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EFFECT OF TOPOGRAPHICAL IRREGULARITIES ON SEISMIC EARTHQUAKE RESPONSE OF CONSTRUCTION SITE – 2D NUMERICAL ANALYSIS OF TRAPEZOIDAL VALLEY UNDER REAL MOTION

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ABSTRACT

Documented observation of destruction distribution after seismic events suggest to topography effects on earthquake intensity. But there exist very few –if any- well documented case studies where topography effects are illustrated for strong ground motion. This is due to complex nature of seismic scattered wave by topographical structures to medium. Although some empirical correlations, obtained from statistical analyses, were proposed in different studies to consider this issue, but these correlations also may not be applicable in general or may be overestimation of what happen in reality. These difficulties and disadvantages can only be solved accurately, economically and under realistic conditions by advanced numerical methods. In this paper a powerful FE program (PLAXIS v.8.2) applied to carry out site response analysis of two dimensional topographic structures (trapezoidal non-alluvium valley) subjected to an earthquake (Manjil earthquake, IRAN, 1990). The applicability and efficiency of the program have been verified through some examples of site response analysis that their solutions are available in literature. At last, the results have been diagramed.

INTRODUCTION

After destructive earthquakes occurring in mountain areas, for example the 1995 Kozani earthquakes in Greece, buildings located at the top of cliffs or hills suffer much more intensive damage than those located at the base. Based on same prior observations (Irpinia ITALY 1980, Mexico 1998, ...), nowadays, it is well-established that surface topography can have crucial influences on damage severity and its spatial distribution during strong earthquakes.

Investigation of seismic waves scattering by topographical structures is example problem which can only be solved accurately and economically by numerical methods under realistic condition. This problem has been the subject of numerous studies e. g., seed and Idriss (1967), Kovacs (1971), Trifunac (1973), Celebi (1987), Geli (1988), Zhang (1991), Sanchez-Sesma (1995), Athanasopoulos (1999), Kamalian (2001), Havenith(2002), Lokmer (2002), Paolucci(2002), Papalou and Bielak (2004), Boucovalas and Papadimitriou (2005), semblate (2005), Assimaki (2005), Timus (2006) and Psarropoulos (2007).

Numerical methods have restrictions and abilities. However, the hybrid type techniques, which combine the effective characteristic of two or more methods, have been proven, but they also have difficulties in implementation and programming. Notwithstanding the restrictions of numerical techniques, their utilization as existing instrument is inevitable in engineering complex applications.

FEM is very powerful numerical method in solving problems with bounded domains, particularly when in homogeneities and nonlinear effects should be treated; but it has limitation in finite dynamic modeling for infinite media. For domains of infinite extensions, standard Finite elements discretization leads to wave reflections at the edges of the FE mesh which can be only party eliminated for some cases by using so-called transmitting, silent, non-reflecting viscous and absorbent boundaries (Lysmer and Kuhlemeyer, 1969; White et al, 1977).

Idriss and Seed (1968) evaluated seismic response of earth bank with finite element method, Kovaks et al. (1970)

Performed laboratory shaking table experiments on clay banks and compared results with Idriss and Seed (1968) studies. They concluded the Physical model results agreed favorably with the FE analyses.

Sincraian & Oliveira (2001) had sensitivity study on the dynamic behavior of a volcanic hill and comparison with 1-D and 3-D FE models but could not find a good fit between field measurements and analytical results.

Despite aforementioned limitations of FEM, dynamic FE analyses can be considered the most complete available instrument for the prediction of the seismic response of geotechnical systems, since they can give detailed indication of both the soil stress distribution and deformation. However, finite element models require to be calibrated in order to obtain a realistic response of the given system subjected to seismic loading. Hence, Plaxis 2D v.8.2 (Brinkgreve, 2002) that includes the dynamic module was selected in this research. Plaxis v.8.2 is two dimensional FE computer program for the analysis of deformation and stability in geotechnical engineering projects. This is simple and quick than the same programs.

This paper evaluated the effects of topographical conditions on seismic response of constructions site by using Plaxis. Analyses of free field motion of a linear elastic half plane subjected to Incident SV wave and earthquake separately and semi-circular valley subjected to SV wave are carried out to illustrate the applicability and efficiency of the technique. Then, the trapezoidal valleys subjected to earthquake were parametrically analyzed to show the topography role in site response. All cases were considered as a layered system. Finally, results have been presented.

NUMERICAL MODELING

Verification of Program

There are very few documents which used Plaxis for site effects analyses (Davoodi and akbari, 2007; Sigaran-Loria and Hack, 2007; Visone et al, 2008). In three following sections, the verification of the program is shown. These schemes were chosen because the solutions of the problems are available in literature and some comparisons can be easily done.

Free Field Motion of Half-Plane Subjected to Incident SV Wave of Ricker Type. We analyzed the site response of a linear elastic, homogeneous half-plane, which is considered as a layered system, subjected to vertical propagating incident SV wave of the Ricker type:

$$F(t) = A_{max}\,[1-2(\pi f_p (t-t_0))^2]\, e^{-(\pi f_p(t-t_0))^2} \quad (1)$$

f_p, t_0 and A_{max} denote the predominant frequency, the time shift parameter of time history and maximum amplitude of the time history which are chosen to be 2.5 HZ, 0.4 sec and 0.001m, respectively.

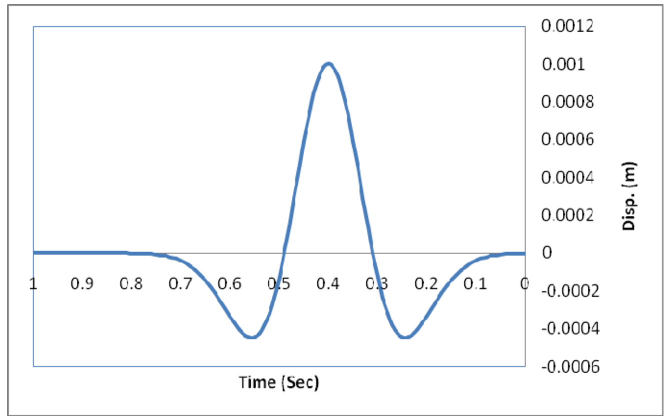

Fig.1. Displacement time history of the incident wave of Ricker type used in analysis.

The finite element model and material properties of the layer are plotted in Fig. 2 and Table 1, respectively.

The geometry model is constituted by a rectangular domain 1000m wide and 70 m height. In order to detract the influence of excess scattered waves from boundaries to medium the lateral boundaries placed far enough (even though no clear indications exist in literature on this aspect), as well as, the absorbent boundaries are employed.

The initial stress generation is obtained by the k_0-procedure in which the value of the earth pressure at rest, k_0 is chosen by means of the well-known formula for the elastic medium:

$$K_0 = \nu/(1-\nu) = 0.389 \quad (2)$$

For accurate representation of wave transmitted in the model, the element sizes should be selected small enough to satisfy the following criteria expressed by Kuhlemeyer and Lysmer (1973):

$$L_e \leq \lambda/8 \quad (3)$$

Where λ is the wave length associated with the highest frequency component that contains appreciable energy and L_e is the length of element.

In this case, the average element size (AES) has been selected about 10m, though it could be selected greater value.
The 15-node triangular elements are employed.

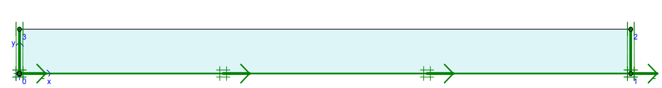

Fig. 2. The model utilized in FE dynamic analysis

Table 1. Material Properties of the Layer

Material Model	Linear Elastic
γ (KN/m^3)	15.5
E (KN/m^2)	5.31×10^5
ν	0.28
V_s (m/s)	362.1

Figure 3 shows the horizontal and vertical displacement time histories calculated at the ground surface. As expected, there exists good agreement between obtained results and analytical solution. The Total horizontal displacement is equal to twice the incident motion and the total vertical displacements are equal to zero.

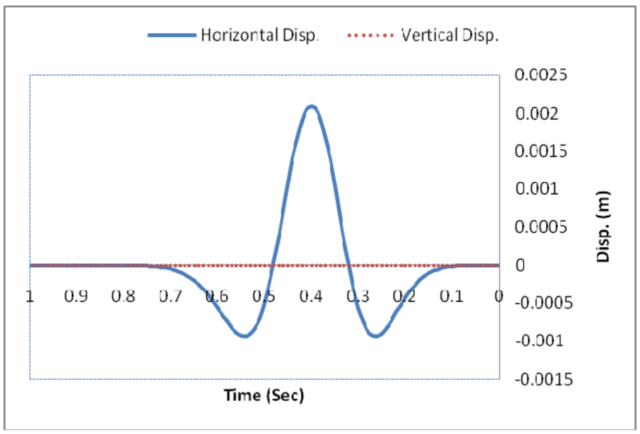

Fig. 3. Horizontal and vertical displacement time histories at surface of the half-plane

Free field motion of half-plane subjected to earthquake. Here, the model with the similar material and geometry to illustrated model in previous section (as plotted in Fig. 2 and Table 1) is subjected to real ground motion.

Also, the AES has been selected about 5m.

The imposed earthquake was registered at AB-Bar station (Manjil earthquake, IRAN, 1990). The sampling frequency, duration and peak acceleration are 200HZ, 53 sec and 5.82m/s^2, respectively. The baseline corrected and filtered signals are used for input motion.

The result explained in frequency domain (see Fig.4). The predominant frequency is very close to the expected theoretical value (Rosset, 1970):

$$A.F= 1/ \sqrt{(\cos^2 ((2\pi. H/V_s). f_n) + ((2\pi. H. D/V_s).f_n))} \qquad (4)$$

Where,
A.F: the amplification function;
H: layer thickness;
V_s: shear wave velocity;
D: material damping (Here, D=5%) and
f_n: nth natural frequency of the layer = V_s /4H (2n-1).

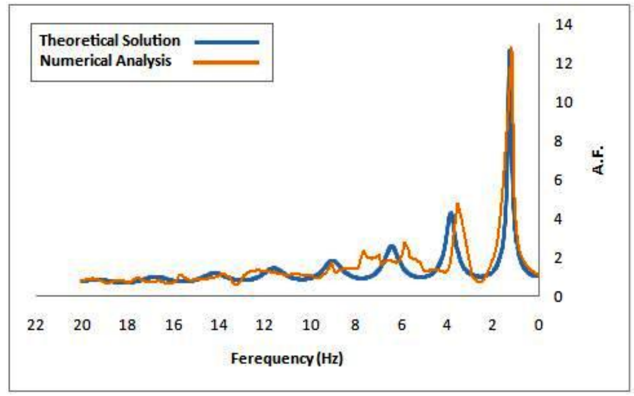

Fig. 4. Earthquake seismic response of free space in frequency domain

semi-circular non-alluvial valley subjected to incident SV wave of Ricker type. Figure 5 shows a semi-circular non-alluvial valley subjected to vertically propagating SV wave of the Ricker type. This problem was studied by Dravinski and Mossessian (1987).

The material properties and inputted motion are similar to what that explained in former section (as plotted in Fig. 1 and Table 1).

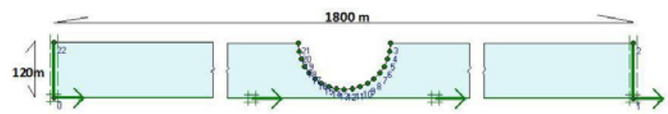

Fig. 5. The FE model of semi-circular valley (Width=1800m, Height=120m, Radius of Valley=100m)

Figure 6 compares the numerical result with those obtained by Dravinski and Mossessian (1987). The acceptable agreement exists, too.

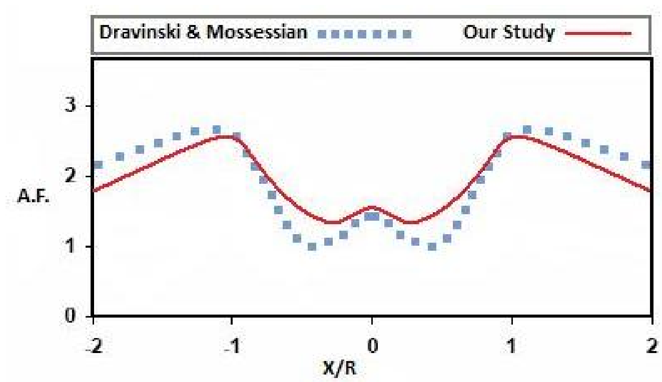

Fig. 6. Comparison between amplification of surface Horizontal displacement, obtained by FE analysis and Dravinski and Mossessian (1987)

Topographic site under earthquake

Very few numerical studies exist that investigated site effects, especially topography effects, under the real strong ground motion (Sigaran-Loria and Hack, 2007; Visone et al, 2008).

With reference to mentioned in foregoing, it can be concluded that Plaxis v.8.2 is acceptable computer program for dynamic analyses of irregular site under the earthquake.

In this section, in order to evaluation of topography effects and its shapes on seismic response of site, numerical parametric analyses on trapezoidal shaped valley (non-alluvial) under Manjil earthquake (Iran, 1990) have been done (by using Plaxis v.8.2). Geometrical parameters, 2D FE model, material properties and geometrical ratios have been shown in Fig. 7, Fig. 8, Table 2 and Table 3, respectively.

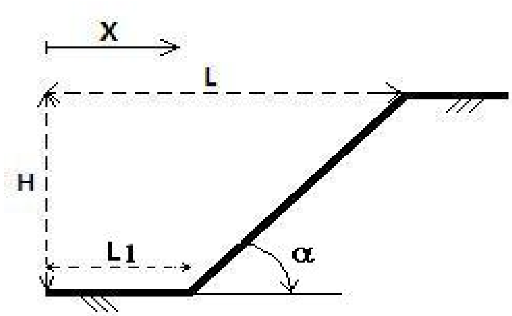

Fig. 7. Geometrical parameters of studied model

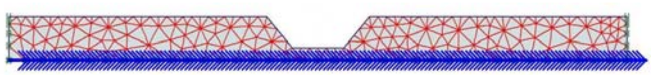

Fig. 8. 2D FE model used in dynamic analysis

As observed in Fig. 8, the model dimension no indicated, since the model dimensions vary by valley size and there is not any specific ratio between them. The model dimensions are obtained after some sensitivity analysis for each valley size.

Table 2. Material Properties of Trapezoidal Valley

Material Model	Linear Elastic
γ (KN/m^3)	27.1
E (KN/m^2)	7×10^6
ν	0.25
V_s (m/s)	1006

The material used here only consist of a dry rock mass and are not took alluvial layers situation into account to investigate geometrical shape effect of valleys, clearly.

Two series of model with different height of valley (H=50m, 100 m) analyzed. Other parameters obtained from following ratios:

Table3. Ratios between Parameters

L1/L	H/L		
	0.2	0.6	1
0	α=11.31°	30.96°	45°
0.25	14.93°	38.66°	53.13°
0.5	21.8°	50.19°	63.43°
0.75	38.66°	67.38°	75.96°

Finally, the results are diagrammed in terms of shape ratio (H/L), dimensionless distance (X/L), ratio of bottom length to crest length (L1/L) and amplification factor (see Fig. 9):

$$A.F. = PGA_x(\text{valley}) / PGA_x(\text{free field}) \quad (5)$$

Where,
(A.F.): Amplification factor;
PGA_x(valley): Peak ground horizontal acceleration across valley;
PGA_x(free field): Peak ground horizontal acceleration on free field.

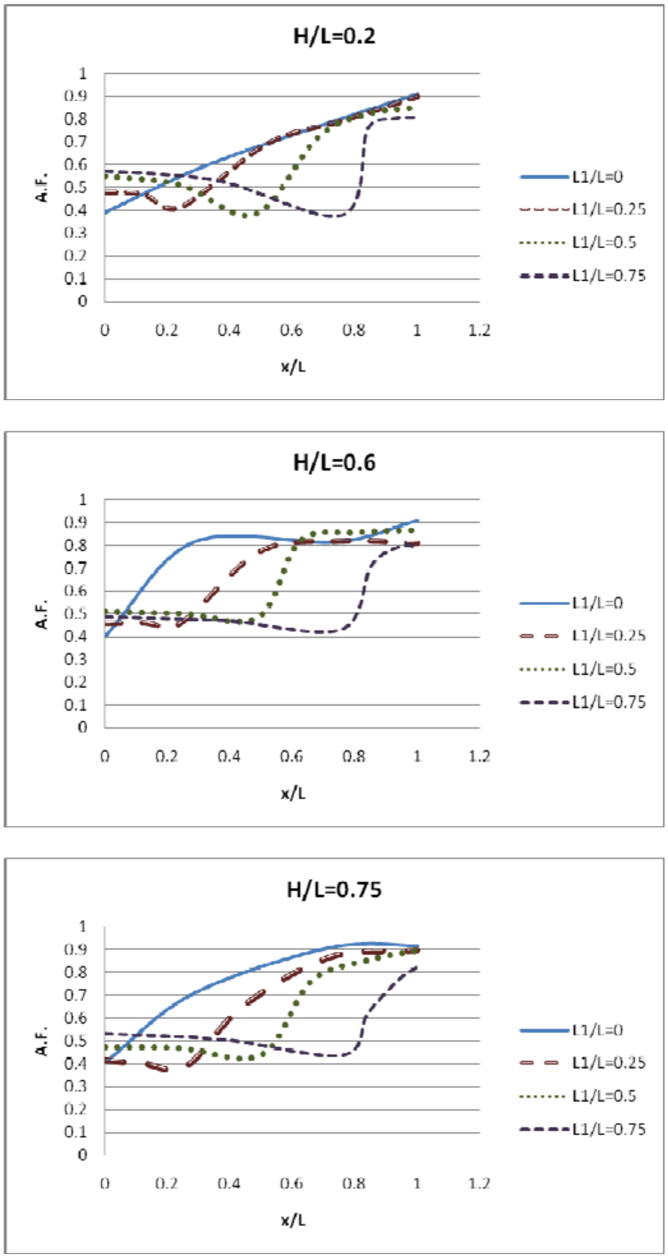

Fig. 9. Results of numerical analysis of trapezoidal valley

CONCLUSION

In this paper, a powerful FE program applied to carry out site response analysis of two-dimensional topographic structures subjected to earthquake.

Here, the applicability and efficiency of PLAXIS v.8.2 have been demonstrated through some examples of site response analysis, including half-plan subjected to incident SV wave and earthquake and semi-circular valley subjected to incident SV wave. Then, this program used in performing site response parametric analysis of trapezoidal valley structures. Numerical results show this computer code is very powerful, user friendly and time-saving than other different presented hybrid algorithms, which have particularly been programmed for this problem and unable to consider the real ground motion and nonlinear behavior of material for practical engineering projects.

Numerical analyses of trapezoidal non-alluvium valleys show that slopes of valleys are critical regions during earthquake. The response intensity increasingly varies of minimum amplification value at the toe to maximum amplification value at the crest of slope. Also, shape of valley further influence in seismic response of slopes.

REFERENCES

Ambraseys N.N., [1960]. *"On the Shear Response of a Two Dimensional Wedge Subjected to an Arbitrary Disturbance"*, Bul. Seismol., Vol. 50, 45-56

Assimaki D., E. Kausel, G. Gazetas, [2004]. *"Topography effects in the 1999 Athens earthquake: engineering issues in seismology"*, Proc. 11th ICSDEE and 3rd ICEGE, UC Berkeley, January, 7-9, 2, 31-38

Athanasopoulus G.A., P.C. Pelekis, E.A. Leonidou, [1999]. *"Effects of surface topography on seismic ground response in the Egion (Greece) 15 June 1995 earthquake"*, Soil Dynamics and Earthquake Engineering, 18: 135-149

Bouchon M., J.S. Barker, [1996]. *"Seismic response of a hill: The example of Tarzana, California"*, Bul. Seismol., 86(1A): 66-72

Bouckovalas G.D., A.G. Papadimitriou, [2005]. *"Numerical evaluation of slope topography effects on seismic ground motion"*, Soil Dynamics and Earthquake Engineering, 25: 547-558

Brinkgreve R.B.J., [2002], *"Plaxis 2D version8"*, A.A. Balkema Publisher, Lisse

Celebi M., [1987]. *"Topographical and geological amplifications determined from strong-motion and aftershocks records of the 3 march 1985 Chile earthquake"*, Bul Seismol, 77, 1147-1167

Dravinski M., T.K. Mossessian, [1987]. *"Scattering of plane harmonic P, SV, and Reyleigh waves by dipping layers of arbitrary shape"*, Bull. Seismol. Soc. Am., 77, 212–235

Geli L., P.Y. Bard, B. Jullien, [1988]. *"The effect of topography on earthquake ground motion: A review and new results"*, Bul. Seismol, 78: 42-63

Havenith H.B., D. Jongmans, E. Faccioli, K. Abdrakhmatov, P.Y. Bard, [2002]. *"Site effect analysis around the seismically induced Ananevo rockslide, Kyrgyzstan"*, Bul. Seismol, 92(8): 3190-3209

Idriss I.M., H.B. Seed, [1967]. *"Response of earthbanks during earthquakes"*, J. Soil Mech. Found. Div. ASCE, 93(SM3), 61-82

Idriss I.M., [1968]. *"Finite element analysis for the seismic response of earth banks"*. J. Soil Mech. Found. Div. ASCE, 94(SM3)

Kovacs W.D., et al., [1971]. *"Studies of seismic response of clay banks"*, J. Soil Mech. Found. Div. ASCE, 97(SM2)

Kuhlmeyer R.L, J. Lysmer, [1973]. *"Finite Element Method Accuracy for Wave Propagation Problems "*, J. Soil Mech. & Found. Div., vol.99 n.5, 421-427

Kamalian M., M.K. Jafari, A. Sohrabi-bidar, A. Razmkhah, B. Gatmiri, [2006]. *"Time-domain two-dimensional site response analysis of non-homogeneous topographic structures by a hybrid BE/FE method"*, J. soil dynamic & earthquake Eng., Elsevier, 753-765

Lokmer I., M. Herak, G.F. Panza, F. Vaccari, [2002]. *"Amplification of strong ground motion in the city of Zagreb, Croatia, estimated by computation of synthetic seismograms"*, Soil Dynamics & Earthquake Eng., 22:105-113

Lysmer J., R.L. Kuhlmeyer, [1969]. *"Finite Dynamic Model for Infinite Media"*, ASCE, J. Eng. Mech. Div., 859-877

Paolucci R., [2002]. *"Amplification of earthquake ground motion by steep topographic irregularities"*, Earthquake Engineering & Structural Dynamics, 31:1831-1853

Papalou A., J. Bielak, [2004]. *"Nonlinear seismic response of earth dams with canyon interaction"*, J. Geotechnical & Geoenvironmental Eng., ASCE, January: 103-110

Psarropoulos P.N., Y. Tsompanakis, Y. Karabatsos, [2007]. *"Effects of local site conditions on the seismic response of municipal solid waste landfills"*, Soil Dynamics & Earthquake Eng., 27: 553-563

Roesset J.M., [1977]. *"Soil Amplification of Earthquakes, Numerical Methods in Geotechnical Engineering"*, Chapter 19, [Ed. Desai C.S., J.T. Christian], McGraw-Hill, 639-682

Semblat J.F., M. Kham, E. Parara, P.Y. Bard, K. Pitilakis, K. Makra, D. Raptakis, [2005]. *"Seismic wave amplification: Basin geometry vs soil layering"*, Soil Dynamics & Earthquake Eng., 25: 529-538

Sigaran-Loria C., H.R.G.K. Hack, [2007]. *"Verification of two-dimensional numerical earthquake site effects on a dam site, Costa Rica"*, Proc. 11th Congress of the International Society for Rock Mechanics: The Second Half Century of Rock Mechanics. Taylor & Francis/ Balkema, Leiden, 1203-1207

Sincraian M.V., C.S. Oliveira, [2001]. *"A 2-D sensitivity study of the dynamic behavior of a volcanic hill in the Azores Islands: Comparison with 1-D and 3-D models*", Pure and Applied Geophysics, 158: 2431-2450

Thimus, J.F., P. Delvosal, S. Waltener, C. Schroeder, N. Boukpeti, [2006]. *"Analysis of seismic wave propagation in soils"*, In P. Verona & R. Hart (eds.), FLAC and Numerical Modeling in Geomechanics, Proc. 4th International FLAC Symposium, 29-31: 181-186

Trifunac M.D., [1973]. "Scattering of plane SH-waves by a semi-cyliderical canyon", Earth. Eng. andstruct. Dyn. , 1, 267-281

Visone C., E. Billota, F. Santucci de Magistris, [2008]. *"Remarks on site response analysis by using Plaxis dynamic module, Plaxis Bulletin"*, issue 23, 14-18

White W., S. Valliappan, I.K. Lee, [1977]. *"Unified boundary for finite dynamic models"*, J. Eng. Mech. ASCE, 964-969

Wolf J.P., [1985]. *"Dynamic soil-structure interaction"*, Prentice Hall, Englewood Cliffs, NJ

Zhang L., A. K. Chopra, [1991]. *"Three-Dimensional Analysis of spatially varying ground motions around a uniform canyon in a homogeneous half-space"*, Earth. Eng. and Struc. Dyn., 20