



Geofisica – Geologia – Geotecnica al servizio della risposta sismica locale: il caso studio di Castel Caldes (Trentino)

Boaga J. ⁽¹⁾, Viganò A. ⁽²⁾, Fedrizzi F. ⁽³⁾, Carrer M. ⁽¹⁾, Martin S. ⁽¹⁾

⁽¹⁾ Dipartimento di Geoscienze e DICEA, Università di Padova

⁽²⁾ Istituto Nazionale di Oceanografia e di Geofisica Sperimentale, CRS, Udine

⁽³⁾ Servizio Geologico della Provincia Autonoma di Trento



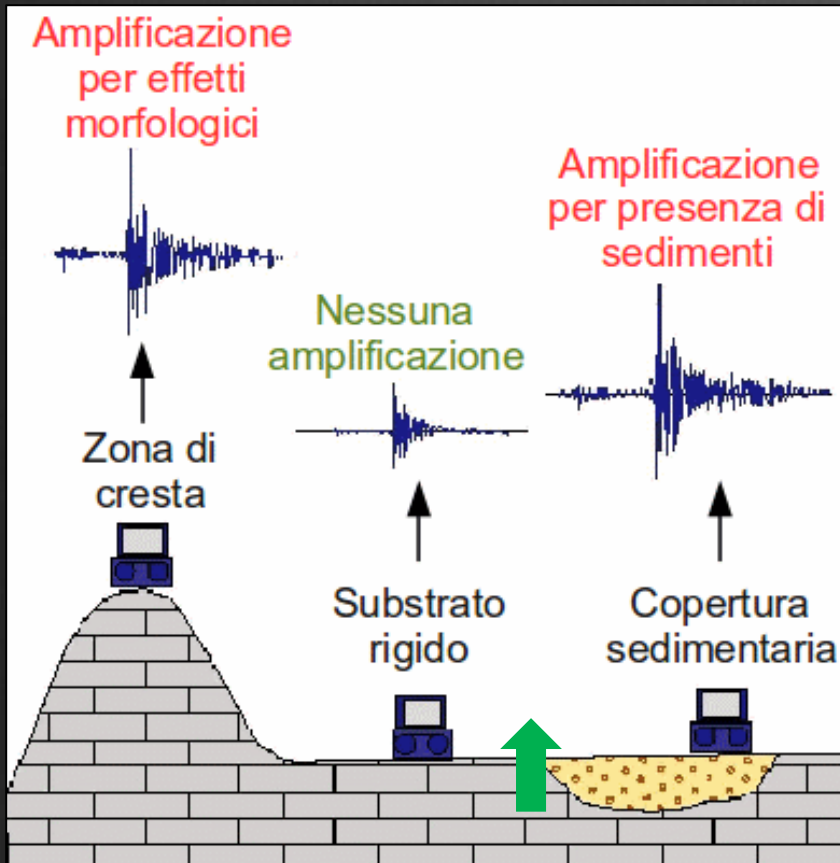
OUTLINE

- **La risposta sismica locale**
- **Il caso studio di Castel Caldes (TN):**
 - **Inquadramento geologico**
 - **Indagini geofisiche**
 - **Indagini geotecniche**
 - **Elaborazioni finali**



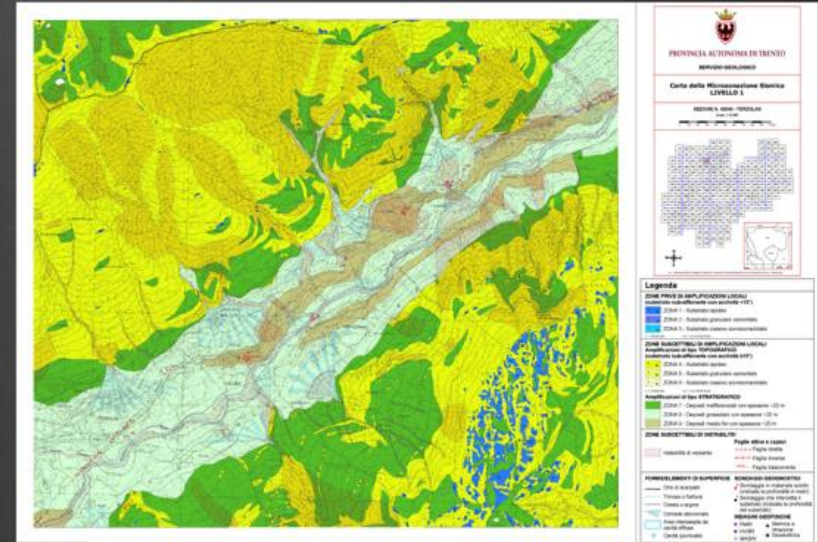
La risposta sismica locale

Modifica del moto sismico: effetto di stratigrafia e topografia



Kramer et al. 1996

Microzonazione Sismica
3 livelli di approfondimento
L1, L2, L3



Livello 1 MS
Provincia Autonoma di Trento (P.A.T.)



La risposta sismica locale

Studi di Microzonazione Sismica

Indagini e Modellizzazione del sottosuolo

Valutazione dell'input sismico

Scenari di scuotimento

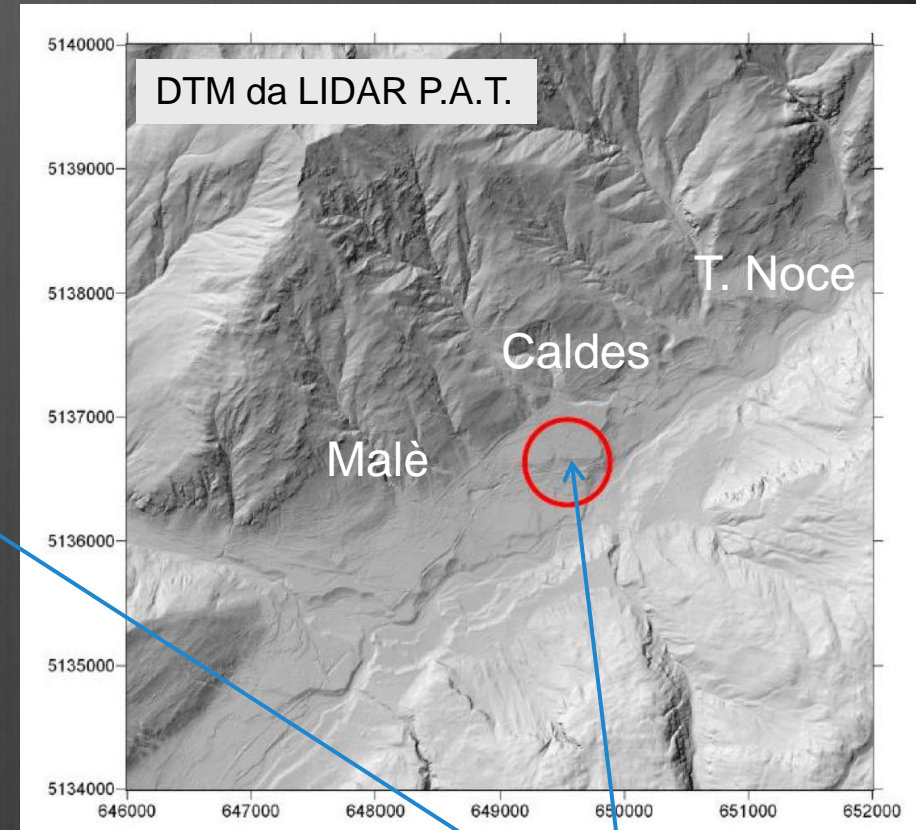
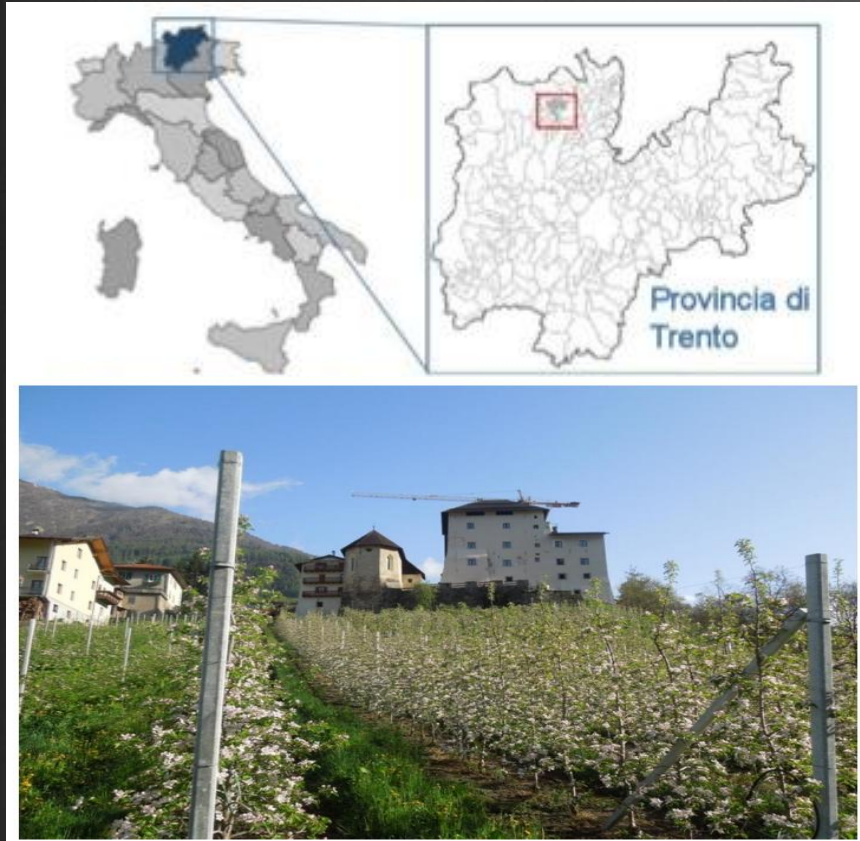
Pericolosità Sismica





Il sito di Caldes

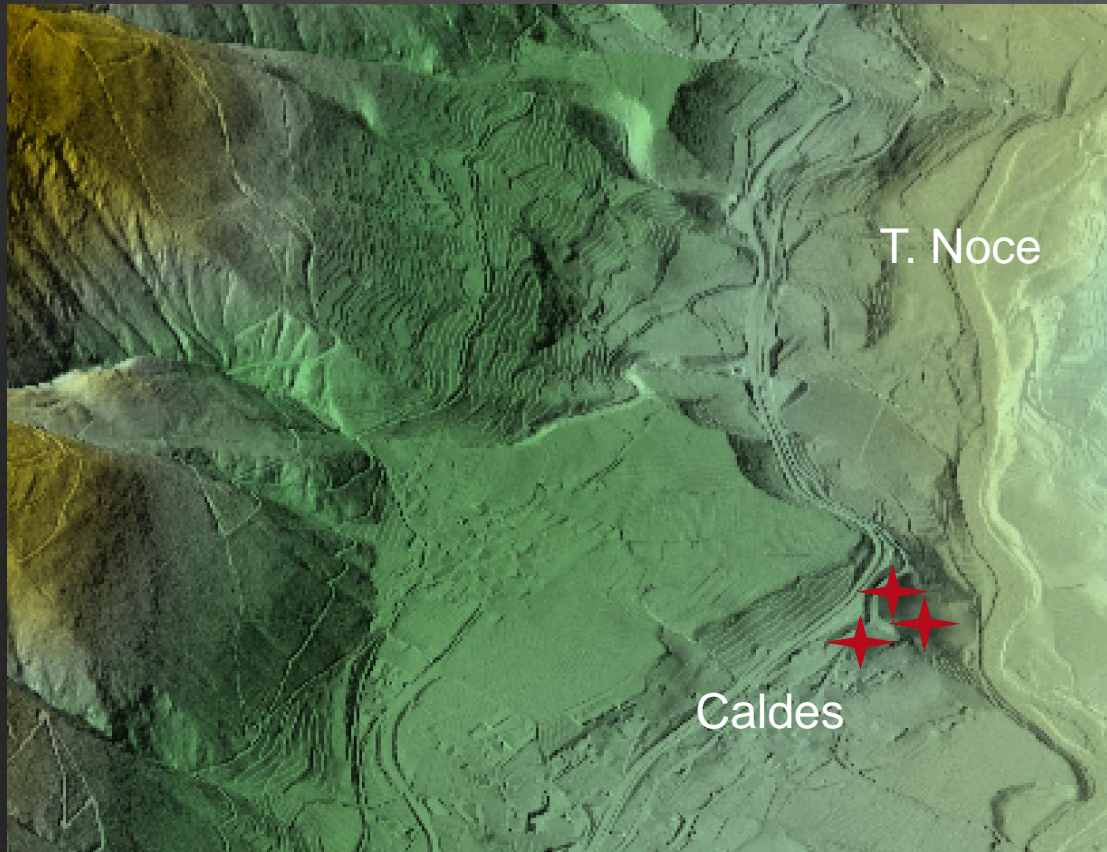
Val di Sole (torrente Noce), s.s. 42



Sito di Caldes



Il sito di Caldes



★ Sondaggi geognostici
eseguiti
presso Caldes

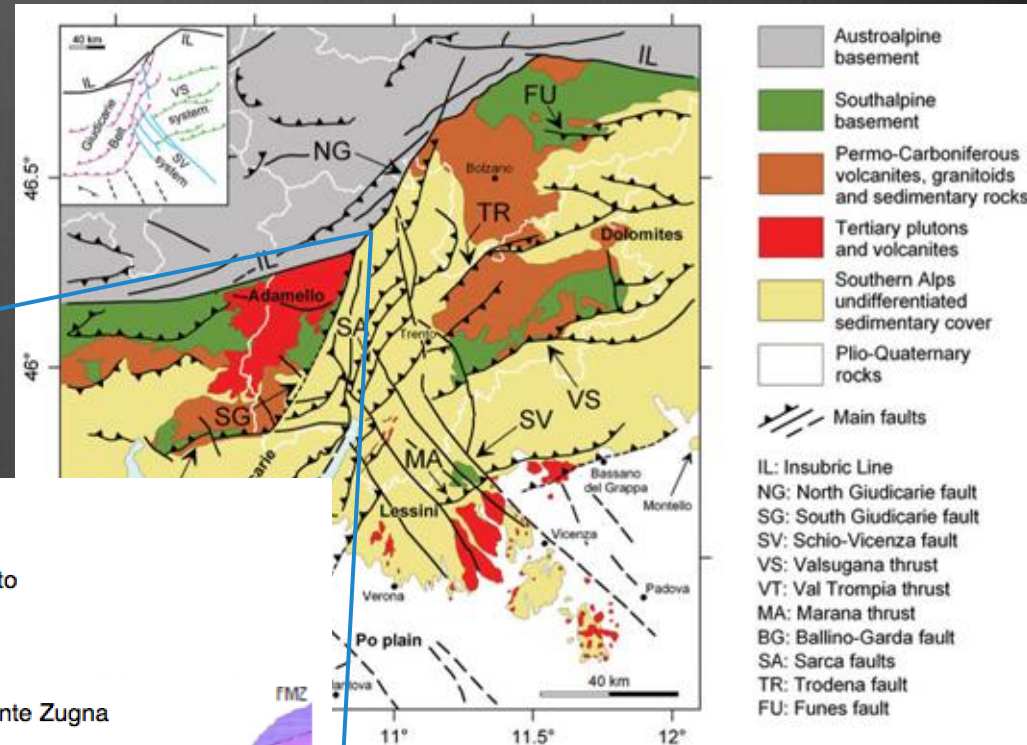
Profondità: 15-25m

Indagini su campioni indisturbati presso il Laboratorio Geotecnico P.A.T.

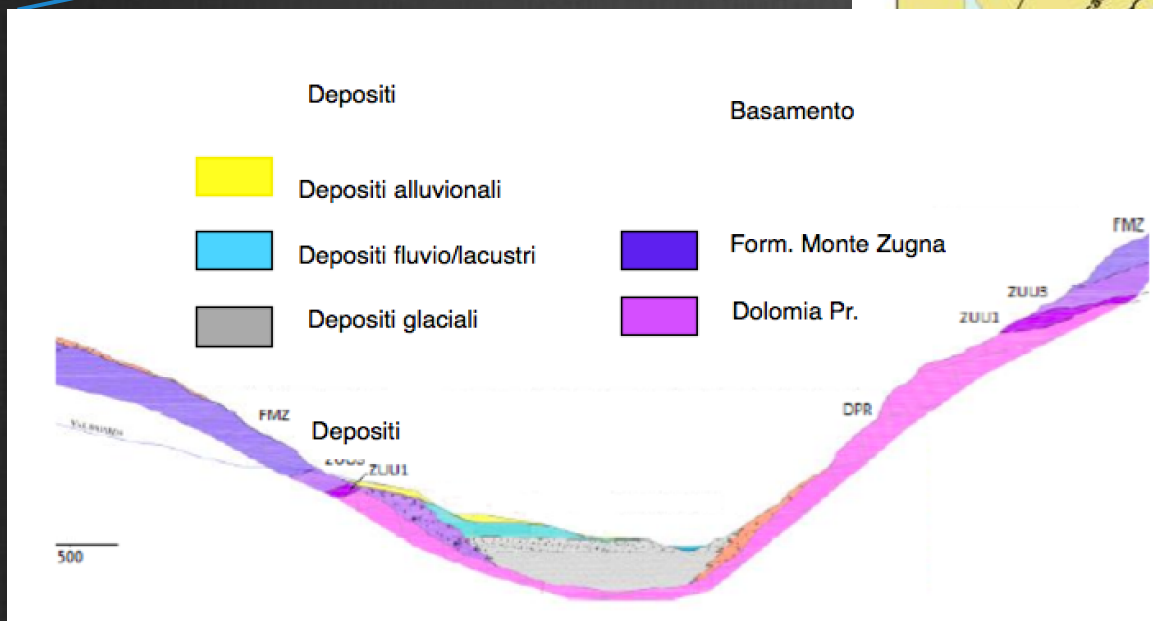


Inquadramento geologico

Tipica vallata alpina con depositi alluvionali, fluvio-lacustri e glaciali, e dal complesso assetto tettonico



Viganò et al. 2013



Zambotti 2011, Martin e Zambotti 2012



Indagini geofisiche

Indagini elettriche ERT

Indagini sismiche MASW

Indagini sismiche FTAN

Indagini sismica passiva
HVSR

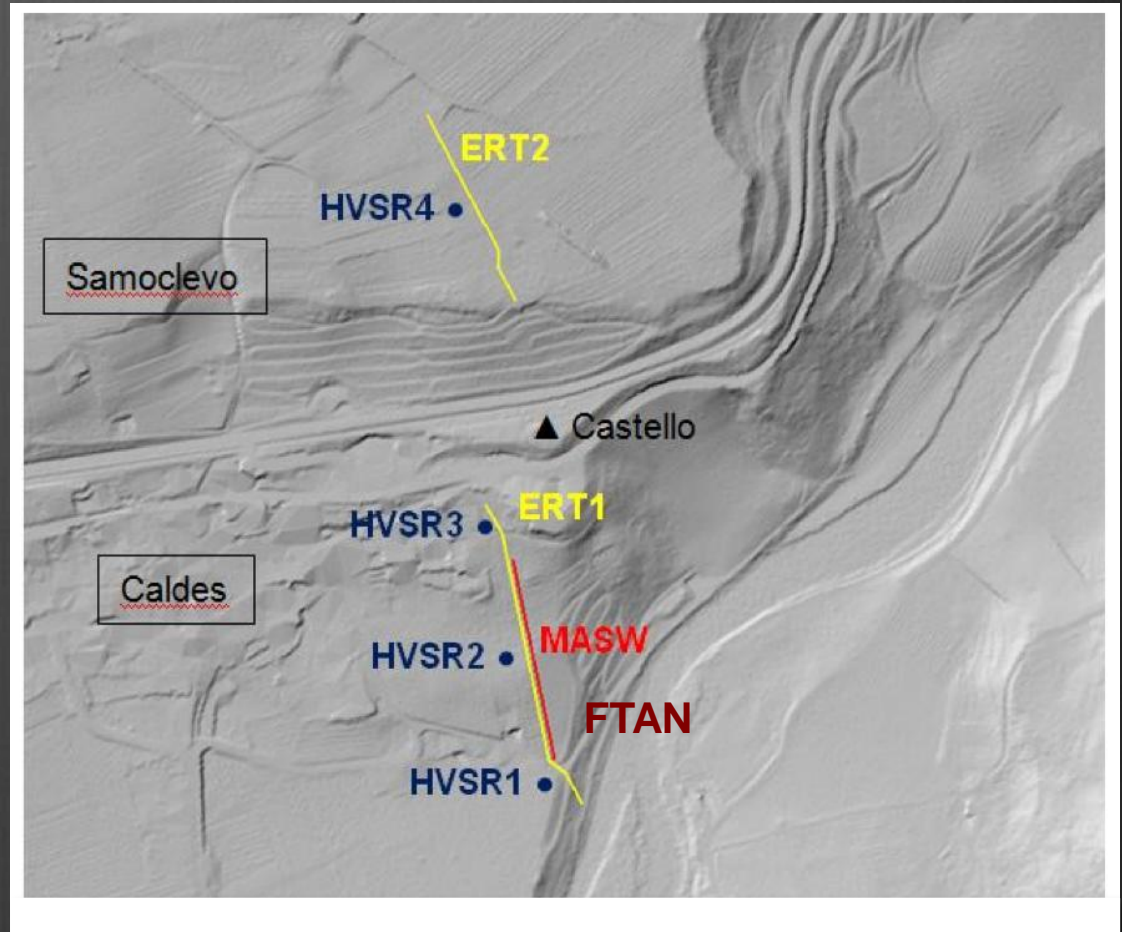
FTAN: 100m length, 1s rec.

MASW: 48 canali – spacing 3m – L. 144m

ERT 1: 48 canali – spacing 5m – L. 235m – config. WS e DD

ERT 2: 48 canali – spacing 2m – L. 94m – config. DD

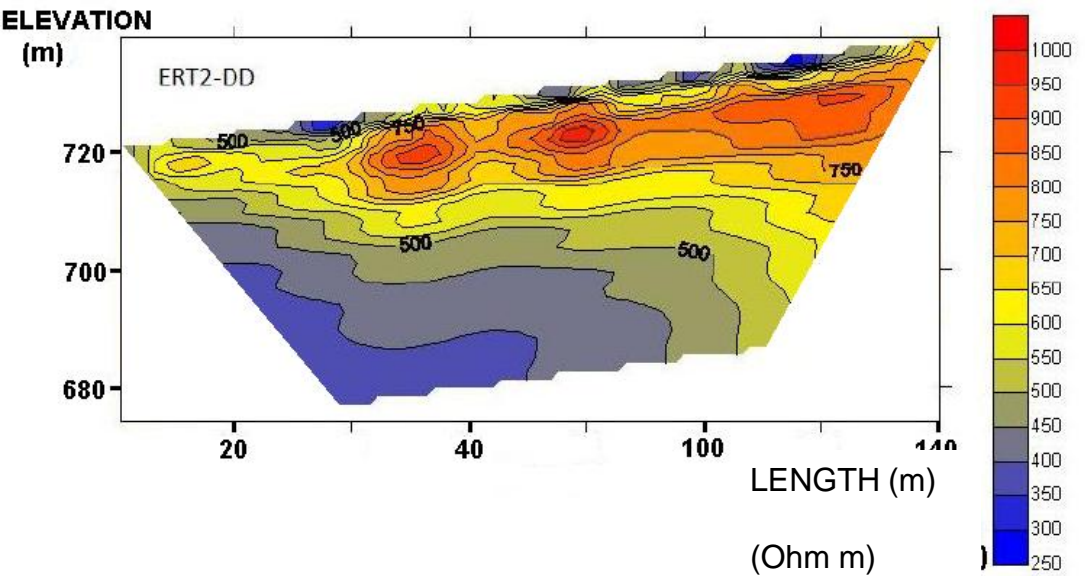
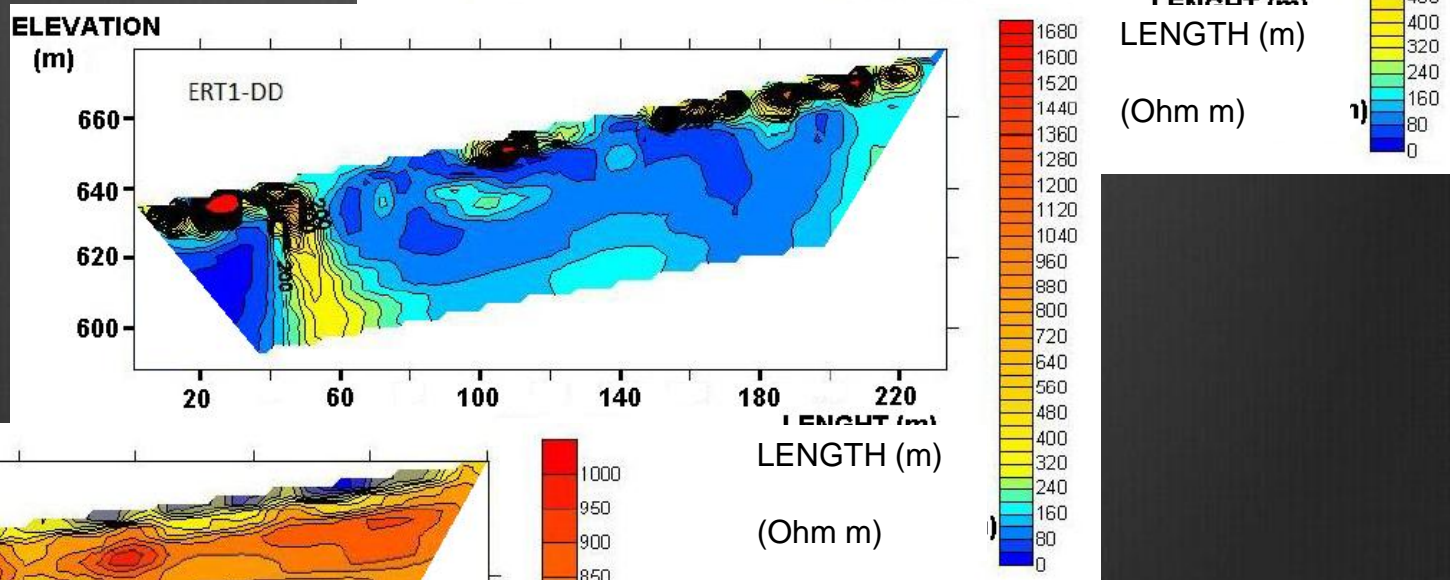
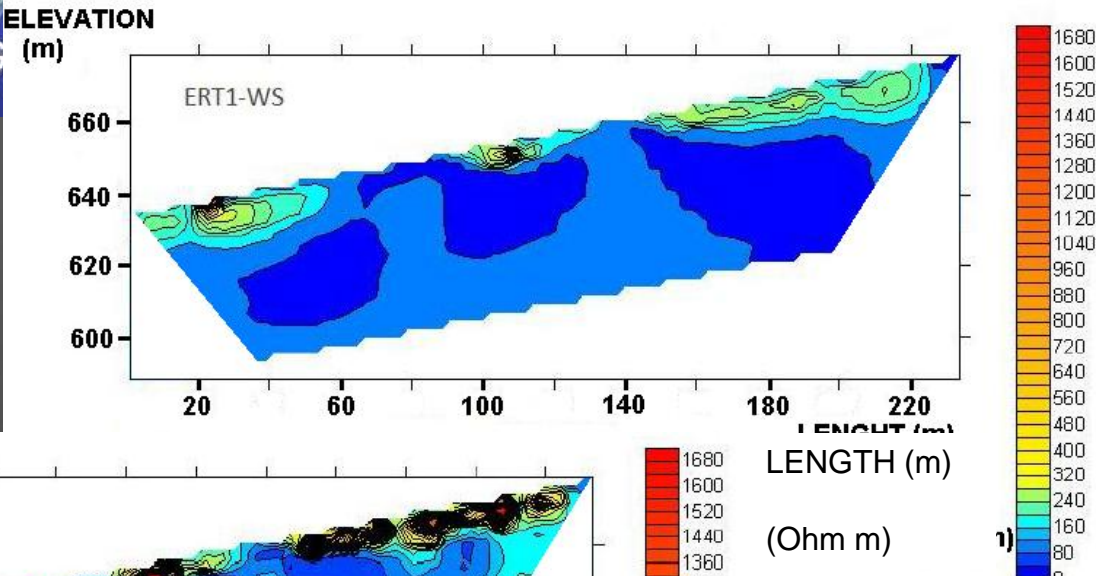
HVSR: 4 prove – rec.time 20 min.





Indagini geofisiche

CASTEL CALDES ERT1



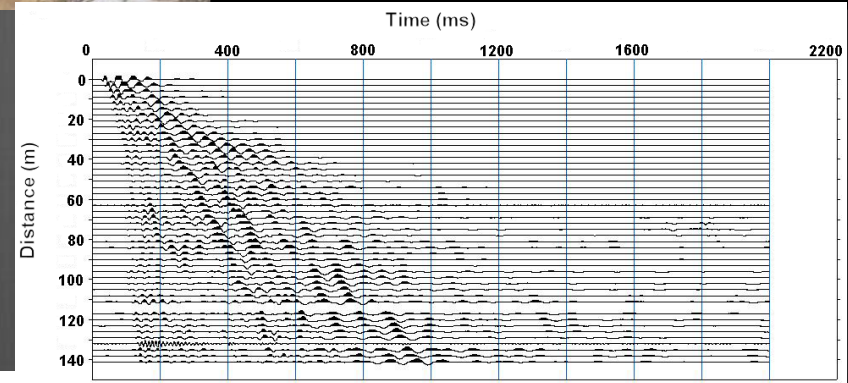
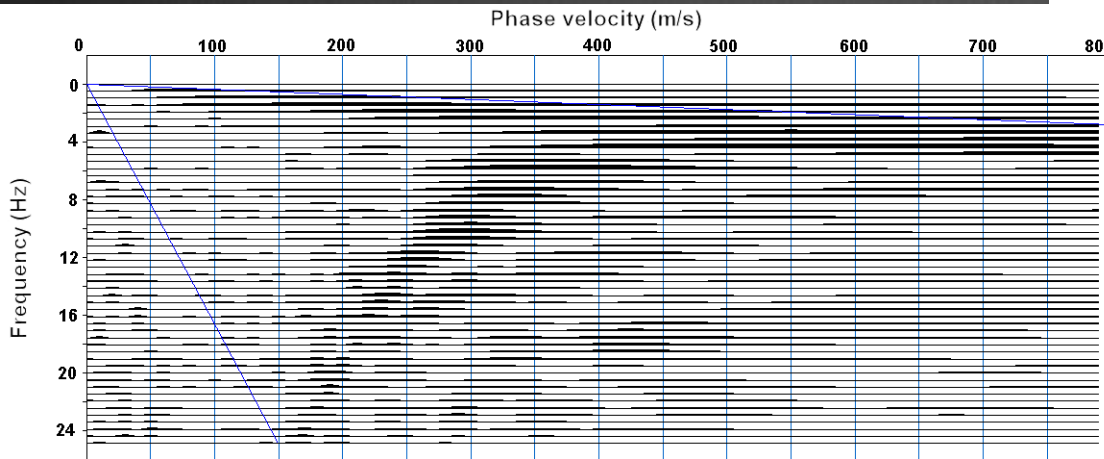
SAMOCLEVO ERT2



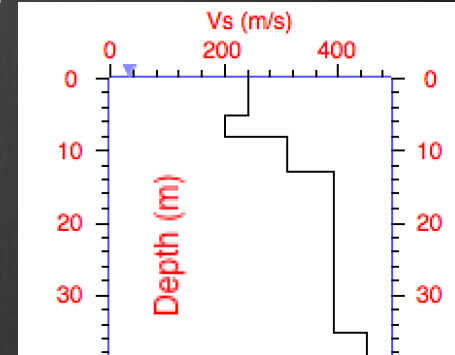
Indagini geofisiche

Indagini MASW

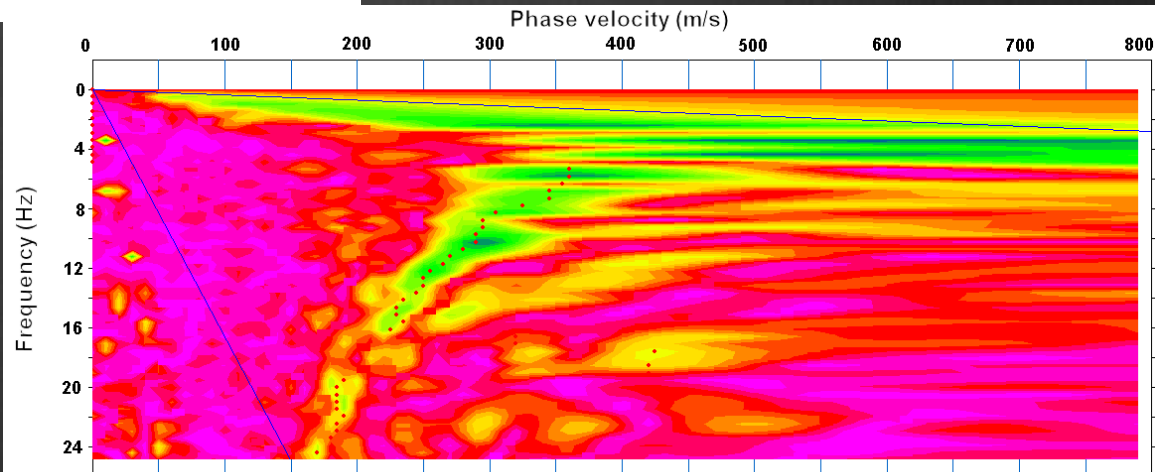
Spettri f-V



Sismogrammi



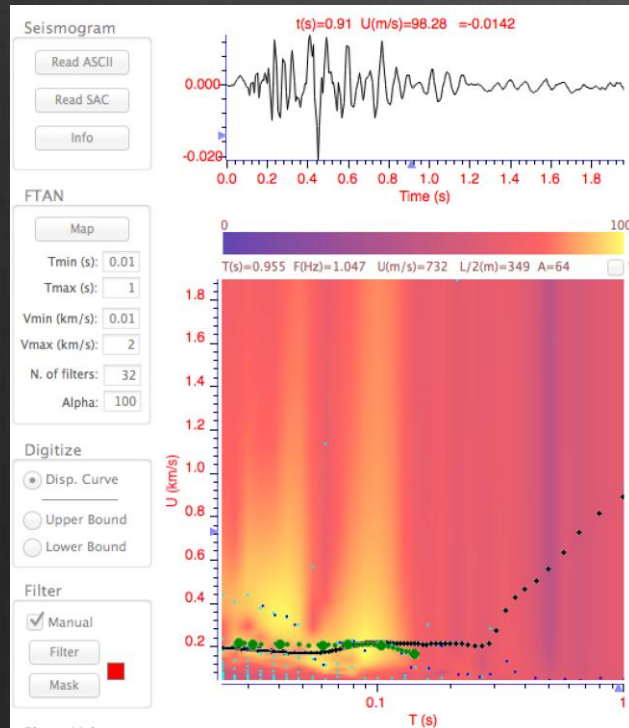
Rec.L.: 2s
 dT: 0.25 ms
 Spac.: 3 m
 Offset: 10 m
 Source: 5 kg hammer/Seismic gun
 Park et al. 1999



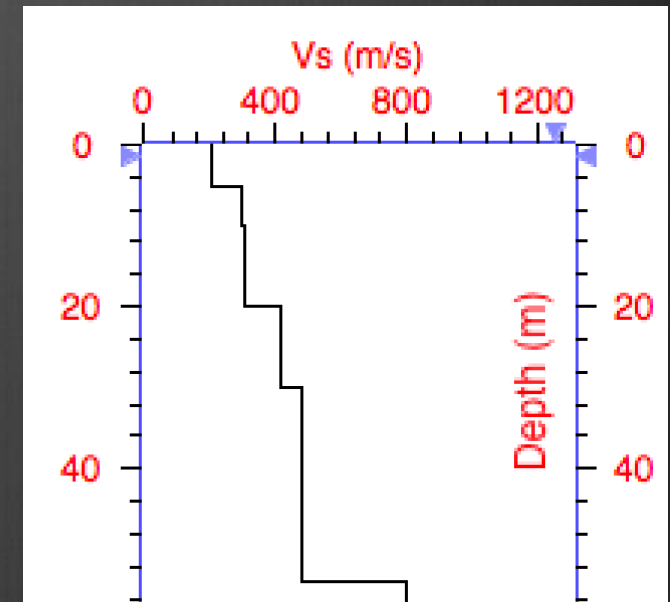


Indagini geofisiche

Indagini FTAN

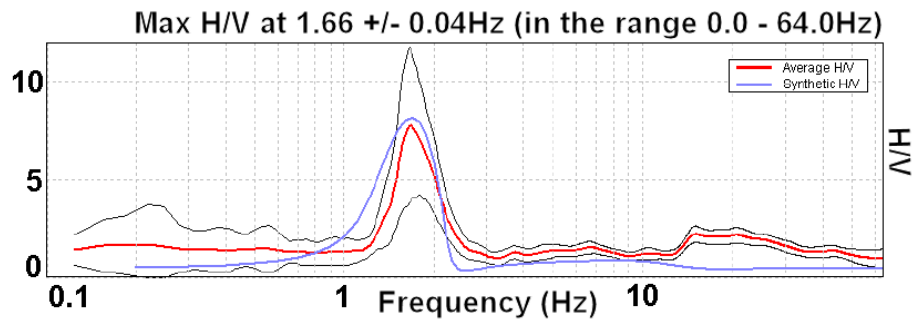


Risultati

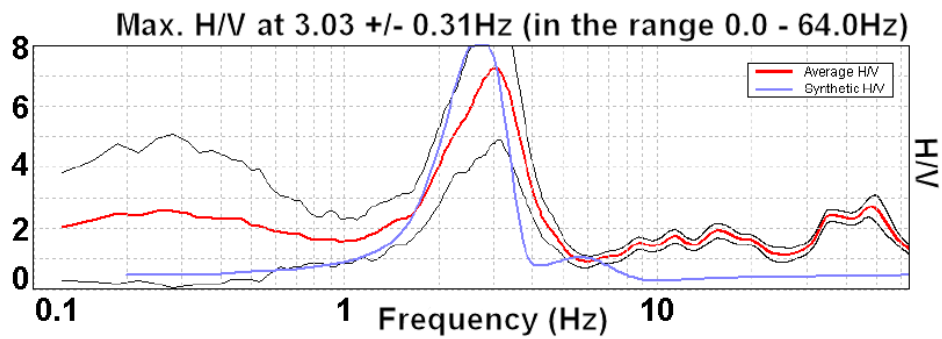


Rec.L.: 2 s
Sampl: 256 Hz
Spac.: 100 m
Offset: 10 m
Source: Seismic gun

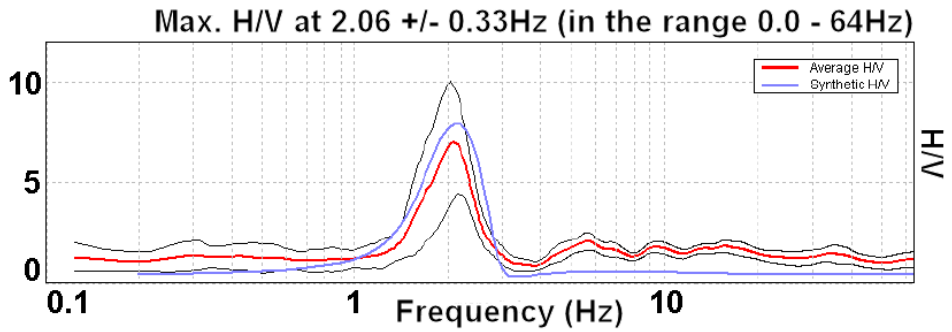
Levshin et al., 1972
Panza, 1989
Boaga, 2013



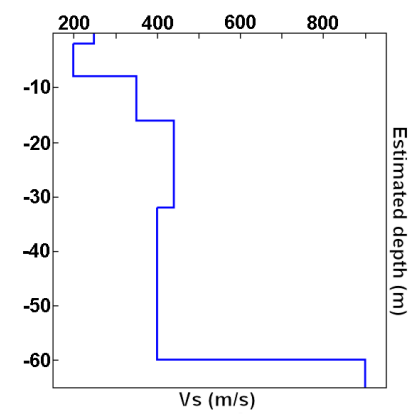
TEST HVSR3



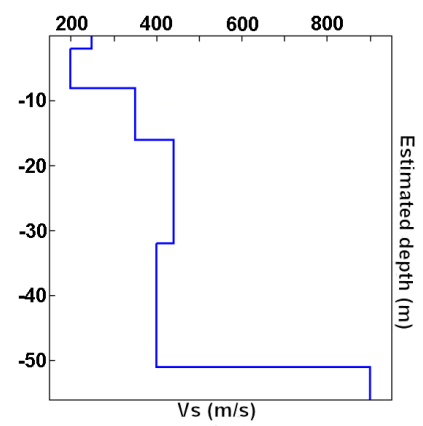
TEST HVSR2



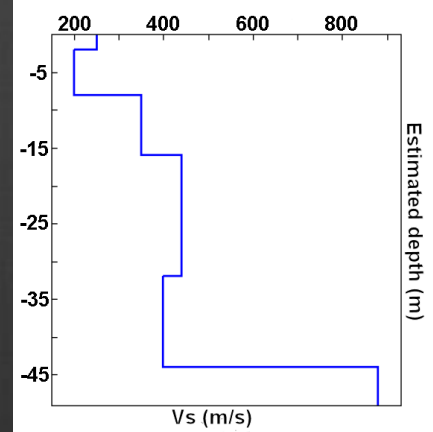
TEST HVSR1



HVSR3 - upstream test		
Thickness [m]	Vs [m/s]	Density [kg/dm ³]
2	250	1,7
6	200	1,8
8	350	1,8
16	440	1,8
28	400	1,9
0	900	2
bedrock depth: 60 m		



HVSR2 - intermediate test		
Thickness [m]	Vs [m/s]	Density [kg/dm ³]
2	250	1,7
6	200	1,8
8	350	1,8
16	440	1,8
19	400	1,9
0	900	2
bedrock depth: 51 m		

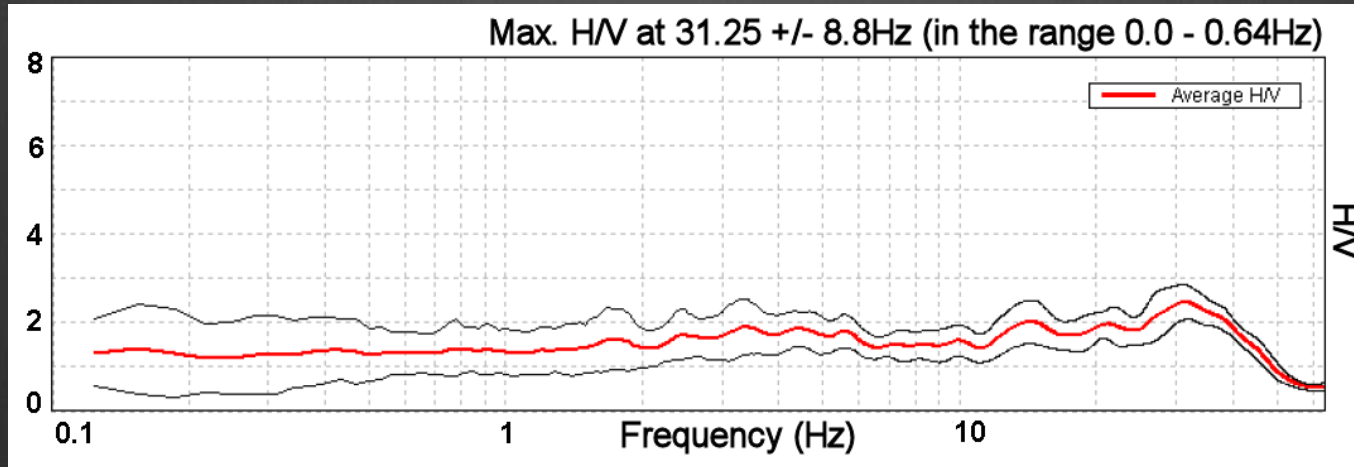


HVSR1 - downstream test		
Thickness [m]	Vs [m/s]	Density [kg/dm ³]
2	250	1,7
6	200	1,8
8	350	1,8
16	440	1,8
12	400	1,9
0	880	2
bedrock depth: 44 m		



Indagini geofisiche

Indagini HVSR Samoclevo



MANCANZA DI UN CONTRASTO D'IMPEDENZA

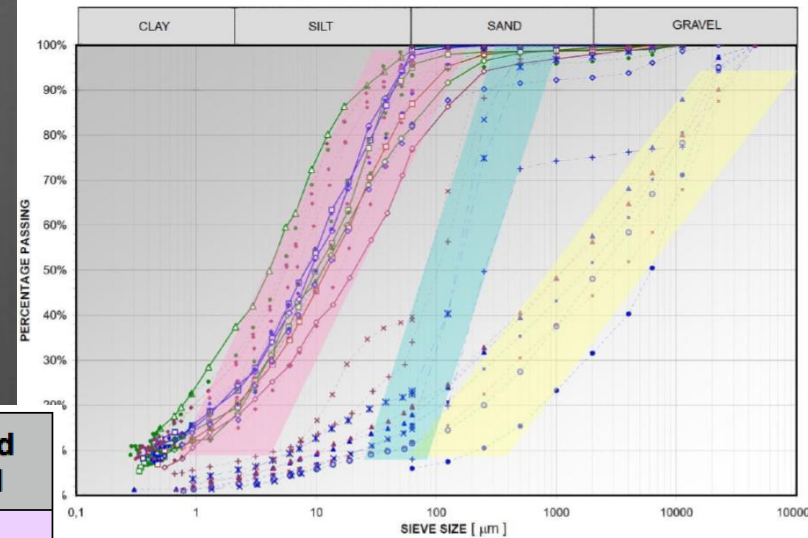


BEDROCK A LIVELLO SUPERFICIALE



Indagini geofisiche e geotecniche

Indagini sismiche:
risultati ed interpretazioni



Depth (m)	Vs (m/s)	Mean Vs (m/s)	Layer type	Assigned Material
0	258	250	sand	SAND
1	253,3			
2	227,3			
4	191,7	200	silt + clay	CALYEEY SILT
6	203,5			
8	251,7			
10	312,1	350	gravel1	GRAVEL
13	365,8			
16	406,7			
21	430,4	440	gravel2	
26	443,5			
31	450,6			



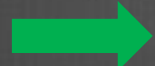
Indagini geotecniche

- caratteristiche fisiche
- proprietà indice
- granulometrie
- limiti di Atterberg
- edometriche
- conducibilità idraulica
- prove triassiali



Indagini geotecniche

Strumentazione di Colonna Risonante (Lab. di geotecnica P.A.T.)



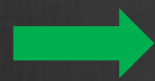
G_{\square} = modulo di taglio dinamico naturale

G = modulo di taglio dinamico di laboratorio

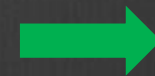
D = smorzamento



PROVE RC



$$\begin{cases} V_s = h \cdot \omega / \beta \\ \omega = 2\pi \cdot Fr \end{cases}$$



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



Amplitude Decay Method



D



LA

Resonant Column Tests

fitting of Yokota *et al.* (1981) model to experimental data obtained on 2 samples: S1-C11 (4.50-5.00 m) and S2-C11 (6.00-6.60 m) at the effective stress of 200 kPa normalized using G_0 coming from the hyperbolic relationship of Hardin e Drnevich

α	β	D_{max}	λ
43.1209	1.1548	19.5943	-2.5964

γ (%)	$\frac{G(\gamma)}{G_0} = \frac{1}{1 + \alpha\gamma^{(\beta)}}$	$\frac{D}{D_{max}} = e^{\lambda \frac{G}{G_0}}$
0.0001	0.999	1.464
0.0002	0.998	1.469
0.0003	0.996	1.475
0.0004	0.995	1.480
0.0005	0.993	1.486
0.001	0.985	1.517
0.002	0.968	1.587
0.004	0.932	1.744
0.01	0.825	2.298
0.02	0.680	3.353
0.03	0.571	4.451
0.04	0.488	5.515
0.05	0.424	6.509
0.1	0.249	10.270
0.2	0.129	14.000
0.3	0.085	15.706

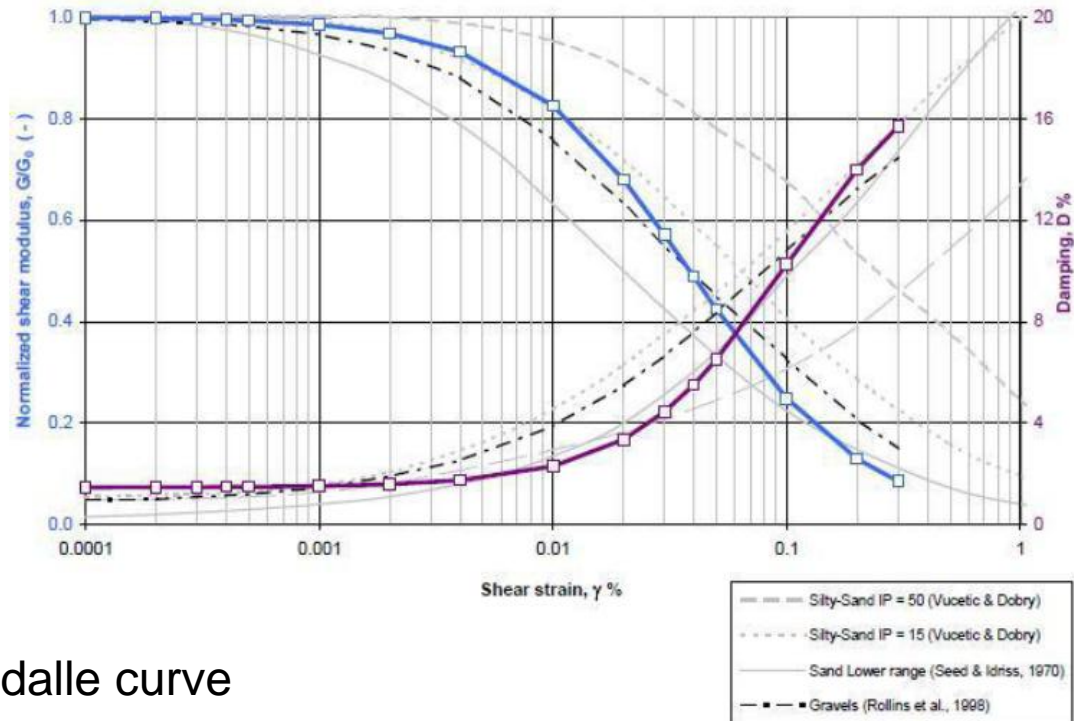
Modello d'interpolazione di Yokota et al. 1981



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

$$\frac{D}{D_{max}} = e^{\lambda \frac{G}{G_0}}$$

Curve di decadimento per i Limi argillosi



Valori selezionati dalle curve



S

Resonant Column Tests

fitting of Yokota *et al.* (1981) model to experimental data obtained on 2 samples: S2-CD L (21.70-22.00 m) and S2-CD M (24.00-24.40 m) at the effective stress of 200 kPa (S2 CD L) and 300 kPa (S2 CD M) normalized using G_0 coming from the hyperbolic relationship of Hardin e Drnevich

α	β	D_{max}	λ
23.3607	0.8887	19.3231	-2.5740

γ (%)	$\frac{G(\gamma)}{G_0} = \frac{1}{1+\alpha\gamma^\beta}$	$\frac{D}{D_{max}} = e^{\lambda \frac{G}{G_0}}$
0.0001	0.994	1.498
0.0002	0.988	1.519
0.0003	0.983	1.539
0.0004	0.978	1.558
0.0005	0.974	1.577
0.001	0.952	1.667
0.002	0.915	1.835
0.004	0.853	2.152
0.01	0.719	3.033
0.02	0.581	4.335
0.03	0.491	5.456
0.04	0.428	6.423
0.05	0.380	7.262
0.1	0.249	10.183
0.2	0.152	13.074
0.3	0.111	14.523

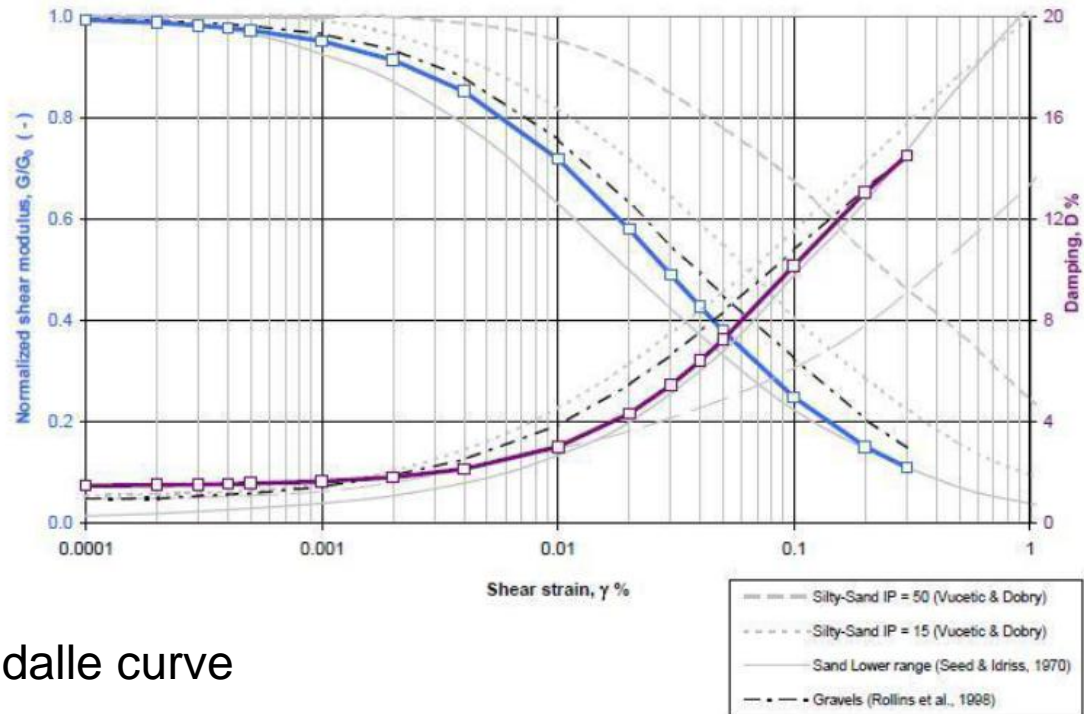
Modello d'interpolazione di Yokota et al., 1981



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

$$\frac{D}{D_{max}} = e^{\lambda \frac{G}{G_0}}$$

Curve di decadimento per le Sabbie

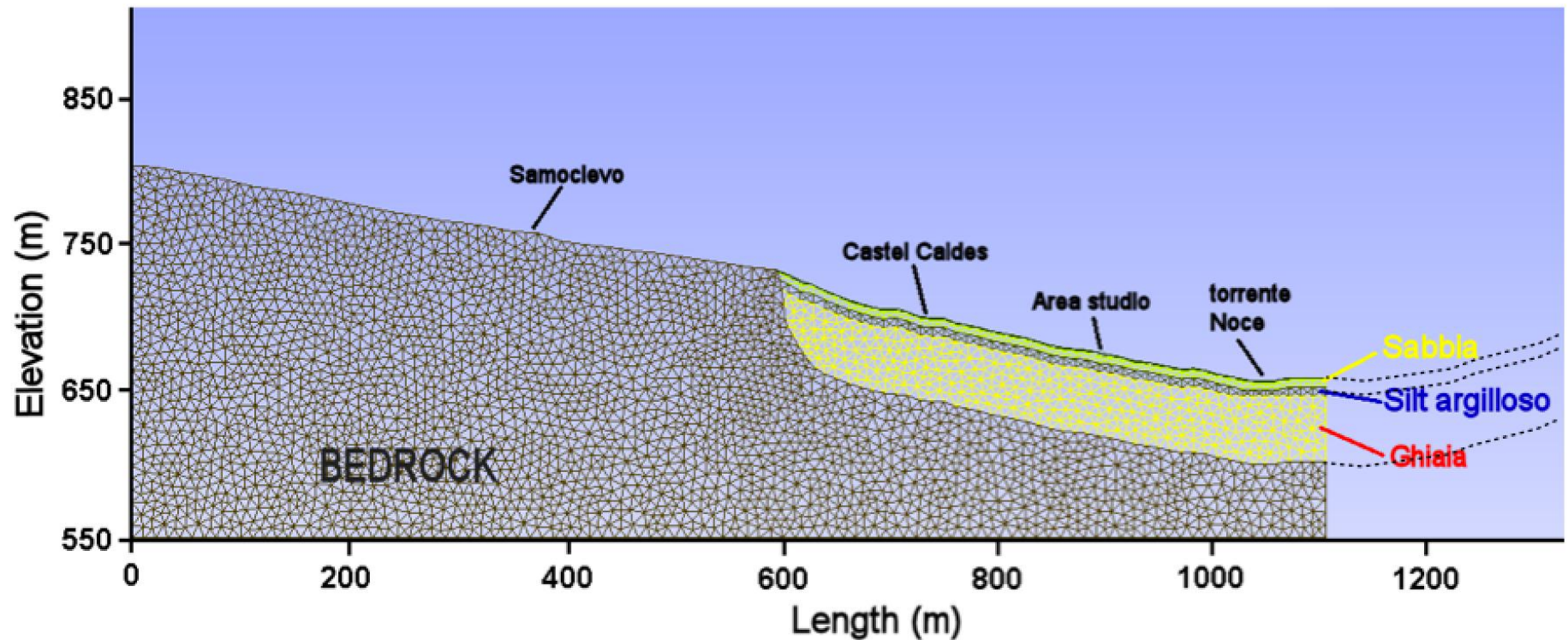


Valori selezionati dalle curve



- Risposta sismica locale

Modello di sottosuolo e mesh (elementi finiti) per la simulazione di scuotimento





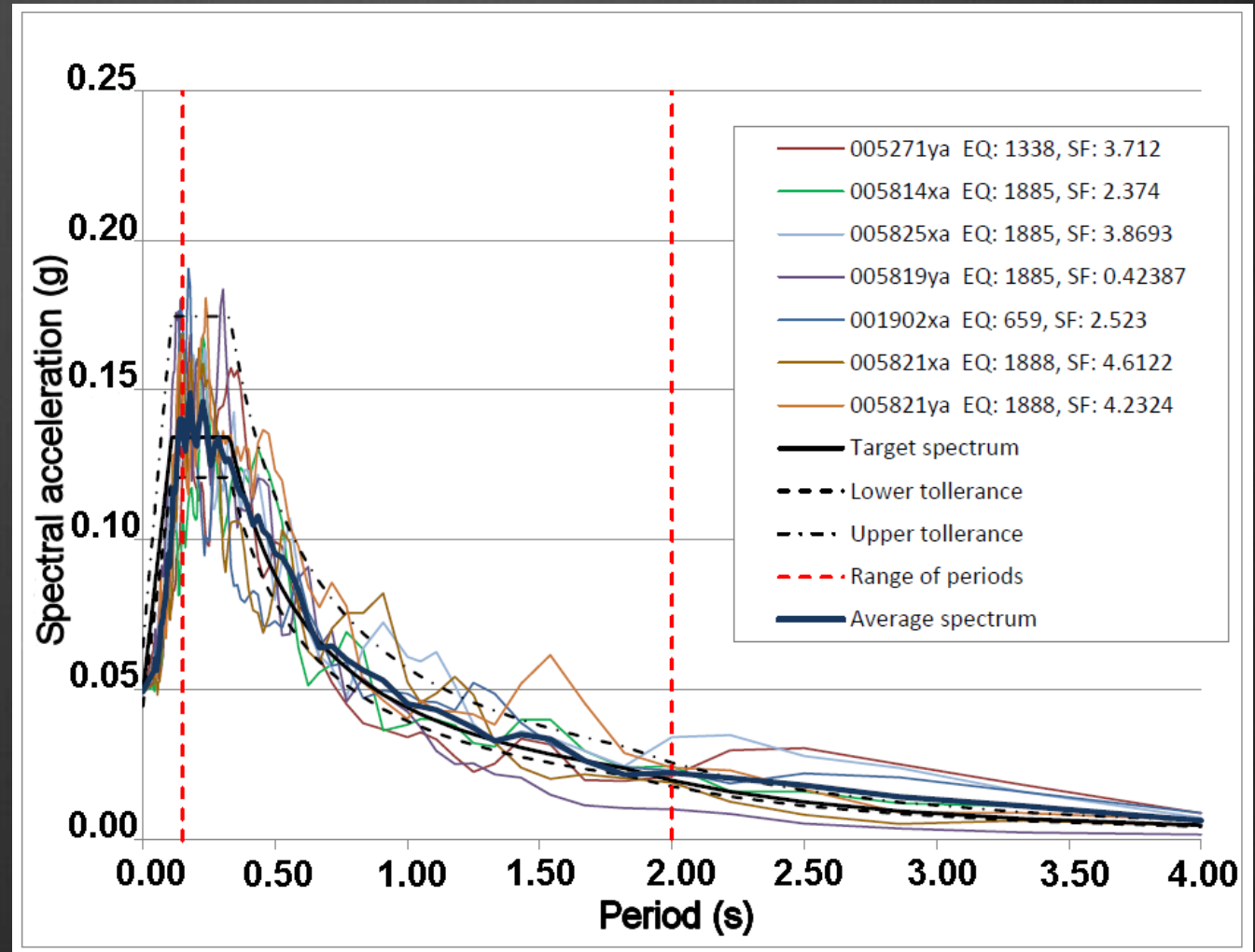
INPUT SISMICO



REXEL

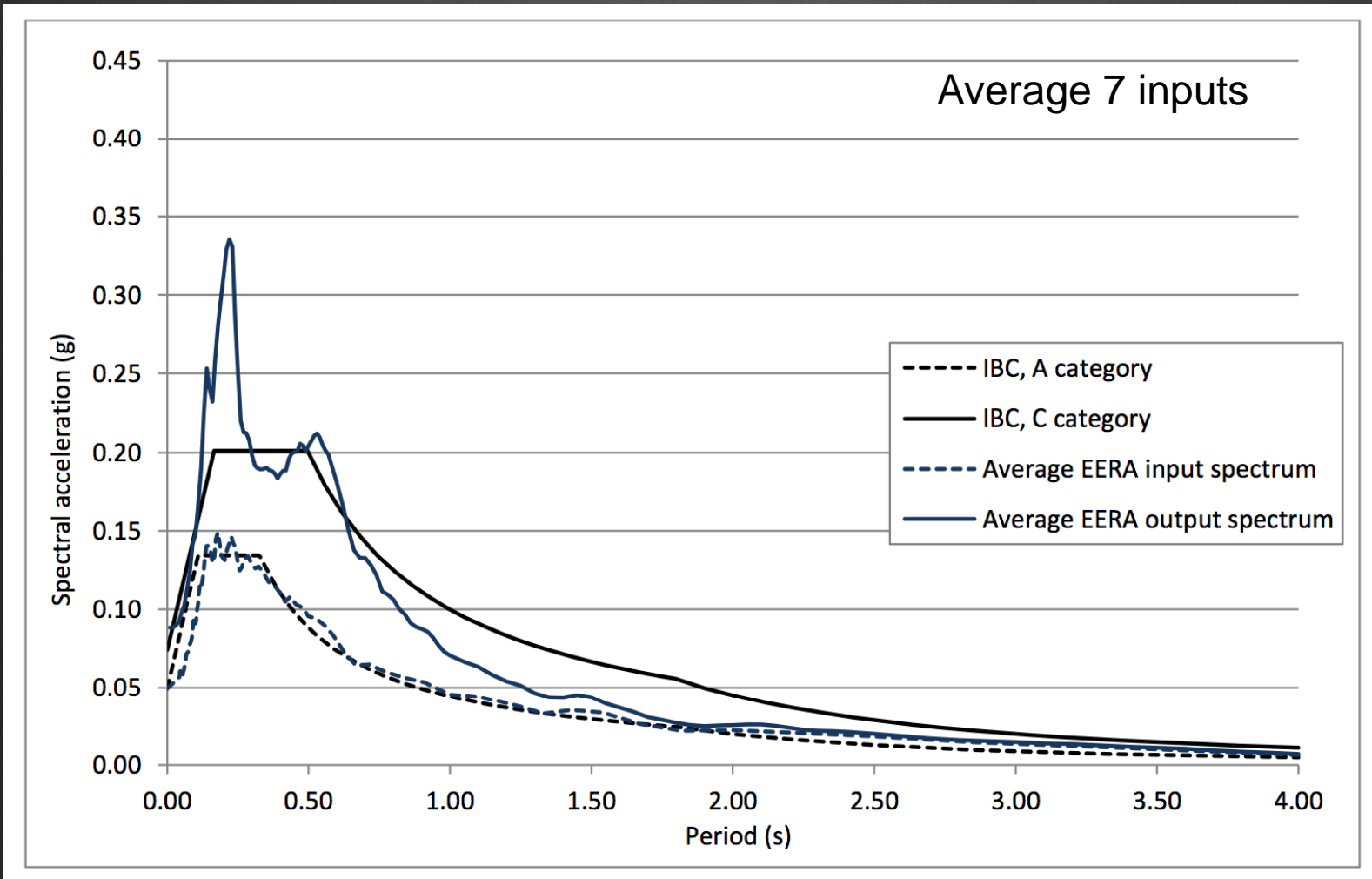


European
Strong-Motion
Dataset





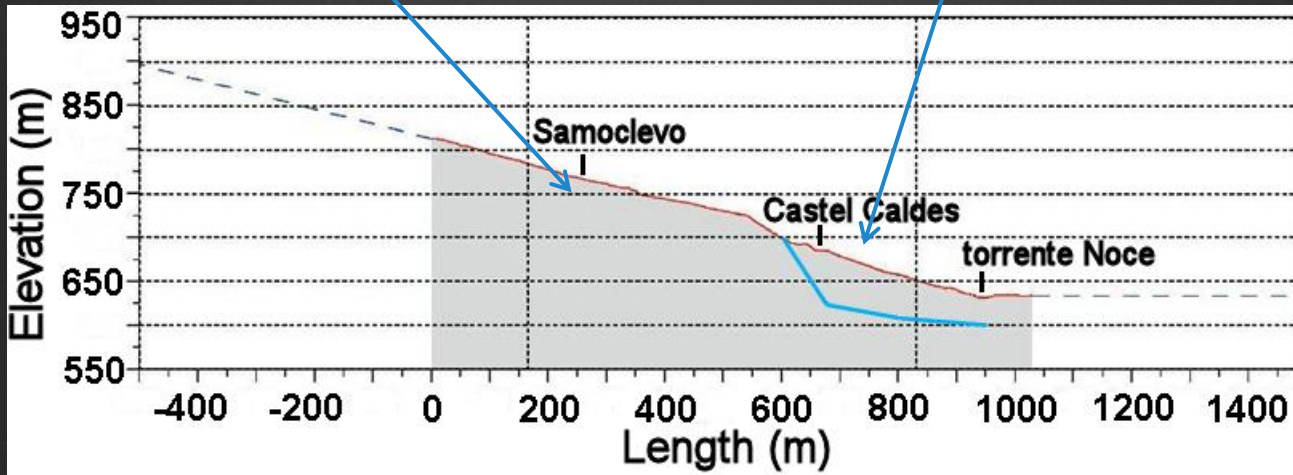
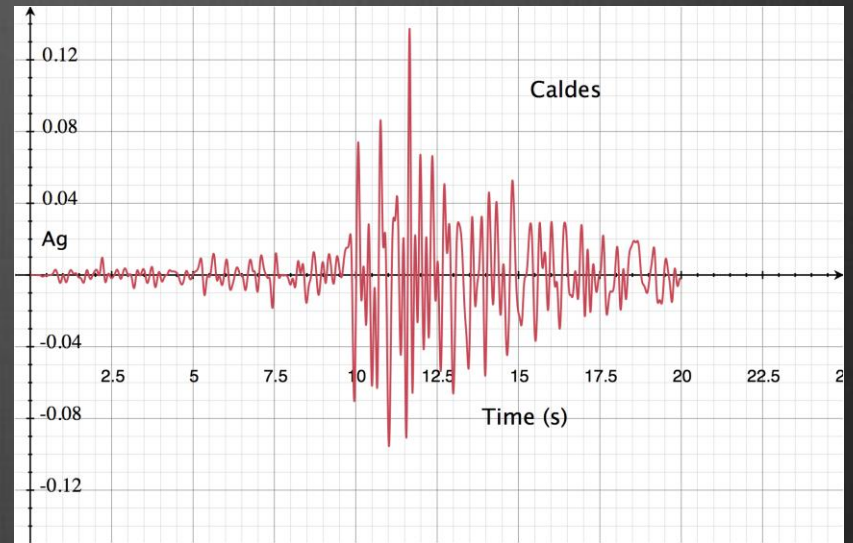
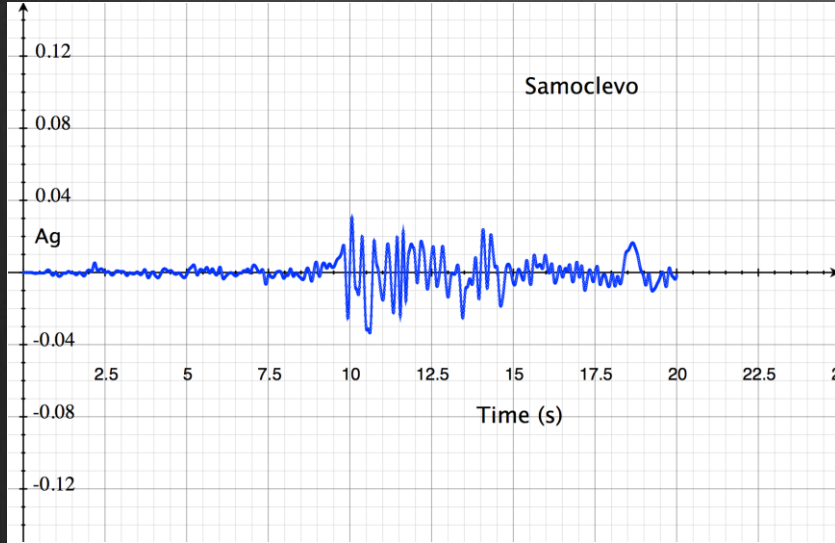
Modello di scuotimento – codice 1-D EERA - NTC





Modello di scuotimento – codice 2-D QUAD4M

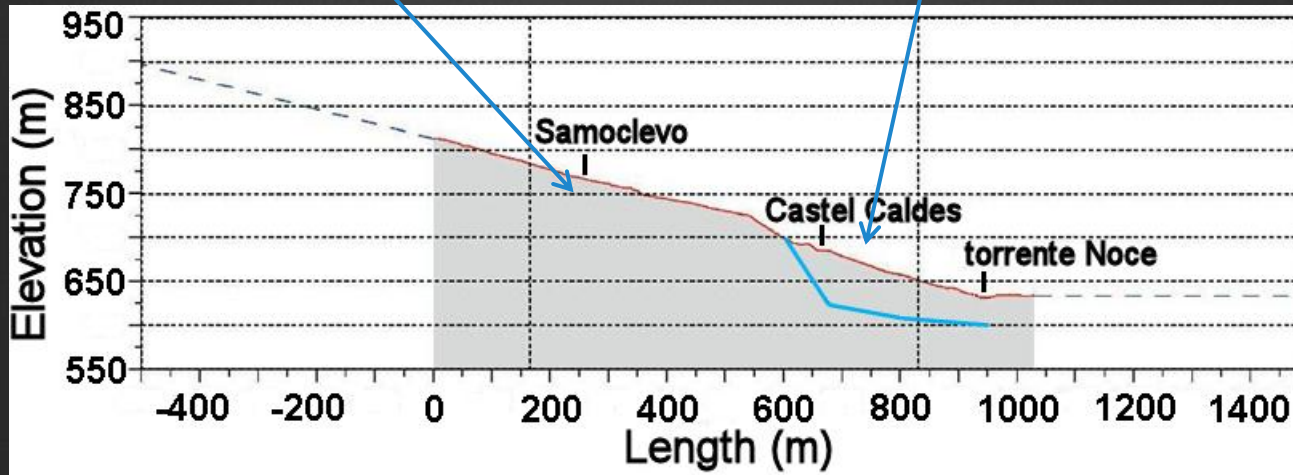
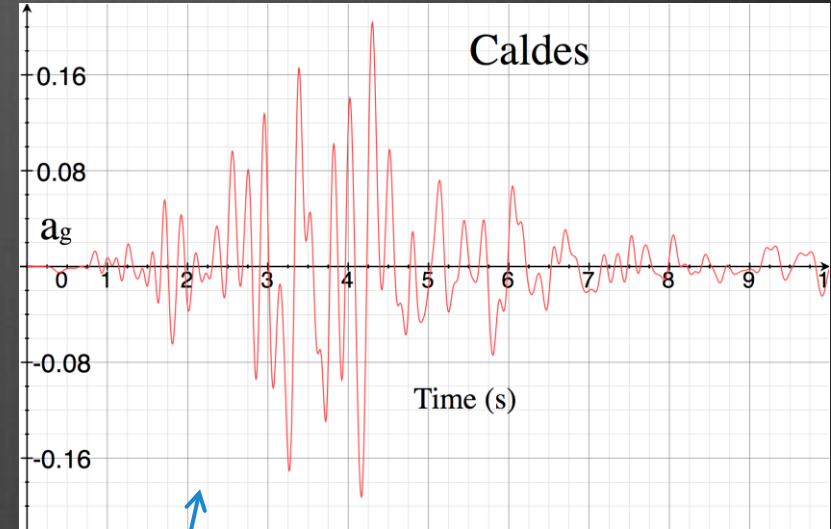
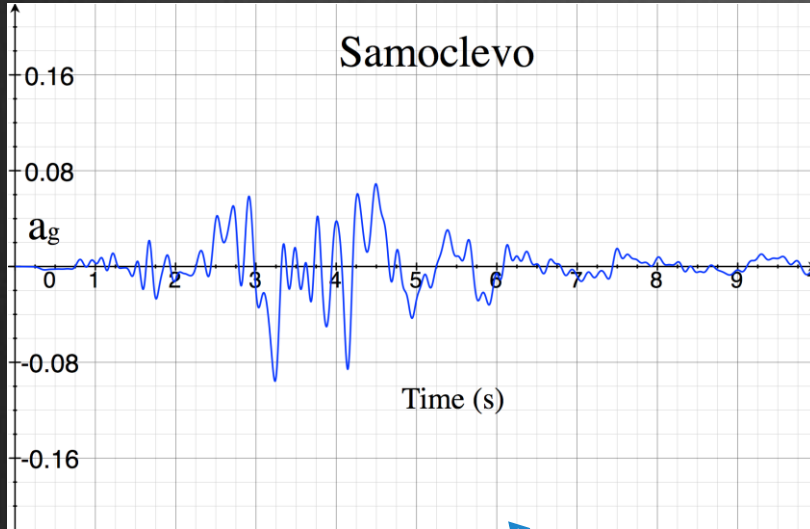
es. Input 1





Modello di scuotimento – codice 2-D QUAD4M

es. Input Merano





CONCLUSIONI

- L'approccio avanzato alla risposta sismica locale richiede un quadro olistico comprendente indagini geologiche, geofisiche e geotecniche
- Le condizioni geologiche locali possono presentare significative e brusche variazioni, specie in contesti montani.
- E' richiesta particolare attenzione nella determinazione degli scenari di pericolosità sismica, necessari per una corretta valutazione e gestione del rischio.



Grazie per l'attenzione

*“Il rimedio, secondo me, non sta nel prevedere la catastrofe per fuggirla,
ma nell’evitarla dal bel principio, studiando il terreno sul quale
edificare e facendosi guidare nella scelta
dall’esperienza e dalla scienza”*

L. Palmieri, 1883