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Ground Improvement Implementation in Sabkha Soils using Wick Drain for the Steel Plate Manufacturing Project, Ras Al Khair, Saudi Arabia

Mohd Reza Bin Melan

Industry personnel, Saudi Aramco

ABSTRACT

Prefabricated Vertical Drain (PVD) wick drain is widely used as a ground treatment method for soft soil especially in clay soil where the soil is low in structural stability. This paper presents a case study on the application of wick drain technology for ground treatment of sabkha soils in a steel plate manufacturing project in Ras Al Khair Industry City, Saudi Arabia. The project site features extensive areas of sabkha soils, characterized by loose to very loose sandy soils, high salinity, and water content, posing significant challenges for foundation design. A comprehensive site investigation and laboratory analysis revealed the presence of different lithological units and sabkha layers with varying thicknesses. Due to the large areas of high-thickness sabkha layers, conventional ground treatment methods were deemed unsuitable, and wick drains were deployed to accelerate soil consolidation and improve stability. The results of the ground treatment program, including settlement monitoring is presented and discussed. The findings demonstrate the effectiveness of wick drain technology in stabilizing sabkha soils, achieving the required settlement and stability for the construction of steel plant facilities. This case study provides valuable insights into the application of wick drain technology for ground treatment of problematic soils, such as sabkha, and can serve as a reference for similar projects in the region.

1. INTRODUCTION

The wick drain method of soil treatment was applied for a land of 183,000,000 million square meter allocated for Steel Plate Manufacturing Project in Ras Al Khair Industry City, in the Eastern Region of Saudi Arabia. The steel plant targets to produce 1.5 Mtpa of high-quality steels plates per annum.

The scope of work of this project encompasses of the general backfilling of the original ground level to achieve the required design elevation of 5.5m Above Sea Level, as specified by the design office consultant, and the implementation of ground treatment measures to address the existing soil conditions, which composes of sabkha layers. The ground treatment targets to establish a firm and stable platform with the required bearing for the facilities of the Steel Plate project.

Based on site investigation data, analysis has been conducted and determined Wick Drain method is suitable for soil treatment in the project and efficient in enhancing soil stability as well as meeting the bearing capacity criteria. One important condition was set for the wick drain to achieve 80% to 90% of the maximum settlement within 90 days from the start of back filling work activities.

2. EXISTING SOIL CONDITION

The topographical setting of the Gulf region is resulted from the continuous accumulation of sediment since Paleozoic Era, a geological period from approximately 541 to 252 million years ago. Around 100 km inland from the present shoreline of the Arabian Gulf coast was before covered by the Sea. This was inferred because of the vast coastal sabkhas on the entire area of the Gulf Coast.

2.1 Sabkha Area (Qsb)

The western and southern Gulf coast is flat and consists of wide spreading sabkha, penetrating up to 10km inland and covering areas of more than 100km². Sabkha is a term used to refer to flat salt-crust desert. The local terminology of the Gulf region describes the extensive, barren, salt encrusted, and periodically flooded coastal flats as well as inland salt flats.

Sabkhas consist of sand or finer unconsolidated substrate and they are mostly flat bottom basins with enclosed drainage that are occasionally filled with water from rain and underlain by clean uniform sand deposited by wind from adjacent dunes. Sabkha deposits are typically gray, brown and white in color. Sabkha is a "problematic" soil due to its loose density, soft consistency, high salinity and water content, which make the Sabkha weak in the foundation soils.

3. CASE STUDY

The data obtained from the field and laboratory investigations reveal the presence of different lithological units at the project site. lithography refers to the description of the physical characteristics of rock. Lithological units are distinct bodies of rock defined by their physical characteristics, for example composition, texture and color.

It is used to distinguish between areas with and without sabkha. The soil profile of sabkha layer consists mainly of sandy soils with loose to very loose compactness on the surface. The soil compactness is improved with the increased depth to dense and very dense. There are also hard elastic silt layers interbedded with the dense and very dense sandy soils. In the south and north extreme of the plot, dense or very dense sandy layers appear on the surface.

These sabkha layers in the project area consist of very loose silty sand (SM) with varying amount of silt, very soft low plasticity silts, with a plastic index below 10 and high content of chlorides, sulphates and carbonate. The thickness of this layer is in general below 4.5 m, which was detected in borehole 1.45 a sabkha layer with a thickness of 6 m.

Because there were large areas of high thickness Sabkha layers, conventional method for ground treatment was not considered and instead wick drain was deployed for ground treatment.

4. PVD WICK DRAIN

PVD wick drains compose of a plastic core encased by a geotextile fabric. Geotextile is a permeable nonwoven or woven fabric that used in geotechnical applications such as separation, filtration, drainage, and reinforcement of soil.

The plastic core provides flow paths along the drain length to collect and transport water out of the soil. The surcharge will increase pore water pressures with time and water will drain away from the soil, and the removal of water will compress and subsequently strengthen the soil. These prefabricated wick drains are used to accelerate the water removal.

4.1 PVD Wick Drain Detail

The strips in the wick drains treatment are made of core and coating as shown in Detail A. When a load is applied on ground surface, the strips accelerate the pore water pressure in soft compressible soils.

Wick drains will be driven where indicated on drawings with spacing and required installation depth according to the zone.

Three types of wick drain mesh which are Type 1, 2 and 2B. Each of these were implemented based on the soil condition and design recommendations. The mesh defines points where the wick drains are installed.

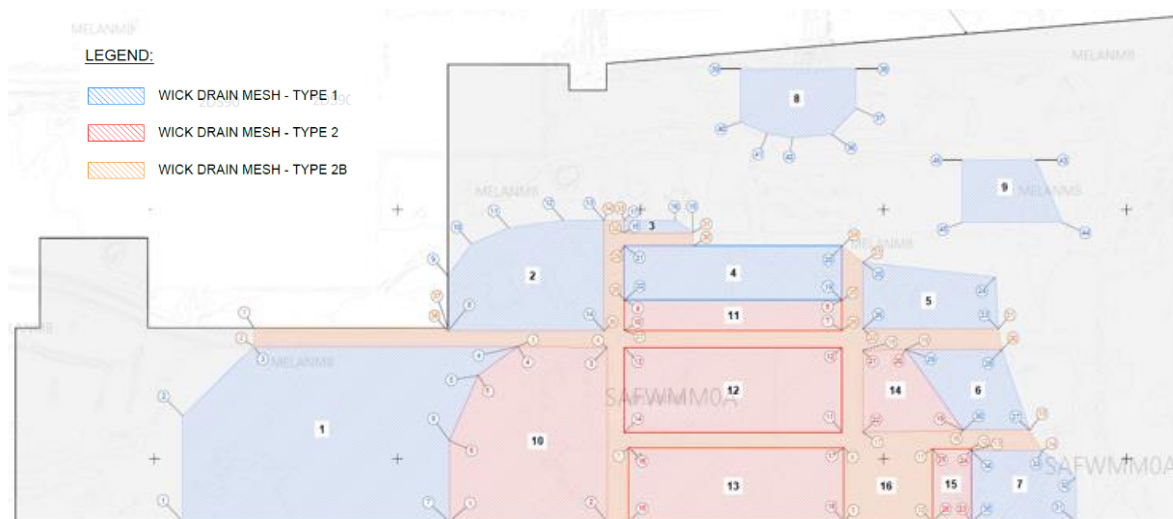


Figure 1.0: Wick Drain general arrangement layout

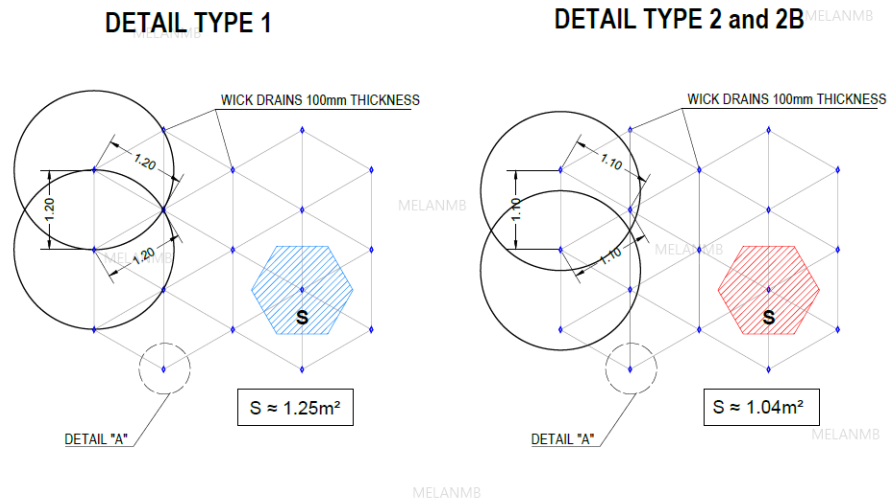


Figure 2.0: Typical Wick Drain Mesh Detail

Figure 2.0 above shows the wick drain mapping based on type 1, type 2 and type 2B. The differential between the types are due to the spacing (S) efficiency of wick drain workability. It also depends on the depth on length installation for wick drain inside the sabkha area. Thickening in sabkha layer will having less of spacing to ensure the water disepation between the pore area is effective. The Wick Drain mesh type shall be follow accordance to zone mention in figure 1.0.

Below table 1.0 shows the estimated length of Wick Drain to be installed. This estimated length is based on the soil investigation data which is give the thcikness of sabkha below the ground. In order to ensure the wick drain is effectively work as ground treatment, the wick drain length shall be enough to reach the sabkha depth.

ID	ZONE (m²)	WICK DRAIN BOTTOM ELEVATION TO BE ACHIEVED (m)	ESTIMATED DRAIN LENGTH (m)
1	192.393	-4.5	7.0
2	64.360	-3.5	6.0
3	3.115	-3.5	6.0
4	48.701	-4.0	6.5
5	32.621	-3.5	6.0
6	27.009	-3.5	6.0
7	28.827	-3.5	6.0
8	29.486	-3.5	6.0
9	22.291	-3.5	6.0
10	104.237	-4.5	7.0
11	27.100	-4.5	7.0
12	75.929	-4.5	7.0
13	65.863	-4.5	7.0
14	24.221	-4.5	7.0
15	11.693	-4.5	7.0
16	151.738	-4.5	10.0

Table 1.0 : Wick drain zoning and estimated length

Example is given in figure 3.0 for the illustration of 7m length wick drain.

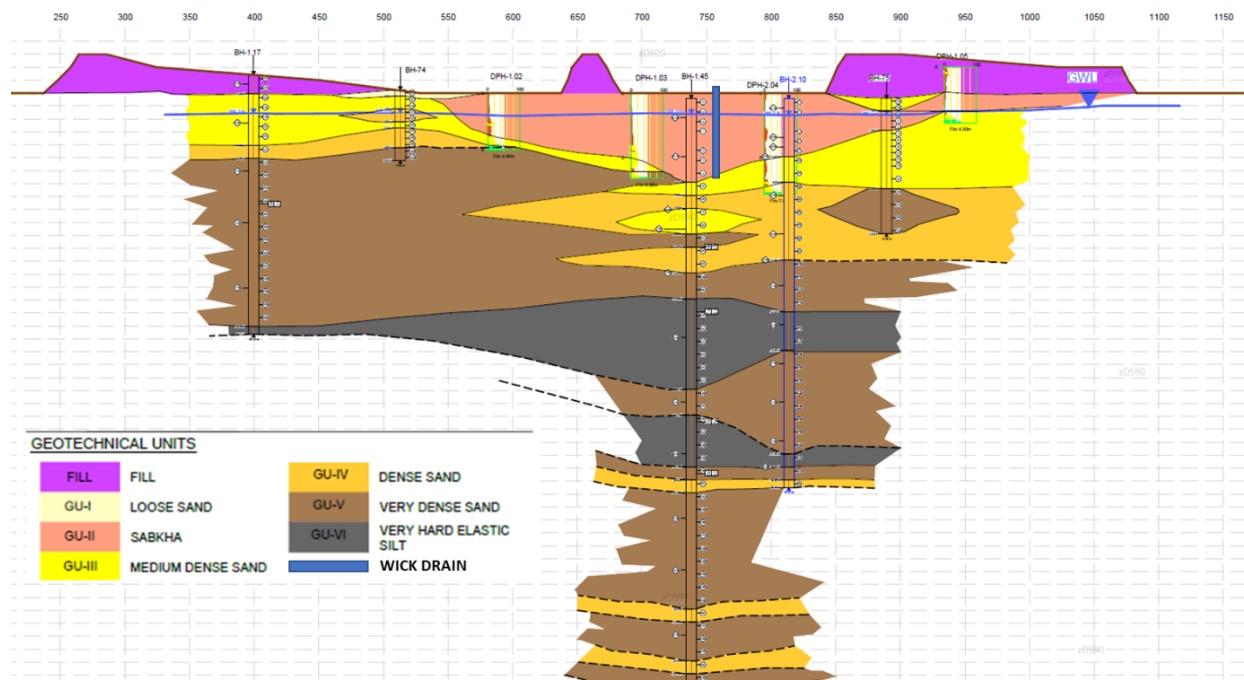


Figure 3.0 : illustration of wick drain underground profile

4.2 Wick Drain Material Specifications

Technical Specifications for strip wick drains are summarized as follow:

- a. Core Structure should be corrugated polyester mesh
- b. Geotextile, should meet the following requirements:
 - i. Structure: Spunbonded continuous strands
 - ii. Weight: 110g/m²
 - iii. Tensile strength: 5,8KN/m
 - iv. Permeability: 6,5x10⁻²m/s
 - v. Porosity: 140 μm
- c. Geo-composite that meet the followings:
 - i. Weight: 72 g/m
 - ii. Rupture elongation: 57% at 2,6KN
 - iii. Discharge capacity: 15l/m²

4.2.1 Gravel for Drainage Layer

Coarse gravel as per ASTM2487 has been used in the soil treatment, with particle that shall pass 3-in (75 mm) sieve and be retained on a 3/4 -inch (19mm) per U.S. Standard sieve.

The gravel collector layer for the wick drains is disposed on the surface with a granular drainage layer with the following specifications:

- a. Thickness for gravel drainage layer > 0.50m
- b. Maximum nominal diameter = 10 cm
- c. Percentage of fines < 5%

4.3 Method of Installation

Site preparation includes the clearing, grubbing, removal of trash, debris and unsuitable material from working area as well as dewatering. In this project, a working platform has been built, where soil resistance is not enough to support loads transmitted by heavy equipment. Then, wick drains were driven down from working platform deeper to reach the sabkha. In hard areas, pre-drilling was considered. After installing the wick drains, gravel drainage layer is laid down and compacted, then the backfill work continue up to +5.50m ASL elevation. Detail construction according to figure 4.0.

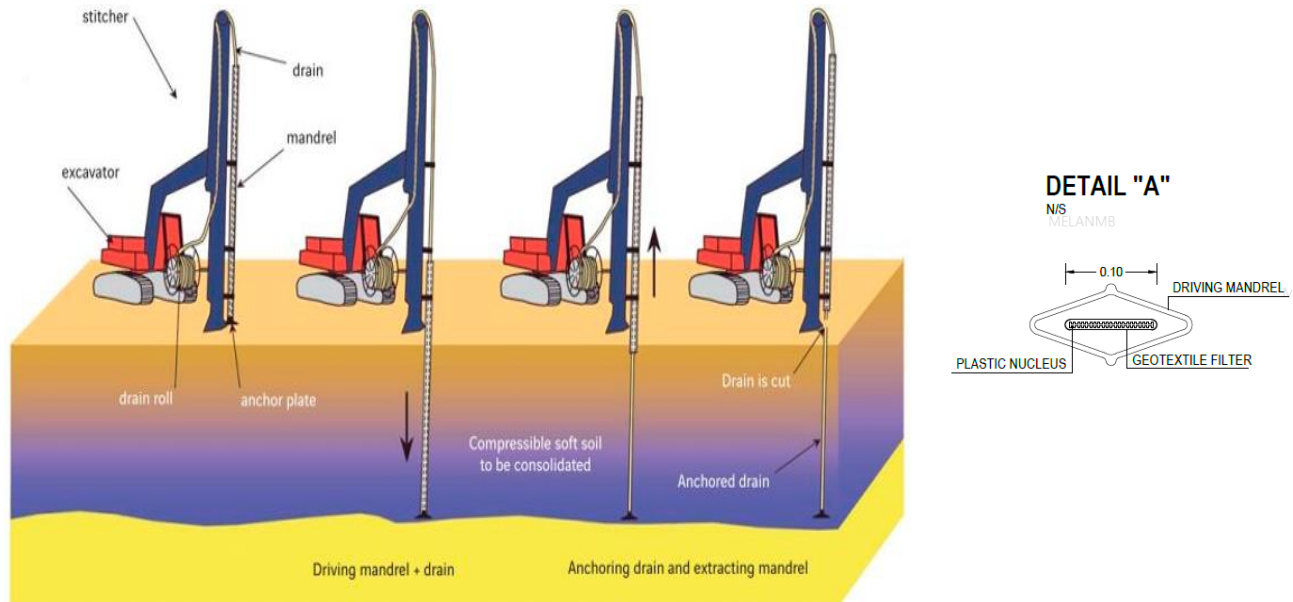


Figure 4.0: Step by step of wick drain installation

Execution processes for wick drains are summarized as follows:

- Set up of wick drain driving machinery.
- Attachment of wick drain strip to the metallic mandrel of the WD machinery. The metallic mandrel is used to drive the wick drain into the soil.
- Driving the WD mandril deeper to reach the Sabkha.
- Removal of metallic mandrel from the ground and cut of the wick drain at the top of the drain.
- Move of WD machinery to a new installation point.

SCALE 1:100

Figure 5.0: Construction detail of wick drain soil treatment layers.

5. RESULT AND DISCUSSION

In order to check the performance of wick drain after the installation, settlement marker was installed to characterize the settlement and consolidation of the terrain. Measurements were taken in regular intervals. At the very beginning, the number of measurements was 1 reading per a week and reduced to 1 reading per a month, after, the settlements have been stabilized. Total 174 numbers settlement plate and 23 numbers vibrating piezometer been installed at site as illustrated in figure 5.0.

The average sabkha thickness measured within the sabkha area is approximately 2.20 m. A rough estimation of the average consolidation settlement within the sabkha presence area would be 20-25 cm.



Figure 6.0: Settlement marker layout and detail

5.1 Settlement Plate Result Summary

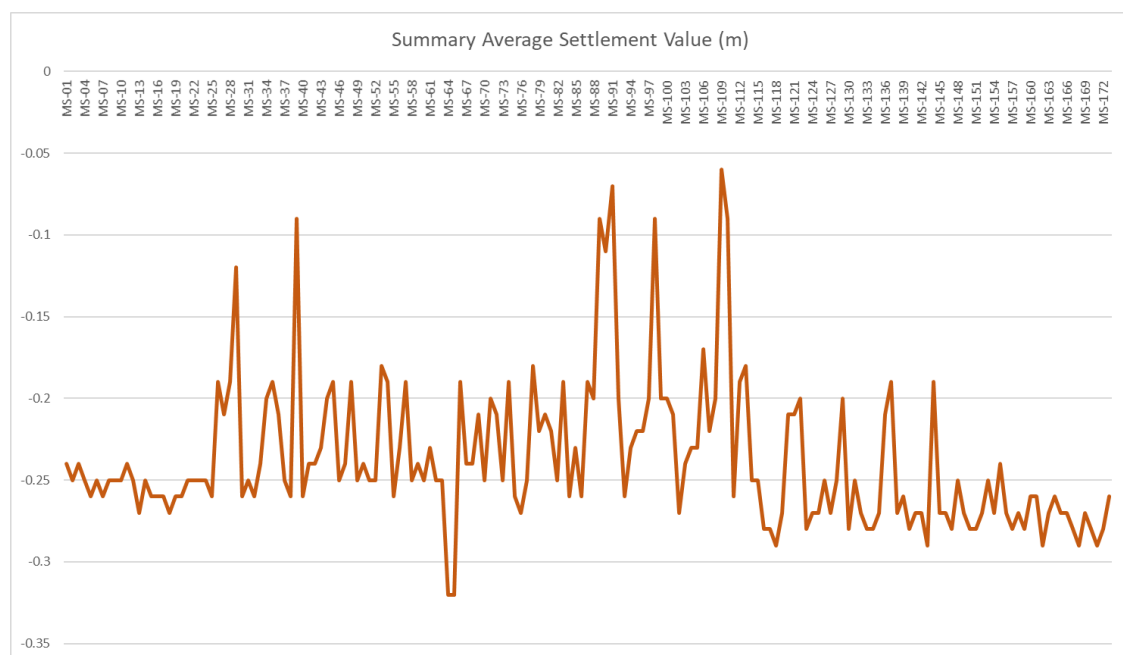


Figure 7.0: Summary of Settlement Value

Based on the settlement monitoring summary results, the average settlement observed for the 174 settlement plate measurement points was 23.7 cm, which is within the specified threshold of 20-25 cm and therefore satisfies the project requirements. Moreover, the monitoring data from June to July 2025, demonstrate that the rate of settlement has gradually decreased, approaching minimum settlement and remained stable, with no significant variations. These findings indicate that the ground settlement is effectively stabilized, and the soil treatment objectives have been achieved. Accordingly, it is concluded that further settlement monitoring is no longer required, and the site conditions fully comply with the technical project requirements and standards.

6. CONCLUSION

The application of wick drain technology for ground treatment of sabkha soils in the Steel Plate Manufacturing Project in Ras Al Khair Industry City, Saudi Arabia, has been successfully demonstrated. The project's objective of achieving a stable and firm platform for the construction of steel plant facilities has been met.

The findings of this project demonstrate the effectiveness of wick drain technology in treating problematic soils, such as sabkha, and provide valuable insights for future projects in similar geological conditions. The project's outcome also highlights the importance of careful site investigation, laboratory testing, and monitoring in ensuring the success of ground treatment programs.

In conclusion, the Steel Plate Manufacturing Project in Ras Al Khair Industry City, Saudi Arabia, has successfully demonstrated the application of wick drain technology for ground treatment of sabkha soils, achieving a stable and firm platform for the construction of steel plant facilities. The project's success serves as a model for future projects in similar geological conditions, and its findings contribute to the advancement of knowledge in the field of geotechnical engineering.

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