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Full Length Research Paper

Improvement in physical properties for ground treated with rapid impact compaction

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Ground improvement has been used on many construction sites to densify granular material, in other word to improve soil properties and reduce potential settlement. This paper evaluates the efficiency of rapid impact compaction (RIC), which is an improvement on the process of deep dynamic compaction, in improving soil properties and controlling soil settlement. In this technique ground improvement is achieved by impacting the ground with a 7 ton weight, 35 times/min, and drop height of 0.8 m at 2.5 m c/c square grid spacing. Evaluation of improvement in soil properties was based on field data by comparing pre-treatment and post-treatment cone penetrometer test (CPT) soundings. An interpretation of soil properties from CPT was made using interpretation software to assess the degree of improvement achieved. Load test was conducted to estimate soil settlement. It was found that the RIC succeeded in improving soil properties like relative density from 45 to 70%, increase the friction angle of soil by an average of 3° and reducing soil settlement criteria by 50%.

Key words: Rapid impact compaction (RIC), granular soils, physical properties, ground improvement, *in-situ* testing, soil compaction, improvement depth, cone penetration test, soil settlement, load test.

INTRODUCTION

Due to the extensive presence of weak and compressible soil in Malaysia, construction work often requires the use of soil improvement works to eliminate significant short and long term settlements. Where the major deficiency of the ground is related to its loose state, in-situ compaction may be the most appropriate type of treatment. Soil compaction can be used to improve the geotechnical properties of natural or man-made soil deposits, consisting primarily of granular materials.

The project site is part of the large tin mining area in and around Ipoh-Perak, Malaysia, primarily in the river valleys where tin has been mined since the beginning of the last century. The tin bearing sediments can be 50 m thick or more. Close to the ground surface, the sediments are often peaty or clayey. They become coarser with depth (Tan and Bachelor, 1981).

The bedrock below the alluvium is comprised of granite or of sedimentary rocks, shale, schist and limestone which have been folded and metamorphosed. The surface of the granite, shale and schist is generally relatively smooth while that of lime stone can be extremely rough with numerous deep crevices, overhangs and high pinnacles (Tan and Bachelor, 1981) which makes pile driving extremely difficult. Sinkholes are common in this area. Soil improvement by rapid impact compaction (RIC) was recommended for this site.

Rapid impact compaction which is the core of this paper was developed in early 1990's by British sheet piling in conjunction with British Army as an improvement on the process of deep dynamic compaction. RIC is rapid, cost effective and can reach challenging locations. (Charels and Watts, 2002; Kristiansen and Davies, 2004).

The objective of this study is to assess the performance of RIC in ground improvement using *in-situ* testing. The most important tool for deciding which soils can be improved by dynamic methods is the cone penetration test (NCHRP, 2007). Pre-treatment and post-treatment penetration testing was conducted to assess the depth and degree of improvement achieved (Mohammed et al., 2010). An interpretation software (CPeT-IT) based on the study of Lunne et al. (1997) was used for soil

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Table 1. Soil behavior type (Lunne et al., 1997).

SBT Zones	SBTn** Zones
1 Sensitive fine grained	1 Sensitive fine grained
2 Organic soil	2 Organic soil
3 Clay	3 Clay
4 Clay and silty clay	4 Clay and silty clay
5 Clay and silty clay	
6 Sandy silt and clayey silt	
7 Silty sand and sandy silt	5 Silty sand and sandy silt
8 Sand and silty sand	6 Sand and silty sand
9 Sand	
10 Sand	7 Sand
11 Very dense/stiff soil*	8 Very dense/stiff soil*
12 Very dense/stiff soil*	9 Very dense/stiff soil*

*Heavily over-consolidated and/or cemented. **Soil behavior type (Normalized), SBT_n (Lunne et al., 1997), SBTn index, I_c: $I_c = ((3.47 - \log Q_{t1})^2 + (\log F_r+1.22)^2)^{0.5}$. Where: normalized cone resistance, $Q_{t1} = (q_t - \sigma_{vo}) / \sigma'_{vo}$, total cone resistance, q_t (MPa) = $q_c + u\ (1-a)$, normalized friction ratio, F_r (%) = $f_s / (q_t - \sigma_{vo}) \times 100\%$ and Friction Ratio, R_f (%) = $(f_s/q_t) \times 100\%$.

characterization.

Direct measurements of settlement characteristics through field loading tests form an important part of a testing program. The scale and duration of such tests vary depending on the objectives of the test and the type of ground being tested (Charels and Watts, 2002).

The principle objective of testing is to estimate the long-term settlement of the treated ground under working load. In this test, the load can be kept constant over a comparatively long period and this can be done by the direct application of dead weight (BS 1377: PART 9, 1990: Clause 4.1).

Mohammed et al. (2010) found that with the compaction energy chosen for this site, the method achieved the required improvement to a 5.0m depth in granular soils where the soil condition was uniform with depth. In this paper, it was found that RIC succeeded in improving the relative density from 45 to 70%, increase the friction angle of soil by an average of 3° and reducing soil settlement criteria by 50%.

Soil and groundwater conditions

In general the soil at the subject site comprised mainly of sand and silty sand, based on the normalized soil behavior type classification (SBTn), (Lunne et al., 1997), through the investigated depth which extended to 10 m (Table 1). Figure 1 shows the geotechnical section at project site and also indicates the existence of soft layers with different thickness within the center of the project site which affected the depth of improvement.

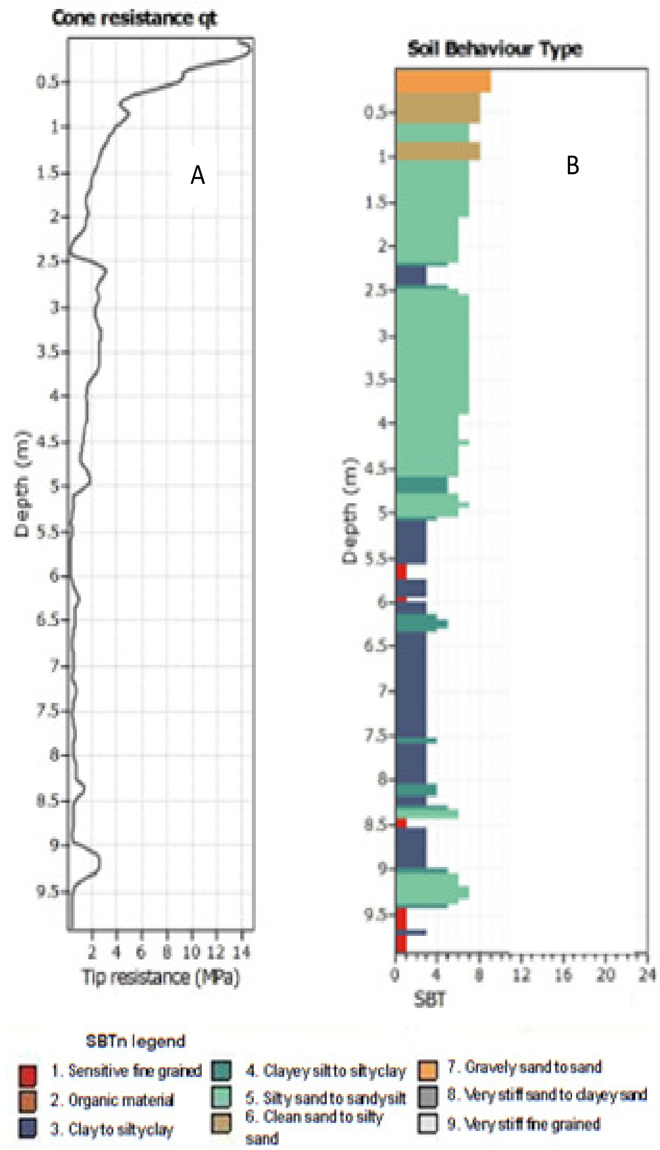

Figure 1. Pre-treatment CPT results (A) and soil profile at the project site (B).

Groundwater was at depth of 0.5 m from the ground surface.

METHODOLOGY

Based on soil condition rapid impact compaction (RIC) was adopted to treat the loose granular soils at the subject site by the compaction of the ground with an energy applied with 7 ton ram, 35 blows/min and drop height of 0.8m. The soil improvement was assessed by comparing the cone tip resistance of pre-treatment and post-treatment CPT soundings. An interpretation of soil properties from CPT was made using interpretation software (CPeT-IT) based on Lunne et al. (1997) to assess the degree and depth of improvement achieved. Pre-treatment and post-treatment

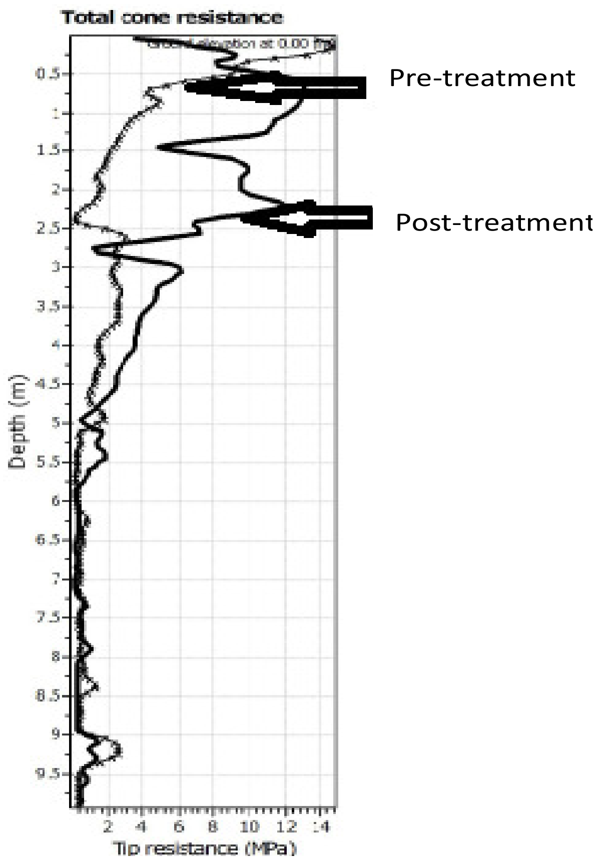

Figure 2. Overlay drawing of pre-treatment and post-treatment cone resistance at project site.

cone tip resistance were obtained according to the following mentioned plan:

1. The construction site was divided into (10.00 × 10.00 m) area to carry out the soil compaction by RIC. The main area covered under this paper where depots and workshop being constructed.
2. Pre-treatment CPT to be conducted at the center of each area. The results of the pre-treatment tests shall be used as the basis to determine the degree of improvement achieved.
3. To carry out the RIC work to achieve the specified improvement and average enforced settlement. Three test areas where treated with applying different energy to assess the degree of improvement achieved.
4. To carry out post-treatment field testing at the center of the treated area to establish the range of improvement achieved.
5. Based on the pre-treatment and post-treatment CPT soundings, the proper parameters of the energy applied to achieve the required improvement in terms of number of blows and drop height are decided based on the ground response to compaction and degree of improvement in soil properties.
6. Settlement estimation from CPT soundings is made based on Schmertmann (1970), strain influence method for footings on sand.
7. Plate bearing test was conducted for the ground improved by RIC. The location of test is at the center of RIC grid to check the bearing pressure and settlements.

Plate bearing test is conducted according to (BS 1377: PART9: 1990: Clause 4.1). Instrumentations consist particularly of four settlement gauges mounted onto an independent datum frame and graded in divisions of 0.02 mm or finer, steel plate (1000 × 1000 mm) and minimum thickness of 25 mm.

Measurements made before and after treatment provide an indication of the effectiveness of the treatment in improving properties and the depth to which improvement has been achieved. CPT measurements are correlated with density index and hence, used to characterize how much improvement attained by the soil in terms of shear strength, compressibility and settlement.

RESULTS

Figure 2 shows the improvement attained by the soil with depth in terms of the increase of total cone resistance. The improvement achieved is based on soil uniformity with depth, and energy applied which is a function of ram weight (kept constant to 7 ton), drop height and number of blows per minute.

The improvement depths achieved at nine locations within the project area are listed in Table 2; values presented are obtained from comparing the pre-treatment and post-treatment cone resistance with depth (Figure 2). The increase of cone tip resistance lead to an improvement in soil properties estimated from data interpretations (Table 3).

Improvement in relative density Dr (%)

Relative density is used as an intermediate parameter to specify compaction criteria. Table 4 shows the values of Dr (%) estimated from CPT soundings for nine locations at the project area, the values presented are for pre-treatment, post-treatment and how much improvement achieved due to compaction. The values are the average along the depth estimated in Table 2.

Improvement in shear strength

The strength is usually expressed in terms of the friction angle of the soil, Φ' or, more precisely as friction, that is tan Φ'. The compaction results in an increase of the horizontal stress, that is, an increase in K_o, which increases the sleeve friction value as it depends on the horizontal stress acting against the sleeve. Table 5 shows the value of pre-treatment, post-treatment and the improvement achieved in degrees.

Improvement in settlement criteria

Settlements estimates from CPT soundings

Table 6 shows the values of the estimated settlements from CPT soundings based on Schmertmann (1970), strain influence method for footings on sand. Calculations have been carried out with the following loading criteria: Designated load = 85 kN/m^2 / Maximum designated load

Table 2. Effective improvement depth at site confirmed by CPT test.

CPT location	29	30A	39A	40	45	46	54	58	64
Estimated improvement depth (m)	5.0	5.0	4.0	3.5	3.5	4.0	4.0	3.5	3.5

Table 3. Pre-treatment and post-treatment soil properties.

CPT	Pre-treatment total cone resistance (MPa)	Post- treatment total cone resistance (MPa)	Pre-treatment Sleeve friction (kPa)	Post-treatment Sleeve friction (kPa)
29	3.25	6.6	24.48	32.88
30A	2.66	7.08	14.46	38.78
39A	6.36	11.28	30.71	81.73
40	5.49	9.93	18.93	45.91
45	4.78	13.52	12.63	52.85
46	9.28	12.43	66.63	55.53
54	3.31	4.67	13.97	28.96
58	2.02	5.72	8.01	26.18
64	3.14	4.31	15	27.82

Table 4. Pre-treatment and post-treatment average Dr (%) and the percentage of improvement achieved.

CPT location	Improvement depth (m)	Average DR (%)		Improvement achieved (%)
		Pre-treatment	Post-treatment	
29	5.0	45.66	64.64	41.57
30A	5.0	44	57.74	31.22
39A	4.0	63.64	81.12	27.47
40	3.5	61.24	80.04	30.70
45	3.5	59.84	87.78	46.70
46	4.00	71.80	86.27	20.15
54	4.00	52.17	58.43	12.00
58	3.50	38.52	63.91	66.00
64	3.50	54.28	60.46	11.40

=127.5 kN/m^2

Load test results

Test loads shall be applied by jacking against a heavy machine in equal increments up to a maximum of two times the specified allowable soil bearing pressure (Figure 3).

Each increment and decrement shall be carried out in stages as shown in Table 7. For each stage the load increment or decrement shall be applied as smoothly and expeditiously as possible and the time settlement readings taken before and after each increment by the four dial gages mounted onto an independent datum frame.

The pressure to apply and the area over which it should be applied will depend on the foundation load and widths. The length of time the load should be maintained is important as the results will have to be extrapolated to predict long-term foundation settlement. The number of tests required at a particular site will depend on the size of the site, the nature of development and the variability of the ground (Charels and Watts, 2002).

After ground improvement with RIC the project area was subjected to two load tests as follows:

Test carried under a designated load = 85 kN/m^2
Maximum designated load = 127.5 kN/m^2

Settlement field records conducted at the workshop area, treated by the application of energy from compacting the

Table 5. Friction angle.

CPT location	Friction angle (°) degree		Improvement achieved (°)
	Pre-treatment	Post-treatment	
29	40.80	44.46	3.66
30A	40.55	43.70	3.15
39A	44.57	47.93	3.36
40	45.38	47.94	2.56
45	43.80	48.41	4.61
46	46	48.02	2.02
54	43.58	44.25	0.67
58	39.79	44.81	5.02
64	43.06	45.14	2.08

Table 6. Settlement estimates at working loading of 85 kN/m^2 and at ultimate loading of 127.5 kN/m^2.

CPT location	Settlement under working load of 85 kN/m^2		Settlement under ultimate load of 127.5 kN/m^2	
	Pre-treatment (mm)	Post-treatment (mm)	Pre-treatment (mm)	Post-treatment (mm)
29	4.59	1.28	7.93	2.21
30A	3.9	1.56	6.73	2.70
39A	2.79	1.23	4.82	2.12
40	3.06	1.24	5.28	2.13
45	1.96	0.81	3.38	1.39
46	3.19	1.10	5.48	1.89
54	4.09	3.72	7.06	6.42
58	4.82	1.91	8.31	3.29
64	4.05	2.57	7.00	4.42

Figure 3. Plate bearing test.

ground by 7 ton weight, 0.8 m drop height and 35 blows/min, showed that at a working load of 85 kN/m^2 the field settlement recorded was 2.39 mm which is much less than the allowable settlement (25 mm) and with

Table 7. Load increments and decrement stages during load test

First cycle		Second cycle	
Applied load as % of allowable bearing pressure	**Minimum time of holding load (min)**	**Applied load as % of allowable bearing pressure**	**Minimum time of holding load (min)**
25	15	50	15
50	15	100	15
75	15	125	15
100	60	150	180
75	15	125	15
50	15	100	15
25	15	50	15
0	60	0	60

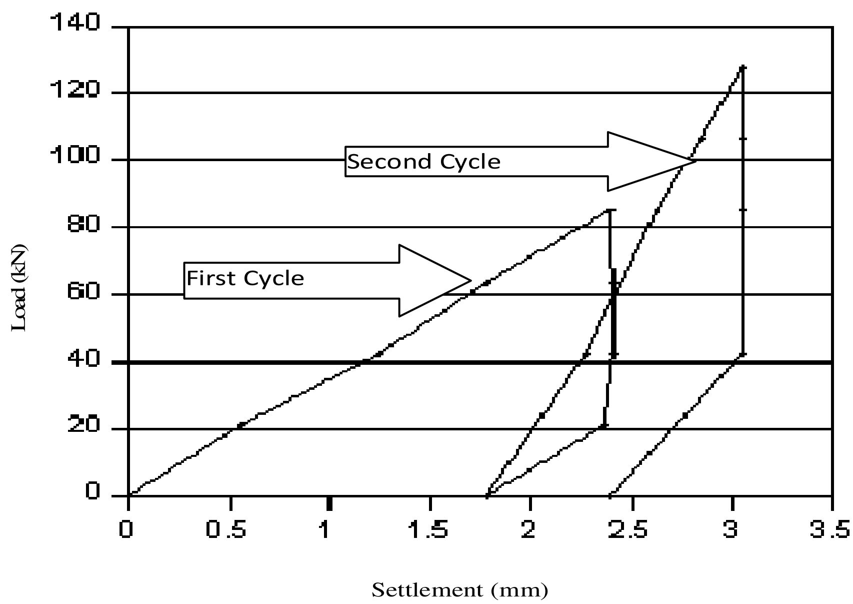

Figure 4. Load cycles during the test, under working load.

ultimate loading of 127.5 kN/m^2, the field settlement record was 3.05 mm which is much less than the allowable settlement of (45 mm). Figures 4 and 5 show the two cycles of loading and unloading conducted during the test.

DISCUSSION

Improvement in soil properties

Following treatment with RIC confirmatory testing was conducted using CPT. The increase in the post-treatment tip cone resistance with relative to the pre-treatment tip resistance showed that treatment with RIC has resulted in significant improvement in soil properties. A minimum increase of 30% in soil properties obtained is considered the accepted improvement depth as indicated in Table 2 and Figure 3.

Improvement in relative density

In this study, the Dr (%) is calculated from the formula (Lunnea et al., 1997):

$$Dr^2 = Q_{tn} / C_{Dr} \qquad (1)$$

where Q_{tn} is the normalized cone resistance and C_{Dr} is the relative density factor.

The aforementioned equation is applicable with SBTn 5, 6, 7 and 8 (silty sand and sandy silt, sand and silty sand and clean sand). Results obtained (Table 4) showed an improvement in relative density from 11% in

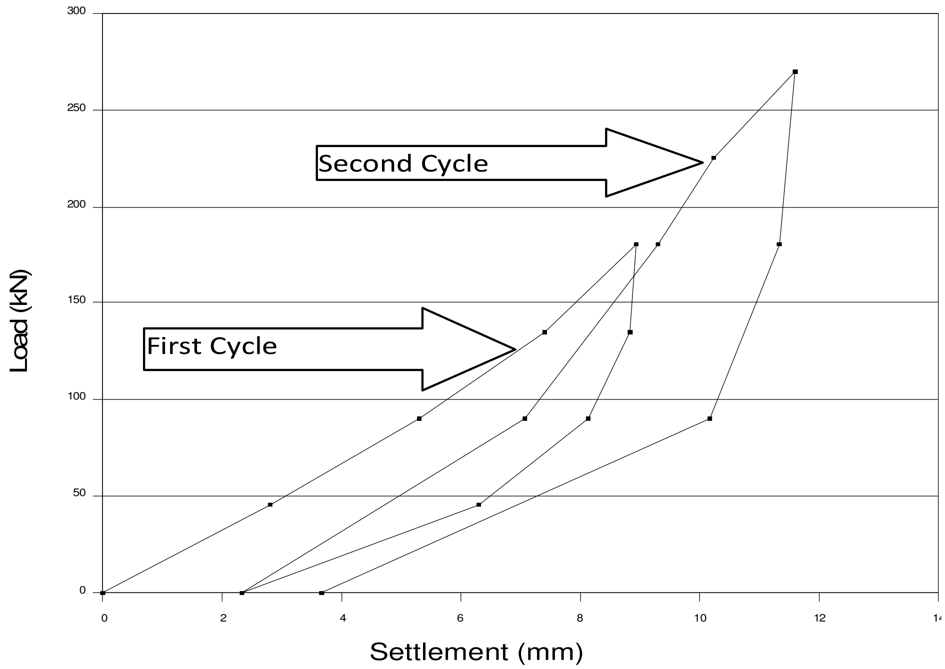

Figure 5. Ultimate load versus settlement.

one location to more than 65% in other location depending on soil uniformity with depth and soil type.

Improvement in shear strength

The strength of soil is controlled by the effective stress frictional envelope, often represented in terms of the Mohr-Coulomb parameters: effective friction angle (Φ') and effective cohesion intercepts (c'). For soil with SBTn 5, 6, 7 and 8 (silty sand and sandy silt, sand and silty sand and clean sand), a commonly used CPT interpretation is based on considerations of an inverted bearing capacity (BC) theory (NCHRP, 2007). The expression for peak friction is given the approximation (c' = 0):

$$\tan \Phi' = 1/2.68[\log (q_c/ \Phi'_{vo}) + 0.29] \qquad (2)$$

where σ'_{vo} is effective overburden stress, $\sigma'_{vo} = \sigma_{vo} - u_o$ and σ_{vo} is the total overburden stress, $\sigma_{vo} = \Phi$ z.

Improvement in settlement criteria

Settlements estimates from CPT soundings

Calculations conducted at a working load of 85 kN/m^2, and settlement estimated is much less than the allowable settlement of 25 mm and with ultimate loading of 127.5 kN/m^2, the settlement calculations showed that values are less than the allowable settlement of 45 mm. RIC succeeded to reduce the settlement of the ground to 50% of the pre-treatment settlement (Table 6).

Settlements from load test

Acceptance criteria of plate bearing test

The allowable soil bearing capacity shall be deemed to have satisfied the requirement if the settlement of the test plate at various stages of loading compiles with the requirements that follows for all ground improvement works (RIC) using a 1000 × 1000 mm test plate:

1. When loaded to the allowable soil bearing capacity, the total settlement of the test shall not exceed 25 mm.
2. When loaded to one and a half times, the allowable soil bearing capacity and the total settlement of the test plate shall not exceed 50 mm.

Test carried under a designated load = 180 kN/m^2
Maximum designated load = 270 kN/m^2
Total Kentledge load requirement = 127.5 × 1.3 = 351 KN

At a working load of 180 kN/m^2 (Figure 4), the field settlement recorded was 8.94 mm which is much less than the allowable settlement (25 mm) and with ultimate loading of 270 kN/m^2 (Figure 5), the field settlement records was 11.61 mm which is lesser than the allowable settlement of 45 mm.

Conclusion

The results show significant increase of cone tip resistance which demonstrates decrease of compressibility.

1. The method succeeded in achieving an improvement in relative density from 45 to 70% to the required improvement depth.
2. RIC achieved an improvement in the shear strength of soil represented by increase in friction angle Φ, the increase achieved ranges from 2 to 5° and the average for nine locations is 3°.
3. Reducing settlement by 50% when compared with pre-treatment soil settlement estimated from CPT soundings, which is also confirmed by load test.
4. RIC managed to control the settlement to be less than 3.0 mm under working load and less than 6.0 mm under ultimate load which complies with the design requirements to be less than 25 and 45 mm, respectively.

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REFERENCES

Charels JA, Watts KS (2002).Treated Ground Engineering Properties and Performance. London: CIRIA C572.

Kristiansen H, Davies M (2004). Ground Improvement using Rapid Impact Compaction.13th World Conference on Earthquake Eng. Vancouver, B.C. Canada, p. 496.

Lunne T, Robertson PK, Powell JJM (1997). Cone penetration test in geotechnical practice.Blacker Acad. Prof., p. 312.

Mohammed M, Roslan H, Firas AS (2010). Effective Improvement Depth for Ground Treated with Rapid Impact Compaction. Sci. Res. Essays, 5(18): 2686-2693.

National Cooperative Highway Research Program (NCHRP), (2007).Cone Penetration Test.SYNTHESIS 368. Georgia Inst. Technol., Atlanta, Georgia.

Schmertmann JH (1970). Static cone to compute static settlement over sand. American Society of Civil Engineers, ASCE J. Soil Mech. Found. Eng., 96(3): 1011–1043.

Tan BK, Bachelor B (1981).Foundation Problems in Limestone Areas – A Case Study in Kuala Lumpur, Malaysia. Proc. Int. Symp. Weak Rock, Tokyo, 3: 1461-1463.