Combined Effects of Topography and Sediments on the Site-period Evaluation of Two-dimensional Sedimentary Valleys

Les effets combinés de topographie et sédiments sur l'évaluation de période de site des vallées sédimentaires bidimensionnelles

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ABSTRACT: This study aims to consider a combination of geometrical and sedimentary effects for estimating the site-period of filled valleys. The parametric studies were conducted by a hybrid program that combines finite elements in the near field and boundary elements in the far field (FEM/BEM). This paper focuses on the modeling of filled alluvial valleys with different filling ratios. Valleys are characterized by their depth, H and their half width at the surface, L. The sediment height is characterized by H_1. In order to study the problem comprehensively the calculations are made for different depth ratios H/L= 0.2, 0.4, 0.6, 1 and Filling ratios, H_1/H=1/3, 2/3 and 1. The impedance ratios of sedimentary materials contrast to bedrock are also assumed to be 0.15, 0.3, 0.45 and 0.6. Seismic solicitation is a vertically incident SV Ricker wave. The results indicate that the site-period decreases by increasing the impedance ratio of materials and by increasing the filling ratio an ascending trend of the site-period can be seen. So, new criterion including geometrical and geotechnical characteristics for evaluating of the site period is presented. Finally the curves, which compile all of models based on the geometrical parameters, filling ratio and impedance ratio are presented for engineering applications.

RÉSUMÉ Cette étude vise à considérer des effets combinés géométriques et sédimentaires pour estimer la période de site des vallées remplies par des sédiments. Les études paramétriques ont été conduites par un programme hybride qui combine la méthode des éléments finis dans le champ proche et la méthode des éléments frontières dans le champ lointain (FEM/BEM). Ce papier se concentre sur la modélisation des vallées alluviales remplies avec des ratios de remplissage différents. Les vallées sont caractérisées par leur profondeur, H et leur moitié de la largeur à la surface, L. La hauteur de dépôt est caractérisée par H1. Pour étudier le problème globalement, les calculs ont été effectués pour des ratios de profondeur différents H/L = 0.2, 0.4, 0.6, 1 et des ratios de remplissage, H1/H=1/3, 2/3 et 1. Les ratios d'impédance de contraste de matériels sédimentaire avec le socle rocheux sont aussi assumés d'être 0.15, 0.3, 0.45 et 0.6. La sollicitation sismique, verticalement incidente, est une onde de SV RICKER. Les résultats indiquent que la période de site diminue en augmentant le ratio d'impédance de matériels. En augmentant le ratio de remplissage une tendance d'augmentation de la période de site peut être vue. Donc, le nouveau critère incluant des caractéristiques géométriques et géotechniques pour évaluer de la période de site est présenté. Finalement, les courbes qui compilent tous les résultats des études sur les paramètres géométriques, le ratio de remplissage et le ratio d'impédance sont présentées pour des applications d'ingénierie.

KEYWORDS: Site Effect; Hybrid Method; Site-Period; Spectral Response; Filling Ratio; Impedance Ratio.

1 INTRODUCTION

It has been recognized that effects of geometrical and geotechnical characteristics of a site can significantly affect the nature of strong ground motion during earthquakes. Certainly in the recent past, there have been numerous cases of recorded motions and observed earthquake damage pointing towards geometrical and geotechnical amplification as an important effect.

The majority of seismic codes rest on seismic site effects by using one-dimensional (1D) model. This consideration allows measuring the influence of nature and thickness of the sedimentary layer on the vertical propagation of volumetric waves regardless of lateral heterogeneities. The following work aims at quantifying the combined effects of topography and sediments on the site-period evaluation of two-dimensional (2D) sedimentary basins subjected to synthetic SV Ricker waves of vertical incidence.

Wave scattering in 2D configurations are studied with a hybrid numerical method, combining finite elements in the near field and boundary elements in the far field (FEM/BEM). This program has been developed by Gatmiri and his coworkers (Gatmiri and Kamalian 2002, Gatmiri et al. 2008, Gatmiri and Dehghan 2005).

This paper focuses on the variation of site-period of alluvial valleys at different filling ratios and impedance ratios. After specifying the critical points under existence of sediments which are located at the center of valleys (Gatmiri and Foroutan 2012, Gatmiri and Amini 2014, Gatmiri et al. 2015), parametric studies are done on these points, and the site-period are analyzed. Finally, practical curves which are based on the geometrical parameters, filling ratio and impedance ratio are presented for engineering uses.

2 PROBLEM PARAMETERS

2 .1 *Geometrical parameters*

In order to give some noticeable features of sedimentary effects, various examples that cover different 2D curved configurations are presented. The shapes of the studied valleys include elliptic, and sinusoidal. Valleys are characterized by their depth, H and their half width at the surface, L. The sediment depth is characterized by H_1 (See Figure 1 and Figure 2).

Simulations are carried out with depth ratios, H/L, equal to 0.2, 0.4, 0.6, 1. Filling ratios, H_1/H, varies between three values 1/3, 2/3 and 1. The value of L for all of the valleys is kept equal to 100m.

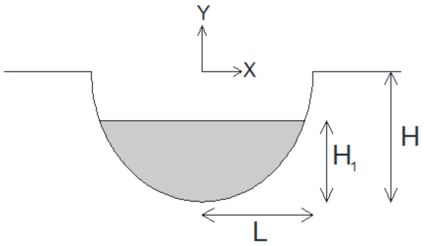


Figure 1. Elliptical Valley Model.

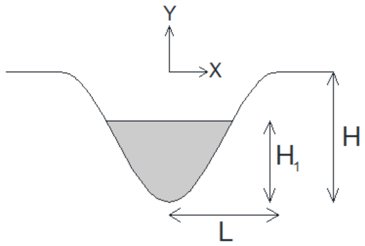


Figure 2. Sinusoidal Valley Model.

2 .2 *Mechanical parameters of materials*

In adopted models, the rocky bed and the alluvial layer are assumed to be dry and homogeneous linear elastic materials. In order to study changes in seismic response of curved valleys according to impedance ratio, site-periods were calculated for different impedance ratios. Material properties are displayed in Table 1. The impedance contrast (β) between sediments and bedrock characterizes the alluvial properties (see Eq. 1). The lower the impedance contrast, the softer the sediments are compared to the bedrock:

$$\beta = \rho_S C_S / \rho_R C_R \tag{1}$$

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 sediment and rock, respectively. The data used as input in this research are the digits and numbers considered for simulation in this program and their practical application calls for assessment of the extent by which they are factual and statistical as well as their sensitivity of results to these parameters, an assessment which is beyond the scope of objectives of this study.

Table 1. Mechanical characteristics.

Parameter	E (MPa)	ν	ρ (Kg/m^3)	C (m/s)	β
Bed Rock	*6720*	*0.4*	*2450*	*1000*	-----
Sediment 1	*3446*	*0.3*	*1630*	*901*	*0.6*
Sediment 1	*1938*	*0.3*	*1630*	*676*	*0.45*
Sediment 1	*861*	*0.3*	*1630*	*450*	*0.3*
Sediment 1	*215*	*0.3*	*1630*	*225*	*0.15*

2 .3 *Incident wave characteristics*

The main focus of this work is the study of the effect of 2D geometrical and geotechnical irregularities on modification of site-period and this study relies on simplified geometrical and geotechnical conditions as seismic loading is considered to be the simplest one; vertically incident SV Ricker wave. Imposed displacements are therefore expressed as Eq. 2.

$$u(t) = A_0 (a^2 - 0.5)\exp(-a^2) \tag{2}$$

Where $a = \pi(t - T_S)/T_P$. Amplification A_0 is constant value of 1; and $T_P = T_S = 0.5$sec. The incident signal lasts 3sec, but it can be seen from Figure 3 that amplitude is nearly zero as soon as it reaches $t = 1$s. That is why the window has been defined from t=0 to t=3s. The predominant frequency f_C is thus equal to 2 Hertz. The width of interval is representative for the study of an eventual lengthening of the seismic response of the site.

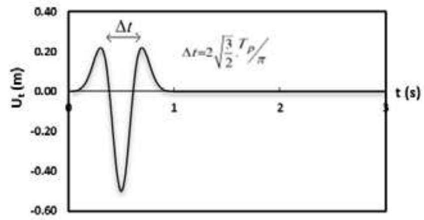


Figure 3. Sinusoidal Valley Model.

3 IMPEDANCE RATIO EFFECT ON SITE PERIOD, T_S

Le pense et al. 2005 studied the seismic response of horizontal soil layers (1D) with various heights and impedance contrasts and proved that when H increases, T_s first increases. If H keeps increasing, for example H=100m, T_s does back to lower periods. They also indicated that when β decreases, T_s increases. An analytical value of T_s as a function of H and β, is obtained, if maximum amplification takes place for the natural period corresponding to the fundamental frequency of soil layer. Eq. 3 was presented for one dimensional models.

$$T_s = \frac{1}{f_0} = \frac{4H}{C_s} = \frac{4\rho_s}{\rho_r C_r}\frac{H}{\beta} \tag{3}$$

The site period for 2D configurations with a significant amplification was studied by Le pense et al. 2005 who defined a criterion that allowed for an estimation of the site period. The evolution of the site period was studied with the parameter $S_1/\beta\sqrt{\beta}$ which combines the soil properties (β) and the geometrical characteristics (S_1). A linear evolution of T_s with $S_1/\beta\sqrt{\beta}$ was observed (see Figure 4). The parameter S_1 is the sediment surface that is shown in Figure 5.

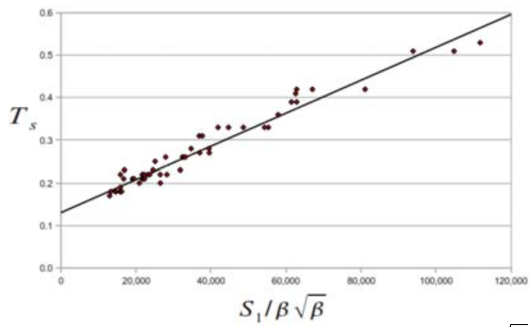
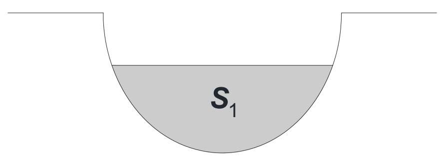


Figure 4. Variation of site period (T_S) as a function of $S_1/\beta\sqrt{\beta}$ (Le pense et al. 2005).

a)



b)

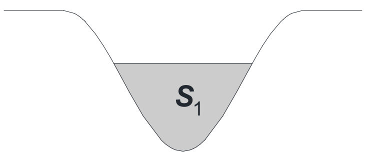


Figure 5. Definition the surface of sediment parameter, a) Elliptical Valley Model, b) Sinusoidal Valley Model.

Geotechnical parameters of sites can significantly affect the site period. Effects of impedance ratio on the site in addition to other geometrical parameters are studied in this section. To assess the impedance ratio effect independently from other variables, the variations of the site period as a function of the impedance ratio are presented separately for each filling ratio in Figures 6-8, each figure is divided into four parts indicating different depth ratios.

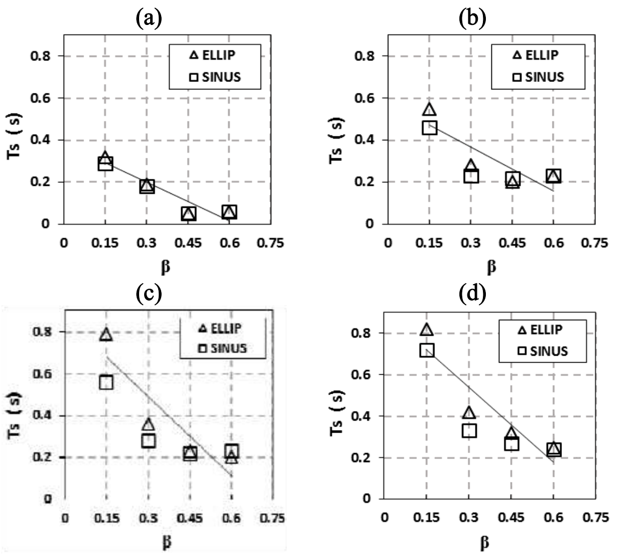


Figure 6. Variation of site period (T_S) as a function of (β) for full valleys, (a) H/L=0.2, (b) H/L=0.4, (c) H/L=0.6, (d) H/L=1.

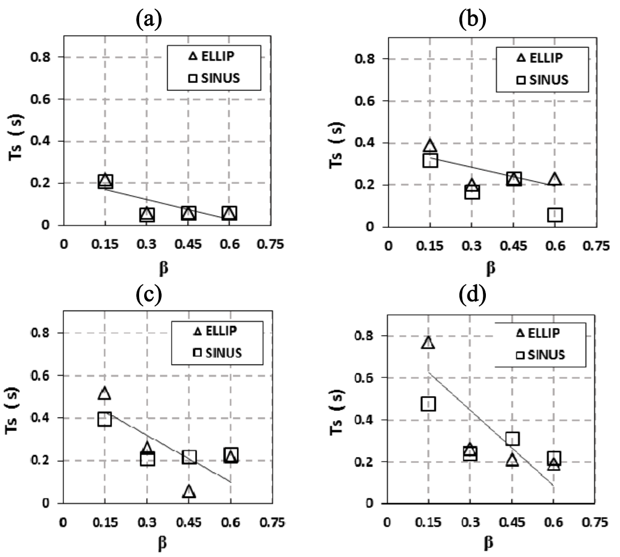


Figure 7. Variation of (T_S) as a function of (β) for valleys with filling ratio 2/3, (a) H/L=0.2, (b) H/L=0.4, (c) H/L=0.6, (d) H/L=1.

The major achieved results are as follows:

1. By increasing the impedance ratio the site period decreases. This observation is true for all shapes of the valley and for all filling ratio.
2. At a constant depth ratio, the rate of the reduction in site period is increased relative to the increase in impedance ratio due to increase in the filling ratio.
3. At a constant filling ratio, the rate of the reduction in site period is increased relative to the increase in impedance ratio due to increase in the depth ratio.
4. No significant changes is seen in the value of T_s for valleys with filling ratio of 1/3.

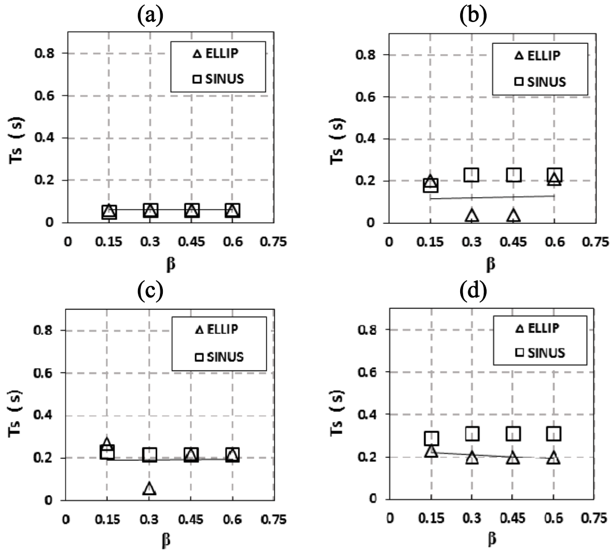


Figure 8. Variation of (T_S) as a function of (β) for valleys with filling ratio 1/3, (a) H/L=0.2, (b) H/L=0.4, (c) H/L=0.6, (d) H/L=1.

As expected, site period has an inverse relationship with impedance ratio. As mentioned by increasing the filling ratio, T_s increases. In a constant depth ratio the surface of sediments, S_1, increases by shifting from valleys with low filling ratio to full valleys. Considering the inverse relationship of the site period and the impedance ratio, the mechanical parameter $1/\beta$ can be multiplied by the geometrical parameter S_1 at the horizontal axis.

In using the sediment surface parameter, another coefficient which represents the depth ratio effect must be used. Thus, the parameter ($H_1/H \times H/L$) or H_1/L can be used in combination with other parameters. (The parameters of H_1/H and H/L indicate filling ratio and depth ratio of alluvial valleys, respectively).

Unique trend as shown in Figure 9 indicates the evolution of the site period variation based on other geometrical and geotechnical characteristics. In order to have a better trend of site period variation, the horizontal axis is considered to be logarithmic. As can be seen, the correlation between $T_s \times H_1/L$, S_1/β is good enough to estimate of the site period of curved alluvial valleys in engineering purposes.

Using this diagram, site-period of the valley based on the results of the center of that for curved valleys can be obtained considering the sediments surface, geometrical dimensions, filling ratio and impedance ratio of alluviums.

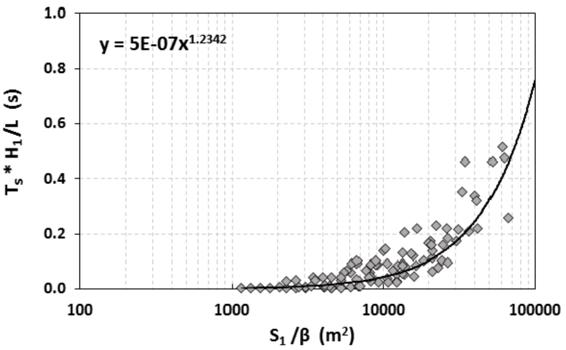


Figure 9. Variation of $T_S * H_1 / L$ as a function of the S_1 / β .

4 CONCLUSION

In this paper new criteria are proposed to determine the predominant site effect at the surface of filled curved valleys subjected to vertically propagating SV wave by means of HYBRID program. In fact, this study provides a simple method to characterize the site-period of two dimensional curved valleys with various geometrical and mechanical characteristics. Valleys have been considered with different depth ratios and filling ratios and various mechanical properties of materials (impedance ratio).

The results indicate that by increasing the impedance ratio the site period decreases. This observation is true for all shapes of the valley and for all filling ratio. It can be said that by increasing the filling ratio, value of site period increases. So at constant depth ratio, full-filled valleys have obtained the maximum value of *Ts*.

When combining the depth ratio, filling ratio and impedance ratio effects on the site period, two parameters S_1/β, $T_s\times H_1/L$ are considered. By increasing S_1/β an ascending trend of parameter $T_s\times H_1/L$ can be seen for curved valleys. As these parameters are obvious, site-period (*Ts*) can be determined. This criterion allows for estimation of the site-period in curved alluvial valleys.

It is obvious that studying real cases with irregular geometries, anisotropic and non-homogeneous material under incidence of realistic seismic signals in 3D through a numerical technique can be a challenging matter. Such studies require large amount of information and data and involve numerical computations which may become very expensive. Still it is an effort to achieve the goal that the building codes consider the site effects as 2D or 3D problems. However, the results could be used in geo-seismic micro-zoning studies.

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