Rete dei Laboratori Universitari di Ingegneria Sismica e Strutturale

Convegno ReLUIS

PROTEZIONE CIVILE
Presidenza del Consiglio dei Ministri
Dipartimento della Protezione Civile

Progetto DPC_ReLUIS 2024-2026

Napoli, 13-14 ottobre 2025

WP 18 - Input sismico, normativa e microzonazione

Roberto Paolucci, Sebastiano Foti

UR WP18 2024-26

N.	RESPONSABILE SCIENTIFICO	UNIVERSITÀ	DIP.	Partecipazione TASK	Responsabilità Task
1	Paolucci Roberto	Politecnico di Milano	D.I.C.A.	1-2-3	1-3
2	Sgobba Sara	INGV	INGV	2-3-4	3
3	Baltzopoulos Georgios	Università degli Studi di Napoli "Federico II"	Di.St.	1-3	1
4	Lai Carlo	Università degli Studi di Pavia	DICAr	2-3-4	4
5	Albarello Dario	Università degli Studi di Siena	DSFTA	1-2	2
6	Foti Sebastiano	Politecnico di Torino	DISEG	2	2
7	Pagliaroli Alessandro	Università di Chieti-Pescara	DIG	2	
8	Lanzo Giuseppe	Università Sapienza di Roma	DISeG	2-4	

Il progetto Reluis WP18 – 2024-26
Input sismico, normativa e microzonazione

- **TASK 1 Pericolosità sismica e normativa**
  (Resp. PoliMI – R. Paolucci & UniNA - G. Baltzopoulos)

- **TASK 2 Categorizzazione sismica del sottosuolo, fattori di amplificazione nella normativa e microzonazione sismica**
  (Resp. PoliTO, S. Foti & UniSI – D. Albarello)

- **TASK 3 Terremoto di progetto e selezione di accelerogrammi**
  (Resp. PoliMI – C. Smerzini & INGV S. Sgobba)

- **TASK 4 Caratterizzazione delle componenti verticali del moto sismico per analisi strutturali**
  (Resp. UniPV, C. Lai)

WP18 Task 1: Pericolosità sismica e normativa

state-of-art on the application of seismic hazard assessment as input for seismic hazard assessment in international seismic norms

Progetto WP18

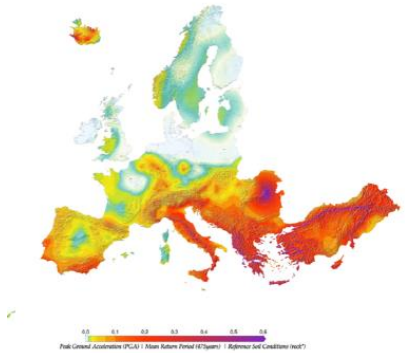
DPC - RELUIS 2024-26

Input sismico, normativa e microzonazione

Intermediate Report

Deliverable WP18-D3

Overview of international norms on seismic input for design



Danciu et al 2021

Table 1. International norms considered for this overview

	Italy	NTC18 (CS.LL.PP. 2018)
	Europe	Eurocode 8 (FprEN 1998-1-1:2024_TC 250)
	USA	ASCE/SEI 7-22
	New Zealand	DZ TS 1170.5:2024 (Draft for public consultation)
	China	GB50011-2010 - Code for seismic design of buildings
	India	Indian Standard Code IS 1893 – Parts 1 to 5 – Year 2016; Draft Standard for Comments Only CED 39(22343)WC April 2023
	México	MANUAL DE DISEÑO DE OBRAS CIVILES DISEÑO POR SISMO (MOC) 2022 Normas Técnicas Complementarias con Comentarios por la Ciudad de Mexico (NTC 2023)
	Turkey	Turkish Earthquake Code (2018)
	Japan	Earthquake Resistant Design Method for Buildings - Ministry of Land, Infrastructure and Transport 2024
	Chile	NCh-433-Of-1996-Mod-2009-DS-61-2011; NCh00433-2022-043
	Switzerland	SIA:2061:2003
	Greece	Ελληνικός Αντισεισμικός Κανονισμός: Υ.Α. Δ17α/115/9/ΦΝ275/2003 ΦΕΚ1154/Β΄12.8.2003

Country Name

Normative Document

(1) Definition of seismic actions for design

(a) Regularized spectral shape, based on few hazard-related parameters
(b) Uniform hazard spectrum
(c) Deterministic design spectrum

(2) Classification of the national territory

(a) Zone-based: no
(b) Site-specific, map-based

(3) Target structural performance

(a) Limit states and importance categories
(b) Association of limit states with return periods
(c) Association with deterministically determined earthquakes

(4) Site categorization, reference site and site amplification factors

(5) Vertical Spectrum

(6) Criteria for ground motion selection and scaling

(a) Classes of accelerograms
(b) Selection criteria
(c) Scaling
(d) Selection and scaling in "special" conditions

(7) Conventional "design earthquake" (M, R)

(8) Miscellanea

(a) other peak-value parameters for design (e.g., PGV)
(b) criteria to account for "complex" site conditions

USGS National Seismic Hazard Maps - Research aricle

The 2023 US 50-State National Seismic Hazard Model: Overview and implications

Il progetto Reluis WP18 – 2024-26
Input sismico, normativa e microzonazione

- **TASK 1 Pericolosità sismica e normativa**
  (Resp. PoliMI – R. Paolucci & UniNA - G. Baltzopoulos)

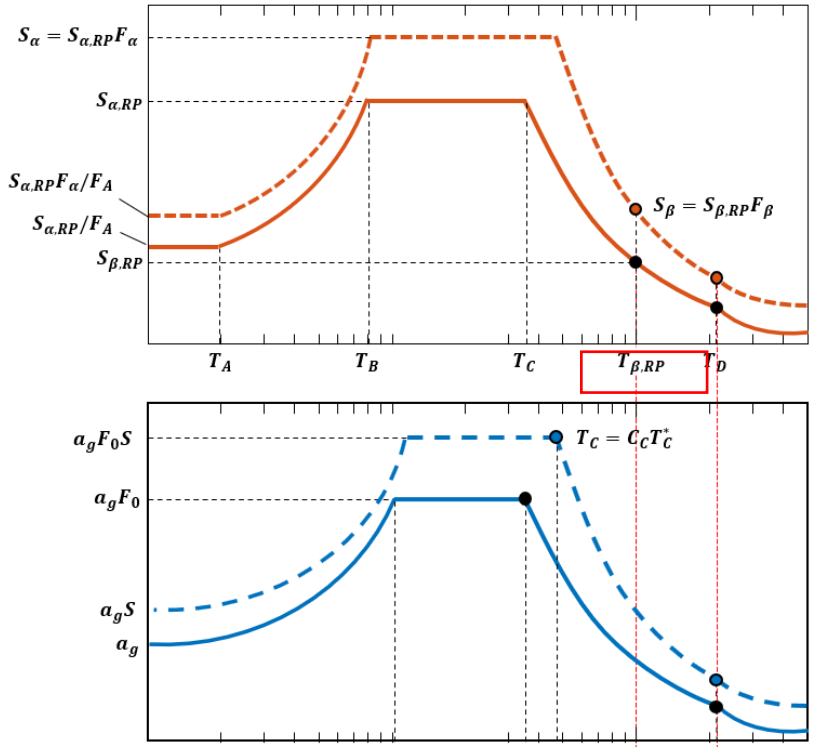
- **TASK 2 Categorizzazione sismica del sottosuolo, fattori di amplificazione nella normativa e microzonazione sismica**
  (Resp. PoliTO, S. Foti & UniSI – D. Albarello)

- **TASK 3 Terremoto di progetto e selezione di accelerogrammi**
  (Resp. PoliMI – C. Smerzini & INGV S. Sgobba)

- **TASK 4 Caratterizzazione delle componenti verticali del moto sismico per analisi strutturali**
  (Resp. UniPV, C. Lai)

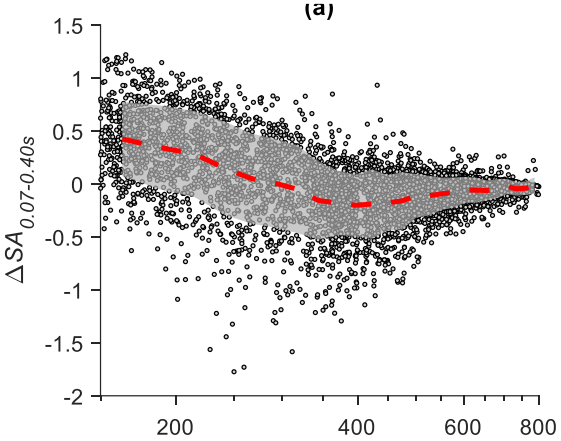
Stato dell'arte: amplificazione stratigrafica nelle normative internazionali

Coefficient-based approaches

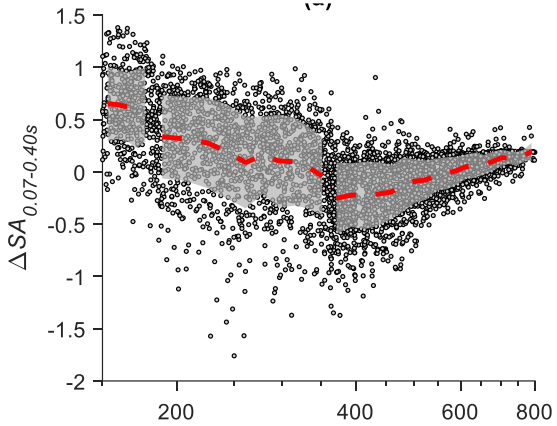


Medium-seismicity level
– PGA = 0.18g

2nd Gen of EC8 (2025)

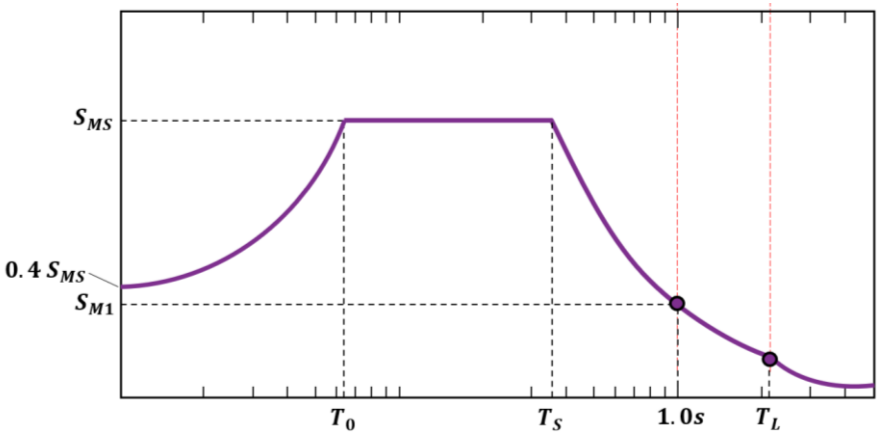


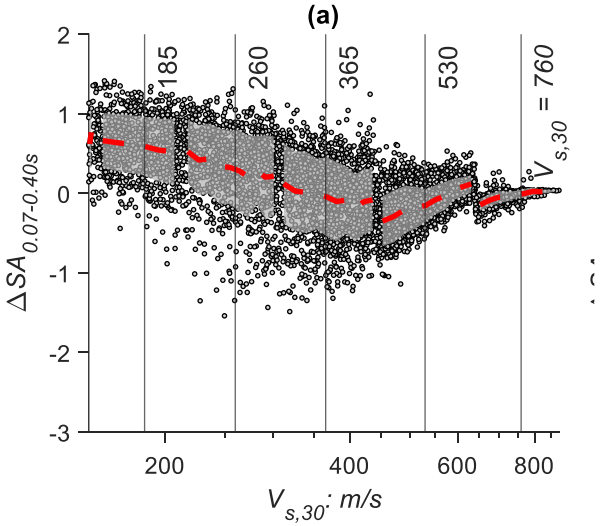
NTC18



Probabilistic class-based approaches

Mapped site-specific response spectra – Based on NSHMs:
ASCE 7-22
NBCC 2020 (Canada)
DZ TS 1170.5:2024 (New Zealand)

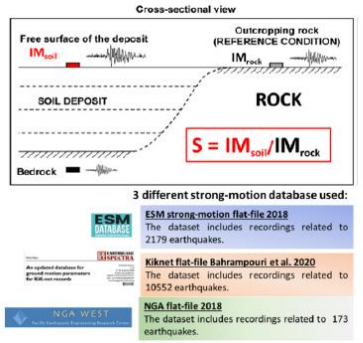


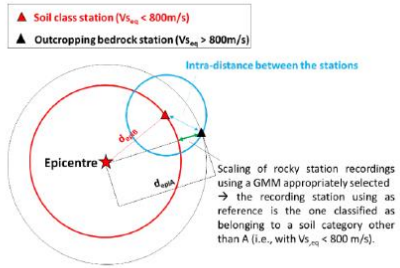


Revisione dei fattori di amplificazione stratigrafica nelle normative (NTC2028 & EC8 2nd gen)

DEFINITION OF HAZARD-DEPENDENT SOIL FACTORS

- NUMERICAL (site response analysis)
- REAL GROUND MOTION DATA





Ss factor

4 different methodologies

Ss

1. $S = \frac{PGA_{soil}}{PGA_{rock}}$
2. $S = \frac{Sa_{max\,soil}}{Sa_{max\,rock}}$

2 methodologies based (revised) on Andreotti et al. 2018

3. $S = \frac{\int_{T=0.07s}^{T=0.40s} Rs\_soil}{\int_{T=0.07s}^{T=0.40s} Rs\_rock}$
4. $S = \frac{\int_{T=0.70s}^{T=2.00s} Rs\_soil}{\int_{T=0.70s}^{T=2.00s} Rs\_rock}$

2 additional methodologies based of EC8 draft:

- Short periods (0.07-0.40s)
- Intermediate periods (0.70-2.0s)

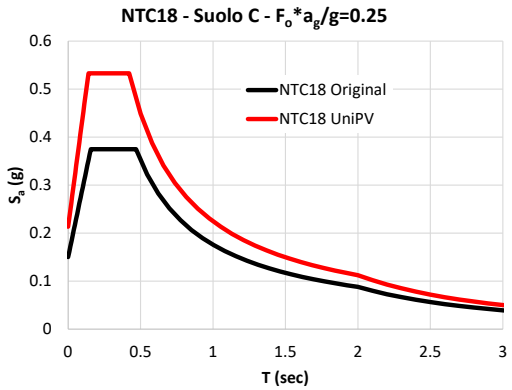
Range values are based on Paolucci et al. (2021)

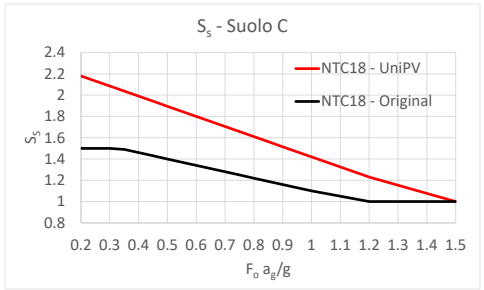
NTC18

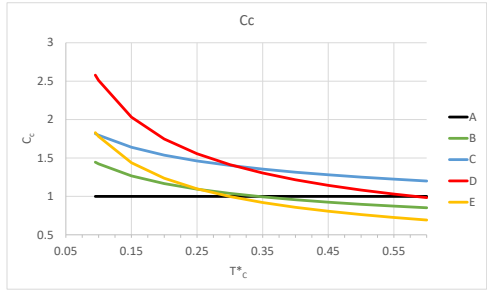
Italian building code NTC18 Soil factor Ss

Soil class	Sa-max	Short period
A	1.00	1.00
B	$1.00 \le 1.72 - 0.36\ F_0\ a_g$	**$1.00 \le 1.88 - 0.46\ F_0\ a_g$**
C	$1.00 \le 2.09 - 0.76\ F_0\ a_g$	**$1.00 \le 2.37 - 0.95\ F_0\ a_g$**
D	**$0.80 \le 1.60 - 0.64\ F_0\ a_g$**	$0.80 \le 1.20 - 0.45\ F_0\ a_g$
E	**$1.00 \le 2.28 - 0.72\ F_0\ a_g$**	$1.00 \le 2.02 - 0.68\ F_0\ a_g$

Soil class	$C_C = \frac{T_C}{T^*_C}$
A	1.00
B	$0.735\ Tc^{*-0.287}$
C	$1.070\ Tc^{*-0.225}$
D	$0.753\ Tc^{*-0.523}$
E	$0.529\ Tc^{*-0.527}$



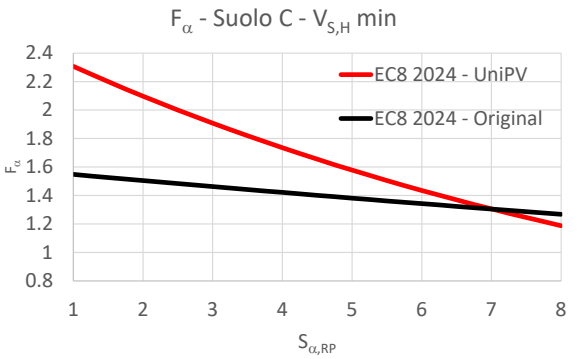


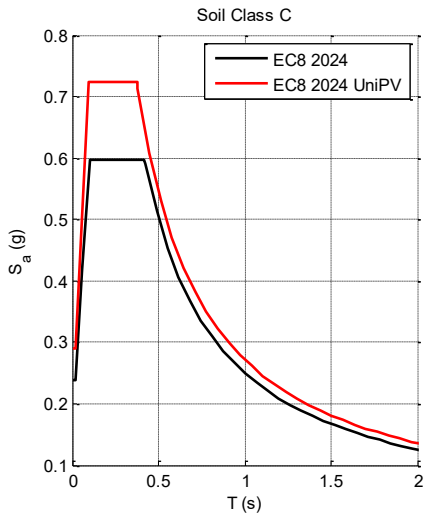


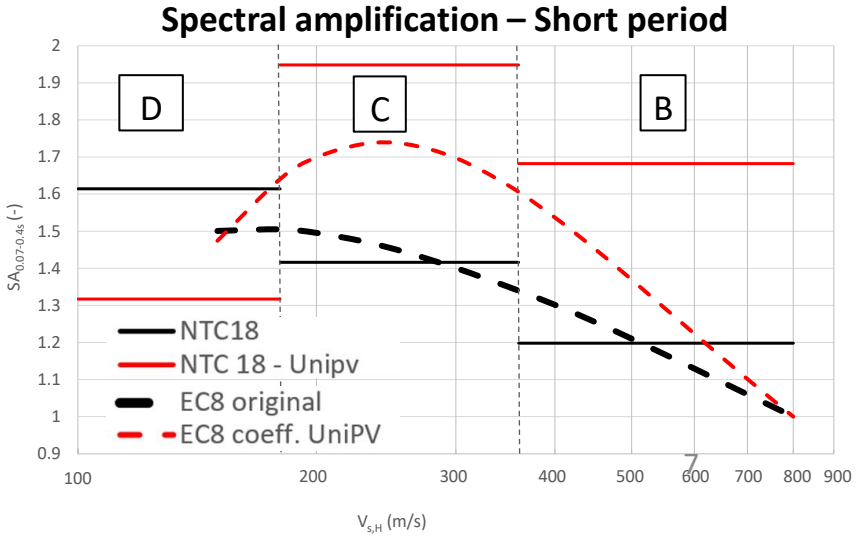
EC8

2024 final draft of EC8 – soil factor S

Soil Class	Short period ≡ F_α defined by Eq.3 Intensity measure S_{amax}	Intermediate period ≡ F_β defined by Eq.4 Intensity measure S_β
A	1.00	1.00
B C D	$0.80 \le \left(\frac{V_{S,H}}{800}\right)^{-0.80\left(1-\frac{Samax}{\frac{V_{S,H}}{250}}\right)}$	$1.00 \le \left(\frac{V_{S,H}}{800}\right)^{-1.00\left(1-\frac{S_\beta}{\frac{V_{S,H}}{600}}\right)}$
E	$1.00 \le \left(\frac{V_{S,H}}{800}\right)^{-0.85\left(1-\frac{Samax}{\frac{V_{S,H}}{250}}\right)}$	$1.00 \le \left(\frac{V_{S,H}}{800}\right)^{-0.80\left(1-\frac{S_\beta}{\frac{V_{S,H}}{700}}\right)}$







Modello Machine Learning per il fattore di amplificazione topografica

sulla base di parametri geometrici, geotecnici e sismici

dataset 18 sezioni di rilievi isolati

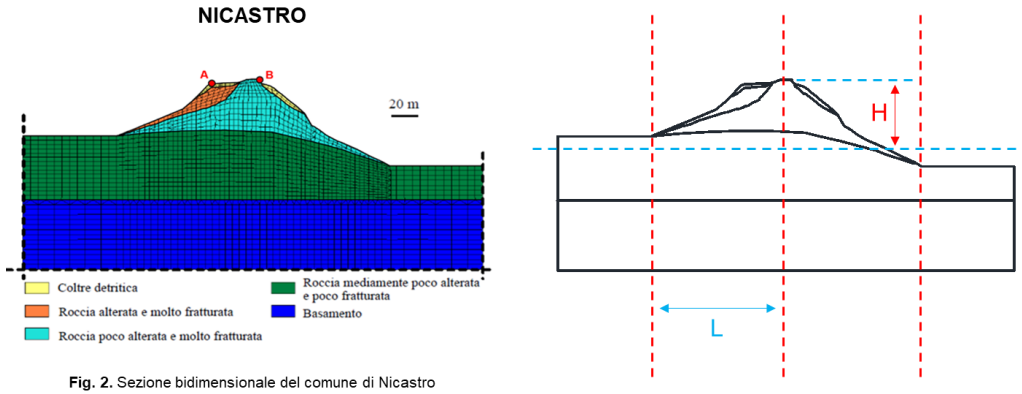
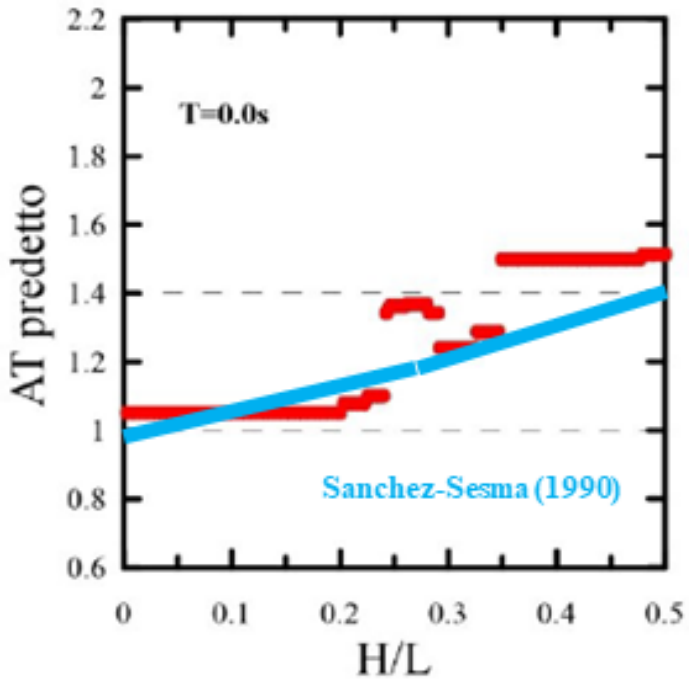
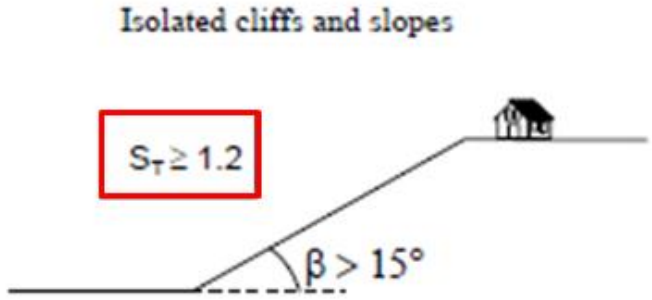
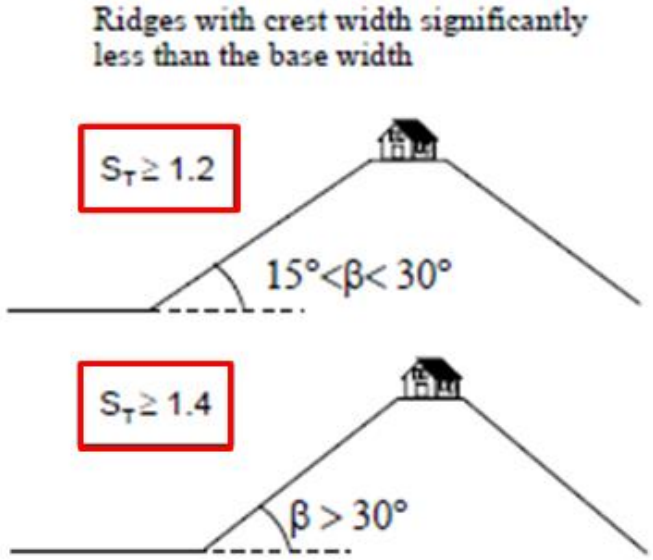


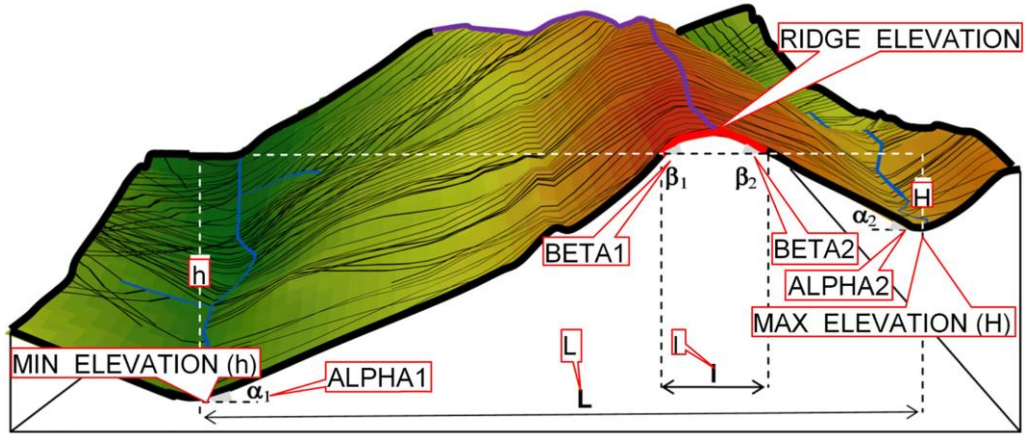
Fig. 2. Sezione bidimensionale del comune di Nicastro





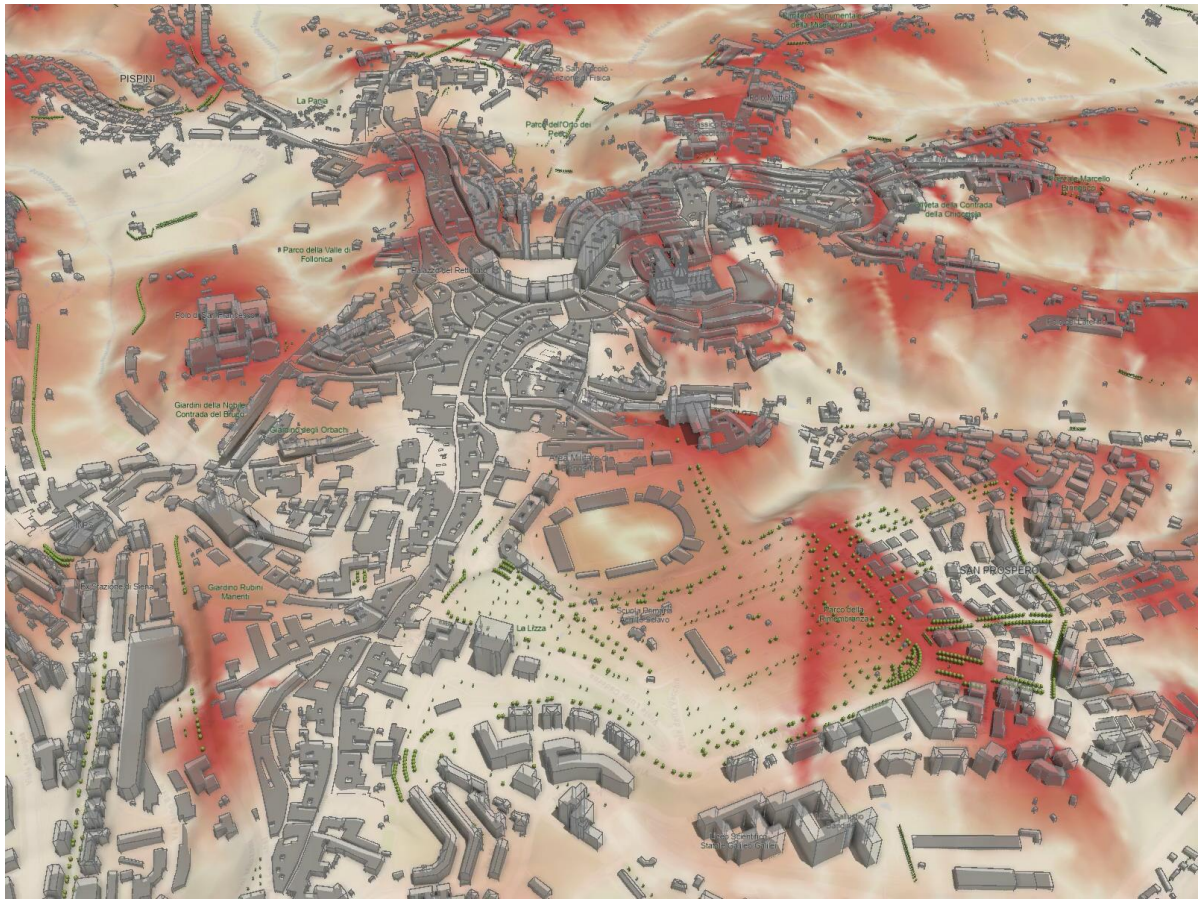


Metodologia automatica per la stima del **fattore di amplificazione** topografica secondo le NTC18 in contesti morfologici reali con la massima risoluzione disponibile del **DEM**



Topographic Category	Characteristics of the topographic surface	St
T1	Flat surface, slopes and isolated reliefs with average inclination **i** ≤ 15°	1
T2	Slopes with average inclination > 15°	1.2
T3	Reliefs with width at the crest much smaller than at the base and average inclination 15° ≤ **i** ≤ 30°	1.2
T4	Reliefs with width at the crest much smaller than at the base and average inclination > 30°	1.4

risultato relativo al centro storico di Siena



Il progetto Reluis WP18 – 2024-26
Input sismico, normativa e microzonazione

- **TASK 1 Pericolosità sismica e normativa**
  (Resp. PoliMI – R. Paolucci & UniNA - G. Baltzopoulos)

- **TASK 2 Categorizzazione sismica del sottosuolo, fattori di amplificazione nella normativa e microzonazione sismica**
  (Resp. PoliTO, S. Foti & UniSI – D. Albarello)

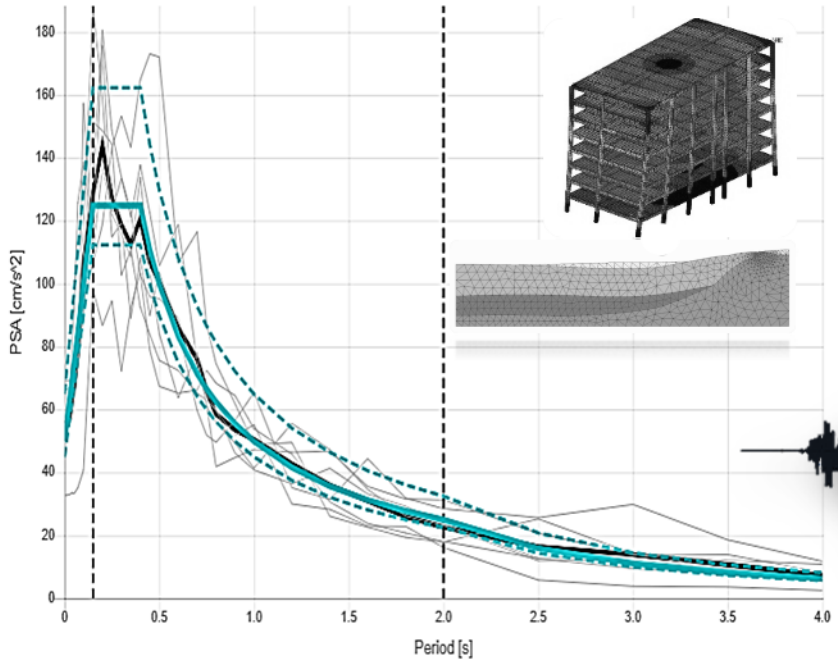
- **TASK 3 Terremoto di progetto e selezione di accelerogrammi**
  (Resp. PoliMI – C. Smerzini & INGV S. Sgobba)

- **TASK 4 Caratterizzazione delle componenti verticali del moto sismico per analisi strutturali**
  (Resp. UniPV, C. Lai)

Task 3: miglioramento dei criteri e degli strumenti di selezione di accelerogrammi spettro-compatibili

Tool di selezione spettro-compatibile

Miglioramento del tool di selezione **RexelWEB** attraverso l'implementazione di nuove funzionalità utili a soddisfare le crescenti esigenze dei professionisti nei settori geotecnico e strutturale



REXELweb

Software per selezione di accelerogrammi registrati spettro-compatibili

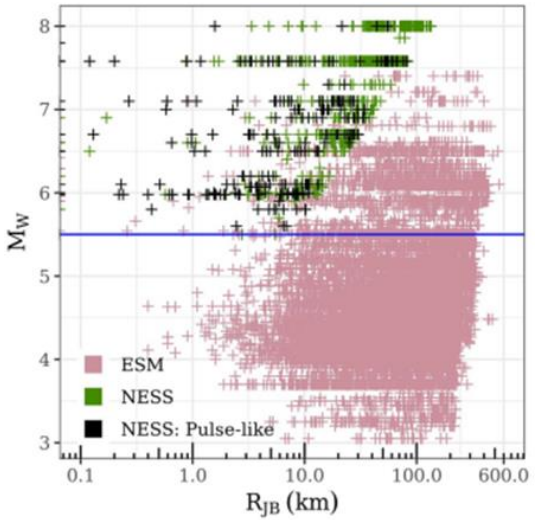
REXELweb

REXELweb

Tasks 2024-2026

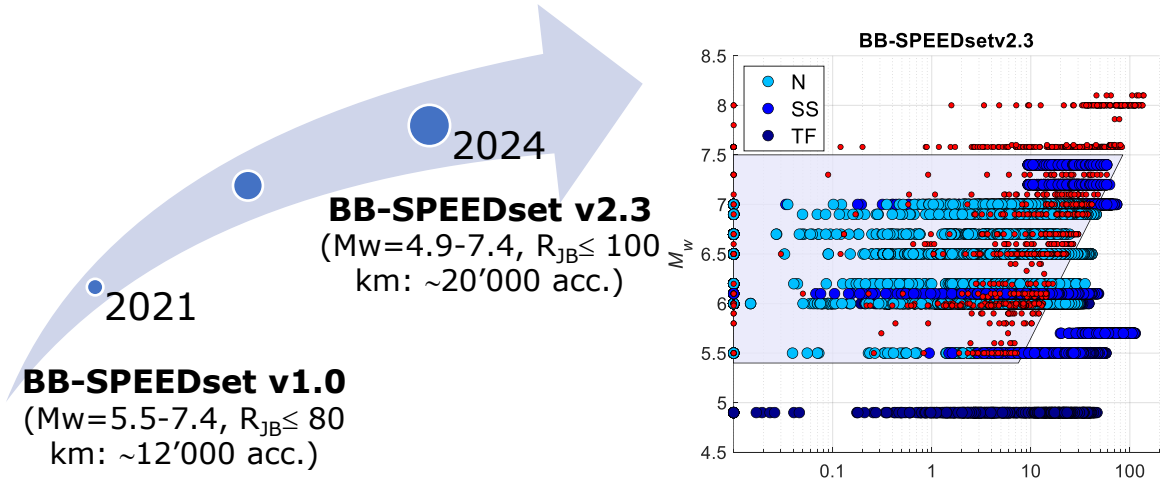
- Aggiornamento ed espansione delle **banche dati** di accelerogrammi, sia da registrazioni di terremoti reali in **campo vicino** che da simulazioni numeriche
- Valutazione e implementazione di vari criteri per definire lo **spettro obiettivo** nella selezione di accelerogrammi spettro-compatibili alla luce del nuovo contesto normativo
- Inclusione di criteri di compatibilità spettrale con un focus sulla **selezione multi-componente** (aggiornamento normativo, introduzione di obiettivi per la componente verticale in linea con lo stato dell'arte più recente, proposta V/H ReLUIS ecc.)
- Definizione del **Terremoto di Progetto**: stato dell'arte e nuove proposte

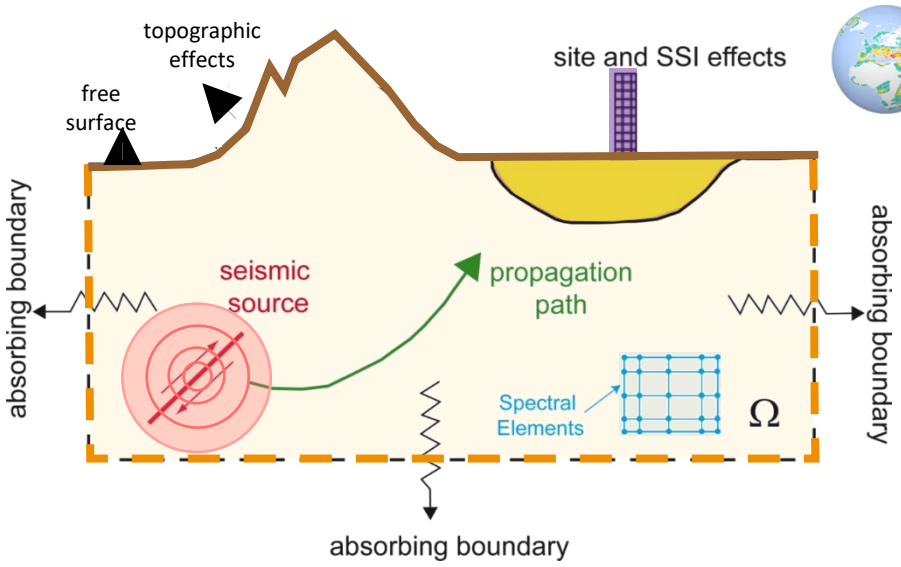
Ampliamento della base dati in campo vicino da dati registrati (**NESS2** – *Sgobba et al., 2021* e sintetici **BB-SPEEDset** – *Paolucci et al. 2021*)



Task 3: integrazione di dataset di accelerogrammi registrati e simulati

Banca dati di accelerogrammi da simulazioni numeriche 3D

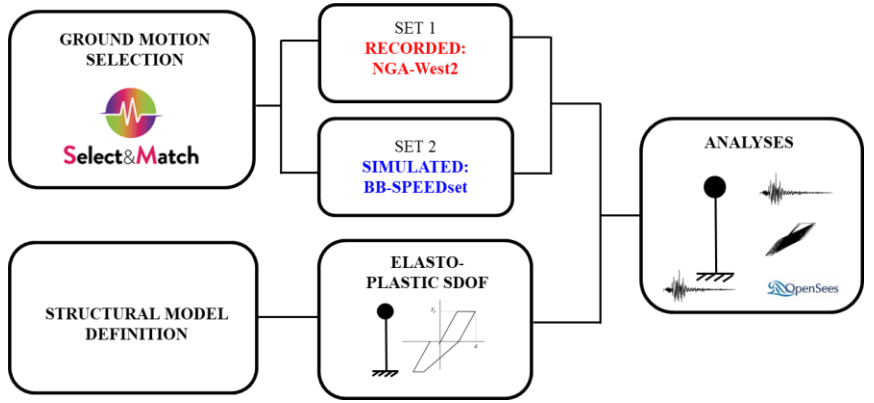


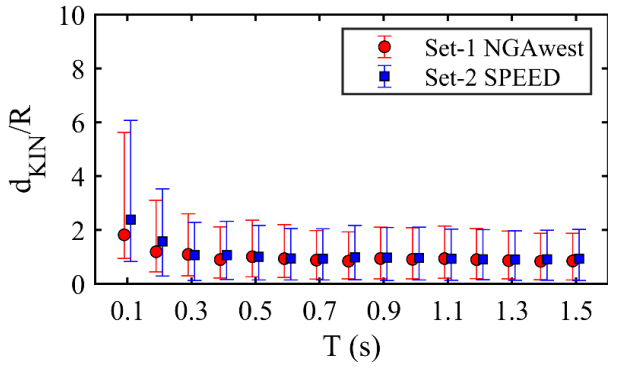


Tasks 2024-2026

- ✓ Ulteriore **ampliamento di BB-SPEEDset** man mano che nuovi scenari simulati (e validati) risultano disponibili
- ✓ Ulteriori studi e "validazioni" su BB-SPEEDset (e.g. utilizzo ingegneristico per ADNL, scenari di danno sismico, analisi sistematica delle diverse componenti della variabilità, in sinergia con WP4)
- ✓ **Integrazione di BB-SPEEDset in REXELweb** al fine di effettuare ricerche di accelerogrammi spettro-compatibili su banche dati ibride (reali + simulati)- fase di testing con Select&Match

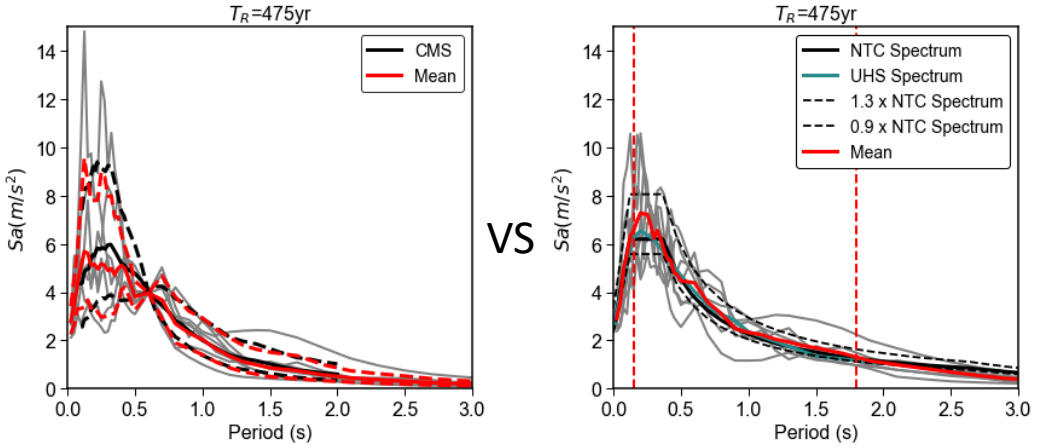
Esempio validazione ingegneristica di BB-SPEEDset

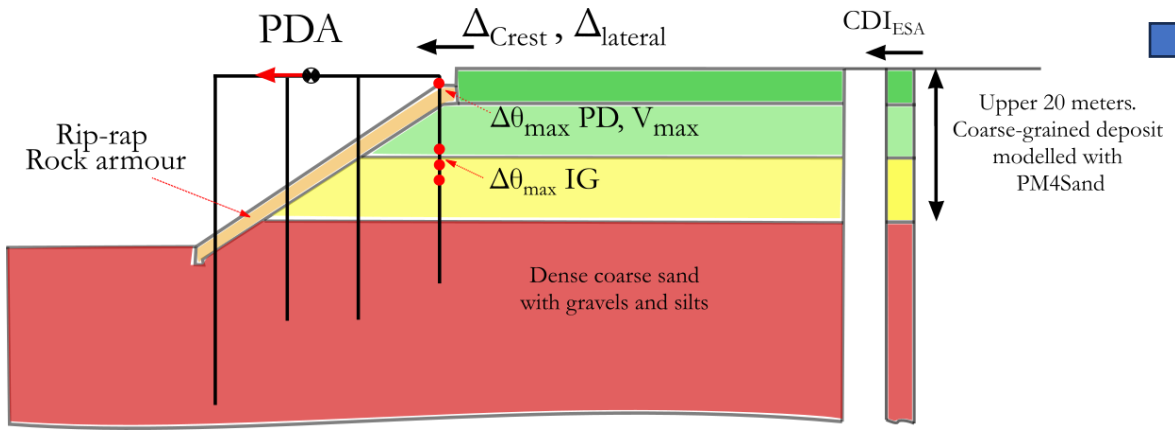




WP18 Task 3: Terremoto di progetto e selezione di accelerogrammi

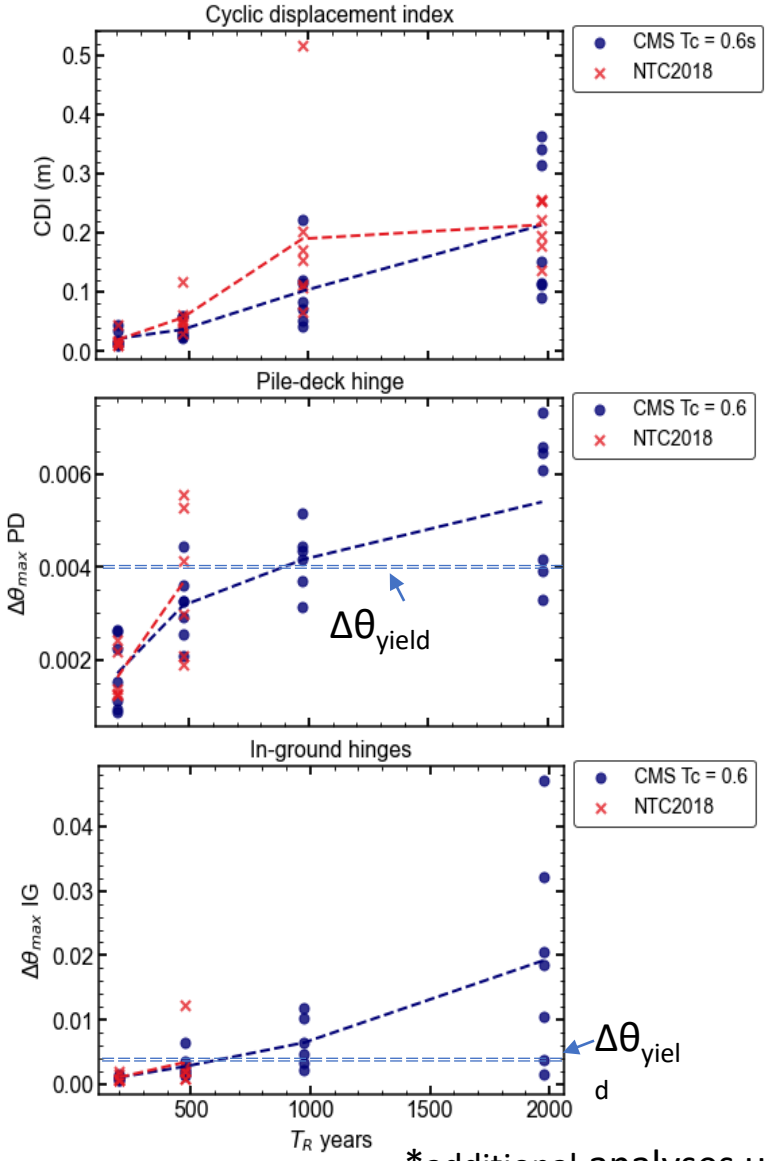
Effects of ground motion selection procedures on the response of complex geotechnical systems





Fully coupled 2D, plane strain, effective stress, DSSI analyses. Nonlinear soil + Nonlinear wharf

Ground and wharf EDPs ↓



*additional analyses underway…

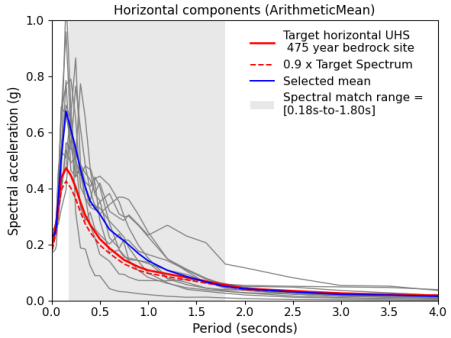
WP18 Task 3: Terremoto di progetto e selezione di accelerogrammi

Impact of Seismic Input Selection Criteria (UHS vs CMS) on the Nonlinear Response of Reinforced Concrete Structures with Emphasis on Vertical Motion

Site Specific UHS

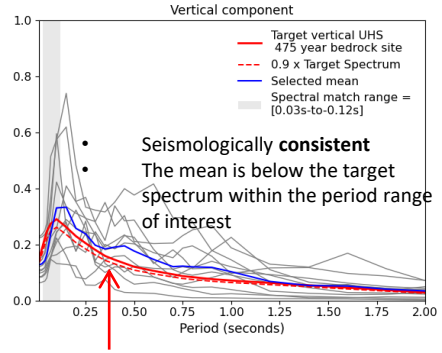
For 6 Storey Regular Frame $T_1 = 0.9$s and $T_v = 0.06$s

Record selection
Select horizontal components and scale records by spectral matching



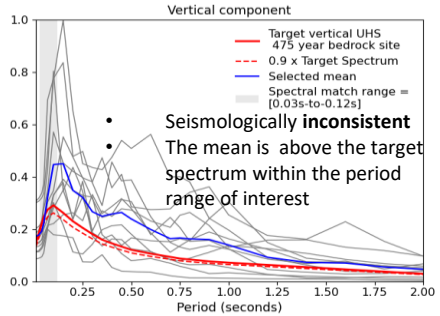
$[0.5T_1$ to $2T_1]$

Approach 1
Use the same SF for horizontal and vertical components



$[0.5T_V$ to $2T_V]$

Approach 2
Compute a separate SF for vertical components

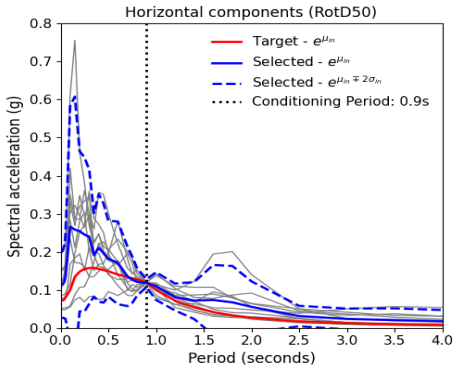


$[0.5T_V$ to $2T_V]$

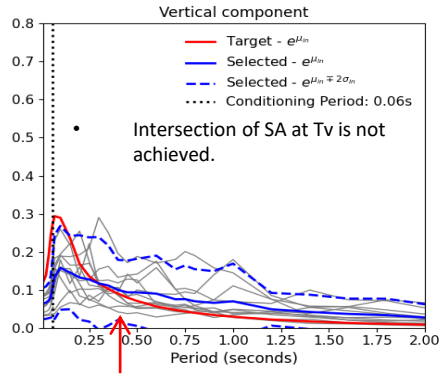
Gulerce and Abrahamson vertical UHS

Conditional Mean Spectrum

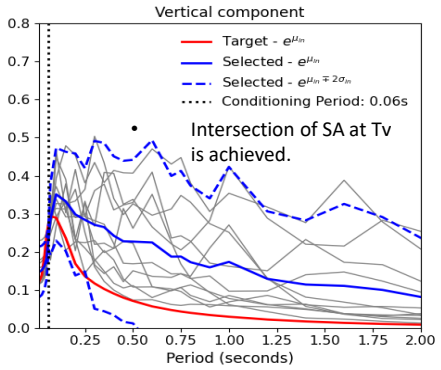
Record selection
Select horizontal components and scale records by spectral matching



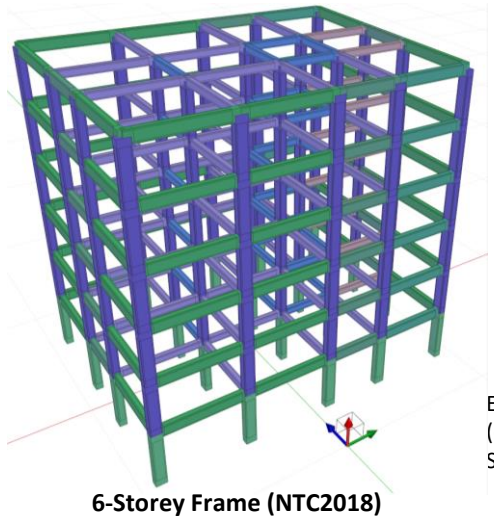
Approach 1
Use the same SF for horizontal and vertical components



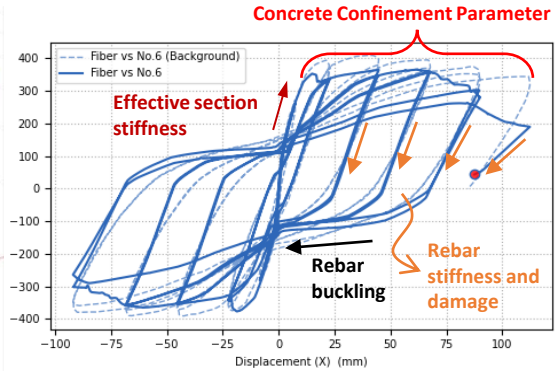
Approach 2
Compute a separate SF for vertical components



Gulerce and Abrahamson vertical CMS



6-Storey Frame (NTC2018)



Element calibration (solid line) to cyclic column tests (dashed line) by Tanaka and Park 1990, No.6 – PEER Structural Performance Database

How would a multi-component record selection strategy that also considers vertical target spectrum and Tv change the assessment results?

Proposed Multi-Component Approach

$\boldsymbol{E(SF)}$ is the 3-component error function for a single record:

$$E(SF) = \frac{1}{W}\sum_{i=0}^{T_N} \omega_H(T_i)\cdot[\boldsymbol{SF} \times Sa_H(T_i) - \mu_H(T_i)]^2 + \omega_V(T_i)\cdot[\boldsymbol{SF} \times Sa_V(T_i) - \mu_V(T_i)]^2 + \lambda \cdot P(SF, T_i)$$

- $\boldsymbol{\lambda}$ and $\boldsymbol{P(SF, T_i)}$ penalizes events that are 10% lower than the target spectra.
- $\boldsymbol{\omega_H(T_i)} = \begin{cases} 1, Ti \in [0.5T_1, 2T_1] \\ 0, \quad otherwise \end{cases}$ and $\boldsymbol{\omega_V(T_i)} = \begin{cases} 1, Ti \in [0.5T_V, 2T_V] \\ 0, \quad otherwise \end{cases}$

Il progetto Reluis WP18 – 2024-26
Input sismico, normativa e microzonazione

- **TASK 1 Pericolosità sismica e normativa**
  (Resp. PoliMI – R. Paolucci & UniNA - G. Baltzopoulos)

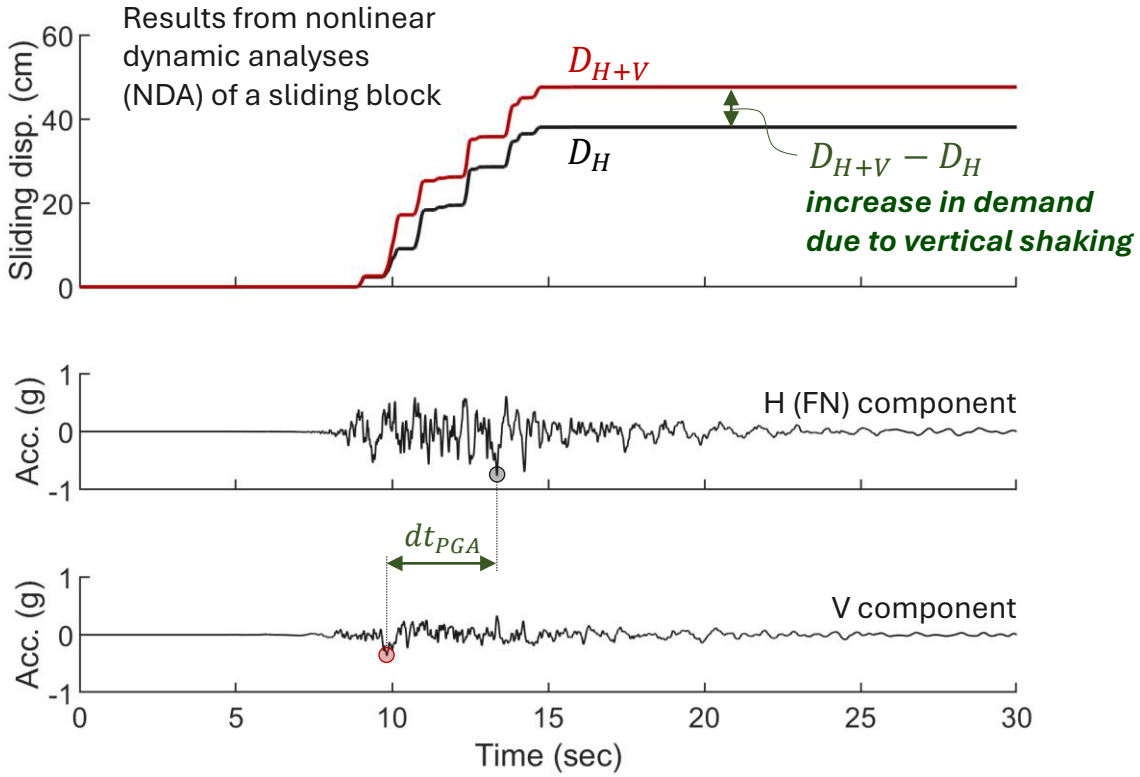
- **TASK 2 Categorizzazione sismica del sottosuolo, fattori di amplificazione nella normativa e microzonazione sismica**
  (Resp. PoliTO, S. Foti & UniSI – D. Albarello)

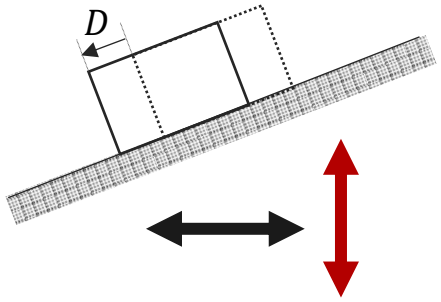
- **TASK 3 Terremoto di progetto e selezione di accelerogrammi**
  (Resp. PoliMI – C. Smerzini & INGV S. Sgobba)

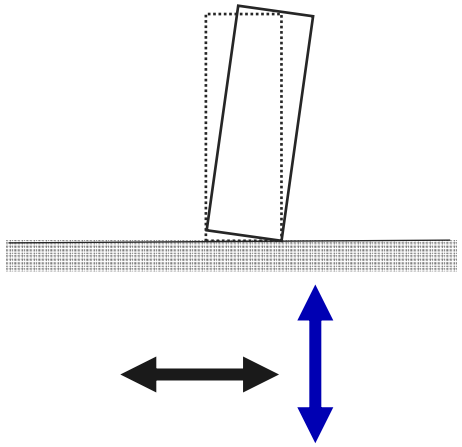
- **TASK 4 Caratterizzazione delle componenti verticali del moto sismico per analisi strutturali**
  (Resp. UniPV, C. Lai)

Task 4: Characterization of the vertical components of seismic motion for structural analysis

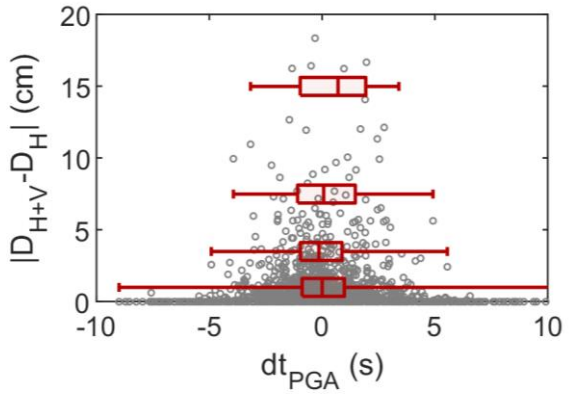
Current objective: to identify ***intensity measures*** **and/or** ***synchronism parameters*** that best correlate with the increase in seismic demand due to the vertical seismic action.

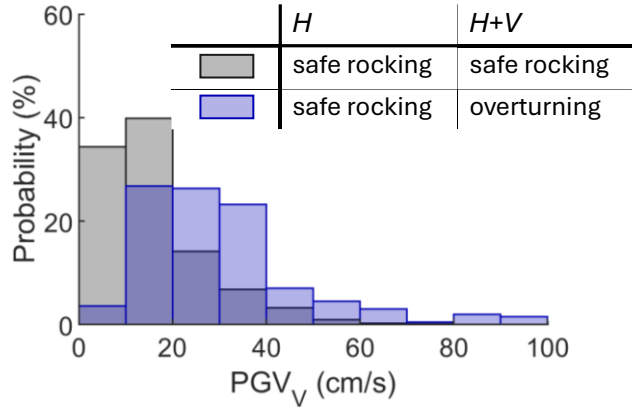






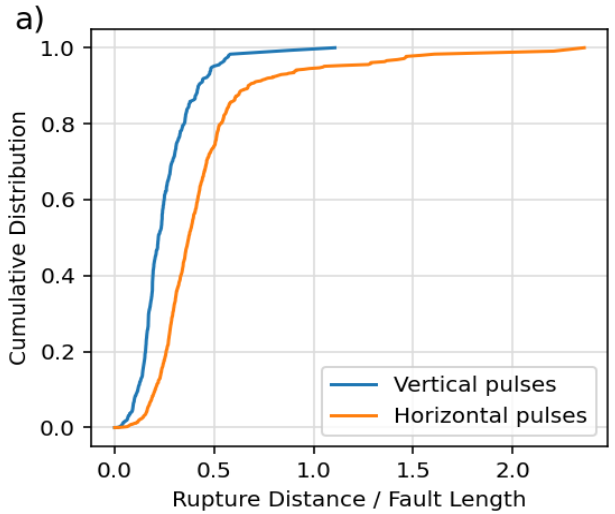
Summary results from ~20,000 NDAs

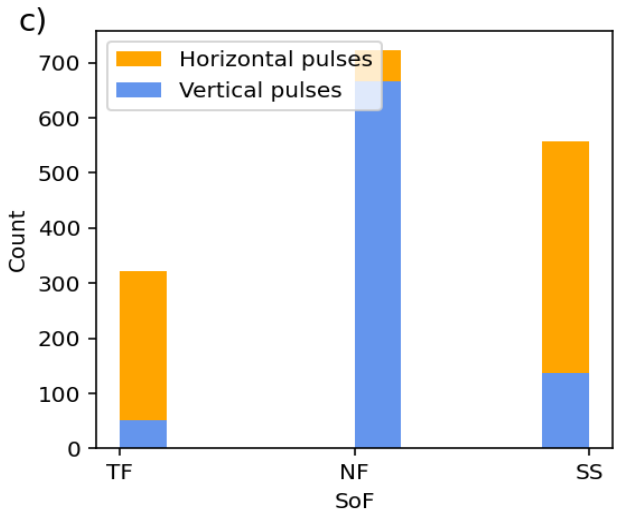




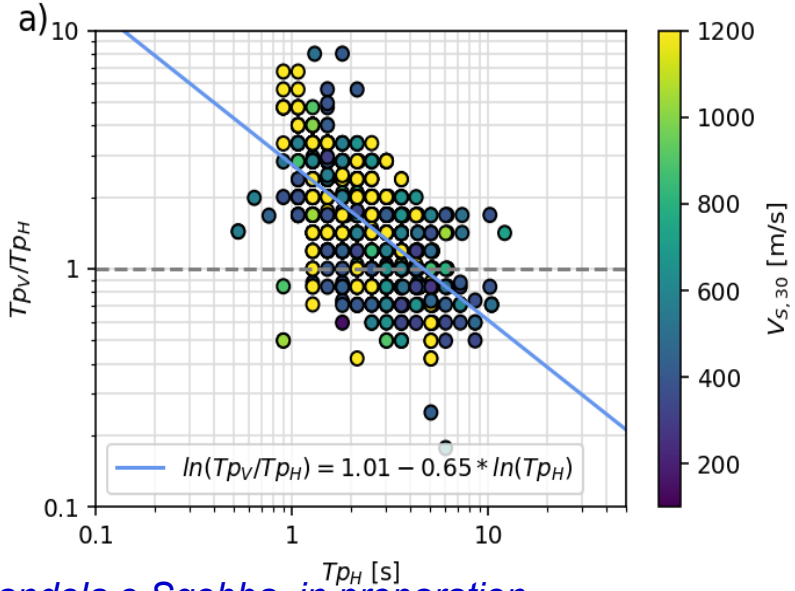
Overarching goal: define specific conditions under which designers should account for the effects of vertical shaking & synchronism (i.e. near-simultaneous arrival of strong H and V components of ground motion).

❑ Impulsi Verticali





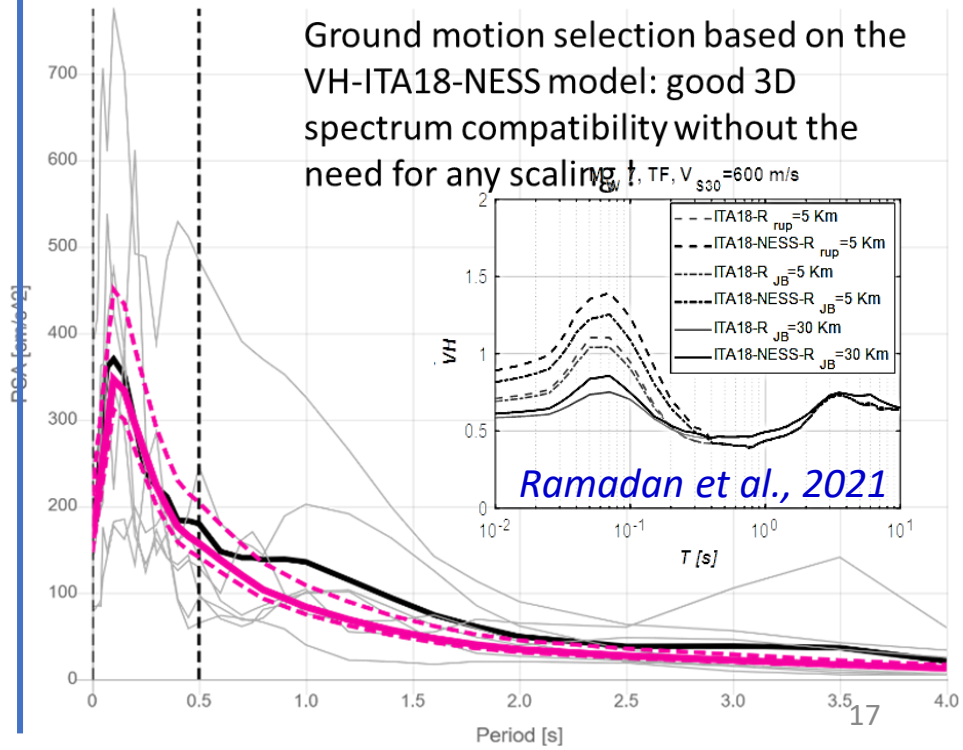
- ✓ **18% (NESS2.0) e 35% (BB-SPEEDset)** mostrano impulsi anche sulla componente verticale. Nella maggior parte dei casi **sincroni**
- ✓ Gli impulsi verticali compaiono soprattutto in terremoti di **alta magnitudo (Mw > 6.5), con meccanismo di fagliazione normale e a distanze ≤ 1 lunghezza di faglia**.



Mascandola e Sgobba, in preparation

❑ Spettro-compatibilità 3D

- ✓ **Spettro-compatibilità** sulla media delle 14 registrazioni (7 coppie di registrazioni) → molto difficile trovare soluzioni con spettro verticale **NTC18**, *ampiezze e contenuto in frequenza non compatibile!*
  → **<u>rapporti VH (es. ITA18-VH-NESS)</u>**

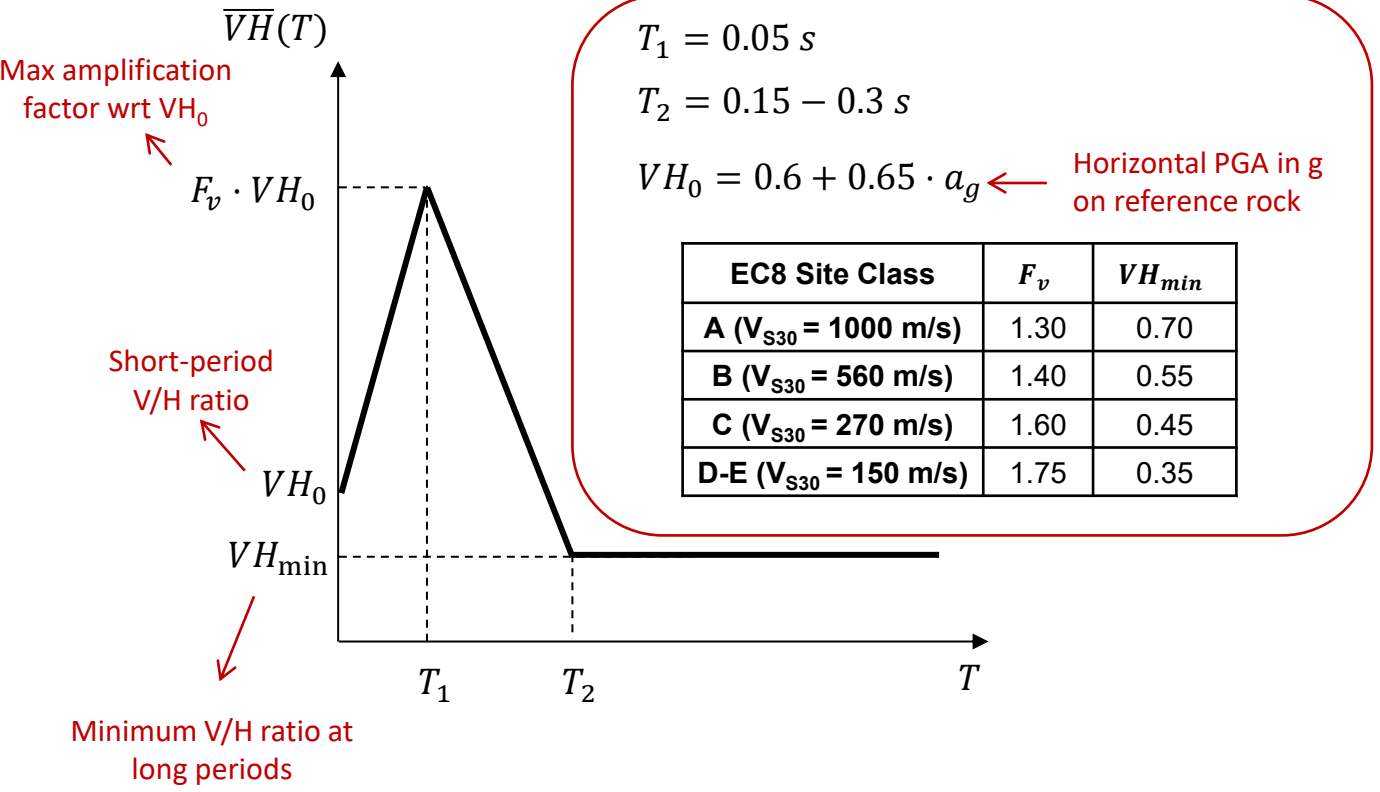


Task 4: proposta di un fattore V/H per lo spettro di progetto verticale

Tasks 2024-2026

- ✓ Criteri per la selezione multi-componente (H+V)
- ✓ Proposta di un fattore V/H, vincolato alle registrazioni, ma parametrizzato in chiave normativa

Parametri basati sul modello empirico per ITA18 - V/H calibratato su registrazioni italiane (Ramadan et al. 2021)



$T_1 = 0.05\ s$

$T_2 = 0.15 - 0.3\ s$

$VH_0 = 0.6 + 0.65 \cdot a_g$ ← Horizontal PGA in g on reference rock

EC8 Site Class	F_v	VH_{min}
A (V_{S30} = 1000 m/s)	1.30	0.70
B (V_{S30} = 560 m/s)	1.40	0.55
C (V_{S30} = 270 m/s)	1.60	0.45
D-E (V_{S30} = 150 m/s)	1.75	0.35

Confronto del fattore proposto con nuovo EC8, NTC18, ASCE 7/22 e rapporti V/H di UHS da PSHA per H e V