

EFFECT OF BASIN EDGE SLOPE ON THE DYNAMIC RESPONSE OF SOIL DEPOSITS

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ABSTRACT

Effects of basin edge slope on the dynamic response of horizontal soil deposits are investigated by using one-dimensional and two-dimensional numerical analyses which incorporate the non linear stress strain behavior of soils by equivalent linear method. For this purpose, 24 basin models having trapezoidal cross section are generated to represent different geometries (i.e. depth of basin, slope of basin edge). A relatively “soft” and a “stiff” soil profile are used to identify the effect of the soil type. Harmonic base motions having a maximum acceleration of 0.15g with different predominant periods (T_p) are used in the analyses. Effect of basin edge slope is assessed by the ratio $PGA_{(2D)}/PGA_{(Rock)}$ which is essentially a dimensionless soil amplification ratio. In order to make a comparison between the results of one-dimensional and two-dimensional analysis, $PGA_{(2D)}/PGA_{(1D)}$ is defined which is also a dimensionless ratio. For a given ratio of natural period of site to the predominant period of ground motion, (T_n/T_p), general behavior is almost the same for different soil types, basin depths and base motions, provided that the basins have the same basin edge slope angle, α . On the other hand, it is found that keeping T_n/T_p constant, the ratio $PGA_{(2D)}/PGA_{(1D)}$ increases within the inclined basin and approaches to 1 with decreasing basin edge slope. For a constant value of (T_n/T_p), it is observed that the ratio $PGA_{(2D)}/PGA_{(rock)}$ increases within the inclined basin with decreasing basin edge slope. The increase in the “amplification” is smooth in basins with gentle slopes as compared to the basins with steep slopes. It is also observed that, the critical region where maximum amplification is observed usually falls in the normalized distance range of 0.8 to 1.4. One-dimensional response analysis predictions are concluded to be conservative by a factor of as low as 0.30 in the slopping edge region, however, beyond this region, one-dimensional analysis results are unconservatively biased by a factor as high as 1.2. For a basin and earthquake couple approaching to resonance state ($T_n/T_p=1$), the PGA predictions by two-dimensional analysis are found to be as high as 40% as one-dimensional analysis results. The critical region where one-dimensional results are found to be unconservative falls again in the normalized distance range of 0.8 to 1.4.

Keywords: *Basin Edge Effect, Dynamic Site Response, Two-Dimensional Analysis, One-Dimensional Analysis, Soil Amplification, Harmonic Base Motion*

INTRODUCTION

The basin/basin-edge topography may have significant effects on the general characteristics of strong ground motion. Damage patterns during 1994 Northridge earthquake have demonstrated the importance of basin effects. One-dimensional and two-dimensional modeling studies were performed

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to understand the mechanism by which geologic structure could affect amplification levels. Chang (1996) attempted to simplify two-dimensional seismic basin response by series of one-dimensional ground response analyses and concluded that one-dimensional simplifications don't produce consistent predictions. Graves et al. (1998) numerically studied basin edge problem and found large amplifications, consistent with field observations.

Bard and Gariel (1986) used an analytical approach to study the two-dimensional response of shallow and deep alluvial basins. One-dimensional and two-dimensional amplification functions at the center of the shallow, flat valley were quite similar, which indicates that one-dimensional analyses would be appropriate for that region. However, closer to the edge of the valley, the amplification functions were found to be considerably different. For the deep valley, the agreement between one-dimensional and two-dimensional amplification functions was much better at the center of the valley than by the edges. A similar trend was not reported for the shallow valley case.

The seismic response of alluvial valleys was studied by Rassem et al. (1997). Three engineering models were developed as part of their analyses. The models were based on one-dimensional, two-dimensional and frame model approaches. The parameters for which the response is investigated include the valley dimensions and geometry, site location, soil type and input rock motion. The geometric parameters are shown in Figure 1. Results show that these parameters may have significant effects on soil response. For narrow and deep valleys ($B/D < 10$), the response approximation provided by one-dimensional analysis underestimates the response predictions in the middle of the deep valley. The only sites, where one-dimensional analysis succeeds in approximating the response of the two-dimensional model are those located near or at the center of wide or shallow valleys ($B/D \geq 10$).

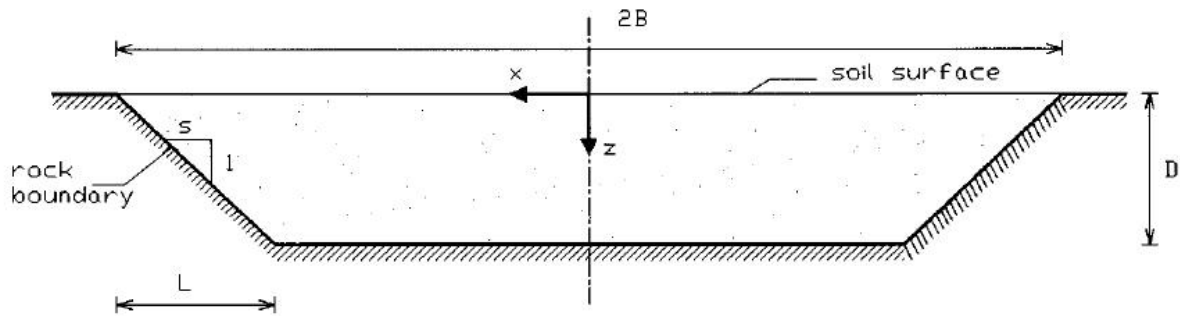


Figure 1: The valley geometry (Rassem et al. 1997)

The aim of this study is to assess the effects of the basin edge slope on the dynamic response of horizontal soil deposits by using one-dimensional and two-dimensional numerical models capable of incorporating the non linear stress strain behavior of soils through utilizing equivalent linear method. One-dimensional approach is based on the assumption that the main response in soil is due to vertical propagation of shear waves from the underlying bedrock. SHAKE91 software is used to analyze one-dimensional response. A finite-element computer code QUAD4M is employed for two-dimensional response evaluation. For the analyses, 24 models are developed to represent different geometries (i.e. depth of basin, slope of basin edge) and soil type. Harmonic base excitations with different periods are used in the analyses, with a maximum acceleration of 0.15g. Effect of basin topography is investigated by the amplification ratio, $PGA_{(2D)}/PGA_{(Rock)}$, defined as the ratio of PGA_{soil} estimated by two-dimensional analysis to PGA_{rock} . In order to make a comparison between the results of one-dimensional and two-dimensional analyses, $PGA_{(2D)}/PGA_{(1D)}$ is defined as a dimensionless ratio. Using the results of these analyses, the main parameters governing the variations of seismic motions in alluvial valley are investigated.

OVERVIEW OF BASIN EDGE MODELS

The subject model is a valley of trapezoidal cross-section with different dimensions, from wide and shallow to narrow and deep, along with different slopes of rock boundary. During the analyses, 24 different models were used. In these models the soil continuum is assumed to consist of horizontal layers, each of which is homogeneous and isotropic. Relatively soft and stiff soil profiles are considered in the models in order to identify the effect of soil type on the response. The utilized harmonic base motions are synthetic with sinusoidal shape and have periods ranging from 0.12sec to 1.00sec with a maximum acceleration of 0.15g.

Geometry of the Model

The trapezoidal geometry of the model is presented in Figure 2 and related dimensions of each model are given in Table 1. Mainly there are three groups with basin depths of 40m, 80m and 120m respectively. For each group the basin edge slope is varying between 9 and 76 degrees.

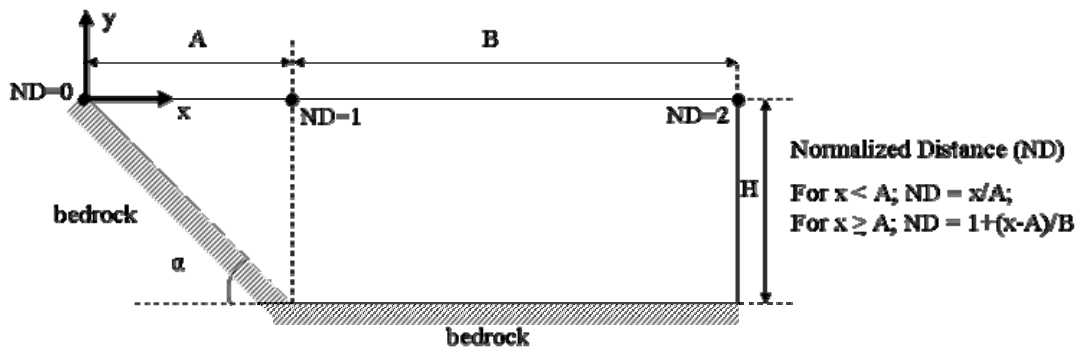


Figure 2: Geometric parameters of the trapezoidal models

Table 1: Geometric dimensions of models.

MODEL NO	α (degree)	A (m)	MODEL NO	α (degree)	A (m)	MODEL NO	α (degree)	A (m)
H=120m & B=500m			H=80m & B=500m			H=40m & B=500m		
1	76	30	9	76	20	17	76	10
2	63	60	10	63	40	18	63	20
3	53	90	11	53	60	19	53	30
4	45	120	12	45	80	20	45	40
5	34	180	13	34	120	21	34	60
6	27	240	14	27	160	22	27	80
7	14	480	15	14	320	23	14	160
8	9	720	16	9	480	24	9	240

Input Soil Properties

Soil type for the basin is selected as clay. For clay, the modulus degradation curve proposed by Idriss (1990) and Seed and Sun (1989) and a damping curve proposed by Idriss (1990) is used as shown in Figure 3. Figure 4 depicts the shear modulus at low strains ($\gamma < 10^{-4}$ %) assumed for relatively soft and stiff clay profiles.

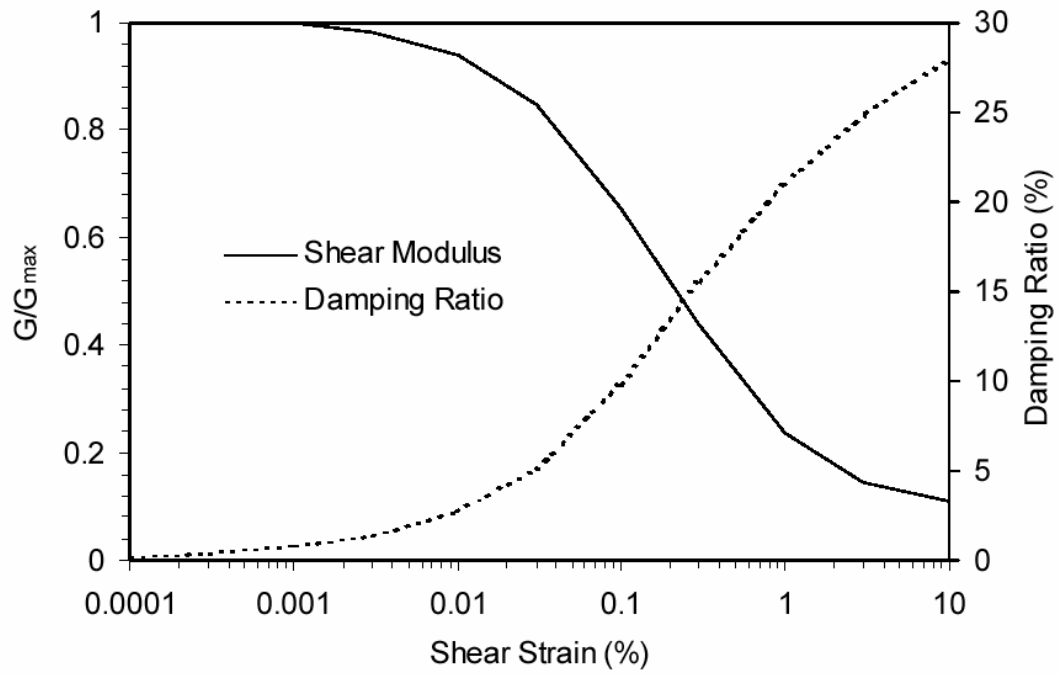


Figure 3: Modulus reduction and damping ratio curves

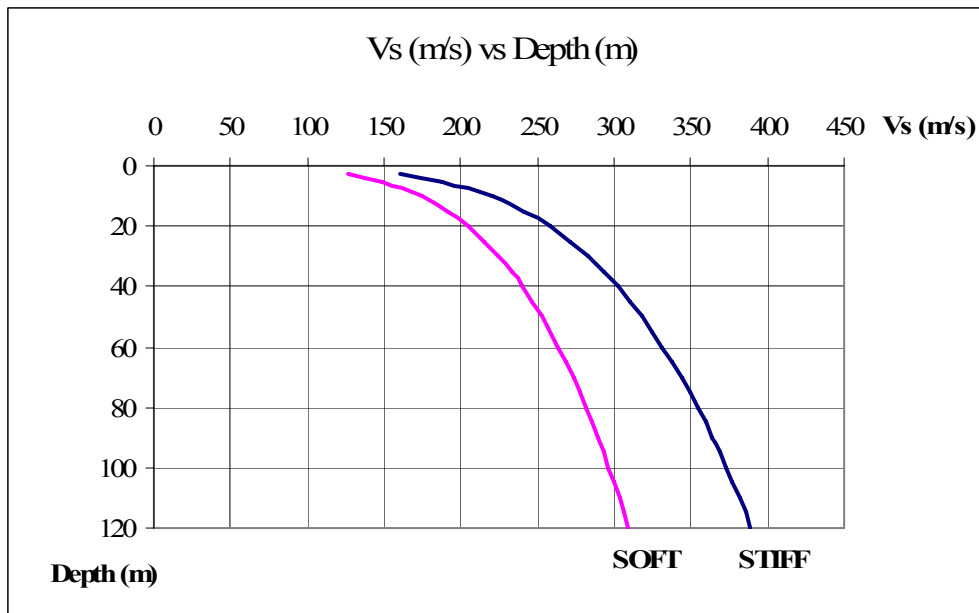


Figure 4: Variation of shear wave velocity with depth for relatively soft and stiff clay

The small strain dynamic shear modulus, G_{\max} , can be expressed in terms of shear wave velocity, V_s , total unit weight of soil, γ_t , and gravitational acceleration, g , as

$$G_{\max} = (V_s^2 \cdot \gamma_t) / g \quad (1)$$

Total unit weight of the soil was taken as 20kN/m³.

Input Motion Characteristics

The characteristics of harmonic base motions used with periods varying between 0.12sec and 1.00sec with a maximum acceleration of 0.15g are indicated in Table 2.

Table 2: Characteristics of harmonic base motions

HARMONIC S	PGA (g)	Predominant Period Tp (s)	Δt (s)	# data points
S-012	0.15	0.12	0.01	2000
S-032	0.15	0.32	0.01	2000
S-052	0.15	0.52	0.01	2000
S-072	0.15	0.72	0.01	2000
S-100	0.15	1.00	0.01	2000

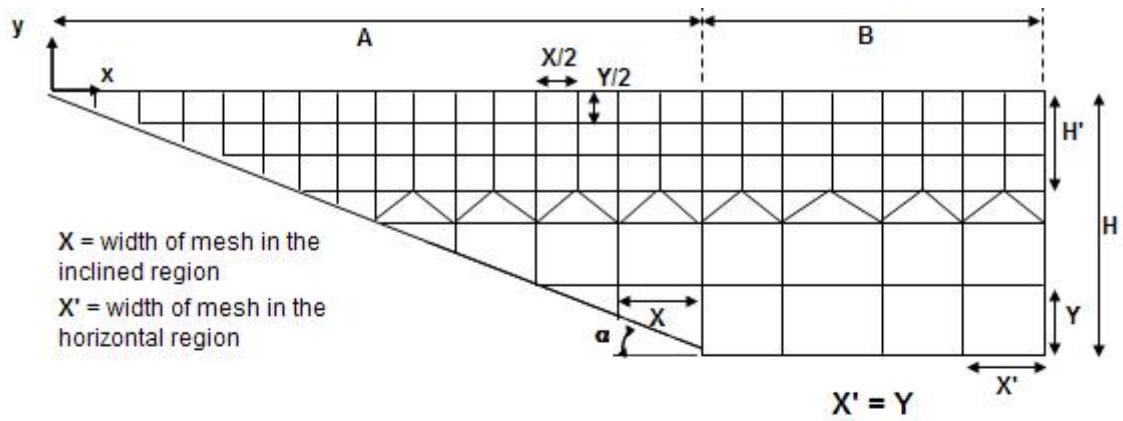
Finite Element Model

The lateral boundary of the models beyond the slope of bedrock is established so as to detect the extent and variation of the effect of buried topography on the ground motion. To determine the dimensioning of the finite element mesh a series of amplification studies on soil columns of the representative profiles are performed by program QUAD4M and SHAKE91. In these studies, a single column of rectangular elements is used to represent the soil layers in the free field. All nodal points are constrained such that they can move only in the horizontal direction. The vertical dimensions of the elements are adjusted, so that the model will simulate the vertical propagation of shear waves in the free field in good agreement with SHAKE91.

The computed response is less sensitive to the choice of the horizontal mesh size. So, in some of the models, horizontal mesh dimensions are taken larger than the vertical mesh dimensions. Finite element mesh is given in Figure 5.

The bedrock is assumed to be infinitely rigid and that the input motion is uniform and in phase on the whole sediment/bedrock interface. For the vertical boundary on the alluvial plain, nodal points are constrained such that they can move in the horizontal direction only.

Soil is modeled by constant strain isoparametric solid elements with 4-node quadrilateral and 3-node triangular shapes.



MODEL NO	α (degree)	A (m)	B (m)	H (m)	H' (m)	X/2 (m)	Y/2 (m)	# nodes	# elements	Output interval in A	Output interval in B
1	76	30	500	120	37.5	2.500	2.500	5141	5112	2.500	2.500
2	63	60	500	120	37.5	2.500	2.500	5333	5308	2.500	2.500
3	53	90	500	120	37.5	1.875	2.500	5717	5700	1.875	2.500
4	45	120	500	120	37.5	2.500	2.500	5717	5700	2.500	2.500
5	34	180	500	120	37.5	3.750	2.500	5717	5700	3.750	2.500
6	27	240	500	120	37.5	2.500	2.500	6533	6500	2.500	2.500
7	14	480	500	120	37.5	2.500	2.500	8165	8100	2.500	2.500
8	9	720	500	120	37.5	3.750	2.500	8165	8100	3.750	2.500
9	76	20	500	80	37.5	2.500	2.500	4241	4218	2.500	2.500
10	63	40	500	80	37.5	2.500	2.500	4345	4324	2.500	2.500
11	53	60	500	80	37.5	1.875	2.500	4553	4536	1.875	2.500
12	45	80	500	80	37.5	2.500	2.500	4553	4536	2.500	2.500
13	34	120	500	80	37.5	3.750	2.500	4553	4536	3.750	2.500
14	27	160	500	80	37.5	2.500	2.500	5005	4972	2.500	2.500
15	14	320	500	80	37.5	2.500	2.500	5909	5844	2.500	2.500
16	9	480	500	80	37.5	3.750	2.500	5909	5844	3.750	2.500
17	76	10	500	40	37.5	2.500	2.500	3357	3340	2.500	2.500
18	63	20	500	40	37.5	2.500	2.500	3389	3372	2.500	2.500
19	53	30	500	40	37.5	1.875	2.500	3453	3436	1.875	2.500
20	45	40	500	40	37.5	2.500	2.500	3453	3436	2.500	2.500
21	34	60	500	40	37.5	3.750	2.500	3453	3436	3.750	2.500
22	27	80	500	40	37.5	2.500	2.500	3605	3572	2.500	2.500
23	14	160	500	40	37.5	2.500	2.500	3909	3844	2.500	2.500
24	9	240	500	40	37.5	3.750	2.500	3909	3844	3.750	2.500

Figure 5: The details of the mesh for each model.

An example acceleration time history computed by QUAD4M at the surface of the selected soil profile (Model 7, node number 1157) for harmonic base motion (S-052) is presented in Figure 6.

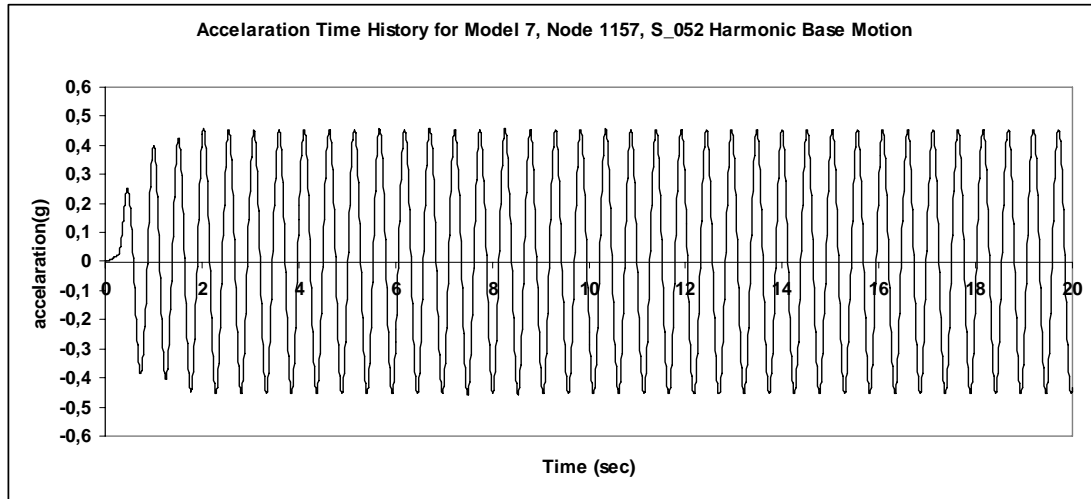
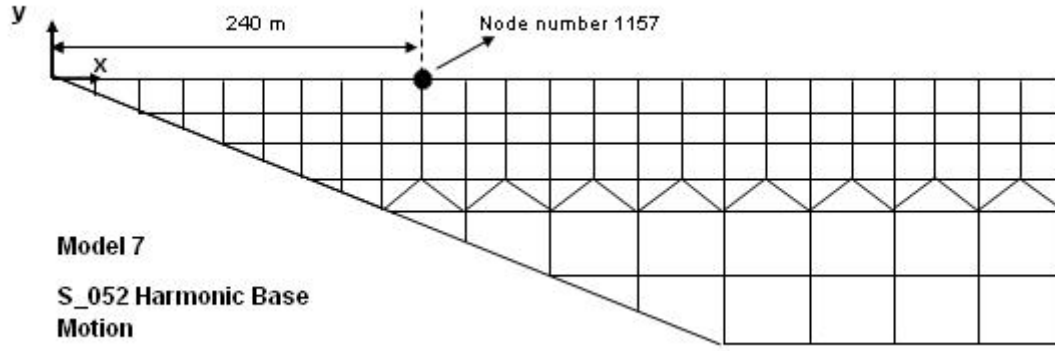


Figure 6: Acceleration Time History for Model 7, Node 1157

RESULT OF ANALYSES

The ratio of $PGA_{(2D)}/PGA_{(1D)}$ is defined as the dimensionless ratio to compare the two-dimensional and one-dimensional analyses results. If this ratio is closer to 1, this means that both two-dimensional and one-dimensional analysis yields the same amplification for the site. To show the basin edge slope effect on ground motion, the ratio of $PGA_{(2D)}/PGA_{(Rock)}$ which is defined as the “amplification factor” is utilized. This parameter is plotted against the dimensionless “normalized distance (ND)”. As shown in Figure 2, where normalized distance, ND, is defined as;

$$\text{For } x < A; ND = x/A;$$

$$\text{For } x \geq A; ND = 1+(x-A)/B$$

The results obtained from the analyses are as follows:

- 1) As shown in from Figure 7 and Figure 8, for the same basin edge slope, the variation of $PGA_{(2D)}/PGA_{(1D)}$ and $PGA_{(2D)}/PGA_{(Rock)}$ with normalized distance for a constant ratio of natural period of site to the predominant period of ground motion, (T_n/T_p) , is almost the same for different soil types, basin depths and predominant period of harmonic base motions.

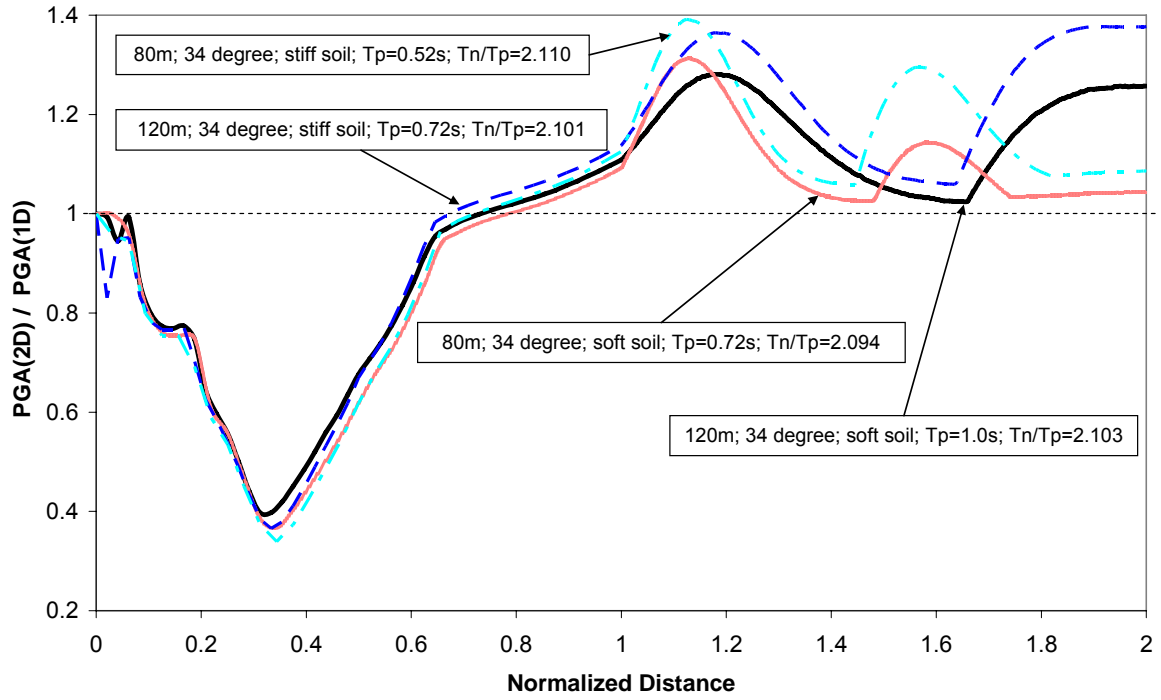


Figure 7: Variation of $PGA(2D)/PGA(1D)$ with normalized distance

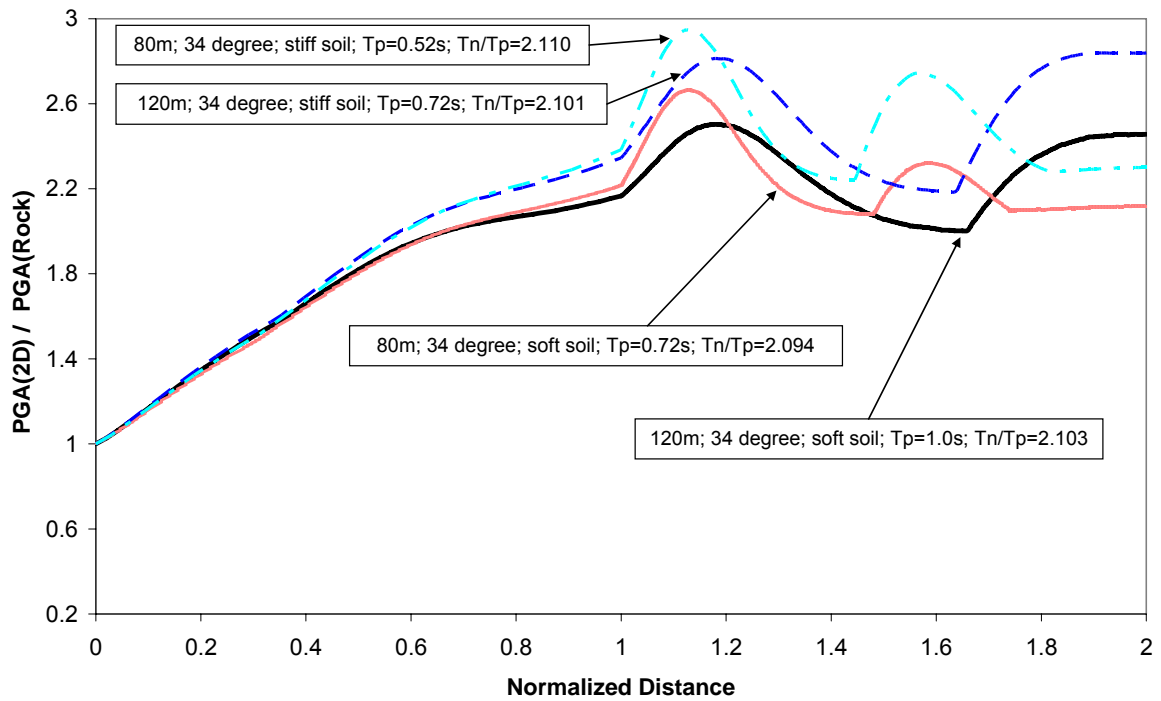


Figure 8: Variation of $PGA(2D)/PGA(Rock)$ with normalized distance

- 2) As shown in Figure 9, one-dimensional seismic response analysis predictions are concluded to be conservative by a factor of as low as 0.30 in the slopping edge region. However, beyond this region, one-dimensional analysis results are unconservatively biased by a factor as high as 1.2. The critical region where one-dimensional results are found to be unconservative falls in the normalized distance range of 0.8 to 1.4.
- 3) Keeping T_n/T_p constant, the ratio $PGA_{(2D)}/PGA_{(1D)}$ increases and approaches to 1 within the inclined region of the basin ($ND < 1$) with decreasing slope as shown in Figure 9. It is also seen that $PGA_{(2D)}/PGA_{(1D)}$ is about 0.97, which is very close to 1 for $ND \gg 1$ expected for horizontal layer, where the small discrepancy can be attributed to basin edge effect and the finite element model.

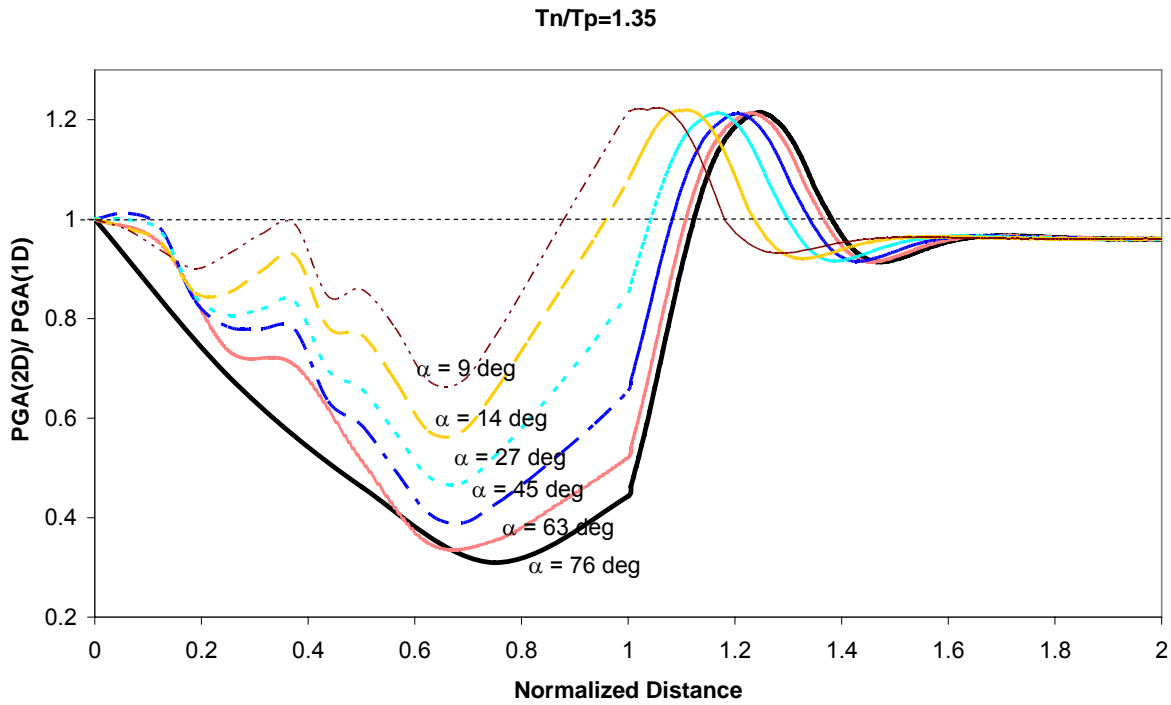


Figure 9: Variation of $PGA_{(2D)}/PGA_{(1D)}$ with normalized distance for constant $T_n/T_p=1.35$

- 4) Keeping T_n/T_p constant, the ratio $PGA_{(2D)}/PGA_{(rock)}$ increases within the inclined basin ($ND < 1$) with decreasing slope as shown in Figure 10. The increase in the “amplification” is smooth in basins with gentle slopes as compared to the basins with steep slopes. For steep slope basins, the amplification sharply increases at $ND = 1$. Usually, the critical region where maximum amplification is observed falls in the normalized distance range of 0.8 to 1.4.
- 5) As shown in Figure 11, keeping basin edge slope constant, a decrease of (T_n/T_p) , where $T_n/T_p > 1$, results in a shift of points of minima of $PGA_{(2D)}/PGA_{(1D)}$ towards the region where the basin is horizontal ($ND > 1$). Figure 11 also illustrates that, for a basin and earthquake couple approaching to resonance state ($T_n/T_p=1$), the PGA predictions by two-dimensional analysis are found to be as high as 40% as one-dimensional analysis results.

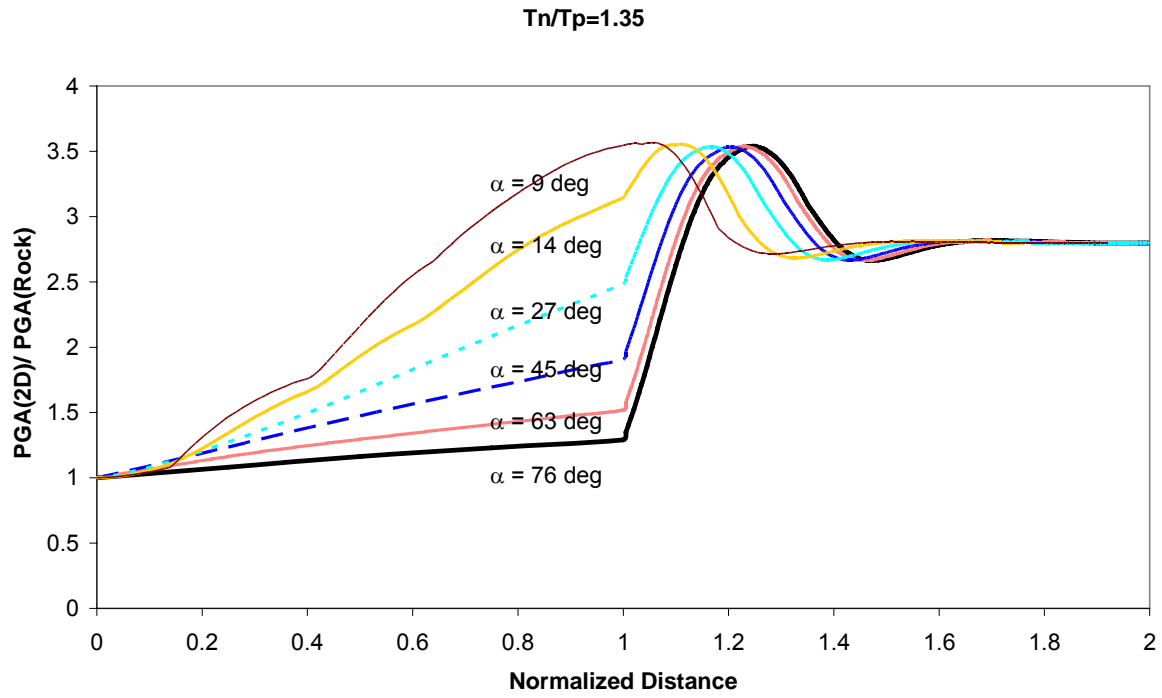


Figure 10: Variation of $PGA_{(2D)}/PGA_{(rock)}$ with normalized distance for constant $T_n/T_p=1.35$

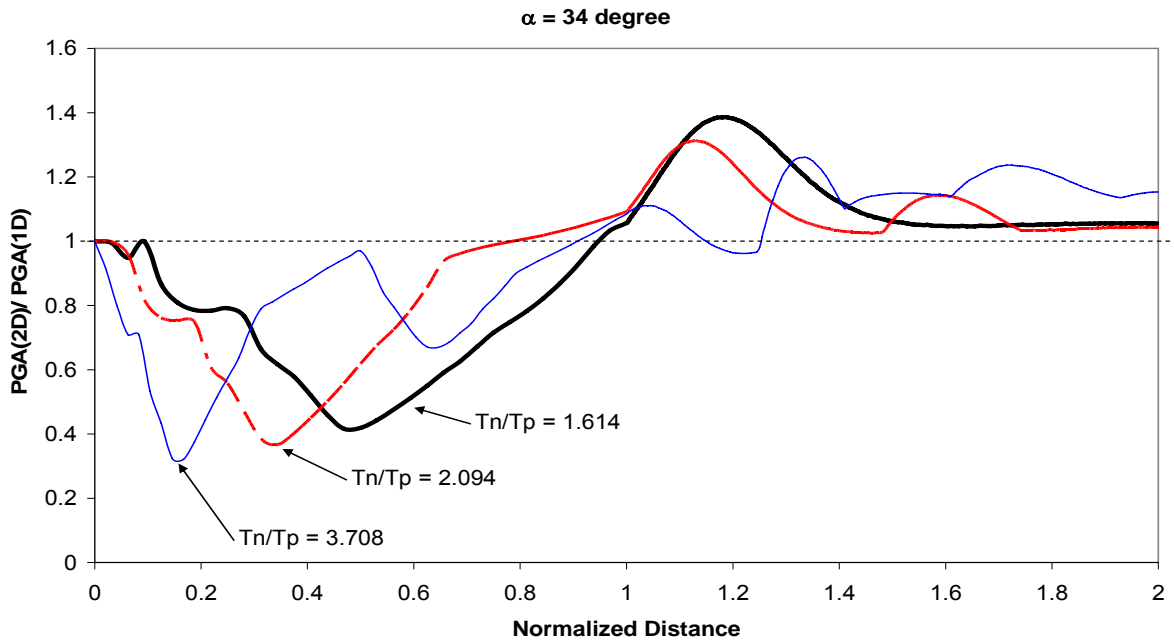


Figure 11: Variation of $PGA_{(2D)}/PGA_{(1D)}$ with normalized distance for constant $\alpha=34^0$

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