A Case Study of Ground Improvement Using Impact™ Piers Method

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ABSTRACT
This paper presents the case study of ground improvement using *Impact Pier*™ soil reinforcement at the Chilliwack General Hospital in southwest British Columbia, Canada. The subject structure is a post-disaster 2-storey emergency room addition to the existing hospital. Subsurface stratigraphy consists of a “firm to stiff” silty clay to clayey silt which extends to 1.5 to 3 metres below ground surface, overlying a “very loose to compact” silty sand/ sand that extends to 4.3 to 5.2 metres. Below this depth a “compact to very dense” sandy gravel to gravelly sand was encountered. The ground water level was observed at 2.7 to 3 metres below ground surface. The loose to compact silty sand was found to be potentially liquefiable. The subject Impact Pier soil reinforcement method was utilized to improve the properties of the liquefiable layer at the subject site.

RÉSUMÉ
Ce papier présente l'étude d’un cas d'amélioration du sol en utilisant le renforcement de sol Jetée d'Impact MD à l'Hôpital général de Chilliwack au sud-ouest de la Columbie-britannique au Canada. La structure en question est une section d’urgence de deux étages utilisée en cas de désastre ajoutée à l'hôpital existant. La stratigraphie de la sous-surface se compose d'une couche de glaise limoneuse à limon glaiseux "solide à rigide" qui s'étend de 1,5 à de 3 mètres sous la surface, au-dessus d’une couche de sable limoneux / sable "très desserré à compact” de 4,3 à 5,2 mètres sous la surface. Sous cette couche, on retrouve un gravier sablonneux / sable caillouteux “compact à très dense”. Le niveau de la nappe phréatique est de 2,7 à 3 mètres sous la surface. On a déterminé que le sable limoneux était potentiellement liquéfiable. Le renforcement de sol Jetée d'Impact MD été utilisé pour améliorer les propriétés de la couche liquéfiable sur le site en question.

1 INTRODUCTION

Soil liquefaction has always been a significant issue during earthquakes when pore pressure may build-up and cause loss of shear strength of soil. In this case, lateral displacement and vertical settlements may occur which damage buildings, roads and other structures. During the last few decades, many ground improvement methods have been developed to prevent pore pressure build-up during earthquake, most of them are based on densifying, reinforcing and draining the potentially liquefiable materials. Many differing techniques can be used to accomplish this, including stone columns and Rammed Aggregate Piers. This paper describes a project where Rammed Aggregate Piers were installed using the ‘Impact Pier System’.

2 BACKGROUND

Chilliwack General Hospital has been in service for many years. The subject building is an addition to the existing hospital and consists of a new 2 storey post-disaster emergency room and lab building. This project will modernize and improve the physical environments in the emergency department and ambulatory care areas.

The site is generally underlain with a series of interbedded, fluvially deposited clayey silt, sand, sand and gravel and silt materials (Figure 1). The clayey silt encountered from the surface to a depth of approximately 1.5 to 3 metres is considered to be potentially compressible and represents a foundation design consideration. The underlying sand/ sand and gravel materials are inferred to be generally compact to dense. However, there are seams of saturated, loose material present within these deposits that represent a seismic design consideration which can be addressed by performing ground improvement in the form of densification using either Vibroflotation or rammed aggregate pier solutions including Impact Pier™ methods.

A reinforcement and densification design has been prepared by *Horizon Engineering Inc.* that addressed the material identified as potentially liquefiable. Deformation analyses for post-liquefaction lateral displacement and vertical settlement were carried out to compare the effect of densification. This analyses show that by improving the top 5 metres of soil media and reducing the potential of liquefaction, post-earthquake deformations decrease significantly to an acceptable range[3]. From a structural point of view, the building maintains serviceability after the design magnitude earthquake.

3 IMPACT™ PIER METHODOLOGY

Rammed Aggregate Pier solutions using the Impact Pier system is a patented technology that uses vertically forced displacement technology, attempting to densify and reinforce loose and weak soil below groundwater, including loose sand, silt, clay, mixed soil layers, and

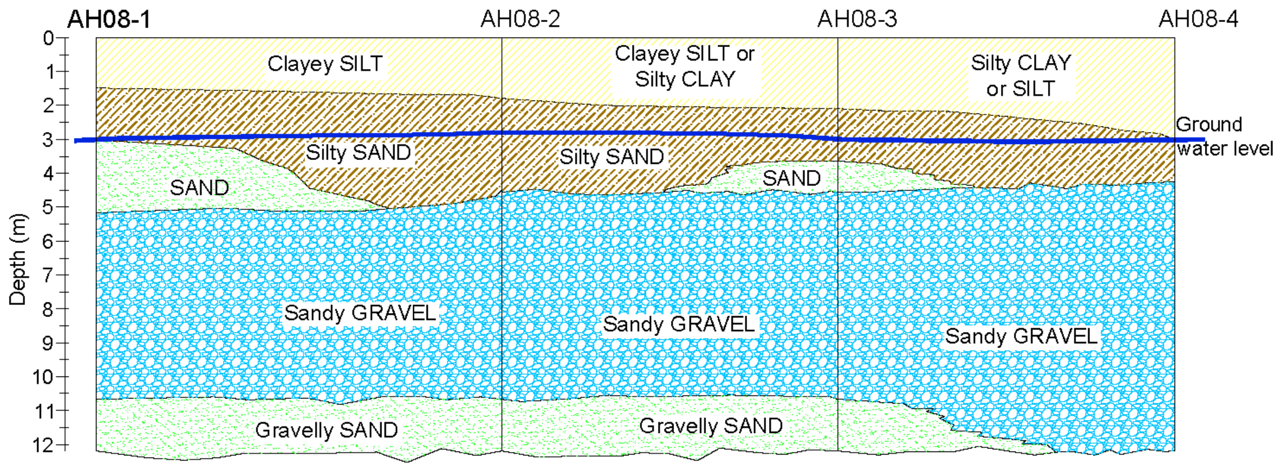

Figure 1. Schematic soil profile in the subject site.

uncontrolled fill. Vertical impact energy combined with downward crowd force effectively drives the steel casing into the soil and also constructs a dense aggregate column and improves the surrounding soil.

The unique installation process displaces soil during installation and utilizes vertical impact ramming energy to construct Rammed Aggregate Pier (RAP) elements. RAP solutions are intended to provide total and differential settlement control and increase bearing support to meet project requirements.

1. The cavity is created to full depth by driving a specially designed mandrel and tamper foot using a large static force augmented by dynamic vertical impact energy. Tamper foot diameters vary from 0.3 to 0.4 m and depths normally range from about 2 to 14 m, depending on design requirements. This method eliminates spoils as all penetrated soils are displaced laterally. A sacrificial cap prevents soil from entering the tamper foot and mandrel.

2. After driving to design depth, the hollow mandrel serves as a conduit for the placement of aggregate. The aggregate is placed inside the mandrel and the mandrel is lifted, leaving the sacrificial cap at the bottom of the pier. The tamper foot is lifted approximately 1 m and then driven back down 0.7 m, forming a 0.3 m thick compacted lift. Compaction is achieved through static force and dynamic impact energy from the hammer. The hammer densifies aggregate vertically and the beveled tamper foot forces aggregate laterally into cavity sidewalls. It is envisaged that this results in coupling with surrounding soils and settlement control. The full displacement piers also lead to densification increases in soils which are densifiable.

3. Following installation, RAP elements reinforce slopes and embankments, support shallow foundations, floor slabs and tank pads. The intent of the elements is also to attract stress, resulting reduced settlements.

This method has already been used in Europe and the United States; however, since the subject site was the first project in Canada utilizing the Impact Pier methodology for ground improvement, Horizon Engineering Inc. designed a test section to evaluate the performance of this method prior to proceed to installation of all piers.

4 TEST SECTION

The most common footing in the subject project is a 1.2m*1.2m footing with contact pressure of 130 kPa which is defined as an "F1 Type Footing". To assess the performance of Impact Pier system, a test program was arranged in which, 9 piers were installed at a portion of site; one of the piers was installed at the centre of an F1 type footing location. A full scale load test was carried out in an effort to assess the performance with respect to soil reinforcement and improved bearing capacity. Eight surrounding piers were installed to provide ground improvement with respect to reducing the potential for liquefaction. A Lock-Block loaded platform (1.2m*1.2m) was used to represent the loading conditions similar to those expected at a F1 type footing under Serviceability State Loading conditions. This loaded platform's settlement was monitored for 48 hours and an immediate settlement of 5mm was measured. No time dependant settlement was observed. The 5mm settlement magnitude is acceptable. Figure 2 illustrates test section layout.

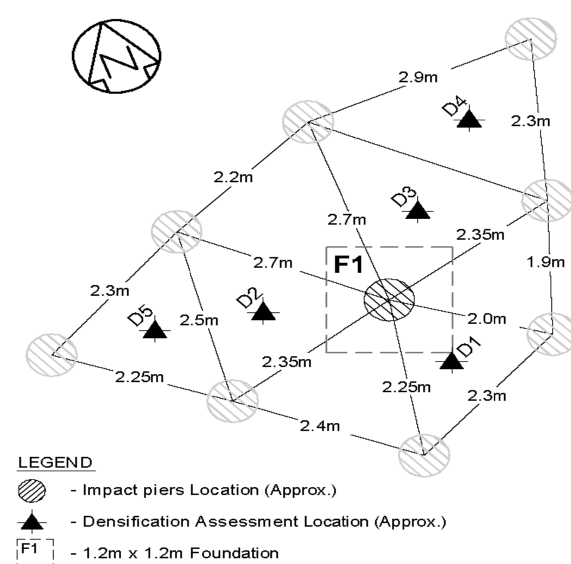

Figure 2. Test section layout.

Also five auger holes and five DCPT soundings were carried out within the extent of this test section to investigate the effect of installing piers on soil compactness. The results are presented in Figure 3. As it implies, DCPT blow counts (N_{60}) after installing piers are between 20 to 470 percent higher than before, which represents satisfactory densification. The data indicates that cleaner sands gain more improvement than silty sands and fine grained soils.

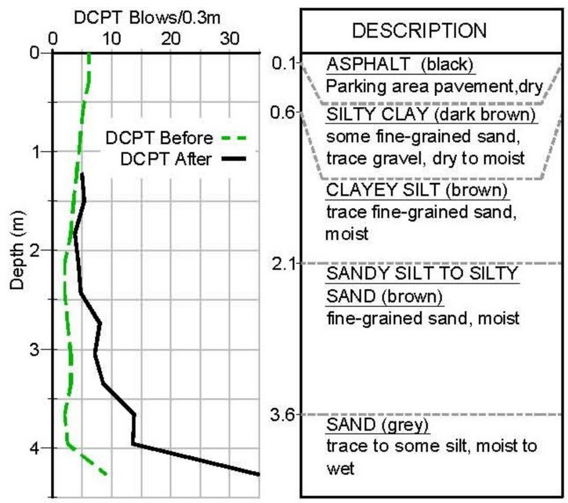

Figure 3. Comparison of average DCPT blows/ft before and after installing piers at Test section.

5 PIERS INSTALLATION

Pier layout prepared by Horizon Engineering comprises a triangulation of 440 points within the subject site with main focus on footing locations.

A specialty contractor *(Rapid Impact Piers Ltd.)* was retained to install the Impact piers. During installation, length of piers and volume of gravel used for each pier were measured; Average pier diameters were then calculated. Actual length of each pier depended on the depth of sandy gravel layer at which point mandrel installation stopped in practice. Pier installations occurred during a period of 15 working days.

Using this field data, spatial distribution of length, average diameter, volume of gravel and date of installation for each Impact Pier are presented in Figure 4. As it can be seen, average pier diameter is about 650 mm to 750 mm with minimum and maximum values of 530 mm and 830 mm. Average diameter of each installed pier can be considered as an indication of local soil density before installation; The bigger is the diameter, the less is the compactness of intact soil.

Shortest piers installed on west side (vicinity of existing hospital) were 3.05 m and longest piers mostly on south-east were 4.90 m in length. Figure 4-b shows that very dense sandy gravel layer is generally deeper on east and south east of the subject site, resulting in longer Impact piers to reach this layer.

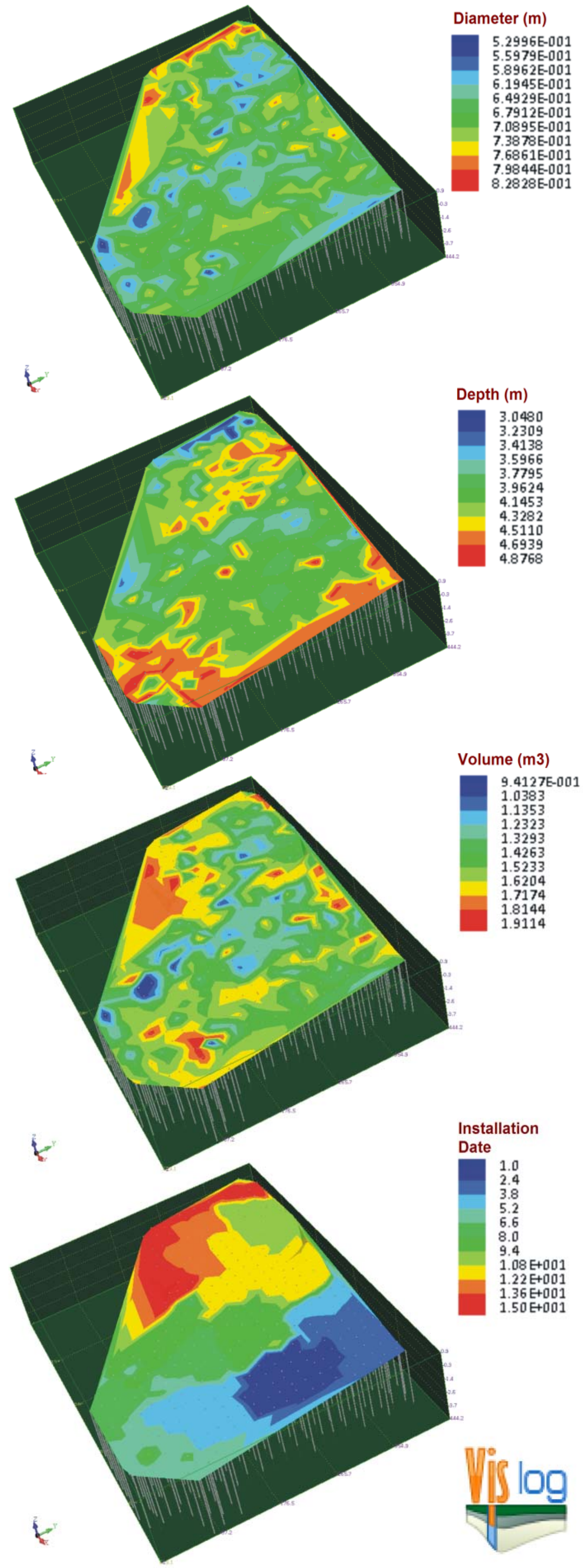

Figure 4: variation of Impact Piers characteristics across the site.

6 QUALITY CONTROL RESULTS

Eight quality control auger holes and eight DCPT soundings were carried out after installing about 200 piers to assess the performance. According to the role of fines content in liquefaction assessment, sieve analyses tests were carried out on samples taken from the auger holes to obtain percent fines and choose an appropriate design curve for target DCPT blows/ft. Laboratory tests show that most of the samples taken from 1 m to 3.5 m of depth, have at least 35 percent of fines content.

Figure 5 compares the DCPT blows/ft (N_{60}) before and after ground improvement with required DCPT blow counts/ft according to design specification. Satisfactory improvement of DCPT blows/ft is observed for most depths whereas DCPTs are close enough to design specification curve between 1.5 m and 2.5 m in which soil consists of silt and silty sand.

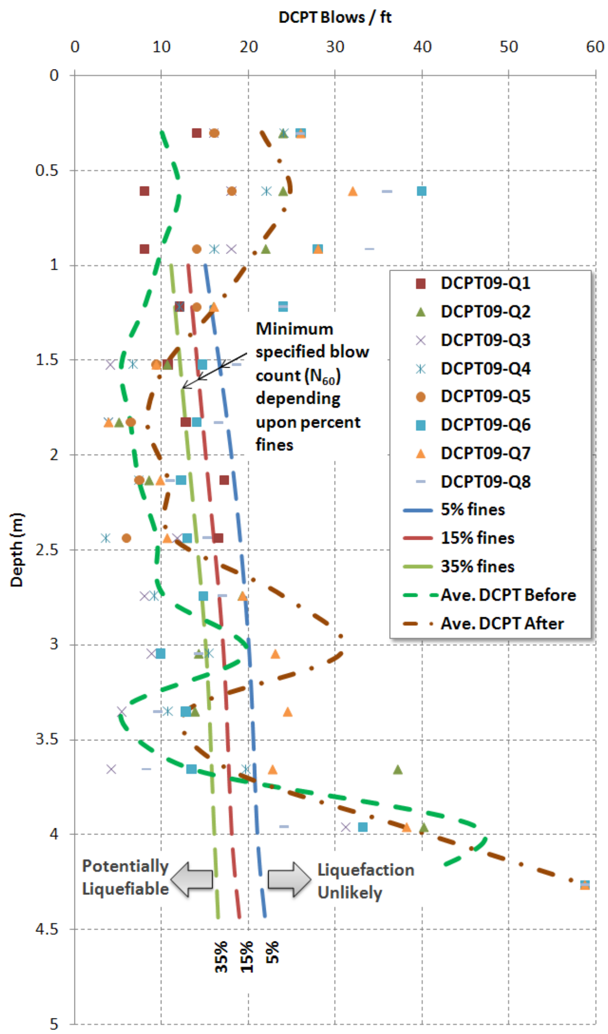

Figure 5. Average DCPT blow counts/ft before and after ground improvement across the site.

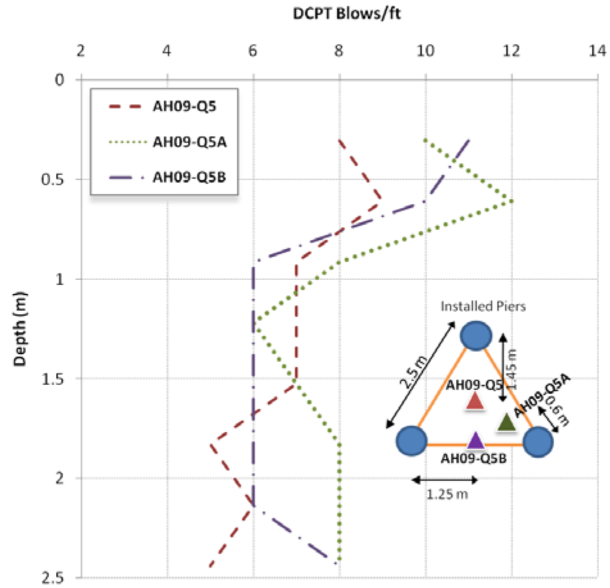

Figure 6. Effect of distance from piers, on soil compactness.

A sensitivity study was also carried out at a triangular grid of Impact Piers to assess the effect of distance from installed piers on soil compactness by performing 3 DCPT soundings with minimum distance of 1.45m, 1.25m and 0.6m from piers, shown as AH09-Q5, AH09-Q5A and AH09-Q5B on Figure 6 respectively. As it implies, soundings at 1.45m and 1.25m distances do not clearly differentiate; while sounding at 0.6m shows higher DCPT values comparatively to the two other soundings.

7 CONCLUSION

According to this case study, the Impact Pier system is a fast ground improvement methodology which increases soil bearing capacity and the ground density. Also, crushed gravels used as the material for installing piers, provide good hydraulic conductivity which can reduce the susceptibility of the soil to liquefaction by preventing pore pressure build-up. The bottom feed method of placing the crushed gravel greatly reduces uncertainty regarding the location of the gravel placement.

Results of this case study show that coarse grained materials gain better improvement rather than fine grained soils.

Impact Pier is considered as an effective method for ground improvement against liquefaction. The vertical elements can be relied upon to attract stress and reduce settlement.

8 ACKNOWLEDGMENT

For the purpose of visualization of data in this paper, *Novo Tech Software Inc.* (www.novotechsoftware.com) has improved their existing *VisLog* software to add

required features for importing and visualizing Impact Piers installation data.

Information regarding Rammed Aggregate Pier™ technology including the Impact™ Pier system has been extracted from websites of *Geopier Foundation* Company, Inc. and *Rapid Impact Compactors Ltd.* (www.geopier.com , www.rapidimpact.ca).

9 REFERENCES

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