Design Considerations for Offshore Structures in the Dead Sea

Aspects de Conception des Structures Offshores à la Mer Morte

El-Mossallamy, Y.
Professor, Ain Shams University, Egypt
Ghalayini, I.
Director of GHCE department Dar al-Handasah
Demerdash, M.
Head of GHCE department Dar Al-Handasah, Egypt
Hammad, W.
Lecturer, Fayoum University, Egypt

ABSTRACT

Exploitation of the Dead Sea minerals using a solar evaporation system is a major industrial enterprise in Jordan that has been in operation since 1982. The process involves the pumping of brine from the Dead Sea to the solar evaporation ponds via a transfer canal. Because of the continual reduction in the Dead Sea water level at a rate of about 1.1 m per annum, a new intake pumping station has been recently commissioned by the Arab Potash Company. The area of interest is located in a vast tectonic depression that is part of the Dead Sea Jordan Rift valley system. The subsoil consists mainly of laminated soft clay followed by crystalline salt formations. The new intake's pumps are supported on a piled steel deck platform and are connected to two twin steel pipelines that convey the brine to the existing brine transfer canal. This paper deals with the geological and geotechnical aspects involved in the design of the new brine intake deep foundations taking into consideration the complex and dynamic environment of the Dead Sea, foreshore. The numerical analyses applied to consider the soil structures interaction of the complex system while considering the horizontal loads on the piles due to lateral movement of the soft clayey layers are emphasized. Different types of piles are deployed to support the structural loads. Results of a load test of a steel tubular pile provided with a reinforced concrete socket in the salt formation are also presented.

RÉSUMÉ

L'exploitation des minéraux de la Mer Morte, au moyen d'un système d'évaporation solaire est l'une des principales entreprises industrielles en Jordanie qui a été en opération depuis 1982. Le processus implique le pompage de la saumure de la Mer Morte aux étangs d'évaporation solaire à travers un canal de transfert. En raison de la réduction continue de niveau de l'eau de la Mer Morte à un taux annuel d'environ 1,1 m, une nouvelle station de pompage a récemment été commandée par l'«Arab Potash Company». La zone d'intérêt est située dans une vaste dépression tectonique qui fait partie du système de la vallée du rift jordanien de la Mer Morte, Le sol se compose principalement des formations d'argile feuilleté molle suivies par des formations en sel cristallin. Les nouvelles pompes sont supportées sur une plate-forme métallique en pieux et sont liées à deux pipelines jumeaux en acier qui véhiculent la saumure à l'actuel canal de transfert. Cet article traite les aspects géologiques et géotechniques dans la conception des fondations de la nouvelle station de prise de saumure en tenant compte de l'environnement dynamique et complexe de la Mer Morte. Les analyses numériques appliquées pour le calcul de l'interaction du système complexe sol structure, tout en considérant les charges horizontales sur les pieux à cause de mouvement latéral des couches argileuses molles, sont soulignées. Différents types de pieux sont déployés pour soutenir les charges de la structure. Les résultats d'un essai de chargement statique d'un pieu circulaire en acier, approvisionné par un encastrement en béton armé dans les formations du sel cristallin, sont présentés.

Keywords : *soft clay, salt formations, large diameter socket piles, down-drag forces, numerical analyses*

1 INTRODUCTION

The new intake pumps rest on a pile supported steel deck platform and is connected to two twin steel pipelines that convey the brine to the existing brine transfer canal. The new steel pipelines are supported on a piled jetty that interfaces with an earth-fill causeway at the shoreline. The piles consist of large diameter driven steel tubular section provided with a reinforced concrete drilled socket in the crystalline salt. On shore the pipelines are supported on piles and are linked-up at a junction further inland with the existing brine transfer conduits which lead ultimately to an outfall at the existing canal (Fig. 1).

The geological conditions of the Dead Sea and its seismic features are briefly reviewed. The required design criteria of the offshore as well as the onshore piles considering the complex geological conditions are explained. The effect of the lateral and vertical movement of the upper clayey deposits (due to lowering of the Dead Sea level) on the pile design (additional horizontal loads and negative skin friction) are also discussed.

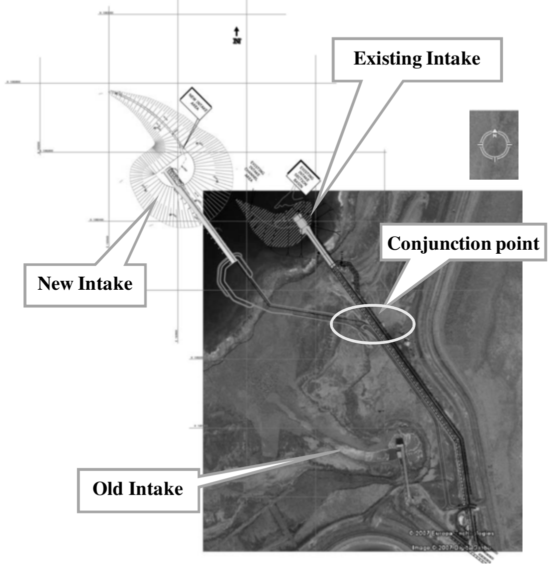

Fig. 1: The new intake at the Dead Sea

doi:10.3233/978-1-60750-031-5-1362

2 GEOLOGY OF THE DEAD SEA

The area of interest is located in a vast tectonic depression that is part of the Dead Sea Jordan Rift valley system. The Dead Sea occupies the deepest part of the rift valley while on its eastern boundary; the depression is characterized by outcrops of rocks and overburden materials of different ages and properties. The major engineering geological structures in the area consist mainly of lake deposits and salt diapers. The lake south to the Lisan Peninsula, where the new intake should be constructed, was partially filled with alternating thin layers of calcite gypsiferous marl, forming a laminated structure of very soft material with different thicknesses. Tectonic movements of a massive Pliocene deposit of halite, belonging to the Sedom formation, beneath the Lisan formation produced a diaper structure that is a salt dome. The salt deposits are inter-fingered by layers of gravel, sand, silt and clay of continental origin and transported by floods. Fig. 2 shows a geological map with the main active faults affecting the geological structure of the Dead Sea.

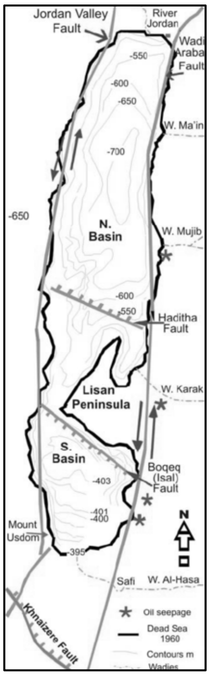

Fig. 2: Main faults affecting the Dead Sea

The main geological features can be summarized as follows:

- The construction area lies in a highly seismic active zone
- There are two main active faults that affects the geological behavior of the Dead Sea (the Jordan valley fault and the Boqeq "Isal" Fault)
- The existing active faults lead to thrust stresses in the ground that resulted in cracks. Some of these cracks can be observed along the embankment of the existing intake.

3 GEOTECHNICAL FEATURES OF SUBSOIL

The general stratigraphy consists of the following units (see Fig. 3), from the oldest to the youngest as follows:

- Sedom formation Pliocene:
  Predominantly crystalline salts.
- Lisan formation - Glacial Pleistocene:
  This formation is composed of alternating layers of soft to firm grey silty carbonate clay, thinly laminated with silt sized aragonite. The laminations vary in thickness from 0.1 mm to a few millimeters. The aragonite laminations are locally cemented to form hard undulated carbonate sheets. Thin layers of gypsum are also relatively common in the formation.
- Surfacial Deposits - Holocene
  This formation is made of evaporates, crystalline halite, laminated marl, inter-fingered with clay, silt, sand and gravel that had been deposited in deep to shallow water.

3.1 *Soft clay*

In-situ vane shear tests were carried out in the boreholes. Summary of these results are given in Fig. 4. The results of the vane shear test shows that the shear strength of the soft clay increases with depth according to the following equation:

$$c_u = 0.22\,\sigma_v'$$

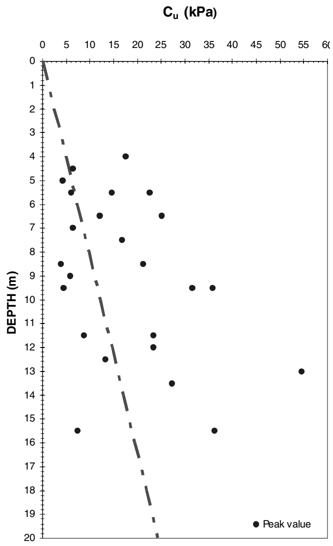

Fig. 4: Variation of undrained shear strength with depth

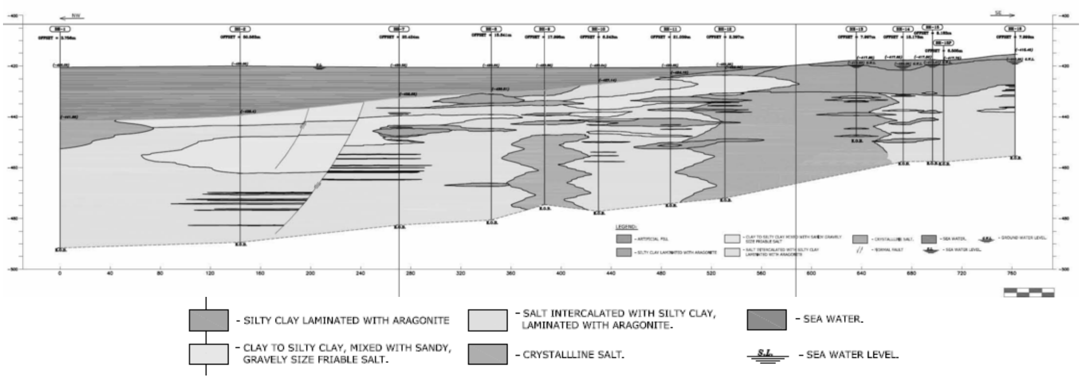

Fig. 3: Geotechnical section

This value agrees well with the well established equations to calculate the shear strength of normally consolidated soft clay (e.g. Skempton & Henkel 1953).

Furthermore, the very low strength of the upper clay layers especially along the waterline was evident by the occurrence of mud waves, i.e. bearing capacity failure, upon placement of a very modest height of fill (about 1.5 m) required for the construction of the earth fill causeway. Fig. 5 shows the mud waves observed near the shore line.

Fig. 5: Mud-wave resulting from placement of fill

Following the continuous decrease in the Dead Sea level, the upper soft clay layers on the shore area undergo lateral movements towards the sea. A number of inclinometers were installed near the existing intake to monitor the lateral movement (Fig.6)

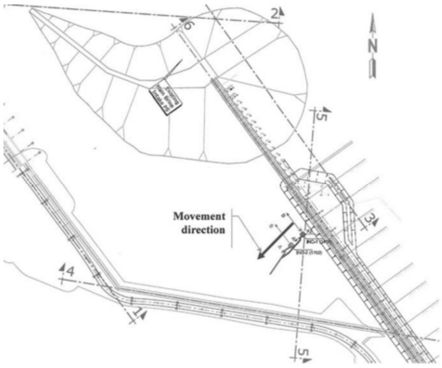

Fig. 6: Installed inclinometers near the existing intake

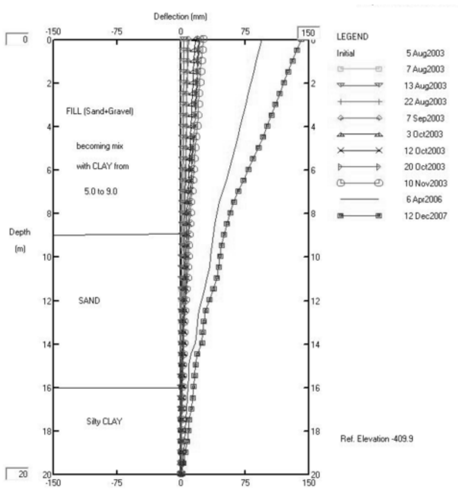

Fig. 7: Horizontal movement with depth

The inclinometer measurements show that the resultant lateral movement is towards the receding waterline and almost perpendicular to the existing ground contour lines.

The displacement is a time dependent phenomena that takes a relatively long time and is still under progress. The measured displacement at ground surface is about 150 mm in about 4 years (Fig. 7). That means the sliding rate is about 30 to 40 mm per year. This horizontal movement is mainly due to creep and consolidation of the clayey layers induced by increasing the effective stresses as the sea water level drops (about 1.1 m per year). These movements in conjunction with the thrust stresses due to the tectonic movements are responsible for the observed cracks near the existing intake. Such displacement will affect the behavior of the pile foundation suggested for the jetty and hence were considered in the design of the new intake. These lateral movements lead to the selection of a piled foundation for the onshore pipe line.

3.2 *Salt*

The rock quality of the Salt formation is mainly poor especially in the upper domain. The unconfined compressive strength of the crystalline salt ranges between about 2.0 to 8.0 MPa. The lower bound of 2.0 MPa was retained in the design. The deformation modulus of the salt rock can be estimated according to the results of the pressuremeter tests in the order of 20.0 MPa for the weak salt to 250.0 MPa for the crystalline salt. The salt exhibits a creep related movement which has a negative impact on the pile tip resistance. Therefore, it was decided to rely only on the shaft adhesion to resist the permanent loads (e.g. dead loads) and consider the contribution of the end bearing capacity only for the transient loads (e.g. seismic loads).

4 LOAD SETTLEMENT BEHAVIOUR OF LARGE DIAMETER SOCKET PILES

A preliminary pile load test was carried out for evaluating the socket skin friction in the crystalline salt layers (Gibb 1996). The test configuration was as shown in figure 8. The Pile was constructed by first driving a permanent steel casing of 0.91 m diameter and then drilling and casting a concrete socket of 0.8 m diameter in the salt formation. To eliminate the end bearing of the socket, a void was deliberately provided at the pile tip. Also an upper sleeve was provided to exclude the effect of the clay layers. Consequently, the pile resistance was provided solely by shaft adhesion of the concrete socket in the salt.

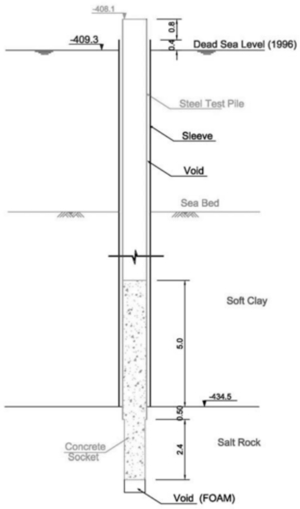

Fig. 8: Test Pile Socketed in Salt

As shown by the load displacement curve of Fig. 9, an ultimate socket friction of about 275 kPa is reached. Consequently, a conservative working design friction value of 110 kPa will be retained for the design of the concrete socket embedded in salt. Furthermore, this value matches well with the lower bound value obtained from the empirical equation (Rowe & Armitage 1984):

$$\tau_{ult} / p_a = 0.63 (q_u / p_a)^{0.5}$$

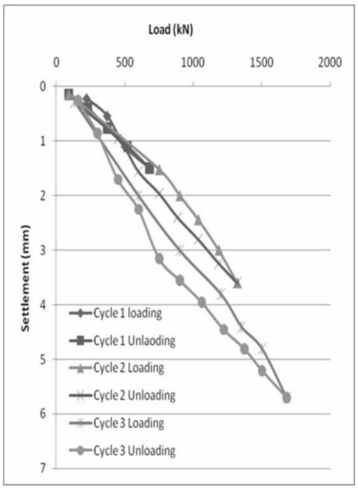

Fig. 9: Results of Pile Load test

5 DESIGN PHILOSOPHY

Due to the complex soil and load conditions, it was decided to support all the intake structural elements (platform, jetty, pipeline and buildings) on piles (deep foundations). The piles are either vertical or raked piles depending on the loads and geometry. Regarding the available geotechnical conditions and the applied loads, three types of piles were considered:

- The platform, the jetty and the onshore twin pipeline will be founded on large diameter driven steel tubular piles with a reinforced concrete drilled socket in the crystalline salt formation.
- Driven large diameter steel tubular piles will be applied for the light constructions. These piles are embedded in the upper weak salt layer (the transition zone)
- Driven steel tubular piles in the soft clay (floating piles) will be used to support the pipeline conjunction in area where the thickness of soft clay exceeds 60 m.

The following design aspects were also considered:

- The lateral pressure acting on the piles due to the landslide of the very soft clay layer.
- The negative skin friction acting on the piles due to the consolidation of the soft clay associated with continual reduction in the Dead Sea water level.
- The drag down loads acting on raked piles due to consolidation of soft clay
- Creep behavior of the relatively weak crystalline salt under static maintained loads. Therefore, the end bearing resistance of the piles will be ignored under dead loads.

5.1 *The lateral pressure acting on piles*

Lateral pressure on piles due to lateral movement of the soft clay were calculated considering the expected relative movement between pile and surrounding soil taking into account the pile soil interaction and the pile stiffness. The soil was modeled as a bilinear springs with a certain limit value (p-y curves). Due to the large expected relative movement between the pile and the soft soil, the limit pressure of the soft clay is fully mobilized. The limit pressure of the soft clay is taken equal to seven times the undrained shear strength.

The piles are modeled as an elastic beam that is simply supported at its head (Fig. 10). The transition zone is modeled through the bilinear horizontal subgrade, where the embedded depth in the salt is modeled as an axial spring with an equivalent stiffness representing the socket length of the pile in the crystalline salt. The axial spring stiffness representing the socket length is calculated using axisymmetric finite element analyses considering the pile group action.

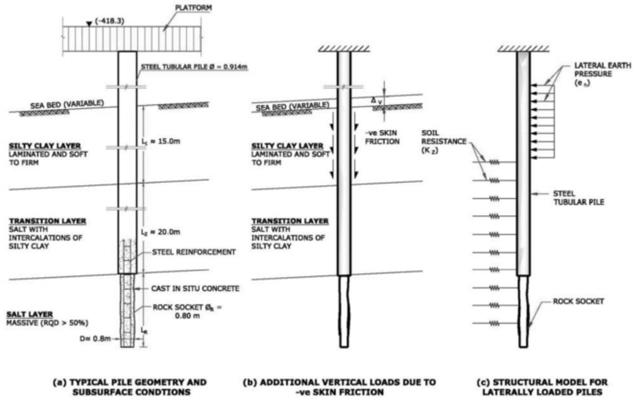

Fig. 10: Pile geometry and idealized structural model

5.2 *The drag down loads*

To reduce the effect of the long term negative skin friction on the pile foundations, the piles are coated with a bitumen coating for the upper part embedded in soft clay deposits. The Negative skin friction is considered in the soft clay applying the following equation:

$$\tau_{-ve} = 0.22\,\sigma_v' \,.\, \alpha$$

$where: \alpha = 0.3$ to consider the effect of bitumen coating according to conducted shear box tests

The drag-down forces acting on raked piles are calculated by applying two dimensional finite element analyses.

6 CONCLUSIONS

The Dead Sea area offers a complex challenging environment for the geotechnical design of structural foundations. Not only were the difficulties related to the consolidation and negaotive skin friction of the soft clayey deposits, but also the lateral movement of the soft clay layers induced by continuous decrease of the Dead Sea level. In addition the underlying salt diaper and the associated continual time-dependant upward movement together with the highly seismic character of the area lead to a highly variable salt formation (both in lateral and vertical extent) with regard to quality, stiffness and strength

ACKNOWLEDGMENT

The authors wish to thank the Arab Potash Company and Dar Al-Handasah Consultant for their support and for providing the technical data related to the site investigation and existing intake jetty.

REFERENCES

Skempton A. W. & Henkel D. J. (1953), “The Post-Glacial Clays of the Thames Estuary at Tilbury and Shellhaven”, 3rd ICSMFE, vol. 1, pp. 302-308.

Rowe R.K. & Armitge H.H. (1984), “Design of Piles Socketed into Weak Rock”, Report GEOT-11-84, London University of Western Ontario.

Sir Alexander Gibb & Partners (1996), “Maintained Load Test on Vertical Sleeved Pile”, Internal Report, Arab Potash Company-Jordan.

Dar Al-Handasah Consultant (2008), “Geotechnical Design of the New Main Brine Intake Pumping Station”, Internal Report, Arab Potash Company-Jordan.