

# Modification of vibratory driving technology for sustainable construction works

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**Abstract.** The Sustainable Development Goals were a remarkable advancement when adopted by the United Nations in 2015. For the first time, the world committed towards a wide spectrum of common goals ranging from climate action to sustainable cities from sustainable economic growth to inclusive industrialization. Sustainability is usually considered as “avoidance of the depletion of natural resources in order to maintain an ecological balance”. In case of civil engineering, it means minimization of environment-related costs of ongoing project, also in terms of temporary deterioration of life quality in vicinity of building site due to noise and mechanical vibrations. Such impacts may constitute environmental load within much longer time-frame than exposure time to negative influences itself. Numerous impacts of construction work on environment, sometimes not covered by any standards, from mechanical damages to facilities and infrastructure, those which are easiest to identify, through negative influence to comfort and health of local residents, to offset the balance of nature (e.g. by chasing out birds during breeding season) are observed. The paper provides exemplary actions which may be undertaken by construction work contractors to reduce adverse dynamic impacts – mechanical vibrations, with regard to geotechnical work related to execution of deep excavation shoring. Conclusions of the paper are of general nature and, independently of rules specified by standards, they can provide guidance on good practices.

## 1 Introduction – dynamic impact of foundation works

Special geotechnical works related to modification of soil substrate [1], pile driving works [2], shoring of deep excavations [3] and earthworks including relocation of huge mass of soil are usually the stage of construction works which exert the highest environmental loading. However both mechanical vibrations and generated noise may be controlled according to respective regulations and standards [4-5]. The papers [6] and [7] provide the methodology of environmental impact monitoring together with adequate examples. In the broader context, even short-term dynamic impacts affect safety and comfort assessment as Structural Health Monitoring of buildings and structures [8-13].

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Endeavours can be made to limit negative effects even when the measured levels of vibrations and noise do not exceed the admissible values [14, 15].

## 2 Methods of dynamic impact reduction

Considerations have been made on selected geotechnical processes how it would be possible to reduce their nuisance. In case of Rapid Impulse Compaction, it is possible to calibrate it by reducing energy of single impulse as shown in [16]. Such action can be based on on-site measurements [16] or on preliminary analysis from numerical modelling [17]. As concerns vibratory processes, the issue is a little more complicated as calibration of this technology must consist in a change of mass or frequency of vibrator, or in reduction of embedding resistance by additional actions which would allow reducing necessary energy with non-dynamic way. Efficiency of such actions is controlled by vibration velocity measurement. The paper will present examples of such actions using kits for vibration measurement placed within the soil substrate (Fig. 1a) or on structures (Fig. 1b).



**Fig. 1.** Vibration control equipment: a) before “sand-bagging” in the ground, b) on the structure

### 2.1 Selecting proper vibrator

When works represent a significant risk for surroundings, like when works are run close to underground gas transmission network, both initial control and continuous monitoring of works progressed are possible. Figure 2 illustrates such three units operating on research plot in south-western Poland.

### 2.2 Softening of substrate

In order to reduce embedding resistance during driving sheet piles or piling works, by ramming or vibratory driving, pre-boring (Fig. 3) or high-pressure water-jetting at the base of steel profile being embedded (Fig.4) may be used. Each of these technologies may considerably accelerate the works and reduce energy necessary to embed steel profiles. It should, however, be remembered that destruction of natural soil structure, at the depth of profile being driven, may reduce its vertical load bearing capacity and lead to unplanned connection of aquifers.



**Fig.2.** Testing of various equipment: a) VIB 625 and VIB 600 (ICE), b) Movax



**Fig. 3.** Pre-boring.



**Fig. 4.** Installation for “water jetting”.

## 3 Examples of field testing

### 3.1 Selecting proper vibrator

During modernizing works close to gas main, it was necessary to embed steel sheet piles in close vicinity of existing and gas-filled pipeline. Monitoring was used throughout the duration of testing on March 24<sup>th</sup>, 2016:

- Measurement of background vibrations from 12:06 to 12:21
- Operation of VIB600 vibrator at a distance c. 2 m from gas main from 12:22 to 12:28
- Operation of Movax vibrator at a distance c. 2 m from gas main from 12:33 to 12:44
- Operation of VIB600 vibrator at a distance c. 2 m from gas main from 13:04 to 13:09

The results given in Table 1 show that vibrator with lower power and higher frequency generated lower dynamic impacts; however the embedding time for a single sheet pile was grown nearly two-fold. It was observed on other building sites that the duration of exposure may be even more annoying for the neighbours than the vibration intensity. Hence, while deciding on technology to be used, one should balance the nuisance related to vibration level and durability of impacts.

**Table 1.** Results of average Peak Particle Velocity (PPV) control within 15 s intervals.

Action	Vibrator frequency [Hz]	Average vibration velocity [mm/s]	Duration of single pile driving [minutes: seconds]
No operation	-----	0.43	-----
VIB600	38-39	9.57	06:00
Movax	43-44	4.74	11:30
VIB600	38-39	9.47	05:45

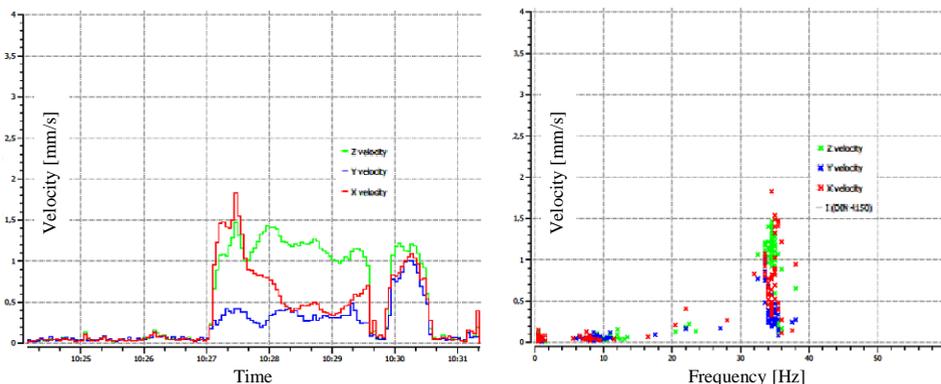
### 3.2 Pre-boring efficiency

Geotechnical conditions, prevailing at area where shoring work for deep excavation is carried out, are juxtaposed in Tab. 2. It was observed that sandy clay was very stiff and surprisingly resistant against sheet pile driving. As the main goal of the contractor was to shorten the duration of works, the ground was softened by means of pre-boring along the sheet pile line.

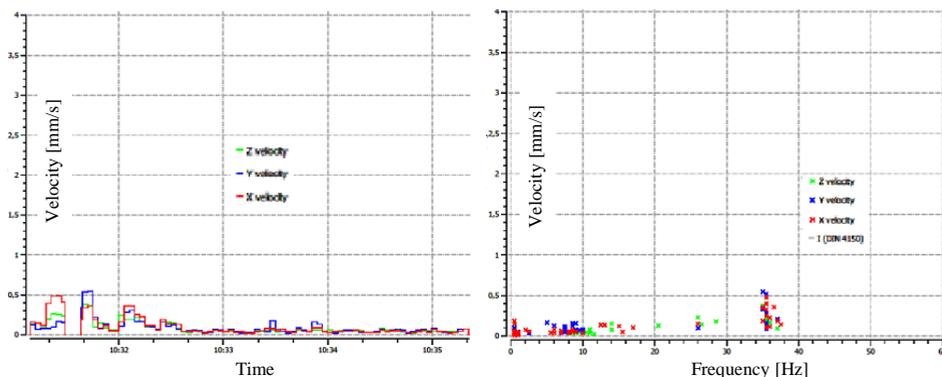
**Table 2.** Soil parameters

Soil type	Thickness	Liquidity index	Specific weight	Young's modulus	Poisson's ratio	Cohesion <i>c</i>	Internal friction angle
	m	<i>I<sub>L</sub></i>	$\gamma$ kN/m <sup>2</sup>	<i>M</i> MPa	$\nu$	kPa	$\phi$
till/ alluvium	1.0	-			-		
silty/sandy clay	1.5	0.15	21.5	58	0.29	41	24
sandy clay	8.5	0.05	21.0	32	0.29	32	25

The investigations were conducted at the point located about 7 meters from the edge of designed vertical excavation support system. Profiles AZ 12-700 with length 6.0 m were driven. Peak particle velocities in 3 directions (vertical, horizontal, and transversal) were recorded in order to be compared with limits established in DIN code [4]. Graphs presented on Fig. 5. and Fig. 6. provides information about recorded velocities without and with pre-boring, in time and frequency domain (respectively).



**Fig. 5.** Results of continuous recording of vibration velocity (without pre-boring)  
 a) time domain, b) frequency domain



**Fig. 6.** Results of continuous recording of vibration velocity (after pre-boring)  
 a) time domain, b) frequency domain

Table 3 summarizes data from field measurements of vibration velocity for version without pre-boring and with pre-boring operation. One can see that intensity of impacts, as measured by vibration velocity on structure under monitoring, was significantly reduced (by 63%). The embedding time for a single steel sheet pile was also significantly shortened. However, it should be borne in mind that pre-boring caused a dramatic change of soil structure in line of embedded sheet piles (increased final displacements of sheet piling wall). Also additional equipment (CFA pile driving unit) was needed to carry out the works (Fig. 3). So again, there is still a big need of some evaluation criteria based on “total footprint” of all the technologies involved.

**Table 3.** Estimated pre-boring efficiency by means of PPV reduction and shortened exposure time.

Action	Vibrator frequency [Hz]	Average vibration velocity [mm/s]	Duration of single pile driving [minutes:seconds]
No operation	-----	0.13	-----
Without pre-boring	32-36	1.10	6:00
With pre-boring	36-38	0.40	3:30
Gain [%]	-----	63 %	42 %

## 4 Summary and recommendations

Sustainable construction works are usually associated with low-emission technologies, which – on a global scale – affect carbon dioxide emission. On local level, geotechnical works affect surroundings mainly by mechanical vibrations and shock caused by transporting building materials and other construction activities. In recent years the increasing importance is also attached to the noise emitted from building site. The examples presented above show that sustainable technologies can be also implemented at construction site. However, this may be at the expense of prolonged duration and possible deteriorating the standard of construction works.

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