Compaction of Silty Sand Due to Previous Jack-up Installations and Seabed Interventions to Avoid Critical Skirted Spudcan-footprint Interactions

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ABSTRACT
Installation and operation of jack-ups often leave depressions in a sandy seabed due to compaction. In particularly, quite significant depressions are observed in spudcan footprints in seabed comprising silty sand. With the densification of the sandy seabed, compactions are beneficial for the operation phase owing to the improved strength and stiffness characteristics of the sandy soil below the spudcans. However, the virgin seabed around the spudcan footprints remains essentially unchanged, and this could bring upon difficulties for following installations of jack-ups with different spudcan geometries, with or without skirts or leg-to-leg distance. This paper presents a case study of a jack-up rig installation in the North Sea where challenges with rack phase difference (RPD) issues in respect to differential settlements were predicted. That is, seabed intervention was deemed necessary as a consequence of a mismatch of the size and leg-to-leg distance with the footprints left by previous installations, and therefore, the spudcans were to be installed on partly virgin soil and partly compacted soil. After considering different seabed intervention methods, i.e. filling with sand /gravel etc., excavation of the seabed around the existing footprints was chosen to be the most suitable solution. Analysing cone penetration tests (CPTs) performed in virgin soil (before any installation) and later carried out in the compacted soil within the footprints (after all previous installations), the change in terms of state and strength due to compaction was approximately quantified. In order to compensate for larger settlements predicted in the virgin soil when assuming a flat seabed, based on previous and recent seabed survey (multibeam ecosounder (MBES) data) and conventional and FE analyses, partial seabed excavations with differential elevations were designed. The designed excavations were confirmed by post excavation survey / bathymetry data, and the rig was successfully installed with measured skirted spudcan penetrations as predicted and without any critical RPD issues.

KEY WORDS: Skirted spudcan-footprint interaction; Sand compaction; Compression loading; Finite element analyses; Conventional analyses; Differential seabed elevation; Seabed interventions/dredging/excavation

INTRODUCTION

Depending on the compressibility of a given sand, compaction happens when subjected to a pressure, which could be applied by a foundation such as a spudcan during jack-up installation. A silty sand tends to have a significantly higher compressibility when compared to a clean sand (e.g. Schultze and Moussa 1961; Jefferies and Been 2016). Studies of Cubrinovski and Ishihara (2002) and Jensen and Kellezi (2023) showed that the void ratio limits of natural sands increase systematically with increasing fines content, indicating for an increasingly porous and unstable soil structure, which explains the higher compressibility of the silty sands. Consequently, significant depressions are often left in the seabed after jack-up installation and operation in silty sands.

Along with the compaction comes a densification of the sandy soil below the spudcans, which may quite significantly improve the strength and stiffness properties. Therefore, the compaction is beneficial for the soil properties related to the operation phase that follows after the installation. On the other hand, the alteration of the seabed could possibly lead to critical skirted spudcan-footprint interactions for following installations of jack-ups with different spudcan geometries or leg-to-leg distance with the depressions of the previous installations. When the soil conditions for various reasons are deemed critical for the installation (or operation phase), measures such

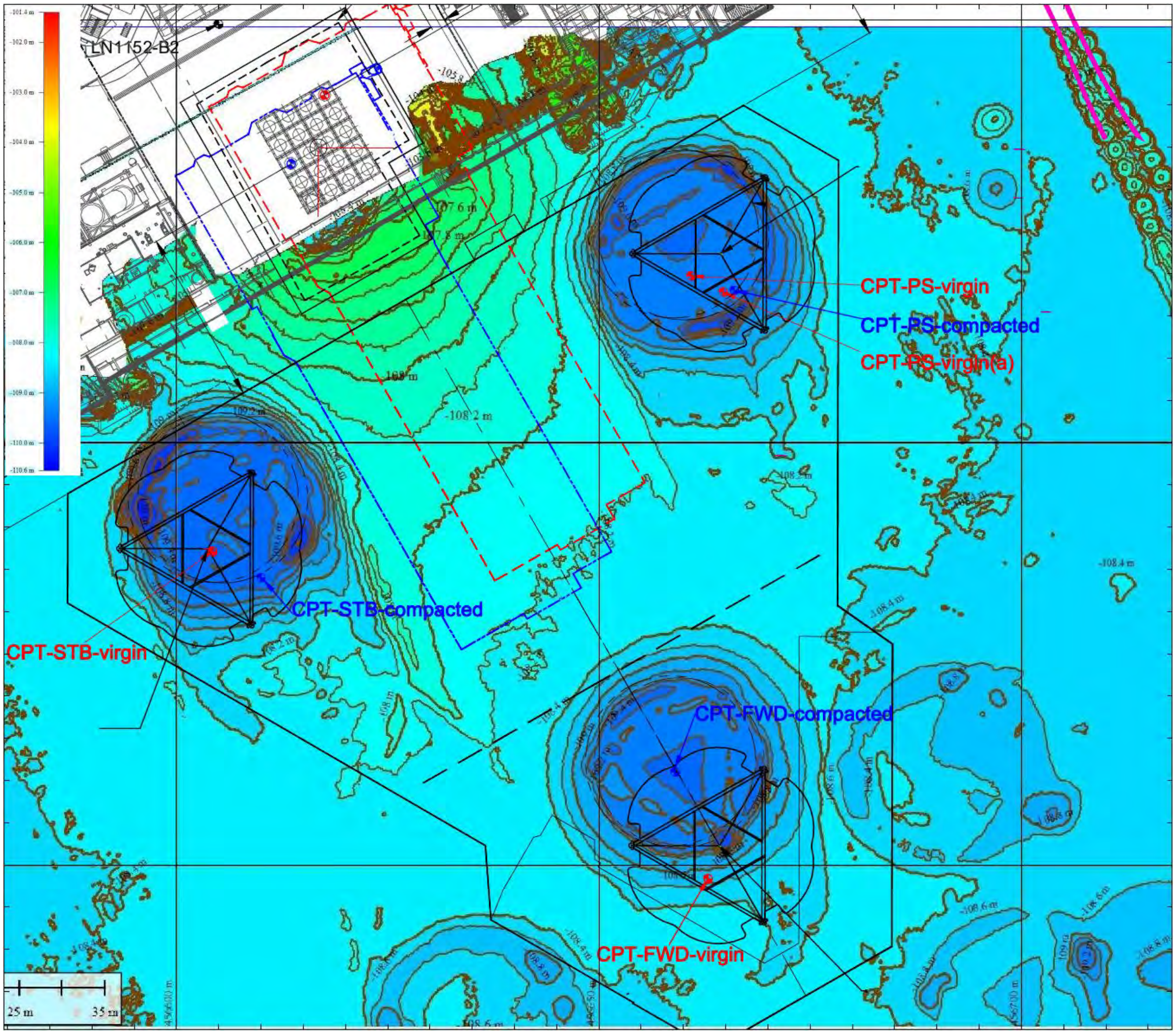


Figure 1 Bathymetry after previous installations showing also the positions of the CPTs performed in virgin seabed (in red) and in compacted seabed (in blue)

as seabed intervention/remediation can be considered (Kellezi and Gjerde 2021; Kellezi and Stadsgaard 2019; Kellezi et al. 2019; Kellezi et al. 2017; Kellezi et al. 2015; Kellezi and Stadsgaard 2012; Kellezi et al. 2008; Kellezi et al. 2007).

This paper presents a case study from the North Sea with cone penetration test (CPT) data from campaigns carried out for assessment of jack-up installations in virgin seabed (before any installation) and later in compacted seabed within the footpints (after all previous installations). This data provide unique insights to the compaction taking place during jack-up installation and operation. As elaborated in more detail later in this paper, the last campaign was carried out because challenges with RPD issues in respect to differential settlements were predicted. That is, seabed intervention was deemed necessary as a consequence of a mismatch of the size and leg-to-leg distance with the footprints left by previous installations, and therefore, the spudcans were to be installed on partly virgin soil and partly compacted soil.

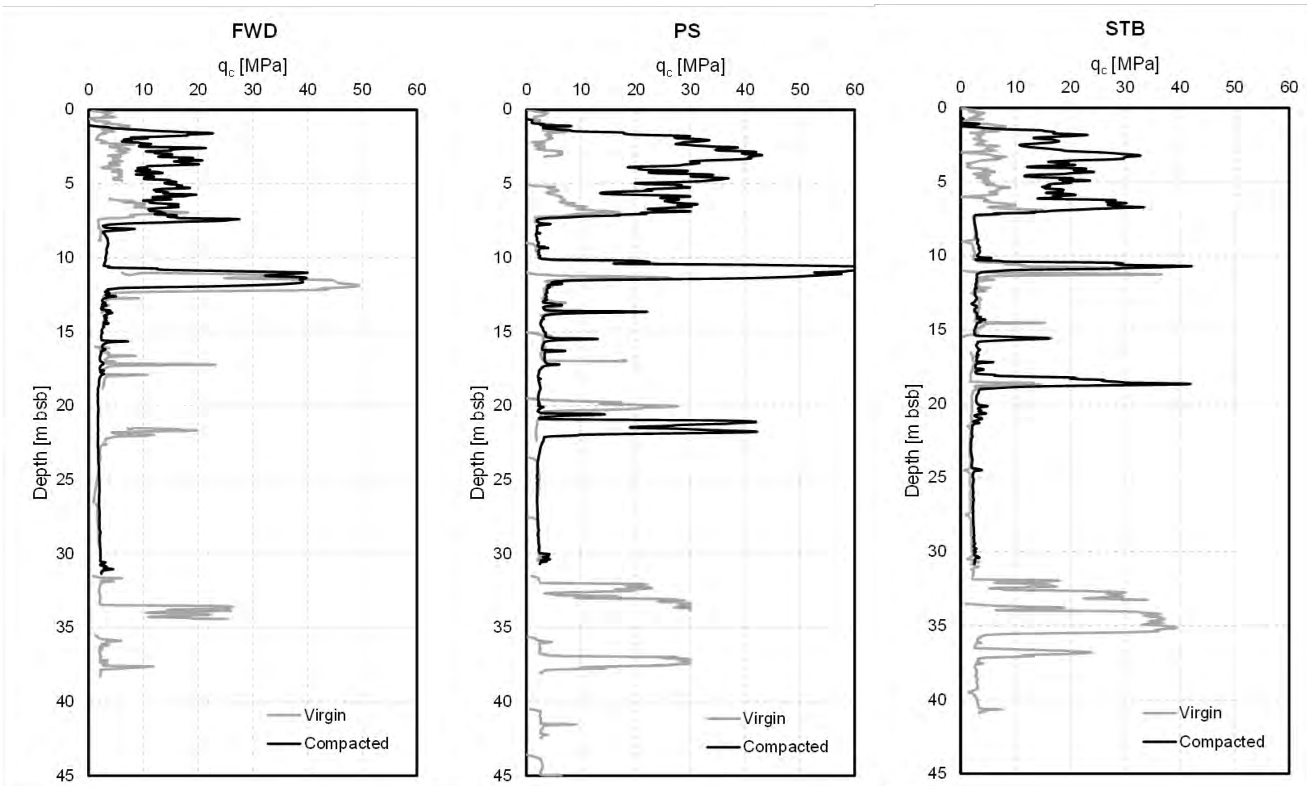


Figure 2 CPT q_c profiles at FWD, PS and STB Legs performed in virgin and compacted seabed

SOIL INVESTIGATION

In 2011, prior to any installation at the location, a soil investigation including a downhole CPT at each of the three planned leg positions (and a re-run at the Port (PS) Leg) was carried out to estimate the virgin soil conditions. Eleven years and several jack-up installations later (in 2022), continuous seabed CPTs were performed in each of the three footprints left by the previous jack-up installations to assess the impact of the soil compaction. The significant depressions (approximately (0.9-1.0) m deep) and the positions of the CPTs in the virgin soil seabed (in red) and in the compacted soil seabed (in blue) are shown in Fig. 1. In addition, boreholes (BHs) with sampling were carried out at the site and a comprehensive laboratory test series performed including simple classification tests, simple strength tests and advanced laboratory tests.

Virgin soil

The cone resistance (q_c) of the three downhole CPTs performed in virgin soil to (40-45) m below seabed (bsb) are shown in Fig. 2. The soil conditions appear to be relatively uniform between the leg positions, and based on a screening-level assessment of the CPT data (including also sleeve friction, f_s, and pore pressure, u, measurements) the soil stratigraphy comprises approximately 7 m of loose to medium dense silty sandy soil overlying varying layers of stiff to very stiff clayey soil and medium dense to dense silty sandy soil (Robertson 2009). The general soil conditions were confirmed by sampling and BH descriptions. The interpreted best estimate (BE) soil profiles are given in Table 1.

The drained friction angles (φ') were estimated based on the in situ peak friction angles (φ'_p) derived according to Schmertmann (1978) (assuming the most conservative 'uniform fine sand') and taking into account some slight reduction in friction angle due to some suppression of dilatancy with increasing foundation pressure (Bolton 1986; Andersen and Schjetne 2013). Particular attention was given to the top sandy layer of which eight particle size distribution tests (PSDs) were performed (see Fig. 3), indicating a fine silty to very silty sand with a fines content of (15-30)% including (5-10)% clay fraction. Furthermore, several consolidated isotropically drained (CID) triaxial tests were performed on samples prepared with an initial relative density (D_r) of (40-60)% and taking also into account the pressure applied to the soil during jack-up installation. The CID tests all revealed a contractive behavior and showed friction angles of approximately (29-31)°, which based on the PSDs in Fig. 3 is in a good agreement with expectations according to Jensen and Kellezi (2023).

Table 1 Interpreted soil parameters at Forward (FWD), Port (PS) and Starboard (STB) Legs for virgin soil conditions

Depth interval (*m*)	*Soil type*	*Effective unit weigth* γ' (kN/m^3)	*Friction angle* φ' (degrees)	*Undrained shear strength* c_u (kPa)	*Oedometer modulus* E_{oed} (*MPa*)	*Young's modulus* E_s (*MPa*)
CPT-FWD-virgin						
(0 - 2)	SAND	9.6	29.5	-	12	8.9
(2 - 7.3)	SAND	9.6	30	-	20	14.9
(7.3 - 10.3)	CLAY	11.2	-	84-116	34.3-46.8	25.5-34.8
(10.3 - 12.5)	SAND	11.2	33.5	-	70	52
(12.5 - 14)	CLAY	11.4	-	144-115	58.2-46.4	43.2-34.5
(14 - 19)	CLAY	11.4	-	163-100	65.8-40.4	48.9-30
(19 - 26.5)	CLAY	9.5	-	113-81	45.6-32.7	33.9-24.3
(26.5 - 33.5)	CLAY	9.5	-	63-94	25.4-38	18.9-28.2
(33.5 - 35.5)	SAND	9.8	32	-	50	37.1
(35.5 - 40)	CLAY	9.8	-	81-100	32.7-40.4	24.3-30
CPT-PS-virgin						
(0 - 3)	SAND	9.6	29.5	-	12	8.9
(3 - 7.2)	SAND	9.6	30	-	24	17.8
(7.2 - 10.1)	CLAY	11.2	-	81-94	32.7-38	24.3-28.2
(10.1 - 12)	SAND	10.7	28.5	-	60	44.6
(12 - 12.9)	CLAY	11.4	-	171-166	69-67	51.3-49.8
(12.9 - 13.8)	CLAY	11.4	-	254-233	102.6-94.1	76.2-69.9
(13.8 - 19.5)	CLAY	11.4	-	169-138	68.3-55.7	50.7-41.4
(19.5 - 20.5)	SAND	9.5	29.5	-	60	44.6
(20.5 - 32)	CLAY	9.5	-	98-123	39.6-49.7	29.4-36.9
(32 - 35)	SAND	9.5	31.5	-	60	44.6
(35 - 36.8)	CLAY	9.5	-	119-133	48.1-53.7	35.7-39.9
(36.8 - 37.85)	SAND	9.5	31.5	-	70	52
(37.85 - 45)	CLAY	9.5	-	133-135	53.7-54.5	39.9-40.5
CPT-STB-virgin						
(0 - 1.5)	SAND	9.6	29	-	12	8.9
(1.5 - 5)	SAND	9.6	28.5	-	20	14.9
(5 - 7.4)	SAND	9.6	29.5	-	28	20.8
(7.4 - 10.4)	CLAY	11.2	-	118-121	47.7-48.9	35.4-36.3
(10.4 - 11.6)	SAND	10.7	29.5	-	60	44.6
(11.6 - 18.5)	CLAY	11.4	-	156-100	63-40.4	46.8-30
(18.5 - 18.9)	SAND	11.4	27.5	-	32	23.8
(18.9 - 23)	CLAY	11.4	-	96-71	38.8-28.7	28.8-21.3
(23 - 29)	CLAY	9.5	-	73-80	29.5-32.3	21.9-24
(29 - 31.8)	CLAY	9.5	-	86-99	34.7-40	25.8-29.7
(31.8 - 35.6)	SAND	9.8	32	-	80	59.4
(35.6 - 40.9)	CLAY	9.8	-	144-144	58.2	43.2-43.2

The undrained shear strength (c_u) profiles were derived with a cone factor, N_{kt}=20, correlated between the CPT net cone resistance (q_{net}) and the undrained triaxial laboratory strength tests performed at corresponding depths (Lunne et al. 1997).

In terms of deformation parameters, the oedometer modulus for the sand layers was estimated according to Lunne and Christofferesen (1983) and the Young's modulus for the clay layers was estimated as E_s=300c_u which is commonly assumed for overconsolidated clay. The corresponding Young's modulus for the sand layers and the oedometer modulus for the clay layers are then readily obtained according to Hooke's law.

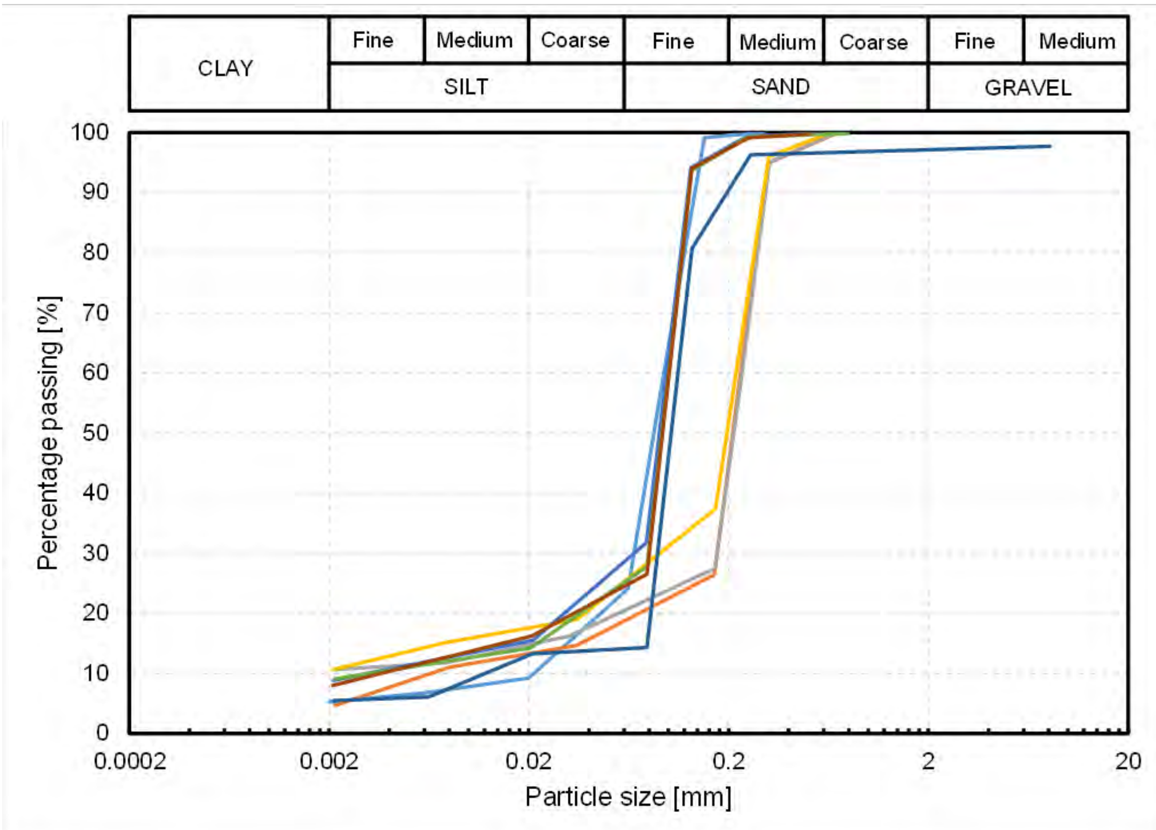


Figure 3 PSDs for the top silty sand (approximately top 7 m)

Compacted soil

The q_c profiles of the three continous seabed CPTs performed in the footprints with compacted soil are shown in Fig. 2 (note that the difference in starting depths of the compacted and virgin profiles reflect the difference in water depth). It is immediately clear that significant densification of the top sandy soil has taken place leading to increased strength as reflected in the q_c profiles when compared to the q_c profiles of the virgin seabed (Fig. 2). The compaction has expectedly taken place during preloading as an immediate settlement followed by creep settlements with possibly drained cyclic loading taking place over the time of operation (which is estimated to be approximately 1850 days). The very significant portion of a total settlement that could possibly result from creep for footings placed on sand was idenfied by Liu and Lehane (2020).

The interpreted BE soil profiles based on the CPTs performed in the compacted seabed are given in Table 2. It is noted that the friction angles in the top sand layer has increased by approximately (3-6)° in the compacted state, and the deformation parameters, E_{oed} and E_s, have increased from approximately (12-24) MPa and (9-18) MPa to (50-70) MPa and (37-50) MPa, respectively. Therefore, a significantly stiffer response is expected for foundations placed on the compacted seabed compared with the virgin seabed. The underlying clay is similarly noted to have increased in undrained shear strength. However, a very loose/soft layer is identified in the upper 0.9 m at STB Leg, which is believed to originate from either mud cutting or sedimentation.

STATE AND STRENGTH OF VIRGIN SOIL VERSUS COMPACTED SOIL

In an attempt to quantify the compaction at a more fundamental level, the relative density of the top sand was estimated with CPT correlations and compared for the CPTs performed in virgin seabed and compacted seabed in Fig. 4. Such CPT correlations are very sensitive to the compressibility of sand (Jamiolkowski et al. 2003; Lunne 2010; Lehane et al. 2022). Therefore, the correlation established with mainly clean sand by Jamiolkowski et al. (2003) was applied together with a fines correction (Lunne 2010); assuming 25% fines. In order to further improve the reliability of the D_r estimates, the interpretations were performed with a varying coefficient of earth pressure at rest (K_0), which was proven by Krogh et al. (2022) to be important for the accuracy in the top 5 m or so.

Table 2 Interpreted soil parameters at FWD, PS and STB Legs for compacted soil conditions

Depth interval (*m*)	*Soil type*	*Effective unit weigth* γ' (*kN/m³*)	*Friction angle* φ' (degrees)	*Undrained shear strength* c_u (kPa)	*Oedometer modulus* E_{oed} (*MPa*)	*Young's modulus* E_s (*MPa*)
CPT-FWD-compacted						
(0 - 2.5)	SAND	9.6	34	-	50	37.1
(2.5 - 6.6)	SAND	9.6	32.5	-	50	37.1
(6.6 - 9.6)	CLAY	11.2	-	151-143	61-57.8	45.3-42.9
(9.6 - 11)	SAND	10.7	34	-	90	66.9
(11 - 15)	CLAY	11.4	-	153-110	61.8-44.4	45.9-33
(15 - 18.5)	CLAY	11.4	-	113-75	45.6-30.3	33.9-22.5
(18.5 - 30.2)	CLAY	9.5	-	75-96	30.3-38.8	22.5-28.8
CPT-PS-compacted						
(0 - 1)	SAND	9.6	30.5	-	16	11.9
(1 - 3)	SAND	9.6	38.5	-	76	56.5
(3 - 6.6)	SAND	9.6	35.5	-	72	53.5
(6.6 - 9.5)	CLAY	11.2	-	93-96	37.6-38.8	27.9-28.8
(9.5 - 11)	SAND	10.7	35	-	110	81.7
(11 - 13)	CLAY	11.4	-	200-160	80.8-64.6	60-48
(13 - 16.7)	CLAY	11.4	-	144-146	58.2-59	43.2-43.8
(16.7 - 18)	CLAY	11.4	-	99-100	40-40.4	29.7-30
(18 - 19.9)	CLAY	11.4	-	115-101	46.4-40.8	34.5-30.3
(19.9 - 21.5)	SAND	9.5	31	-	70	52
(21.5 - 23)	CLAY	9.5	-	150-98	60.6-39.6	45-29.4
(23 - 29.3)	CLAY	9.5	-	91-99	36.8-40	27.3-29.7
(29.3 - 30)	CLAY	9.5	-	158-135	63.8-54.5	47.4-40.5
CPT-STB-compacted						
(0 - 0.9)	SAND	9.6	23.5	-	4	3
(0.9 - 6.6)	SAND	9.6	34.5	-	52	38.6
(6.6 - 9.6)	SAND	11.2	-	110-166	44.4-67	33-49.8
(9.6 - 10.5)	CLAY	10.7	31.5	-	70	52
(10.5 - 15)	SAND	11.4	-	136-119	54.9-48.1	40.8-35.7
(15 - 17.3)	CLAY	11.4	-	135-134	54.5-54.1	40.5-40.2
(17.3 - 18.3)	SAND	9.5	31	-	60	44.6
(18.3 - 21)	CLAY	11.4	-	148-133	59.8-53.7	44.4-39.9
(21 - 22.4)	CLAY	9.5	-	105-90	42.4-36.3	31.5-27
(22.4 - 30.2)	CLAY	9.5	-	105-126	42.4-50.9	31.5-37.8

At all legs, the sandy soil of the virgin seabed appears to be loose to medium dense with D_r=(45-60)%. Despite the very soft/loose top soil at STB Leg (possibly originating from mud cutting or sedimentation), the CPTs performed at the compacted seabed show that, D_r at the Aft Legs (PS and STB Legs) has increased significantly to about (80-100)%, and the soil is now considered as a very dense sandy soil within these footprints. A slightly smaller change is observed at the FWD Leg, where the compacted sand is now dense with D_r=(70-80)%, this even though all legs for the previous installations are expected to have had a similar maximum preload applied; i.e. approximately (18500-19000) tons/leg. The still water reaction (SWR) during operation was approximately 10800 tons/leg at the Aft Legs and only 8300 tons/leg at the FWD Leg. The difference in SWRs during operation possibly explains the difference in compaction between the Aft Legs and the FWD Leg and show the significant amount of compaction taking place over time due to creep settlements in sandy soil.

In addition, void ratio limits (e_{min} and e_{max}) were determined with classification tests for the top sandy layer as e_{min}≈0.60 and e_{max}≈1.23. Considering the PSD curves in Fig. 3, these relatively high values are in a good agreement with expectations according to Jensen and Kellezi (2023), and indicate for a very porous and unstable soil structure

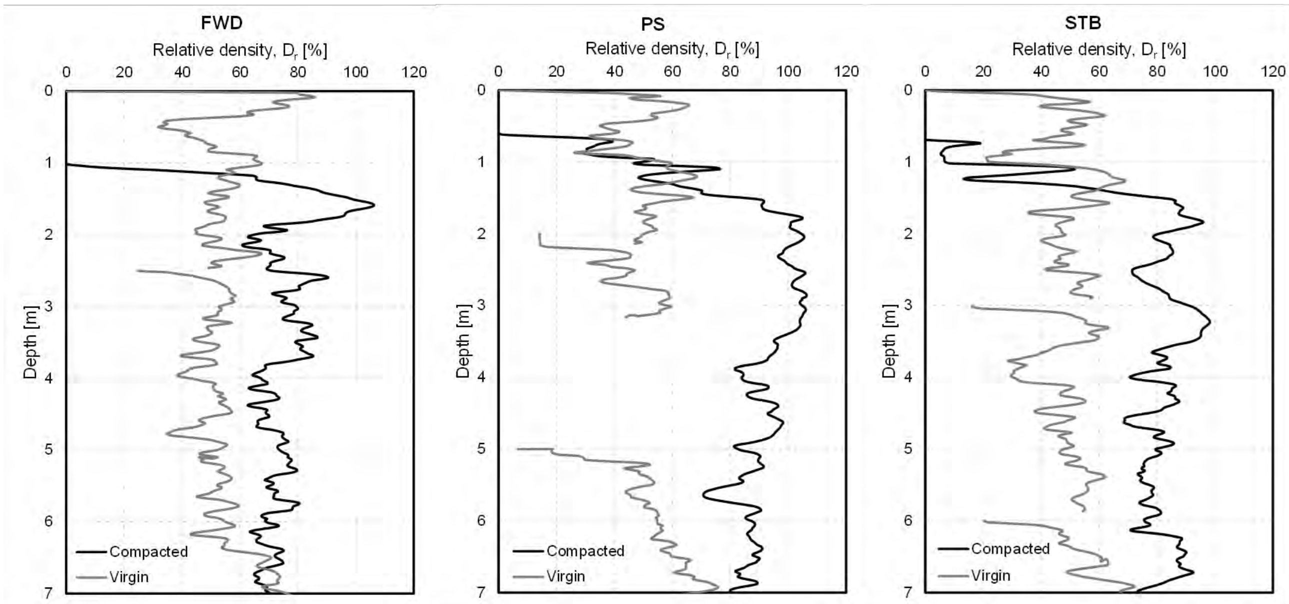


Figure 4 Comparison of D_r profiles derived based on CPT data from virgin and compacted seabed

for the looser virgin seabed and also indicate for a high potential for compaction of the silty top sand. Relating the derived D_r profiles in Fig. 4 with void ratio considerations, the increase in friction angle of (3-6)° in the compacted soil compared with the virgin soil is similarly in keeping with the observations by Jensen and Kellezi (2023).

CONVENTIONAL LEG PENETRATION ANALYSES

As it appears in Fig. 1, the new jack-up rig to be installed at the location has a slightly different leg-to-leg distance and different size spudcans compared to the previous installations, and hence, the spudcans will be placed in partly virgin seabed and partly compacted seabed. Furthermore, the spudcans of the new jack-up have 2.3 m skirts (measured from full base contact to skirt tip) and spudcans of the previous installations had no skirts.

Conventional penetration analyses following the guidelines given in SNAME (2008) and ISO (2016) are shown in Fig. 5 for each leg assuming virgin and compacted soil conditions based on the BE soil profiles given in Tables 1 and 2. To conventionally define footing penetration depths versus load, the calculation of static bearing capacity of the spudcan at various depths is carried out. Different failure mechanisms are assumed during the footing penetration in multi-layered plastic medium. The spudcan bearing capacity is calculated conventionally based on Hansen (1970) and Geo's in-house program developed from the experience with spudcan penetration predictions (Kellezi and Kudsk (2009) etc.). The spudcan is simplified to a circular footing with a flat bottom. The effect of the actual spudcan shape is taken into account. The penetration resistance of skirt elements is calculated as sum of end and skin resistance.

The reference depth of penetration is taken as the chord tip, which is 3.3 m deeper than full base contact. Therefore, it follows from Fig. 5 that full base contact or slightly more is expected at all legs for max preloads following the BE soil parameters. More specifically, for virgin soil conditions penetrations of (3.4-3.6) m bsb are expected, and for compacted soil conditions penetrations of (3.2-3.3) m bsb are expected. In addition, punch through is predicted at load levels higher than the max preloads. However, feedback from the previous installations, where higher maximum preloads were applied (when made equivalent to the geometry of the spudcans of the current jack-up), showed penetrations equal to full base contact or slightly more. Therefore, a punch through scenario could be confidently ruled out at all legs, confirmed by back analyses of the soil parameters and conventional and FE analyses of punch through peak capacities.

SEABED INTERVENTION

A representative cross section for each leg is seen in Fig 6, showing the variation of the seabed underneath each spudcan. The depths of the footprints are seen to be approximately (0.9-1.0) m, and the variation of the seabed was assessed to be potentially critical for RPD with respect to differential settlements between the chords. Hence,

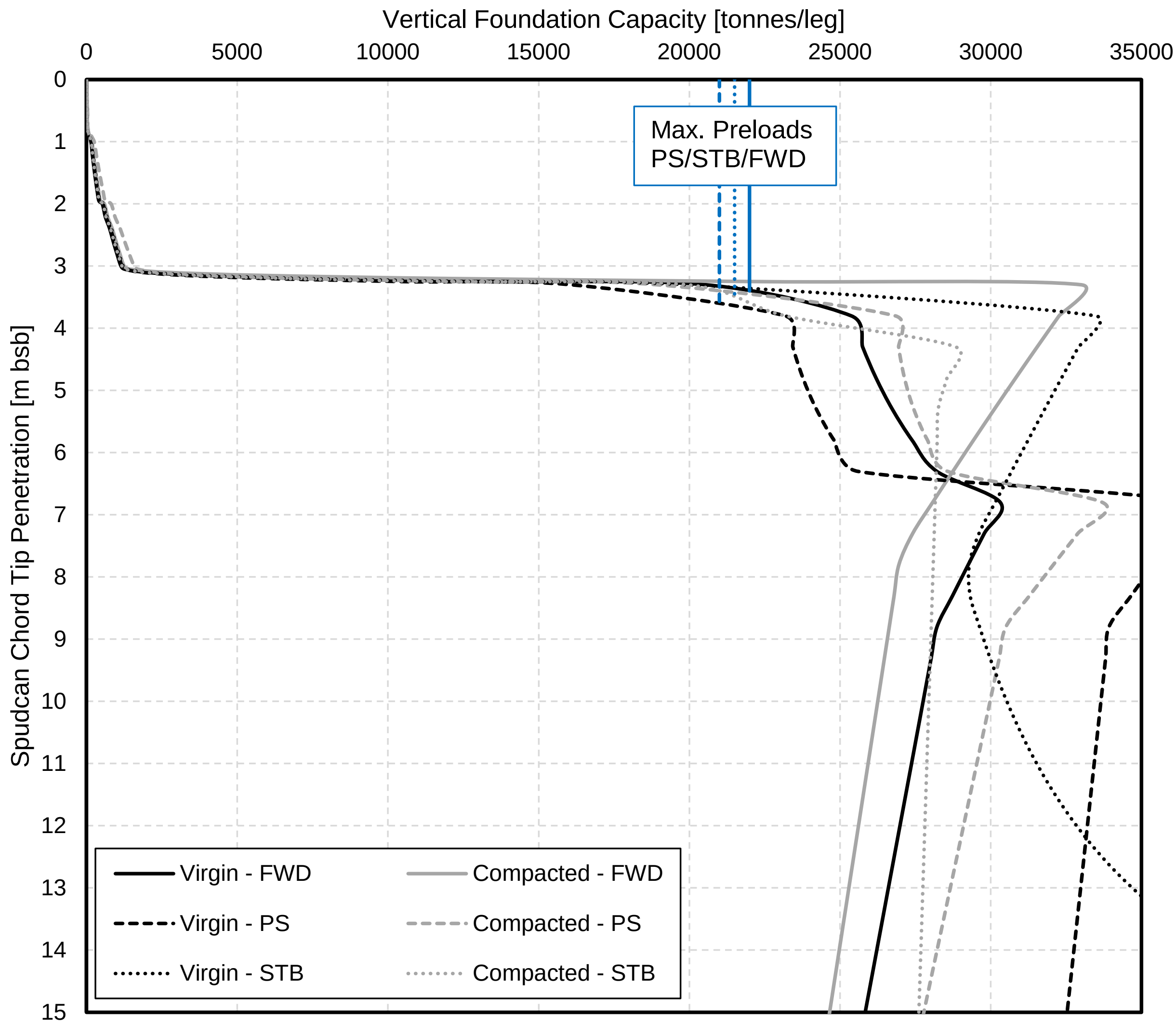
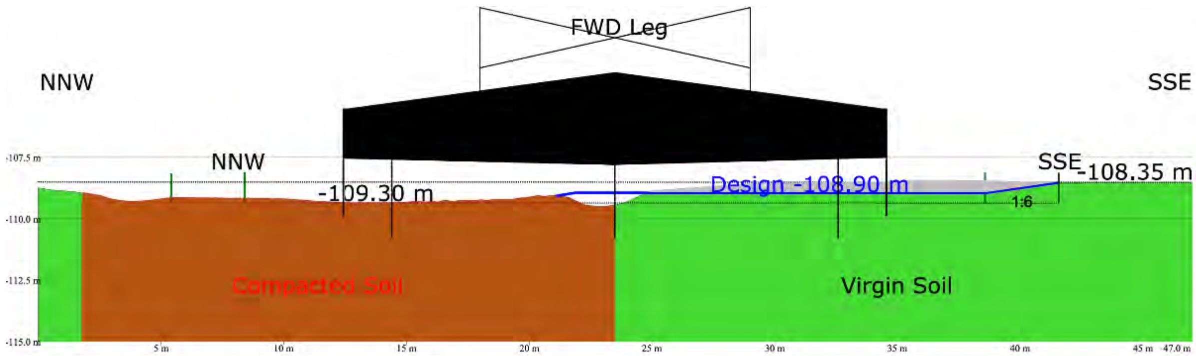


Figure 5 Conventional leg penetration analyses based on BE soil parameters of virgin and compacted seabed for FWD, PS and STB Legs

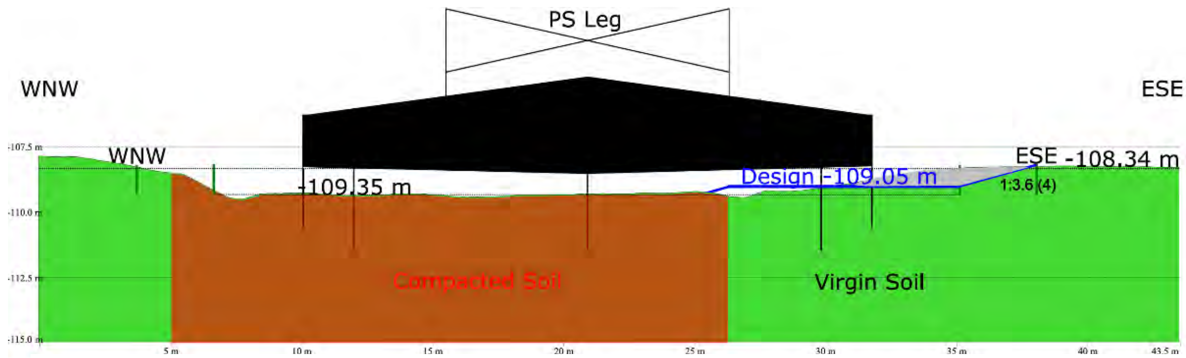
it was immediately clear that seabed intervention or remediation was necessary. Various options were assessed and discussed, i.e. filling with sand /gravel etc., and the most suitable solution was found to be dredging of the virgin top sand in order to flatten the seabed. However, the next challenge was the expected much softer response in the virgin seabed compared with the compacted, which could similarly bring upon issues for RPD. Therefore, simplified FE analyses with PLAXIS 2D (version 22.02) were carried out in order to assess the differential settlements by incorporating the soil deformation characteristics and the interaction between the compacted and virgin soil conditions underneath the spudcan; this is presented in the following section.

Partial Excavation

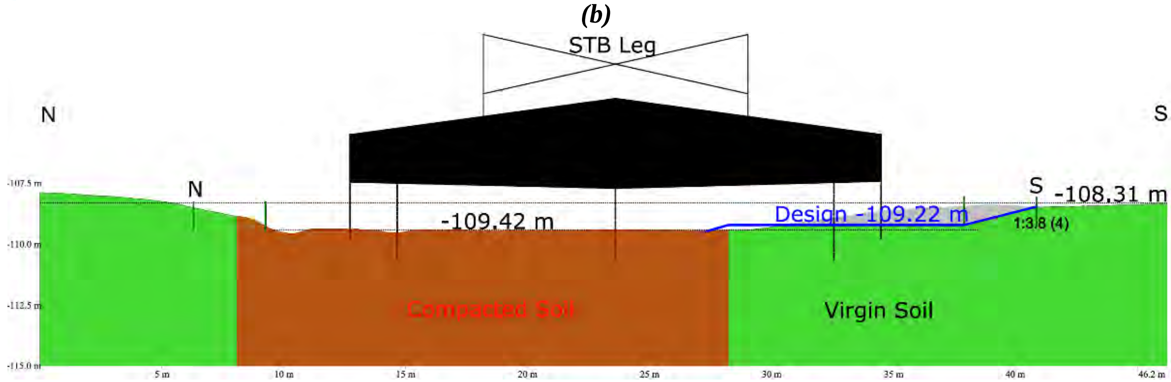
Figure 7 shows an example (of FWD Leg) of how the skirted spudcans placed on a flat seabed with partly virgin soil and partly compacted soil was modelled in PLAXIS 2D to assess the differential settlements. Ideally, due to the spudcan geometry, this case should be modelled in 3D. However, with the problem at hand, an approximate estimate of the differential settlement was targeted (assuming a flat seabed), and a 2D plane strain model was considered sufficient for the purpose. The mesh was generated using 15-noded triangular finite elements, and the



(a)



(b)



(c)

Figure 6 Representative cross sections showing the variation of the seabed below the spudcans and the design differential seabed elevations for (a) FWD Leg, (b) PS Leg and (c) STB Leg

spudcan is modelled as a weightless elastic (drained) body, while the skirts are modelled employing plate elements. The sand is modelled in drained conditions and the clay is modelled in undrained conditions using Mohr-Coulomb constitutive models (soil parameters are given in Tables 1 and 2). Plastic analyses (small deformation theory) are carried out with an applied line load corresponding to the maximum preload at each leg.

The total displacements for each leg are depicted in Fig. 8, showing as expected a tilt towards the virgin soil for all legs. At FWD Leg, a differential settlement of about 0.3 m is seen, while at PS & STB Legs a differential settlement of about 0.2 m and 0.1 m, respectively, appears. The smaller differential settlement at STB Leg (compared to FWD & PS Legs) is reflecting the compensating effects of the top 0.9 m of loose/soft material in the compacted soil profile.

In order to compensate for the larger settlements in virgin soil when assuming a flat seabed, a partial seabed excavation with differential elevations of the seabed was decided upon. The design differential elevations are shown in Fig. 6; being +0.4 m, +0.3 m and +0.2 m for FWD Leg, PS Leg and STB Leg, respectively. Based on

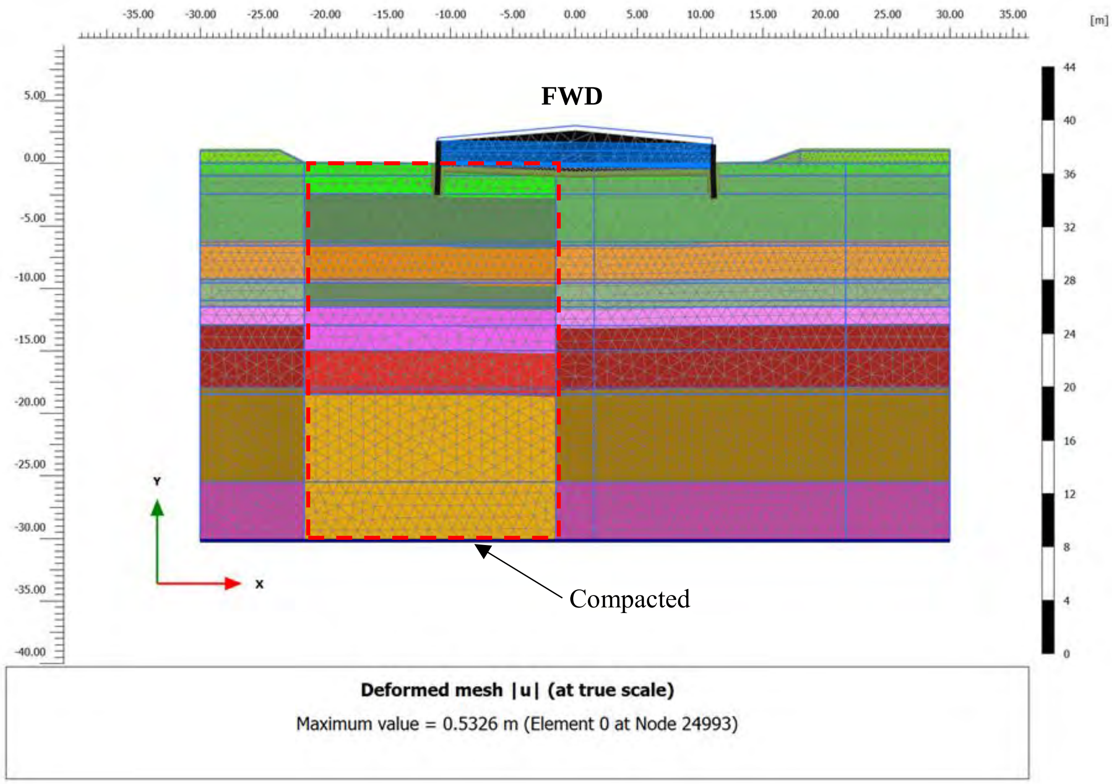


Figure 7 Example (of FWD Leg) of the skirted spudcan placed on partly virgin soil and partly compacted soil modelled in PLAXIS 2D (plane strain)

the design differential elevations, the spudcans were to be placed on slightly inclined seabed with slope towards the compacted area during rig installation, which was expected to be corrected during preloading due to larger settlements on virgin soil. The post-dredging MBES survey shown in Fig. 9 was assessed and the excavation was found to be within the tolerance of +/-0.1 m at all legs, and hence, acceptable.

Feedback from installation

After the installation of the rig, feedback was received from the client (see Table 3), which revealed a successful installation. The measured skirt tip penetrations were recorded as (3.5-3.6) m as in perfect agreement with the conventional analyses shown in Fig. 5. Furthermore, the RPD measurements indicate a maximum difference between the chords of 73 mm, which is well within the limit. It is the authors' opinion that, without the seabed intervention, the difference between the chords could have been significantly larger, and hence, the RPD measurements could have been unacceptable to ensure the structural integrity of the legs.

Table 3 Installation feedback from installation after seabed intervention

Leg	*Preload* (tons/leg)	*Penetration* (m)	*RPD (Lowest zero)* *Chord A* (mm)	*Chord B* (mm)	*Chord C* (mm)
FWD	22000	3.5	42	0	5
PS	21000	3.5	70	0	7
STB	21500	3.6	73	0	44

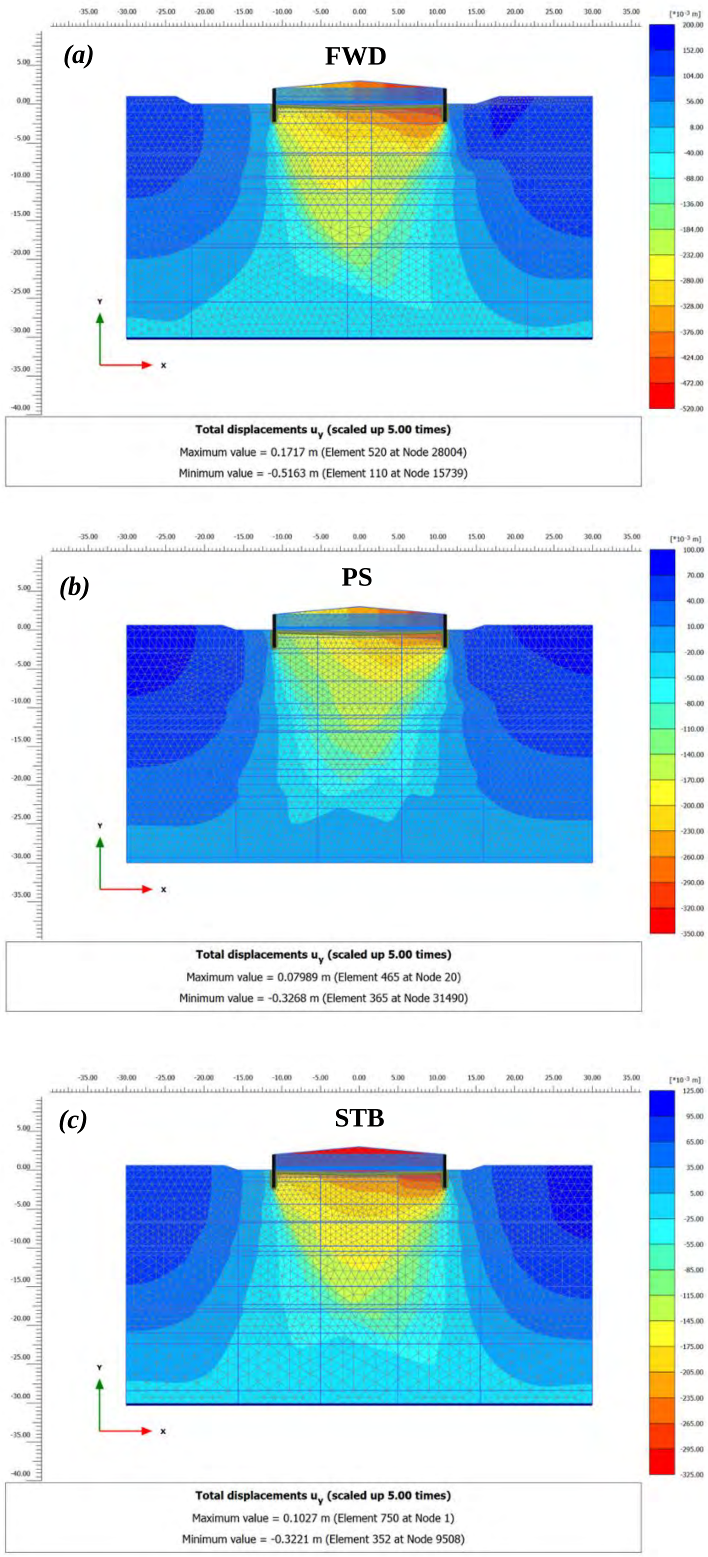


Figure 8 PLAXIS output of total displacement of (a) FWD Leg, (b) PS Leg and (c) STB Leg

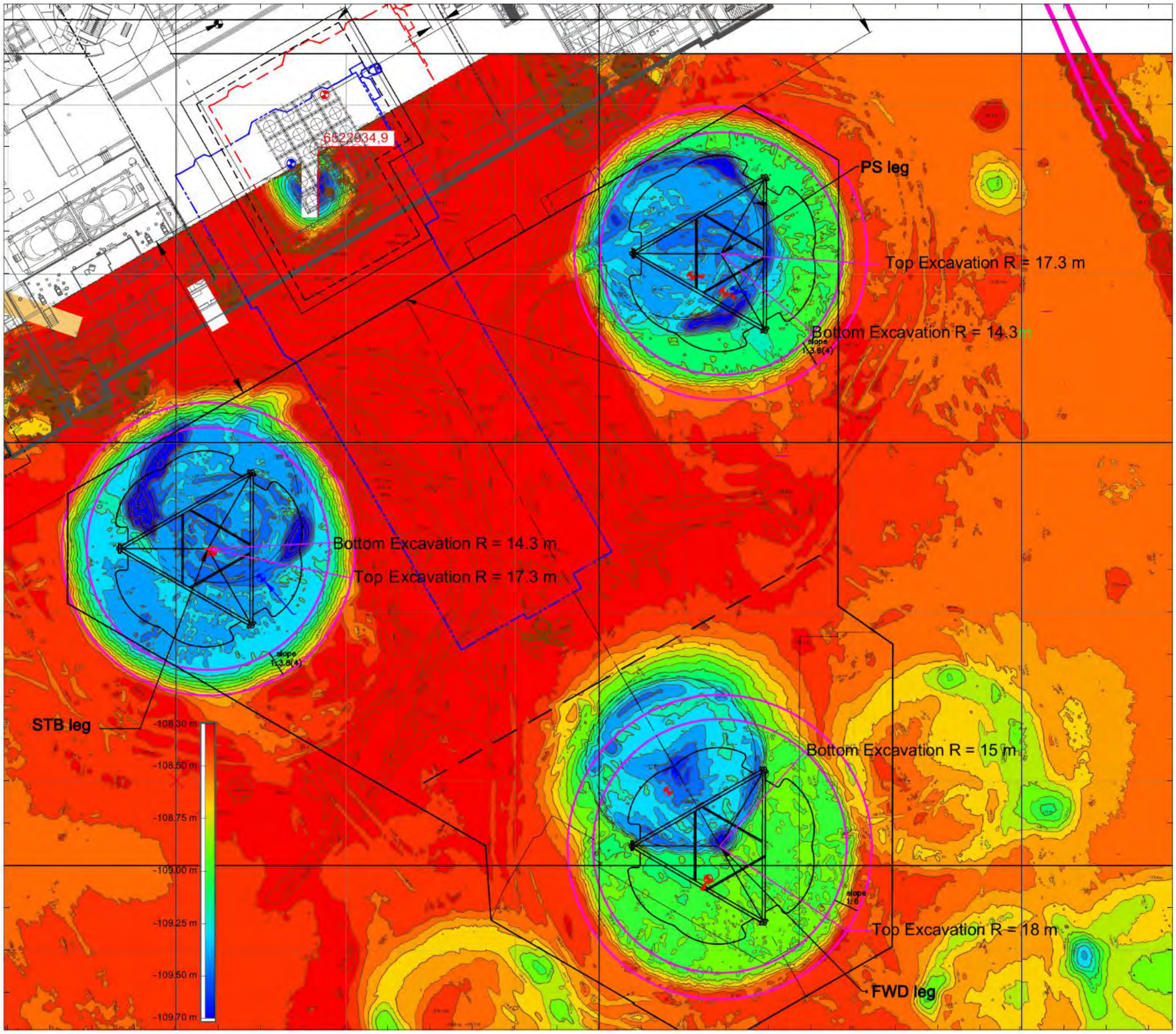


Figure 9 Post-dredging MBES survey indicating an acceptable dredging performed within the tolerances

DISCUSSION

This case study provides unique CPT data, which demonstrate the substantial compaction taking place in a silty sand during a jack-up installation and operation. The densification of the sandy soil improves the strength and stiffness characteristics of the sandy soil, and hence, is very beneficial for the operation phase. Therefore, in addition to compensating for the differential settlements, the partial seabed excavation, that is showcased in this paper, is at the same time ensuring the compaction in the virgin seabed.

For one of the CID triaxial tests performed during the soil investigation, the sample was consolidated to a pressure corresponding to the in situ vertical effective stress +200 kPa to account for the pressure applied by the jack-up. For this sample, D_r increased from the initially prepared state to the end of consolidation by approximately 12% (in absolute terms). The CPTs presented in this paper indicate that the pressure applied by the jack up gave rise to an increase in D_r of (25-40)% (in absolute terms) in the silty sand. It is uncertain how much of the compaction that has taken place as an immediate settlement and how much has taken place over time due to creep settlements. However, this stresses the importance of considering the pressure applied by the jack-up when designing laboratory tests when assessing various strength and stiffness properties for the operation phase. When the samples (as commonly) are prepared in accordance with density estimates based on CPTs performed in virgin soil and consolidated with the in situ stress conditions, over-conservative estimates of strength and stiffness may result.

SUMMARY AND CONCLUSIONS

Unique CPT data are presented in this paper, i.e. CPTs performed at spudcan positions before and after jack-up rig installations, providing valuable insights to the significant compaction taking place in a silty sand below the spudcans. While noting that substantial compaction might have taken place over time as creep settlements, an increase in relative density of the top silty sand of approximately (25-40)% (in absolute terms) is assessed in the footprints. This demonstrates the significant improvement of strength and stiffness properties of the silty sand below the spudcans that takes place during installation and operation.

However, with the compaction of the soil underneath the spudcans comes an alteration of the seabed (i.e. footprints) which could possibly lead to critical skirted spudcan-footprint interactions for following installations of jack-ups with different spudcan geometries or leg-to-leg distance compared to the depressions left by previous installations. The CPTs presented in the paper belongs to a case study from the North Sea where RPD issues in respect to differential settlements were predicted. That is, seabed intervention was deemed necessary as a consequence of a mismatch of the size and leg-to-leg distance with the footprints left by previous installations, and therefore, the spudcans were to be installed on partly virgin soil and partly compacted soil. Based on FE analyses estimating differential settlements, excavations around the footprints with differential seabed elevations were designed, and installation feedback revealed a succesful installation with no issues for RPD and the leg penetrations being in good agreement with convential leg penetration analyses performed.

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