

LANDPAC GROUND ENGINEERING LTD
INTELLIGENT GROUND IMPROVEMENT

Postal Address: **Calleo House**
49 Theobald Street
Borehamwood
Herts. WD6 4RT

Telephone Nos: **08455005533**

Facsimile: **02082367022**

E-Mail: **dkelly@landpac.co.uk**

Our Reference: LP1009FR

Dermot Kelly (BEng)
LANDPAC UK

INTRODUCTION

The Tanger MED 2 project in Morocco requires 140 (Phases 1 + 2) Hectare area to be constructed, through a dredging/backfilling operation and deep/surface ground improvement, prior to pavement construction for a future container terminal. Up to five million cubic metres of "borrow material" will be dredged, sourced offshore, and backfilled onto an area behind quay walls. The backfilled dredged material is then Deep Vibro Compacted (DVC) from the surface to full depth. The CPTU results, from previous DVC works within Tanger MED site, have indicated that specification is only achievable $\geq -2\text{m}$ below ground level. DVC is not capable of achieving specification from the surface.



The aim of the HEIC trials was to investigate the performance of HEIC after Deep Vibro Compaction (DVC) conditions, in order to achieve the specification requirements, as DVC was unable to do so $\leq 2\text{m}$ below the surface. LANDPAC conducted HEIC trials on Tanger MED 2 for BSTM (Besix & Somagrec JV) in June/July 2011. Three HEIC trial areas were prepared for the works and 7 HEIC zones were evaluated:

HEIC Trial Area 1 - Zones Z1, Z2-1 & Z2-2, which were on existing dredged sands that was placed for some time.

- a. Z1 – no rock layer on surface
- b. Z2-1 – 250mm rock layer on surface (0-80mm Ep = 25)
- c. Z2-2 – 500mm rock layer on surface (0-80mm Ep = 25)

HEIC Trial Area 1 - Zones Z3-A & Z4-A, but were excavated -2m and re-placed again with same materials, prior to HEIC.

- d. Z3-A – 250mm rock layer on surface (0-80mm Ep = 25)
- e. Z4-A - no rock layer on surface

HEIC Trial Area 1 - Zones P3Z-1 & P3Z-2, which was Zones Z1, Z2-1 & Z2-2, but then excavated -2m and re-placed again with same materials, prior to HEIC

- f. P3Z-1 – 250mm rock layer on surface (0-80mm Ep = 25)
- g. P3Z-2 - no rock layer on surface

For the purposes of this paper, this document is a summary of HEIC test data (CIR & CIS) and external test data (CPTUs & PLTs), a discussion on the performance/progress of HEIC on Tanger MED 2 on meeting specification requirements (Zones P3Z-1) and a conclusion based on a prediction model for future works after Deep Vibro Compaction (DVC).

SPECIFICATION REQUIREMENTS

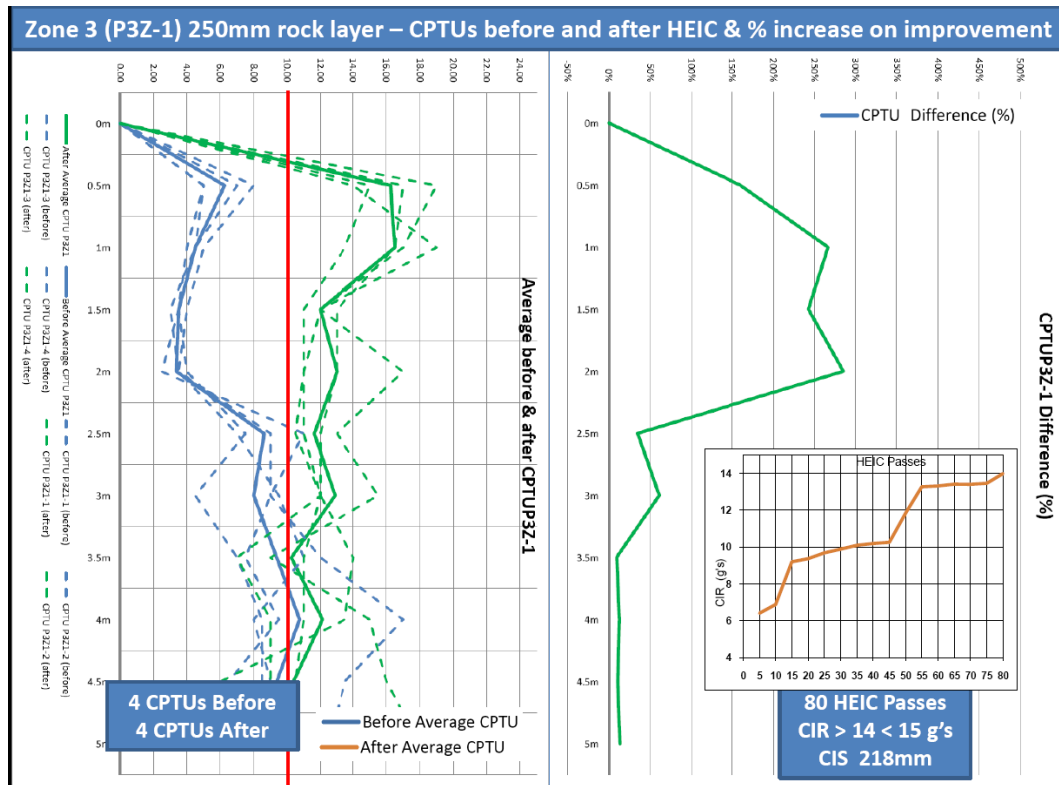
The future project development platform (140 Hectares) requires the following criteria to be achieved, prior to pavement construction (after HEIC):

- 1. CPTU $\geq 10\text{Mpa}$, $\leq 2\text{m}$ below the surface
- 2. Ev2 $\geq 100\text{Mpa}$, at the surface
- 3. K (Ev2/Ev1) ≤ 2 , at the surface

HEIC TRIAL AREA 3 - ZONES P3Z-1

Zone P3Z-1 (Z1), was excavated -2m below ground level (bgl) and re-placed again with same materials, as to attempt to emulate similar conditions that would normally be expected after Deep Vibro Compaction (DVC). The re-placed materials were found to be very loose prior to the HEIC application, -2m bgl of CPTU ≥ 1.5 to ≤ 12 Mpa. The CPTUs (on Zone P3Z-1 with rock layer) before HEIC came closest to represent typical CPTUs values after Deep Vibro Compaction (DVC), although on the lower end of the scale – refer to Appendix H. 80 HEIC passes were conducted to achieve CIS criteria of < 5 to 10mm in the last batch of 5 to 10 HEIC passes, respectively, and/or CIR criteria of “no increase in g values” in the last batch of 5 to 10 HEIC passes. Zone P3Z-1 is discussed separately below.

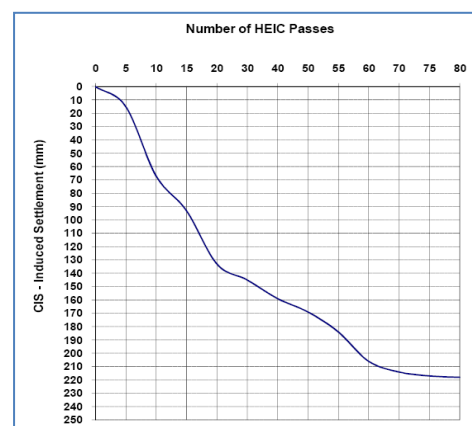
The following data sheets show CPTUs before and after HEIC for each Zone. The graphical representation shows the minimum specification line CPTU ≥ 10 Mpa. The second graph, on the right hand side of the data sheet, shows the percentage increase in strength after HEIC. Also represented is the CIR progress graph for each batch of HEIC passes.



The data sheet above shows CPTUs before (3 no) and after (3 no) HEIC. Also tabled below is the CIS progress graph for each batch of HEIC. See Appendix F, for detailed test data (CPTUs, PLTs, CIR & CIS HOSSs).

Summary of test data:

- 250mm rock layer (0-80mm $E_p = 25$)
- Before CPTU ≥ 2.5 to ≤ 8 Mpa, -2m bgl
- 80 HEIC passes
- CIR > 14 < 15 g's, max 18.16 g's
- CIS average 218mm, max 287mm
- After CPTU
 - CPTU P3Z-1-1, ≥ 10 Mpa ≤ -3.45 m bgl (compliant)
 - CPTU P3Z-1-2, ≥ 10 Mpa ≤ -3.20 m bgl (compliant)
 - CPTU P3Z-1-3, ≥ 10 Mpa ≤ -5.00 m bgl (compliant)
 - CPTU P3Z-1-4, ≥ 10 Mpa ≤ -4.25 m bgl (compliant)
- Max. % increase up to 285% @ 2m bgl
- Plate Load Test (PLT) data:
 - S1 – 107 (Ev2), 1.72 (k), 8 passes (TR) (compliant)
 - S2 – 145 (Ev2), 1.81 (k), 8 passes (TR) (compliant)
 - S3 – 109 (Ev2), 1.79 (k), 8 passes (TR) (compliant)
 - S4 – 136 (Ev2), 2.00 (k), 8 passes (TR) (compliant)



Zone P3Z-1 had 250mm rock layer on the surface and resulted in final CIR values > 14 < 15 g's.

CIS resulted in the greatest amount of induced settlement of 218mm and a large number of HEIC passes of 80, mainly due to the low CPTU values prior to HEIC (≥ 2.5 to ≤ 8 Mpa, -2m bgl).

Optimum number of HEIC passes would have been 70, according to CIS only, but 80 HEIC passes was needed as CIR data continued increasing.

It is understood that CPTUs before HEIC were similar (lower end of scale) to that would normally be recorded/expected for CPTUs after Deep Vibro Compaction (VDC).

All Plate Load Test data (S1 to S4) achieved $E_{v2} > 100$ Mpa and k values ≤ 2 (not taking into account PLTs taken 14 & 21 days after HEIC).

DISCUSSION

In the following discussion Zones Z2-1, Z4-A & P3Z-2 were not considered as no rock layer was placed on the surface prior to HEIC, CPTUs after HEIC showed < 10 Mpa at some depth locations < -2 m bgl (not within specification) and PLTs also showed $E_{v2} < 100$ Mpa (not within specification).

The following table is a summary of all the HEIC trial zones where rock was placed on the surface prior to HEIC.

HEIC Trial Area	Area 1						Area 2			Area 3			
Zone Number	Z2-1			Z2-2			Z3-A			P3Z-1			
Rock Layer	250mm			500mm			250mm			250mm			
Before CPTU $\leq$ -2m bgl	Z2-1 1, 2 & 3			Z2-2 1, 2 & 3			Z3-A 1, 2 & 3			P3Z-1 1, 2, 3 & 4			
Minimum	> 7 Mpa			> 9 Mpa			> 1.5 Mpa			≥ 2.5 Mpa			
Maximum	≤ 19 Mpa			≤ 19 Mpa			≤ 6 Mpa			≤ 8 Mpa			
Final HEIC Passes	40			40			60			80			
Final Average CIR	$> 12 < 13$ g's			$> 12 < 13$ g's			$> 13 < 14$ g's			$> 14 < 15$ g's			
Final Average CIS	69mm			77mm			161mm			218mm			
After CPTU	Z2-1	Z2-2	Z2-3	Z2-1	Z2-3		Z3-A-1	Z3-A-2	Z3-A-3	P3Z-1-1	P3Z-1-2	P3Z-1-3	P3Z-1-4
> 10 Mpa	≥ 10 Mpa	≥ 10 Mpa	≥ 10 Mpa	≥ 10 Mpa	≥ 10 Mpa		≥ 10 Mpa	≥ 10 Mpa	≥ 10 Mpa	≥ 10 Mpa	≥ 10 Mpa	≥ 10 Mpa	≥ 10 Mpa
< -2 m bgl	> -2 m	> -2 m	> -2 m	> -2 m	> -2 m		< -1.25m	> -2 m	< -1.4m	> -2 m	> -2 m	> -2 m	> -2 m
PLT data after HEIC	P1	P2	P3	P1	P2	P3	P1	P2	P3	S1	S2	S3	S4
Ev2 > 10 Mpa	112	136	112	110	107	112	118	132	125	107	145	109	136
k < 2 (Ev2/Ev1)	2.27	1.97	2.35	2.4	1.87	1.75	1.47	1.67	1.62	1.72	1.81	1.79	2
Traditional Roller Passes	10 + 12 (2nd 250mm rock layer)			12 passes			8 passes			8 passes			

Note: Red X, in the table above, denotes where test data does not meet specification and/or where CPTU data, prior to HEIC, does not typically represent CPTUs after Deep Vibro Compaction (VDC) – refer to Appendix H

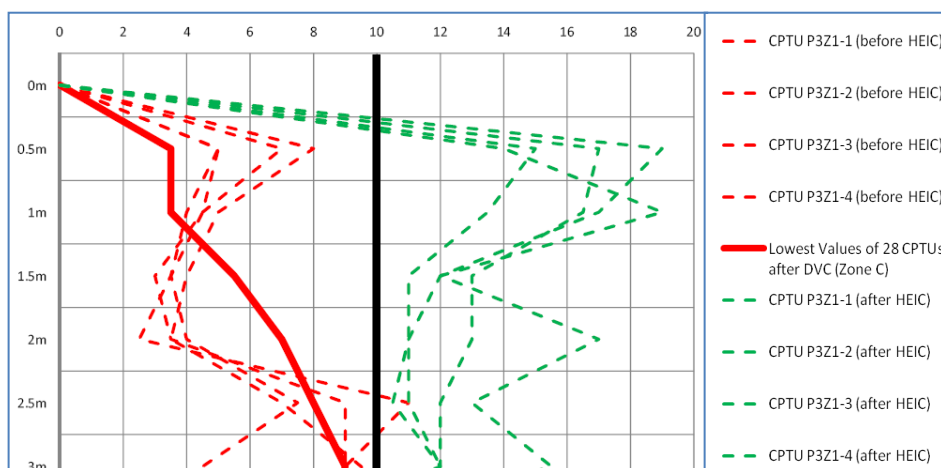
CPTUs, prior to HEIC, on Zones Z2-1, Z2-2 & Z3-A do not typically represent CPTUs after Deep Vibro Compaction (VDC), much higher than expected – refer to Appendix H.

CPTUs, prior to HEIC, on Zone P3Z-1 came closest to represent typical CPTUs after Deep Vibro Compaction (VDC), although on the lower end of the scale – refer to Appendix H

Zone P3Z-1 (250mm rock layer), passed all specification criteria:

1. CPTU ≥ 10 Mpa, ≤ 2 m below the surface after 80 passes of HEIC
2. $E_{v2} \geq 100$ Mpa, at the surface, after 8 passes of TR after 80 passes of HEIC
3. K (E_{v2}/E_{v1}) ≤ 2 , at the surface, after 8 passes of TR after 80 passes of HEIC

For Zone P3Z-1 (3rd HEIC Trial Area), which passed all specification criterion after 80 HEIC passes, the following graphical representation shows the comparison to CPTUs prior to HEIC trials (after DVC - Zone C) and CPTUs after HEIC:



As per the HEIC trial on P3Z-1, 80 passes may not be required after DVC, during future HEIC works on the project. The strength of CPTUs, after DVC, may typically be greater in strength than that recorded on HEIC trial Zone P3Z-1, prior to HEIC, as shown below:

Depth bgl	Typical CPTU after DVC (Zone C)
-1.0m	- similar to Zone P3Z-1
-1.5m	- 25 to 60% > Zone P3Z-1
-2.0m	- 75 to 180% > Zone P3Z-1

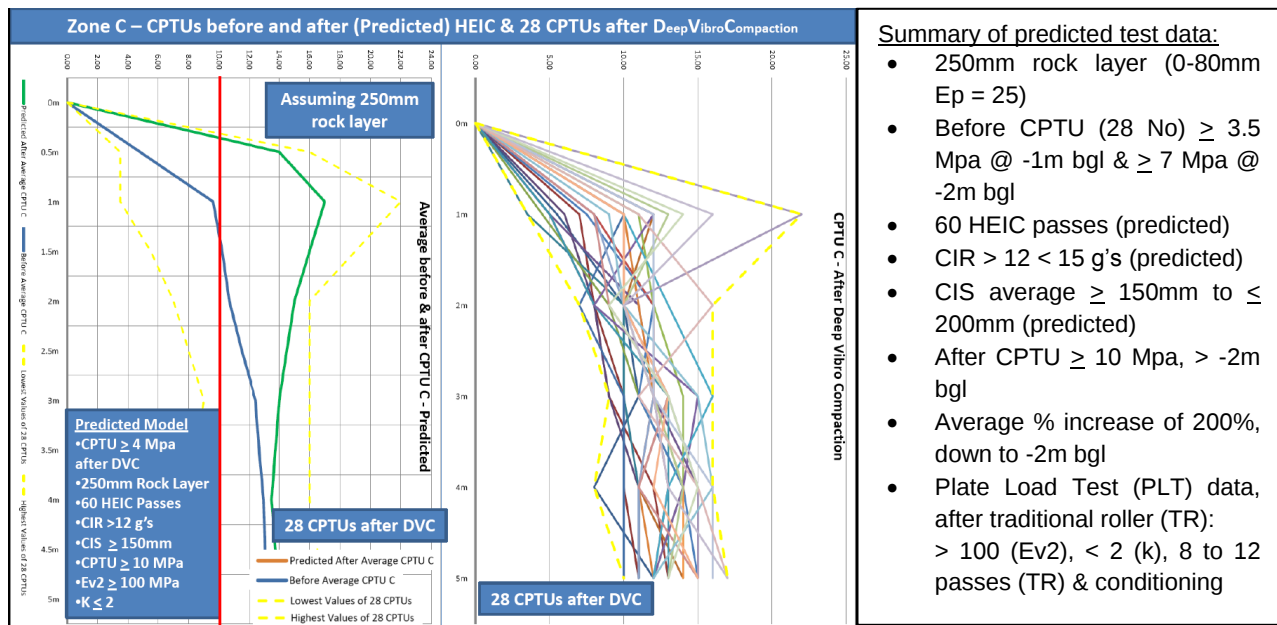
If Deep Vibro Compaction (DVC) continues on achieving CPTUs ≥ 3.5 Mpa @ -1m bgl & ≥ 7 Mpa @ -2m bgl, HEIC will meet specification ≤ -2 m below ground level. The plate load testing (PLTs) were achieved by applying traditional smooth drum roller (TR) after HEIC. HEIC improves materials at depth and the surface after HEIC can be disturbed, due to the high energy impact of the HEIC application, especially when applying 60 to 80 passes. Once care was taken, after HEIC, on moisture conditioning the surface and careful application of TR evenly across the HEIC trial surface for 8 passes, the PLTs were achieved on Zone P3Z-1.

ZONE C – PREDICTION MODEL – FUTURE HEIC WORKS

In conclusion, the following prediction model has been compiled and can be confidently adopted, as the baseline used on predicting the final HEIC improvement data was based on the lowest CPTU data recorded on Zone C (CPTUs after DVC) and the lowest CPTU values recorded on Zone P3Z-1, prior to HEIC, and finally the successful CPTU values recorded on Zone P3Z-1, after HEIC.

Zone C, was Deep Vibro Compacted (DVC) previously, some time ago. The CPTU data would typically be the profile of CPTU values at depth, where HEIC was expected to improve ≥ 10 Mpa, ≤ 2 m below the surface.

In this section the CPTU data from Zone C (after DVC) was compared to the before CPTU data for each of the HEIC three trial areas (seven zones) and a predicted model was calculated as to what the after CPTU data, more than likely would achieve after HEIC, based on the after CPTU data achieved for each of the HEIC trial areas/zones.



The data sheet above shows CPTUs before (28 after DVC) and after (predicted average) HEIC. The graph also shows the minimum specification line CPTU ≥ 10 Mpa. The second graph, on the right hand side of the data sheet, shows all 28 CPTUs individually, before HEIC (after DVC). See Appendix H, for detailed test data (CPTUs).