Evaluation of Rapid Impact Compaction Method for Soil with Different Fine Content

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Abstract

Rapid Impact Compaction (RIC) is an alternative compaction technique which fills the gap of improving depth between shallow and deep compaction. The RIC technique is done by dropping the weight hammer on the circular base of the steel base on the ground. This study presents the RIC field trail test with different energy, filling thickness and fine content. The result of field test before and after improvement, which are Cone Penetration Test (CPT), Plate load test (PLT), is presented in this study to check the efficiency of the RIC technique. Field test results show that low-fine soil is significantly improved. However, improvements are not clearly visible for soils with high fine content. The strength and stiffness of soil after improvement was significantly effects by the fine content of material. The effective depth of improvement by RIC is 4 m. from the ground surface.

Keywords: Rapid Impact Compaction, Ground Improvement, Fine Content

1. Introduction

Rapid impact impaction (RIC) firstly introduced in 1990 as a method to repair military airfield runway by the British; [1][6][8]. RIC consisted of dropping the weight hammer on the circular steel base that remained on the surface during the process. RIC techniques have been used developed and used in many civilian works as this method is more cost efficiency and environment friendly compared to others treatment method; [1][5][8] RIC has ability to compact the soil from surface to maximum of 6.5 meters which will fulfill the gap between the near surface compaction and deep compaction method.

Most of the time RIC method will be selected as a compaction method where the subsurface condition are cohesionless soil. According to [5], RIC has been used to mitigate the effect of soil liquefaction. Soil conditions consisted of 0.3m. granular fill over interbedded sand and sandy silt. Bashar, the RIC has been used for Villa construction project. From these 2 cases, the improvement can be significantly observed to the maximum depth of 6 m. In the other hand, there is not much information of the RIC on the cohesive soil. From the case study by [6], the RIC techniques performed on loess soil with high fine content and high moisture content. The result from one of the trial field shows, no significant immediate improvement but weaker plastic behavior under increased pore pressures can be observed which required further study. From the previous studies, there are limited studies for RIC for soil with high fine content. The comparative study with different soil condition could be benefit to engineering to choose RIC as ground improvement for a high fine grain soil.

In this study the RIC technique will be applied to the challenging soil condition, which has high fine content and high-water level. Three type of fill was evaluated in this study with different fine content. The applied energy from RIC was varied in 4 levels. The test results will provide a general procedure for construction of an apron of an airport by using RIC.

1.1 General information

In the early 1990's, Rapid Impact Compaction (RIC) was introduced to fill the gap between those compaction techniques; [1][7]. RIC was firstly used as a method to repair the damaged military airfield runway. At that stage, RIC was operated via by hammering the modified hydraulic piling hammer on the circular steel footing. The RIC mainly consists of hydraulic piling hammer mounted on a tracked excavator and compaction footing. Often, 5 to 9 t weight hammer will fall in a small height around 1.5 m at a rate of 40 to 60 times a minute, generate energy about 59 to 106 kNm. per blow depends on the weight of the hammer and the height of the drop.

1.2 RIC mechanic and design

The RIC compaction process begins with dense plugging the surface soil immediately in the early blow. Then the further blow which drives this plug deeper to compact the soil in the deeper layer; [2][6][7]. During the compaction process, the steel compaction footing will remain rest on the ground, So the energy is efficiently transferred to the soil than the conventional drop weight compaction.

For RIC design, a compaction field trial is crucial, as effectiveness of RIC method may be different at different site depend on the sub surface condition. A performance of the RIC treatment will be analyzed through this procedure. Compaction design will be performed until the improvement met the designed requirement. The compaction design criteria in each compaction point are maximum number of blows, maximum crater depth travel or minimum footing settlement per blow. When any of these criteria have been reach, the process of compaction at the location will be ended [1][7][8]. Then, degree of compaction will be evaluated by a field testing (standard penetration test (SPT), cone penetration test (CPT), plate bearing test, etc.) to confirm the ability of RIC treatment.

2. Site condition

2.1 Site location

The experiment was done at Ban Chang District, Rayong Province, Thailand in the U-Tapao International Airport construction site. The area was design to be an Apron of the airport. Approximately 6740 m2 of area was used in this trial test.

Fig. 1 Site condition

2.2 Subsurface condition

Fill material used in this project are selected base on the available and convenient transportation. A total of 2 sources of soil were used as a fill material. First source is from borrow pit located near to the construction site represent as soil A and second sources is the soil available at the project area represent as soil B and soil C. Where soil A has a requirement as follows:

1. Not contain organic material and having density more than 1,440 kg/m^3
2. Soil particle with diameter less than 0.075 mm. or passing sieve #200 should not exceed 20% of soil mass.
3. Swelling index obtained from California Bearing Ratio Test (CBR) should not exceed 3% at 95% of maximum dry density obtained from Standard Compaction Test.
4. CBR value obtained from California Bearing Ratio Test (CBR) should not exceed 10% at 95% of maximum dry density obtained from Standard Compaction Test.

While Soil B and Soil C are original soil located inside of the construction site near the testing area. The different between Soil B and Soil C is that Soil C will have a maximum fine content of 20%. Sample of soils were collected, and the laboratory test was conducted including Particle-Size analysis, Soil Compaction Test and California Bearing Ratio test.

2.2.1 Particle-Size Analysis of soils

The particle size analysis of soil was conducted under the ASTM D 422 and washing sieve method was used and gradation curves is shown in figure 2.

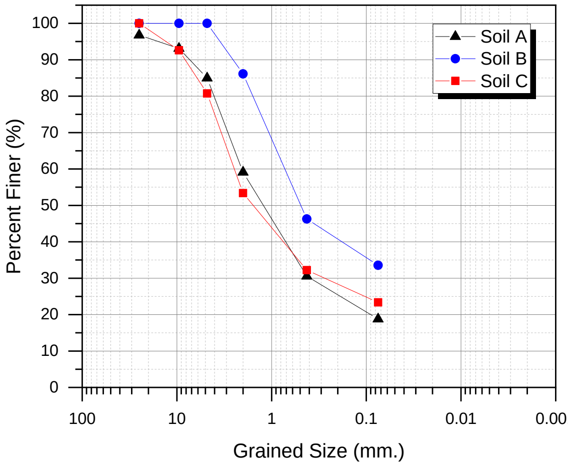

Fig. 2 Particle size distribution of Soil A, B and C

As the fine content is the major concern in this experiment, soil A has the lowest fine content at 18.78% while Soil B which is the original soil at the site has very high fine content at 33.55%. and Soil C at 21.24% was used as a testing material in this field trails test to show the effect of fine content of the RIC compaction method.

2.2.2 Laboratory Compaction Characteristics of Soil Using Standard Proctor

Soil compaction test was conducted under ASTM D 698. A 4 inches diameter mold was used. The compaction was done under this circumstance, The soil sample was compacted in 3 layers and each layer were compacted by 25 blows of 5.5lb hammer (standard proctor) with the dropping height of 12 inches. Specification material, soil A has the highest dry density at 1.967 g/cm^3 follow with soil B at 1.934 g/cm^3 and the soil C at 1.867 g/cm^3.

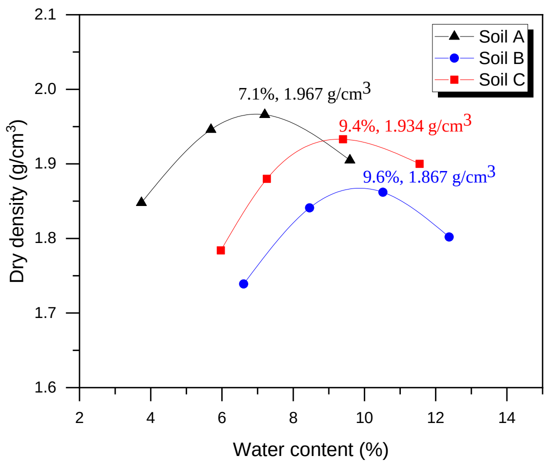

Fig. 3 The relationship of Dry density and Water content

2.2.3 California Bearing Ratio Test

The experiment was done under ASTM D 1883 standard. The sample was tested at optimum moisture content obtained in compaction test and %CBR at 95% maximum density was reported. The results are summarized in table1.

Table 1 Summarize result of CBR test

Sample	CBR (%)	Max Swell (%)
Soil A	13.7	0.00
Soil B	4.3	0.09
Soil C	4.7	0.07

2.3 RIC equipment

The rapid impact compaction equipment consists of mainly two parts including the compaction rig and track excavator. The compaction rig works as a compactor. Example of compaction rig mounted on the excavator was shown in figure 4. In this study the RIC9000 was used, and the machine specification is:

Table 2 Specification of RIC machine

Dropping rate	40-60 blows/min
Dropping weight	9,000 kg
Dropping height	1.2 m.
Footing diameter	1.5 m.

Fig.4 The RIC compaction rig mounted on excavator.

3. Testing plan

3.1 Testing layout

A testing layout is divided in to 9 testing set each has approximately of 13 x 13 m. area. In each set the fill material and fill thickness was varied. Each compaction set consisted of four zones of compaction where in each zone the energy applied is based on the energy of the compaction afford of standard proctor compaction varied from 50, 100, 150 and 200 blows per impact point. A square grid pattern was used with the total of 5 impact points in 1 compaction set. The detail is listed in table 3. And the overall testing layout are shown in figure 5.

Table 3. Fill material and thickness detail of testing set.

Testing set	Fill material	Fill thickness (m.)
A-1	Soil A	0.5
A-2		3.0
A-3		5.0
B-1	Soil B	0.5
B-2		3.0
B-3		5.0
C-1	Soil C	0.5
C-2		3.0
C-3		5.0

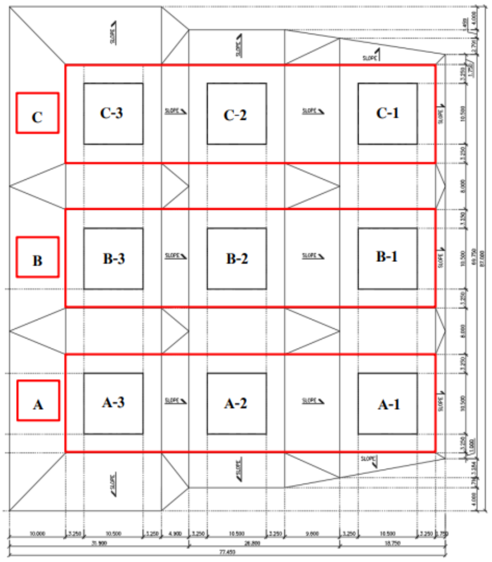

Fig. 5 Overall Testing layout

3.2 Procedure

In this field trial the RIC compaction will be compacting 50 blows per part which mean in zone 1 the RIC compaction will consist of 1 part and in the zone 4 which required a total of 200 blows, there will be a total of 4 parts. During the compaction in each part if the crater depth reaches 1m. or the settlement per blow is smaller than 1 cm. the RIC machine will be stop. If any stopping criteria occurred, the testing area will be fill with the same soil and continue compacting until 50 blows is reached. A total of 72 Electronical Cone Penetration tests (CPT) were conducted with the desirer depth of 10m. from testing elevation. CPT was conducted in accordance with ASTM D5778. Furthermore, 36 of Plate Load Test was performed after the compaction. The tests were performed under ASTM D1195-21. The testing plan in each set are shown in figure 6.

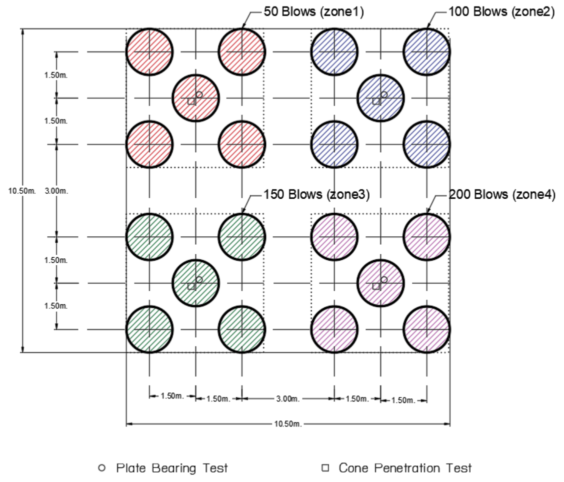

Fig. 6 Detail of testing plan

The procedure of field trials are as follows:

1. Fill with the specific material to the designed elevation.

2. Perform field tests on pre-improved soil (CPT, plate load test)

3. RIC compacting first part (50 blows)

4. If more compactions are required, Fill the compacted area and compact with a roller compactor.

5.RIC compacting second part (50blows)

6. Repeat step 4 and 5 until compaction blow reach the requirement

7. Filling and compact the soil by roller compactor

8. Perform field tests on post-improved soil (CPT, plate load test)

The stopping criteria will be considered in every part of compaction. The performing example of Cone Penetration test (CPT) and Plate Load Test (PLT) was shown in figure 7 and 8.

Fig. 7 Cone Penetration Test

Fig. 8 Plate Load Test

4. Result

4.1 Electrical Cone Penetration Test (CPT)

Figure 9 and 10 shows the improvement of cone resistance after, 100, and 200 blows of compaction in terms of the increase of the cone resistance (qc) of Soil A (specification material) and soil B (Non specification material).

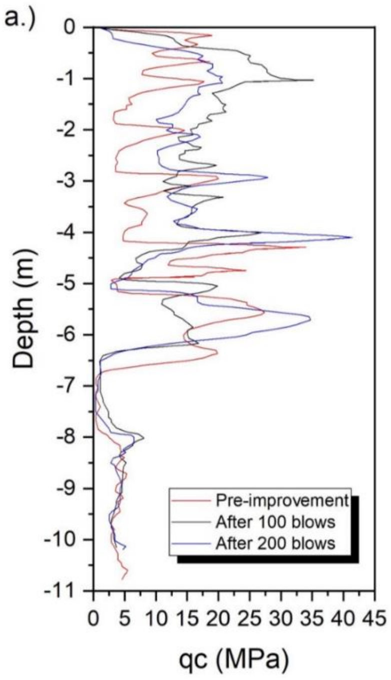

Fig. 9 Cone resistance of Soil A after 100 and 200 blows

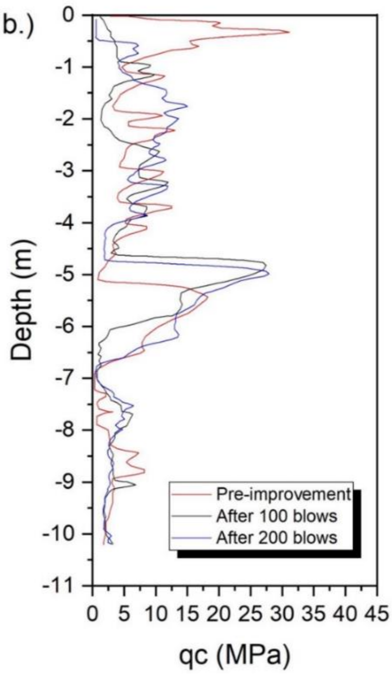

Fig.10 Cone resistnace of Soil B after 100 and 200 blows

These two sets of data come from the trail done on the 5m fill embankment. At the depth of 5-6 m. under the surface stiff layer was found for both cases. This layer indicated the old, compacted ground surface before the filling. However, above 5m., significant improvement can be seen in specification material, Soil A. The RIC create the dense layer in in first 100 blows at 1-2m. depth. And in further blows, the RIC drives this stiffened layer deeper to compact the soil in deeper layer. The maximum cone resistance of 41.37 MPa was reached at 4.1 under the compaction point. Show the depth of improvement of RIC for the specification material is around 4m under the impact point. In the other hand, for non-specification materials, no notable improvement observed between the surface to the pre-treatment stiff layer. However, the result from CPT reveals the Pre-compaction stiff layer between 0.5 and 1.5 m. The stiff layer was breaking down during 100 blows of the RIC compaction. But the RIC did not show any symbolic progress between non-compacted and after 200 blows of compaction of non-specification soil.

4.2 Plate Load Test (PLT)

Stain modulus E_V obtained from the PLT after treatment are summarize in table 4

Table 4 Result from Plate Load Test

Soil type	Fill thickness (m.)	Strain Modulus (E_V)			
		50 blows	100 blows	150 blows	200 blows
A	0.5	6.84	14.78	5.96	8.00
	3	33.70	38.60	27.16	26.73
	5	5.35	16.70	31.82	40.49
B	0.5	2.93	2.80	6.49	6.13
	3	9.71	19.47	5.27	8.73
	5	13.74	6.58	6.24	10.48
C	0.5	3.36	1.66	2.90	9.67
	3	6.56	10.21	11.12	15.04
	5	4.53	9.47	9.12	8.41

According to the result form Plate bearing test, the strain modulus shows the interesting outcome. The trials on 0.5 m. embankment of all three material show similar value of strain modulus value which means by filling the stiffer layer on top of the soft layer will not improve the efficiency of RIC compaction. By comparing strain modulus after 200 blows of RIC treatment, the specification material, Soil A obtained the highest strain modulus, E_V of 40.49 while for Soil B and Soil C obtained only 10.48 and 8.41.

4.3 Effects of fine content

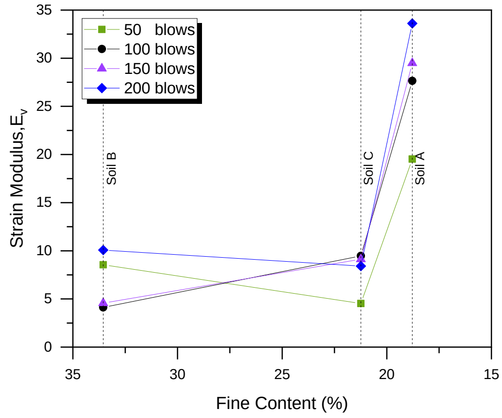

Fig. 11 A relationship of Strain Modulus, E_v and fine content

According to the result form Plate load test, the relationship between Strain Modulus, E_v and fine content were shown in figure 11. The strain modulus obtained from selected material Soil A is increasing with the applied energy. However, in Soil C with higher fine content, the improvement can be seen in 100 blows, but the improvement cannot be noticed in the further blows as the soil reached to their maximum density and will dilate after this stage. And Soil B with the highest fine content, the results were completely random.

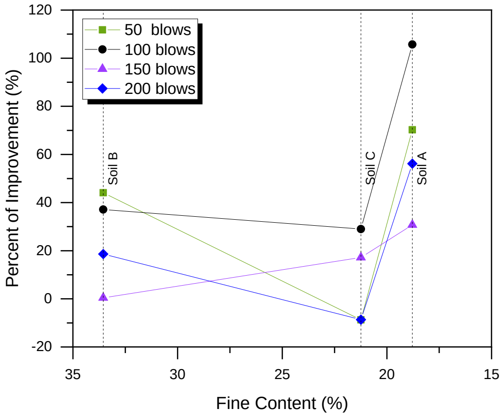

Fig. 12 A Relationship of Percent of improvement and fine content

Additionally, the relationship of percent of improvement with fine content shows the similar trend. The percent of improvement was calculated from the result of Cone Penetration test at the depth between 1.5 m. and 4 m. to avoid effect previous stiff layer as shown as follows:

$$\left(\frac{\Sigma q_{cf} - \Sigma q_{ci}}{\Sigma q_{ci}}\right) \times 100 = Percent\ of\ improvement \qquad (1)$$

Where q_{ci} is cone resistance before the RIC treatment and q_{cf} is the cone resistive after the RIC treatment obtained with CPT.

The improvement of soil A, low fine content, can be visible. At 100 blows, Soil A has been improved about 105%. Then, at 150 blows the percent of improvement has decreased 30% and risen in further blows. For soil B and C with higher fine content, the improving efficiency was low, about 0-40 %. The results were similar trend with the study from [7] where RIC was deployed for Villas construction project. The soil in the area is a loose to very loose fine to medium sand layer. The percent of improvement increase rapidly from 17.69% in the first RIC pass to 55.1443% in second RIC pass. And in the third pass only 8% of improvement can be seen. Soil C shows the improvement of 50% at 100 blows and random trends in the further blows. And completely random trends can be seen in Soil B.

The explanation of these phenomenon can be express by the study from [9]. Wang stated that the compaction efficiency is increased when the fine content is increased to the certain percent and after that the compaction efficient will rapidly reverse exponentially decrease with higher fine content

During the compaction, the soil particles were forced to compact into denser arrangement where most of fine content will be fill the void between large soil grain. As the fine content increased, some fine content will occupy location near the contact points between two sand grain and reduced the contraction between these sand particles. Furthermore, with higher fine content the loosely packed particle will be generate instead of granular structure. The collapse of this loosely package will create the pore pressure between grain. This relation can be seen in this RIC field trials test. The significant reduced of percent of improvement can be seen between Soil A and Soil B where the different of fine content is at only 2.46% while different from Soil B and C is not clearly visible.

5. Conclusions

To conclude the finding of this RIC compaction trails test in different materials:

1. The result from both CPT and PLT show that the percent of fine content have a major effect to the efficiency of this compaction method
2. The improvement depth of RIC in the specification materials are up to 4-5 m. from the impact point.
3. By replacing the upper layer of soil with stiffer material, the efficiency of RIC method will not improve.

Acknowledgement

Writers would like to give a special thanks to King Mongkut's University of Technology Thonburi for provided facilities for conducted the test in this study.

References

[1] Adam, D. (2007). Rapid Impact Compactor – An Innovative Dynamic Compaction Device For Soil Improvement.

Improvement of Soil Properties, Bratislava, Slovakia, 4-5 June 2007, pp.183-193.

[2] Adam, D. and Fürpass, J. (2007). Deep Dynamic Compaction light with the Rapid Impact Compactor. *TERRA-MIX*, Wettmannstätten, Austria, 9 February 2007.

[3] Adam, D., Adam, C., Falker, F. and Paulmichl, I. (2011). Vibration emission induced by Rapid Impact Compaction. *Proceedings of the 8th International Conference on Structural Dynamics*, Leuven, Belgium, 4-6 July 2011, pp.914-921.

[4] Braithwaite, E.J. and Du Preez, R.W. (1997). Rapid Impact Compaction in Southern Africa. *Geology for Engineering, Urban Planning, and the Environment*, *South African Institute of Engineering Geologists*, 13-14 November 1997.

[5] Kristiansen, H. and Davies, M. (2004). Ground Improvement Using Rapid Impact Compaction. *13th World Conference on Earthquake Engineering*, Vancouver, B.C., Canada, 1-6 August 2004.

[6] Serridge, C. J. and Synac, O. (2006). Application of the Rapid Impact Compaction (RIC) technique for risk mitigation in problematic soils. *IAEG*, London, United Kingdom.

[7] Tarawneh, B. and Hakam, Y. (2017). Performance of Rapid Impact Compaction as a Middle-Deep Ground Improvement Technique. *19th International Conference on Soil Mechanics and Geotechnical Engineering*, Seoul, South Korea, September 2017, pp.2623-2626.

[8] Theses, G. and Becker, P. J. (2011). *Assessment of Rapid Impact Compaction for Transportation Infrastructure Applications*. Master Dissertation, Iowa State University, United States.

[9] Wang S., Chan D. and Lam k. (2009). Experimental study of the effect of fines content on dynamic compaction grouting in completely decomposed granite of Hong Kong. *Construction and Building Materials,* vol 23, issue 3, pp. 1249-1264