Ground Improvement at the Prestons Subdivision, Christchurch

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ABSTRACT

The Prestons Road Subdivision, located on the north side of Christchurch City, is a residential subdivision currently under development, with a total area of approximately 160 hectares for approximately 1600 residential houses. As part of the site development geotechnical investigations identified that the soil type was predominantly beach sand with localised areas of peat interbedded with dune sand. Liquefaction assessment identified that the site technical classification, in accordance with the Ministry of Business, Innovation and Employment Guidelines, comprised areas of TC1 and TC2 equivalent. Liquefiable layers tended to be located within the upper 3m of the soil profile with further liquefiable layers at depths of greater than 8m. As the more significant liquefiable layers were relatively shallow, the opportunity was taken to assess ground improvement options to densify the upper soil layer and reduce the liquefaction potential at the site. The selected ground improvement method was rapid impact compaction. To confirm the suitability of the ground improvement technique, full scale site trials were carried out. This indicated that ground densification could be consistently achieved in the upper 3m. In addition, the trials also highlighted possible construction issues that would need address during full site ground improvements. As part of the subdivision development ground improvement has consequently been undertaken using an impact compactor to reduce the liquefaction potential and allow TC1 equivalent site classification. This paper defines the geotechnical model used on the site, it details the selection of an appropriate ground improvement method and discusses the use of trials to identify an appropriate construction methodology.

Keywords: liquefaction, ground improvement, impact compactor, full scale site trials

1 INTRODUCTION

The Prestons Road Subdivision, located on the north side of Christchurch City, is a residential subdivision currently under development, with a total area of approximately 160 hectares for approximately 1600 house sites. The subdivision development at Plan Change and Subdivision Stage included extensive geotechnical investigations including liquefaction assessments that determined the future seismic performance of the land. The liquefaction assessment and client directives identified the need for ground improvement. This paper discusses the ground improvement, in particular the use of an impact compactor, to densify the upper soil profile to minimise the liquefaction susceptibility.

2 SITE CONDITIONS

2.1 Site Location and Regional Geology

The Prestons Subdivision is located on the northern side of Christchurch City between the Marshlands and Burwood area, and it is approximately 2km from the coast. The site is bound by Styx River to the north, Mairehau Road to the south and Prestons Road runs approximately through the centre. The overall subdivision is approximately 160ha in area.

The regional geology of the site is described in the 1:250,000 scale geological map – '*Geology of the Christchurch Area*,” published in 2008 by the Institute of Geological and Nuclear Sciences. The map indicates the underlying geology comprises *“Dominantly sand of fixed and semi-fixed dunes and beach deposits”* and '*drained peat swamp*'. Beach sand and dune sand deposits are associated with the marine regression that formed the Canterbury coast and the peat swamp areas are back beach deposits that can typically form behind dune areas.

2.2 Ground Conditions

The subdivision development investigations comprised an extensive geotechnical testing regime that included test pits, CPTs and window sampling. CPTs reached depths in the order of 15m to 25m without refusal. CPTs were the primary investigation tools, as they are a relative quick test and provided information required to undertake detailed liquefaction assessments. Window samples and laboratory testing were correlated to CPT results.

The geotechnical testing indicated that the ground conditions were predominantly fine to medium grained beach sands with higher elevated areas (dune remnants) comprising of fine to medium grained dune sands. Areas of peat were present in either continuous surficial layers along parts of the western boundary or in localised pockets underlying the dunes sands.

Typical CPT logs showing the soil profiles are presented in Figure 1. The CPT in Figure 1a is located in an area of dune sands, while Figure 1b in located in an area of predominately beach sands. It can be seen that the soil profile to depths in excess of 15m comprise predominantly of sand with a thin organic layer underlying the dune sands in Figure 1a.

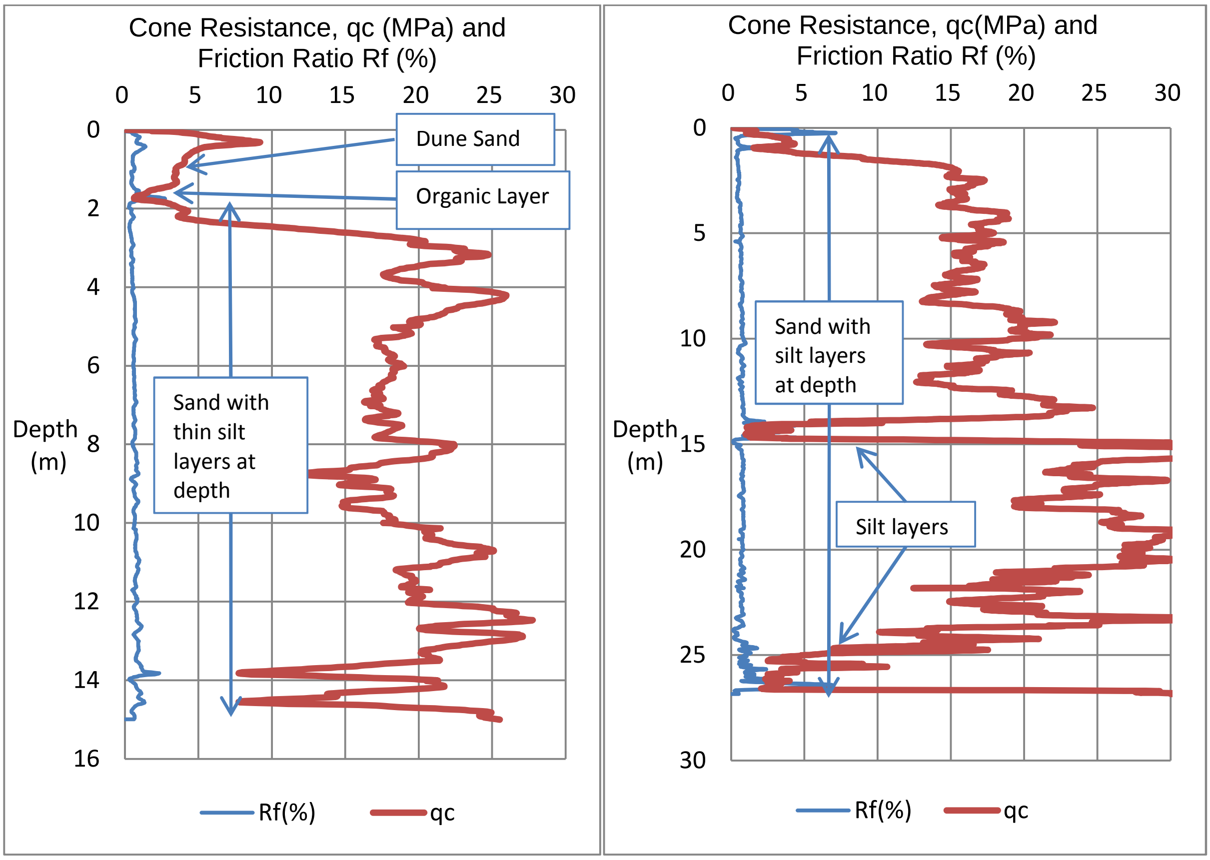

Figure 1a) Typical CPT profile in an area of dune sand and b) typical CPT profile in a beach sand area

3 LIQUEFACTION ASSESSMENT

The liquefaction analysis was undertaken on the CPT information using the Idriss and Boulanger (2008) method as detailed in the Ministry Business, Innovation and Employment (MBIE) Guidelines (2012) and the National Centre for Earthquake Engineering Research (NCEER) method as outlined by Youd et al. (2001), and recommended in the NZGS (2010) Guidelines.

The earthquake cases assessed included a Serviceability Limit State (SLS) and Ultimate Limit State as defined by the MBIE Guidelines with peak ground accelerations (PGA) of 0.13g and 0.35g respectively, at a Magnitude 7.5. In addition, an assessment was carried out on an intermediate earthquake case with PGA of 0.2g and Magnitude 7.5, which based on NZS1170.5 (2004) is a 1 in 150 year return period.

The liquefaction analysis identified that liquefiable layers tended to be located within the upper 3m of the soil profile with further liquefiable layers at depths of greater than 7m. The typical liquefaction analysis profiles for the ULS case are provided in Figure 2. Free field liquefaction settlements were in the range of Technical Categories TC1 and TC2 for the upper 10m, in accordance with MBIE

Guidelines. The technical classification was generally governed by the liquefiable layers in the upper 2m to 3m of the soil profile, as shown in Figure 2.

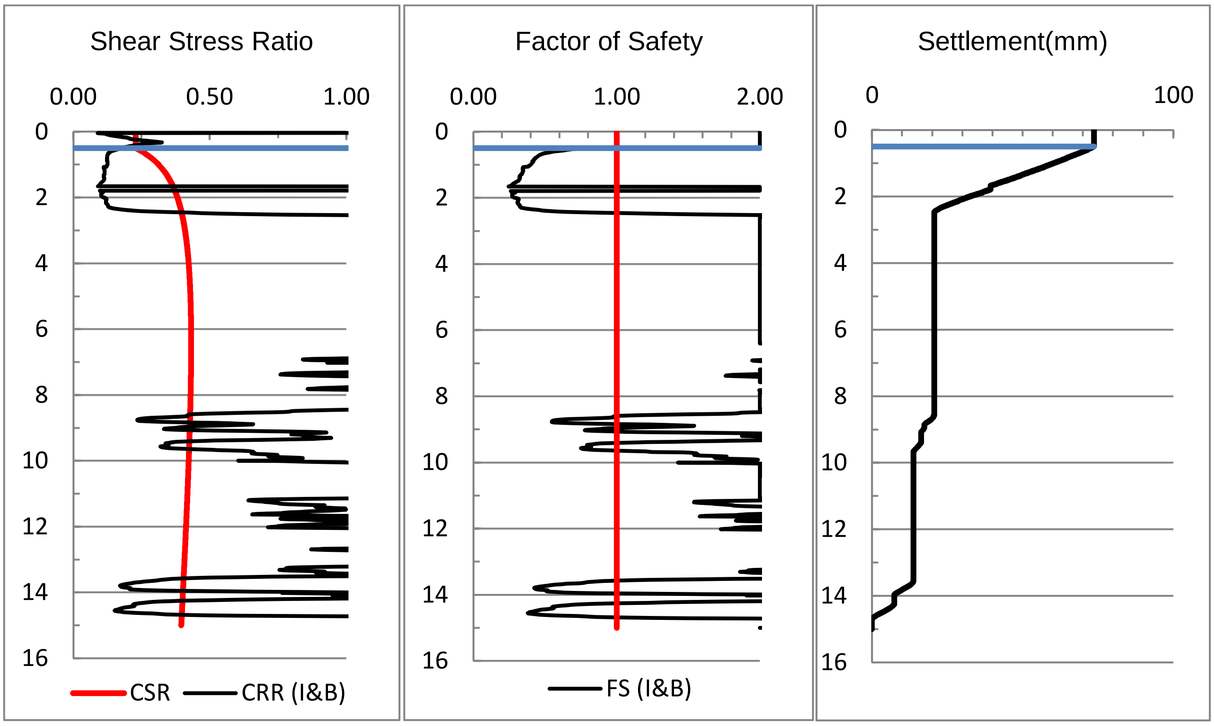

*Figure 2aTypical liquefaction profile within the **dune sand** for the ULS case, based on the Idriss and Boulanger method*

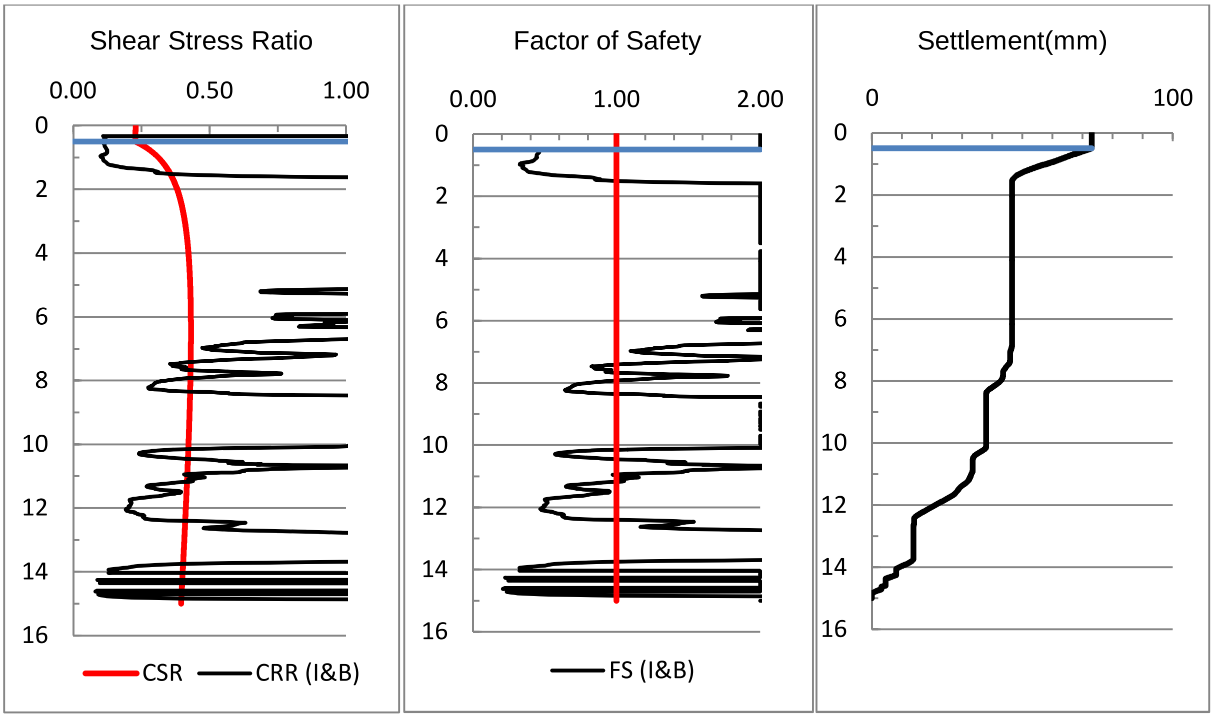

*Figure 2bTypical liquefaction profile within the **beach sand** for the ULS case, based on the Idriss and Boulanger method*

4 ENGINEERING PHILOSOPHY

The soil comprises predominately beach and dune sands with the liquefaction susceptibility governed by the upper 3m of the soil profile. Therefore a ground improvement technique was required to densify the upper soil layers over large areas. By densifying the upper 3m the near surface liquefaction potential and liquefaction settlements are reduced, which would form a thick non-liquefiable crust in the order of 7m to 8m thick, once the deeper non-liquefiable sandy soils to 7m to 8m are included. Thereby liquefaction induced ground damage on the site would be unlikely and the site would be able to be classified as MBIE TC1 equivalent.

At the time of our assessment Landpac was introducing a high energy impact compaction (HEIC) technique into the Christchurch market. The HEIC machine used in this particular case comprised of a 3-sided dual drum impact compactor with a kinetic energy rating of 135kJ (Figure 3). The impact compactor densifies soils using a modular weight dropping from a height at a regular rate.

Figure 3 Impact compactor working at the Prestons Subdivision

As ground conditions over the site comprised sand, the impact compactor was considered to be a potential technique to densify soil to significantly reduce liquefaction susceptibility. However, it was unknown whether impact compactors can be successfully employed on Christchurch soils. Most published studies comprised overseas experience and the client considered that the lack of local application may pose a high programme and financial risk. Therefore, with the support of Landpac, field trials were undertaken on site to confirm the effectiveness and applicability of the impact compactor.

5 IMPACT COMPACTOR TRIALS

The impact compactor trials were undertaken in four locations across the subdivision. The trial areas were chosen as these were representative of the wider site ground conditions. Pre-stripping or topsoil removal was not carried out as it was identified by Landpac on their past experience that the running surface was firm enough for the impact compactor and the topsoil would not affect the impact energy transmission.

A series of baseline CPT tests were carried out within the trial areas. The CPTs were limited to 6m depth, as it was understood that the depth of influence of the impact compactor was unlikely to be greater than 3m, viz. the depth of the potentially liquefiable soils. Three CPTs were carried out in each trial area, with one located at the centre of the trial site and two either side at approximately quarter points. The CPT testing carried out pre and post trials were taken at approximately the same location to allow the pre and post-trial result to be compared. The sequence of impact compactor passes and testing carried out as part of the trial are presented in Table 1.

From discussions with Landpac and from a review of overseas case studies (Jumo and Geldenhuys,2004; Kelly and Gil, 2012) 40 passes was considered the maximum number of passes for sandy soil, beyond which there was no significant ground improvement. As the intention was to improve the ground to TC1 equivalent, then it was considered appropriate to achieve the maximum ground densification and apply 40 passes with the impact compactor.

Table 1 - Sequence of trial compaction and CPT testing (from Aurecon Report 2012)

Stages	Site 1	Site 2	Site 3	Site 4
1) Pre-Trial CPT	CPT201 to CPT203	CPT204 to CPT206	CPT207 to CPT209	CPT214 to CPT216
2) Compaction	40 passes	40 passes	40 passes	40 passes
3) CPT Testing	CPT301 to CPT303	CPT304 to CPT306	CPT307 to CPT309	CPT414 to CPT416
4) Additional Compaction	10 passes	20 passes	10 passes	N/A
5) Final CPT Testing	CPT401 to CPT403	CPT404 to CPT406	CPT407 to CPT409	N/A

Profiles showing the CPT Qc for two of the CPTs carried out as part of the trial are shown on Figures 4a and 4b. Figure 4a shows the CPT profile for a test location within Site 3, where CPT207 is the pre-compaction, CPT307 following 40 passes and CPT407 following an additional 10 passes. Figure 4b shows the CPT profile for a test location within Site 4, where CPT215 is the pre-compaction and CPT415 following 40 passes.

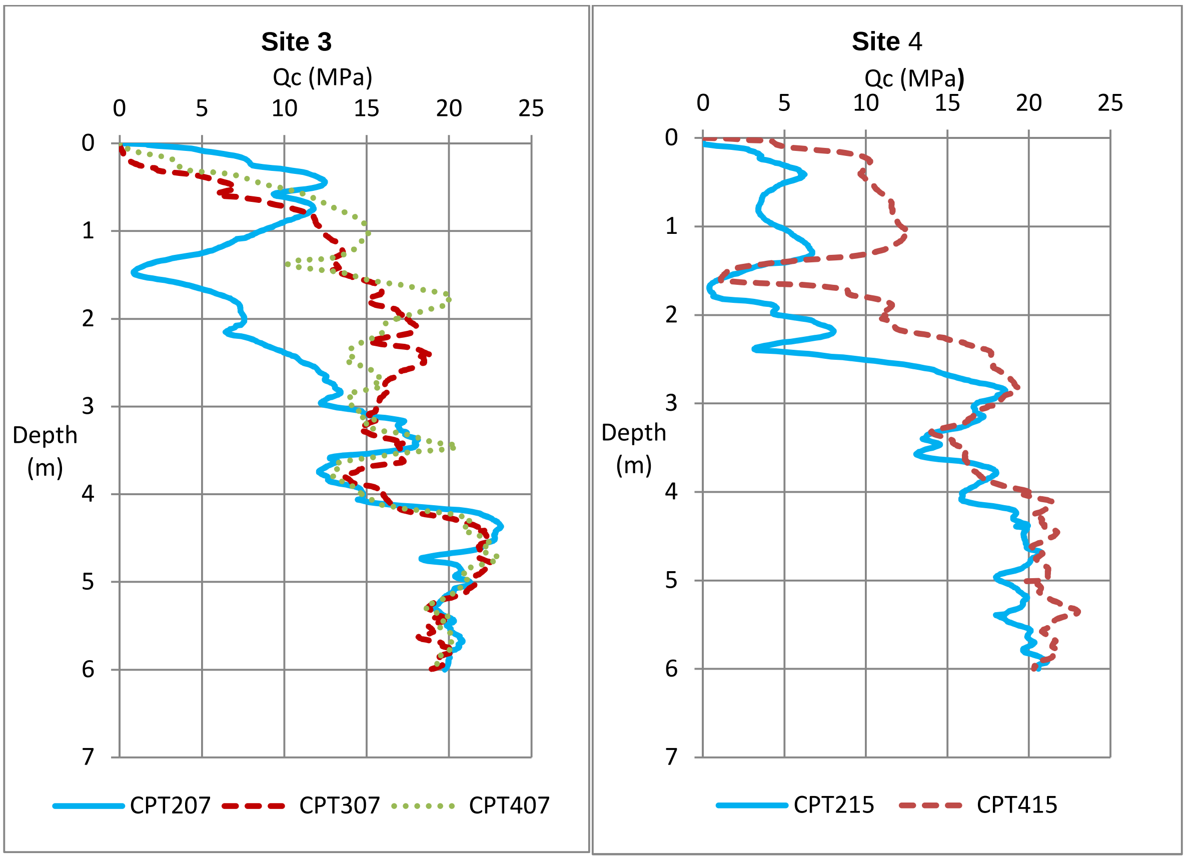

Figure 4a) Site 3 CPT profile comparison for CPT207, CPT307 and CPT407 b) Site 4 CPT profile comparison for CPT215 and CPT415

It is evident that there is reasonable ground improvement in the upper 3m. The CPT profiles also show that 40 passes appear to be the maximum number of passes, after which there is no significant improvement. Detailed analysis also indicated that where organic layers were present, as seen at a depth of 1.7m at Site 4, there was little to no ground improvement of the organic layers.

Liquefaction analysis indicated that the upper 3m of the soil profile was sufficiently densified to suppress liquefaction susceptibility. Liquefaction induced free field settlements in the upper 3m were reduced in the order 40% to 90%, depending on soil type.

The trial provided good evidence that the impact compactor had the potential to densify the sandy soils. The trial also indicated that large areas could be treated in a relatively short time. From these trials the client decided to utilise the Landpac impact compactor to reduce the liquefaction susceptibility on the project site. To achieve the required ground improvement, it was decided to use an end result specification approach, in that the ground had to be improved to TC1 equivalent, with the trials indicating that 40 passes with impact compactor was required.

6 IMPACT COMPACTOR QUALITY ASSURANCE

It was important to ensure that the impact compaction was achieving the required results therefore a quality assurance regime was prepared to monitor the ground improvement work. The quality assurance regime comprised reviewing the Continuous Impact Response and CPT testing.

6.1 Continuous Impact Response

Continuous Impact Response (CIR) technology was used to measure the relative soil response to the dynamic loads induced by the impact drums. The recorded soil response measured in g-values (deceleration) is used to identify sub-surface weak materials and indicate relative soil stiffness across the compaction areas.

The recorded g-values (deceleration) and the locations for each impact load are presented on a plot with the g-values categorised by colours representing low (Red), medium (Yellow), high (Green) and very high soil (Blue) responses.

This provided a good index tool to determine if maximum compaction force was consistently applied to the ground. An initial 5 passes with the impact compactor would be carried out to provide a soil response. If low soil responses were identified, such as soft, wet topsoil, then the soft soils were over excavated and only the subgrade treated. During the production run the CIR plots were required on 100% of the overall treated area.

6.2 CPT Testing

Assessment of the ground improvement was carried out using CPT tests. Prior to any impact compaction, pre-compaction CPTs were carried out to confirm the pre-existing soil densities. Once the required 40 passes were completed post compaction CPTs were carried out near the pre-compaction CPTs. A comparison of pre and post compaction CPTs was undertaken to confirm the increase in cone resistance. Liquefaction assessment was then undertaken on the post compaction CPTs to confirm the extent of the liquefaction potential after impact compaction. Two of the CPT comparisons are presented in Figure 5, show the indicative densification achieved in the upper soil profile.

7 CONSTRUCTION WORKS

Impact compaction was used on areas which were identified as TC2 and monitoring the site work with the CIR and CPTs confirmed that the required ground improvement was being achieved. To this date the ground improvement has been successful in densifying the upper soil profile and to allow the subdivision to be classified as MBIE TC1 equivalent (Aurecon Reports 2013 and 2014).

One of the construction aspects that were critical to achieve the required ground improvement was a reasonably competent subgrade to run the impact compactor. If the subgrade was soft then the energy of the drums would not penetrate to the greater depths.

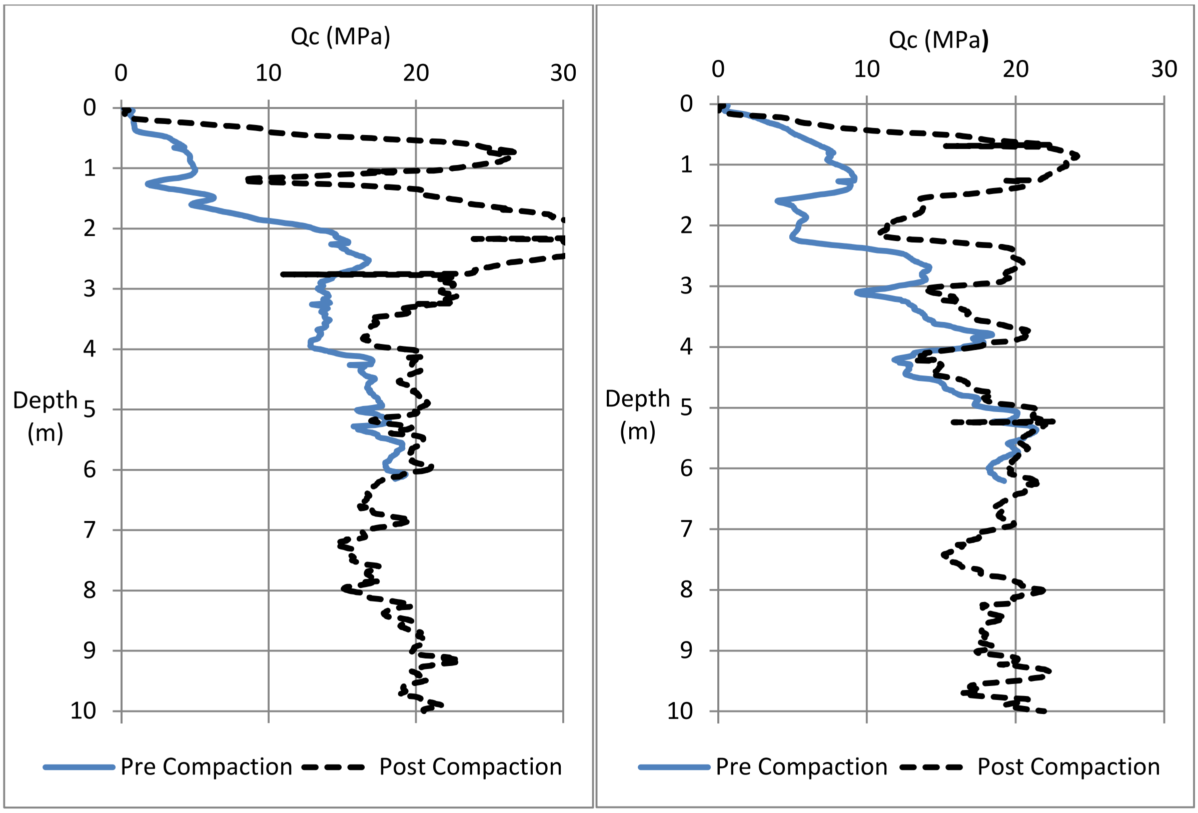

Figure 5a) and b) Two CPT profile comparisons where impact compaction was undertaken

The trials and initial impact compaction on the site was carried out on the topsoil. This proved to be a suitable subgrade until the site work extended into the wetter months and the topsoil stiffness deteriorated. In selected areas topsoil was stripped to the underlying sand and a gravel capping layer was placed. This proved a suitable working surface for the impact compactor and resulted in the some of the higher levels of densification of the underlying sand.

The use of a gravel capping layer was also required where groundwater was close to the surface to minimise pumping and weaving of the subgrade. Where there was a reasonable depth to the groundwater, such as on the dunes, the sand subgrade was wetted and compacted with a conventional compactor to form a dense layer to run the impact compactor.

Although groundwater was relatively high in parts of the site at a depth of approximately 0.5m below ground level, it did not appear to have any adverse effects on the impact compaction. The relatively permeable nature of the sand and the compaction rate, which for a large area of compaction would be approximately 10 passes in a day, allowed excess pore water pressures within the soil to dissipate. Thin organic layers, in the order of less than 200mm were present in localised areas through the project site. The presence of these organic layers did not affect the impact compaction results as the sand above and below the layer showed improvement, however there was no significant improvement of the organic layer.

8 CONCLUSION

The Prestons Subdivision case study is an example where defining the geotechnical model and liquefaction potential for the site was critical in determining the appropriate ground improvement method. The conclusions are as follows:

- The geotechnical investigation identified the site is predominantly beach and dune sand.
- The liquefaction analysis in accordance with MBIE indicated the liquefaction and technical category was governed by the shallow liquefiable layers.
- As shallow liquefiable layers were present, ground improvement of the upper soil layer was required to reduce the site liquefaction susceptibility.

- Ground improvement was carried out using an impact compactor to densify the upper soil profile.
- To confirm the likely ground improvement, field trials of the impact compactor were carried out which identified that upper 3m of the soil profile was sufficiently densified to suppress liquefaction susceptibility. Liquefaction induced free field settlements in the upper 3m were reduced in the order 40% to 90%, depending on soil type.
- Subsequent use of the impact compactor on the site has included continual quality assurance testing which includes reviewing the CIR and comparisons of pre and post CPT testing.
- To date the impact compactor has been successful in densification of the upper soil profile to allow the subdivision to be classified as MBIE TC1 equivalent.

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