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Original Scientific Paper

DEFINING SEISMIC PARAMETERS FOR AN ESSENTIAL ELECTRIC POWER FACILITY

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Abstract. *For the purpose of building a new electric power facility a project to determine seismic potential and seismic parameters for design is produced. Multiple in-situ geophysical investigations have been performed and soil samples have been taken to the laboratory where simple shear tests are done to determine the dynamic parameters of the soil layers. As a result, the dynamic shear modulus and damping ratio vs shear strain relationships of characteristic soil materials were defined. The response analysis was done using these curves, where the effects of the sub-surface local soil medium have a dominant influence upon the amplitude and frequency modification of the expected ground motion. Finally, the seismic design parameters, maximum accelerations at foundation level for design and maximum earthquake site-specific response spectrum have been obtained.*

Key words: *simple shear tests, response analysis, seismic design parameters.*

1. Introduction

The investigations presented in this report have been carried out for the purpose of defining the seismic potential of a site where an essential electric power facility is planned to be built. These investigations represent continuous work for the site that started with the determination of local hazard and selection of earthquakes that will be used in the analysis done by the department of Natural and Technological Hazards and Ecology part of the Institute of Earthquake Engineering and Engineering Seismology- IZIIS, Skopje [1,2,3,4,5]. Field geophysical and geotechnical surveys carried out using the seismic refraction tomography method – SIRT were used to define the regional and local seismotectonic,

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geological and seismological data. A final product of these investigations is the definitions of Vp and Vs – seismic velocities and d – thickness of the layers. From the velocities, additional information can be gained such as: distinguishing of lithophysical media within the terrain structure and dynamic values of the geomechanical elastic parameters (Table 1). Soil samples were taken from three different boreholes (BH-14, BH-17, and BH-22), that were made on the site, at different depths from 4 to 12m. The laboratory testing of samples was performed in the Soil Dynamic Testing Laboratory, Department of Geotechnics and Special Structures, using a direct simple shear apparatus (DSSA) to determine the shear modulus and damping in correlation with shear strain curves. These curves have been implemented in mathematical models of the soil for the analysis of the seismic site response. The analyses have been carried out by using the software Shake2000. The results from the analysis are used to determine the seismic design parameters for different serviceability periods.

2. Geophysical Survey

For the geophysical measurements 34 channel SoilSpy Rosina digital seismograph was used, also geophones with a natural frequency of 4.5 Hz were used for recording the seismic energy. Measurements using the seismic refraction method were performed along 8 seismic profiles with a total length of 740 meters: 4 seismic profiles of 80 m, 2 seismic profiles of 85 meters, 1 seismic profile of 100 m, and 1 seismic profile of 150 m. The distance between the geophones was 5-5.3 meters and the minimal offset (distance between the source and the receiver) was 5-5.3 meters. The acquisition was done by a sampling frequency of 1024 Hz and a time duration of 0.5 seconds. Seismic energy was generated by hammer blows with a hammer that weighs 8 kg upon an aluminum plate.

2D models were obtained from the analysis of the geophysical data where 5 lithological media are distinguished and are characterized by different physical-mechanical characteristics such as:

- Surface layer – clay, with values of seismic velocities: Vp=450-900 m/s; Vs=160-320 m/s
- Subsurface layer – clay, with seismic velocities values: Vp=950-1200 m/s; Vs=350-440 m/s
- Clay, with seismic velocities values: Vp=1250-1600 m/s; Vs=460-590 m/s
- Clay, coal clay, with seismic velocities values: Vp=1650-2200 m/s; Vs=610-840 m/s
- Clay, coal clay, with seismic velocities values: Vp>2200 m/s; Vs>840 m/s

The dynamic elastic parameters are calculated using empirical calculations following correlative relationships between the seismic velocities and the corresponding geomechanical parameter according to the literature [6,7,8]. The complete results for all the layers are shown in Table 1.

Table 1 Interval values of dynamic elastic parameters

Parameter	Surface layer	Subsurface layer	Clay	Clay, Coal clay	Clay, Coal clay
Vp (m/s)	450-900	950-1200	1250-1600	1650-2200	Vp>2200
Vs (m/s)	160-320	350-440	460-590	610-840	Vs>840
g (kN/m^3)	16-18	18-19	19-20	20	22
m_{din}	0.42	0.42	0.42	0.42-0.41	0.42
Edin (MPa)	110-570	630-1050	1130-1960	2110-3860	>4000
Gdin (MPa)	41-200	220-370	400-690	740-1370	>1400
Kdin (MPa)	230-1180	1310-2180	2350-4080	4390-7150	>7300

3. Dynamic Laboratory Investigation

The behaviour of soil deposits under expected seismic loading at the site is nonlinear, this will influence the ground motion parameters during the expected earthquakes and the dynamic interaction between soil and the facilities. The nonlinearity is most commonly presented by variation of dynamic shear modulus and the damping coefficients with increasing of the amplitudes of shear deformations. The definition of nonlinear dynamic relationships of soil layers at the site was carried out based on the results of the experimental tests on the soil samples performed by cyclic simple shear tests. The DSSA (Figure 1) previously mentioned was used for testing two cylindrical models simultaneously restrained rigidly in vertical direction by three loading plates, while in radial direction with series of Polytetrafluoroethylene (PTFE) coated steel rings [9]. The dynamic excitation in the form of shear strains is applied in horizontal direction through the central loading plate placed between the two models. Through the relative horizontal displacement of the rings the dynamic excitation is uniformly applied along the entire height of the model. Due to simple cyclic shear in the element shear strains will develop and hysteresis relationships can be obtained (Figure 2).

Fig. 1 DSSA in the laboratory for soil dynamics

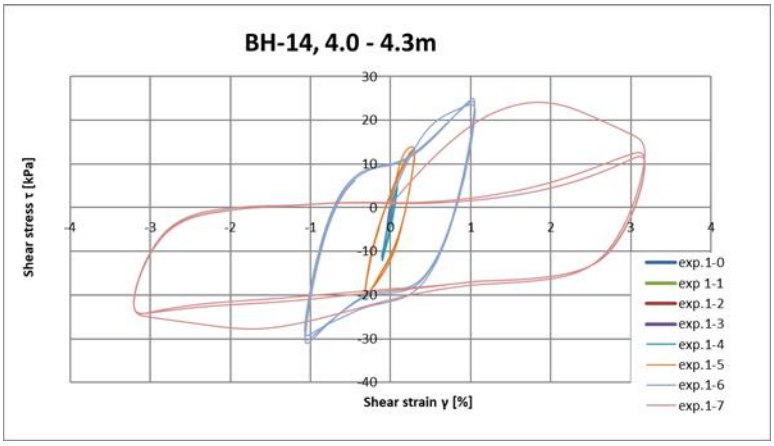


Fig. 2 Shear-strain relationship from one of the tests

The selection of the tested materials was made by careful examination of the received samples. Clay samples from boreholes BH-14, BH-17, and BH-22 were tested including characteristic horizons within each borehole. The testing material – borehole cores were received in plastic bags and placed in a wet chamber. The samples were tested as relatively undisturbed samples, with water content as preserved in the received samples and consolidated under effective pressure that corresponds to the investigated horizon. The excitation was applied step-by-step, eight steps in total, with variation of the maximum amplitude of shear strains in the range of g= 1.0x10-3% to g = 3%. The dynamic shear modulus are defined as a secant shear modulus (Gsec) that corresponds to the extreme points of the hysteretic curves for each strain level. By using the obtained values for the shear modulus

G-g diagrams are established (figure 3 and 4). Normalized shear modulus are obtained by dividing G/Gmax for each strain level, those are the ones used in the analysis [10,11]. Damping of the soil was defined by damping ratio D that represents a percentage of the critical damping. It is determined by using the following relation:

$$D = \frac{A_H}{4\pi A_{0ab}} * 100\ (\%)$$

where, D -damping ratio, A_H – area bounded by the hysteretic curve, A_{0ab} – Area of the triangle bounded by the secant passing through the extreme points of the curve. The damping ratios are also determined for each shear strain level and after that relationships are established (Figure 5).

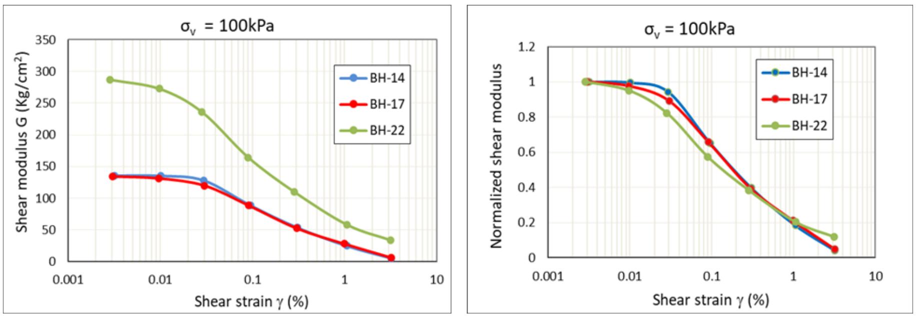


Fig. 3 Dynamic shear modulus vs shear strain for upper layers

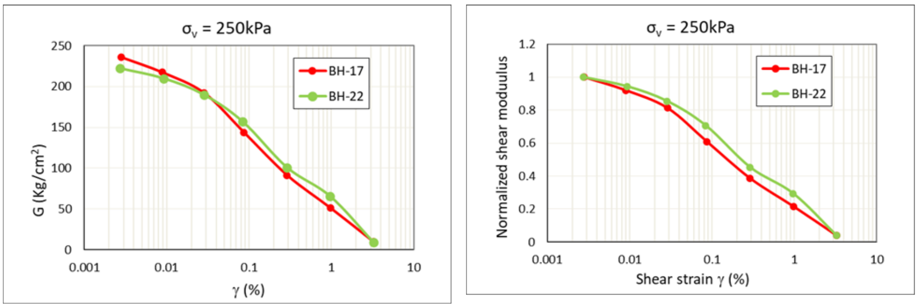


Fig. 4 Dynamic shear modulus vs shear strain for lower layers

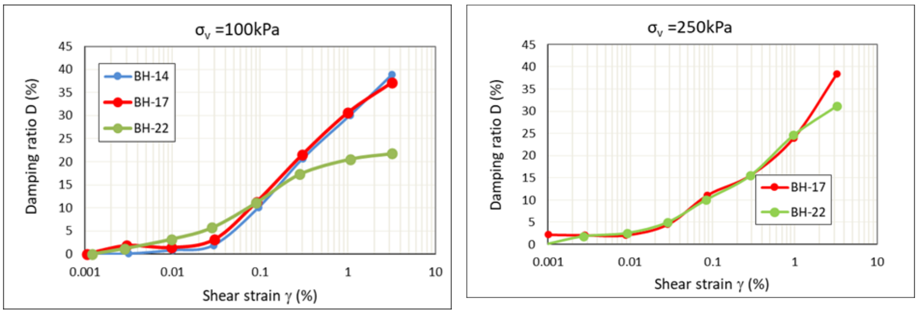
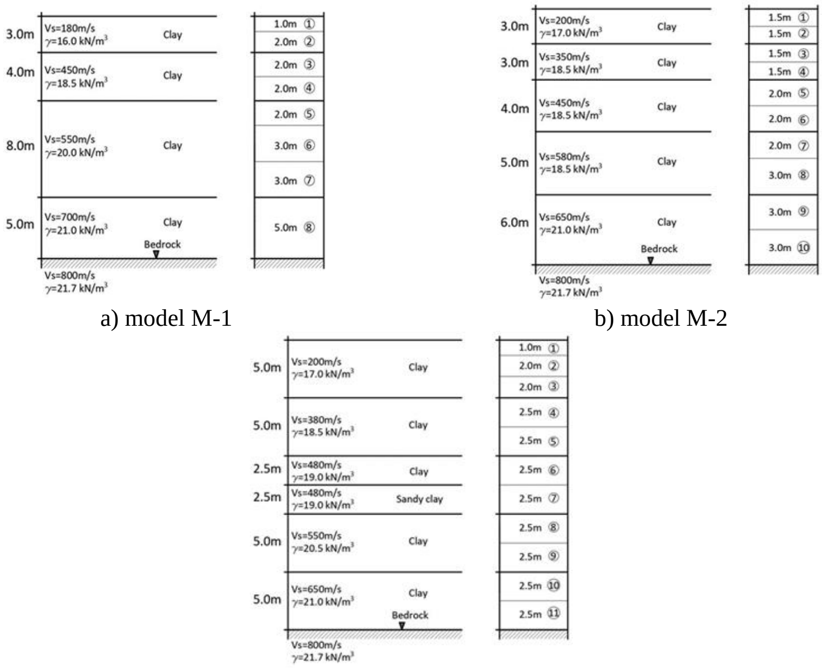


Fig. 5 Damping ratio vs shear strain for both layers

4. Effect of Local Geotechnical Media

The local geotechnical medium has a specific effect on the characteristics of the ground motion upon the surface during the earthquake. Depending on the characteristics of the local geotechnical medium and the characteristics of the excitation at the level of the seismic subsoil, the mentioned effect can be higher or lower [12]. The effect of the local geotechnical medium has been defined by analysis of the dynamic response of the mathematical models of soil (figure 6), called seismic site response. The analysis has been carried out by using the software SHAKE2000 which applies the method of vertical propagation of shear seismic waves through a liner-visco-elastic system that is based on the Kanai's solution of wave equation. The physical-mechanical and dynamic characteristics of the amplification medium at the site are represented by three representative geodynamical models. The ground classification scheme was done according to recommendations in Eurocode 8, where identification of ground types (classes) is performed using the value of the average shear wave velocity $V_{s,30}$.



a) model M-1 b) model M-2

c) model M-3

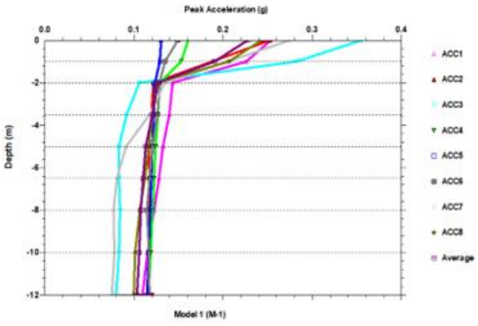
Fig. 6 Geodynamical and mathematical models at the site

Accelerograms of eight recorded earthquakes have been selected then scaled to expected ground acceleration. These time histories cover the prevailing period of the site and expected magnitudes, as well as frequency ranges with maximal amplitudes of seismic waves from the local and distant sources. The predominant periods resulting from the site response analysis for each model are given in Table 2.

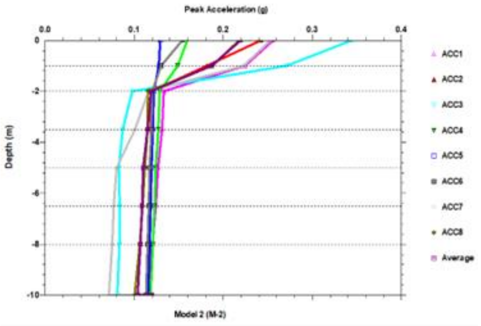
Table 2 Model predominant periods

Model	Period T (s)
M-1	0.105
M-2	0.086
M-3	0.126

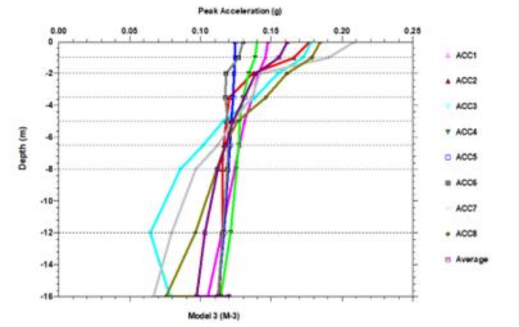
The accelerations along the depth of the models are presented in figure 7. The results emphasize that the surface layers amplify the seismic effect of the earthquakes. This layer has seismic shear velocity below 300 m/s and it has significant influence on the amplification and frequency effect on the earthquake motion [13]. Therefore, this layer was discarded as an option for foundation layer and the foundation was placed in the following layer ranging from -2.0 to -5.0 m. The dynamic amplification factor for the investigated location ranges from 1.05 for model M1 up to 1.16 for model M3. For further analysis and definition of input seismic parameters, the recommended value of the dynamic amplification factor (DAF) is considered as 1.2.



a) model M-1



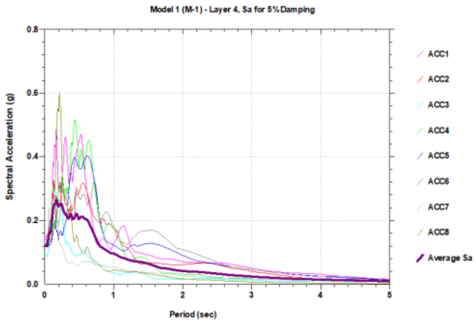
b) model M-2



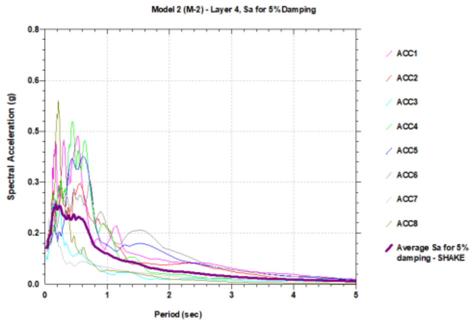
c) model M-3

Fig. 7 Acceleration along the depth for the selected accelerograms

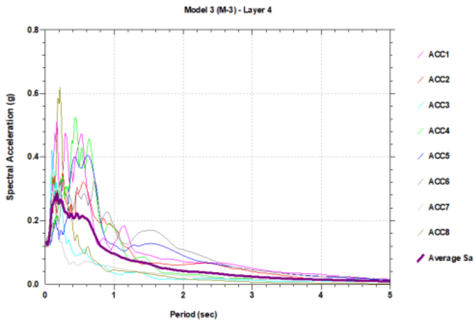
The acceleration response spectra have been computed for the selected earthquakes and for 5% damping with an input maximum acceleration of amax=0.12g. The obtained spectra for each model show similar results (figure 8) where the dominant amplitudes occur in the period range of 0.2 to 0.3s.



a) model M-1



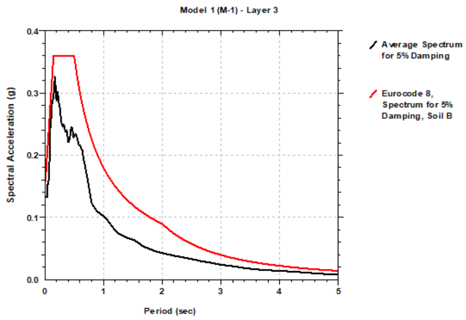
b) model M-2



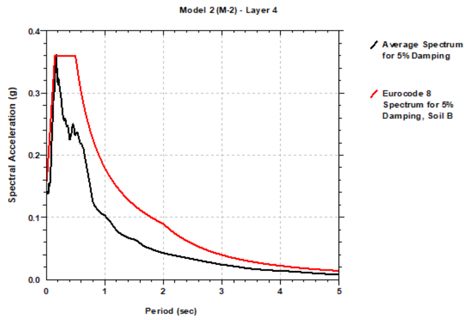
c) model M-3

Fig. 8 Spectral acceleration for 5% damping

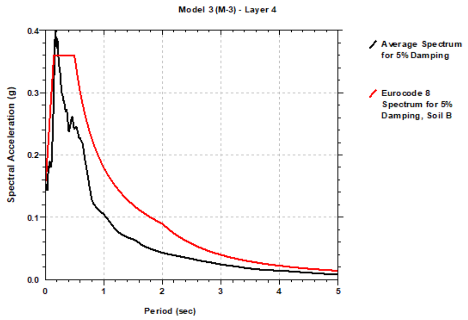
In addition, the computed average normalized spectra have been compared with normalized spectra defined by the Eurocode8, ground type B. As can be seen the amplitudes of the calculated average site response spectra are in the range or smaller than the amplitudes of proposed spectra from Eurocode (figure 9).



a) model M-1



b) model M-2



c) model M-3

Fig. 9 Spectral acceleration for 5% damping compared with Eurocode requirements

5. Seismic Design Parameters

The seismic parameters have been defined taking into consideration the seismic hazard at the site, seismicity at the site expressed in probabilistic way, and through application of the seismic risk methodology, which includes not only technical but also economic and technological elements of design [14]. Taking into account the need for dynamic analysis and design of the structures, the seismic parameters are given in the form of expected maximum acceleration. For future structures most important are maximum accelerations at the foundation level (amax) that depend on the maximum accelerations at bedrock (a_0) and the seismic effect of the local soil medium, expressed by the dynamic amplification factor (DAF). The main seismic design parameters, the maximum accelerations, have been defined based on the results from the seismic hazard and risk analysis under the following assumptions:

- the serviceability period of the main structures is 100 years (Table 3)
- the serviceability period of the auxiliary structures is 50 years (Table 4)
- for the design earthquake the acceptable seismic risk level is 30%
- for the maximum earthquake, the acceptable seismic risk is 10%

Table 3 Seismic design parameters for foundation level for main structures

Serviceability period (years)	Seismic risk level %	Earthquake type	Max. acceleration a_{max} (g)	Corresponding return period
100	30	Design	0.124	281
	10	Maximum	0.169	950

Table 4 Seismic design parameters for foundation level for auxiliary structures

Serviceability period (years)	Seismic risk level %	Earthquake type	Max. acceleration a_{max} (g)	Corresponding return period
50	30	Design	0.108	141
	10	Maximum	0.145	475

6. SUMMARY AND CONCLUSIONS

At the request of the investors, in-situ geophysical measurements, laboratory and analytical investigations were carried out in order to define the seismic potential of the site. Based on the results the following conclusions are drawn:

- The loose surface and subsurface layers are characterized by weak physical-mechanical characteristics and represent a critical zone of the investigated location. These surface layers significantly amplify the seismic effect, therefore these layers are not recommended to be used as a foundation layer for the planned structures.
- Based on the results from in-situ geophysical measurements and the recommendations from Eurocode 8, the soil conditions of the site can be categorized as ground type B.
- The definition of nonlinear dynamic relationships of soil layers at the site based on results from experimental testing of soil samples was of great importance in the analysis. Using literature curves could significantly affect the analysis and further away from the correct results.

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DEFINISANJE SEIZMIČKIH PARAMETARA ZA KLJUČNO ELEKTRO-ENERGETSKO POSTROJENJE

Za potrebe izgradnje novog elektroenergetskog objekta izrađuje se projekat za utvrđivanje seizmičkog potencijala i seizmičkih parametara za projektovanje. Izvršeno je više geofizičkih istraživanja na licu mesta i uzorci zemljišta su odneti u laboratoriju gde se vrše jednostavna ispitivanja smicanja radi određivanja dinamičkih parametara slojeva tla. Kao rezultat, definisani su dinamički modul smicanja i odnos prigušenja u odnosu na smičnu deformaciju karakterističnih materijala tla. Analiza odziva je urađena korišćenjem ovih krivih, gde uticaji podzemnog lokalnog zemljišnog medija imaju dominantan uticaj na modifikaciju amplitude i frekvencije očekivanog kretanja tla. Konačno, dobijeni su seizmički projektni parametri, maksimalna ubrzanja na nivou temelja za projektovanje i maksimalni spektar odgovora specifičnog za lokaciju zemljotresa.

Ključne reči: *jednostavna ispitivanja smicanja, analiza odziva, parametri seizmičkog projektovanja*