PROPAGATION OF VIBRATIONS AT THE ZEMUN SIDE OF THE ZEMUN-BORČA BRIDGE

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Summary: *Experimental and numerical analysis of vibration propagation at the Zemun side of the Zemun-Borča bridge due to construction works is presented, as well as the slope stability analysis of the loess plateau, which is about 15-20m above the Danube level and with very steep, almost vertical slope.*

Keywords: *Propagation of vibrations due to construction works, vibration measurements, slope stability*

1. INTRODUCTION

At the Zemun side of the Zemun-Borča bridge over the Danube there is a loess plateau about 15-20m above the Danube with very steep slope. In the proximity of the bridge construction site there are various properties, mostly small residential buildings of rather poor construction. Before the beginning of the major construction works related to the bridge abuttment (the pier number 1, consisting of 12 piles and the foundation block), it was necessary to make assessment of the construction works induced vibrations and its influence upon the nearby structures, particularly the two buildings at the very edge of the loess plateau, left and right of the construction site. Also, it was necessary to make assesment of the slope stability during construction works having in mind the properties of the loess soil, the slope shape and various machines, like the rotary drilling rig for installment of the drilled piles, the concrete mixer, excavating bager, crawling crane, etc.

2. VIBRATION PROPAGATION

Having in mind all circumstances related to construction works-induced vibrations, especially the fact that it was necessary to make an assessment of the induced vibrations

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prior to the begining of the actual construction works, the general approach to vibration propagation analysis was to conduct the vibration transmission measurements due to controled simulated construction works representing the worst case scenario, with respect to vibrations, of the future construction works. Also, prior to that, the ambient vibrations in the broader area of the site were made. Results of conducted sets of measurements are presented, among other forms, as the corresponding vibration distribution maps of ambient microtremor and of simulated construction works-induced vibrations. After that, assessment of vibration effects upon all buildings surrounding the site, and particularly upon the two most affected buildings at the edge of the loess plateau on both sides of the site, was made according to British and German standards BS 7385 (Part 2) and DIN 1450 (Part 3), as well as according to other available vibration assessment criteria. Vibration measurements were made by recording velocities and, for control purposes, accelerations. The basic measurements were done using the instrument TM-3C400, which is the seismometric 24-bit acquisition system with integrated GPS receiver. Three-axial velosimeters of the frequency range 0.1 - 600Hz were connected to the system. The system has an autonomus power supply of high capacity (48 hours of continuous work). Three-axial GeoSpace sensors were connected to the system, and measured data were stored in the computer memory. The sampling rate is 400 samples per second (400Hz), i.e. with the period, or the time interval of 2.5ms. During the acquisition of data the software package AcDat was used, while the later processing of data was done using the sowtware packages GeoDas 2.11, Grapher 8 and Surfer 8. The control measurements were related to measurements of accelerations. As the main acquisition system the instrument MGCPlus by Hottinger Baldwin Messtechnik was used, which has 8-channel modul for acquisition of dynamic outputs from accelerometers with the differential voltage. The conversion is 20-bit, so the high precission of measurements is enabled. Vibrations were registred by the MEMS sensors by SILICODESIGNS, with the measurement range of $\pm$2g, i.e. $\pm$20m/s^2. The sensitivity of sensors is 2V/g, in the frequency range of 0 - 300Hz, which enables the precission of measurements of about 0.001m/s^2. Figure 1 represents the layout of the measurement points and the instrument TM-3C400.

Fig. 1(a) Location of measurement points

Fig. 1(b) Measurement instrument

In considered case of future construction works, the probable source of vibrations could be the movement of heavy trucks over uneven ground and resulting shock loads. Also, the works related to soil compaction during construction of the access road are to be expected. Having in mind the future dominant construction works with the most potential for generation of vibrations, for the simulation of construction works a concrete mixer, a heavy truck and a tracked excavator (bagger) were selected. Figure 2 represents the machines selected to represent the simulated construction work.

Fig. 2(a) Heavy truck and a mixer

Fig. 2(b) Tracked excavator (bager)

Obtained results, presented in the form of the soil velocities distribution, or, as the velocity maps, for the ambient vibrations, or microtremor, and for induced vibrations due to simultaneous heavy truck and concrete mixer excitation, are given in the Figure 3. Velocity maps are isolines of measured ambient and induced velocity components.

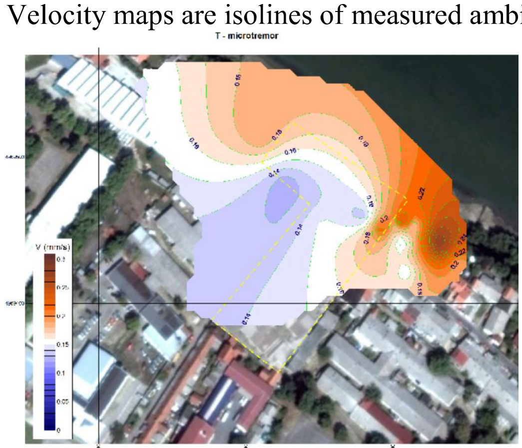

Fig. 3(a) Velocity map for microtremor (distribution of ambient vibrations)

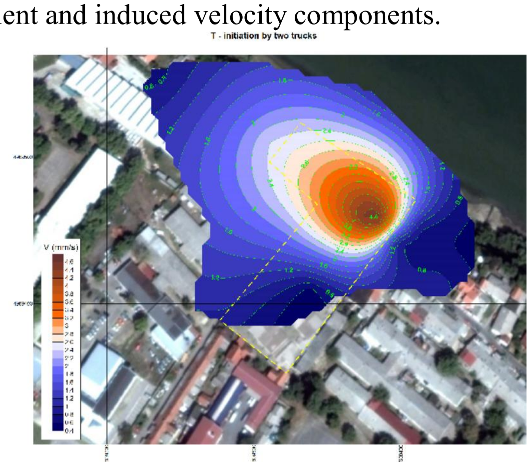

Fig. 3(b) Velocity map for induced vibrations due to heavy truck and a mixer

Velocity distribution maps give the overview of the vibration propagation through the soil in the construction site area. Induced vibration velocity map, Fig. 3(b), clearly represents that the soil at the site is quite inhomogeneous, with varous discontinuities, since the velocity propagation from the source is guite different in various radial directions. The corresponding attenuation (vibration propagation) laws for three dominant horizontal directions are defined using data presented in the Fig. 3(b). The time history of induced vibration velocities close to one of the houses at the edge of the loess plateu, called the House-1, is given in the Figure 4. Assessment of vibration effects upon building is mostly defined through the frequency dependant maximum velocities of the soil particles, the so-called PPV („Peak-Particle-Velocity"), which are measured at basement, i.e. at the soil near the wall on the side of vibration source: $PPV=v(t)_{max}$.

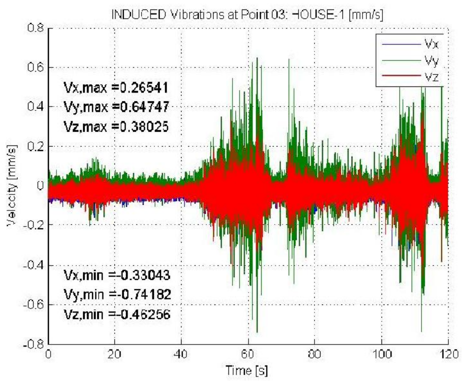

Fig. 4(a) Measured velocity time history near the House-1 (all 3 components)

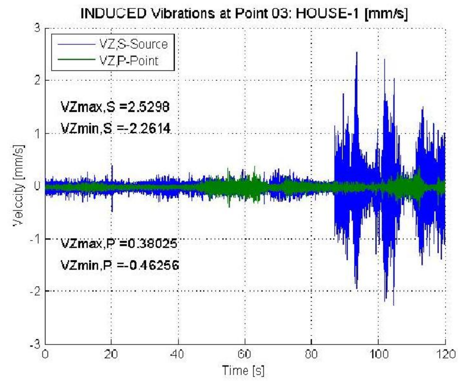

Fig. 4(b) Comparative time histories of vertical velocities Vz (source and House 1)

There are various international criteria, (but not Serbian!), related to vibration effects upon the houses and upon the people in houses, mostly based upon the *PPV* values. For the dominant vibration frequency range in considered case, allowable *PPV* values for buildings are BS 7385-2: 15-20mm/s, DIN 1450-3: 5mm/s, Swiss criteria: 5mm/s, etc. For people in buildings, *PPV* based criteria are 11mm/s (Reiher), 5mm/s (Whiffen), 6.1mm/s (Wiss), but DIN 1450-2 defines the so-called KB_f parameter, as a measure for vibration effects upon people. Definition of $KB_f(t)$ is rather complicated, so it is not given here. According to DIN 1450-2 the criteria is: $KB_{f,max} < A_u$ and, in this case, $A_u=0.20$. Calculated values $KB_{f,max}$ for the most exposed buildings were 0.0395 (House-1), 0.0297 (House-2) and 0.0430 (House-3), therefore, significantly bellow 0.20. Also, all *PPV* values were significalnly bellow the adopted 5mm/s limit, so the main conclusion related to vibration propagation due to construction works and its effects upon the properties and people in the vicinity of the site is that the palnned construction works produce no harmfull vibrations to surrounding buildings and people.

3. SLOPE STABILITY ANALYSIS

Location of the construction site at the Danube bank on the Zemun side is a loess plateau which is for about twenty meters above the Danube level. The house called the House-1, even though it is outside of the construction site, is the most endangered property with respect to the slope stability. First, it is closest to the edge (some 5-5.5m) towards the Danube and second, the slope gradient towards the Danube at that location is greater then at other locations in the surroundig, it is almost vertical. Slope stability analysis was conducted using the program SLOPE/W, which is the part of the computer code

GEOSTUDIO by the company GEO-SLOPE, Inc. Respecting the geotechnical soil properties, with some variations of the soil strength parameters, representing the geometric configuration of the slope, given underground water level etc., several numerical models of the slope were made. All ten different soil layers were presented in the numerical models, with the corresponding characteristics (soil thickness *h*, strength parameters γ, φ, *c*). The level of the Danube was presented as the corrsponding hydraulic pressure. At location of the House-1, the corresponding surface overpressure, representing the weight of the house, was given too. The slope stability analysis, i.e. determination of the slip surfaces and the factors of safety, was performed using the Morgenstern-Price method. View at the slope by the House-1 and results of the slope stability analysis are given in Fig. 5.

Fig. 5(a) View at the slope by the House 1

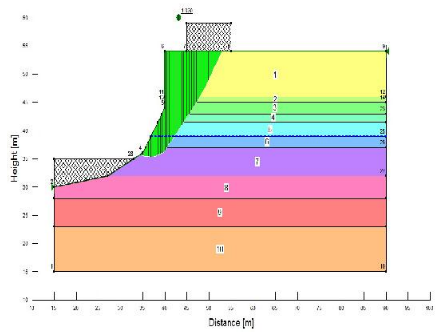

Fig. 5(b) Slope stability analysis (House 1)

The conclusion was that the slope is conditionally stable, i.e. the factor of safety is about 1.0. However, one should keep in mind that the strength parameters of the soil are the result of soil investigation of only one, relatively far away, drillhole, so the obtained soil data are not sufficently reliable. Having in mind the the soil data, above all the strenght parameters, are not sufficently reliable, it may be concluded that the slope at location of the House-1 is conditionally stable. If into the soil under the house fundations, or in the immediate surrounding, some larger quantity of water appears, e.g. due to some damage of plumbing or sewage pipes, there is the great possibility of rapid violation of the slope stability at any moment. Consequently, the corresponding measures were prescribed.

Besides the slope stability analysis of the profile just outside the construction site limits (location of the House-1), slope stability analysis was performed for the position of the bridge abuttment no.1 (longitudinal axis of the bridge). Due to slightly less steep profile towards the Danube, the factor of safety of 1.070 was obtained, which is slightly better then 1.030, but it is still low. After the removal of some 2.0m of the top layer soil, as presented in the Fig. 2(b), the factor of safety was obtained as FoS=1.199. Various phases of the work process related to construction of the abuttment no.1 were simulated (drilling of the piles, construction of the concrete block connecting the piles, the final indentation of the slope edge towards the Danube, protective coffer-dam in the Danube, etc.) and the correspodnig factors of safety of the slope stability were determined. Based upon such analysis, the working range of heavy machines, especially the rotary drilling rig and the excavation bager, was defined and limited. For instance, prior to drilling of the 12 piles, the rotary drilling rig (or any heavy machine) was not allowed to come closer then 9.0m from the edge of the slope. After construction of piles the slope is somewhat stabilized and the factor of safety is increased. Therefore, the limiting position of the excavator bager, which was used to form the final edge of the slope, was limited to 5.0m from the edge. Some phases of the slope stability analysis are given in the Fig. 6. Fig. 6(a) represents the closest position of the rotary drilling rig, while Fig. 6(b) represents the case when all 12 piles are constructed. The effect of piles for the slope stability is obvious: FoS is increased from 1.199 to 1.789 due to the presence of piles.

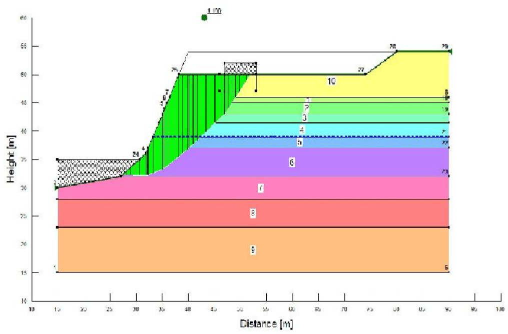

Fig. 6(a) The closest position of the rotary drilling rig (9.0m from the slope edge)

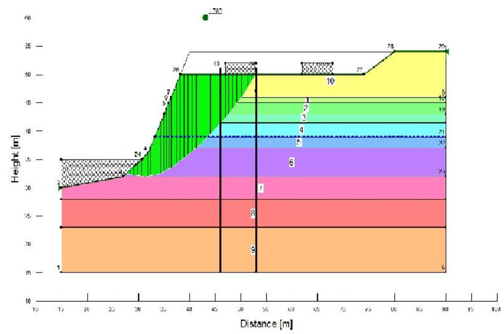

Fig. 6(b) Two heavy machines after construction of the piles

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ПРОПАГАЦИЈА ВИБРАЦИЈА НА ЗЕМУНСКОЈ СТРАНИ МОСТА ЗЕМУН-БОРЧА

Резиме: *Приказује се експериментална и нумеричка анализа пропагације вибрација на земунској страни моста Земун-Борча насталих услед грађевинских радова приликом изградње моста, као и анализа стабилности косине лесног платоа који је око 15-20м изнад нивоа Дунава и са веома стрмим, скоро вертикалним нагибом.*

Кључне речи: *Пропагација вибрација услед грађевинских радова, мерење вибрација, стабилност косине*