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S3 Project - RU 7 DIGA-UNINA - *Definition and assessment of different approaches to evaluate site effects for Shakemap processing*

Preliminary assessment of site stratigraphic amplification for Shakemap processing

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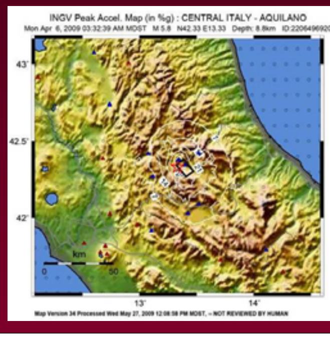
A ***shakemap*** is a map of the peak ground motion parameters (PGM), generated by the software package *ShakeMap®* developed by the U.S.G.S. Earthquake Hazards Program (Wald et al., 2006).
The package itself generates maps of ground shaking in terms of various peak ground motion parameters (PGA, PGV, PSA at 0.3, 1.0 and 3.0 s and instrumentally derived intensities IM).
ShakeMap is a seismologically-based interpolation algorithm that exploits the available data of the observed ground motions to determine maps of ground motion at local and regional scales.
Fundamental ingredients towards obtaining accurate maps are:

-a seismic station distribution, that provides dataset of the groud motion parameters after any recorded event;

- ground motion predictive relationship as function of distance at different periods and for different magnitudes;

- realistic descriptions of the amplifications that the local site geology (**site effects**) induces on the incoming seismic wavefield.



Objectives and background

The research activity carried out by **RU 7 DIGA-UNINA** in the first year of the project was aimed to the definition of a simplified procedure to include non-linear site effects in *Shakemap*.

Site stratigraphic amplification is represented by the factor $\mathbf{S_S = a_s/a_r}$, which can directly multiply the reference ground motion amplitude $\mathbf{a_r}$ generated by *Shakemap* on a stiff and flat rock outcrop to obtain the surface motion $\mathbf{a_s}$.
Two different non-linear relationships between the stratigraphic amplification factor, S_S, and peak ground acceleration at bedrock, a_r, can be considered:

-the set of factors suggested by Borcherdt (1994), currently implemented in *Shakemap*, which for each average shear wave velocity interval assigns a stepwise variation of the amplification coefficient, to different ranges of a_r

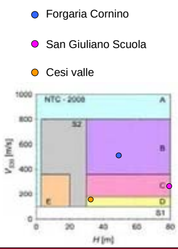
- the coefficients provided by the National Technical Code (DM 14.I.2008) for each soil class, including non-linear dependency on the ground motion, expressed as a function of the peak spectral acceleration ($F_o \cdot a_r$)

1. Experimental amplification factors

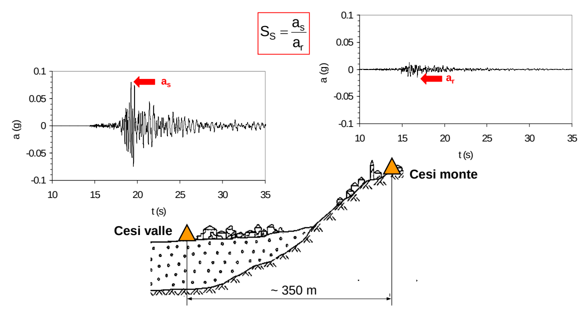
A first set of experimental amplification factors was obtained by analyzing the data sorted out from national seismic databases (ITACA and SISMA). The data have been taken at those stations for which a record of the same event exists at a nearby station located on outcropping rock and on deformable soil. In particular, three sites have been identified, representative of as many NTC classes:
- class B: Forgaria Cornino (deformable) / San Rocco (rock)
- class C: San Giuliano di Puglia: School (deformable) / Church (rock)
- class D: Cesi Valle (deformable) / Monte (rock)

The characteristics of the stations and of the events considered are reported in the following table:

Site	Soil class (NTC 2008)	relative distance (m)	n° of the processed events	Recording time Interval	M	Epicentral distance (km)	PGA (g)
Forgaria Cornino	B	776	8	18.V.1976 - 16.IX.1977	4.1 - 6.1	5.1 - 25.8	0.026 - 0.249
San Rocco	A						0.058 - 0.352
S.Giuliano scuola	C	435	12	10.XI.2002 - 01.XII.2002	3.5 - 4.3	8.0 - 15.0	0.0012 -0.0351
S.Giuliano chiesa	A						0.0004 - 0.0091
Cesi valle	D	350	20	07.X.1997 - 21.V.1998	2.2 - 5.3	2.6 - 141.3	0.018 - 0.184
Cesi monte	A						0.006 - 0.078



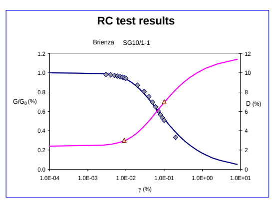
Cesi: event of 3.IV.1998 M_L = 5.3

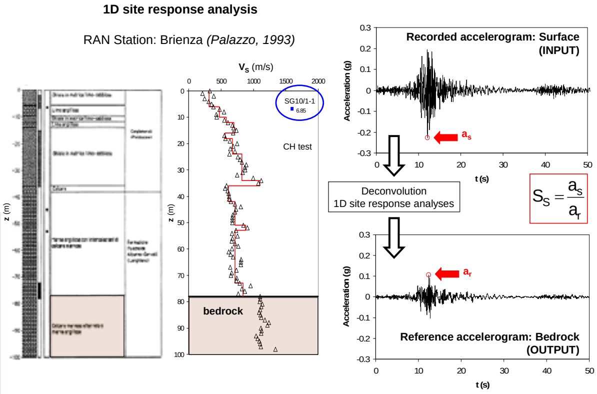


2. Amplification factors from 1D site response analysis on real subsoils

A second set of experimental data has been obtained by analysing the accelerograms of the two national databases recorded at those stations where the subsoil is adequately characterized in terms of properties most significantly affecting the site response (layering, bedrock depth, shear wave velocity profile, non-linear soil behaviour).
The recorded data have been de-convolved to the bedrock, allowing to back-figure the originally related seismic motion.
At the moment we selected 8 sites (following table), where the bedrock is quite clearly detectable and the data on the mechanical characterization are consistent; seven of them pertain to class B and only one can be classified as C subsoil.
A detailed subsoil geotechnical characterization has been carried out, allowing the numerical non-linear de-convolution analyses to be performed.
The amplification factors has been obtained as the ratio of the maximum surface acceleration, a_s, read on the recorded signal and the peak reference value, a_r, obtained through deconvolution.

Site	Soil class (NTC 2008)	n° of the processed events	Recording time interval	M	Epicentral distance (km)	PGA (g)
Tricarico	B	3	23.XI.1980 - 26.V.1991	4.5 - 6.5	31.6 - 73.0	0.018 - 0.047
Vieste	B	2	23.XI.1980 - 03.XII.1980	4.6 - 6.5	131.0 - 143.0	0.020 - 0.034
San Severo	B	4	23.XI.1980 - 01.XI.2002	3.7 - 6.5	13.0 - 102.4	0.015 - 0.061
Brienza	B	5	14.V.1980 - 05.V.1990	4.0 - 6.5	20.7 - 42.2	0.003 - 0.227
Mercato S.Severino	B	3	23.XI.1980 - 13.XII.1981	4.9 - 6.5	42.6 - 46.1	0.014 - 0.140
Calitri	B	6	23.XI.1980 - 03.IV.1996	4.5 - 6.5	6.8 - 45.7	0.011 - 0.176
Garigliano	C	3	23.XI.1980 - 07.V.1984	4.6 - 6.5	49.2 - 135.7	0.009 - 0.062
L'Aquila (AQV)	B	1	06.IV.2009	5,8	4,9	0.56 - 0.63

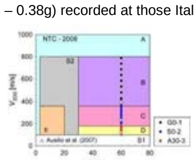


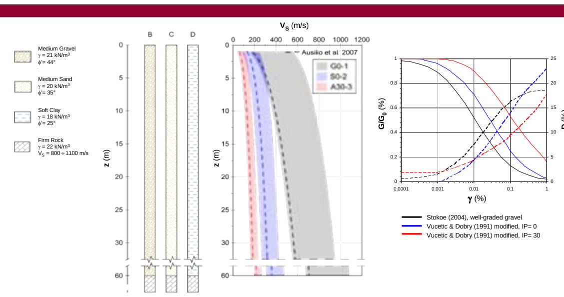


3. Amplification factors from 1D site response analysis of virtual subsoils

A third set of data came from a 1D numerical analysis of local seismic response performed on three virtual subsoil profiles, lithologically homogeneous (medium gravel, medium sand, soft clay).
10 $V_S(z)$ profiles are assigned to each subsoil, consistently with the ground classification criteria suggested by the EC8 – NTC 2008.
The non-linear soil behaviour has been modelled using standard curves from literature.
The analyses have been performed using 74 acceleration time histories (M_L = 4.3 – 6.6, a_r = 0.03 – 0.38g) recorded at those Italian seismic stations classified as rock sites (class A).

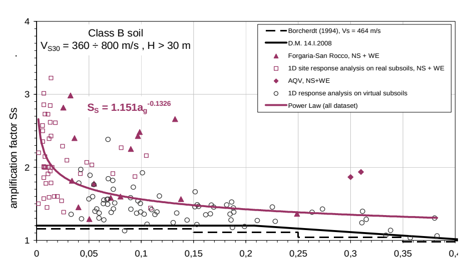
ID	soil	I_P (%)	γ (kN/m³)	φ' (°)	V_{S30} (m/s)	Class
G0-1	gravel	-	21	44	368-788	B
S0-2	sand	-	20	35	183-351	C
A30-3	clay	30	18	25	103-179	D

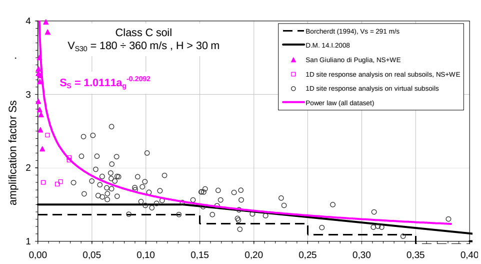


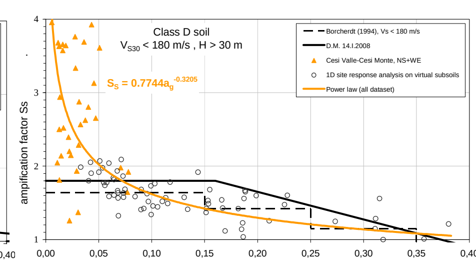


4. Results

All the values of the S_S coefficients were then plotted against the peak ground acceleration recorded at bedrock (a_r) for each class of soil. The experimental data were interpreted with the following power functions:







Conclusions

The effects of non-linearity are evident for each analyzed data set and they are clearly shown by the fitting.functions.
The obtained amplification factors corresponding to the lower values of the reference acceleration are systematically higher than those provided by the National Technical Code (DM 14.I.2008) and by the relationships suggested by Borcherdt (1994), currently implemented in *Shakemap*.
Instead, in the higher ranges of acceleration, the amplification factors are higher (class B), similar (class C) and lower (class D) than those provided by the National Technical Code (DM 14.I.2008) and by Borcherdt (1994).
The empirical relationships need to be assessed on further data, which will be soon available from the analyses currently in progress. Also, it is expected to add other significant data from the recent Abruzzo earthquake sequence.