A POORLY GRADED SAND COMPACTION CASE STUDY

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ABSTRACT: One 350 hectare artificial island using hydraulic dredging sand is newly formed in North Jakarta. The sand is poorly graded with most particle size in the range of 0.2 ~ 0.5 mm in loose and saturated condition. Dynamic Compaction and Vibroflotation method are used to improve the sand. Pre-CPT is performed in 50x50 m grid to indicate the sand depth as well as the fine content. Dynamic compaction and vibroflotation method are used to improve the areas in which the sand depth is less than 6.0 m or beyond 6.0 m respectively. However, in this case, it is found that vibroflotation method requires more effort than common cases; meanwhile the maximum value of CPT's cone resistance after improved by dynamic compaction is higher than vibroflotation method. To well understand the phenomenon of dynamic compaction and vibroflotation in poorly graded sand, the behavior and response between poorly graded sand particles is explored by considering the following factors: particle size distribution, shape & roughness of particle, water table and fine content.

Keywords: Poorly graded sand, dynamic compaction, vibroflotation, shape & roundness of particle, particle size grading, fine content ratio.

1. INTRODUCTION

Jakarta government made a giant master plan (Figure 1) for north Jakarta giant sea wall and land development as the solution for continuous settlement and flood problem in North Jakarta area, as well as the Jakarta city development and exploration (2014). This master plan consists of several artificial islands and continuous sea wall & drain system. Recently, one 350 hectare artificial island is newly formed in North Jakarta as the pioneer effort of the master plan. The location of this island is showed as Figure 2. This case could be the typical case and reference for the following artificial islands construction in the future.

Figure 1. Master plan of Jakarta

Figure 2. Location of the artifical island

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2. SAND CONDITON

The island is backfilled with hydraulic sand filling. The sand is dredged from sea with some content of shell. Sand samples were taken from the sand quarry for sieve analysis test. The Lab test result, shown as Figure 3, indicated that the sand is poor graded with 64% of the particle size is in the range of 0.2 ~ 0.5 mm. It could be described as fine ~ medium sand with shells. The fine content of those sand samples is about 5%.

The sand is in loose and saturated status after hydraulic filling. Several CPTu test were performed to indicate the soil conditions. Figure 4 is a typical CPTu test result. The seismic analysis using acceleration 0.3g and Magnitude 7.7 was performed based on those CPTu test result which indicated that there is liquefaction potential due to loose condition of sand. Therefore, compaction methods shall be employed to improve the sand to guarantee the safety of the whole island, especially the dike of the island.

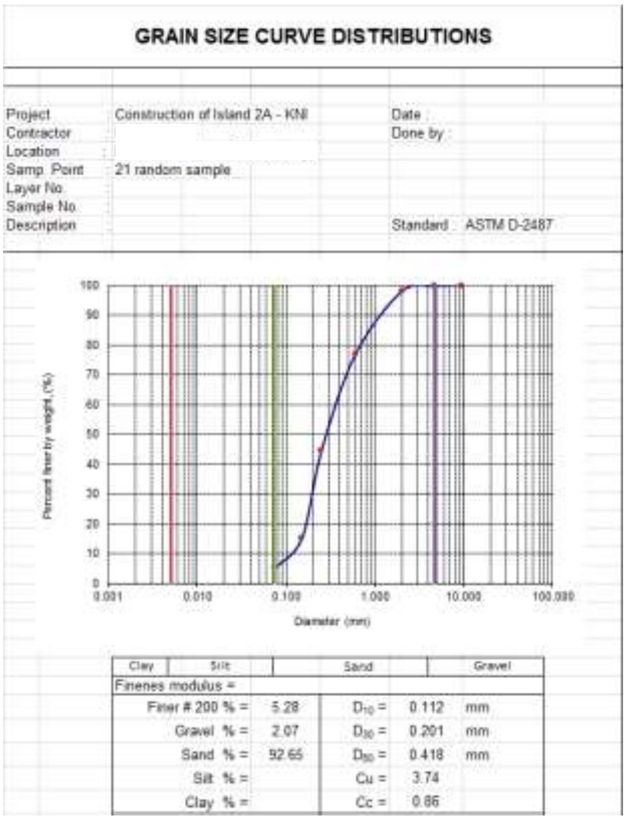


Figure 3. Typical sieve analysis result of sand sample from sand quarry

3. SAND COMPACTION METHOD AND TRIAL

Sand is a kind of granular soil material. Generally, there are two concepts to compact sand. One concept is using impact energy and the other one is using vibrating energy (described as Figure 5).

Dynamic compaction (DC) is a typical compaction method by impact energy. DC compact the soil by dropping a temper from a certain height to the ground. The dropped temper generates instantaneous impact energy to the ground, which shall significantly compact the granular soil in a very short time. The most effective part of such impact energy is the vertical energy which will be decreased along depth. Generally speaking, DC is most effective and economical when the target soil is not deep than 6 m.

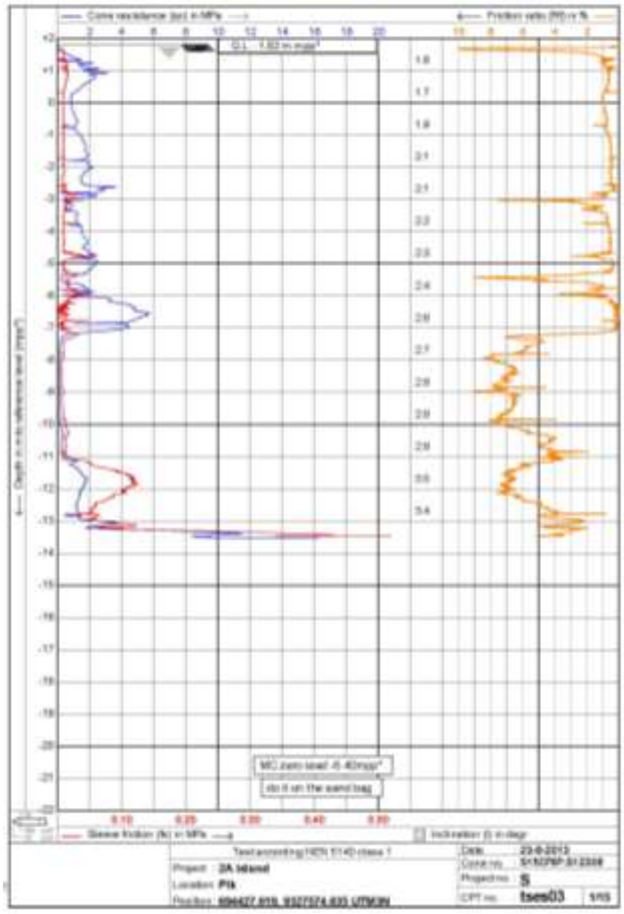
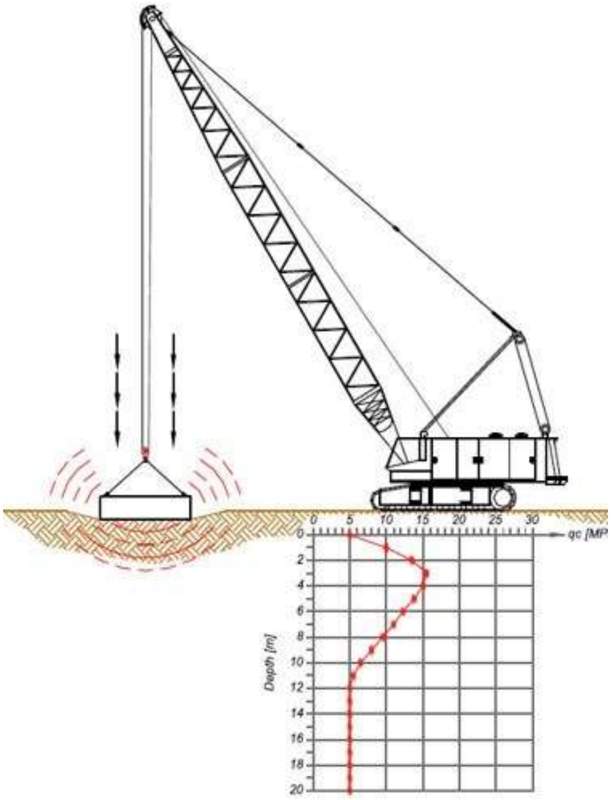


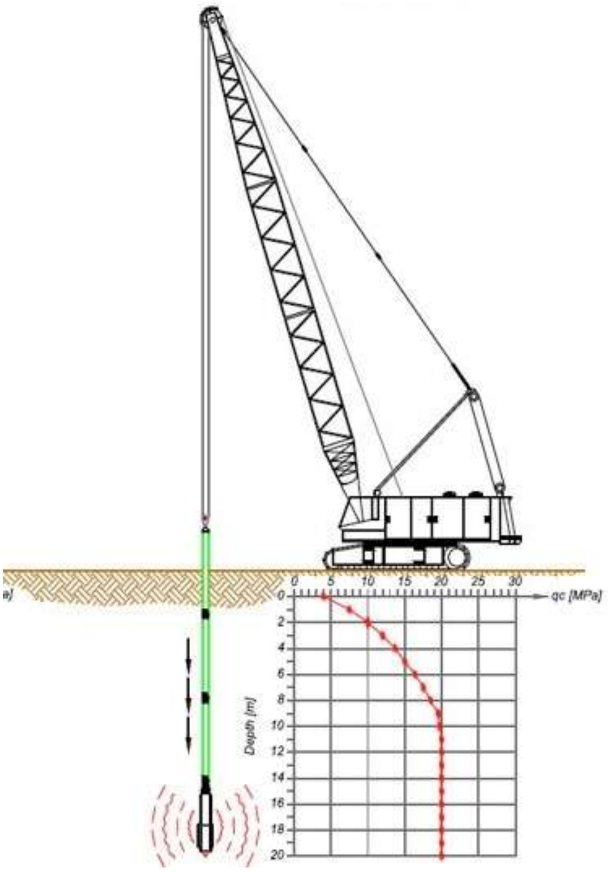
Figure 4. Typical CPTu test result

Vibroflotation method is a typical compaction by vibration energy. This method sends high frequency vibrating probes into the ground which transfer continuous horizontal-spread vibration energy to granular soil to make soil densified. The improvement of vibroflotation can reach relative deep soil because the vibrating probes can be pressed and lifted by tubes. Vibroflotation is more effective and economical for soil depth beyond 6 m.

It is designed to use dynamic compaction method and vibroflotation method to improve the areas in which the sand depth is less than 6.0 m or beyond 6.0 m respectively. Considering the project covers a relatively big area, the depth of sand not uniformed distributed. The Pre-CPT test shall be performed in 50x50 m grid in advance to indicate the sand depth as well as the fine content. Meanwhile, a trial of compaction methods was performed to verify the compaction effect of each method.



a) Dynamic Compaction



b) Vibroflotation

Figure 5. Sketch of compaction methods

The compaction trial was performed in two locations for dynamic compaction and vibroflotation method separately.

The trial for dynamic compaction was performed in south part of the island. Pre-CPT result indicated that the sand depth in DC trial area is about 5.0 m. The required compaction energy is estimated by:

$$D = n\sqrt{WH} \quad (1)$$

Where:

D—depth of improvement in meters

W—mass of tamper

H— drop height in meters

n— empirical coefficient that is less than 1.0, which was found to be related to soil type as shown in Table 1.

Table 1. Recommended n Value for Different Soil Types

Soil Type	Degree of Saturation	Recommended n Value
Pervious Soil Deposits Granular Soils	High	0.5
	Low	0.5-0.6
Semipervious Soil Deposits Primarily Silts with Plasticity Index of <8	High	0.35-0.4
	Low	0.4-0.5
Impervious Deposits Primarily Silts with Plasticity Index of >8	High	Not Recommended
	Low	0.35-0.40 Soil should be at water content less than the plastic limit

Based on above estimation, a 17 ton temper made of steel was employed to perform DC trial. The temper was lifted to 17 m and feel fall to ground and there are 5 blows for every compaction point. The spacing of compaction point is 4 m × 4 m. It is observed that the deformation in center of the compaction point reached 1.3 ~ 1.4 m. The average settlement after compaction and leveling is about 40 cm. Post-CPT was performed 7 days after compaction to evaluate the compaction effect which is showed as Figure 6. It is obtained that the q_c value from 2.0 ~ 5.0 m is significantly increased and the maximum value reached 18.00 MPa.

Obviously, the loose and saturated sand from surface to – 5.0 m is significantly improved by DC method, using 289 T*m compaction energy. Meanwhile, a relatively hard zone in which the q_c value is beyond 10 MPa is generated between 2.5 ~ 4.0 m. However, the q_c value decrease remarkably along the depth.

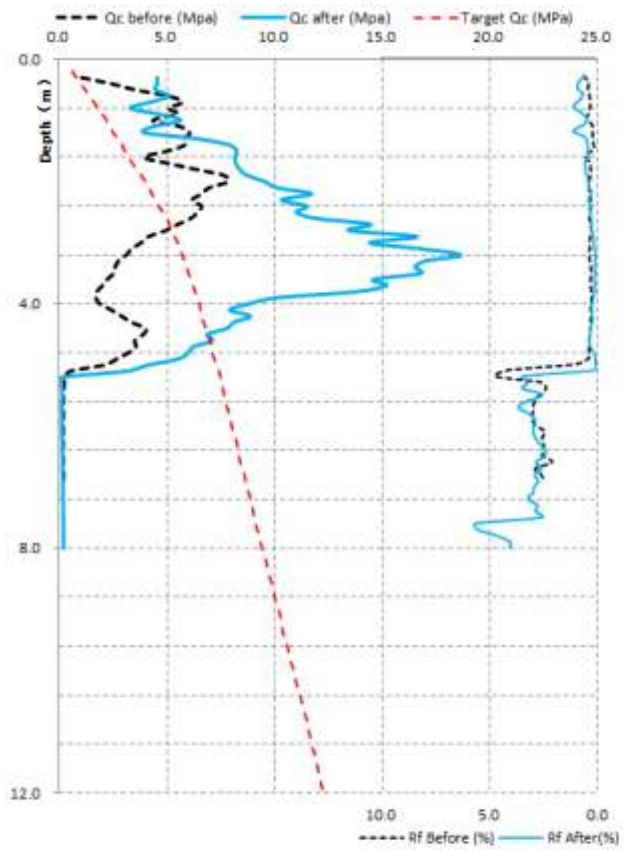


Figure 6. Pre-Post- CPT result of DC trial

The trial for vibroflotation was performed in north part of the island. Pre-CPT result indicated the sand depth in vibroflotation trial area is 9 ~ 11 m. The trial area was divided into 5 sub-zones and each sub-zone was performed with different vibroflotation parameters. The vibroflotation parameters of 5 sub-zones are listed as Table 2. Two type of vibrator with different power were employed to perform the trial. The specification each vibrator type is listed as Table 3.

Table 2. Summary of vibroflotation parameters

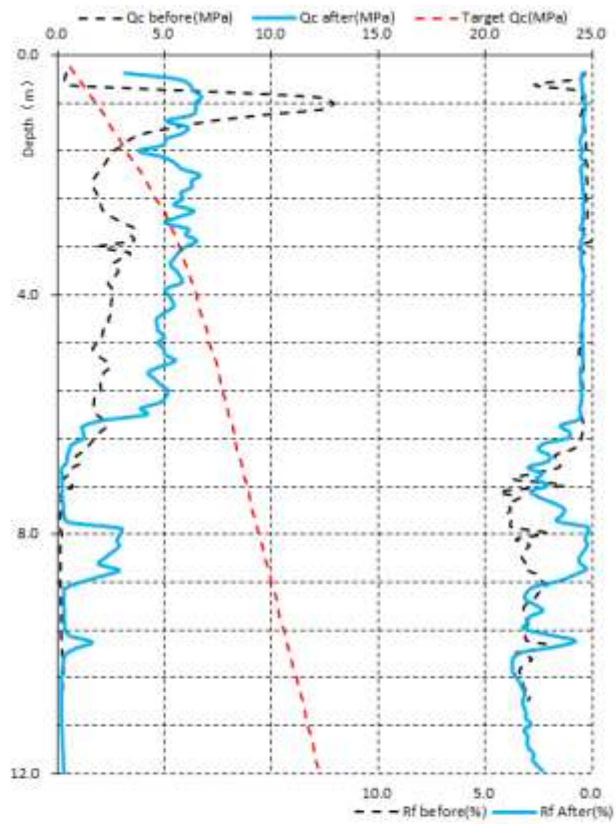
No.	Vibrator type	Spacing (m)	Vibrating period (s)
Zone-1	BJV130	3.0	20
Zone-2	BJV130	3.0	40
Zone-3	BJV130	2.5	20
Zone-4	BJV130	2.5	40
Zone-5	ZCQ 75	2.5	40

Table 3. Specification of vibrators

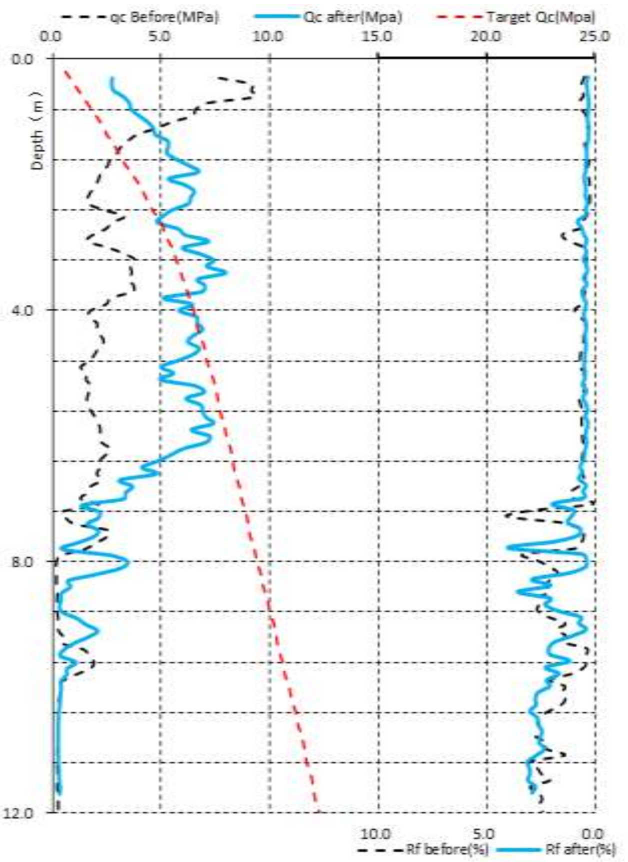
Parameter	BJV130	ZCQ75
Power (KW)	130	75
Centrifugal force (KN)	200	160
Amplitude (mm)	19	19
Diameter (m)	377	426
Length (m)	3.35	2.6
Frequency (Hz)	24	24

The pre-CPT and post-CPT results of each sub-zone are listed in Figure 7. It is obtained that the post-CPT in zone-1 and zone-2 can only reached the target q_c from ground surface to -3.5 m which means the improvement by BJV130 vibrator & spacing 3.0 m is not good enough. What is more, the improvement effect of vibrating period 40s didn't show difference with vibrating period 20s. The maximum post q_c value of zone-1 and zone-2 is about 7.98 MPa.

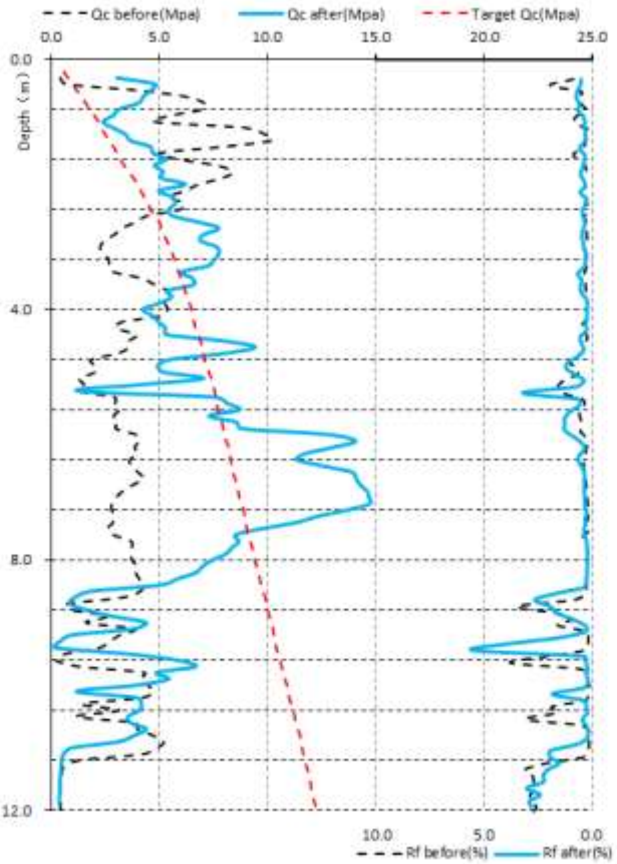
On the other hand, the post-CPT of zone-3and zone-4 can reach the target q_c from ground surface to -7.5 m which means spacing 2.5 m is more effective with the same vibrator. Furthermore, q_c value of CPT-4 is higher than CPT-3 which means vibrating period 40s result better improvement than vibrating period 20s. The maximum q_c value of CPT-4 is 14.68 MPa and the maximum of CPT-3 is 11.53 MPa. Besides, another vibrator ZCQ75 with lower power was employed to perform the trial for comparison with spacing 2.5 m. The q_c value can reach the target q_c from ground surface to -7.0 m and the maximum q_c value is 10.80 MPa. This comparison indicated that the improvement effect of BJV130 is better than ZCQ75 under the condition of spacing 2.5 m. Both of BJV130 and ZCQ75 can improve the sand up to depth 7.5 m in this case. However, post-CPT result of both type of vibrator showed the same phenomena that the improvement of soil below -7.5 m is really limited. This is related with the fine content influence.



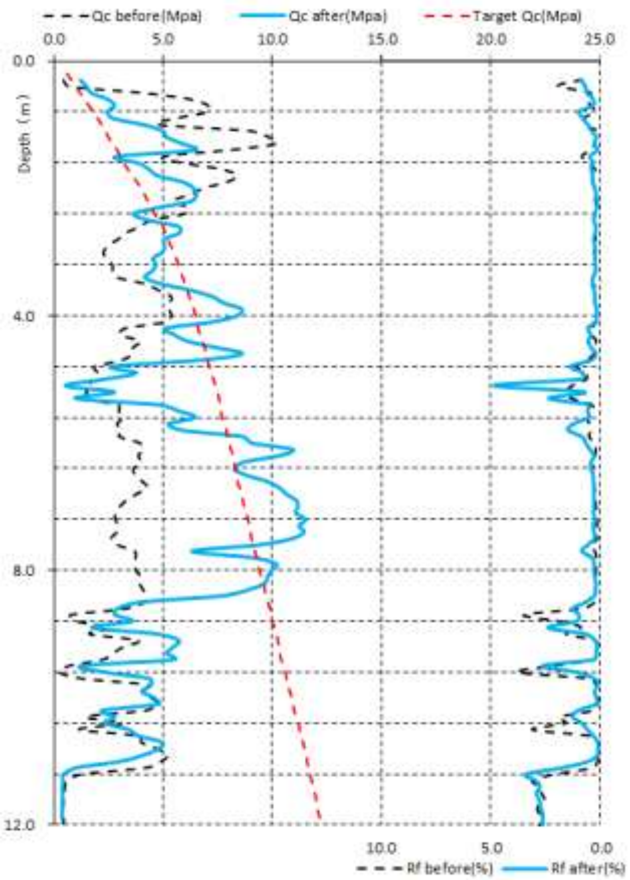
a) Zone-1 CPT result



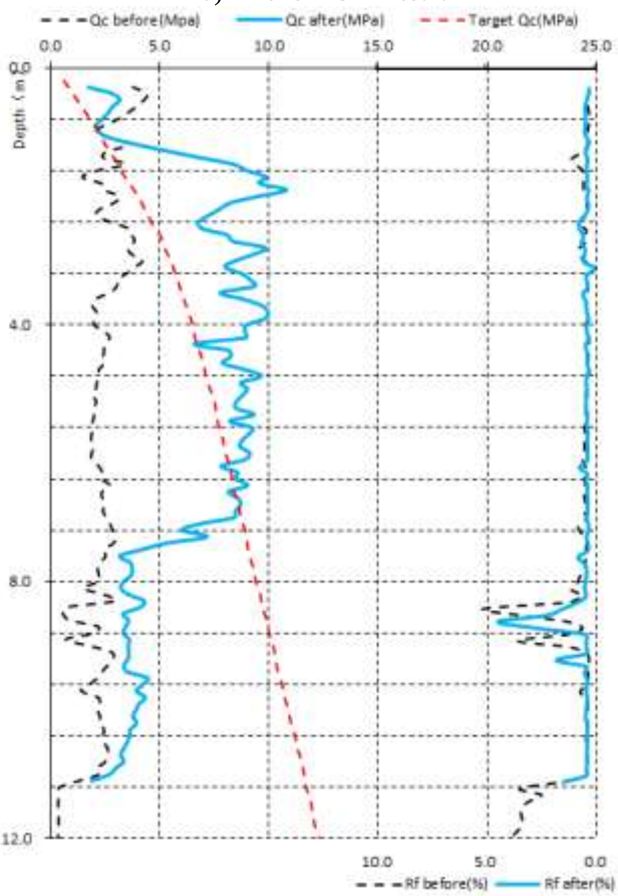
b) Zone-2 CPT result



d) Zone-4 CPT result



c) Zone-3 CPT result

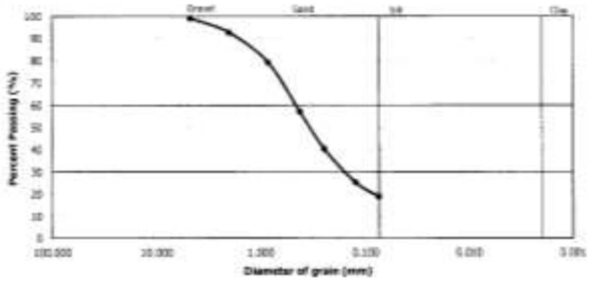


e) Zone-5 CPT result

Figure 7. Pre-Post-CPT result of vibroflotation trial

Project : GOLF ISLAND
Location : Pantai Indah Kapuk - Jakarta Utara
Tested By : Sadiri
Project No :

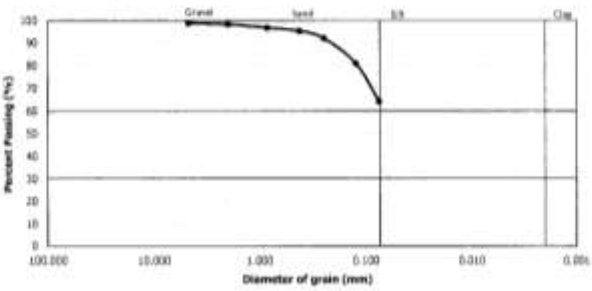
Weight of soil =		554.52			
Sieve No	Diameter of grain	Mass Retained	Percent Retained	Percent Cumulative Retained	Percent Passing
#	(mm)	(gr)	(%)	(%)	(%)
	49.900	**0.00**	0.00	0.00	100.00
1	25.000	**0.00**	0.00	0.00	100.00
.3/4	19.000	**0.00**	0.00	0.00	100.00
.1/2	12.500	**0.00**	0.00	0.00	100.00
.3/8	9.500	**0.00**	0.00	0.00	100.00
4	4.750	**5.18**	0.93	0.93	99.07
10	2.000	**35.09**	6.33	7.26	92.74
20	0.840	**74.97**	13.52	20.78	79.22
40	0.425	**122.56**	22.10	42.88	57.12
60	0.250	**92.72**	16.72	59.60	40.40
100	0.125	**84.28**	15.20	74.80	25.20
200	0.075	**35.40**	6.38	81.19	18.81
		450.20			



a) Sieve analysis of 7.5 ~ 7.95 m soil sample

Project : GOLF ISLAND
Location : Pantai Indah Kapuk - Jakarta Utara
Tested By : Sadiri
Project No :

Weight of soil =		435.22			
Sieve No	Diameter of grain	Mass Retained	Percent Retained	Percent Cumulative Retained	Percent Passing
#	(mm)	(gr)	(%)	(%)	(%)
	49.900	**0.00**	0.00	0.00	100.00
1	25.000	**0.00**	0.00	0.00	100.00
.3/4	19.000	**0.00**	0.00	0.00	100.00
.1/2	12.500	**0.00**	0.00	0.00	100.00
.3/8	9.500	**0.00**	0.00	0.00	100.00
4	4.750	**5.10**	1.17	1.17	98.83
10	2.000	**2.78**	0.64	1.81	98.19
20	0.840	**6.32**	1.45	3.26	96.74
40	0.425	**6.35**	1.46	4.72	95.28
60	0.250	**14.13**	3.25	7.97	92.03
100	0.125	**48.06**	11.04	19.01	80.99
200	0.075	**73.27**	16.84	35.85	64.15
		156.01			



b) Sieve analysis of 11.5 ~ 11.95 m soil sample

Figure 8. Sieve analysis result of soil samples

It is observed that when Rf value is relatively higher than 2%, the increment of corresponding q_c value is quite limited. Meanwhile, the Rf value of the soil below -7.5 m is obviously higher than the top sand layer and the corresponding post q_c value is obviously lower. It is believed that the improvement of vibroflotation is really limited if the fine content is high. Sand samples of different depth were taken on site and tested in Lab. Sieve analysis result (showed as Figure 8.) proved that the fine content of the sand below -7.0 m beyond 18.8% and significantly increase along the depth.

Based on the CPT result and borehole data, there is a transition zone is distinguished from -7.5 m to -11.0 m. The backfilled sand is mixed with original soft clay in seabed and mixing behavior occurred in several meter depth range. It is impressive that the transition zone could be 3.0 ~ 4.0 m thickness due to sand penetration and soft clay squeezing. The liquefaction potential shall be re-evaluated in the transition zone.

4. DISCUSSION OF SAND BEHAVIOUR UNDER COMPACTION

Generally, sand soil is an aggregate of granular material. Sand soil behavior is greatly determined by particle size distribution, particle shape & roundness, density and water content.

In mostly cases, particle size distribution determines the minimum void ratio e_{min} and maximum void ratio e_{max}. For poor graded sand, most of the particles are in a narrow size range which means most of the particles are in a nearly same size. Therefore, if assume all particle are round and smooth, it is predictable that the difference between e_{min} and e_{max} shall be relatively small and it is more difficult to compact poor graded sand to reach a high relative density Dr.

On the other hand, the friction stress between sand particles is greatly determined by the particle shape & roundness. Figure 10 show some scanning photo of sand particles (Liu Yu, 2010). In fact, natural sand particles are in different shapes and always rough on surface. Even in the same equivalent size, different shape and roundness will result different particle contact behavior under compaction. The particle contact behavior could be divided into two stages. The first stage is shape contact which means the contact determined by particle shape. Rearrange of particle location or position could significantly change the shape contacts. The second stage is microscopic roundness contact which is determined by particle roundness. Microscopic roundness contact could not be influenced by re-location or re-position. However, instantaneous impact forces could change microscopic roundness contact significantly.

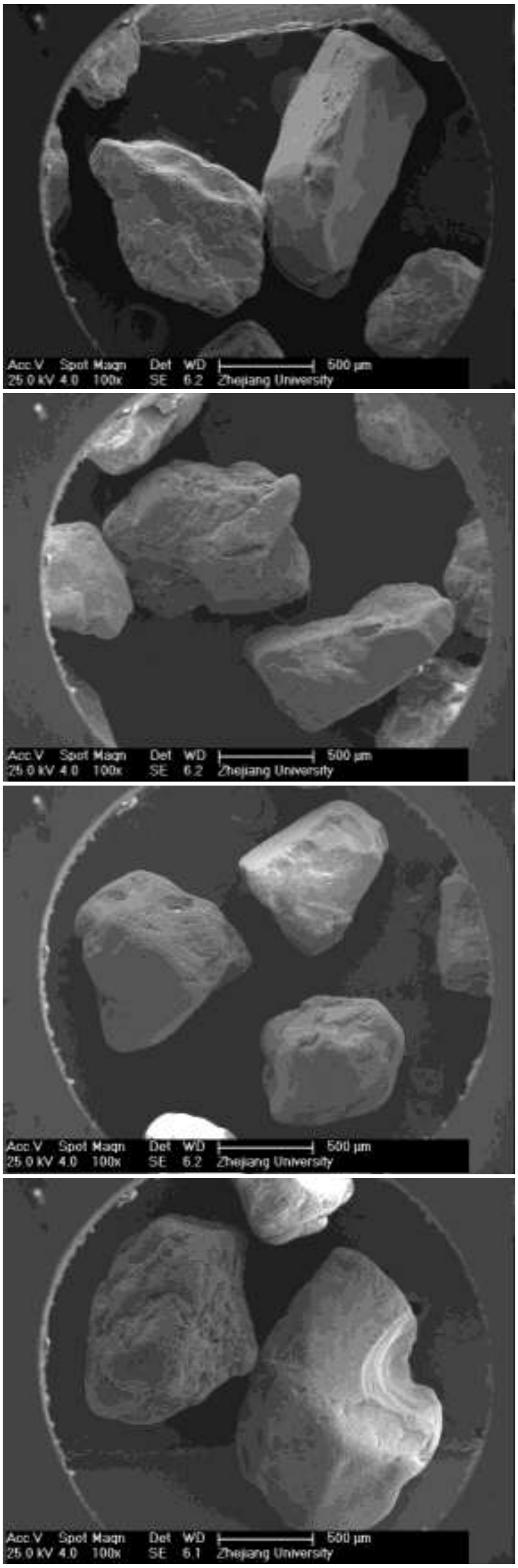


Figure 10. Scanning photo of sand particles

The concept of vibroflotation method is to gain higher shear strength by liquefying and re-building sand particle contact structure. The sand particle behavior under vibroflotation compaction is mainly referred to the first stage contact domain. Therefore, poor-graded sand requires more effort for vibroflotation compaction, such as shorter spacing or longer vibrating period.

On the other hand, the concept of dynamic compaction is to densify sand soil by instantaneous impact energy. The sand particle behavior under dynamic compaction is referred to both stage contact domains. This is the reason why there is a hard layer with higher q_c value generated from -2.5 ~ 4.0 m in the DC trial. The difference between maximum q_c value of DC and that of vibroflotation comes from the contribution of the enhanced microscopic roundness contact. Moreover, this phenomenon is found in most of DC cases and it indicates that DC tends to result an over-consolidated hard layer on shallow depth and the improvement effect decreased remarkably along the depth. Therefore, DC can effective improve poor-graded sand due to the contribution of enhanced microscopic roundness contact.

Water table is another important aspect for compaction works. Obviously, water could absorb a lot of seismic energy, especially for instantaneous energy. Thus, DC is more sensitive about water table. In most cases, water table is required to be below -2.0 m from ground surface to enhance the improvement effect of DC.

Fine content is more sensitive for vibroflotation method than DC. Basically, the trial result proved the general instruction that the improvement of vibroflotation is greatly influenced by fine content, especially if the fine content is above 15%.

5. CONCLUSIONS AND FORECAST

One 350 hectare artificial island is newly formed in North Jakarta, using hydraulic dredging sand. The sand is poorly graded with most particle size in the range of 0.2 ~ 0.5 mm in loose and saturated condition. Dynamic compaction and vibroflotation method are used to improve the sand. The compaction trials are performed, separately for dynamic compaction and vibroflotation.

A 17 ton temper made of steel was employed to perform DC trial. The temper was lifted to 17 m and feel fall to ground and there are 5 blows for every compaction point. The spacing of compaction point is 4 m × 4 m. Post-CPT was performed 7 days after compaction to evaluate the compaction effect which that the loose and saturated sand from surface to – 5.0 m is significantly improved by DC method and the maximum value reached 18.00 MPa. Meanwhile, a relatively hard zone in which the q_c value is beyond 10 MPa is generated between 2.5 ~ 4.0 m. However, the q_c value decrease remarkably along the depth.

The trial for vibroflotation was performed in north part of the island in which the sand depth is 9 ~ 11 m. The trial area was divided into 5 sub-zones and each sub-zone was performed with different vibroflotation parameters. Two spacing distance, 2.5 m and 3.0 m, as well as two vibrating period, 20s and 40s, were tested separately for comparison. Besides, two types of vibrators, BJV130 and ZCQ75 were employed to do the trial. The Post-CPT result indicated that spacing 2.5 m and vibrating period 40s are more effective in this case. No significant difference was found between the effects of two types of vibrators. However, post-CPT result of both type of vibrator showed the same phenomena that the improvement of soil below -7.5 m is really limited. It is observed that the Rf value of the soil below -7.5 m is obviously higher than the top sand layer and the corresponding post q_c value is obviously lower. Sieve analysis result proved that the fine content of the sand below -7.0 m beyond 18.8% and significantly increase along the depth. In conclusion, the improvement of vibroflotation is greatly influenced by fine content.

Sand soil behavior is greatly determined by particle size distribution, particle shape & roundness, density and water content. For poor graded sand, most of the particles are in a narrow size range which means the difference between e_{min} and e_{max} shall be relatively small and it is more difficult to compact poor graded sand to reach a high relative density Dr.

The friction stress between sand particles is greatly determined by the particle shape & roundness. The particle contact behavior could be divided into two stages. The first stage is shape contact and the second stage is microscopic roundness contact. Shape contact is greatly influenced by re-location or re-position but microscopic roundness contact is mainly influenced by instantaneous impact forces.

Poor-graded sand requires more effort for vibroflotation compaction, such as shorter spacing or longer vibrating period. Meanwhile, vibroflotation is very sensitive to fine content, especially if the fine content is above 15%.

On the other hand, DC can effective improve poor-graded sand due to the contribution of enhanced microscopic roundness contact. However, the effective improvement depth of DC is limited and very sensitive to water table.

ACKNOWLEDGEMENTS

Prof. Paulus P. Rahardjo, Ph. D, Parahyangan Catholic University, Indonesia

REFERENCES

Kementerian Koordinator Bidang Perekonomian Republik Indonesia.(2014). National Capital Integrated Coastal Development Master Plan (Draft).

Liu Yu. (2010). Research on Sand Shear Wave Velocity based on Particle Contact Model (Thesis for Ph.D of Geotechnical Engineering). Zhejiang University.