METHODOLOGY OF MAPPING AND DIGITALIZATION OF V_{S_30} FOR THE SEISMIC HAZARD ASSESSMENT IN BIG CITIES

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ABSTRACT. This publication presents the data sources, methodology, digitalization and mapping of the soil ground conditions reflected by the parameter Vs_30. This parameter is an integral characteristic of the ground conditions used in almost all procedures of the seismic hazard mapping software. The Vs_30 means the velocity of the transverse seismic waves to the depths of 30 meters of the ground layers measured from the ground surface. It depends of many factors like density and type of rocks and sediments, ground waters level, the seismic wave's velocity propagation, etc. and modifying the influence of the seismic waves to the structures located on the surface. This influence is measured by observed intensity, registered seismic acceleration and other dynamic parameters affected the built structures located on earth's surface. The methodology used a lot of archive data, because in situ measurements are difficult, frequently impossible to be done due to the intensive build environment of the big cities. The digitalization of this parameter is the main task solved for several big cities of Bulgaria intended to the seismic hazard and risk assessment. Examples of the solutions are presented.

Keywords: Vs_30, ground conditions, seismic hazard

МЕТОДОЛОГИЯ ЗА КАРТИРАНЕ И ДИГИТАЛИЗАЦИЯ НА V_{S_30} ЗА ОЦЕНКА НА СЕИЗМИЧНАТА ОПАСНОСТ ЗА ГОЛЕМИ ГРАДОВЕ

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РЕЗЮМЕ. Публикацията представя източниците на данни, методологията, дигитализацията и картирането на грунтовите повърхностни условия, отразени в параметъра *Vs_30.* Този параметър представлява интегрална характеристика на повърхностния грунтов слой и се използва в почти всички софтуерни програми за оценка на сеизмичната опасност. С него се означава стойността на скоростта на вторичните сеизмични вълни до дълбочини 30 метра. Зависи от много фактори – вид на скалите и седиментите, здравина на земната основа, ниво на грунтовите води, и др. и демонстрира модифициращите свойства на грунта върху скоростта на разпространение на сеизмичните вълни и тяхното въздействие върху построеното на повърхността. Това влияние се отразява върху наблюдаваната сеизмична интензивност, регистрираното ускорение на вълните и други техни динамични параметри. Методологията използва много архивни данни, поради невъзможността да бъдат правени *in situ* измервания, което се дължи на интензивното застрояване в големите градски агломерации.

Ключови думи: Vs_30, грунтови условия, сеизмична опасност

Introduction

The mapping of the natural hazards and environmental threats, vulnerability of structures and risk assessment and management are important issues to the prevention of population and the infrastructure as presented in (Frantzova, 2016a; Frantzova, 2017). The assessment of the damages and losses is the most important task in case of huge catastrophes and frequently influencing the GDP of any country (Frantzova, 2016b). The most advanced techniques and technologies are extensively used for the research and assessment of the consequences of the natural and technological disasters such as space remote sensing, high effective communication systems, etc. (Frantzova, 2012a; Frantzova, 2012b).

The seismic hazard and risk assessment in the recent times are exploited and implemented using different technologies, the most popular of which are models for simulation and risk management. This study is focused to the Vs_30 determination and digitalization as the very important parameter to the seismic hazard modeling.

The Vs_30 means the average velocity of the transverse seismic waves (S-waves) to the depths of 30 meters. This important characteristic is responsible for the S wave's velocity changes in the most upper ground layer and is an essential element included in the most calculus software packages for seismic hazard and risk assessment (HAZUS, EMERCOM, etc.) (Frolova, et al., 2019). Increased difficulties appear when the Vs_30 determination is necessary to be done for the seismic microzonation, seismic hazard and risk assessment, vulnerability of structures in the populated zones, urban areas etc., and have to be performed in large scales (Muco et al., 2012). All methods described above are very difficult to perform, due to the complicated measurement conditions. It is absolutely impossible to make regular grid, to perform bore holing and/or to take samples. Due to these difficulties a lot of archive materials have to be extracted, collected, digitized and interpret (Ranguelov et al., 2001), which is the main task in this work.

Data and Materials

The used materials have mostly the archive origin (the archive information is useful, having in mind that the ground conditions are conservative and did not change a lot in the time domain). In the urban environment frequently this is the only way to obtain reliable primary data and information. The collected and exploited data and materials are as follows:

- Data and information about former direct measurements of Vs_30 (seismic exploration data
- Data and information about former direct measurements of Vp_30 (obtained by different seismic methods) and the following calculation of Vs_30 using well known relationships.
- Former borehole data extracted by borehole direct (seismic) and non-direct (densitometry) measurements
- Archive information about geology (maps of different scales, layers of petrology composition, age, time of origin, thickness, roughness of the layers overlapping boundaries, lateral inhomogeneity, etc.)
- Hydrogeology information including archive data about depth of the ground waters level, pore permeability, liquefaction potential, etc.
- Laboratory tests data about samples taken earlier (use of the petro physical properties relationships to determine Vs (when possible), granulometry data, penetration tests, loading tests, etc.)
- Seismological data about macro seismic field of former earthquakes, intensities observed in the area, local inhomogeneity, observed liquefaction, cracks, sand volcanoes, land sliding and subsidence, etc. [8].
- Recent DEM, river's network, water bodies.
- Other data about former earthquakes, the macro seismic maps, acceleration records, attenuation lows.
- Geophysical maps and data about active faults, block structures, regional geophysical fields, geophysical prospecting information, etc.

In-situ measurements are performed, when possible, including direct seismic methods (Vp, Vs estimation), ground water level measurements, possible landslide surfaces determination, angle of slopes assessment.

To obtain the former data and information is necessary to discover, transform and use the archives, to transfer the searched information into recent measurement units and to present effectively analogue data collected in former times and not used until now. This is not an easy task. The transformation from analogue format to the digital one is performed using different software and processing platforms. For example, the short list of data and information sources about Sofia city is presented in Table 1. The advantages of the information digitalization are useful. The data are easy accessible and ready for computer processing.

Table 1. *Sources of data and information for Sofia city*

Source	Quantity	Referred to:
Geology maps	2	Published
Seismology maps	3	Published
Data from boreholes	8	Archive units
Lab tests	11	Archive units
In situ measurements	4	Field measurements
Geophysical maps	5	Archive units

Methodology

The methodology used for the data processing and interpretations includes:

- Graphic presentation of the investigated site as a polygon. This gives a possibility to cover the whole area of the urban territory following the curvature of the city shape.
- Construction of the dense network of longitudinal and latitudinal lines (in different scales, if necessary) and formation of a grid.
- Interpolation procedures and calculation of the investigated parameter as weighted average value (Vs_30).
- Performing the comparative analysis of all available date, processing the information and assessing the reliability of obtained values of Vs_30 as input data introduced
- Attribution to each sell of the grid the two obtained values of Vs_30 (the minimal and the maximal value). This provides the conservative approach and the user can choose the minimum value, the maximum value or the average one. This gives the possibility of the multiparameter approach for selection of the different variants for further calculations (Paskaleva, Ranguelov, 2015).
- Creation of the final map containing all geology units (simplified and presented like blocks for practical use), digital Excel table containing the presented on the map values of Vs_30 (min and max), together with the geography coordinates (in preferred by the user coordination system) thus forming the digital data base for the users Muco et al., 2012).
- Presentation of the explanatory notes considering the liquefaction potential, the landslide potential and the possible modification of the amplitudes and velocities of S waves due to the different hardness of the ground (Frolova, et al., 2019).
- The data for former earthquakes and their influences are presented as well. It includes, intensities, macroseismic maps, observed secondary effects generated by strong earthquakes (liquefaction, surface cracks, triggered landslides and stone falls, subsidence, generated tsunamis, avalanches and other gravitational phenomena, etc. (Ranguelov, 2011).

Similar approach gives the possibility of the interpreter to select the best fit of the data and information to the task and required elements thus providing flexibility and multi variances.

The algorithms and models used consider the scale of the investigated area, the density of buildings and structures, the population distribution, etc., but need most accurate ground condition assessment. Frequently it is not possible to assure such accuracy due to the intensive variability of the ground conditions and needs to use different approximations and extrapolation.

Example, Results and Discussion

The collected and processed data and information as well as the described methodology have been performed for a seismic vulnerable urban area of Sofia city. The presented maps illustrate the results obtained to the different modeled results and the reliability of the calculations. The grid selection (250x250 meters) is dominated by the practical consideration of convenient use and reliable input data to the seismic hazard maps generation. Two maps are presented to illustrate the obtained results.

Fig. 1 shows the digital map of Vs_30. On it the boundaries of the city are presented as polygon enveloping the urban limits of Sofia. As background the geology unified (based on the parameter Vs_30) blocks are separated.

Each block represents the unit with similar values of Vs_30. Two values are expressed: Vs_30min and Vs_30max. The consideration of this separation is practical. The user can vary in its calculations and use the minimum or maximum value according the main task and the purposes of the seismic hazard assessment, as well as to use average value as integral characteristic. This variability is rather convenient especially in case of lateral changes of the ground conditions.

The main difficulties from methodological point of view was the separation of the sediments of Block 1 to three sub blocks – 1.1; 1.2 and 1.3. The sedimentary characteristics especially according the genesis of sediments are valuable from geological constrains, but the geophysical properties are very similar and thus influenced the urban environment under possible seismic loading. Another peculiarity is related to the petrophysical properties of Block 2 – the Neogene sediments.

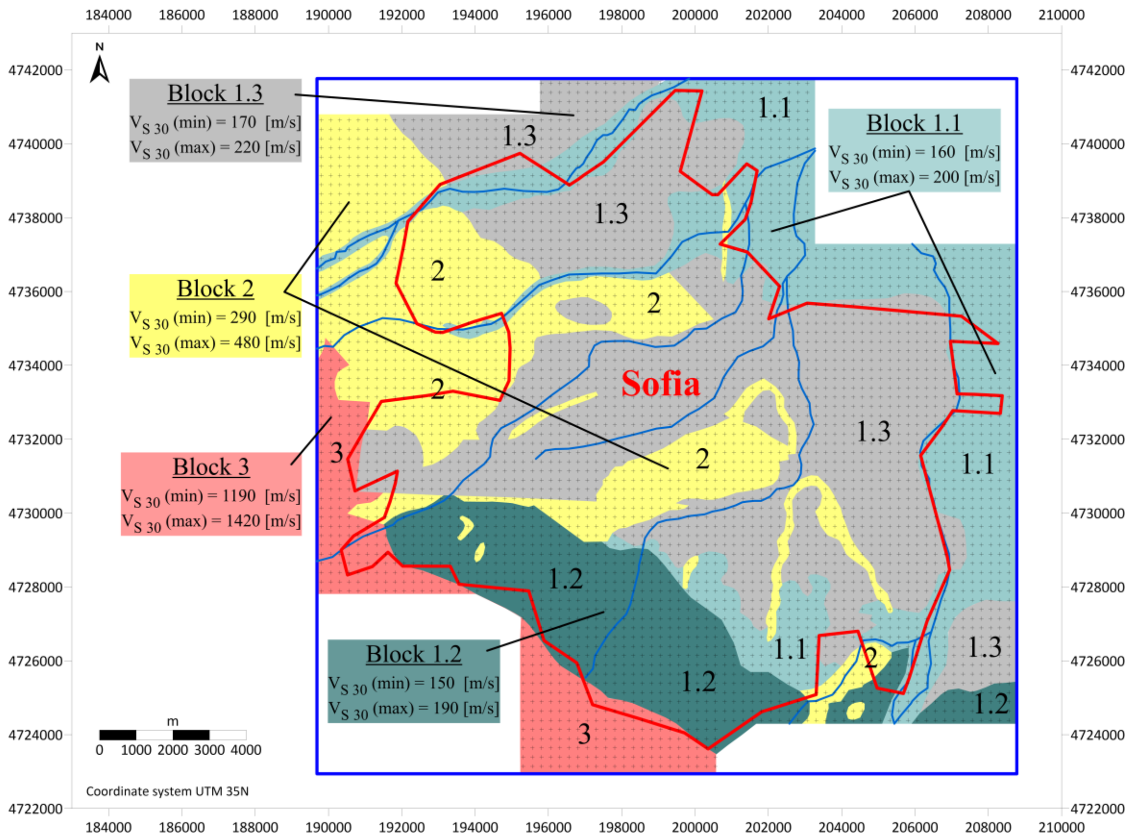

Fig. 1. Digital map of Vs_30 for Sofia city

They are very different and variable in their geophysical properties – mainly to Vs_30 values. That's why these variations attribute this block to two separate groups of ground properties (up to 280 m/s and between 280 and 360 m/s) according the international standards. The calculation homogenization procedures required to attribute this block to one of the two groups. To avoid this inconsistency two variants are suggested:

- To use the average value, which means to attribute the values of this block to the second standard group, or
- To calculate two variants – one with the minimum value (i.e. attribute to the first group) and one with the maximum value – assessment by second standard group.

It is well known that in Sofia region there are areas with landslides or other gravitational processes development. To get and asses the influence of the gravitational expected effects in case of strong earthquake, the DEM of the region is attached – Fig. 2. DEM or Digital Elevation Model is the innovative presentation of the ground elevations covering wide range of scales. It is clear visible that the largest gradient is presented at the footnotes of Vitosha Mountain, where the most gravitational processes are strongly developed. From point of view of the seismic danger it is also important to mention the possibilities of activation of the snow avalanches during strong earthquake if it occurs in winter times. Such secondary activated phenomena are now incorporated in the seismic hazard assessment procedures and must be included in the calculations. Another part of Sofia valley is flat and no needs the DEM application.

The important part of the prepared map models include the digital data base of the parameter Vs_30. It consists of coordinates of the grid points and values of Vs_30 for each point. In our case more than 4 300 values are calculated and ready for use just by import to the main software of the seismic hazard assessment procedure. The seismic hazard assessment of Sofia city itself is not the target to this publication and will be developed in future research and applications.

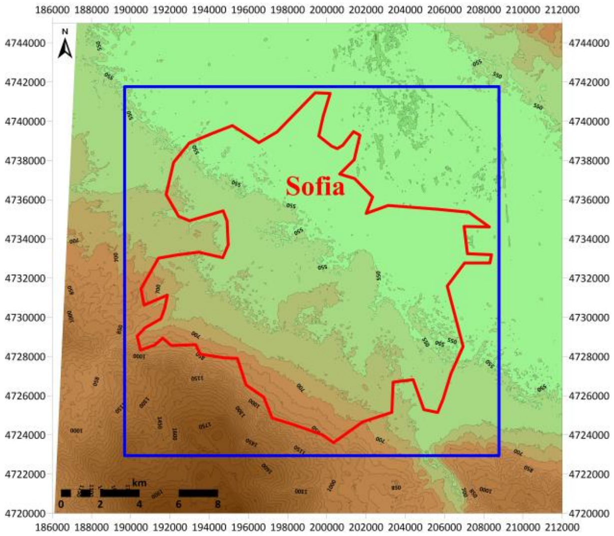

Fig. 2. DEM for Sofia city

Conclusions

The updated digital methodology for assessment of the integral values of Vs_30 is developed for practical purposes. It is intended to be in use for the massive electronic calculations of the digital seismic hazards maps for big cities in Bulgaria. In total six cities are selected (Varna, Rousse, Plovdiv, Blagoevgrad, Veliko Tarnovo and Sofia, located in seismic prone areas), but for the illustration purposes only one sample is presented (Sofia). The performed methodology including mostly archive materials (but also some in-situ measurements) shows high effectiveness and reasonable results. The new element is the suggestion of the two values of the Vs_30 (Vs_30min and Vs_30max). This provides the users of the newly calculated maps, wide diapason in variability of this parameter and gives the possibility for multi variant approach.

Sofia case is specific due to the peculiarities of the Neogene and Holocene sediments. The first are large variable in their seismic velocities properties. The second demonstrates variability which is due to their different genetics.

The performance of the model in different ground conditions in different case studies and seismic hazards calculations needs near future verification (Ranguelov et al., 2010).

Acknowledgements. This work has been carried out in the framework of the National Science Program "Environmental Protection and Reduction of Risks of Adverse Events and Natural Disasters", approved by the Resolution of the Council of Ministers № 577/17.08.2018 and supported by the Ministry of Education and Science (MES) of Bulgaria (Agreement № Д01-322/18.12.2019).

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