



COMPORTAMENTO DINAMICO DEI TERRENI



ENNA 20 e 21 giugno 2013

Via delle Olimpiadi

Presso i locali del Laboratorio di Geotecnica Università degli Studi di Enna "Kore"

Contributo scientifico:

UNIVERSITA' DEGLI STUDI
"KORE" DI ENNA



Contributo tecnico:



PATROCINATO:



ORDINE REGIONALE
GEOLOGI DI SICILIA

AGI

Associazione
Geotecnica
Italiana

COMPORTAMENTO DINAMICO DEI TERRENI

Casi di Studio

Enna, 21 Giugno 2013

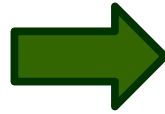
prof. Francesco Castelli



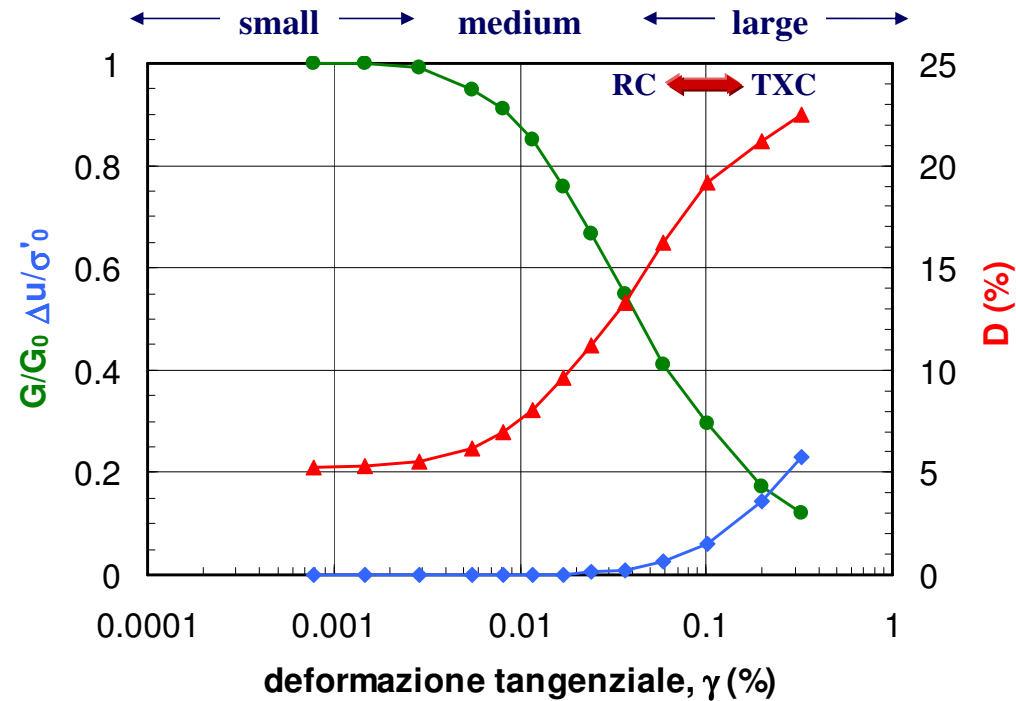
Facoltà di Ingegneria e Architettura
Università degli Studi di Enna "Kore"

DIPENDENZA DEL COMPORTAMENTO DAL LIVELLO DEFORMATIVO

*All'aumentare della
deformazione γ*

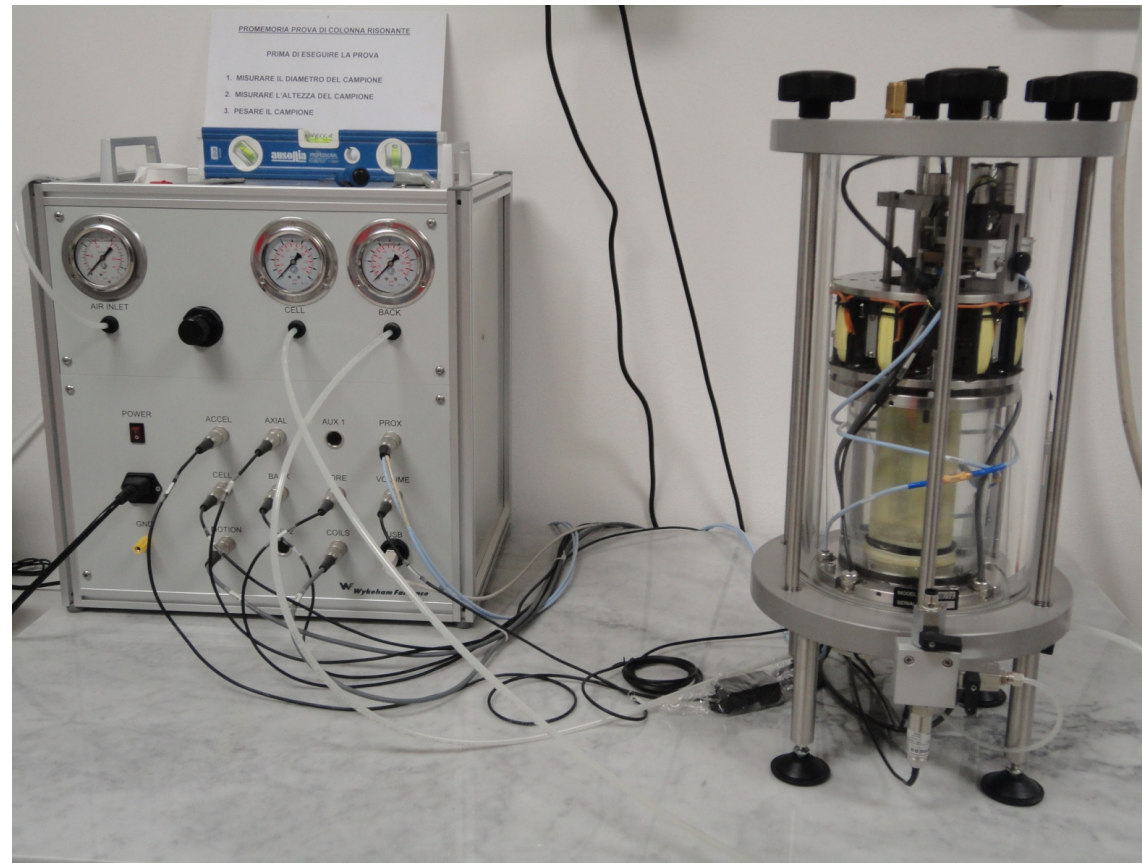


- ❖ La rigidezza G diminuisce
- ❖ Lo smorzamento D aumenta





RESONANT COLUMN AND TORSIONAL CYCLIC SHEAR SYSTEM



Riferimenti Normativi

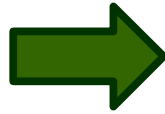
ASTM D 4015 (1995)



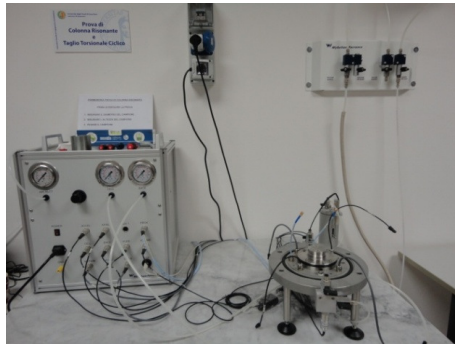
PROCEDURA DI PROVA

Colonna Risonante - Taglio Torsionale Ciclico

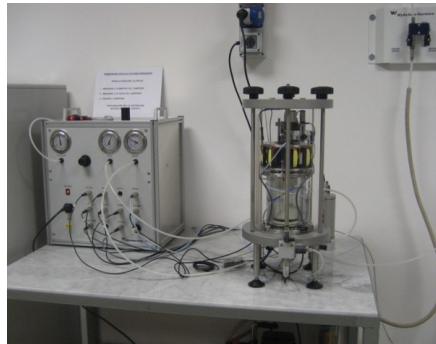
Fasi della prova



- ❖ **Fasi preliminari:** riempimento serbatoio e saturazione circuiti
- ❖ Saturazione del **provino**.
- ❖ Consolidazione del **provino**.
- ❖ Prova di colonna risonante (RC) e/o taglio torsionale ciclico (TS).



Attrezzatura



*Posizionamento membrana
sul campione*



PRINCIPIO DI FUNZIONAMENTO

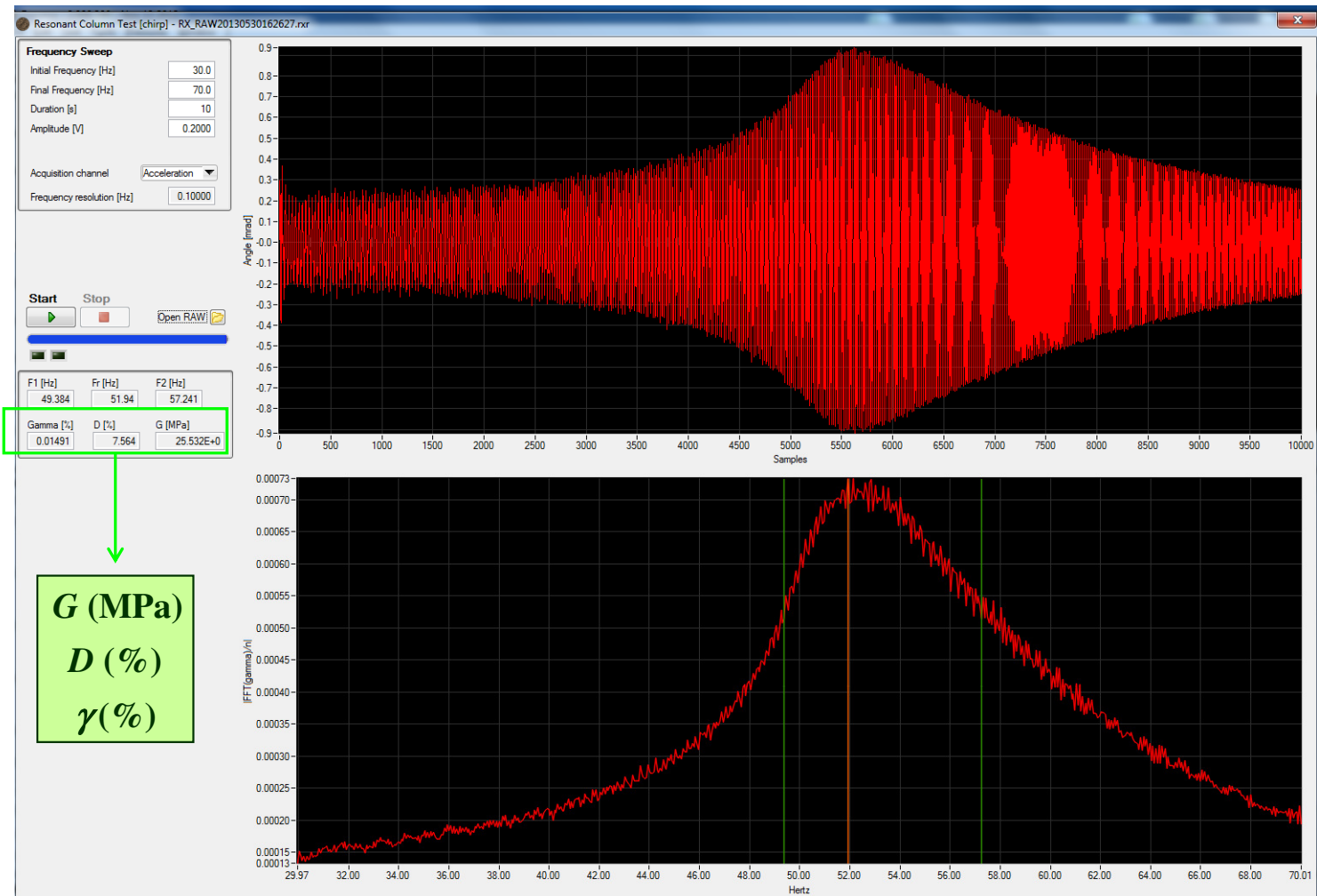
L'attrezzatura include il **motore** per l'applicazione del carico torsionale alla testa del provino, una serie di **trasduttori** con condizionatore di segnale, un **sistema elettropneumatico** di controllo della pressione in cella e un **datalogger** per l'acquisizione dei dati.

- ❖ Nella prova di **colonna risonante** il provino, tenuto fisso alla base, viene sollecitato dinamicamente alla sommità. La sollecitazione è generata da un motore elettromagnetico (**attuatore**) costituito da otto bobine che interagiscono con 4 magneti permanenti resi solidali con la testa del provino mediante una piastra. Il range di frequenza generata varia fino ad un massimo di **100 Hz**.
- ❖ Nella prova di **taglio torsionale** viene applicata al provino una coppia torcente ciclica a bassa frequenza (**max 1 Hz**), monitorando continuamente la torsione e la deformazione angolare.

E' possibile determinare la relazione tra modulo di taglio G e il rapporto di smorzamento D in funzione della deformazione γ

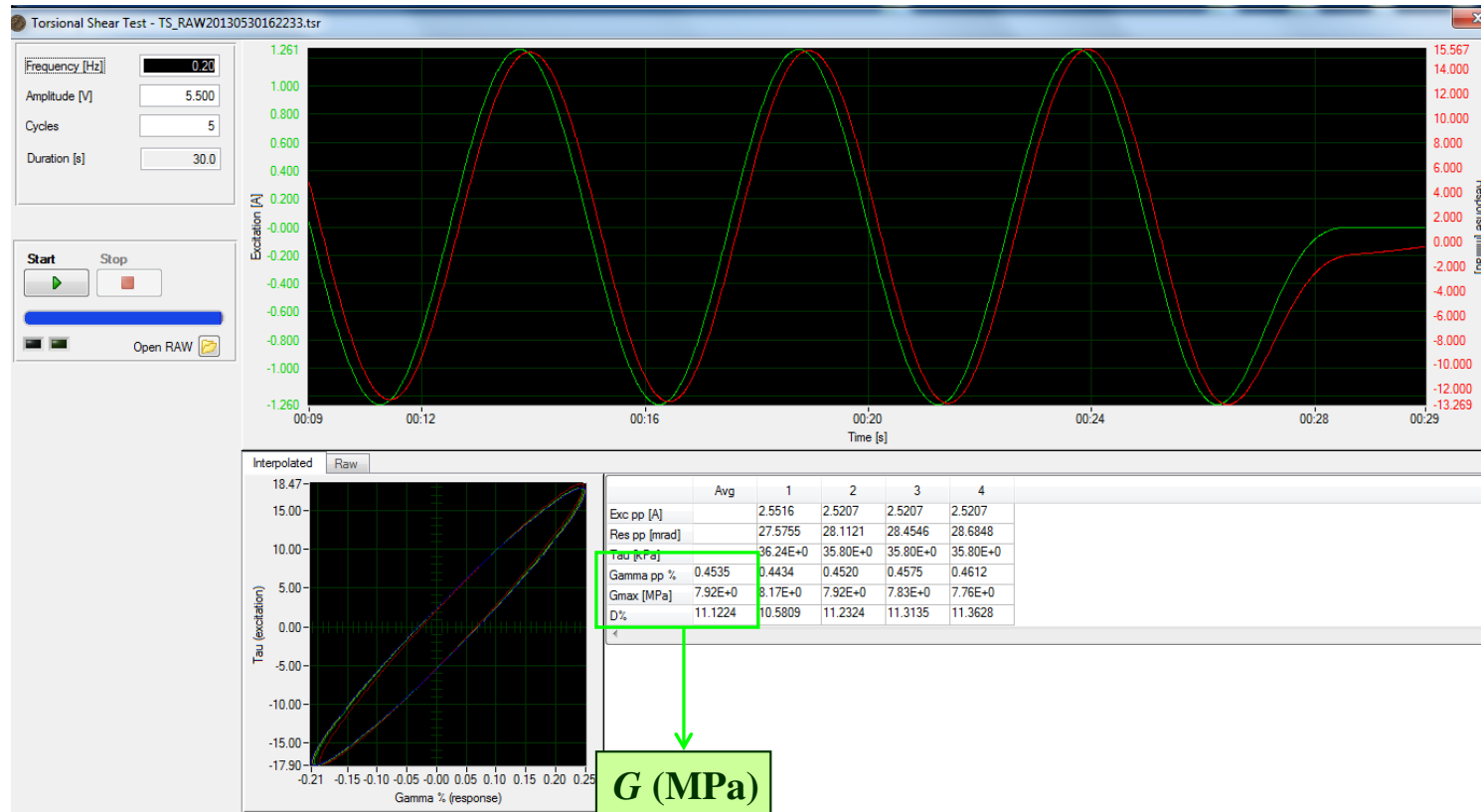


COLONNA RISONANTE





TAGLIO TORSIONALE



G (MPa)

D (%)

γ (%)

TRIASSIALE CICLICO

L'apparecchio consiste in:

- ❖ una **cella triassiale** posizionata al di sotto di un sistema di contrasto;
- ❖ un **sistema elettropneumatico**, costituito da un generatore di funzioni elettrico, che produce un segnale successivamente convertito in un segnale pneumatico per l'azionamento di un cilindro (**attuatore**) che produce sforzi assiali ciclici.
- ❖ un **registratore oscillografico** e un **registratore digitale** a 4 canali collegato a un computer, che consente di registrare i carichi assiali, le deformazioni assiali, le pressioni di cella e le pressioni interstiziali.

Riferimenti Normativi

ASTM D 3999-91 (2003)

ASTM D 5311-92 (2004)



PROVA TRIASSIALE CICLICA (TxC)

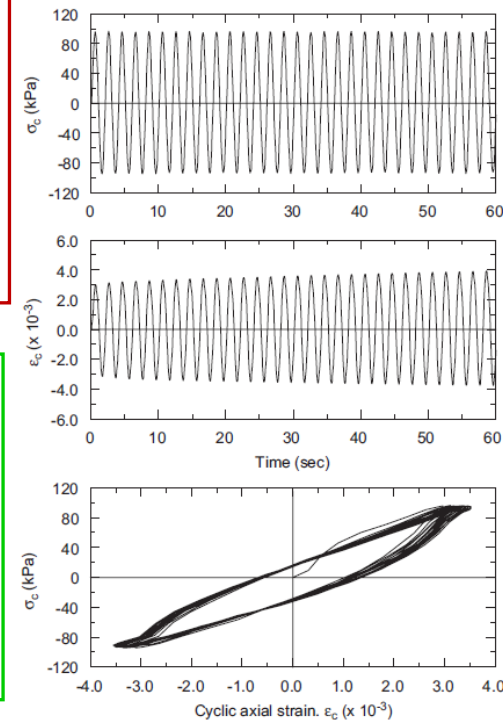
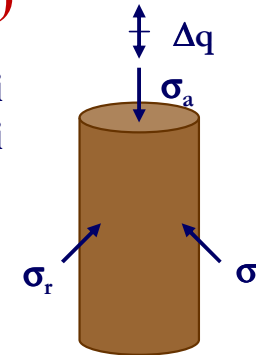
Le prove triassiali cicliche vengono eseguite a frequenze f variabili nell'intervallo tra **0.01 - 1 Hz** e deformazioni di taglio γ variabili nell'intervallo **10^{-2} - 5 %**.

La prova triassiale ciclica prevede tre fasi:

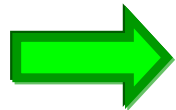
- ❖ **consolidazione** isotropicamente o anisotropicamente;
- ❖ **applicazione del carico assiale ciclico** in condizioni non drenate a sforzo o deformazione controllati;
- ❖ **riconsolidazione** del provino mediante l'apertura dei drenaggi e consentendo la dissipazione delle sovrappressioni interstiziali.

I risultati di una prova triassiale ciclica consentono di rappresentare:

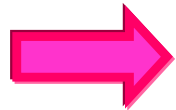
- ❖ l'andamento nel tempo dei **carichi**, delle **deformazioni** assiali e delle pressioni interstiziali;
- ❖ i **cicli di isteresi** sul piano $\tau - \gamma$;
- ❖ i parametri G e D ad alti livelli deformativi.



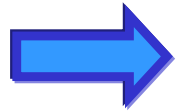
CASI DI STUDIO



Catania - ST Microeletronic Modulo M6



Enna - Laboratorio “LEDA”



Saline di Augusta - IACP di Siracusa





CASE STUDY

ST MICROELETTRONIC - CATANIA



**SECOND INTERNATIONAL CONFERENCE ON PERFORMANCE-BASED DESIGN IN
EARTHQUAKE GEOTECHNICAL ENGINEERING**

TAORMINA CONFERENCE CENTER - May 28 - 30, 2012 TAORMINA (ITALY)

**DYNAMIC CLAY PROPERTIES BY IN SITU AND LABORATORY TESTS
FOR AN INDUSTRIAL BUILDING IN CATANIA (ITALY)**

Francesco CASTELLI, Valentina LENTINI, Michele MAUGERI

ST MICROELECTRONIC - CATANIA

On September 2000 in the industrial area of **Catania** (Sicily, Italy) started the construction of a reinforced concrete building on clayey deposits.

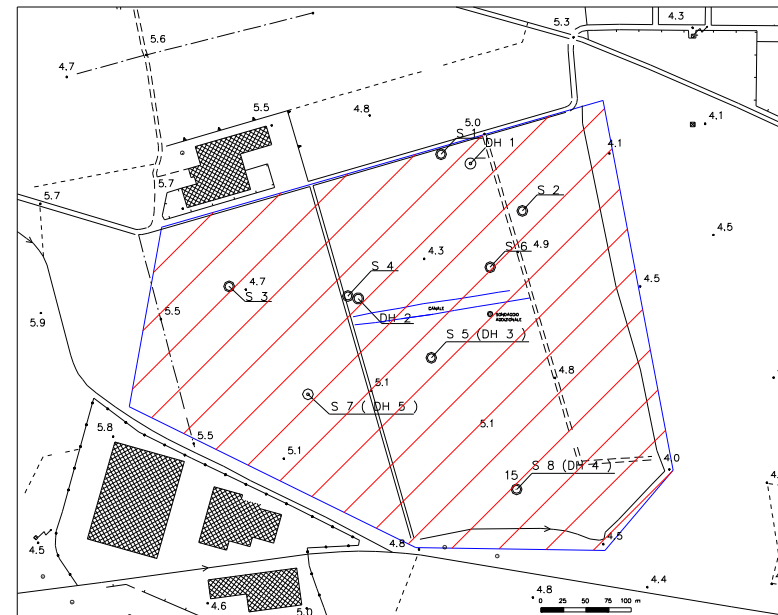
- ❖ The site was well investigated by in **situ** and in **laboratory** test.
- ❖ Boreholes, SPT, CPT, PLT and **dynamic in situ tests** were carried out. Among them Down-Hole (DH), Cross-Hole (CH), SASW and Seismic Dilatometer Marchetti Tests (SDMT) have been carried out with the aim to evaluate the **shear waves velocity profile (V_s)**.
- ❖ **Laboratory tests** were carried out on undisturbed samples, such as: Oedometer test, Direct Shear Test, Triaxial Test, Resonant Column and Torsional Shear Test.



IN SITU TEST

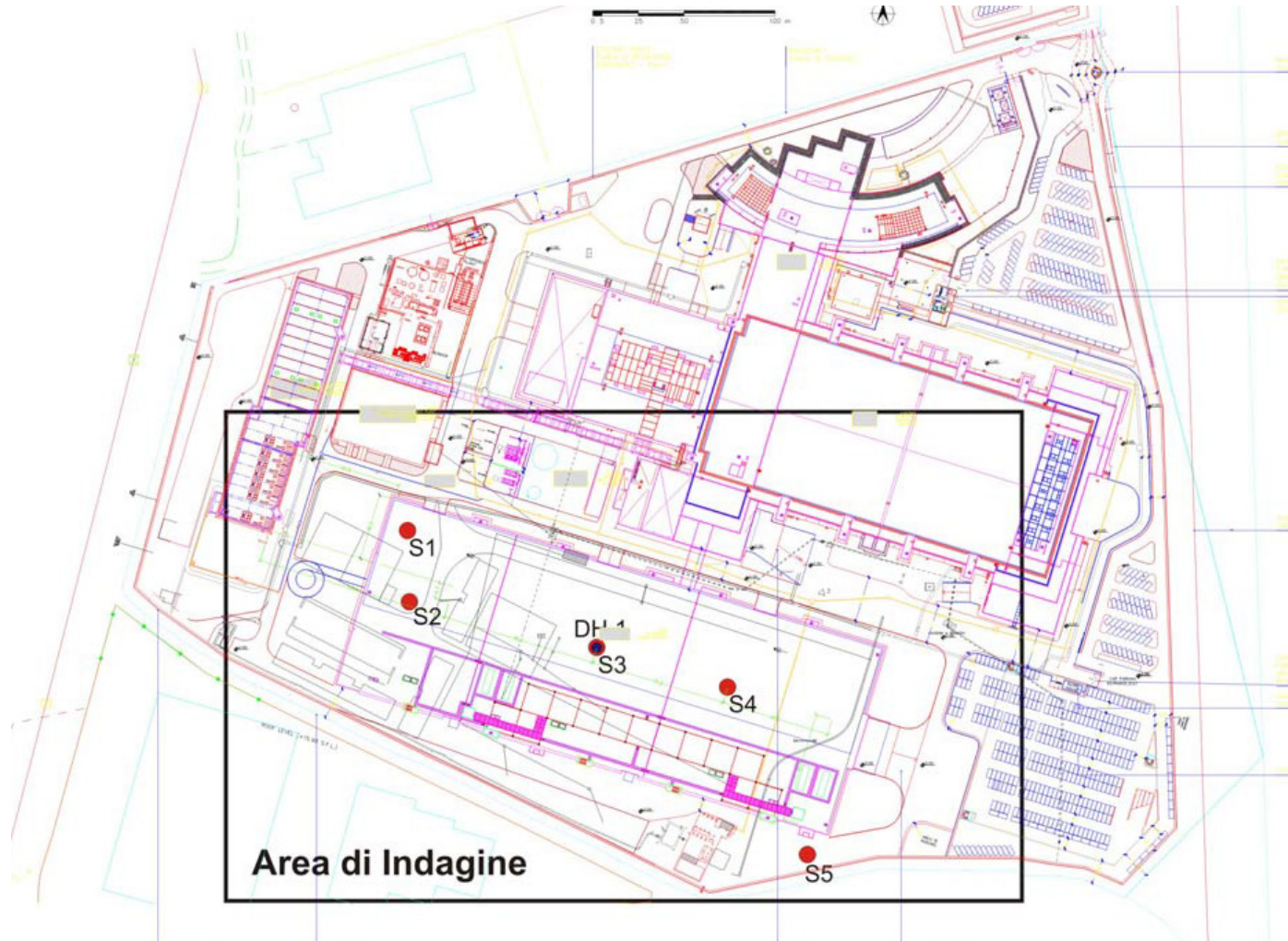
To evaluate the geological profile and the geotechnical properties of the soil, the site was well investigated by means of in-situ tests as well as laboratory tests

- ❖ **no.8 boreholes**, performed to a maximum depth of 100 m;
- ❖ **Standard Penetration Tests (SPT)** inside the boreholes S3-S8 ;
- ❖ **Down-Hole Tests (DH)** inside the boreholes S3-S8 ;
- ❖ **no.22 Cone Penetration Tests (CPTU)**;
- ❖ **no.15 Plate Loading Tests (PLT)**;
- ❖ **Spectral Analysis of Surface Wave (SASW)**;
- ❖ **Seismic Dilatometer Marchetti Tests (SDMT)**

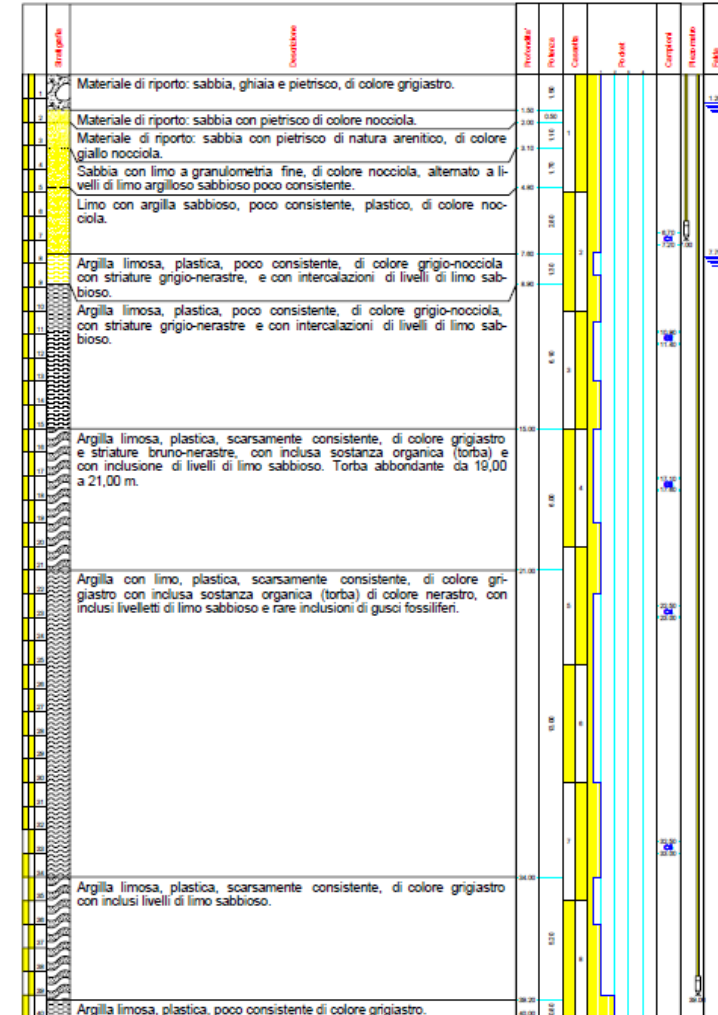




IN SITU TEST



SONDAGGIO S2



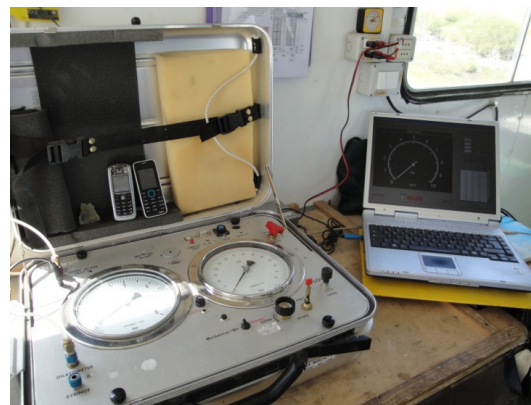


The index properties and the mechanical characteristics of the soil have been evaluated from laboratory tests, classifying the soil as clayey-silt and silty-clay.

- ❖ Liquidity limit w_l varies from 40 up 70%;
- ❖ Plasticity limit w_p is about 35%;
- ❖ Consistence index I_c varies from 0.4 up 1.0;
- ❖ Natural moisture content w_n ranges between 30 and 50% as depth increasing;
- ❖ Unit weight γ varies from 15.74 up to 18.21 kN/m³.

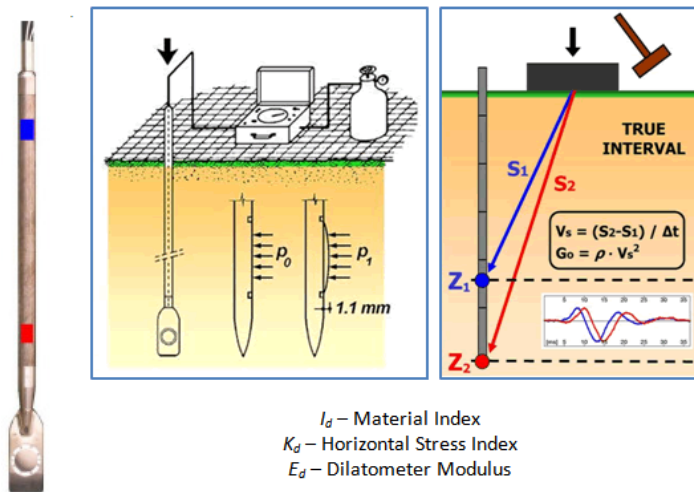
Tests	Depth (m)	γ (kN/m ³)	G_s (kN/m ³)	w_n (%)	w_l (%)	w_p (%)	I_p	I_L	I_c
S1 C1	5,50 - 6,00	17,93	2,65	31,87	34,37	21,66	12,71	0,80	0,20
S1 C2	11,10 - 11,60	17,51	2,60	48,65	59,60	36,29	23,32	0,53	0,47
S1 C3	18,00 - 18,50	16,46	2,61	58,50	72,00	39,87	32,16	0,58	0,40
S1 C4	25,00 - 25,50	17,37	2,61	48,32	66,58	48,32	24,99	0,27	0,73
S1 C5	39,50 - 40,00	17,42	2,67	36,03	59,22	34,85	24,37	0,05	0,95
S2 C1	6,70 - 7,20	17,65	2,62	37,41	49,33	30,52	18,81	0,37	0,63
S2 C2	10,90 - 11,40	17,55	2,60	44,06	56,44	31,41	25,00	0,50	0,50
S2 C3	17,10 - 17,60	16,76	2,61	50,58	65,93	34,74	31,19	0,51	0,49
S2 C4	22,50 - 23,00	18,01	2,66	41,93	55,23	35,58	19,65	0,32	0,68
S2 C5	32,50 - 33,00	17,45	2,68	56,89	61,32	39,41	21,91	0,80	0,20
S3 C1	3,80 - 4,30	18,21	2,61	29,84	29,68	23,46	6,21	1,03	--
S3 C2	15,30 - 15,80	16,28	2,59	55,17	68,67	36,92	31,75	0,57	0,43
S3 C3	22,00 - 22,50	17,45	2,66	72,70	64,22	41,01	23,21	1,37	--
S3 C4	27,00 - 27,50	15,74	2,58	53,56	73,22	40,79	32,43	0,39	0,61
S3 C5	35,50 - 36,00	17,36	2,68	50,74	61,65	41,39	20,26	0,46	0,54
CPTU2	56,00 - 56,50	17,37	2,66	34,74	66,22	37,56	28,67	--	1,10

IN SITU TEST BY SDMT - ST MICROELECTRONIC (Catania)



SEISMIC DILATOMETER MARCHETTI TEST

The seismic dilatometer (*SDMT*) is the combination of the mechanical flat dilatometer (DMT), introduced by Marchetti in 1980, with a seismic module for measuring the shear wave velocity V_s .

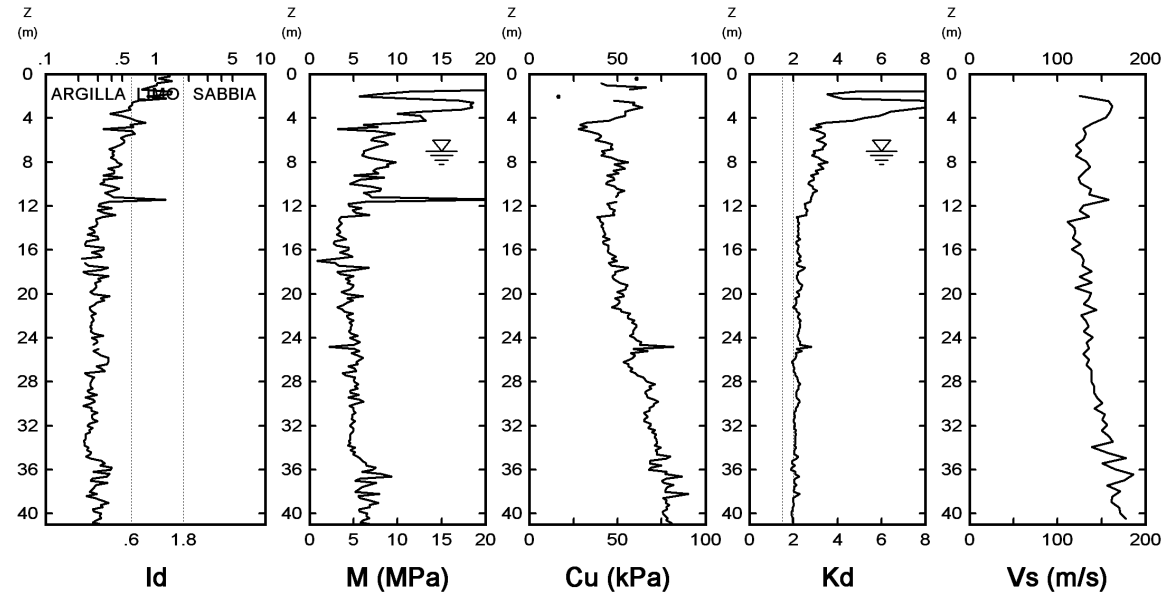


By means of correlations the index parameters are used to interpret the following parameters:

- M - Oedometer modulus (both in cohesive and cohesionless soils)
- c_u - Undrained shear strength (cohesive soils)
- K_0 - In situ earth pressure coefficient (cohesive soils)
- OCR - Overconsolidation ratio (cohesive soils)
- Φ - Friction angle (cohesionless soils)

- ❖ The seismic module is a cylindrical element placed above the DMT blade, provided with two receivers spaced 0.50 m.
- ❖ V_s is obtained as the ratio between the distance of 0.50 m between the two receivers ($S_2 - S_1$) and the delay of the arrival of the impulse from the first to the second receiver (interval time Δt).
- ❖ V_s measurements are typically obtained every 0.50 m of depth.

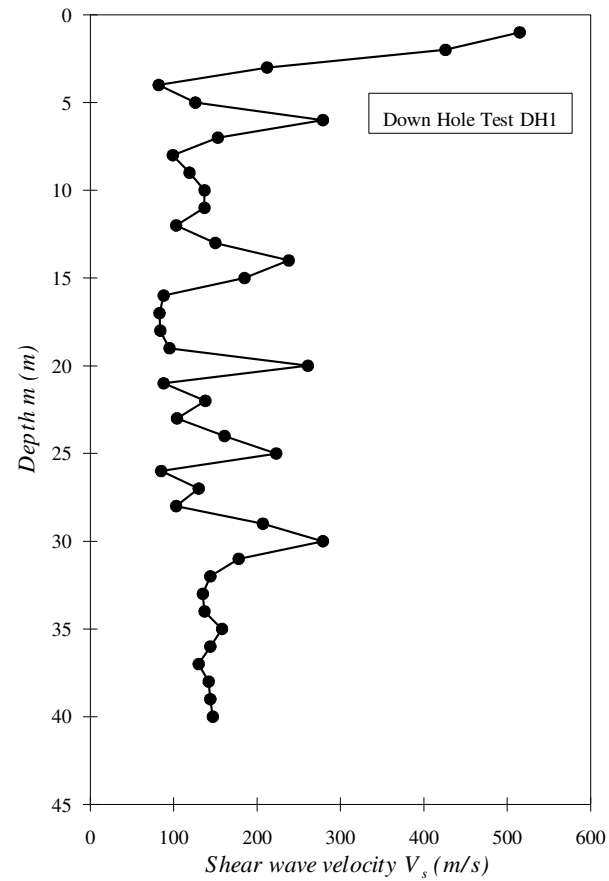
SDMT performed up to a depth of 42 meters



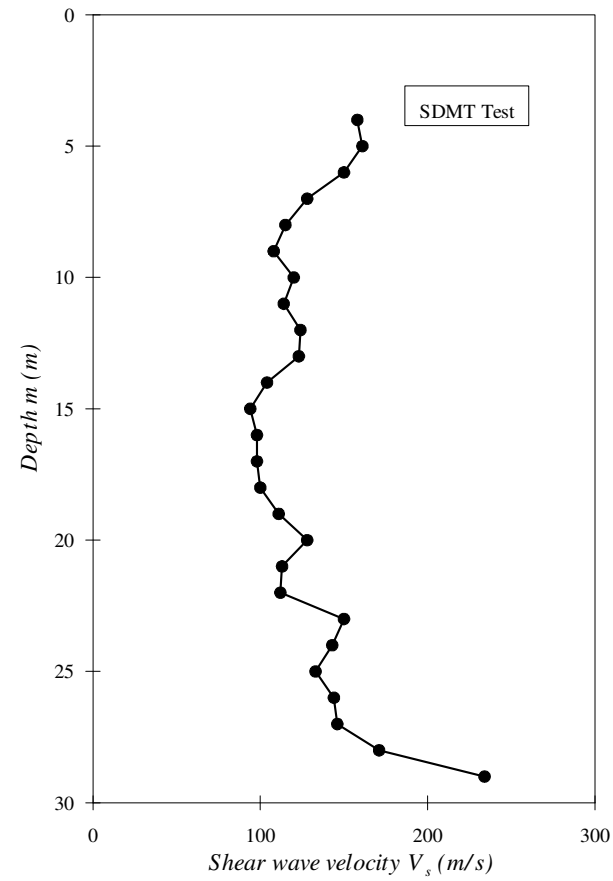
- ❖ The material index I_d values can be classified as clay-siltly material;
- ❖ The constrained Modulus M values assume different values ranging between 2 MPa up to about 20 MPa;
- ❖ The horizontal stress index K_d is similar in shape to the profile of the overconsolidation ratio OCR. $K_d = 2$ indicates in clays OCR = 1;
- ❖ The shear waves velocity V_s generally slight increasing with depth, with an average values of about 100 - 200 m/sec.



**Shear waves velocity profile (V_s) obtained from
Down Hole (a) and SDMT (b) tests.**



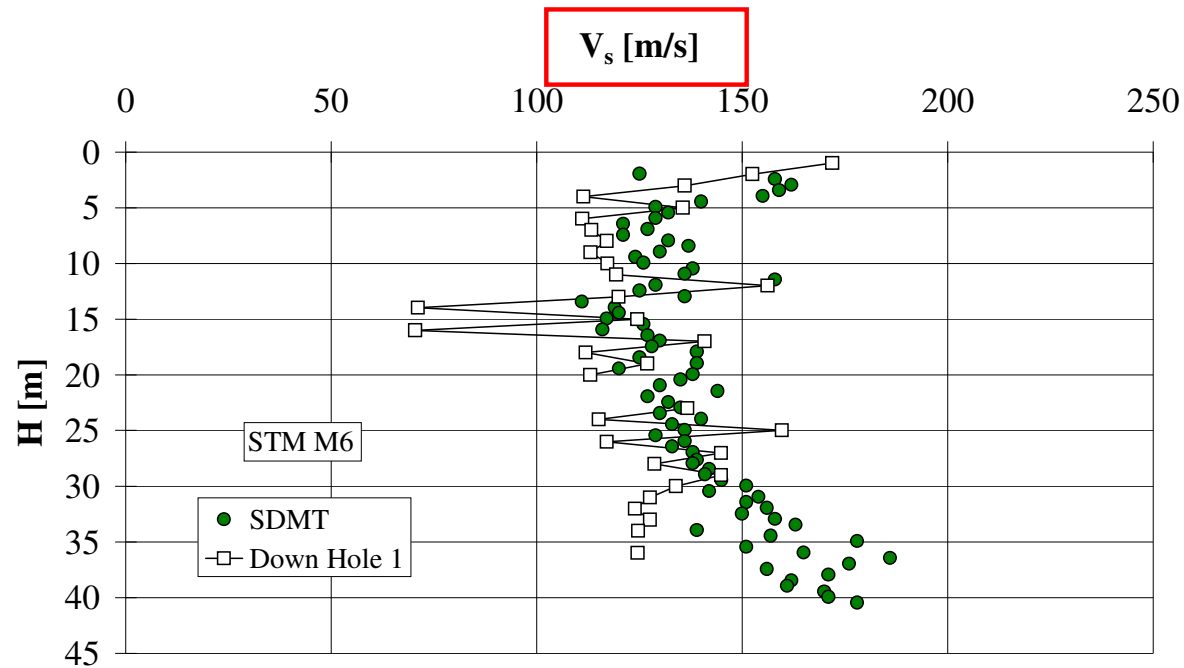
(a)



(b)



COMPARISON BETWEEN IN SITU AND IN LABORATORY TEST



Cavallaro et al. (2008)

Shear wave velocity V_s evaluated by D-H and SDMT

EVALUATION OF SHEAR WAVE VELOCITY BY SPT TESTS

The shear wave velocity V_s can be evaluated by means of the following empirical correlations based on standard penetration test (SPT) results.

Ohta & Goto (1978)



$$V_s = 54.33 \cdot (N_{SPT})^{0.173} \cdot \alpha \cdot \beta \cdot \left(\frac{z}{0.303} \right)^{0.193}$$

Yoshida & Motonori (1988)



$$V_s = \beta \cdot (N_{SPT})^{0.25} \cdot \sigma'_{vo}{}^{0.14}$$

Imai & Yoshimura (1970)



$$V_s = 76 \cdot (N_{SPT})^{0.33}$$

Ohba & Toriumi (1970)



$$V_s = 8 \cdot (N_{SPT})^{0.31}$$

N_{SPT} = number of blows from SPT

$$G_o = \rho \cdot V_s^2$$

ρ = mass density of the soil



EVALUATION OF SHEAR MODULUS G_o FROM EMPIRICAL CORRELATIONS

It is possible to evaluate G_o by means of empirical correlations based on standard (CPT) and Seismic Dilatometer Marchetti Test (SDMT) results

Hryciw (1990)



$$G_o = \frac{530}{\left(\sigma'_v / p_a\right)^{0.25}} \cdot \frac{\gamma_D / \gamma_w - 1}{2.7 - \gamma_D / \gamma_w} \cdot K_o^{0.25} \cdot \left(\sigma'_v - p_a\right)^{0.5}$$

Mayne & Rix (1993)



$$G_o = \frac{406 \cdot q_c^{0.696}}{e^{1.13}}$$

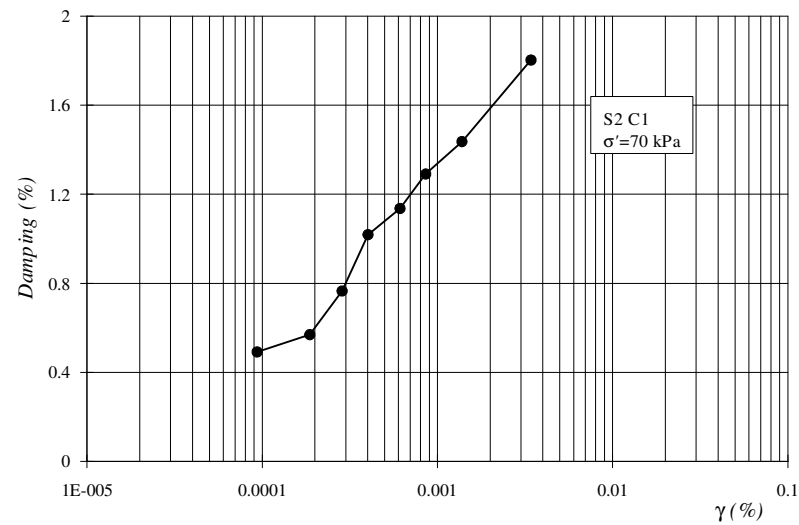
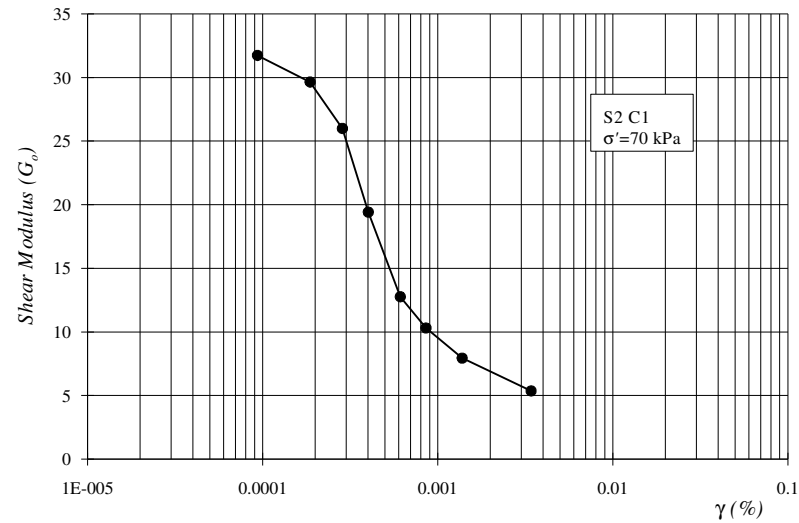
Jamolkowski et al. (1995)



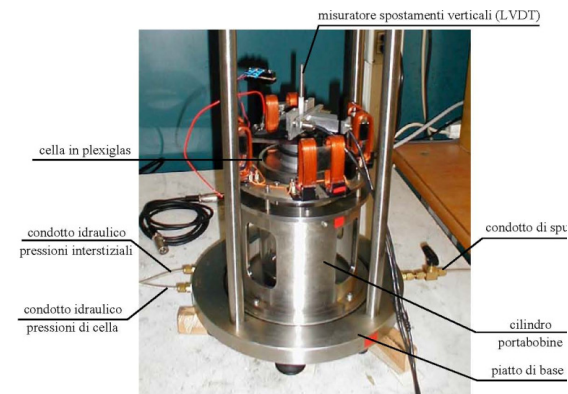
$$G_o = \frac{600 \cdot \sigma_m'^{0.5} \cdot p_a^{0.5}}{e^{1.3}}$$

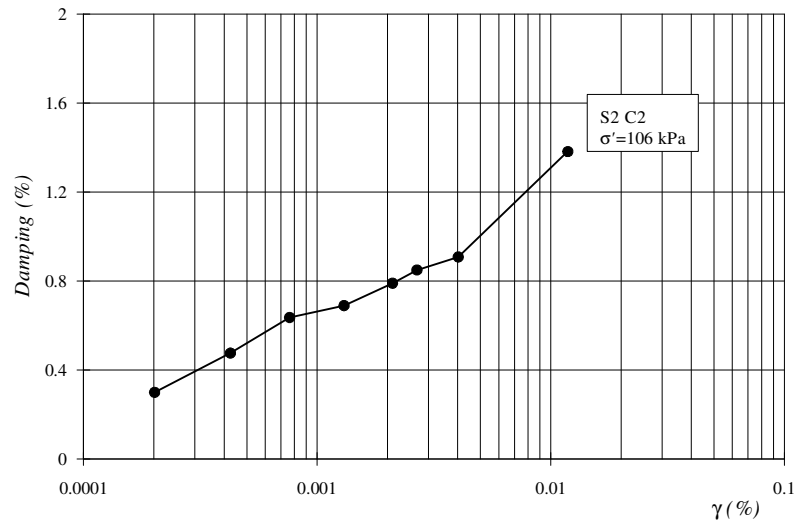
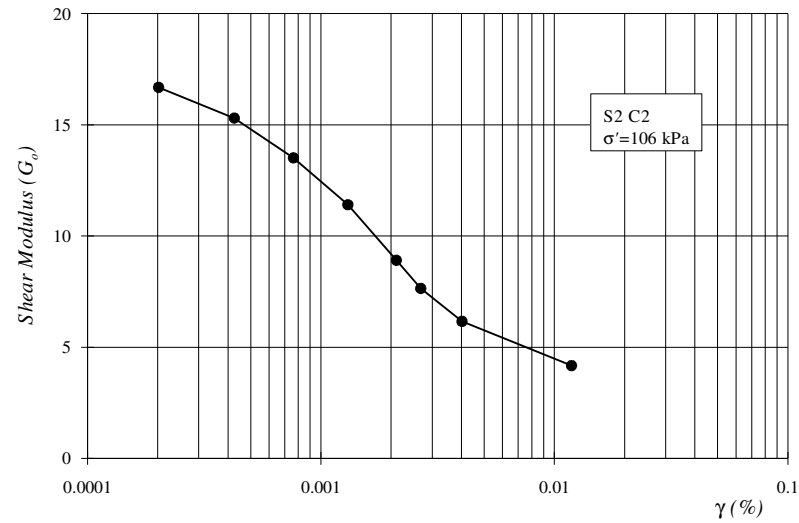


Shear modulus G_o and damping D versus shear strength γ for soil sample S2 C1.



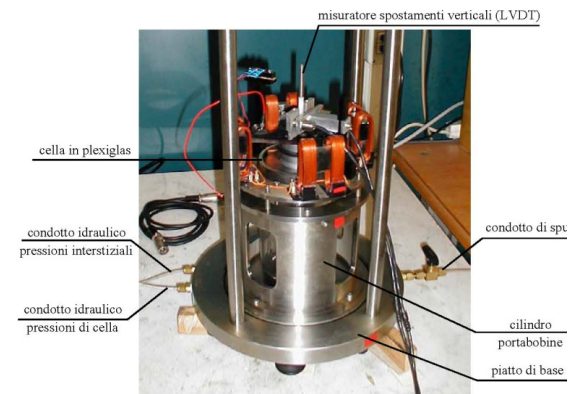
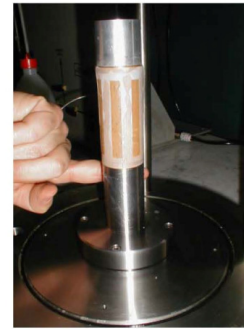
Resonant Column Test



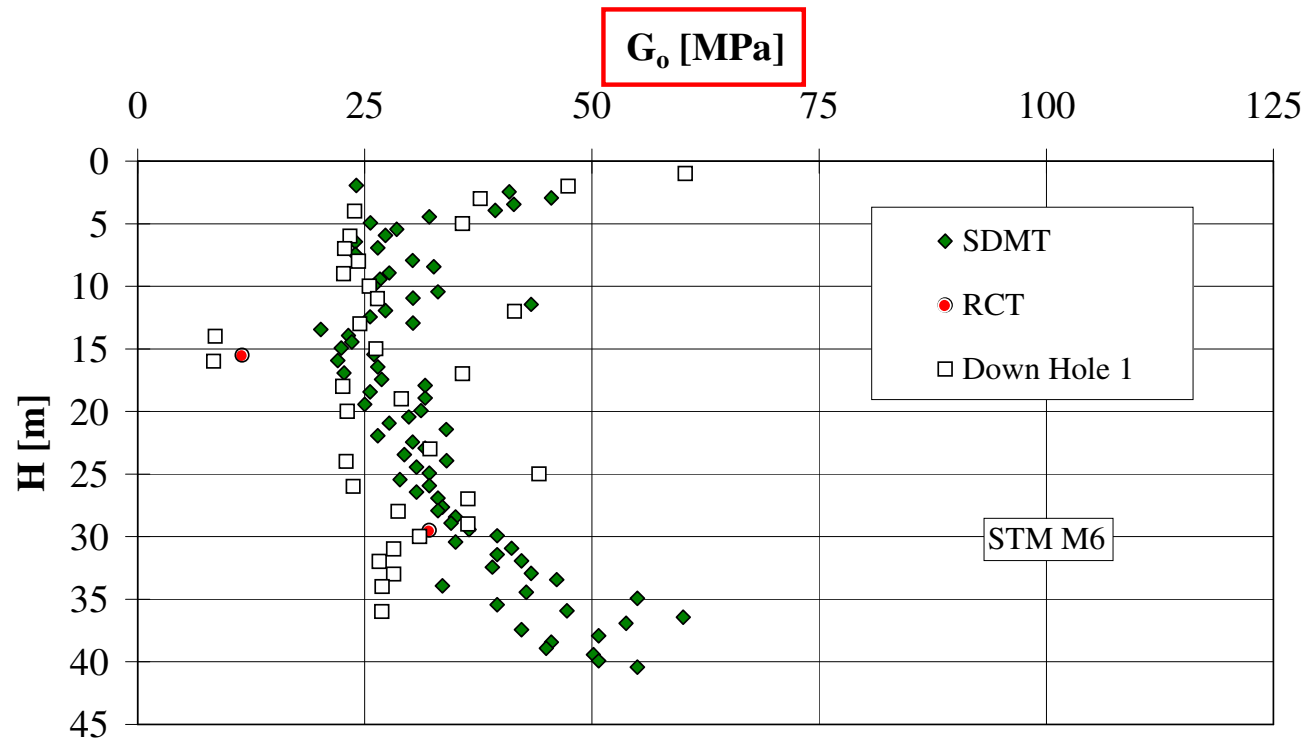


Shear modulus G_0 and damping D versus shear strength γ for soil sample S2 C2.

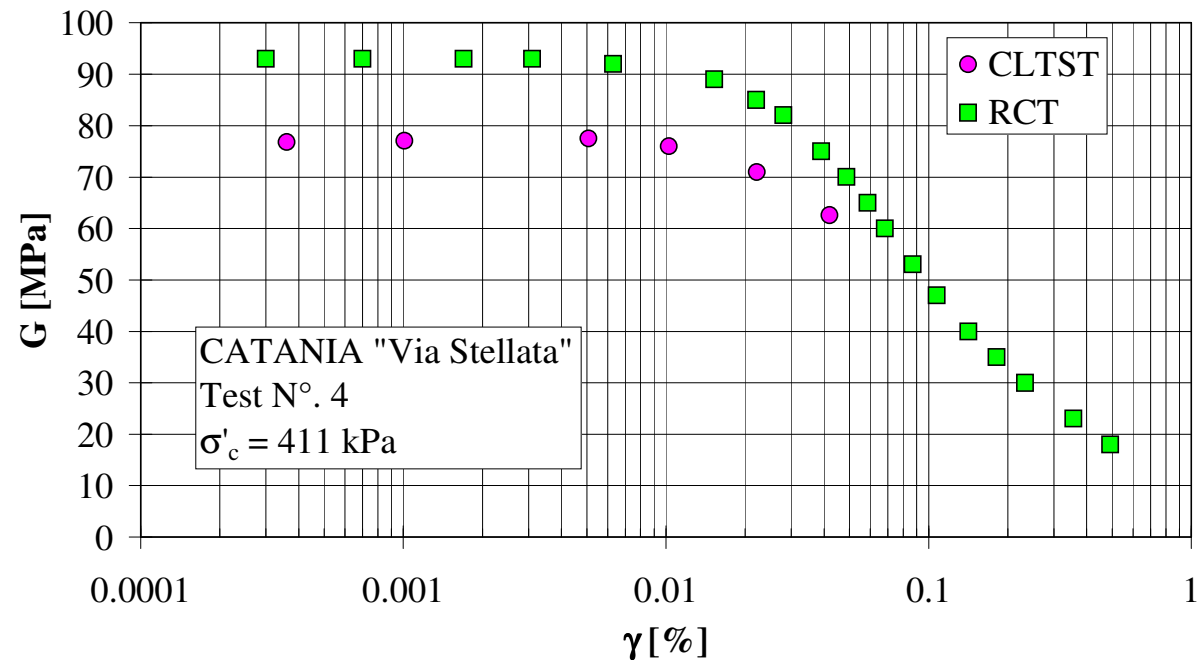
Resonant Column Test



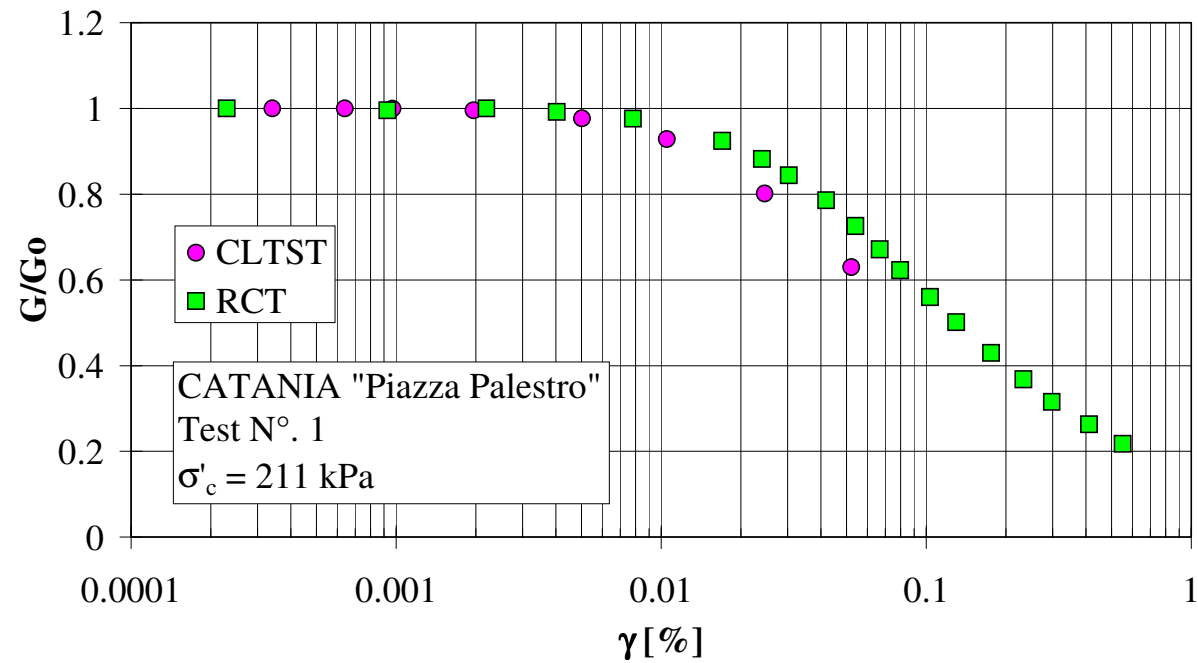
COMPARISON BETWEEN IN SITU AND IN LABORATORY TEST



Cavallaro A., Grasso S., Lentini V. & Maugeri M. (2008). Geotechnical characterization of a soft clay soil subjected to a preloading embankment. Proc. 6th International Conference on Case Histories in Geotechnical Engineering, Arlington, VA, August 11-16, 2008.



**Modulo di taglio da prove Torsionali Cicliche e di
Colonna Risonante (*Via Stellata*)**



**Modulo di taglio normalizzato da prove Torsionali
Cicliche e di Colonna Risonante (*Piazza Palestro*)**



DECADIMENTO DEL MODULO DI TAGLIO CON IL LIVELLO DI DEFORMAZIONE

EQUAZIONE DI YOKOTA *et al.* (1981)

$$\frac{G(\gamma)}{G_o} = \frac{1}{1 + \alpha \gamma (\%)^\beta}$$

dove:

- $G(\gamma)$ = modulo di taglio dipendente dalla deformazione;
- γ = deformazione di taglio;
- α, β = costanti del terreno.



SHEAR MODULUS AND DAMPING RATIO VERSUS STRAIN LEVEL FROM RC TESTS

The experimental results of specimens obtained by RCT were used to determine the empirical parameters of the equation proposed by *Yokota et al. (1981)*

Yokota et al. (1981)

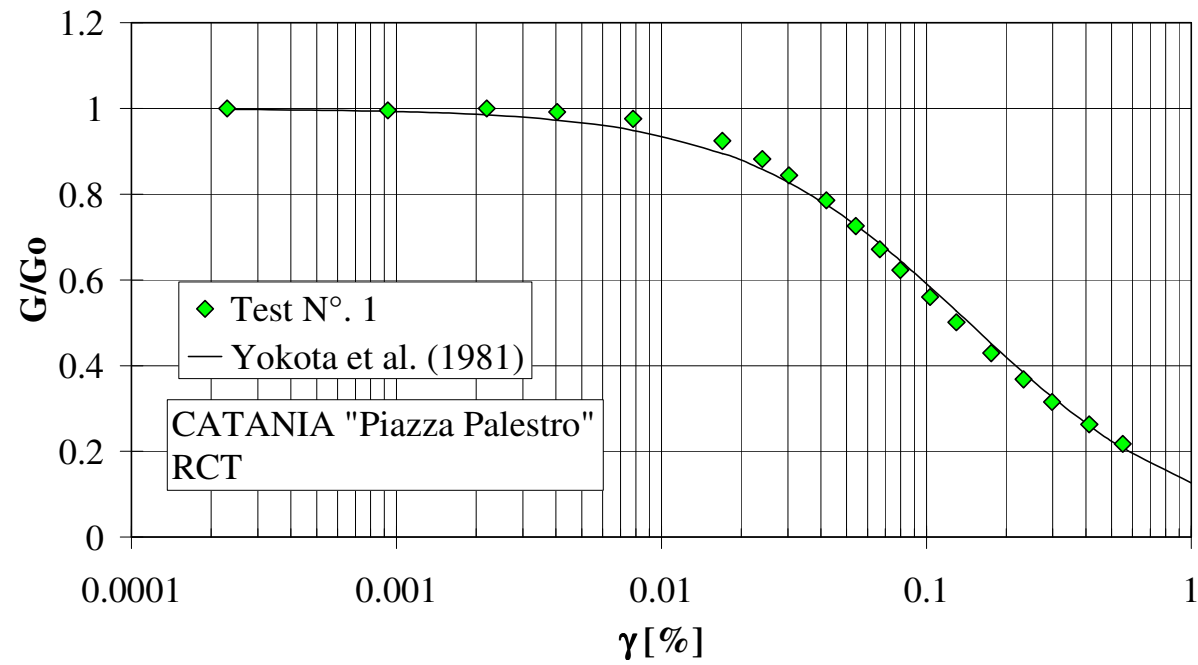


$$\frac{G(\gamma)}{G_o} = \frac{1}{1 + \alpha \gamma(\%)^\beta}$$

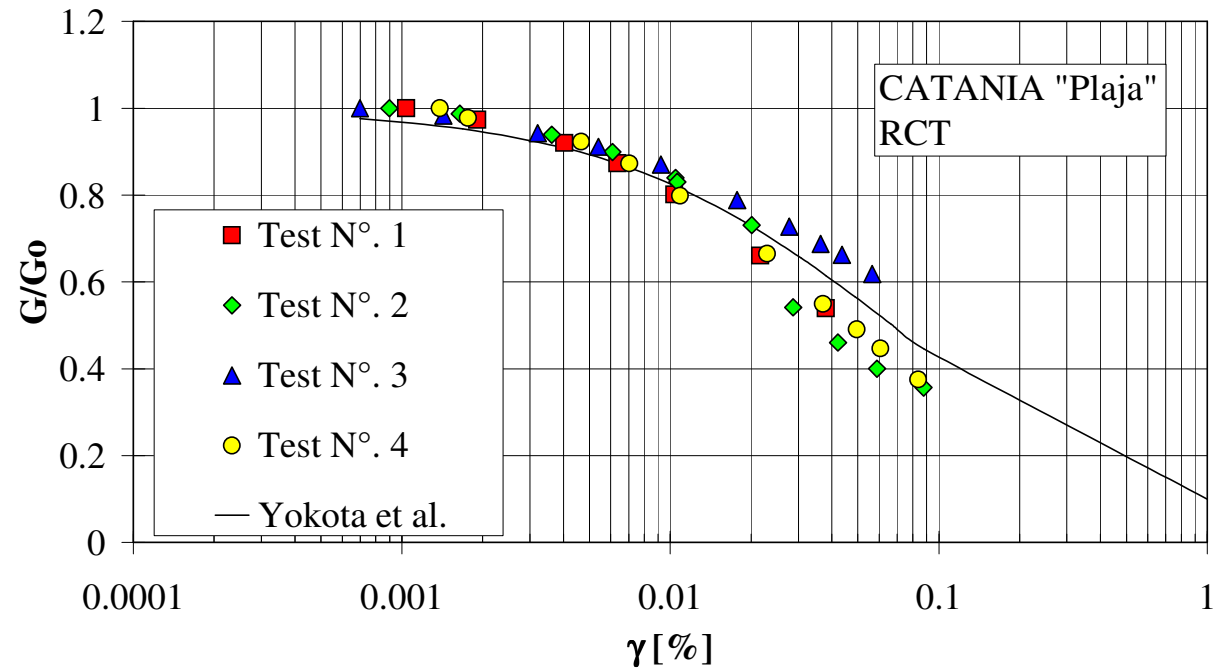
$$D(\gamma)(\%) = \eta \cdot \exp \left[-\lambda \cdot \frac{G(\gamma)}{G_o} \right]$$

$\alpha = 7.15$ and $\beta = 1.223$ were obtained for the Catania clay (Sicily, Italy) by **Carrubba and Maugeri (1988)**.

$\eta = 28.12$ and $\lambda = 2.50$ were obtained for the Catania clay (Sicily, Italy) by **Carrubba and Maugeri (1988)**.



**Curve G/G_0 - γ da prove di Colonna Risonante
(*Piazza Palestro*)**



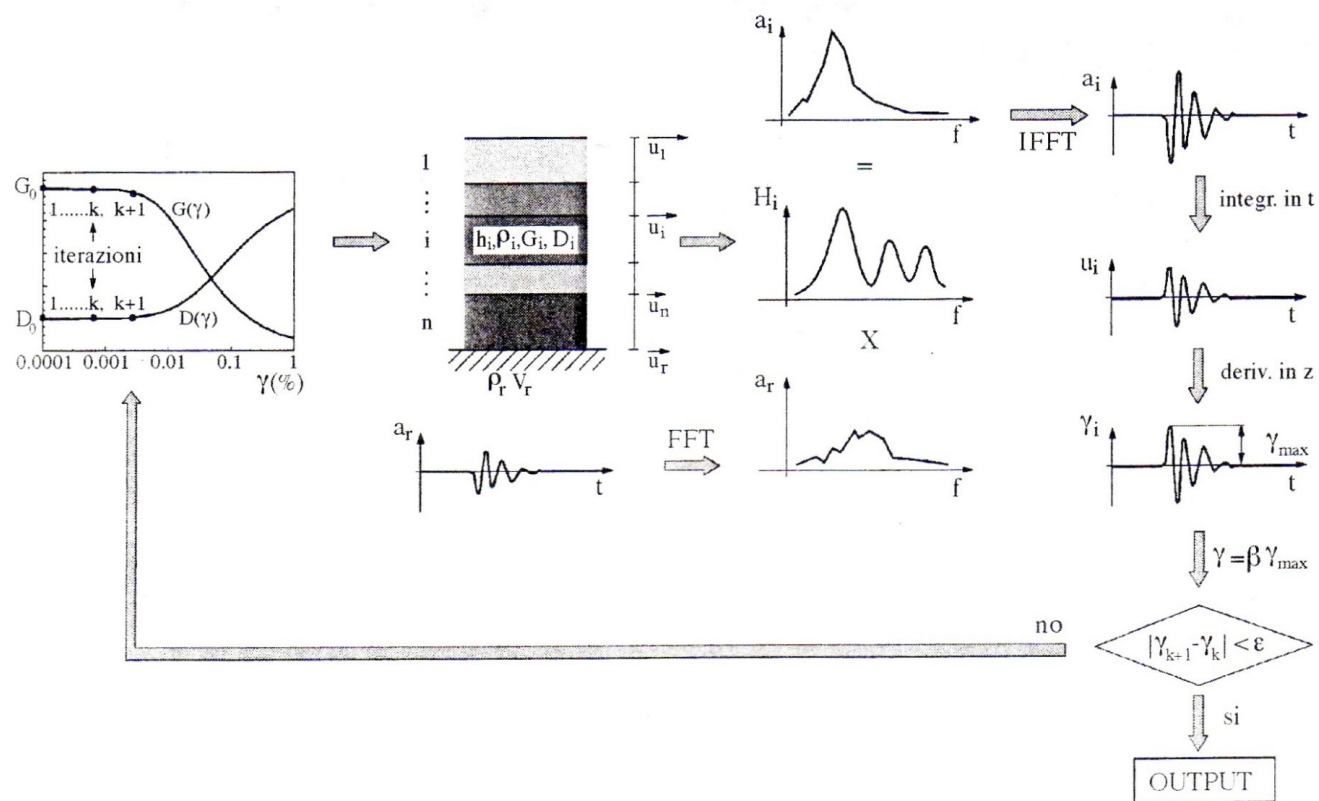
Curve G/G_0 - γ da prove di Colonna Risonante (*Plaja*)



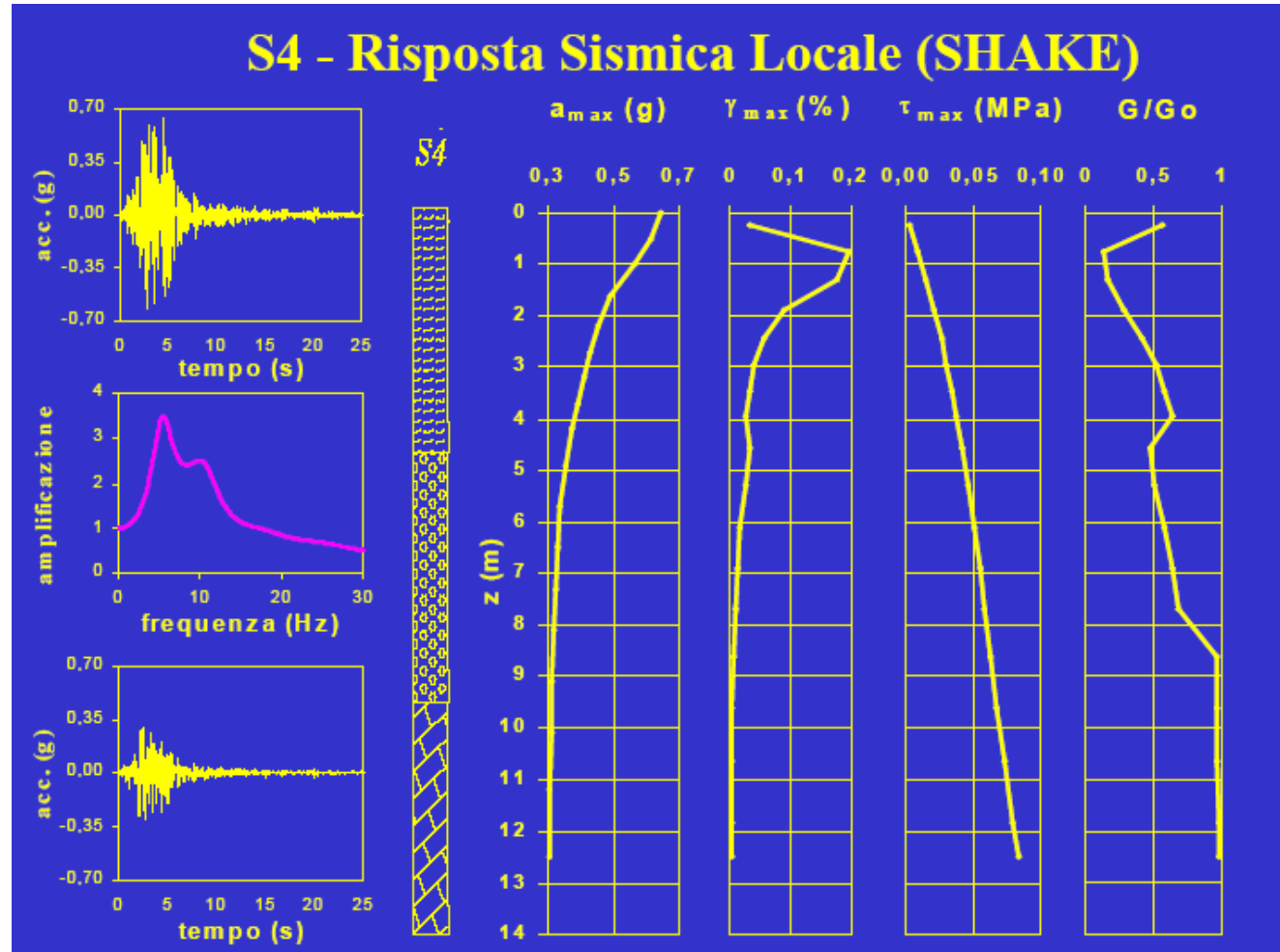
SOIL CONSTANT VALUES FOR EVALUATION OF $G(\gamma)$ and $D(\gamma)$

- ❖ sites no. **1, 2** and **12** clayey soil in the Catania plain;
- ❖ site no. **3** silica sandy soil;
- ❖ sites no. **5** and **11** clayey soil in the central area;
- ❖ site no. **6** volcanic sand;
- ❖ sites no. **7** and **9** scoriaceous lava;
- ❖ site no. **8** clayey soil in the central area.

1 Sito	α	β	η	λ
2 Piana di Catania (STM - M5)	21,225	1,325	18,69	-1,642
3 Piana di Catania (ENEL box)				
4 Piana di Catania (STM – M6)				
5 Plaja beach	9	0,815	80	4
6 Tavoliere	--	--	--	--
7 Via Stellata	11	1,119	31	1,92
8 Villa Comunale				
9 Piazza Palestro	6,9	1	23	2,21
10 San Nicola alla Rena Church	7,5	0,897	90	4,5
11 Via Monterosso				
12 Via Dottor Consoli	16	1,2	33	2,4
13 Monte Po	--	--	--	--



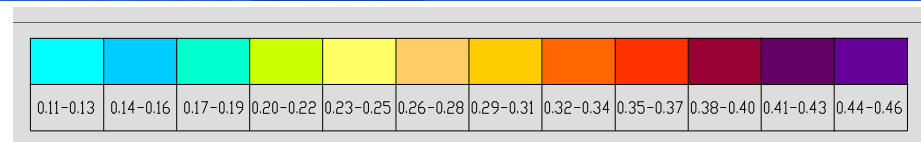
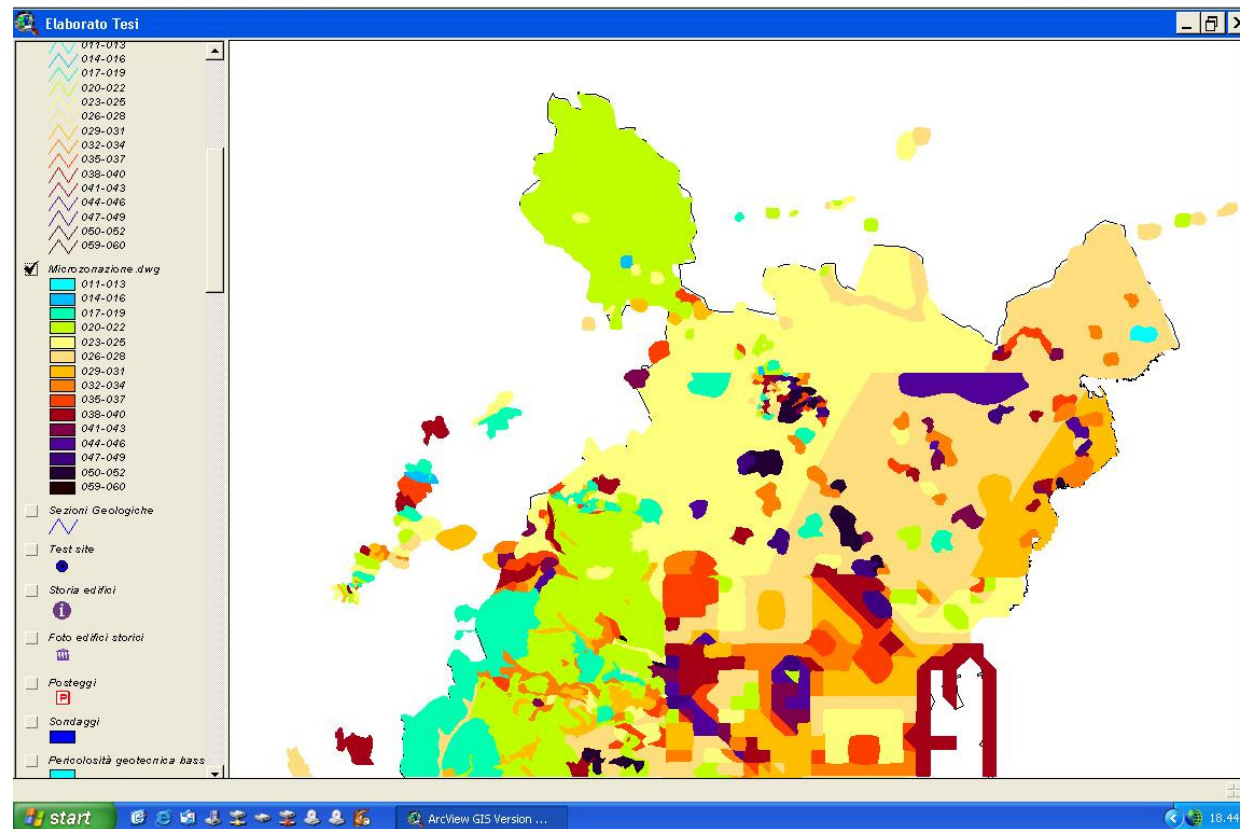
Modellazione numerica monodimensionale: codice SHAKE (Schnabel et al., 1972)



Modellazione numerica monodimensionale: codice SHAKE (Schnabel et al., 1972)



MICROZONATION FOR GROUND MOTION OF THE CATANIA CITY





CASO STUDIO **ISTITUTO AUTONOMO CASE POPOLARI - AUGUSTA**



**POST-EARTHQUAKE ANALYSIS FOR A SEISMIC RETROFITTING:
THE CASE HISTORY OF A PILED FOUNDATION IN AUGUSTA (ITALY)**

Michele MAUGERI & Francesco CASTELLI



IACP - AUGUSTA

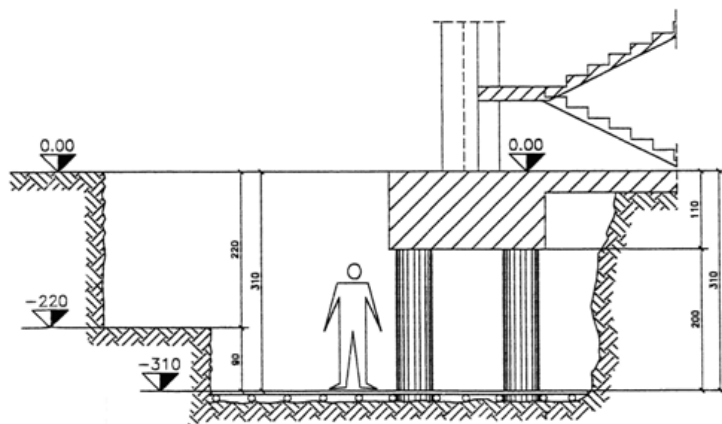
- ❖ **IACP Augusta (Siracusa)**
- ❖ **Adeguamento sismico lotto 100 alloggi**
- ❖ **Edificio Pilota - 20 alloggi**
- ❖ **Danneggiato dal terremoto del 13.12.1990**



Danni nell'edificio in c.a. da adeguare sismicamente

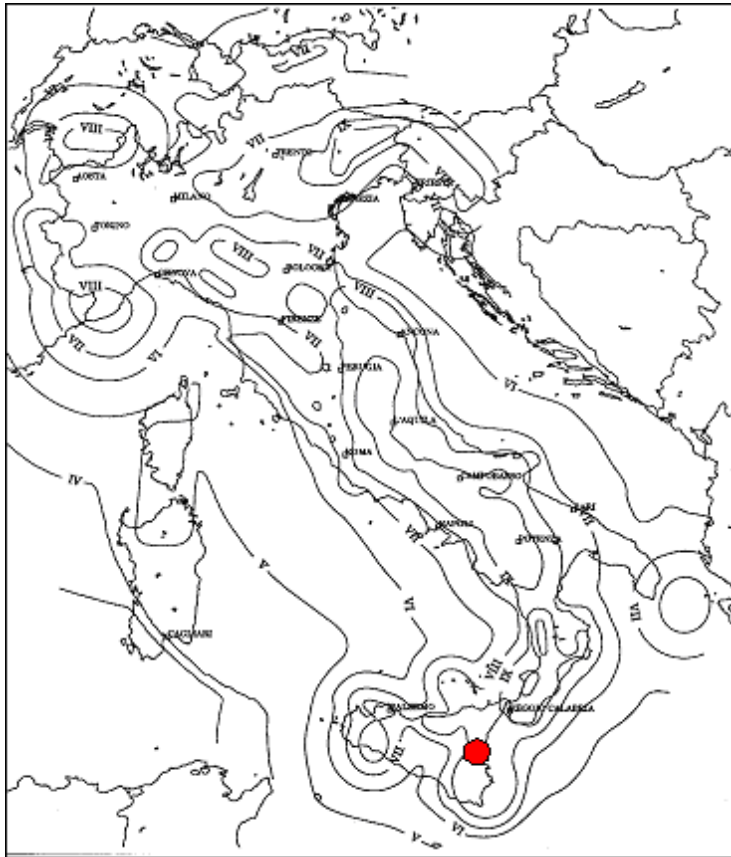


Indagini sulle fondazioni dell'edificio in c.a.

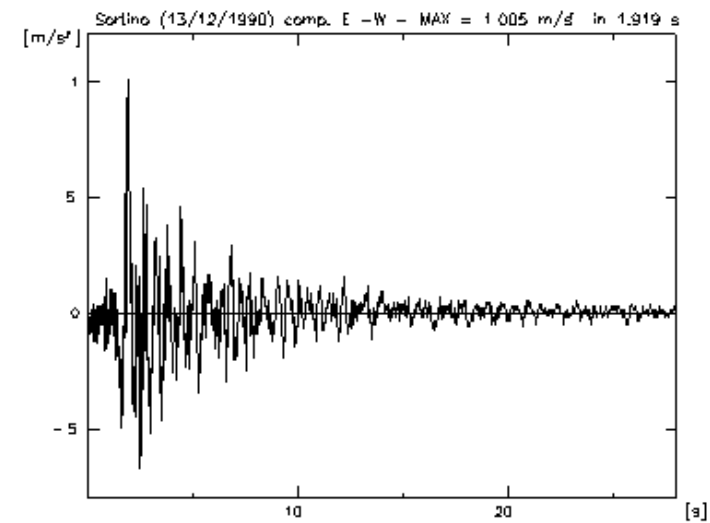




Localizzazione del Sito in Esame



Registrazione di Sortino (SR) Componente E-W



Terremoto Sicilia Orientale del 13.12.1990



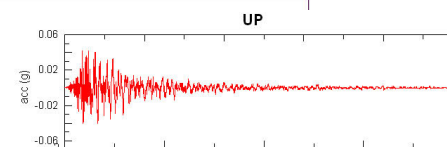
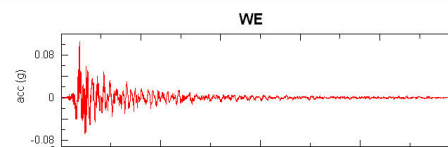
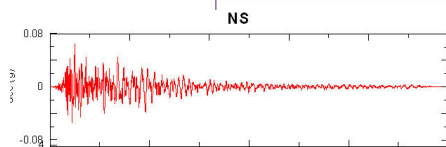
Sicilia Orientale 13.12.1990

General Data

<i>Eqk Name</i>	Sicilia-Orientale	<i>Station Name</i>	Sortino	
<i>Eqk Date</i>	13/12/1990	<i>Epicentral Distance [km]</i>	28.48	
<i>Eqk Time</i>	00:24:26	<i>J&B Distance [km]</i>	0.0	
<i>Ml</i>	5.4	<i>Hypocentral Distance [km]</i>	29.33	
<i>Local Intensity</i>	Unknown	<i>Closest Distance [km]</i>	0.0	
		<i>Azimuth</i>	0	

Ground Motion Parameter Values

	NS	WE	NS-WE Mean	UP
<i>PGA [g]</i>	0.064	0.106	0.082	0.042
<i>PGV [cm/s]</i>	3.193	7.013	4.732	2.551
<i>PGD [cm]</i>	0.394	1.266	0.706	0.357
<i>Sa (1.0 s) [g]</i>	0.042	0.098	0.064	0.019
<i>Predominant Period [s]</i>	0.08	0.08	0.08	0.08
<i>Mean Period [s]</i>	0.37	0.46	0.41	0.39
<i>Arias Intensity [m/s]</i>	0.0472	0.0545	0.0507188	0.0223
<i>Housner Intensity</i>	0.0	0.0	0.0	0.0
<i>Uniform Duration [s]</i>	14.19	8.16	10.76	12.97
<i>Significant Duration [s]</i>	12.4	9.21	10.69	10.12





SITE OF ITALIAN STRONG MOTION ACCELEROGRAMS

<http://sisma.dsg.uniroma1.it>

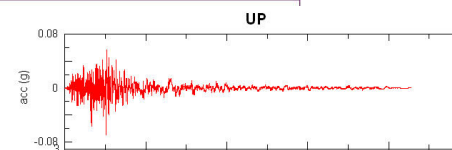
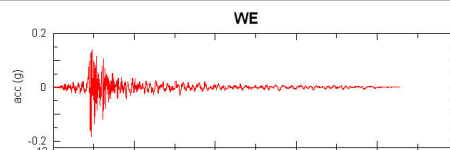
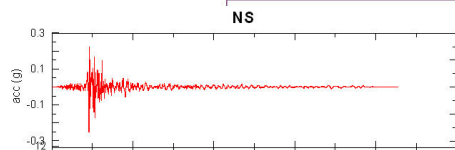
General Data

Sicilia Orientale 13.12.1990

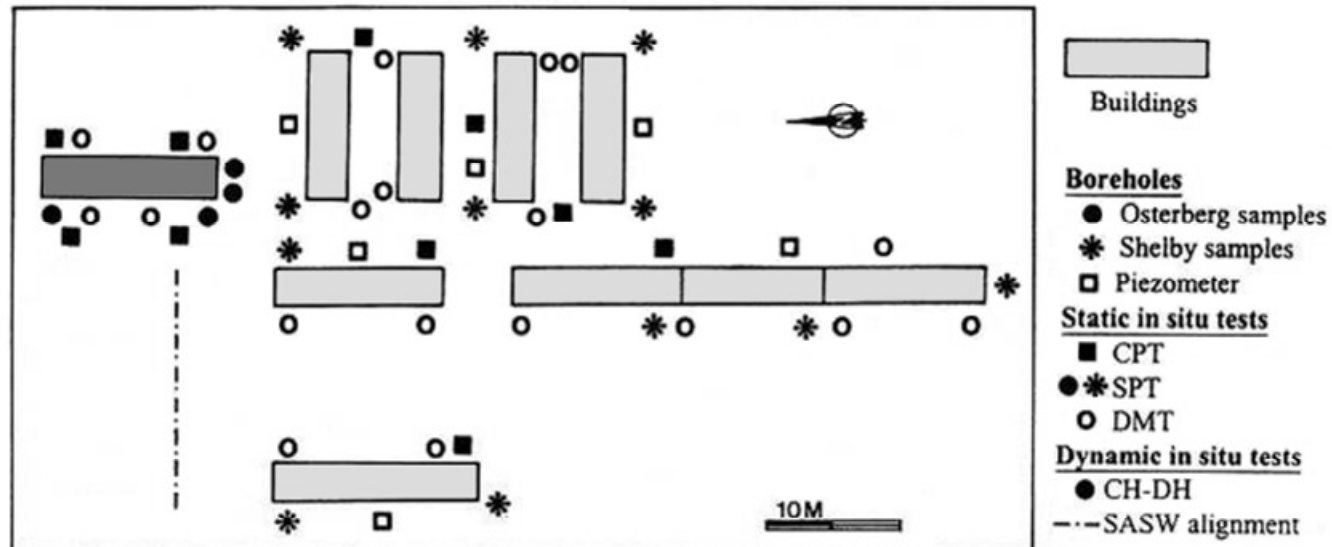
Eqq Name	Sicilia-Orientale	Station Name	Catania-Piana	
Eqq Date	13/12/1990	Epicentral Distance [km]	31.3	
Eqq Time	00:24:26	J&B Distance [km]	0.0	
MI	5.4	Hypocentral Distance [km]	32.07	
Local Intensity	Unknown	Closest Distance [km]	0.0	
		Azimuth	0	

Ground Motion Parameter Values

	NS	WE	NS-WE Mean	UP
PGA [g]	0.252	0.185	0.216	0.069
PGV [cm/s]	8.951	10.597	9.739	2.402
PGD [cm]	1.003	1.366	1.17	0.701
Sa (1.0 s) [g]	0.074	0.076	0.075	0.028
Predominant Period [s]	0.18	0.12	0.15	0.14
Mean Period [s]	0.27	0.3	0.28	0.28
Arias Intensity [m/s]	0.2342	0.174	0.2018683	0.034
Housner Intensity	0.0	0.0	0.0	0.0
Uniform Duration [s]	5.6	9.16	7.16	11.78
Significant Duration [s]	7.61	11.29	9.27	12.86



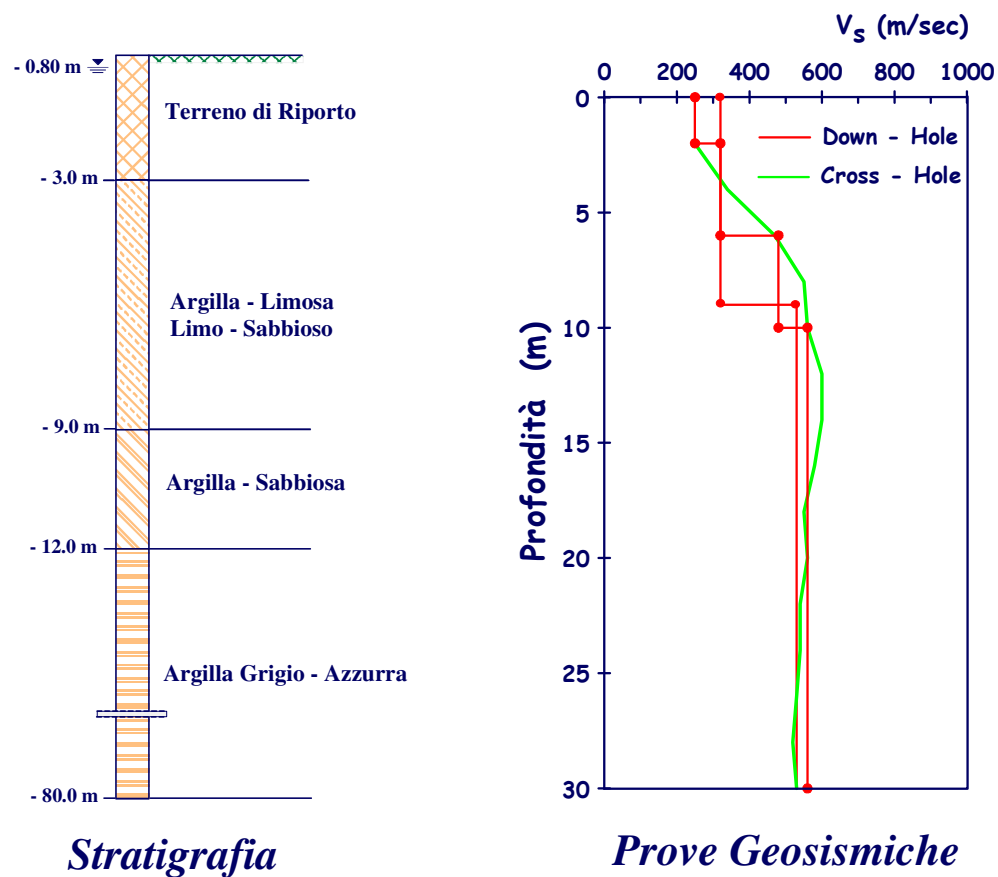
Tipologia e ubicazione delle indagini in situ



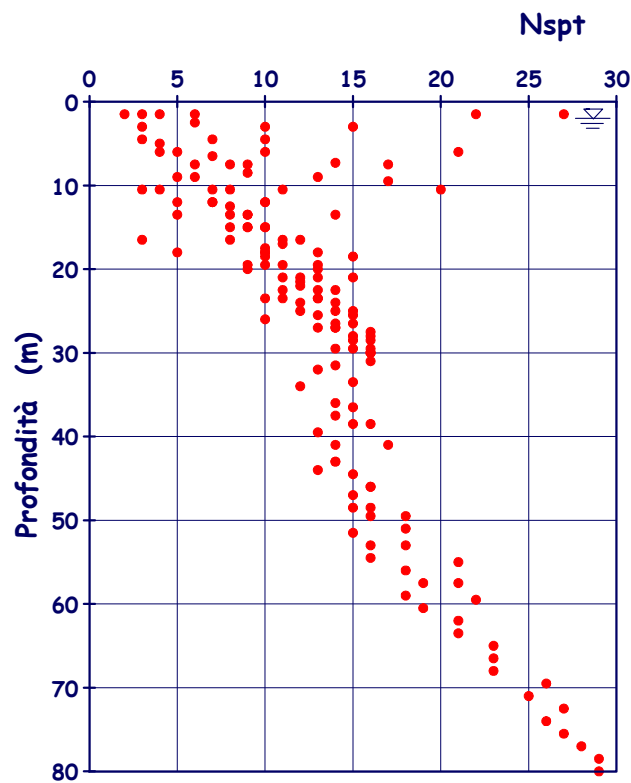
- Sondaggi Geognostici a Carotaggio Continuo
- Prove SPT (Standard Penetration Test)
- Prove CPT (Cone Penetration Test)
- Prove Dilatometriche (DMT)
- Prove Cross-Hole e Down-Hole
- Prove SASW



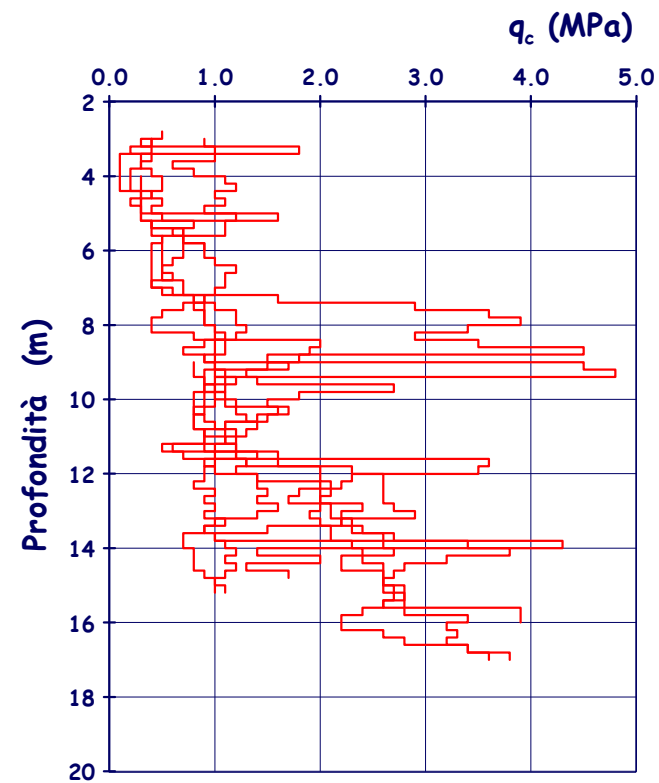
Augusta (SR) - Risultati Indagini in Situ



Augusta (SR) - Risultati Prove Penetrometriche

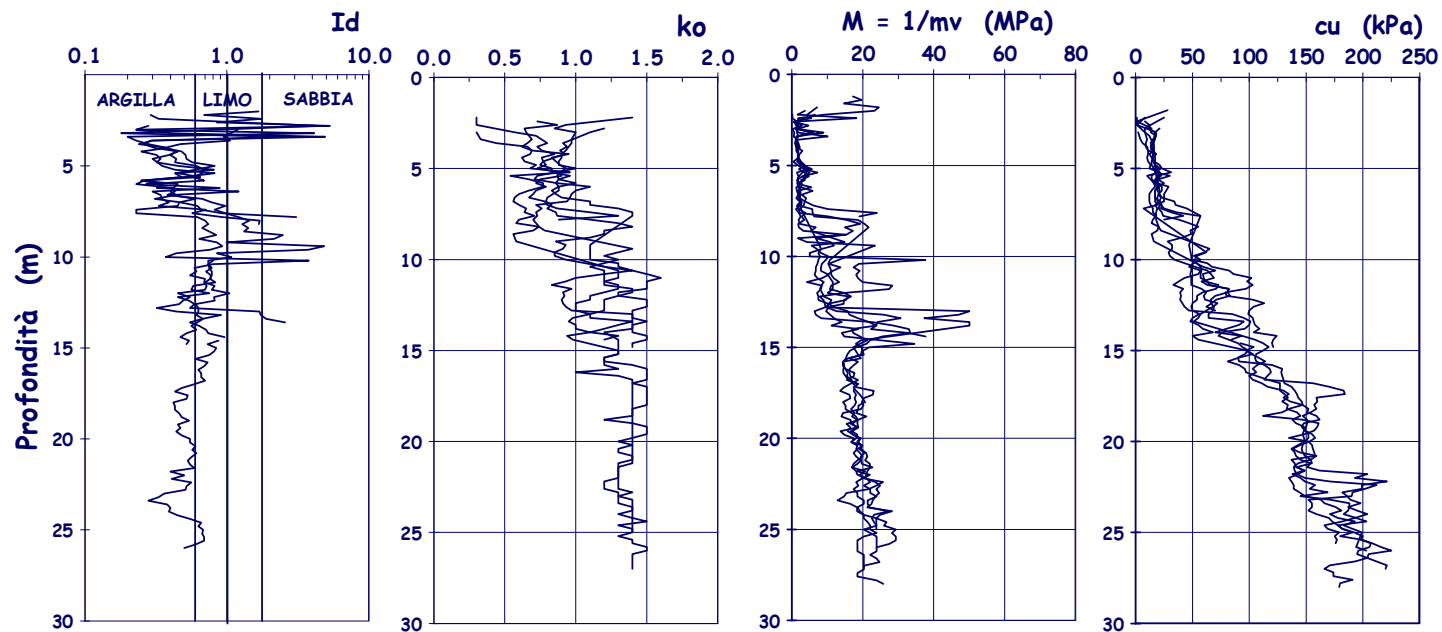


Standard Penetration Test



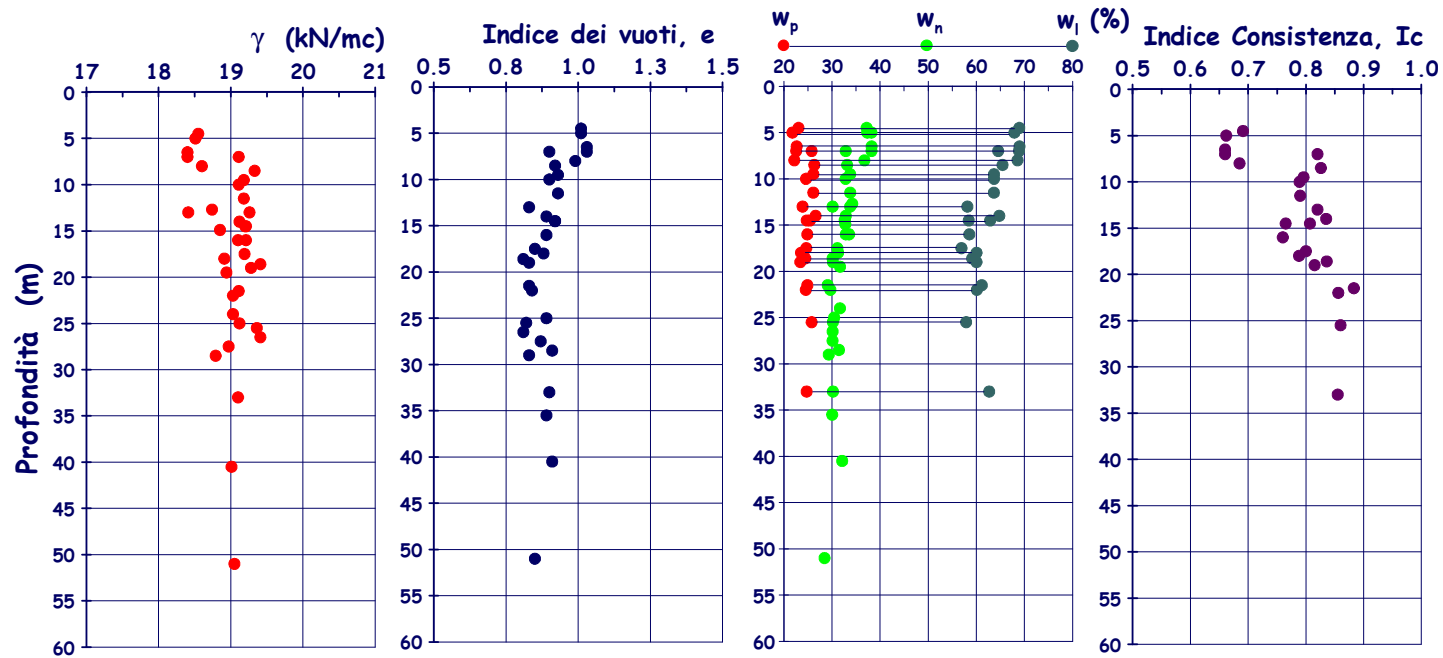
Cone Penetration Test

Augusta (SR) - Risultati Prove Dilatometriche (DMT)



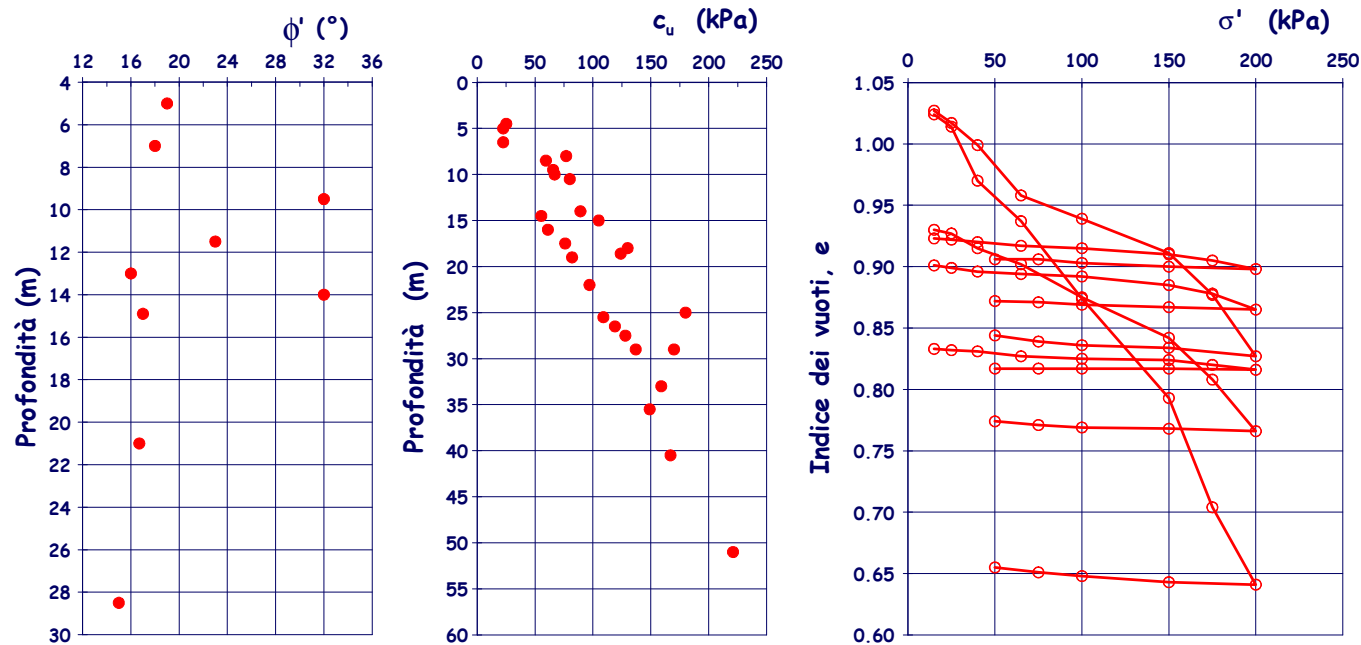
Castelli F., Maugeri M. (2004): "Analysis of the behaviour of the piled foundations of a group of earthquake damaged buildings", Proc. V International Conference on Case Histories in Geotechnical Engineering, New York, 13-17 April, 2004, paper no.1.45, 6 p.

Augusta (SR) - Risultati Prove di Laboratorio



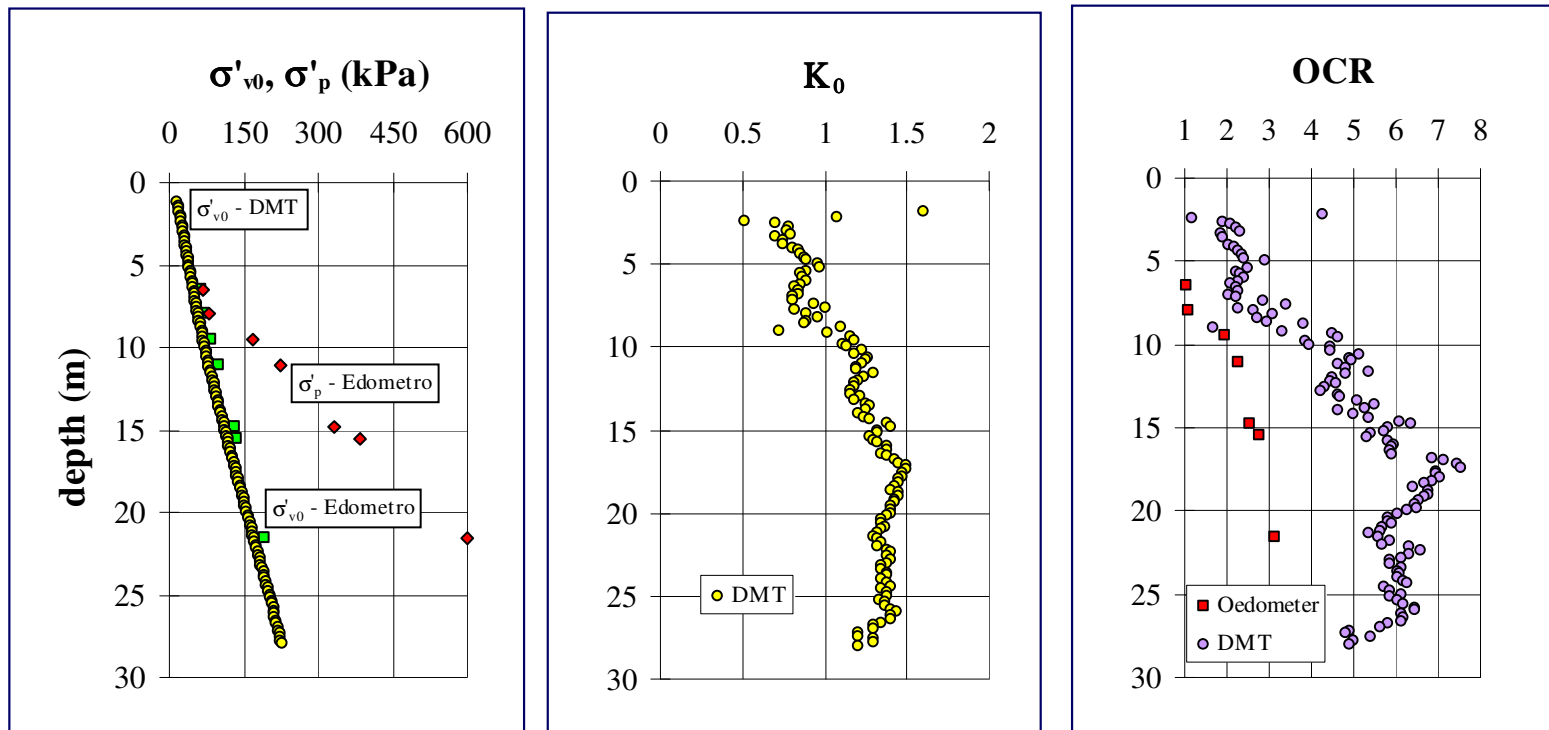
Castelli F., Maugeri M. (2004): "Analysis of the behaviour of the piled foundations of a group of earthquake damaged buildings", Proc. V International Conference on Case Histories in Geotechnical Engineering, New York, 13-17 April, 2004, paper no.1.45, 6 p.

Augusta (SR) - Risultati Prove di Laboratorio



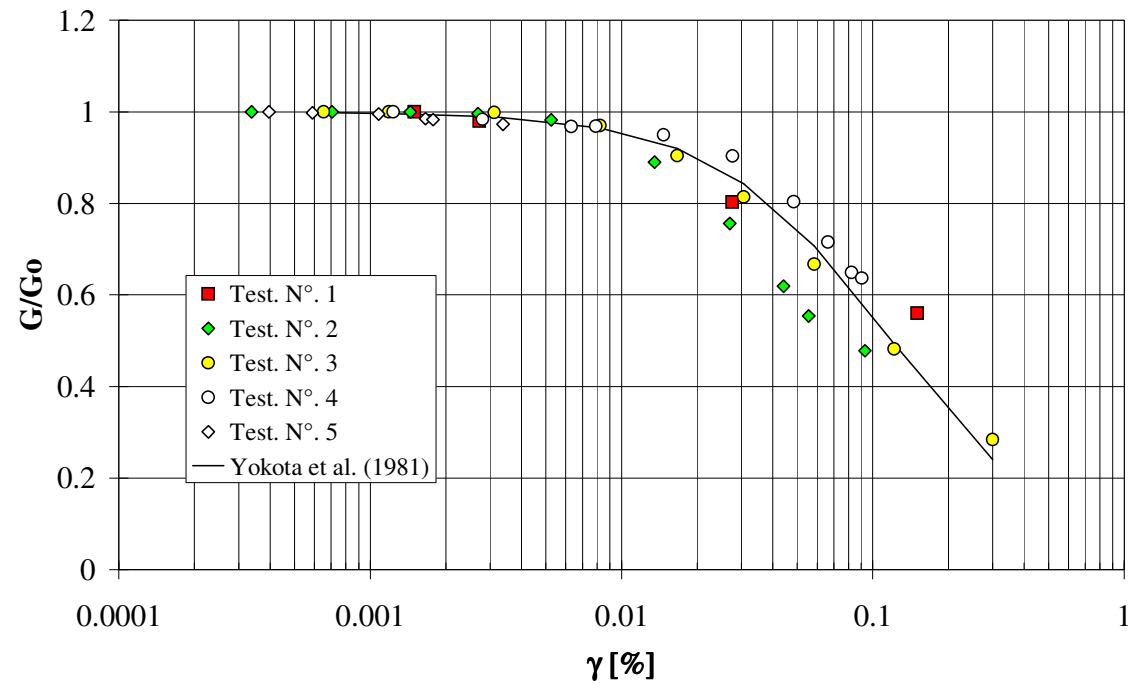
Castelli F., Maugeri M. (2004): "Analysis of the behaviour of the piled foundations of a group of earthquake damaged buildings", Proc. V International Conference on Case Histories in Geotechnical Engineering, New York, 13-17 April, 2004, paper no.1.45, 6 p.

Augusta (SR) - Storia Tensionale da Prove in Situ e di Laboratorio





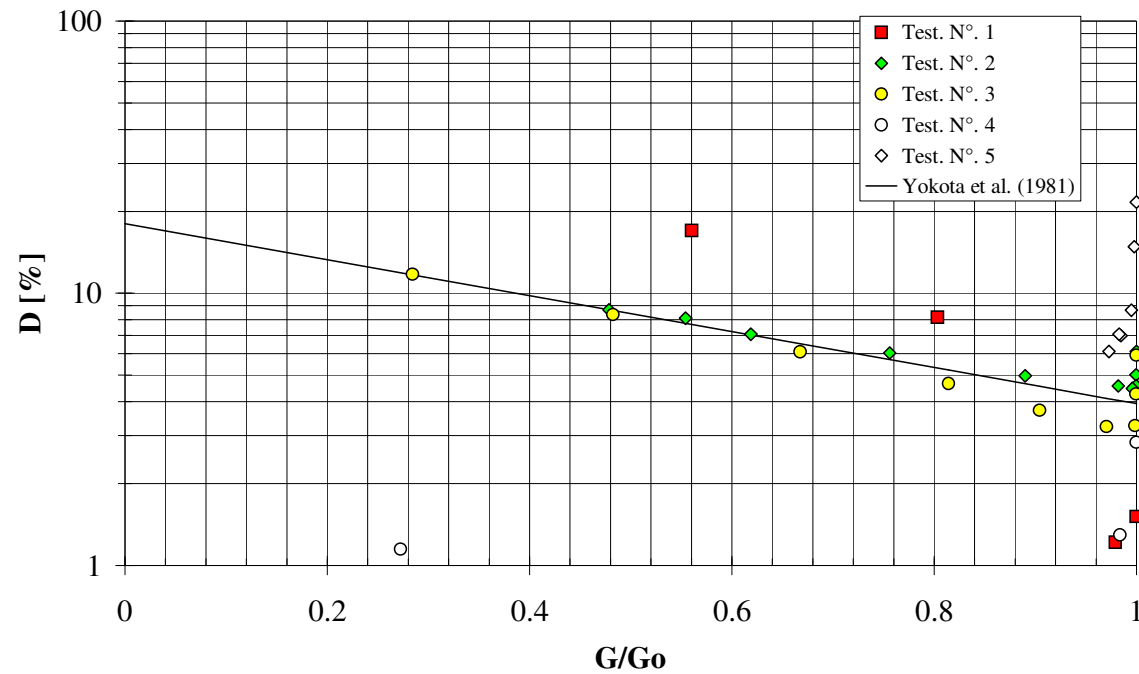
Augusta (SR) - Curve G/G_0 - γ da Prove di Colonna Risonante



$\alpha = 14$ and $\beta = 1.24$ were obtained for the Augusta clay (Sicily, Italy) by Cavallaro & Maugeri (1996)

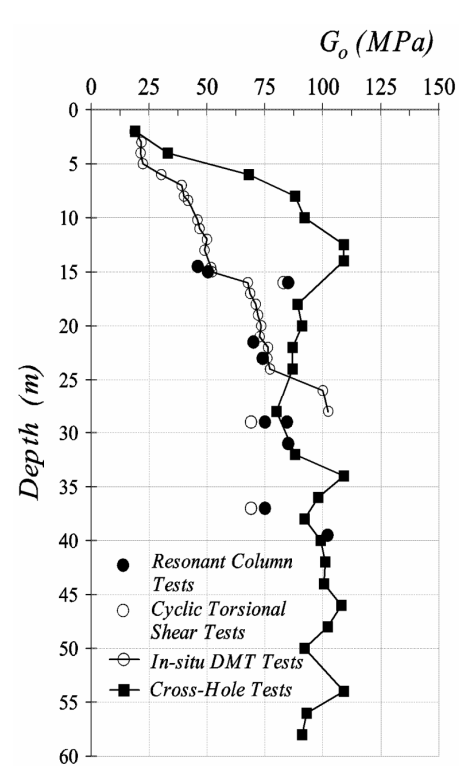


Augusta (SR) - Curve $D-G/G_o$ da Prove di Colonna Risonante

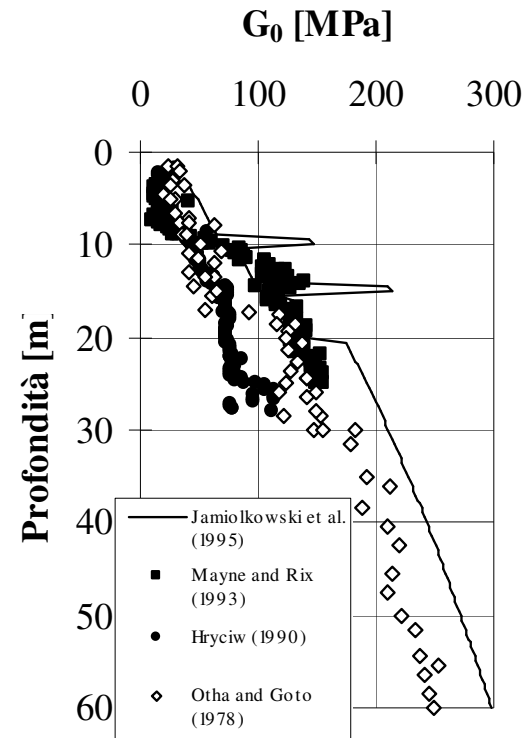


$\eta = 18$ and $\lambda = 1.52$ were obtained for the Augusta clay (Sicily, Italy) by Cavallaro & Maugeri (1996)

Augusta (SR) - Confronto tra prove in situ e di laboratorio e correlazioni empiriche

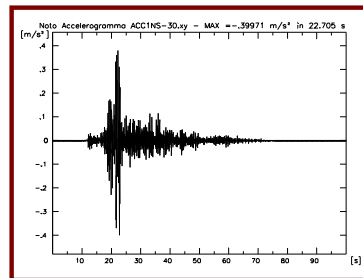
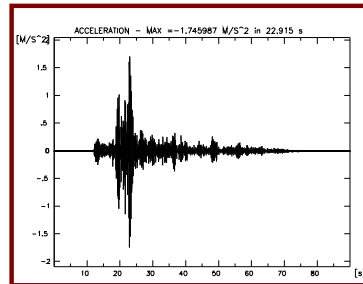
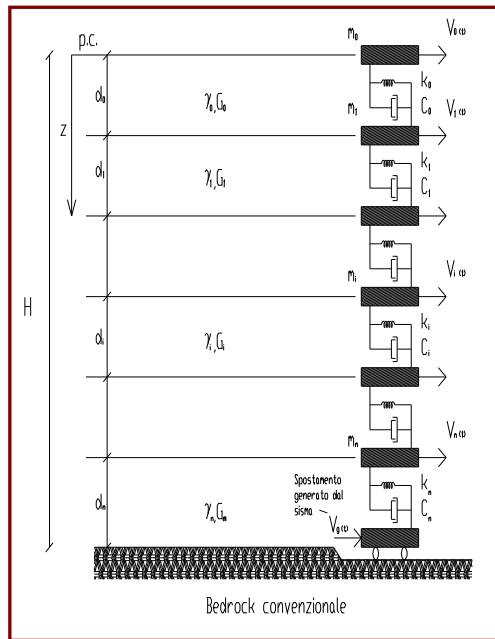


G_o da prove in situ
e di laboratorio



G_o da correlazioni empiriche

SEISMIC SITE RESPONSE EVALUATION



$$a_{max} = -1.746 m/s^2$$

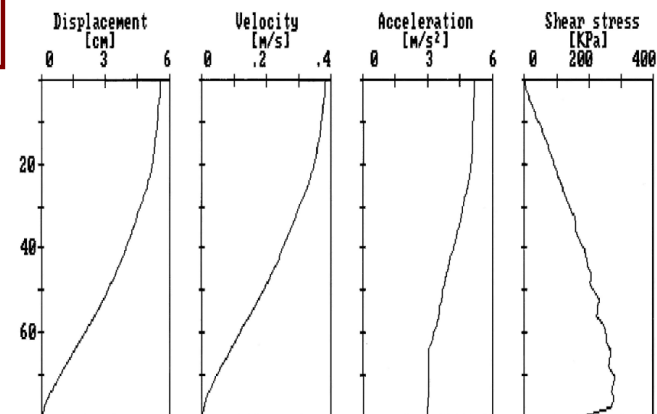
$$a_g \cdot S$$

$$a_{max} = -0.399 m/s^2$$

$$a_g$$

Soil amplification factor $S_s = 5$ for the 1990 earthquake

Maugeri M. and Frenna S.M. (1995): Soil-response analyses for the 1990 South-East Sicily earthquake. *Proc. III Int. Conference on Recent Advances in Geotechnical Earthquake Eng. and Soil Dynamics, St. Louis, Vol.II, no.9.17, 653-658.*





CASO STUDIO
ISTITUTO AUTONOMO CASE POPOLARI - AUGUSTA

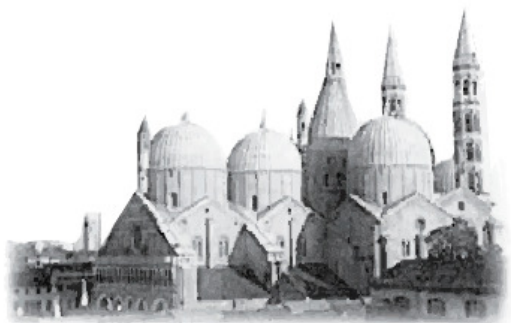


ADEGUAMENTO SISMICO DELL'EDIFICIO IN C.A.



XV ANIDIS

CASE STUDY L.E.D.A. - ENNA



CARATTERIZZAZIONE DINAMICA DEI
TERRENI NELL'AREA DEL NUOVO
LABORATORIO DI DINAMICA STRUTTURALE
E GEOTECNICA L.E.D.A. DI ENNA

Padova, 30 Giugno - 4 Luglio 2013

XV Convegno ANIDIS - L'ingegneria sismica in Italia

Padova, 30 Giugno - 4 Luglio 2013



UNIVERSITÀ
DEGLI STUDI
DI PADOVA



ANIDIS 2013
L'INGEGNERIA SISMICA IN ITALIA





OBIETTIVO DELLO STUDIO

Caratterizzazione statica e **dinamica** per la realizzazione del **L.E.D.A.**
Laboratory of Earthquake engineering and Dynamic Analysis ricadente
nella zona industriale di Enna.

FASI DELLO STUDIO

- ❖ Prove di Colonna Risonante/Taglio Torsionale Ciclico per la determinazione delle leggi di degradazione del **modulo di deformazione tangenziale G** e di incremento dello **smorzamento D** in funzione del livello di deformazione **γ**
- ❖ Risultati sperimentali in accordo con le **curve di letteratura** relative a terreni di uguale natura.
- ❖ **Analisi della risposta sismica locale** mediante l'utilizzo di un codice di calcolo monodimensionale sulla base dei risultati ottenuti.



PROGETTO LEDA

Laboratory of Earthquake Engineering and Dynamic Analysis

Il Progetto L.E.D.A., recentemente finanziato all'Università degli Studi di Enna "Kore" dal Programma Operativo Nazionale "Ricerca & Competitività" (PON "R&C" 2007-2013), prevede la realizzazione di un **Centro di Ricerca** nel settore dell'**Ingegneria Sismica**.

- | | | |
|-------------------------|---|--|
| ❖ Dinamica Sperimentale | → | Tavole vibranti a 6 D.O.F. |
| ❖ Dinamica dei terreni | → | Colonna Risonante/Taglio Torsionale Ciclico e Triassiale Ciclico |



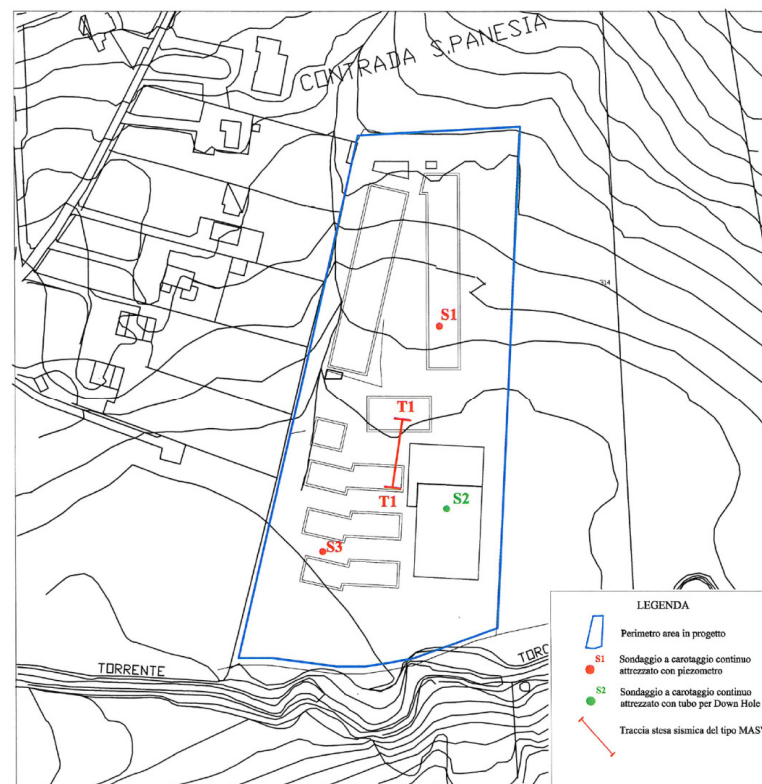


Laboratory of Earthquake Engineering and Dynamic Analysis



PLANIMETRIA DELL'AREA INVESTIGATA

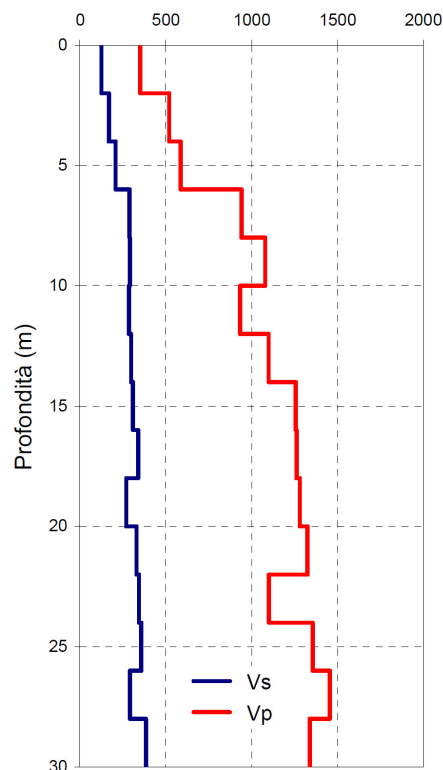
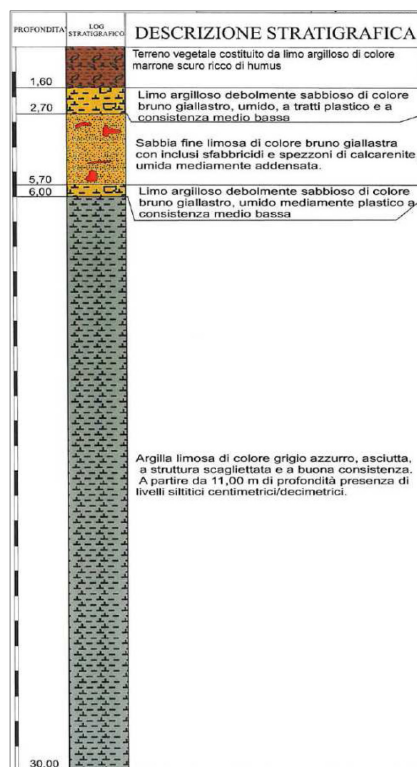
- ❖ Sono stati eseguiti **n.3 sondaggi** verticali a carotaggio continuo spinti fino alla profondità di 20 m (**S1** e **S3**) e di 30 m (**S2**) dall'attuale piano campagna.
- ❖ Il sondaggio S2 è stato attrezzato per eseguire prove sismiche in foro del tipo **Down-Hole (DH)**.
- ❖ I sondaggi denominati S1 e S3 sono stati attrezzati con **piezometro**, allo scopo di monitorare il livello della falda acquifera.





PROVE IN SITU

Down-Hole (DH)



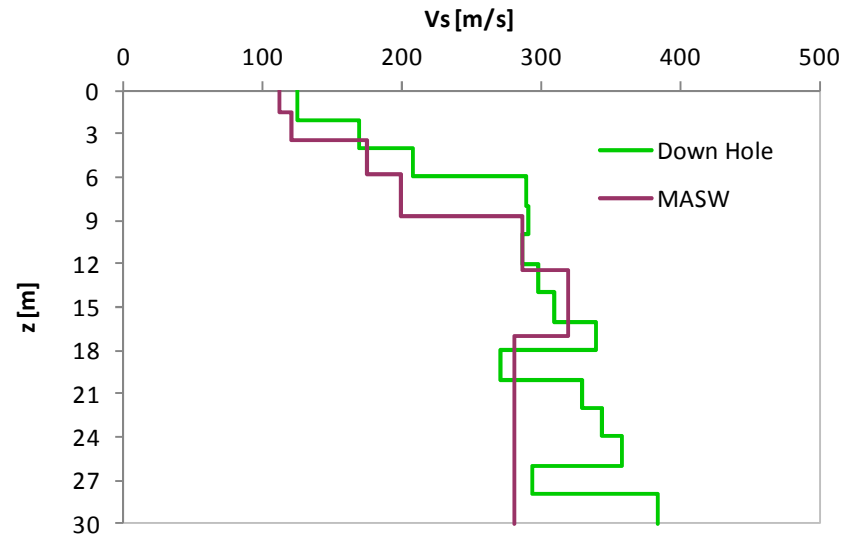
Profondità (m)	Denominazione
0 - 1.5	Terreno vegetale di copertura
1.5 - 6.0	Sabbia fine limosa e/o limo argilloso debolmente sabbioso
6.0 - 30.0	Argilla limosa grigia azzurra

- ❖ Velocità di propagazione delle onde di volume dalla prova **Down-Hole (DH)** in corrispondenza del sondaggio **S2**.
- ❖ L'andamento dei due profili evidenzia un progressivo incremento con la profondità sia dei valori di V_s che di V_p , con un range di variazione compreso rispettivamente tra circa **124** e **384** m/sec (V_s) e tra circa **351** e **1340** (V_p).



PROVE IN SITU

Prova Sismica MASW

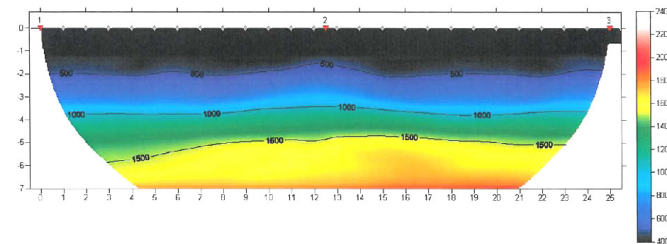


Strato	Profondità (m)	Spessore (m)	V_s (m/sec)	H/V_s
1	1,51	1,51	111	0,0136
2	3,40	1,89	121	0,0156
3	5,77	2,36	175	0,0135
4	8,72	2,95	200	0,0148
5	12,41	3,69	286	0,0129
6	17,03	4,62	320	0,0144
7	30,00	12,98	281	0,0462

❖ I risultati della prova Down – Hole in termini di V_s sono in buon accordo con quelli ricavati mediante una indagine sismica di superficie di tipo MASW;

❖ I risultati della prova Down – Hole in termini di V_p sono in buon accordo che con quelli ricavati mediante una tomografia sismica di superficie.

Tomografia sismica di superficie





PROVE DI LABORATORIO

Sono state eseguite sui campioni prelevati nel corso dei sondaggi prove di laboratorio comprendenti:

Classificazione e parametri fisici

Camp.	Prof.	A	L	S	γ	w_n
	(m)	(%)	(%)	(%)	(kN/m ³)	(%)
S1/C2	6,00	39,36	41,31	19,32	20,21	19,90
S2/C1	2,00	12,34	14,46	71,59	19,26	19,33
S2/C2	5,50	30,73	39,50	25,61	19,66	31,26
S2/C4	15,5	35,33	44,94	19,74	20,01	20,02
S3/C1	1,50	11,75	17,97	64,41	19,01	20,99
S3/C2	4,00	5,39	2,25	89,38	19,67	13,76
S3/C3	8,00	20,60	27,07	52,29	20,26	20,27
S3/C4	15,3	28,50	48,71	22,79	20,05	22,74

- ❖ analisi granulometrica;
- ❖ peso dell'unità di volume;
- ❖ peso specifico dei grani;
- ❖ contenuto naturale d'acqua;
- ❖ limiti di consistenza.

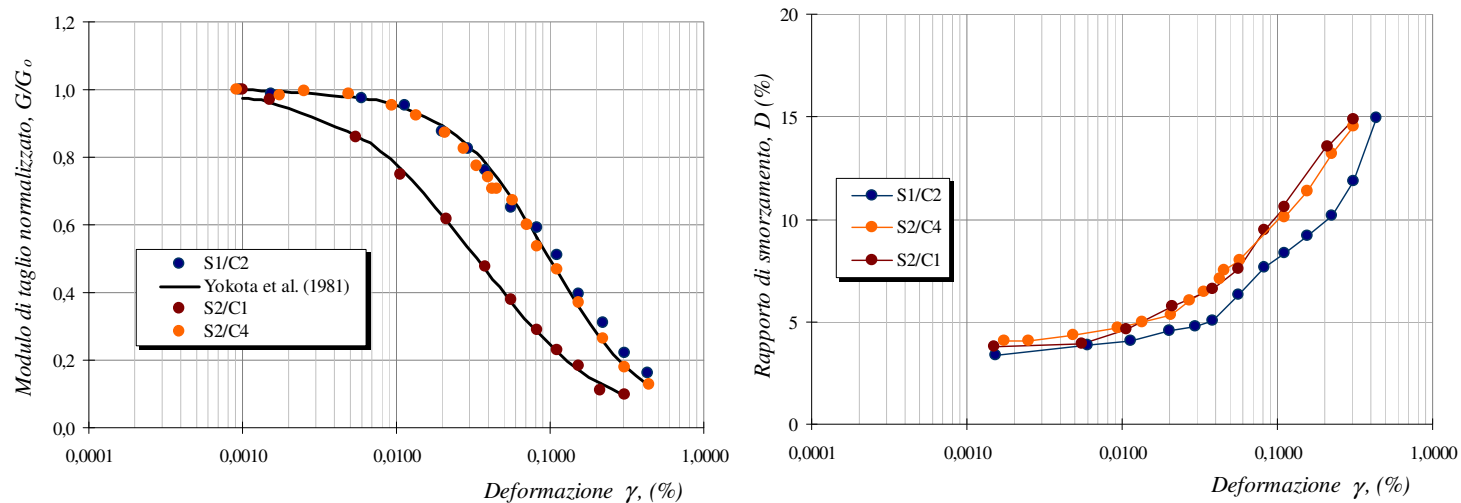
Resistenza e deformabilità

Camp.	Prof.	γ_c	I_n	e_n	c_u	ϕ'
	(m)	(kN/m ³)	(%)		(kN/m ²)	(°)
S1/C2	6,00	24,34	-	-	77	22
S2/C1	2,00	25,55	-	-	-	-
S2/C2	5,50	25,52	33,47	0,731	44	-
S2/C4	15,5	24,87	42,12	0,581	-	-
S3/C1	1,50	25,47	11,58	-	-	-
S3/C2	4,00	25,57	-	0,584	-	31
S3/C3	8,00	27,03	8,58	0,569	153	-
S3/C4	15,3	25,23	48,84	0,608	--	-

- ❖ prove di compressione edometrica;
- ❖ prove di taglio diretto;
- ❖ prove triassiali UU.

CARATTERIZZAZIONE DINAMICA DA RC TEST

Le prove RC sono state condotte su provini di forma cilindrica con raggio di 50 mm ed altezza di 100 mm.



Le leggi di variazione del modulo di taglio G e del rapporto di smorzamento D per alcuni dei campioni sottoposti a prova di Colonna Risonante

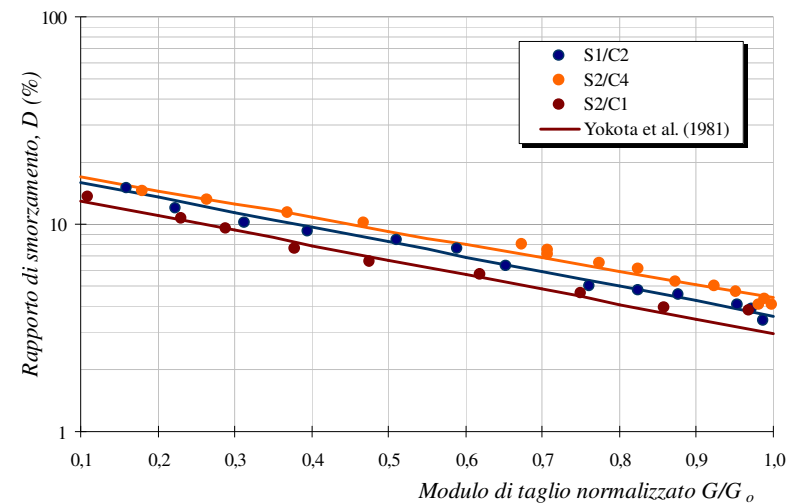
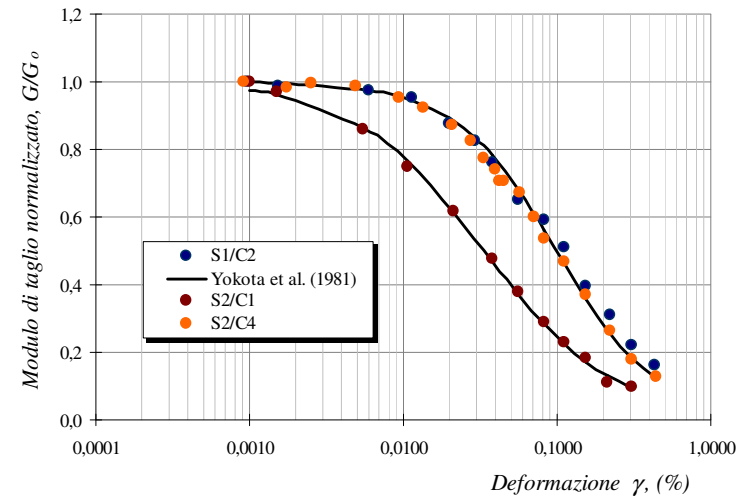
I risultati sperimentali sono stati utilizzati per determinare i parametri empirici dell'equazione proposta da Yokota et al. (1981)

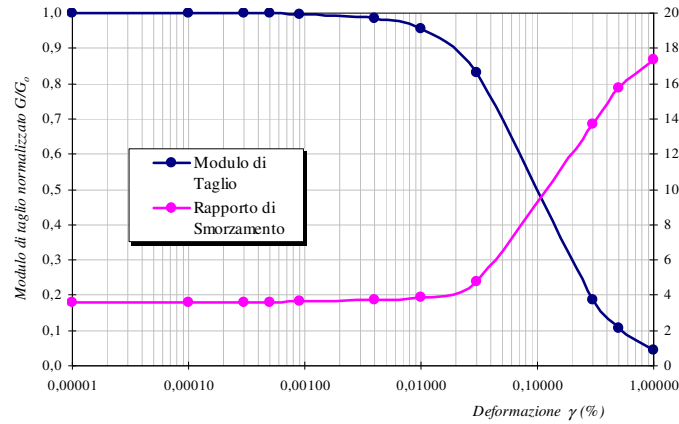
Yokota et al. (1981)

$$\frac{G(\gamma)}{G_o} = \frac{1}{1 + \alpha \gamma(\%)^\beta}$$

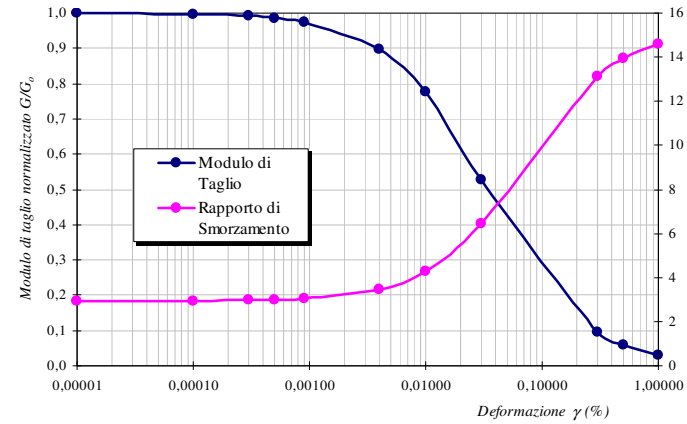
$$D(\gamma)(\%) = \eta \cdot \exp\left[-\lambda \cdot \frac{G(\gamma)}{G_o}\right]$$

Camp.	Prof. (m)	σ'_v (kN/m ²)	G_o (MPa)	α	β
S1/C2	6,00	121	33,19	21,22	1,325
S2/C1	2,00	39	25,93	32,52	1,025
S2/C4	15,0	180	142,04	21,22	1,325

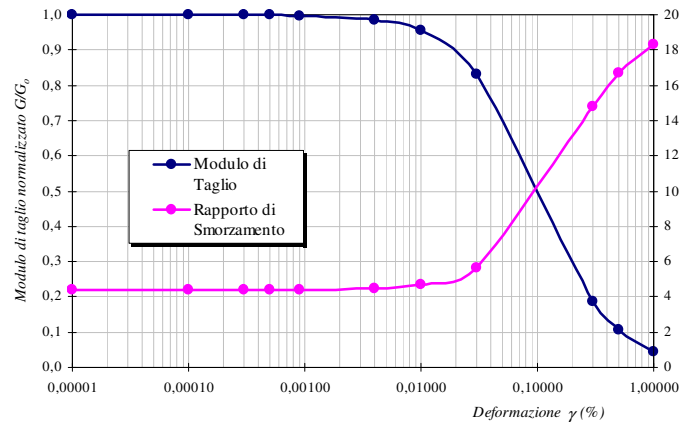




S1/C2	α	β	η	λ
	21,225	1,325	18,69	-1,642



S2/C2	α	β	η	λ
	32,524	1,025	15,35	-1,651



S2/C4	α	β	η	λ
	21,225	1,325	19,57	-1,491

Yokota et al. (1981)

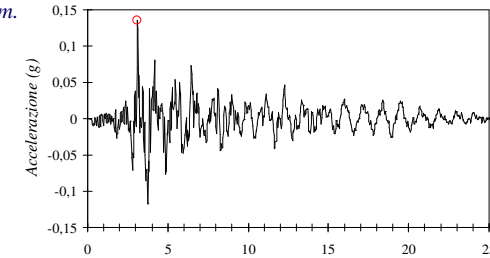
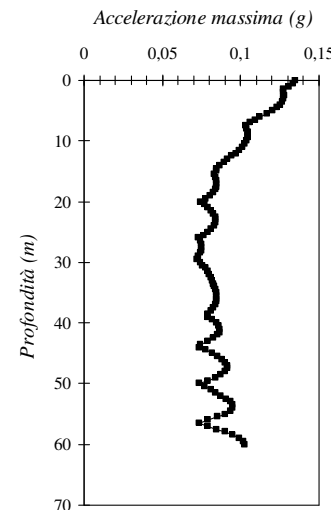
$$\frac{G(\gamma)}{G_0} = \frac{1}{1 + \alpha \gamma(\%)^\beta}$$

$$D(\gamma)(\%) = \eta \cdot \exp \left[-\lambda \cdot \frac{G(\gamma)}{G_0} \right]$$

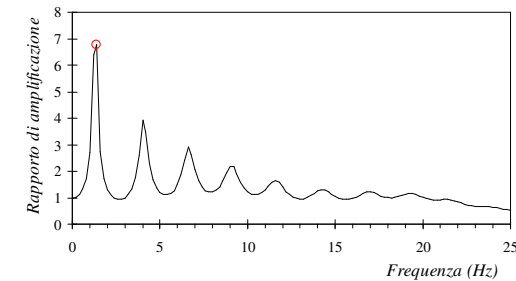
ANALISI DI RISPOSTA SISMICA LOCALE

- ❖ Per valutare la risposta sismica del terreno è stato utilizzato il codice di calcolo 1-D EERA (*Bardet et al., 2000*).
- ❖ La schematizzazione del profilo del sito è stata condotta mediante la definizione di strati di terreno caratterizzati dai valori di V_s ricavati dalla prova Down-Hole.
- ❖ Per le leggi di variazione dei parametri dinamici G e D si è fatto uso delle equazioni proposte da *Yokota et al. (1981)* con i parametri ricavati dalle prove di Colonna Risonante (RC).

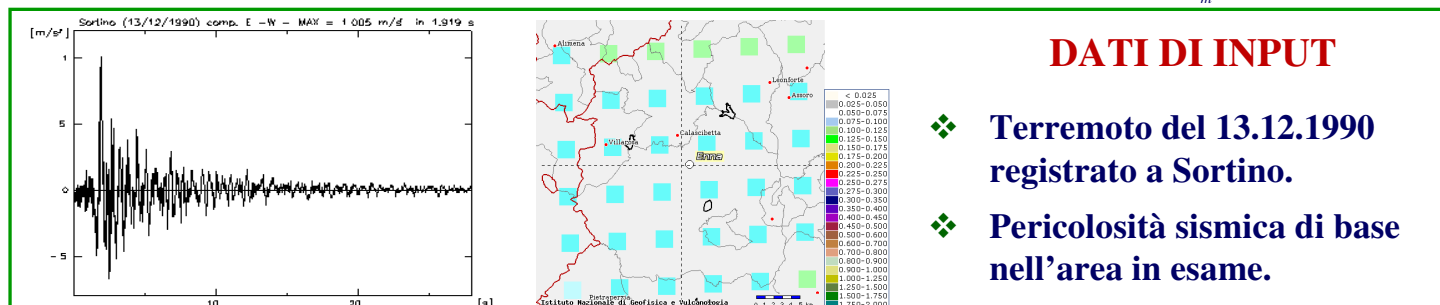
Profilo valori massimi di accelerazione indotti in uno strato rigido di profondità 60 m.



Accelerogramma ottenuto mediante risposta in superficie.

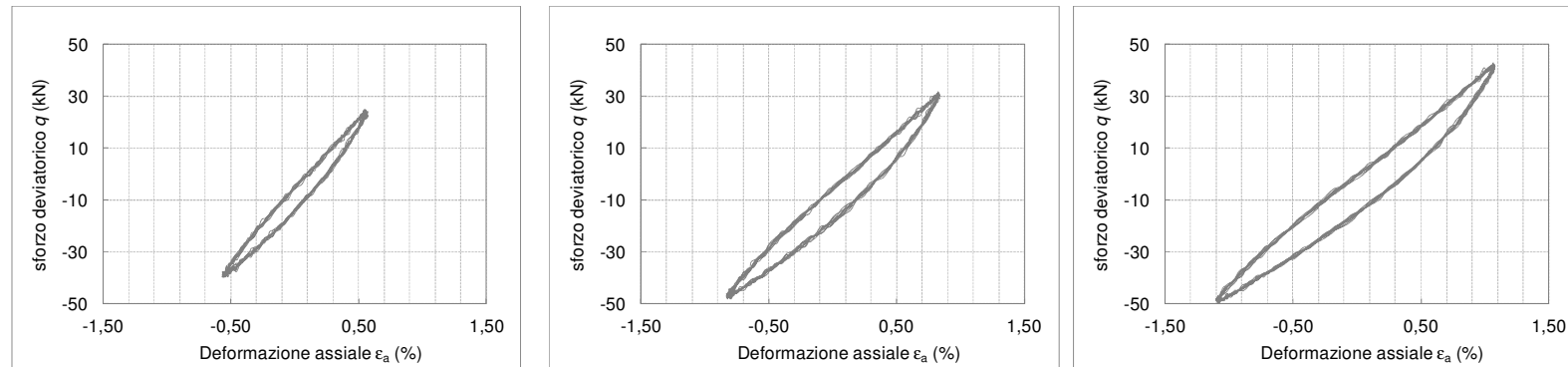


Fattore di amplificazione massimo tra superficie e basamento ($H_m = 60$ m) indotto dal sisma.

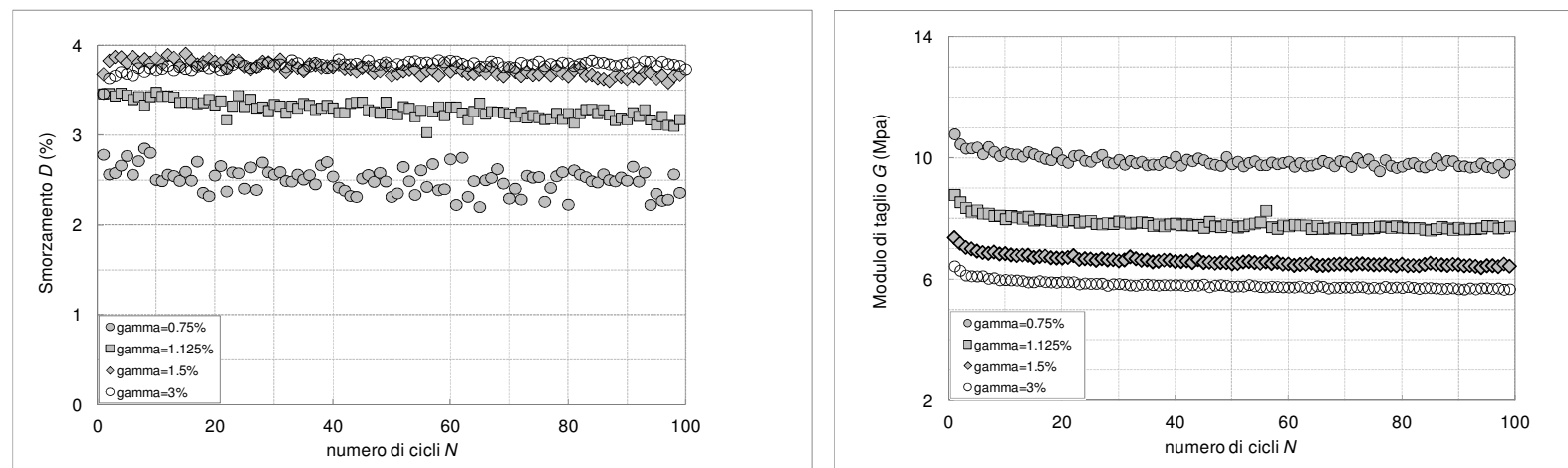


Prova Triassiale Ciclica - BIBLIOTECA UNIKORE

Sforzo deviatorico q al variare della deformazione assiale ε_a



Modulo di deformazione tangenziale G e smorzamento D al variare del numero di cicli N

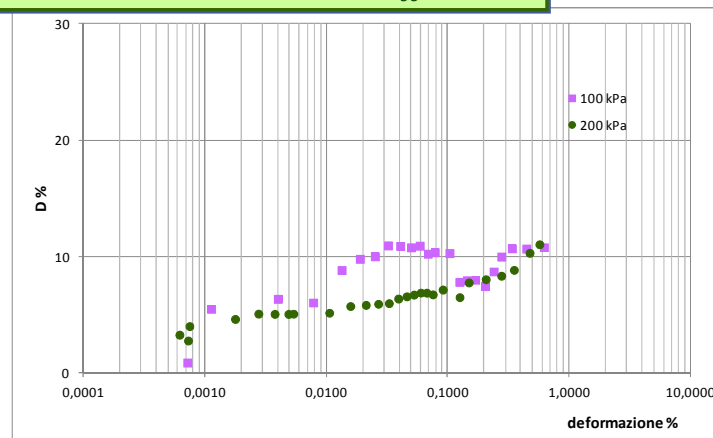
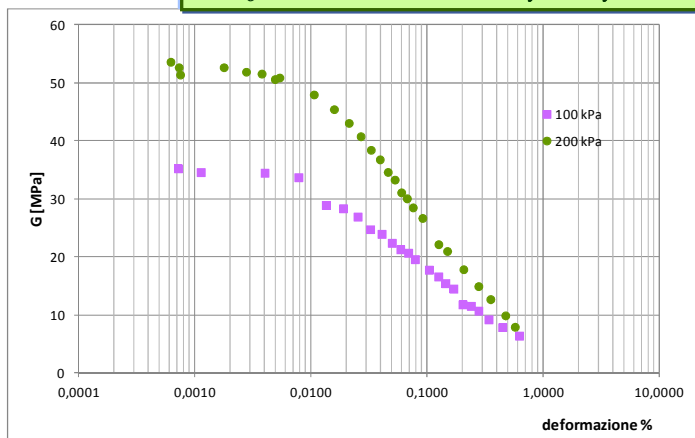




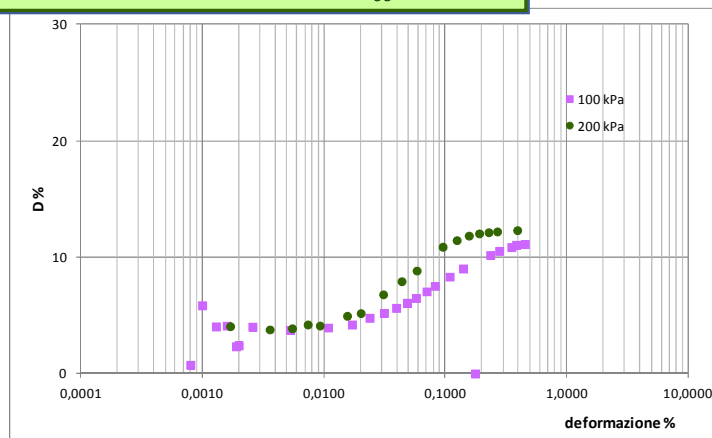
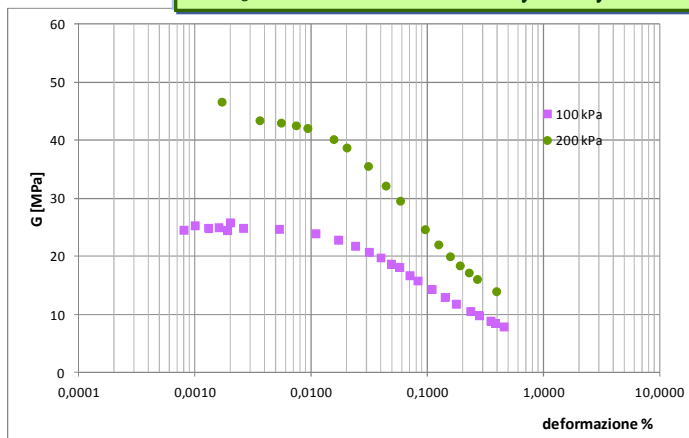
Prova Colonna Risonante e Taglio Torsionale Ciclico

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Confronto tra le curve $G-\gamma$ e $D-\gamma$ ottenute da RC al variare della tensione efficace σ'



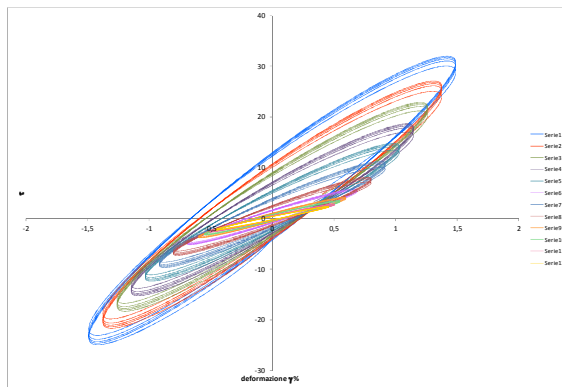
Confronto tra le curve $G-\gamma$ e $D-\gamma$ ottenute da TS al variare della tensione efficace σ'



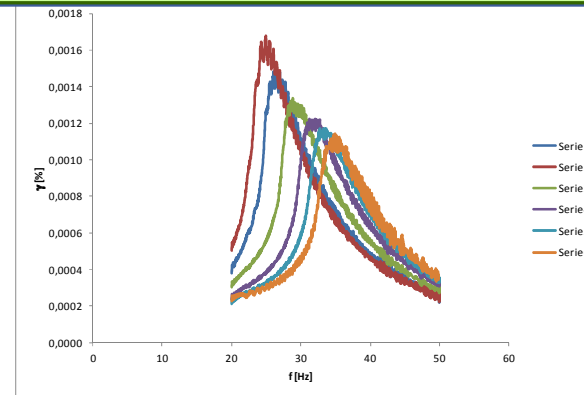
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Cicli di isteresi da TS - $\sigma' = 100$ kPa



Frequenza di risonanza da RC - $\sigma' = 100$ kPa



Confronto tra le curve G- γ e D- γ ottenute da RC e da TS - $\sigma' = 100$ kPa

