The impact of Rapid Impulse Compaction (RIC) of large non-cohesive material deposits on the surrounding area

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Abstract. Rapid Impulse Compaction technology makes it possible for improving the ground physical properties, especially when the large thickness of non-cohesive material layers is considered. It is also very efficient for compaction of large deposits of spoil rock from the mining industry or from the demolition works. It also allows making columns out of mining recycled aggregate or construction debris to improve weak cohesive soils. Equipment used in this method ensures fast completion of the work; however, it may cause large noise and severe vibrations. This environmental impact on the neighbourhood and adjacent structures may bring some threats and cause discussions over the technology application limits. Nevertheless, there are effective monitoring tools enabling a control over the whole process, achieving good engineering effects and running the work without negative influence (or within acceptable criteria) to the surrounding buildings and infrastructure facilities. The presented case studies show: how the intensity of vibrations is dependent on the distance from the source of the dynamic impact. In the case of analysed Rapid Impulse Compaction. The results were compared to the previously published results of computer modelling of such an impact. All the research activities were granted by DABI SM BUDNY Company as a part of their Research and Development program. Numerous cycles of vibration monitoring control were conducted on the building site in Wrocław (Poland). The major part of readings was made in course of compaction of non-cohesive layers, partially replaced by sorted debris from crushing of concrete elements from demolition works. Similar results were achieved in course of forming controlled fills composed of spoil material (crushed rock) from the mining industry. The presented research result is a part of the joined Polish-Russian program of training periods under the supervision of Jaroslaw Rybak, PhD from Wrocław University of Science and Technology.

1. Introduction - principles of Rapid Impulse Compaction

Rapid Impact Compaction is a very efficient method of strengthening weak or non-compacted soils down to depths of over 4 m. Impulse compaction process allows for getting a distinct improvement of density index and mechanical properties of the soil processed. It is applied wherever it is necessary to get better compaction of existing soil (figure 1), to improve strength and to reduce future settlement.
Impulse compaction is carried out with dedicated machine on tracked excavator undercarriage with weight of about 60 tons (figure 1), equipped with hydraulic hammer 5-12 tons, which is dropped at high frequency to a specially constructed steel foot of 1.5 m diameter, which - with each impact - submerges itself in soil and transmits energy to subsequent layers of soil substrate causing its compaction. The machine operates at the level of the working platform at a determined grid of points to get envisaged parameters (figure 2). Impulse compactor is generally equipped with automatic GPS guidance system which ensures that each point will be made at a precise location on a plot, and with an electronic control module, which monitors and records most important data of compacting process.

Impulse compaction is most often used for sandy soils – sands, sandy gravels and gravels. The final effect of impulse compaction, independently of the original condition, is a homogenous soil substrate of standardized properties [1]. When recycled concrete aggregate is reused [2], local strengthening is possible by means of stone columns creation [3-6]. It is of special importance for soils of the non-uniform degree of compaction or for areas with numerous voids or caverns [7]. A real effect of compaction, depending on the type of soil, reaches even down to 4-6 m. Re-aggregation of natural soil grains requires a considerable amount of energy which fans out and affects neighbouring construction works, mainly the adherence between concrete and reinforcement. Recent studies by Wojtowicz [8,9] made it possible to juxtapose the results of dynamic monitoring of building sites with special regard to this important factor. Numerous references provide information about measured dynamic effects with regard to geotechnical technology [10-15], need for sustainable production [16] and respect to normative requirements [17].

![Figure 1. Ground improvement works by means of Rapid Impulse Compaction](image1)

![Figure 2. Exemplary grid of points of dynamic compaction by means of Rapid Impulse Compaction](image2)
2. Determining the intensity of vibrations caused by various technologies

The main goal of the current examination was to determine safe distances from building machines and equipment to neighbouring objects and structures. As the whole project was conducted in a close vicinity to already existing buildings (figure 3), such information gave the basis for the optimization process in technological design of Rapid Impulse Compaction. The technology, due to the adjustable drop height of the hammer gives an option to reduce the energy of the single blow. The prize that has to be paid is the enlarged time of the works. In the case of transient vibration, prolonging of the schedule is usually less influencing the neighbourhood than the intensity of dynamic impact.

The point layout of continuous control of vibration velocities was agreed with the owner of adjacent residential buildings. Prior to the execution of works (at a determined grid of points) the technology was calibrated on the test field in a distant part of the area designed for compaction. Both dynamic technologies (vibratory roller and Impulse Compactor) were checked concerning imposed vibration velocities and continuity of the measured impact.

![Figure 3. Dynamic compaction by the use of Rapid Impulse Compaction](image)

![Figure 4. Frequency vs. Velocity graph according to DIN4150](image)

3. Site measurements

All the control procedures presented for the purpose of the current study were performed during the training period of Vlada Shkodkina at Wrocław University of Science and Technology in June 2019. The building site was located in Wrocław (Poland). The methodology of monitoring was based on the recording of vibration velocities and corresponding frequencies (figure 4). The main recording device was Minimate® Pro4 vibration control tool made by Instantel®. The Sample Rate was 2048 Hz. Interval duration was set to 15 s. The minimum recorded value of vibration velocity was 0.1 mm/s. Minimate® Pro4 sensor was consequently placed on the ground level and covered with a bag of sand (temporarily removed only for the purpose of taking pictures of it).

Results of vibration velocities were measured at the distance range 1m to 60m from the Rapid Impulse Compactor (figure 5) and 1 m to 30 m from the second source of vibrations (the roller in figure 6) respectively. The tests were performed in June 2019 at the building site, where large amounts of the crushed debris and local sandy soil were expected to be used for earthworks. Detailed layout of control points is presented in figure 7, however, the recording was continuous and shows also the time when compacting machine (RIC) changes its position, only small values of “background” vibrations are recorded at that period.
4. Vibration monitoring results and primary conclusions

In the case of Rapid Impulse Compaction, testing covers both: standard machine operation at work (figure 8a) with a random position of compaction points and testing the points along the straight line (figure 7) presented in figure 8b. The maximum value of vibration velocity by means of PPV reached around 200 mm/s when the RIC started the work near the vibration sensor (figure 8a). Such a value is absolutely unacceptable for building structures. But the amplitudes of velocity decreased rapidly with the distance between the sensor and source of dynamic impact. When the distance reached app. 25 m, vibrations measured at the ground level (usually much higher than the ones measured on the structures) decreased to acceptable limits. When the machine approached again at the distance of app. 3 m from the accelerometer, a significant increase of vibrations could be observed (figure 8b). The results given in figures 8a and 8b, prove that the impact of Rapid Impulse Compaction has a transient nature and it is to some extent adjustable.
The maximum value of vibration velocity by means of Peak Particle Velocity PPV in course of compacting (work of vibratory roller) reached around 55 mm/s when the roller approached at the distance of app. 1 m from the accelerometer. The results are given in figure 9 and seem to have a continuous nature at approaching and leaving. A closer operation was technically possible but the limit distance was set for equipment safety reason. It is important to underline that using more than one source of vibration at the same time might seriously affect the above mentioned range of values.

5. Conclusions
It is important to underline again that using more than one source of vibrations at the same time might affect the above mentioned range of values due to the superposition of the dynamic impact and possible interference of the stress waves in the ground. The last mentioned phenomenon may give some chances for further development of vibration protection by means of active generators. The mathematical description of the active generator impact can be found in work of Herbut [18]. So far, the practical impact and implementation are rather limited in the building industry, but at least in numerical modelling, the perspectives are very promising.
The presented results can be helpful for the planning of geotechnical works in the neighbourhood of vibration sensitive buildings. It may be noticed that the results are highly dependent on the ground conditions and the vibration energy at the source. The necessity of further examination and juxtaposing of the results in experience databases is recommended as the final conclusion of the presented study.

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