Performance of Rapid Impact Compaction as a Middle-Deep Ground Improvement Technique

Bashar Tarawneh, Ph.D, P.E
Associate Professor, Civil Engineering Department, The University of Jordan, Amman, Jordan, btarawneh@ju.edu.jo

Yasser Hakam
Technical and Business Development Manager, Menard Vibro Middle East, Dubai, UAE

ABSTRACT: Rapid Impact Compaction (RIC) is a modern dynamic compaction technique mostly used to compact sandy soils, where silt and clay contents are little. The device uses the piling hammer technology to increase the bearing capacity and reduce the potential settlement of soils. The RIC device uses "controlled impact compaction" of the ground using a 9-ton hammer dropped from height between 0.3 m to 1.2 m onto a 1.5 m diameter steel patent foot. To evaluate the performance of this technique, the results of ground improvement work for a project site using RIC is presented in this paper. In the project site, a loose to very loose fine to medium sand was encountered at a depth ranging from 1.0m to 4.0m below the ground level. Cone Penetration Tests (CPT) were carried out before and after ground improvement. It was shown that soil was improved to a depth of about 5.0m below the ground level. CPT tip resistance was significantly increased post ground improvement work. This study demonstrates the successful application of the RIC for middle-deep improvement and compaction of the ground. Foundation design criteria were achieved in all site post RIC work.

KEYWORDS: Rapid Impact Compaction, Ground Improvement, CPT

1 INTRODUCTION

The RIC system uses "controlled impact compaction" of the ground using a 9-ton hammer dropped from height between 0.3 m to 1.2 m onto a 1.5 m diameter steel patent foot delivering about 26,487 to 105,948 Joules of energy per drop. RIC can be used to densify loose soils down to a depth of about 4 m to 6m. RIC consists of an excavator-mounted hydraulic pile-driving hammer striking a circular plate (patent foot) that rests on the ground. The tamper typically strikes the plate at a rate of 40 to 60 blows per minute. Figures 1A and B show rapid impact compactor and impact foot with driving cap.

Figure 1A. Rapid Impact Compactor

Rapid Impact Compaction (RIC) is considered an innovative dynamic compaction device mainly used to compact sandy soils, where silt and clay contents are low. RIC closes the gap between the surface compaction methods (e.g. roller compaction) and the deep compaction methods (e.g. deep dynamic compaction) and permitting a middle-deep improvement of the ground. RIC has been used to treat a range of fills of a generally granular nature (Watts and Charles 1993) and some natural sandy and silty soils (Braithwaite and Preez 1997).

Figure 1B. Impact Foot with Driving Cap

The compaction sequence is designed to work from the outside in, so that compaction of the lower zone soils occurs first followed by compaction of the upper zone. Data monitoring during the compaction process and the online display in the operator’s cab enables compaction control, an economic application of the compaction tool, and a work integrated quality control. The total impact depth of the impact foot, the number of blows, and the final settlement of the impact foot after a blow define the stopping criteria.

The way in which RIC improves the ground is a “top-down” process, compared to Dynamic Compaction (DC) which is a “bottom-up” process. The first few blows in rapid impact compaction create a dense plug of soil immediately beneath the compaction foot. Further blows advance this plug deeper, which compacts soil in a deeper layer. This process progresses until little further penetration of the compaction foot can be achieved with increasing blows (Serridge and Synac 2006).

2 STUDY AREA

In this paper, RIC is used as a middle deep ground improvement technique in a project site near Dubai, UAE to improve the soil bearing capacity and reduce the settlements.

The project site is a development to construct Villas. Each Villa is built on about 500 m^2. In some areas of the project site, a loose to very loose fine to medium sand layer is encountered at a depth ranging from 1.0m to 4.0m below the ground level. Cohesive soil was not encountered in the project area. Water table was encountered at a depth of 0.5m to 2.0m below the ground level.

The designer proposed the bottom of footings (B.O.F) to be constructed at 1.0m below the ground level. The design criteria, for the foundation, are to use square footing (2.5m by 2.5 m), 200 kPa bearing pressure, and settlement shall not to exceed 25mm in order to minimize differential settlement.

It's proposed to use Schmertmann (1978) method to carry out the settlement calculations. The bearing capacity and settlement criteria could not be met based on the existing soil conditions. Therefore, a ground improvement is needed to meet the foundation design criteria.

Considering the soil profile of loose to very loose fine to medium sand, three soil improvement techniques were considered namely: Vibrocompaction, Dynamic Compaction, and Rapid Impact Compaction. Those methods were considered because they are suitable for granular soil and available in the local market.

Vibro-Compaction is effective in improving the relative density of granular soils with suitable gradations and limited fines contents (not more than 5%). A vibroflot is penetrated to the required design depth, assisted by water jetting from the nose cone. Upon reaching design depth water jetting is reduced before the vibroflot is slowly extracted, with pauses at regular intervals to ensure satisfactory levels of compaction are achieved at each depth. The vibroflot is withdrawn back to the surface where a zone of compacted ground is formed around the insertion point. In this method, the soil particles are forced into a denser configuration by the generation of radial vibrations, resulting in a soil matrix with greater density and increased mechanical properties (shear strength, stiffness, and bearing capacity).

DC was first popularized by Menard and Broise (1975) and has become a well-known ground improvement technique due to its simplicity, cost-effectiveness, and the considerable depth it affects. With this technique, the ground can be repeatedly impacted by a large pounder weighing typically 6 to 40 tons, which is dropped onto predetermined grid points on the ground surface in free fall from a height varying from 10 to 40 m to increase the degree of compaction and bearing capacity and decrease collapsibility of loess within a specified depth of improvement (Lutenegger 1986).

The Vibrocompaction is not suitable, for the existing soil profile, because the fine content of the existing soil is more than 5%. The dynamic compaction is not suitable for this project due to nearby existing structures which may be damaged due to vibrations. RIC is a productive technique, cost effective, and a less time consuming method when compared to the other two methods (Tarawneh and Matraji (2014).

3 GROUND IMPROVEMENT USING RIC

Considering the cost and the schedule, it was concluded that performing RIC using the proposed design criteria is the optimum alternative. Among the evaluated soil improvement techniques, RIC was selected because it reduced the cost and time when compared to Vibro compaction, and DC. The RIC work was finished within three weeks for whole project area which is about (35,000 m^2). One Cone Penetration Test (CPT) was carried out at each villa location before the commencement of the compaction to evaluate the soil conditions and to determine the needed degree of compaction to meet the design criteria.

Preliminary compaction trials are crucial to any extensive RIC works to provide the designer with the necessary information to allow refinement of the compaction procedure. Two Villa locations were used as a trial area to establish a compaction design criteria. Moreover, as the main RIC works are proceeding, ongoing monitoring and testing is necessary to ensure that the appropriate amount of energy is being transferred to the soil and that performance requirements are being met. The compaction trial is important for the evaluation of ground response. The optimal number of blows per pass is typically taken as the value beyond which continued blows produce negligible further penetration of the compaction foot.

The process of compaction started by using a 6m grid then compacting a 3m grid in order to allow for deep improvement. Figure 2 shows the sequence of the compaction.

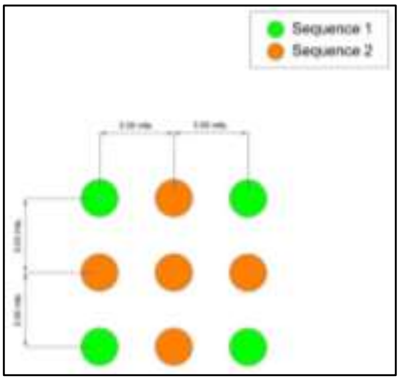

Figure 2. Compaction Grid

Compaction was delivered at each point until one of the following criteria was satisfied:

A. Maximum number of blows = 60
B. Maximum foot travel = 800 mm
C. Minimum foot settlement = 8 mm

Compaction of the 6m and 3m grid is considered one pass (sequence 1 and 2). One CPT test per villas was carried out after each pass. The project design criteria (settlement and bearing pressure) were met after the third pass. After completing the trial area, It's concluded that three passes are required using the above mentioned compaction criteria.

The sequence of the RIC works involved excavation to foundation level, pre-treatment CPT testing, first pass of RIC, leveling, second pass of RIC, leveling, third pass of RIC, leveling, level survey, and finally post treatment testing.

4 POST GROUND IMPROVEMENT TESTING

Testing is necessary to assure that appropriate amount of energy is being transferred to the soil and that performance requirements are being met. The degree of compaction is evaluated by comparing the pre and post CPTs and calculating the expected settlements.

Following the RIC work, one CPT per villa was carried out to provide post-treatment evaluation. The post-treatment CPTs were advanced, near to pre-treatment CPTs, to depths of about 5.5 meters approximately two days after the RIC treatment to allow for dissipation of pore water pressure. The corresponding post-treatment CPTs indicate an increase in the tip resistance within these same depths. Figure 3 shows the tip resistance for the pre-improvement, post 1st, 2nd, and 3rd Pass. It can be noted that the first pass energy was consumed to break the existing hard layer (crust) at the top while the 2nd and 3rd passes improved the soil.

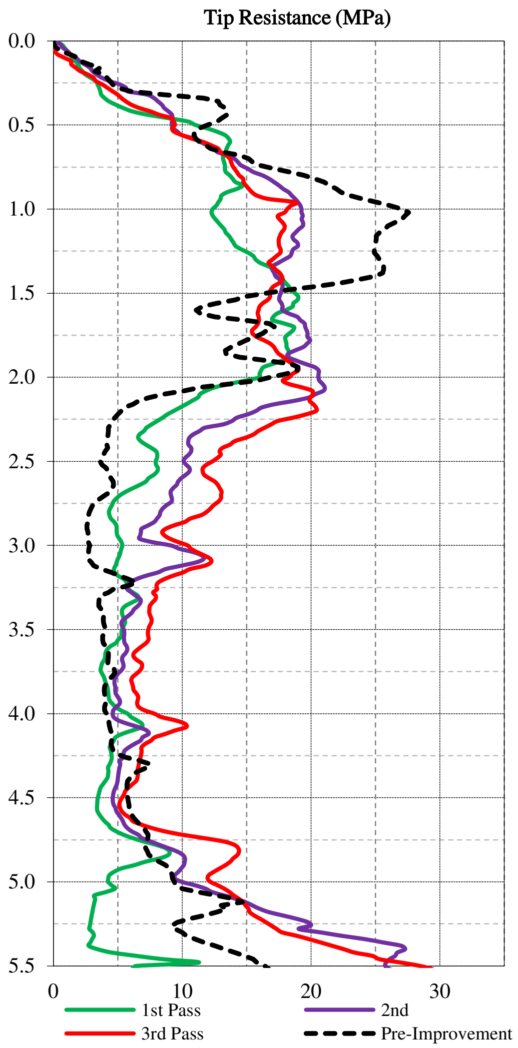

Figure 3: Tip Resistance for the Pre and post Improvement Passes

Figure 3 shows a loose layer approximately between 2.5m to 4.5m below the ground level. The goal is to improve this layer by increasing the tip resistance so the foundation design criteria can be met. It's clear that the tip resistance values were significantly increased approximately between the depths of 1.0m to 5.0m below the ground.

Settlement calculations were carried out using the method proposed by Schmertmann et al. (1978). Settlement values were less than 25mm for all project area when the size of the footing is (2.5m by 2.5m) and the bearing pressure is 200 kPa.

5 CONCLUSIONS

The results of ground improvement work project presented in this paper benefited from RIC, essentially by meeting the foundation design criteria, reducing foundation system costs and construction time. Results of the field pre and post improvement testing indicate improvement of soil to depths of about to 5.0 meters below the ground level. Settlements calculations showed that the RIC method reduced the expected settlement. RIC is considered to have less cost and more productivity when compared to other ground improvement techniques such as Dynamic Compaction and Vibrocompaction. It also, has less vibration effect when compared to dynamic compaction. No known damage to nearby utilities has occurred at the time RIC was performed.

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