A Field Prototype Test of Rapid Impact Compaction for Ground Improvement and Backfill Compaction at U-Tapao Airport

Sompote Youwai[1]
Sirasak Detcheewa [2]
Warat Kongkitkul[1]
Suniti Suparp[3]
Athasit Sirisonth[4]

[1]*Associate Professor*
[2]*Master Student*
Department of Civil Engineering, King Mongkut's University of Technology Thonburi
[3]*Associate Professor*
Department of Civil and Environmental Engineering, Faculty of Engineering, Srinakharinwirot University

[4]*Vice President, Engineering Department, Sino-Thai Engineering & Construction Public Company Limited*

ABSTRACT: Rapid impact compaction (RIC) is a ground improvement technique that densifies shallow granular soils by pounding them with a hydraulic hammer. This paper presents the application of RIC to improve the stiffness of ground and compaction of backfill at U-Tapao Airport in Thailand, a strategic development project in the eastern economic corridor. The paper reports the results of a field prototype test that measured the soil properties before and after RIC using cone penetration test (CPT), standard penetration test (SPT) and plate load test. The paper also analyzes the optimal compaction effort and the factors affecting the performance of RIC, such as fine content, effective depth and pre-compaction layer. The paper proposes a correlation between SPT and CPT based on the data collected from the site.

KEYWORDS: Rapid impact compaction, Airport, Cone penetration test

1. INTRODUCTION

Rapid impact compaction (RIC) is a technique that uses high-energy mechanical impacts to improve the soil's load-bearing capacity by compacting it. It is commonly applied in large infrastructure projects such as airports and highways, where the soil needs to support the weight of the structure (Cheng et al., 2021; Mohammed et al., 2013; Simpson et al., 2008; Spyropoulos et al., 2020, 2020; Tarawneh & Matraji, 2014; Vukadin, 2013)The effectiveness of RIC depends on various factors, such as the soil's silt content, compaction sequence, energy applied, stiffness of existing ground, ground water characteristics and drainage of soil(Ghanbari & Hamidi, 2014; Serridge & Synac, 2006; Tarawneh & Matraji, 2014). These factors vary in different site conditions and need to be considered in the design of RIC to optimize the compaction method. Therefore, it is advisable to conduct a trial before the actual construction.

This paper reports on a field trial of using RIC (rapid impact compaction) in the U-Tapao International Airport Project. The trial involved different soil types, fill heights, energy levels and construction sequences. The compaction uniformity was assessed by cutting the embankment and testing at different levels in the compacted mass. The trial had two phases: phase one evaluated the effects of different energy levels and soil types; phase two examined the uniformity of the compacted fill. The paper presents the correlation between different types of fill and field tests.

2. FIELD TEST

2.1 Rapid impact compaction machine

The site used a Rapid Impact Compactor (RIC) machine with a 90-kN drop hammer and a 1.5-m diameter circular plate. The plate rested on the ground and transferred stress to the low stiffness soil below, increasing its density. Figure 1 illustrates the compaction process, which was analogous to the laboratory compaction test with a hammer. The machine compacted the soil at 50 blows per minute, taking 1-2 minutes per location. The plate spacing and compaction effort were optimized to achieve the target field density and reduce construction costs and time. The literature suggested that the hammer weight varied from 50 to 120 kN and the drop height was about 1.2-1.5 m. A higher drop height increased the compaction energy but also the compaction time. The soil and site conditions determined the choice of these parameters. Excessive compaction effort could create deep craters or holes that could topple the machine. The next section discusses how to select the applied energy**.**

Fig.1 The RIC machine

2.2 Geotechnical characteristics of the construction site

The geotechnical characteristics pose a challenge to us RIC because of the high fine content of the ground, the high groundwater table and the weak layer of silt. The construction site is located near the sea and the ground condition consists of medium dense sand. The fine content of sand is quite high at 30-40 %. It can be classified as silty sand (SM).

The RIC can improve the density and stiffness of sand. However, there is a small silt layer at a depth of 2 m from the ground surface in some areas. The compaction process of RIC might cause this layer to fail and create punching shear through this layer. The platform of the compacted layer needs to be set up on top of the aforementioned silt layer. This layer, 0-1 m, has a higher stiffness than the underground layer. Near the ground surface, the value of cone resistance (QC) is about 4 MPa. Then it decreases with depth. The lowest value of cone resistance (QR) is at a depth of 7 m to be about 2 MPa. Then it increases with deeper depths. The groundwater table is very shallow at about 2 m from the ground surface. The platform for compaction is strongly required to prevent water from pumping out from the crater of compaction.

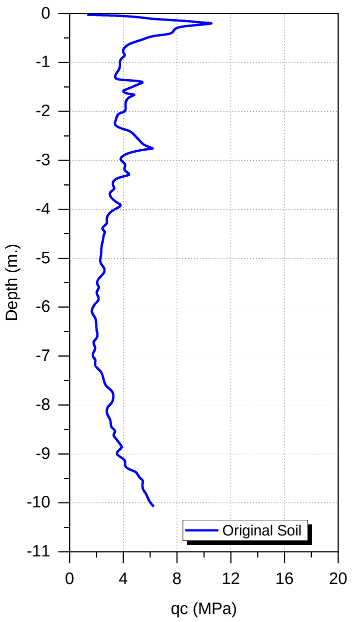

Figure 2 Cone resistance at the original area.

2.3 Test Embankment I

The prototype test design aims to improve the compaction of an existing ground and to develop a method of construction for fill embankment in Apron. The maximum fill height is 5 m from the surface. The RIC method is used for compaction of the fill embankment. The literature suggests that the effective depth of RIC is about 3 to 5 m depending on fine content of soil. However, since the fill material with high fine content is cheaper than the one with low fine content, the compaction depth is tested in two scenarios: 3 m and 5 m thick of fill. Three types of fill were used from the soil cut from a construction site with high fine content and soil imported from outside with fine content lower than 20 %. This idea was to check whether we can use the soil fill from cut section in site or not. It can save the construction cost.

Table 1 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*

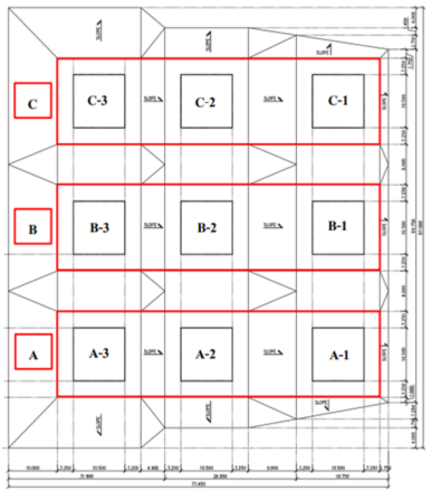

Figure 3 Overall Testing layout

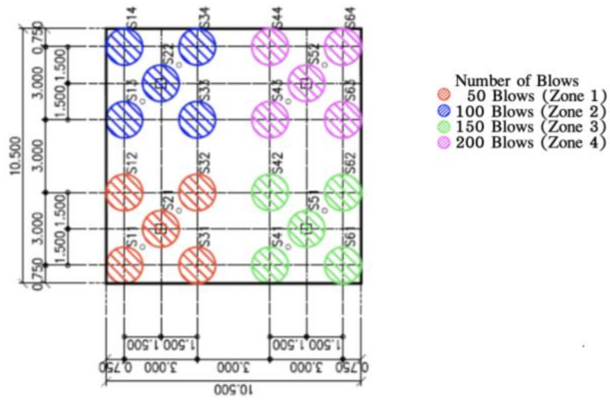

Figure 4 Compaction layout

The experimental design is shown in Fig. 3. Three types of soil (A, B, and C) with different fine contents (19%, 32%, and 24%, respectively) and three embankment heights (0.5, 3, and 5 m) were used as shown in Table 1. The 0.5 m height simulated a platform for compacting the existing ground. The optimal depth for compaction was tested with the 3 and 5 m heights. Different compaction efforts (50, 100, 150 and 200 blows) were applied using a rapid impact compactor (RIC) for each unit cell zone in the field (Fig. 4). The 100-blow RIC was equivalent to the standard proctor compaction energy.

2.3.1 Testing Results

The optimum compaction effort of RIC is 100 blows per location, as shown by the overall test results. Over compaction may reduce the strength of compacted soil due to punching failure. Fig. 5 presents the cone penetration test results for RIC ground improvement with varying fill thicknesses, compaction efforts, and material types. The type of compacted soil influences the strength improvement of the soil. For low fill thickness (0.5 m), the compaction affects the existing ground with high fine content, leading to the lowest QC increase compared to thicker fill cases. The strength at shallow depth decreases when the compaction effort exceeds 100 blows per location due to punching failure. For fill thicknesses of 3 and 5 m, the QC values of the fill increase significantly with increasing compaction effort. However, over compaction also lowers the QC when the compaction effort is more than 100 blows.

The depth of compaction influence was about 3 m from the ground surface, as shown in Fig. 5. Beyond this depth, the compaction effect was similar regardless of the compaction energy. Compared to previous research, the effective compaction depth was lower in this case study. This could be due to the high fine content of the compacted soil, which was more than 15%. The actual embankment construction could be divided into two layers, each not exceeding 3 m. For example, for an embankment height of 5 m, the first layer could be 3 m and the second layer could be 2 m.

The compaction strength of soil depends on its fine content and the compaction effort applied, as shown in Fig. 5. The percent of improvement is defined as the average ratio of QC of unimproved and improved ground. The results support the previous paragraph that the soil strength decreases when the compaction blows exceed 100. The highest blow at 200 produces the weakest soil. The compaction also creates a deep crater in the fill, more than 0.8 m, which can cause instability of the compaction machine. Therefore, the crater should be filled with more soil to reduce the risk of overturning. The fine content has a strong effect on the compaction efficiency. Soil A, which has the lowest fine content, shows the highest efficiency. This is consistent with previous research that RIC (rapid impact compaction) is more effective for soils with low fine content. For soils with high fine content, RIC is not a suitable method for ground improvement (Spyropoulos et al., 2020). The optimum compaction effort is clearly shown in Fig. 7. The percent of improvement increases with increasing compaction effort until it reaches a peak and then decreases when overcompaction occurs with compaction effort higher than 100 blows. This occurs with every soil type. The QC of soil C, high fine content, decreases with increasing compaction effort.

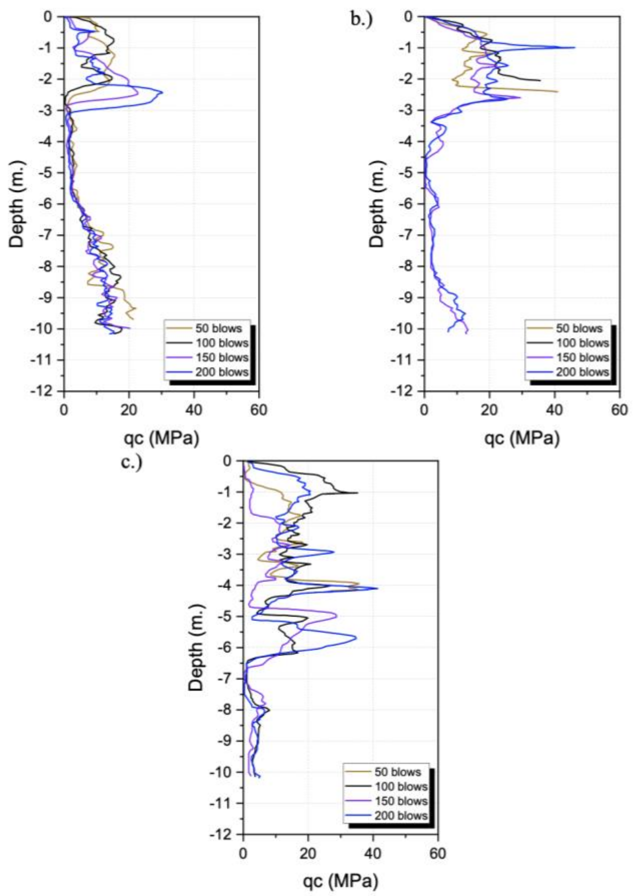

Figure 5 Cone resistance, qc of Soil A with fill thickness of a.) 0.5m. b.)3 m. and c.) 5 m. after 50, 100,150 and 200 blows

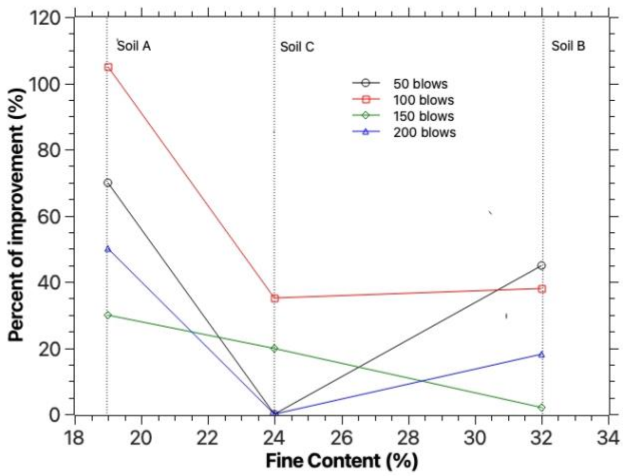

Figure 6 A relationship of Percent of Improvement and Fine content

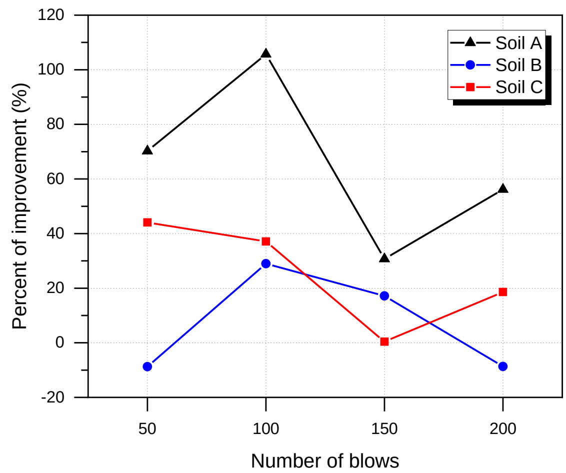

Figure 7 A Percent of Improvement and Number of Blows

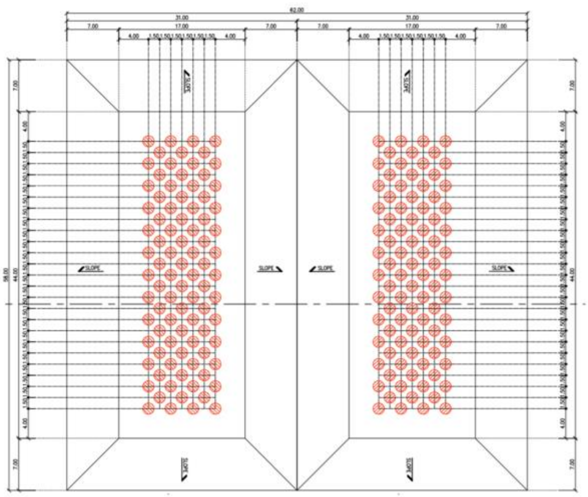

Figure 8 plan view of test embankment 2

2.4 Test Embankment II

The test embankment no. 2 simulated the real construction sequence of RIC and assessed its uniformity with a fill thickness of 3 m, based on the previous section's influence depth of compaction (Fig. 8). The compaction effort was 50 blows per impact point on the ground surface, with a penetration criterion of 0.5 cm per blow for the last three blows. This was based on the first phase results that showed the adequate strength of the compacted fill for airport apron subgrade construction. The backfill soil was compacted before the RIC to prevent instability of the RIC equipment. Two types of existing fill compaction were compared: Type A with three 1m-thick layers and Type B with two 1.5m-thick layers. The degree of compaction achieved by RIC depended on the existing soil condition before the treatment. Plate load tests, Cone penetration tests, and Standard penetration tests were performed before and after the treatment at three different depths (1m, 2m, and 3m).

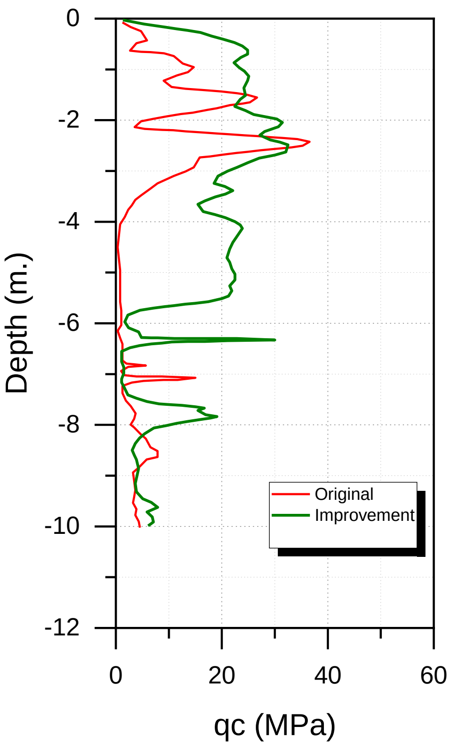

Figure 9 Cone resistance before and after improve with RIC

Figs. 9 and 10 show the RIC compaction results by cone penetration test and SPT. The pre-compaction layer significantly affects the compaction outcomes. The effective compaction depth can reach up to 6 m from the surface, which is deeper than the first test embankment. This might be due to the larger compaction area in test No. 2, which can influence the soil at greater depths. The compaction effectiveness is much higher than the unit cell concept compaction in the first embankment. The pre-compaction layer might act as a large raft that densifies the underlying soil layer. The existing soil strength can increase up to 6 times compared with the first test section. The compaction results of pre-compaction type A and B are similar. Therefore, the embankment construction with pre-compaction can use 2 compaction layers with 1.5 m thickness before applying RIC. This can save time and cost for the pre-compaction stage.

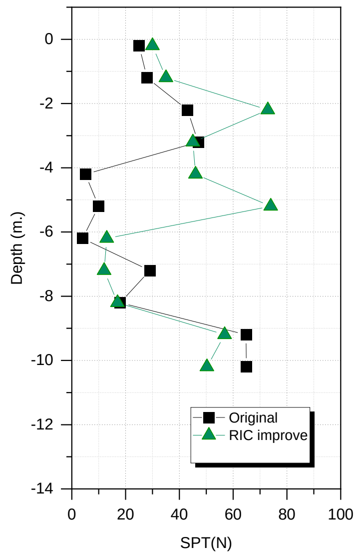

Figure 10 SPT value before and after improving with RIC

2.4.1 Test Results

The test was conducted using a plate loading test according to ASTM D1195 Standard test method for repetitive static plate load tests of soils and flexible pavement components for use in evaluation and design of airport and highway pavements. This method applies a constant load on a circular steel plate and measures its deflection on different types of soils. The test was performed before and after Rapid Impact Compaction (RIC) at depths of 1-3 m. The strain modulus values from the plate loading test were converted to the subgrade modulus values of the soil, as shown in Fig. 11. The results showed that RIC significantly increased the subgrade modulus compared to before RIC. The increase was up to 2 times in the unimproved area, especially at the surface where the RIC hammer directly impacted. This indicates that RIC improved the strength and stiffness of the soil by densifying it through repeated impacts. Plot B had a higher overall stiffness than plot A because it had a lower compaction thickness before RIC. The field density test results agreed with the plate loading test results, as shown in Fig. 12. The density of compacted soil was relatively uniform throughout the compaction depth and slightly decreased with depth. It can be simplified that they had equal efficiency.

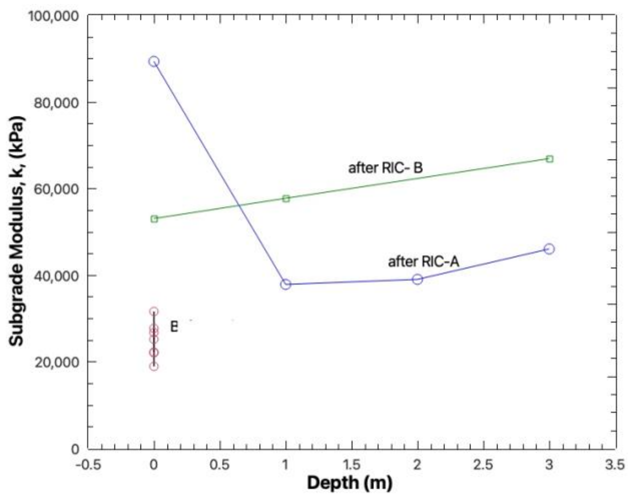

Fig. 11 The results of plate loading test before and after improvement with RIC

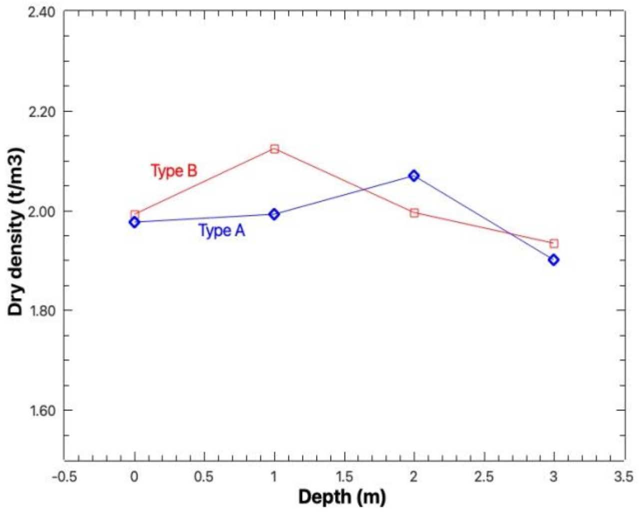

Fig. 12 Dry density after improvement with RIC

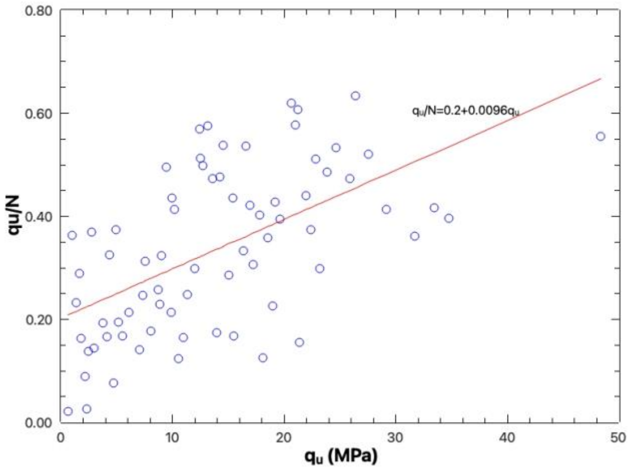

Fig. 13 Relationship between SPT and cone penetration test

The relationship between cone tip resistance and CPT value is plotted in Fig. 24. The relationship is quite scattered due to the attempt to use a dynamic test, SPT, to correlate with a static loading test (CPT). However, a site-specific empirical equation can be derived as follows:

$$\frac{q_u}{N} = 0.2 + 0.0096 q_u$$

Where q_u is the cone tip resistance. N is standard penetration test value (N)

3. CONCLUSIONS

This study investigated the effects of rapid impact compaction (RIC) on the strength and stiffness of compacted soil. The main findings are:

- The optimal range of blows for RIC is 50-100 blows. Beyond this range, the strength of the compacted soil decreases.
- The effectiveness of RIC depends significantly on the fine content of the soil. The fine content should not exceed 20% to achieve the benefits of RIC.
- The effective depth of RIC varies from 3 to 6 m depending on the area of compaction zone. A higher area of compaction ints increases the influence zone up to 6 m.
- The pre-compaction layer is important for enhancing the performance of RIC. The recommended method for constructing the pre-compaction layer is to use a vibrator compaction machine to compact a 1.5 m thick layer of soil.
- The subgrade modulus increases with RIC applied to the layer. The subgrade modulus of the pre-compaction layer using 1.5 m for each compaction layer is higher than that using 0.5 m for each compaction layer.
- A relationship between standard penetration test (SPT) and cone penetration test (CPT) was proposed in this study.

4. REFERENCES

Cheng, S.-H., Chen, S.-S., & Ge, L. (2021). Method of estimating the effective zone induced by rapid impact compaction. *Scientific Reports*, *11*(1), 18336.

Ghanbari, E., & Hamidi, A. (2014). Numerical modeling of rapid impact compaction in loose sands. *Geomechanics and Engineering*, *6*, 487–502.

Mohammed, M., Roslan, H., & Firas, S. (2013). Assessment of rapid impact compaction in ground improvement from in-situ testing. *Journal of Central South University*, *20*(3), 786–790.

Serridge, C. J., & Synac, O. (2006). *Application of the Rapid Impact Compaction (RIC) technique for risk mitigation in problematic soils*.

Simpson, L. A., Jang, S. T., Ronan, C. E., & Splitter, L. M. (2008). Liquefaction potential mitigation using rapid impact compaction. In *Geotechnical Earthquake Engineering and Soil Dynamics IV* (pp. 1–10).

Spyropoulos, E., Nawaz, B. A., & Wohaibi, S. A. (2020). A Case Study on Soil Improvement with Rapid Impact Compaction (RIC). *World Journal of Engineering and Technology*, *08*(04), 565–589. https://doi.org/10.4236/wjet.2020.84040

Tarawneh, B., & Matraji, M. (2014). Ground improvement using rapid impact compaction: Case study in Dubai. *Građevinar*, *66*(11.), 1007–1014.

Vukadin, V. (2013). The improvement of the loosely deposited sands and silts with the Rapid Impact Compaction technique on Brežice test sites. *Engineering Geology*, *160*, 69–80.