Case Study for Hollow Tubular Offshore Pile

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Abstract: During the past centuries, the using of offshore piles has increased because of the progressive elaboration that has been happened in the civil and coastal engineering industry in offshore fields. This paper is discussing a case study for design of an axial pile, the theoretical capacity of the mono pile and measure the actual capacity of the pile. The location of the execution of the pile driving was in Hamriyah port located in Sharjah, UAE.

Keywords: offshore pile, mono pile, theoretical pile capacity, actual pile capacity,

I. INTRODUCTION

The location of the execution of the pile driving was in Hamriyah port located in Sharjah, UAE. The pile driving activity was part of rehabilitation project for a liquefied natural gas terminal. This case study paper is measuring the variance between the theoretical and actual axial bearing capacity of the hollow tubular pile.

II. ENVIRONMENTAL AND DESIGNING CONSIDERATIONS

The environmental and designing considerations for calculation the theoretical axial bearing capacity of the hollow tubular pile based on the assigned boreholes & the pile cross-section characteristics [1].

A. Details of the Soil Layers

The details for the soil layers pile is shown below as per table I.

| Soil layer                        | Top of layer | Bottom of layer | Unit weight | Average SPT | Theoretical friction angle | Elasticity modulus |
|-----------------------------------|--------------|-----------------|-------------|-------------|---------------------------|--------------------|
| Medium dense calcareous sand      | 10.5 CD      | 14.5 CD         | 18.5 kN/m³  | 25          | 37°                       | 40,000 kN/m²       |
| Very dense sand                   | 14.5 CD      | 16.5 CD         | 18.5 kN/m³  | 65          | 42°                       | 90,000 kN/m²       |
| Very weak to weak calcareous sandstone | 16.5 CD      | 30.0 CD         | 18.5 kN/m³  | More than 100 | 45°                     | 110,000 kN/m²      |

B. Details of the Tubular Steel Pile

The details for the tubular steel pile is shown below as per table II.

| Details of the tubular steel pile |
|-----------------------------------|
| Diameter of the pile              | 610 mm       |
| Thickness of the pile             | 20 mm        |
| Raking of the pile                | 0° (Vertical) |
| Pile head level                   | + 3.5 CD     |
| Pile toe level                    | - 20.50 CD   |
| Pile Length                       | 23.5 m       |
| Moment of inertia of the pile     | 1614896433 mm² |
| Elastic Modulus                   | 210000 N/mm² |
| F_Yield Strength                  | 355 N/mm²    |
III. THEORETICAL AXIAL PILE CAPACITY

Pile vertical capacities are calculated as the ultimate vertical capacity $Q_d$ of a pile in cohesion-less soil is the sum of the shaft resistance $Q_f$ and the toe resistance $Q_p$. The API method equations are presented below [2]-[3].

$$Q = Q_f + Q_p$$  \hspace{1cm} (1)

$$Q_f = f \cdot A_s + q \cdot A_p$$  \hspace{1cm} (2)

1) Where
   a) $Q_d$ it is the ultimate vertical capacity.
   b) $Q_f$ it is the shaft resistance capacity.
   c) $Q_p$ it is the toe resistance capacity.
   d) $f$ it is the unit skin friction capacity.
   e) $A_s$ it is the side surface area of pile.
   f) $q$ it is the unit end bearing capacity.
   g) $A_p$ it is the gross end area of pile.

For piles in cohesion-less soils, unit skin friction can be calculated by the equation (3) below [2]-[3].

$$f = K \cdot \tan(\delta) \cdot P_0$$  \hspace{1cm} (3)

2) Where
   a) $K$ it is the coefficient of lateral earth pressure.
   b) $\delta$ it is the friction angle between pile and soil.
   c) $P_0$ it is the unit effective overburden pressure at the centre of depth increment $d$.
   d) $A_p$ it is the gross end area of pile

For piles in cohesion-less soils, unit end bearing can be calculated by the equation [2]-[3].

$$f = N_q \cdot P_0$$  \hspace{1cm} (4)

3) Where
   a) $N_q$ it is the bearing capacity factor.
   b) $P_0$ it is the effective overburden pressure at pile tip.
   c) $A_p$ it is the gross end area of pile

The resistance from the top 4 m of medium dense soil is neglected to account for the presence of carbonate content in this layer. The allowable axial Load is calculated by dividing the ultimate capacity by a factor of safety of 2 [2]. Pile capacity analysis was calculated for both plugged and no plug conditions.

In no-plug condition, soil penetrates the pile profile and provide friction resistance on both sides of the casing i.e. inside and outside. Plugged condition occurs when soil squeezes inside and plugs the pile profile preventing further ingress of soil into pile thus providing outside friction and end bearing resistances.

Design pile capacity considered has the lowest from both the analysis, which in the present case corresponds to no-plug condition. In general, very dense cemented sands are expected to be in no-plug conditions. The ultimate vertical capacity was calculated 1014 KN and the allowable vertical capacity was calculated to be 507 KN, as shown in Fig. 1.
Fig. 1 The ultimate vertical capacity calculations and the allowable vertical capacity calculations

IV. ACTUAL AXIAL PILE CAPACITY

The implementation of the driving pile activity was done in two stages. First stage was driving the pile to embedded depth equal to 9.63 m using vibro-hammer, as shown in Fig. 2 and Fig. 3.

Fig. 2 The vibro-hammer ICE 815C
Fig. 3 Driving the pile to embedded depth equal to 9.0 m using vibro-hammer

The second stage was driving the pile to extra embedded depth equal to 0.37 m using hydro-hammer. The second stage of the pile driving activity has been implemented seven days after the first stage. We have monitored the dynamic load testing beginning of re-strike by applying a hammer blows to the top of the pile. IHC S-90 hydraulic hammer with 4.5-tons weight was then used for application of hammer blow. The average set per blow measured after the final test blow for the pile was 11.94 mm (370 mm/31 blows). In the field, the pile driving analyser records the data measured during dynamic testing and interprets it according to the Case Method equations based on the impact wave-down and the response wave-up calculated from the pile driving analyser force and velocity measurements near the pile top. The team evaluated the dynamic test results for hammer performance, pile head compression stresses, structural integrity, and static pile capacity. CAPWAP analyse has provided more accurate and detailed estimates of capacity and strength and help to assess the effects of changes in pile cross-section or material, as shown in Fig. 4, Fig. 5, Fig. 6, Fig. 7, Fig. 8 and Fig. 9.
Fig. 6 Pile driving using hydro-hammer IHC S-90

| Pile Identification | RL-01 |
|---------------------|-------|
| Test Time & Date (h.m/s/day) | 14:02 12/19/2018 |
| Driving Status | Beginning of Re-strike (BCR) |
| Final Pile Penetration (m) | 10.00 |
| Permanent Set measured at Final Blow (mm) | 11.94mm (370mm/21 blows) |
| Sealed Elevation (m) | -10.836 |
| Initial Pile Tip Elevation (m) | -20.403 |
| Final Pile Tip Elevation (m) | -20.816 |
| Equivalent Blow Count (blow/m)² | 84 |
| Hammer Energy (kJ-m) | 90 |
| Maximum Hammer Transfer Energy (kJ-m) | 53.7 |
| Allowable Compression Stress (MPa) | 319.5 |
| Allowable Tension Stress (MPa) | 319.5 |
| Maximum Compression Stress (MPa) | 166.8 |
| Maximum Tension Stress (MPa) | 90.4 |
| Maximum Mobilized Case Capacity, RX4 (kN) | 1.746 |
| Maximum Mobilized Case Capacity, RX5 (kN) | 1.629 |

Fig. 7 PDA and CAPWAP results

Fig. 8 PDA and CAPWAP charts (1/2)
V. CONCLUSIONS

The theoretical ultimate capacity of the axial tubular pile was calculated is 1014.0 KN [2]-[3], while the actual capacity of the axial tubular pile was measured as 1669.6 KN. The actual results is of the pile capacity is 164.65 % of the theoretical capacity for the same design characteristics & criteria.

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