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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 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 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.

TABLE I
Details of the tubular steel pile

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/m^3	25	37°	40,000 kN/m^2
Very dense sand	- 14.5 CD	- 16.5 CD	18.5 kN/m^3	65	42°	90,000 kN/m^2
Very weak to weak calcareous sandstone	- 16.5 CD	- 30.0 CD	18.5 kN/m^3	More than 100	45°	110,000 kN/m^2

B. Details of the Tubular Steel Pile

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

TABLE III
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 mm^4
Elastic Modulus	210000 N/mm^2
F_{Yield} Strength	355 N/mm^2

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].

$Q_{f} = Q_{f} + Q_p$ (1)

$Q_{f} = f * A_s + q * A_p$ (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].

$f = K * \tan(\delta) * P_0$ (3)

2) *Where*
a) K it is the coefficient of lateral earth pressure.
b) δ 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].

$f = N_q * P_0$ (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.

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Soil Profile						
From	**To**	**Soil Type**	**SPT N**	**Density (kN/m^3)**	**Cu**	**Phi**
0	2	Medium dense Sand	24	18.5	-	35
2	4		27	18.5	-	35
4	6	Very dense Sand	65	20	-	42
6	30	Calcareous Sandstone	> 100	22	-	45

End Bearing Capacity Calculations							Ultimate End bearing capcity (kN)	
Methods	Angle of internal friction	Nq	Pile Embedded depth (m)	Effective density BWL (kN/cu.m.)	Effective over burden (kPa)	Ultimate End Bearing Pressure (kPa)	**Pile Annulus**	**Plug (50% of total pile area)**
API	45	50	10	12.2	103.9	5195	**193**	**759**

From	To	Density (kN/m3)	Angle of internal friction	Effective over burden [kPa} (Pd)	Soil Pile Friction Angle(δ)	K	Tan δ	f_0 [kN/m^2]	**Fs Ultimate [kN] Outer**	**Fs Ultimate [kN] Inner**
0	0.5	18.5	35	2.2	25	0.80	0.47	0.8	0.8	0.7
0.5	1	18.5	35	6.6	25	0.80	0.47	2.5	2.4	2.2
1	1.5	18.5	35	11.0	25	0.80	0.47	4.1	3.9	3.7
1.5	2	18.5	35	15.4	25	0.80	0.47	5.7	5.5	5.1
2	2.5	18.5	35	19.8	25	0.80	0.47	7.4	7.1	6.6
2.5	3	18.5	35	24.2	25	0.80	0.47	9.0	8.7	8.1
3	3.5	18.5	35	28.6	25	0.80	0.47	10.7	10.2	9.6
3.5	4	18.5	35	33.0	25	0.80	0.47	12.3	11.8	11.0
4	4.5	20	42	37.8	30	0.80	0.58	17.4	16.7	15.6
4.5	5	20	42	42.9	30	0.80	0.58	19.8	19.0	17.7
5	5.5	20	42	48.0	30	0.80	0.58	22.1	21.2	19.8
5.5	6	20	42	53.1	30	0.80	0.58	24.5	23.5	21.9
6	6.5	22	45	58.7	35	0.80	0.70	32.9	31.5	29.4
6.5	7	22	45	64.8	35	0.80	0.70	36.3	34.8	32.5
7	7.5	22	45	70.9	35	0.80	0.70	39.7	38.0	36.0
7.5	8	22	45	77.0	35	0.80	0.70	43.1	41.3	38.6
8	8.5	22	45	83.1	35	0.80	0.70	46.5	44.6	41.7
8.5	9	22	45	89.2	35	0.80	0.70	50.1	48.0	44.9
9	9.5	22	45	95.3	35	0.80	0.70	53.4	51.1	47.8
9.5	10	22	45	101.4	35	0.80	0.70	57.2	54.8	51.2
Total Skin friction Excluding top 4 m									**424**	**397**

Vertical Capacity

Criteria 1: External skin friction + End bearing on the pile wall annulus + Total internal skin friction

Criteria 2: External skin friction + End bearing on the pile wall annulus + End bearing of the plug

Ultimate vertical capacity = minimum of criteria 1 and criteria 2

Criteria 1 = 1014 kN

Criteria 2 = 1376 kN

Hence ultimate vertical capacity =	1014 kN
Allowable vertical capacity =	507 kN

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.

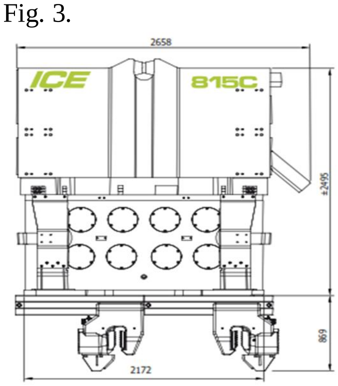

Fig. 2 The vibro-hammer ICE 815C

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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 11.94mm (370mm/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.

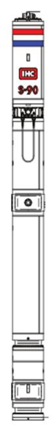

Fig. 4 The hydro-hammer IHC S-90

Fig. 5 PDA installation

Fig. 6 Pile driving using hydro-hammer IHC S-90

SUMMARY OF PDA RESULTS

Pile Identification	PL-01
Test Time & Date (h:m m/d/y)	14:02 12/19/2018
Driving Status	Beginning of Re-strike (BOR)
Final Pile Penetration (m)	10.00
Permanent Set measured at Final Blow (mm)	11.94mm (370mm/31 blows)
Seabed Elevation (m)	-10.835
Initial Pile Tip Elevation (m)	-20.435
Final Pile Tip Elevation (m)	-20.835
Equivalent Blow Count (blow/m)*	84
Hammer Energy (kN-m)	90
Maximum Hammer Transfer Energy (kN-m)	53.7
Allowable Compression Stress (MPa)	319.5
Allowable Tension Stress (MPa)	319.5
Maximum Compression Stress (MPa)	166.6
Maximum Tension Stress (MPa)	92.4
Maximum Mobilized Case Capacity, RX4 (kN)	1,746
Maximum Mobilized Case Capacity, RX5 (kN)	1,629

*Final Set of Blows

SUMMARY OF CAPWAP RESULTS

Pile Identification	PL-01
Mobilized Capacity - MC (kN)	1,669.6
Allowable Vertical Load – AVL (kN)	507
Ultimate Vertical Load – UVL (kN)	1,014 (2 x AVL)
Hammer Theoretical Energy (kN-m)	90
Maximum Hammer Transfer Energy (kN-m)	54.7
Maximum Compression Stress (MPa)	167.3
Maximum Tension Stress (MPa)	85.98
Case Damping Factor (Jc)	0.47
Factor of Safety (F.S. = MC / AVL)	3.29

Fig. 7 PDA and CAPWAP results

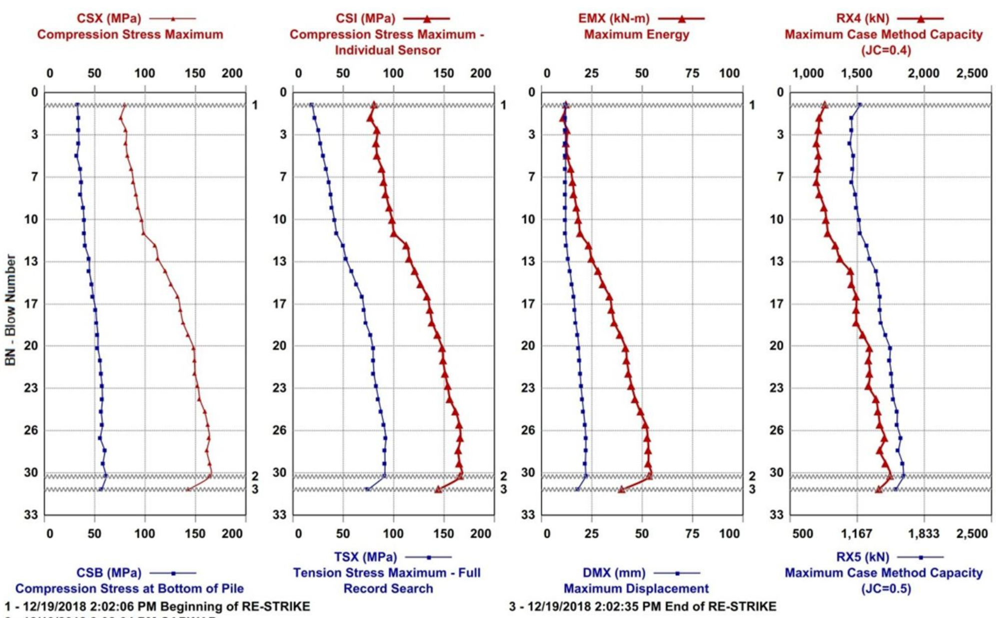

Fig. 8 PDA and CAPWAP charts (1/2)

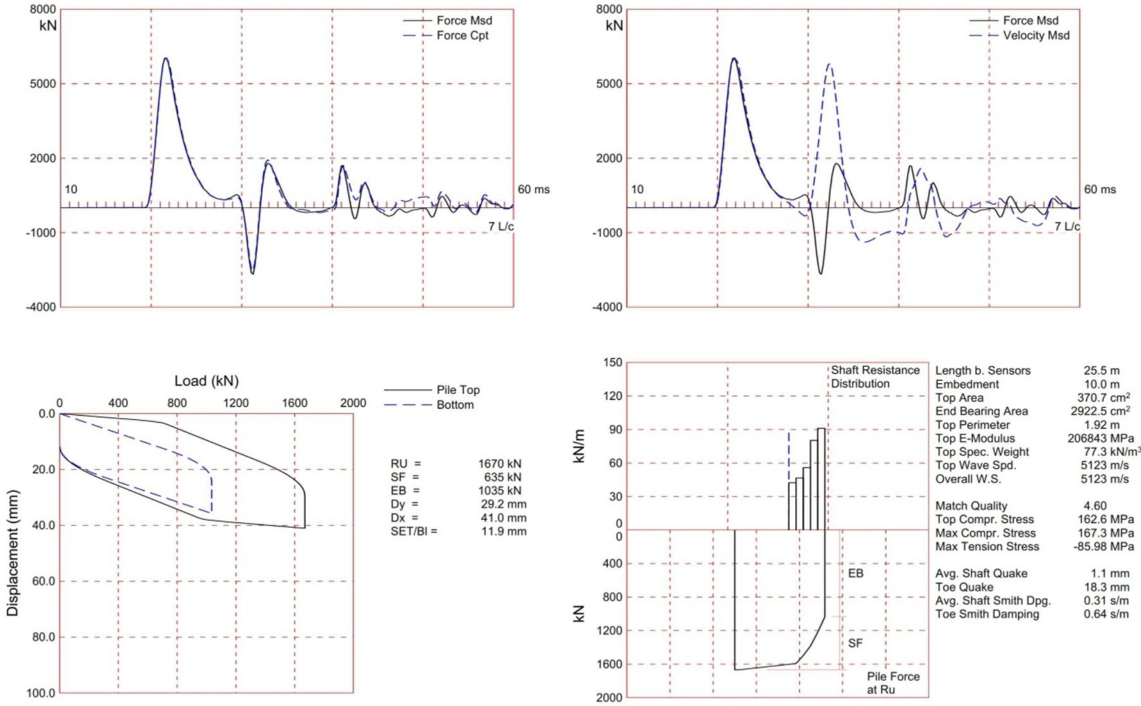

Fig. 9 PDA and CAPWAP charts (2/2)

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.

VI. ACKNOWLEDGMENT

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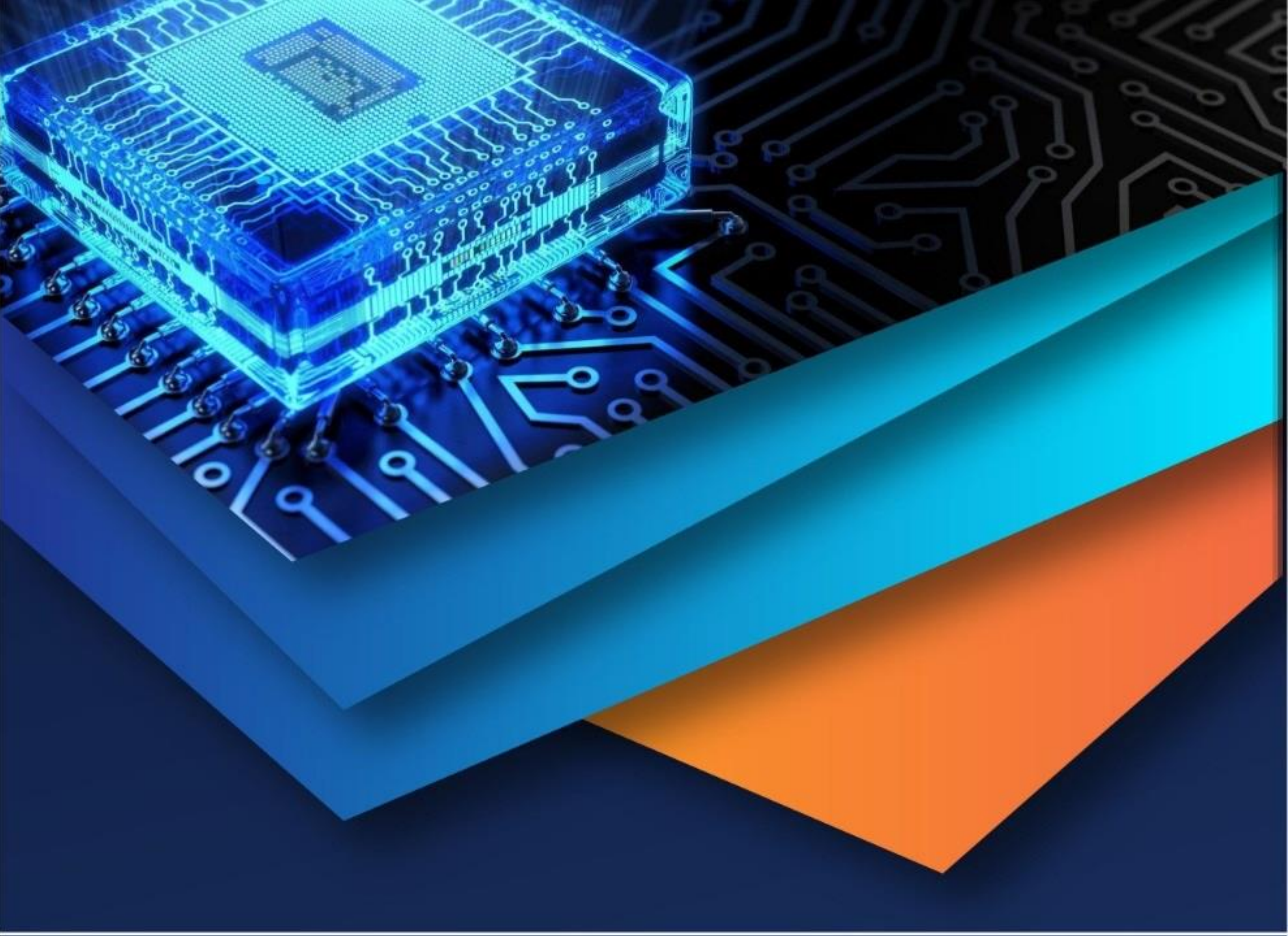

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