Performance assessment of ground improvement with rapid impact compaction

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Abstract: Ground improvement has been used on many construction sites to densify granular materials, in other word to improve soil properties and reduce potential settlement. The research site comprises the construction of workshop and Depots as part of railway development project at Batu Gajah-Ipoh, Malaysia. Subsurface soil comprised mainly of sand and silty sand through the investigated depth which extended to 10 m. Groundwater is approximately 0.5m below the ground surface. This paper presents a case study of ground improvement using Rapid Impact Compaction (RIC). Evaluation of improvement was based on the results of pre- and post- improvement Cone Penetration Test (CPT). An interpretation software has been used to evaluate the improvement achieved in soil properties. Load test was conducted to estimate soil settlement. It was found that the technique succeeded in improving soil properties namely relative density from 45% to 70%, increase the friction angle of soil by an average of 3^{o}, and reducing soil settlement by 50%. The technique succeeded to improve soil properties to approximately 5.0 m depth depending on soil uniformity with depth.

1. INTRODUCTION

Due to the extensive presence of weak and compressible soil in Malaysia, construction works often require the use of soil improvement techniques 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.

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.

An interpretation software (CPeT-IT) based on the study of Lunne et al. (1997) was used for soil 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 successfully achieved the required improvement to a 5.0m depth in granular soils where the soil condition was uniform with depth.

2. SITE CHARACTERIZATION

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 RIC was recommended for this site.

3. SOIL AND GROUNDWATER CONDITIONS

In general the soil at the subject site comprised mainly of sand and silty sand, through the investigated depth which extended to 10 m. Figure (1) shows the cone resistance and friction ratio with depth from CPT soundings.

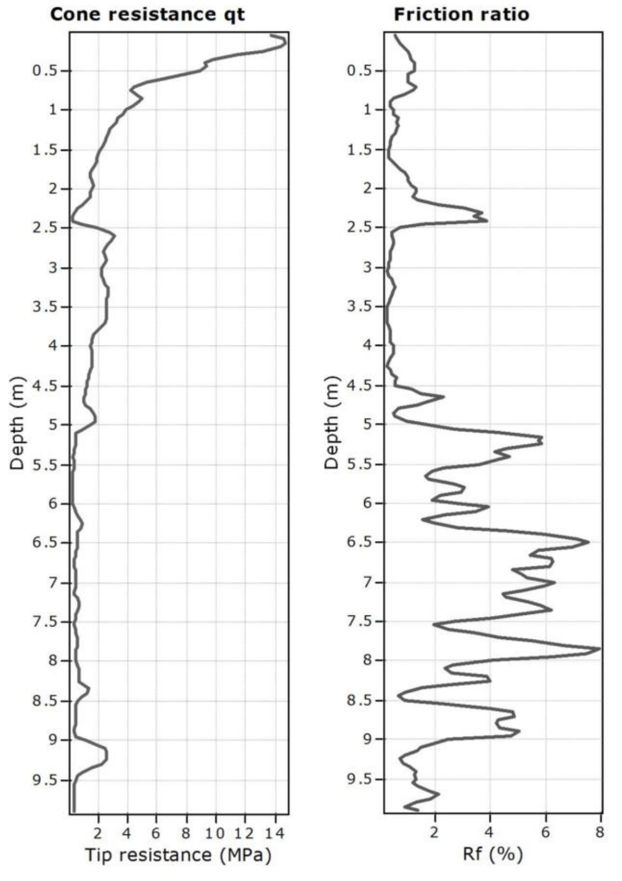

Figure 1 – Cone resistance and friction ratio with depth at site

4. METHODOLOGY

Based on site condition RIC was adopted to treat the loose granular soils at the subject site by tamping the ground 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.

Construction site was divided into square area of 10mX10m pretreatment and post treatment cone tip resistance was obtained 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 and post treatment to establish the range of improvement achieved.

Settlement estimation from CPT soundings is made based on Schmertmann (1970), Strain Influence Method for footings on sand.

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 was conducted according to (BS 1377: PART 9:1990: Clause4.1). Instrumentations consists particularly of four settlement gauges mounted onto an independent datum frame and graded in divisions of 0.02 mm or finer, steel plate (1000mm X 1000mm) 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.

5. RESULTS AND DISCUSSION

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 (1); values presented are obtained from comparing the pre treatment and post treatment cone resistance with depth, Fig (2). The increase of cone tip resistance indicates an improvement in soil properties as shown in Table (2).

5.1. 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 (1) & Figure (2).

5.2. Improvement in Relative Density (Dr %)

Relative density is used as an intermediate parameter to specify compaction criteria. Table (2) shows the values of Dr% estimated from CPT soundings for nine locations at

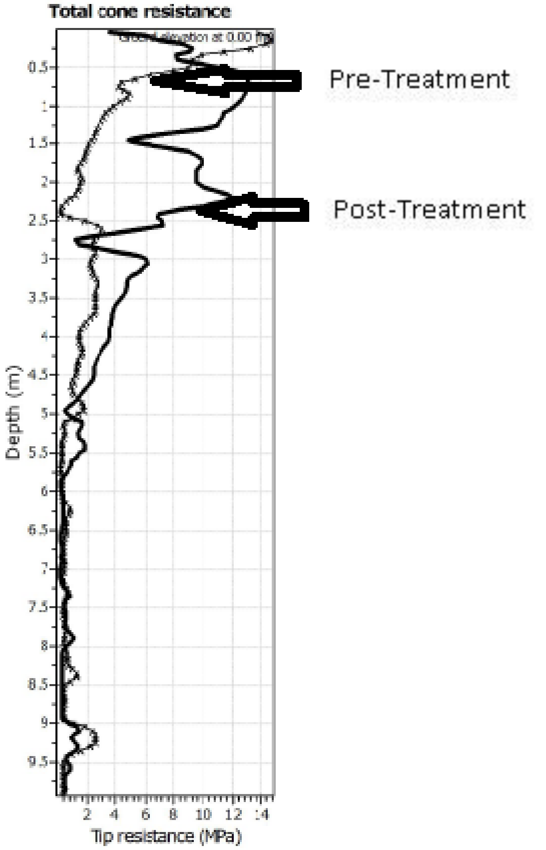

Figure 2 – Overlay drawing of pre-treatment and post treatment cone resistance at project site.

the project area. Improvement achieved is the average of Dr% along the depths estimated in Table (1).

Results obtained showed an improvement in relative density from 11% in one location to more than 65% in other location depending on soil uniformity with depth and soil type.

Table 1 – Effective improvement depth at site confirmed by CPT test

CPT location	1	2	3	4	5	6	7	8	9
Estimated improvement depth(m)	5.0	5.0	4.0	3.5	3.5	4.0	4.0	3.5	3.5

Table 2 – Pre Treatment and Post treatment soil properties

CPT	**Total cone resistance (MPa)**		**Sleeve friction (kPa)**		**N60 (blows)**		**Dr%**		**Friction angle (degree)**	
	Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
1	3.25	6.6	24.48	32.88	6.2	11.49	45.66	64.64	40.80	44.46
2	2.66	7.08	14.46	38.78	5.01	11.92	44	57.74	40.55	43.70
3	6.36	11.28	30.71	81.73	10.86	19.21	63.64	81.12	44.57	47.93
4	5.49	9.93	18.93	45.91	9.46	16.50	61.24	80.04	45.38	47.94
5	4.78	13.52	12.63	52.85	8.11	21.56	59.84	87.78	43.80	48.41
6	9.28	12.43	66.63	55.53	15.86	20.34	71.80	86.27	46	48.02
7	3.31	4.67	13.97	28.96	6.06	8.45	52.17	58.43	43.58	44.25
8	2.02	5.72	8.01	26.18	3.84	9.87	38.52	63.91	39.79	44.81
9	3.14	4.31	15	27.82	5.7	7.89	54.28	60.46	43.06	45.14

5.3. Improvement in shear strength

The strength is usually expressed in terms of the friction angle of the soil, ϕ' or, more precisely as friction, i.e. 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. From Table (2) the value of improvement achieved ranging from 2^o-5^o degrees.

5.4. Improvement in Settlement Criteria

5.4.1. Settlements estimates from CPT soundings.

Table (3) shows the values of the estimated settlements from CPT soundings based on Schmertmann (1970), strain influence method for footings on sand. Calculations had been carried out with the following loading criteria: Designated load = 85 kN/m^2 and Maximum designated load =127.5 kN/m^2

Table 3 – Settlement estimated at working loading and at ultimate loading

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)
1	4.59	1.28	7.93	2.21
2	3.9	1.56	6.73	2.70
3	2.79	1.23	4.82	2.12
4	3.06	1.24	5.28	2.13
5	1.96	0.81	3.38	1.39
6	3.19	1.10	5.48	1.89
7	4.09	3.72	7.06	6.42
8	4.82	1.91	8.31	3.29
9	4.05	2.57	7.00	4.42

Calculations conducted at a working load of (85 kN/m^2) and settlement estimated is much less than the allowable settlement (25mm) and with ultimate loading of 127.5 kN/m^2 the settlement calculations showed that values are less than the allowable settlement of (45mm). RIC succeeded to reduce the settlement of the ground to 50% the pre-treatment settlement, Table (3).

5.4.2. Load test results

Test loads shall be applied by equal increments up to a maximum of two times the specified allowable soil bearing pressure.

Each increment and decrement shall be carried out in stages. 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 ground by 7 ton weight, 0.8m drop height and 35 blows/min, showed that at a working load of 85 kN/m^2 the field settlement recorded was 2.39mm which is much less than the allowable settlement (25mm) and with ultimate loading of 127.5 kN/m^2 the field settlement record was 3.05mm which is much less than the allowable settlement of (45mm).

6. CONCLUSION

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

The method succeeded in achieving an improvement in relative density from 45 to 70% to the required improvement depth.

RIC achieved and improvement in the shear strength of soil represented by an increase in friction angle (ϕ), the increase achieved ranges from 2 to 5° and the average for nine locations is 3°.

Reducing settlement by 50% when compared with pre-treatment soil settlement estimated from CPT soundings, which is also confirmed by load test.

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 25 and 45 mm, respectively.

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