The use of Impact Compaction for the Near Surface Compaction on Dredged Sand Land Reclamation Projects

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ABSTRACT

The growth in world trade and the rapid population and economic growth in coastal urban areas has led to the increase in onshore Land Reclamation. The land reclamation is mostly carried out with the hydraulic deposition of dredged material that requires stabilisation. The stabilisation of dredged Sands is normally carried out with the use of Dynamic Compaction and Vibro-compaction on deep fill areas. With the use of Dynamic and Vibro-Compaction on non-cohesive soils the upper 3 metres or so remains loose after the deep compaction is completed. High Energy Impact Compaction (HEIC) has been used recently on land reclamation projects to compact the loose upper 3 metres or so on deep fills after the Dynamic or Vibro-compaction is completed and on shallow Sand fills to around 5 metre depth without the use of Dynamic or Vibro-compaction. The use of Impact Compaction on Land Reclamation projects is discussed and Case studies are presented on the use of High Energy Impact Compaction for the near surface compaction on three onshore land reclamation projects.

Keywords: Reclamation, Dredged Sand, Compaction, Impact Compaction,

1 INTRODUCTION

Densification and improvement of hydraulic fills are usually required before they are suitable for most uses (Shen and Lee 1995). Sladen (1990) inferred that with hydraulic placement the subaqueous material is generally looser than the materials above the tidal range. Vibrocompaction or Vibratory-probe compaction and Dynamic Compaction are commonly used for the densification of the looser Sand hydraulic fills. The compaction of the deeper soils is usually conducted over the denser soils above the water level. The absence of confining pressure in the upper levels on cohesionless soils tends to loosen the upper 2-3 metres of denser soils during the Vibrocompaction and Dynamic Compaction operations. Leycure and Schroeder (1987) attributed this to “over-vibration” which occurs with high particle acceleration and low overburden pressure. Covil, Luk and Pickles (1997) also reported a loose zone above the tidal range from the effects of Vibrocompaction on the Chek Lap Kok airport project.

Impact Compaction has been used on a number of Sand Reclamation projects for the surface compaction of the upper levels after the completion of Vibrocompaction or Dynamic Compaction. Impact Compaction was first developed in the 1970’s in South Africa and was introduced into Australia in the late 1980’s and into Europe and North America in the late 1990’s. It has been used on large infrastructure projects worldwide.

2 PRINCIPLES OF IMPACT COMPACTION

2.1 Description

Impact Compaction is a form of dynamic compaction that derives the compaction energy from the rise and fall of non-circular drums attached to mobile plant that travels at approximately 10-15km/h. The dynamic loads exerted on the surface enable compaction to depths of approximately 5 metres (Kelly 2000). This form of compaction generically referred to, as “Impact Compaction” or “Impact Rolling” should not be confused with Dynamic Compaction that consists of heavy tamping with heavy weights dropped from a crane and that imparts energy into the ground orders of magnitude much greater than Impact Compaction.

2.2 Depth of Influence

The depth of influence with Impact Compaction increases with an increase in the stress induced in the soils by the impact loads and thus in addition the type and properties of the soil is directly related to the weight and drop height of the impact drum assembly.

The dynamic action of Impact Compactors is complex that with the wide range of soil characteristics make it difficult to quantify the induced soil stress for each application. Nevertheless, comparisons can be made between various Impact Compactors in a similar way to that of Dynamic Compaction on the basis of the weight of the impact drum assembly and the height it raises and falls during operation. The impact drum assembly with the plant at operating speed possess kinetic energy in the form of translation and rotational energy and with the drum in the raised position potential energy (See Fig 1) that converts to kinetic energy as it falls. A theoretical and empirical analysis conducted by the University of Pretoria showed that on impact with the ground the rotation and horizontal velocities reduce proportional to the stiffness of the ground and as such only a portion of the total kinetic energy is imparted into the ground. They concluded the Potential Energy (mgh) of the raised impact drum assembly approximates the energy imparted into the ground and the changes in translation and rotational energy mostly only compensate for the gravitational losses from the impact drum linkage mechanisms that inhibit the true free fall of the impact drums.

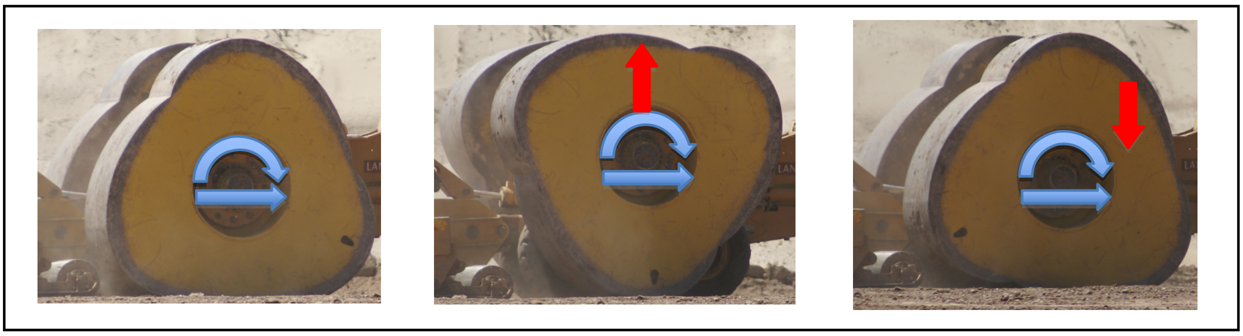

Figure 1. Dynamic Action of Impact Drums

Table 1 compares the energy factors of some Impact Compactors. It illustrates the relative difference in the impact loads that will be imparted during compaction with different impact compactors, which relates directly to the depth of influence.

Table 1: Impact Compactor Criteria

	3-sided (Heavy)	5-sided (Standard)	4-sided (Standard)
Impact Drum Assembly Weight	14 Tonne	11 Tonne	8 Tonne
Drop Height	230mm	150mm	150mm
Energy Factor (Weight x Drop Height)	3,220 Tonne.mm	1,650 Tonne.mm	1,200 Tonne.mm
Energy Factor Comparison	**100%**	**51%**	**38%**

3 CASE STUDIES

3.1 Port Botany Expansion Project

The container terminal at Port Botany in Sydney has been expanded with the reclamation of 60Ha with 1,850 metres of additional wharf face. Approximately 7.5 million cubic metres of fill was dredged using cutter suction dredgers and discharged in a slurry form by Spreader pontoon, Surface discharge or Aerial discharge methods. A new public boat ramp facility was also constructed in the vicinity of the new terminal reclamation area with dredging and reclamation of approximately 3 Ha.

3.1.1 Dredged Sand Fill Compaction

Vibrocompaction was used for the densification of the deep Sand fills in the counterfort wall trenches and counterfort wall backfill and adjacent to the previous terminal retaining walls to depths of approximately 30m. Dynamic Compaction was utilised on the remaining new terminal areas to depths of approximately 20m. Because of the non-cohesive nature of the sand fill and loosening effects of the upper 2-3 metres during the Vibrocompaction and Dynamic Compaction works, Impact Compaction was used for the near surface compaction of the upper 2-3 metres. Figure 2 shows the typical reclamation profile in the new terminal area. In the public boat ramp area Impact Compaction was used for the densification of the dredged fill improvement and the loose sandy seabed sediments to 5-6-metre depth. Figure 3 shows a typical particle-grading curve for the near surface sand fill. The sand fill was predominantly medium gained with traces of silt/clay and gravel being shell fragments.

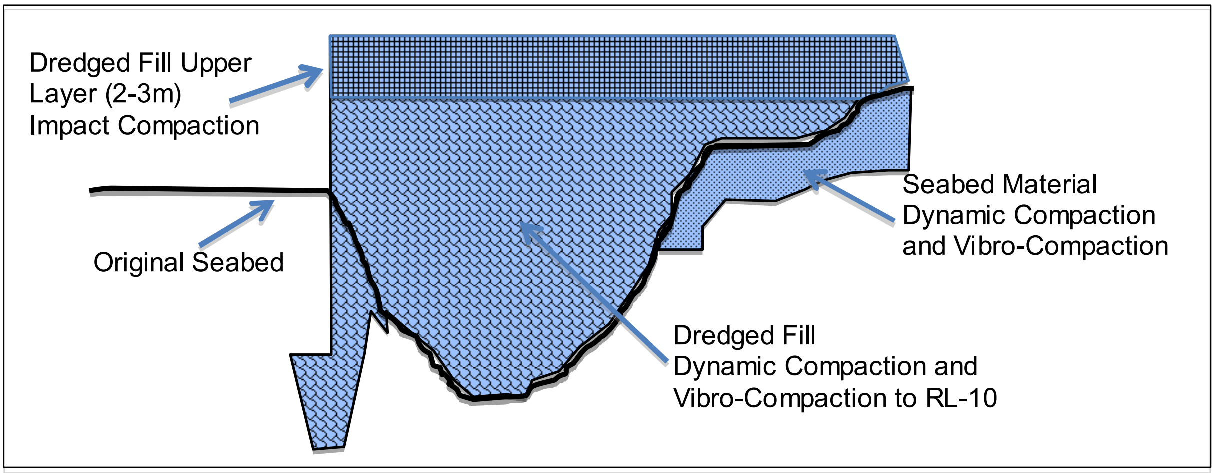

Figure 2. Cross-section of typical Reclamation profile in the New Terminal Area

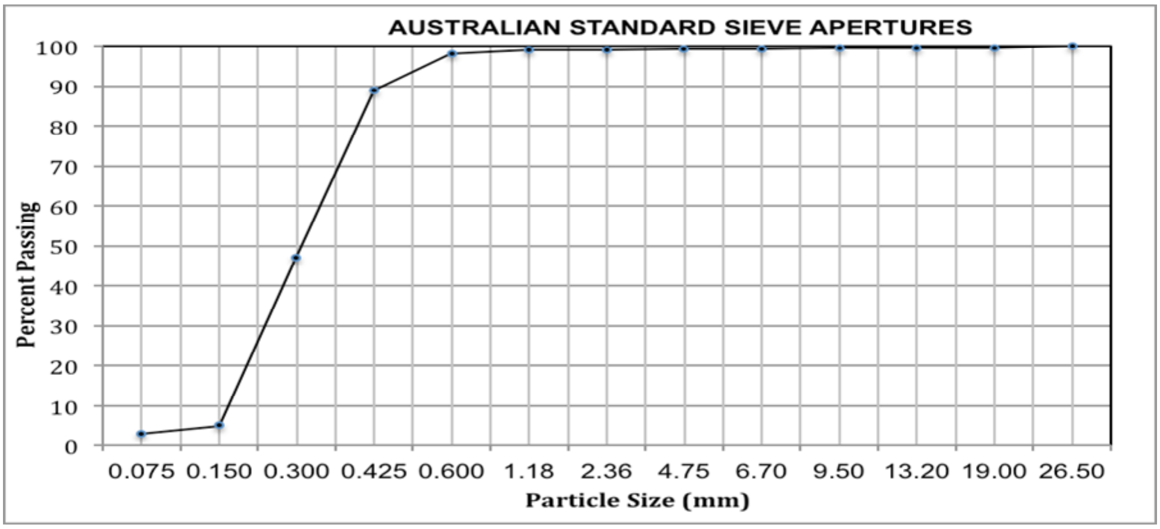

Figure 3. Typical near surface Sand Fill Port Botany Expansion Grading curve (AS1289.3.6.1 -1995)

Coefficient of Uniformity: $Cu = D_{60}/D_{10} = 0.33/0.16 = 2$

Coefficient of Curvature: $Cc = (D_{30})^2/D_{10} \times D_{60} = (0.23)^2/0.16 \times 0.33 = 1$

The project specification called for compaction to 75% Density Index to 2m below the reclamation level and 70% Density Index from 2-3m depth in the new terminal areas. For reclamation material below the Mean Low Water Neaps and 4 metres below the existing in-situ surface levels in the new terminal areas and boat ramp area a CPT cone resistance value (Qc) greater than 5MPa for a minimum of 90% of the cone profile was specified.

3.1.2 Impact Compaction Test Results

The Impact Compaction was carried out in three distinct areas, viz; Public Boat Ramp area, Early Works area and New Terminal area.

The Impaction Compaction in the Early Works areas were carried out on a nominal 300mm Sandstone constraining layer that was placed over the sand fill that had been subject to either Vibrocompaction or Dynamic Compaction. The 300mm layer formed part of a working layer for the construction access and hardstand areas. Cone Penetrometer testing was carried out (NEN 5140 Class 1) on these areas to verify the compaction results. The average Cone Resistance (Qc-MPa) values are presented in Figure 4.

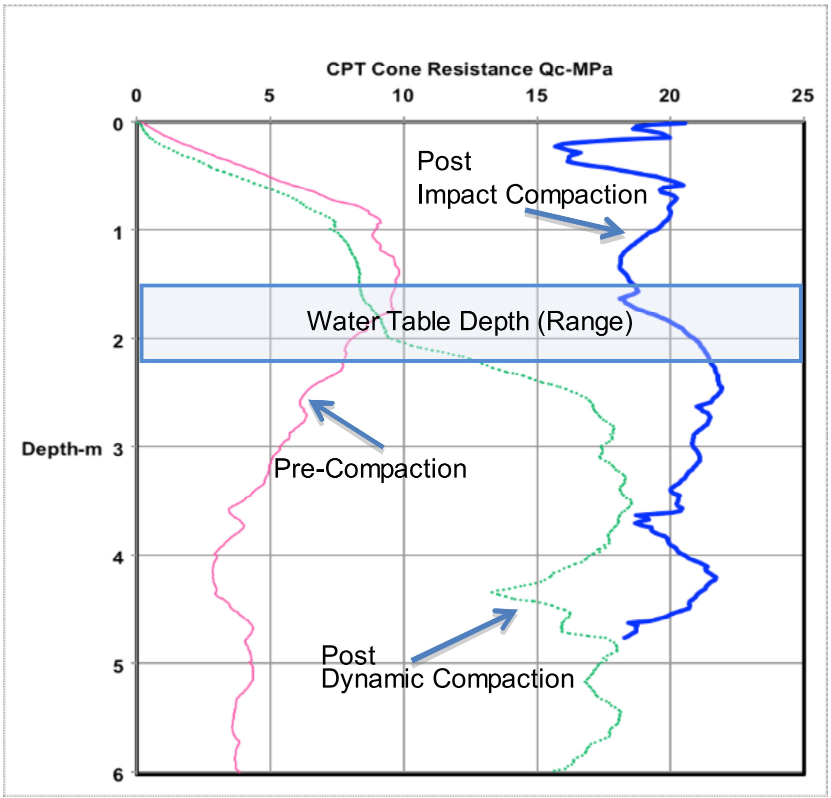

Figure 4. Early Works CPT's (Average Qc Values)

The Impact Compaction in the New Terminal area was carried out on the Sand Fill surface that had been subject to either Vibrocompaction or Dynamic Compaction. Density tests were carried out in test pits to verify the compaction results. The average density test results are presented in Table 2.

Table 2: New Terminal Density Test Results (Average)

Test Depth	No. of Tests	Field Dry Density (t/m3)	Field Moisture Content AS1289 2.1.1 (%)	Field Wet Density AS1289 5.8.1 (t/m3)	Max. Dry Density AS1289 5.5.1 (t/m3)	Min. Dry Density AS1289 5.5.1 (t/m3)	Compaction Density-Id AS1289 5.6.1 (%)	Failure Rate <75%Id (%)
100-400	60	1.7	6.30%	1.81	1.68	1.38	106.6%	0
400-700	78	1.71	6.20%	1.81	1.68	1.39	108.3%	2.56%
700-1000	70	1.7	6.30%	1.81	1.67	1.39	109.5%	1.5%
1000-1300	70	1.68	6.40%	1.79	1.67	1.4	104.2%	2.95%
1300-1600	59	1.68	7.50%	1.81	1.67	1.4	106.4%	0
1500-1800	30	1.69	11.80%	1.89	1.67	1.4	104.9%	0
Overall	**367**	**1.7**	**6.90%**	**1.81**	**1.68**	**1.39**	**106.9%**	**1.36%**

Dynamic Compaction or Vibro-Compaction was not carried out on the Public Boat Ramp area prior to Impact Compaction. Cone Penetrometer testing was carried out on this area to verify that the compaction results meet the project specification. The average Cone Resistance (Qc-MPa) values are presented in Figure 5.

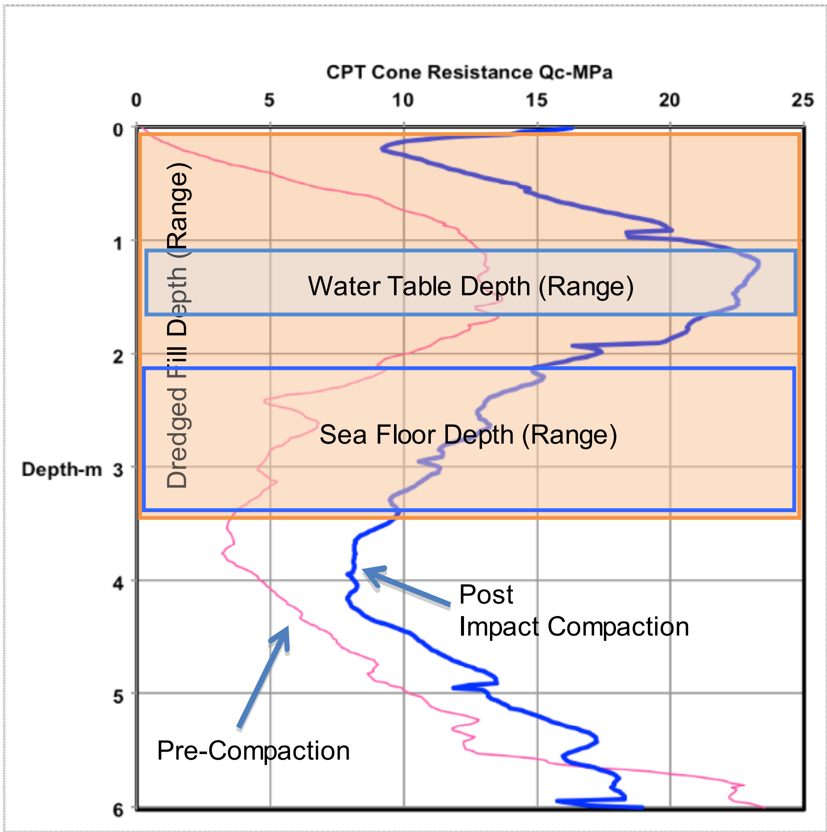

Figure 5. Public Boat Ramp CPT's (Average Qc Values)

The project specifications in all three areas (Viz; New Terminal; Early Works and Public Boat Ramp) were achieved using Impact Compaction.

3.2 Port Tanger Project, Morocco

The Tanger MED 2 project in Morocco requires a 140ha area to be constructed, through a dredging/backfilling operation and densification and improvement of the hydraulic fills, prior to pavement construction for a planned container terminal. Up to five million cubic metres of "borrow material" will be dredged, sourced offshore, and backfilled onto an area behind quay walls.

3.2.1 Dredged Sand Fill Compaction

The backfilled dredged material will be Deep Vibro Compacted (DVC) to the full depth. The Cone Penetrometer Test results, from previous DVC works within the Tanger MED site, have indicated that specification is only achievable greater than 2m below ground level. A trial was conducted on site using Impact Compaction for the compaction of the upper surface materials to 2-3m depth.

The project specification requires the following criteria to be achieved in the upper 2 metres, prior to pavement construction.

- CPT Cone Resistance Qc ≥10MPa
- Modulus Ev2 ≥100MPa, at the surface
- (Ev2/Ev1) ≤ 2, at the surface

Three trial areas were selected to assess the most suitable Impact Compaction methodologies. The results of the preferred methodology are presented. To emulate the Deep Vibrocompaction (DVC) results elsewhere on site the trail area presented (See Fig 6) was prepared with the removal of 2 metres of previously hydraulic placed dredged fill and re-placed in a very loose to loose condition. A nominal 250mm rock layer was placed over the re-placed sand fill prior to the Impact Compaction.

Figure 6. Trial Area with Rock Layer

3.2.2 Impact Compaction Test Results

The average cone resistance values of three CPT's prior to Impact Compaction and three CPT's after Impact Compaction are presented in Figure 7. The post compaction values indicate that compaction exceeded the minimum project specification line CPTU ≥ 10MPa to a depth of approximately 4.5 metres.

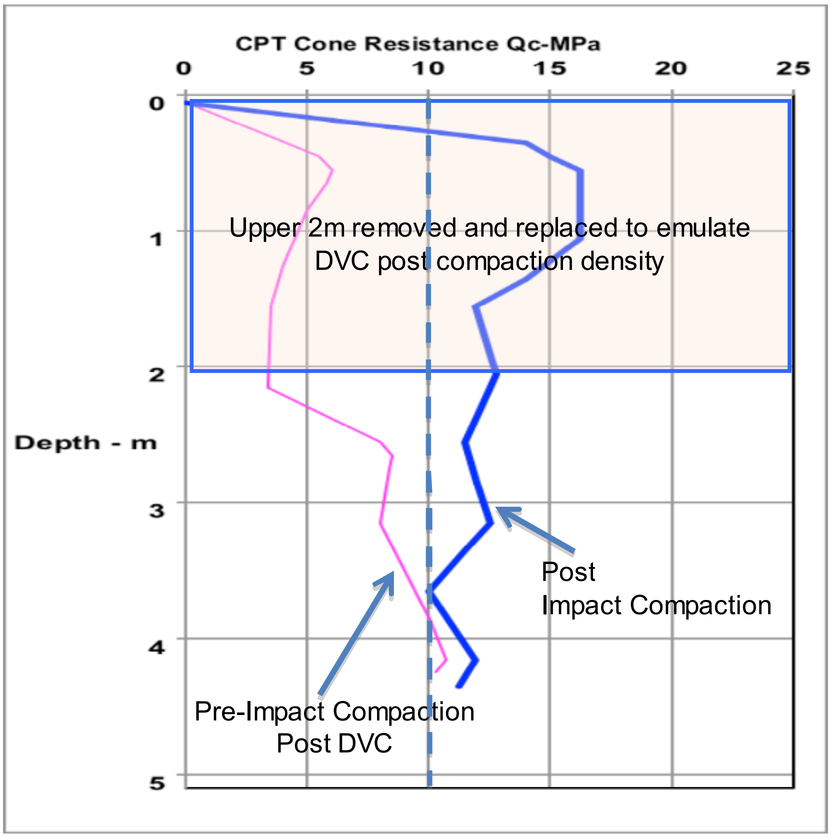

Figure 7. Preferred Trial Area CPT's (Average Qc Values)

The results of the plate load test conducted after Impact Compaction are presented in Table 3. The post compaction Plate Load test values indicate that compaction exceeded the minimum project specification.

Table 3: Post Compaction Plate Load Test Results

Plate Load Test No	Modulus (Ev2-MPa)	k (Ev2/Ev1)
S1	107	1.72
S2	145	1.81
S3	109	1.79
S4	136	2.00

3.3 Newcastle Kooragang Coal Expansion Terminal

The proposed capacity of the Newcastle Kooragang Island Coal Expansion Terminal north of Sydney will be 30 Mtpa coal throughput, which is the largest single stage development of a new coal terminal of this magnitude in the world. The project involved dredging to construct a serviceable port for the export of coal. The 3.5 million cubic metres of Dredged Sands were re-used as construction fill. The coal stockpile and reclaimer area is approximately 40Ha in size and is located on dredged fill placed over Quaternary fluvial, estuarine and marine sediments of variable depth and consistency. The upper alluvium comprises layers of very soft/soft clays and very loose/loose silts and sands typically 2 to 4m thick.

3.3.1 Dredged Sand Fill Compaction

Dynamic Replacement was used on a crushed rock/gravel layer on the original ground level on a triangular grid with columns to around 5 to 6m depth. Dredged fill was hydraulically placed to 3-5m depth over the Coal Stockyard area after completion on the Dynamic Replacement. The dredged fill comprised medium to coarse-grained Sands. The Dredged Fill was subject to further compaction after hydraulic placement with Impact Compaction using Landpac 3-sided Impact Compactors.

The project specification required compaction of the dredged fill to a medium density.

3.3.2 Impact Compaction Test Results

The average cone resistance values of nine CPT's prior to Impact Compaction and six CPT's after Impact Compaction are presented in Figure 8. The post compaction values indicate that compaction exceeded the minimum project specification of medium density to a depth of approximately 5 metres.

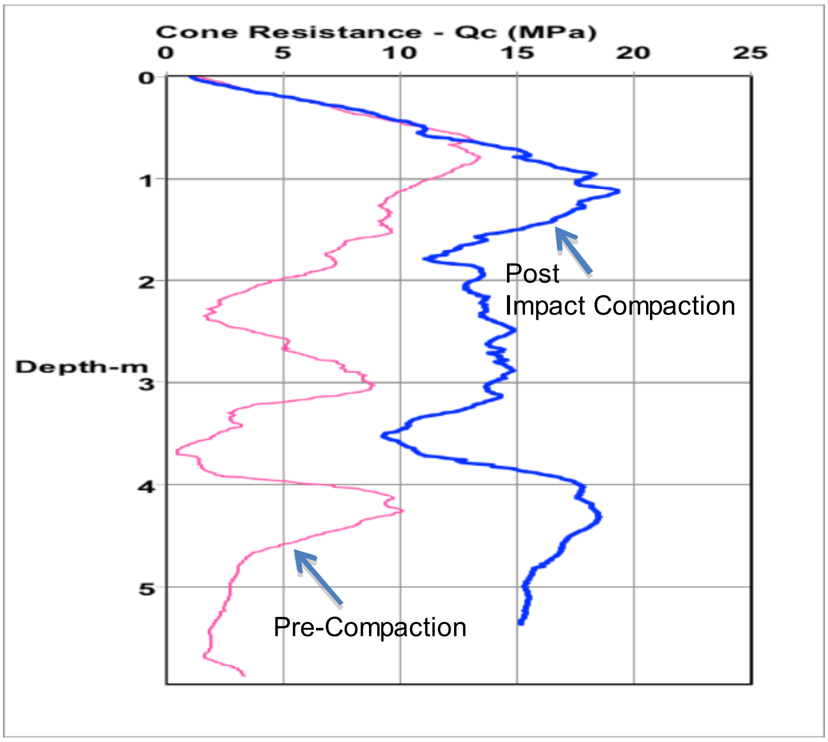

Figure 8. Coal Reclaimer Area CPT's (Average Qc Values)

4 CONCLUSION

Impact Compaction is an effective means with the appropriate equipment and methodology of compacting the upper 3 metres of dredged Sand reclamation fills after deep compaction using Vibrocompaction or Dynamic Compaction. Impact Compaction is also an effective alternative to Dynamic Compaction or Vibrocompaction for the compaction of dredged sand reclamation fills to a medium density to depths of 5 metres.

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