JACK-UP FOUNDATION PERFORMANCE AT THE UNFORESEEN PUNCH THROUGH CONDITION LOCATION– A CASE HISTORY

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ABSTRACT

It is uncommon for a jack-up rig to be installed at relatively deepwater in frontier area whereby Jack-up leg performance is not present. The utilisation leg length is within the critical limit and close to the allowable leg reserve. In view of geo-hazard's free location operators often forget to consider possible rapid penetration or punch through situation that can be present and would become critical to leg reserve margin. It is common to encounter very soft soil condition in relatively deepwater area in Southeast Asia whereby the Cohesive CLAYS are under consolidation or at normally consolidated state condition. The soil strength is generally low and gently increases with depth or almost constant with depth. Therefore, the calculated leg penetration appears to be a steep curve that does not reflect a possible rapid penetration or a punch through case. As the location is much farther away from the shore, in deep water, the environmental condition at site can be relatively higher than normal as it is exposed to ocean environmental forces, especially in terms of wave height with long period. This set of conditions has impact to jack-up rig installation. As there is no punch-through condition prediction in the leg penetration curves, the operator often treats the location as normal rig move operation. This paper illustrates the case history of jack ups experienced highly rapid penetration with uncontrollable leg penetration and ended with hull at a list. This paper attempts to address the possible reasons behind the event and provide possible guidelines to identify such soil conditions in advance and propose minimize risk and mitigation measures or recommendation on the preloading strategy.

KEYWORDS

Jack-up Rig, Minimise Risk, Normally Consolidated Clay, Punch-Through, Spudcan Penetration, Thixotropy.

INTRODUCTION

Jack-ups are generally vulnerable to the seabed conditions, and a risk assessment should be undertaken for all locations to be sufficiently prepared for the expected leg penetration. Leg penetration in soft cohesive material, set in the relatively deep water with high airgap requirement under extreme weather exposure could be vulnerable during installation on-site. Geotechnical characteristics and behaviour should not be overly simplified, as this could jeopardize the accountability of the foundation performance.

This paper presents the conditions and shows the risk involved should the preparation of the site not be taken care of in advanced for the safe installation and operating condition of a jack up rig.

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GEOLOGICAL SETTING, GROUND AND ENVIRONMENTAL CONDITIONS

The site is located in between the end of Song Hong Basin and Upper Phu Khanh basin, as presented in Figure 1 and 2. There are shallow Paleo in-filled channel present over the period of time. Environmental conditions especially current and long period ocean wave and swell coupled with high tidal variation provide the site challenging for Jack-up installation especially in relatively deep water with steep slope trending Southwest-Northeast direction.

Several Site Survey campaigns have been conducted in the area between 2018 and 2020 to provide appraisal for gas discovery in the North Vietnam. There was not a geo-hazard issue in the early MODU installation, as the wells were explored and drilled by either a Semi-submersible units or Drillship. Hence, it was not well understood how the site should be seriously treated for a Jack-up rig installation and operation. Moreover, the oil and gas supporting infrastructure in this area is very limited.

BACKGROUND OF JACK UP RIG INSTALLATION

In early April 2019, the first Jack-up rig was installed on-site and suffered an unexpected rapid leg penetration with a list of 4.5^{o} at this frontier area. However, the jack up rig was able to recover the legs and continued full preloading at the location. Geotechnical Investigation at the location was based on only one sampling borehole and one continuous Piezocone Penetrometer Test to 40 metres below mudline. The Geophysical Survey was carried out, including shallow geological profiles that indicates a very soft to firm CLAY to 10 metres followed by firm silty CLAY to 38 metres and firm to Stiff Clay to 51 metres. There are 3 base channels at 67, 91 and 127 metres. Details are presented in Figure 3 and Table 1. There are other features found in the survey such as pockmarks, pinnacles and possible shallow gas hazard which is located over 100 metres away from the well. Boring logs and Leg Penetration Analysis were conducted and presented in Figure 4.

Incident case report was made with the following sequence of events:

Date/Time	Activity
1100-1200	Rig final Pin and raise hull 10ft, wait 5 minutes, lower hull to 14ft draft, stamp legs 3 times. Raise hull 4 ft draft, wait 5 min. Raise hull to zero airgap. Take initial reading (Bow-24.7', Port-24.2', Stb -24.9')
1200 - 1230	Hull up to minimum airgap, check RPD – ok (less than 1.0)
1230 - 1500	Prepare 3 deep well pumps start simultaneous preloading. Deploy ROV
1500 - 1800	Wx slightly picks up. All legs were slightly settling to 40% preload at min. airgap. Unable to control all legs. Preload stop and adjust leg.
1800 - 1930	As all legs keep on settling – unable to keep up. Preload strategy changed. Change procedure to single leg preload. Dumped Bow and Port Legs preload and continue Starboard leg single preload.
1945 -	Starboard leg suddenly rapid settling at 98% preload
1945 - 2000	Raise General Alarm and inform town. Full head count.
2030	Start pumping out preload water by bilge pumps, inspect all legs for damage. Leg recovery.

Possible caused:

- At the beginning initial penetration was slightly deeper than predicted but then at 98% preload reaction (16,500 kips) the leg penetration on starboard leg went down to 41.2 ft. It was noted from 14,000 kips onward leg settled faster than the hull can be kept level.
- It is possible preload water was filled onboard too fast while starboard leg was unable to react and followed resulting hull listed to 4.5 deg leaning instability towards Starboard leg.
- Leg movement is so sensitive to additional rate of loading. Surface effect of water moving from one side to the other probably contributed to one leg leaning stability.

In view of the incident, the operator conducted Geotechnical investigation but at this time 3 sampling boreholes and 3 PCPT.

In March 2021, the same rig was taken and preloaded. The soil conditions are very similar with the 2019 soil boring, as presented in Figure 5.

However, this time hourly preload tracking and RPD measurement were taken in detail. A table and plotted leg penetration were plotted. Preload strategy is as follows:

1. First Stage Single leg Preload at 2 ft draft
- Round 1: up to spudcan preload reaction 12,000 kips. – hold 30 minutes, then dump,
- Round 2: up to Spudcan preload reaction 14,000 kips – hold 30 minutes, then dump.
- Round 3: up to final spudan preload reaction of 16,800 kips – hold 30 minutes – then dump,
2. Second stage is Single leg preload at min. airgap.

Table 3 presents Preload Tracking example and Leg Penetration Observations are given on Figure 8 to 10.

LEARNING EXPERIENCE

Based on leg penetrations observation it appears that settlement could still take place longer than 30 minutes, even after unloading of preload was carried out. It is often that “artificial crust or thixotropy” can be developed due to delay or preload or temporary stoppage of preload. For this type of normally consolidated clay with little increase in strength with depth or completely constant strength with depth plus significant amount of SILT inclusion can potentially develop a rapid penetration scenario, especially if single leg preload is adopted to full 100%. Thus, the third leg may have to wait sometime for its turn to be preloaded.

This paper attempts to provide awareness of such soil conditions with distinct features, especially when the strength magnitude is between 30 and 60 kPa whereby the rate penetration or settlement is very sensitive to the increase of preload. Thus, adjustment of preloading rate shall be considered. Driving the leg over this type of soil can develop other issues such as RPD and leaning instability if location is in deep water.

Based on the geological setting there are areas in the region which have similar potential challenges as in Song Hong Basin. However, other environmental challenges such as strong current and long wave period shall be studied and considered in the preloading strategy.

CONCLUSION REMARKS

Jack-up installation and operation in challenging shallow geology setting, soil conditions and environmental conditions shall be planned in advance especially if typically type of rig design capability is required. Perhaps a study or to perform Thixotropic Test in the Soil Laboratory may assist to identify in advance on the soil condition features and thus could eliminate the potential unforeseen rapid penetration scenario at frontier province.

ACKNOWLEDGEMENT

The authors express the gratitude to ENI Team to allow us to utilize the information required for the benefit of other Operators and Drilling contractors as such awareness and potential risks can be identified early and mitigation measures and mimimise risk shall be planned and developed prior to rig move.

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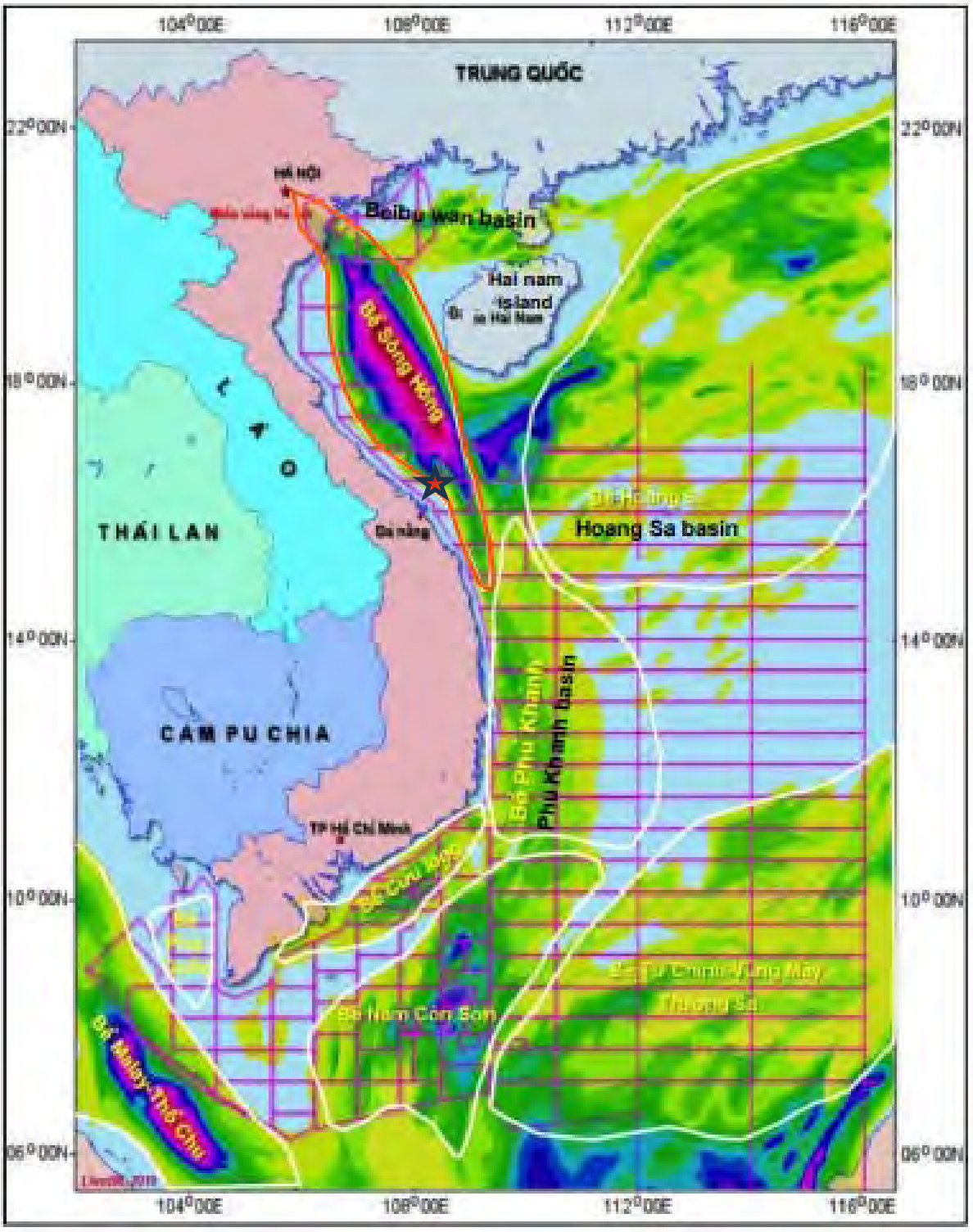
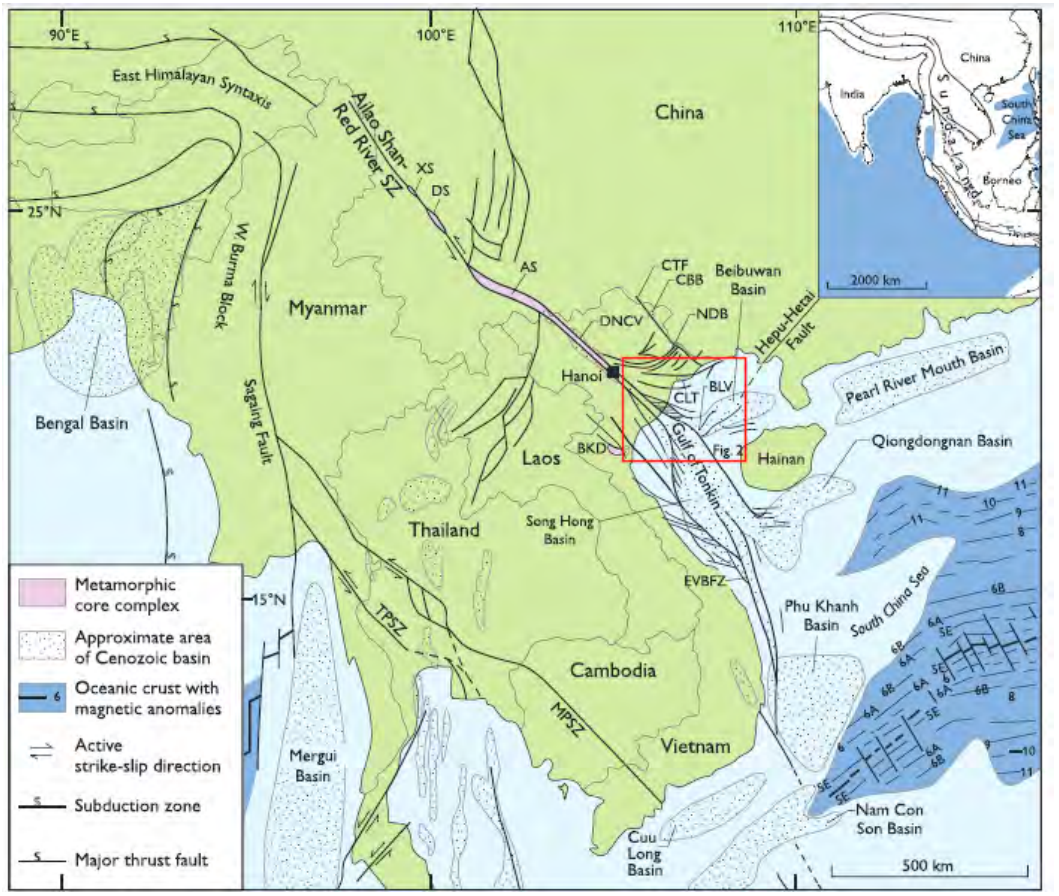
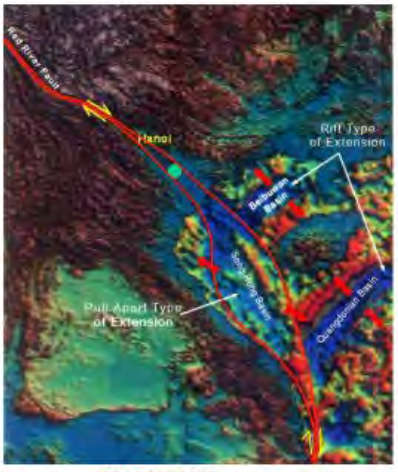


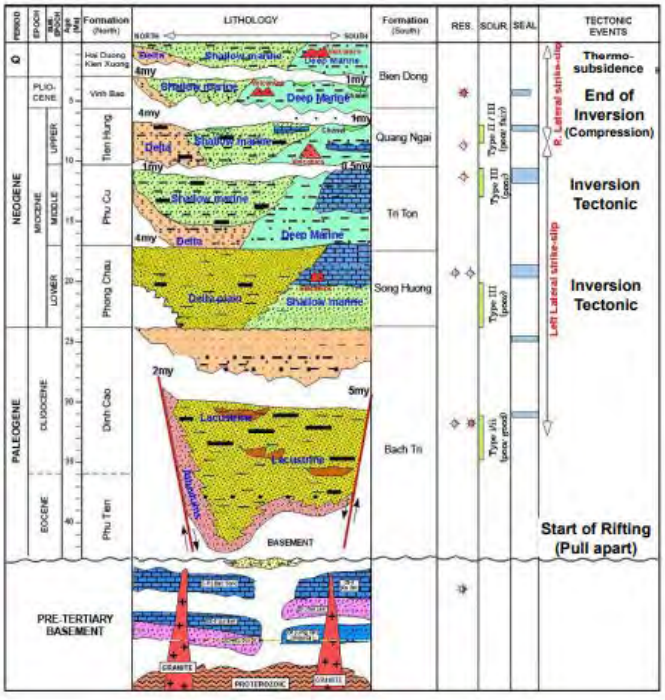
Figure 1 Lower Song Hong Basin and Phu Khanh Basin



A Tertiary sedimentary basin was formed from a NW-SE trending pull-apart graben, the flanks of which are bounded by strike-slip and normal fault systems.



(OMV, 2001)



(Huyen N.M, 1998, revised, 2004)

Figure 2 Song Hong Basin – geology structure

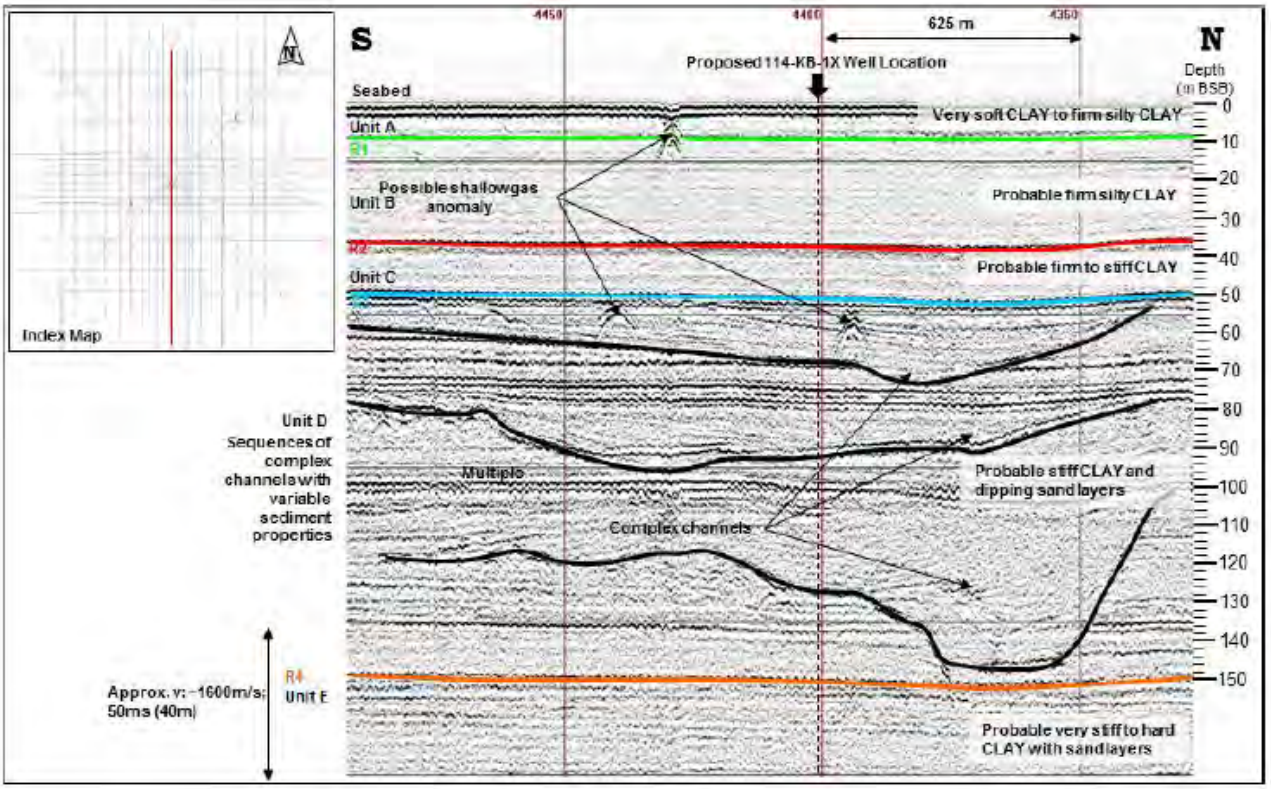


Figure 3 Extract of sub-bottom profile showing the reflectors and units

Table 1: Shallow geology stratification – based on geophysical survey

Unit	Reflector/ Base of Unit	Reflector Depth at the proposed 114-KB-1X Location	Reflector Depth at the proposed Ken Bau N Location	Reflector Depth at the proposed Ken Bau S Location	Interpreted Shallow Sediments	Remarks
Unit A					Very soft CLAY to firm silty CLAY	Uppermost sedimentary unit cover the entire site and truncated by a seafloor channel at the north-eastern and south-western part of the survey area. Variable sediment properties are expected within the channel infill sediments
	Reflector R1	10 m BSB	10 m BSB	8 m BSB		
Unit B					Probable predominantly firm silty CLAY	Weak parallel internal reflectors
	Reflector R2	38 m BSB	38 m BSB	36 m BSB		
Unit C					Probable predominantly firm to stiff CLAY	Weak parallel internal reflectors
	Reflector R3	51 m BSB	52 m BSB	52 m BSB		
Unit D	Channel	67 m BSB	n.a.	67 m BSB	Probable stiff CLAY and dipping sand layers	Variable sediment properties are expected within the complex channel infill sediments
	Channel	91 m BSB	94 m BSB	90 m BSB		
	Channel	127 m BSB	146 m BSB	132 m BSB		
	Reflector R4	152 m BSB	n.a.	149 m BSB		
Unit E					Probable very stiff to hard CLAY with sand layers	The base of the unit is beyond the available shallow sub-bottom data

Notes:
-The thicknesses of units and depths were calculated using an assumed acoustic velocity of 1600 m/s.
-Sediment interpretations are solely based on seismic characteristics except for the surface sediment which was correlated to the sediment samples.

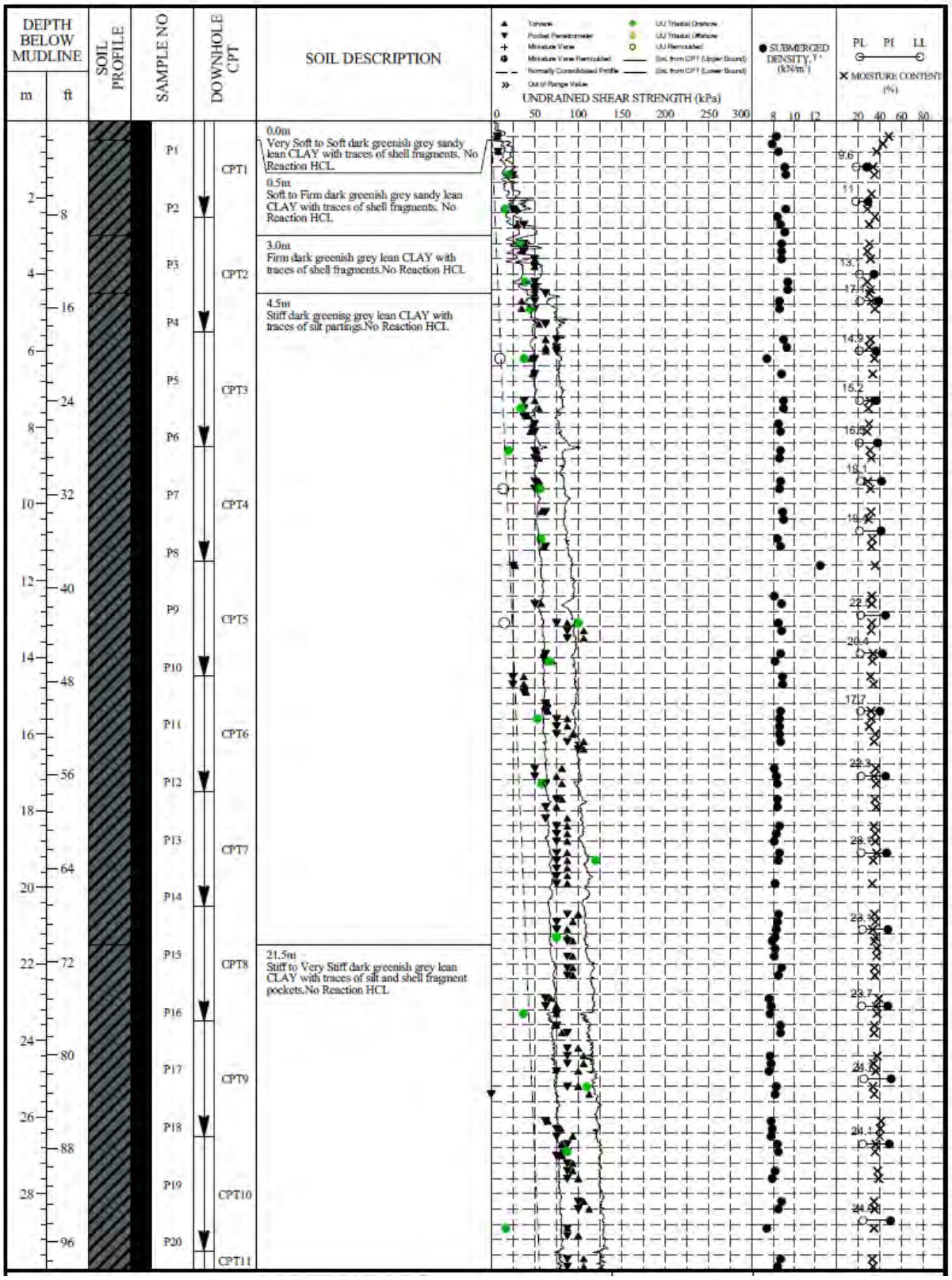


Figure 4 Boring log and PCPT log – explored in 2019

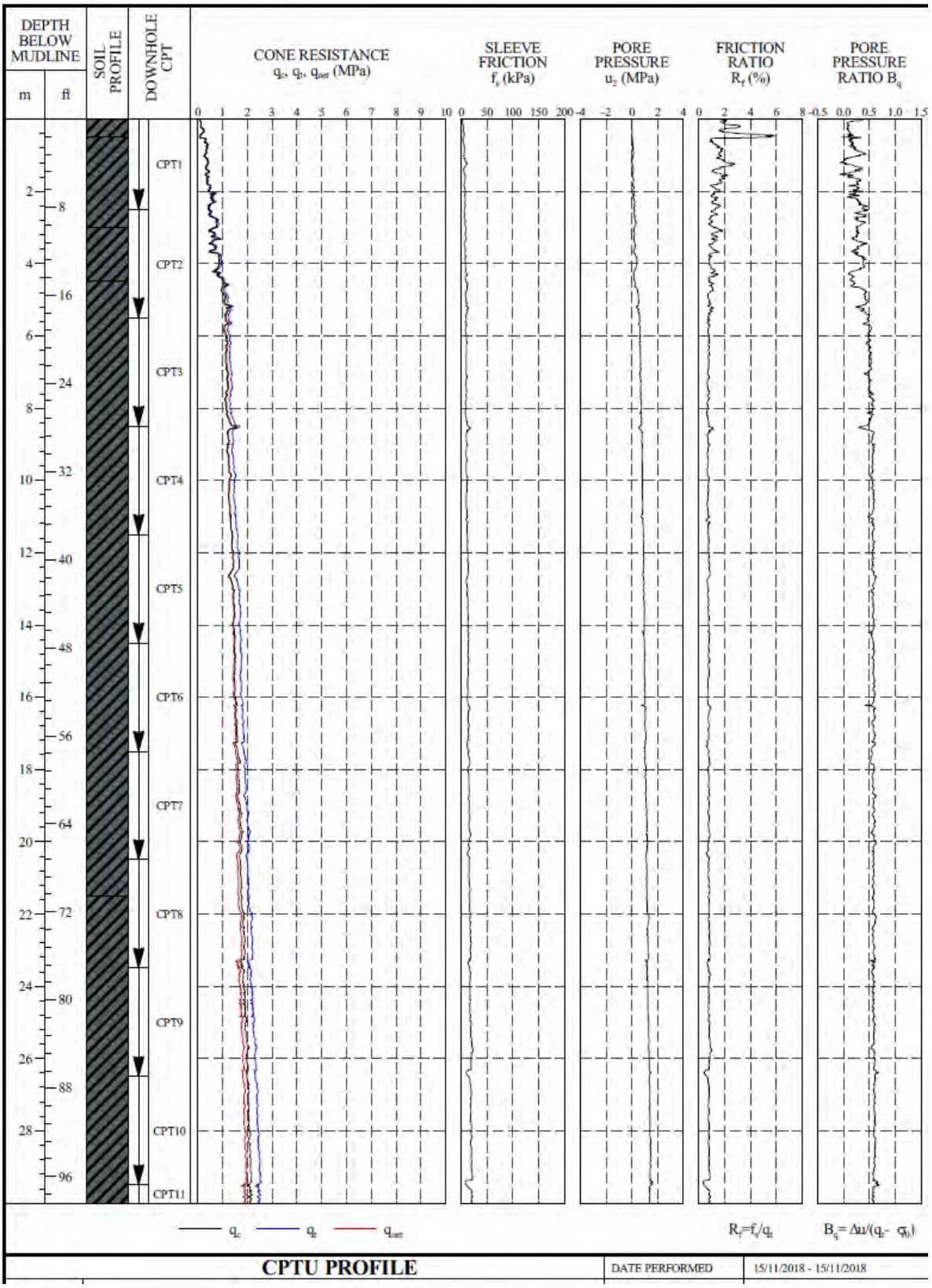
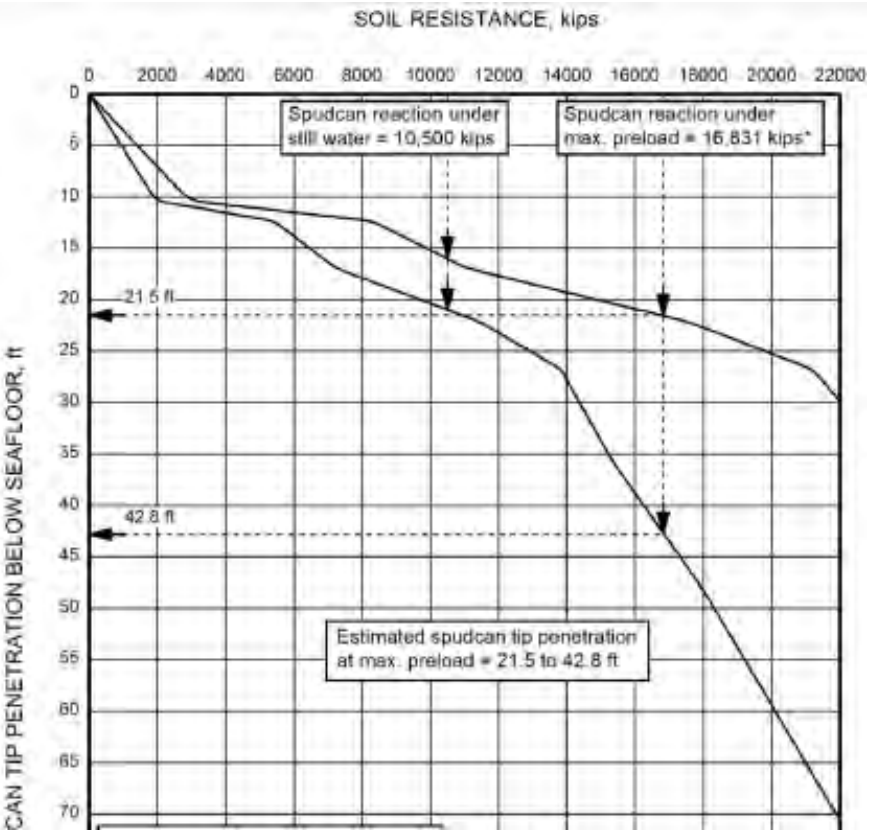


Figure 5 PCPT log – explored in 2019section

Table 2 Soil Stratigraphy (2019)

Stratum	Investigated Depth Below Mudline (m)		Layer Thickness (m)	Soil Consistency/Description
	From	To		
1	0.0	0.5	0.5	Very Soft to Soft sandy lean CLAY
2	0.5	3.0	2.5	Soft to Firm sandy lean CLAY
3	3.0	4.5	1.5	Firm lean CLAY
4	4.5	21.5	17.0	Stiff lean CLAY
5	21.5	41.5	20.0	Stiff to Very Stiff lean CLAY



Notes:
Initial Penetration: Bow – 24.7; Port – 24.2 and Starboard 27.9 ft
Final Penetration: Bow – 34.3; Port 35.7 and Starboard 45.2 ft.

Figure 6 Leg Penetration (2019)

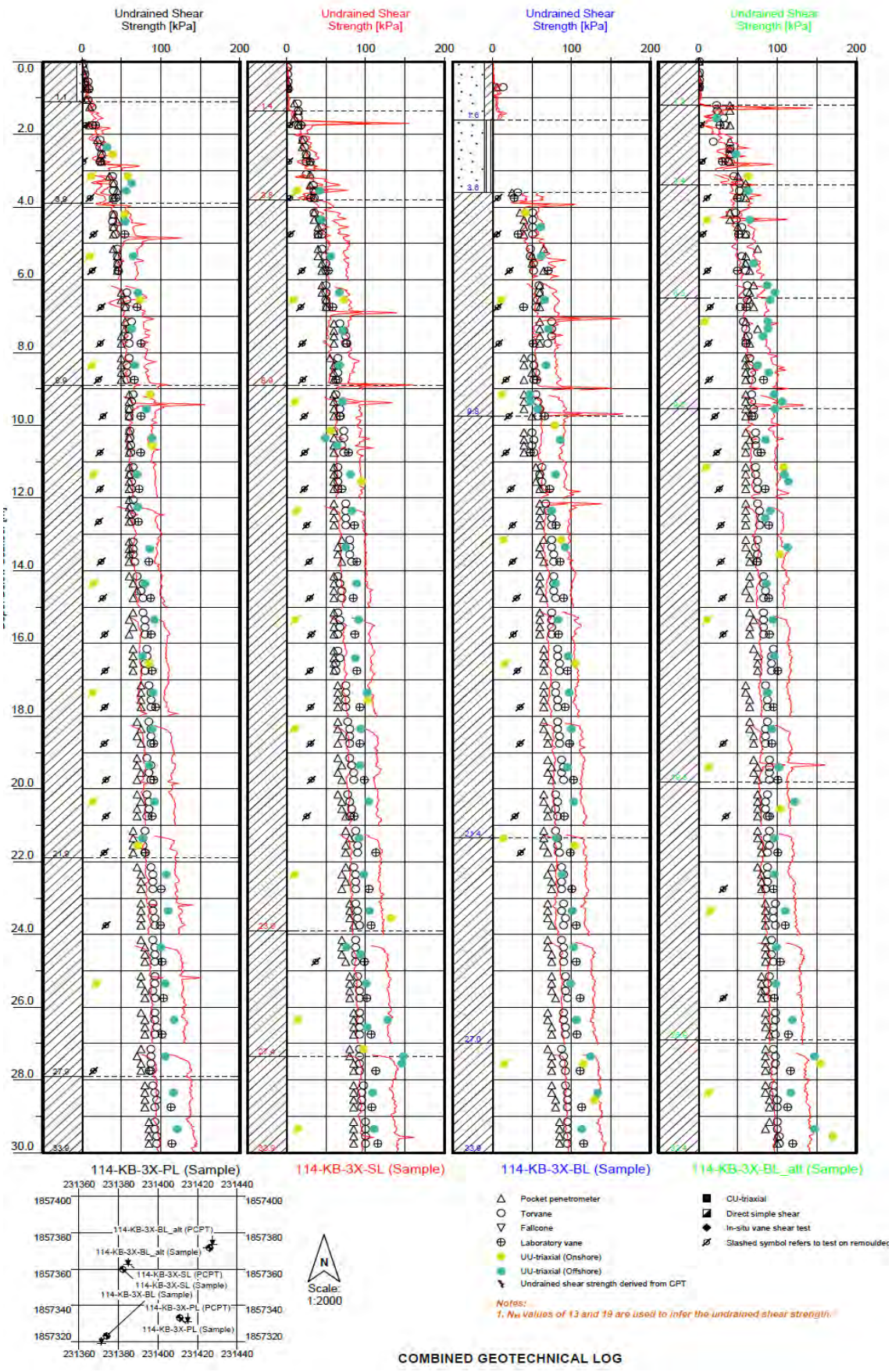
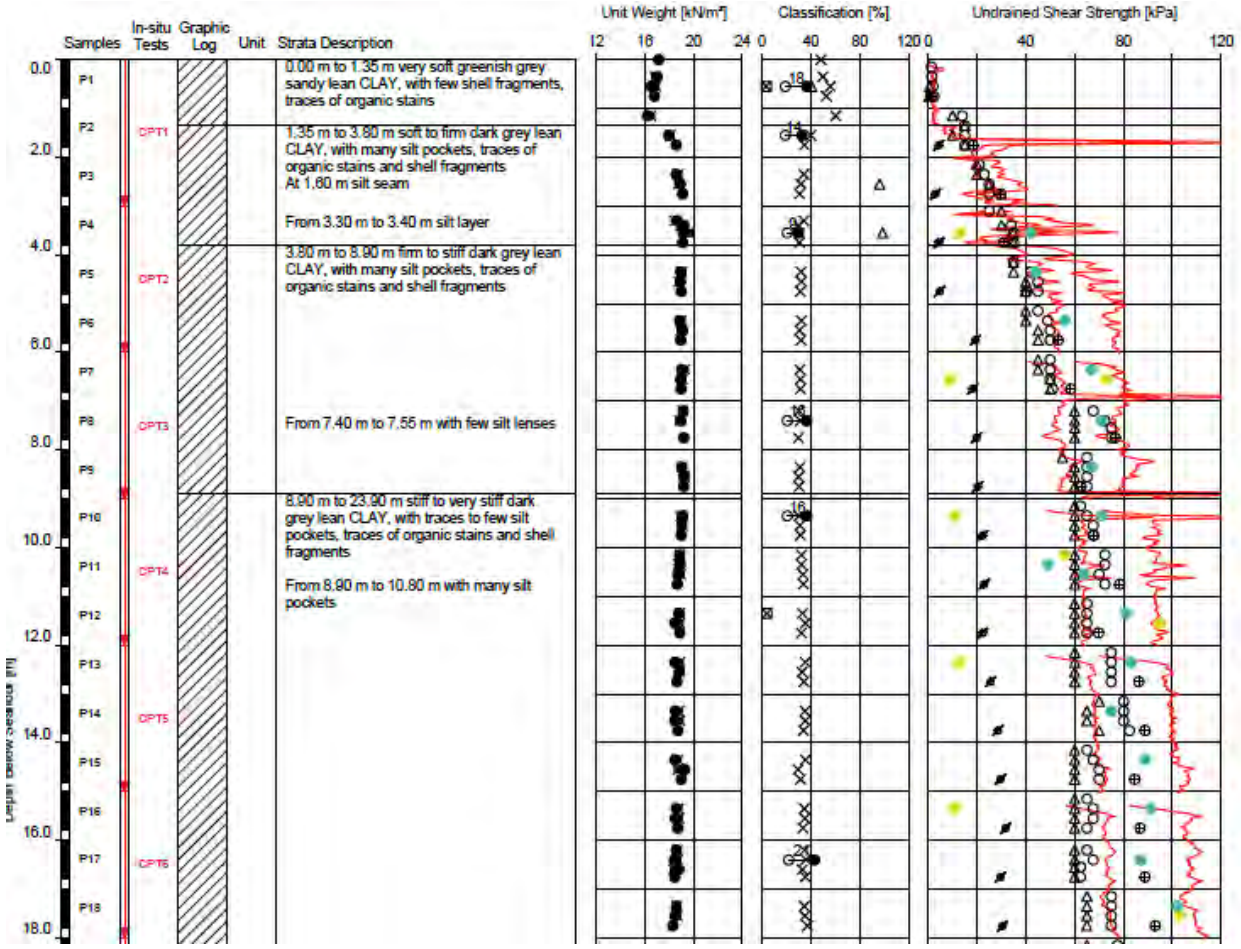


Figure 7 Four sets PCPTs and Sampling Boreholes (2021)



Note : Silt inclusions

Figure 8 Borehole sampling Log (2021)

Table 3 – Preload Tracking

PRELOADING TRACKING REPORT AT KB-3X													
Date	Time	Initial		18		Initial		18		Initial		17.5	
		BOW				STBD				PORT			
		SC Reaction (Kip)	SC Reaction (%)	Penetration (ft)	Draft(-) Air(+) (ft)	SC Reaction (Kip)	SC Reaction (%)	Penetration (ft)	Draft(-) Air(+) (ft)	SC Reaction (Kip)	SC Reaction (%)	Penetration (ft)	Draft(-) Air(+) (ft)
01-03-21	0800	Commence preloac											
	0900	11,384		18.5	-1	9,973		18	-1	10,019		17.5	-1
	0930	12,525		18.8	-1	9,881		18	-1	9,932		17.8	-1
	0930	Commence hold 30 mins											
	1000	Completed hold 30 mins, dump preload on bow leg											
	1010	Commence preload starboard leg 1st stage, round 1											
	1100	11,122		18.8	-1	11,065		18.2	-1	10,084		17.8	-1
	1150	10,849		18.8	-1	12,519		18.2	-1	10,197		17.8	-1
						Commence holding 30 mins							
	1210					Level the rig / Re-holding							
	1240					Completed holding 30' /Dump preload							
	1300									Commence preload on port leg 1st stage			
		10,955		18.8	-1	11,890		18.5	-1	10,208		17.8	-1
	1400	10,706		18.8	-1	11,936		18.5	-1	11,602		18	-1
	1420	10,510		18.8	-1	12,090		18.5	-1	12,514		18	-1
										Commence holding for 0.5 hrs			
	1450			COMMENCE CONTINUE PRELOAD 1ST STAGE- ROUND 2						Continue take preload on port leg			
	1500	10,510		18.8	-1	12,130		18.5	-1	12,704		18	-1
	1600	10,236		18.8	-1	12,198		18.5	-1	14,150		18.2	-1
	1620	10,153		18.8	-1	12,222		18.5	-1	14,508		18.5	-1
	1625	Level the rig								Commence hold 30 mins			
	1700									Dumping preload of port leg			
	1715	Commence preload FWD 1st stage, round 2											
		10,380		18.8	-1	12,119		18.5	-1	13,338		18.5	-1
	1800	11,852		18.8	-1	12,246		18.5	-1	13,341		18.5	-1
	1900	13,159		18.8	-1	12,129		18.5	-1	13,221		18.5	-1
	1945	14,576		19.1	-1	11,956		18.5	-1	13,073		18.8	-1
	1950	Commence hold bow leg 30 mins											
	2020	Level the rig due to bow leg settlement, bow leg penetration 19.6 ft											
	2050	Dump preload on bow leg											
	2100	Commence preload starboard leg 1st stage, round											
	2200	13,534		19.6	-1	13,465		18.5	-1	13,268		18.8	-1
	2255	13,284		19.6	-1	14,509		18.5	-1	13,331		18.8	-1
		Commence hold starboard leg 30 mins											
	2320	Level the rig due to stb leg settlement, stb leg penetration 18.8 ft											
	2350			COMMENCE CONTINUE PRELOAD 1ST STAGE- ROUND 3									
		Continue take preload on stb leg											
02-03-21	0000	13,262		19.6	-1	14,595		18.8	-1	13,338		18.8	-1
	0100	12,597		19.6	-2	15,133		19.6	-2	12,264		18.8	-2
	0115	12,521		19.6	-2.5	15,430		20	-2.5	12,410		18.8	-2.5
	0115	Dump preload on stb leg to jackable, jack hull up to 1ft draft											
	0145	Continue take preload on stb leg											
	0200	13,435		19.6	-1	14,489		20	-1	13,181		18.8	-1
	0255	STBD start leg settlement at 15821 Kip											
	0300	11751		19.6	-3	14724		22	-3	12119		18.8	-3
	0310	Dump preload on stb leg to jackable, jack hull up to 1ft draft											
	0320	Continue take preload on stb leg at 1 ft draft											
	0400	13319		19.6	-1	15112		23.5	-1	13464		18.8	-1
	0500	12260		19.6	-1.8	16240		24.5	-1.8	13480		18.8	-1.8
	0530	11700		19.6	-2.5	16292		25	-2.5	13144		18.8	-2.5
	0535	Dump preload on stb leg to jackable, jack hull up to 1ft draft											
	0600	Continue take preload on stb leg at 1 ft draft											
	0605	13418		19.6	-1	14227		25	-1	13171		18.8	-1
	0700	13281		19.6	-1	15501		25.4	-1	13332		18.8	-1
	0800	12585		19.6	-1.5	16327		26	-1.5	13363		18.8	-1.5
	0845	12590		19.6	-3	16350		27.5	-3	13320		18.8	-3
	0850	Dump preload on stb leg to jackable, jack hull up to 1ft draft											

Table 3 – Preload Tracking continue..

	0920	Continue take preload on stb leg at 1 ft draft											
	1000	13,695		19.6	-1	15,015		28	-1	13,267		18.8	-1
	1100	13,126		19.6	-1.5	15,876		28	-1.5	13,017		18.8	-1.5
	1200	12503		19.6	-1.8	16783		29.2	-1.8	13501		18.8	-1.8
	1230	12444		19.6	-2	16841		29.5	-2	13565		18.8	-2
		Completed loading preload 16841 Kip for STBD on 12:30 hrs at 2 ft draft, and start holding in 1hr											
	1300	Level up the rig / Re-holding				16841		30	-2				
	1400	No settlement observed - Dumping preload on STBD											
	1420	Completed dumping											
	1430	Level up the rig and then Commence start preload on Bow leg 1st stage round											
	1500	14,768		21	-1	13,584		30	-1	13,164		18.8	-1
	1600	16,110		22.3	-1	13,463		30	-1	13,136		18.8	-1
	1630	16,615		25	-2	13,225		30	-2	13,539		18.8	-2
	1640	The rig settlement, Dumping preload on Bow leg to jackable, jack hull up to 1ft draft											
	1700	Level up the rig and continue preload on bow leg											
		13,789		25.5	-1	13,592		30	-1	13,476		18.8	-1
	1800	14,985		27	-1.5	13,183		30	-1.5	13,093		18.8	-1.5
	1825	The rig settlement, Dumping preload on Bow leg to jackable, jack hull up to 1ft draft											
	1845	Level up the rig and continue preload on bow leg											
	1900	13,888		30	-1	13,564		30	-1	13,508		18.8	-1
	2000	15,390		30	-1.5	13,143		30	-1.5	13,040		19	-1.5
	2045	15,732		30	-3	12,049		30	-3	12,033		19	-3
	2045	Dump preload on Bow leg to jackable, jack hull up to 1 ft draft.											
	2105	Level up the rig and continue preload on bow leg											
	2200	15,366		30	-1	13,463		30	-1	13,426		21.2	-1
	2300	16,828		30	-1.5	13,106		30	-1.5	13,049		22	-1.5
	2330	16,924		30	-2	12,836		30	-2	12,839		22	-2
		Completed loading preload 16924 Kip for Bow on 23:30 hrs at 2 ft draft, and start holding in 1hr											
03-03-21	0000	Continue holding preload on bow leg, no settlement observe											
	0030	No settlement observed - Dumping preload on bow											
	0055	Completed dumping, jacking hull up to 1 ft draft											
	0100	Level up the rig and start preload on Port leg 1st stage round 3											
	0200	13,288		30	-1	12,960		30	-1	14,540		25	-1
	0300	12,608		30	-2	12,432		30	-2	15,427		27	-2
	0315	12,146		30	-3	12,228		30	-3	15,568		27.5	-3
	0317	Dump preload on Port leg to jackable, jack hull up to 1 ft draft.											
	0330	Level up the rig and continue preload on Port leg											
	0400	13,528		30	-1	13,063		30	-1	14,807		28.5	-1
	0500	13,176		30	-1	13,003		30	-1	15,832		29	-1
	0555	12,639		30	-1.5	13,236		30	-1.5	16,930		29.5	-1.5
	0600	Completed loading preload 16930 Kip for Port on 06:00 hrs at 1.5 ft draft, and start holding in 1hr											
	0630	Level up the rig / Re-holding											
	0700	Port leg settlement, level rig ,Re-holding											
	0700	12,260		30	-2	13,105		30	-2	16,930		30	-2
	0730	Level up the rig / Re-holding in 1 hr											
	0830	No settlement observed - Dumping preload on port											
	0915	Completed dumping for jackable to air gap											
	0923	Jacking rig to air gap for preloading at 2nd stage											
				COMMENCE CONTINUE PRELOAD 2nd STAGE									
	1100	Commence fill in preload on Bow leg											
	1130	14,234		33.1	4	13,673		33.7	4	13,847		33.8	4
				Corrected at 0 airgap				Corrected at 0 airgap				Corrected at 0 airgap	
	1300	14,717		33.1	4	13,401		33.7	4	13,526		33.8	4
	1320	14,951		33.1	4	13,387		33.7	4	13,501		33.8	4
		Completed loading preload 14951 Kip for Bow leg on 13:20 hrs at 4 ft airgap, and start holding in 2hrs											
	1520	Completed 2 hrs holding, no settelement, commence dump preload bow leg											
	16 10	Completed dumping											
	1611	Commence fill in preload on Stbd leg											
	1620	9,794		33.1	4	13,426		33.7	4	12,994		33.8	4
	1700	9,633		33.1	4	14,223		33.7	4	13,129		33.8	4
	1740	9,302		33.1	4	14,976		33.7	4	13,232		33.8	4
		Completed loading preload 14976 Kip for STBD leg on 17:40 hrs at 4 ft airgap, and start holding in 2hrs											
	1900	Continue holding preload on STBD leg, no further settlement											
	1940	Completed 2 hrs holding, no settelement, commence dump preload STBD leg											
	2020	Completed dumping. Commence fill in preload port leg											
	2100	10,341		33.1	4	12,723		33.7	4	14,406		33.8	4
	2120	10,203		33.1	4	12,767		33.7	4	14,972		33.8	4
		Completed loading preload 14,972 Kip for Port leg on 2120 hrs at 4 ft airgap, and start holding in 2hrs											
	2300	Continue holding preload on Port leg, no further settlement											

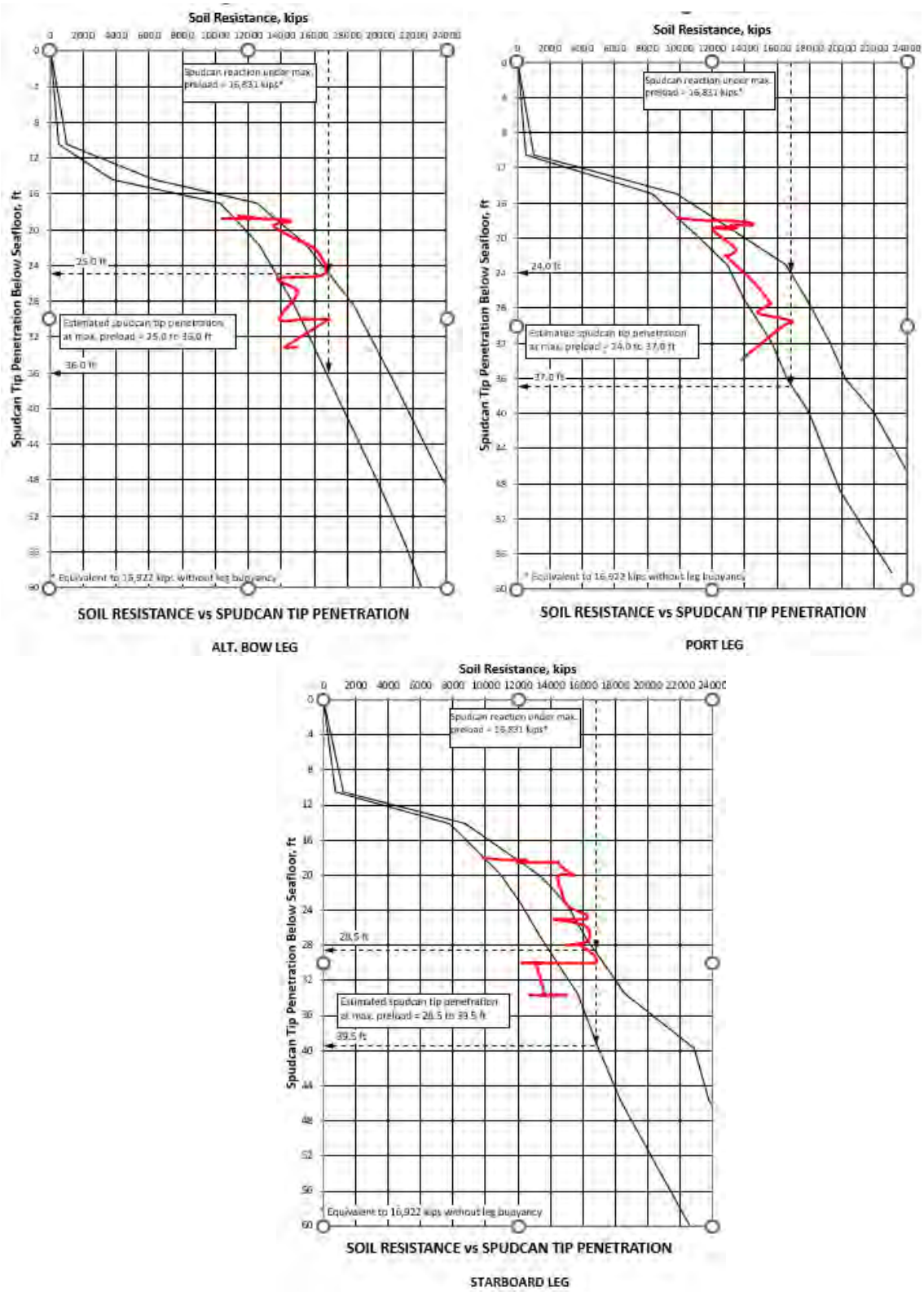


Figure 8 Leg Penetration with observed penetrations (2021)