International Conference on Advances in Geotechnical Engineering, Perth, Australia, Nov.7-9, 2011, ISBN: 978-0-646-55142-5

Application of Dynamic Replacement in a Steel Pipe Factory

Babak Hamidi[1], Hamid Nikraz[2] and Serge Varaksin[3]
[1]PhD Candidate, Curtin University
[2]Head of Department and Professor of Civil Engineering, Curtin University
[3]Deputy General Manager, Menard

Synopsis: Prior to the construction of Al Jazira Steel Pipe Factory (AJSPF), almost all buildings in the Industrial City of Abu Dhabi were constructed on piles. This was due to the presence of compressible layers of soil, especially a superficial layer composed of one to four metres of soft sandy silts and clays. To the knowledge of the authors AJSPF is the first project in this area that has been built without the implementation of any piles and founded on shallow foundations improved by Dynamic Replacement. Variations of loading conditions and design criteria has made this pioneer project of special interest. While classical Dynamic Replacement was used for some ground slabs, pre-excavated Dynamic Replacement was applied under single footings and heavily loaded storage areas. As a cost saving method, sand from local Abu Dhabi excavations was used as granular material in lieu of the more commonly used crushed stone. Pressuremeter Tests (PMT) and finite element analysis was able to demonstrate that acceptance was achieved.

Keywords: dynamic replacement, ground improvement, soil improvement, Menard pressuremter.

1. Introduction

1.1 The project's Description

Al Jazirah Steel Pipe Factory (AJSPF) has recently been constructed on Plot 203ER6 of Industrial City Abu Dhabi (ICAD) Phase 1 Extension in the UAE. The plot of land is approximately a chamfered square with an area of 397,889 m^2. As can be seen in Figure 1, 6 buildings were considered for the first phase of AJSPF. These included the 31,200 m^2 main and annexed building, the 2,700 m^2 workshop, the 3,300 m^2 hot bending building, the 17,00 m^2 administration building, a mosque with associated washrooms, and the fire water tank and pump room.

Different activities including plate stacking, preparing, rolling and bending, welding, inspecting and controlling are undertaken in the main building and the maximum vertical load on a stanchion of this building was estimated to be 2,500 kN with floor loads ranging from as low as 40 kPa to as high as 200 kPa. The annexed building mainly consists of storage areas, laboratories and changing rooms, and its maximum vertical column load was estimated to be 300 kN.

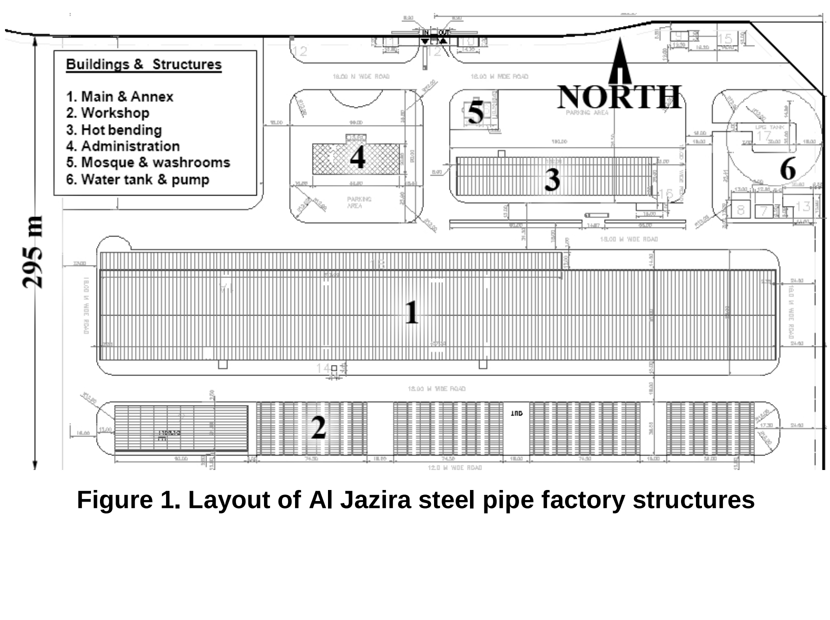

Figure 1. Layout of Al Jazira steel pipe factory structures

The workshop and hot bending buildings each have 50 columns with vertical loads up to 1,000 kN. and carry crane loads. The administration building was the only two storey structure on site with column loads were up to 1,500 kN.

1.2 Ground Conditions

A preliminary geotechnical investigation had been undertaken by the developer of ICAD Phase 1 Expansion. This investigation included a number of SPT (Standard Penetration Test) boreholes and CPT (Cone Penetration Test) of which two SPT and one CPT fell within the limits of AJSPF.

Ground level was generally 1 m below final finished levels of the buildings, and groundwater level was 1.8 to 1.6 m below site ground level.

SPT results suggested that the geotechnical profile of the site was composed of 11 to 12 m of soil followed by bedrock. The SPT blow counts in the upper 5 m were as low as 10, but then the soil became very dense with blow counts exceeding 50. It identified that up to 2 m of a compressible soil was located at the depth of 1.5 to 2 m which was high in fines.

CPT results illustrated a more problematic condition, identifying a soft layer of silty or clayey material with minimum cone resistance of 0 MPa intercepted at a depth of about 1.5 to 2 m. The thickness of this layer was about 2 m.

Supplementary Menard Pressuremeter Tests (PMT) that were later carried out proved that the CPT was more representative of the ground conditions. Limit pressure (P_{LM}) in the soft layer was generally in the range of 2 MPa and Menard modulus (E_M) was as low as 15 kPa.

The history of almost all projects in ICAD resorting to piling as their foundation system due to poor ground conditions was enough evidence for the project's developer to comprehend that they were dealing with a site that required the implementation of special measures for safely transferring the structural loads to the ground.

2. The foundation Solution: Dynamic Replacement

The developer of AJSPF considered alternatives of either piling or performing ground improvement and utilising shallow footings. Piling was well established in the region and was a method that was technically acceptable; however cost studies were quick to reveal that installation of 2,500 piles was more expensive than ground improvement. Among possible soil improvement technologies Stone Columns and Dynamic Replacement (DR) were proposed, but after considering the technical and financial aspects of each method, it was the latter method that was deemed as the more appropriate of the two. A design and build contract was awarded to a proposing specialist geotechnical contractor using dynamic replacement method.

2.2 Design and Acceptance Criteria

Hamidi et al. [1] have reviewed different approaches for stipulating ground improvement specifications for acceptance criteria and conclude that the most appropriate way is to define acceptance criteria based on the actual needs of a project; i.e. the design criteria. The same philosophy was adopted for this project and acceptance criteria was based on the design criteria of each component of the project. A summary of the design criteria is shown in Table 1.

Acceptance was based on PMT with the method used by Menard [2] for the interpretation of the results. Alternately, finite element analysis was used for settlement calculations.

2.3 The Concept of Dynamic Replacement and Its Application to the Project

Dynamic Replacement (DR) was invented by the late French engineer, Louis Menard in 1975 for improving the properties of soft saturated fine grained soils by dynamically driving granular inclusions into the soil. Similar to Dynamic Compaction and as shown in Figure 2, in this technique a heavy pounder is dropped from a relatively significant height onto a print a number of times. Unlike Dynamic Compaction where craters are formed due to the densification of the soil, in Dynamic Replacement holes of considerable size are formed due to largely plastic displacements of soil under the impact points and the holes are backfilled with granular material and compacted with the falling pounder.

Table 1. Summary of design criteria

Type	Allowable Bearing Capacity (kPa)	Maximum Settlement	
		Total (mm)	Differential
Building footings	200 kPa, 1.5 to 3.5 m below finished floor levels	25	1/1,000 to 1/500
Equipment footings	generally 75, locally up to 200	25	1/1,000
Ground slabs			
Steel plate storage	100	75	1/500
Water tank	150	50	1/500
Other industrial	40	35 to 50	1/500
Other non-industrial	15 to 25	25	1/500

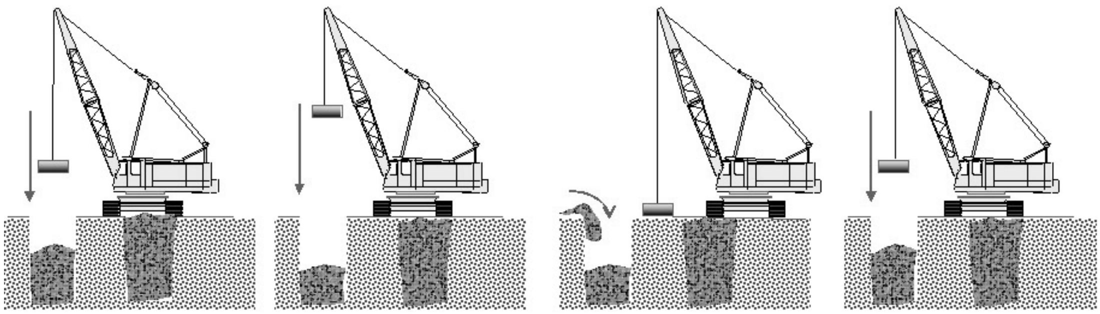

Figure 2. The process of Dynamic Replacement

Dynamic Replacement columns can be used both as individual inclusions or as a group of inclusions to support point and uniform loads. The presence of a granular transition layer between the base of footing and the columns can assist the distribution of the load using the arching effect [3].

Initial calculations suggested that heavy point loads would require a number of DR columns to safely transfer the loads to the foundations, and a cost study suggested that it would be more economical to pre-excavate the soft soils, backfill the foundation with granular material and compact the soil by Dynamic Compaction rather than to create a group of individual DR columns under the load. It should be noted that this decision was made attractive because the excavated material did not contain any contaminated soils that would have required treatment and it was possible to economically distribute the excavated material throughout the vacant factory boundaries. Thus the soft soil was pre-excavated and replaced with granular material under the stanchion and equipment footings. In the storage areas with 100 and 150 kPa of uniform loading and smaller footing locations the excavation and removal was limited to the DR column locations only.

Although Dynamic Replacement is frequently carried out using crushed stone due to its material's achievable high strength and low compressibility properties, in fact any granular material including demolished concrete can be used for creating DR columns [4].

The closest stone quarries were about 300 km away from the project, and this would have incurred a considerable transportation cost to the project. Assessment of alternatives confirmed that it would be possible to meet the design and acceptance criteria by using locally sourced sand. The emirate of Abu Dhabi is essentially flat ground and suitable sand quarries were still about 100 km away; thus as a further step towards optimization, sand was sourced from excavation sites within the metropolitan region. The portion of the upper sandy soils that were themselves low in fines and not contaminated by the fines of the compressible layer during pre-excavation of the DR columns were also used for backfilling.

(a) **(b)**

Figure 3. (a) Pre-excavation, (b) backfilling with sand and compacting with a heavy pounder

Figure 3(a) shows the excavation of a stanchion down to the depth of about 5 m. As shown in Figure 3(b) this was later backfilled with sand and compacted with a 13 ton pounder. Drop heights were from 10 to 20 m.

Mobilisation, calibration, completion of 37,000 m^2 of Dynamic Replacement and testing was performed during a period of less than 4 months.

2.4 Testing and Verification

In addition to the six PMT that was performed during calibration, an additional 41 PMTs were carried out during the works. 37 of these tests were performed after ground improvement for verification purposes.

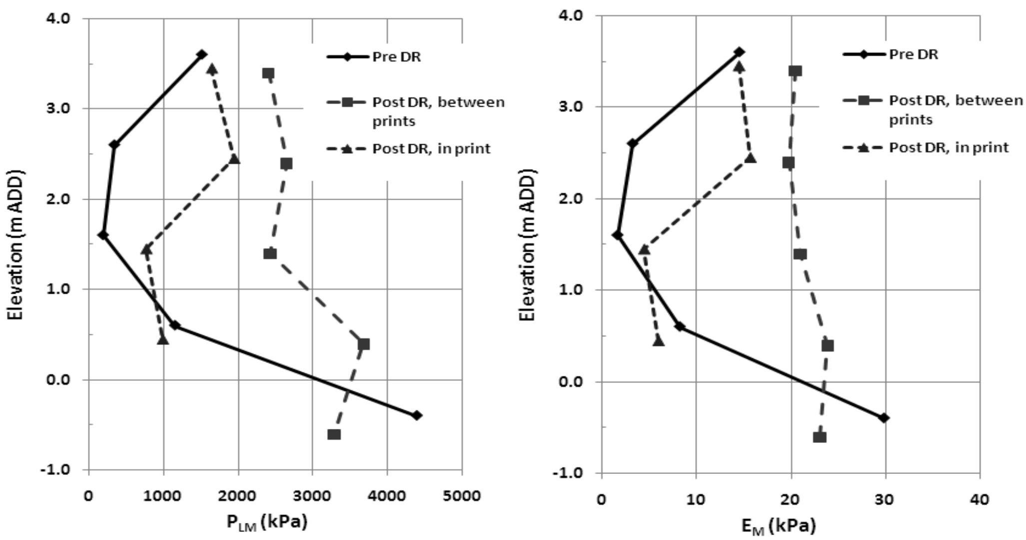

Figure 4. PMT limit pressure and Menard Modulus before DR, between prints and in DR print

The results of three PMTs are shown in Figure 4. For comparative purposes a PMT was performed before Dynamic Replacement. The same location fell in between pre-excavated DR prints, and was re-tested after ground improvement. Also, a PMT was performed in one of the print locations next to the location that had been tested earlier. Ground level at the testing points was +4.4 m ADD (Abu Dhabi Datum). It can be seen that in this area the soft layer was from about +1.5 to +2.5 m ADD. After Dynamic Replacement P_{LM} and E_M have both increased in upper 5 m of both the test inside the DR column and the test in between the DR prints.

The improvement in the soft layer appears to be less than the other layers; however during design it was conservatively assumed that the soil in this layer would, if at all, improve marginally. This layer has marginally improved because in reality the cohesive layer was silt and clay which contained some sand. Hence the impact did not strictly lead to a plastic displacement, and the impact energy was able to improve this layer.

The results demonstrated the amount of improvement in the DR print is considerably more than in between the prints. This should be expected in any case because the pounder impact turns the soil right under it into a very dense plug. However, it can be well observed that after ground treatment the ratio of inside DR print to in between DR prints improvement is most in the layer that has been replaced. Comparison of PMT values shows that at about elevation +3.5 and +2.5 m ADD the average improvement in P_{LM} and E_M were respectively 1.41 and 1.33 times, but the same was respectively 3.16 and 4.67 times more at elevation +1.5 m ADD.

The harmonic mean of P_{LM} in the pre-excavated DR column is 2,817 kPa. Assuming that the lower layers also have the same limit pressure value, it can be calculated (Menard, 1975) that a sandy soil with a footing that is on ground surface will be able to provide a safe bearing of 800 kPa with a safety factor of 3. Bearing capacity will be even higher for embedded footings, but in such cases it will be settlement criteria that will dominate. For example, calculations for a 3.5x4.5 m^2 stanchion footing demonstrates that the footing will settle 9 mm under the 2,500 kN load. Clearly, settlement under a load of 12,600 kN (800x3.5x4.5) would far exceed settlement criteria of 25 mm.

It is also important to consider that engineers regularly use formulas for predicting bearing capacity that are based on a 25 mm settlement. This project, where settlement criteria vary and not necessarily equal to 25 mm, is a very good example of how this approach could provide potentially erroneous results. Bearing capacity and settlement are two different phenomena. Each should be individually assessed with criteria governing the design.

Detailed calculations were carried out using the PMT results to verify that all design criteria had been satisfied.

3. Conclusions

Al Jazira Steel Pipe Factory was the first in a series of ground improvement projects in the Industrial City of Abu Dhabi. In this project pre-excavated Dynamic Replacement was successfully used to provide foundations for footings and slabs on a site that contained saturated layers of soft soil.

In lieu of the commonly used crushed stone for DR column material, sand from local excavations in the metropolitan area were used to create the columns.

Post improvement test results indicate that while the upper 5 m of soil in between the DR prints improved, the amount of improvement in the soft layer was noticeably less than other layers. However, in the DR column, the replaced layer improved in a similar manner to all other layers.

4. Acknowledgement

The authors would like to express their gratitude and appreciation to Menard for providing the technical data that has been used in this paper.

5. References

1. Hamidi, B., Nikraz, H. and Varaksin, S., “Ground Improvement Acceptance Criteria”, Proceedings, 14th Asian Regional Conference, 23-27 May 2011, Hong Kong.
2. Menard, L., “D60 The Menard Pressuremeter”, Sols Soils, No. 26, 1975, 43 pages.
3. Hamidi, B., Nikraz, H. and Varaksin, S., “Arching in Ground Improvement”, Australian Geomechanics Journal, 44(4), 2009, pp 99-108.
4. Hamidi, B., Varaksin, S. and Nikraz, H., “Dynamic Replacement for Constructing Embankments and Walls on Soft Soil”, 3rd International Conference on Problematic Soils (PS10), Adelaide, 7-9 April 2010, pp 105-112.