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ASSESSMENT OF SOIL BEHAVIOR IN SEISMIC EXCITATIONS BY EXPLORING DIFFERENT APPROACHES

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Abstract

In geotechnical earthquake engineering seismic site response analysis is a very complex task, which has gained an increasing importance for the last decades. This paper aims to numerically simulate the effect of an earthquake input in different types of soil layers in order to get the dynamic amplification factor. The methodology for correctly simulation of seismic waves propagation includes thorough theoretical background aided with different softwares (Shake, Strata,DeepSoil and Plaxis) which allow the simulation of soil as nonlinear material model or small strain linearly elastic material.
The verification of the model is done by comparison of numerical results in relation to two different soil profiles from Varazdin, Croatia and from Skopje, Macedonia. The proposed approach should demonstrate and illustrate the special points in taking into account the modelling of different layers. The earthquake input is given as acceleration signal which in case of low densities of soil material are prone to initiate higher amplifications. Finally, the advantages and limitations of the proposed numerical model are discussed in detail.

Key words

Site response analysis, SHAKE2000, Plaxis2d, Strata,DeepSoil

1 Introduction

In the last decades, earthquakes have shown the importance of site effects in the distribution of damages during seismic events. In 1985 a large earthquake with magnitude Mw=8.1 which occurred in Mexican subduction zone proved that the earthquake effects increased in soft soil areas composed mainly of clay layers in the Valley of Mexico (Chavez-Garcia and Bard 1994). The damage has been attributed to the amplification of seismic waves. In 1989 during the Loma Prieta earthquake the complex pattern of alluvial sediment thickness contributed to the variability of site response and presence of spectral resonance peaks at some sites (Hartzell, Carver and Williams 2001). In 2019 during the Durres earthquake with magnitude Mw=6.4 the effects of soil layers played important role in site amplification (Sheshov, Apostolska et al. 2021). The Earthquake in Zagreb, Croatia also showed that the site response amplification should be given importance (Markušić, Stanko et al. 2020, Atalić, Uroš et al. 2021).
In seismic zonation studies the local site amplification presents one of the most important factors which is not only correlated with soil thickness but also with soil properties such as shear wave velocities and

material damping as well as soil densities (Stanko, Gülerce et al. 2019). In the same time, the soil nonlinearity is to be considered during the destructive earthquakes. In modelling soil medium strain dependency of shear modulus and damping ratio should be evaluated with previous laboratory tests or the layer properties must be presented by measurement of shear wave velocities by geophysical models.

2 Model analysis

The site response analysis of soils to earthquake excitation is complex and depends on number of factors which cannot be obtained with certainty. In this work, two different soil profiles from Varazdin, Croatia and from Skopje, N.Macedonia have been selected in order to compare different soil responses from softwares Shake2000 (Ordonez 2000), Deepsoil(Hashash, Groholski et al. 2008), Strata (Rathje and Ozbey 2006) and Plaxis2D (García Ros, Jiménez Valera et al. 2022). The site from Skopje in the municipality of Kisela Voda (Bojadjieva, Dojchinovski et al. 2023) and Varazdin are shown below:

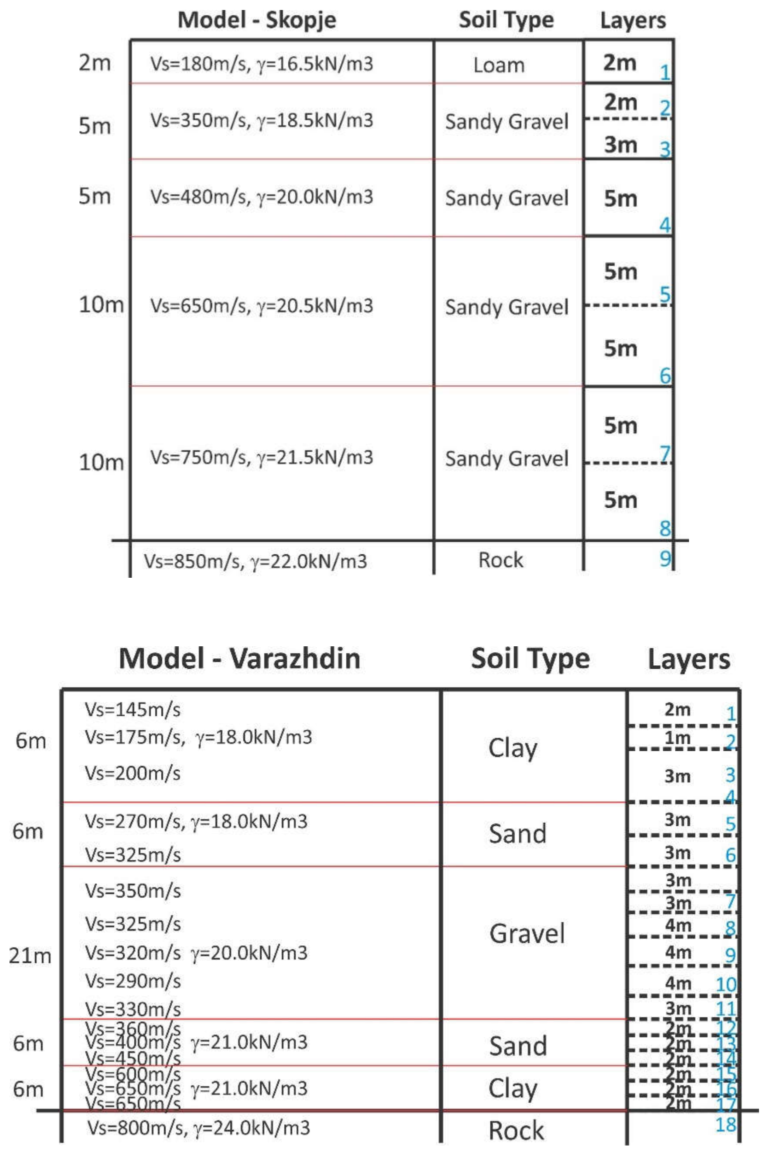

Figure 1. Mathematical model of analysis for Skopje and Varazdin models

The soil layers have been characterized by their shear wave velocity and unit weights. The soil layer materials in both models contain sand, clay and gravel without presence of groundwater. The numerical modelling of soil material has been done using small strain linear elastic models. Generally, the shear

behaviour of soils is expected to have effect on the response of the soil to earthquake excitation. As the soil layers depth increases the frequency of the layers increases which makes the upper layers more susceptible to strain increase.
In the analysis the following earthquakes time histories are used as input signals: ACC1: The North-South Center, USA, 1940, with a magnitude of M=6.7. It was selected as a representative event for earthquakes from neighbouring epicentres with magnitudes ranging from 6.5 to 7; ACC2: Bar N-S, recorded in the seismic records during the earthquake in Montenegro on April 15, 1979, with a magnitude of M=7.0. It was chosen as a representative event of a high-magnitude earthquake with a relatively broad frequency range of maximum amplitudes; ACC3: Ulcinj - Albatross N-S, recorded on a seismograph during the earthquake in Montenegro on April 15, 1979, with a magnitude of M=7.0; ACC4: Petrovac, Oliva N-S, recorded on a seismograph during the earthquake in Montenegro on April 15, 1979, with a magnitude of M=7.0. It was selected as a representative event of a high-magnitude earthquake with maximum amplitudes in the period range of 0.25-0.5 seconds; ACC5: Ulcinj - Olympic N-S, recorded on a seismograph during the earthquake in Montenegro on April 15, 1979, with a magnitude of M=7.0. It was chosen as a representative event of a high-magnitude earthquake with a relatively broad frequency range of maximum amplitudes.
The spectra from Earthquake inputs are shown in Fig.2 where it is clearly seen the difference in frequency content and amplification of the earthquakes which make the site response challenging.

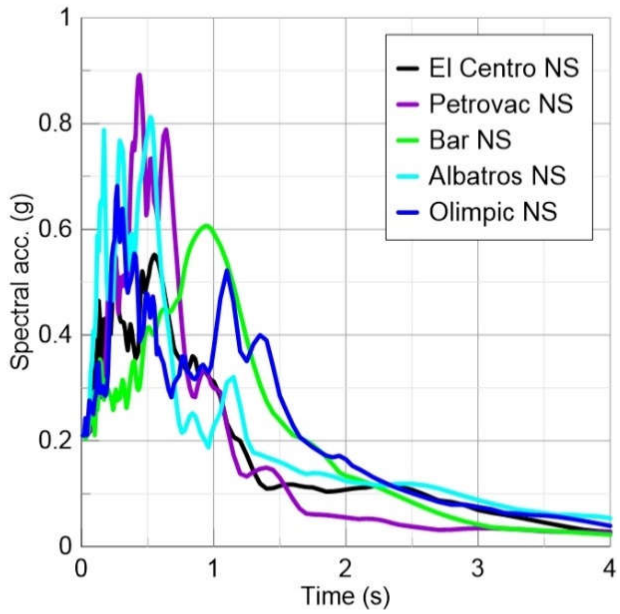

Figure 2. Spectra of input earthquakes with PGA of 0.21g

As can be seen from Fig.2 the spectra of input earthquake of Petrovac NS and Albatros NS have highest peeks and are expected to have greatest impact on the response analysis. On the other hand, the earthquake record of Olimpic NS has smaller but several peeks and is expected to have impact on different frequencies. The length of the records is approximately same and is around 30seconds.

3 Results

4

The cyclic loading due to earthquake which is imposed on soils can seriously affect the soil strength by lowering the shear stiffness and in the same time increasing the shear strain of the soil layers. Although the angle of friction is not affected by cyclic loading, the soil particle bonds are affected and strength reduction follows which enables alteration in the PGA during the excitation. The analysis of Skopje site comparing their peak ground acceleration is shown in Fig.3 below.

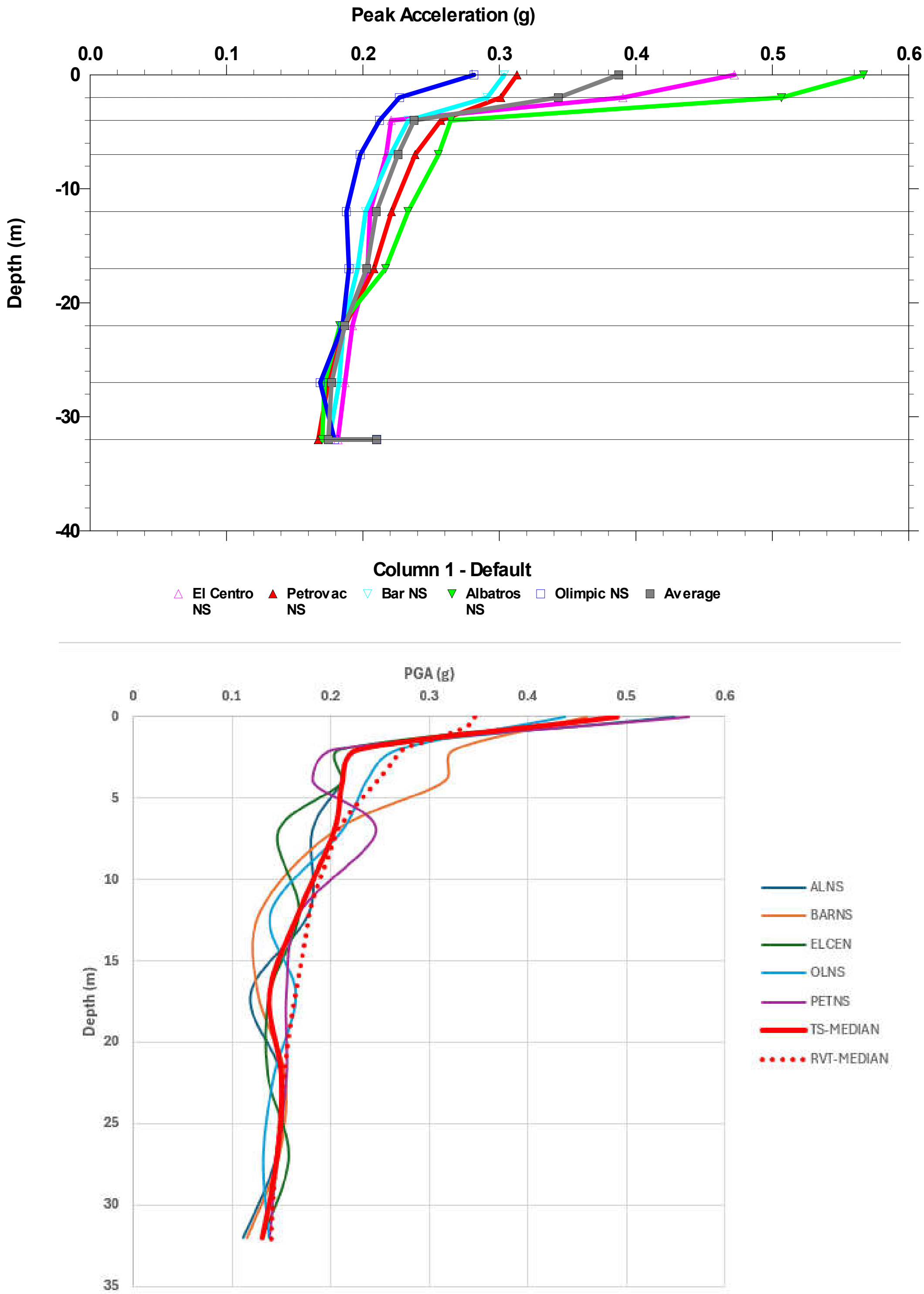

Figure 3. Comparison of Peak Ground Acceleration of Skopje model between Shake2000 and Deepsoil Softwares

As can be seen from Fig.3 the comparison is done with Shake2000 and Deepsoil Softwares. On the other hand, the comparison of results for the Varazdin model between the Shake2000 and Strata software are given in Fig.4.

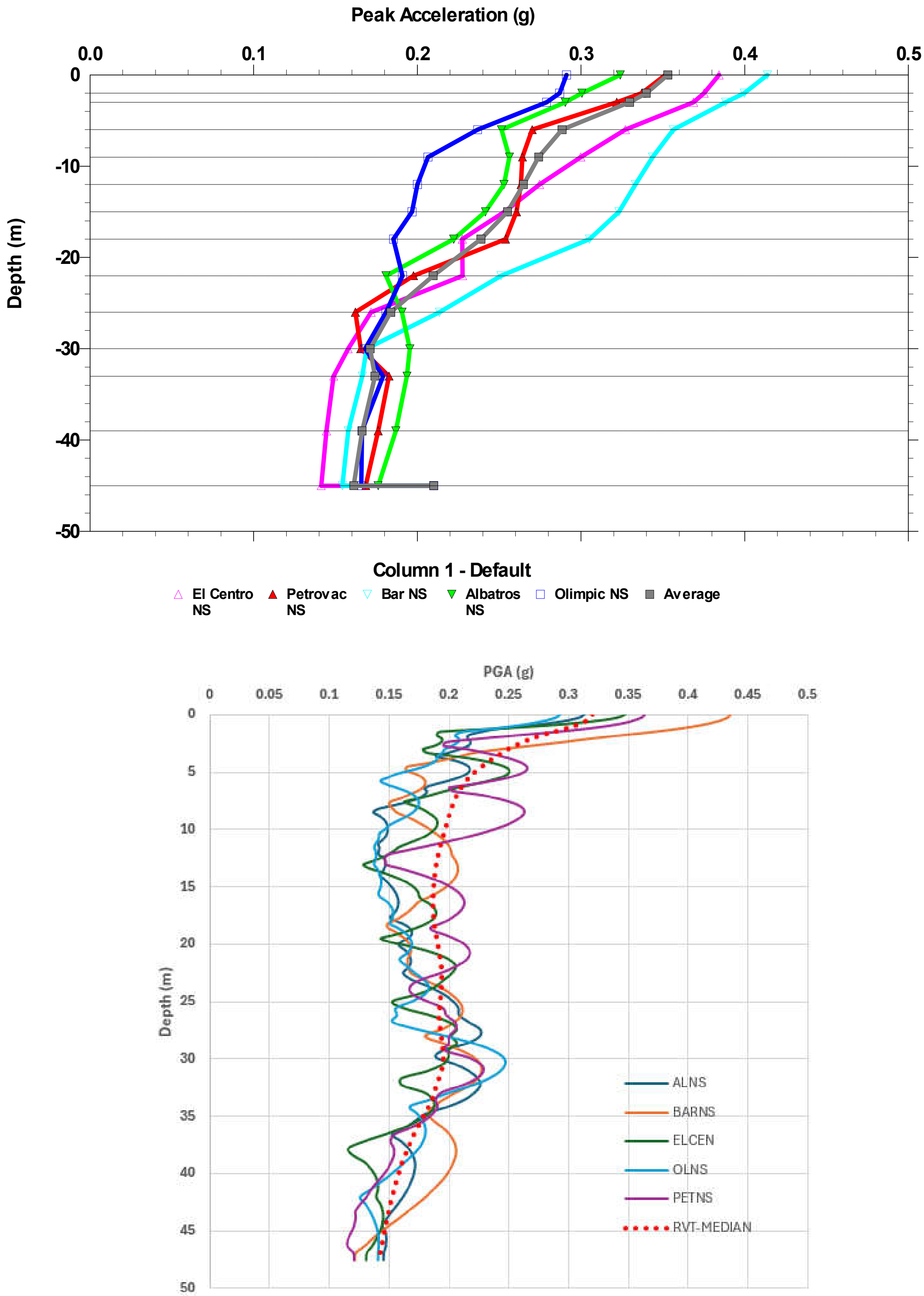

Figure 4. Comparison of Peak Ground Acceleration of Varazdin model between Shake2000 and Strata Softwares

As can be seen from Fig.3 and Fig.4, both sites show strength loss due to the earthquake excitations. The comparison of different softwares is in good accordance with each other. Here, it should be noted that the software work in 1d and the material definition is in small strain ranges. In order to compare the results with a 2d Software the Skopje model has been analysed using the Plaxis2d software with the Hardening soil Material model (Schanz, Vermeer and Bonnier 2019). Plaxis 2D is an advanced finite element method software intended for analysing two dimensional problems of deformation and stability in geotechnical engineering. In defining the hardening soil model, the calibration of the model using the given shear wave velocity parameters have been done (Edip 2013). The output of the software is given in Fig.5 below.

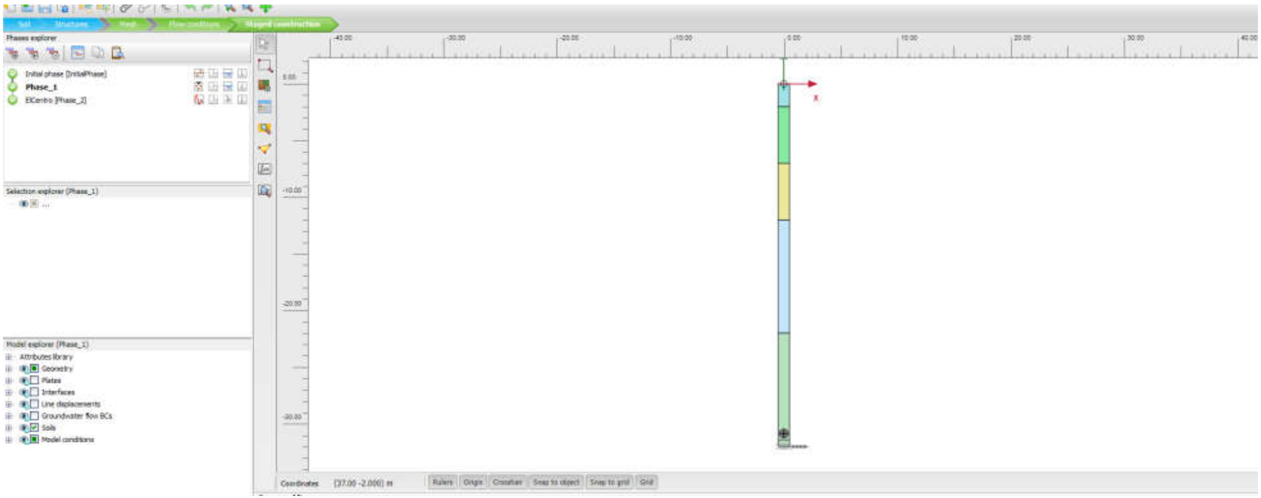

Figure 5. Modelling of horizontal layered soil profile in Plaxis 2d

As can be seen from the Fig.5 the modelling in Plaxis2d is straightforward and can be used in a simple manner when layers of soils are horizontal. In using 2d software the main point is to have big number of nodal points in order to obtain consistency in the analysis performed. In our case the meshing has been done using medium size of elements in order to have reasonable timing of analysis. Next the results of El Centro and Albatros earthquake records are given.

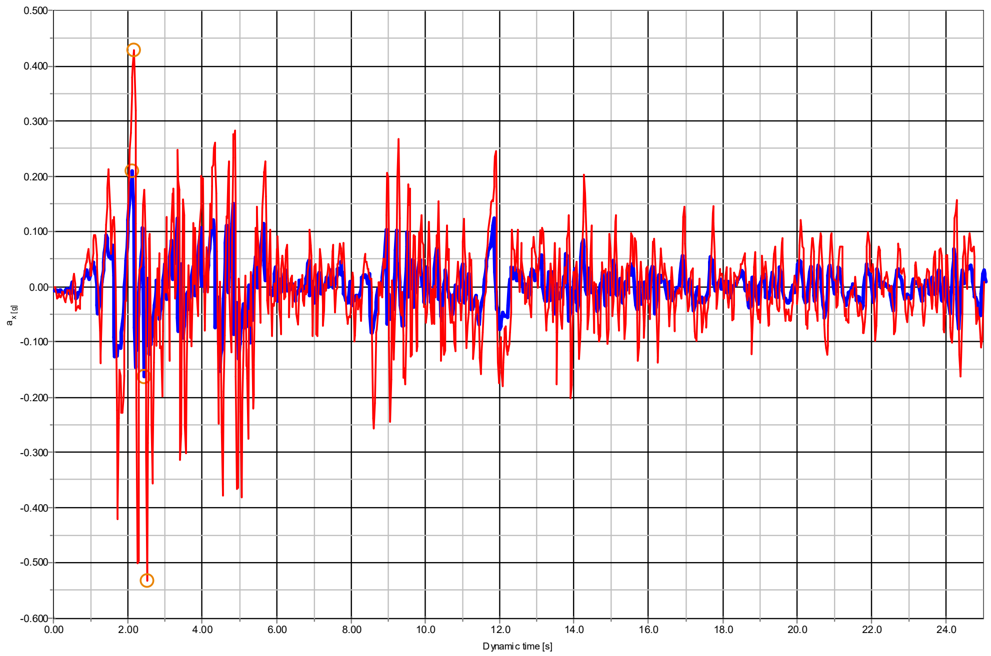

Figure 6. Output results of El Centro earthquake from Plaxis2D software

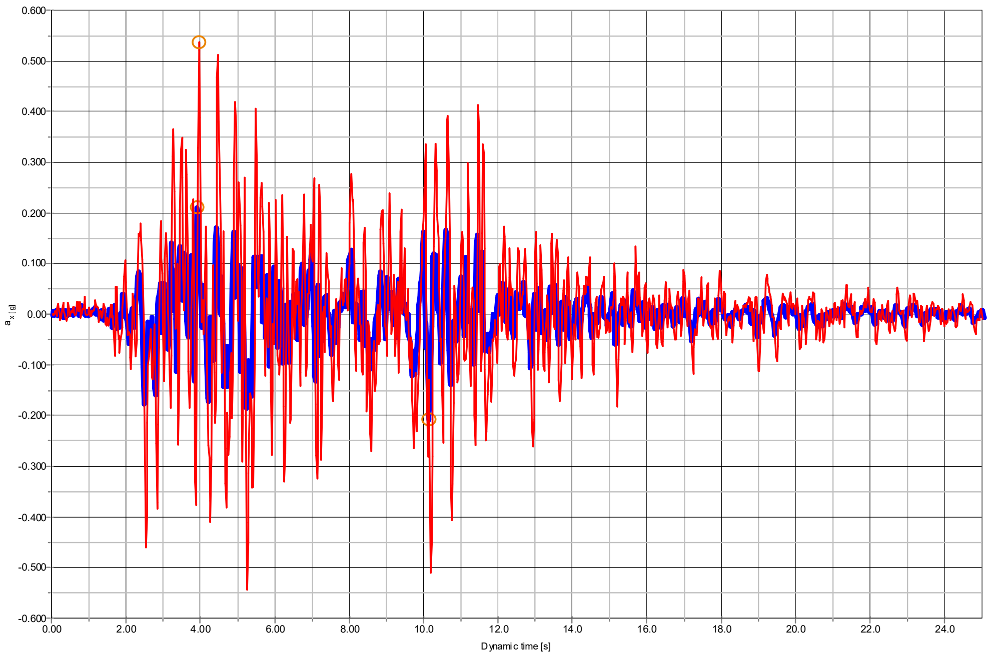

Figure 7. Output results of Albatros NS earthquake from Plaxis software

From Fig. 6 and Fig.7 the results show that the nodal values at bottom and top layers simulate the site response in a correct way. The maximum values obtained are in good correlation with the results from the Fig. 3. Namely, the values of El Centro earthquake record from the Shake2000 and Deepsoil software have similar values with Plaxis2d. On the other hand, the earthquake analysis with Albatros NS earthquake from site specific analysis has similar results of peak ground acceleration which are 0.55g and 0.56g. This proves the correctness of the 2d analysis by using the software Plaxis2D although further investigations are required in the material definition.
In order to obtain the effects of the soil profiles in the amplification of the earthquake inputs next the response spectra have been compared at the top layers for different earthquake records.

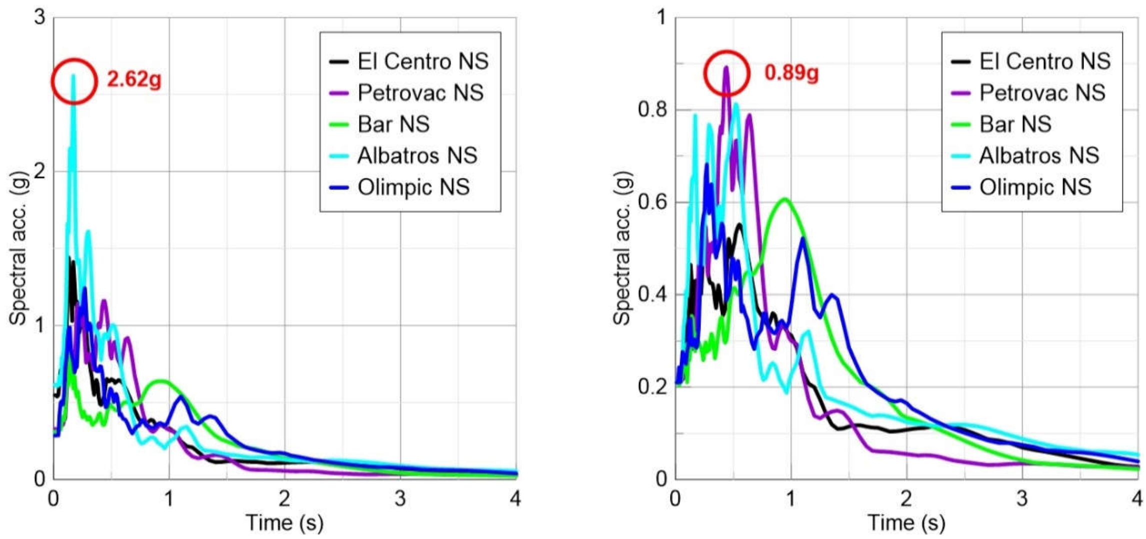

Figure 8. Response Spectra of input earthquakes at the top layer in Skopje model (left) and Varazdin model (right)

From Fig.8 it can be clearly seen that in selecting the earthquake recordings it is of important to capture the features of rupture propagation, path and site effects which makes the selection of recorded accelerations important. For Skopje model comparison is done for Albatros NS earthquake among the softwares and following results are obtained.

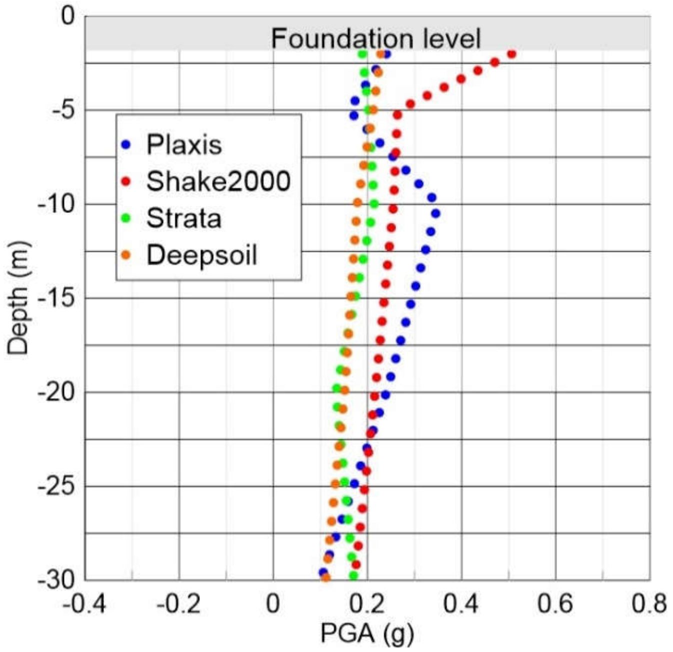

Figure 9. Comparison of different softwares for the Skopje model to Albatros earthquake input

As can be seen from Fig.9 the response of different sofwares are in general in agreement, although the results vary as the depth of the soil profile becomes small. The software Shake2000 has biggest values at the top layers due to the layer thickness assumptions. On the other hand, the Plaxis2d results vary in the depth of around -10m due to the fact that the integration meshing of the soil medium which need further increase in the number of elements which is not economically appropriate for this type of analysis.

4 Conclusion

In conclusion, the analyses which were performed in this work show that the site response analysis is of importance and should be considered when dealing with seismic response analysis. Stiffness of soil layers, foundations depth and vibration characteristics play important role and contribute to the overall safety and serviceability. Using different softwares, complete results have been obtained for input ground acceleration of 0.21g. Results show that the assumption of constant unit weight and shear wave velocity for soil layers can underestimate the variability of maximum horizontal acceleration. It can be concluded that the reliability of the results should be verified with on site measurements. This study's aim is to validate site response analysis by model and to investigate possible 2-D softwares seismic effects which can increase the ground motion amplifications due to local surface waves or possible 2-D resonance in deep valleys. These effects are strictly related to the geophysical properties of the local soil layers formations but are not compared and verified with experimental strong-motion data because they are missing in the selected sites. In fact, the soil strain increases and shear modulus reduction in upper layers of soil layers produce the shift toward higher natural periods and the amplitude attenuation from performed analysis.

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