Material Strength and Applied Mechanics
A. Khotsianovsky and Y. Chen (Eds.)

doi:10.3233/ATDE240575

Assessing Local Site-Specific Response Spectra Based on Site Data in Győr

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Abstract. It is essential to understand seismic ground motion in order to understand how dynamically a structure responds to earthquakes. Due to variations in seismic loading, strong ground vibrations can damage structures to varying degrees. The different essential traits of powerful ground motions help explain this ground diversity during moderate to large earthquakes. This study mainly focuses on the comparison between ground motion parameters such as the Peak Ground Acceleration (PGA), and local site spectra considering the design response spectrum and site-specific response spectra of varying soil profiles in Győr. Multichannel Analysis of Surface Waves (MASW) data from eleven different places in Győr were considered and analyzed using the 1-dimensional response analysis software, STRATA, and a detailed comparison was carried out between the different site locations in terms of PGA, and local site spectra. The result revealed the sites with the highest amplifications based on peak ground values of acceleration, velocity, and displacements. With 1-dimensional STRATA software, peak ground acceleration profiles, and response spectrum results are obtained and compared to Eurocode 8 standards.

Keywords. Earthquake, peak ground acceleration, ground motion amplification, and specific site acceleration spectrum

1. Introduction

The amplification of ground motion data from bedrock to the ground surface is affected by soil properties, which are equally capable of vibrating structures giving rise to base shear, moment, and torsion. These forces, which are the consequence of vibratory motion, cause displacements and rotations at the soil-foundation interface. Additionally, these displacements result in energy loss through hysteretic soil damping and radiation damping, both of which have a major impact on the damping of the entire system [1].

A soil profile is made up of distinct layers with different thicknesses depending on the characteristics of the soil. The soils strata are often recorded from borehole samples, discretized based on the kind of soil, or inferred from a shear-wave velocity profile. Each layer is distinguished in a seismic site response analysis by its thickness, mass density, shear-wave velocity, and nonlinear characteristics [2].

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The surface waves move through various materials at varying soil profiles and speeds, which is used in seismic analysis. Any change in the soil qualities may alter the expected surface motion and its standard deviation since the dynamic response of a site is dependent on the soil properties which have a significant impact on the propagation of seismic waves and are typically influenced by the magnitude and travel time of seismic waves such as soil stiffness, density, and damping [2].

2. Ground Motion Data

An earthquake effect manifests as a combination of source, path, and site characteristics. Aside from earthquake magnitude, site conditions play an important role in earthquake damage to infrastructure. Due to the amplification of seismic waves, an earthquake that appears to have no impact above solid ground may inflict significant damage in places above soft or unconsolidated sediments [3].

2.1. Classification of ground motion data

Classification of ground motion data is the process of categorizing earthquake records according to their spectral characteristics and other attributes [4]. In his preliminary studies, Sucuoğlu et al. noted that the following six characteristics are among the most notable for a general evaluation of ground motions [4]: peak ground acceleration, peak ground velocity, strong motion duration, pulses and pulse sequences, energy content, and spectral response forms for regions and building types. However, Kamal investigated those parameters that help in the characterization of strong motion data and are classified into four major groups: velocity, acceleration, displacement, and frequency [5].

In correlation with the above two statements, Derakhshani [6], stressed that various seismic variables determine the parameters of strong ground motion. Source, path, and site effects are the most critical seismological aspects affecting the Peak Ground Acceleration (PGA), Peak Ground Velocity (PGV), and Peak Ground Displacement (PGD) [6]. Crowley [1] highlighted that building and infrastructure damage in an earthquake is more directly tied to ground motion, which PGA is a measure of, than the magnitude of the earthquake itself. Damage is frequently connected with PGV in severe earthquakes, while PGA is a decent indicator of damage in moderate earthquakes. PGV is a seismic parameter that measures the maximum velocity of ground motion caused by an earthquake. PGV is used to evaluate the potential for non-structural damage, such as damage to piping systems, electrical wiring, and other equipment that are sensitive to vibrations [7].

2.2. Acceleration and displacement response spectra

The typical earthquake ground motion response spectrum is an envelope of numerous single-degree-of-freedom (SDOF) systems' peak responses over a range of period lengths [8]. The relationship between a SDOF system's natural period of vibration and the highest absolute acceleration that it can experience due to the ground motion is known as the acceleration response spectrum. Like this, the peak displacement, in relation to the ground, of numerous SDOF systems with various periods is often represented by a displacement response spectrum. Thus, numerous different SDOF systems are analyzed to generate a response spectrum. The value of each point on the spectrum represents the peak response of a SDOF system over a specific period [7].

2.3. Ground motion scaling

Ground Motion Scaling is a process used in seismology to predict the ground motion characteristics, such as PGA, PGV, and PGD, that can be expected at a particular site during an earthquake event. The scaling relationship between earthquake magnitude and ground motion parameters is a fundamental concept in earthquake engineering and has been extensively studied over the past decades [8].

For the sake of this study, the magnitude scaling methodology defined in the software package REXEL [9], is used to identify base motions, by considering key earthquake parameters such as the soil type and classification, average distance of the earthquake epicenters, etc. were analyzed and imported into STRATA for motion amplification determinations which is then compared to Eurocode 8 criteria.

2.4. Characteristics of soil profiles

Geotechnical engineering practice depends heavily on geology since the qualities of soil can vary significantly even within a few centimeters. As such, understanding the characteristics of soil at a specific site is a fundamental responsibility of geotechnical engineers. Soil, which is formed from rock weathering, is a complex substance that can vary considerably. Boore [8] notes that soil is a complex substance with great variability. Therefore, geotechnical engineers need to deeply understand the soil properties at a site to ensure the success of engineering projects. Unrealized geological formations and groundwater conditions have been responsible for the failures of many geotechnical systems and increased construction costs. Kegyes-Brassai [10] further classified the soil types of Győr into eight classes based on their seismic amplification class established by Eurocode 8 (EN 1998-1: 2004 E) as shown in Figure 1.

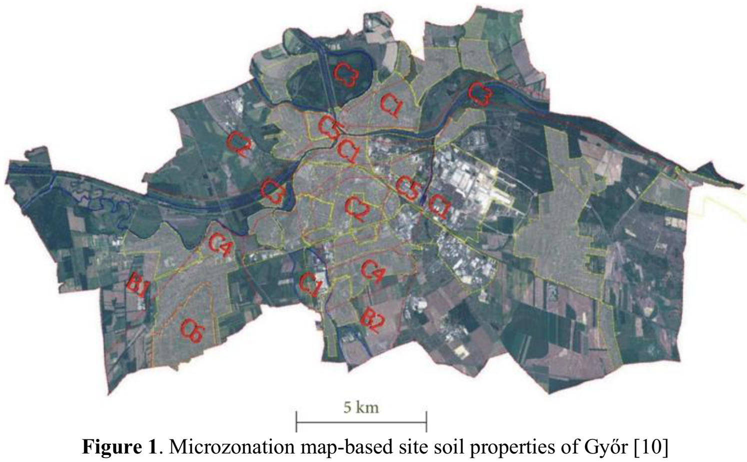

Figure 1. Microzonation map-based site soil properties of Győr [10]

Based on Eurocode 8, the primary factor used to classify soils seismically is the average soil shear wave velocity for the upper 30 meters of the site, or V_{s30}, which is a stiffness factor at modest upper soil stratum deformations which helps in understanding the properties of soil and their behaviors in seismicity zones.

3. Materials and methods

Multi-Channel Surface Wave (MASW) seismic data were acquired at eleven preselected sites in Győr, a city in Northern Hungary. The primary objective of this study is to generate and compare soil categorizations based on shear wave velocity profiles and thickness with the specifications of the National Earthquake Hazards Reduction Program (NEHRP). The average shear wave velocity values obtained from the MASW data were used in the 1-dimensional STRATA software to determine peak ground acceleration, and local site acceleration spectra for the selected locations in Győr.

To analyze the site response, the computer software STRATA was employed, which uses equivalent linear site response analysis in the frequency domain. This software allows for the randomization of site characteristics using time domain input motions or random vibration theory methodologies. By considering strain-dependent dynamic soil properties, STRATA computes the dynamic site response of a one-dimensional soil column [2].

The propagation of wave amplitudes in STRATA is calculated using recursive formulas that maintain the compatibility of displacement and shear stress at the boundaries between layers. These formulas are applicable to layers with uniform soil characteristics and wave amplitudes. To determine the response at the surface of each site, the wave amplitudes for soil site profiles (A, B and C) are utilized at each frequency, assuming that the stiffness and damping within each layer are known [2].

4. Data collection and presentation

In this study, A Multi-Channel Surface Wave (MASW) which is a known non-destructive geophysical method used to determine the shear-wave velocity profile of the subsurface was employed in the preselected sites as mentioned earlier, which were chosen based on their geological and geophysical characteristics. The MASW data were collected using a multi-channel seismic instrument, and the results show that the shear-wave velocity varies significantly across the study area, indicating variations in the subsurface structure and geology as shown in Figure 2.

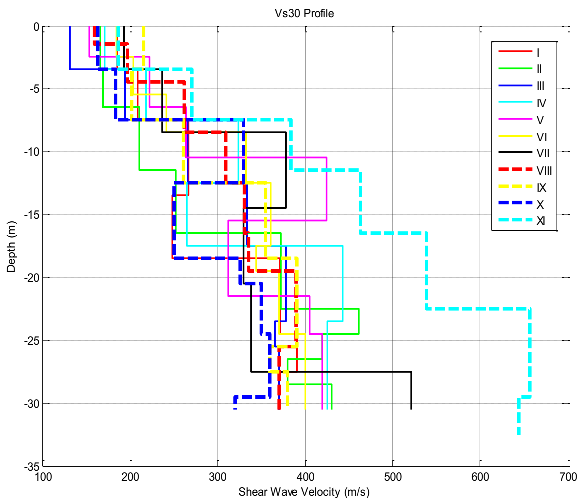

Figure 2. Shear wave Velocity profile for the eleven considered sites

5. Results and discussion

Based on the applied methodology the Multi-Channel Surface Wave (MASW) seismic data obtained from eleven preselected sites in Győr a city in Northern Hungary, were fed appropriately into a 1-dimensional STRATA software in line with the objectives of the study, and the following results of the Peak Ground Acceleration (PGA), and the local acceleration site spectral were collated.
Since MASW deals with shallow investigation depths ranging from 0 to 30 meters, it is important to correlate these depths by understanding the characteristics of surface wave amplifications with respect to the bedrock-fixed PGA of 0.12 g. Hence, to determine the suitable depth of the bedrock, three soil profiles were considered based on the highest, intermediate, and lowest amplification values and the first and second dominant frequencies for the return period of 475 years as also noted by [8]. Following that, a sensitivity depth test was done using a 1-dimensional STRATA analysis for the PGA only. This was done by varying the depth of the soil layers after 30 meters. Depths of 50 m, 100 m, 150 m, 200 m, and 250 m respectively were compared, and the observed outcomes were also noted as follows.

5.1. Soil profile A

Soil profile A has the lowest amplification value for a return period of 475 years for Gyor as published by Kegyes-Brassai [10]. Based on the results obtained for 1-dimensional STRATA software it is seen that peak ground acceleration increases with respect to the depth hence, the deeper you go the lesser the peak ground acceleration shown in Figure 3. Additionally, the plotted curves of shear waves become closer to each other. Figure 3 is the plotted graph of depth (meters) against peak median ground acceleration (g) as obtained from the STRATA software.

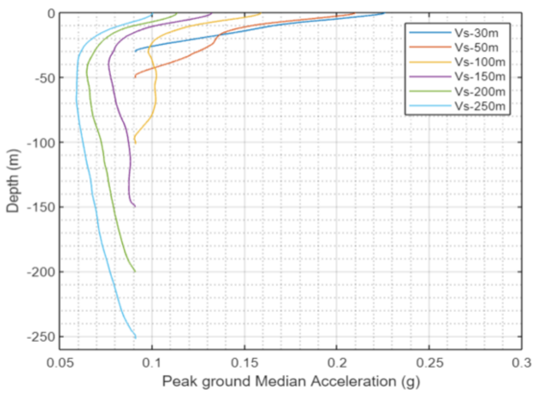

Figure 3. Sensitivity depth of soil profile A

For a considered 225 years of the return period (at 0.09g peak ground acceleration at Bedrock) based on the Hazard Map of Hungary in the NAD of EC8) in the case of depth sensitivity test and analysis, soil profile A shows that.

1) The deviation difference in PGA between 30m and 50m is roughly 4.3%.
2) 30.4% difference between 50m and 100m.
3) 12.5% for 100m and 150m

While the rest maintained at roughly 5 – 7% at maximum showing a massive decrease in peak ground acceleration with respect to depth.

5.2. Soil profile B

Soil profile B has an intermediate amplification value for a return period of 475 years corresponding to 225 years return period for Gyor [8]. Based on the results obtained for 1-dimensional STRATA software, it is seen that peak ground acceleration increases with respect to the depth as specified in the case of Soil Profile B as shown in Figure 4.

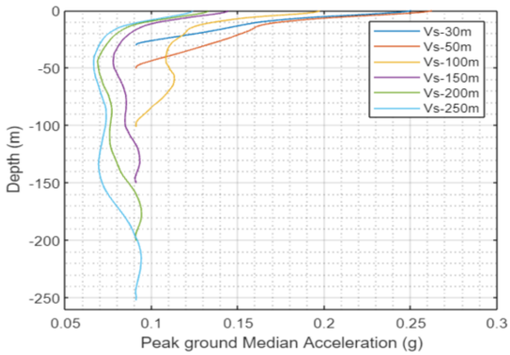

Figure 4. Sensitivity depth of soil profile B.

For a considered 225 years of return (at 0.09g peak ground acceleration at Bedrock) in the case of depth sensitivity test and analysis, soil profile III shows that.

1) The deviation difference in PGA between 30m and 50m is roughly 3.8%.
2) 23.5% difference between 50m and 100m.
3) 27.6% for 100m and 150m

While 150m, 200m, and 250m were maintained roughly at 5 – 7% at maximum showing a massive decrease in PGA with respect to depth as shown in Figure 4.

5.3. Soil Profile C

Lastly for soil profile C with the highest amplification value of 2.904 meters for a return period of 475 years corresponding to 225 years return period for Gyor [8]. Based on the results obtained from the soil profile C from 1-dimensional STRATA software, the following corrections were noted (Figure 5):

1) The deviation difference in PGA between 30m and 50m is roughly 7.8%.
2) 4.0% difference between 50m and 100m.
3) 23.3% for 100m and 150m

While 150m, 200m, and 250m recorded roughly at 23.8% and 13.6% for 200m and 250m this change in sequence is likely due to the higher amplification of soil profile C.

The variation in soil profiles (A, B, and C) is consistent and uniformly ranged between 100-150 m, as opposed to depths greater than 150 m. As a result of the findings, a depth of 150 meters was determined to be the best option since it offers an acceptable result with the smallest error for the less depth – optimizing effort to obtain data and the acceptable result for further consideration of this study based on the sensitivity depth test and analysis, on a 225-year return period with a PGA of 0.09g at Bedrock as seen in Table 1. This is because the variation in the sequence from the three analyzed soil profiles at 150 meters and below keeps falling within the range of values with a difference of 20% with an intermediate balance of 0.16g on average with the smallest error.

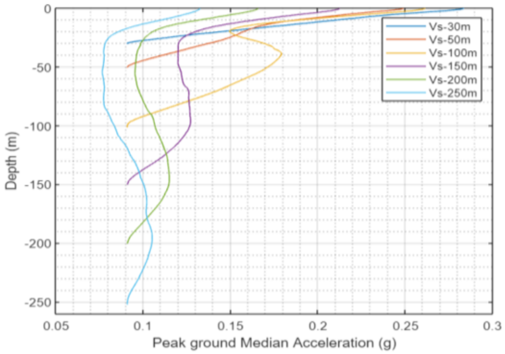

Figure 5. Sensitivity depth of soil profile C.

Table 1. PGA deviation summary

	Deviation difference in PGA (%)				
Soil Profile	**30–50 m**	**50–100 m**	**100–150 m**	**150–200 m**	**200–250 m**
A	4.3	30.4	12.5	5-7	
B	3.8	23.5	27.6	5–7	
C	7.8	4.0	23.3	23.8	13.6

6. Acceleration response spectrum

To determine the structural response to the motion of the selected sites, the acceleration response spectrum is plotted for the eleven sites. This involved creating a graphical representation of all the acceleration response spectrums and followed by the maximum and minimum responses of a structure to ground motion at different frequencies as shown in Figure 6.

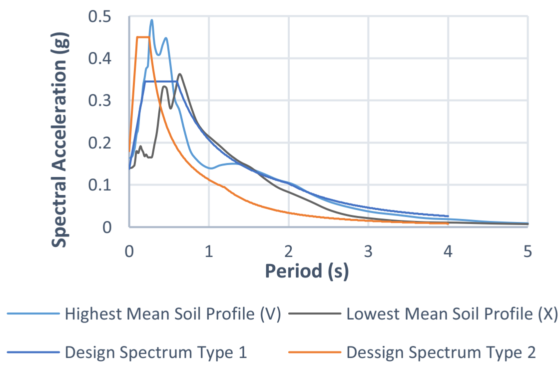

Figure 6. Acceleration response spectrum of the highest mean profiles of the considered sites based on Soil Type C.

Based on the acceleration response spectrum graph above (Figure 6), the eleven soil profiles are grouped and categorized into two groups according to their highest and lowest mean profiles (after running 100 realizations for each profile). These two groups are considered and compared with the design spectrum Type 1 and Type 2, as specified in Eurocode 8 respectively based on soil type C. Results indicate that soil profile V with a peak ground acceleration of 0.17 g for a return period of 475 years, a peak ground acceleration of 0.12 g at bedrock, making it the highest among all soil profiles. Additionally, soil profile V has the highest spectral acceleration of 0.49 g. It is essential to note that the design spectrum Type 1 falls within the lowest mean class of 0.35 g of the soil profiles, which is represented by soil profile X. Furthermore, the design spectrum Type 1 aligns closely with the period axis. Conversely, the design spectrum Type 2 falls within 0.04 g of the highest mean soil profile, represented by soil profile V. These findings provide valuable insights into the seismic response of the soil profiles and can be used to inform the design of earthquake-resistant structures.

The Hungarian Chamber of Engineers recommends the utilization of Type 1 design spectra. Nevertheless, based on the results obtained, a site-specific acceleration response spectrum would provide a more suitable fit. Therefore, it is advisable to consider this spectrum for design purposes as well. The findings highlight the essentiality of carrying out a thorough local site assessment to ensure optimal design outcomes.

7. Conclusions

Different site positions were successfully explored through a comprehensive analysis of Multichannel Analysis of Surface Waves (MASW) data obtained from eleven preselected sites in Gyor. The use of 1-dimensional STRATA software enabled the determination of PGA profiles, and acceleration response spectrum considering 100 realizations for each profile, two out of the eleven profiles (the highest and lowest mean profiles) were subsequently compared to appropriate standards of the design spectrum Type 1 and Type 2, as specified in Eurocode 8 respectively based on soil type C. The findings of this research have practical implications for seismic hazard assessment and mitigation in Gyor as both the Type 1 and Type 2 spectra were seen exhibiting lower amplifications than the site-specific spectra shown in Figure 6, these provides essential information about the ground motion characteristics and soil properties of the region.
Sensitivity test on depth characteristics were also noted and conducted to understand the relationship between depth of shear wave velocity and the surface amplification. This was noted on all the eleven selected microzonation points shown in Figure 1 and the results of the surface wave amplifications were seen to have been decreasing with respect to the height. This implies that upper V_s30 has higher amplification depending on the class of soils as there is a tendency of obtaining a firm stratum as the depth progresses as shown in Figures 3, 4 and 5 respectively.

These results can be used as a guide for the design of earthquake-resistant structures, soil improvement measures, and other seismic risk reduction strategies. The study also underscores the importance of MASW data in seismic site characterization and highlights the usefulness of 1-dimensional STRATA software in seismic hazard analysis and the exploitation of the site-specific amplifications.

In summary, this research has contributed to the body of knowledge on local seismic hazard assessment and has provided valuable insights into the ground motion characteristics and soil properties of Gyor. The results of this study are relevant not only to the local seismic hazard assessment and mitigation efforts but also to the wider earthquake engineering community. The findings of this research have practical applications in seismic risk reduction and can be used as a guide for future seismic hazard studies in Gyor and other regions with similar geological conditions with limitations for the upper V_s30 shear wave velocities in Gyor.

References

[1] Crowley H, Despotaki V, Silva V, Dabbeek J, Romão X, Pereira N, et al. Model of seismic design lateral force levels for the existing reinforced concrete European building stock. Bulletin of Earthquake Engineering, 2021;19(7), 2839–2865. doi:10.1007/s10518-021-01083-3

[2] Kottke AR, Wang X, Rathje EM. STRATA Technical Manual. 2019.

[3] D'Amico S, Akinci A, Pischiutta M. High-frequency ground-motion parameters from weak-motion data in the Sicily Channel and surrounding regions. Geophysical Journal International, 2018; 214(1): 148–163. doi:10.1093/gji/ggy107

[4] Sucuoğlu H, Yücemen S, Gezer A, Erberik A. Statistical evaluation of the damage potential of earthquake ground motions. Structural Safety, 1998;20(4), 357–378. doi:10.1016/S0167-4730(98)00018-6

[5] Kamal M, Inel M. Correlation between ground motion parameters and displacement demands of mid-rise RC buildings on soft soils considering soil-structure interaction. Buildings, 2021;11(3). doi:10.3390/buildings11030125

[6] Derakhshani A, Foruzan AH. Predicting the principal strong ground motion parameters: A deep learning approach. Applied Soft Computing Journal, 2019;80: 192–201. doi:10.1016/j.asoc.2019.03.029

[7] Building Seismic Safety Council. NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures. FEMA P-750. 2014.

[8] Boore DM, Atkinson GM. Ground-motion prediction equations for the average horizontal component of PGA, PGV, and 5% damped PSA at spectral periods between 0.01 s and 10.0 s. Earthquake Spectra, 2008;24(1), 99-138. doi:10.1193/1.2830434

[9] Iervolino I, Galasso C and Cosenza E. REXEL: Computer Aided Record Selection for Code-Based Structural Analysis. Bulletin of Earthquake Engineering, 2010;8:339-362. doi:10.1007/s10518-009-9146-1

[10] Kegyes-Brassai OK. Earthquake hazard analysis and building vulnerability assessment to determine the seismic risk of existing buildings in an urban area. Journal of Civil Engineering and Management, 2015;21(7), 886-898. doi:10.3846/13923730.2014.897904