Study of impact sheet pile and Franki NG pile driving on weir construction

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Abstract. The proper quality and the safe execution of geotechnical works imposes the necessity of monitoring techniques to prevent the threats arising from the vibrations. This work presents authors experience gained during sheet piling and Franki pile driving in time of construction of water power plant. Dynamic impact of foundation works can be perceptible by humans and can affect structures and technical devices. The immediate reason for the dynamic analysis was the occurrence of clearly perceivable vibration of the weir. The measurements were performed during sheet wall installation and Franki pile driving at various measuring points. Wave parameter measurements and recording of shocks and vibrations in the close vicinity of the construction site were juxtaposed for different installation phases and measuring points. A comparison of the two technologies shows that the largest vibrations occur during formation of the cast-in-situ (over)expanded Franki pile base. Sheet pile wall installation supported by additional processes such as pre-boring turned out to be as less harmful.

1. Introduction

Vibrations caused by civil works, vehicle traffic, etc. are monitored according to respective guidelines and standards, which specify admissible amplitudes of vibrations depending on their frequency and the type of civil structure [1],[2], [3]. Presented measurements are carried out to investigate the effects of application of two different technologies: sheet pile wall and Franki NG pilling.

Typical “resonance-free” vibration hammers operate at high frequencies of 30-40 Hz; they are higher than typical resonance frequencies of buildings (4-6 Hz) [4].

Most common methods of sheet pile installation in soil are driving, vibrating and jacking, nevertheless still most popular is vibratory method, because of its highest effectiveness. Traditional installation can be supported by additional processes such as drilling or high pressure jetting. The examination of vibration was carried out on September 2019 during sheet piling works for deep excavation. The sheet piles were installed through vibration using preliminary drilling. Assumptions were made that vibrations are harmonic and long-lasting. In the pre-prepared excavation, Franki Pile NG were made as the foundation of the turbine chamber in water power plant. The Franki piling process has undergone several reformations since it was conceived in the early twentieth century [5]. A modern version of this technology is the Franki NG, cast-in situ concrete foundation pile with recovered driving pipe. The manufacturing of Franki Pile NG process consists of the following main phases:

1. Set driving pipe in place, fill in stopper gravel and ram in. Positioning of the tube and construction of a water-tight gravel plug at the bottom of the casing preventing soil and/or water from entering it.
2. Ramming in the driving pipe through inner ramming with free fall pile hammer. Bottom driving on the plug using an internal hammer, due to friction developed between the steel and the concrete. This operation causes the casing to compress the soil strata by lateral displacement and penetration into the earth to the installation depth.
3. Ramming down the gravel whilst pulling the pipe, with simultaneous refilling of gravel.
4. Ramming back the pipe into the gravel previously rammed down, followed by expulsion of the plug at the installation depth of the pile and insertion of dry concrete for the formation of the cast-in-situ (over)expanded base.
5. Forming a pile base through ramming down concrete
4. Lowering of the reinforcement before continuing the concreting phase
5. Concreting of the shaft.
6. Withdrawal and recovery of the driving tube.

The finished foundation element resists compressive and lateral loads, and has excellent uplift capacity. The construction site under consideration allows the comparison of the dynamic impact of these two technologies due to the same geotechnical conditions and the same element lengths. Sheet pile profile and the driving pipe have length of 16 m. The power plant turbine will be founded on piles to mitigate the potential risks of loosening of sands induced by the dynamic loads during the power plant turbine operation.

2. Research object and site conditions
The existing barrage “Wróblin” is located at km 157.700 of the Odra River course, between the barrage “Opole” (km 150.530) and the barrage “Dobrzeń” (km 164.200). The ongoing investment is located on the northern suburbs of the Opole city. This project relates to the entire hydraulic complex “Wróblin”, and the Odra River channel with adjacent areas. According to the construction design, the new fish pass was build and the sectoral weir “Wróblin” will be modernized [6]. The reconstruction of the weir involves the replacement of sectional closures with flap ones. The control room are reconstructed as well and new accompanying facilities will be built. The scope of hydrotechnical and construction works is as follows:
- reconstruction and adjustment of the barrage to a flap closure,
- construction of downstream erosion protection,
- reconstruction of the control room on the right abutment, construction of the machine rooms on the left abutment and both pillars,
- construction of the new fish pass at the left abutment of the barrage.

Figure 1. View of the left abutment.
Figure 2. Cross section of machine room on the left abutment with locations of vibration measurements points (◆).
At the same time, a hydroelectric power plant is being built on the left bank and its geotechnical works affect the weir. The view of the weir and the location of the measuring points are shown in figures 1 – 3. Figure 4, presents view of the weir gallery. The weir closures are subjected to significant variable loads during the flow of water [7]. Hydrodynamic forces constitute an additional load in addition to hydrostatic and static load, which is transmitted to the abutment of the weir. Extra dynamic loads will be created during the geotechnical works, which should be controlled.

3. Acquisition and Processing of Data

Very wide range of sensors can be used for vibration monitoring. Most often used accelerometers allow to measurement of velocity, acceleration and frequency of dynamic effects, which can come from different sources [6]. Dynamic measurements were performed with the use of Profound VIBRA+ equipment. The Profound geophone designed for the VIBRA range has 3 channels (x-, y-, z-direction). Each accelerometer has sensitivity 23.3 Vs/m and mass 11±0.5 g. velocity data save level adjustable between 0.01-100 mm/s. Besides continuously monitoring the x-, y-, z- direction, the VIBRA also automatically corrects the measurement data for individual sensitivity of each geophone channel.

On the left abutment and on the fish pass the vibration control is carried out. The nearest measuring points are located 22 m from power plant construction works.

The following research / measuring points were adopted:
- retaining wall - reinforced concrete wall of the fish pass, benchmark No. 18, Point No. 1,
- ceiling weir staircase, level +2, Point No. 2,
- ceiling weir staircase, level +0, Point No. 3,
- weir gallery, Point No. 4.

The sensors were located as presented in the photographs Fig. 2, Fig. 4.

Measurements were taken using VIBRA geophone in combination with the VIBRA+ system. Data are directly presented on screen, numerically as well as graphically. The software shows the data according to DIN standard [8] or another standard [9], [10] depending on measurements settings. Apart from the above-mentioned standards and methods of vibration impact estimation, the use of reliability methods is also justified [12],[13], [14].

4. Dynamic excitation and dynamic measurements during Franki NG pilling

The dynamic impact varies in subsequent stages of pile manufacturing, described earlier.

The most harmful impact of vibration was observed in the phase “4” when the casing pipe were rammed back into the gravel previously rammed down and dry concrete was inserted for the formation of the cast-in-situ (over)expanded base. In this phase the biggest possible pile hammer drop height equal to 15 m was applied and potential energy was transferred to the plug. The mass of the free fall pile hammer is equal to 4 Mg, and potential energy at highest drop height is equal to 588,60 kJ. This
energy is transformed into kinetic energy, which is transmitted to the plug at the installation depth. Observed vibration frequencies on construction works are low: 4 - 12 Hz, which is closer to construction’s self frequencies. The observations on the top surface of fish pass wall expressed an important impact of piling works on existing structures. After execution Franki NG piles in the amount of 88 pieces, dilatation damage on the fish pass was observed.

The figures 5 and figure 6 show the measured amplitudes in the form of the velocity - time and acceleration-time graphs for the point No.1 and for the point No. 4 respectively during the entire piling process. The figures contains also division into phases of Franki NG pile manufacturing.

![Figure 5](image1.png)
**Figure 5.** Results of vibration during Franki NG pile driving on Point No. 1.

![Figure 6](image2.png)
**Figure 6.** Results of vibration during Franki pile driving on weir gallery (Point No. 4).

Acceleration amplitudes had values of 1.4 m/s² both in the point No. 1 (fish pass) and in the point No. 4 (weir gallery). The amplitudes of velocity had value of 4 -10 mm/s point No. 1 (fish pass). The amplitudes obviously depend on the geotechnical conditions around the pile. The process of making a single pile is quite long and takes from 1.5 to 2.5 hours, which in total substantially lengthened the dynamic impacts on weir.

5. **Dynamic excitation and dynamic measurements during sheet pile wall driving**

The length of the vibrating sheet pile was 16 m, i.e. comparable with the length of the used pile casing tube. The sheet piles were installed through vibration using preliminary boring, as single or double (paired) [11]. The figure 7 shows the measured amplitudes in the form of the velocity - time and acceleration - time graphs for the point No.1. First part of the graph presents amplitudes by driving of
single sheet pile, second part (after short pause) presents amplitudes by driving of double (paired) sheet pile. The vibration hammer operated at high frequencies of 30-40 Hz.

![Figure 7. Amplitudes of sheet pile driving a) velocity, b) acceleration](image)

The amplitudes of velocity at the point No. 1 (fish pass) had value of 1.0 - 1.5 mm/s for single sheet pile and 1.8 - 2.4 mm/s for paired sheet piles. The level of vibrations was more suitable at that point than in case Franki NG pilling and was at least two times smaller. The measurement was repeated for other measurements points, where this observation was also confirmed.

6. Conclusions

Test points were located at different distances from the works performed, usually in the range of 20 - 26 m for all measurements. Usually, the simple change of frequency makes it possible to avoid resonance. However, this is limited if Franki NG pilling is considered. The harmful vibrations caused by singular impacts (blows) during heavy piling works may be to some extent reduced by means of single blow energy (drop height) reduction. If no energy losses occur in the system during freefall, the kinetic energy at impact would be equivalent to the potential energy [15]. However, losses invariably occur due to friction, ram misalignment and resulting in a kinetic energy at impact which is lower than the potential energy prior to hammer release. For single sheet pile profile vibration, the velocity and acceleration amplitudes are definitely lower than those of Franki NG pile. For more complex conditions in construction site, pre-boring decreases the impact and at least shortens the duration of sheet piling works. The most harmful impact of vibration was observed when the casing pipe were rammed back into the gravel previously rammed down and dry concrete was inserted for the formation of the cast-in-situ (over)expanded base. In this phase occurs biggest possible pile hammer drop height equal to 15 m. It is noteworthy to mention that the readings of vibrations measurement did not indicate the exceeded standard values. Horizontal amplitudes are definitely higher than vertical amplitudes. The vibrations were safe for the structure, but damage to the finish surface elements was observed.

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