Installation Feedback of Suction Pile Foundations and Caissons: Experience in the Deep Water Mediterranean Offshore

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Saipem is one of the world leaders in drilling services, as well as in the engineering, procurement, construction and installation of pipelines and complex projects, onshore and offshore, in the oil & gas market. The company has distinctive competences in operations in harsh environments, remote areas and deepwater. Saipem provides a full range of services with “EPC” and “EPCI” contracts (on a “turn-key” basis) and has distinctive capabilities and unique assets with a high technological content.

Our Numbers

REVENUES

- 2017 ≃**9** B€
- 2018 guidance ≃**8** B€

THE COMPANY

- Operating in more than 60 countries
- ~ 37,000 employees from ~ 120 nationalities
- More than 20 engineering and project execution centres worldwide
- 9 fabrication yards on 5 continents

Abstract

This presentation focuses on the description of the field feedback from the installation of different foundation systems during a recent experience in deep water Mediterranean offshore:

- **suction piles** used as subsea structure foundation;
- **caissons** used as dead man anchor.

For both types of structures, the field feedback has provided considerable insight into their behaviour during installation - expected self-weight penetration and the required suction to achieve the target design penetration, the retrieval operation - useful to verify and refine the design assumptions on these rather tricky aspects for future experiences.

Suction Pile Foundations

N.2 LARGE PILES

OD = 9m

TP = 13m

Pile ~ 130t

Module ~ 210t

N.1 SMALL PILE

OD = 4m

TP = 9m

Pile ~ 35t

Module ~ 30t

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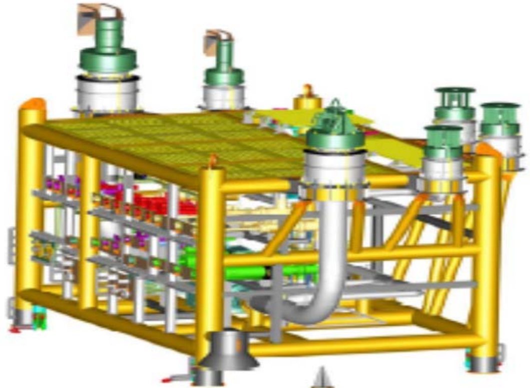
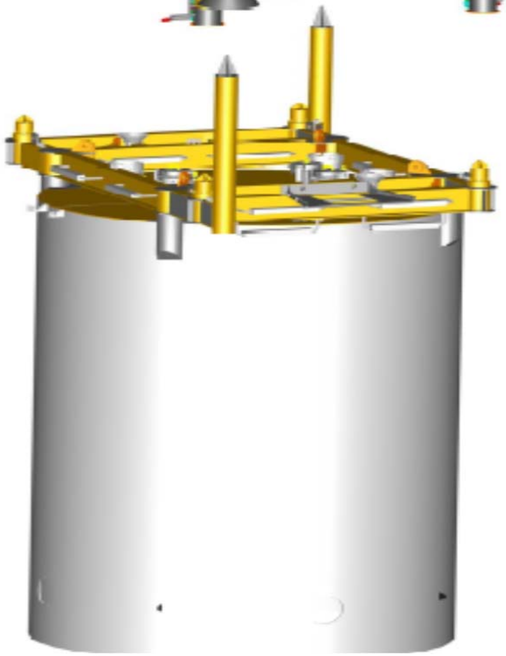
Suction Pile Foundation Design





The geotechnical design of the suction piles includes the study of the following aspects:

- **INSTALLATION**
  - **Self Weight Penetration.**
  - **Required Suction Pressure.**
  - **Allowable suction Pressure.**
  - **Removal / Retrieval Analysis (required pressure).**

- **OPERATING CONDITION → PILE CAPACITY**

  SETTLEMENTS

Suction Pile Installation - Design

Soil Resistance to Penetration

$$Q_{tot} = Q_{side} + Q_{tip} = A_{wall}\alpha S_{u,avg} + \left(N_c S_{u,tip} + \gamma' z\right) A_{tip}$$

THE SITE SPECIFIC PARAMETERS FOR INSTALLATION ANALYSIS ARE:

1) **RELIABLE SOIL DATA**
2) **THE α FACTOR**

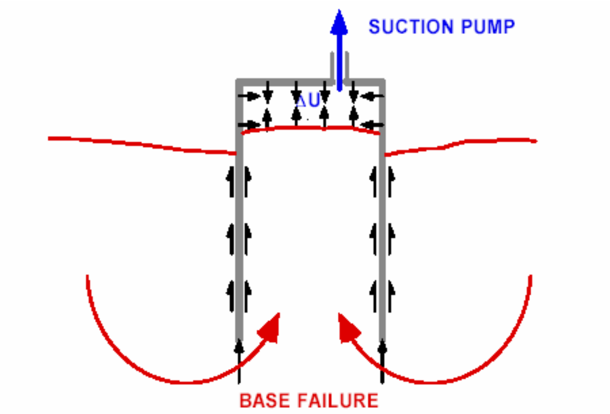
Required Suction Pressure

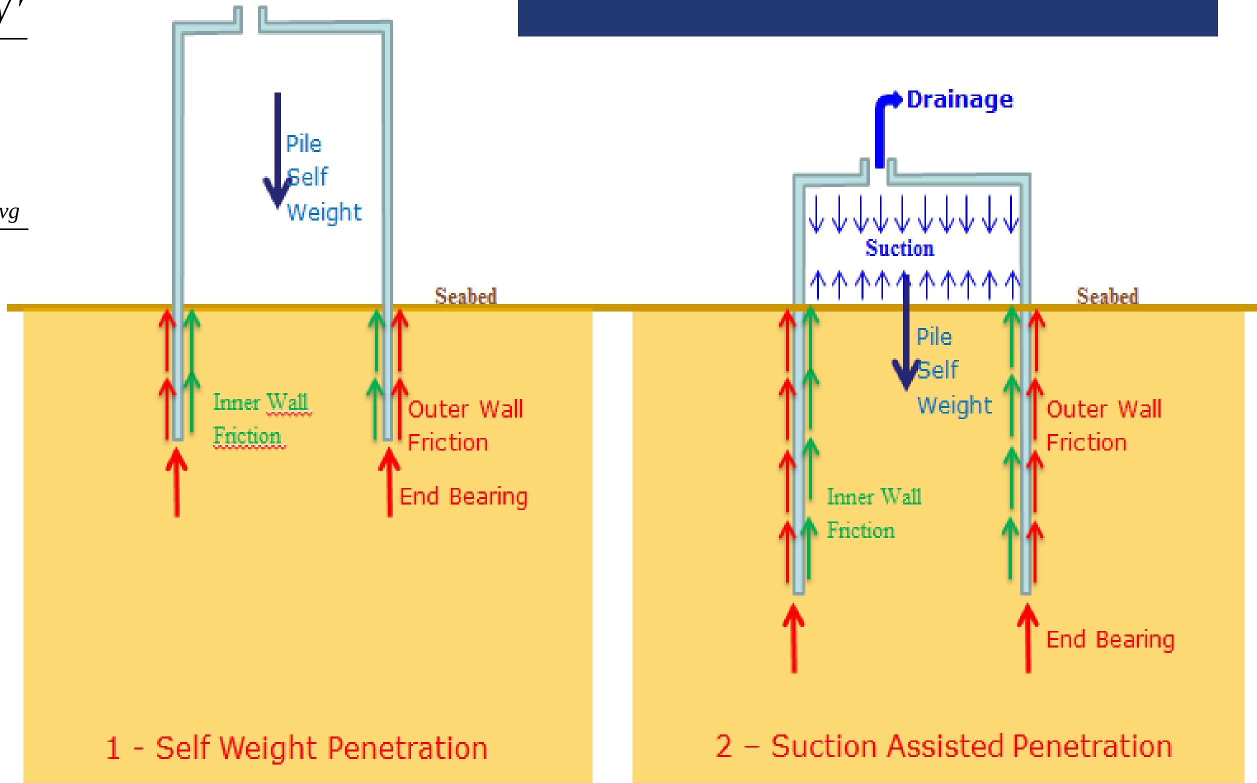
The underpressure needed within the skirt compartment in order to penetrate the skirts

$$\Delta u_n = \frac{Q_{tot} - W'}{A_{in}}$$

Allowable Suction Pressure $\Delta u_a = N_c \cdot S_{utip} + A_{inside} \cdot \frac{\alpha \cdot S_{u,avg}}{A_{in}}$

The maximum applicable suction pressure is evaluated taking into consideration that it must be limited to avoid heave of soil into the pile interior





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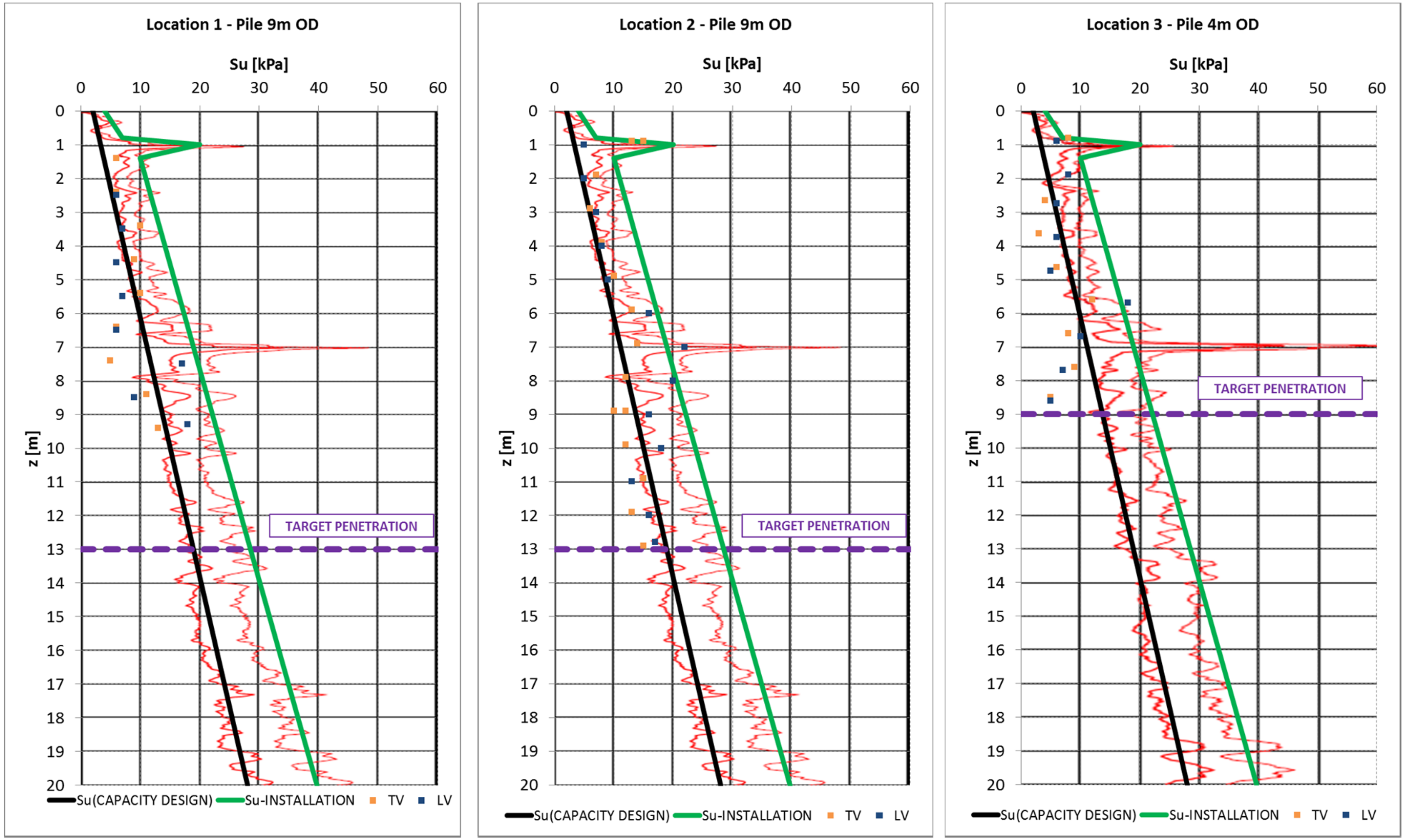
Suction Pile Installation – Reliable Soil Data

SOIL LOWER BOUND (LB)

PILE CAPACITY

SOIL UPPER BOUND (UB)

INSTALLATION ANALYSIS



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Suction Pile Installation – α Factor

- **α is the adhesion factor during installation usually defined as the ratio of remolded shear strength over undisturbed shear strength; the inverse of clay sensitivity (S_t)**

- **Design value of S_t for this project is 3, resulting in α:**

		ADHESION FACTOR (α)
SHORT TERM	AS INSTALLED	1/3 = 0.33
	1 DAY	1.15*(1/3) = 0.38
	10 DAY	1.3*(1/3) = 0.43
LONG TERM	≥ 2 MONTHS	0.65

THIXOTROPY EFFECT

- **From previous Saipem experience and from experiences available in literature, the installation of suction piles in deep water soft clays is often characterized by large friction degradation.**

In the Gulf of Guinea clays, the low penetration resistances observed during suction piles installation correspond to large friction degradation and clay sensitivity of 4 to 6 → α = 0.16 to 0.25

SENSITIVITY ANALYSIS ON α FACTOR: 0.20 – 0.33 – 0.38

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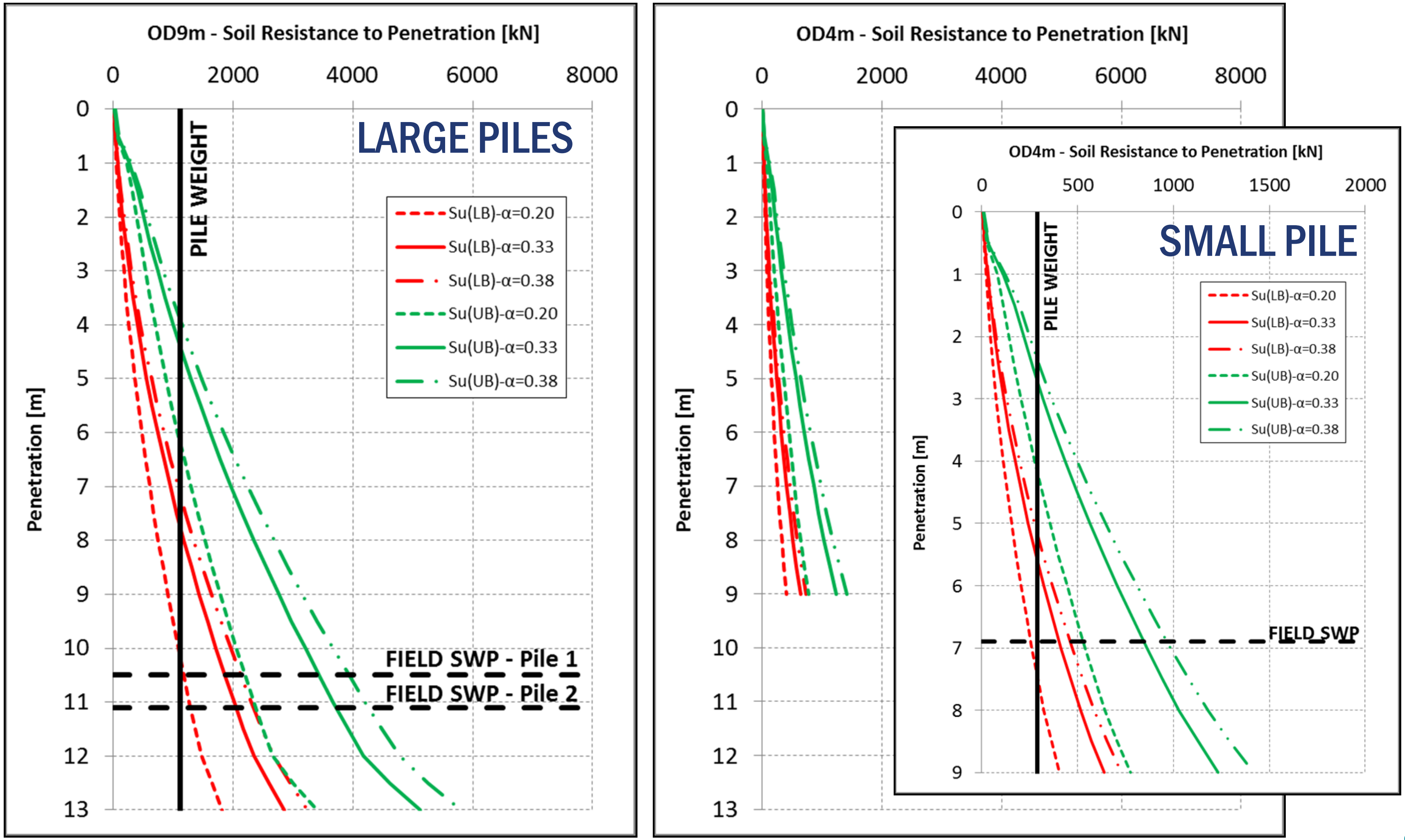
J.L. Colliat, "Friction degradation and strength regain along suction piles in soft deepwater Gulf of Guinea clays" Frontiers in Offshore Geotechnics III, London, 2015

Field Feedback – Self Weight Penetration

For the estimation of pile self weight penetration, the most meaningful case is:

SOIL LB & α=0.2



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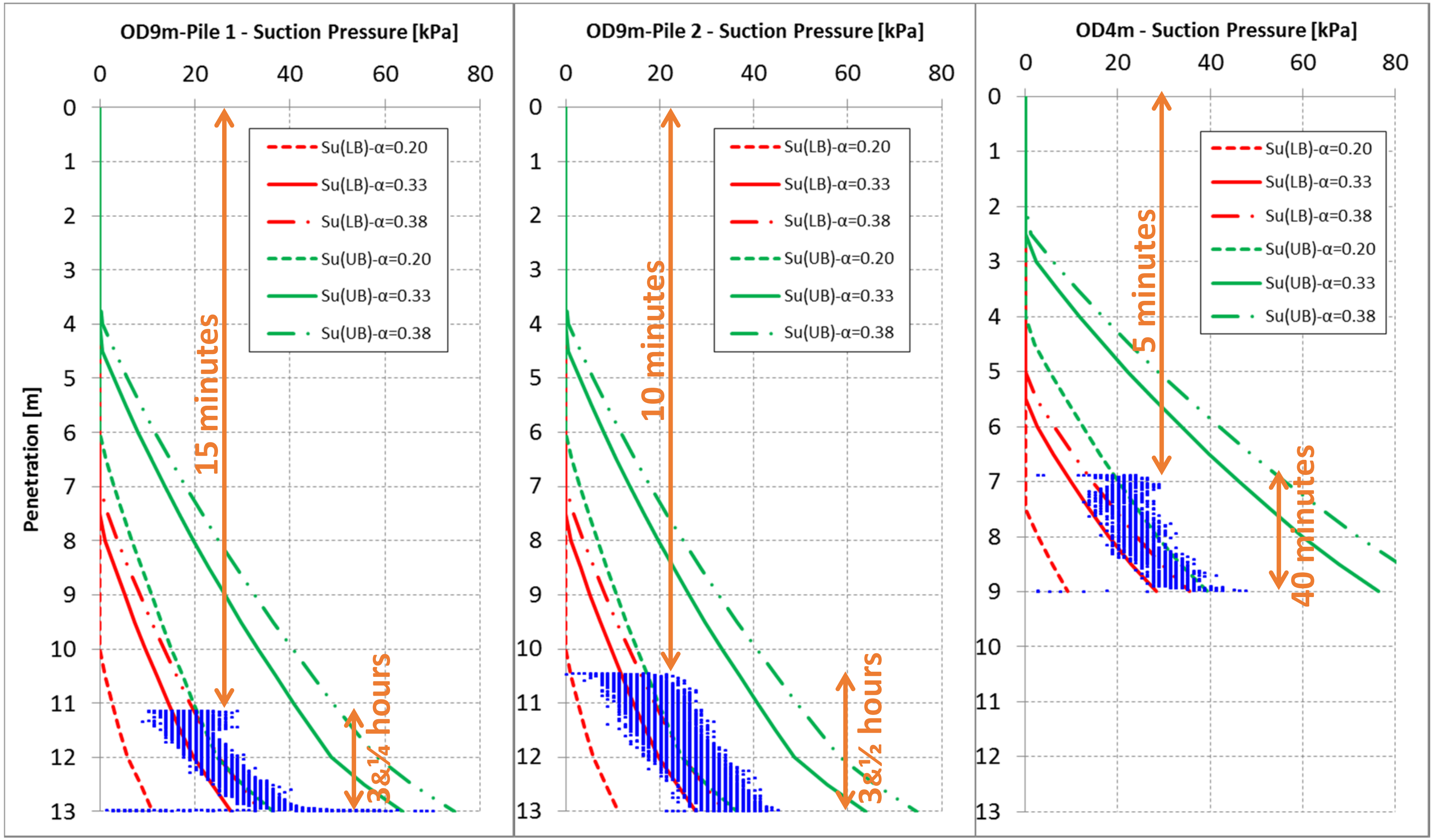
Field Feedback– Required & Allowable Suction Pressures

For the estimation of suction pressure, the most meaningful cases are:

<u>**SOIL LB & α=0.33**</u>

<u>**SOIL LB & α=0.38**</u>

<u>**SOIL UB & α=0.20**</u>



Suction Piles Installation – Lessons Learnt

The field feedback highlights that:

- **For the estimation of pile self weight penetration:** SOIL LB & α=0.2
- **For the estimation of suction pressure:** SOIL LB & α=0.33
  SOIL LB & α=0.38
  SOIL UB & α=0.2

Penetration resistance increases
Degradation effect decreases

THE SOIL IN FIELD IS ONE AND PROBABLY SOMETHING INTERMEDIATE BETWEEN THE LOWER AND UPPER BOUND SOIL CONDITIONS CONSIDERED FOR THE DESIGN;

THEREFORE THIS MEANS THAT THE DEGRADATION EFFECT DURING THE SELF WEIGHT PENETRATION IS HIGHER THAN THE DEGRADATION DURING THE SUCTION PHASE (DIFFERENT PENETRATION RATES).

FOR FUTURE PROJECTS: THE ADOPTION OF SOIL UPPER BOUND CONDITION IN CONJUCTION WITH A α FACTOR HIGHER THAN 0.2 (St<5) IS VERY CONSERVATIVE AND SHOULD BE INVESTIGATED IN DETAIL IN CASE THE CORRESPONDING REQUIRED SUCTION PRESSURES SHOULD RESULT IN PILE OVERSTRESS.

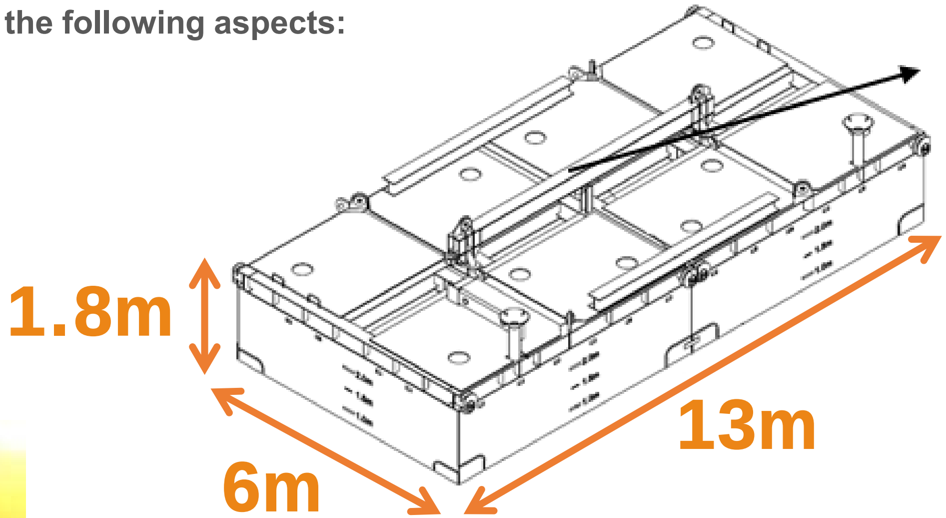
A PROPER GEOTECHNICAL ANALYSIS FOR α FACTOR CALIBRATION IS USEFUL TO AVOID ANY «FALSE» STRUCTURAL PROBLEMS

Dead Man Anchor Caissons

- The geotechnical design of these caissons piles includes the study of the following aspects:

- CAISSON INSTALLATION
  - Self Weight Penetration.
  - Removal / Retrieval Analysis (required pressure).

- OPERATING CONDITIONS → ANCHOR CAPACITY



WEIGHT~95t

Dead Man Anchor Caissons - Retrieval

Soil Resistance to Retrieval

$$F_{retrieval} = F_{ext,sk} + \min(\underbrace{W_{plug} + Q_{suction,tip}}_{\text{PLUGGED MECHANISM}};\ \underbrace{F_{int,sk} + Q_{suction,plate}}_{\text{UNPLUGGED MECHANISM}})$$

Suction force at skirts of foundation base:

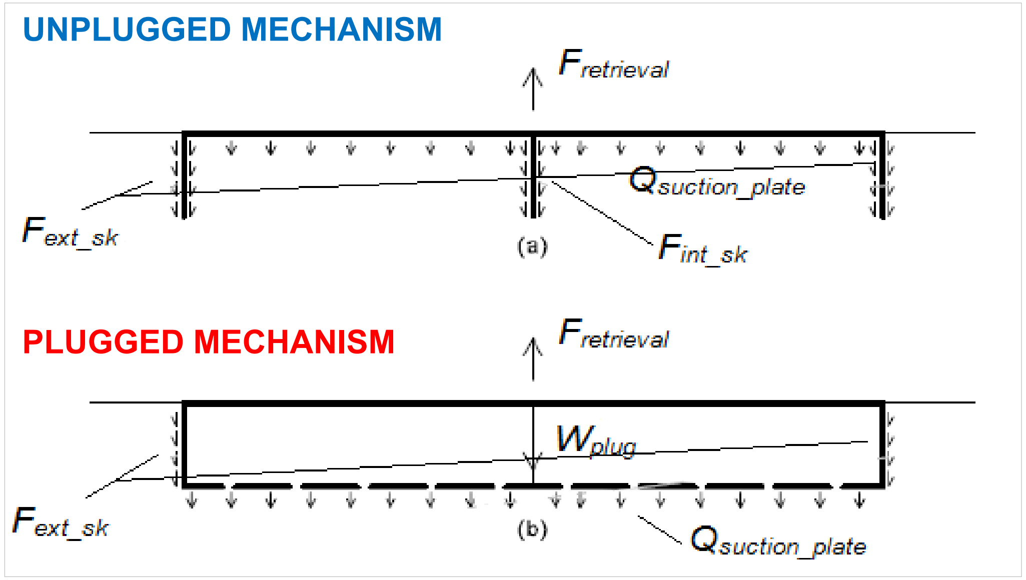
$$Q_{suction} = N_t * Su * B * L$$

Skirt wall friction :

$$F_{SK} = \alpha * Su_{ave} * A_{wall}$$

THE SITE SPECIFIC PARAMETERS FOR INSTALLATION ANALYSIS ARE:

1) **RELIABLE SOIL DATA**
2) **THE α FACTOR**



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Dead Man Anchor Caissons – Retrieval – Design

During the DESIGN PHASE, the uncertainties related to the time between DMA installation and retrieval were taken into account considering conservatively high α factor values:

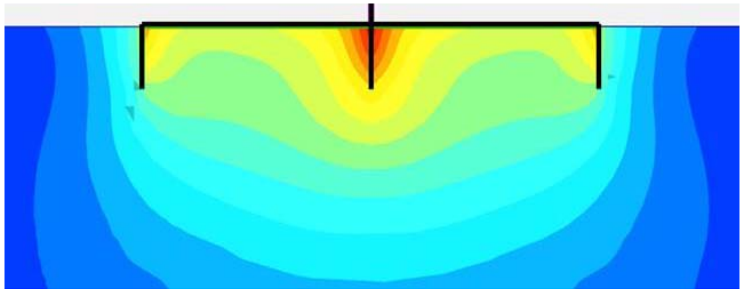
- **α = 0.50: retrieval in the first 7 days after installation**
- **α = 0.75: retrieval 7 days after installation**

During the BACK ANALYSIS PHASE, a further case:

- **α = 0.4: more reliable value for a 7 days period**

PLUGGED MECHANISM

UNPLUGGED MECHANISM



	α=0.5	
	SOIL (LB)	SOIL (UB)
Submerged weight of anchor: W_{anchor} [kN]	810	810
Skirt-soil external wall friction: $F_{ext\ sk}$ [kN]	109	328
Submerged weight of the plugged soil: W_{plug} [kN]	569	783
Suction force at the skirts tip: Q_{suct_tip} [kN]	687	1683
Skirt-soil internal wall friction: $F_{int\ sk,stiff}$ [kN]	194	587
Suction force at the foundation base plate: Q_{suct_plate} [kN]	316	633
Soil resistance to breakout (plugged with suction) [kN]	2175	3604
Soil resistance to breakout (unplugged with suction) [kN]	1429	2358
Soil resistance to breakout (plugged without suction) [kN]	1488	1921
Soil resistance to breakout (unplugged without suction) [kN]	1113	1725
Total soil resistance to breakout with suction: F_{retr} [kN]	**1429** unplugged	**2358** unplugged
Total soil resistance to breakout without suction: F_{retr} [kN]	**1113** unplugged	**1725** unplugged

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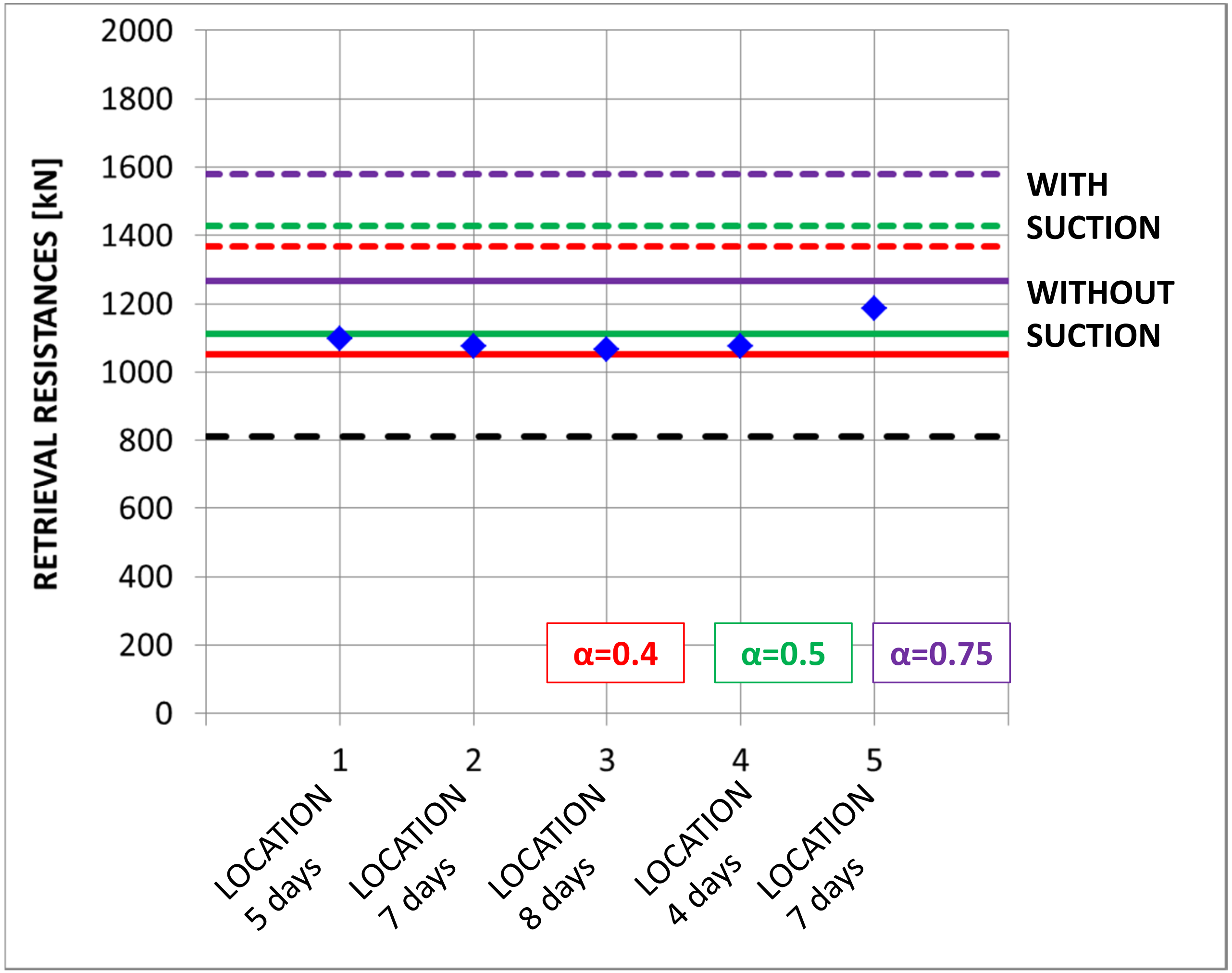
Dead Man Anchor Caissons – Retrieval – Field Feedback

The effective retrieval load in field is very uncertain to be calculated since significantly influenced by the operations procedure adopted on board.

In general, the design approach has been confirmed as conservative for its purpose:

SAFE & TIMELY RECOVERY OF THE CAISSON WITHOUT DAMAGE



THANK YOU FOR YOUR ATTENTION

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