3 < P_G \leq 0.7$	medium
$0.1 < P_G \leq 0.3$	low
$P_G \leq 0.1$	extremely low to none

IPL = 25,74

PL = 92,55

LDI = 5,410 Stot = 0,496 (mt)

LD = 0,00 (mt)

SLiq = 13,20 (mt)

LSN = 73,54 PG = 1,00

CPT-based liquefaction triggering analysis for a single sounding

Environments: C Hill-H Plain-P Coast-C Behaviours: Sand like-S

Computer constants: no. n=350

soil classification: Sand-Clay-SC

Probabilità e potenziale di liquefazione

Probabilità e suscettibilità di liquefazione

PL Overall Probability

Robertson & Wride, agg. 2009

PROVA "CPTE 5"



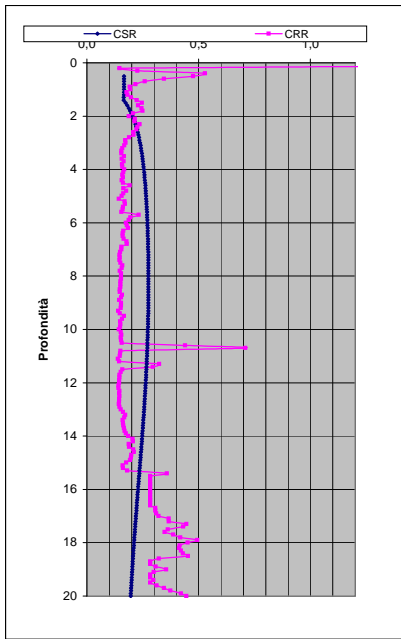
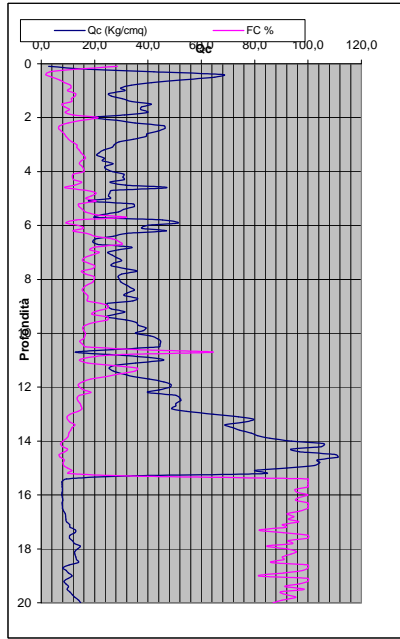
Potential flow failure (N) (kPa) < 10 and (q1N)/65 No flow liquefaction if (q1N)/65

Summary table with columns for input parameters (Peak ground accel, Earthquake magnitude, etc.), soil classification, computer constants, and various probability and liquefaction parameters.

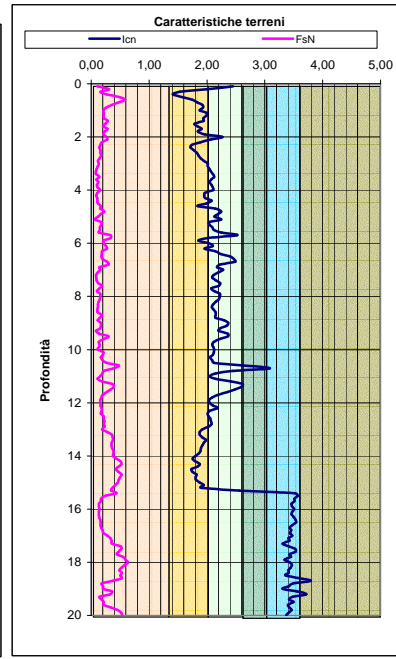
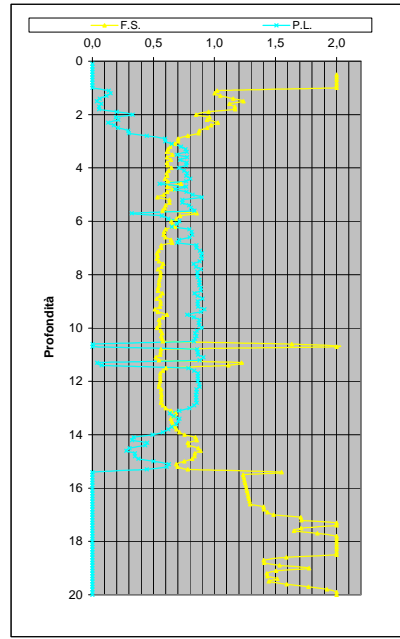
Table with columns for Depth (m), q1N (kPa), fs (kPa), etc., and a row for PROFONDITA' DI CALCOLO (mt da p.c.): 0,0

Main data table with columns for Depth (m), q1N (kPa), fs (kPa), and various soil parameters and liquefaction indices for each depth from 0.1 to 10.1 meters.

DIAGRAMMI DI RIFERIMENTO VERIFICA LIQUEFAZIONE - METODO R. & W. , 2009



PROVA CPT E 5



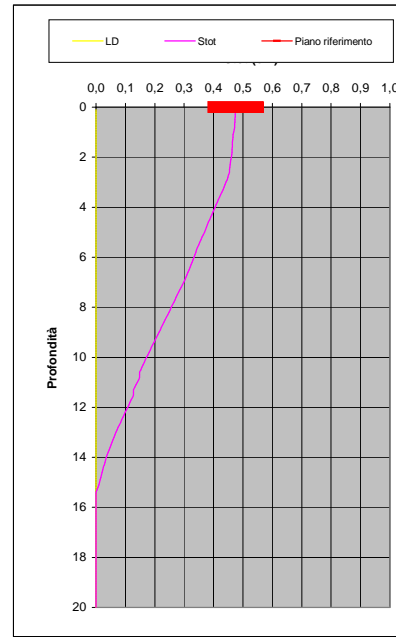
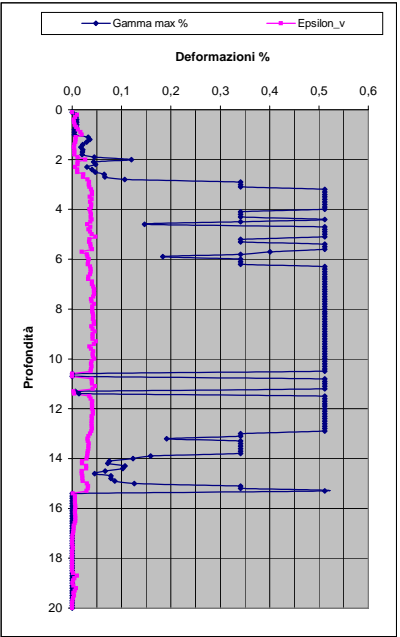
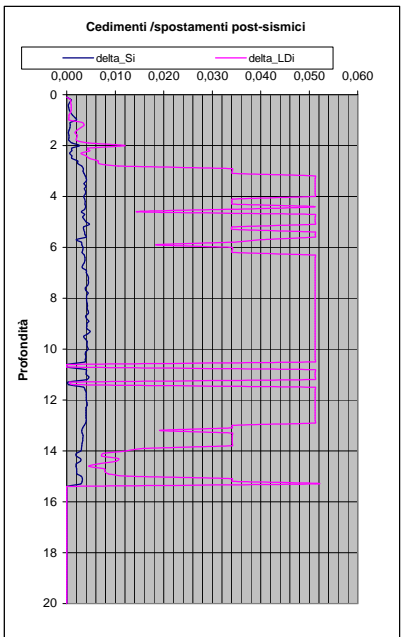
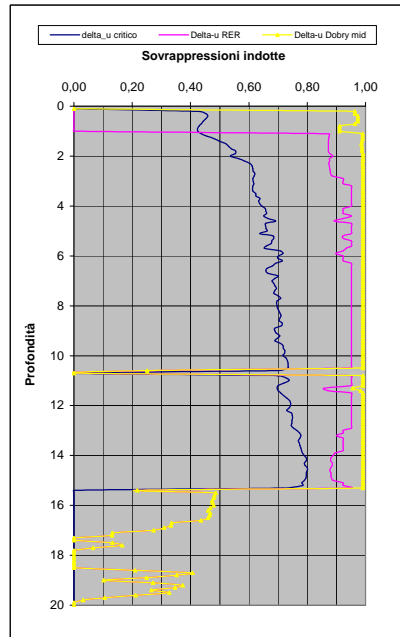
Soil Classification	Zone No.*	Range of CPT Index $I_c$ Values
Organic Clay Soils	2	$I_c > 3.60$
Clays	3	$2.95 < I_c < 3.60$
Silt Mixtures	4	$2.60 < I_c < 2.95$
Sand Mixtures	5	$2.05 < I_c < 2.60$
Sands	6	$1.31 < I_c < 2.05$
Gravelly Sands	7	$I_c < 1.31$

After Robertson and Wride (1998).  
\*Note: Zone number per Robertson SBT (1990).

- Argille - terreni organici
- Argille - argilla/argilla limosa
- Miscela di limi - limo argilloso/argilla limosa
- Miscela di sabbie - sabbia limosa/limo sabbioso
- Sabbie - sabbie pulite/sabbie limose
- sabbie ghiaiose / sabbie dense

LEGENDA

- Qc** = Res. alla penetraz. (Kg/cmq)
- FC** = Fine content - passante 0.074 mm (%)
- FsN** = Attrito laterale (Kg/cmq)
- F** = rapporto di frizione
- Qtn** = parametro di resist. alla punta normal.
- Icn** = Soil behaviour index normalized (ad)
- qc1N-cs** = Resist. alla pentrez. corretta all'FC e normalizzata
- $\xi$  = parametro di stato
- KH** = fatt. correttivo per spessore strato (ad)
- Rd** = stress reduction coefficient (ad)
- CN** = fattore di normalizzazione per carico litostatico (ad)
- K $\sigma$**  = fatt. correttivo per sovraccarico-profondità (ad)
- K $\alpha$**  = fatt. correttivo per sforzi di taglio (ad)
- MSF** = magnitudo scaling factor (ad)
- F.S.** = Fattore di sicurezza (CRR/CSR con correzioni) (ad)
- CSR** = Cyclic Stress ratio (ad)
- CRR** = Cyclic Resistance Ratio (ad)
- P.L.** = Probabilità di liquefazione (ad)
- IPL** = Indice del potenziale di liquefazione (ad)
- $\gamma_{max}$**  = deformazione di taglio massima indotta dal sisma (%)
- ev** = vertical reconsolidation strain
- $\Delta s_i$**  = cedimento -esimo dello strato (mt)
- Su** =  $S_u / \sigma'_{vc}$  resistenza totale non drenata - strati coesivi (ad)
- Sur** =  $S_{ur} / \sigma'_{vc}$  resistenza totale residua non drenata - strati coesivi (ad)
- qc1N-sr** = Resist. alla pentrez. corretta all'FC e normalizzata
- Sr** =  $S_r / \sigma'_{vc}$  resistenza residua - strati incoerenti (ad)
- Ruc** =  $\Delta u / \sigma'_{vc}$  critico - stima sogliadi innesco fenomeni di instabilità/liquefazione
- $\Delta u$  RER =  $\Delta u / \sigma'_{vc}$  sovrappressioni circ. 112/2007 - tabella 2 R.E.R.
- $\Delta u$  Dobry M. =  $\Delta u / \sigma'_{vc}$  Dobry et al. 1984 "mean" x sabbie-Robertson '09 x argille
- $\Delta u$  Dobry L. =  $\Delta u / \sigma'_{vc}$  Dobry et al. 1984 "lower bound" x sabbie-Robertson '09 x argille
- $\Delta u$  Dobry U. =  $\Delta u / \sigma'_{vc}$  Dobry et al. 1984 "Upper bound" x sabbie-Robertson '09 x argille
- Stot** = Cedimento post-sismico totale (mt)
- LDI** = Lateral Displacement Index (mt)
- Dr** = Densità relativa (ad)
- $\theta$  = angolo di attrito interno (deg)
- OCR** = rapporto di sovraconsolidazione (sabbie e argille) (ad)
- St** = coefficiente di sensitività delle argille (ad)
- LSN** = Liquefaction Severity Number (ad)



LSN Range	Expected ground surface damage
0-10	Little to no expression of liquefaction, minor effects
10-20	Minor expression of liquefaction, some sand boils
20-30	Moderate expression of liquefaction, with some sand boils and structural damage
30-40	Moderate to severe expression of liquefaction, settlement can cause structural damage
40-50	Major expression of liquefaction, undulations and damage to ground surface, severe total and differential settlements of structures
>50	Severe damage, extensive evidence of liquefaction as surface, severe total and differential settlements affecting structures, damage to services.

\* Table based on Table 13.1 from I&T report: Liquefaction Vulnerability Study

Probability	Description of the risk of liquefaction-induced ground failure
$0.9 < P_G$	extremely high to absolutely certain
$0.7 < P_G \leq 0.9$	high
$0.3 < P_G \leq 0.7$	medium
$0.1 < P_G \leq 0.3$	low
$P_G \leq 0.1$	extremely low to none

IPL = 26,59

PL = 93,73

LDI = 5,276 Stot = 0,475 (mt)

LD = 0,00 (mt)

SLiq = 13,00 (mt)

LSN = 71,26 PG = 1,00

CPT-based liquefaction triggering analysis for a single sounding

Enviromenti: C Hill-H Plain-P Coast-C Behaviours: Sand like-S

Computer constants: no. n=10, N=101.32, Patm=101.32, cov=0.35-35%, kDR=350, MSF=NECEER, alpha(N)=1, beta=1.2, gamma=1.2, delta=1.2, epsilon=1.2, zeta=1.2, eta=1.2, theta=1.2, iota=1.2, kappa=1.2, lambda=1.2, mu=1.2, nu=1.2, xi=1.2, omicron=1.2, pi=1.2, rho=1.2, sigma=1.2, tau=1.2, upsilon=1.2, phi=1.2, chi=1.2, psi=1.2, omega=1.2, A=1.2, B=1.2, C=1.2, D=1.2, E=1.2, F=1.2, G=1.2, H=1.2, I=1.2, J=1.2, K=1.2, L=1.2, M=1.2, N=1.2, O=1.2, P=1.2, Q=1.2, R=1.2, S=1.2, T=1.2, U=1.2, V=1.2, W=1.2, X=1.2, Y=1.2, Z=1.2

Probabilità e potenziale di liquefazione

Probabilità e suscettibilità di liquefazione

PL Overall Probability

Robertson & Wride, agg. 2009

PROVA "CPTE 6"



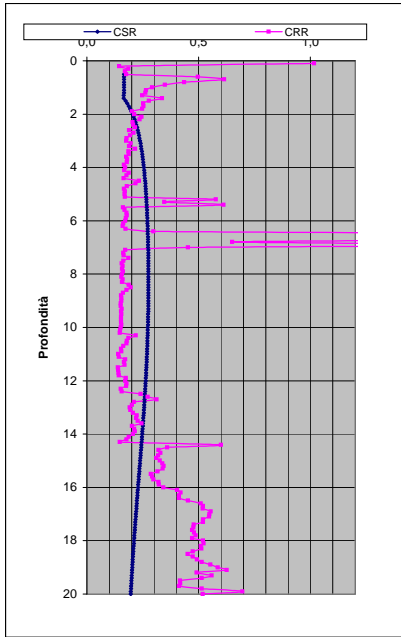
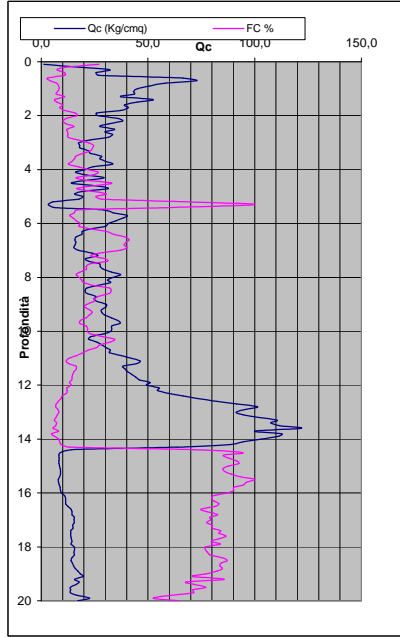
Potential flow failure if (N) < 100-cv<10 and (q) < 100-cv<10. No flow liquefaction if (q) < 100-cv<65.

Table with columns for input parameters (Peak ground accel, Earthquake magnitude, Water table depth, etc.), soil classification, and various geotechnical parameters (Q, Qn, F, Ic, etc.).

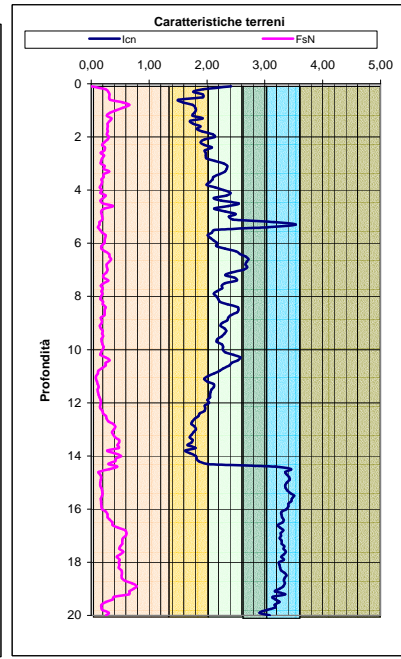
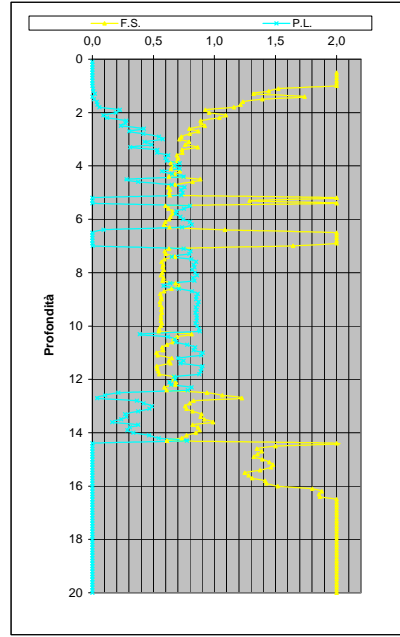
Summary table with columns: PROFONDITA' DI CALCOLO (mt da p.c.), LDI = 4,366, Stot = 0,368 (mt), IPL = 20,64, PL = 80,33, LD = 0,00 (mt), PG = 1,00, SLiq = 11,1 (mt), LSN = 55,8.

Main data table with columns: Depth (m), q (kPa), qn (kPa), F (kPa), Ic, N1(60), n, Kc, Layer, etc. Each row represents a depth interval with associated soil properties and calculated values.

DIAGRAMMI DI RIFERIMENTO VERIFICA LIQUEFAZIONE - METODO R. & W. , 2009



PROVA CPT E 6



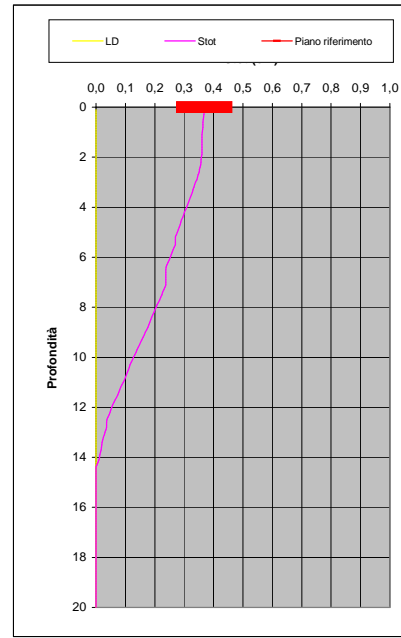
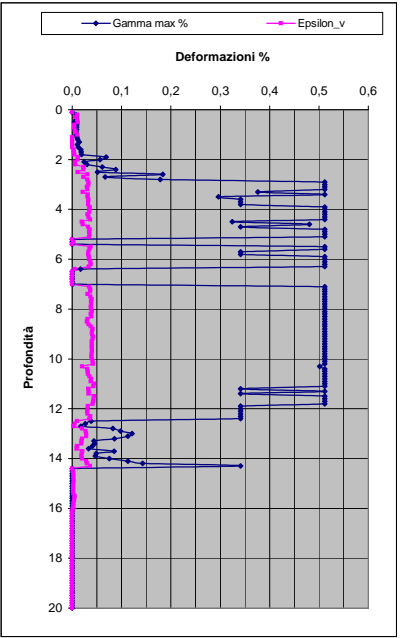
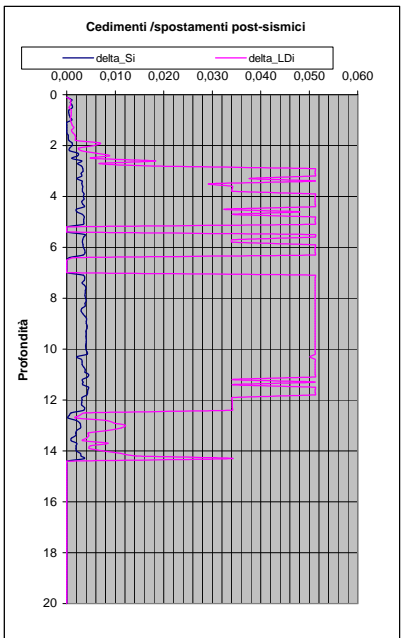
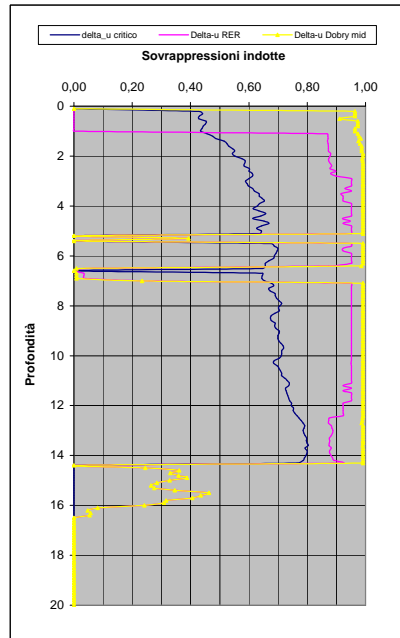
Soil Classification	Zone No.*	Range of CPT Index $I_c$ Values
Organic Clay Soils	2	$I_c > 3.60$
Clays	3	$2.95 < I_c < 3.60$
Silt Mixtures	4	$2.60 < I_c < 2.95$
Sand Mixtures	5	$2.05 < I_c < 2.60$
Sands	6	$1.31 < I_c < 2.05$
Gravelly Sands	7	$I_c < 1.31$

After Robertson and Wride (1998).  
\*Note: Zone number per Robertson SBT (1990).

- Argille - terreni organici
- Argille - argilla/argilla limosa
- Miscela di limi - limo argilloso/argilla limosa
- Miscela di sabbie - sabbia limosa/limo sabbioso
- Sabbie - sabbie pulite/sabbie limose
- sabbie ghiaiose / sabbie dense

LEGENDA

- Qc** = Res. alla penetraz. (Kg/cmq)
- FC** = Fine content - passante 0.074 mm (%)
- FsN** = Attrito laterale (Kg/cmq)
- F** = rapporto di frizione
- qtn** = parametro di resist. alla punta normal.
- Icn** = Soil behaviour index normalized (ad)
- qc1N-cs** = Resist. alla pentrez. corretta all'FC e normalizzata
- $\xi$  = parametro di stato
- KH** = fatt. correttivo per spessore strato (ad)
- Rd** = stress reduction coefficient (ad)
- CN** = fattore di normalizzazione per carico litostatico (ad)
- K $\sigma$**  = fatt. correttivo per sovraccarico-profondità (ad)
- K $\alpha$**  = fatt. correttivo per sforzi di taglio (ad)
- MSF** = magnitudo scaling factor (ad)
- F.S.** = Fattore di sicurezza (CRR/CSR con correzioni) (ad)
- CSR** = Cyclic Stress ratio (ad)
- CRR** = Cyclic Resistance Ratio (ad)
- P.L.** = Probabilità di liquefazione (ad)
- IPL** = Indice del potenziale di liquefazione (ad)
- $\gamma_{max}$**  = deformazione di taglio massima indotta dal sisma (%)
- ev** = vertical reconsolidation strain
- $\Delta s_i$**  = cedimento -esimo dello strato (mt)
- Su** =  $S_u / \sigma'_{vc}$  resistenza totale non drenata - strati coesivi (ad)
- Sur** =  $S_{ur} / \sigma'_{vc}$  resistenza totale residua non drenata - strati coesivi (ad)
- qc1N-sr** = Resist. alla pentrez. corretta all'FC e normalizzata
- Sr** =  $S_r / \sigma'_{vc}$  resistenza residua - strati incoerenti (ad)
- Ruc** =  $\Delta u / \sigma'_{vc}$  critico - stima sogliadi innesco fenomeni di instabilità/liquefazione
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- $\Delta u$  Dobry M. =  $\Delta u / \sigma'_{vc}$  Dobry et al. 1984 "mean" x sabbie-Robertson '09 x argille
- $\Delta u$  Dobry L. =  $\Delta u / \sigma'_{vc}$  Dobry et al. 1984 "lower bound" x sabbie-Robertson '09 x argille
- $\Delta u$  Dobry U. =  $\Delta u / \sigma'_{vc}$  Dobry et al. 1984 "Upper bound" x sabbie-Robertson '09 x argille
- Stot** = Cedimento post-sismico totale (mt)
- LDI** = Lateral Displacement Index (mt)
- Dr** = Densità relativa (ad)
- $\phi$  = angolo di attrito interno (deg)
- OCR** = rapporto di sovraconsolidazione (sabbie e argille) (ad)
- St** = coefficiente di sensitività delle argille (ad)
- LSN** = Liquefaction Severity Number (ad)



IPL= 20,64      PL= 80,33      LDI = 4,366      Stot = 0,368 (mt)      LD = 0,00 (mt)      SLiq = 11,10 (mt)      LSN = 55,80      PG= 1,00

LSN Range	Expected ground surface damage
0-10	Little to no expression of liquefaction, minor effects
10-20	Minor expression of liquefaction, some sand boils
20-30	Moderate expression of liquefaction, with some sand boils and structural damage
30-40	Moderate to severe expression of liquefaction, settlement can cause structural damage
40-50	Major expression of liquefaction, undulations and damage to ground surface, severe total and differential settlements of structures
>50	Severe damage, extensive evidence of liquefaction as surface, severe total and differential settlements affecting structures, damage to services.

\* Table based on Table 13.1 from I&T report: Liquefaction Vulnerability Study

Probability	Description of the risk of liquefaction-induced ground failure
$0.9 < P_G$	extremely high to absolutely certain
$0.7 < P_G \leq 0.9$	high
$0.3 < P_G \leq 0.7$	medium
$0.1 < P_G \leq 0.3$	low
$P_G \leq 0.1$	extremely low to none

CPT-based liquefaction triggering analysis for a single sounding

Input parameters table including Peak ground accel (g), Earthquake magnitude (M), Water table depth (m), Average above water table (N60)30, Average below water table (N60)30, and Equipment (CPT-CPT1).

Environments: Hill-H Plain-P Coast-C. Behaviours: Sand-like-S.

Soil Classification table with columns for Soil Classification, Zone No., Range of CPT Index / Values, and Soil Name.

Computer constants: (B' 2007 - Cref' 2004 - NCEER - Blake)

Computer constants table with parameters like alpha (N) = 0.35, Patm = 101.32, and various stress ratios.

Probabilità e potenziale di liquefazione

Table for Probabilità e potenziale di liquefazione with columns for Probabilità, Pot di Liq, and IPL.

Probabilità e suscettibilità di liquefazione

Table for Probabilità e suscettibilità di liquefazione with columns for Probabilità, Suscettibilità, and FS>1.2.

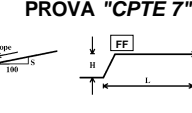
PL Overall Probability

Table for PL Overall Probability with columns for Risk lev., IPL, and PL.

Robertson & Wride, agg. 2009

Table for Robertson & Wride parameters including PL, PL54, and PL52.

PROVA "CPTE 7"



DISPLACEMENT PARAMETERS and other test parameters.

Table for DISPLACEMENT PARAMETERS with columns for LSN, LSN Expression, and Severe Damage.

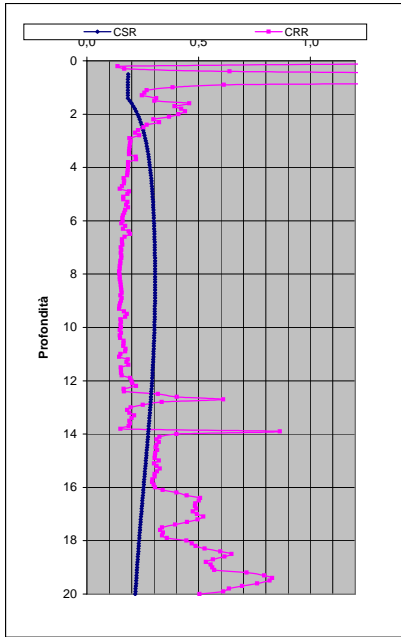
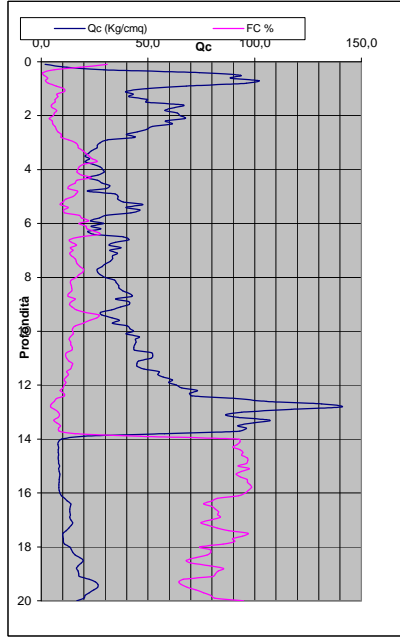
Main data table header with columns for Depth (m), q (kPa), qc (kPa), fs (kPa), and various soil strength and liquefaction parameters.

PROFONDITA' DI CALCOLO (mt da p.c.): 0,0 | LDI = 4,501 | Stot = 0,393 (mt) | IPL = 26,85 | PL = 94,06 | LD = 0,00 (mt) | PG = 1,00 | SLiq = 11,0 (mt) | LSN = 58,3

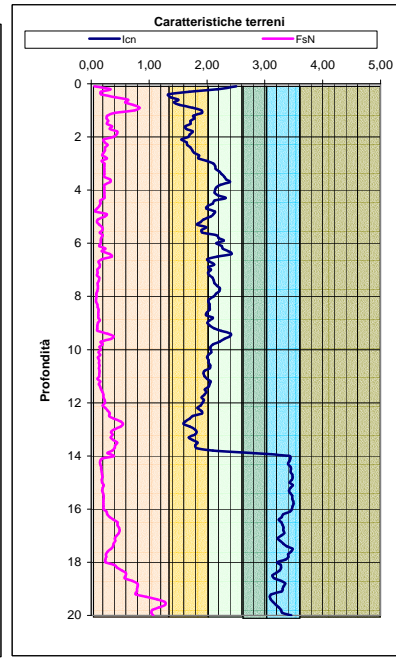
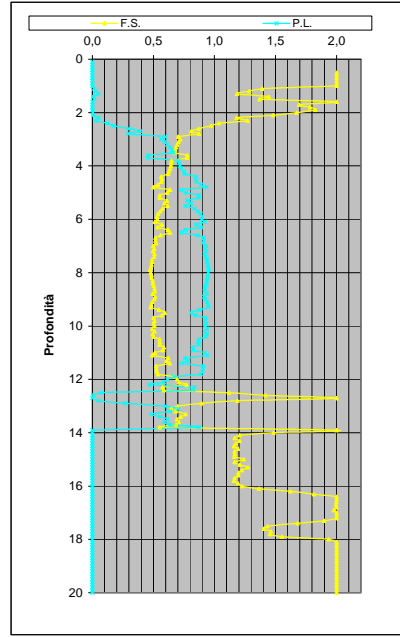
Main data table body containing 101 rows of soil test data, including depth, cone resistance, sleeve friction, and calculated liquefaction parameters.



DIAGRAMMI DI RIFERIMENTO VERIFICA LIQUEFAZIONE - METODO R. & W. , 2009



PROVA CPTE 7



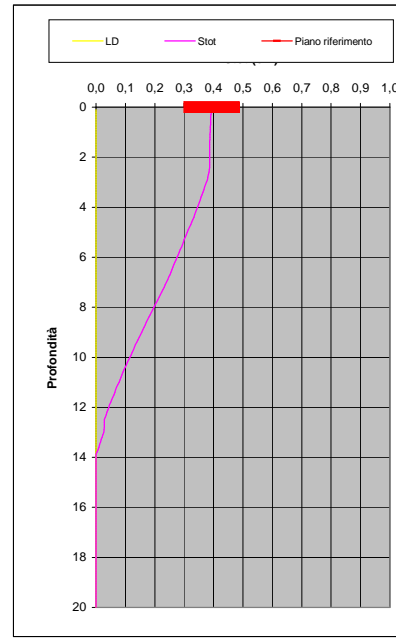
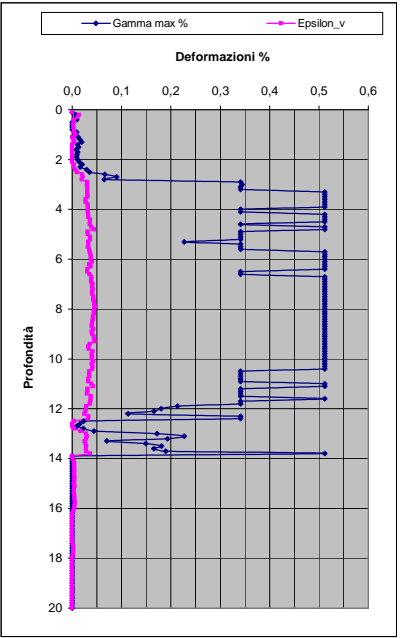
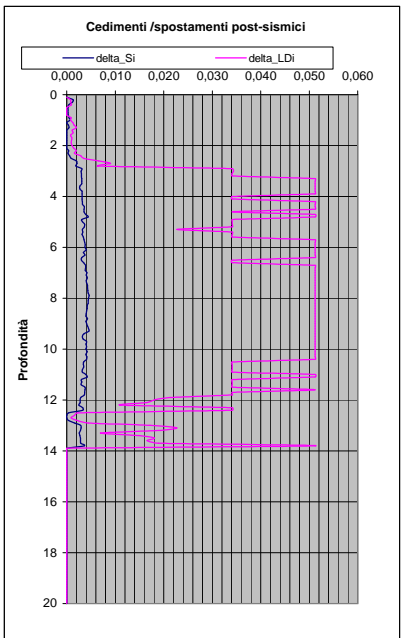
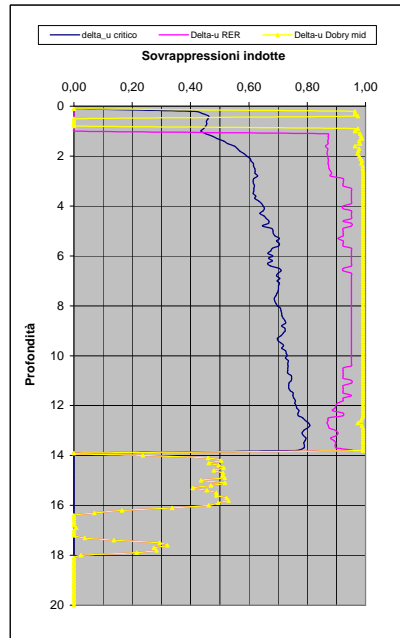
Soil Classification	Zone No.*	Range of CPT Index $I_c$ Values
Organic Clay Soils	2	$I_c > 3.60$
Clays	3	$2.95 < I_c < 3.60$
Silt Mixtures	4	$2.60 < I_c < 2.95$
Sand Mixtures	5	$2.05 < I_c < 2.60$
Sands	6	$1.31 < I_c < 2.05$
Gravelly Sands	7	$I_c < 1.31$

After Robertson and Wride (1998).  
\*Note: Zone number per Robertson SBT (1990).

- Argille - terreni organici
- Argille - argilla/argilla limosa
- Miscela di limi - limo argilloso/argilla limosa
- Miscela di sabbie - sabbia limosa/limo sabbioso
- Sabbie - sabbie pulite/sabbie limose
- sabbie ghiaiose / sabbie dense

LEGENDA

- Qc** = Res. alla penetraz. (Kg/cmq)
- FC** = Fine content - passante 0.074 mm (%)
- FsN** = Attrito laterale (Kg/cmq)
- F** = rapporto di frizione
- Qtn** = parametro di resist. alla punta normal.
- Icn** = Soil behaviour index normalized (ad)
- qc1N-cs** = Resist. alla pentrez. corretta all'FC e normalizzata
- $\xi$  = parametro di stato
- KH** = fatt. correttivo per spessore strato (ad)
- Rd** = stress reduction coefficient (ad)
- CN** = fattore di normalizzazione per carico litostatico (ad)
- K $\sigma$**  = fatt. correttivo per sovraccarico-profondità (ad)
- K $\alpha$**  = fatt. correttivo per sforzi di taglio (ad)
- MSF** = magnitudo scaling factor (ad)
- F.S.** = Fattore di sicurezza (CRR/CSR con correzioni) (ad)
- CSR** = Cyclic Stress ratio (ad)
- CRR** = Cyclic Resistance Ratio (ad)
- P.L.** = Probabilità di liquefazione (ad)
- IPL** = Indice del potenziale di liquefazione (ad)
- $\gamma_{max}$**  = deformazione di taglio massima indotta dal sisma (%)
- ev** = vertical reconsolidation strain
- $\Delta s_i$**  = cedimento i-esimo dello strato (mt)
- Su** =  $S_u / \sigma'_{vc}$  resistenza totale non drenata - strati coesivi (ad)
- Sur** =  $S_{ur} / \sigma'_{vc}$  resistenza totale residua non drenata - strati coesivi (ad)
- qc1N-sr** = Resist. alla pentrez. corretta all'FC e normalizzata
- Sr** =  $S_r / \sigma'_{vc}$  resistenza residua - strati incoerenti (ad)
- Ruc** =  $\Delta u / \sigma'_{vc}$  critico - stima sogliadi innesco fenomeni di instabilità/liquefazione
- $\Delta u$  RER =  $\Delta u / \sigma'_{vc}$  sovrappressioni circ. 112/2007 - tabella 2 R.E.R.
- $\Delta u$  Dobry M. =  $\Delta u / \sigma'_{vc}$  Dobry et al. 1984 "mean" x sabbie-Robertson '09 x argille
- $\Delta u$  Dobry L. =  $\Delta u / \sigma'_{vc}$  Dobry et al. 1984 "lower bound" x sabbie-Robertson '09 x argille
- $\Delta u$  Dobry U. =  $\Delta u / \sigma'_{vc}$  Dobry et al. 1984 "Upper bound" x sabbie-Robertson '09 x argille
- Stot** = Cedimento post-sismico totale (mt)
- LDI** = Lateral Displacement Index (mt)
- Dr** = Densità relativa (ad)
- $\theta$  = angolo di attrito interno (deg)
- OCR** = rapporto di sovraconsolidazione (sabbie e argille) (ad)
- St** = coefficiente di sensitività delle argille (ad)
- LSN** = Liquefaction Severity Number (ad)



IPL = 26,85

PL = 94,06

LDI = 4,501 Stot = 0,393 (mt)

LD = 0,00 (mt)

SLiq = 11,00 (mt)

LSN = 58,35 PG = 1,00

LSN Range	Expected ground surface damage
0-10	Little to no expression of liquefaction, minor effects
10-20	Minor expression of liquefaction, some sand boils
20-30	Moderate expression of liquefaction, with some sand boils and structural damage
30-40	Moderate to severe expression of liquefaction, settlement can cause structural damage
40-50	Major expression of liquefaction, undulations and damage to ground surface, severe total and differential settlements of structures
>50	Severe damage, extensive evidence of liquefaction at surface, severe total and differential settlements affecting structures, damage to services.

\* Table based on Table 13.1 from I&T report: Liquefaction Vulnerability Study

Probability	Description of the risk of liquefaction-induced ground failure
$0.9 < P_G$	extremely high to absolutely certain
$0.7 < P_G \leq 0.9$	high
$0.3 < P_G \leq 0.7$	medium
$0.1 < P_G \leq 0.3$	low
$P_G \leq 0.1$	extremely low to none

CPT-based liquefaction triggering analysis for a single sounding

Environment: Hill-H Plain-P Coast-C  
Behaviours: Sand like-S

Computer constants: α (N) = 1.0, N = 101.32, Patm = 101.32, MSF NCEER = 0.0337, MSF NEER = 0.0337

Probabilità e potenziale di liquefazione

Probabilità e suscettibilità di liquefazione

PL Overall Probability

Robertson & Wride, agg. 2009

PROVA "CPTE 8"



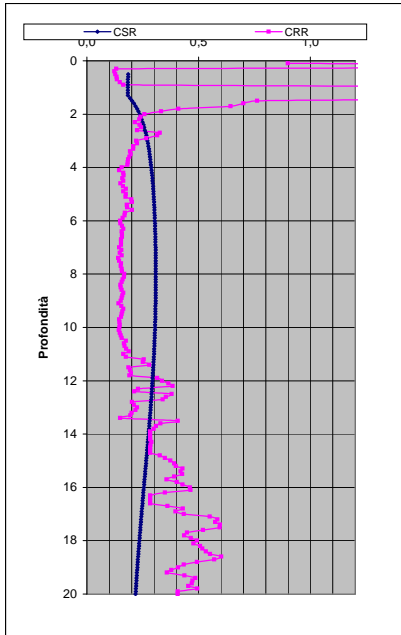
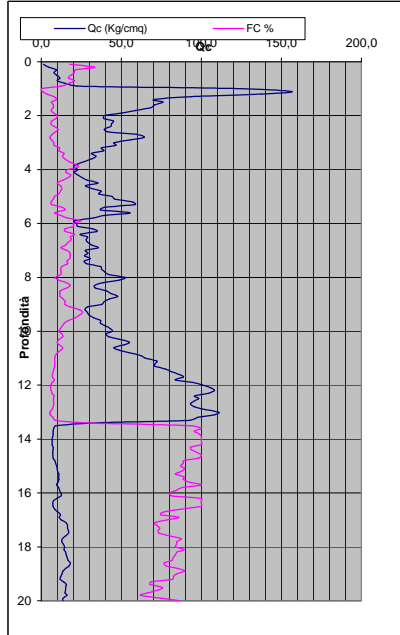
Table with 2 columns: LsN, LsN Expression. Values range from >50 to 0-10.

Table with 30 columns: Depth (m), q (kPa), qc (kPa), fs (kPa), etc. Includes various soil parameters and calculated values.

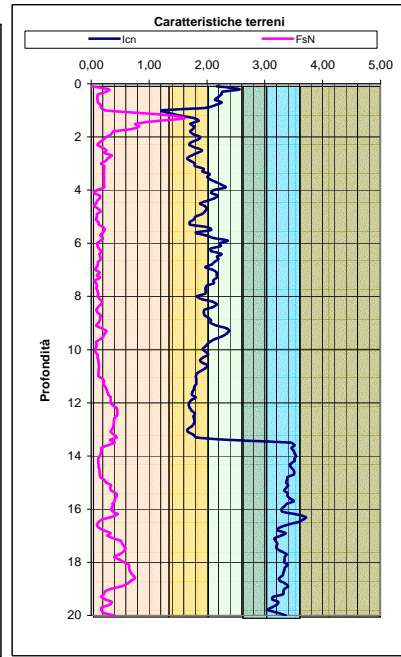
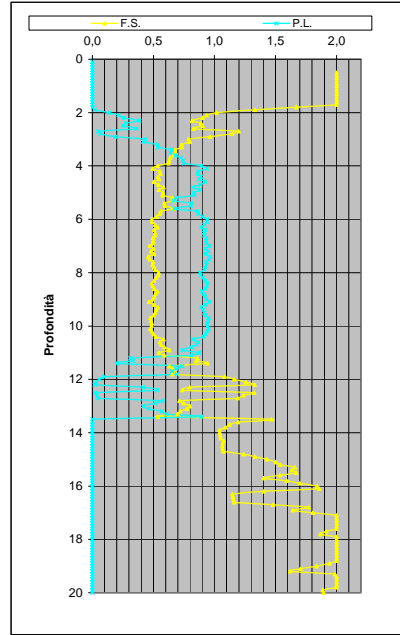
PROFONDITA' DI CALCOLO (mt da p.c.): 0,0 | LDI = 3,855 | Stot = 0,392 (mt) | IPL = 25,90 | PL = 92,79 | LD = 0,00 (mt) | PG = 1,00 | SLiq = 10,5 (mt) | LSN = 56,6

Main data table with 30 columns: Depth (m), q (kPa), qc (kPa), fs (kPa), etc. Contains 100 rows of data for different soil depths.

DIAGRAMMI DI RIFERIMENTO VERIFICA LIQUEFAZIONE - METODO R. & W. , 2009



PROVA CPT E 8



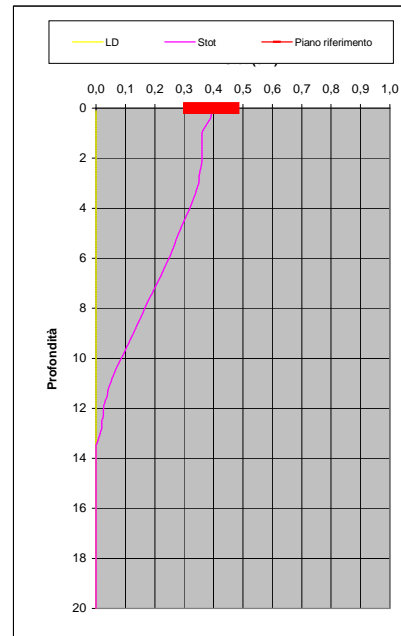
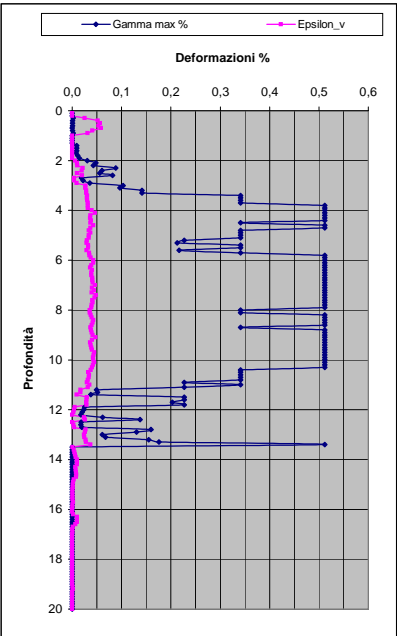
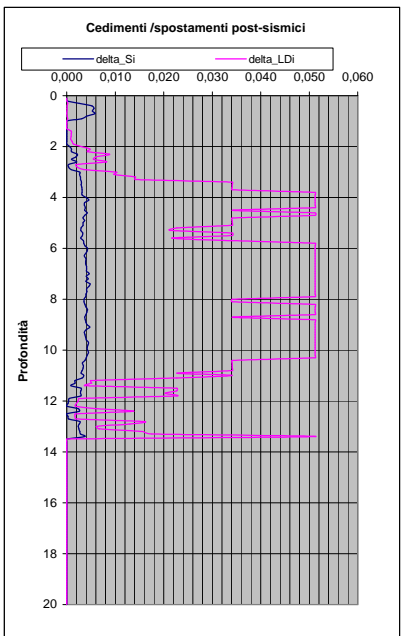
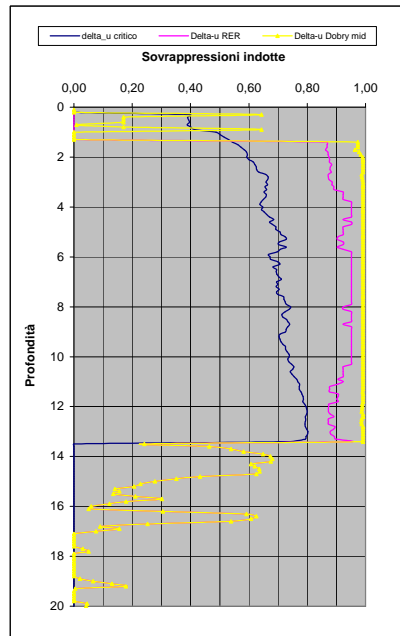
Soil Classification	Zone No.*	Range of CPT Index $I_c$ Values
Organic Clay Soils	2	$I_c > 3.60$
Clays	3	$2.95 < I_c < 3.60$
Silt Mixtures	4	$2.60 < I_c < 2.95$
Sand Mixtures	5	$2.05 < I_c < 2.60$
Sands	6	$1.31 < I_c < 2.05$
Gravelly Sands	7	$I_c < 1.31$

After Robertson and Wride (1998).  
\*Note: Zone number per Robertson SBT (1990).

- Argille - terreni organici
- Argille - argilla/argilla limosa
- Miscela di limi - limo argilloso/argilla limosa
- Miscela di sabbie - sabbia limosa/limo sabbioso
- Sabbie - sabbie pulite/sabbie limose
- sabbie ghiaiose / sabbie dense

LEGENDA

- Qc** = Res. alla penetraz. (Kg/cmq)
- FC** = Fine content - passante 0.074 mm (%)
- FsN** = Attrito laterale (Kg/cmq)
- F** = rapporto di frizione
- qtn** = parametro di resist. alla punta normal.
- Icn** = Soil behaviour index normalized (ad)
- qc1N-cs** = Resist. alla pentrez. corretta all'FC e normalizzata
- $\xi$  = parametro di stato
- KH** = fatt. correttivo per spessore strato (ad)
- Rd** = stress reduction coefficient (ad)
- CN** = fattore di normalizzazione per carico litostatico (ad)
- K $\sigma$**  = fatt. correttivo per sovraccarico-profondità (ad)
- K $\alpha$**  = fatt. correttivo per sforzi di taglio (ad)
- MSF** = magnitudo scaling factor (ad)
- F.S.** = Fattore di sicurezza (CRR/CSR con correzioni) (ad)
- CSR** = Cyclic Stress ratio (ad)
- CRR** = Cyclic Resistance Ratio (ad)
- P.L.** = Probabilità di liquefazione (ad)
- IPL** = Indice del potenziale di liquefazione (ad)
- $\gamma_{max}$**  = deformazione di taglio massima indotta dal sisma (%)
- ev** = vertical reconsolidation strain
- $\Delta s_i$**  = cedimento i-esimo dello strato (mt)
- Su** =  $S_u / \sigma'_{vc}$  resistenza totale non drenata - strati coesivi (ad)
- Sur** =  $S_{ur} / \sigma'_{vc}$  resistenza totale residua non drenata - strati coesivi (ad)
- qc1N-sr** = Resist. alla pentrez. corretta all'FC e normalizzata
- Sr** =  $S_r / \sigma'_{vc}$  resistenza residua - strati incoerenti (ad)
- Ruc** =  $\Delta u / \sigma'_{vc}$  critico - stima sogliadi innesco fenomeni di instabilità/liquefazione
- $\Delta u$  RER =  $\Delta u / \sigma'_{vc}$  sovrappressioni circ. 112/2007 - tabella 2 R.E.R.
- $\Delta u$  Dobry M. =  $\Delta u / \sigma'_{vc}$  Dobry et al. 1984 "mean" x sabbie-Robertson '09 x argille
- $\Delta u$  Dobry L. =  $\Delta u / \sigma'_{vc}$  Dobry et al. 1984 "lower bound" x sabbie-Robertson '09 x argille
- $\Delta u$  Dobry U. =  $\Delta u / \sigma'_{vc}$  Dobry et al. 1984 "Upper bound" x sabbie-Robertson '09 x argille
- Stot** = Cedimento post-sismico totale (mt)
- LDI** = Lateral Displacement Index (mt)
- Dr** = Densità relativa (ad)
- $\theta$  = angolo di attrito interno (deg)
- OCR** = rapporto di sovraconsolidazione (sabbie e argille) (ad)
- St** = coefficiente di sensitività delle argille (ad)
- LSN** = Liquefaction Severity Number (ad)



LSN Range	Expected ground surface damage
0-10	Little to no expression of liquefaction, minor effects
10-20	Minor expression of liquefaction, some sand boils
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40-50	Major expression of liquefaction, undulations and damage to ground surface, severe total and differential settlements of structures
>50	Severe damage, extensive evidence of liquefaction at surface, severe total and differential settlements affecting structures, damage to services.

\* Table based on Table 13.1 from I&T report: Liquefaction Vulnerability Study

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$0.9 < P_G$	extremely high to absolutely certain
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$0.3 < P_G \leq 0.7$	medium
$0.1 < P_G \leq 0.3$	low
$P_G \leq 0.1$	extremely low to none

IPL = 25,90

PL = 92,79

LDI = 3,855 Stot = 0,392 (mt)

LD = 0,00 (mt)

SLiq = 10,50 (mt)

LSN = 56,55 PG = 1,00

CPT-based liquefaction triggering analysis for a single sounding

Environments: C Hill-H Plain-P Coast-C  
Behaviours: E Sand like-S

Computer constants: no. 101.32  
MSF NECEER  
Patm = 101.32 (cov=0.35-35%)  
KOR = 350  
IP COR = 1.2

Probabilità e potenziale di liquefazione

Probabilità e suscettibilità di liquefazione

PL Overall Probability

Robertson & Wride, agg. 2009

PROVA "CPTE 9"



Potential flow failure if (N1)60<=10 and (q1)N60<=50  
No flow liquefaction if (q1)N60<=65

Table with 2 columns: LsN, LsN Expression. Values range from >50 to <10.

Main data table with columns: Depth (m), q1 (kPa), q2 (kPa), F, Ic, IcN2, N1(60), n, Kc, Layer, etc. Includes various soil parameters and test results.

PROFONDITA' DI CALCOLO (mt da p.c.): 0,0

LDI = 3,484

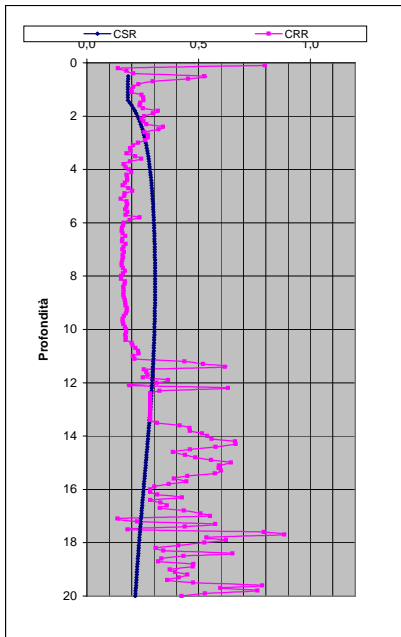
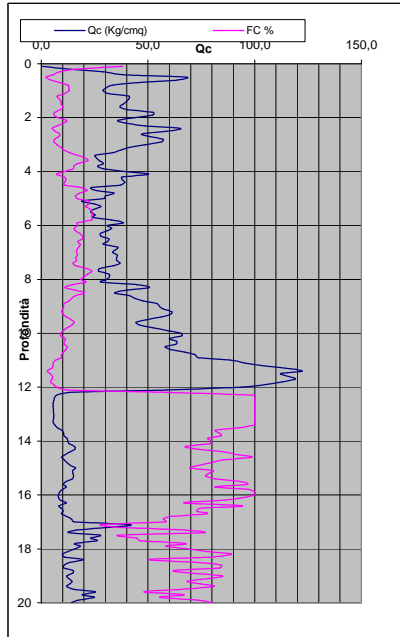
Stot = 0,311 (mt)

IPL = 21,73

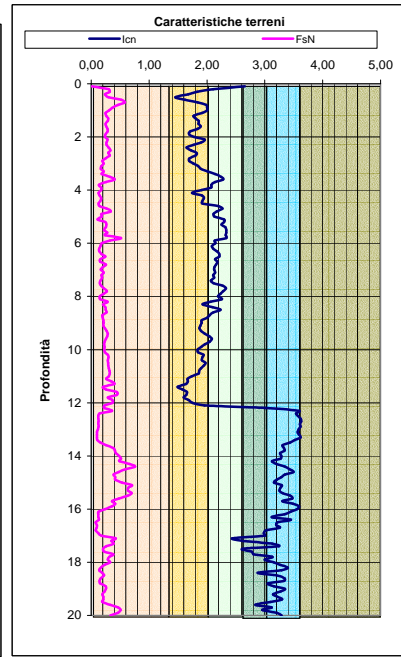
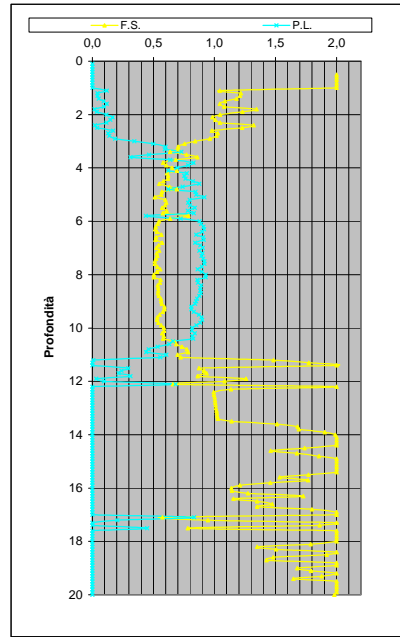
PL = 83,82 LD = 0,00 (mt) PG = 1,00 SLiq = 9,3 (mt) LSN = 50,3

Main data table containing 100 rows of soil test data, including depth, stress, and liquefaction parameters.

DIAGRAMMI DI RIFERIMENTO VERIFICA LIQUEFAZIONE - METODO R. & W. , 2009



PROVA CPT E 9



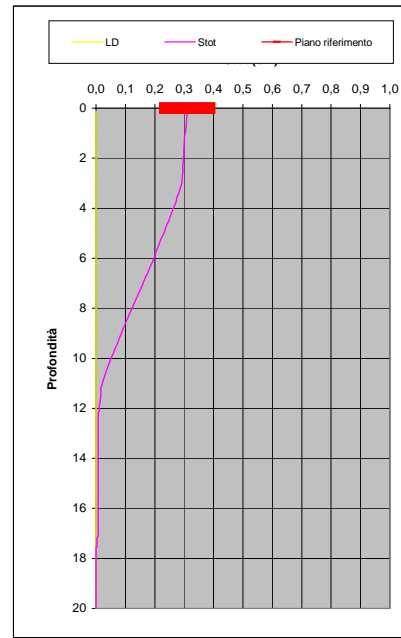
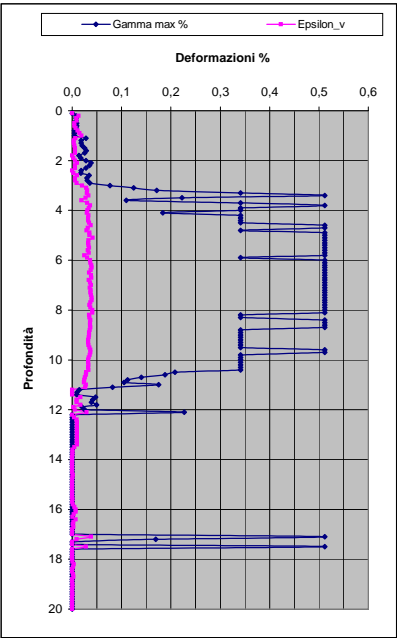
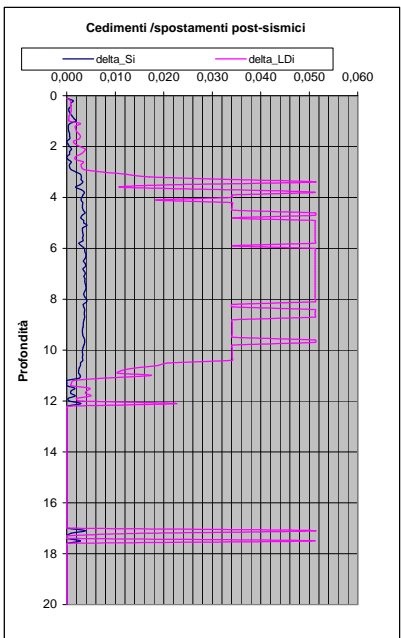
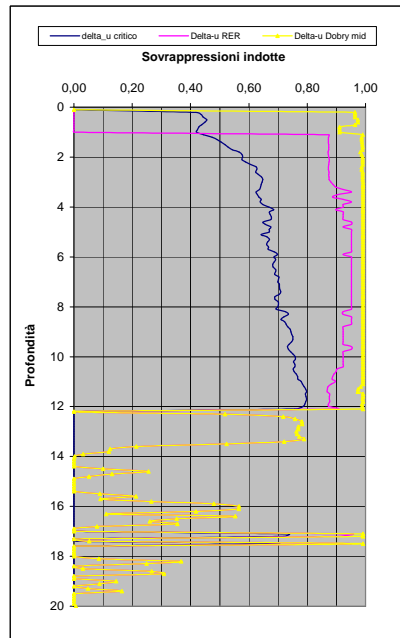
Soil Classification	Zone No.*	Range of CPT Index $I_c$ Values
Organic Clay Soils	2	$I_c > 3.60$
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Sands	6	$1.31 < I_c < 2.05$
Gravelly Sands	7	$I_c < 1.31$

After Robertson and Wride (1998).  
\*Note: Zone number per Robertson SBT (1990).

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LEGENDA

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- F.S.** = Fattore di sicurezza (CRR/CSR con correzioni) (ad)
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- Ruc** =  $\Delta u / \sigma'_{vc}$  critico - stima sogliadi innesco fenomeni di instabilità/liquefazione
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- Dr** = Densità relativa (ad)
- $\theta$  = angolo di attrito interno (deg)
- OCR** = rapporto di sovraconsolidazione (sabbie e argille) (ad)
- St** = coefficiente di sensitività delle argille (ad)
- LSN** = Liquefaction Severity Number (ad)



LSN Range	Expected ground surface damage
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\* Table based on Table 13.1 from I&T report: Liquefaction Vulnerability Study

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$0.3 < P_G \leq 0.7$	medium
$0.1 < P_G \leq 0.3$	low
$P_G \leq 0.1$	extremely low to none

IPL = 21,73      PL = 83,82

LDI = 3,484      Stot = 0,311 (mt)

LD = 0,00 (mt)

SLiq = 9,30 (mt)

LSN = 50,30      PG = 1,00

CPT-based liquefaction triggering analysis for a single sounding

Table with multiple columns: Input parameters (Peak ground accel, Earthquake magnitude, Water table depth, etc.), Soil Classification (Sand-Clay-SC), Building environment, Probabilità e potenziale di liquefazione, and various probability and risk assessment metrics.

Main data table with columns for Depth (m), Soil Classification, and various parameters (Q1, Qn, F, Ic, N1(60), etc.). Includes a summary row at the bottom with values like LDI = 3,474, Stot = 0,319, IPL = 19,85, and LSN = 49,2.

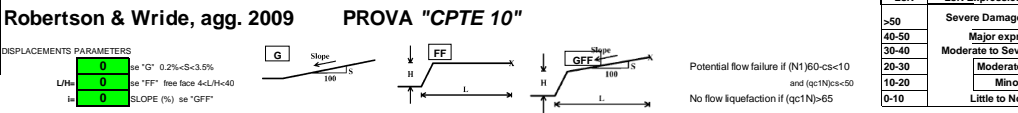
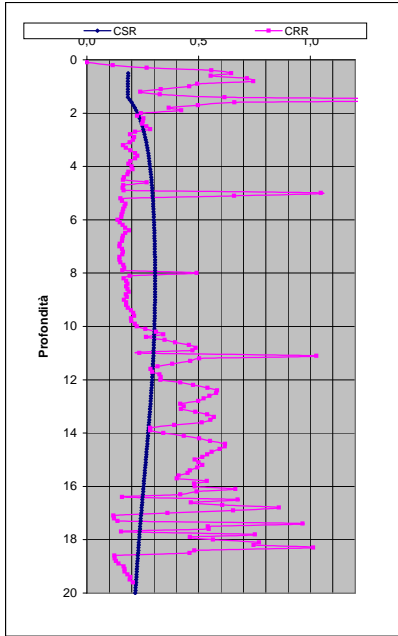
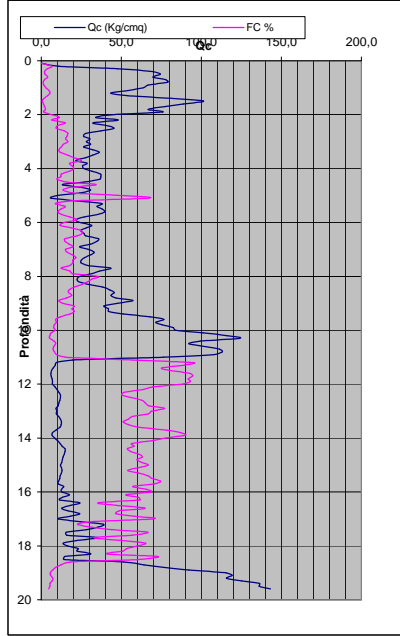
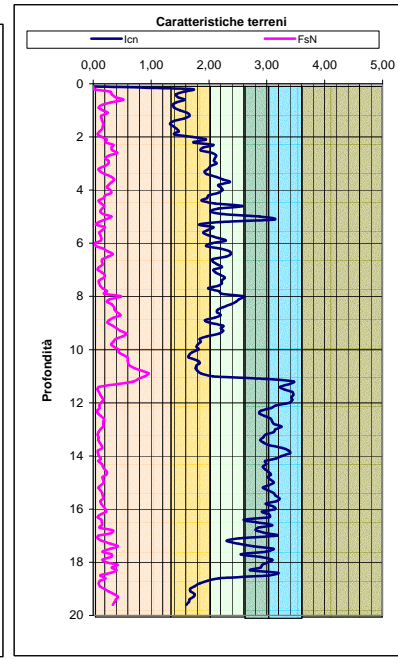
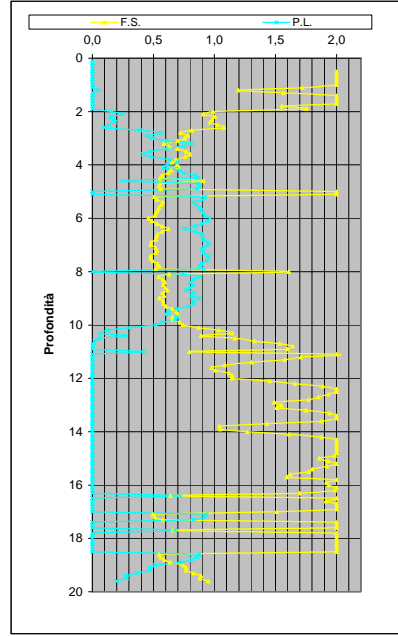


Table titled 'ROBERTSON & WRIE, agg. 2009' containing various parameters and their values, such as 'Risk level', 'IPL', 'PL', and 'FS=1.2'.

DIAGRAMMI DI RIFERIMENTO VERIFICA LIQUEFAZIONE - METODO R. & W. , 2009



PROVA CPT E 10



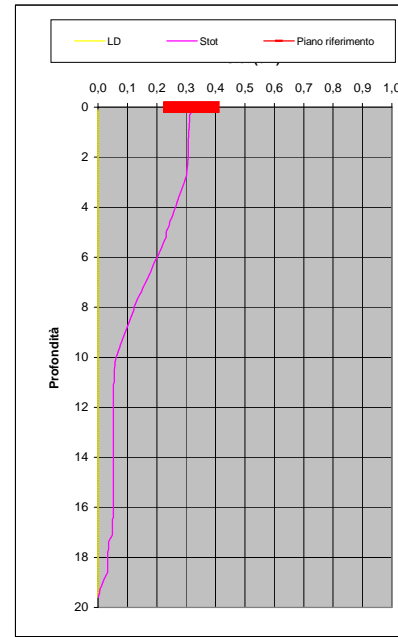
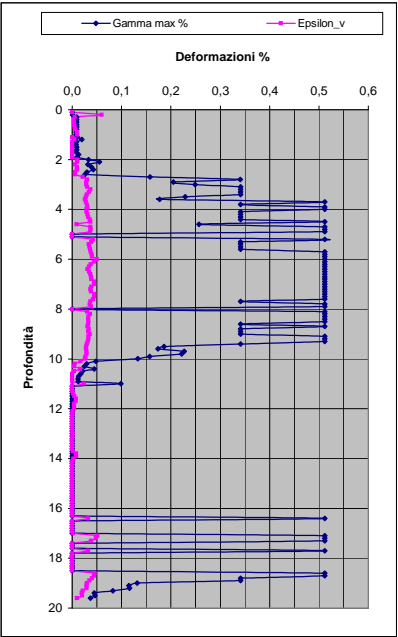
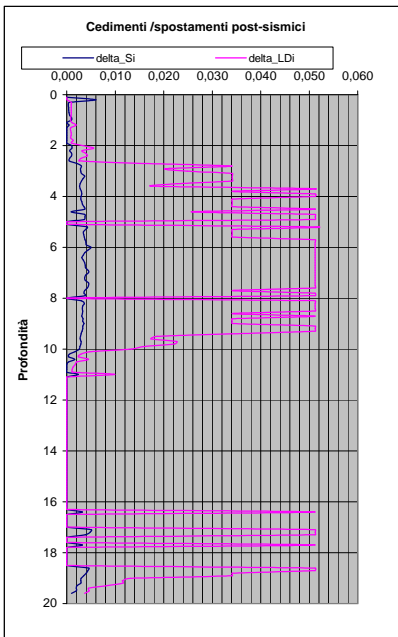
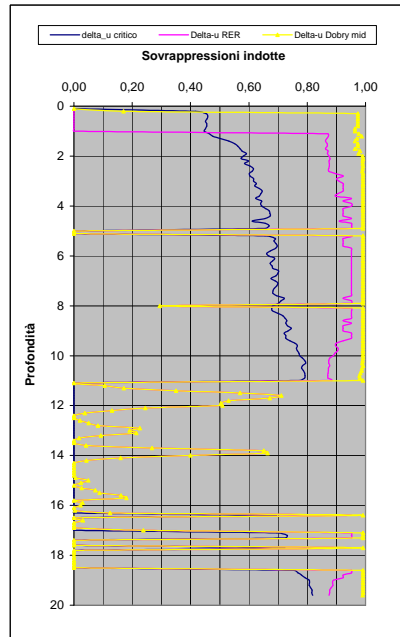
Soil Classification	Zone No.*	Range of CPT Index $I_c$ Values
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After Robertson and Wride (1998).  
\*Note: Zone number per Robertson SBT (1990).

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LEGENDA

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- IPL** = Indice del potenziale di liquefazione (ad)
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- $\theta$  = angolo di attrito interno (deg)
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$0.1 < P_G \leq 0.3$	low
$P_G \leq 0.1$	extremely low to none

IPL= 19,85

PL= 77,48

LDI = 3,474 Stot = 0,319 (mt)

LD = 0,00 (mt)

SLiq = 9,40 (mt)

LSN = 49,18 PG= #NUM!

CPT-based liquefaction triggering analysis for a single sounding

Enviromenti Behaviours

Computer constants

Probabilità e potenziale di liquefazione

Probabilità e suscettibilità di liquefazione

PL Overall Probability

Robertson & Wride, agg. 2009

PROVA "CPTE 11"

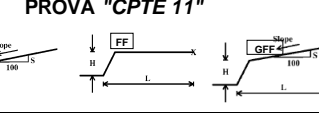
Input parameter table with columns for soil classification, water table depth, and average water table.

Soil Classification table with columns for soil type, zone, and classification code.

Computer constants table with columns for alpha, N, and other parameters.

Probabilità e potenziale di liquefazione table with columns for probability and potential.

Probabilità e suscettibilità di liquefazione table with columns for probability and susceptibility.



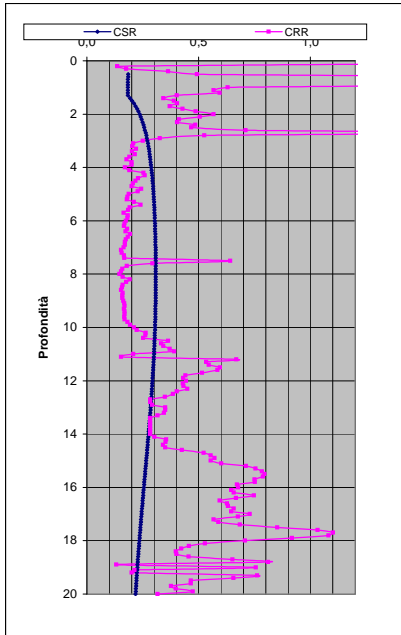
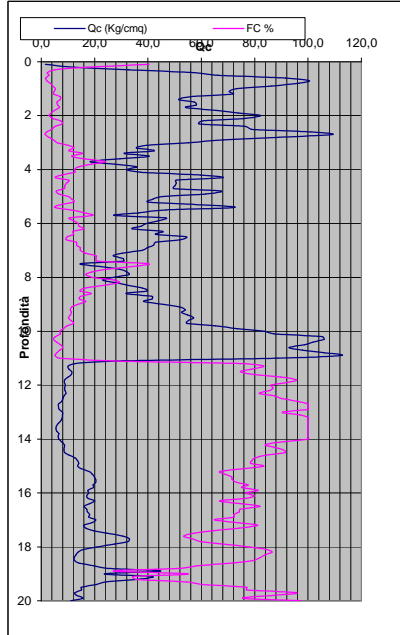
Displacements parameters table with columns for various parameters like LSN, LSN Expression, etc.

Main data table header with columns for depth, soil type, and various geotechnical parameters.

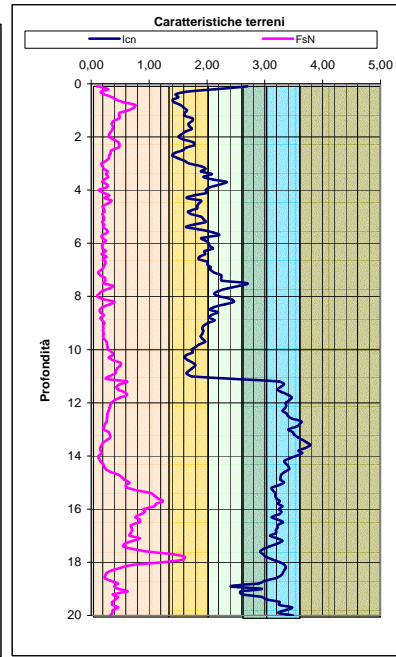
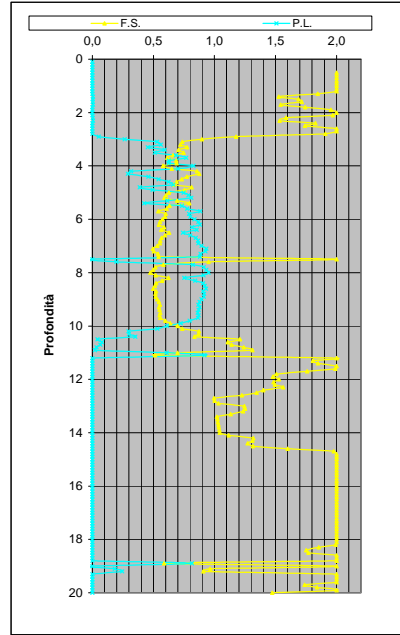
Main data table body containing multiple rows of geotechnical data for different soil depths.



DIAGRAMMI DI RIFERIMENTO VERIFICA LIQUEFAZIONE - METODO R. & W. , 2009



PROVA CPT E 11



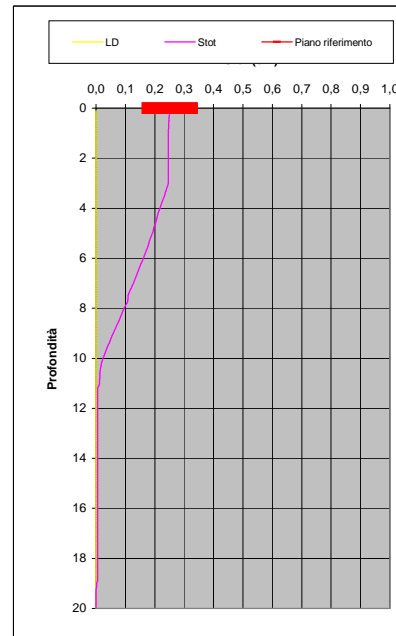
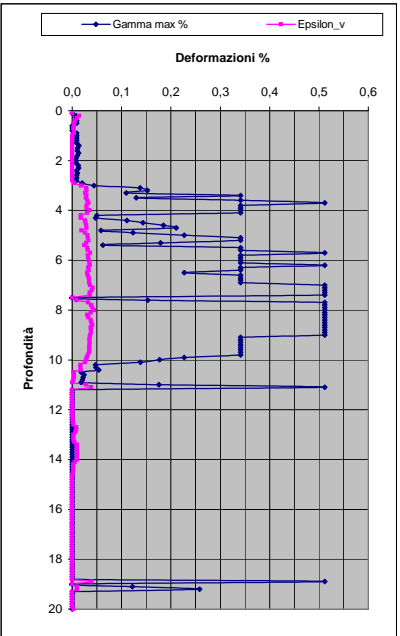
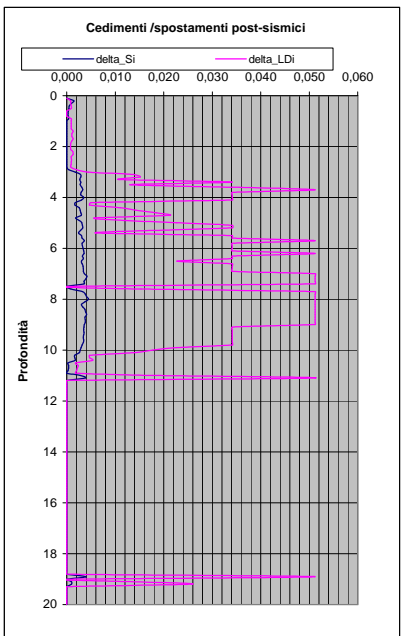
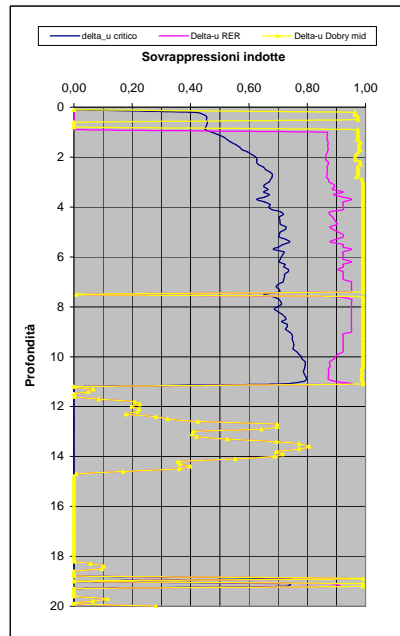
Soil Classification	Zone No.*	Range of CPT Index $I_c$ Values
Organic Clay Soils	2	$I_c > 3.60$
Clays	3	$2.95 < I_c < 3.60$
Silt Mixtures	4	$2.60 < I_c < 2.95$
Sand Mixtures	5	$2.05 < I_c < 2.60$
Sands	6	$1.31 < I_c < 2.05$
Gravelly Sands	7	$I_c < 1.31$

After Robertson and Wride (1998).  
\*Note: Zone number per Robertson SBT (1990).

- Argille - terreni organici
- Argille - argilla/argilla limosa
- Miscela di limi - limo argilloso/argilla limosa
- Miscela di sabbie - sabbia limosa/limo sabbioso
- Sabbie - sabbie pulite/sabbie limose
- sabbie ghiaiose / sabbie dense

LEGENDA

- Qc** = Res. alla penetraz. (Kg/cmq)
- FC** = Fine content - passante 0.074 mm (%)
- FsN** = Attrito laterale (Kg/cmq)
- F** = rapporto di frizione
- Qtn** = parametro di resist. alla punta normal.
- Icn** = Soil behaviour index normalized (ad)
- qc1N-cs** = Resist. alla pentrez. corretta all'FC e normalizzata
- $\xi$  = parametro di stato
- KH** = fatt. correttivo per spessore strato (ad)
- Rd** = stress reduction coefficient (ad)
- CN** = fattore di normalizzazione per carico litostatico (ad)
- K $\sigma$**  = fatt. correttivo per sovraccarico-profondità (ad)
- K $\alpha$**  = fatt. correttivo per sforzi di taglio (ad)
- MSF** = magnitudo scaling factor (ad)
- F.S.** = Fattore di sicurezza (CRR/CSR con correzioni) (ad)
- CSR** = Cyclic Stress ratio (ad)
- CRR** = Cyclic Resistance Ratio (ad)
- P.L.** = Probabilità di liquefazione (ad)
- IPL** = Indice del potenziale di liquefazione (ad)
- $\gamma_{max}$**  = deformazione di taglio massima indotta dal sisma (%)
- ev** = vertical reconsolidation strain
- $\Delta s_i$**  = cedimento i-esimo dello strato (mt)
- Su** =  $S_u / \sigma'_{vc}$  resistenza totale non drenata - strati coesivi (ad)
- Sur** =  $S_{ur} / \sigma'_{vc}$  resistenza totale residua non drenata - strati coesivi (ad)
- qc1N-sr** = Resist. alla pentrez. corretta all'FC e normalizzata
- Sr** =  $S_r / \sigma'_{vc}$  resistenza residua - strati incoerenti (ad)
- Ruc** =  $\Delta u / \sigma'_{vc}$  critico - stima sogliadi innesco fenomeni di instabilità/liquefazione
- $\Delta u$  RER =  $\Delta u / \sigma'_{vc}$  sovrappressioni circ. 112/2007 - tabella 2 R.E.R.
- $\Delta u$  Dobry M. =  $\Delta u / \sigma'_{vc}$  Dobry et al. 1984 "mean" x sabbie-Robertson '09 x argille
- $\Delta u$  Dobry L. =  $\Delta u / \sigma'_{vc}$  Dobry et al. 1984 "lower bound" x sabbie-Robertson '09 x argille
- $\Delta u$  Dobry U. =  $\Delta u / \sigma'_{vc}$  Dobry et al. 1984 "Upper bound" x sabbie-Robertson '09 x argille
- Stot** = Cedimento post-sismico totale (mt)
- LDI** = Lateral Displacement Index (mt)
- Dr** = Densità relativa (ad)
- $\phi$  = angolo di attrito interno (deg)
- OCR** = rapporto di sovraconsolidazione (sabbie e argille) (ad)
- St** = coefficiente di sensitività delle argille (ad)
- LSN** = Liquefaction Severity Number (ad)



LSN Range	Expected ground surface damage
0-10	Little to no expression of liquefaction, minor effects
10-20	Minor expression of liquefaction, some sand boils
20-30	Moderate expression of liquefaction, with some sand boils and structural damage
30-40	Moderate to severe expression of liquefaction, settlement can cause structural damage
40-50	Major expression of liquefaction, undulations and damage to ground surface, severe total and differential settlements of structures
>50	Severe damage, extensive evidence of liquefaction at surface, severe total and differential settlements affecting structures, damage to services.

Probability	Description of the risk of liquefaction-induced ground failure
$0.9 < P_G$	extremely high to absolutely certain
$0.7 < P_G \leq 0.9$	high
$0.3 < P_G \leq 0.7$	medium
$0.1 < P_G \leq 0.3$	low
$P_G \leq 0.1$	extremely low to none

IPL = 18,22

PL = 70,70

LDI = 2,579 Stot = 0,251 (mt)

LD = 0,00 (mt)

SLiq = 7,90 (mt)

LSN = 39,38 PG = 1,00

CPT-based liquefaction triggering analysis for a single sounding

Enviroments: C Hill-H Plain-P Coast-C Behaviours: Sand like-S

Computer constants: no. n=350 (B' 2007 - C'efin' 2004 - NCEER - Blake) alpha (N) = 1.2 MSF NCEER

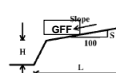
Probabilità e potenziale di liquefazione

Probabilità e suscettibilità di liquefazione

PL Overall Probability

Robertson & Wride, agg. 2009

PROVA "CPTe 12"



Potential flow failure if (N1)60<=10 and (q1)N60>50 No flow liquefaction if (q1)N60<=5

Table with 2 columns: LsN, LsN Expression. Values range from >50 to 0-10.

Input parameter: Peak ground accel (g) = 0.236, Earthquake magnitude, M = 6.14, Water table depth (m) = 1.18, Average > above water table (N60)30 = 1.18, Average < below water table (N60)30 = 1.18

Soil Classification table with columns: Zone No., Range of CPT Index / Values, Soil Name, Soil Class.

Soil Classification: Sand-Clay-SC, Building (V)M, Sedimentary environment, CPTs - CPTu=1

Carico Kpa = 210, Prof (m) = 1.1, L (m) = 10, Cst(Kpa) = 98

Probabilità e suscettibilità di liquefazione table with columns: Probabilità, Suscettibilità, PL Overall Probability, Risk lev., IPL, PL

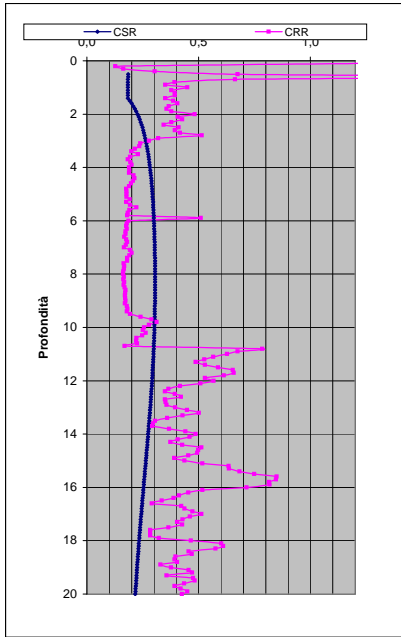
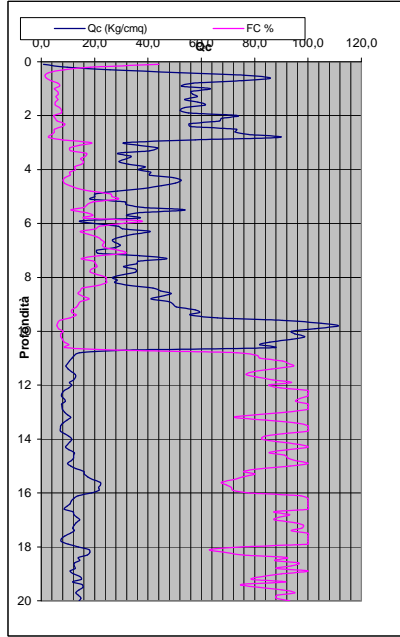
DISPLACEMENT PARAMETERS table with columns: Delta H, ALDI, Vertical recons. Strain, ASI, Fmax PL, JUNG, F, I, Ru, Au, Au', Ru, Dr, Ruc, Suo/vc, OCR, qc1N, Sr, Su, LsN

Main data table with columns: Depth (m), q1, qn, F, Ic, Ic2, N1(60), n, Kc, Layer, Flag, FC, Kh, Interpret, qc1N, On-cs, R, CSR, Ks, xi, Kc, crr, CRR, Factor of Safety FS, MSF SAND & CLAY, Limiting shear strain, PL Overall Probability, Risk lev., IPL, PL, Delta H, ALDI, Vertical recons. Strain, ASI, Fmax PL, JUNG, F, I, Ru, Au, Au', Ru, Dr, Ruc, Suo/vc, OCR, qc1N, Sr, Su, LsN

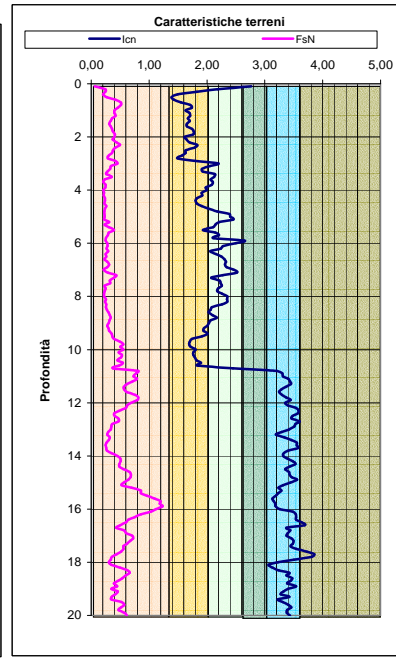
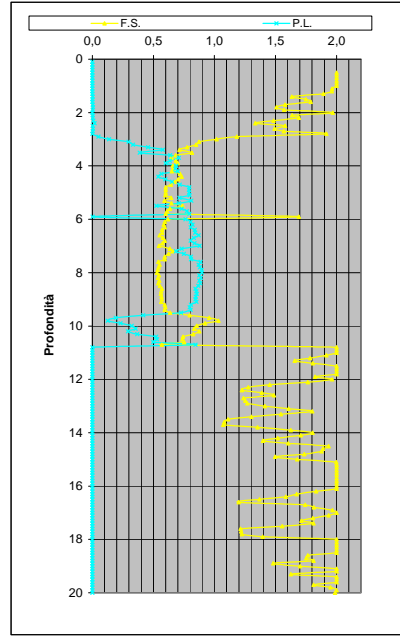
PROFONDITA' DI CALCOLO (mt da p.c.): 0,0 LDI = 2,697 Stot = 0,235 (mt) IPL = 17,31 PL = 66,39 LD = 0,00 (mt) PG = 1,00 SLiq = 7,5 (mt) LSN = 37,3

Main data table with columns: Depth (m), q1, qn, F, Ic, Ic2, N1(60), n, Kc, Layer, Flag, FC, Kh, Interpret, qc1N, On-cs, R, CSR, Ks, xi, Kc, crr, CRR, Factor of Safety FS, MSF SAND & CLAY, Limiting shear strain, PL Overall Probability, Risk lev., IPL, PL, Delta H, ALDI, Vertical recons. Strain, ASI, Fmax PL, JUNG, F, I, Ru, Au, Au', Ru, Dr, Ruc, Suo/vc, OCR, qc1N, Sr, Su, LsN

DIAGRAMMI DI RIFERIMENTO VERIFICA LIQUEFAZIONE - METODO R. & W. , 2009



PROVA CPT E 12



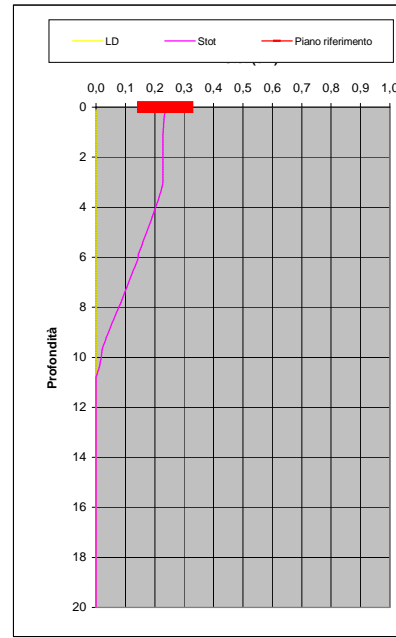
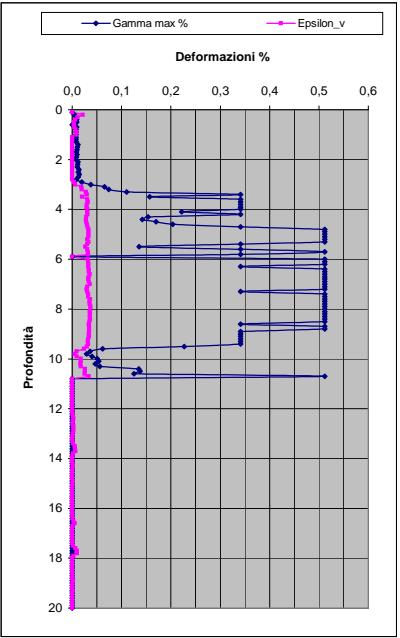
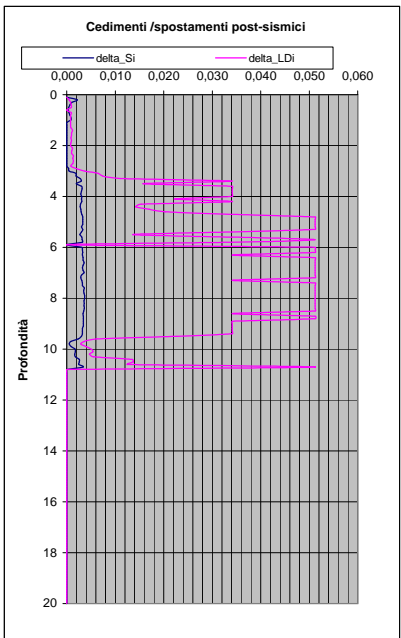
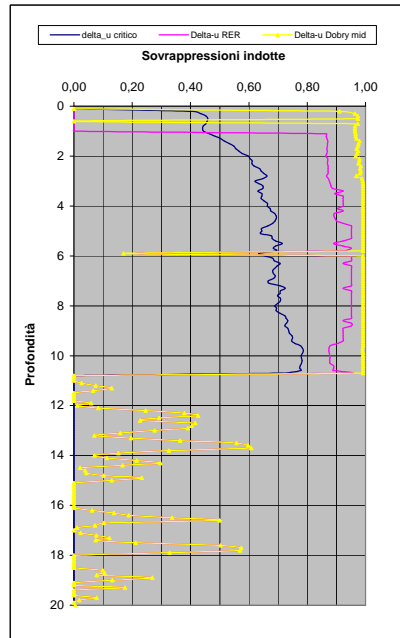
Soil Classification	Zone No.*	Range of CPT Index $I_c$ Values
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Sands	6	$1.31 < I_c < 2.05$
Gravelly Sands	7	$I_c < 1.31$

After Robertson and Wride (1998).  
\*Note: Zone number per Robertson SBT (1990).

- Argille - terreni organici
- Argille - argilla/argilla limosa
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LEGENDA

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- FC** = Fine content - passante 0.074 mm (%)
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- Qtn** = parametro di resist. alla punta normal.
- Icn** = Soil behaviour index normalized (ad)
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- $\xi$  = parametro di stato
- KH** = fatt. correttivo per spessore strato (ad)
- Rd** = stress reduction coefficient (ad)
- CN** = fattore di normalizzazione per carico litostatico (ad)
- K $\sigma$**  = fatt. correttivo per sovraccarico-profondità (ad)
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- MSF** = magnitudo scaling factor (ad)
- F.S.** = Fattore di sicurezza (CRR/CSR con correzioni) (ad)
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- $\Delta s_i$**  = cedimento i-esimo dello strato (mt)
- Su** =  $S_u / \sigma'_{vc}$  resistenza totale non drenata - strati coesivi (ad)
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- Ruc** =  $\Delta u / \sigma'_{vc}$  critico - stima sogliadi innesco fenomeni di instabilità/liquefazione
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- $\Delta u$  Dobry M. =  $\Delta u / \sigma'_{vc}$  Dobry et al. 1984 "mean" x sabbie-Robertson '09 x argille
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- $\theta$  = angolo di attrito interno (deg)
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- LSN** = Liquefaction Severity Number (ad)



LSN Range	Expected ground surface damage
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>50	Severe damage, extensive evidence of liquefaction at surface, severe total and differential settlements affecting structures, damage to services.

\* Table based on Table 13.1 from I&T report: Liquefaction Vulnerability Study

Probability	Description of the risk of liquefaction-induced ground failure
$0.9 < P_G$	extremely high to absolutely certain
$0.7 < P_G \leq 0.9$	high
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$P_G \leq 0.1$	extremely low to none

IPL= 17,31      PL= 66,39      LDI = 2,697      Stot = 0,235 (mt)      LD = 0,00 (mt)      SLiq = 7,50 (mt)      LSN = 37,32      PG= 1,00

CPT-based liquefaction triggering analysis for a single sounding

Environments: C Hill-H Plain-P Coast-C Behaviours: E Sand like-S

Computer constants: no. 10,32 (B' 2007 - 'Cefin' 2004 - 'NCEER' - 'Blake') alpha (N) 1 MSF NCEER

Probabilità e potenziale di liquefazione

Probabilità e suscettibilità di liquefazione

PL Overall Probability

Robertson & Wride, agg. 2009

PROVA "CPTU 1" - Colonia Montecatini

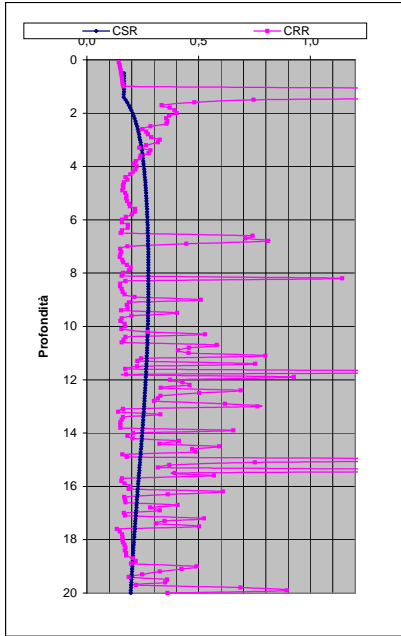
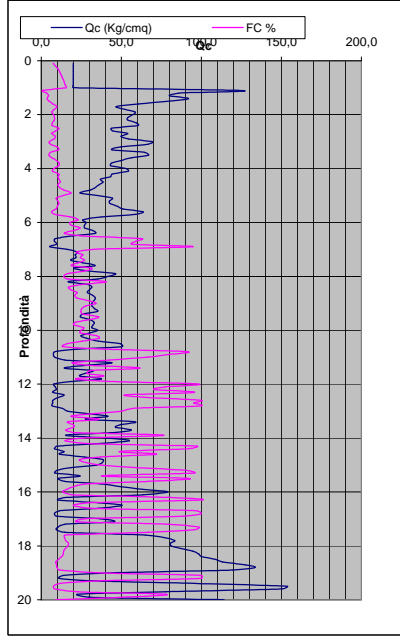
Table with 2 columns: LsN, LsN Expression. Values range from >50 to 0-10.

Main data table with columns: Depth (m), q1, qn, F, Ic, N1(60), n, Kc, Layer, etc. Includes various soil parameters and calculated values.

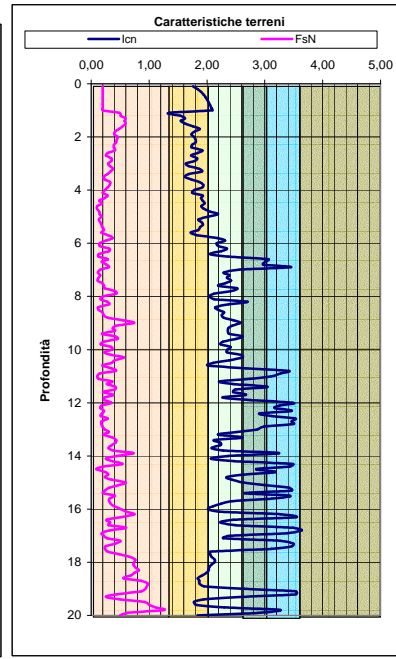
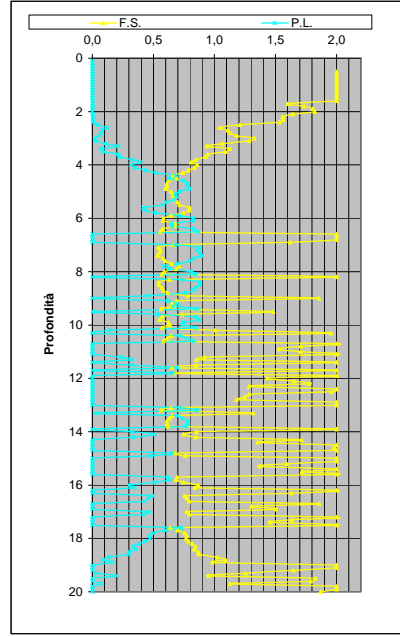
PROFONDITA' DI CALCOLO (mt da p.c.): 0,0 LDI = 3,961 Stot = 0,346 (mt) IPL = 15,88 PL = 59,15 LD = 0,00 (mt) PG = 1,00 SLiq = 10,3 (mt) LSN = 40,8

Main data table with columns: Depth (m), q1, qn, F, Ic, N1(60), n, Kc, Layer, etc. This is the largest table containing the primary data for the sounding.

DIAGRAMMI DI RIFERIMENTO VERIFICA LIQUEFAZIONE - METODO R. & W. , 2009



PROVA CPTU 1 - Colonia Montecatini



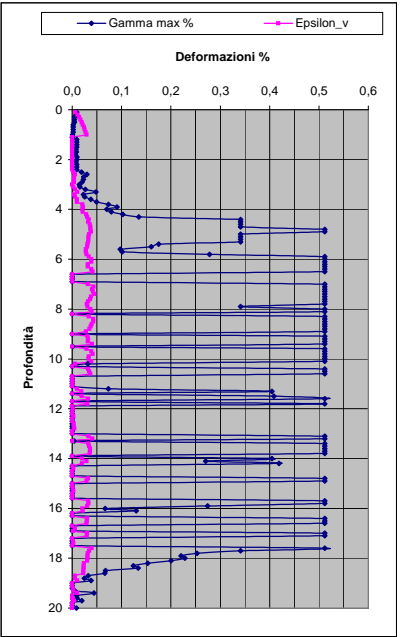
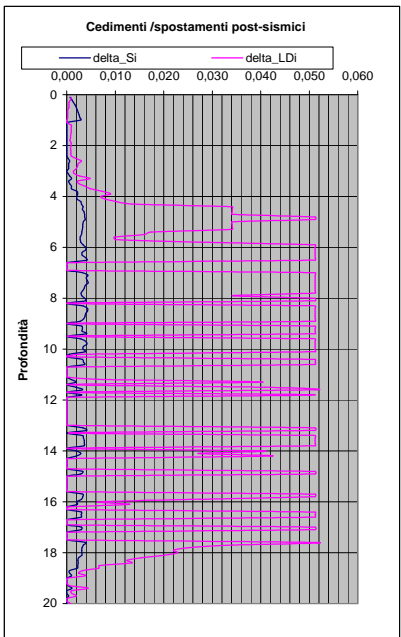
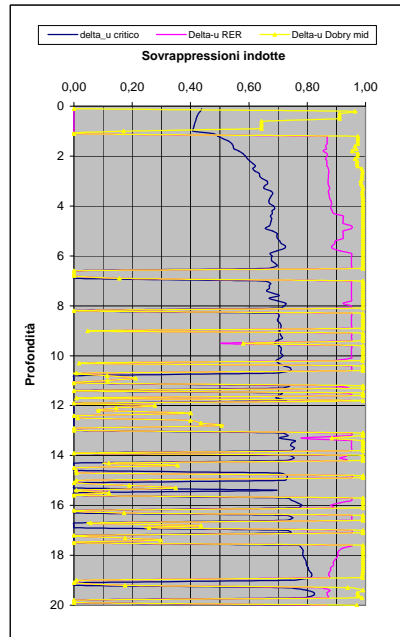
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Clays	3	$2.95 < I_c < 3.60$
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Sands	6	$1.31 < I_c < 2.05$
Gravelly Sands	7	$I_c < 1.31$

After Robertson and Wride (1998).  
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LEGENDA

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- St** = coefficiente di sensitività delle argille (ad)
- LSN** = Liquefaction Severity Number (ad)



IPL= 15,88

PL= 59,15

LDI = 3,961 Stot = 0,346 (mt)

LD = 0,00 (mt)

SLiq = 10,30 (mt)

LSN = 40,75 PG= 1,00

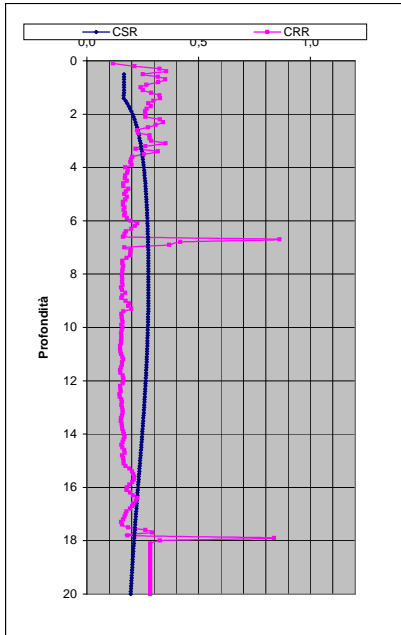
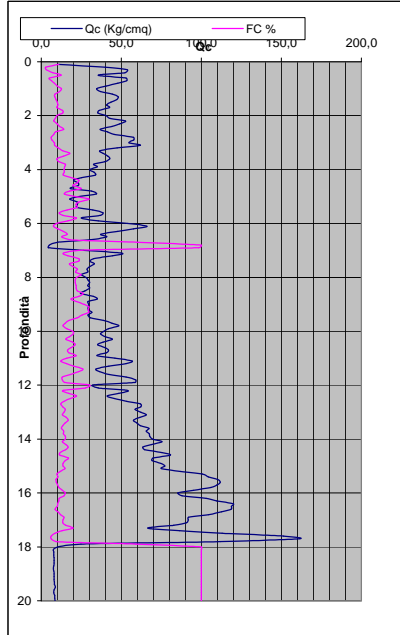
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>50	Severe damage, extensive evidence of liquefaction as surface, severe total and differential settlements affecting structures, damage to services.

\* Table based on Table 13.1 from I&T report: Liquefaction Vulnerability Study

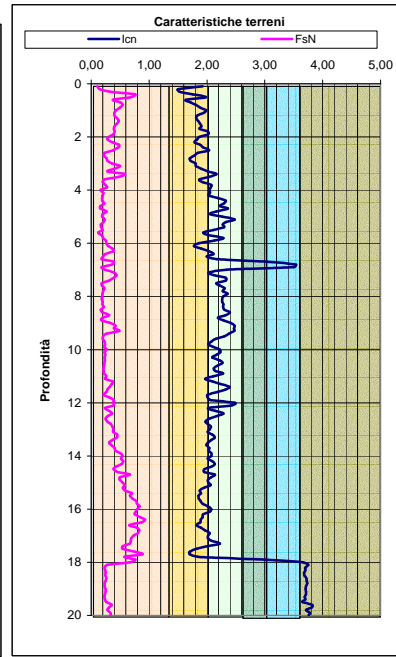
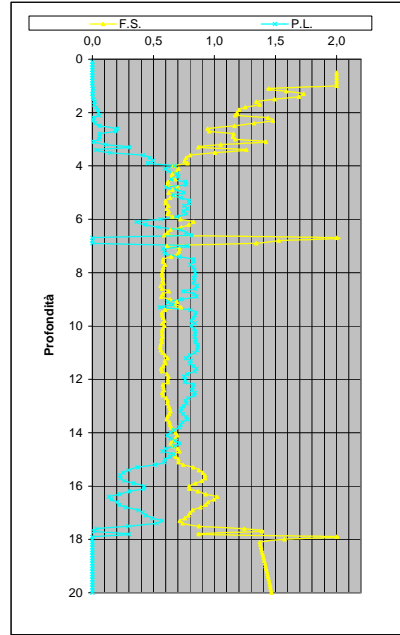
Probability	Description of the risk of liquefaction-induced ground failure
$0.9 < P_G$	extremely high to absolutely certain
$0.7 < P_G \leq 0.9$	high
$0.3 < P_G \leq 0.7$	medium
$0.1 < P_G \leq 0.3$	low
$P_G \leq 0.1$	extremely low to none



DIAGRAMMI DI RIFERIMENTO VERIFICA LIQUEFAZIONE - METODO R. & W. , 2009



PROVA CPTU 2 - Il Canalino



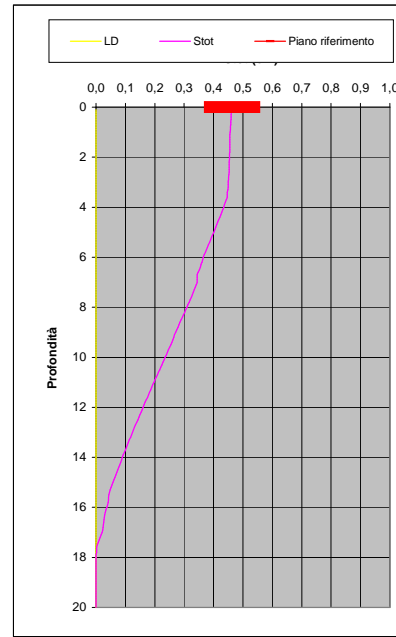
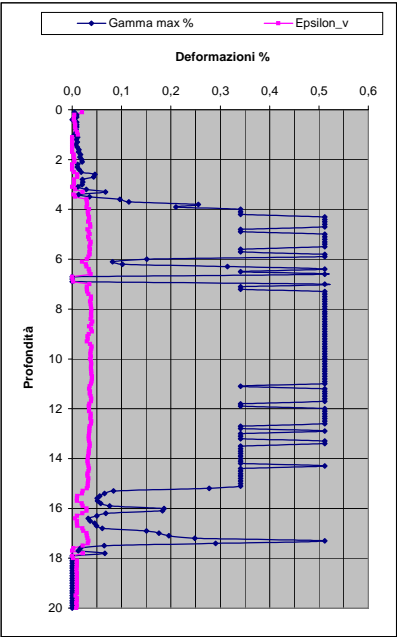
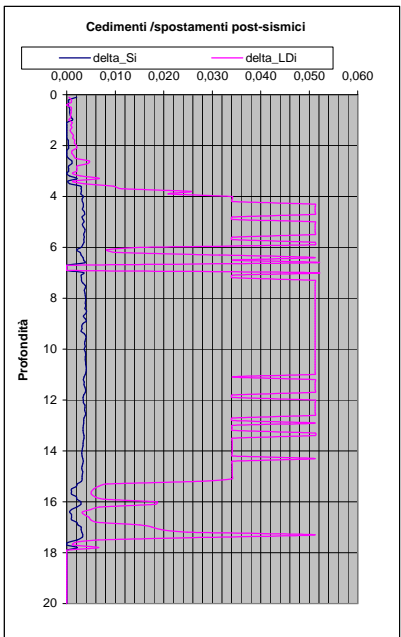
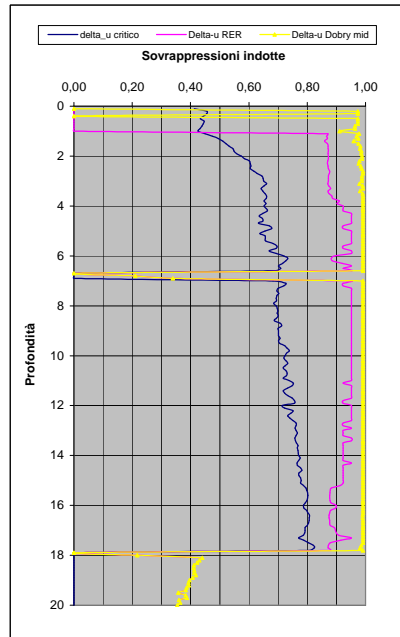
Soil Classification	Zone No.*	Range of CPTU Index $I_c$ Values
Organic Clay Soils	2	$I_c > 3.60$
Clays	3	$2.95 < I_c < 3.60$
Silt Mixtures	4	$2.60 < I_c < 2.95$
Sand Mixtures	5	$2.05 < I_c < 2.60$
Sands	6	$1.31 < I_c < 2.05$
Gravelly Sands	7	$I_c < 1.31$

After Robertson and Wride (1998).  
\*Note: Zone number per Robertson SBT (1990).

- Argille - terreni organici
- Argille - argilla/argilla limosa
- Miscela di limi - limo argilloso/argilla limosa
- Miscela di sabbie - sabbia limosa/limo sabbioso
- Sabbie - sabbie pulite/sabbie limose
- sabbie ghiaiose / sabbie dense

LEGENDA

- Qc** = Res. alla penetraz. (Kg/cmq)
- FC** = Fine content - passante 0.074 mm (%)
- Fsn** = Attrito laterale (Kg/cmq)
- F** = rapporto di frizione
- Qtn** = parametro di resist. alla punta normal.
- Icn** = Soil behaviour index normalized (ad)
- qc1N-cs** = Resist. alla pentrez. corretta all'FC e normalizzata
- $\xi$  = parametro di stato
- KH** = fatt. correttivo per spessore strato (ad)
- Rd** = stress reduction coefficient (ad)
- CN** = fattore di normalizzazione per carico litostatico (ad)
- K $\sigma$**  = fatt. correttivo per sovraccarico-profondità (ad)
- K $\alpha$**  = fatt. correttivo per sforzi di taglio (ad)
- MSF** = magnitudo scaling factor (ad)
- F.S.** = Fattore di sicurezza (CRR/CSR con correzioni) (ad)
- CSR** = Cyclic Stress ratio (ad)
- CRR** = Cyclic Resistance Ratio (ad)
- P.L.** = Probabilità di liquefazione (ad)
- IPL** = Indice del potenziale di liquefazione (ad)
- $\gamma_{max}$**  = deformazione di taglio massima indotta dal sisma (%)
- ev** = vertical reconsolidation strain
- $\Delta s_i$**  = cedimento i-esimo dello strato (mt)
- Su** =  $S_u / \sigma'_{vc}$  resistenza totale non drenata - strati coesivi (ad)
- Sur** =  $S_{ur} / \sigma'_{vc}$  resistenza totale residua non drenata - strati coesivi (ad)
- qc1N-sr** = Resist. alla pentrez. corretta all'FC e normalizzata
- Sr** =  $S_r / \sigma'_{vc}$  resistenza residua - strati incoerenti (ad)
- Ruc** =  $\Delta u / \sigma'_{vc}$  critico - stima sogliadi innesco fenomeni di instabilità/liquefazione
- $\Delta u$  RER =  $\Delta u / \sigma'_{vc}$  sovrappressioni circ. 112/2007 - tabella 2 R.E.R.
- $\Delta u$  Dobry M. =  $\Delta u / \sigma'_{vc}$  Dobry et al. 1984 "mean" x sabbie-Robertson '09 x argille
- $\Delta u$  Dobry L. =  $\Delta u / \sigma'_{vc}$  Dobry et al. 1984 "lower bound" x sabbie-Robertson '09 x argille
- $\Delta u$  Dobry U. =  $\Delta u / \sigma'_{vc}$  Dobry et al. 1984 "Upper bound" x sabbie-Robertson '09 x argille
- Stot** = Cedimento post-sismico totale (mt)
- LDI** = Lateral Displacement Index (mt)
- Dr** = Densità relativa (ad)
- $\theta$  = angolo di attrito interno (deg)
- OCR** = rapporto di sovraconsolidazione (sabbie e argille) (ad)
- St** = coefficiente di sensitività delle argille (ad)
- LSN** = Liquefaction Severity Number (ad)



LSN Range	Expected ground surface damage
0-10	Little to no expression of liquefaction, minor effects
10-20	Minor expression of liquefaction, some sand boils
20-30	Moderate expression of liquefaction, with some sand boils and structural damage
30-40	Moderate to severe expression of liquefaction, settlement can cause structural damage
40-50	Major expression of liquefaction, undulations and damage to ground surface, severe total and differential settlements of structures
>50	Severe damage, extensive evidence of liquefaction as surface, severe total and differential settlements affecting structures, damage to services.

\* Table based on Table 13.1 from I&T report: Liquefaction Vulnerability Study

Probability	Description of the risk of liquefaction-induced ground failure
$0.9 < P_G$	extremely high to absolutely certain
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$P_G \leq 0.1$	extremely low to none

IPL= 22,67

PL= 86,41

LDI = 5,301 Stot = 0,463 (mt)

LD = 0,00 (mt)

SLiq = 14,00 (mt)

LSN = 54,87 PG= 1,00