A Review of Seismic Site Amplification by Considering Geometrical and Geotechnical Characteristics of Sites

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ABSTRACT
An extensive numerical analysis on the seismic site effects due to local topographical and geotechnical characteristics is carried out. Two dimensional (2D) configurations under incidence of vertically propagating SV waves is modeled with the aid of HYBRID program, combining finite elements in the near field and boundary elements in the far field. A parametric study is conducted to examine the combined effects of topography and geology on the amplification of the response spectrum at various points across the valley. The influence of different parameters is considered, such as filling ratios (from empty to full valleys), impedance contrasts between bedrock and sediments, and dimensions. Finally, some criteria are proposed in terms of engineering applications to assess the spectral response at the surface of sedimentary valleys.

RÉSUMÉ
Une analyse numérique sur les effets de site sismiques dus aux caractéristiques topographiques et géotechniques locales est effectuée. Les configurations bidimensionnelles (2D) soumises aux ondes SV se propageant verticalement sont modélisées à l'aide du code HYBRID, combinant la méthode des éléments finis dans le champ proche et la méthode des éléments de frontière dans le champ lointain. Une étude paramétrique est menée pour étudier les effets combinés de la topographie et de la géologie sur l'amplification du spectre de réponse à différents endroits dans la vallée. L'influence des différents paramètres est considérée, comme le taux de remplissage, l'impédance entre le substratum rocheux et les sédiments, et les dimensions des vallées. Enfin, certains critères sont proposés en termes d'applications d'ingénierie pour évaluer la réponse spectrale sur la surface des vallées sédimentaires.

1 INTRODUCTION

Local geological and geotechnical characteristics may generate significant amplification of ground motion and concentrated damage during large earthquakes. The modification of the seismic movement due to local topographical and geotechnical conditions is called *site effect*. The majority of seismic codes consider seismic site effects by one-dimensional (1D) models that allow measuring the influence of geological characteristics and thickness of the sedimentary layer on the vertical propagating of volumetric waves regardless of lateral heterogeneities. The purpose of this paper is to contribute to establishment of a simple method to include complex site effects in two-dimensional (2D) sedimentary valleys in a building code.

In this study, scattering of elastic waves under 2D irregularities are simulated by HYBRID program, combining finite elements in the near field (sediments filling valleys) and boundary elements in the far field (substratum) [Gatmiri and Kamalian, 2002; Gatmiri and Dehghan, 2005; Gatmiri and Nguyen, 2005; Maghoul et al., 2013]. Gatmiri and his colleagues [Gatmiri et al. 2009] studied topographic irregularities in empty valleys and considered various examples that cover different 2D geometries. The achieved conclusions are presented briefly as follows: in general, the seismic ground motion is amplified at the crest of ridges, at the upper corner of slopes and at the edges of canyons and it is attenuated at the base of these relives. The effects of topography are also affected by the slope angle of the relief. Generally, the stiffer the slope of the relief is, the more the effects of topography due to this relief are accentuated. In empty valleys, the spectral acceleration responses are classified according to a unique geometrical criterion that can be used directly by engineers: the "*S/A*" ratio (where *S* is the area of the valley opening and *A* indicates the angle between the horizontal line and slope in the above corner) (Figure. 1) [Gatmiri et al. 2009].

Figure 1. Definition of parameters, S and A

In this paper, sedimentary aspect of 2D alluvial valleys is underlined. At first, the influence of bi-dimensionality on the response of the site is studied. For this purpose, acceleration responses of filled valleys are compared with the responses of 1D column of soil. The height of the 1D reference column is chosen equal to the thickness of the sedimentary layer under the observation point considered on the surface of the filled valley. The aim is to identify the preponderant site effect in a point of the surface of a given shape. Secondly, the filling ratio effects of alluvial valleys and the influence of the changes in impedance ratio between sediments and the bedrock are investigated in order to establish simple methods to include 2D combined site effects in building codes.

The 2D wave scattering is studied at the surface of sedimentary valleys by using the HYBRID code. The seismic solicitation is a vertically incident SV Ricker wave. The predominant frequency of the incident signal is fixed and equal to 2 Hz. In the simulation, soils are assumed to be dry and linearly elastic. The reference is taken as the scattering of the Ricker incident wave on a flat bedrock surface.

2 2D SITE EFFECTS IN FILLED VALLEYS

The aim of this section is to study the influence of 2D effects on the seismic response of filled valleys. Acceleration response of filled valleys is compared with the responses of 1D columns of soil. The height of the 1D reference column is chosen equal to the thickness of the sedimentary layer underlying the observation point considered in the filled valley. The geometrical characteristics of valleys are displayed in Figure 2. It is assumed that valleys are completely filled by a homogeneous sedimentary layer. For triangular, trapezoidal, and rectangular valleys, the angle formed by the slope of the relief relatively to the horizontal line in the above corner is considered, for the ellipsoidal and truncated ellipsoidal configurations, α is the angle between the tangent at the top corner of the valley and the horizontal line. The values of L_1 for the trapezoidal and truncated ellipsoidal valleys are chosen to be equal to 0, 40, and 100 m. The value of L for all the valleys equals to 100 m. In the present work, simulations are carried out with a depth (H) equal to 20, 40, 60, or 100 m.

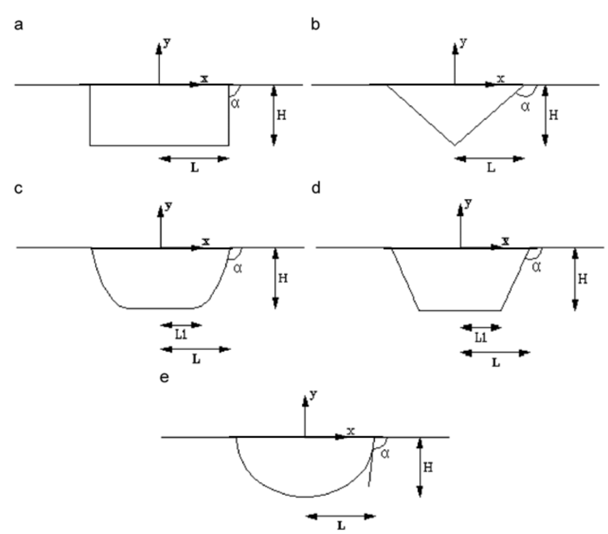

Figure 2. Configurations of the studied filled valleys: (a) rectangle; (b) triangle; (c) truncated ellipse; (d) trapezium; (e) ellipse.

Table 1. Mechanical parameters of the alluvial layer and rock

	E (MPa)	v	ρ (Kg/m^3)	C (m/s)
Sediments	382	0.3	1630	300
	900	0.3	1630	461
	1527	0.3	1630	600
	2385	0.3	1630	750
Rock	6720	0.4	2400	1000

2.1 Mechanical parameters of the materials

In the adopted model, the rocky bed and the alluvial layer are assumed to be homogeneous linear elastic materials. The main parameters of the alluvial layer are given in Table 1. The impedance contrast $\beta = \rho_S C_S / \rho_R C_R$ is equal to 0.31, where ρ_S and ρ_R are the volumetric masses of sediment and rock, respectively; C_S and C_R are the shear wave's velocities of sediments and rock, respectively.

2.2 Study of combined effects (2D) in the various filled valleys

From the spectral ratio curves obtained at different observation points at the surface of the filled valleys (Figure 3), the following is observed:

1. All curves have two parts. A decreasing part from the central point (X/L = 0) to a point whose abscissa is between X/L = 0.5 and 1, and an increasing part between the intermediate point and the top of the slope X/L = 1. For the first part, it is obvious that as we move away from the central point, amplitude decreases, due to a decreasing influence of the sedimentary effect. The increasing part of the curve shows the predominance of topographical effects on the slopes covered by sediment. In the central part of the valley, 1D sedimentary effect controls the local response of the site. On the slopes of the sedimentary basin, the presence of alluvium attenuates the predominant topographical amplification.
2. Practically, on all curves, the maximal amplification is reached at the central point of the valley (X/L = 0). This point seems to be the most critical.

If topographical effects and geological effects at mid-slope are compared, it can be seen that topographical effects are lightly predominant in comparison with geological effects. The mid-slope point is thus good transition point: from this point, up to the edge of the valley (X/L = 1), topographical effects dominate the site response (i.e. the preponderance of site effects is reversed). In conclusion, in the central zone (from X/L = 0 to midslope), results provided by 1D analyses can be used to estimate the spectral acceleration response of a filled valley (similar to actual paraseismic codes), and in the lateral zone, the spectral response of the sedimentary valleys can be deduced from the characteristic spectra of topographical effects, shown in [Gatmiri et al. 2009].

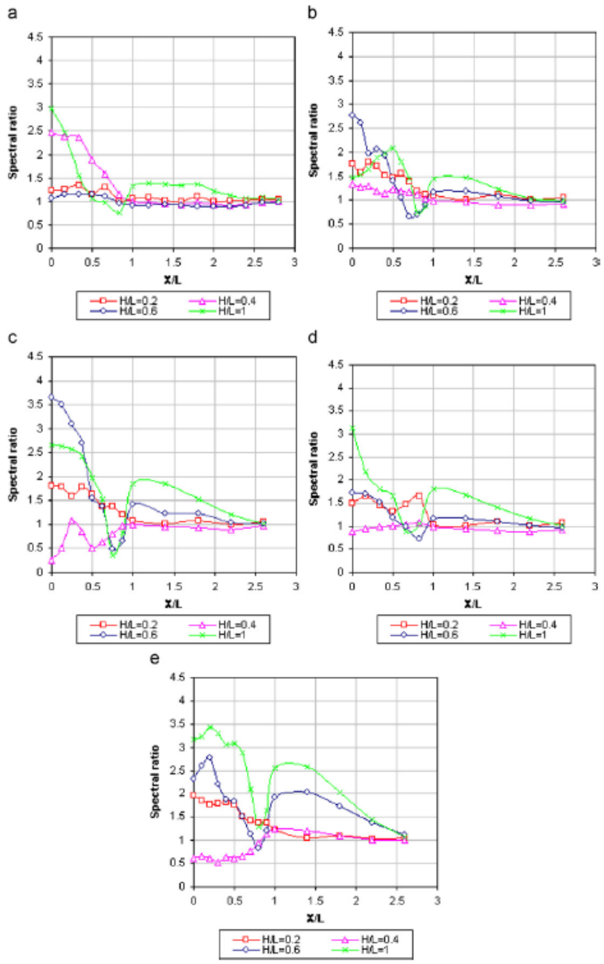

Figure 3. Spectral ratio versus a dimensional offset variable X/L for the various empty valleys: (a) triangle; (b) trapezium; (c) truncated ellipse; (d) ellipse; (e) rectangle.

3 2D SITE EFFECTS IN PARTIALLY-FILLED VALLEYS

3.1 Soil properties

As mentioned before, materials are assumed to be dry homogeneous and linear elastic. Material properties considered in filling ratio as well as impedance ratio effects analysis are presented in Table 2.

Table 2. Mechanical parameters materials

	E (MPa)	v	ρ (Kg/m^3)	C (m/s)
Soil	900	0.3	1630	465
Rock	6720	0.4	2450	1000

3.2 Geometrical characteristics

The studied valleys are the same as presented in Figure 2. Let S_1 be the surface of the section filled with sediments (Figure 4).

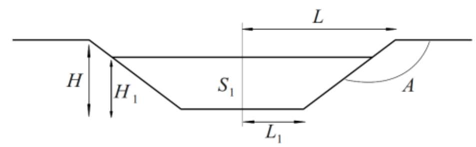

Figure 4. Geometrical parameters

The half-width L is equal to 100 m. We study triangular valleys corresponding to L1/L = 0 and trapezoidal valleys corresponding to L1/L = 0.4. The calculations are made for different shape ratios H/L = 0.2, 0.4, 0.6, 1 and filling ratios H1/H = 0, 0.25, 0.5, 0.75, 1.

3.3 Spatial evolution

First, we study the evolution of the spectral ratio with the spatial location of the studied point [Gatmiri et al. 2011]. The spectral ratio is represented as a function of the non-dimensional offset variable x/L for different configurations. By increasing the filling ratio, we go from empty valley behavior with a maximum amplification at the edge of the valley to fully-filled valley behavior with maximum amplification at the center of the valley. For a quarter-filled valley the behavior is the same as that of an empty valley (Figure 5).

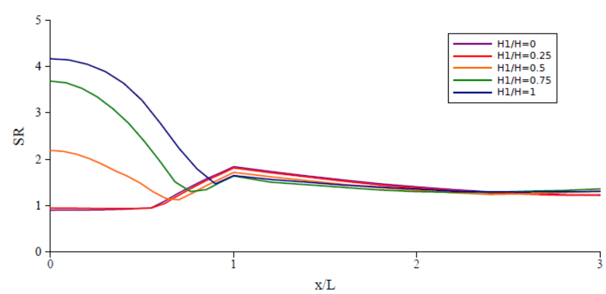

Figure 5. Spatial evolution of spectral ratio for various filling ratios (trapezoidal valley with H/L = 0.6 and β = 0.3)

For intermediate filling ratios, there is a local maximum at the edge of the valley, a local maximum at the center of the valley and a minimum at the contact point between sediments and bedrock. There is also a decrease of the spectral ratio by moving away from the valley (Figure 6).

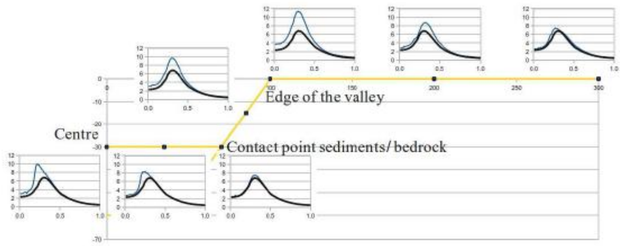

Figure 6. Response spectrum evolution along a trapezoidal valley (H/L = 0.6, H/H = 0.5, β = 0.3) (Reference spectrum in black)

3.4 Contact point sediments/bedrock

At the contact point between sediments and bedrock of partially-filled valleys, the spectral ratio is always lower than that of the corresponding empty valley with the same dimensions. It means that from this point up to the edge of the valley, topographical effects prevail upon geological effects. So, for points which are located on the rock (i.e. outside the area filled with sediments), it is possible to consider only the topographical site effect due to an empty valley. The response spectra calculated by this method will always be higher than the ones of the real cases.

3.5 Centre of the valley

It is of interest to define a criterion allowing an estimation of the site period for configurations with a significant amplification. We propose to study the evolution of the site period T_s with the parameter $S_1 / \beta\sqrt{\beta}$ which combines the soil properties (β) and the geometrical characteristics (S_1) (Figure 7). For $S_1 / \beta\sqrt{\beta} < 13\ 000$ the amplification is not significant enough to determine a representative site period T_s. For $S_1 / \beta\sqrt{\beta} > 120\ 000$, we ignore the case corresponding to H/L = 1, β = 0.2, H_1/H = 1 and β√β = 156 000 for which the site period goes back to low periods. We observe a linear evolution of T_s with $S_1 / \beta\sqrt{\beta}$ (Figure 7).

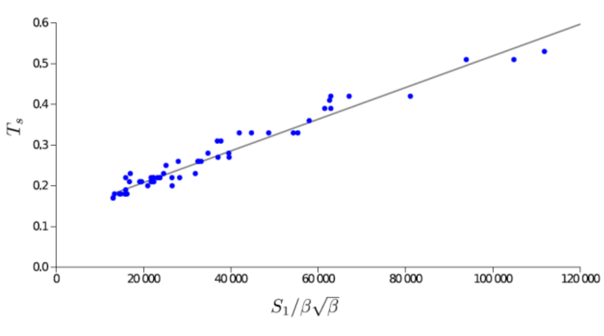

Figure 7. Evolution of the site period Ts with $S_1/ \beta\sqrt{\beta}$ for trapezoidal and triangular valleys.

In terms of spectral ratio, we propose a representation of $(SR - 1)S_1$ as a function of the parameter $S_1 / \beta\sqrt{\beta}$ governing the site period. For triangular and trapezoidal valleys, our numerical results are represented on Figure 8. The amplification is negligible up to a threshold corresponding to $S_1 / \beta\sqrt{\beta} = 13\ 000$. Afterwards, the evolution of (SR − 1) S_1 with $S_1 / \beta\sqrt{\beta}$ shows a parabolic tendency. From these curves, knowing the geometrical characteristics of the valley S_1 and its soil properties β, we can now calculate the coefficient $S_1 / \beta\sqrt{\beta}$. With this coefficient, we can read an estimation of the site period T_s and the coefficient (SR − 1) S_1 and then deduce the value of the spectral ratio SR (Figure 7 and Figure 8).

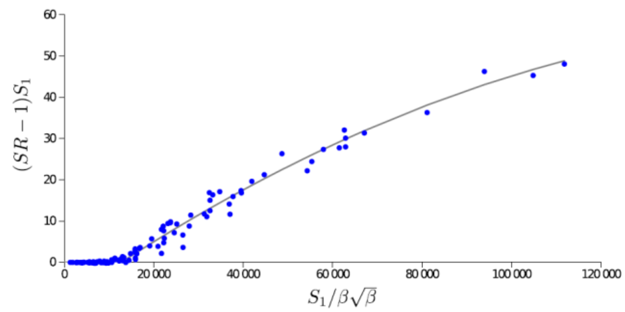

Figure 8. Evolution of (SR − 1) S1 with S1/ β√β.

4 CONCLUSION

Site effects in alluvium valleys are studied by means of a hybrid numerical technique. The main results of this study are:

- In an alluvial valley, fully- or partially-filled with sediments, from the contact point between sediments and bedrock up to the edge and outside of valleys, topographical effects prevail upon geological effects.
- At the central point of the valley, the evolution of the site period Ts with the parameter S1/ β√β has a linear tendency. This parameter combines the soil properties and the geometrical characteristics of the valley.
- At the centre of the valley we can estimate the spectral ratio SR from the curve representing the evolution of (SR − 1) S1 as a function of S1/ β√β (Figure 8).

5 REFERENCES

Gatmiri, B. and Kamalian, M. 2002. Two-dimensional transient wave propagation in an elastic saturated porous media by a hybrid FE/BE method, Proceedings of the fifth European conference of numerical methods in geotechnical engineering, Paris, France, 947–56.

Gatmiri, B. Dehghan, K. 2005. Applying a new fast numerical method to elasto-dynamic transient kernels in HYBRID wave propagation analysis, Proceedings of the sixth conference on structural dynamics (EURODYN2005), Paris, France, p.1879–84.

Gatmiri, B. and Nguyen, K.V. 2005. Time 2D fundamental solution for saturated porous media with in compressible fluid, Int. J. Commun. Num. Meth. Eng., 21:119–32.

Gatmiri, B., Maghoul, P. and Arson, C. 2009. Site-specific spectral response of seismic movement due to geometrical and geotechnical characteristics of sites, Soil Dynamics and Earthquake Engineering, 29:51-70.

Gatmiri, B., Le Pense, S. and Maghoul, P. 2011. A multi-scale seismic response of two-dimensional sedimentary valleys due to the combined effects of topography and geology, Journal of Multiscale Modeling, 3(3): 133-149.

Maghoul, P., Gatmiri B., Fredlund M. and Duhamel D. 2013. A Boundary Element Formulation for the Wave Propagation in the Unsaturated Soils, 5th Biot Conference on Poromechanics, Vienna, Austria, July 10-12.