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Dynamic Compaction for Treating Millions of Square Meters of Sand

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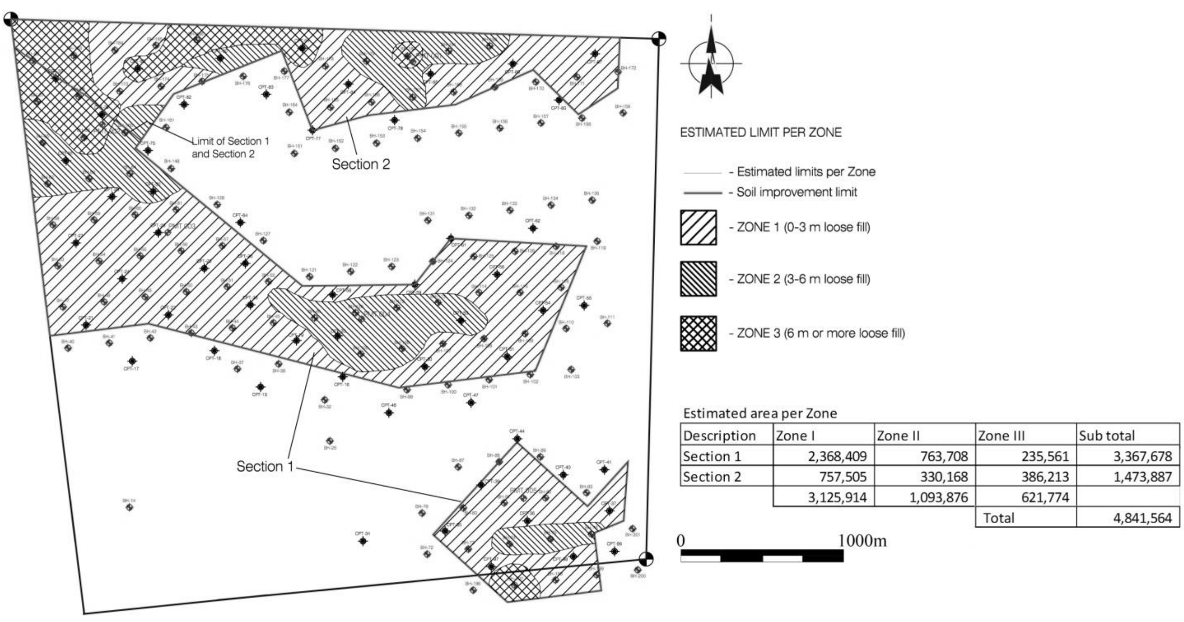
Synopsis: To the knowledge of the authors, the 4.84 million square meter ground improvement project of Al Falah Community Development in Abu Dhabi is the physically largest single contract that has ever been undertaken by a specialist ground improvement contractor. The peak ground improvement production rate of 966,000 m^2 per month also appears to be a new world record. This paper will describe the initial ground conditions of the project, the development of a foundation solution based on the utilization of ground improvement technology and the account of how mobilization, execution of Dynamic Compaction for the treatment of loose desert sands and verification testing by the Menard Pressuremeter Test were all realized within a mere period of 7 months.

Keywords: dynamic compaction, ground improvement, Menard pressuremeter test, CPT.

1. Introduction

As part of the development of Abu Dhabi, Al Falah Community Development, a mega project with an estimated value of 2.56 billion USD and an area of 12.7 million m^2, was launched in 2008 in the outskirts of the capital city of UAE. The project was anticipated to include 5,000 villas, 2,300 townhouses, 2,100 apartment houses, 14 schools, a hospital, a shopping mall, a number of hotels, restaurants, and health clubs.

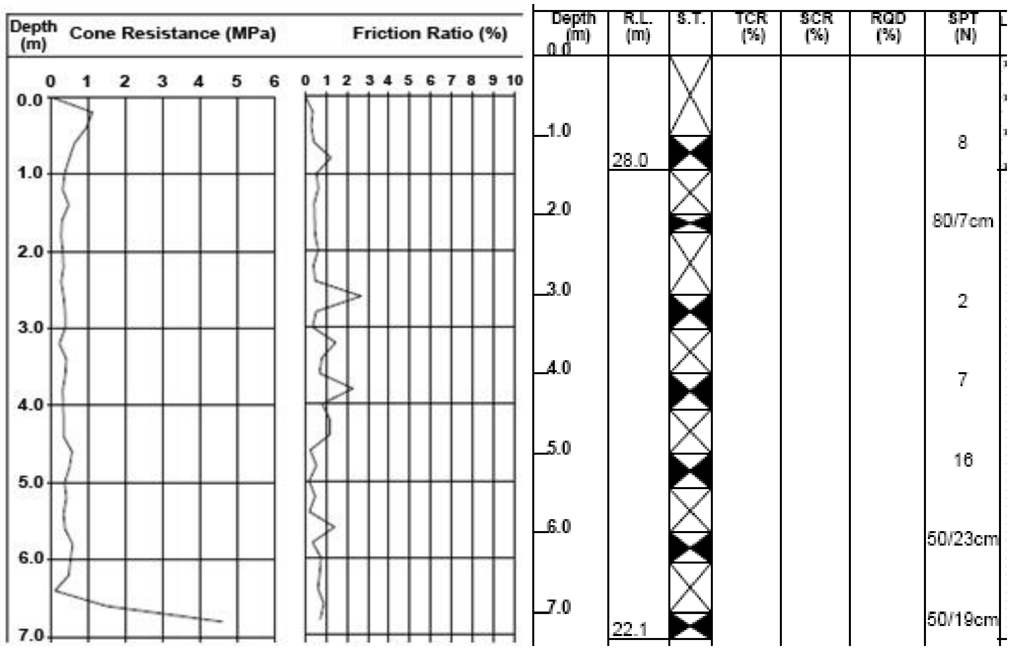
The geotechnical investigation of the project indicated that the site was covered with a superficial layer of silty sand with a variable thickness of only a few centimetres to more than 18 m followed by sandstone or siltstone bedrock. The soil (white area in Figure 1) in a large portion of the site was very dense and it was possible to construct shallow foundations without any difficulty. The SPT blow counts in these areas were consistently more than 50 and CPT penetration would generally reach refusal within the first meter.



Estimated area per Zone

Description	Zone I	Zone II	Zone III	Sub total
Section 1	2,368,409	763,708	235,561	3,367,678
Section 2	757,505	330,168	386,213	1,473,887
	3,125,914	1,093,876	621,774	
			Total	4,841,564

Figure 1. Site plan, ground improvement zones and sections



(a) **(b)**

Figure 2. Two test results of initial ground conditions (a) CPT, (b) SPT

However, the ground conditions were not suitable throughout the entire site, and the test results indicated the presence of loose soil layers in an area of 4.84 million m^2 (hatched areas shown in Figure 1). In these areas the SPT blow counts in the superficial layer were generally from 7 to 12 and occasionally as low as 2. Similarly, CPT cone resistance was mostly from 2 to 3 MPa. Fines content of these loose layers were usually less than 25% but occasionally higher, and the CPT friction ratio was generally less than 1% but occasionally as high as 3%. Typical SPT and CPT results are shown in Figure. 2.

It was observed that while the groundwater level was relatively deep and from 11 to 18 m below the ground surface, the moisture content of the ground varied from 8 to 35% in the non-saturated layers.

Further study revealed that the thickness of loose soil deposits was less than 3 m in 64% of the site (see hatched areas in Figure 1). 23% of the loose soils had a thickness of 3 to 6 m, 8% had a thickness of 6 to 10 m and 5% had a thickness of more than 10 m and exceptionally up to 18 m. Consequently, a study and assessment of the geotechnical report and preliminary calculations indicated that the mentioned above areas with poor ground conditions could not support shallow foundations with the design criteria that the project's designers had in mind. Shallow foundations were required to satisfy the below criteria:

- Allowable bearing capacity: 150 kPa for conventional strip or pad foundations with maximum dimensions of $1.5m \times 1.5m^2$ (villa areas) or $3 \times 3\ m^2$ (heavy loads).
- Maximum total settlement: 25 mm for a maximum pressure of 150 kPa applied to the above mentioned footings.
- Differential settlement: 1:500 measured between surface points not closer than 8 m apart.
- Liquefaction mitigation: for an earthquake with magnitude 6 and peak ground acceleration equal to 0.15g.

Although feasible, it was assessed that piling was not a method of choice because it was not only costly, but could not be carried out within the allocated time frame for foundation works, and consequently would delay and disturb the entire schedule.

2. The Ground Improvement Solution: Dynamic Compaction

Based on the experiences of a number of very large size ground improvement projects such as the 2.7 million m^2 (KAUST) King Abdulla University of Science and Technology [1], 1.5 million m^2 Nice Airport [2], 1.1 million m^2 Al Quoa New Township [3], 1.05 million m^2 Changi Airport (paper not published), 0.9 million m^2 Abu Dhabi New Corniche [4] and 460,000 m^2 Changi Airport [5] one of the specialist ground improvement contractors that was invited to tender proposed the implementation of Dynamic Compaction [6, 7] and was awarded a 240 day contract to carry out the ground improvement works for an area of approximately 4.84 million m^2.

To the knowledge of the authors and the ground improvement construction team, this project is physically the largest soil improvement project that has ever been undertaken by one specialist ground improvement contractor in one phase. More challenging was the fact that the schedule was very tight and it was expected that the average ground improvement production rate during the contract period had to exceed 700,000 m^2 per month for the project to be delivered on time. Noting that production would not begin on the first day of the contract, but would realistically build up gradually with the introduction of additional Dynamic Compaction rigs during the mobilisation period, peak production rate was expected to exceed 900,000 m^2 per month. This, meant that the construction team were required to set a new world record for the rate of ground improvement production by surpassing what was then understood to be the world record that was established in KAUST at 600,000 m^2 per month in [1].

2.1 Optimisation and Execution of Works

Dynamic Compaction is the systematic dropping of a heavy pounder from a significant height to treat loose layers of dominantly granular soils [8]. The depth and amount of improvement is a function of pounder weight, drop height, pounder dimensions, number of compaction phases, grid size per phase, number of blows per impact location, interval between phases and initial ground conditions.

It is obvious that meeting both the technical specifications and contractual programme of what is understood to be the world's physically largest ground improvement project with the world's most demanding programme requires an optimised effort and any locally small number can have an enormous effect on the total amount of works.

A key target for optimisation is the treatment energy. This can be achieved by taking a number of parameters into account. These include:

- Depth of improvement: geotechnical information indicated that the treatment depth was variable from less than 3 m to more than 10 m and exceptionally up to 18 m. Hence, it would be logical to divide the treatment zones according to treatment thicknesses (0 to 3 m, 3 to 6 m, 6 to 10 m, and 10+ m).
- Amount of improvement: The amount of load that the soil had to support was not the same throughout the project (lesser loads for the villas and higher loads for the apartments), so it would be rational to improve the ground conditions of each area based on the requirements of that area rather than developing one compaction pattern for all zones with the same thickness.
- Number of blows per print: Once the requirements for depth of treatment and energy intensity have been established it will be necessary to design the blows. Achieving the same energy intensity will require lesser blows with a heavier pounder; however lifting pounders heavier than about 13 to 16 tons requires special lifting rigs. Hence, logistics are introduced to the equation and in a very large project, programming the equipment will have to take the limitations of reality into account as well. The experience of Dynamic Compaction in KAUST, to the knowledge of the authors the project that has utilised the most number of Dynamic Compaction rigs [1], indicated that it was possible to enforce management techniques to mobilise large numbers of rigs in a relatively short period.

Figure 3. Implementation of 11 special cranes for DC (not all shown in this picture)

Prior to the commencement of production a full scale calibration Dynamic Compaction was performed to verify the assumed work parameters. As part of this programmes 18 Menard Pressuremeter Tests (PMT) and 32 cone penetration tests (CPT) were also carried out.

Thus, with the intention to optimise production a combination of different pounders weighing up to 23 tons were utilised by 11 Dynamic Compaction rigs working in two shifts. Six rigs can be seen carrying out Dynamic Compaction works in Figure 3.

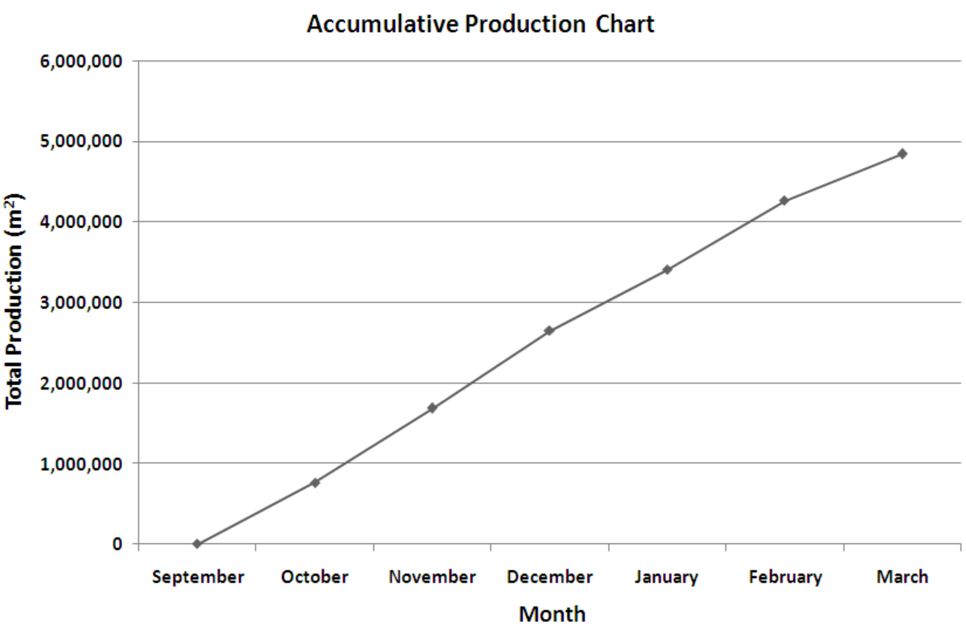
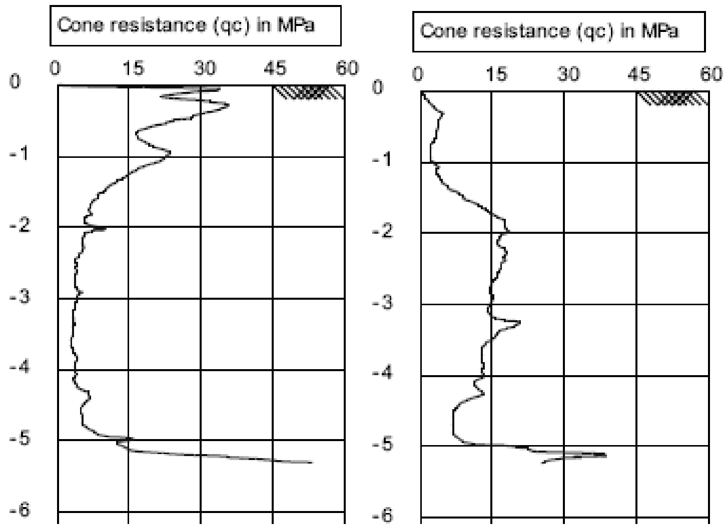


Figure 4. Accumulative treated area



(a) **(b)**

Figure 5. Two CPT test results (a) before Dynamic Compaction, (b) After Dynamic Compaction

The optimization of the Dynamic Compaction design and ability to provide sufficient number of rigs allowed the completion of the project before the handover date, i.e. in 7 months. Figure 4 shows the accumulative production chart of Dynamic Compaction works. It can be observed that the maximum ground improvement monthly production rate was set at 966,000 m^2 which to the knowledge of the authors is the current world record.

2.2 Testing

The project specification required that bearing and settlements to be verified by performing Menard Pressuremeter Test (PMT). Also, it was anticipated to carry out CPT for verification of liquefaction mitigation and as an additional control measure. Consequently, in addition to field tests that performed during the calibration programme, a total of 282 PMT and 1,029 CPT were also carried out to confirm the project requirements had been met.

It can be calculated that the ratios of treated ground to PMT and CPT are respectively about 1 in 17,000 m^2 and 1 in 4,700 m^2. The authors note that these ratios are much larger than what is occasionally requested in project specifications. However, it must be made clear that this is possible due to the nature of Dynamic Compaction works. In this technique each impact point in itself can represent a pseudo test whereas the amount of ground and crater settlement can be correlated to the soil parameters. The successful application of Dynamic Compaction in other large size projects with similar area to test ratios (for example 180 PMT tests or 1 test per 14,400 m^2 was carried out in KAUST [1]) and the development of methods for predicting soil parameters using imposed ground subsidence [9] justify the logic of such testing programme. Indeed, without such an optimised approach, testing in itself could become a critical issue rather than a means of verification.

CPT cone resistance before and after Dynamic Compaction in the same location is shown in Figure 5. The latter test has been carried out before ironing, thus while the cone resistance in the deeper values has increased by about 3 times to 15 MPa, the uppermost layer of soil is exhibiting a reduction in strength. This layer can reach higher strength values after performing the ironing phase.

3. Conclusions

To the knowledge of the authors, Al Falah Community Development is not only physically the world's largest ground improvement project at 4.84 million m^2 but is also the holder of the world record for ground improvement treatment rate for the production of 966,000 m^2 during the period of one month. Accomplishing this achievement has been made possible by utilising an optimised design of Dynamic Compaction parameters with consideration of different ground profiles, pounder weights, drop heights, pounder dimensions, number of Dynamic Compaction phases, grid sizes per phase, number of blows per impact locations and intervals between phases. Furthermore, the ground improvement contractor was able to mobilize sufficient numbers of Dynamic Compaction rigs in a timely and organized manner to reach completion of the works before the contractually specified milestone.

The homogeneity of the ground treatment enabled the testing program to include sufficiently optimised but controlled number of field tests to ensure the achievement of the criteria throughout the site without making testing itself a critical task on the schedule of works.

4. Acknowledgement

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5. References

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