LANDPAC
GROUND ENGINEERING
Technologies in Marine Engineering Applications

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The main features of the high energy impact compaction (HEIC) process include the following:

- **Compaction Loads:** typical compaction loads of between 1200kN and 2500kN generated, depending upon the type and condition of the material being compacted.

- **Material Moisture Condition:** ability to compact material to a higher maximum dry density at lower moisture contents; compaction of material over a wider range of moisture conditions, particularly dry of optimum moisture content.

- **Depth of Influence:** typically measured to effective depths of 2m-3m, with depths of up to 5m being recorded in some applications.

- **Soil Compressibility:** energy parcels are transferred in the form of a “rolling impact” over an extended load transfer duration leading to a softer soil response to the load and hence enhanced soil compressibility is achievable.

- **Compaction Productivity:** high operating speed and depth of influence of the HEIC process leads to very high productivity of compaction; can be between 2 and 5 times higher than that of conventional shallow compaction equipment when performing fill work.

A new approach for testing and certification of ground improvement using twin drum HEIC equipment revolves around the direct measurement of engineering properties of the material.

**Continuous Impact Response (CIR)**

The Landpac developed Continuous Impact Response (CIR) System is capable of measuring the soil response to every impact of the impact compactor, resulting in a direct measurement of the material stiffness. The system measures peak decelerations of the compaction masses with each impact. Each of these points is recorded relative to its position on site as determined by an integrated global positioning system. These accurately measured and recorded decelerations are then correlated back to a measurement of engineering properties using traditional testing methods, such as density, Cone Penetration Testing (CPT), Dynamic Cone Penetration (DCP), Plate Load Testing (PLT), Zone Load Testing (ZLT), and California Bearing Ratio (CBR). The CIR system generates colour coded maps indicating the relative measure of the appropriate engineering property. The maps generated by the CIR system can be used in conjunction with conventional testing techniques to provide a quality assurance system capable of certifying the entire site at a reduced cost and an increased level of certainty. The system is currently widely used and has proven to be a very useful tool in controlling the ground improvement process.

The CIR provides a quality control system that quantifies the ground strength and stiffness during the compaction process whilst also monitoring the number of coverages and actual area compacted. These ground improvement maps can be used in the following ways:

- To indicate relative strength of the material during the varying stages of the ground improvement process and monitor improvement;
- To pin point focused areas for conventional testing;
- To identify weak areas requiring additional testing and remedial action; and
- To spread the conventional test results over the entire site thereby enhancing the quality assurance of the ground improvement.

**Continuous Induced Settlement (CIS)**

In addition to Continuous Impact Response (CIR) measurement, it is also possible to simultaneously measure the relative settlement that is induced by the impact compaction ground improvement process. The measurement of such settlement can be continuously monitored and colour coded maps of such Continuous Induced Settlement (CIS) can be generated. Such CIS maps can be used in the following ways:

- To indicate continuous settlement throughout the process;
- To indicate relative differential settlement;
- To monitor areas and volumes; and
- To monitor the absolute level of the ground improvement operation.
Value Engineering
Elimination of excavation requirements, Thick lift compaction, Elimination of layers and imported material, Reduction in crushing requirements, Reduction of water requirements, Utilisation of on-site materials, etc.

Unique Solutions
Non-conventional alternative methodology.

Fast Tracking
Increased productivity.

Cost Savings
Value engineering, unique solutions and fast tracking combined.

Quality Control
Specialised monitoring CIR and CIS technologies.

Project Management
Process control and reporting.

TECHNICAL CASES

Compaction of Mixed Fills, Malmo, Sweden

- Description: Although of a poor and varied quality, the majority of the mixed fill materials were to be improved through the process of HEIC, investigative CIR & CIS and soft spot identification/removal/replacement with the following controlling specification requirement having been set as the minimum: Ev2 > 30MPa and k-value (Ev2/Ev1) < 2.5.

- Quality Control using CIR: CIR stiffness profile monitoring was used during the HEIC application to characterise and verify Ev2 specification, after correlation with CIR, of the site existing fill material. The CIR data was correlated with numerous Dynamic Plate Test (DPT) results, which allowed a site-wide characterisation and also determined the soil replacement areas for the client, which resulted in minimising costly excavations.

- HEIC Treatment: The site was treated with HEIC and specification was achieved involving the following methodology:
  - Treat with a Landpac 5 sided 22kJ HEIC, to induce maximum settlement possible and Ev2 > 30MPa.
  - Dynamic Plate Testing (DPT) at surface and at varying depths.
  - Correlate CIR and DPT data.
  - CIR characterisation of the treated area/s to identify soft spots needing removal and replacement.
  - Soft sections, highlighted and precisely marked using the CIR, were removed, replaced and recompacted to specification.
Compaction of Marine Sands, Jebel Ali Port, Dubai

- Description: Extended Berth 21 was created by deposition of dredged sand between a new quay wall and the existing container terminal platform. The material below sea level was initially improved by means of Vibro Compaction (VC).

- Results of VC Treatment: Results obtained after Vibro Compaction showed that compaction was generally poor down to approximately 2.0m depth, with a weighted average Qc=4.8MPa.

- Expected Treatment: Normally, excavation and re-compaction by means of conventional vibratory rollers would be expected.

- Alternative HEIC Treatment and Results: Surface ironing using a 3 sided 25 kJ high energy impact compactor was used as an alternative resulting in significant increases in material consistency to depth, reduction in differential settlement concerns, increase in bearing strength by densification and increase in aging, thereby reducing the rate of secondary creep settlement. Results showed improvement recorded up to 5.0m deep, with the weighted average Qc improving from 4.8 MPa to 11.6 MPa in the top 2m and from 8.9 MPa to 13.6 MPa through the measured 4.8m depth profile.

Compaction of Marine Sands, Port Botany, Sydney, Australia

Early Work Area:
- Description: Nominal 300mm Sandstone constraining layer that was placed over the sand fill that had been subject to Dynamic Compaction (DC).
- Results of DC Treatment: Average Qc<8MPa @ 0-2m.
- Results of HEIC Treatment: Average Qc=15MPa @ 0-2m; and Average Qc>20MPa @ 2-4m.

New Terminal Area:
- Material: Sand fill surface that had been subject to either Vibro Compaction or Dynamic Compaction.
- Results of HEIC Treatment: The average density recorded in the depth range from 100-1800mm below the compacted surface, at an average field moisture content of 6.9%, was 106.9%.

Public Boat Ramp Area
- Results of HEIC Treatment: Average Qc=15MPa @ 0-1m; Average Qc>20MPa @ 1-2m; and Average Qc=10MPa @ 2-3m.

With the specification set to achieving a density index of 75% in the top 2m and a Cone Resistance (Qc) exceeding 5 MPa in the full depth of the reclamation area, HEIC was successfully used to improve the top 4m that would not have met specification post treatment by the deep ground improvement techniques that had been employed. Results beyond 4m were within the requirements of the specification. The combination of the two technologies certainly offered a cost effective solution to the project.