# EFFECTS OF EARTHQUAKE DEPTH IN A FRAME STRUCTURE CONSIDERING SOIL STRUCTURE INTERACTION DURING 2016 SEPTEMBER SKOPJE EARTHQUAKE

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## EXTENDED ABSTRACT

The Seismic excitation experienced by structures is a function of the earthquake source, travel path effects, local site effects and soil structure interaction whose results have been analysed in the last decades. On 11th of September 2016 at 13.10h UTC time an earthquake with magnitude of 5.2 hit the city of Skopje. Although moderate in magnitude, the earthquake was felt strongly in the city with moderate structural damages experienced in the reinforced concrete buldilngs. The earthquake was monitored by many local and regional stations in which the data for the depth of the hypocenter were given as 4km while USGS reported the depth of 10km. In this work the ground motion prediction equations according to Boore and Stewart [1] have been used in order to define the target spectra for both depths as given in Fig.1 below.

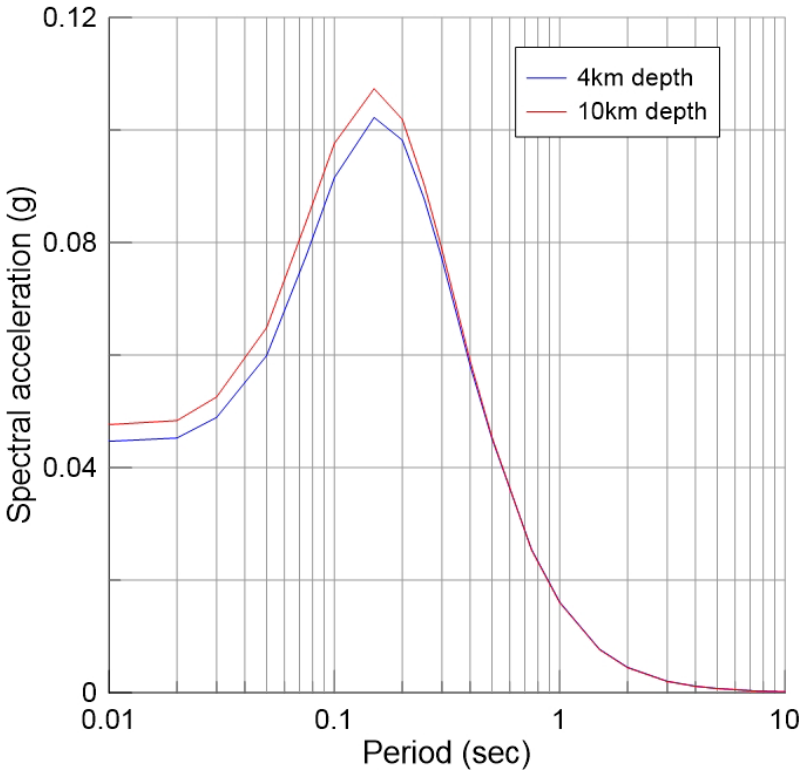


Fig. 1 Target spectra for different depths of rupture

The target spectra reveal significant differences between the two depth scenarios, particularly in the spectral acceleration values across various periods. The deeper hypocenter prediction generates slighthly higher spectral accelerations in the short-to-medium period range, which is critical for the response of low-to-mid-rise structures. These target spectra serve as the basis for generating spectrum-compatible artificial accelerograms that will be used in the subsequent dynamic analyses. Based on the target spectra, artificial earthquake records have been created in order to evaluate the effects of the earthquakes in the structural response of a three-storey frame structure as given in Fig.2 below.

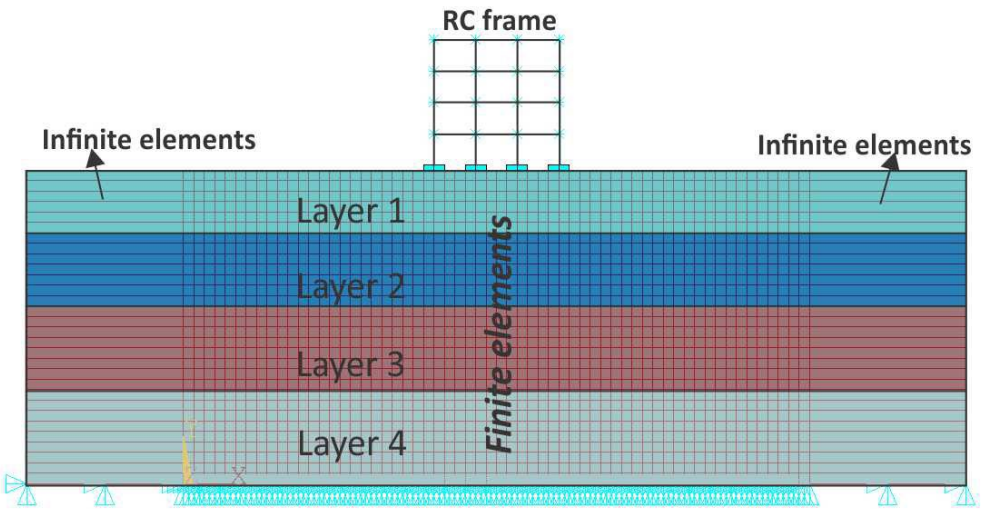


Figure 2. Numerical model of SSI

The numerical model incorporates both the superstructure and the surrounding soil medium to capture the complete soil-structure interaction effects. The three-storey reinforced concrete frame represents a typical building configuration found in Skopje's building stock. The foundation is modeled with appropriate contact elements, while the soil domain extends sufficiently in all directions to minimize boundary effects. Infinite elements are implemented at the outer boundaries to simulate the semi-infinite nature of the soil medium and prevent spurious wave reflections that could contaminate the structural response. The generated earthquake records have been gnerated by using the open source software Code Aster [2]. The generation of earthquakes for 4km and 10km depth is given below in Figure 3.

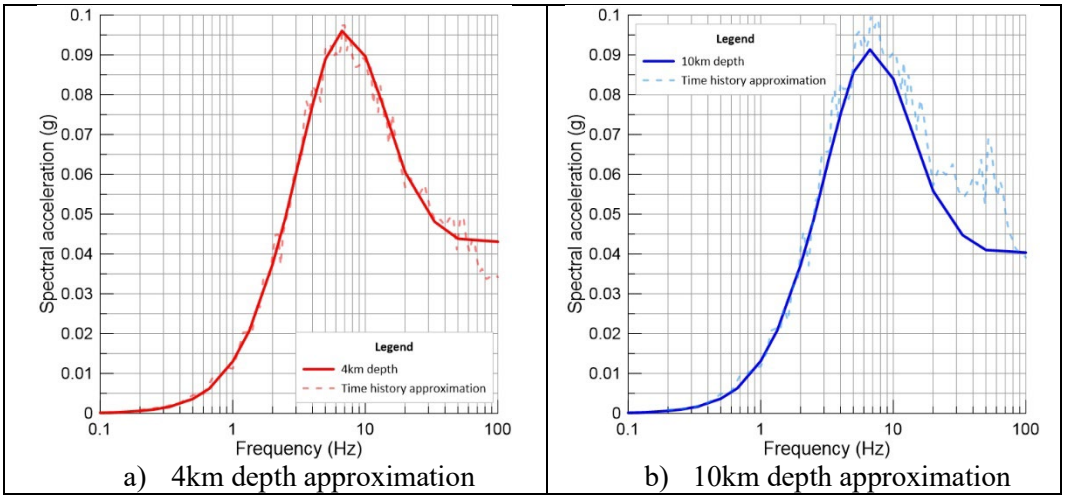


Figure 3: Comparison of artificial earthquakes with the spectra

As can be seen in the Figure 3 the results of spectra show better approximation in the lower frequencies which is used in our case. The artificial accelerograms demonstrate excellent agreement with their respective target spectra, particularly in the period range of 0.1 to 1.0 seconds, which governs the dynamic response of the analyzed frame structure. The spectral matching procedure ensures that the generated ground motions preserve the key characteristics of earthquakes occurring at different hypocentral depths while maintaining realistic time-domain properties. Minor deviations at higher frequencies have negligible impact on the structural response given the predominant periods of the structure under investigation. The obtained earthquakes relating to the spectra are shown next in Figure 4.

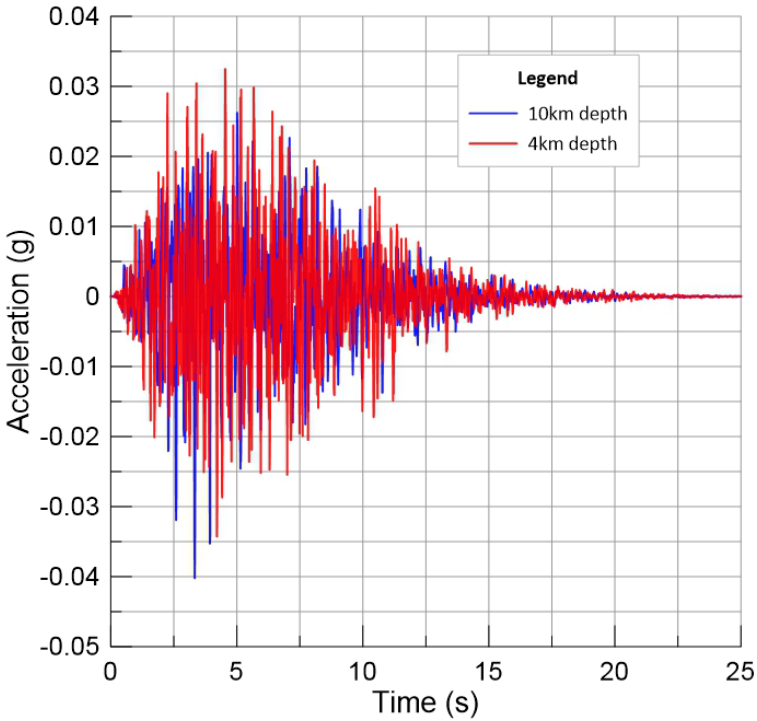


Figure 4: Earthquake time histories of 4 and 10 km depth

The soil medium is considered to be either dense or soft sandy material, which can be classified as Type B and Type C soils, respectively, according to Eurocode 8 classification. The simulation considers a nonlinear behavior with respect to the soil modelling [3]. All analysis are performed in ANSYS computer package in which user defined elements [4-6] are used for calculations. These analyses enable the performance of both the soil and the structure to be accurately modelled. Seismic evaluations and comparisons for all earthquakes are given in detail for earthquake time histories from the target spectra. The seismic behavior of the structure considers results considering deformations, structural moments at the top of the structure and acceleration at the ground level. Two soil conditions—dense and soft—are analyzed to assess the influence of soil stiffness on the structural response The results are summarized in the Table 1 below:

Table 1 Comparison of results

| Depth | Soil Medium | Max. displacement (cm) | Max. acceleration ($m/s^2$) | Max. moment (kNm) |
|---|---|---|---|---|
| 10km | Dense | 2.50 | 7.65 | 153.10 |
| | Soft | 2.37 | 3.87 | 56.43 |
| 4km | Dense | 2.57 | 8.03 | 168.41 |
| | Soft | 2.45 | 4.06 | 60.94 |

The results have demonstrated interesting outcomes showing the combined influence of earthquake depth and soil stiffness on the seismic response of the frame structure. For both soil conditions, the shallower earthquake scenario (4 km depth) consistently produces higher maximum displacements, accelerations and bending moments compared to the deeper event (10 km depth), indicating stronger near-source effects. Dense soil conditions lead to noticeably higher accelerations and internal moments than soft soil, while the differences in maximum displacement remain relatively small. In conclusion it can be stated that the soft soil significantly reduces acceleration and moment demands despite comparable displacement levels, illustrating the filtering effect of compliant soil and the importance of soil–structure interaction in modifying structural response. Last but not least, this work shows the critical influence of small differences in prediction of earthquake hypocenter depth on the structural demand parameters, emphasizing the need for accurate seismic source characterization in vulnerability assessments and design application.

KEYWORDS: Skopje Earthquake, Soil Structure Interaction, Numerical Modelling, Infinite Elements

## REFERENCES

Boore, D.M., J.P. Stewart, E. Seyhan, and G.M. Atkinson, NGA-West2 equations for predicting PGA, PGV, and 5% damped PSA for shallow crustal earthquakes. Earthquake Spectra, 2014. 30(3): p. 1057-1085.

Code-Aster. Fem Software, https://code-aster.org/. 2018.

Edip, K., V. Sheshov, J. BOJADJIEVA, T. KITANOVSKI, and J. CHANEVA, Numerical simulation of triaxial tests. ce/papers, 2018. 2(2-3): p. 621-626.

Edip, K., V. Sesov, C. Butenweg, and J. Bojadjieva, Development of coupled numerical model for simulation of multiphase soil. Computers and Geotechnics, 2017.

Edip, K., V. Sheshov, W. Wu, and J. Bojadjieva, Numerical modelling of saturated boundless media with infinite elements. Acta Geotechnica, 2021. 16(8): p. 2683-2692.

Edip, K., Development of three phase model with finite and infinite elements for dynamic analysis of soil media. 2013, Ss. Cyril and Methodius: Institute of Earthquake Engineering and Engineering Seismology.