University of West Hungary

Theses of PhD dissertation

Determination of earthquake site effect parameters by geophysical methods

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Preliminaries

The author of the dissertation has dealt with the mapping of earthquake site conditions since the early 2000s as research fellow of the Engineering Department of Eötvös Loránd Geophysical Institute of Hungary (ELGI). This activity has been connected to the general trend of the increasing attention paid to the heavy damages of earthquakes occurred in areas covered by loose sediments, as consequences of the modified wave propagation properties of this kind of formations (Mexico City 1985, Northridge 1994, Kobe 1995, Izmit, Taiwan 1999).

A number of analytical and empirical methods are used for estimation of earthquake site effects, which can model the observed amplifications of a site or at least the characteristic resonance frequencies. It is a natural requirement that the seismic codes and risk assessment methods also can include and handle earthquake amplification caused by the local geological structure. For these goals there is a need to introduce a classification which can be represented on maps and built on structural design procedures. Because of the large data demand and the strong direction dependence of different empirical and analytical methods a simpler parameter was searched for. This was found as the average shear wave velocity to a depth of 30 m ($V_{S,30}$) of geologic formation of the investigated site. This parameter and the defined site classes were incorporated first into the 1994 NEHRP Provisions (National Earthquake Hazard Reduction Program) and the 1997 UBC (Uniform Building Code).

Several in-situ measurements and large scale geologic information are needed for preparing an appropriate $V_{S,30}$ based site condition map. A number of geophysical methods are known for shear wave profiling, but drilling of rather expensive boreholes are necessary for most of these measurements. The aim of the presented project was to find a cost-effective surface method for this task. It was highly supported by the results of the research team led by László Hermann at ELGI dealing with multichannel surface wave inversion. Another issue of site condition mapping is the spatial extension of measurement results. The sheets of a large scale engineering geologic map series constructed for Budapest by a project team of the Geological Institute of Hungary and other institutions led by Györgyné Raincsák gave the suitable geological and geotechnical background of the work.

Objectives

The aims of the research program presented in the thesis are as follows:

- Development of effective surface wave measurement system and processing methodology for in-situ determination of $V_{S,30}$ values
- Efficient use of the available geological data for spatial extension of the measurement results

Parallel with the progress of the program new challenges and possibilities have been emerged pointing toward new goals:

More sophisticated procedures are necessary for mapping areas with different features either in terms of measurement techniques or using geologic data.

- Surface wave measurements in noisy areas with heavy traffic
- Using information of maps in highly variable geological environment

New mapping technics in the bibliography which cannot be ignored:

- Testing of topographic slope maps

Realistic test of the parameter – investigation an area hit by earthquake

- comparing the site effect parameter map and damage distribution in Dinar, Turkey

An additional aim of the thesis to present the role of $V_{S,30}$ parameter and site classes on the earthquake hazard assessment process

The research

The author of the thesis carried out extensive review of bibliography concerning the transmission of the near-surface loose sediments, surface wave methods and mapping procedures.

The author carried out field experiments based on developments completed in the Eötvös Loránd Geophysical Institute of Hungary applying literature information and his experiences on fieldwork and data processing to ensure the proper penetration depth, robustness against noise and spectral resolution. A suitable measurement system has been developed after processing of the gathered data. He implemented a passive surface wave processing technique in MATLAB, and after synthetic testing it was applied in practice. More than one hundred measurements were carried out in the three areas presented in the thesis, together with (partly or completely) the related data processing steps.

Besides the usual approach of the literature, in addition to covered geological map, uncovered geological, formation thickness and engineering geological maps were also involved for spatial extension of the measurement data. Review of geological information was done by studying repository fata, editing digital geological maps, in a subsequent stage by using GIS programs. The scanned geological sections were digitized, data converted by a MATLAB script for representation on maps. The topographic slope maps were completed by using SRTM digital elevation model processed by Surfer program.

New scientific results

Thesis No. 1

a.

A surface wave measurement system was developed by the author resulted in dispersion curves which are capable of characterizing the upper 30 m strata's seismic shear wave velocity profile. The process was established taking into account the available seismic instruments and data processing programs incorporating bibliography recommendations and experimental results. The obtained dispersion curves make it possible to reliably determine the average shear wave velocity to 30 m depth ($V_{S,30}$) providing homogeneous database according to the valid seismic codes. The measurement system was tested near to known velocity profiles determined by borehole measurements, validating the applicability of the method.

b.

In addition to widely used geological maps, uncovered geological, formation thickness and engineering geological maps were also involved for spatial extension of measurement data. Units with comparable stiffness characteristics were established based on similar facies of their deposits. These units support the choice of measurement points, and the verification of the resulted soil type classification.

c.

The appropriate choice of units were verified by their similar seismic velocity values determined by surface wave measurements, and the Eurocode 8 based soil condition map of District XVIII of Budapest was completed using this unification.

d.

One of the passive surface wave methods reported in the literature was successfully adapted to measurements in heavy traffic downtown area. The algorithm of the method was coded and tested on synthetic data. The system established by the results of these tests was used in field measurements. Results of the passive measurements were used for completing the Eurocode 8 based soil condition map of District VIII of Budapest.

Thesis No. 2

a.

Engineering geological condition maps for different depth ranges were correlated to the corresponding values of shear wave velocity profiles thus seismic velocity values were assigned to these maps. Average shear wave velocities of near-surface formations – which are usually consisting of quarter

sediment layers – were determined using GIS operations on these parametric maps.

b.
Delineation of the areas potentially falling in „E" ground type class has been made based on geological cross sections constructed for the Series of Engineering Geology Maps after their georeferencing and display on the maps.
Average shear wave velocity values were assigned to the deeper strata of the investigated 30 m depth range based on shear velocity profiles and different GIS databases.

c.
Site condition map of Óbuda situated in an area with complex geological setting was completed with the above described operations based on measurement results using GIS data and field measurement results.

Thesis No. 3
A number of surface wave measurements were carried out in Dinar (Turkey). Soil condition and velocity distribution maps were constructed based on the measurement results and compared with the damage distribution reported by previous studies. It was concluded, that the pattern of the damage distribution cannot be explained by only the poor site conditions, 3D, namely basin edge effect also have an influence on it.
The author was personally responsible for preparing the methodological part of the research plan, field detection and obtaining the dispersion curve from the records. The author had important role in visualisation and interpretation of the results, the final report and the published study including the revision work.

Thesis No. 4
The author investigated the topographic slope technique for site condition estimation based on the measurement results. Correlation of measured and assigned estimated $V_{S,30}$ values showed that the correlation is valid for Hungary in general, but applying the process for large scale maps it was found that in a number of cases like steep areas with possible landslides it can lead to significant discrepancies between measured and calculated $V_{S,30}$ values. It was concluded, that it is more reliable to use detailed geological and geotechnical maps for large scale site condition mapping.

Possibilities of utilizing the results

In recent decades new structural design standard series were established in Europe containing an independent part for earthquake resistant design (Eurocode 8). Before the introduction there was no obligatory regulation for seismic design in Hungary, so it was associated with a number of new concepts, test methods and design processes for the Hungarian experts. One of the new concepts was the seismic site effect and its appearance in the code as the well specified ground type category.

At the beginning of the described project the ground types were based mainly on geologic descriptions, but after a number of modifications in the 2004 draft similarly with the UBC regulations a more accurate classification was established in terms of a representative average shear wave velocity to a depth of 30 m ($V_{S,30}$). The standard which is mandatory in Hungary from 2010 was accepted in that form. Thus the constructed soil condition maps are very useful addition to the National Annex of the standard to help the geotechnical experts in the related tasks. Of course, it doesn't mean direct use of these maps in determination of site classes because of the scale and resolution constraints, rather the presented maps with an appropriate explanation can greatly help geotechnical experts in specifying related site specific tests and investigations to fulfil the regulations of EC 8.

In terms of methodology side different kinds of surface wave methods are rapidly growing recently in near-surface geophysics with useful geotechnical applications like landslide monitoring or basement and foundation characterization.

Related publications

Kanlı, A. I., Tildy P., Prónay Zs., Pınar A. and Hermann L., $V_{S,30}$ (2006) Mapping and Soil Classification for Seismic Site Effect Evaluation in the Dinar Region of SW Turkey, Geophysical Journal International, **165**, 1, pp 223-235

Kanli, A.I., Kang, T.S., Pinar, A., Tildy, P. and Pronay, Zs. (2009) A systematic geophysical approach for site response of the Dinar region, Southwestern Turkey: Journal of Earthquake Engineering, **12,** S2, pp. 165-174.

Bánné Győri E., Hermann L., Tildy P., Törös E. (2009) Geological/geotechnical and practical aspects of Eurocode 8, *Mélyépítés,* **7**(1) (*in Hungarian*)

Kegyes-Brassai, O., Ray R. P. and Tildy, P. (2015) Predictive equations for soil shear-wave velocities of Hungarian soils based on MASW and CPT measurements around Győr Acta Geodaetica et Geophysica **11**, pp 1-23

Related reports in Hungarian

Tildy P. (2003) Urban geophysics (Site condition mapping), Final Report, Manuscript, Eötvös Loránd Geophysical Institute of Hungary, Budapest

Tildy P. (2004) Urban geophysics (Site condition mapping), Annual Report, Manuscript, Eötvös Loránd Geophysical Institute of Hungary, Budapest

Neducza B., Tildy P. (2005) Urban geophysics (Site condition mapping), Annual Report, Manuscript, Eötvös Loránd Geophysical Institute of Hungary, Budapest

Neducza B., Tildy P. (2006) Urban geophysics (Site condition mapping), Final Report, Manuscript, Eötvös Loránd Geophysical Institute of Hungary, Budapest

Tildy P. (2007) Urban geophysics (Site condition mapping), Annual Report, Manuscript, Eötvös Loránd Geophysical Institute of Hungary, Budapest

Tildy P. (2008) Urban geophysics (Site condition mapping), Annual report, Manuscript, Eötvös Loránd Geophysical Institute of Hungary, Budapest

Related presentation abstracts in English

Tildy P., Hermann L, Neducza B. and Prónay Zs, (2003) Seismic Microzoning Based on Shear Wave velocity measurements, EEGS-ES 9th Meeting — Prague, Czeh Republic, 31 August – 4 September, **P-003**

Tildy P., Kanlı, A. I., Prónay Zs., Pınar, A. and Hermann L. (2005a) MASW measurements for soil classification in Dinar, Turkey, EEGS-ES 11th Meeting — Palermo, Italy, 4–7 September, **P019**

Tildy P., Hermann L., Kanlı A. I., Prónay Zs., Pınar A., and Törös E., (2005b) MASW measurements for Seismic Site Effect Evaluation, Fourth Congress of Balkan Geophysical Society, Bukarest, Románia, október 9-12, **O5–03**

Tildy P., Hermann L., Neducza B., (2007) Problems and Possible Solutions of Geophysics in Eurocode 8 Based Soil Classification. EEGS-ES 13th Meeting — Istanbul, Turkey 3-5 September, **P01**

Tildy P., Hermann L., Kanlı A. I., (2008) Multichannel Analysis of Surface Waves Technique in Geotechnical Studies. EEGS-ES 14th Meeting, Krakow, Poland, 15–17 September, **P13**

Tildy P., Prónay Zs., Taller G., 2013 Condition Mapping using Topographic Slopes, P-18800, 7th Congress of Balkan Geophysical Society – Tirana, Albania 7-10 October, **P-18880**

Related presentations in Hungarian

Tildy P., Hermann L., Prónay Zs., Törös E. (2004) Site condition mapping using soil class parameters of recent standards, Conference of Seismic Safety of Hungary, Széchényi István University, Győr, 4-5 November

Hermann L., Neducza B., Prónay Zs., Tildy P., Törös E., (2005) Determination of earthquake site effect parameter by surface wave method Results on National Earthquake Research Lectures in the frame of the Celebration of Hungarian Science, Budapest, 7 November

Tildy P., Hermann L., Neducza B., Törös E. (2007) Geotechnics and seismic safety — Eurocode 8 ground classes, VI. Conference on Geologic Hazards, Tengelic, 30 May

Tildy P., Hermann L., Neducza B., Törös E. (2007) Geotechnics and seismic safety — Eurocode 8 ground classification, Conference on Geotechnics 2007, Ráckeve, 16-17 October

Tildy P., Hermann L., Neducza B., Törös E. (2007) Geotechnical aspects of Eurocode 8, Conference of Seismic Safety of Hungary, Széchényi István University, Győr, 25-26 October

Tildy P., Hermann L., Törös E. (2008) Geological–geotechnical aspects and practice of applying Eurocode 8, Conference on Geotechnics 2007, Ráckeve, 28-30 October

Tildy P., Prónay Zs., Taller G., Törös E., Hermann L.† (2015) Site condition mapping in MFGI 34th Autumn Meeting of the Hungarian Geophysical Society, Budapest, 24-26 September