INFLUENCE OF GEOTECHNICAL WORKS ON NEIGHBORING STRUCTURES

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ABSTRACT

Geotechnical works are closely related to civil engineering works, both in the initial phase of a construction and, in special cases, after the construction when new structures are built in the vicinity. Depending on the foundation ground capacity, many types of works must be developed such as various pile driving methods, slope containment, deep excavation, ground improvement or treatment, etc. Associated with special types of works there are the vibrations propagated in the ground from depth to the surface which, depending on the propagation velocity and wave frequency, can damage nearby older structures. To prevent these situations, it is common to perform preliminary numerical studies and continuous ground vibration monitoring in the existing neighboring structures. This technique allows for classifying ground vibrations in different categories according to the purpose of neighboring structures (historical, residential and industrial) and the vibrations' parameters propagation velocity and wave frequency. Aiming to guarantee the safety of the construction site and neighboring area, via the equipment used in ground vibrations monitoring, it becomes possible to define energy boundaries of the equipment used in different geotechnical works. First attempts to reduce this impact by an active generator were also already presented in the literature. This article was based on case studies of works developed in Poland: in Wrocław and Lubin (Poland), regarding ground vibration monitoring on rapid impulse compaction (RIC) technique. Similar experience was gained on sheet piles driving in Szczecin and Wrocław. The main advantages and limitations of the implementation of methods are shortly discussed for each case on the basis of authors' experience. The results are analysed with the aim to understand the technology applicability.

Keywords: vibrations, sheet piling, Impulse Compaction, monitoring, calibration

INTRODUCTION

Most of the performed tests, forming the basis of this article, were done in cooperation with Wrocław University of Science and Technology where the Author: Filipa Oliveira passed her training period concerning on-site testing procedures in various fields of foundation engineering, within Erasmus program in 2014. All the procedures concerning dynamic monitoring of buildings and engineering structures in course of soil improvement works and pile (or sheet pile) driving, were agreed with construction companies working on building sites.

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Standard methods of sheet pile driving generate vibrations (Figure 1). Also, non-cohesive soil improvement works are usually related to compaction by means of vibrations (surface vibrating rollers and vibroflotation or vibroreplacement to bigger depths) as described by Hiller and Hope [1]. High energy single impacts are widely developed through Rapid Impulse Compaction, Dynamic Replacement and others (Hwang and Tu [2]). Also, non-cohesive soil improvement works are usually related to compaction by means of vibrations (surface vibrating rollers and vibroflotation or vibroreplacement to bigger depths). High energy single impacts are widely developed through Rapid Impulse Compaction, Dynamic Replacement and others. Numerous examples of case studies can be found in works of Athanasopoulos and Pelekis [3], Bachmann and Ammann [4], Woods [5] and recently Rybak and Schabowicz [6] and Srbulov [7].

Based on those observations numerous codes of practice and simple recommendations were proposed. Authors like Skipp [8], Brzakała et al. [9], Herbut and Rybak [10] juxtaposed existing codes and provided their own experience gained on building sites and referred to particular cases. The possibility of active design and technology calibration also became an important issue in the last years. Methods and examples of changing technology parameters like vibrator frequency or hammer drop height were presented in work of Pieczynska and Rybak [11], and recently Rybak and Tamrazyan [12]. Dynamic impact can be to some extent reduced by means of water-jetting and pre-boring (Figure 2). The most sophisticated methods of reducing harmful effects of vibrations and impacts were presented in work of Herbut [13], where the author analyze the applicability of active generator.

Fig. 1. Vibratory driving

Fig. 2. Pre-boring before vibratory driving

HARMFUL TECHNOLOGIES AND THEIR DYNAMIC IMPACT

Three main methods of sheet pile embedding in soil are distinguished. These are: impact driving, vibrating and pushing. These methods can be additionally supported by pre-emptive drilling or water jetting. Traditionally, installing of sheet piles was made by driving. It is an effective and relatively fast method, however currently of relatively rare use, most often for sheet piles loaded with substantial vertical forces. Impact driving provides an outlook about embedding resistances which can be the basis of initial conclusion about the loading capacities obtained for the elements introduced into soil.

This method together with up to date pile driving equipment enables to get very high precision of the works. However, this is obviously the method which can adversely affect the surroundings to the highest degree (low frequency vibrations, noise). So, when considering sheet pile driving, it is necessary to balance the savings resulting from this efficient method with possible costs of remedying the damages caused by unavoidable dynamic effects. It is also worth noting the psychological aspect – nervous reactions of people living in direct neighborhood of construction site (which are often unjustified from the technical point of view). At present, an engineering standard for steel sheet piles installation is to use non-resonance high frequency vibratos. Working frequencies of vibrators, which usually are adjustable over some limited or full range, are most often about 30-40 Hz and far exceed typical natural frequencies of buildings and structures. The principle of their operation consists in accelerating the rotating masses (prior they are moved apart by eccentrics) to gain working rotational speeds. This allows to eliminate negative effects of transitional resonance phenomenon because during momentary transition through the natural vibration of buildings and structures, the vibrator oscillations are minimal. Hence, when the operation is carried out knowingly, this equipment provides no direct risk for neighboring buildings. However, we cannot exclude some secondary influences on adjacent structures or underground installations (e.g. resulting from settlement of compacted soils or soil displacements in earth slopes of temporary excavations). The propagation velocity is not always the same; it depends on the environment characteristics as porosity, permeability, density, and more. It must be noticed that water affects the wave propagation. To understand its propagation, it must be understood that vibration decomposes in separated waves: P-wave, responsible for compression stress, and S-wave, responsible for shear stress. Once these waves reach the ground surface, together compose the Rayleigh waves, or R-waves – this is the type of wave that can be studied on the monitoring of ground vibrations. It propagates along the ground surface through vertical and horizontal components [9].

A separate issue for vibrating penetration of sheet piles refers to possible and unintentional compaction of non-cohesive soil layers located in the subsoil. This leads to settlement of structures despite no perceptible vibrations occur. A successive phenomenon which should be expected during vibrating penetration of steel sheet piles is the possible local liquefaction of soil. These phenomena may happen in loose and medium-compacted watered and fine-grain soils (fine and silty sands). Hence, the knowledge of foundation method (direct, indirect) and of subsoil of structures adjacent to the work progressed is of importance. In each case, decision about application of specific technology, or about changing it, should be based on substantive grounds. Modern technique enables to use reliable control methods for foundation works. Results of measurements and observations should be, after appropriate analysis, the basis for decision taking about the selection of technology or about changing it.

When vibrators cannot be used due to sensible surroundings or due to conditions of the subsoil, an alternative solution is to apply equipment for static pressing of the steel sheet piles. This method is under constant and intense development for the sake of its numerous advantages. More and stronger and effective equipment is manufactured which in practice can eliminate dynamic effects while still the economic parameters are maintained. Continuous monitoring applied for numerous works, having been progressed in Poland with this process, confirmed that pressing equipment generates vibrations not exceeding those of the background level. The sole vibrations can be generated by engines (e.g. of the cooperating crane). In case of high pressing resistances, the process can be boosted by water jetting or preliminary drilling. In the near future, we can expect that pressing method shall dominate the market, especially for project in urban areas as it is versatile and imposes rationally no influence on the vicinity.

PURPOSE OF VIBRATION MONITORING FOR GEOTECHNICAL WORKS

A low level of engineering knowledge at decision makers about methods of monitoring and supervising foundation works, and resulting fear of taking improper decision causes that technically sound and cost-effective foundation technologies are often rejected. The other problem is the awareness of threats (or rather lacking it) among residents. Subjective fears and nervous reactions of residents caused by phenomena not appearing before (like glass jingling in a chest of drawers or, which is much more dangerous, sounds related to resonance of finishing elements in or on the buildings) are most often based on little knowledge about the project progressed (= lack of proper information policy) and could bring irreparable damage, including stoppage of works. Social acceptance thresholds for construction work execution usually are definitely lower than those of technical nature and to a large extent they depend on the duration of the project. Foundation works, which usually start the project execution cycle, can – on one side – bank on higher acceptance levels, but on the other hand, as the first ones introduce changes to living conditions of residents, so they bring forth reactions, sometimes quite violent. Properly run information action requires money, so it should be considered as a financial component of the project planned. From technical point of view, we can assume that destructive effect of vibrations is the function of vibration amplitude (accelerations, velocity) and duration time. The highest amplitudes are recorded when the vibration source is close to the object monitored, and when the working frequency is similar to the natural frequency of the object (resonance). Often it is impossible to draw back from existing object. Modern vibrating hammers allow to modify the working frequency in some range or in full range of operation. Such action used during constructing retaining walls of the tunnel beside the fence of Powazki Military Cemetery in Warsaw enabled considerable reduction of vibrations recorded on protected objects of the cemetery [11]. One should however remember that "retuning" the vibrator can reduce efficiency of driving the sheet piles and extend the time of works, or even make that the continuation with vibration technology becomes impossible.

Table 1. Scale for evaluating harmfulness of vibrations (Eurocode 3 [14], Table 12.3.6.2)

Type of facility	Amplitude of vibration speed [mm/s]	
	Continuous vibrations	Temporary vibrations
Historical facility	2	4
Residential buildings	5	10
Light commercial facilities	10	20
Heavy commercial facilities	15	30
Underground systems	25	40

The vibration generated during driving in or vibration hammering of sheet piles can be measured, for example, by sensors with sampling frequency of 1,024 Hz. The device memory records maximum values of vibration speed measured during each successive 15 seconds of measurement duration, with speed values higher than 0.1 mm/s. The records are taken for speed, acceleration and frequency of vibrations. Those values may be compared to limits given according to Eurocode 3 – Table 1. Table 1 provides admissible values of vibration speed (continuous and temporary) with respect to various types of building structures. The purpose of performed examinations is to compare the level of dynamic influences from works carried out (related vibration hammering and/or driving in sheet piles or piles) with the values specified in the standard DIN or EC3 for specific facility as the safe ones. The categories of facilities are also distinguished according to the below nomogram (Fig. 3) from the standard DIN 4150 [15].

- Category 1: especially sensitive facilities, which cannot be included in two below categories, such as structures covered by preservation maintenance, facilities equipped with special electronic or mechanical equipment,
- Category 2: residential buildings,
- Category 3: industrial facilities and similar structures.

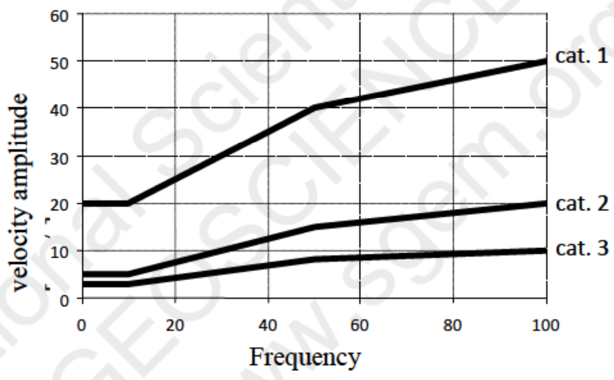

Fig. 3. Scale to evaluate vibration harmfulness according to velocity amplitudes [15].

EXAMPLE OF MONITORING <u>Raclawicka (Wroclaw, Poland)</u>

A new school was being built in the construction site. The major problem at this location was the different densities which could be found on the site due to its previous use – dumping field. The fact that this was happening in this site meant that, if any work of soil improvement work didn't occur there, there would be different types of mechanical behaviors of the ground, which could lead to very damaging and expensive problems. A vibrating roller machine was used to smooth the topography and to carry out a small initial compaction at first work stage (Fig. 4). The other work stage was carried out by the rapid impulse compaction machine (Fig. 5).

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Fig. 4. Vibratory roller

Fig. 5. Rapid Impulse Compaction

In this constructions site, as explained before, it was possible to monitor for several occasions geotechnical works. At the first monitoring day, September 18th, due to delayed work stage, it was not possible to study the influence of rapid impulse compaction on the neighboring structures, mainly residential buildings. In spite of it, it was possible to observe a small vibration caused by the works from a vibrating roller on the board of a balcony from a building next to the construction site. Although the noise caused by these works could be heard by humans, the vibrations can barely be felt by them. When rapid impulse compaction was introduced the situation changed significantly (Fig. 6).

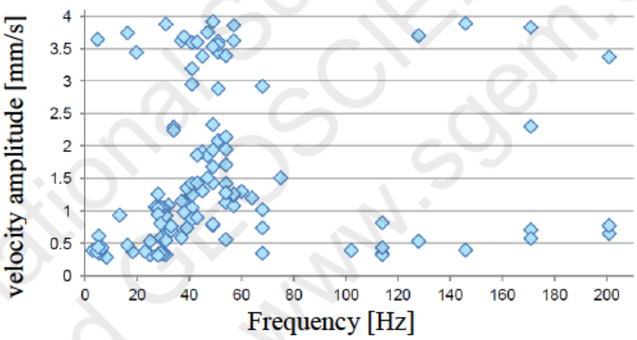

Fig. 6. All the vibrations caused by geotechnical works are marked in blue [15].

EXAMPLE OF MONITORING Lubin (Poland)

Geologically, the location is characterized by a geological profile mainly constituted by layers of organic and anthropogenic soils; at some deep depth, there was sand. Two residential buildings were being built in the construction site. The major visible problem at this location was regarding the fact that water ground level was supposed to be lower than it was at that moment (Fig. 7). There so, the company was trying to repair the situation by pumping the water out of the site and, at the same time, compacting the soil through resorting to rapid impulse compaction method. All the vibrations caused by geotechnical works are marked in green on Figure 8.

Fig. 7. Initial problem in Lubin

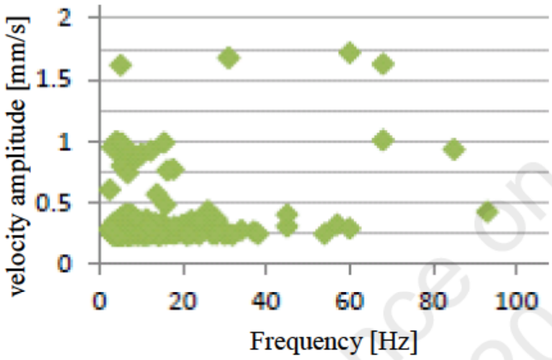

Fig. 8. Rapid Impulse Compaction

This monitoring aimed to verify if the energy used by the rapid impulse compaction machine on geotechnical works at one specific row was strong enough to compact the soil on the construction site and weak enough not to damage any neighboring structure near this site. As the results show (Fig. 8), the values are according to the acceptable standard, regarding the safety and welfare of human being and structures in the surrounding areas. As it can be seen, water did not affect much the propagation of vibration, but the soil was not compacting, which led to a new problem – the soil was moving to the sides of the compaction holes. There so, the contractor chose to suspend the works and study a new solution to this aggravated problem. This new solution consisted in pumping the water out of the site – lowering the water level, adding 1m of sand to the ground surface and then, resume the soil improvement works. As the maximum energy to be used for soil compaction was previously defined in this site, it was not necessary to extend the monitoring of works.

CONCLUSIONS

Despite most of the vibrations registered during the monitoring could be felt by humans, specially by foot, it did not mean those vibrations could jeopardize the safety and health of humans and building structures on the surrounding areas of the construction sites from this study. Regarding the soil improvement works, the contractors must notice that higher impulse compaction energy may take less time to compact the soil but it may cause damage or unpleasant situations on neighbouring structures. The direction of compaction, by the rapid impulse compaction method, should be towards the neighbour buildings for two main reasons. The first reason lays on a creation of a safety zone, constituted by a more compacted soil, between the neighbour buildings and the construction site. The other is because this way of proceeding works as insurance for the contractor as the closest compactions points are achieved in the last days. Complains take some time to fill so when they are finally valid, the original contractor is no longer responsible for the alleged damage. At Wroclaw – Raclawicka case, in the upper softer zone, characterized by the anthropogenic soil, the interstitial water did not allow the vibration propagation, while occurring the rapid impulse compaction works. Similar remarks may be concluded on the sheet pile vibratory driving.

Here, it is worth to mention that measuring techniques in construction industry are, most probably, the field of fastest development. Companies executing specialist works, including foundation works, make the measurements, as required in the contract, by themselves, just being assisted by R&D bodies or specialist companies. Equipment available on the market enables to measure and to record the vibrations transmitted to surroundings and such which additionally allow for measurement and recording the noise. The other issue is geodesic monitoring of dynamic action effects. It allows for current evaluation of settlements caused by compacting subsoil layers under buildings in the immediate vicinity of works. It is now available to arrange very complicated programmes of monitoring activities accompanying the wall works under progressing. The difficulty is to fix proper balance between real needs, appropriate scope of monitoring and project owner capabilities to pay for it. The cost of such examinations is however very low with respect to the value of works executed and the effects of damages which could be avoided thanks to such monitoring.

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REFERENCES

[1] Hiller D.M., Hope V.S., Groundborne vibration generated by mechanized construction activity, Proc. Institution of Civil Engineers (131), pp. 223-232, 1998.

[2] Hwang J.H., Tu T.Y., Ground vibration due to dynamic compaction, Soil Dynamics and Earthquake Engineering, vol. 26, pp. 337-346, 2006.

[3] Athanasopoulos G.A., Pelekis P.C., Ground vibrations from sheet pile driving in urban environment: measurements, analysis and effects on buildings and occupants, Soil Dynamics and Earthquake Engineering, 19, pp. 371-387, 2000.

[4] Bachmann H., Ammann W., Vibration in Structures Induced by Man and Machines, International Association for Bridge and Structural Engineering, 1987.

[5] Woods R.D., Dynamics effects of pile installations on adjacent structures. NCHRP253, Washington D.C.: National Academy Press, 1997.

[6] Rybak J., Schabowicz K., Survey of vibrations generated in course of geotechnical works. NDE for Safety: Proc. 40th Int Conf and NDT exhibition, Brno: University of Technology. Faculty of Mechanical Eng., pp. 237-246, 2010.

[7] Srbulov M., Practical Soil Dynamics, Case Studies in Earthquake and Geotechnical Engineering, Springer, 2011.

[8] Skipp B.O., Ground vibration – codes and standards. Ground dynamics and man-made processes, The Institution of Civil Engineers, 1998.

[9] Brzakala W., Herbut A., Rybak J., Recommendations for ground vibrations survey in course of geotechnical works, 14th SGEM 2014, Albena, Vol. 2, pp. 747-754, 2014.

[10] Herbut A., Rybak J., Guidelines and recommendations for vibration control in the case of rapid impulse compaction. Advances and trends in engineering sciences and technologies II. eds. M. Al Ali and P. Platko, CRC Press, Taylor & Francis Group, cop. 2017. pp. 761-766, 2017.

[11] Pieczynska-Kozlowska J., Rybak J., Vibration monitoring as a tool for a calibration of geotechnical technologies, 14th SGEM 2014, Albena, Vol. 2, pp. 1043-1050, 2014.

[12] Rybak J., Tamrazyan A.G., Calibration of rapid impulse compaction on the basis of vibration velocity control, 16th SGEM 2016, Albena, Book 1, Vol. 2, pp. 715-722, 2016.

[13] Herbut A., A study of the reduction of ground vibrations by an active generator, Soil Dynamics and Earthquake Engineering, vol. 88, pp. 328-344, 2016.

[14] EN 1993-1: Eurocode 3, Design of steel structures - Part 1-1: General rules and rules for buildings, CEN, Brussels, 2005.

[15] DIN 4150-3, Vibration in building - Part 3: Effects on structures, DIN Standards Committee Building and Civil Engineering, Berlin, 2015.