EVALUATING THE IMPROVEMENT FROM IMPACT ROLLING ON SAND

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Abstract

Impact rolling, utilising a non-circular towed compaction module to improve ground characteristics, has been used for many decades over a wide variety of applications in various parts of the world. Although the methods and principles of rolling dynamic compaction are well established, verification methods vary widely.

Site and ground conditions are described for an industrial property in Sydney, Australia. The geology comprises Botany Sands, which are uniformly graded, poorly cemented, fine to medium grained quartz sands. Former structural footings and underground tanks had disturbed the ground to a depth of 1-2m over parts of the site. Ground conditions were initially investigated with trial pits, boreholes and Standard Penetration Tests.

Ground improvement with the “square” impact roller was selected in order to produce a denser more uniform sub-grade for the proposed site re-development, suited to the construction of light industrial structures supported on shallow footings, with ground-bearing floor slabs and conventional pavements. The more costly and time-consuming alternatives would have been piled foundations and, possibly, suspended floor slabs, or the necessity to backfill excavations with engineered fill and re-work existing fill.

Immediately prior to and after impact rolling, sonic piezo-cone tests were carried out. Dynamic cone penetrometer tests were utilised by the supervising geotechnical engineers to monitor the effects of the impact roller, and surface settlements were also measured. Ground vibrations and the response on adjacent structures were monitored.

The depth of ground improvement is seen to reach at least 3m below the surface. The Improvement Index for Densification (I_d), which is related to the specific energy of penetration computed from the cone penetrometer tip resistance before and after impact rolling, is used to quantify the degree of ground improvement.

1 Introduction.

A relatively small industrial property in Banksmeadow, on Sydney's Botany Sands, has been subjected to ground improvement using the "square" impact roller, avoiding any conventional compaction other than for the under-slab finishing layer. Impact rolling, providing deep in situ compaction achieved by a non-circular module, has been in use for more than 20 years [1].

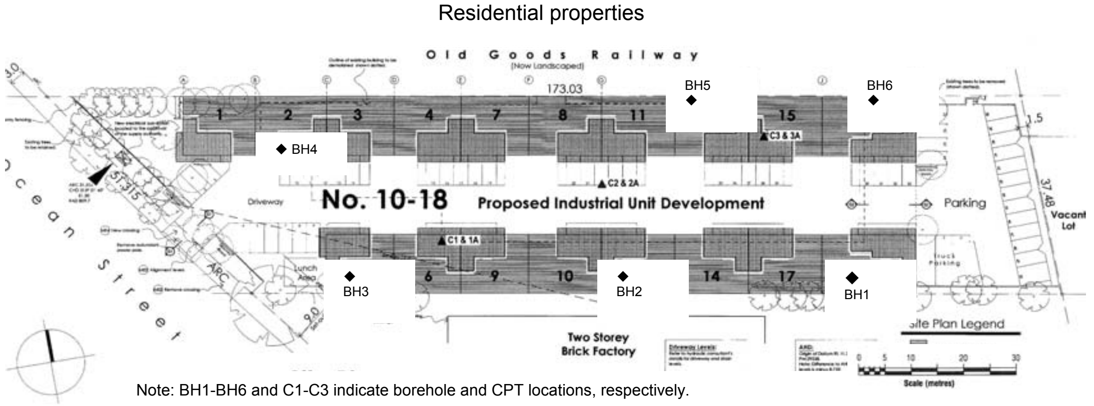
The site posed constraints with its former underground tanks, fill and existing adjacent industrial and neighbouring residential buildings. A range of penetration tests was carried out to characterise the site before, during and after impact rolling, supported by borehole and trial pit data, and the monitoring of settlement and vibrations.

2 Site Description And Ground Conditions.

Banksmeadow, near Sydney's major international airport and close to Botany Bay, includes industrial land, some of which has a relatively long history of contaminative use, particularly in the chemical and petrochemical industries. Many sites in this area are undergoing remediation and are being re-developed.

The geology of the area is dominated by Quaternary sediments, the most prominent of which is the Botany Sands, which consists of uniformly graded fine to medium sized quartz grains, with an average thickness of 15m [2].

The subject of the case study for this paper is a former industrial site, approximately 38m by 150m. The layout of the proposed development is illustrated in Figure 1, along with site investigation locations referred to later in the text.



Note: BH1-BH6 and C1-C3 indicate borehole and CPT locations, respectively.

Figure 1. Plan showing development layout.

The site was subjected to borehole and trial pit investigations, with Standard Penetration Tests (SPT) [3]. Borehole locations are indicated in Figure 1. Former underground tank pits were excavated (see Figure 2).

Figure 2. View of site facing north, showing former tank farm excavation prior to backfilling. (Note the proximity of existing residences.)

Apart from a thin layer of crushed concrete spread to give a working base, there was some sand fill of limited thickness and the tank excavation was also backfilled with sand. Essentially, the soil profile is sand in the upper 6-8m (and deeper), which exhibited an increasing strength with depth, particularly below the water table (4-4.6m). Table 1 summarises the soil profile at the site.

Depth Range (m)	**Description**
0-0.2m	Fill - crushed concrete
0.2-1.4m (approx.)	Fill - sand (generally 0.5-1.4m deep, locally to 2m at former tank farm)
1.4-8m+	Sand: Loose, becoming Loose to Medium Dense, becoming Medium Dense, becoming Dense
4.0-4.6m	Groundwater table

Table 1. Summary of ground conditions.

The results of the SPTs carried out in the boreholes are illustrated in Figure 3. As is evident, the relatively lower densities in the upper zone (of most significance for shallow footings and pavements) and general variability in relative density at any particular depth, indicate the likelihood of significant differential settlements under the building, floor and traffic loads associated with the new development.

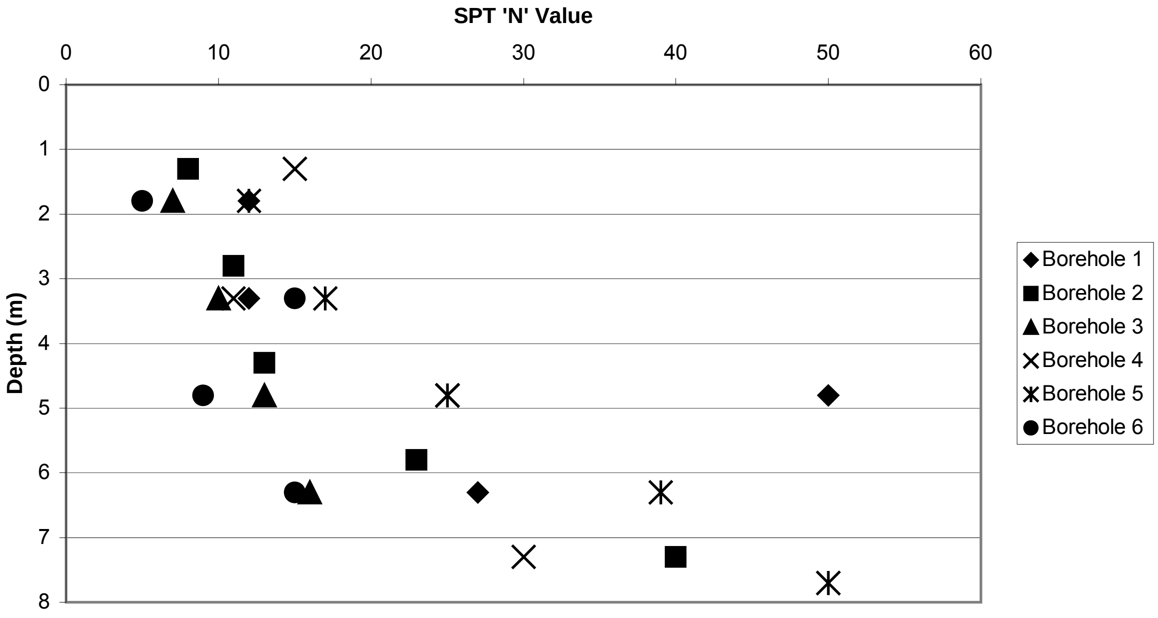


Figure 3. Initial (pre-improvement) SPT results.

The decision was made to apply ground improvement using the Broons BH-1300 "Square" Impact Roller. The objective was to produce a denser and more uniform foundation zone to support shallow footings, ground-bearing slabs and pavements, with potential differential settlements within acceptable tolerances.

The specification for impact rolling was to perform at least 20 passes in conjunction with settlement monitoring and geotechnical testing using the dynamic cone penetrometer (DCP) and the friction-cone penetrometer (CPT). In view of the proximity of existing nearby structures, a brick factory building within 3m of the southern boundary and residences about 15m to the north, vibration monitoring was undertaken.

3 Impact Rolling, Settlement Monitoring And Vibration Monitoring.

Impact rolling was carried out in September 2004, with work along the southern boundary restricted to Saturdays to minimise possible disturbance to weekday workers from vibrations due to the proximity of the building to the rolling area. Figure 4 shows impact rolling and other site activities in progress.

Figure 4. Facing south, impact rolling in progress. Note CPT rig on left, with geotechnical and vibration monitoring personnel near the southern boundary.

Settlement monitoring was carried out using robotic total station equipment. At the start the surface was trimmed and levelled, and then every five passes of the impact roller, the surface was lightly graded to even out indentations from the "square" module and level readings were taken on a regular grid. The results were averaged for the whole site and plotted against the number of passes. It was noted that the northern half of the site underwent more settlement than the southern half, so the data for those areas were also plotted separately. All three graphs are illustrated in Figure 5.

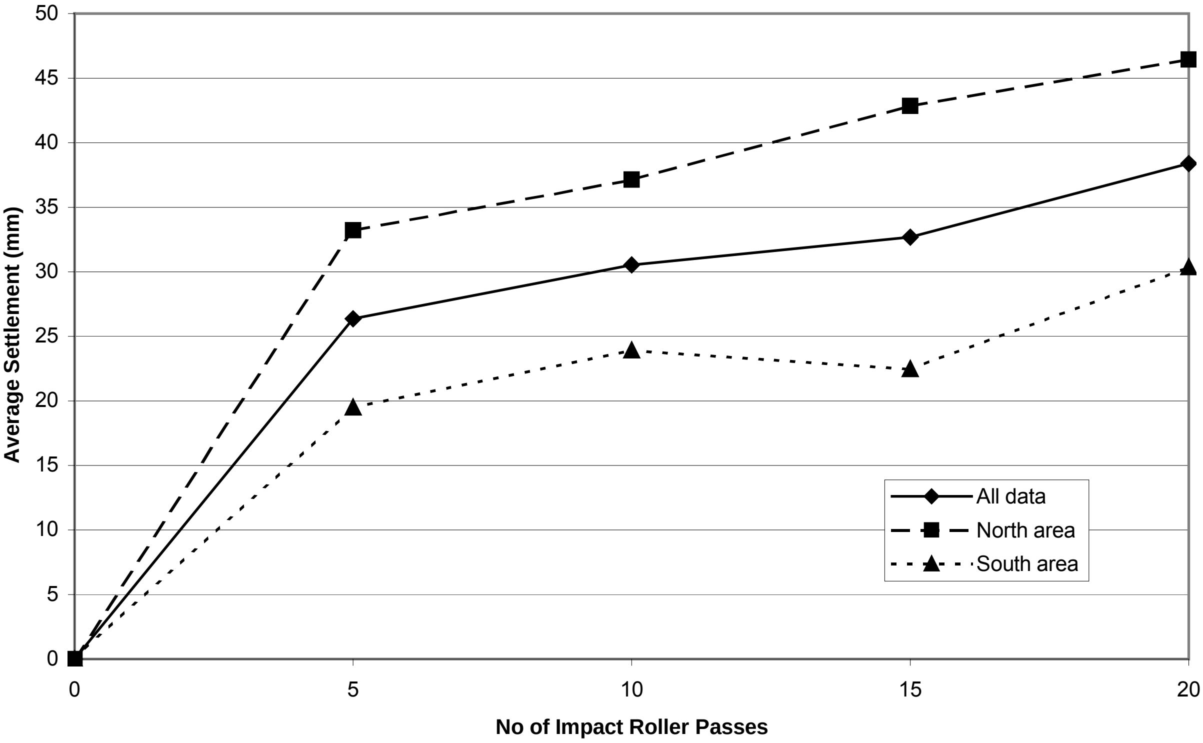


Figure 5. Surface settlements during impact rolling.

The main reason for the evident difference in settlement between the two halves of the site would appear to relate to past use. Entrance to the site is at the south-west corner and the former driveway for truck access ran along the southern side of the site, with the tank farm and the former building occupying the central and northern areas. As can be seen from Figure 5, most of the settlement at this site occurred during the first 5-10 passes. Although continuing to settle at 20 passes, the rate of settlement had reduced significantly. The effect of the impact module is to "rearrange" the surface material during impact rolling, sometimes resulting in actual or evident "heave" (i.e. negative settlement) at one or more levelling points – this can be seen for the 15 pass average in the "South area", but the overall magnitude of incremental settlement after the first 5 passes is relatively small for this part of the site and a best-fit curve would reflect a reducing rate of positive settlement, on average.

The impact roller module imparts blows at the rate of approximately two per second, generating surface waves radiating out from each impact. The magnitude of the wave and its potential for distress is measured on the ground surface or on the side of the building and reported as peak particle velocity in mm/s. The local authority responsible for building approvals in this area placed limitations on acceptable vibrations for both the industrial building to the south and the residences to the north, and vibration monitoring was consequently carried out throughout the impact rolling activities. The vibrations were measured as the impact roller moved progressively from the centre of the site towards each side, and site-specific distance limits were established during the work so as not to exceed the nominated vibration limits. Impact rolling approached as close as 5m from the industrial building, approximately 2m within the site boundary, while treatment was possible to the northern boundary edge, being approximately 15m from residential buildings.

4 DCP And CPT Output.

The DCP used for this work was the "Perth Penetrometer", a 16mm diameter flat-tipped rod driven by a 9kg mass dropping 600mm [4]. The blows are recorded for each 150mm of penetration. Tests were undertaken at various locations before, during and after impact rolling. The results of each group of DCP tests carried out before impact rolling, after 10 passes and at the end, after 20 passes, respectively, have been averaged and are presented in Figure 6.

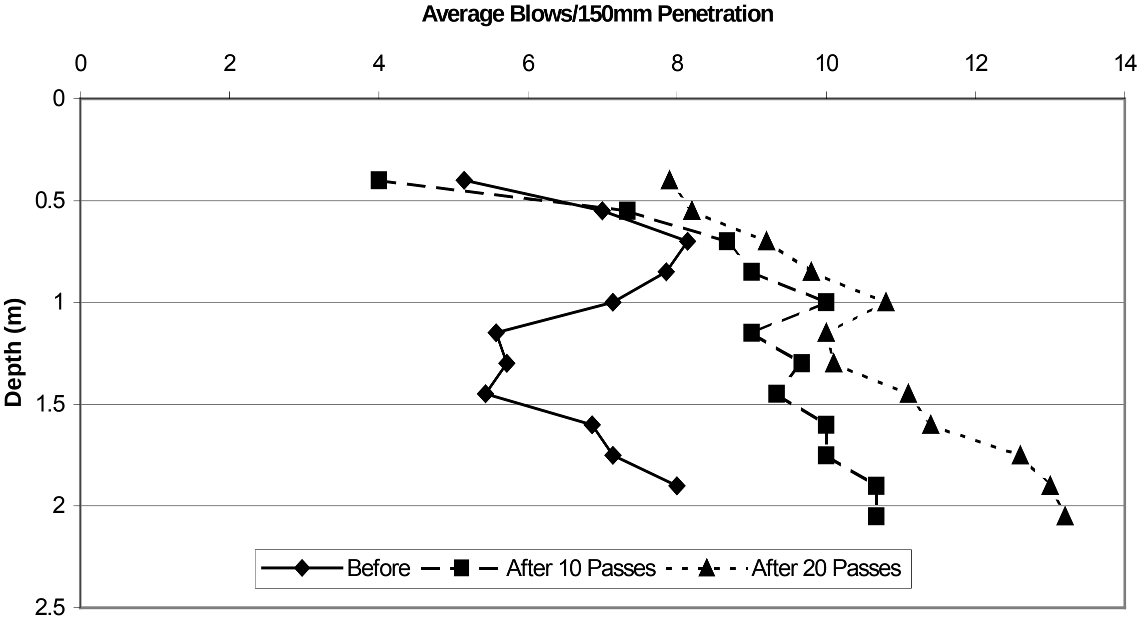


Figure 6. Summary results of Perth Penetrometer DCP tests.

The results in Figure 6 reflect a significant increase in penetration resistance, or ground strength, below 0.5m, to at least the 2m depth limit of these tests.

CPTs were carried out at three locations, diagonally across the site (see Figure 1), prior to impact rolling, using a sonic piezo-cone penetrometer. The test essentially follows the standard method for electrical cones [5]. At location C1, the test was repeated after 5 passes, and at locations C2 and C3 after 20 passes, with each repeat test offset approximately 0.5m from the original location.

The CPT output confirmed a sand profile to the depth tested (maximum depth 6.5m), with groundwater at 4.2-4.5m. The comparative graphs for cone tip resistance, q_c, are shown in Figure 7.

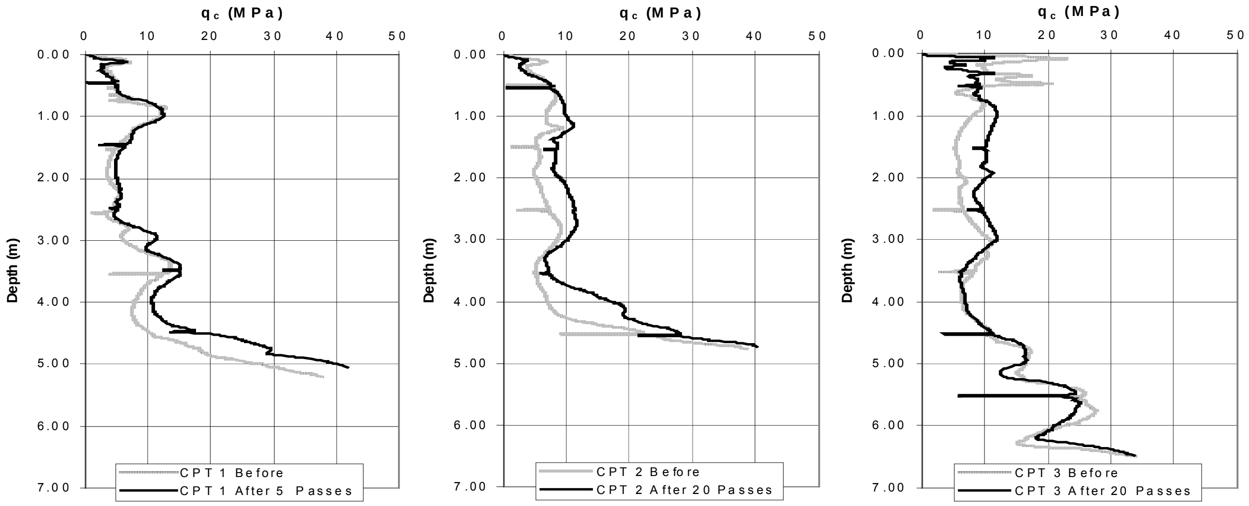


Figure 7. CPT tip resistance graphs for locations C1, C2 and C3.

It is evident from the comparative graphs in Figure 7 that there is an improvement in strength after impact rolling. At location C1, after only 5 passes, there appears to be a slight increase in tip resistance from about 0.5m to over 3m, with the divergence below 3.5m possibly due to local stratigraphic variability. The effect of 20 passes of the impact roller is seen to produce a significant improvement at both locations C2 and C3 from a depth of approximately 0.5m to more than 3m. Cone tip resistance increases from around 5MPa to around 10MPa in this zone of improvement. The sleeve friction graphs show a similar trend, with a more uniform and significantly higher sleeve friction between those depths. A reduction in strength is sometimes evident in the upper zone to about 0.3-0.5m, which reflects the disturbance of the impact module on the layer of crushed concrete that was placed as a running surface for construction plant and the impact roller – final pavement construction always requires a conventional roller for the sub-base and base courses.

5 Analysis Of CPT Data.

The degree of ground improvement reflected by the CPT tip resistance data has been evaluated in terms of the Improvement Index for Densification (I_d) [6]. This method utilises the specific energy of penetration of the CPT, as represented by the tip resistance, q_c. I_d is a normalised parameter relating the initial and final states of the site, $q_{c\text{-before}}$ and $q_{c\text{-after}}$, respectively. The index is defined as:

$$I_d = \{(q_{c\text{-after}})/(q_{c\text{-before}})\} - 1$$

The improvement zone in this case study is above the groundwater table, so correction for pore pressure is not required. The disadvantage of this definition, however, is its sensitivity to sudden changes in q_c with depth due to small-scale changes in stratigraphy on each profile. Dove et al [6] propose an alternative definition using the area under the tip resistance profile:

$$I_d = (A_{after}/A_{before}) - 1$$

where A_{before} and A_{after} are the areas under the pre- and post-improvement q_c graphs, respectively. They can be computed by numerical integration of a series of trapezoidal segments for a depth interval, say, Δx, as follows:

$$A = (\Delta x/2)(q_{c1} - q_{c2})$$

where q_{c1} and q_{c2} are the two adjacent values of q_c a depth Δx apart. Figure 8 shows the profiles of I_d for the three CPT locations at this site, for which a depth increment Δx = 2cm was utilised.

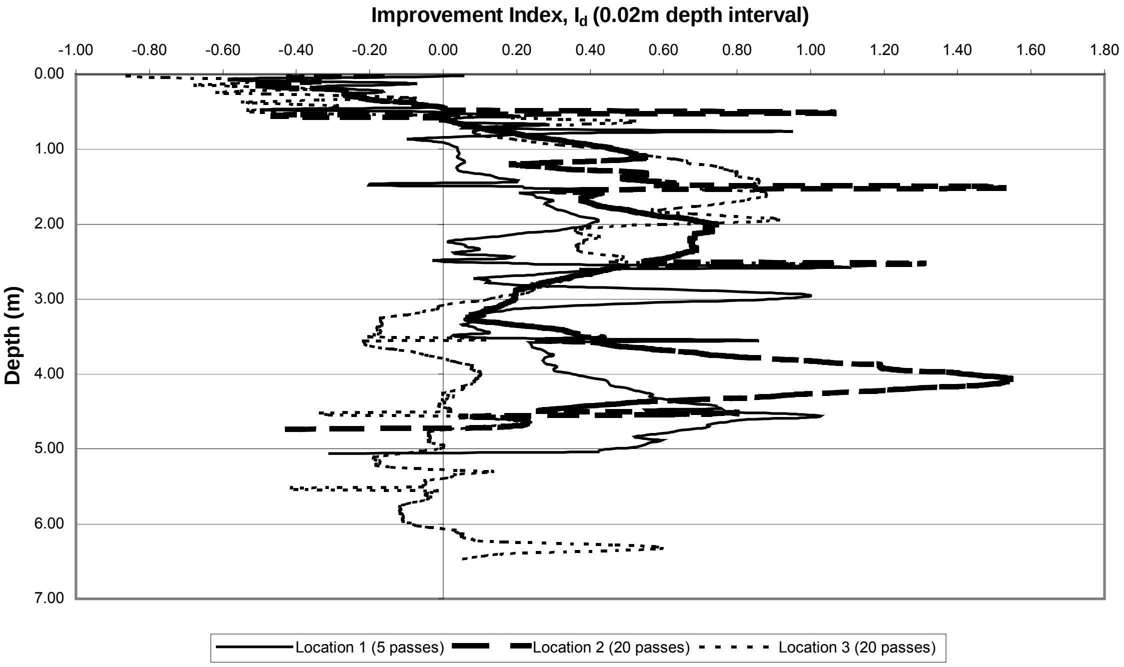


Figure 8. I_d profiles for a 0.02m depth interval.

As is evident in Figure 8, there is significant improvement, with I_d generally positive to at least 3-5m, fluctuating as high as 1.5. In order to reduce the sharp fluctuations in the profile, Figure 9 has been produced showing the average I_d per 0.5m depth interval.

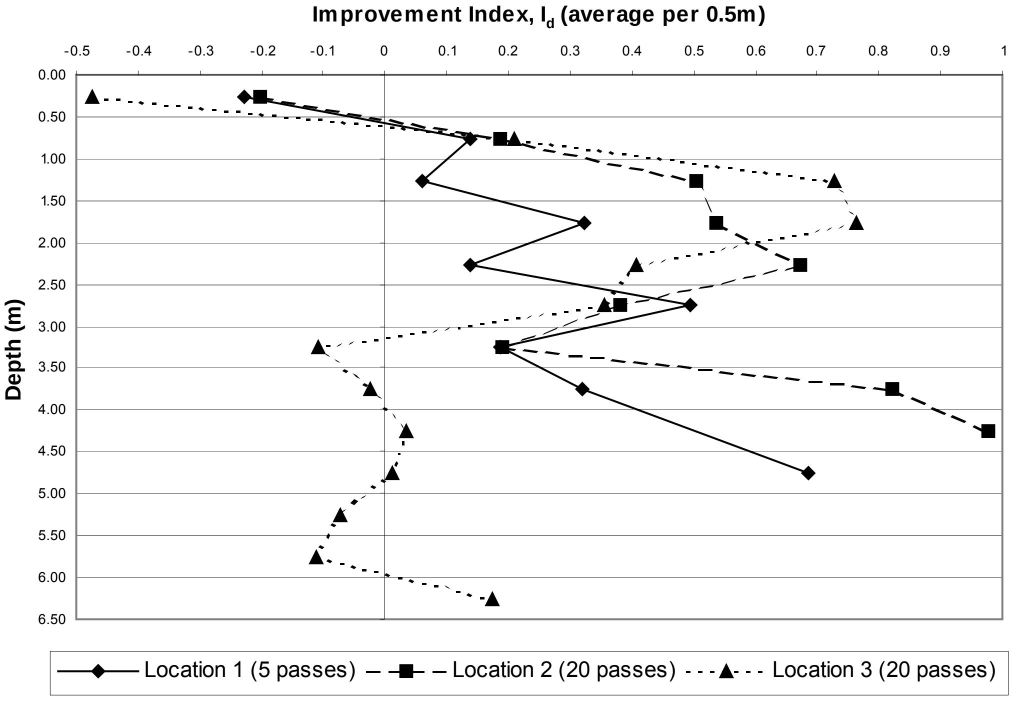


Figure 9. I_d profiles for a 0.5m depth interval.

Figure 9 shows an I_d of about 0.2 in the improvement zone for the location 1, which had 5 passes at the time of the second test. Very similar I_d profiles are seen for locations 2 and 3 (20 passes) to a depth of about 3m, with Id values in the range 0.2-0.75. The calculated average I_d values for the depth range 0.5-3m are 0.23 for location 1 (5 passes) and 0.46 and 0.49 for locations 2 and 3 (20 passes), respectively. Locations 1 and 2 continue to reflect improvement below 3m, although variations in local stratigraphy due to test location offsets may account for some of that difference.

6 Conclusions.

The use of a specific energy concept for the assessment of ground improvement due to impact energy would appear to have some merit. The Improvement Index for Densification (I_d) can be computed from CPT profiles, and increasing the averaging depth interval can smooth the sharpness of profile variation. At this stage, the I_d values, while giving clear indications as to the depths of significant improvement in ground strength in sand soils, provide no link to engineering design parameters or performance specifications. Relationships between the I_d and other field tests, surface settlements and ground vibrations warrant further investigation.

7 Acknowledgments.

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8 References.

[1] Avalle, D. L. (2004). Ground improvement using the "square" Impact Roller - case studies. 5th International Conference on Ground Improvement Techniques, Kuala Lumpur.

[2] McNally, G. H., and Branagan, D.F. (1998). An overview of the engineering geology of the Botany Basin. Environmental Geology of the Botany Basin. Eds. McNally, G. H., and Jankowski, J. Sydney, Conference Publications: 1-23.

[3] Australian Standard AS 1289.6.3.1-2004. Methods of testing soils for engineering purposes - Soil strength and consolidation tests - Determination of the penetration resistance of a soil - Standard penetration test (SPT).

[4] Australian Standard AS 1289.6.3.3-1997. Methods of testing soils for engineering purposes - Soil strength and consolidation tests - Determination of the penetration resistance of a soil - Perth sand penetrometer test.

[5] Australian Standard AS 1289.6.5.1-1999. Methods of testing soils for engineering purposes - Soil strength and consolidation tests - Determination of the static cone penetration resistance of a soil – Field test using a mechanical and electrical cone or friction-cone penetrometer.

[6] Dove, J. E., Boxill, L.E.C., and Jarrett, J.B. (2000). A CPT-Based Index for Evaluating Ground Improvement. Advances in Grouting and Ground Modification, Geo-Denver 2000, Denver, Colorado, ASCE.