Progetto DPC-ReLUIS 2024-2026 WP 18
Task 2: Categorizzazione sismica del sottosuolo, fattori di amplificazione nella normativa e microzonazione sismica

PROTEZIONE CIVILE
Presidenza del Consiglio dei Ministri
Dipartimento della Protezione Civile

Hazard-dependent soil factors for site-specific elastic acceleration response spectra for Italian and European seismic building codes – an update from recorded accelerograms

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OVERVIEW

Most seismic building codes worldwide allow the definition of the seismic action (horizontal component of ground motion) using a simplified approach based on modifying the ordinates of an elastic acceleration or displacement response spectrum expected on outcropping bedrock through appropriate soil factors.
In 2018 the authors have published an article on Bulletin of Earthquake Engineering on assessing the reliability of current Eurocode 8 and the Italian building code (NTC18) soil factors using the results of a large number of numerical simulations. In this work the same authors update their 2018 study by including strong motion data from real recordings. Updated hazard-dependent soil factors for Eurocode 8 and the Italian building code (NTC18) are defined by complementing numerical and real ground motion data. The role of epistemic uncertainty in specifying soil amplification factors is highlighted also through a comparison with soil factors calculated from other international building codes (e.g. 2021 IBC and ASCE 7-16) and recent publications.

SOIL FACTORS IN CURRENT BUILDING STANDARDS

NTC18

$$S_e(T) = \begin{cases} a_g \cdot \boldsymbol{S_S} \cdot \left[\frac{T}{T_B} \cdot (\eta \cdot F_0 - 1) + 1\right] & 0 \le T \le T_B \quad (1.1) \\ a_g \cdot \boldsymbol{S_S} \cdot \eta \cdot F_0 & T_B \le T \le T_C \quad (1.2) \\ a_g \cdot \boldsymbol{S_S} \cdot \eta \cdot F_0 \cdot \left[\frac{T_C}{T}\right] & T_C \le T \le T_D \quad (1.3) \\ a_g \cdot \boldsymbol{S_S} \cdot \eta \cdot F_0 \cdot \left[\frac{T_C \cdot T_D}{T^2}\right] & T_D \le T \quad (1.4) \end{cases}$$

EC8

$$\begin{cases} a_g \cdot \boldsymbol{S} \cdot \left[\frac{T}{T_B} \cdot (\eta \cdot F_0 - 1) + 1\right] & 0 \le T \le T_B \quad (2.1) \\ a_g \cdot \boldsymbol{S} \cdot \eta \cdot F_0 & T_B \le T \le T_C \quad (2.2) \\ a_g \cdot \boldsymbol{S} \cdot \eta \cdot F_0 \cdot \left[\frac{T_C}{T}\right] & T_C \le T \le T_D \quad (2.3) \\ a_g \cdot \boldsymbol{S} \cdot \eta \cdot F_0 \cdot \left[\frac{T_C \cdot T_D}{T^2}\right] & T_D \le T \le 4s \quad (2.4) \end{cases}$$

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$$S_e(T) = \begin{cases} \frac{S_\alpha}{F_A} & 0 \le T \le T_A \quad (3.1) \\ \frac{S_\alpha}{T_B - T_A}\left[\eta(T - T_A) + \frac{T_B - T}{F_A}\right] & T_A \le T \le T_B \quad (3.2) \\ \eta\, S_\alpha & T_B \le T \le T_C \quad (3.3) \\ \eta \frac{S_\beta T_\beta}{T} & T_C \le T \le T_D \quad (3.4) \\ \eta\, T_D \frac{S_\beta T_\beta}{T^2} & T \ge T_D \quad (3.5) \end{cases}$$

Where:

$$T_B = \begin{cases} \frac{T_C}{\chi} & 0.05s \le \frac{T_C}{\chi} \le 0.10 \\ 0.05s & 0.05s < \frac{T_C}{\chi} \\ 0.10s & \frac{T_C}{\chi} > 0.10s \end{cases}$$

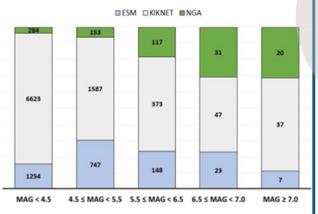
$$T_C = \frac{S_\beta T_\beta}{S_\alpha}$$

$$S_\alpha = F_T\, \boldsymbol{F_\alpha}\, S_{\alpha,RP} \quad (3.6)$$

$$S_\beta = F_T\, \boldsymbol{F_\beta}\, S_{\beta,RP} \quad (3.7)$$

COMPOSITE DATASET OF GROUND MOTION

A composite dataset of weak and strong-motion recording has been constructed using three accelerometric archives: ESM (Lanzano et al. 2018), Kik-Net (Baharampouri et al. 2021), PEER-NGA West (Ancheta et al. 2013). The composite dataset includes recordings that were simultaneously recorded by pairs of seismic stations located at outcropping bedrock sites (i.e. soil class A) and at the ground surface (i.e. soil classes other than A).



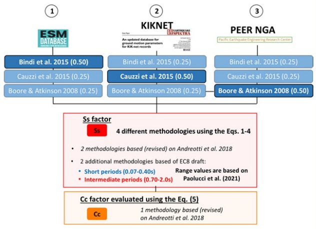
To correct the potential differences in the strong motion data due to the source-to-site distances between soil and bedrock outcropping seismic stations, the recordings have been scaled using appropriate ground motion models (GMM).

	A-B			A-C			A-D			A-E		
	ESM	Kik-Net	Peer NGA	ESM	Kik-Net	Peer NGA	ESM	Kik-Net	Peer NGA	ESM	Kik-Net	Peer NGA
Earthquakes	255	6419	186	189	5840	173	77	2369	18	92	0	38
Outcropping rock condition stations	71	68	113	65	67	113	39	50	105	48	0	42
Stations belonging to the soil class	153	389	907	107	175	696	9	14	88	16	0	55
Tot records	6296	112345	49764	3504	51954	26270	552	3062	2877	789	0	760
Records after criteria application	40	87	76	0	75	62	0	0	2	4	0	30
Total number of stations	203			137			2			34		

METHODOLOGY

A multi-parametric study that robustly calculated intensity-dependent soil amplification factor for building code applications. Strict criteria have been imposed to increase the accuracy of the results. The influence of the methodology used to define the soil amplification factors thereby investigating the epistemic uncertainty. **Four** distinct methods were employed to calculate the soil amplification factors Ss for both the current Italian building code NTC18 and the 2024 final draft of EC8, while **one** formulations were used for the definition of the soil coefficient Cc.

Logic tree approach



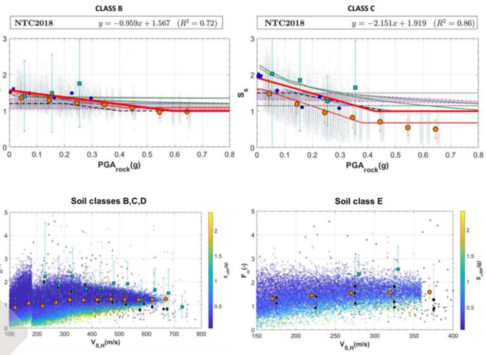
$$S_S = \frac{PGA_{soil}}{PGA_{rock}} \qquad S_S = \frac{Sa_{maxsoil}}{Sa_{maxrock}}$$

$$S_S \approx F_\alpha = \frac{\int_{0.07s}^{0.40s} RS_{soil}}{\int_{0.07s}^{0.40s} RS_{rock}} \qquad S_S \approx F_\beta = \frac{\int_{0.70s}^{2.00s} RS_{soil}}{\int_{0.70s}^{2.00s} RS_{rock}}$$

$$C_C = \frac{T(Sa_{maxsoil})}{T(Sa_{maxrock})}$$

RESULTS

New formulations of amplification factors are proposed in this study according to the approach prescribed by the Italian Building Code (NTC18) and the 2024 final draft of EC8 with different intensity measures considered. The parameters of empirical relationships were derived using the analytical formulation defined by two standards. Formulations of amplification factors proposed, obtained from an integrated dataset composed of real and synthetic ground motions, have been compared with those specified in major building codes worldwide.



NTC18

$$y = p1(x) + p2$$

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$$y = \frac{V_{S,H}}{800}^{\,p1*\left(1-\frac{x}{V_{S,H}/p2}\right)}$$

PROPOSAL OF UPDATE

NTC18

Italian building code NTC18 Soil factor Ss		
Soil class	Sa-max	Short period
A	1.00	1.00
B	$1.00 \le 1.72 - 0.36\, F_0\, a_g$	$\boxed{\mathbf{1.00 \le 1.88 - 0.46\, F_0\, a_g}}$
C	$1.00 \le 2.09 - 0.76\, F_0\, a_g$	$\boxed{\mathbf{1.00 \le 2.37 - 0.95\, F_0\, a_g}}$
D	$\boxed{\mathbf{0.80 \le 1.60 - 0.64\, F_0\, a_g}}$	$0.80 \le 1.20 - 0.45\, F_0\, a_g$
E	$\boxed{\mathbf{1.00 \le 2.28 - 0.72\, F_0\, a_g}}$	$1.00 \le 2.02 - 0.68\, F_0\, a_g$

Soil class	T_C (s)	$C_C = \frac{T_C}{T_C^*}$
A	1.00	1.00
B	0.093 + 0.703 Tc*	$0.735\, Tc^{*-0.287}$
C	0.119 + 0.905 Tc*	$1.070\, Tc^{*-0.225}$
D	0.252 + 0.558 Tc*	$0.753\, Tc^{*-0.523}$
E	0.146 + 0.522 Tc*	$0.529\, Tc^{*-0.527}$

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Table 6 Proposed empirical relationships of soil factor S for 2024 final draft of EC8 obtained using four different definitions (Eqs. 1–4) expressed as functions of different intensity measures defined at the outcropping bedrock (PGA, S_{amax}, $S_\beta \equiv Sa_{(T=1s)}$ expressed in g) and soil deposit properties $V_{S,H}$

2024 final draft of EC8 – soil factor S				
Soil class	PGA defined by Eq.1 Intensity measure PGA	S_{amax} defined by Eq.2 Intensity measure S_{amax}	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	1.00	1.00
B C D	$0.80 \le \left(\frac{V_{S,H}}{800}\right)^{-0.95\left(1-\frac{PGA}{V_{S,H}/800}\right)}$	$0.80 \le \left(\frac{V_{S,H}}{800}\right)^{-0.95\left(1-\frac{Samax}{V_{S,H}/800}\right)}$	$0.80 \le \left(\frac{V_{S,H}}{800}\right)^{-0.80\left(1-\frac{Samax}{V_{S,H}/250}\right)}$	$1.00 \le \left(\frac{V_{S,H}}{800}\right)^{-1.00\left(1-\frac{S_\beta}{V_{S,H}/600}\right)}$
E	$1.00 \le \left(\frac{V_{S,H}}{800}\right)^{-0.85\left(1-\frac{PGA}{V_{S,H}/250}\right)}$	$1.00 \le \left(\frac{V_{S,H}}{800}\right)^{-0.85\left(1-\frac{PGA}{V_{S,H}/250}\right)}$	$1.00 \le \left(\frac{V_{S,H}}{800}\right)^{-0.85\left(1-\frac{Samax}{V_{S,H}/250}\right)}$	$1.00 \le \left(\frac{V_{S,H}}{800}\right)^{-0.80\left(1-\frac{S_\beta}{V_{S,H}/700}\right)}$

Soil class	T_C (s)
A	1.00
B C D	$\left(\frac{V_{S,H}}{800}\right)^{-0.70\left(1-\frac{S_\beta}{V_{S,H}/250}\right)} * S_{\beta,RP} * T_\beta$ $\left(\frac{V_{S,H}}{800}\right)^{-0.40\left(1-\frac{S_\alpha}{V_{S,H}/300}\right)} * S_{\alpha,RP}$
E	$\left(\frac{V_{S,H}}{800}\right)^{-0.70\left(1-\frac{S_\beta}{V_{S,H}/200}\right)} * S_{\beta,RP} * T_\beta$ $\left(\frac{V_{S,H}}{800}\right)^{-0.40\left(1-\frac{S_\alpha}{V_{S,H}/150}\right)} * S_{\alpha,RP}$

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