The Use of Rapid Dynamic Compaction (RDC) for Soil Improvement

By Abdullah S. Algrayan, Anwar K. Bloch & Ziyad F. Alzamil

Introduction

There are several soil improvement techniques such as roller compaction, vibro compaction, and dynamic compaction. Every type has its advantages and disadvantages. In this paper, we are going to discuss a special application of dynamic compaction called Rapid Dynamic Compaction (RDC). We are also going to go over the design criteria and implementation of this technique in the flare area of a gas plant project.

Problem Statement

The flare area (2.5 x 3.0 km) is a large area covered with a massive natural sand dune terrain. That area needs ground improvement for project specified facilities including but not limited to pipe racks, flare stacks, Deadman anchors, retaining walls, road networks, and burn pits.

The flare area is divided into 10 blocks with 19 different areas as seen in Figure 1. Due to the large surface area, typical ground improvement techniques like roller compaction is deemed unpractical. Instead, RDC shall be used due to the large area with no nearby structures. RDC was used to compact after backfill of around 3 million m3 in around one year instead of using conventional methods, i.e., backfilling in 300 mm layers with roller compaction that could take a significantly longer time.

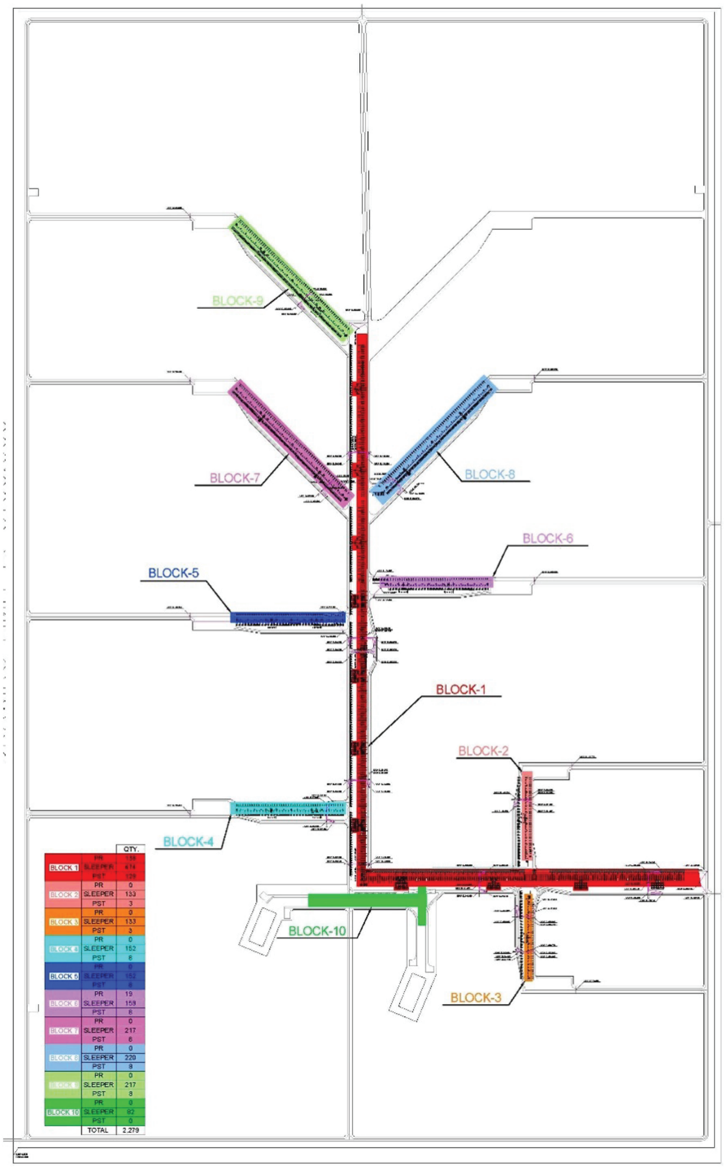

Figure 1: Flare Area Blocks

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Rapid Dynamic Compaction (RDC) Technique

Rapid Dynamic Compaction (RDC) technique (also known as Rapid Impact Compaction) is a recently developed soil improvement technique, used for shallow treatment of granular soils (for fine content <15%) up to 4m deep, as a special application of Dynamic Compaction (DC) method for shallow treatment. The RDC machine consists of a hydraulic excavator base with a strengthened arm to which a compaction hammer is attached (as shown in Figure 2).

Figure 2: RDC Machine

The compaction energy generated by the fall of 12-16-ton hammer from height of up to 1.2 m. The automated hammer falls on a compaction foot having a diameter ranging from 2.0 to 2.6m, in contact with the ground. The energy is in turn transferred to the ground pushing the material into a denser structure. The dense compaction pattern with overlapping influence zones guarantees homogenous compaction and provides the required bearing capacity of soil for the development of required structures.

Design Criteria

Due to the difficulties in obtaining undisturbed samples of cohesionless soils, geotechnical engineers often rely on field tests to obtain in-situ soil characteristics. Due to its relatively lower cost, simplicity, continuous measurement with depth and excellent repeatability and accuracy, the electronic cone penetration test (CPT) has emerged as one of the most popular tools for ground investigation and estimation of the relative density of in-situ soils in geotechnical engineering.
Based on the project requirement, ground should be improved adequately to withstand the loads and comply with the following criteria:

- Minimum Relative Density of 85.0% for the cohesionless granular soils of additional fill materials as well as for loose material at natural ground surface shall be achieved by RIC / RDC method.
- Minimum dry density of 95% (MDD) shall be achieved by Roller Compaction Method.

Relative density is estimated by reverse calculating the required degree of relative density (Dr) to cone tip resistance (qc) values based on a standard, thereby creating performance lines and comparing them to the post compaction cone resistance values; for the proposed improvement strategy in the current document, a performance line for qc values has been developed according to three correlation formulas for relative density of 85% as shown below:

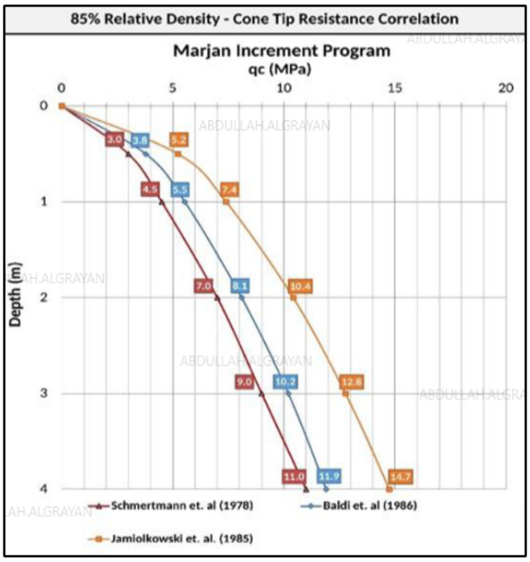

Figure 3: Correlation Formulas for 85% Relative Density

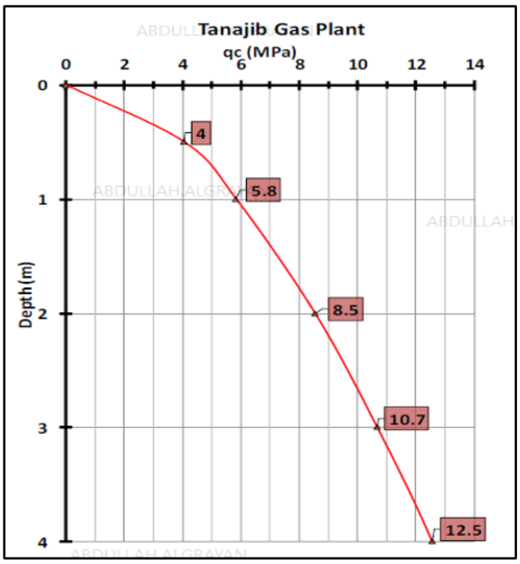

Figure 4: qc Performance Line

Implementation of Rapid Dynamic Compaction (RDC)

Prior to the commencement of actual compaction works, a trial/calibration area was carried out to confirm the suitability of the above-mentioned technique and to optimize the design parameters according to the in-situ soil conditions. The calibration work consists of performing pre-compaction tests on loose fill, followed by compaction of that fill location. Post treatment tests are carried out once the compaction has been completed. The observed behavior of soil during compaction and the results of the post treatment tests help decide the anticipated compaction parameters. The compaction parameters are:

A. The grid spacing
B. The number of blows per print by RDC machine
C. The drop height of hammer
D. The number of phases and passes

Calibration work is usually carried out at the locations presenting most challenging conditions for soil improvement. Also, calibration work is very indicative with regards to the level of improvement achieved based on the comparison of the pre and the post-treatment test results. The trial area taken is 1,000 m2 divided into boxes with spacing of 2.5m x 2.5m, 2.75m x 2.75m, 3.0m x 3.0 m and 3.5m x 3.5m grids (see Figure 5).

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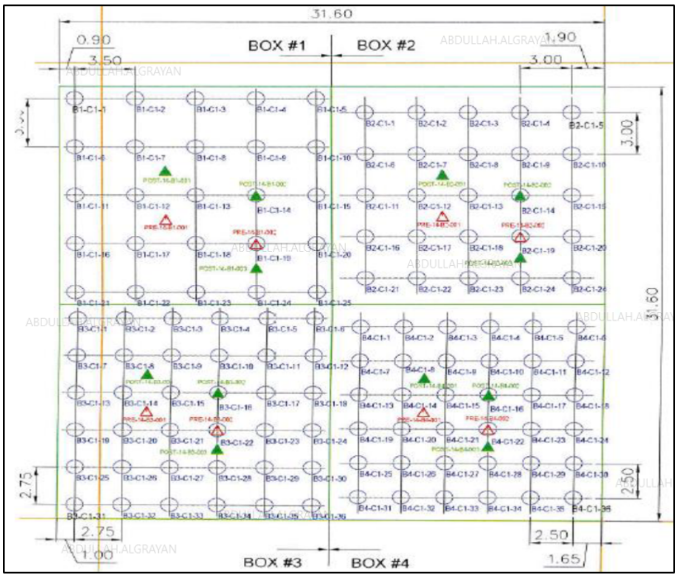

Figure 5: Trial Area Grids

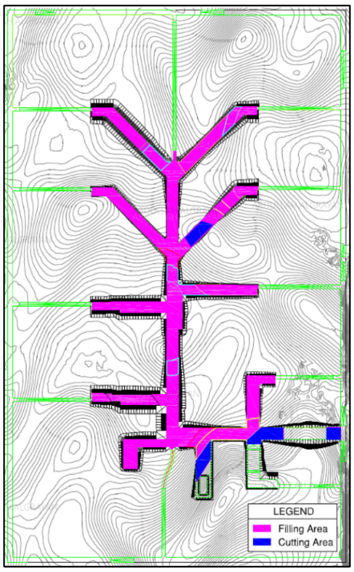

Figure 6: Soil Improvement Area for Natural Soil at Flare Area

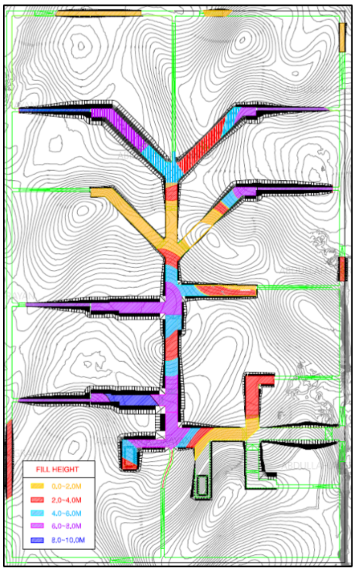

Figure 7: Additional Fill at Flare Area

The location of the trial test area should be selected based on the existing soil conditions and thickness of backfill. Due to the limited information about the subsurface formations, the field trial locations were selected after performing the pre-CPT testing to get a better idea about the exiting subsoil formation within the flare area. After calibration works, one pre-CPT shall be carried out for every 1,000 m2 up to 6 m deep for main compaction works.
The portion in the figure is proposed to be improved by Rapid Impact Compaction / Rapid Dynamic Compaction for natural loose soil and additional fill soils.

For the initially proposed flare area, soil density was varying from generally medium dense to very dense in conditions from the existing site grade, groundwater elevation is about EL -10.0m from existing ground level and fine content is almost less than 15% – obviously loose layer was encountered at the depth various from 0.3 to 1.2m below the existing ground layer for many boreholes, thus RDC will be the most suitable technique to improve the subsoil for these borehole areas. RDC using in-situ sand as the backfilling materials will be performed in the remaining areas as well. Figure 8 illustrates the proposed sequence of the RIC/RDC works within the flare area.

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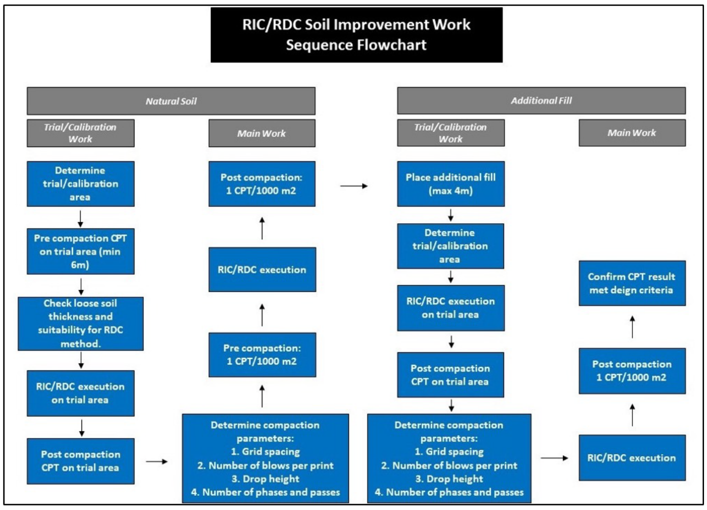

Figure 8: Work Sequence of Soil Improvement Using RDC

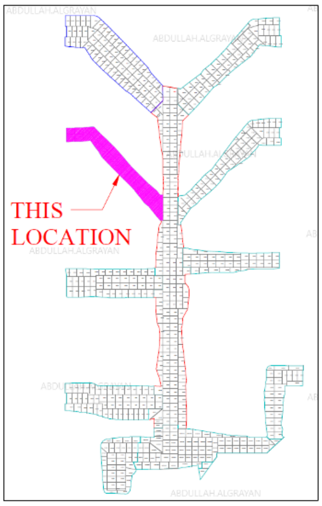

Figure 10: Flare Area 7

Results

Taking Flare Area #7 as an example (See Figure 10), pre-CPTs were executed on the natural ground level, while post-CPTs were done after the compaction of natural soil (Stage 1) and after compaction of fill material (Stage 2).

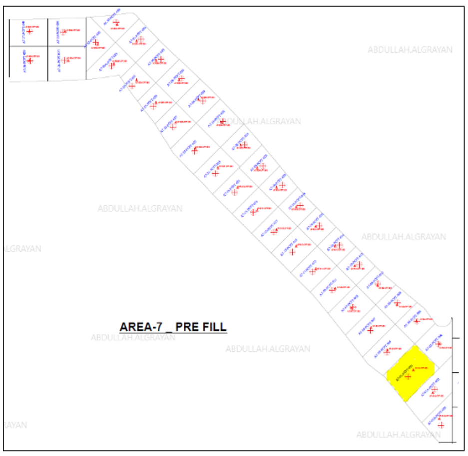

Figure 9: Box ID #1 in Flare Area 7

For Box ID #1, as highlighted in Figure 9, tests were done and the cone penetration readings are as seen in Figure 11 and Figure 12. The Pre-CPT tests signify that at some depths the cone resistance (qc) falls below the target performance line. After the implementation of RDC, we can see from Figure 12 that the cone resistance for all depths are well within the target performance line as indicated in the design criteria.

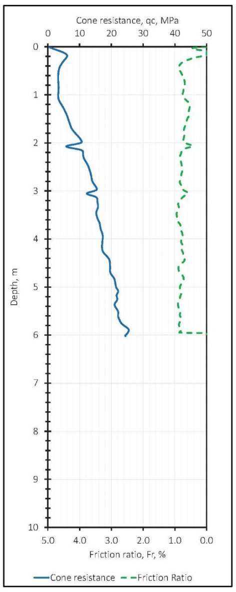

Figure 11: Pre-CPT for Box ID #1

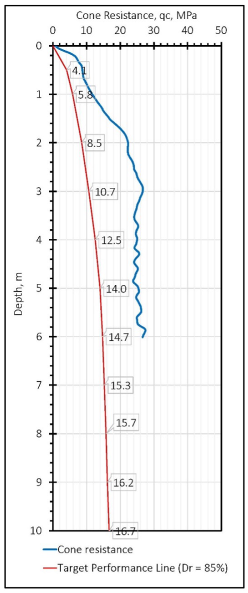

Figure 12: CPT Results for Box ID #1 After RDC Implementation

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Conclusion

As the plot area is quite big and conventional backfilling and compaction methods for soil improvement are not feasible. RDC is utilized for compaction to improve the ground after filling the area around 8 to 9m deep. Although this technique needs a special crew to work with it under complete and active supervision to avoid any machinery breakout due to improper use, it saves a significant amount of time and has positive impact on the project schedule.

References

1. Alaaeldin, A., Spyropoulos, E. and Orabi, A. (2020) Unified Approach to Assess Engineering Performance of Fill Improved by Shallow to Deep Compaction Based Techniques Using Relative Density. Open Journal of Civil Engineering, 10, 239-249. https://doi.org/10.4236/ojce.2020.103020