Evaluation of seismic site effects in Lombardia (Italy) by numerical analyses for urban planning

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Abstract: Many field reports on past seismic events have pointed out that the effects due to some geologic and geomorphologic situations have produced different damage to similar buildings. To obtain a qualitative and quantitative classification of these situations, different qualitative and quantitative approaches have been used.

In the paper the application of a methodology for the evaluation of site effects in an area of Lombardia Region (Italy) is shown. During the project 15 localities were analyzed. In this paper the results of some representative situations are presented.

The objective of the project was to develop a methodology that may be easily repeated, to take into account site effects in urban planning. Therefore, a series of geologic, geomorphologic (1:5 000 scale) and geotechnical analyses have been carried out, to identify the areas affected by site effects and to characterize the lithotechnical units. The expected seismic inputs have been calculated and numerical analyses using one-dimensional (1D) code, analyzing single soil columns, and two-dimensional (2D) codes, working with finite or boundary elements on sections, have been done.

The results, in terms of elastic pseudo-acceleration spectra and amplification coefficients, as a ratio between spectral intensity calculated using the pseudo-velocity spectra, in the periods of 0.1-0.5s and 0.5-1.5s of output and input, give elements for planning, both for urban general choices and for building design. The results of all the analyzed situations, provide some correlations between the geometric and geotechnical characteristics of the sites and the values of the amplification coefficients. These correlations could be used as a tool for extrapolations in similar situations, in the same area, when only the geologic, geophysical and geotechnical characteristics of a site are known.

Our results showed amplification for all three lithologies considered: 'silt with clay' being the greatest and 'Gravel' the least, with significant differences seen between the two shear wave velocity – depth profiles used in this study.

Résumé: Plusieurs études ont montré que les conditions géologique et géomorphologique causent différent dégât à constructions similaire. Pour obtenir une classification qualitatif et quantitatif de ces situations, ont été utilisé approches qualitatifs et quantitatifs.

Dans l'article on montre l'application d'une méthodologie pour l'évaluation des effets de site dans quinze municipalités de la Région Lombardia (Italie). On présent aussi les résultats les plus importants.

Le projet a développé une procédure, facile a reproduire, pour évaluer les effets de site dans le cadre de plans de urbanisme. Donc, ont a effectué des analyses géologique, géomorphologique et géotechnique, pour reconnaître les zones dans les quelles peuvent se produire des phénomènes d'amplification et pour identifier les unités litho techniques. Pour quantifier les effets d'amplification on a choisi les accélérogrammes attendus que ont été utilisés pour les analyses numériques: 1D pour analyser des colonnes stratigraphiques spécifiques, 2D pour des section géologiques.

Pour chaque situation on a évalué les spectres de réponse en pseudo accélération et un facteur d'amplification défini comme rapport entre l'intensité spectrale de l'accélérogramme calculé et de celui attendu: pour la définition de l'intensité spectrale on a choisi les intervalles des périodes compris entre 0.1-0.5s et 0.5-1.5s.

Les résultats permettent de définir des corrélations entre les caractères géométriques et géotechniques des sites et l'entité des amplifications. Les corrélations peuvent être utilisées pour extrapoler à des situations similaires dans la même région lors que on connaît seulement les caractères géologique, géomorphologique et géotechnique du site.

Keywords: Earthquake, Numerical models, Planning, Risk assessment, Seismic response, Seismic risk.

INTRODUCTION

The problem of the ground motion amplifications correlating with site effects, during an earthquake, is well-known and different methods and approaches have been suggested to quantify these effects, using both numerical and experimental methods.

These studies allowed to develop some hypotheses on the causes that can make some areas more dangerous than others: cliff area and rocky ridge producing amplification due to morphologic condition; valley with incoherent alluvium and slope deposits or talus cone producing amplification caused by high impedance contrast; area affected by lithologic discontinuities producing differential settlements in connection with the characters of lithologies; very soft soil producing permanent deformations or landslides.

In the case of experimental approaches, the evaluation of the amplifications is done through the analyses of the seismograph recordings, which can be generated by strong earthquakes, by far earthquakes, by artificial sources and micro-tremors. These methods derive from the studies on the spectral analysis and on the method of spectral ratio. The spectral ratios are performed as a ratio between the spectrum recorded at a site with that recorded at a reference site on bedrock (King and Tucker, 1984; Malagnini et al., 1996; Tucker and King, 1984) and as a ratio between the horizontal and vertical component, using both earthquakes (Lanston, 1979; Moya et al., 2000) and noise (Nakamura, 1989; Zaslavsky et al., 1984).

In the case of numerical methods one-dimensional (1D), two-dimensional (2D) and three-dimensional (3D) models can be used. Some of these models are very well tested, other are in a phase of testing (Casadei and Gabellini, 1997; Chavez-Garcia et al., 2000; Paolucci et al., 1999; Pitilakis et al., 2001; Semblat et al., 2000).

Clearly the choice of the methods and approaches, the working scale and the types of analyses depends on the objectives and goals of the work. In this case the objective was to give, to the Regional Government, a methodology that may be used repetitively at the level of urban planning, For this reason the choice was to perform a numerical analysis using the 1D and 2D models, to have an adequate balance between the need of basic analyses and the quality of the applicable results. In particular the main aim of the project was to provide some correlations between the geometric and geotechnical characteristics of the sites and the values of the amplification coefficients, to use these correlations as a tool for extrapolations in similar situations, when only the geologic, geophysical and geotechnical characteristics of a site are known.

METHODOLOGY

During the project the following steps have been performed:

- selection of the representative localities in the Region: in particular the situations characterized by large valleys with terraced alluvial deposits and gravels, little valleys with debris and valleys with recent alluvial deposits, silts with sands and silts with clays are been selected; generally, for the all situations, the bedrock is characterized by limestone and marl;
- preparation of geologic and geomorphologic maps (1:5.000 scale) for each situation;
- determination of geotechnical parameters: soil unit weigh, initial shear modulus, initial damping ratio, Poisson ratio and relationships between shear modulus and damping ratio variation as a function of shear strain; the pre-existing geotechnical information have been collected and a series of new investigations have been done in the study areas: 10 bore-holes, 7 CPT tests, 5 SPT tests and 11 geotechnical laboratory tests aimed to obtain the static and dynamic parameters, as soil characteristic tests, unconfined monotonic compression loading tests, monotonic loading triaxial tests, resonant column tests and cyclic loading torsional shear tests;
- acquisition of geophysical parameters; the pre-existing geophysical information have been collected and a series of new investigations have been done in the study areas: 10 downhole studies to obtain the velocity of shear (Vs) and longitudinal (Vp) waves;
- preparation of geologic and geophysical 2D cross sections, relating to the complexity of the geologic and geomorphologic conditions and to the urban settlements;
- identification of typical stratigraphic sequences, that can produce amplification effects due to lithologic conditions, on the basis of the lithology and the behaviour of the Vs with the depth, in particular three set of sequence have been considered: gravel lithology, silt with clay lithology and silt with sand lithology;
- identification of situations that can produce amplification effects due to morphologic condition such as rocky ridges;
- calculation of expected seismic input in terms of elastic pseudo-acceleration response spectra and accelerograms: for the definition of the seismic input a probabilistic approach has been adopted, because the areas are located in a region where the seismic structures are still not very well known. Therefore, being impossible to separate the seismic hazard contribution coming from the possible sources, the cumulative contribution, on a probabilistic basis was derived from all relevant neighbouring seismogenetic areas, which better represents an envelope of the expected seismic actions. The probabilistic approach also fits with the aim of the project that is the evaluation of a set of parameters to be entered in codes for urban planning and for building construction. Seismic input has been defined as the uniform probability spectra with a return period of 475 years corresponding at 10% probability of being exceeded in 50 years. Since most of the site amplification analyses required accelerations as reference input, non-stationary time-histories matching both the reference spectra and the peak ground accelerations have been generated (Sabetta and Pugliese, 1996): in particular the numerical analyses have been done using two set of accelerograms representing the highest and the lowest expected values of peak ground acceleration in the Region (Figure 1);

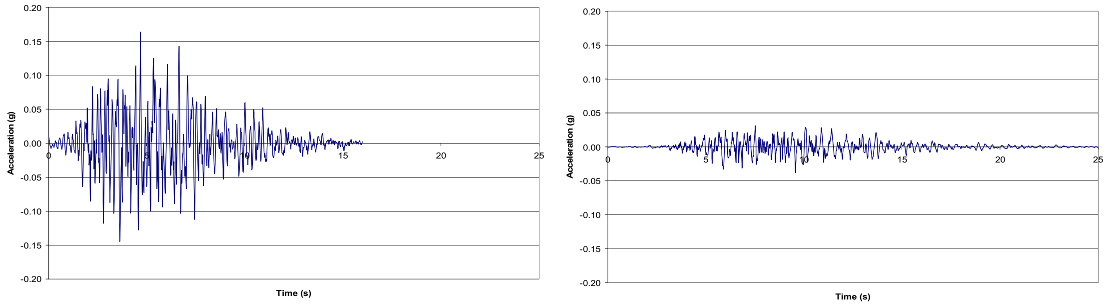


Figure 1. Example of two accelerograms used in the analyses representing the highest and the lowest expected values of peak ground acceleration in the Region

- numerical analyses and choice of the measure of amplification (Pergalani et al., 1997; 2003): for each situation, 1D and 2D numerical analyses have been performed, depending on the geologic and geomorphologic conditions. In the case of typical sequences the 1D models have been applied, in the case of rocky ridges the 2D models have been used. The 1D numerical analyses have been performed using the code SHAKE91 modified (Idriss and Sun, 1992); the program has been designed to analyze sites approximated as horizontal infinite layers with shear waves propagating in the vertical direction. Each layer is homogeneous and isotropic with known thickness, mass, shear modulus and damping ratio; the program also incorporates non-linear soil behaviour, applying an equivalent linear model. The 2D analyses have been performed using a boundary elements method (ELCO, Callerio et al., 2000). The program gives the possibility to take into account geometrical configurations such as basins, ridges and cliffs. The program performs a discretization of the field surface depending on the range of frequencies and on the frequency steps. Any angle of incidence of the waves coming from the bedrock can be considered and both vertical and horizontal shear waves are analyzed. The program performs only elastic analyses, so that, the method has been employed when analyzing situations are characterized by the presence of rocks.

For each situation, a series of elastic pseudo-acceleration response spectra are calculated; the spectral intensity (SI) (Housner, 1952) has been selected to represent the seismic amplification as it relates better to seismic structural behaviour than other ground motion parameters. Spectral intensity has been computed in the period ranges 0.1–0.5s and 0.5–1.5s:

$$SI_{0.1\text{-}0.5}(PSV) = \int_{0.1}^{0.5} \mathrm{PSV}(\mathrm{T},\xi)\mathrm{dT} \qquad SI_{0.5\text{-}1.5}(PSV) = \int_{0.5}^{1.5} \mathrm{PSV}(\mathrm{T},\xi)\mathrm{dT}$$

where PSV are the pseudo-velocity spectral ordinates, T is the period and ξ is the damping, set to 5% of the critical damping. The spectral intensities were computed for the following seismic motions:

1. SI (input), spectral intensity of each reference spectrum;
2. SI (output), spectral intensity of each computed amplification spectrum. Then, the amplification coefficient (Fa) pertaining to local site conditions was defined on the basis of the ratio between the spectral intensity of output (SI output) and spectral intensity of input (SI input):

$$\mathrm{Fa}_{0.1\text{-}0.5} = \frac{\mathrm{SI}_{0.1\text{-}0.5}(\mathrm{output})}{\mathrm{SI}_{0.1\text{-}0.5}(\mathrm{input})} \qquad \mathrm{Fa}_{0.5\text{-}1.5} = \frac{\mathrm{SI}_{0.5\text{-}1.5}(\mathrm{output})}{\mathrm{SI}_{0.5\text{-}1.5}(\mathrm{input})}$$

theses ranges can be considered representative of the dominant period of the typical building of the area: the first range is representative of small, regular and rigid structures, the second of high and flexible structures.

Considering all the analyzed cases, some relationships between the values of the amplification coefficient (Fa) and the geotechnical and geometric characteristics of the site have been established, as a tool that allows to estimate the value of the Fa, in the case of availability of geologic and geotechnical data, without performing the analyses.

REPRESENTATIVE RESULTS

In this section the most representative results, in term of Fa values, of the analyses are shown: the results obtained for the gravel lithology, silt with clay lithology and silt with sand lithology in the case of lithologic amplifications, and the results obtained for the rocky ridges in the case of morphologic amplifications.

Gravel lithology

In the Figure 2 the behaviour of the shear waves velocity (Vs) with the depth (Z), deriving by the geophysical analyses, is shown. This behaviour has been used to identified the possible sequences that have been used in the numerical analyses.

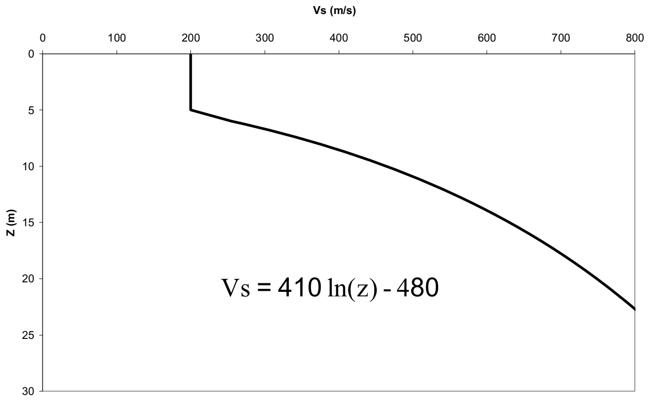


Figure 2. Behaviour of the Vs with the Z

In Figure 3 the relationships between the normalized shear modulus (G/G_0) and the damping ratio (D) variation as a function of the shear strain (γ) are presented (Rollins, 1998).

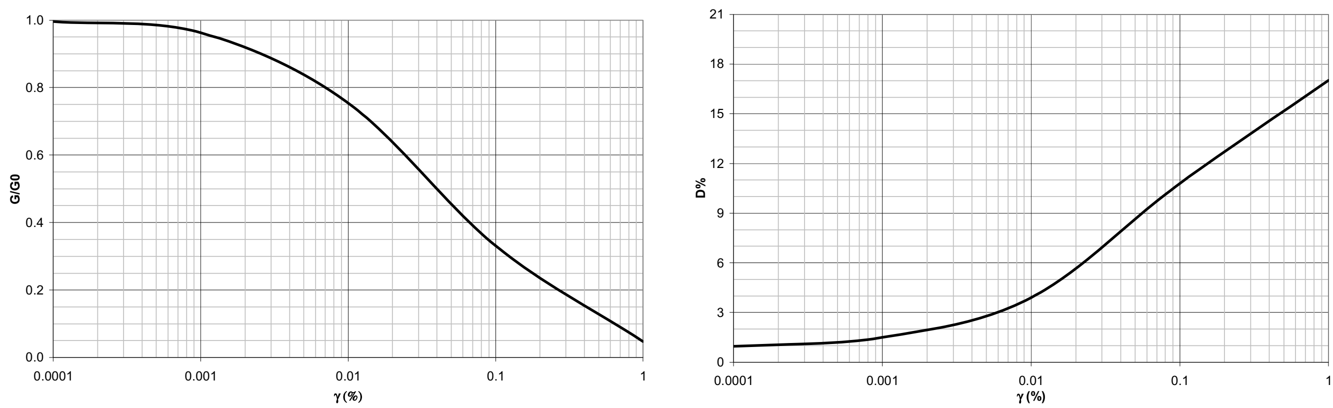


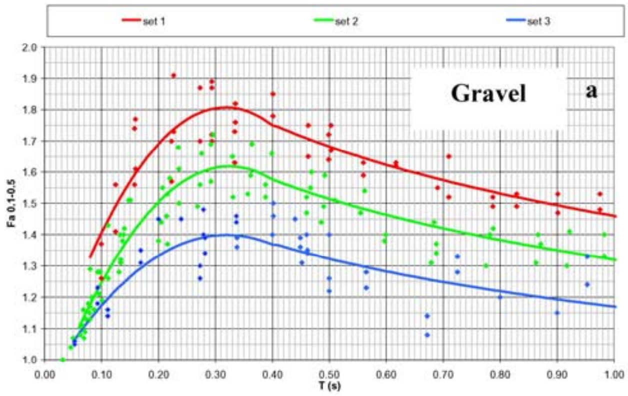
Figure 3. Relationships between G/G_0 and D variation as a function of γ

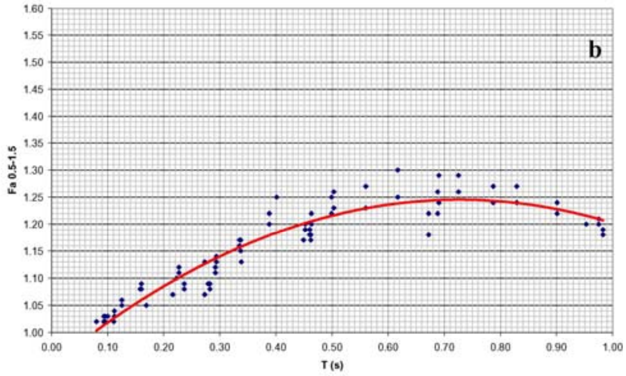
The results of the analyses performed for each stratigraphic sequence have been plotted on a graph where are shown the relationships between the values of amplification factor (Fa), in the two period ranges 0.1–0.5 and 0.5–1.5s, and the dominant period (T) of the sequences defined as:

$$T = (4 \times \sum_{i=1}^{n} h_i)/((\sum_{i=1}^{n} Vs_i \times h_i)/\sum_{i=1}^{n} h_i)$$

where T is the period, Vs and h are respectively the shear wave velocity and the thickness of the layer. The results show a good correlation considering the period ranges 0.5-1.5s, instead the values considering the period range 0.1-0.5s present a scattering. This scattering has been eliminated grouping the couple values in function of the value of the Vs and h of the surface layer, so three set of data have been individuated.

In Figure 4 the correlation curves and the formulas between the values of Fa and T for the range period 0.1-0.5s and 0.5-1.5s are presented (in the graph some results of the analyses are plotted).





Set 1	$0.08 < T \leq 0.40$	$0.40 < T \leq 1.00$
	$Fa_{0.1\text{-}0.5} = -8.5T^2 + 5.4T + 0.95$	$Fa_{0.1\text{-}0.5} = 1.46 - 0.32LnT$
Set 2	$0.06 < T \leq 0.40$	$0.40 < T \leq 1.00$
	$Fa_{0.1\text{-}0.5} = -7.4T^2 + 4.8T + 0.84$	$Fa_{0.1\text{-}0.5} = 1.32 - 0.28LnT$
Set 3	$0.05 < T \leq 0.40$	$0.40 < T \leq 1.00$
	$Fa_{0.1\text{-}0.5} = -4.7T^2 + 3.0T + 0.92$	$Fa_{0.1\text{-}0.5} = 1.17 - 0.22LnT$

$$Fa_{0.5\text{-}1.5} = -0.58T^2 + 0.84T + 0.94$$

Figure 4. Correlation curves and formulas between the values of Fa and T in the range period 0.1-0.5s (a) and 0.5-1.5s (b) (Gravel lithology)

For the range period 0.1-0.5s the choice of the curves is related to the value of the Vs and h of the surface layer, in the Figure 5 the range of validity of each curves is shown. In particular the grey areas identify the situations in which the curves are not applicable, the grey lines areas identify the situations in which the influence of amplification can be considered negligible due to the low thickness of the deposits and the coloured areas show the situations in which each curve can be considered appropriated.

Surface layer thickness (m)

Surface layer Vs (m/s)	1	2	3	4	5	6	7	8	9	10	12	14	16	18
200				1	1									
250				2	2	2								
300				3	3	3	3							
350				3	3	3	3	3						
400				3	3	3	3	3	3					
450				3	3	3	3	3	3					
500				3	3	3	3	3	3	3				
600				3	3	3	3	3	3	3	3	3		
700				3	3	3	3	3	3	3	3	3	3	3

Figure 5. Range of validity of each curve

Generally the influence on the results of the use of different accelerograms can be considered negligible: in fact the difference are limited in a variation of ± 0.1 of the Fa values.

Silt with clay lithology

In Table1 is reports the geotechnical characteristics of the lithology, derived from geotechnical analyses performed on the samples.

Table 1. Main geotechnical characteristic

Parameter		Range
Unit weight of soil	γ [kN/m^3]	19.5-20.0
Unit weight of solid particles	γ_s [kN/m^3]	25.7-26.7
Water content	w [%]	20-25
Liquid limit	w_L [%]	30-50
Plastic limit	w_P [%]	15-20
Plasticity index	I_P [%]	15-30
Void ratio	e	0.5-0.7
Degree of saturation	S_r [%]	90-100
Coefficient of earth pressure at rest	K_0	0.5-0.6
Compression index	C_c	0.15-0.30
Swelling index	C_s	0.02-0.06
Rate of secondary consolidation	C_a	0.001-0.005
Degree of consolidation	OCR	1-5
SPT blow count	SPT (N)	15-30

For this stratigraphic sequence, through the geophysical analyses, two behaviours of the shear waves velocity (Vs) depth (Z) profiles have been identified (Figure 6). These behaviours have been used to identify the sequence type (type 1 or type 2) that have been used in the numerical analyses.

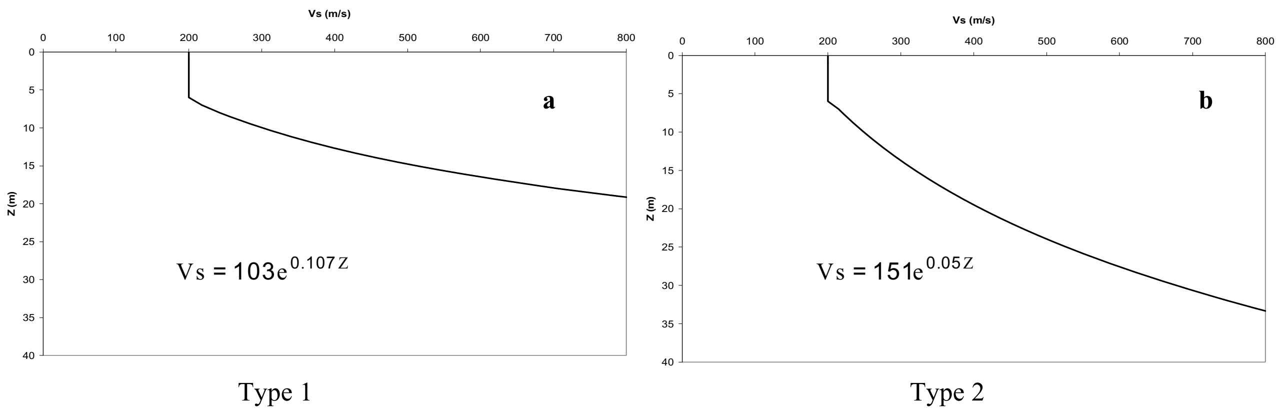


Figure 6. Behaviours of the Vs with the Z for the sequences type 1 (a) and type 2 (b)

In Figure 7 the relationships between the normalized shear modulus (G/G_0) and the damping ratio (D) variation as a function of the shear strain (γ) are presented, deriving by the geotechnical analyses performed on the samples.

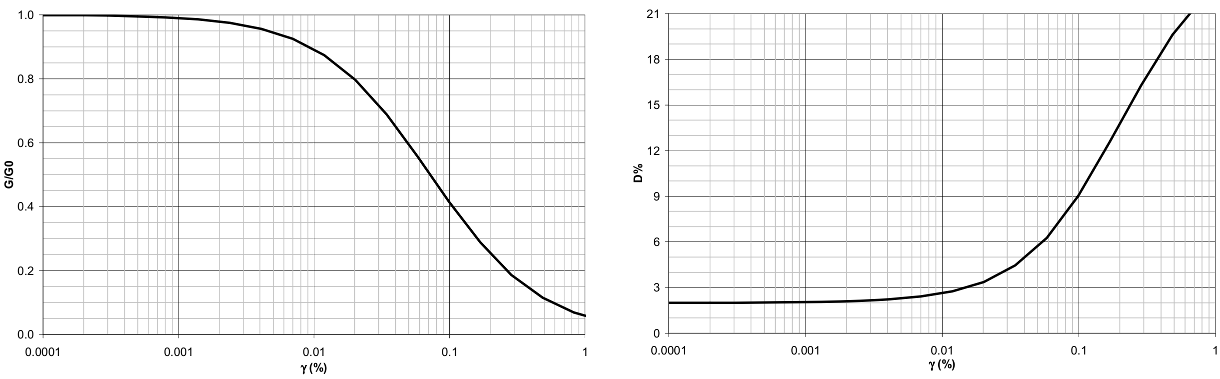
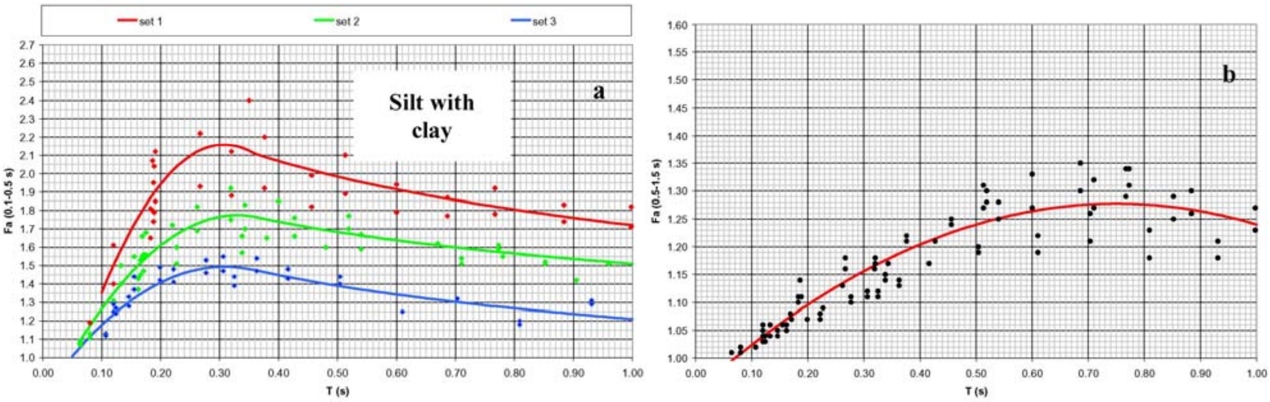


Figure 7. Relationships between G/G_0 and D variation as a function of γ

The results of the analyses performed for each stratigraphic sequence have been plotted on a graph where are shown the relationships between the values of amplification factor (Fa), in the two period ranges 0.1–0.5s and 0.5–1.5s, and the dominant period (T). The results show a good correlation considering the period ranges 0.5-1.5s, instead the values considering the period range 0.1-0.5s present a scattering. This scattering has been eliminated grouping the couple values in function of the value of the Vs and h of the surface layer, so three set of data have been individuated.

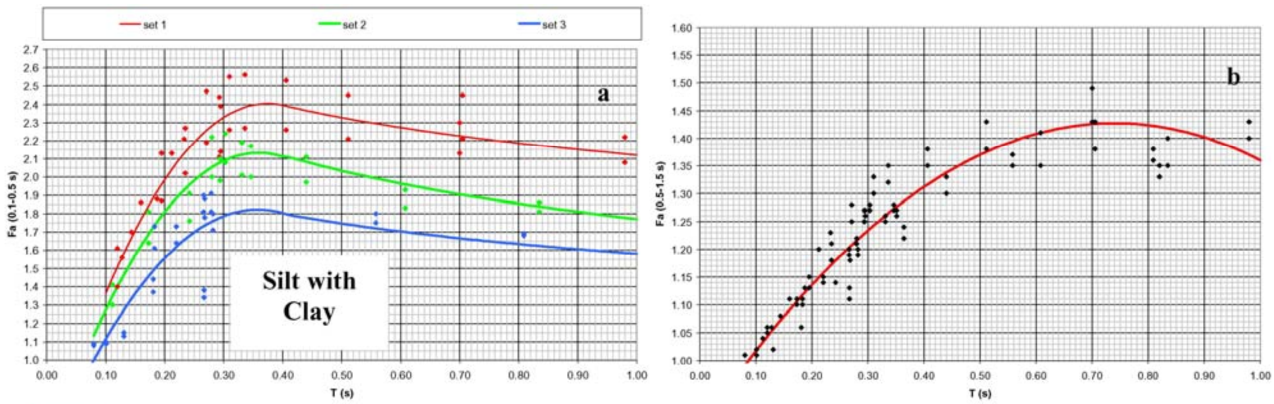
In Figure 8 and 9, respectively for the sequence type 1 and type 2, the correlation curves and the formulas between the values of Fa and T for the range period 0.1-0.5s and 0.5-1.5s are presented (in the graph some results of the analyses are plotted).



Set 1	$0.08 < T \leq 0.35$	$0.35 < T \leq 1.00$
	$Fa_{0.1\text{-}0.5} = -18.7T^2 + 11.5T + 0.39$	$Fa_{0.1\text{-}0.5} = 1.72 - 0.38 LnT$
Set 2	$0.06 < T \leq 0.35$	$0.35 < T \leq 1.00$
	$Fa_{0.1\text{-}0.5} = -9.5T^2 + 6.3T + 0.73$	$Fa_{0.1\text{-}0.5} = 1.51 - 0.25 LnT$
Set 3	$0.05 < T \leq 0.35$	$0.35 < T \leq 1.00$
	$Fa_{0.1\text{-}0.5} = -7.3T^2 + 4.5T + 0.80$	$Fa_{0.1\text{-}0.5} = 1.21 - 0.26 LnT$

$$Fa_{0.5\text{-}1.5} = -0.6T^2 + 0.9T + 0.94$$

Figure 8. Correlation curves and formulas between the values of Fa and T in the range period 0.1-0.5s (a) and 0.5-1.5s (b), for the type 1



Set 1	$0.10 < T \leq 0.40$	$0.40 < T \leq 1.00$
	$Fa_{0.1\text{-}0.5} = -13.9T^2 + 10.4T + 0.46$	$Fa_{0.1\text{-}0.5} = 2.12 - 0.30 LnT$
Set 2	$0.08 < T \leq 0.40$	$0.40 < T \leq 1.00$
	$Fa_{0.1\text{-}0.5} = -12.8T^2 + 9.2T + 0.48$	$Fa_{0.1\text{-}0.5} = 1.77 - 0.38 LnT$
Set 3	$0.05 < T \leq 0.40$	$0.40 < T \leq 1.00$
	$Fa_{0.1\text{-}0.5} = -10.6T^2 + 7.6T + 0.46$	$Fa_{0.1\text{-}0.5} = 1.58 - 0.24 LnT$

$$Fa_{0.5\text{-}1.5} = -T^2 + 1.48T + 0.88$$

Figure 9. Correlation curves and formulas between the values of Fa and T in the range period 0.1-0.5s (a) and 0.5-1.5s (b), for the type 2

For the range period 0.1-0.5s the choice of the curves is related to the value of the Vs and h of the surface layer, in the Figure 10 the range of validity of each curves is shown both for the type 1 and type 2. In particular the grey areas identify the situations in which the curves are not applicable, the grey lines areas identify the situations in which the influence of amplification can be considered negligible due to the low thickness of the deposits and the coloured areas show the situation in which each curve can be considered appropriated.

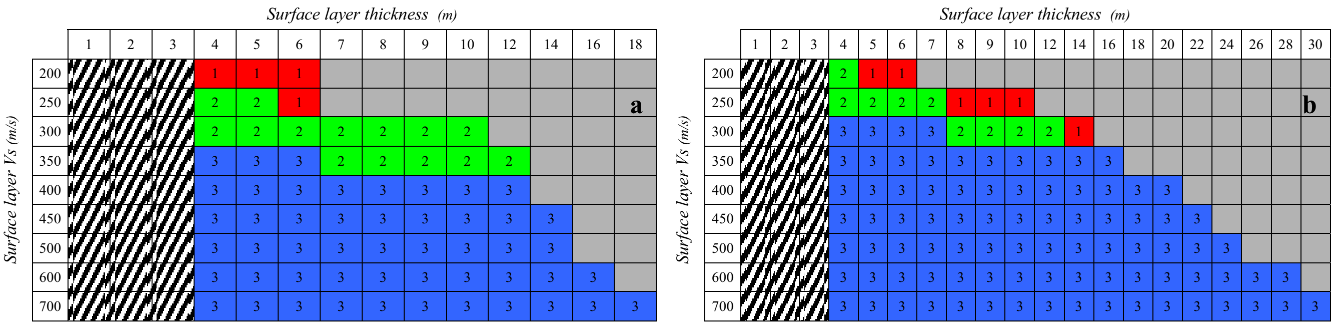


Figure 10. Range of validity of each curve respectively for type 1 (a) and type 2 (b)

Generally the influence on the results of the use of different accelerograms can be considered negligible: in fact the difference are limited in a variation of ± 0.1 of the Fa values.

Silt with sand lithology

In Table 2 is reported the main geotechnical characteristic of the lithology, deriving by the geotechnical analyses performed on the samples.

For this stratigraphic sequence, through the geophysical analyses, two behaviour of the shear waves velocity (Vs) with the depth (Z) are been individuated (Figure 11). These behaviours have been used to identified the possible sequences (type 1 and type 2) that have been used in the numerical analyses.

Table 2. Main geotechnical characteristic

Parameter		Range
Unit weight of soil	γ [kN/m^3]	18.5-19.5
Unit weight of solid particles	γ_s [kN/m^3]	26.0-27.9
Water content	w [%]	25-30
Liquid limit	w_L [%]	25-35
Plastic limit	w_P [%]	15-20
Plasticity index	I_P [%]	5-15
Void ratio	e	0.6-0.9
Degree of saturation	S_r [%]	90-100
Coefficient of earth pressure at rest	K_0	0.4-0.5
Compression index	C_c	0.10-0.30
Swelling index	C_s	0.03-0.05
Rate of secondary consolidation	C_a	0.002-0.006
SPT blow count	Nspt	0-20

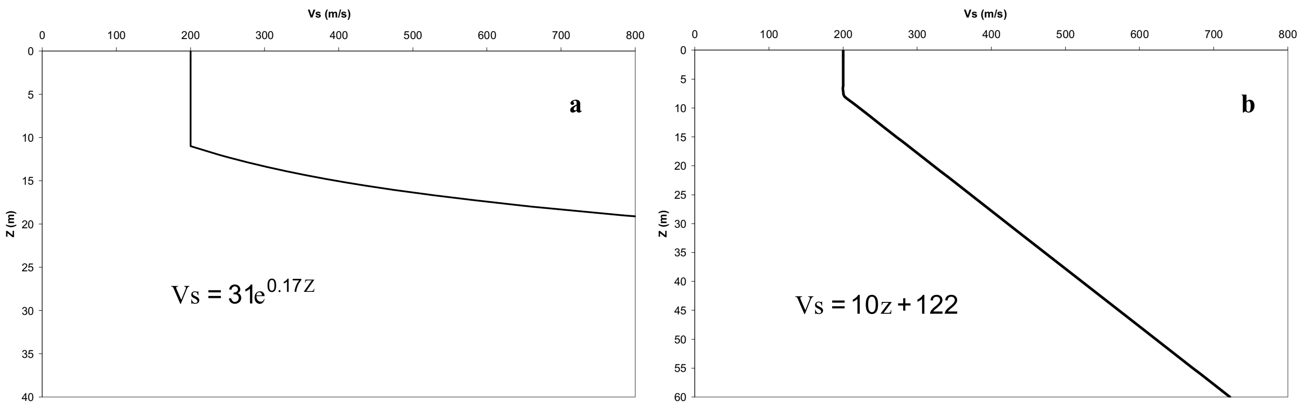


Figure 11. Behaviours of the Vs with the Z for the sequences type 1 (a) and type 2 (b)

In Figure 12 the relationships between the normalized shear modulus (G/G_0) and the damping ratio (D) variation as a function of the shear strain (γ) are presented, deriving by the geotechnical analyses performed on the samples.

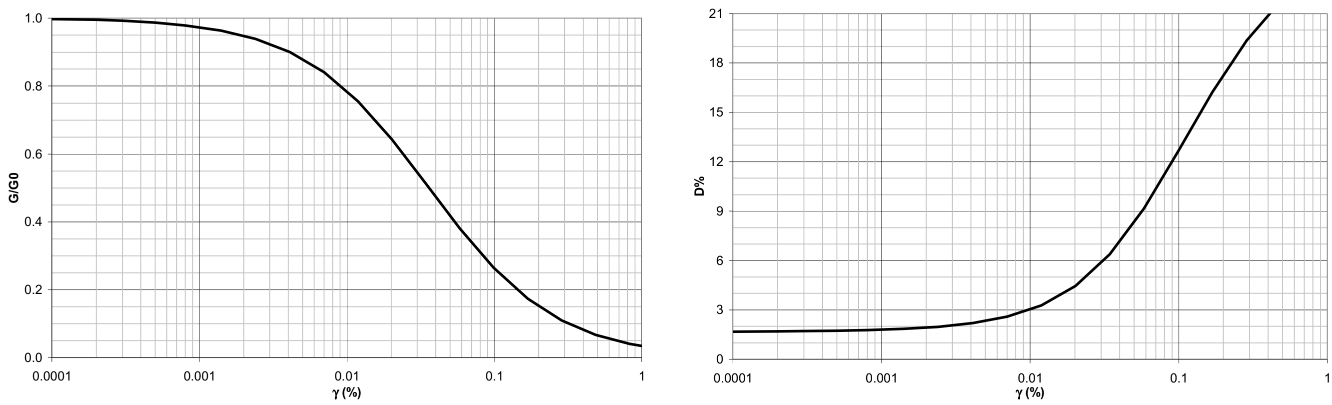
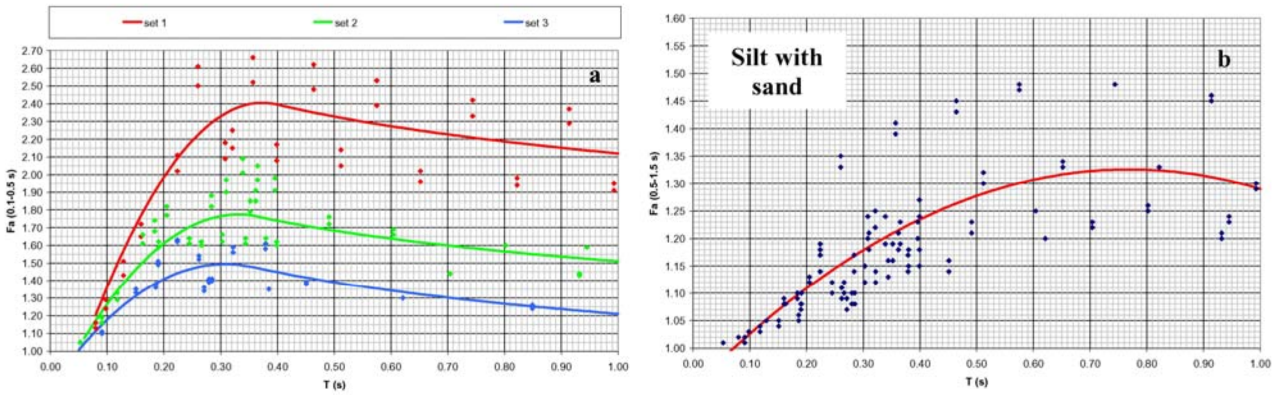


Figure 12. Relationships between G/G_0 and D variation as a function of γ

The results of the analyses performed for each stratigraphic sequence have been plotted on a graph where are shown the relationships between the values of amplification factor (Fa), in the two period ranges 0.1–0.5s and 0.5–1.5s, and the dominant period (T). The results show a good correlation considering the period ranges 0.5-1.5s, instead the values considering the period range 0.1-0.5s present a scattering. This scattering has been eliminated grouping the couple values in function of the value of the Vs and h of the surface layer, so three set of data have been individuated.

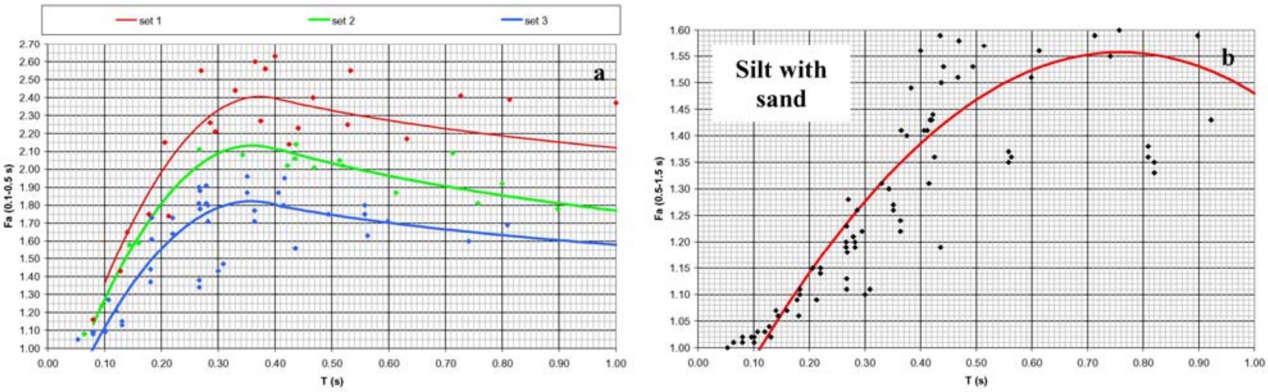
In Figure 13 and 14, respectively for the sequence type 1 and type 2, the correlation curves and the formulas between the values of Fa and T for the range period 0.1-0.5s and 0.5-1.5s are presented (in the graph some results of the analyses are plotted).



Set 1	$0.08 < T \leq 0.40$	$0.40 < T \leq 1.00$
	$Fa_{0.1\text{-}0.5} = -13.9T^2 + 10.4T + 0.46$	$Fa_{0.1\text{-}0.5} = 2.12 - 0.30LnT$
Set 2	$0.06 < T \leq 0.35$	$0.35 < T \leq 1.00$
	$Fa_{0.1\text{-}0.5} = -9.5T^2 + 6.3T + 0.73$	$Fa_{0.1\text{-}0.5} = 1.51 - 0.25LnT$
Set 3	$0.05 < T \leq 0.35$	$0.35 < T \leq 1.00$
	$Fa_{0.1\text{-}0.5} = -7.3T^2 + 4.5T + 0.80$	$Fa_{0.1\text{-}0.5} = 1.21 - 0.26LnT$

$$Fa_{0.5\text{-}1.5} = -0.67T^2 + 1.3T + 0.93$$

Figure 13. Correlation curves and formulas between the values of Fa and T in the range period 0.1-0.5s (a) and 0.5-1.5s (b), for the type 1



Set 1	$0.10 < T \leq 0.40$	$0.40 < T \leq 1.00$
	$Fa_{0.1\text{-}0.5} = -13.9T^2 + 10.4T + 0.46$	$Fa_{0.1\text{-}0.5} = 2.12 - 0.30 LnT$
Set 2	$0.08 < T \leq 0.40$	$0.40 < T \leq 1.00$
	$Fa_{0.1\text{-}0.5} = -12.8T^2 + 9.2T + 0.48$	$Fa_{0.1\text{-}0.5} = 1.77 - 0.38 LnT$
Set 3	$0.05 < T \leq 0.40$	$0.40 < T \leq 1.00$
	$Fa_{0.1\text{-}0.5} = -10.6T^2 + 7.6T + 0.46$	$Fa_{0.1\text{-}0.5} = 1.58 - 0.24 LnT$

$$Fa_{0.5\text{-}1.5} = -1.33T^2 + 2.02T + 0.79$$

Figure 14. Correlation curves and formulas between the values of Fa and T in the range period 0.1-0.5s (a) and 0.5-1.5s (b), for the type 2

For the range period 0.1-0.5s the choice of the curves is related to the value of the Vs and h of the surface layer, in the Figure 15 the range of validity of each curves is shown both for the type 1 and type 2. In particular the grey areas identify the situations in which the curves are not applicable, the grey lines areas identify the situations in which the influence of amplification can be considered negligible due to the low thickness of the deposits and the coloured areas show the situation in which each curves can be considered appropriated.

(a) *Surface layer thickness (m)* / *Surface layer Vs (m/s)*

Vs \ h	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
200				1	1	1	1	1	1	1	1	1						
250				2	2	2	2	2	2	1	1	1						a
300				2	2	2	2	2	2	2	2	2	2					
350				3	3	3	3	3	3	3	3	3	3	2				
400				3	3	3	3	3	3	3	3	3	3	3	3	3		
450				3	3	3	3	3	3	3	3	3	3	3	3	3		
500				3	3	3	3	3	3	3	3	3	3	3	3	3	3	
600				3	3	3	3	3	3	3	3	3	3	3	3	3	3	
700				3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

(b) *Surface layer thickness (m)* / *Surface layer Vs (m/s)*

Vs \ h	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	20	25	30	35	40	50	60
200				1	1	1	1	1	1	1												
250				2	2	2	2	2	2	1	1	1	1	1	1							b
300				3	3	3	3	3	2	2	2	2	2	2	2	2						
350				3	3	3	3	3	3	3	3	3	3	3	3	3	3					
400				3	3	3	3	3	3	3	3	3	3	3	3	3	3	3				
450				3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3			
500				3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3		
600				3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
700				3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

Figure 15. Range of validity of each curve respectively for type 1 (a) and type 2 (b)

Generally the influence on the results of the use of different accelerograms can be considered negligible: in fact the difference are limited in a variation of ± 0.1 of the Fa values.

Rocky ridge

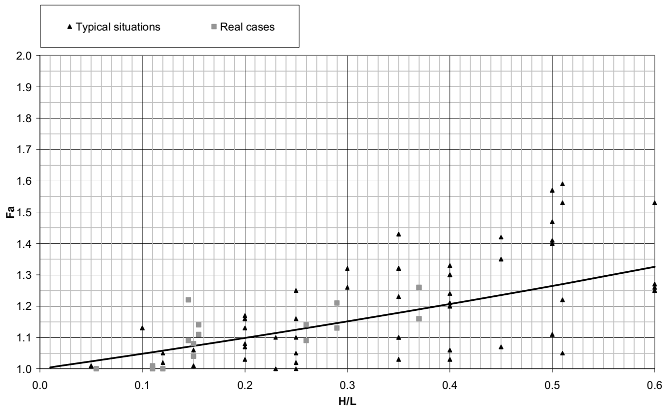
For the morphologic amplification the attention has been paid to the rocky ridges, in particular on the basis of real cases, characterized by topographic irregularities with the presence of rock, the typical situations has been identified and the numerical analyses, applying the 2D models, has been performed. The results have been checked, furthermore, applying the numerical analysis on some real cases.

The rocky ridge is identified by geometrical characteristics: slope angle ≥ 10°, base length (L) defined in correspondence of morphologic ruptures, minimum elevation difference (h), maximum elevation difference (H) and ratio h ≥ 1/3 H.

The analyses have been performed applying, to the rock, the values of shear waves ranging between 800-1500 m/s and the values of unit weight between 22-24 kN/m^3. The results in term of Fa values, in the two period ranges 0.1–0.5s and 0.5–1.5s, calculated on the top of the ridge have been correlated with the values of the ratio H/L; the results show a scattering considering the period ranges 0.1-0.5s and the values considering the period range 0.5-1.5s present a large influence of the applied accelerograms, therefore they are not sufficient to represent in a univocal way the site response. For this reason the procedure has considered only the results of the period ranges 0.1-0.5s and the scattering has been eliminated grouping the couple values in function of two parameters: the morphology of the ridge and the base length. For the morphology of ridge, two situations have been considered:

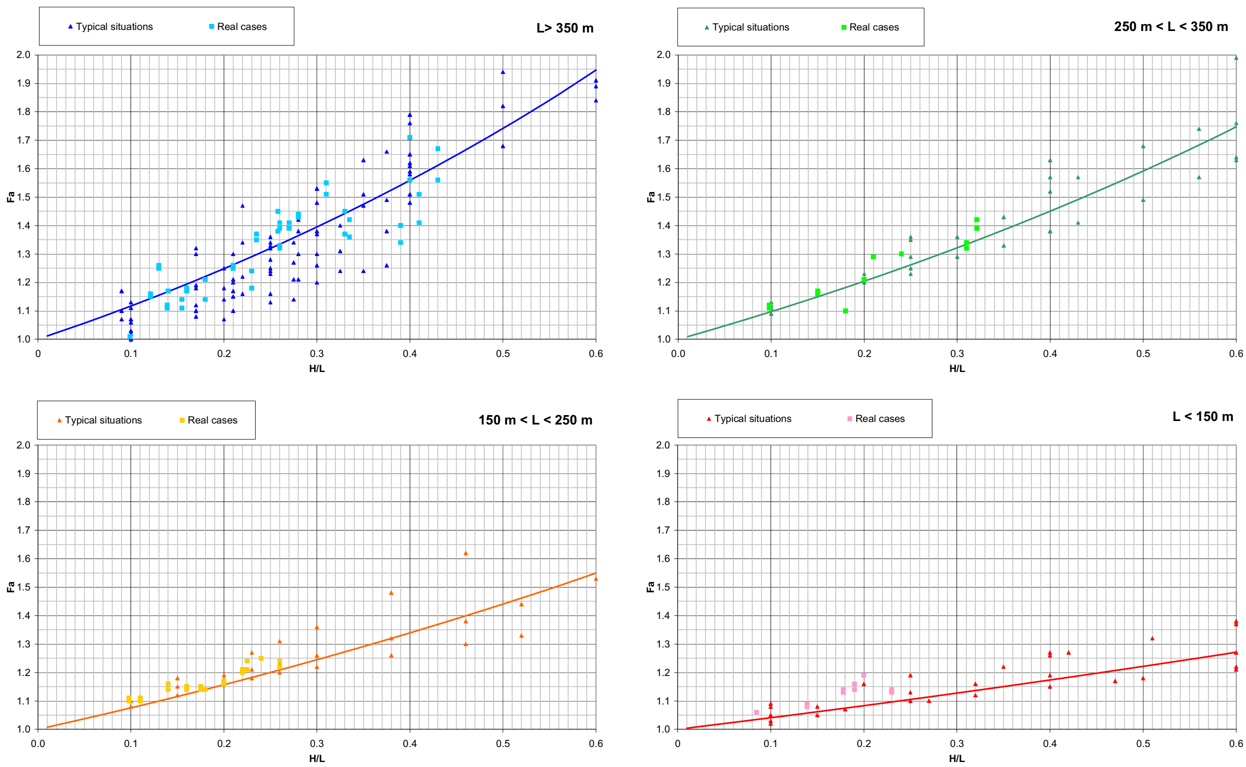
- rounded ridges, characterized by a length on the top (l) quite similar (≥ 1/3) to the base length (L), the top is flat and the slope angle is ≤ 10°;
- pointed ridges, characterized by a top length very smaller to the base length.

For the rounded ridges the different couple values of Fa and H/L are not influenced by the values of the base length, therefore the correlation curve is unique (Figure 16), instead for the pointed ridges four correlation curves have been individuated, depending on the values of the base length (Figure 17). In the graphs some results of the analyses performed on both typical situations and real cases, are plotted.



$$Fa_{0.1\ 0.5} = e^{0.47 H/L}$$

Figure 16. Correlation curves and formula between the values of Fa and H/L in the range period 0.1-0.5s, for the rounded ridges



$L \geq 350$	$250 \leq L < 350$	$150 \leq L < 250$	$L < 150$
$Fa_{0.1-0.5} = e^{1.11 H/L}$	$Fa_{0.1-0.5} = e^{0.93 H/L}$	$Fa_{0.1-0.5} = e^{0.73 H/L}$	$Fa_{0.1-0.5} = e^{0.40 H/L}$

Figure 17. Correlation curves and formulas between the values of Fa and H/L in the range period 0.1-0.5s, for the pointed ridges and for different values of base length (L)

The procedure provide that the Fa values are assigned to the top area, instead along the slope the values are scaled in a linear way, reaching the value 1 to the base of the slope.

The validation, considering real case, has shown that the maximum variation of the Fa values is ± 0.1 and it is notice that, considering the real situations, the ratio H/L is lower than 0.4.

CONCLUSION

In the paper a procedure for the evaluation of the seismic site effects are shown. The aim of the work was to point out a methodology that may be used repetitively at the level of urban planning, when only the geologic, geophysical and geotechnical characteristics of a site are known.

Therefore, a series of geologic, geomorphologic and geotechnical analyses have been carried out, to identify the areas affected by site effects and to characterize the lithotechnical units. The expected seismic inputs have been calculated and numerical analyses using one-dimensional code, analyzing single soil columns, and two-dimensional codes, working with boundary elements and analyzing the morphologic amplifications, have been done.

The results of the analyses, in term of correlation curves between some geometric and geophysical characteristics and the values of the amplification coefficients, allow to the identification of the expected amplification factors: for the lithologic amplifications it is necessary to know the prevalent lithology, the behaviour of shear waves velocity with the depth and the dominant period of the sequence; for the morphologic amplification it is necessary know the geometry of the ridges such as the top and base length, the slope angle and the maximum and minimum values of the elevation difference.

The expected amplification factors give elements for urban planning, both for urban general choice and for building design.

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