Vibration reduction techniques for Rapid Impulse Compaction (RIC)

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Abstract. New investments on anthropogenic soils bring the necessity for reliable and sustainable soil improvement methods. When the fill contains mainly non-cohesive soils and large thickness of material layers is considered, its physical properties can be improved by means of Rapid Impulse Compaction technology. Large energy of every impulse imposed by the mass of the hammer and drop height (with acceleration) makes it possible for relatively fast completion of works but causes large noise and severe vibrations. Environmental impact on adjacent structures may also cause some destruction and form the basis for legal claims. When serious damages appear in neighbouring buildings and structures, complains and claims are inevitable. Reduction of this negative impact may be achieved by means of technology calibration or other active and passive measures. The paper presents the description of that problem, some literature review and a case study describing how the intensity of vibrations may be to some extent reduced by means of hammer drop height reduction and digging a trench around the worksite.

1. Introduction – the need for sustainable civil engineering technologies

Constant development of urban areas brings the need for new building sites within metropolitan areas. That demand can be partially covered by post-industrial sites that are, however, subject to some disadvantages like: contamination of soils, large amount of debris from demolition works [1], appearance of large deposits of anthropogenic fills characterized by material variability and their poor quality. Another issue that deserves the attention is a large amount of materials extracted from deep and open pit mines and stored in possible development destinations. A lot of these by-product materials are produced in the course of mining production and processing of extracted products [2]. The use of waste material from empty rocks, enrichment tailings and demolition works in civil engineering as earthwork construction material should be considered. Depending on the amount of the material to be used for the construction of embankments or fillings, the cost of its processing and storing before reuse and environmental cost of its transport should be considered too. The implementation of sustainable technologies may reduce the environmental cost of construction works, as well as minimize the negative impact on the region ecology and comfort of neighboring inhabitants.

Almost every geotechnical technology related with shocks and vibrations brings the risk for adjacent area [3,4]. Examples of dynamic monitoring for various technologies are provided in works [5,6], with a special regard to Structural Health Monitoring of buildings in the close vicinity.
2. Dynamic impact of Rapid Impulse Compaction
Rapid Impact Compaction is a very effective method of compacting of granular soils and non-cohesive fills down to depths of over 5 m. Impulse compaction makes it possible for a distinct improvement of density index and other mechanical properties of the material processed [7]. It may be used mainly wherever it is urgent to get better compaction of existing soil (figure 1), to improve strength and to reduce future possible settlements with regard to current environmental impact [8]. It must be mentioned here that possible negative impact is not only related to the neighbourhood but the works may also affect the new structure (new concrete works) under construction mainly the adherence between concrete and reinforcement. Recent studies [9,10] made it possible to juxtapose the results of dynamic monitoring of building sites with special regard to this important factor.

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 relatively high frequency to a specially constructed steel foot of 1.0-1.5 m diameter, which - after each blow - submerges itself in the ground and transmits kinetic energy to subsequent layers of soil substrate causing its compaction. 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. The machine operates at the level of working platform at prescribed grid of points to obtain requested parameters (figure 2). Impulse compactor is generally equipped with automatic GPS guidance system which ensures that each point will be made at precise location on a plot, and with electronic control module, which monitors and records most important data of compacting process. The data are stored in cloud of results and are accessible online. That is why the technology may be easily implemented within Building Information Systems (BIM) Impulse compaction is most often used for sandy soils – sands, sandy gravels and gravels. Final effect of impulse compaction, independently of original condition, is a homogenous soil substrate of standardized properties [11]. When recycled concrete aggregate is reused [1,12], local strengthening is possible by means of stone columns creation [13-14]. It is of special importance for soils of non-uniform degree of compaction or for areas with numerous voids or caverns like post-industrial fields with remaining of old infrastructure.

3. Measures to reduce intensity of vibrations caused by Rapid Impulse Compaction
There are plural possible ways of controlling the intensity of vibrations. The technology, due to adjustable (to some extent) drop height of the hammer gives an option to reduce energy of the single blow. However, the prize that has to be paid is the reduced efficiency and enlarged time of the works.
In the case of transient vibration, prolonging of the schedule is usually less influencing the neighborhood than the intensity of dynamic impact [15]. Another possibility is just digging a trench between the source of vibration and the protected object. That helps to reduce Rayleigh wave propagation in course of the works [16]. Other ideas related to the possible use of active wave generators areas are still in the “science-fiction phase” of development [17-19].

4. Case study – measurements of vibration velocities

The main goal of preliminary dynamic monitoring (current examination) was to determine safe distances from building machines and equipment to neighbouring objects and structures. As the whole project was conducted in close vicinity to already existing buildings (figure 3) such information gave the basis for optimization process in technological design of Rapid Impulse Compaction. The point layout of continuous control of vibration velocities was agreed with the owners of adjacent industrial and commercial buildings. Prior to execution of works (at determined grid of points) the technology was calibrated on test field in a distant part of the area designed for compaction.

Figure 3. Case study of soil improvement by means of Rapid Impulse Compaction.

Figure 4. Frequency vs. Velocity graph according to DIN4150

Figure 5. Minimate® Pro4
Impulse Compaction was checked concerning imposed vibration velocities and continuity of the measured impact. Numerous references provide information about measured dynamic effects with regard to geotechnical technology [3-8], need for sustainable production [1-2] and respect to normative requirements [8]. The building site was located in southern Poland.

The methodology of monitoring was based on recording of vibration velocities and corresponding frequencies (figure 4). The main recording device was Minimate® Pro4 vibration control tool made by Instantel® (figure 5). 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 solid elements of adjacent buildings and structures (figures 6a-d).

**Figure 6.** Location of monitoring points a-d.
5. Results and primary conclusions from gained experience

Results of vibration velocities were measured at the distance range 16m to over 100m from the Rapid Impulse Compactor (figure 2). The tests were performed in September 2019 at the building site, where large amounts of the crushed debris and local sandy soil with large cohesive interbeddings were found in the soil profile. Detailed layout of control points is presented on figure 2, 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.

Figure 7
Vibration control in course of Rapid Impulse Compaction at testing phase:
- reduction of the impact during changing of machine position at operational phase of works (a),
- operation with standard energy of a single blow (b),
- decrease of the impact after changing drop height of the hammer (c).

In the case of Rapid Impulse Compaction, testing usually covers both: standard machine operation at work in various positions from the monitored structure (figure 7a) and testing the reduced energy (figure 7b-c) guaranteed by reduction of hammer drop height. The maximum value of vibration velocity by means of PPV reached around 6 mm/s when the RIC started the work at shortest distance (app. 15 m) from vibration sensor (figure 7a). Such a value was not acceptable for an office building due to possible architectural damage. The amplitudes of velocity decreased slowly with the distance between the sensor and source of dynamic impact.

When the distance reached app. 20 m, and the PPV value decreased to 4 mm/s (which was still risky) the machine was switched to “reduced energy” mode and measured vibrations decreased to acceptable limits (2-3 mm/s). The results given on figures 7 a-c, prove that the impact of RIC has a transient nature and it is to some extent adjustable.

The second test was performed in another place – a commercial building with large windows. Maximum value of vibration velocity by means of Peak Particle Velocity PPV in course of compacting reached around 34 mm/s when RIC worked at the distance of app. 1 m from the trench and 8 m from the accelerometer on the building. Closer operation was technically possible but the limit distance was set for equipment safety reason. The results given on figure 8a are absolutely unacceptable anyway.

Moving the machine to the distance of app. 22 m from the building made it possible to decrease the impact to 8 mm/s. It is important to underline that despite of the trench the values were over the acceptable limits. Further geological examination revealed large deposit of clay that might seriously affect the above mentioned range of values due to it impact on vibration transmission.
Figure 8. Vibration control in course of Rapid Impulse Compaction at testing phase:
- operation of RIC in standard conditions just behind the trench (a) (8 m from building),
- decrease of the impact when the distance increased to (b) (22 m from building).

6. Final remarks
It is important to underline again that the nature of vibration transmission is highly dependent on
gеotechnical conditions and vibration energy at source that might affect the above mentioned range of
values due to possible interference of 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 active generator impact can
be found in works of Herbut [17-19]. So far, the practical impact and implementation is rather limited
in building industry but at least in numerical modeling the perspectives are very promising [20,21].

The presented results can be helpful for planning of geotechnical works in the neighbourhood of
vibration sensitive buildings. 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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