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Comparison of acceleration spectra modelled with Eurocode 8 procedures and detailed seismic wave propagation in 2D.

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ABSTRACT

For seismic design of structures based on European Codes the designers take the peak ground acceleration (PGA) values on ground type A (rock) from the seismic hazard map of Albania. Based on these values and the type of the ground is formed the response spectra which serves as input for seismic analysis of structures. Recent measurements and studies of different authors have emphasized that for the ground classification accepted in EC8 response spectrum values in some cases do not match with reality. So it is necessary, especially when we built on soft soils to do a detailed analysis for propagation and amplification of seismic waves. These analyses are even more important if for the calculation of the structure will be used seismic dynamic analysis in which time history of acceleration is used as input. The paper gives for a real example the wave propagation modelling, the choice of soil parameters, damping coefficients, boundary modelling, finite element size and the integration constants. After all the parameters are calibrated based on the literature and 1D solutions, in the model output results are obtained time histories of acceleration and corresponding spectra. Obtained spectra are compared with spectra generated by Euro Code 8 procedures and is seen that they change. Based on the results are given the recommendations for seismic analysis of the structures on soft soils. In these cases the designers must use a detailed analysis given in the study for propagation and amplification of seismic waves.

Keywords: *Wave propagation, EC8 response spectrum, wave propagation modelling*

INTRODUCTION

The seismic input used for seismic analysis of structures is taken by designers from seismic hazard maps of maximum acceleration (Peak ground Acceleration) values in bedrock (Soil type A) for a return predetermined period of recommended by design codes based on the importance of the structure [1]. Based on this value by applying amplifying spectral and site response coefficients different for each type of predefined category of soil on which will be constructed the structure are obtained the values for calculating seismic input. This approach has been used almost by all the worldwide design codes of structures. Coefficients are taken considering factors influencing the maximum values of seismic excitation in the rock (the proximity of the source, type of fracture, etc.) and ground type categories where the structure will be constructed. Classification of different soil types plays the primary role in selecting appropriate coefficients. In Albania the designers already used soil classification recommended by EC8. Recent studies such as Pitiliakis et al., or measurements made during the real earthquakes events as for Aquila Italy earthquake have shown that the classification recommended by EC8 is quite simplistic and in many cases does not correspond to reality.

For this reason, in certain cases should be made a detailed site response study to determine accurately the seismic input. In any case, the process is complex and incorporates several factors such as technical, scientific as well as political from decision-making authorities.

SITE RESPONSE ANALYSIS

Site response analysis involves many technical factors ranging from seismological, geological, geotechnical and analytical and numerical modelling. To determine the site response the designer may use different approaches that can be classified as empirical, analytical or numerical in time or frequency domain with models 1D, 2D or 3D and also combination of above mentioned approaches or so called hybrid methods.

Here after are given the general principles of analytical/ numerical approaches which are based on propagating of seismic wave in a layered soil body.

The wave equation of motion for a vertical direction is [3]:

$$\rho\frac{\partial^2 u}{\partial t^2} = G\frac{\partial^2 u}{\partial z^2} + \eta\frac{\partial^3 u}{\partial z^2 t} \quad (1) \quad \rho\frac{\partial^2 u}{\partial t^2} = G\frac{\partial^2 u}{\partial z^2} + \eta\frac{\partial^3 u}{\partial z^2 t}$$

This equation has the solution u(z,t) in the form given in equation 2.

u(z,t)=Aei(wt+k*z)+Bei(wt-k*z) (2)

After the establishment of boundary displacement compability conditions and knowing that in surface τ=0, we can take the values of A,B amplitudes for each layer and determine in frequency domain the transfer function of motion.

Wave equations become independent of frequency by replacing the viscous damping with damping ratio as given in equation 3.

$$\eta = \frac{2G}{\omega}\xi \quad (3)$$

Soil behaviour is taken as a Kelvin-Voigt solid and is given by:

$$\tau - G\gamma + \eta\frac{\partial \gamma}{\partial t} \quad (4)$$

If the problem will be analysed in time domain, the solution is taken through direct integration using the calculated velocities at the end of each time step as the initial velocities for the next step as shown in equation 5.

$$\dot{U}_{i,t+}\Delta t = \dot{U}_{i,t} + \frac{\Delta t}{\rho\Delta^2}\left(\tau_{i+1,t} - \tau_{i,t}\right) \quad (5)$$

Once the boundary conditions are defined, integration starts from the bottom, as the source of incoming motion, until layer after layer reaches the surface. The total value is taken by summing all the incremental values for each integration time step [3] . These solutions can be taken analytically for simply geometric shapes and horizontal stratification, but for all other cases must be used numerical analysis.

Numerical methods can simulate the seismic motion in any condition. The main numerical methods are “finite element”, “finite difference” and the less used “boundary element” method. The numerical methods recently have made significant progress in wave propagation solution techniques, boundary simulation, material behaviour modelling and soil structure interaction allowing them to solve the complex problem from the source (far field) to the analysed structure including all the possible soil-rock conditions.

In Finite element methods, numerical modelling of wave motion can be performed by means of direct integration in time or through solutions based on frequency calculations. The latter due to their simplicity are widely used in the analysis of structures, but in modelling of ground wave motion are not very suitable. Numerical modelling through time integration allows easier implementation of the laws of advanced material behaviours that take into account the time dependency and material nonlinearity. In all these formulations, we should take into account a number of factors which will influence the numerical analysis such as: formulation of the mass matrix, the determination of the damping matrix, boundary conditions, critical time integration step, finite element size, etc., the damping coefficients must be chosen to match 1D wave propagation in elasto-plastic soil columns [5, 6]. The boundaries can be modelled by adaption of material properties of boundary elements, infinite elements and viscous boundaries. The last two methods are used mostly and the response of the system in both cases is the same [2]. Numerical methods are in many cases the only methods by which you can get the solution.

Selection and use of soil parameters for numerical analysis given in the chosen example

EXAMPLE. PLAXIS 2D USE IN SITE RESPONSE ANALYSIS.

Construction site that is taken in consideration is in the city of Elbasan. City of Elbasan positioned in central Albania is located in an area with high seismic activity. The Graben area zone is part of the transverse tectonic line Lushnjė-Elbasan, with average sinking process during Quaternary. Normal fault secessions directed north- northeast, that form the Graben are good evidenced in sectional seismic profiles. This tectonic line “Lushnjė Elbasan-Dibra” has an expanding regime outlined clearly by location earthquakes epicenters, and migration of earthquake epicenters. It is a tectonic line that is activated in the last two centuries in almost all its length, representing the most important tectonic line from the seismic standpoint for Albania [4].

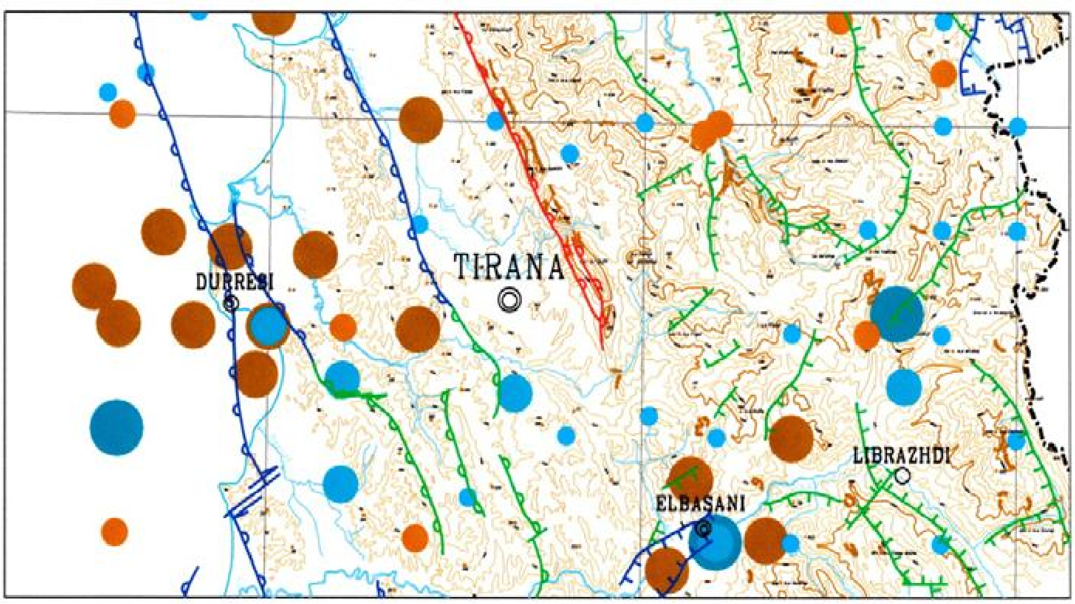

Figure 1: Tectonic map and strong earthquake epicenters for Elbasan city area

SEISMIC INPUT

Due to many uncertainties of a seismic event, the best way for seismic input evaluation is performing probabilistic seismic hazard analysis. Based upon the results of this analyse, we can have the desired parameters of seismic input (ground motion parameters) in any point. For numerical analysis, we need the time histories of this motion that are compatible with the design spectra given by the codes

For normal buildings structures, lifetime is 50 years and consequently the return period will be TR = 475 years [1]. For evaluation of Hazard, we have used the computer program CRISIS 2007. Since the data for seismic parameters must be derived from analysis of earthquakes catalogue, we have accepted the zones (seismic sources) characterized of the data given by "Geoscience Institute" [4]. The most influential zone for the site is the Pan Adriatic zone with the lower and upper limit of magnitude mo = 4.5 and mu = 6.9. Gutenberg-Richter model parameters of seismic event recurrence for this zone are b = 1.031 [4], a = 4.599 (number of events per year that have the magnitude > mo). Division of the zone was made with 10 km grid step and the grid is corrected considering the points where real earthquakes have been registered. We consider also as seismic source one tectonic line and the seismicity model for this tectonic lines is taken the characteristic earthquake model (not Gutenberg-Richter) with magnitude M = 6.5 [4].

After the evaluation of the PGA, the seismic input is taken as a real accelerograms from ESD database using the software Rexel [8] and scaling the accelerograms with the software Seismosoft [9]. The chosen accelerogram according to EC8 spectra is compatible with PGA taken from probabilistic seismic hazard analysis for TR = 475 years [4]. For taking into account the convulsion from surface to the depth in which is generated the input in the model a scaled factor is applied to the accelerograms. Three components of the selected accelerogram are given in Figure 2.

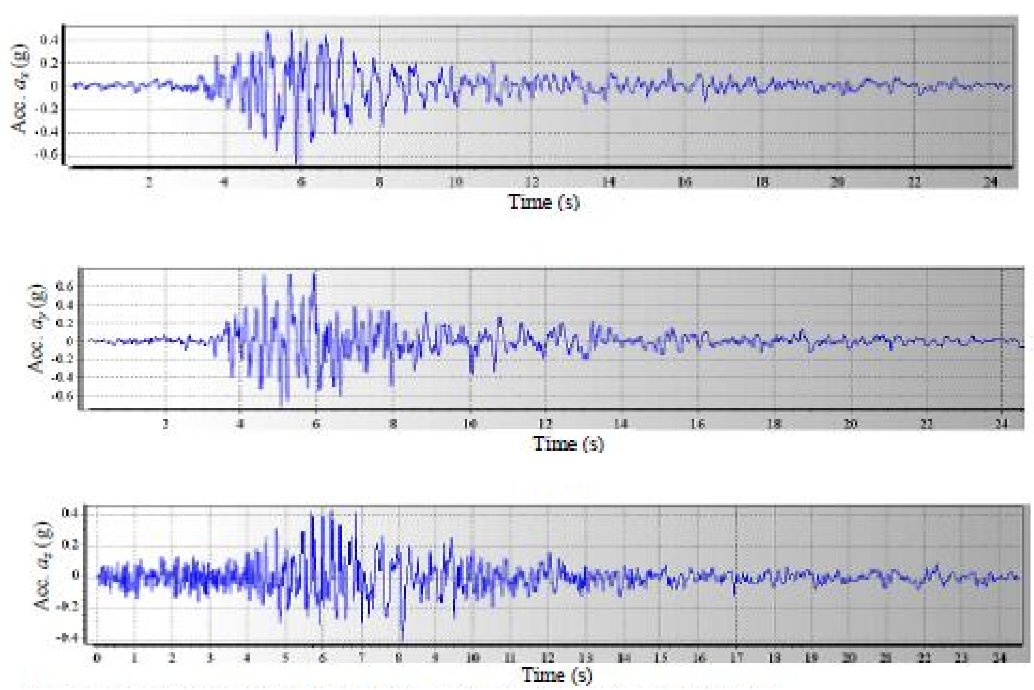

Figure 2. Time history of acceleration in x, y and z direction for the Montenegro earthquake

NUMERICAL MODEL

For numerical calculation we have used the software “PLAXIS 2D” [5].

The model is taken 100m long and 30m deep. It has 2431 elements with average length 1.2 m (< 1/4-1/8 wave length) [2,5] with medium mesh triangular 15 node finite elements. The material model behaviour is taken as a first attempt the classic elasto-plastic material model (Mohr-Coulomb) and finally after the calibration of the parameters the small-strain stiffness soil model (HSsmall). The Mohr-Coulomb material model parameters are estimated from site tests, laboratory tests and geophysical tests, the small-strain stiffness soil model parameters from the correlation given in literature. The model boundaries in Plaxis are created by absorbent viscous boundaries that give the same results as infinite element boundaries [2]. In our model, the relaxation coefficients that determined the normal (C1) and shear (C2) stresses absorbed by the damper are taken 1 and 0.25 [5]. The geological formations in our case are sandy clay gravel mixtures and the material damping Rayleigh coefficients are taken by using the analysis in plaxis material model for natural frequency and input motion predominant frequency (f1=2.4Hz, f2=8.8Hz) and comparison with 1D models (αR=0.1885, βR=0.00049). For the small-strain stiffness soil model (HSsmall) the shape of the shear modulus decrease is taken from Vucevic et al [5] . The model is shown in Figure 3.

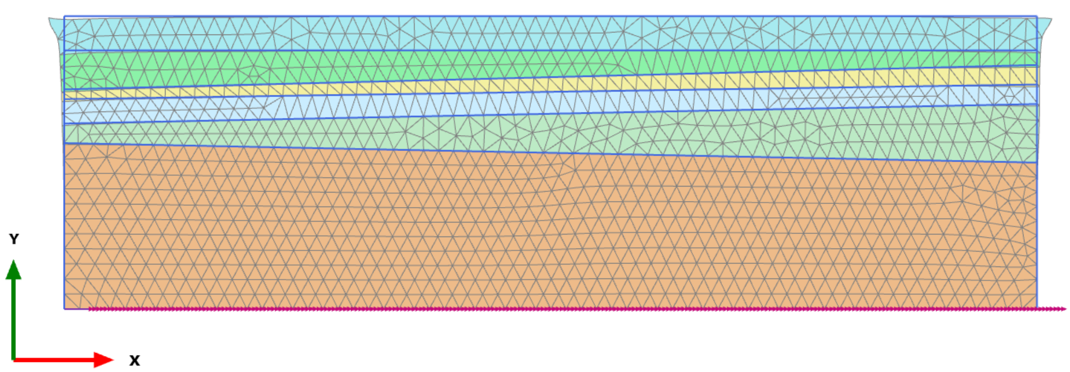

Figure 3. 2D Model of the site

Geotechnical parameters for Hardening Soil small soil behaviour (HSsmall) for each layer are given in table 1.

Table 1. Geotechnical parameters for each layer

Identification		1-2 fill	3 Sand	4 Sand-Clay	5 Sand	6 Gravel	7 Clay- Sand
$\gamma_{\_unsat}$	N/m³	15,60	16,00	16,60	17,00	20,00	18,60
$\gamma_{\_sat}$	N/m³	19,20	19,00	19,60	19,80	21,20	19,80
Rayleigh α		0,000	0,000	0,000	0,000	0,000	0,000
Rayleigh β		0,000	0,000	0,000	0,000	0,000	0,000
$E_{\_50^{\wedge}ref}$	N/m²	8000	6000	12,00E3	14,00E3	35,00E3	13,00E3
$E_{\_oed^{\wedge}ref}$	N/m²	8000	6000	12,00E3	14,00E3	35,00E3	13,00E3
$E_{\_ur^{\wedge}ref}$	N/m²	24,00E3	18,00E3	36,00E3	42,00E3	105,0E3	50,00E3
power (m)		0,5000	0,5000	0,5000	0,5000	0,5000	0,5000
$c_{\_ref}$	N/m²	16,00	10,00	23,00	8,000	5,000	21,00
ϕ (phi)		21,00	18,00	19,00	24,00	34,00	23,00

ψ (psi)		0,000	0,000	0,000	0,000	0,000	0,000
$\gamma_{0.7}$		0,2000E-3	0,2000E-3	0,2000E-3	0,2000E-3	0,2000E-3	0,2000E-3
$G_{0^{ref}}$	N/m²	65,00E3	65,00E3	85,00E3	156,0E3	326,0E3	682,6E3
ν_{ur}		0,2000	0,2000	0,2000	0,2000	0,2000	0,2000
p_ref	N/m²	100,0	100,0	100,0	100,0	100,0	100,0
$K_{0^{nc}}$		0,6416	0,6910	0,6744	0,5933	0,4408	0,6093
R_f		0,9000	0,9000	0,9000	0,9000	0,9000	0,9000
Tension cut-off		Yes	Yes	Yes	Yes	Yes	Yes
Failure criterion		Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb
K_0,x		0,6416	0,6910	0,6744	0,5933	0,4408	0,6093
OCR		1,000	1,000	1,000	1,000	1,000	1,000
POP	N/m²	0,000	0,000	0,000	0,000	0,000	0,000

RESULTS AND DISCUSSIONS

The model with simple elasto-plastic behaviour of soil materials with Rayleigh damping coefficients gives very different results from the formulation given by The EuroCode 8 and Pitiliakis [1, 7]. Taking from plaxis 2D analysis only site amplification factor "S" from bedrock to surface and constructing the response spectrum for this site it's seen that the results of the three approaches will be quite different. Acceleration spectra of the three approaches are shown in Figure 4.

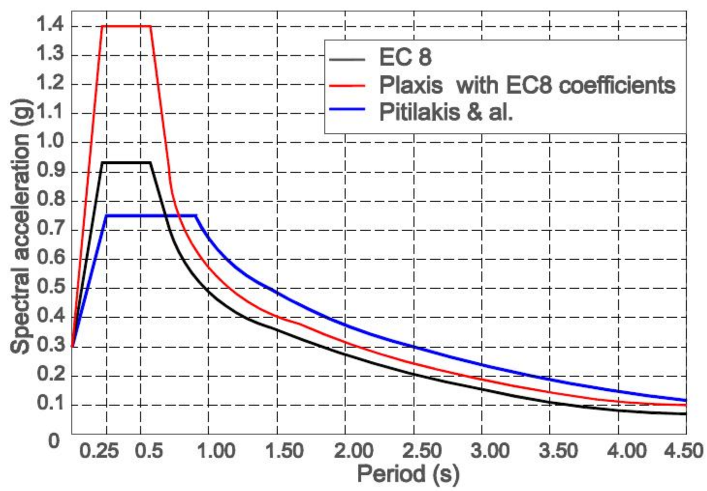

Figure 4. Spectral acceleration for 3 approaches. Plaxis model with Mohr-Coulomb soil behavior

So it becomes necessary to use advanced models of soil behaviour. Advanced material models cannot capture material damping for small strains and accumulation of strain, so we must add also the Rayleigh material damping coefficients [7].

Repeating the analysing process in Plaxis 2D we take the amplification soil factor "S" from bedrock to surface and build the acceleration response spectrum for this site by the Plaxis 2D software procedure. It is seen that the peak values are similar to those proposed by EC8 but have quite large range (TC corner period quite large). Spectra under three approaches are shown in Figure 5.

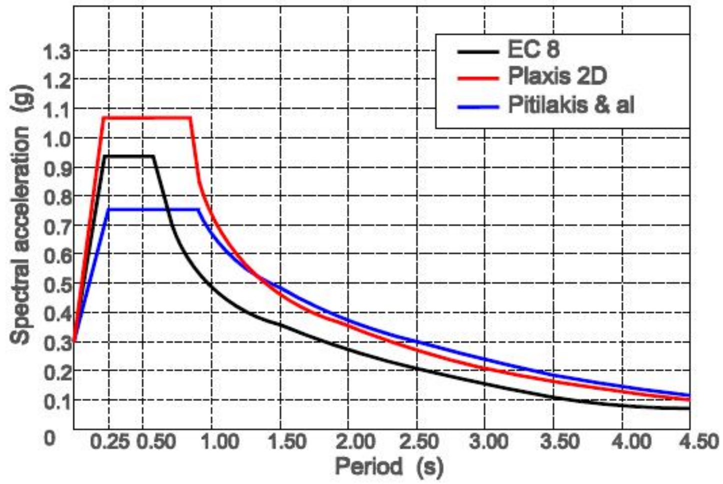

Figure 5. Spectral acceleration for 3 approaches. Plaxis model with Hardening-Soil-Small soil behavior

CONCLUSIONS

Use of the response spectra according to Eurocode 8 procedures gives smaller acceleration values for periods greater than 1s, and therefore quite small values of seismic loads for structures with predominant period greater then 1s. It is therefore necessary that for these structures when constructed in soft soil formations of type “C” and “E” and partly “D” to do a detailed seismic site response analysis. Spectrum values generated from 2D Plaxis results for non-horizontal layered site for small periods are approximatively the values given by EuroCode 8 spectrum and for large periods approximate values suggested by Pitiliakis et al.

The most efficient use of 2D numerical models with dimensions several tens of meters is the generation of acceleration time histories that are sufficiently realistic for the design of structures.

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