Progetto DPC-ReLUIS 2022-2024 WP 16

Task1: Risposta Sismica Locale e Liquefazione

PROTEZIONE CIVILE
Presidenza del Consiglio dei Ministri
Dipartimento della Protezione Civile

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

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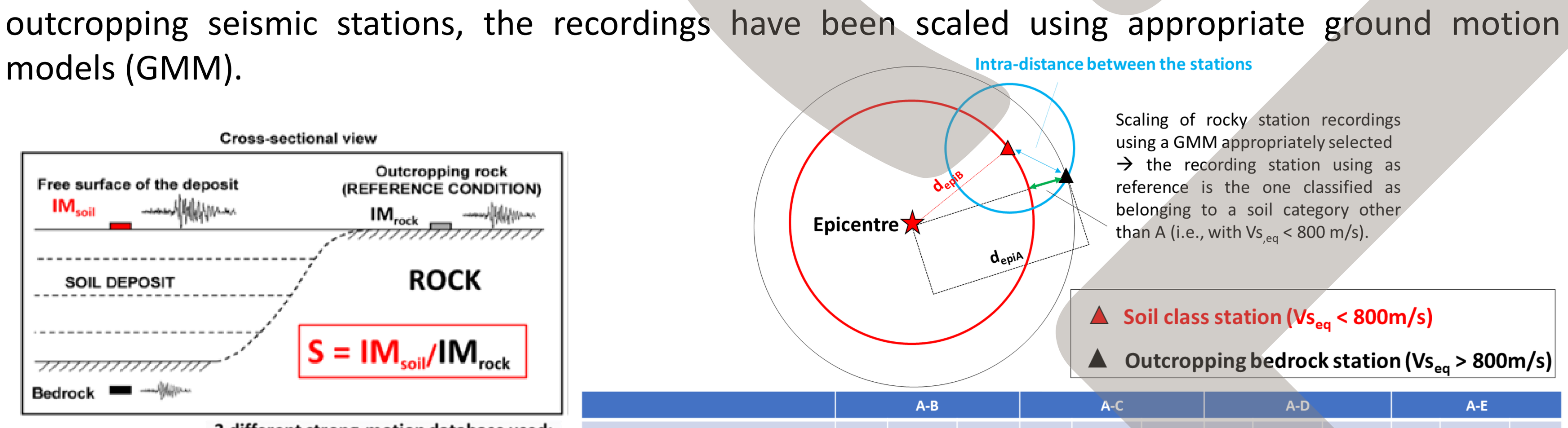
OVERVIEW

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 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

COMPOSITE DATASET OF GROUND MOTION

A composite dataset of weak and strong-motion recording has been constructed using three accelerometric archives: ESM, Kik-Net, PEER-NGA West. 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).



3 different strong-motion database used:

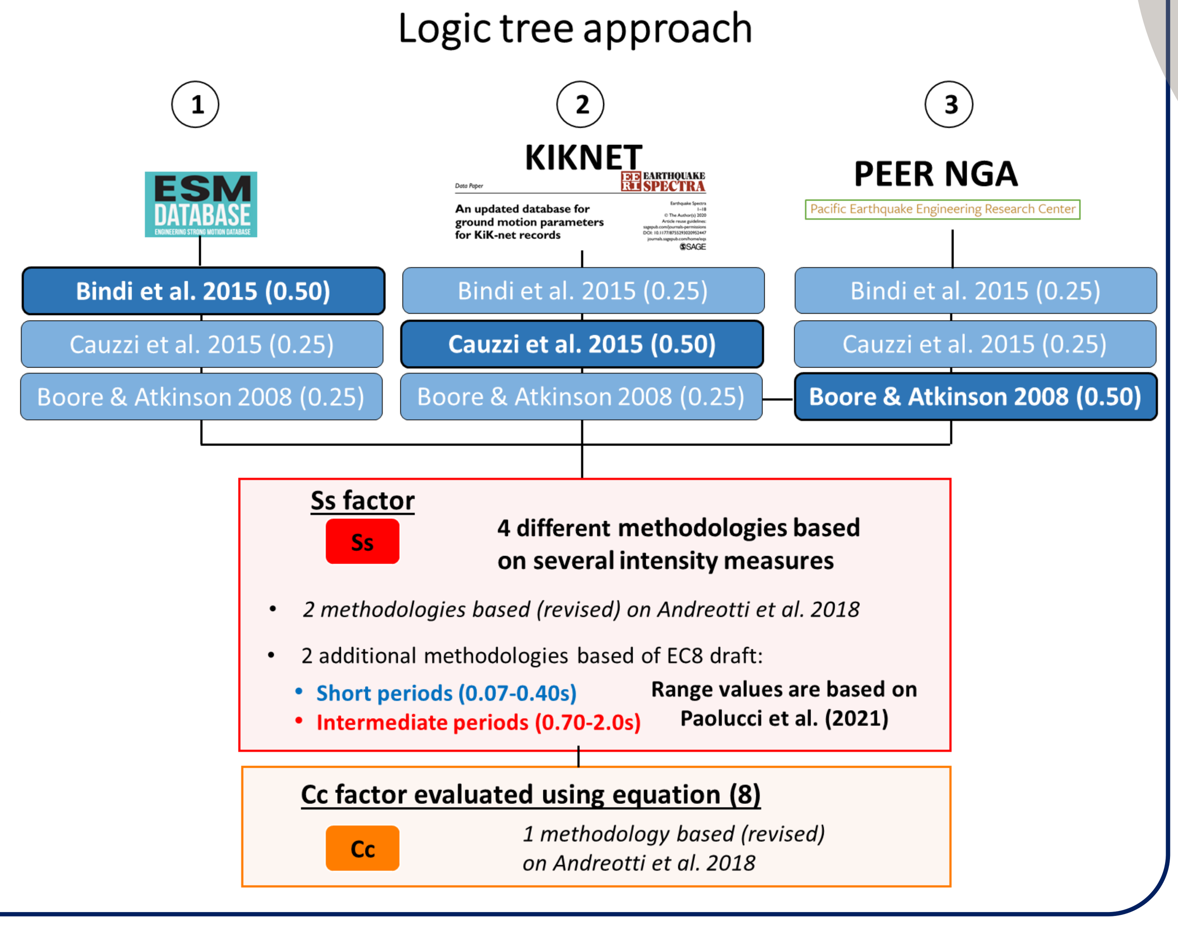
- ESM strong-motion flat-file 2018 – The dataset includes recordings related to 2179 earthquakes.
- Kiknet flat-file Bahrampouri et al. 2020 – The dataset includes recordings related to 10552 earthquakes.
- NGA flat-file 2018 – The dataset includes recordings related to 173 earthquakes.

	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 2021 draft of EC8, while two formulations were used for the definition of the soil coefficient Cc

Logic tree approach



SOIL FACTORS IN CURRENT BUILDING STANDARDS

NTC18

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

EC8

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

2021-DRAFT EC8

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

Where:

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

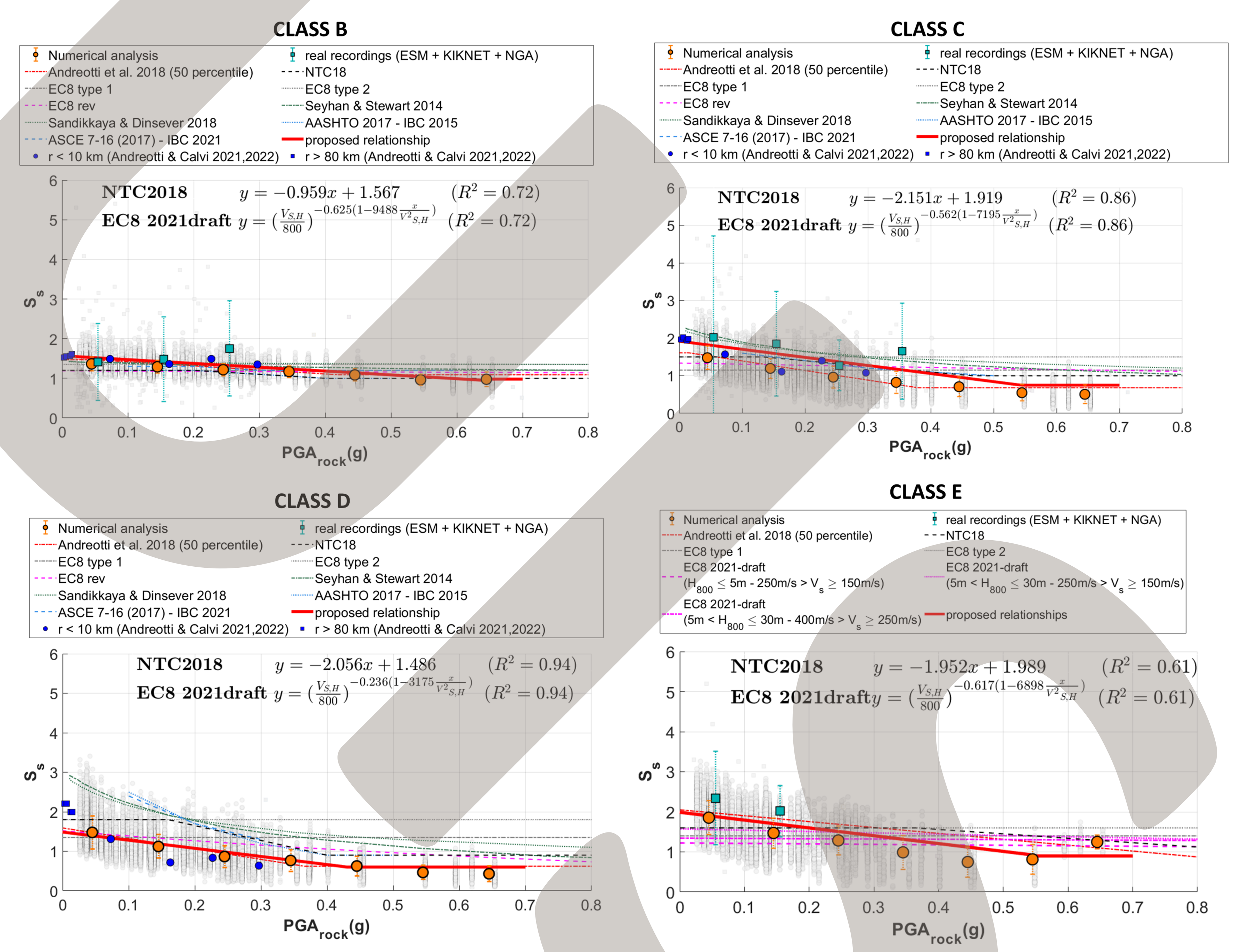
$$T_C = \frac{S_\beta\, T_\beta}{S_\alpha}$$

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

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

RESULTS

Empirical relationships were proposed for soil factors Ss and Cc according to the approaches proposed by the Italian Building code (NTC18) and the 2021-draft EC8 with different intensity measures were proposed. The newly proposed soil factors, obtained from an integrated dataset composed of real and synthetic ground motions, have been compared with those specified in major building codes worldwide



Italian building code NTC18 - Ss

Soil Class	PGA	Sa-max	Short period	Intermediate period
A	1.00	1.00	1.00	1.00
B	$0.98 \le 1.57 - 0.96\, a_g$	$1.00 \le 1.72 - 0.36\, F_0\, a_g$	$\mathbf{1.00 \le 1.91 - 0.49\, F_0\, a_g}$	$1.49 - 0.19\, S_\beta$
C	$0.75 \le 1.92 - 2.15\, a_g$	$0.68 \le 2.10 - 0.79\, F_0\, a_g$	$\mathbf{0.68 \le 2.37 - 0.95\, F_0\, a_g}$	$2.20 - 1.24\, S_\beta$
D	$0.60 \le 1.49 - 2.06\, a_g$	$\mathbf{0.62 \le 1.43 - 0.49\, F_0\, a_g}$	$0.40 \le 1.38 - 0.73\, F_0\, a_g$	$1.86 - 0.97\, S_\beta$
E	$0.90 \le 1.99 - 1.95\, a_g$	$0.95 \le 2.28 - 0.72\, F_0\, a_g$	$\mathbf{0.75 \le 2.20 - 0.68\, F_0\, a_g}$	$1.25 \le 2.60 - 2.68\, S_\beta$

NTC18 - Tc

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 $Tc^{*-0.527}$

2021-draft EC8 – soil factor S

Soil Class	PGA	Sa-max	Short period (F_α)	Intermediate period (F_β)
A	1.00	1.00	1.00	1.00
B	$0.98 \le \left(\frac{V_{S,H}}{800}\right)^{-0.625\left(1-9488\frac{PGA}{V_{S,H}^2}\right)}$	$1.00 \le \left(\frac{V_{S,H}}{800}\right)^{-0.752\left(1-3235\frac{Samax}{V_{S,H}^2}\right)}$	$1.00 \le \left(\frac{V_{S,H}}{800}\right)^{-0.897\left(1-4018\frac{Samax}{V_{S,H}^2}\right)}$	$\left(\frac{V_{S,H}}{800}\right)^{-0.560\left(1-1936\frac{S_\beta}{V_{S,H}^2}\right)}$
C	$0.75 \le \left(\frac{V_{S,H}}{800}\right)^{-0.562\left(1-7195\frac{PGA}{V_{S,H}^2}\right)}$	$0.68 \le \left(\frac{V_{S,H}}{800}\right)^{-0.616\left(1-2207\frac{Samax}{V_{S,H}^2}\right)}$	$0.68 \le \left(\frac{V_{S,H}}{800}\right)^{-0.717\left(1-2363\frac{Samax}{V_{S,H}^2}\right)}$	$\left(\frac{V_{S,H}}{800}\right)^{-0.654\left(1-3323\frac{S_\beta}{V_{S,H}^2}\right)}$
D	$0.60 \le \left(\frac{V_{S,H}}{800}\right)^{-0.236\left(1-3175\frac{PGA}{V_{S,H}^2}\right)}$	$0.62 \le \left(\frac{V_{S,H}}{800}\right)^{-0.213\left(1-782\frac{Samax}{V_{S,H}^2}\right)}$	$0.40 \le \left(\frac{V_{S,H}}{800}\right)^{-0.193\left(1-1211\frac{Samax}{V_{S,H}^2}\right)}$	$\left(\frac{V_{S,H}}{800}\right)^{-0.369\left(1-1197\frac{S_\beta}{V_{S,H}^2}\right)}$
E	$0.90 \le \left(\frac{V_{S,H}}{800}\right)^{-0.617\left(1-6898\frac{PGA}{V_{S,H}^2}\right)}$	$0.95 \le \left(\frac{V_{S,H}}{800}\right)^{-0.741\left(1-2200\frac{Samax}{V_{S,H}^2}\right)}$	$0.75 \le \left(\frac{V_{S,H}}{800}\right)^{-0.631\left(1-2384\frac{Samax}{V_{S,H}^2}\right)}$	$1.25 \le \left(\frac{V_{S,H}}{800}\right)^{-0.858\left(1-7237\frac{S_\beta}{V_{S,H}^2}\right)}$

2021-draft EC8- 1 – Tc

Soil Class	T_C (s)
A	1.00
B	$\dfrac{\left(\frac{V_{S,H}}{800}\right)^{-0.560\left(1-1936\frac{a_g}{V_{S,H}^2}\right)} * S_{\beta,RP} * T_\beta}{\left(\frac{V_{S,H}}{800}\right)^{-0.897\left(1-4018\frac{a_g}{V_{S,H}^2}\right)} * S_{\alpha,RP}}$
C	$\dfrac{\left(\frac{V_{S,H}}{800}\right)^{-0.654\left(1-3323\frac{a_g}{V_{S,H}^2}\right)} * S_{\beta,RP} * T_\beta}{\left(\frac{V_{S,H}}{800}\right)^{-0.717\left(1-2363\frac{a_g}{V_{S,H}^2}\right)} * S_{\alpha,RP}}$
D	$\dfrac{\left(\frac{V_{S,H}}{800}\right)^{-0.369\left(1-1197\frac{a_g}{V_{S,H}^2}\right)} * S_{\beta,RP} * T_\beta}{\left(\frac{V_{S,H}}{800}\right)^{-0.193\left(1-1211\frac{a_g}{V_{S,H}^2}\right)} * S_{\alpha,RP}}$
E	$\dfrac{\left(\frac{V_{S,H}}{800}\right)^{-0.858\left(1-7237\frac{a_g}{V_{S,H}^2}\right)} * S_{\beta,RP} * T_\beta}{\left(\frac{V_{S,H}}{800}\right)^{-0.631\left(1-2384\frac{a_g}{V_{S,H}^2}\right)} * S_{\alpha,RP}}$

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