Use of PANDA Dynamic Cone Penetrometer for Site Investigation following Blast Liquefaction Testing

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ABSTRACT

The PANDA variable energy dynamic cone penetrometer (DCP) is a mobile, instrumented DCP that enables rapid site investigation by one user. The PANDA was utilized in this study to measure cone tip resistance and develop site profiles at a blast liquefaction test site in Christchurch, New Zealand. The blast liquefaction testing occurred at two areas within the site. The first blast test was performed in soil that had been improved by resin-injection, whereas the second test was performed in untreated soil. Measurements were performed with the PANDA DCP prior to liquefaction and following liquefaction to evaluate changes in soil resistance as a result of liquefaction. Cone tip resistance profiles were developed for depths to 4.5 m and took approximately 30 min to complete. Results of the testing showed changes in cone tip resistance as a result of liquefaction for the untreated site where a decrease in resistance was observed. In addition, the PANDA DCP results were compared with cone penetration tests that were performed prior to liquefaction at both test areas and showed good agreement. The PANDA DCP was found to be a useful tool for site investigation following blast liquefaction tests as tests could be completed within 30 min of deployment in difficult to access areas.

INTRODUCTION

Dynamic cone penetrometer testing has been utilized for shallow investigation of soil properties for many years (Sowers and Hedges, 1966). DCP testing has been shown to be a useful alternative to conventional testing (e.g. Standard Penetration Test (SPT), Cone Penetration Test (CPT)) when site accessibility is challenging, or rapid testing is required (Green et al. 2011). Scenarios where DCP testing offers advantages in this regard are for reconnaissance following natural hazards, including earthquakes and hurricanes. Researchers have utilized DCP tests for development of site profiles and liquefaction evaluation following several earthquake events (Green et al. 2011; Green et al. 2012; Hashemi and Nikudel, 2016). Recently, advances have been made in instrumenting the DCP for ease of data collection and interpretation (Benz-Navarrete et al. 2019). Additionally, the instrumented DCP, specifically the PANDA® that was developed in the 1980s and used in this study, is capable of reaching greater penetration depths in soils than traditional DCPs. PANDA DCP data can be collected quickly (approximately 30 minutes for setup, data collection, and breakdown in this study) and viewed instantaneously, which allows for rapid site investigation and decision-making about further testing. Several studies have also compared PANDA DCP results with CPT and other in-situ tests and developed correlations that show good agreement (Benz-Navarrete et al. 2019; Benz-Navarrete et al. 2020). This paper will summarize the use of an instrumented DCP for evaluation of cone tip resistance prior to and following blast liquefaction testing. Comparisons will be made with pre-blast CPT data for the test site. PANDA DCP tests were performed within hours following blast liquefaction testing to enable investigation of the changes in soil resistance resulting from liquefaction. The maneuverability and efficient testing time of the PANDA DCP allowed for changes in cone tip resistance to be captured following blast liquefaction with minimal interference to concurrent testing performed at the site.

TEST LOCATION AND METHODS

Blast liquefaction tests were performed in Christchurch, New Zealand in December 2019 adjacent to the Avon River in an area that experienced extensive liquefaction during the 2010-2011 Canterbury Earthquake Sequence (Cubrinovski, 2013; Bastin et al. 2015). The testing site is shown on the map in Figure 1 in relationship to the general Christchurch area. Figure 2 shows the specific test locations of PANDA DCP tests that were performed at the site, which consisted of fine sand and silt. The groundwater table was located at a depth of 1.1 meters. There were two different blast liquefaction tests that were performed: one in resin-injected soils to evaluate performance of ground improvement and one in the native soils. The blasting was conducted in a circular setup with a diameter of approximately 10 m. The treated and untreated blast circles were approximately 28 m apart (center to center). There was a significant amount of field testing equipment that was used to capture the response of the site (pore pressures, shear wave velocity, dilatometer, LiDAR mapping); however, the focus of this paper will be on the PANDA DCP tests to evaluate pre and post liquefaction soil stiffness.

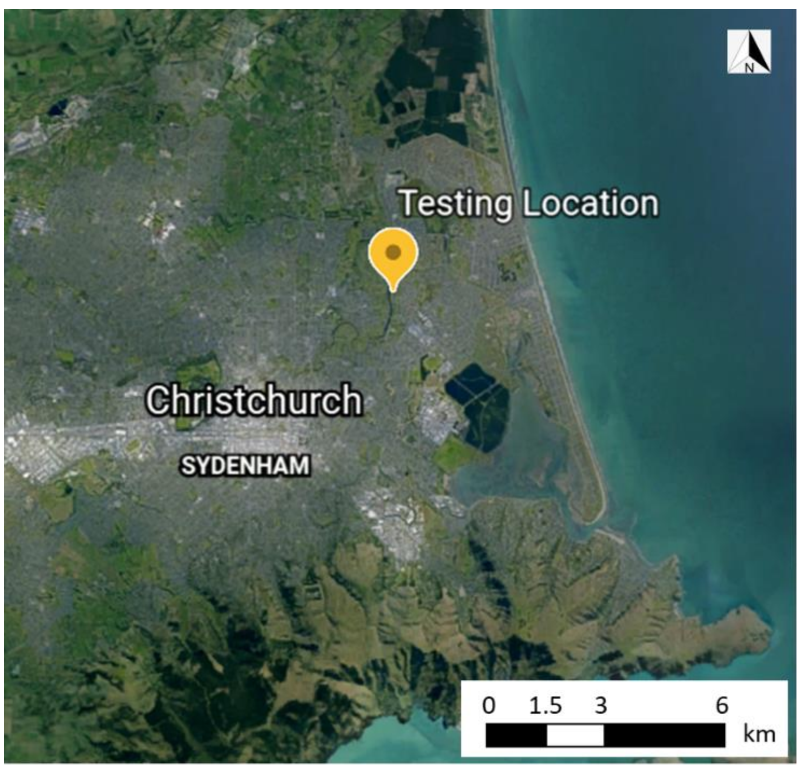

Figure 1. Test Site in relation to Christchurch Region (Map data © 2020 Google)

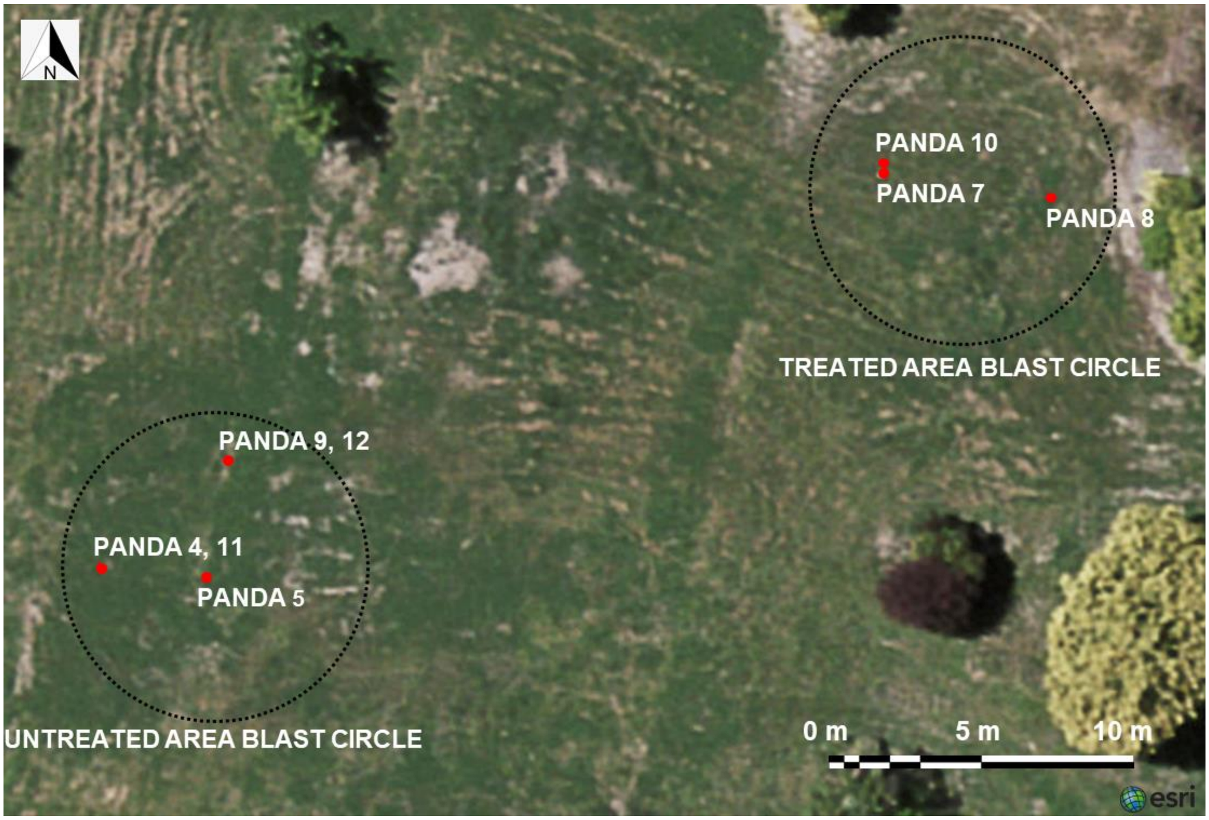

Figure 2. Site of Blast Testing and PANDA DCP Testing in Christchurch, NZ (Esri, 2019)

The PANDA DCP is an instrumented dynamic cone penetrometer that can be utilized to develop site profiles for near surface soils. The typical operating depth range for the PANDA is between 4 to 6 meters when the hammer is user operated. The PANDA is lightweight, with a total equipment weight of 18.5 kg, which makes it attractive for use in difficult to reach areas or for rapid testing following natural hazard events. The case and all equipment can be carried to the testing location by an individual user, which enabled quick access to the test location following the blast. The equipment consists of a driving cone (2 cm^2 or 4 cm^2), a small tablet that displays real-time blow results and site profiles, a 1.7 kg hammer, an anvil for striking with the hammer, a central acquisition unit which measures rod movement and guides the rods in a vertical manner, ten 50 cm long rods, and a mechanical rod extractor. The PANDA can be easily operated by one user, and tests generally took about 30 minutes, including setup and rod retrieval from the ground, to perform the test and view relevant data. In this investigation, the PANDA reached depths to 4.5 meters at the site, which consisted of fine sand and silt. The PANDA proved to be efficient in terms of maneuverability and testing time, which allowed for tests to be performed following blasting that could not have occurred with a larger test rig. The test site had a significant amount of instrumentation, which would have made it very difficult to perform a penetration test with a larger test rig following the blast when data capture is critical to understanding the effects of elevated pore pressures on soil stiffness. The PANDA tests were performed within hours of the blast; however, tests could have been performed even sooner if prioritized over other post-blast testing at the site (e.g., shear wave velocity measurements). Additionally, the profiles could be viewed instantaneously to make decisions about subsequent testing. Figure 3 shows the PANDA in use at the test site.

Figure 3. PANDA DCP in use following Blast Testing

PANDA DCP SITE PROFILES

PANDA DCP tests were performed at both the untreated and treated areas at the test site prior to and following blast liquefaction. The post liquefaction tests were performed on the same day, several hours after the blast. Results are presented for the PANDA in terms of depth versus q_d which is the dynamic cone tip resistance, and is given by the following Dutch formula:

$$q_d = \left(\frac{1}{A}\right)\left(\frac{E}{e}\right)\left(\frac{1}{1+\frac{P}{M}}\right)$$

where A is the cone area, E is the variable energy from each blow, e is the measured depth of each blow, P is the weight of the driven system into the soil (including anvil, rods, and cone), and M is the weight of the hammer. The value of q_d is reported in units of MPa in this study.

A total of 8 PANDA tests were performed (5 at the untreated site and 3 at the treated site). Data is presented for tests that compare the DCP with CPT performed at both areas prior to blasting (Figure 4), the pre liquefaction resistance at the treated and untreated areas (Figure 5), the pre and post liquefaction resistance at the untreated area (Figure 6), and the pre and post liquefaction resistance at the treated area (Figure 7).

Figure 4 presents a comparison of the PANDA DCP and CPT performed prior to blast testing. DCP cone tip resistance (q_d) can be directly compared to CPT cone tip resistance (q_c), and several studies have developed correlations between q_c from the CPT and q_d from the DCP. Benz-Navarette et al. (2020) summarized comparisons between 107 CPT and 187 PANDA DCP tests and developed empirical relationships for the correlation of q_c/q_d. The minimum relationship from the data produces a q_c/q_d value of 0.71, while the maximum relationship from the data produces a q_c/q_d value of 1.22. Therefore, directly comparing the cone tip resistances of the PANDA and CPT should show similar results, which indeed was the case when observing the cone tip resistances in Figure 4. The untreated area shown in Figure 4a matches very well for the CPT and PANDA DCP throughout the entire 4 m penetration depth of the DCP. The untreated area had an average q_c/q_d ratio that was 0.72. The treated area shown in Figure 4b shows slightly more variability below 2 m depth. The treated area had an average q_c/q_d ratio of 1.20. The increased q_c/q_d ratio for the treated area may be due to the inherent variability of the soil improvement technique. Overall, the q_c/q_d ratios observed in this study fell within the range reported by Benz-Navarette et al. (2020).

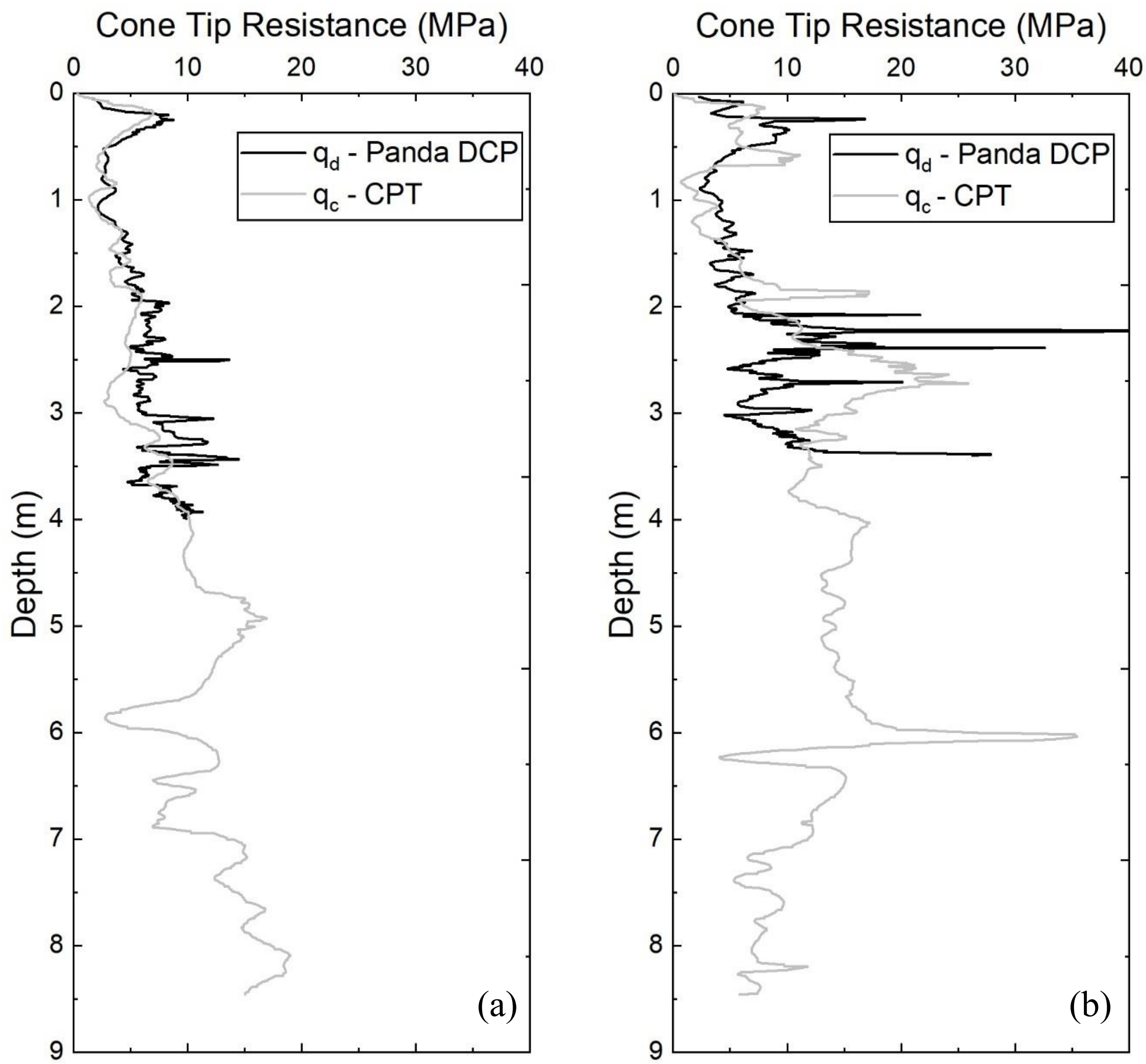

Figure 4. Comparison of PANDA DCP with CPT at (a) Untreated Area and (b) Treated Area

Figure 5 shows the cone tip resistance at the treated and untreated areas prior to blast liquefaction. This data serves as a baseline to the differences in measured resistance due to the resin-injected improvement technique that was utilized for the treated area. Figure 5 shows that the treated area has slightly higher resistances, specifically with spikes in resistance seen below the depth of 2 meters. The cone tip resistance was similar in the depth range from 0 to 2 meters.

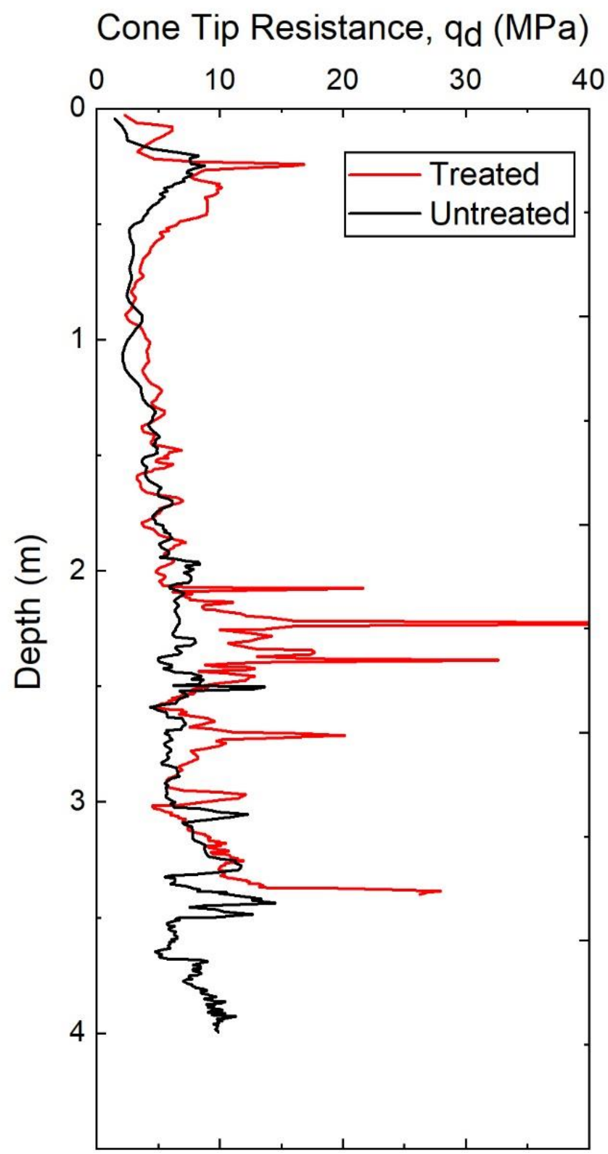

Figure 5. Comparison of Treated and Untreated PANDA DCP Profiles

Figure 6 shows the cone tip resistance at the untreated area prior to and following blast liquefaction. The profiles show that the untreated area saw a decrease in cone tip resistance between the depths of 1 to 4 meters following the blast. It was observed that the untreated area liquefied following the blast test and the results show that the stiffness of the site also decreased. A greater decrease in measured q_d was seen below 3 meters (approximately 50-75% decrease) compared to the 1 to 3 meter range where a percent decrease in q_d of approximately 50% or less was observed.

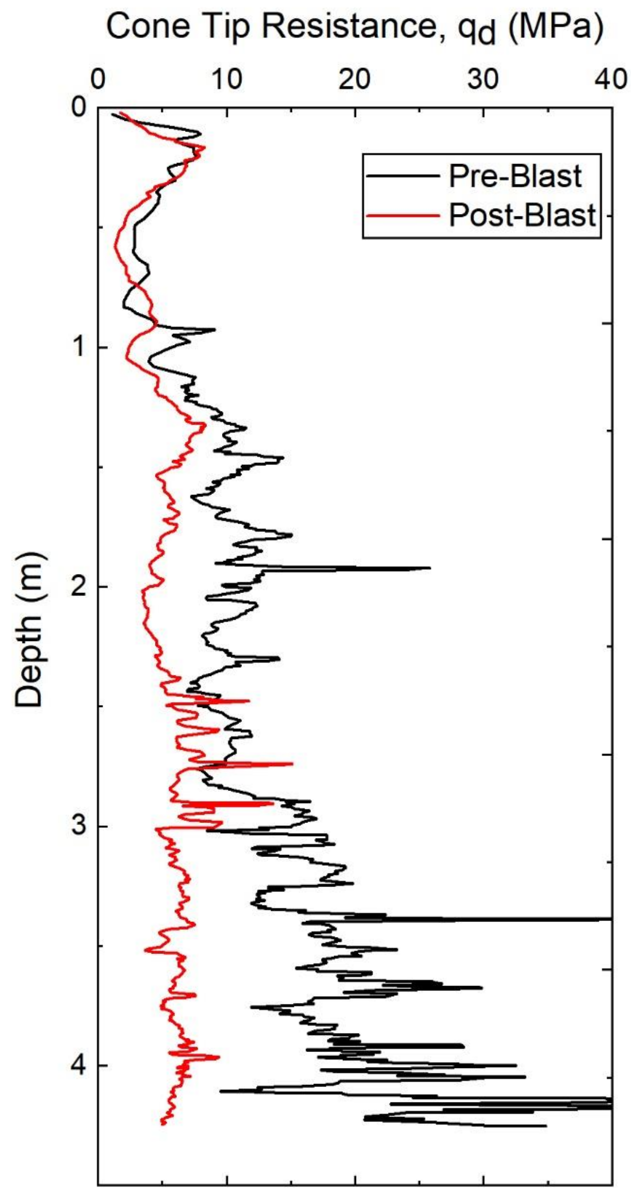

Figure 6. Comparison of Pre and Post Blast Liquefaction PANDA DCP Profiles for Untreated Area

Figure 7 shows the cone tip resistance at the treated area prior to and following blast liquefaction. It was observed that the treated area liquefied following the blast test, but the results show that the stiffness of the soil did not significantly change. For practical purposes, the profiles can be considered to be the same. This shows that the resin-injection had an effect on the performance of the soils during and following the blast test as there was not a decrease in resistance as seen in Figure 6 for the untreated soils.

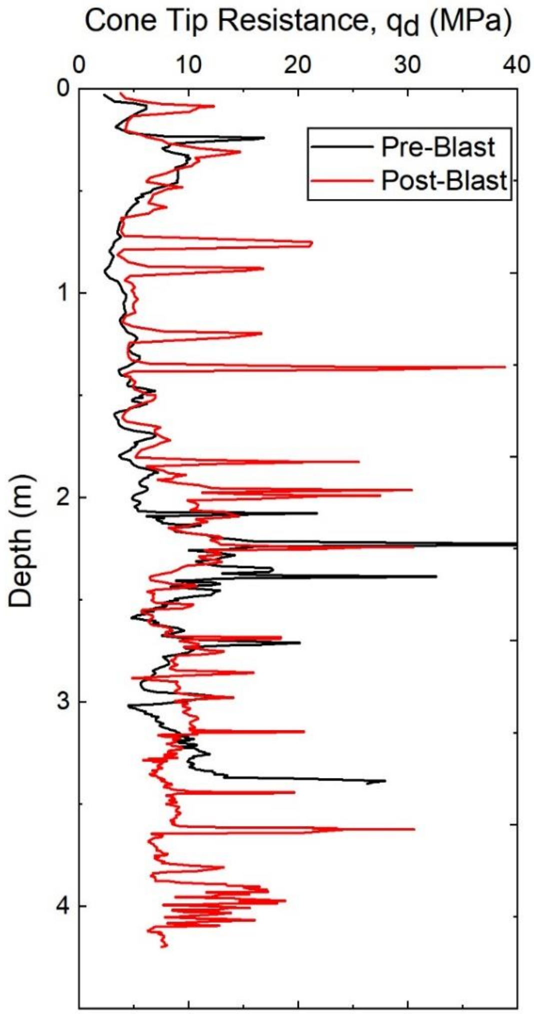

Figure 7. Comparison of Pre and Post Blast Liquefaction PANDA DCP Profiles for Treated Area

SUMMARY AND CONCLUSIONS

An instrumented PANDA DCP was utilized for site investigation prior to and following blast liquefaction testing in Christchurch, NZ. The blast test program included two areas at the test site, one area for native soil testing and one area for resin-injected soil testing. PANDA tests were performed in both testing scenarios. The results for cone tip resistance of the PANDA tests produced similar results to CPT performed prior to blast liquefaction testing, agreeing with existing literature. Pre and post blast cone tip resistance results showed that the treated site did not change in stiffness (i.e., cone tip resistance) as a result of blasting, while the untreated site saw a significant decrease in cone tip resistance following blast induced liquefaction. The PANDA DCP was found to be a useful tool for site investigation following blast liquefaction tests as tests could be completed within 30 minutes of deployment in difficult to access areas. The maneuverability and efficient testing time of the PANDA DCP allowed for changes in soil stiffness to be captured following blast liquefaction with minimal interference to concurrent testing performed at the site.

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