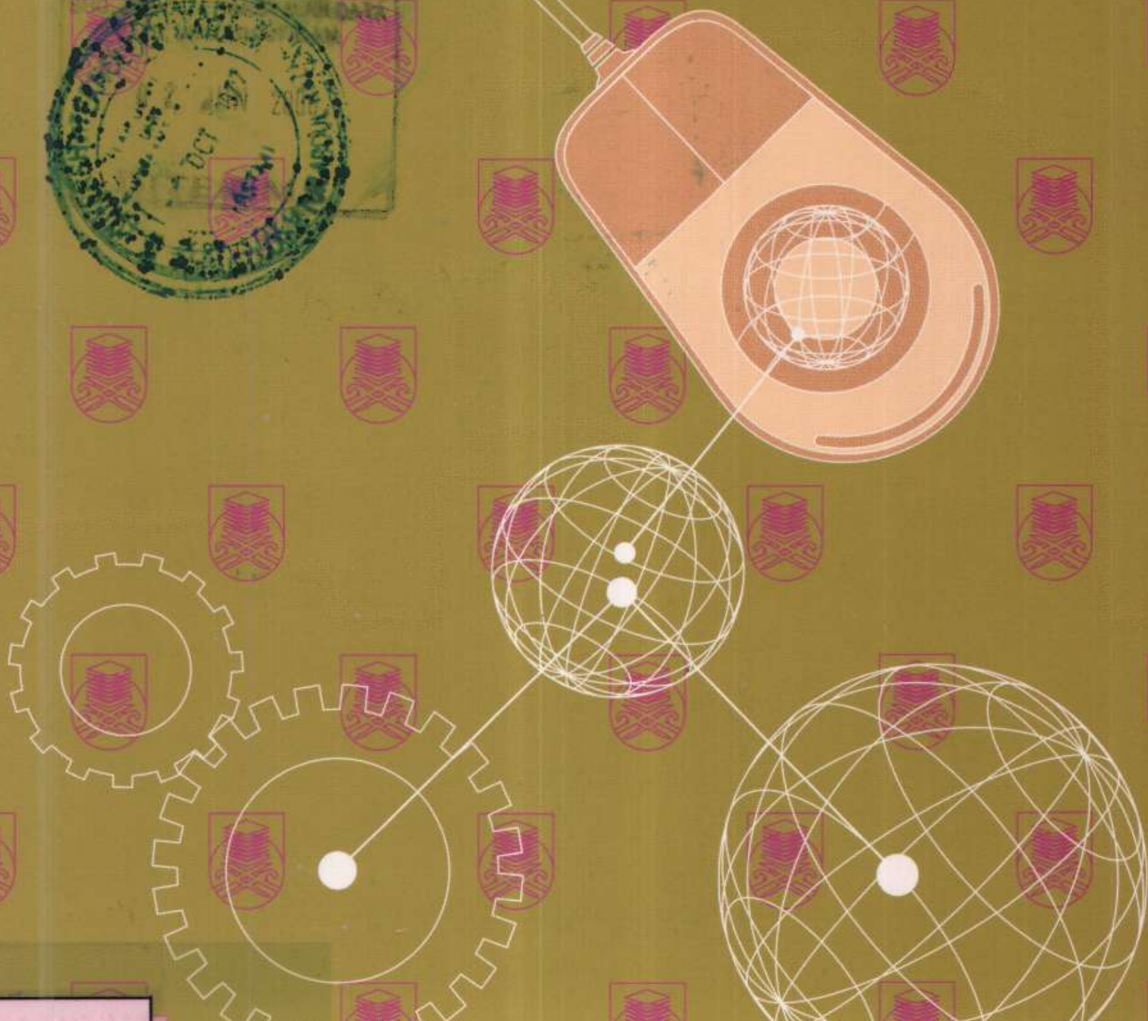
ESTEEM

ACADEMIC JOURNAL VOLUME 1. 2003 • ISSN: 1675-7939



Universiti Teknologi MARA Pulau Pinang

ESTEEM

Volume 1, December 2003

CONTENTS

A Study On The Effectiveness Of Ground Improvement Techniques

M.F.Ahmad[1], N.A. Zakaria[2], M.R. Selamat[3],
[1]Lecturer, UiTM, Penang
[2]Director, River Engineering and Urban Drainage Research Centre, USM
[3]Lecturer, School of Civil Engineering, USM

Abstract

A railway track has been constructed connecting industrial petrochemical complexes in Terengganu to Kuantan Port, all are in the east coast of Peninsular Malaysia. The route passes mostly through low lying swampy areas which are seasonally affected by monsoon flooding. Site investigations conducted along the route had indicated the dominant presence of soft, fine grained and soft, loose, coarse grained soils, except in a few hill locations. As railway tracks are sensitive to settlement and have small tolerance for it, a massive ground improvement work was implemented at site.

Because of high cost investment for equipment in the implementation of the ground improvement work, specialist contractors implementing them are local branches of international contractors. The non-availability of published local research on ground improvement techniques results in ineffective selection of technique for ground improvement work. With these limitations, based on experience from the field work on the railway track, work is on going to compare the effectiveness of ground improvement technique.

The four main ground improvement methods that were implemented and will be studied are Prefabricated Vertical Drain (PVD), Vibro-Compaction (VC), Dynamic Compaction (DC), and Stone Column (VR). From actual field data collected, comparison between one form of improvement to another in terms of the original soil type corresponding to, amount of work required by, and constraints faced while carrying out each type of improvement will be studied.

Keywords: Ground Improvement; Site Investigation; Prefabricated Vertical Drain (PVD); Vibro-Compaction (VC); Dynamic Compaction (DC); Stone Column (VR).

Introduction And Objective

Introduction

A railway project has been completed in the east coast of Peninsular Malaysia to connect Kerteh Industrial Petrochemical Complex and Gebeng Industrial Petrochemical Complex with Kuantan Port for the purpose of transporting petrochemical feedstock and products between these three locations.

The track passes through mostly swampy areas with soft fine grained soil and soft loose grained soil formations. More than 80% of the track has to be constructed on raised embankment. As railway tracks are sensitive to settlement and have small tolerance for it, a massive ground improvement work has been implemented, instead of pile embankment, to optimize the use of fund.

This paper relates the experience in planning and construction, and current findings of comparative study on the ground improvement work performed. This paper and future study will focus on the PVD, DC, VC and VR.

Observational technique was utilised on site to ensure the optimization of ground improvement work. The technique requires pre testing to be conducted to verify suitability of design and subsequently post testing and monitoring to be conducted to determine the effectiveness of the studied ground improvement work.

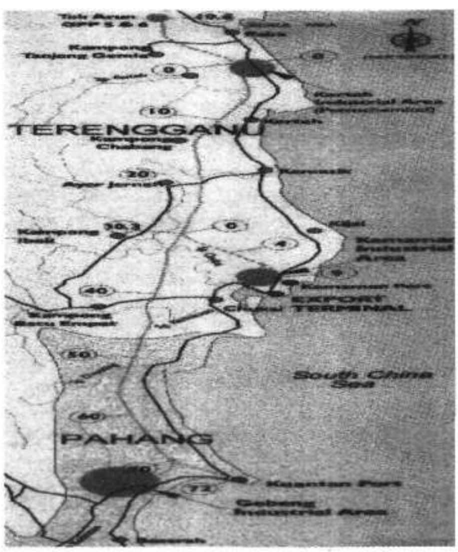
Industry Limitation

The local Malaysian construction industry has the following limitations in implementing ground improvement work:

1) Ground improvement work is controlled by international contractors with Malaysian operations.
2) Local contractors and designers do not have sufficient technical experience to design and manage ground improvement work.
3) Existing semi empirical guidelines do not give clear recommendation on the type of ground improvement to be chosen.
4) The available guideline only provides in terms of suitability and not which method will give a better result in terms of improvement.

Objective

Work is ongoing to compare the effectiveness of field performance of VC, VR, DC and PVD on Malaysian ground based on extensive data collected in a railway project. The objective of the paper is to present experienced gained in the construction, data collection and finding to date on the comparison of effectiveness of the ground improvement work performed.



Legend:
____: Railway route

Photo 1: Picture showing route for Kuantan-Kerteh Railway System

This paper relates the experience in planning and construction, and current findings of comparative study on the ground improvement work performed. This paper and future study will focus on the PVD, DC, VC and VR.

Observational technique was utilised on site to ensure the optimization of ground improvement work. The technique requires pre testing to be conducted to verify suitability of design and subsequently post testing and monitoring to be conducted to determine the effectiveness of the studied ground improvement work.

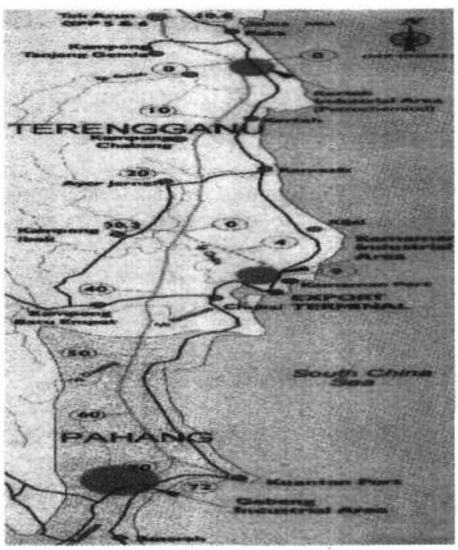
Industry Limitation

The local Malaysian construction industry has the following limitations in implementing ground improvement work:

1) Ground improvement work is controlled by international contractors with Malaysian operations.
2) Local contractors and designers do not have sufficient technical experience to design and manage ground improvement work.
3) Existing semi empirical guidelines do not give clear recommendation on the type of ground improvement to be chosen.
4) The available guideline only provides in terms of suitability and not which method will give a better result in terms of improvement.

Objective

Work is ongoing to compare the effectiveness of field performance of VC, VR, DC and PVD on Malaysian ground based on extensive data collected in a railway project. The objective of the paper is to present experienced gained in the construction, data collection and finding to date on the comparison of effectiveness of the ground improvement work performed.



Legend:
____: Railway route

Photo 1: Picture showing route for Kuantan-Kerteh Railway System

Data Collection

During planning of the ground improvement work, two stages of soil investigations were conducted. In the first, when alignment was identified, a preliminary soil investigation was conducted. This stage was called the feasibility study, from which the results were used in preparing preliminary soil profile along the alignment and in estimating the cost of the project. Based on this preliminary soil investigation, a detailed "stage two" soil investigation was conducted to finalise the design of the ground improvement work for tendering purposes.

During construction stage, further soil tests were conducted as part of observational method to optimize the design. The result of the soil tests will be used to study the effectiveness of the ground improvement technique

Ground Improvement	QC Test	Frequency
Dynamic Compaction (DC)	Pre-treatment CPT	1 for every 1000 m2
	Post-treatment CPT	1 for every 1000 m2
	Plate Bearing Test	1 for every 5000 m2
Vibro-Compaction (VC)	Pre-treatment CPT	1 for every 1000 m2
	Post-treatment CPT	1 for every 1000 m2
	Plate Bearing Test	3 for every 5000 m2
Stone Column	Pre-treatment CPT	1 for every 1000 m2
	Plate bearing test	3 for every 5000 m2

Table 1 – Data Collection During Construction

Overall, substantial amount of soil investigation was conducted for the planning and construction of the ground improvement work. The total amount is provided in Table 2.

Soil Investigation Work	Number of Points
Soil Boring	319
Cone Penetration Test	90
Mackintosh Probe	631
Hand Auger	393
Trial Pit	113

Table 2 - List of Soil Investigation Work

The effectiveness of PVD was monitored and evaluated using instruments namely the settlement plate, the piezometer, and the inclinometer.

A plate bearing test at a stone column site is shown in Photo 2.

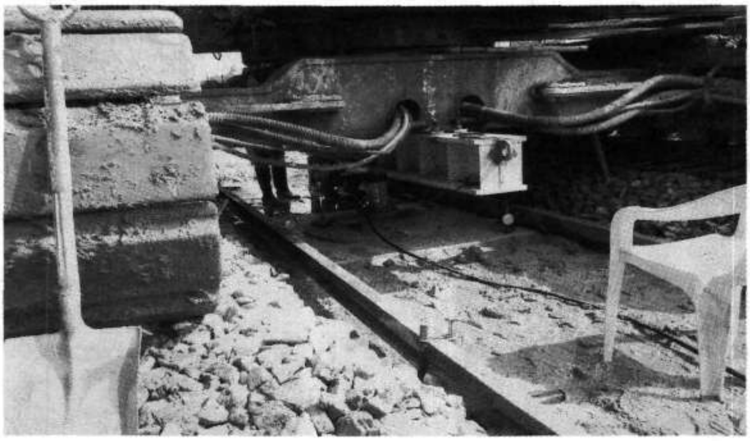


Photo 2 - Plate bearing test at a stone column site

Conclusion

Prefabricated Vertical Drain (PVD)

The subsoil improved by this method generally consisted of 2.0 m to 3.0 m thick of peat with organic matter at the surface underlain by very soft sandy clay/sandy silt to about 12.0 m from the ground surface. Undrained shear strength of the associated soils ranged from 8 kPa to 13 kPa to a depth of around 10 m. The typical soil parameter of a borehole in PVD area is as shown in Table 3. An installation of PVD is shown in Photo 3.

Depth	Vane or SPT	Liquid Limit %	Plastic Limit %	Plasticity Index %	Gravel %	Sand %	Silt %	Clay %
1.5	7.07/2.5	-	-	-	5	26	66	3
3	10.24/3.2	80	45	35	1	27	62	10
4.5	11.5/3.7	85	36	49	1	5	60	34
6	11.9/4.10	80	36	44	0	4	65	31
9.5	2	43	31	12	1	54	35	10
10.5	1	-	-	-	2	61	36	1
12.5	1	54	30	24	6	9	59	26
13.5	2	-	-	-	-	-	-	-
15	2	-	-	-	-	-	-	-
16.5	17	-	-	-	21	68	11	-
22.5	30	-	-	-	4	94	2	-
25.5	12	44	29	15	1	14	83	2
31.5	21	40	30	10	0	17	71	12
34.5	50	38	28	10	0	19	79	2

Table 3 - Soil Parameters for PVD area (BH-1)

Photo 3 - PVD installation in progress

During the installation of PVD at early chainages, a very high resistance to PVD installation penetration was encountered for the first meter from the surface. Concern for safety was raised as clips attached to the mandrel frequently broke under the severe stress which caused dangerous 'flying' clips.

Upon investigation, it was found that the hard layer was due to replacement sand compacted by passing trucks. The planned thickness of 0.6 m had became 2.0 m due to the various compactions created by the passing trucks and filling of sand to support the load of the trucks.

Monitoring of embankment constructed on areas improved by PVD using instruments such as settlement plate, piezometers, and inclinometers was critical to ensure the safety of the embankment. The monitoring has assisted in controlling filling rate, evaluating settlement, and observing lateral movement of the embankment.

Dynamic Compaction (DC)

The subsoil near Sungai Kerteh where this work was performed predominantly consisted of loose to medium dense sands in the upper 10.0 m and underlain by layers of sandy silt and loose sandy silt down to 20.0 m below ground surface. The undrained shear strength ranged from 12 kPa to 40 kPa. The typical soil composition of samples taken from a borehole was as shown in Table 4. A work of DC is shown in Photo 4.

Depth (m)	Gravel %	Sand %	Silt %	Clay %
1.50	7	63	29	1
3.00	6	75	19	0
9.00	8	83	9	0
16.50	0	93	7	0

Table 4 - Soil Parameters for DC (BH-22)

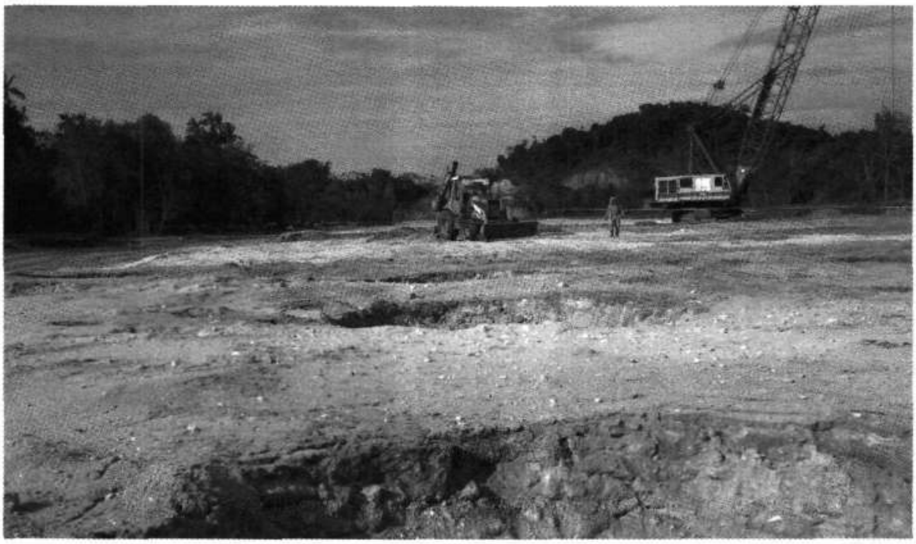


Photo 4 - A DC in progress

The high water table encountered during construction has reduced the effectiveness of dynamic compaction work. This was due to the dissipation of energy by ground water which has caused additional resistance to pounder penetration. Furthermore, the high water table has created stability concern for the crane while pulling the pounder out of the craters – the extra load was due to suction. To lower the water table, an earth drain was dug around the DC area and pumping was carried out. In addition, a1.0 m thick sand was placed on the surface to improve the condition for the rig to stand on.

Vibro-Compaction (VC) Work

This work was performed near Kerteh Airport road. The area was gently undulating terrain and the subsoils were predominantly sand with occasional lenses of silt and clay at depths of between 7.0 m to 12.0 m below ground surface. The typical parameters of soil from samples taken from one of the associated boreholes are as shown in Table 5. A VC at work is as shown in Photo 5.

Depth (m)	Bulk Density (Mg/m^3)	C KN/m^2	ϕ Angle	Gravel %	Sand %	Silt %	Clay %
4.5	-	-	-	0	94	6	0
9.5	1.689	23	1	1	29	51	19
12.5	1.71	22	1	1	30	52	17

Table 5 - Soil Parameters for VC (BH-27)

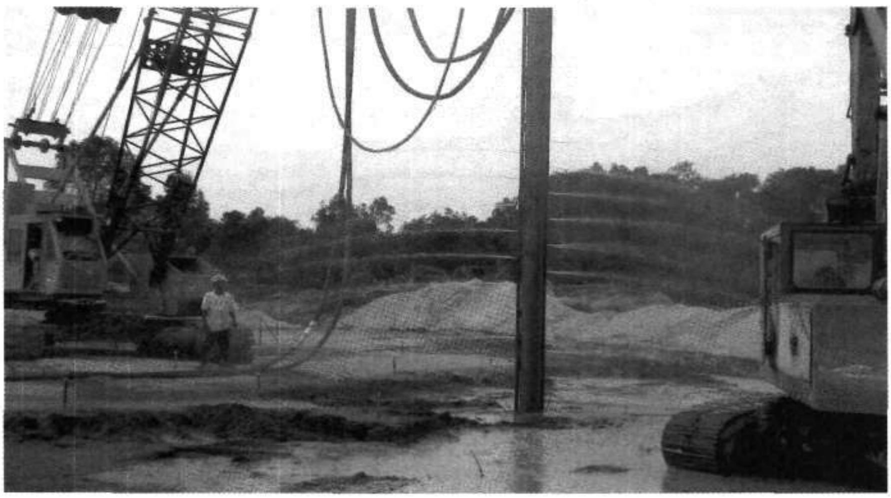


Photo 5 : A VC in progress

For the area, one hundred percent of the embankment base was treated. Once VC work was completed, a roller compactor was used to compact the top 0.3 m to 0.6 m of soil as required by the procedure.

Stone Column (VR)

This work was performed near Sungai Chabang, Kerteh. The typical soil parameter from one borehole near Sg Chabang is as shown in Table 6. A VR at work is as shown in Photo 6.

Depth	SPT N or In Situ Vane	Gravel %	Sand %	Silt %	Clay %
1.5	2	0	6	43	51
3.0	31.75/5.00	5	42	50	3
4.5	1	-	-	-	-
6.0	2	2	44	42	12
7.5	1	-	-	-	-
9.0	2	5	68	26	1
10.5	3	10	77	13	-
12	4	-	-	-	-
13.5	Rock	-	-	-	-

Table 6 - Soil Parameters for Stone Column (BH-31)

Photo 6 – A VR in Progress

Stone column can be installed either using dry method or wet method using water jet to assist penetration of vibro-compactor. As wet method of VR was used on site, a silt trap was required at the treatment area to prevent siltation from polluting the downstream water course.

Further, once the treatment has been performed on the base, the embankment constructed on it has to be monitored for the mushroom phenomenon, where the column swells. Once this effect was taken care of, the area was ready for the preparation of the subgrade.

Preliminary Finding

Effectiveness of Vibro-Compaction Technique

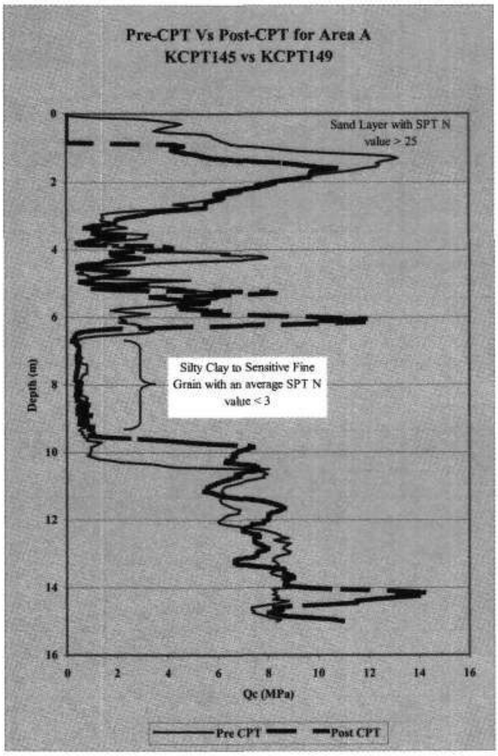


Figure 1 – A Comparison of Pre-CPT and Post-CPT result at the VC improved site

Based on Figure 1, it can be seen that there is no improvement at depths between 6.5 m to 9.5 m due to the prescence of soft fine grained material. It is also observed that where this improvement does not work, the friction ratio is less than 1.5% - such conclusion has also been proposed by Massarsch (1994).

A reduction in bearing capacity was also observed at depths between 1.50 m and 1.80 m and between 12.2 m and 13.5 m. It is believed that the action of water jet which was used to assist penetration has resulted in dense coarse grained soil becoming soft during treatment at depths of 12.2 m to 13.5 m. Whereas the lack of overburden pressure has resulted in reduction of bearing capacity between 1.5 m to 1.8 m below original ground level.

For all areas, where VC was performed, further roller compactions were required to densify the ground surface. This fact is also recorded by Bell (1992). Nevertheless, a 30% improvement in qc was recorded at between 9.7 m to 13.7 m and a 100 % improvement was recorded between 5.6 m to 6.3 m.

Effectiveness of Dynamic Compaction Technique

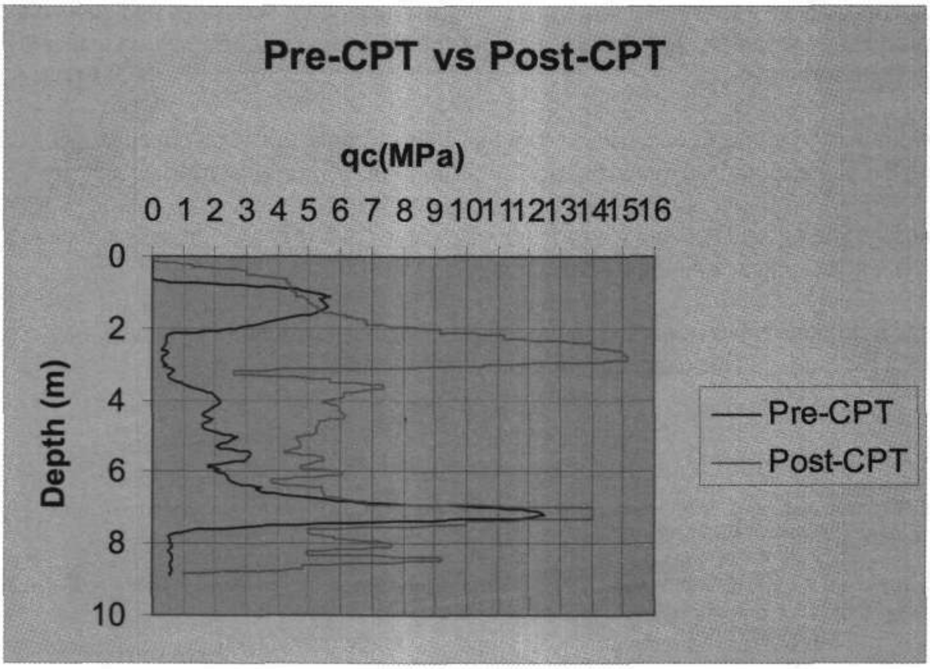


Figure 2: Pre-CPT vs Post-CPT for DC work at CH [illegible]

Figure 2 indicates that soil having qc less than 1 MPa achieved more than 400% improvement. Soils with qc around 2 MPa achieved around 100% improvement in their qc values.

The soils which achieved the 400% improvement are at depth of 1 m, 3 m and 9 m. These are coarse grained soils with 80% or more of sand and gravel sieving sizes.

Further, soil with bearing capacity of more than 5 MPa shows minor improvement after the treatment.

Discussion And Future Works

Findings to date indicated that the Dynamic Compaction(DC) and Vibro-Compaction(VC) are effective ground improvement techniques. The finding also shows that the effectiveness of VC is significantly affected by fine-grained content and the ground improvement work itself.

The appropriate subsequent step towards a further understanding of the effect of ground improvement work would be to further evaluate the effectiveness of ground improvement methods and compare their performances with each other. The comparison will be in terms of suitability of the method for an associated soil type and the actual improvement in each layer of soil. The vastness of soil data available allows a significant recommendation based on the comparison to be made.

Conclusions

The experience gained from extensive ground improvement work performed and data collected in the project has presented an opportunity to improve the understanding on the subject matter of ground improvement techniques.

The preliminary findings to date have shown that Vibro-Compaction is an effective method of improving loose coarse-grained materials to 30% to 100 % of their original bearing capacity.

Preliminary finding on Dynamic Compaction also shows that it is an extremely effective ground improvement technique, with improvement ranging from 100% to 400%.

Findings from other types of ground improvement techniques will guide us to effectively compare and select the most suitable technique for ground improvement.

References

Ahmad, M.F., N.A. Zakaria & M.R. Selamat (2002). *"Ground Improvement Works for Kuantan-Kerteh Railway Project" MUTRF, Universiti Malaya, KL.*

Ahmad, M.F., N.A. Zakaria & M.R. Selamat (2002). *"A Trial Vibro-Compaction Improvement Work For Kerteh Road Embankment Project". Proceedings of the 5th Malaysian Road Conference.*

Bell F.G. (1992). *"Engineering Treatment of Soils". F&N Spon, London*

Bergado D T et al (1996). *Soft Ground Improvement in Lowland and Other Environments, ASCE Press, New York.*

Massarsch, K.R. (1994). *"Deep aspects of deep vibratory compaction". Proceedings of the Seminar on Ground Improvement Methods, Hong Kong, 61-74.*

Lunne,T ,Robertson, P.K., Powell, J.J.M., (1997) *"Cone Penetration Testing In Geotechnical Practice" E&FN Spon, London*

Hausmann, M.R., (1990) *Engineering Principles of Ground Modification, McGraw Hill, New York.*

Mitchell, J.K. (1970) *In place Treatment of Foundation Soils, Proc. American Society of Civil Engineers, Journal Soil Mechanics and Foundations Division, 96(SM1), 73-100*