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APPLICATION OF NAKAMURA METHOD IN INTERPRETATION OF SHALLOW GEOLOGY

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Abstract

In order to examine the shallow geology under the site of the Skopje Seismological Observatory (SKO), Nakamura technique was used on a set of selected seismic records from its strong motion instruments. The assessment of site conditions and amplification behavior was performed under different input levels of seismic ground motions. The datasets for analysis consisted of three types of seismic registrations: the first type were the microtremor measurements, the second type was a nearby man-made explosion, and the third type was a moderate size local earthquake with a magnitude of M_L5.3 which occurred on 11th of September 2016.

Horizontal vs. vertical ratio of the components recorded for all three types of source vibration were calculated. Similar predominant peaks and frequency distribution were observed when records from the local earthquake, the explosion and the ambient noise were analyzed.

The results of the analysis with Nakamura method were compared with interpretations from the geological and geotechnical maps at the station location. Our findings support the idea that such geophysical methods can detect the underlying structural profile to a first approximation and can be used to develop consistent velocity models for large areas without expensive drilling deployments.

Key words: *earthquake records; strong motion (SM) analysis; Nakamura method*

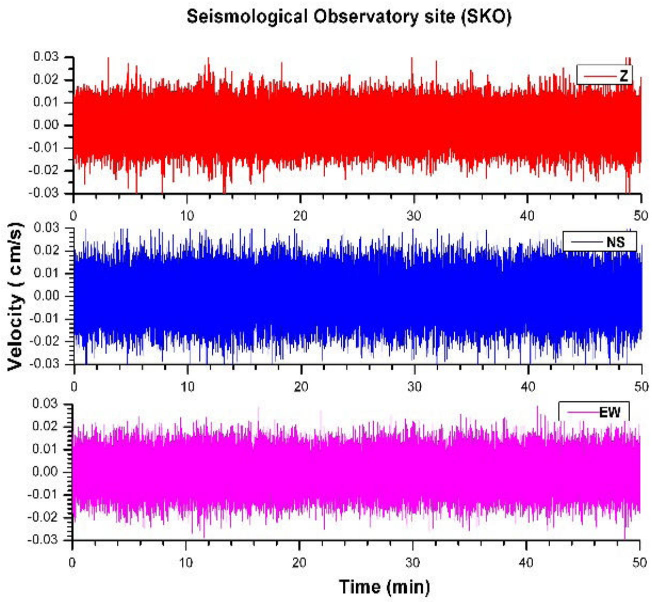
INTRODUCTION

Soil undergoes inelastic deformation after different intensity of ground shaking and the nonlinear behavior of soil should be taken into account when performing ground response analysis. The site response analysis is based on the assumption that superficial soil layers extend horizontally on elastic rock and that vertically propagating horizontally-polarized waves (SH waves) dominate the ground motion wavefield. The site response analysis consists of four steps: definition of the local shear wave velocity, selection of appropriate dynamic soil properties (shear modulus and impedance), specification of the input ground motions, and its estimation of propagation from the surface through the layers.

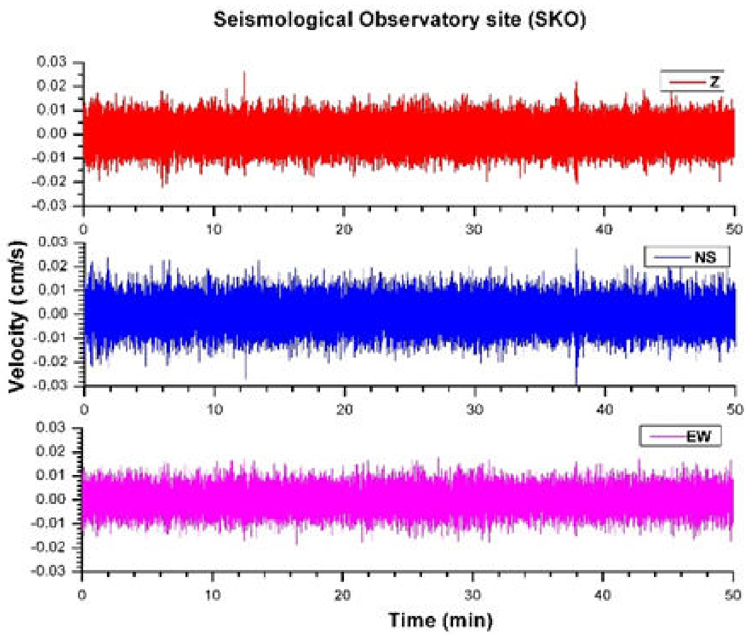
Here, we examine the shallow geology under the site of the Skopje Seismological Observatory (SKO), applying the Nakamura technique on a set of selected seismic records from station's strong motion instruments. The assessment of site conditions and amplification behavior was performed under three different input levels of seismic ground motions: the first type were the microtremor measurements of the ambient noise, the second type was a nearby man-made explosion, and the third type was a moderate size local earthquake with a magnitude of ML5.3 which occurred on 11th of September 2016.

MATERIALS AND METHODS

Ambient seismic noise becomes more and more important and helpful in assisting velocity model inversion, earthquake detection and ground motion prediction. Based on the analysis of the continuous seismic data, we try to find the dominant frequency and peaks that match the behavior of the soil model under different ground excitations. The microtremors for the SKO station are mainly from the anthropogenic activities which might have daily or weekly repeatability and some seasonal variations. Figure 1 shows two sections of a daily SKO record at a randomly chosen day in winter of January 2021 and in summer of July 2021.



a)



b)

Figure 1. Microtremor recording at SKO seismological station:
a – January 2021; b – July 2021

The 3-component recording at the SKO seismological station of explosion in Banjani quarry, about 10 km away, is shown in Figure 2. We try to correlate the size of the tabelised blasts at the mine and get an approximate value for the released seismic energy, equivalent to an earthquake of a magnitude between 1 to 1.5 on the Richter scale.

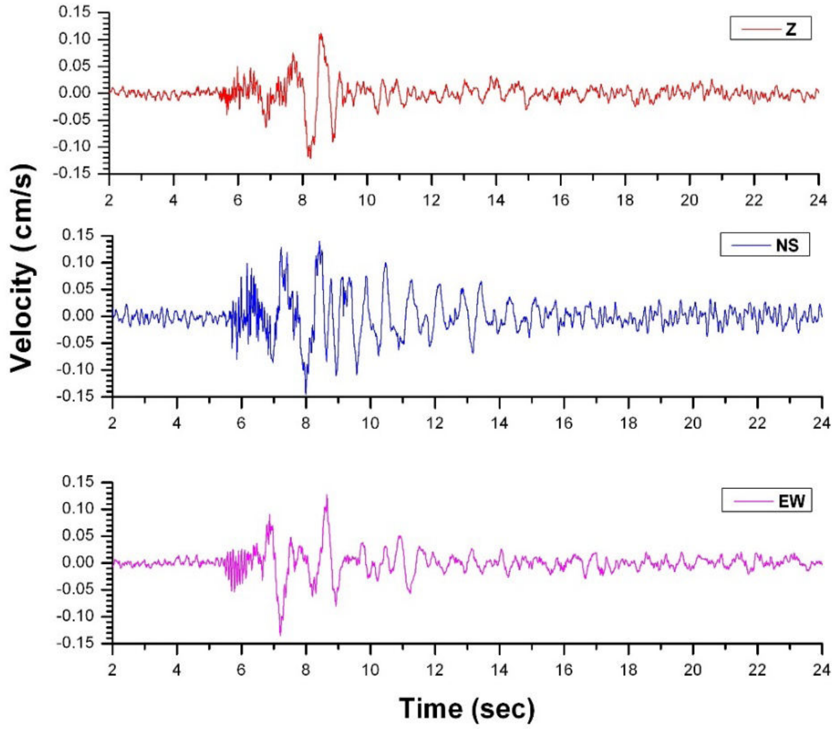


Figure 2. Three-component recording at the SKO seismological station of the explosion in Banjani quarry

On 11th of September 2016. at 13:10 UTC time a strong, magnitude ML5.3, earthquake occurred under the Macedonian capital Skopje. More than 100 people were injured and required medical assistance according to the MIA news agency. Using the data from the local and regional seismic stations, the UKIM Seismological Observatory SKO estimated its location at 42.008 °N and 21.488 °E [1, 2]. Global seismic records favored a shallow focal depth of about 10 km [3].

In the Seismological Observatory SKO at epicentral distance of approximately 7.2 km, the acceleration was recorded by the EpiSensor Kinemetrics instrument installed on bedrock. It is a multi-component set consisting of three force balance accelerometer modules mounted orthogonally [7] and with full-scale recording ranges of ± 0.25 to ± 4 g, that is especially useful at near fault locations and in a variety of structure types.

The 3-channel acceleration record of the 11th of September 2016 magnitude ML5.3 earthquake at the SKO location is shown in Figure 3. The maximum acceleration was on the Z-component; a measured zero-to-peak value of 555,000 counts or peak ground acceleration (PGA) of 0.140 g, the N-S component PGA was 0.10 g, and the E-W component PGA was 0.07 g.

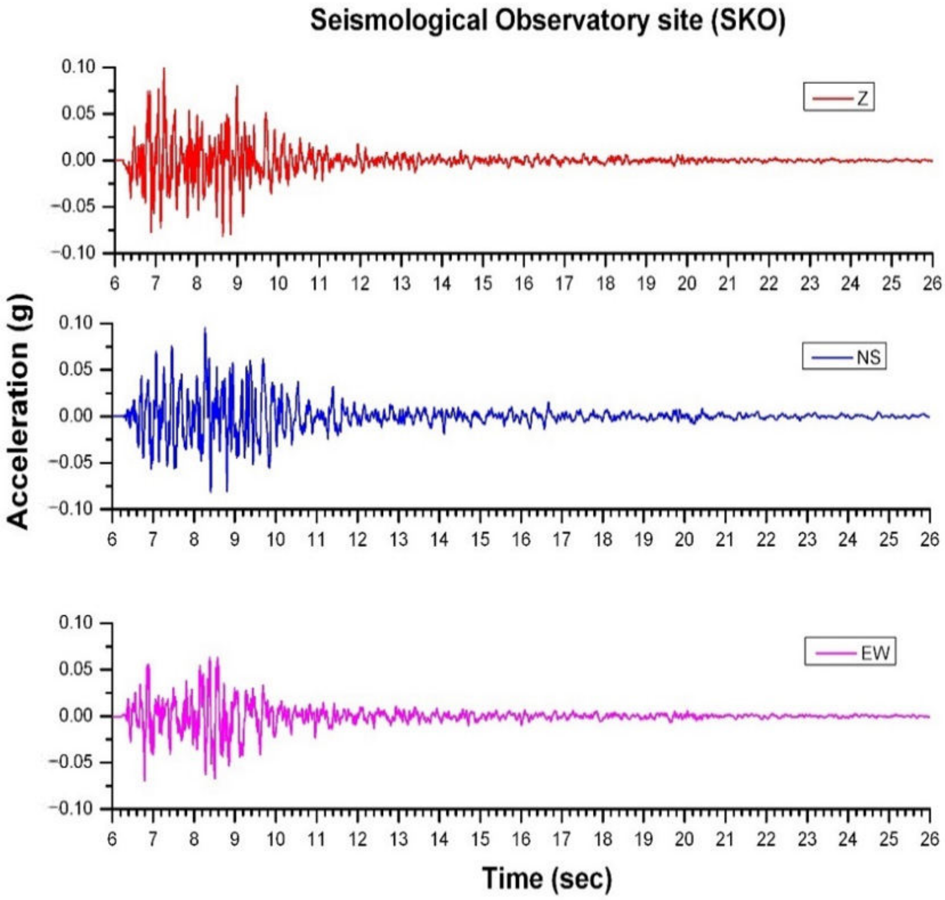


Figure 3. The acceleration record of the 11th of September 2016 magnitude 5.3 earthquake at the station SKO

NAKAMURA METHOD

The accelerograms from the three types of the ground motions at the Skopje station were analyzed using the complete records in raw format and applying the Nakamura method [11, 12]. The theory predicts that on soft ground, the horizontal motion is larger than the vertical motion. However, on rock, horizontal and vertical motions should be similar, both in the maximum amplitudes and in the waveform content. We used the software [8] to automatically select the parts/windows of the waveform and calculate the maximum values of the H/V ratio and compare them with the ground characteristics for the selected stations. The basic assumptions upon which the Nakamura method is based then, as a first approximation, the resonance frequency, f_0, of the superficial layer and the amplification level $A(f_0)$, are given by the equations:

$$f_0 = \frac{V_1}{4H}$$

$$A(f_0) = \frac{V_2 r_2}{V_1 r_1}$$

where V_1 and V_2 are the S-wave velocities in the upper layer and the bedrock, respectively. The corresponding densities of the materials are r_1 and r_2, usually read from lab tests, and H is the thickness of the superficial layer.

Thus, the amplification characteristics of horizontal motions by surface layers can be estimated from the ratio of horizontal-motion spectra measured at soft soil and bedrock sites. However, it is often difficult to determine the resonance frequency corresponding to the surface layer because the spectral ratio can have several peaks [5, 6, 13]. That phenomenon was recognized to be caused mainly by surface waves. Therefore, although uncertain, the method can assist to distinguish the amplification caused by multiple reflections of the vertically polarized waves in the top layers, which is important during forming the velocity models for further computational analysis.

According to the results of the surface layer investigation, the depth estimates depend on the velocity of the top material. The amplitudes of the peaks then match certain combinations of layers with given velocities, and the solutions might be ambiguous. It is common practice to discard the extreme solutions that are not physically possible and keep the most plausible.

RESULTS AND DISCUSSION

Horizontal vs. vertical ratios of the records from the three types of the ground motions at the Skopje station where the instrument is installed on rock, are shown in Figure 4. A similar peak distribution was noticed when records from the ambient noise, the local explosion, and the moderate size earthquake were analyzed. The predominant peaks and frequency found on the seismic station SKO record are at 2, 2.5, and 3.75 Hz, while some spikes below 0.5 Hz could be artifacts of the processing.

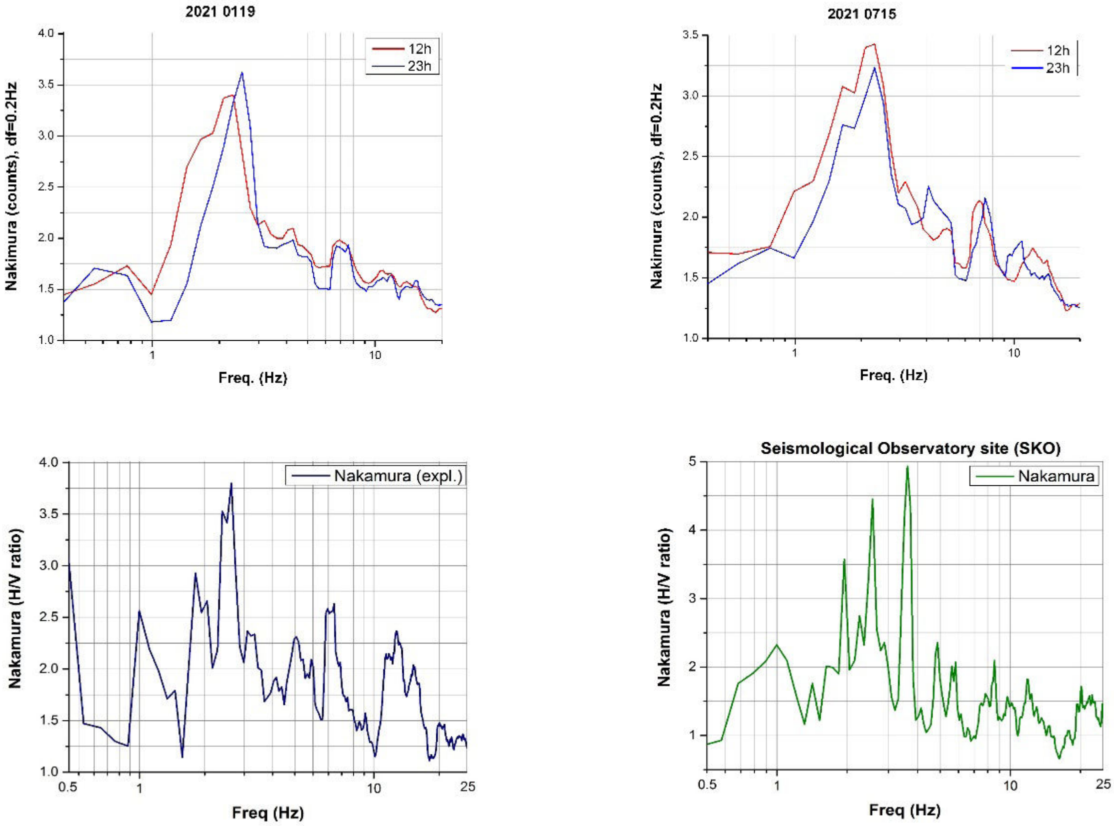


Figure 4. Horizontal vs. vertical ratio of the SKO records: top – ambient noise (day and night); bottom left – explosion; bottom right – 11th of September 2016 magnitude ML5.3 earthquake

CONCLUSION

The preliminary results of the analysis with the Nakamura method were compared with the interpretations from the geological and geotechnical maps at locations in Skopje [4, 14], SKO being one of the three seismic stations that recorded the 11th of September 2016 ML5.3 earthquake (Figure 5). Using the general values for velocities in soft rock [9, 10], the thickness of the top cover can be approximated to 70 m, which is in line with the Eurocode-8 classification of type A.

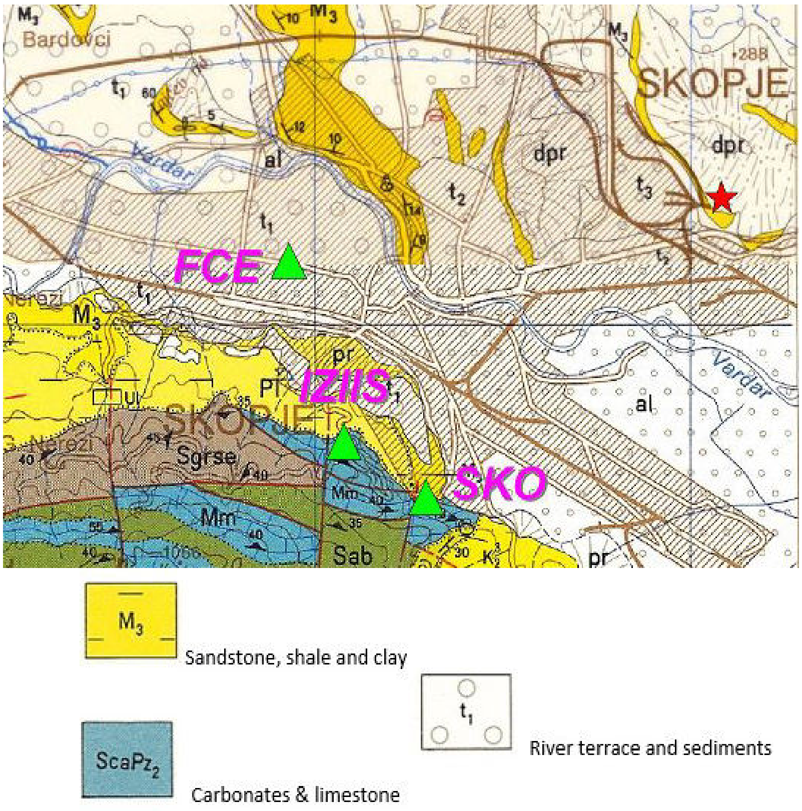


Figure 5. The recording station positions (triangles): SKO - Seismological Observatory, FCE – Faculty of Civil Engineering, IZIIS – Institute of Earthquake Engineering and Engineering Seismology, and the epicenter (star) of the 11th of September 2016 ML5.3 earthquake in respect to the geology around Skopje city (shaded area)

Our findings support the idea that such geophysical methods can detect the underlying geology to a first approximation and can be used to develop consistent velocity models for large areas without expensive drilling schemes. Further layered structures and corresponding frequencies are possible to be revealed upon analysis of more detailed geophysical profiles.

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Резиме

Со цел да се испита плитката геологија под локацијата на Сеизмолошката опсерваторија Скопје (SKO), техниката Накамура беше искористена на избрани сеизмички записи од нејзините инструменти за силни движења. Проценката на условите на локацијата и однесувањето на засилување беше извршена при различни влезни нивоа на сеизмички движења на тлото. Збирката на податоци за анализа се состоеше од три типа на сеизмички регистрации: првиот тип беа мерења на микротремори, вториот тип беше вештачка експлозија во близина на локацијата и третиот тип беше локален земјотрес со умерена големина со јачина M_L5.3 што се случи на 11-ти септември 2016 година.

Пресметан е односот меѓу хоризонталата и вертикалата на компонентите снимени за сите три типа на вибрации на изворот. Слични доминантни амплитудии дистрибуција на фреквенција беа забележани кога се анализираа записите од локалниот земјотрес, експлозијата и шумот од околината.

Резултатите од анализата со методот Накамура беа споредени со толкувања од геолошките и геотехничките карти на локацијата на станицата. Нашите наоди ја поддржуваат идејата дека таквите геофизички методи можат да го детектираат основниот структурен профил во прва апроксимација и може да се користат за развој на модели на конзистентна брзина за големи области без скапи опреми за бушење.

Клучни зборови: *записи на земјотреси; анализа на силно движење (SM); Накамура метод*