Resin injection ground improvement for liquefaction mitigation at Poverty Bay Rugby Club, Gisborne

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ABSTRACT

Gisborne is located near the Hikurangi Subduction Zone which in accordance with the 2022 NSHM (i.e. the 2022 revision of the NZ's National Seismic Hazard Model) is significantly affected by subduction interface and intraslab seismic events. This increase in the seismic demand, coupled with Gisborne's wider geological/geotechnical setting consisting of potentially liquefiable sand deposits, has resulted in the need for ground treatment for larger structures across the region.

This project used Mainmark's Teretek Resin injected into the subgrade at the Poverty Bay Rugby Club Grandstand in Gisborne. The purpose of the ground treatment was to improve the ground properties such as increasing the density of the underlying sand layers and supress liquefaction triggering for a future Ultimate Limit State (ULS) seismic loading of M_w 6.4 and a peak ground acceleration (PGA) of 0.41g. The treatment depth ranged from 1.5 to 4.2 m below ground level (mbgl). The key specific targets for this project were to achieve 67% NBS (New Building Standard) with an average improvement of $q_{c1N,cs}$ (clean sand cone penetration resistance normalized to 100 kPa) of 30%, and an increase in relative density (D_R) of greater than 60%.

At the conclusion of the works, key specific targets were achieved across the injection depth range. The works met the 67% NBS target with a non-liquefiable crust being established throughout the injection zone. The results showed an average increase in $q_{c1N,cs}$ and D_R by 33% and 66% respectively. Liquefaction evaluation derived Cyclic Resistance Ratio (CRR) and Cyclic Stress Ratio (CSR) also showed a 68% increase in resistance and 16% decrease in demand respectively.

This project demonstrated that Resin Injection was an effective method for ground improvement at this site, providing liquefaction mitigation and potentially reducing the earthquake demand/load in future seismic events.

1 INTRODUCTION

Recent earthquake events such as the 2016 Kaikoura and 2010-2011 Canterbury earthquake sequences highlight the significant seismic hazard that is present in New Zealand (NZ), and the catastrophic damage that can be induced by earthquake ground motions and subsequent liquefaction. These events imposed significant impact to the cultural and economic sectors of the country, shining a light on the importance of ground improvement beneath existing structures. This subsequent ground improvement will improve the seismic resilience of new and existing infrastructure and their surrounding soils.

Gisborne is located near the Hikurangi Subduction Zone which in accordance with the 2022 NSHM (Gerstenberger, Bora, & Bradley, 2022) is significantly affected by subduction interface and intraslab seismic events. This increased in the seismic demand, coupled with Gisborne's wider geological/geotechnical setting consisting of potentially liquefiable sand deposits, has resulted in the need for ground treatment for larger structures across the region.

The Poverty Bay Rugby Club serves as a key governing body for rugby in the main Gisborne district and the surrounding area of Poverty Bay. The "Rugby Park" located at the end of Childers Road serves as the base for the ground and serves a pivotal role as the home ground for the Men's First team which competes in the National Provincial Championship currently named the "*Heartland Championship"*.

Following fundraising from the community and sponsors, Poverty Bay Rugby Club invested into redeveloping the grandstand that overlooks "Rugby Park". This resulted in a full redevelopment of the existing structure with the inclusion of an extension to the structure being built to better facilitate players, referees and other respective staff of the rugby club. As part of the redevelopment of the Poverty Bay Rugby Club Grandstand, it was identified that the ground below the proposed structure consisted of potentially liquefiable soils which would not meet the seismic NBS requirements for the structure.

% of New Building Standard (%NBS) is a high level assessment of the seismic risk of a structure compared to a building built to the current building code as presented in the Guidance for Territorial Authorities and Property Owners on Initial Seismic Assessments (MBIE, SeSOC, NZSEE, & NZGS, 2014). The guidance recommend that an NBS percentage of 67% should be targeted as there is a questionable earthquake risk deeming the structure an Earthquake Risk Building (ERB). As this requirement was not initially met, this constituted the requirement for ground improvement to mitigate / supress liquefaction triggering by creating a sufficient non-liquefiable crust, increased bearing capacity below the existing foundation depth, and in addition increase the % NBS with regards to liquefaction triggering.

For the grandstand and the wider Poverty Rugby club redevelopment, seismic strengthening over the 67% NBS is the target. The ground was potentially liquefiable and ground treatment proposed as an option to mitigate / supress liquefaction triggering by creating a sufficient non-liquefiable crust, increase the bearing capacity below the existing foundation depth, and in addition increase the %NBS with regards to liquefaction triggering.

2 GROUND CONDITIONS & TREATMENT TARGETS

Geotechnical investigations were carried out (Initia, 2020) which comprised of 1 machine drilled borehole and 7 CPT's around the existing structure. The results from these CPT's were compared and found a consistent soil profile throughout the site without significant changes in both the vertical and horizontal directions. This allowed for the CPT results to be averaged out as a baseline for all design calculations throughout the project. *Figure 1* shows the results from these initial CPT results.

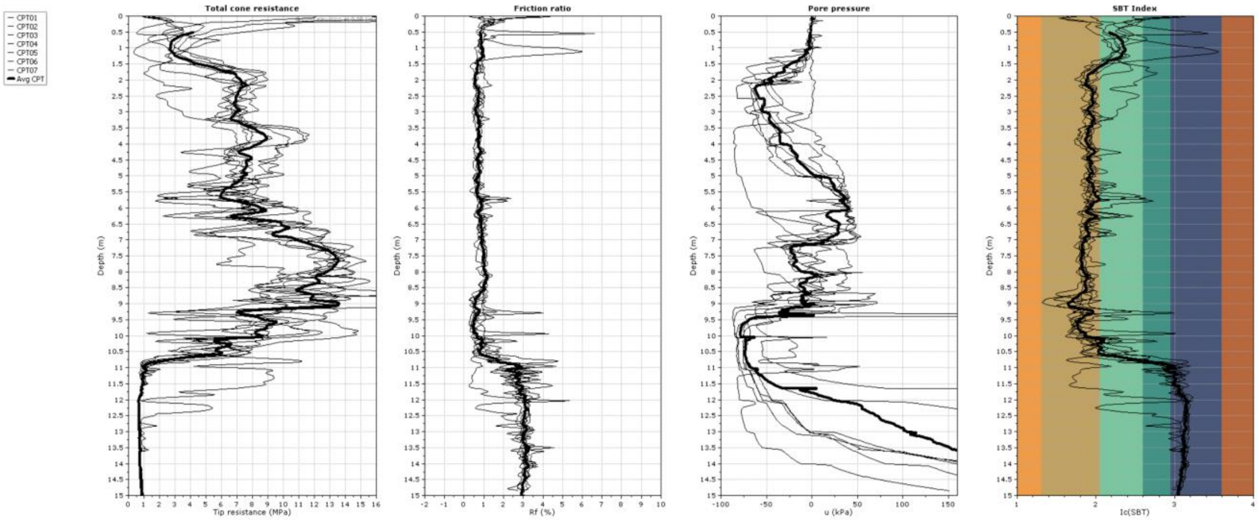

Figure 1: Initial (pre-treatment) CPT ground investigations and their derived averaged CPT trace (bold black line)

Following the testing shown in *Figure 1,* it was determined that the soil profile consisted of a layer of loose to medium dense with depth silty sand below the existing topsoils/fill, until reaching the underlying soft to firm clayey silts at a depth of approximately 11.0 mbgl. Groundwater was measured within installed piezometers to a depth ranging from 1.1 m to 1.6 mbgl. The conservative assumption of 1.1 mbgl was taken as the GWL (groundwater level) for the liquefaction triggering analysis.

The liquefaction assessment conditions were for the ULS seismic loading conditions associated with a magnitude 6.4 event and a peak ground acceleration (PGA) of 0.41g, as both proposed and confirmed by LDE. In addition, the reduction of the liquefaction triggering to levels over 67% NBS (i.e. 0.67x0.41=0.27g), with the subsequent 'creation' of a sufficiently thick non-liquefiable crust to avoid potential punching failure and increase the ground's ultimate bearing capacity are the required targets for the ground treatment.

Liquefaction triggering analysis was completed using the analysis software "CLiq" (Geologismiki, 2023). It was assumed that no liquefaction susceptibility and triggering occurred below 5.0 m. The entire length was used only for the purpose of the calculation. The B&I (2014) analysis method (Boulanger & Idriss, 2014) was used for all liquefaction analysis conducted. The results for the averaged CPT values are shown in *Figure 2*.

The liquefaction analysis in *Figure 2* shows a potentially liquefiable layer with large vertical settlements being induced of over 100 mm. These results, in conjunction with the requirement to meet the 67% NBS target mentioned previously, resulted in a design with the following specification to ensure that the initial targets of the project are met:

- Treatment depth ranging from 1.5 to 4.2 mbgl, applicable to the entire footprint or beneath individual pad foundations.
- Ground heave during treatment should be limited to less than 25 mm.
- The desired outcome is the creation of a non-liquefiable crust, ideally resulting in an additional 'improvement' of the current NBS%.
- The target for ground/liquefaction triggering is set at 67% NBS, with a post-liquefaction threshold at 0.67 times the PGA at Gisborne (confirmed by LDE as 0.41g), which equates to 0.27g. It should be noted that the 'equivalent' PGA for 70% NBS used in our verification analysis and presented herein (i.e. 0.29g).

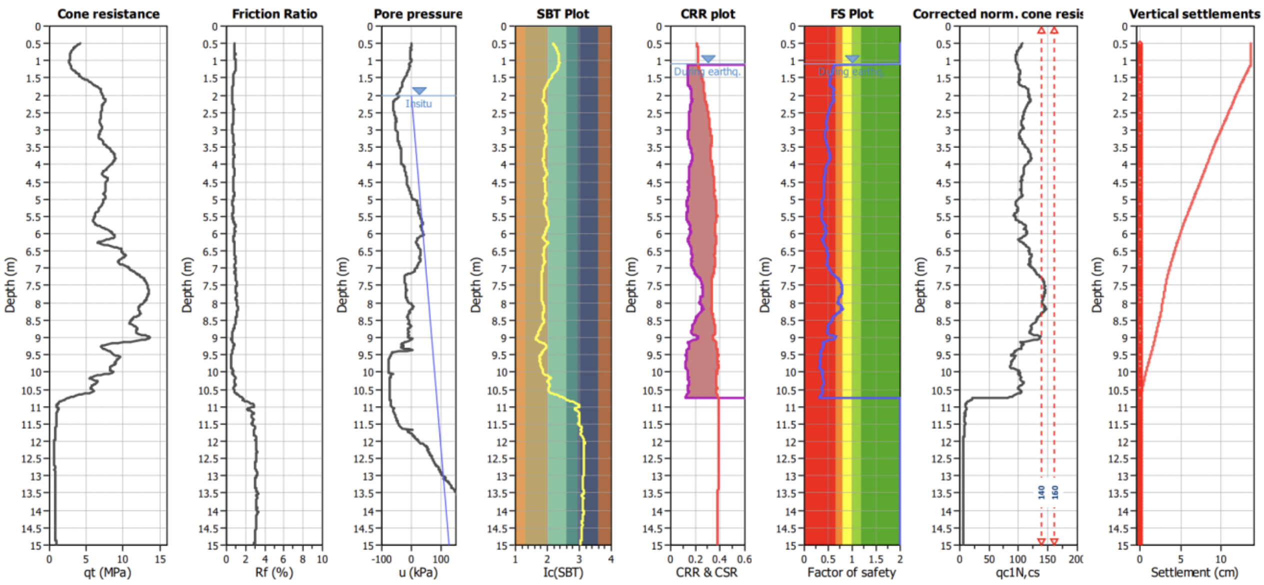

Figure 2: CLiq Liquefaction Analysis Results.

- An ultimate bearing capacity of at least 300kPa is required.
- The average target for $q_{c1N,cs}$ improvement was 30%, translating to a range of greater than 140 to 160, deemed sufficient for ground treatment within the depth of 1.5 to 4.2 meters below ground level.
- Under the adopted ULS seismic loading conditions (Mw=6.4 and PGA=0.41g), the target for 70% NBS is a 0.29g PGA, with the minimum 30% target designed to establish a 4.2-meter non-liquefiable crust.
- An increase in relative density (D_R) to a level greater than 60%.

3 PROJECT WORKS

3.1 Site Set Up and Project Constraints

Prior to the Resin Injection works, the main contractor for the redevelopment project excavated the existing grandstand's slab. This posed an issue due to the removal of the existing surcharge caused by the slab. This existing surcharge on the ground was accounted for in the design and a substitute for this had to be designed. Multiple options were considered for this including the reinstatement of a compacted fill and/or the addition of concrete blocks to provide external surcharge to the ground. The chosen solution was the combination of a compacted hardfill over the top of the excavated surface as well as a capping layer using resin injection. The capping layer was installed at a depth of 1.25 m (0.25 m above the treatment zone) and provided additional resistance for any vertical heave that could be caused by the ground improvement resin injection works.

Another constraint for the project was the inclement weather that occurred during the flood events that occurred in the region between late 2022 and mid 2023. This resulted in all works outside of the existing grandstand footprint to be exposed to the elements. To counter this issue, scaffolding with plastic wrap was constructed for the areas of the project that occurred outside of the existing grandstand . This ensured that works could efficiently continue without further disruption due to inclement weather. *Figures 3 and 4* show the site set up for the project.

Figure 3 & 4: Images of the Site Setup (Following the construction of the scaffolding - Left, During Stage 1 of Full-Scale works – Right)

3.2 Trial Works

Following the finalisation of the design to complete the works, trial works on-site commenced to verify all assumptions within the design and to ensure that the Resin Injection works would meet the specifications outlined above. The trial works were conducted in an area close to the existing grandstand and within the full-scale Resin Injection area. This location as well as pre- and post-injection geotechnical testing verified the Resin Injection for the full works. *Figure 5* below shows the injection point layout for the trial as well as the geotechnical testing locations that were conducted to verify design.

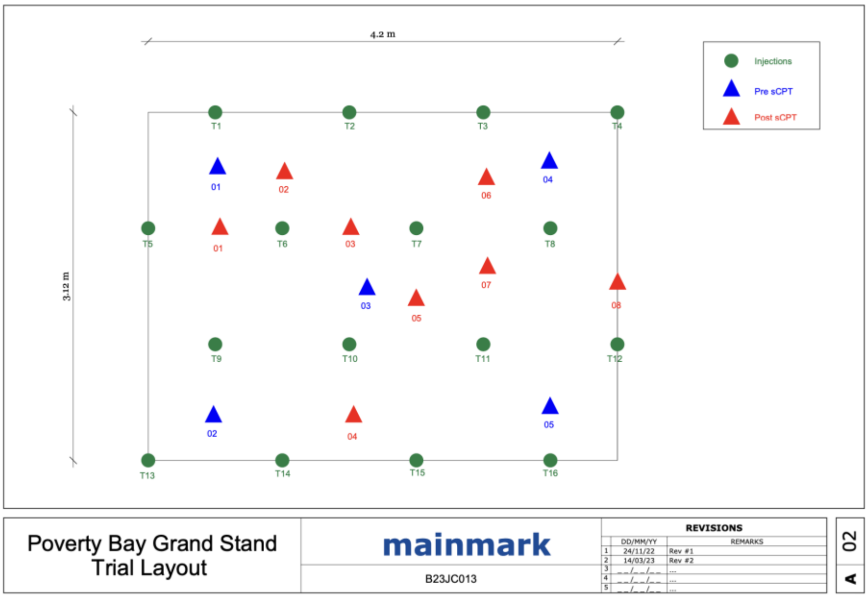

Figure 5: Trial Works Injection and Geotechnical Investigation Layout.

Following the trial works and the geotechnical investigations, it was confirmed that the methodology of resin injection between 1.5 mbgl to 4.2 mbgl was a viable solution to meet the design specifications.

3.3 Full-Scale Works

Once verification of the design was complete via the trial, full-scale works began. Full-scale works included an area of approximately 861 m^2 which split the proposed footprint of the new grandstand into four stages. For each stage of works, two pre- and post-injection geotechnical investigations were completed to ensure that the target design continued to be met throughout the project. *Figure 6* below shows the proposed staging for the full-scale works.

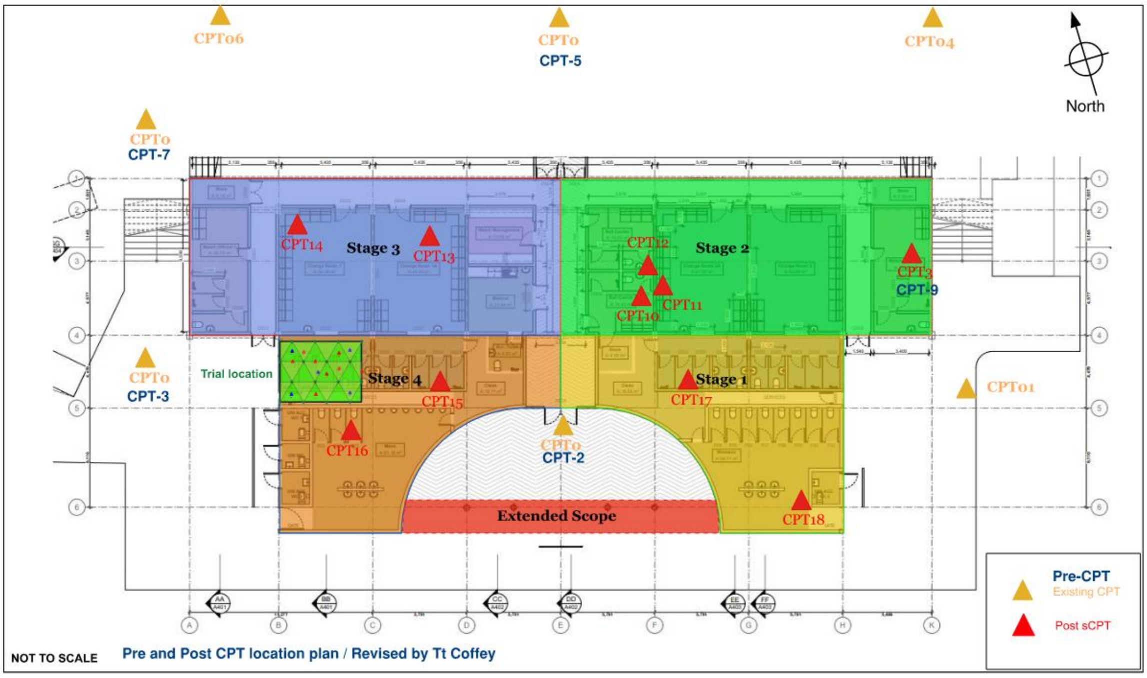

Figure 6: Full-Scale Works Staging and Existing & Post Works Geotechnical Investigation Layout.

Throughout the full-scale works, additional construction considerations had to be adhered to as specified by the design specification. This included the monitoring of heave to the structure to not exceed the 25 mm threshold set out as well as ensuring that all existing underground services are located and not damaged during works. Both of the specifications were met during the construction process with the maximum of 16 mm heave recorded for the full-scale works. This also included the successful identification and avoidance of all underground services present on-site.

4 PROJECT OUTCOMES

Following the completion of the full-scale works, the geotechnical testing that was conducted throughout the project was averaged and compared with the baseline average established with the initial CPT's conducted prior to the works. The results of the CPT's showed an increase to the specified values in the design up to the requirements. These results are shown in *Figure 7*.

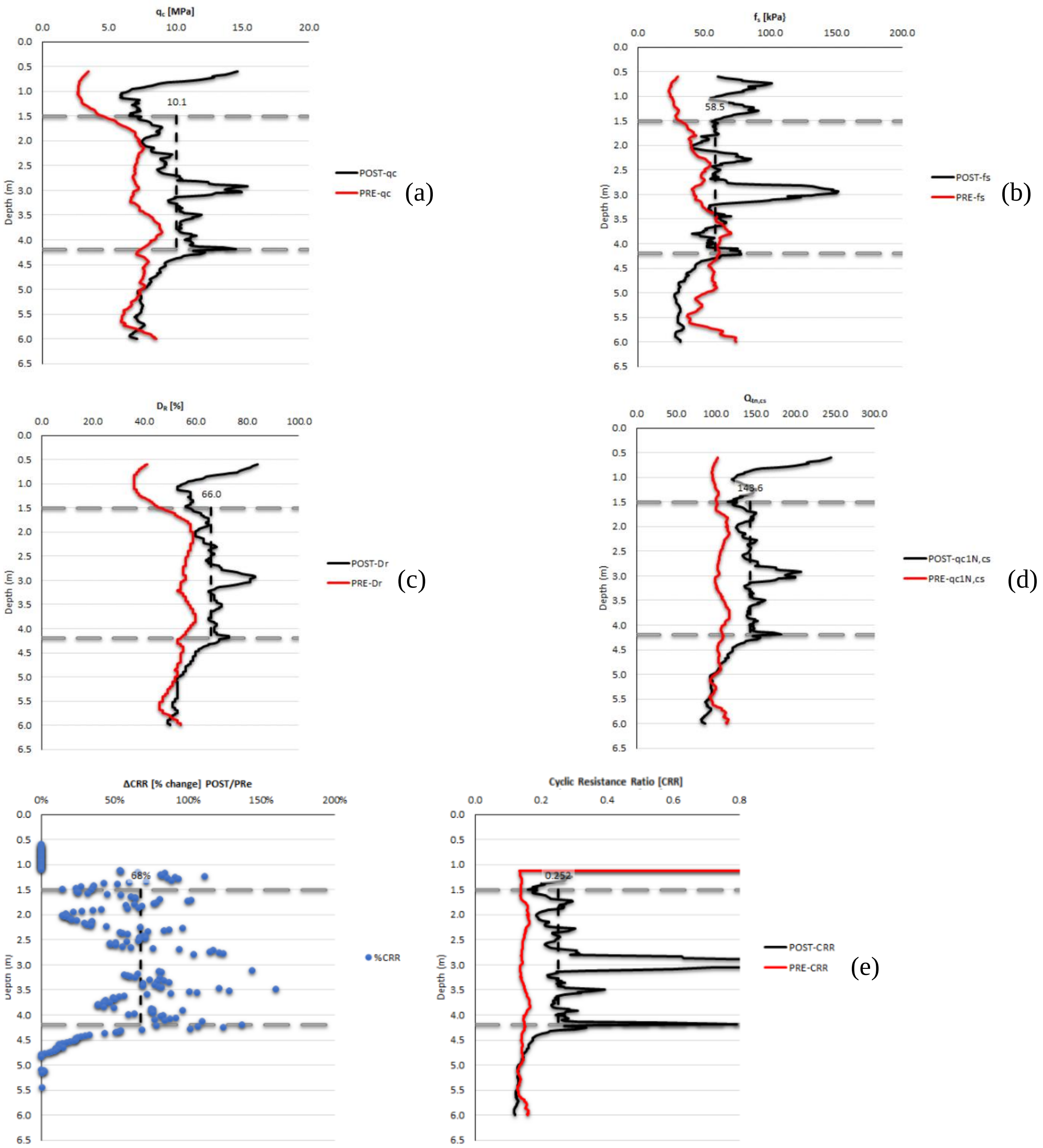

Figure 7: Comparison between pre and post treatment CPT results (a – cone tip resistance q_c, b - cone side friction f_s, c - Relative Density D_R, d – normalised clean sand cone penetration resistance $\mathbf{q_{c1N,cs}}$, e – cyclic resistance ratio CRR)

A summary of the results achieved with the Resin Injection ground improvement is set out as follows:

1. **Treatment Depth**: The treatment effectively spanned depths ranging from 1.5 to 4.5 meters, however with variable depth increments demonstrating different degrees of improvement with regards to the measured or evaluated parameters.
2. **Cone Resistance (q_c)**: Post-treatment CPTs indicated a 36% median increase in cone resistance, with average values rising from 7.2 to 10.1 MPa.
3. **Cone Side Friction (f_s)**: Measured cone side friction saw a 19% increase, increasing from 50.7 to 58.5 kPa.

4. **Relative Density (D_R)**: The ground treatment resulted in an 18% increase in relative density, elevating it from 56% to 66%.
5. **$q_{c1N,cs}$**: A 33% increase in $q_{c1N,cs}$ (clean sand cone penetration resistance normalized to 100 kPa) was observed, surging from 107.4 to 143.6, i.e. over the assumed 140 average target.
6. **Cyclic Resistance Ratio (CRR)**: The treated subgrade exhibited an average 68% increase in CRR, signifying enhanced soil capacity or liquefaction resistance, rising from 0.148 to 0.252.
7. **Cyclic Stress Ratio (CSR)**: A subsequent 15.7% decrease in CSR within the treated subgrade implying a reduction in future earthquake demand/load due to the treated ground.
8. **Non-Liquefiable Crust**: Under the assumed seismic loading conditions of 0.29g (or 70% NBS), an estimated average non-liquefiable crust within the treated subgrade was established.

These results highlighted the effectiveness of ground improvement approach using resin injection, meeting the design targets initially set out for the project.

5 CONCLUSIONS

It was identified that Gisborne was a seismic risk location due to the Hikuranga Subduction zone that is located east of the region. This in conjunction with the plans to redevelop the existing Poverty Bay Rugby Park grandstand resulted in the requirement for ground improvement to be conducted. Liquefaction analysis was conducted with the existing geotechnical investigations to identify the key design specifications. This resulted in the proposed option of resin injection. This option was required to mitigate / supress the liquefaction triggering by creating a sufficient non-liquefiable crust, increase the bearing capacity below the existing foundation depth, and in addition, increase the %NBS with regards to liquefaction triggering.

A trial was conducted to verify the Resin Injection method would adhere to the design specifications set out. Following the successful verification of this option, full-scale works commenced for the whole redevelopment footprint for the grandstand. All design specifications that were initially set out prior to the commencement of the project were met, establishing that resin injection was a viable option for ground improvement in the soil profile.

6 REFERENCES

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