GH

GROUND IMPROVEMENT

PROJECT TRACK RECORDS

Version *2.0*

2017

上海港湾集团
GEOHARBOUR

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AUSTRALIA PTY LTD

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1.1 CHANGSU, JIANGSU PROVINCE, CHINA – ROAD

1.1.1 Project Overview

- Project planning: Road
- Client: Changsu Kunchenghu Co., Ltd
- Area: 4,260 m^2
- Duration: 164 days

1.1.2 Geological Condition

The typical soil profile comprises the following layer.

①$_1$ Fill： Grey to greyish yellow, loose, soft， plastic, the depth varied between 2.4 and 8.9m.

②$_2$ Muddy Soil： Grey to greyish black, fluid, plastic, formed from artificial filling muddy

② Silty clay: Soft, high plasticity, thickness between 0.0 to 1.5m, medium to high compressibility, medium strength, the bearing strength was 120～130kPa.

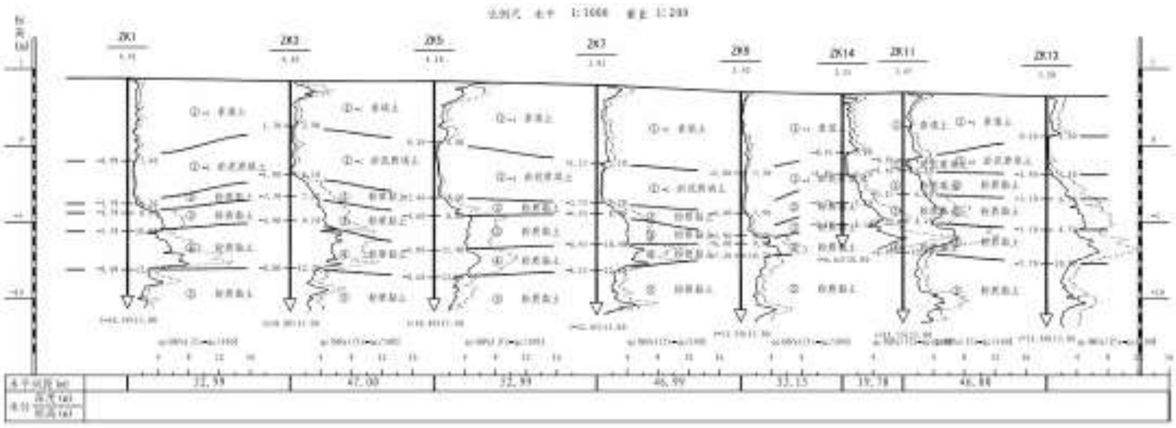

Figure 1.1.a Typical Soil Profile

1.1.3 Construction Photos

Figure 1.1.b Excavation

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Figure 1.1.e Horizontal Drain Placement

Figure 1.1.f Spreading Geotextile

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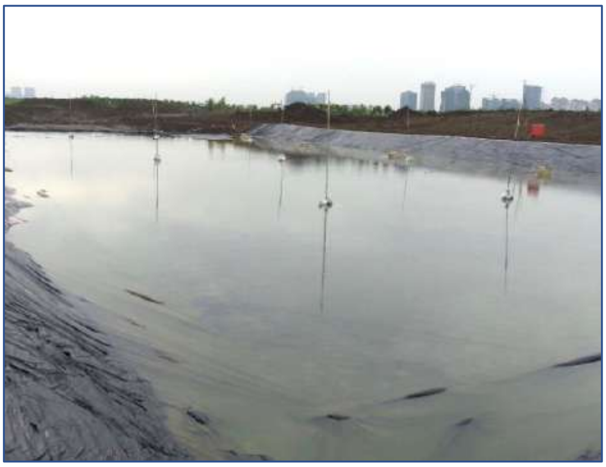


Figure 1.1.i Vacuum Preloading

Figure 1.1.j Water Surcharge

Figure 1.1.k Water Surcharge Height Reached

1.1.4 Results

The results are summarised in the following tables.

Table 1.1.a Bearing Capacity before and after Ground Improvement

Layer No.	Before treatment（kPa）	After treatment（kPa）	Increased（%）
①-1	88.8	138.8	56.3
①-2	74.6	95.8	28.4

Table 1.1.b Soil Resilient Modulus

Test No.	Soil resilient modulus（MPa）	Design requirement（MPa）
1	18	9
2	12	
3	15	
Average value	15	

Table 1.1.c Soil Properties before and after Ground Improvement

	Moisture Content (%)		Unit weight (kN/m^3)		Void Ratio e		Plasticity Index I_p		Cohesion c_u (kPa)		Friction angle ϕ(°)		Es (MPa)	
	①-1	①-2	①-1	①-2	①-1	①-2	①-1	①-2	①-1	①-2	①-1	①-2	①-1	①-2
Before	36.0	44.5	18.0	17.2	1.044	1.133	0.93	1.24	22.3	9.7	5.5	6.4	3.13	2.35
After	27.2	34.3	19.3	18.5	0.763	0.948	0.41	0.81	28.0	20.2	8.4	12.1	4.91	5.39
Changing percentage（%）	**-24.4**	**-22.9**	**7.2**	**7.6**	**-26.9**	**-16.3**	**-55.9**	**-34.7**	**25.6**	**108.2**	**52.7**	**89.1**	**56.9**	**129.4**

Table 1.1.d SPT N-number and Bearing Capacity before and after Improvement

Layer No.	Before treatment		After treatment		Bearing Capacity increment（%）
	Average Value of SPT	Bearing Capacity (kPa)	Average Value of SPT	Bearing Capacity (kPa)	
①-1	1.7	70.8	4.67	137.5	**94.2**
①-2	1.25	60.6	2.5	88.75	**46.4**

1.2 RIZHAO CITY, CHINA – RECLAMATION AREA

1.2.1 Project Overview

- Project planning: Foundation
- Area: 140,000 m^2

1.2.2 Geological Condition

The typical soil profile comprises the following layer.

(1) Silt. The thickness is between 0.6m and 8.2m, greyish black, saturation, fluid and plastic.

(2) Silt. The thickness is between 1.6m and 12.6m, fluid and plastic, with thin silty sand layer.

(3) Silty Clay. Plastic, with small amounts of coarse sands.

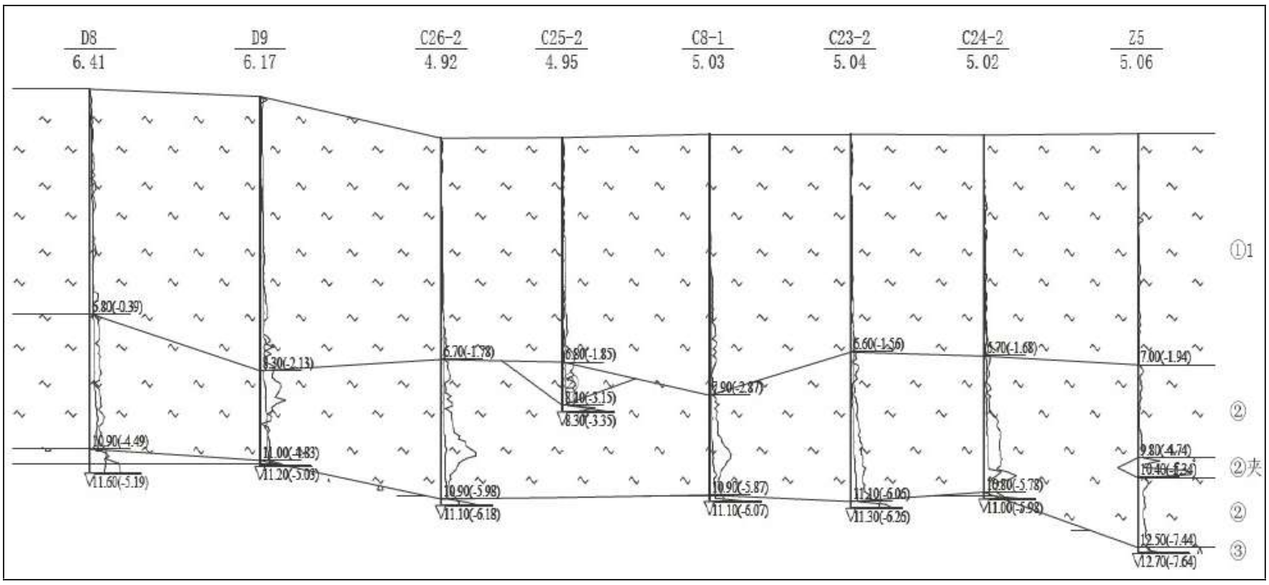


Figure 1.2.a Typical Soil Profile

1.2.3 Construction Documentation

Figure 1.2.b Original Site

Figure 1.2.c Original Soil Condition

Figure 1.2.d Working Platform Preparation

Figure 1.2.e Sand Blanket Preparation

Figure 1.2.f PVD Installation

Figure 1.2.g Vacuum Consolidation Running

1.2.4 Results

Below are the CPT test results before and after ground improvement.

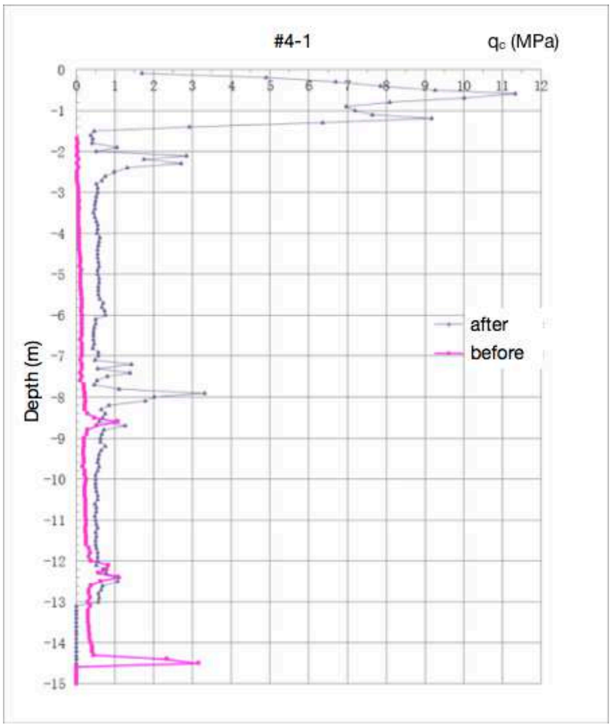


Figure 1.2.h CPT Cone Resistance before and after Improvement (No. 4-1#)

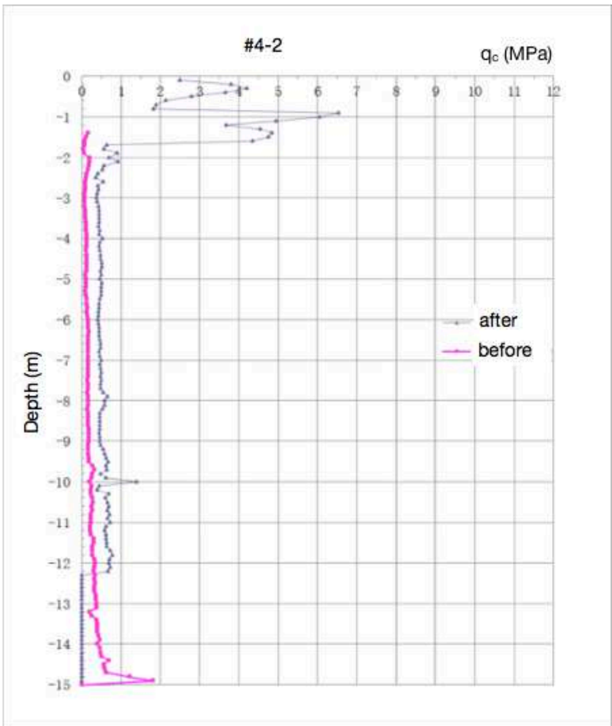


Figure 1.2.i CPT Cone Resistance before and after Improvement (No. 4-2#)

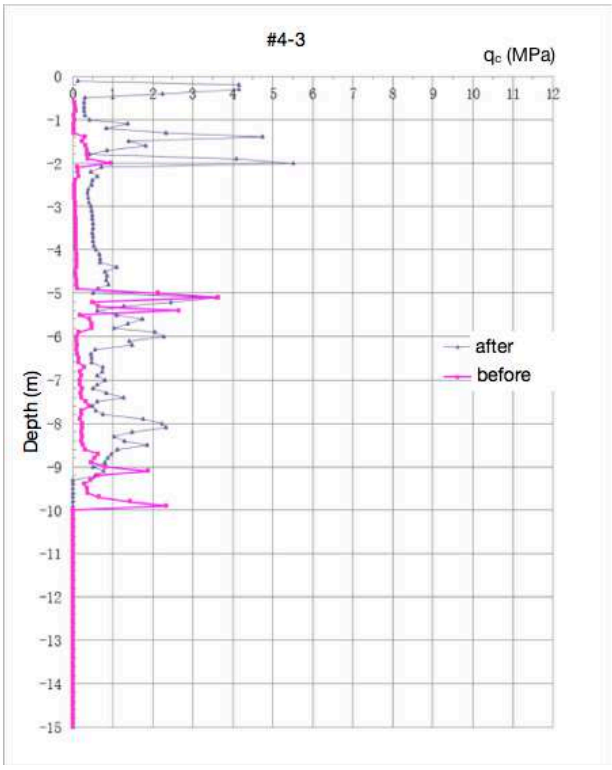


Figure 1.2.j CPT Cone Resistance before and after Improvement (No. 4-3#)

1.3 BANTEN, JAVA, INDONESIA – POWER PLANT

1.3.1 Project Overview

- Project planning: Power Plant 3 x 315MW
- Client: PLN
- Area: 420,000 m^2
- Duration: 12 months

1.3.2 Geological Condition

Typical soil profile is shown in Figure 1.3.a

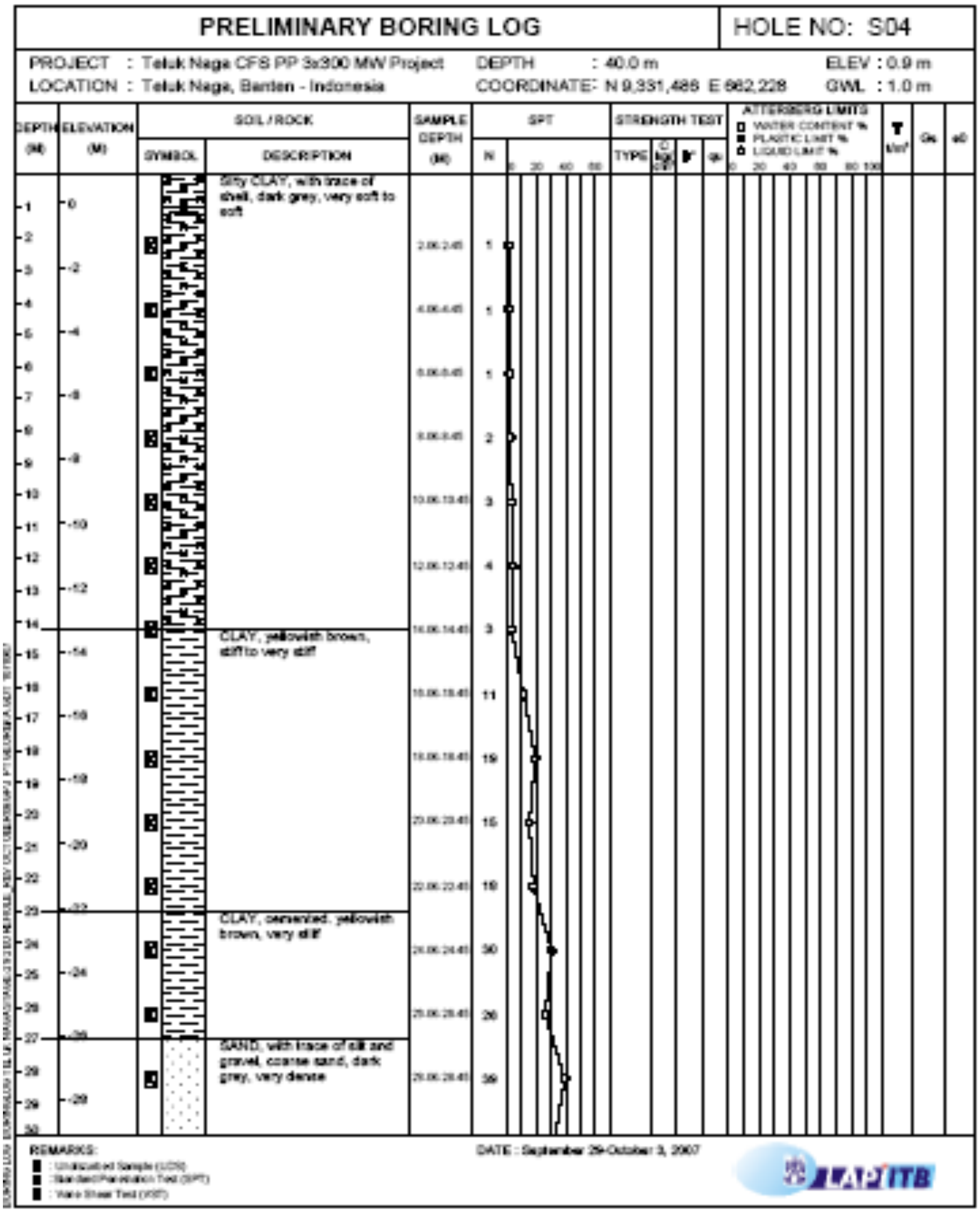


Figure 1.3.a Typical Soil Profile

1.3.3 Construction Documentation

Figure 1.3.b Original Swampy Site

Figure 1.3.b Original Soil Condition

Figure 1.3.d Vacuum Preloading

Figure 1.3.e Water Surcharge

Figure 1.3.f Site Condition before Vacuum Consolidation

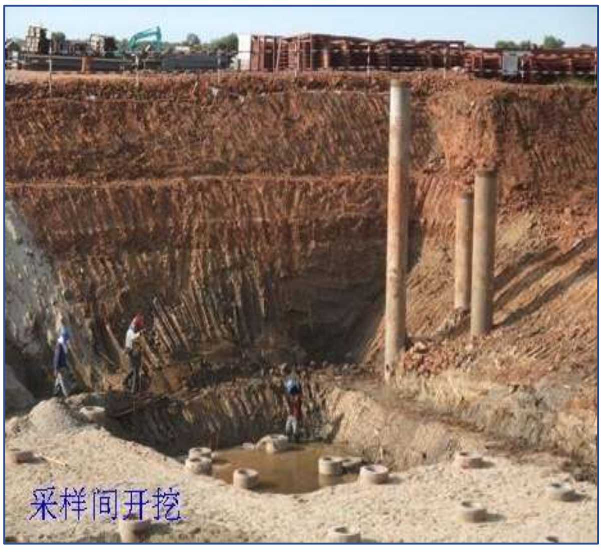


Figure 1.3.g Site Condition after Vacuum Consolidation

1.3.4 Results

The results are summarised in the following figures.

Main Building Area, PVD depth 7 m.

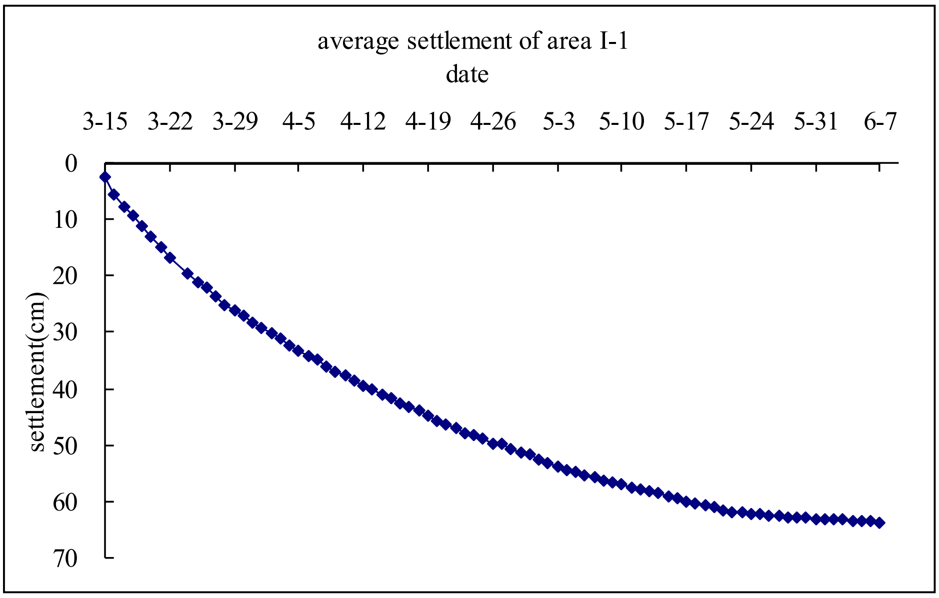


Figure 1.3.h Average Settlement

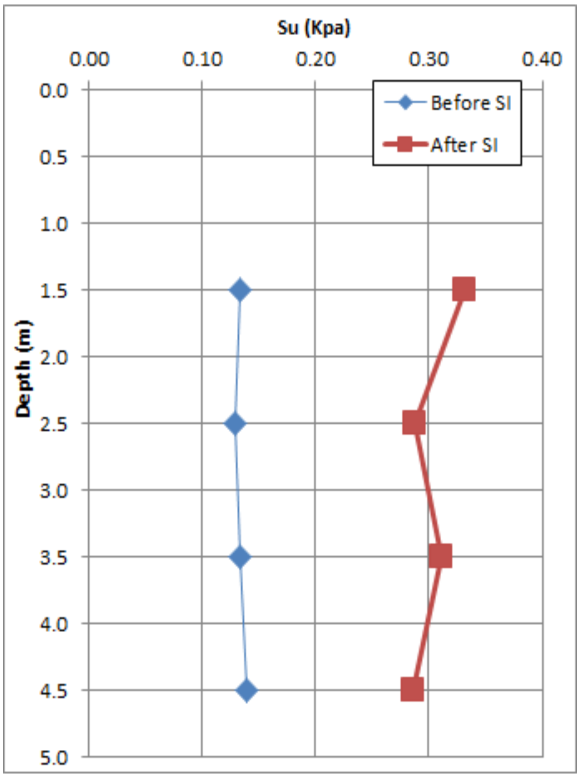


Figure 1.3.i Undrained Shear Strength before and after improvement

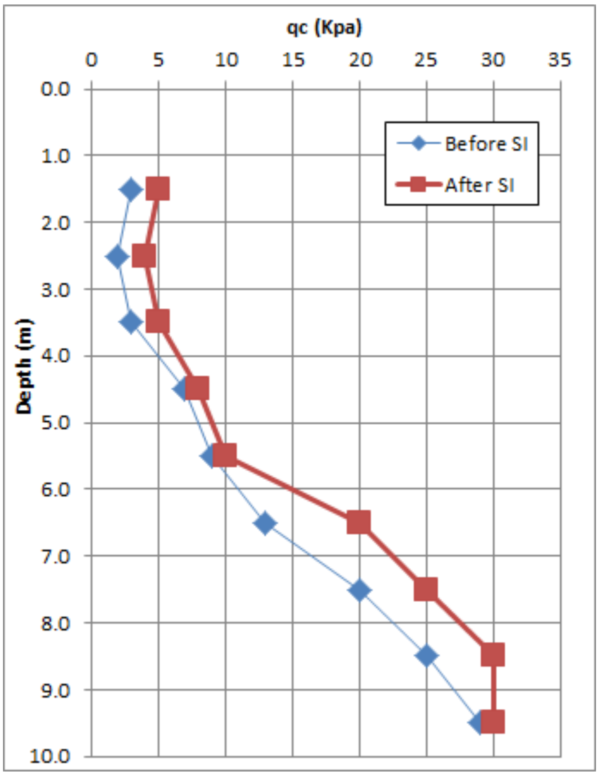


Figure 1.3.j CPT Cone Resistance before and after improvement

1.4 BALINGIAN, MALAYSIA – POWER PLANT

1.4.1 Project Overview

- Project planning: Coal fired power station
- Client: Shanghai Electric
- Method: Vacuum Consolidation + Fill Surcharge
- Area: 38,210 m^2
- Design Requirement:
  (1) CPT Cone Resistance of soft soil ≥ 0.3Mpa;
  (2) Degree of consolidation ≥ 90%;
  (3) Post construction settlement ≤ 35cm under operating load of 108 kPa.

1.4.2 Geological Condition

The typical soil profile comprises the following layers.

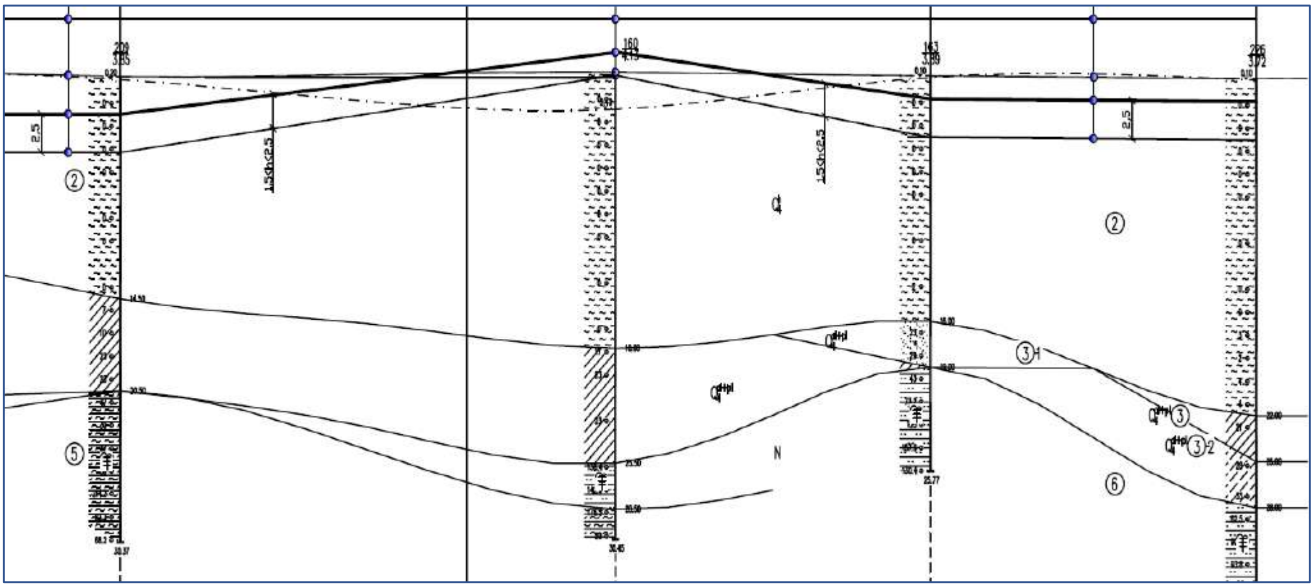


Figure 1.4.a Typical Soil Profile

❖ LAYER 1 PEAT: The thickness of peat layer varied between 3~4.2 m in most areas.

Figure 1.4.b Layer 1 - Peat

❖ LAYER 2 SILT: Dark brown, very wet, soft and plastic with high liquidity index (I_L>0.75), mixed with vegetation and altered to peat locally.

Figure 1.4.c Layer 2 - Silt

❖ LAYER 3 CLAY: Greyish Brown, stiff and plastic (0<I_L≤0.25), very wet, slightly mixed with fine sands, silts and gravels.

❖ LAYER 3-1 SAND: Greyish Brown, saturated, mostly medium dense (15<N≤30) and partially slightly dense(10<N≤15), mixed with clayey soils, silts and gravels.

❖ LAYER 3-2 SILT: Greyish Black, very wet, mostly medium dense (15<N≤30), mixed with clayey soils and fine sands.

1.4.3 Construction Sequences

- ❖ Removal of peats
- ❖ Backfilling with fine or medium sands
- ❖ Consolidation with vacuum and fill surcharge

1.4.4 Construction Photos

Figure 1.4.d Vertical Drain Installation

Figure 1.4.e Slurry Wall Construction

Figure 1.4.f Horizontal Drain Installation

Figure 1.4.e Placement of Geotextile

Figure 1.4.h Spreading Geomembrane

Figure 1.4.i Vacuum Operation

Figure 1.4.j Fill Surcharge

1.4.5 Results

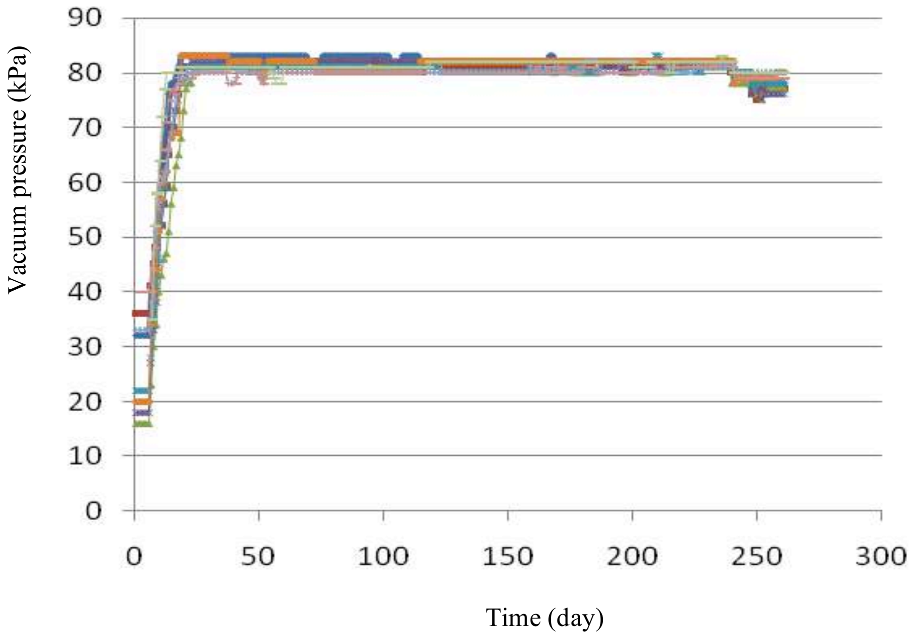


Figure 1.4.k Vacuum Gauges Record

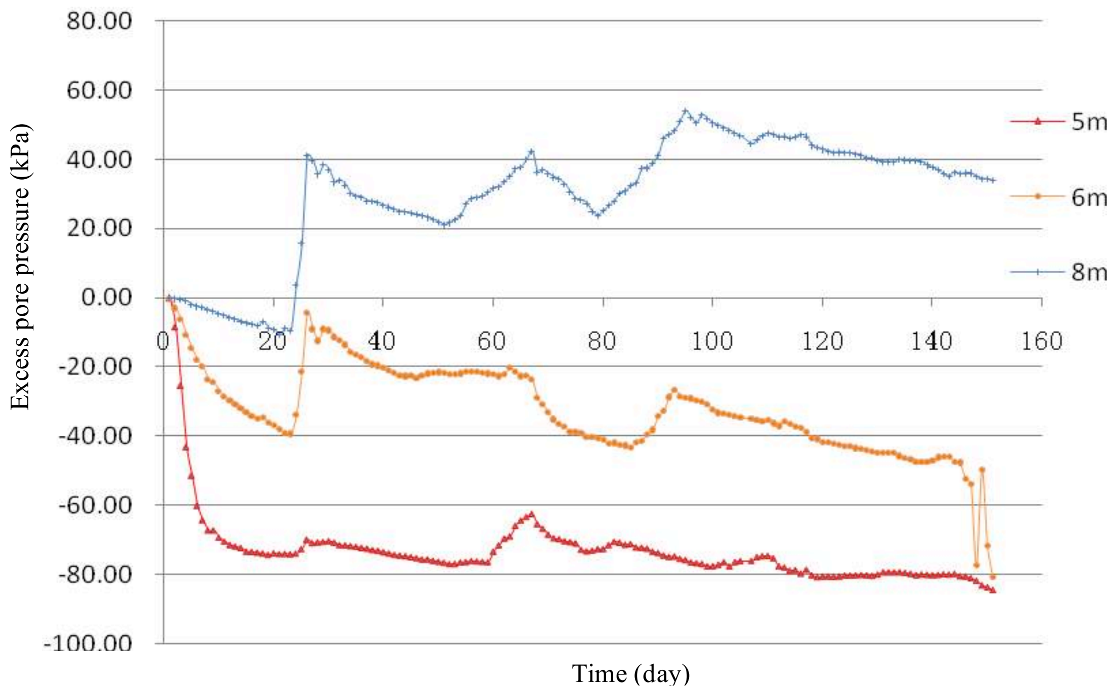


Figure 1.4.l Excess Pore Pressure Record

Figure 1.4.m Settlement Record

Table 1.4.a CPT Cone Resistance Results before and after Improvement

No.	P_s values in soft layers （P_s<1MPa） （MPa）				Average value increased percentage (%)
	before		after		
	minimum	average	minimum	average	
CPT1.2	0.1	0.286	0.34	0.534	87
CPT1.3	0.05	0.164	0.33	0.547	234
CPT1.5	0.06	0.192	0.55	0.695	261
CPT2.3	0.01	0.181	0.47	0.697	285
CPT2.13	0.01	0.212	0.45	0.782	269
CPT2.14	0.01	0.171	0.4	0.818	378
CPT2.15	0.06	0.256	0.47	0.631	146
CPT3.2	0.13	0.32	0.31	0.46	44
CPT3.5	0.26	0.347	0.3	0.455	31
CPT2.4	0.1	0.209	0.31	0.516	147

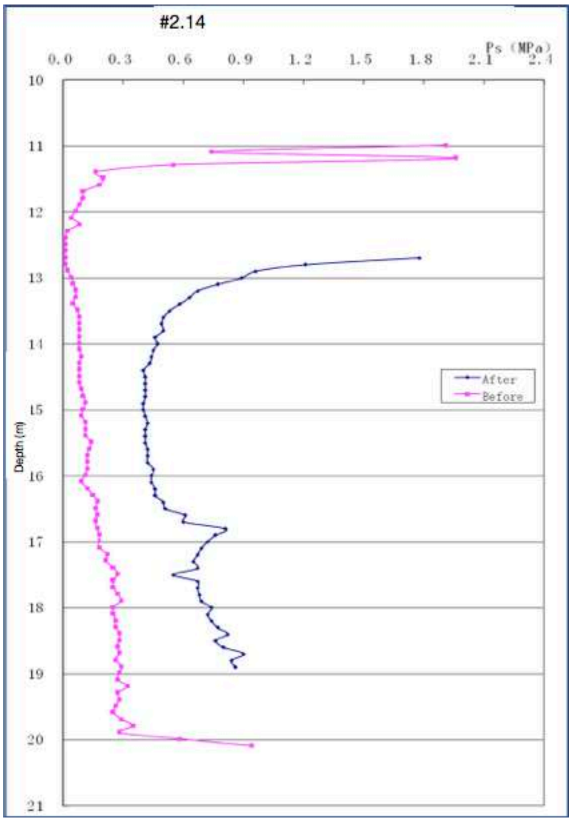


Figure 1.4.n CPT #2.14

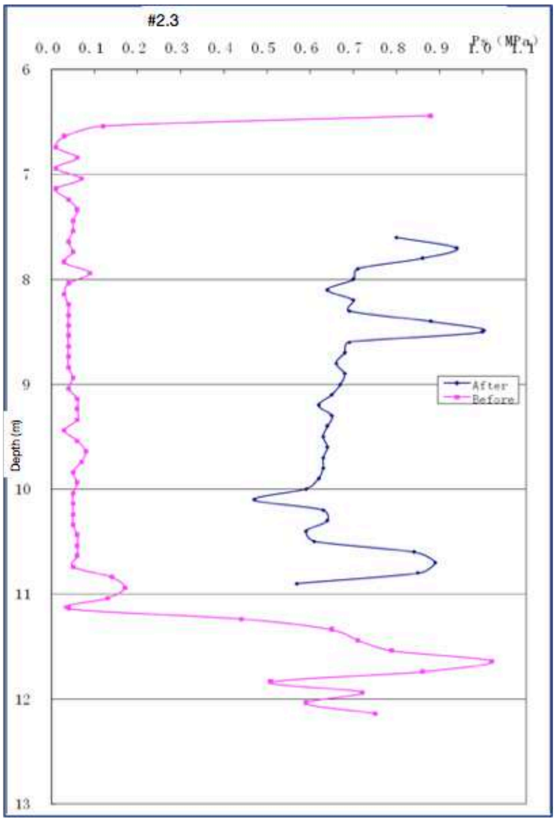


Figure 1.4.o CPT #2.3

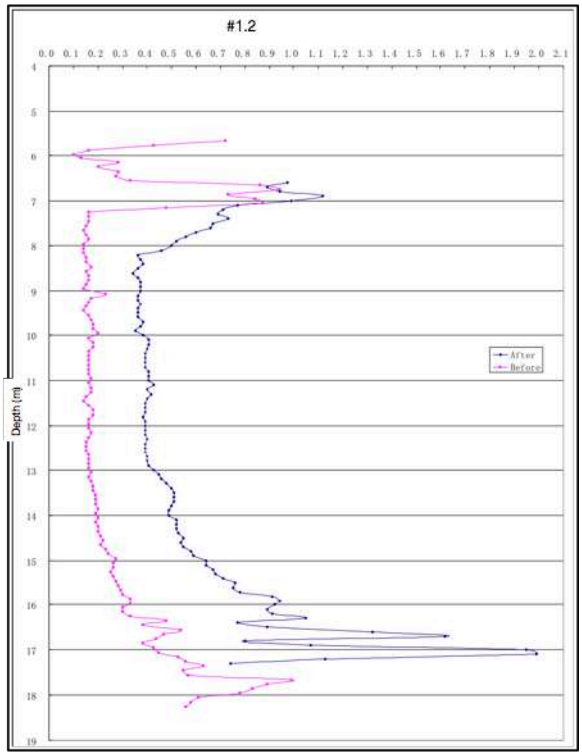


Figure 1.4.p CPT #1.2

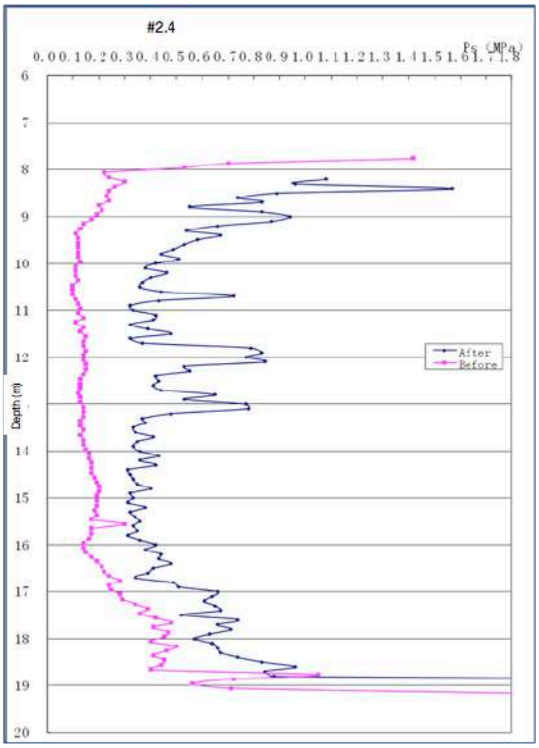


Figure 1.4.q CPT #2.4

1.5 JAWA 7, BANTEN, INDONESIA – POWER PLANT

1.5.1 Project Overview

- Project Name: PLTU JAWA 7 2x1050MW, Bojonegara, Banten, Indonesia
- Client: Energy China ZTPC
- Duration: 12 Months (29 July 2016 – now)
- Design Requirement: 90% degree of consolidation
- Method: Vacuum combine with water surcharge
- Project Scale: 250,000m^2

1.5.2 Soil Properties

Table 1.5.a Soil Profile

Borehole No	Test Depth (m)	Soil Type by Visual Assessment	Ultimate Undrained Shear Strength (kPa)		Sensitivity
			Undisturbed	Remolded	
BH-A	3.00 – 3.40	Clay, gray	10.7	2.6	4.20
	5.00 – 5.40	Clay, gray	11.0	2.9	3.75
	7.00 – 7.40	Clay, gray	11.0	4.4	2.50
	9.00 – 9.40	Clay, gray	11.7	3.7	3.20
	11.00 – 11.40	Clay, gray	12.4	2.9	4.25
	13.00 – 13.40	Clay, gray	23.4	5.9	4.00
BH-B	3.00 – 3.40	Clay, gray	75.4	3.7	20.60
	5.00 – 5.40	Clay, gray	75.4	2.9	25.75
	7.00 – 7.40	Clay, gray	75.4	2.9	25.75
	9.00 – 9.40	Clay, gray	75.4	5.1	14.71
	11.00 – 11.40	Clay, gray	75.4	6.6	11.44
	13.00 – 13.40	Clay, gray	75.4	15.4	4.90
BH-C	3.00 – 3.40	Clay, gray	11.0	4.4	2.50
	5.00 – 5.40	Clay, gray	11.0	2.9	3.75
	7.00 – 7.40	Clay, gray	11.5	2.6	4.50
	9.00 – 9.40	Clay, gray	15.3	3.6	4.29
BH-01	2.00 – 2.40	Clay, gray	2.6	0.8	3.33
	4.00 – 4.40	Clay, gray	4.1	1.3	3.20
	6.00 – 6.40	Clay, gray	6.70	2.0	3.25
	8.00 – 8.40	Clay, gray	14.8	2.6	5.80
	10.00 – 10.40	Clay, brownish gray	26.6	6.7	4.00
	12.00 – 12.40	Sandy silt, greenish gray	22.0	5.9	3.75
BH-02	2.00 – 2.40	Clay, brownish gray	3.6	0.8	4.67
	4.00 – 4.40	Clay, gray	2.6	0.8	3.33
	6.00 – 6.40	Clay, gray	7.7	2.0	3.75
	8.00 – 8.40	Clay, gray	15.3	3.8	4.00
	10.00 – 10.40	Clay, gray	18.4	3.8	4.80
	12.00 – 12.40	Clay, brownish gray	27.8	10.3	2.71
	14.00 – 14.40	Clay, brownish gray	40.9	10.2	4.00
BH-03	2.00 – 2.40	Clay, brownish gray	1.5	0.8	2.00
	4.00 – 4.40	Clay, gray	7.7	2.0	3.75
	6.00 – 6.40	Clay, gray	9.0	2.3	3.89
	8.00 – 8.40	Clay, gray	7.7	1.3	6.00
	10.00 – 10.40	Clay, gray	24.9	6.6	3.78
	12.00 – 12.40	Clay, brownish gray	65.9	11.7	5.63
BH-04	2.00 – 2.40	Clay, brownish gray	5.4	1.5	3.50
	4.00 – 4.40	Clay, gray	7.7	2.3	3.33
	6.00 – 6.40	Clay, gray	7.7	2.6	3.00
	8.00 – 8.40	Clay, gray	9.7	2.8	3.45
	10.00 – 10.40	Clay, gray	12.8	4.1	3.13
	12.00 – 12.40	Clay, brownish gray	35.8	4.6	7.78
	14.00 – 14.40	Clay, brownish gray	47.1	9.5	4.97

1.5.3 Construction Photos

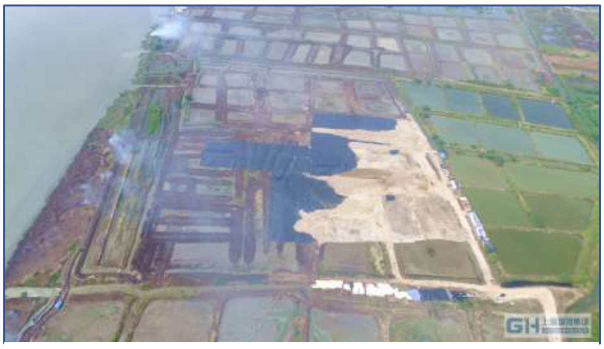


Figure 1.5.a Initial Work Preparation

Figure 1.5.b Working Platform Preparation

Figure 1.5.a PVD Installation

Figure 1.5.d Spreading Geomembrane

Figure 1.5.e Water Surcharge over Vacuum Consolidation

After Improvement

Figure 1.5.f Excavation after Improvement

1.6 NAKHON SI THAMMARAT, THAILAND – AIRPORT

1.6.1 Project Overview

- Project Name: Nakhon Si Thammarat Airport Apron and Taxiway Expansion Project
- Client: The Department of Civil Aviation (Nakhon Si Thammarat)
- Duration: 10 Months (01/04/2015~17/02/2016)
- Design Requirement: 95% degree of consolidation
- Project Scale: 39,756 m^2

1.6.2 Geological Conditions

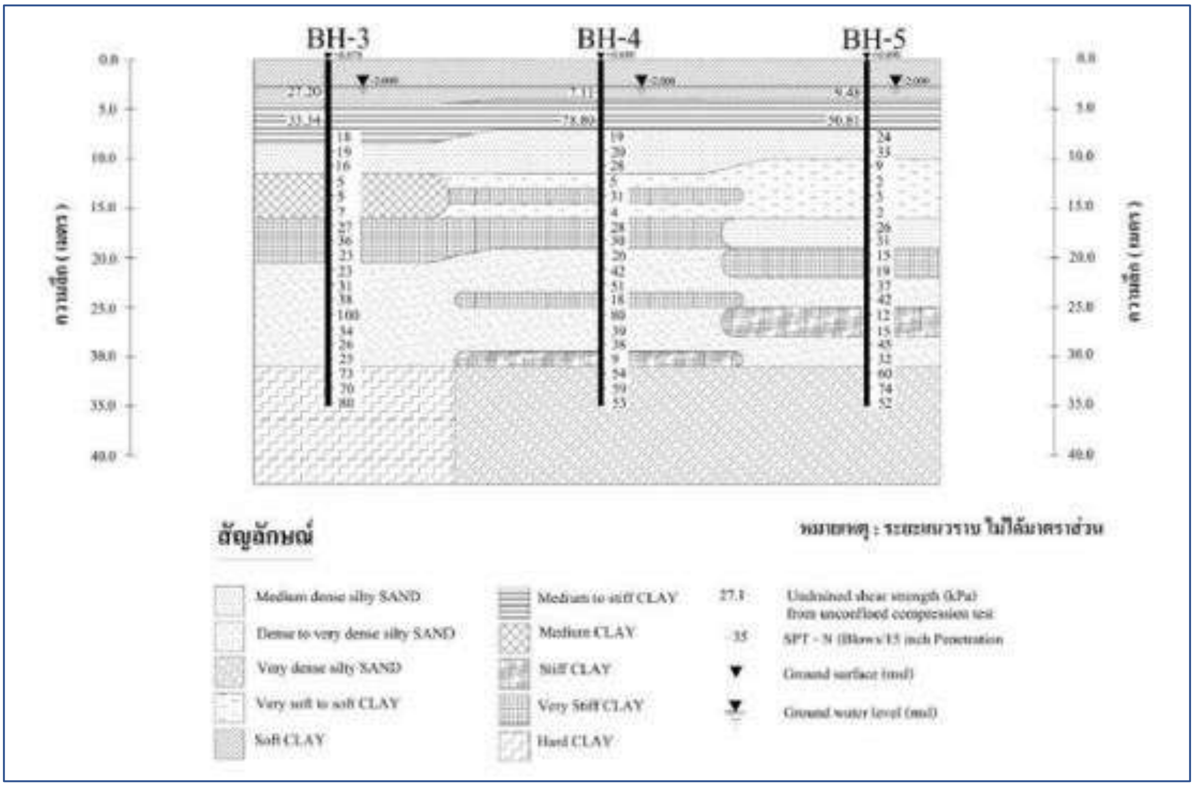


Figure 1.6.a Typical Soil Profile

1.6.3 Construction Photos

Figure 1.6.b Original Site Condition

Figure 1.6.c Installation of Vacuum System

Figure 1.6.d Spreading Geomembrane

Figure 1.6.e Sealing Trench Construction

Figure 1.6.f Site Use after Ground Improvement

1.6.4 Test Results

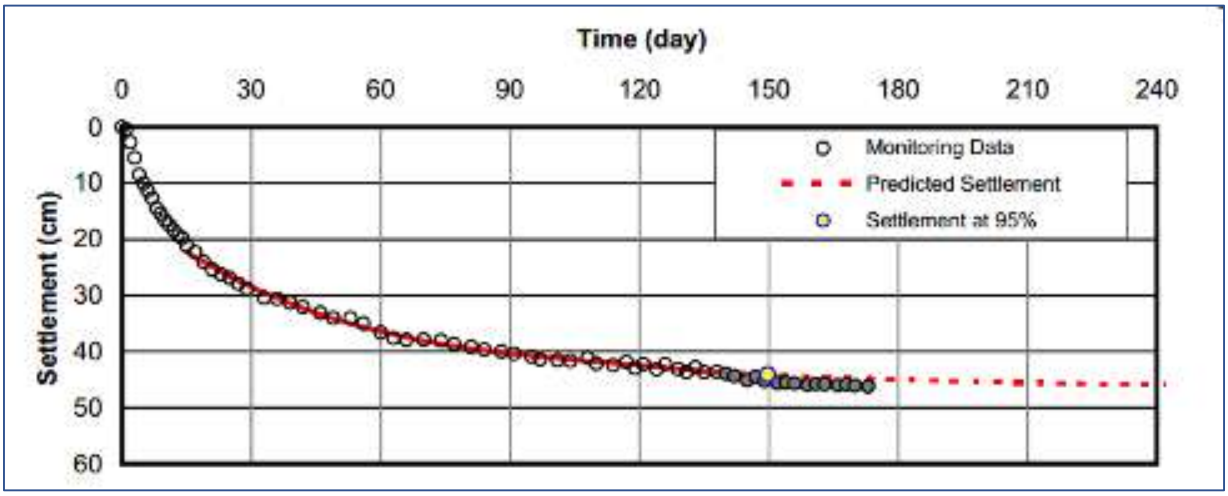


Figure 1.6.g Settlement Record

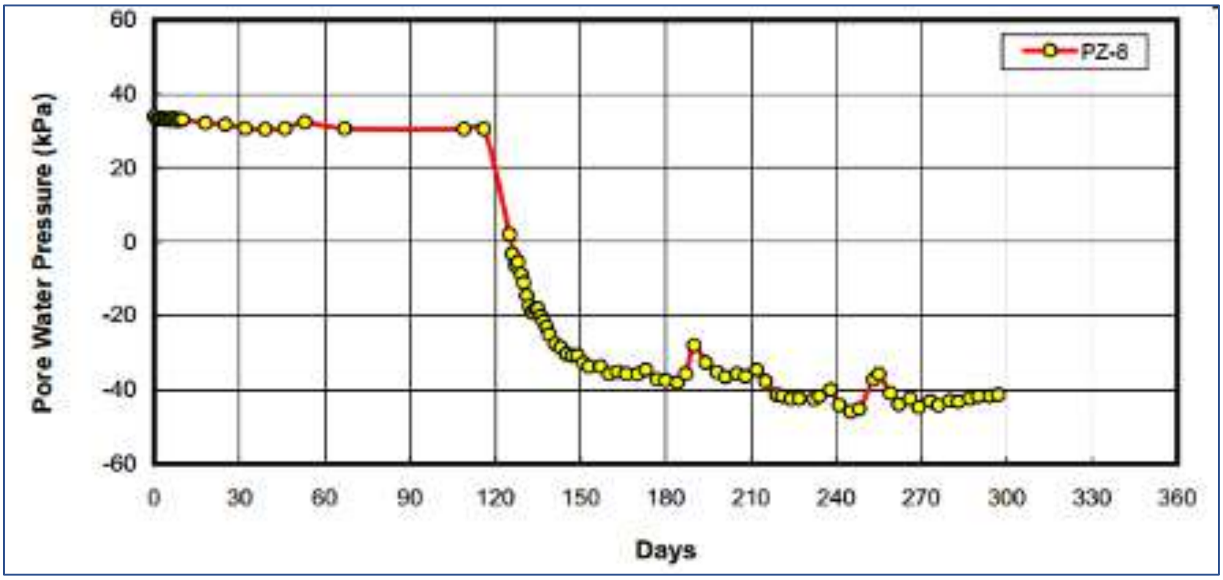


Figure 1.6.h Pore Pressure Record

1.7 CHANGI TERMINAL 5, SINGAPORE – AIRPORT

1.7.1 Project Overview

- Project Planning: Changi Airport Development
- Client: Singapore Ministry of Transport
- Duration: 24 Months
- Design Requirement: 95% degree of consolidation
- Project Scale: About 6,500,000m^2, including 300,000m^2 near Existing Runway #2 and 65,0000m^2 near Existing Air Base Runway #3.
- Vacuum work: Vacuum preloading was proposed to replace Jet Grouting Method, to save 2 billion CNY (about 400 million AUD) and reduce CO^2 emissions by more than 300, 000 tons. Vacuum consolidation covered an area of approximately 300,000m^2, and consumed PVD of about 8000m.
- Site view of Changi Airport Project

Figure 1.7.a Site Location

1.7.2 Geological Conditions

Based on the existing investigation report, soil profile can be described as follows:

- LAYER 1 Fill ($2 \leq N \leq 27$) SAND
  This layer mainly consists of fine grained and fine to medium grained sand with shell debris. Gravelly Sand, Marine Clay and Silty Sand were occasionally found in a few boreholes.

- LAYER 2 (a) Marine Member (KALLANG FORMATION, M) ($0 \leq N \leq 4$) Marine CLAY. This layer consists of very soft to soft, greenish grey Marine Clay.

- LAYER 2 (b) Transitional Member (KALLANG FORMATION, E) ($4 \leq N \leq 7$) Organic CLAY. This layer consists of soft to firm, dark brownish grey, Organic Clay.

- LAYER 2 (c) Alluvial Member (KALLANG FORMATION, F2) ($2 \leq N \leq 18$) Silty Clay, Clay, Sandy Clay. This layer mainly consists of soft to very stiff Silty Clay.

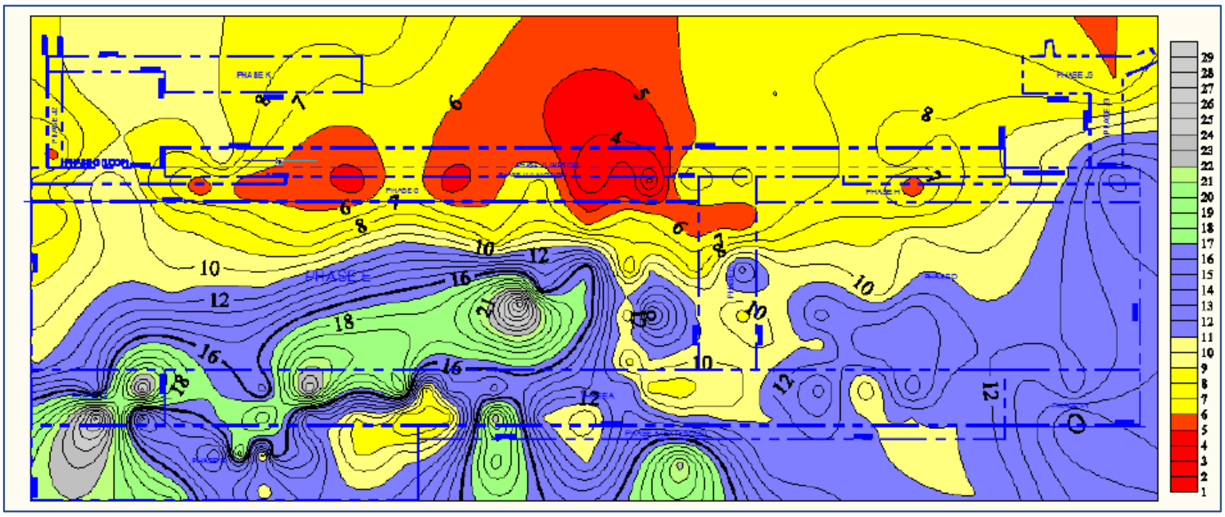


Figure 1.7.b The Contour Map of Fill Sand Thickness

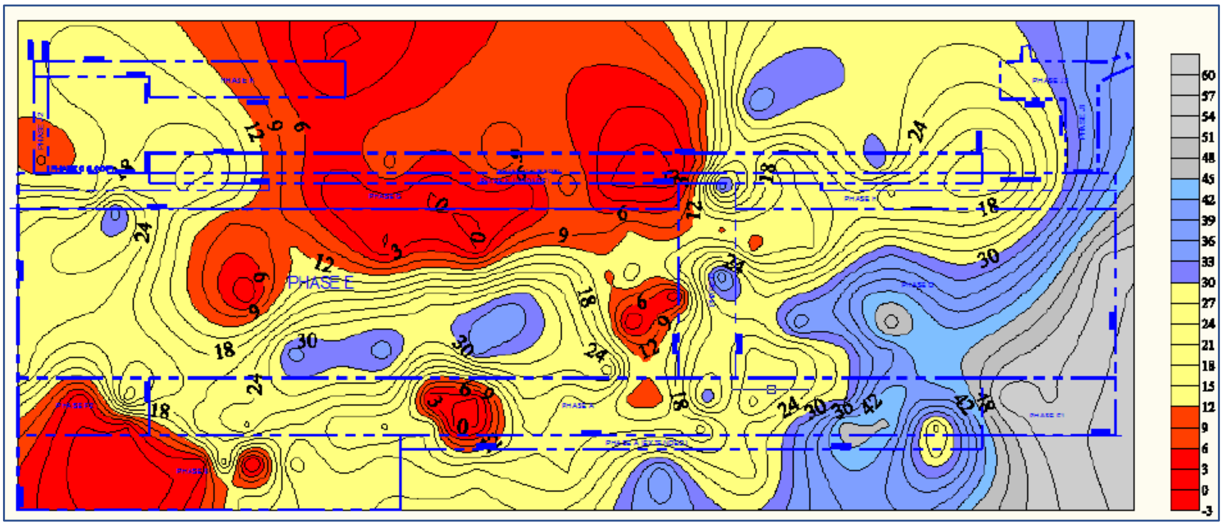


Figure 1.7.c The Contour Map of the Bottom Level for Soft Soil Layers

1.7.3 Construction Photos

Figure 1.7.d PVD Installation

Figure 1.7.e Slurry Wall Construction

Figure 1.7.f Installing Horizontal Drainage

Figure 1.7.g Geotextile Installation

Figure 1.7.h Geomembrane and Sealing Trench Construction

Figure 1.7.i Installing Vacuum Pump

Figure 1.7.j Vacuum Pump Running

Installation of Instrumentations

Surface Settlement Plate

Piezometer

Inclinometer

Vacuum Gauge

Extensometer

Figure 1.7.k Instrumentation for Trial Panel T-2-1 P2

1.7.4 Results

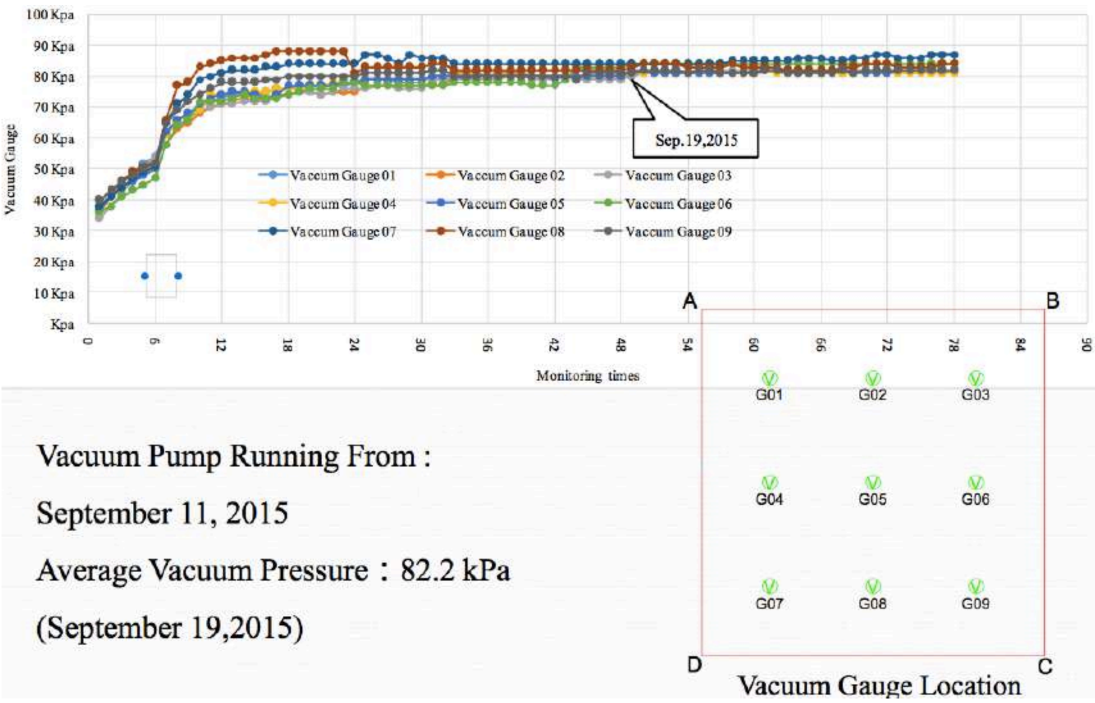


Figure 1.7.l Vacuum Gauge record

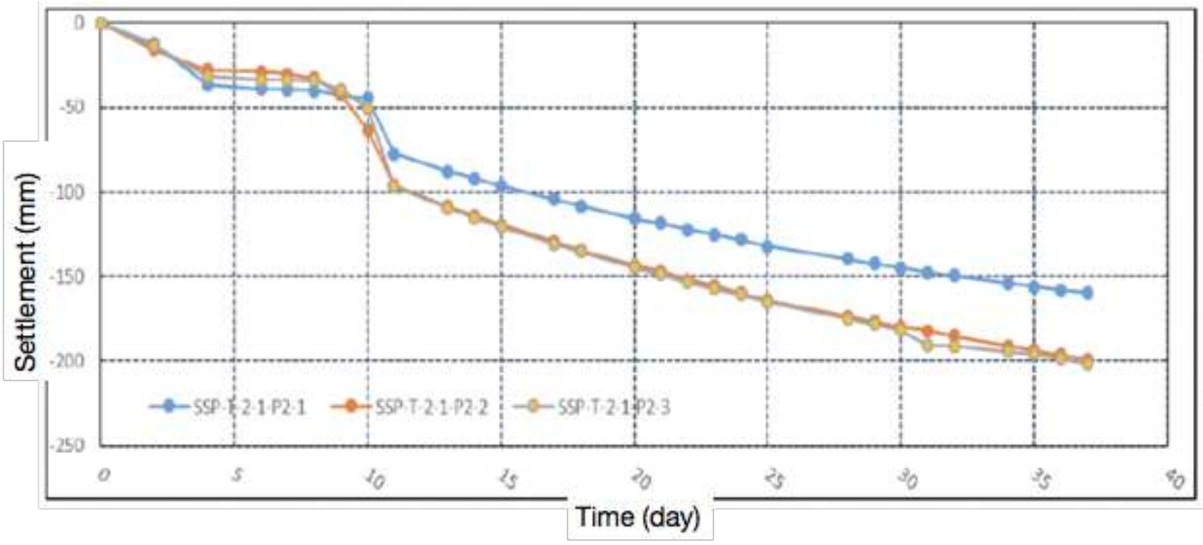


Figure 1.7.m Surface Settlement Record

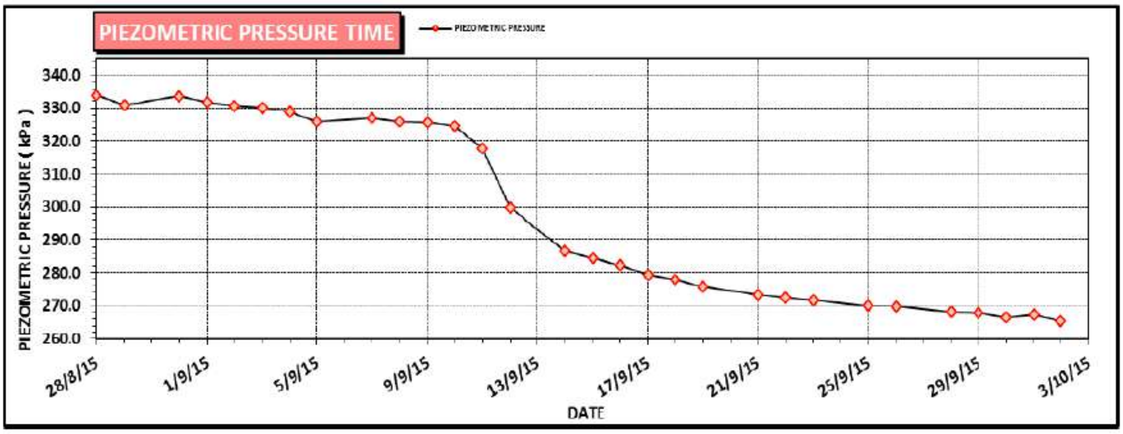


Figure 1.7.n Pore Water Pressure Monitoring at Depth 37m

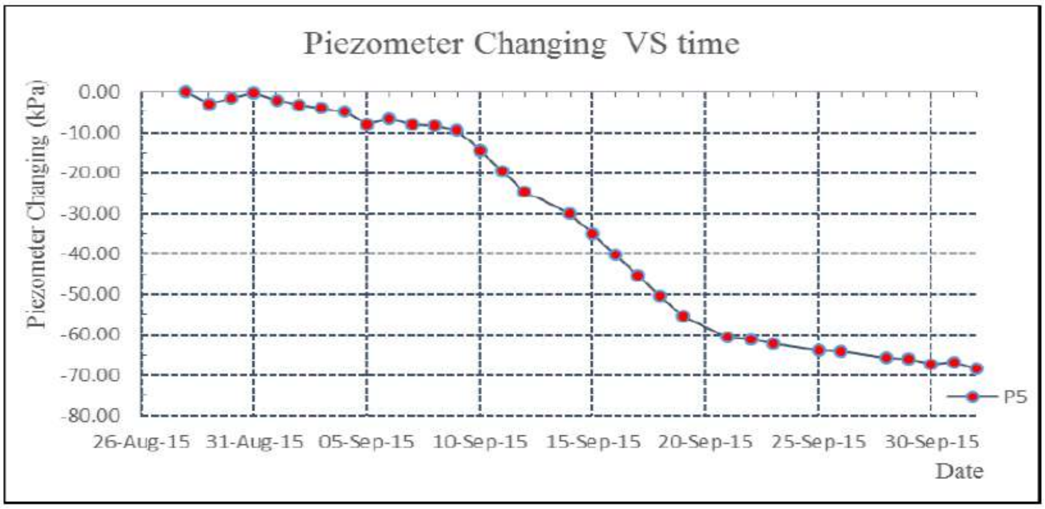


Figure 1.7.o Pore Water Pressure Monitoring at depth 37m

1.8 PALEMBANG-INDRALAYA, SOUTH SUMATERA, INDONESIA – TOLL ROAD

1.8.1 Project Overview

- Toll Road length: 22 km
- Client: Hutama Karya (Persero)
- Duration: 24 Months (September 2015~now)
- Design Requirement: 90% degree of consolidation
- Project Scale: 22 km toll road, wide 45~50 m.

1.8.2 Geological Conditions

Table 1.8.a Soil Profile

Depth (m)	BH-01	BH-02	BH-03	BH-04	BH-05	BH-06	BH-07	BH-08	BH-09	BH-10	BH-11	BH-12	BH-13	BH-14
STA	1+000	1+850	3+650	5+900	7+125	8+050	9+625	12+000	14+100	16+100	17+650	19+000	20+050	21+400
1.5	0	0	0	0	0	0	2	4	0	19	1	5	0	18
3.0	0	1	0	2	0	0	0	8	0	13	0	7	2	16
4.5	1	1	2	2	0	1	0	9	2	16	0	8	6	16
6.0	3	1	0	5	1	5	0	12	2	18	0	7	13	13
7.5	0	1	2	9	1	5	6	9	3	20	4	8	19	14
9.0	0	2	4	17	5	5	6	7	10	17	3	6	31	18
10.5	1	3	7	13	5	2	8	1	7	19	2	11	36	15
12.0	2	4	9	4	7	3	0	1	8	53	2	14	40	18
13.5	6	4	12	9	7	10	2	2	3	56	18	14	40	21
15.0	14	12	14	9	15	11	2	3	10	58	13	32	32	15
16.5	8	13	35	9	20	19	4	8	15	36	14	25	35	16
18.0	10	14	50	23	20	18	5	17	24	41	10	26	38	17
19.5	23	16	50	22	20	25	6	15	24	40	14	27	40	21
21.0	24	18	8	26	50	27	13	16	30	34	15	23	41	20
22.5	28	22	43	29	50	40	31	15	27	49	11	21	39	34
24.0	25	24	27	20	50	62	35	17	36	41	50	21	40	39

1.8.3 Construction Photo

Figure 1.8.a Original Condition

Figure 1.8.b Working Platform

Figure 1.8.c PVD Installation

Figure 1.8.d Geotextile Installation

Figure 1.8.e Geomembrane Installation

Figure 1.8.f Geomembrane Perimeter Lock

Figure 1.8.g Vacuum Process

Figure 1.8.h Backfill on Top of Vacuum Area during Vacuum Process

Figure 1.8.i Aerial Overview

Figure 1.8.j After Improvement – High Backfill on Top of Improved Area

1.8.4 Test Result

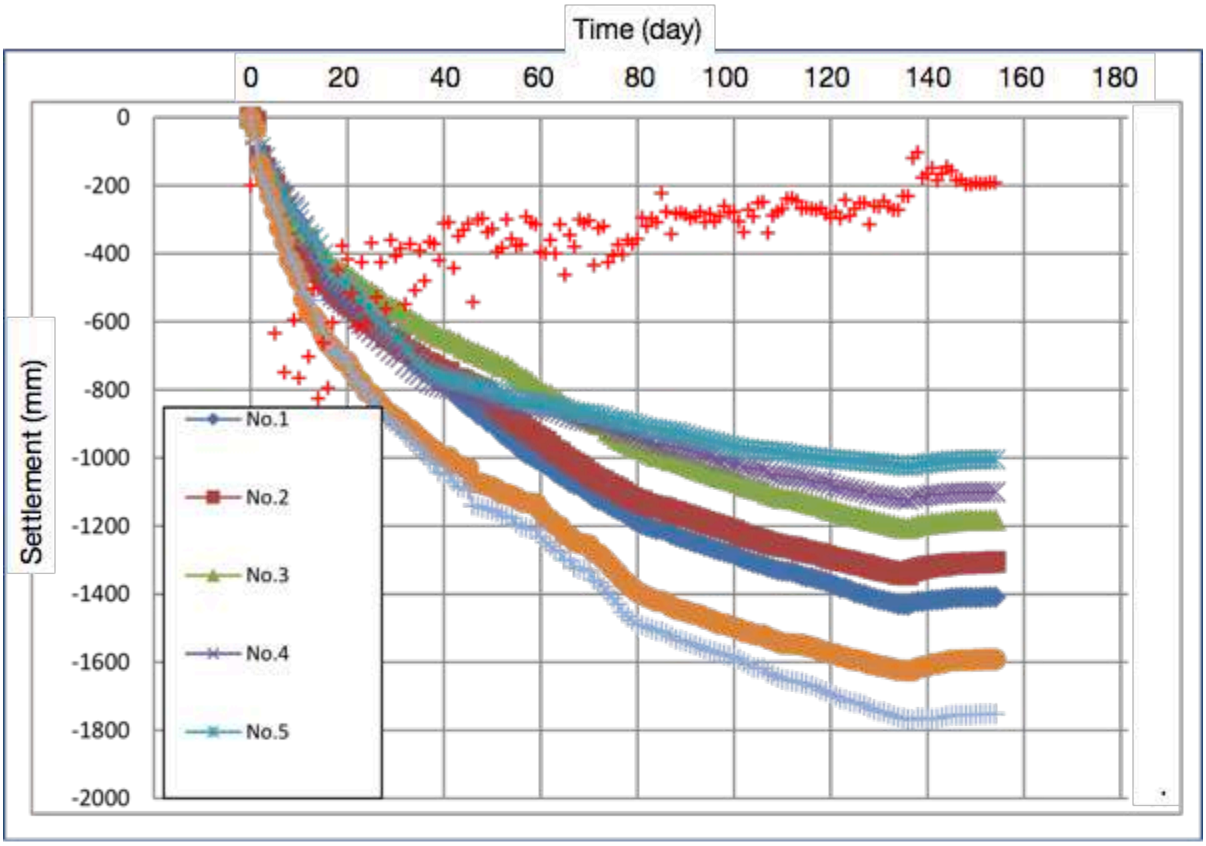


Figure 1.8.k Settlement Curve at Zone 1 (STA 0+050 – 0+700)

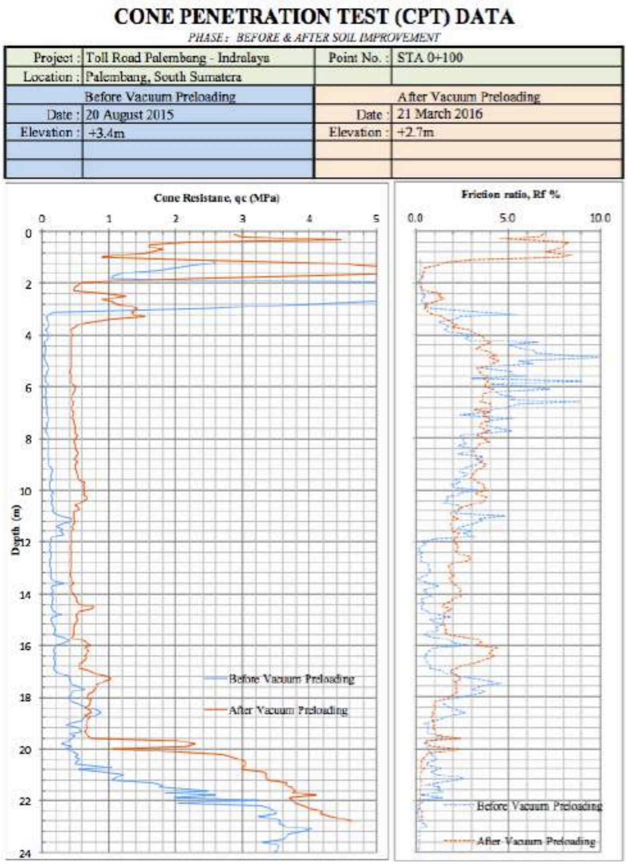


Figure 1.8.l CPT Results at STA 0+100

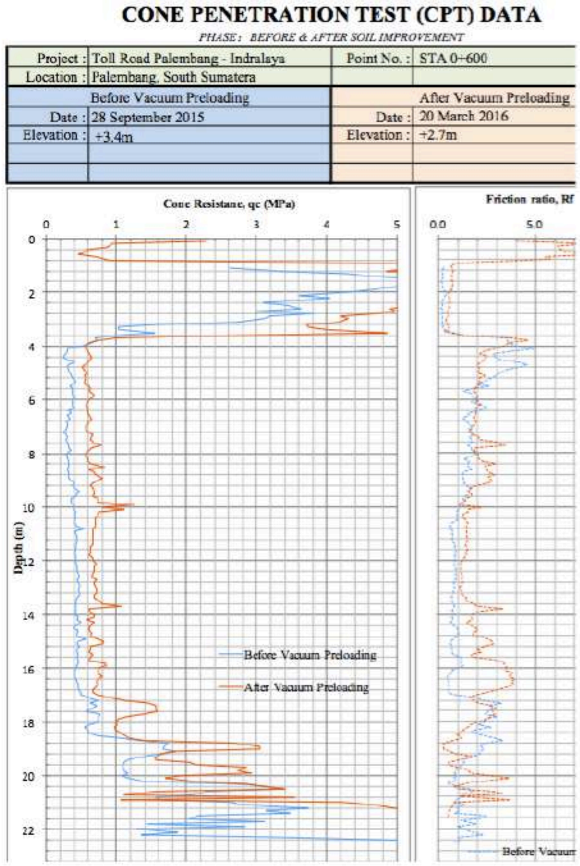


Figure 1.8.m CPT Results at STA 0+600

2 HIGH VACUUM DENSIFICATION METHOD (HVDM)

2.1 HANGZHOU BAY - INDUSTRY PARK AND ROADS

2.1.1 Project Overview

- Project title: Ground Improvement for Industry Park and Municipal Roads of New Town Area in Shangyu City
- Project location: Shangyu, Zhejiang, China
- Project scale: 212.5 ha
- Construction time: Jun. 2010~Dec. 2013
- Design requirements: Ground improvement depth 6~8 m; bearing capacity 120~140kPa; resilient modulus greater than 25 MPa
- Geoharbour's role: Design, Consulting and Construction

2.1.2 Geological Conditions

The site condition is basically characterized by tideland geomorphology near Hangzhou Bay, and the soils were classified into various layers as follows：

- LAYER 1: RECLAIMED FILL, which mainly consisted of pale yellow and grey silts (fluid and plastic), but also contained a relatively large amount of clays (16.5 % in average). This layer was under-consolidated, and the thickness varied between 2.2 and 7m
- LAYER 2: SILTY, with thickness of 15~17 m, and could be subdivided into:
    - LAYER 2-1 SATURATED SILT with high amount of clays, with medium compressibility
    - LAYER 2-2 SATURATED GRAY SILT with small amount of silty sands, with low to medium compressibility
    - LAYER 2-3 SATURATED SILT (yellow green to yellow-grey), medium dense and with low to medium compressibility
    - LAYER 3 MUDDY SILTY CLAY (grey), fluid and plastic, with high compressibility
    - LAYER 4 SILTY CLAY (grey) with high plasticity, plenty of silts, small amount of organic substances and some shell debris, with medium to high compressibility

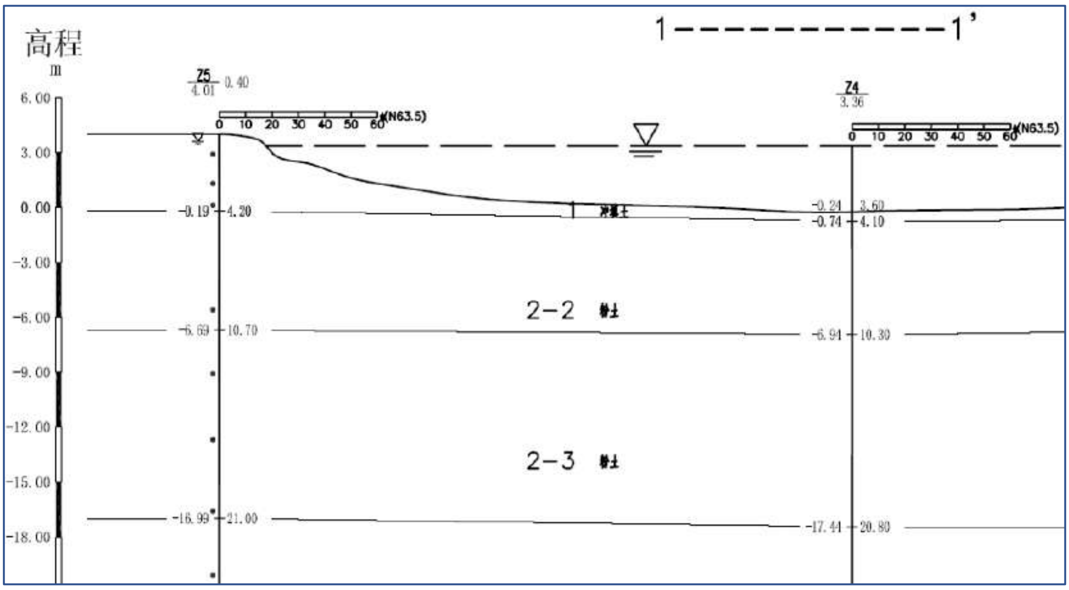


Figure 2.1.a Typical Soil Profile

2.1.3 Technical Parameters

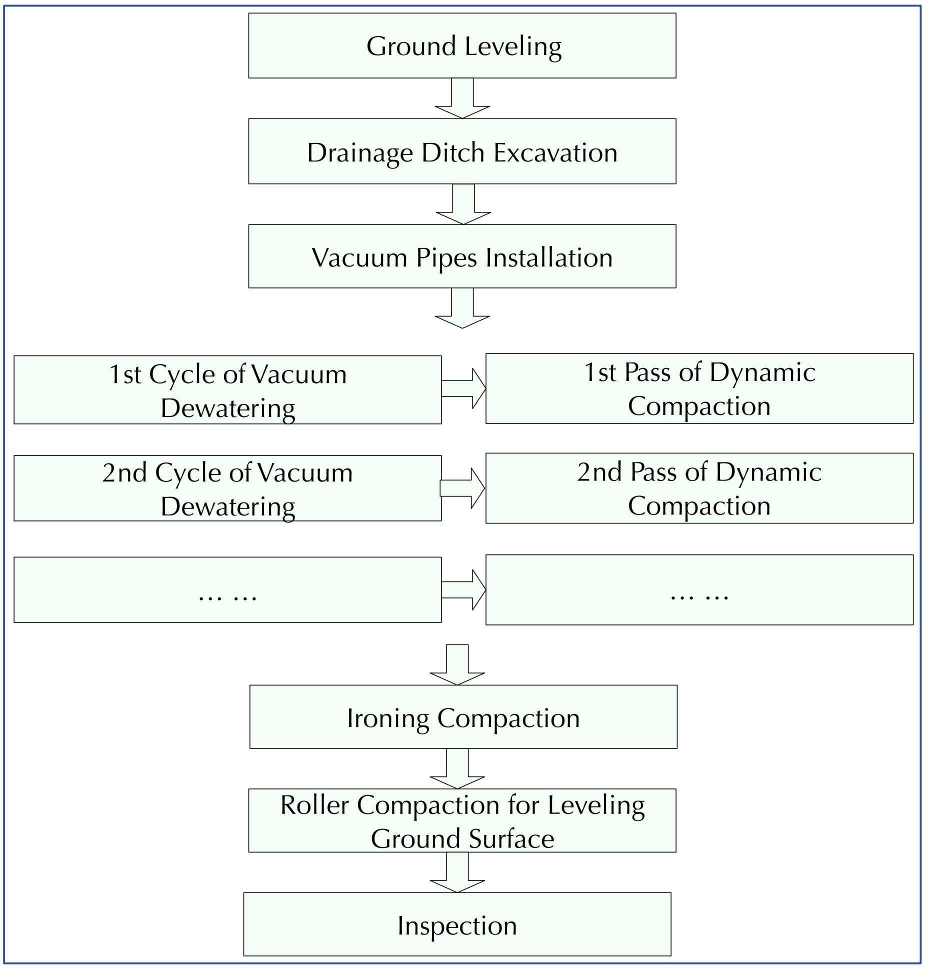


Figure 2.1.b Typical Construction Procedures of HVDM

Table 2.1.a Technical Parameters of HVDM Work

Items		Parameters
Vacuum Pipes	Length	Shallow Pipes: 3~4m; Deep Pipes:5~6m
	Spacing	Shallow Pipes: 3.5×3.5m; Deep Pipes: 3.5m×3.5m
	Duration for Dewatering	First Cycle: 4~7 days Second and Third Cycles: 3~5 days
Dynamic Compaction		1st Pass: 3 blows; Energy per blow: 1500kN·m; Spacing: 3.5m×7m 2nd Pass: 4 blows; Energy per blow:2000kN·m; Spacing: 3.5m×7m 3rd Pass: 4 blows; Energy per blow: 2200kN·m, Spacing: 3.5m×7m Ironing Pass: 1~2 blows; Energy per blow: 900~1000 kN·m

2.1.4 Construction Photos

Figure 2.1.c Original Site Condition

Figure 2.1.d Dewatering with Vacuum Pipes

Figure 2.1.e Dynamic Compaction

Figure 2.1.f Roller Compaction to Level Surface

Figure 2.1.g Road built on the Improved Ground

2.1.5 Results

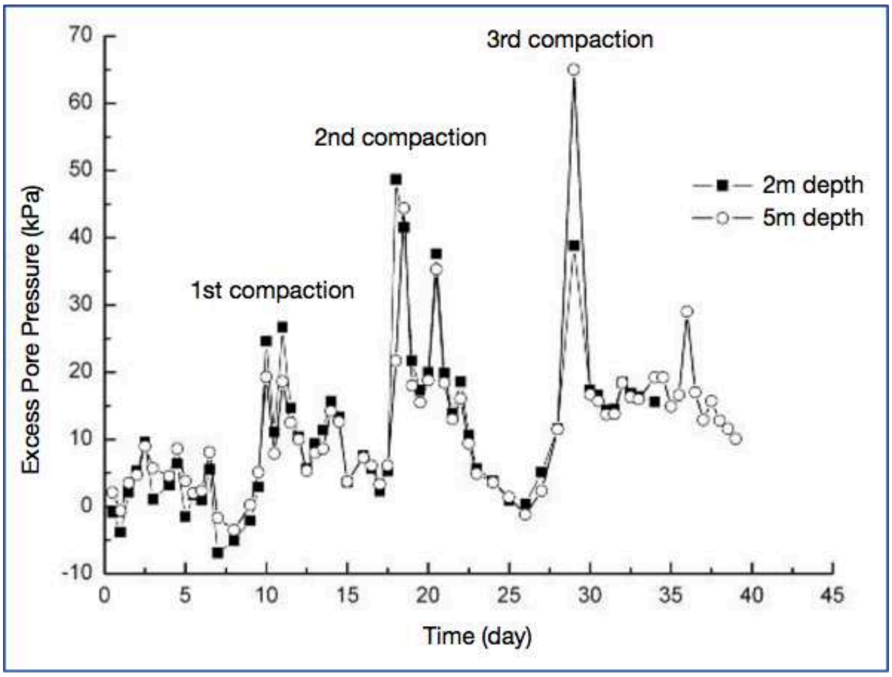


Figure 2.1.h Excess Pore Pressure Monitoring During Construction

Table 2.1.b Ground Surface Settlement Monitoring During HVDM Construction

Step	1st Compaction	2nd Compaction	3rd Compaction	*'Ironing'* Compaction
Settlement (cm)	23.4	31.3	10.8	7.1
Final settlement (cm)	72.6			

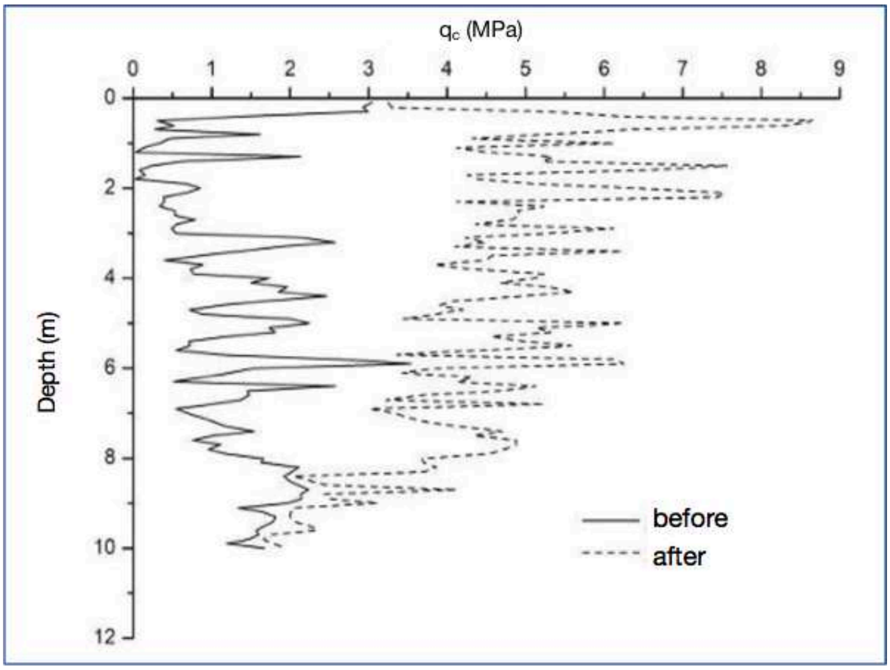


Figure 2.1.i Comparison of CPT Cone Resistance before and after Ground Improvement

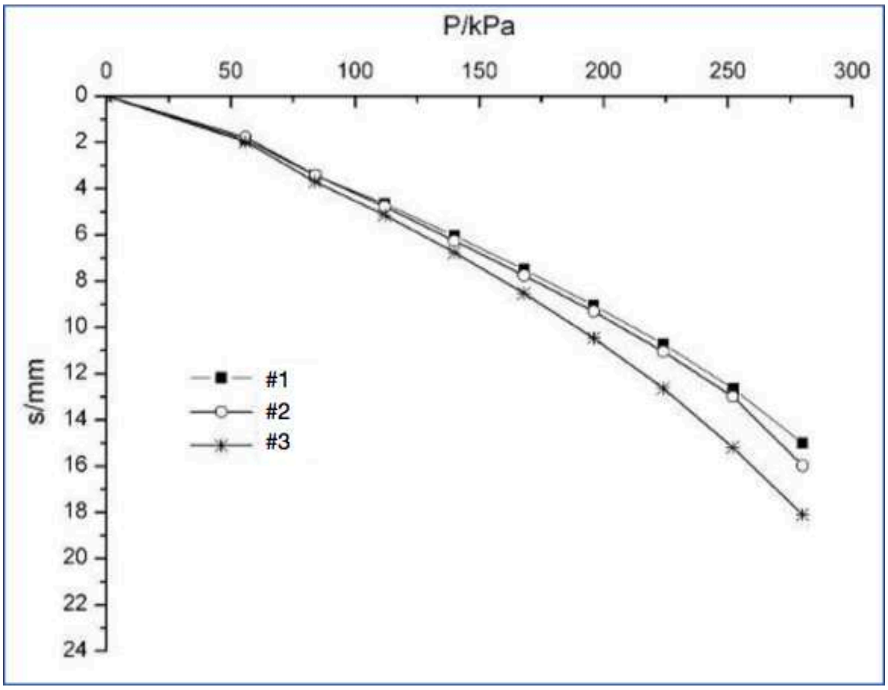


Figure 2.1.j Plate Loading Test Results after Ground Improvement

2.2 TANGSHAN PORT - MINING WHARF EXPANSION

2.2.1 Project Overview

- Project title: Ground Improvement for Caofeidian Port Mining Wharf Expansion at Tangshan Port
- Project location: Caofeidian, Tangshan Port, Hebei, China
- Project scale: 63 ha
- Construction time: Mar. 2010~Feb. 2012
- Design requirements: Bearing capacity ≥ 150kPa; resilient modulus ≥ 25 MPa
- Geoharbour's role: Design, Consulting and Construction

2.2.2 Geological Conditions

The soils being treated are mostly reclaimed fills:

- LAYER 1-1: SILTY SAND, 6 m thick in average, with sandwich layers of silts and silty clays
- LAYER1-3: SILTY SAND
- LAYER 2-1: SILTY CLAY
- LAYER 2-2: SILTS AND SILTY SAND
- LAYER 2-3 SILTY CLAY AND CLAY

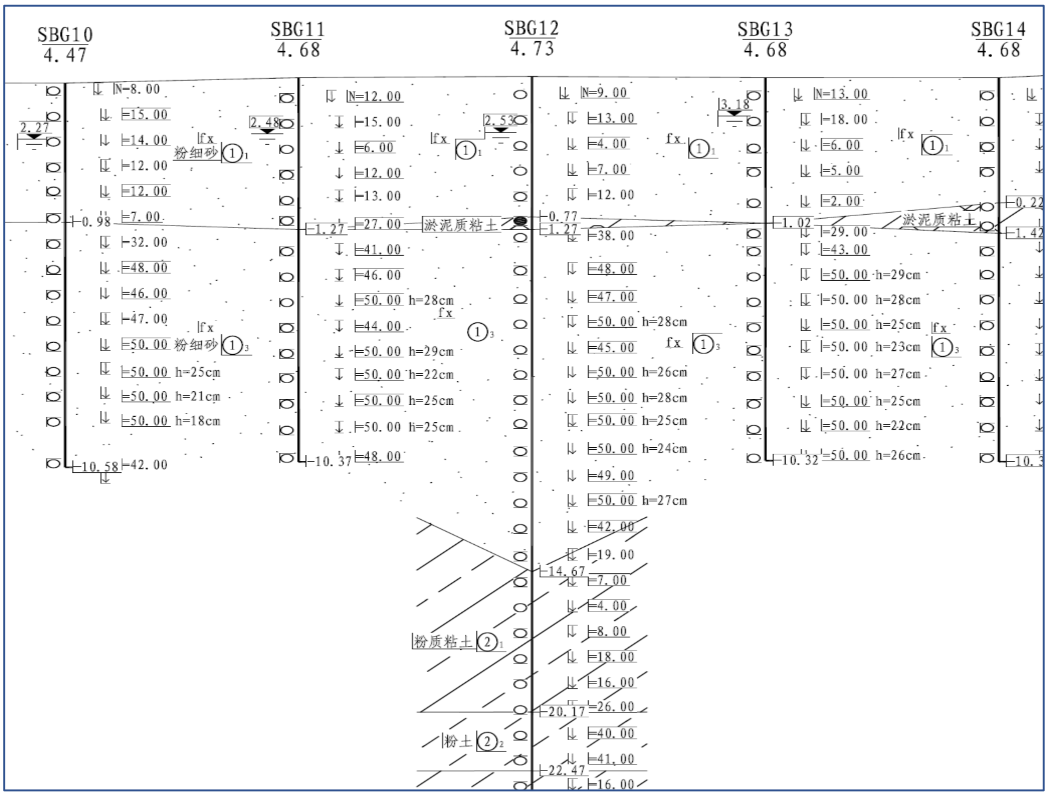


Figure 2.2.a Typical Soil Profile

2.2.3 Technical Parameters

Table 2.2.a Technical Parameters of HVDM Work

Items		Parameters
Vacuum Pipes	Length	Shallow Pipes: 4m; Deep Pipes: 6m
	Spacing	Shallow Pipes: 3.5m×7 m; Deep Pipes: 3.5m×3.5m
	Duration for Dewatering	First Cycle: 15 days Second Cycle: 10 days
Dynamic Compaction		1st Pass : 8~10 blows; Energy per blow: 1500kN·m 2nd Pass : 10~12 blows; Energy per blow: 2500kN·m; Triangular pattern Ironing Pass: 2~3 blows; Energy per blow: 600 kN·m.

2.2.4 Construction Photos

Figure 2.2.b Original Site Condition

Figure 2.2.c HVDM Dynamic Compaction

2.2.5 Test Results

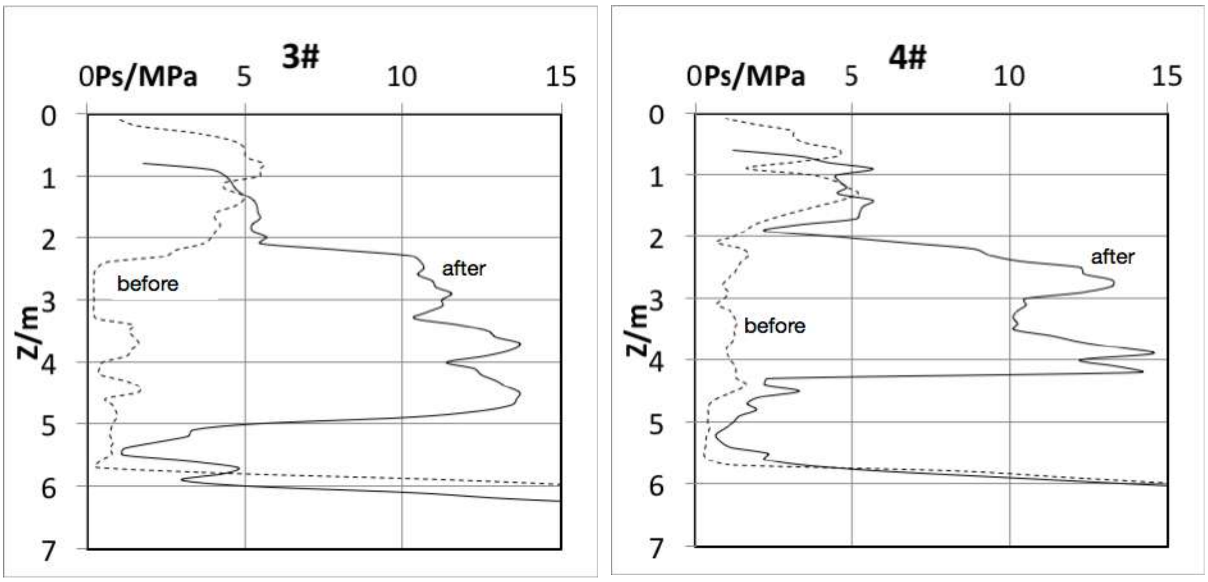


Figure 2.2.d Comparison of CPT Cone Resistance before and after Ground Improvement

2.3 CAOFEIDIAN - ROADS

2.3.1 Project Overview

- Project title: Ground Improvement for Hebei #1 and #2 Roads, Caofeidian, Hebei
- Project location: Caofeidian, Hebei, China

2.3.2 Geological Conditions

The topsoil on the site mainly consists of reclaimed silt sands, silts and silty clays. The soils are characterised by loose structure, high water content, low bearing capacity, and high clayey contents.

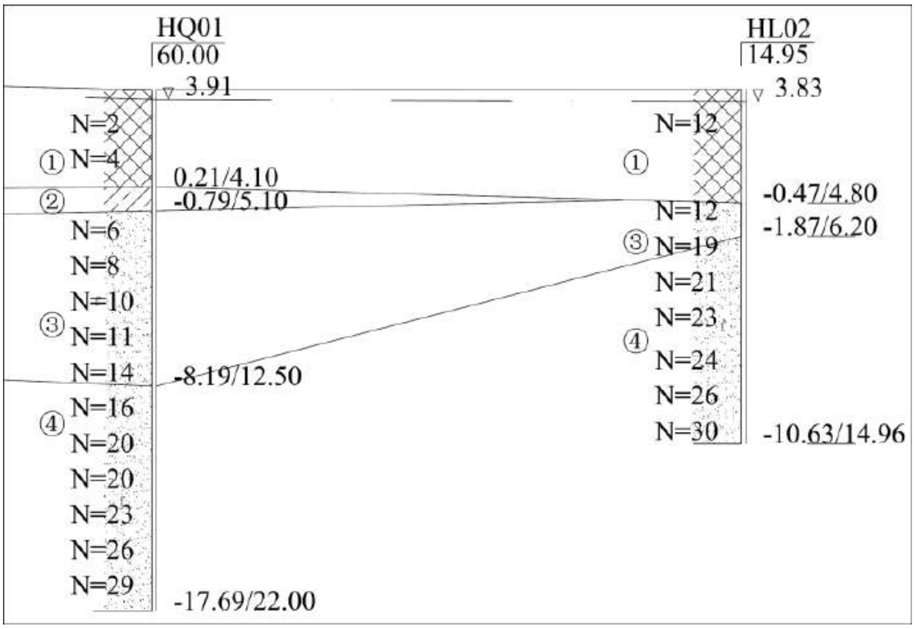


Figure 2.3.a Typical Soil Profile with SPT N-number

2.3.3 Technical Parameters

Table 2.3.a Technical Parameters of HVDM Work

Items		Parameters
Vacuum Pipes	Length	Shallow Pipe: 3~4m, Deep Pipe:6m
	Spacing	Shallow Pipe: 3.5m×5.5m, Deep Pipe: 3.5m×5.5m
	Duration for Dewatering	First Cycle: 15 days Second and Third Cycle: 10 days
Dynamic Compaction		1st Pass: 3~4 blows; Energy per blow: 1500kN·m 2nd Pass: 4~5 blows; Energy per blow:2000kN·m; triangular pattern 3rd Pass: 4~5 blows; Energy per blow: 2200kN·m; triangular pattern
Roller Compaction		Using dynamic roller compaction to dense the surface soil

2.3.4 Test Results

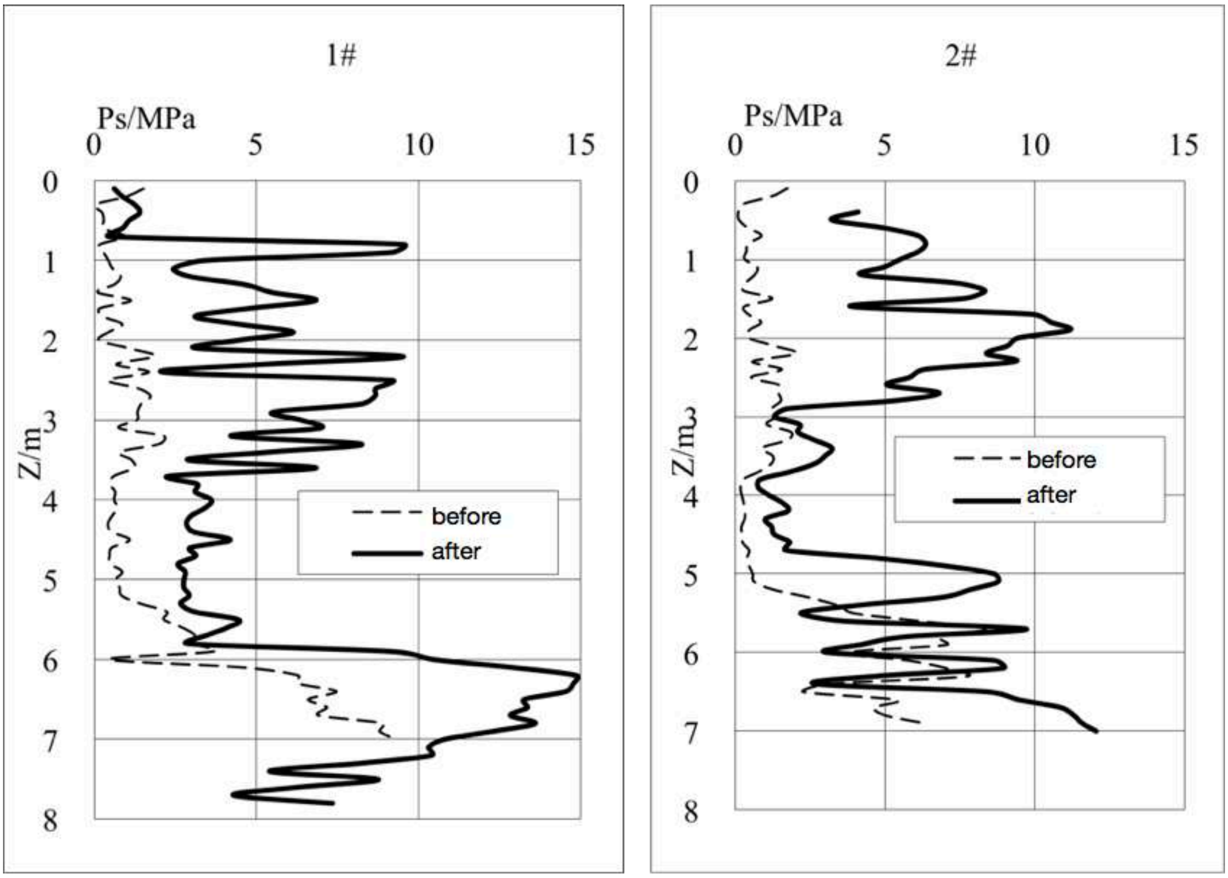


Figure 2.3.b Comparison of CPT Cone Resistance before and after Ground Improvement

2.4 SHANGHAI PUDONG AIRPORT #2 RUNWAY

2.4.1 Project Overview

- Project title: Ground Improvement for #2 Runway Project of Shanghai Pudong International Airport
- Project location: Pudong, Shanghai, China
- Project scale: 174.43 ha
- Construction time: 2003
- Design requirements: Bearing capacity ≥ 160kPa; Post-construction settlement ≤ 10 cm; Differential settlement slope ≤ 1/1000
- Geoharbour's role: Design, Consulting and Construction

2.4.2 Geological Conditions

Shanghai Pudong International Airport is located at the Yangtze River Delta alluvial plain front. The soil profile was mainly comprised of:

- LAYER 1: ARABLE SOIL AND ALLUVIAL SOIL, with rotten vegetation
- LAYER 2-1-1: SILTY SAND (brown), with medium compressibility, 0.1~2.2 m thick
- LAYER 2-1-2: SILTY CLAY (brown), with medium compressibility, medium plastic, 0.25~2.7 m thick
- LAYER 2-2: SILTY CLAYS (grey), saturated, nonhomogeneous, with medium compressibility, 0.60~5.90 m thick
- LAYER 2-3: SANDY SILTS (grey), saturated, nonhomogeneous, with medium compressibility, 1.00~9.10 m thick

2.4.3 Construction Photos

Figure 2.4.a HVDM Construction

Figure 2.4.b #2 Runway under Operation

2.4.4 Results

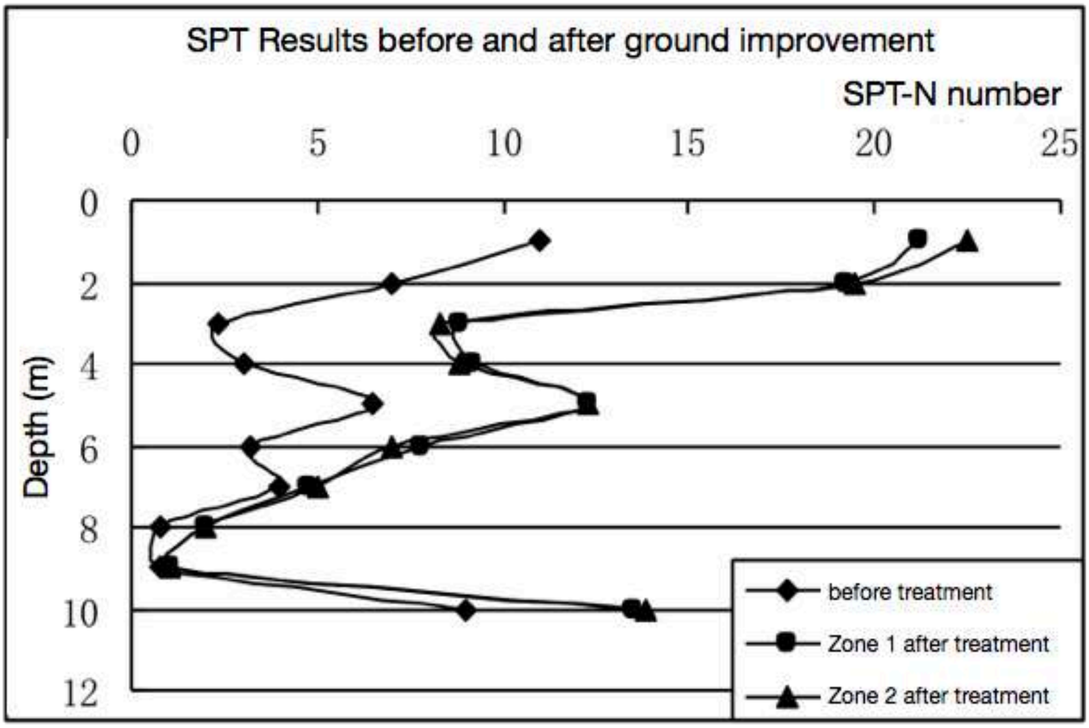


Figure 2.4.c Comparison of SPT N-number before and after Ground Improvement

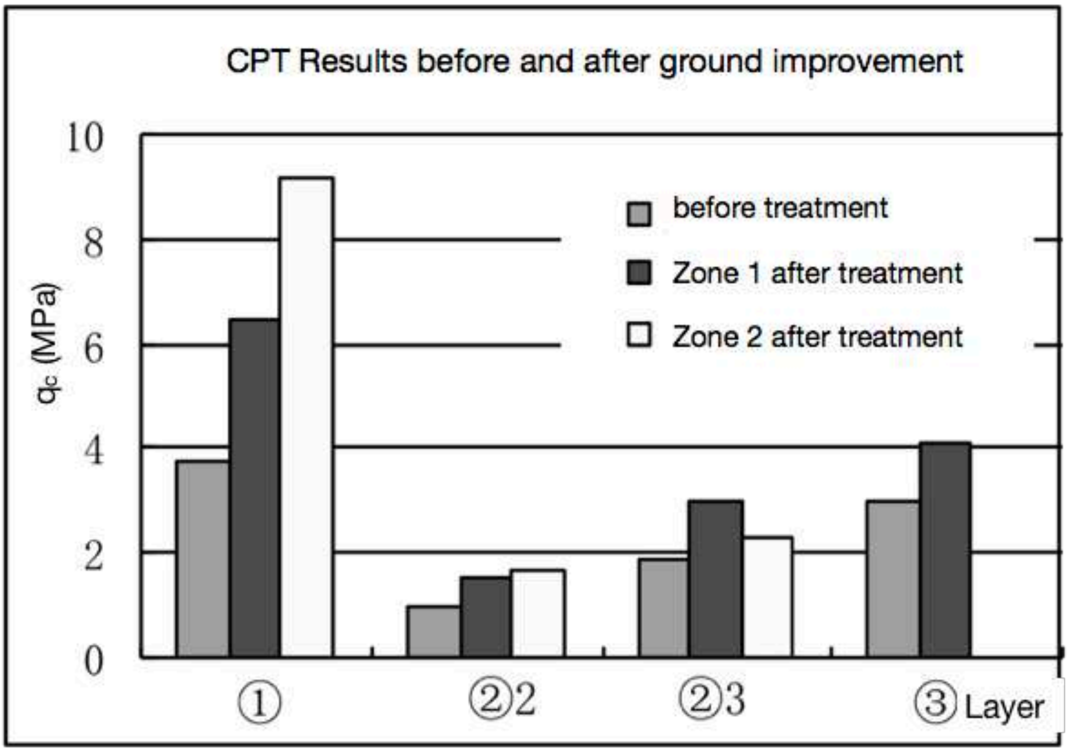


Figure 2.4.d Comparison of CPT Cone Resistance before and after Ground Improvement

Table 2.4.a Test results before and after treatment

Area	CBR (MPa)	Foundation Modulus K (MPa/m^3)	Resilient Modulus E_0 (MPa)
Overall area, before treatment	0.89	20.80	43.03
Area I, after treatment	8.83	61.32	71.73
Area II, after treatment	8.68	56.93	66.25

Table 2.4.b Comparison with #1 Runway adopting other Ground Improvement Method

Item	Runway 1#	Runway 2#
Ground Improvement Method	Dynamic compaction with adding slags	HVDM
Construction settlement	35cm	55.7cm
Post-construction settlement	30cm	10cm
cost	-	saved about 125 million CNY (≈25 million AUD)
Construction duration	12 months	4 months

2.5 BEILUN PORT - INTERNATIONAL CONTAINER TERMINAL

2.5.1 Project Overview

- Project title: Ground Improvement for International Container Terminal Project (Stage 2 of Phase 3) at Beilun Port, Ningbo, Zhejiang
- Project location: Ningbo, Zhejiang, China
- Project scale: 47 ha
- Construction time: 2007
- Design requirements: Bearing capacity ≥ 120kPa; Construction settlement ≥ 60 cm; Ground improvement depth: 6~8 m.
- Geoharbour's role: Design, Consulting and Construction

2.5.2 Geological Conditions

Table 2.5.a Soil Properties

Layer	Soil type	thickness (m)	Soil properties					
			Cohesion c (kPa)	Friction angle ϕ (°)	Compression coefficient a0.1~0.2 (MPa^{-1})	Compression modulus $Es_{0.1\sim0.2}$ (MPa)	Void ratio e	Water content w (%)
1	Dredged fills (fly ashes)	2.8~4.2						
2-1	Silty Clays	1.2~2.9	15	8.3	0.89	2.58	1.306	46.8
2-2	Silty Clays	6.4~9.6	16.3	9.1	0.8	2.83	1.205	43.5

2.5.3 Construction Photos

Figure 2.5.a High Vacuum Dewatering

Figure 2.5.b Dynamic Compaction

Figure 2.5.c Site Condition after Improvement

Figure 2.5.d Excavation after Improvement

2.5.4 Results

Table 2.5.b CPT Cone Resistance results before and after treatment

CPT No.	Depth (m)	p_s (MPa)	
		Before treatment	After treatment
C1-1	0.0~2.7m	0.81	2.14
C1-1	2.8~8.0m	0.4	0.78
C1-2	0.0~2.7m	0.97	3.65
C1-2	2.8~8.0m	0.43	0.74
C1-3	0.0~2.7m	0.94	4.77
C1-3	2.8~8.0m	0.42	0.95
C1-4	0.0~2.7m	0.9	4.61
C1-4	2.8~8.0m	0.41	0.83
C1-5	0.0~2.7m	0.82	3.79
C1-5	2.8~8.0m	0.43	0.83
C1-6	0.0~2.7m	0.91	4.26

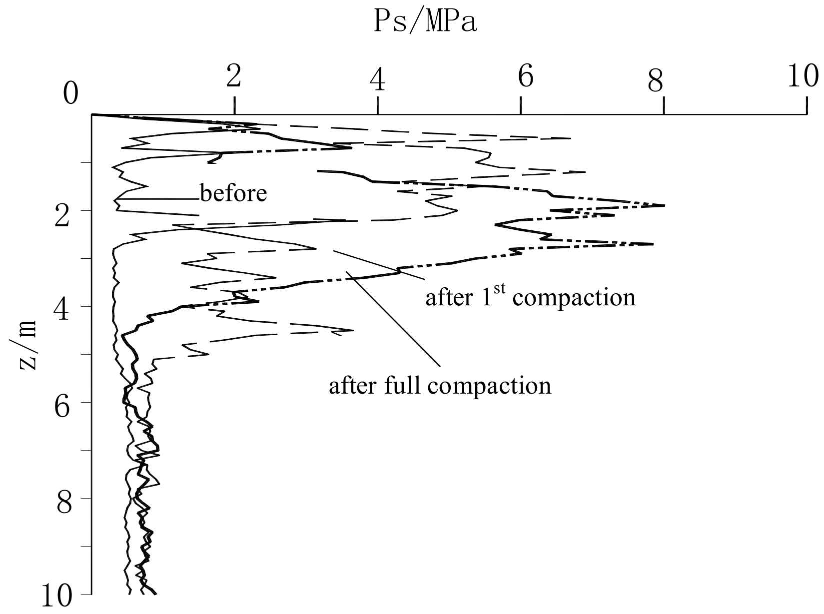


Figure 2.5.e Comparison of CPT Cone Resistance before and after Ground Improvement

3 HVDM COMBINED WITH OTHER METHODS

3.1 DEQING, CHINA - ROAD FOUNDATION

3.1.1 Project Overview

- Project planning: Municipal Administration Road
- Location: Deqing Zhejiang Province
- Area: 48,000 m^2
- <u>**Improvement Methods: HVDM + Vacuum Preloading**</u>

3.1.2 Geological Condition

The typical soil profile comprises of the following layer

- FILL. Loose, slightly wet, upper part of the cultivated soil, including vegetation roots
- SILTY CLAY. The Thickness was from 1.2m to 2.6m, saturated, soft and plastic
- SOFT CLAY. Saturated, fluid and plastic, with small amount of silts and silty clays, the thickness was about 25m
- SILTY CLAY. Saturated, plastic with thickness about from 3.2 to 7.4m

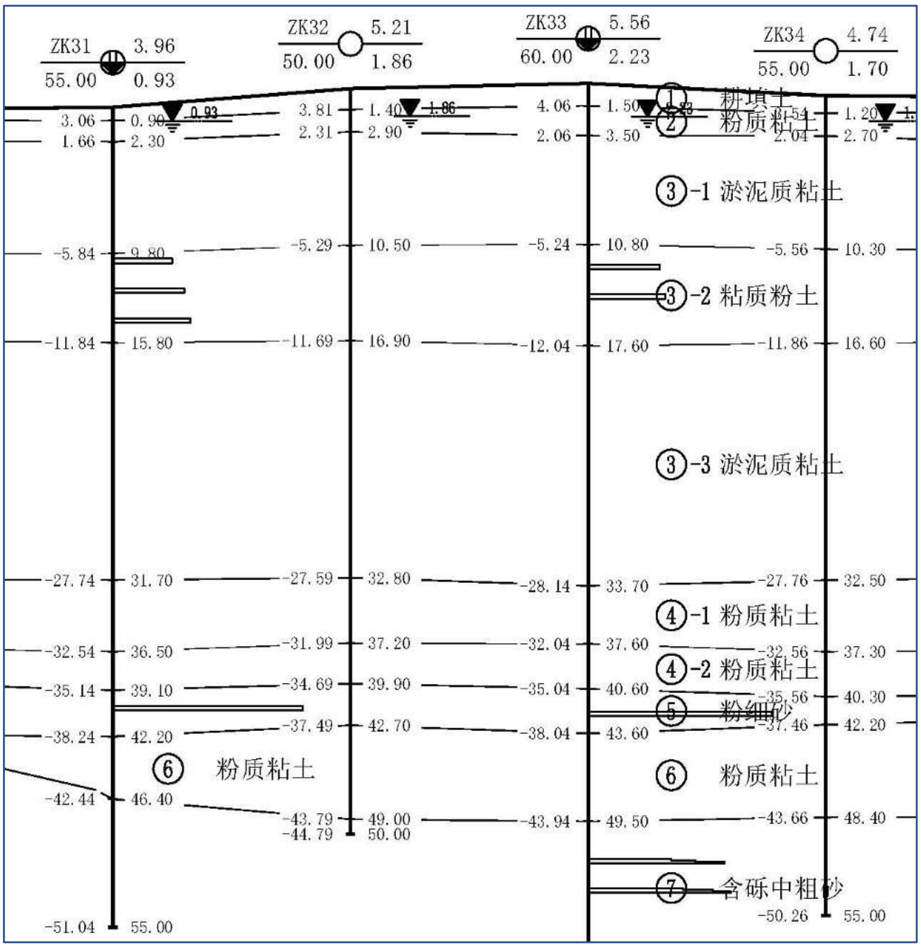


Figure 3.1.a Typical Soil Profile

3.1.3 Construction Photos

a. ***Vacuum Preloading (VCM)***

Figure 3.1.b Original Soil Condition

Figure 3.1.c PVD Installation

Figure 3.1.b Spreading Geotextile

Figure 3.1.e Spreading Geomembrane

Figure 3.1.f Vacuum Preloading

Figure 3.1.g Water Surcharge

b. ***High Vacuum Densification Method (HVDM)***

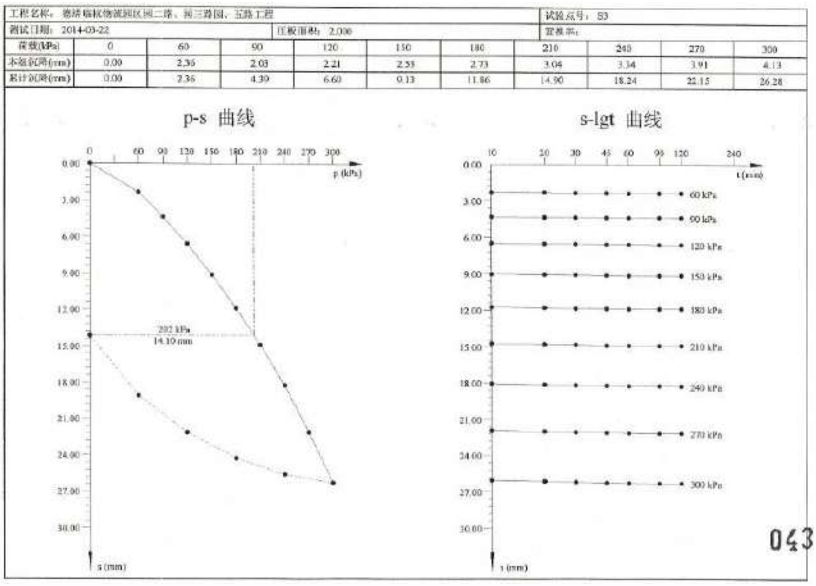
Figure 3.1.h Vacuum Pipe Installation

Figure 3.1.i Dynamic Compaction

Figure 3.1.j Excavation after soil improvement

3.1.4 Results

Plate loading test after the ground improvement by a third party showed that the bearing capacity was greater than 150kPa while the design requirement was 120kPa. And CPT result was enhanced by about 50%. All the index met the design requirements.



荷载(kPa)	0	60	90	120	150	180	210	240	270	300
本级沉降(mm)	0.00	2.36	2.03	2.21	2.53	2.73	3.04	3.34	3.91	4.13
累计沉降(mm)	0.00	2.36	4.39	6.60	9.13	11.86	14.90	18.24	22.15	26.28

Figure 3.1.k Bearing Capacity Test Report (p-s、s-lgt)

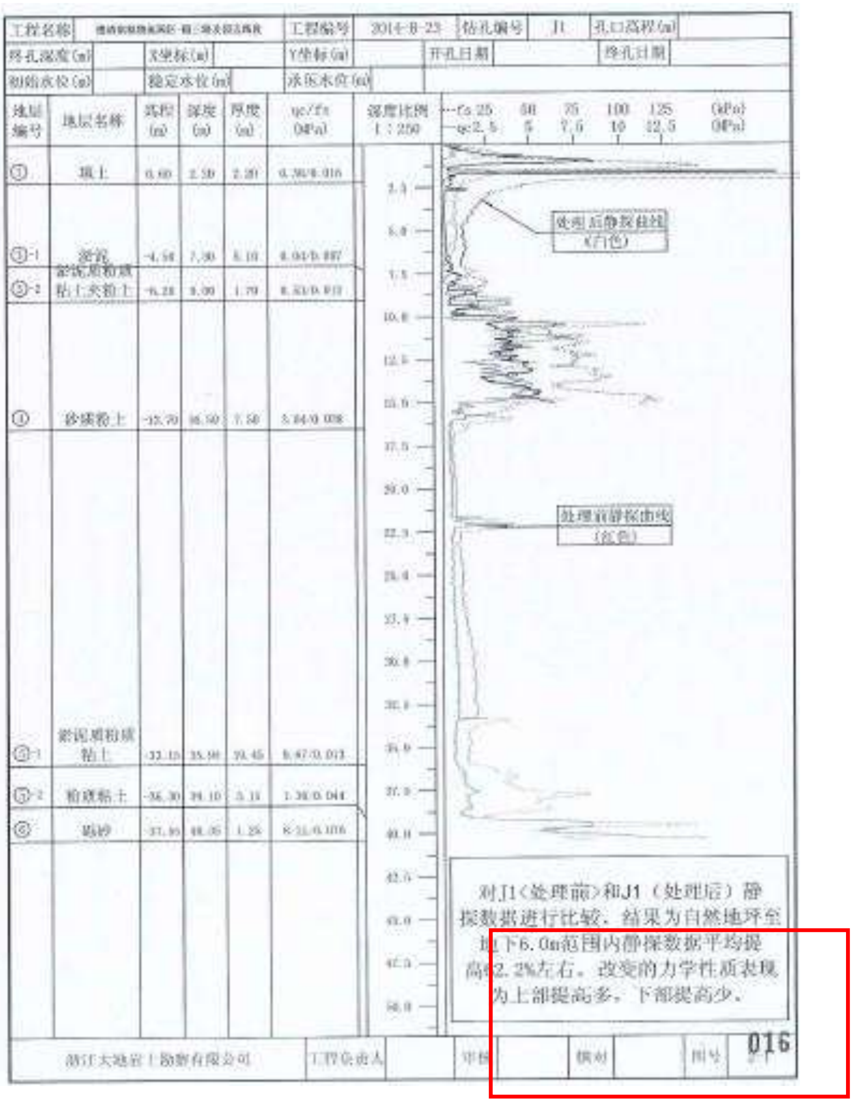


Figure 3.1.l Comparison of CPT Cone Resistance before and after Ground Improvement

3.2 WUJIANG, CHINA - ROAD FOUNDATION

3.2.1 Project Overview

- Project title: Ground Improvement for Municipal Roads in Wujiang City
- Location: Wujiang, Jiangsu, China
- **Improvement Methods: HVDM + Vacuum Preloading**
- Project scale: HVDM: 62.5 ha; HVDM+Vacuum: 77.4 ha
- Construction time: Aug. 2009~Feb. 2015 (for five roads)
- Design requirements: Ground improvement depth 6~18 m; bearing capacity 110kPa; resilient modulus 30~35 MPa
- Geoharbour's role: Design, Consulting and Construction

3.2.2 Geological Condition

The typical soil profile consists of the following layer:

- LAYER 1: FILL, with loose and inhomogeneous structure, 0.30~3.19 m thick
- LAYER 2: SILTY CLAY (greyish yellow to grey), soft and plastic, with medium compressibility, 0.70~3.60 m thick
- LAYER 3: SILTY CLAY (grey), fluid and plastic, 1.50~21.20 m thick
- LAYER 4-1: SILTY CLAY (greyish yellow), stiff and plastic, and with medium compressibility, 1.80~5.60 m thick

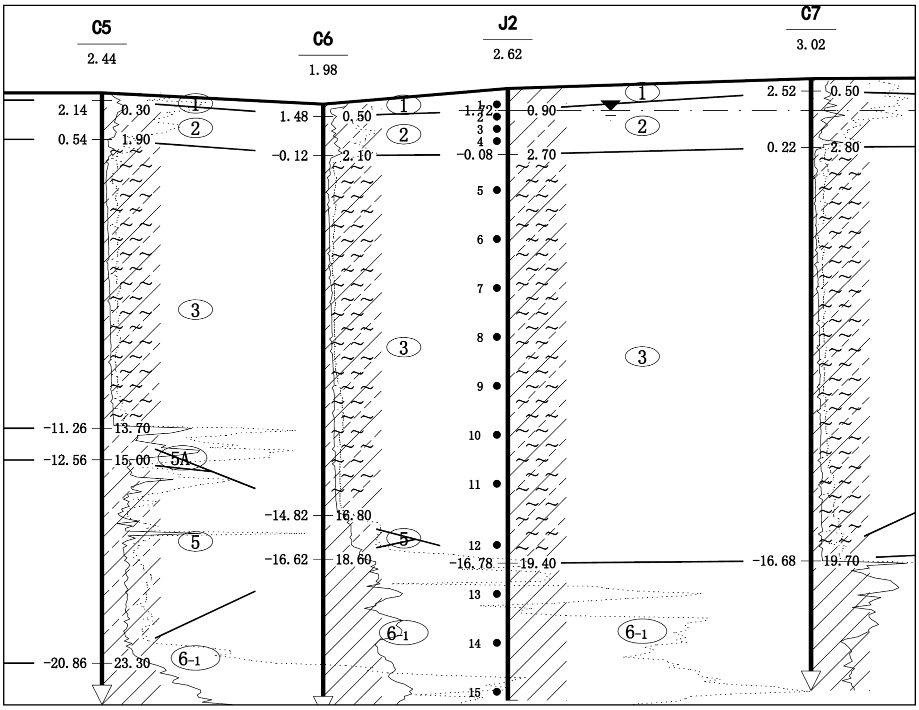


Figure 3.2.a Typical Soil Profile

3.2.3 Construction Documentation

a. Vacuum Preloading (VCM)

Figure 3.2.b Original Soil Condition

Figure 3.2.c Mud Removal

Figure 3.2.d Sand Blanket Placement

Figure 3.2.e Horizontal Drain Placement

Figure 3.2.f Spreading Geotextile

Figure 3.2.g Spreading Geomembrane

Figure 3.2.h Membrane Sealing at Cut-off Wall

Figure 3.2.i Vacuum Operation

Figure 3.2.j Water Surcharge

Figure 3.2.k Settlement Monitoring

Figure 3.2.l Under-membrane Vacuum Monitoring

b. High Vacuum Densification Method (HVDM)

Figure 3.2.m Vacuum Pipe Installation

Figure 3.2.n Vacuum Pipe System

Figure 3.2.o HVDM Dynamic Compaction

Figure 3.2.p Roller Compaction on Surface

Figure 3.2.q Site Condition after Improvement

Figure 3.2.r Excavation on the Improved Ground

Figure 3.2.s Road Built on the Improved Ground

3.2.4 Results

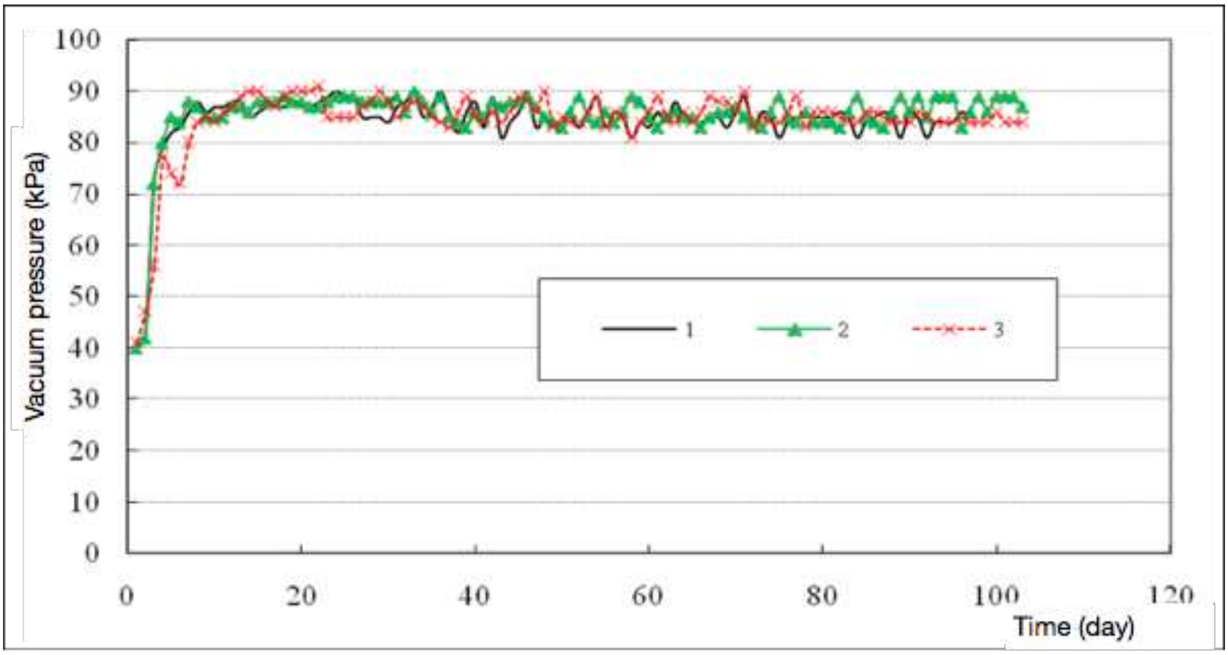


Figure 3.2.t Vacuum Monitoring during Vacuum Preloading

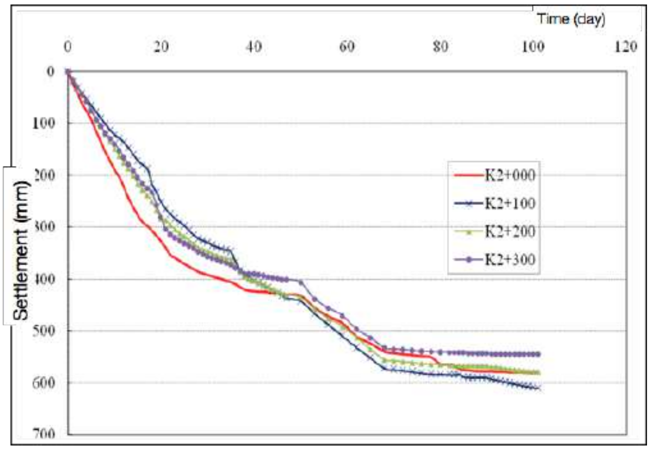


Figure 3.2.u Settlement Monitoring during Vacuum Preloading

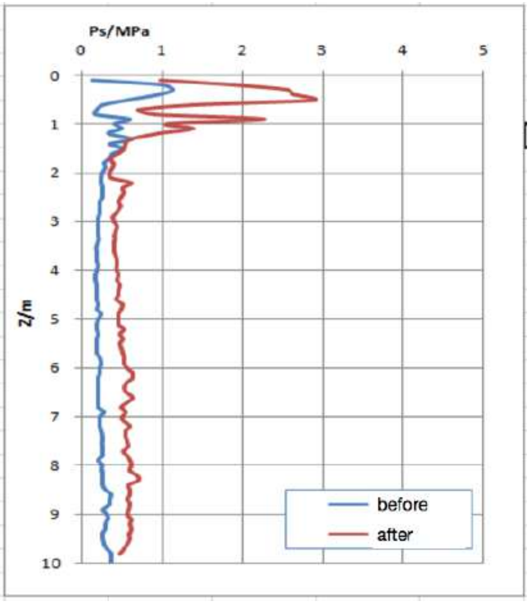


Figure 3.2.v Comparison of CPT Cone Resistance before and after Ground Improvement

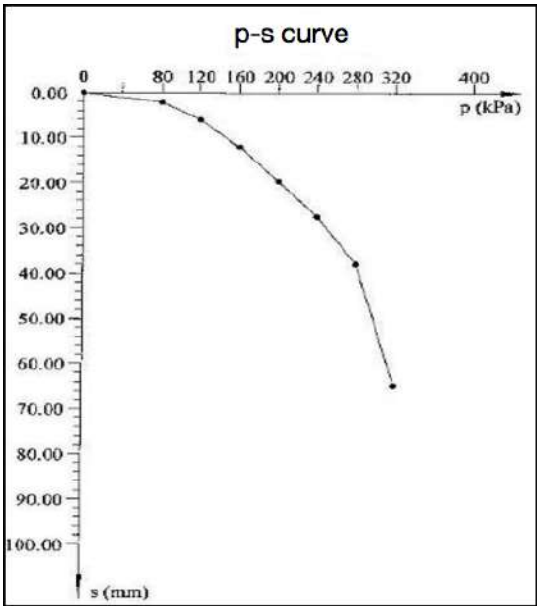


Figure 3.2.w Plate Loading Test Result (showing bearing capacity > 240 kPa)

3.3 PINGTAN UNION HOSPITAL

3.3.1 Project Overview

- Project title: Ground Improvement for Union Hospital Project at Jinjing Bay, Pingtan, Fujian
- Project location: Pingtan, Fujian, China
- Project scale: 7 ha
- Construction starting time: Dec. 2012
- Design requirements: Bearing capacity greater than 120kPa; CPT values increased ≥ 60 cm; Eliminating liquefaction of the surface sands
- Geoharbour's role: Design, Consulting and Construction
- **Improvement methods: HVDM+PVD**

3.3.2 Geological Condition

The topsoil is reclaimed medium-fine sand.

- LAYER 1 EARTH FILL, showing grey colour and being loose to slightly dense, mainly consist of fine to medium grained sands, including a little shell debris. The layer was under-consolidated, and its depth varied between 0.5 and 8.3 m.
- LAYER 1-2 EARTH FILLS MIXED WITH GRAVELS, showing grey colour and being loose to slightly dense, mainly consist of weathered granite blocks. This layer was under-consolidated, and its depth varied between 0.4 to 2.5 m.
- LAYER 2-1 SILT (dark grey), fully saturated and characterized by high water content and high plasticity. This layer mainly consists of silty clays, and was under-consolidated, with thickness varying between 1.2 to 14.6 m.
- LAYER 2-2 SILTY SOIL (dark grey to black), fully saturated and characterized by high water content, high plasticity and high compressibility. It mainly consists of silty clays, and was under-consolidate. The thickness varied from 0.7 to 10.3m.
- SILTY CLAY, saturated, plastic, with the thickness about from 3.2 to 7.4 m.

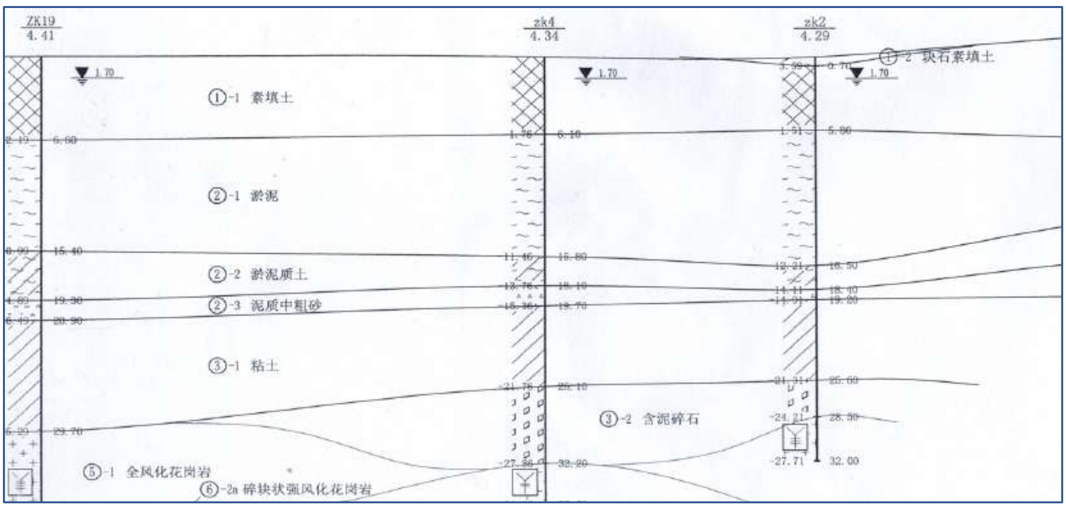


Figure 3.3.a Typical Soil Profile

3.3.3 Technical Parameters

Table 3.3.a Technical Parameters of HVDM Work

<table>
<tr><th colspan="2">Items</th><th>Specification</th></tr>
<tr><td rowspan="3">Vacuum Pipes</td><td>Length</td><td>Shallow Pipe: 4m, Deep Pipe:6m</td></tr>
<tr><td>Spacing</td><td>Shallow Pipe: 4m×4m, Deep Pipe: 4m×4m</td></tr>
<tr><td>Duration for Dewatering</td><td>First Cycle: 5 days
Second Cycle: 5 days</td></tr>
<tr><td colspan="2">PVD</td><td>1.1m spacing in square pattern; average depth of 25m</td></tr>
<tr><td colspan="2">Dynamic Compaction</td><td>1st Pass: 3~5 blows; Energy per blow: 1400~1800kN·m
2nd Pass: 3~5 blows; Energy per blow: 2000~2400kN·m, triangular pattern
Ironing Pass: 1~2 blows; Energy per blow: 800 kN·m</td></tr>
</table>

3.3.4 Construction Photos

Figure 3.3.b Original Site Condition

Figure 3.3.c PVD Installation

Figure 3.3.d Slurry Wall Construction

Figure 3.3.e HVDM Dewatering and Dynamic Compaction

Figure 3.3.f Excavation after Ground Improvement

3.3.5 Results

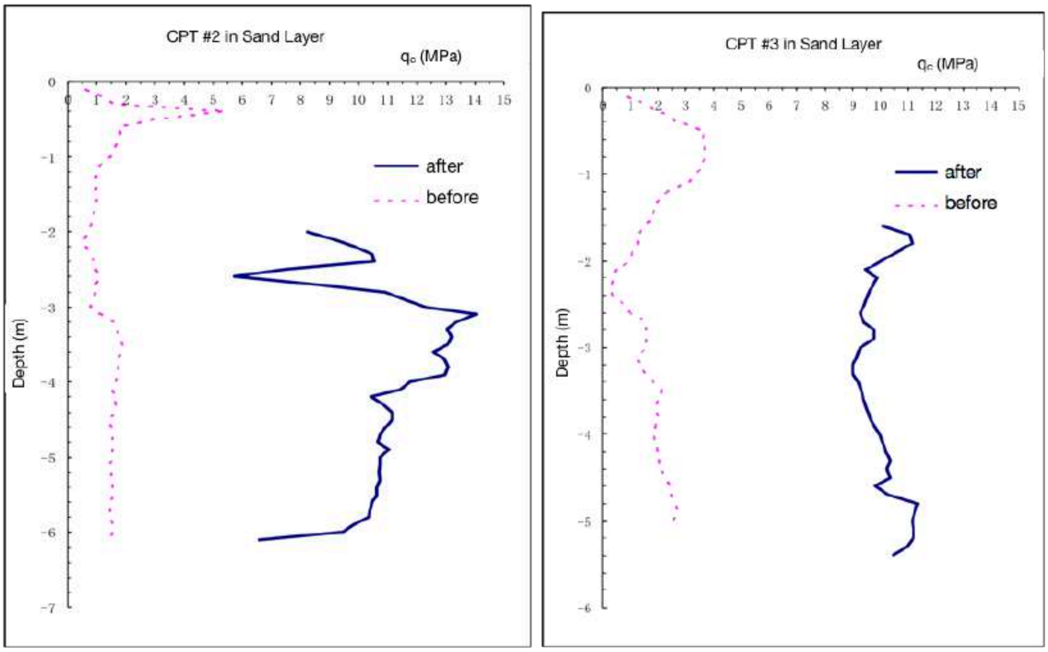


Figure 3.3.g Comparison of CPT Cone Resistance before and after Improvement in Sand Layer

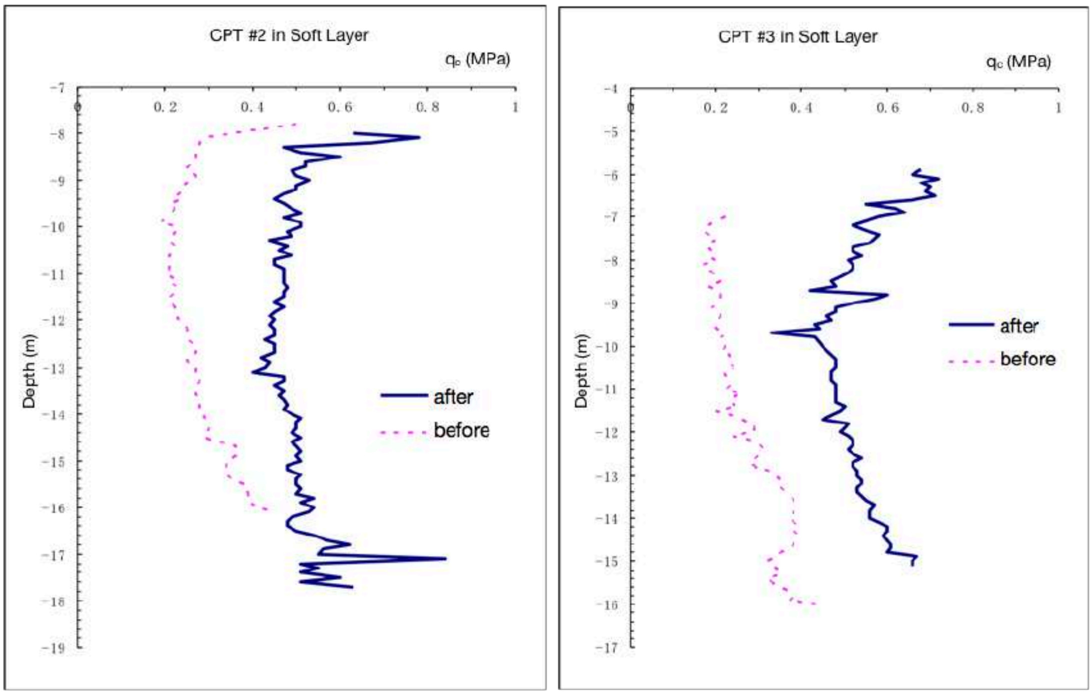


Figure 3.3.h Comparison of CPT Cone Resistance before and after Improvement in Soft Soil Layer

Table 3.3.b Settlement before and after Ground Improvement

	PVD+HVDM treated Areas				
	Area I	Area II	Area III	Area IV	Area V
Surface settlement (m)	0.95	1.14	1.03	0.69	0.66
Average settlement (m)	0.90				

3.4 SHANGHAI PORT, CHINA - PORT

3.4.1 Project Overview

- Project title: Ground Improvement for Road and Yard (Phases II~V) Project at Waigaoqiao, Shanghai Port
- Location: Waigaoqiao, Shanghai, China
- **Improvement Methods: HVDM + Vibroflotation**
- Project scale: 420 ha
- Construction time: 2000~2004
- Design requirements: Bearing capacity 150kPa; resilient modulus 40 MPa
- Geoharbour's role: Design and Construction

3.4.2 Geological Condition

The original site was farming field, with reclaimed fine sands of 2~2.5 m. Reclaimed Sands contained muds of less than 5%. Underlying layers are: Silty Clay, Sandy Silt, Silty Clay, Clayey Silty, and Silty Clay.

3.4.3 Construction Photos

Figure 3.4.a Vibroflotation Construction

Figure 3.4.b HVDM Construction

Figure 3.4.c Site Use after Ground Improvement

3.4.4 Test Results

Table 3.4.a Settlement after Ground Improvement

No.	Test	Results	
1	Plate Loading Test	Bearing Capacity ≥ 150kPa	
2	Resilient Modulus Test	1#: 60.23MPa	2#: 63.44MPa
3	N63.5	1#: 16~18	2#: 16~18
4	N10	1#~6#: > 50	

3.5 HUANGDAO PETROLEUM

3.5.1 Project Overview

- Project title: Ground Improvement for Huangdao Petrolem Project
- Location: Qingdao, Shandong, China
- **Improvement Methods: HVDM + Stone Columns**
- Project scale: 11.95 ha
- Construction time: 2006
- Design requirements: Bearing capacity ≥ 120kPa; Construction settlement: 30~35 cm; CPT results increased by at least 200% for Layer 2 and Layer 3
- Geoharbour's role: Design and Construction

3.5.2 Geological Condition

- LAYER 1: FILL, mainly silty clays, inhomogeneous, and roughly 2m thick
- LATER 2: SILTY CLAY, fluid and plastic, and 0.4~3.7 m thick
- LAYER 3: SILT, saturated, fluid and plastic, soft and weak, containing sandy silts, highly compressible, and 2.5~8.5 m thick
- LAYER 4 SILTY CLAY and SILTY SAND, saturated, loose, fluid and plastic, inhomogeneous, high void ratio and water content, highly compressible, and 0.5~7.3 m thick

3.5.3 Construction Photos

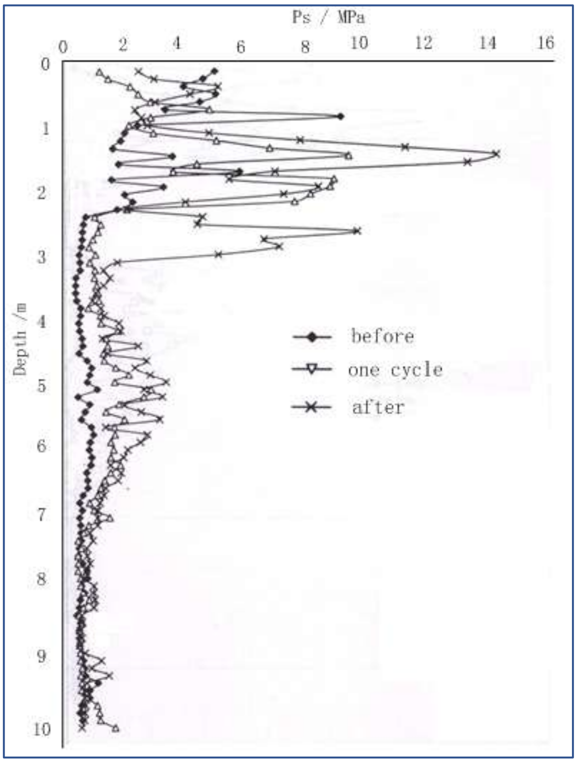
Figure 3.5.a Construction of Stone Columns

Figure 3.5.b Sand Cushion Construction

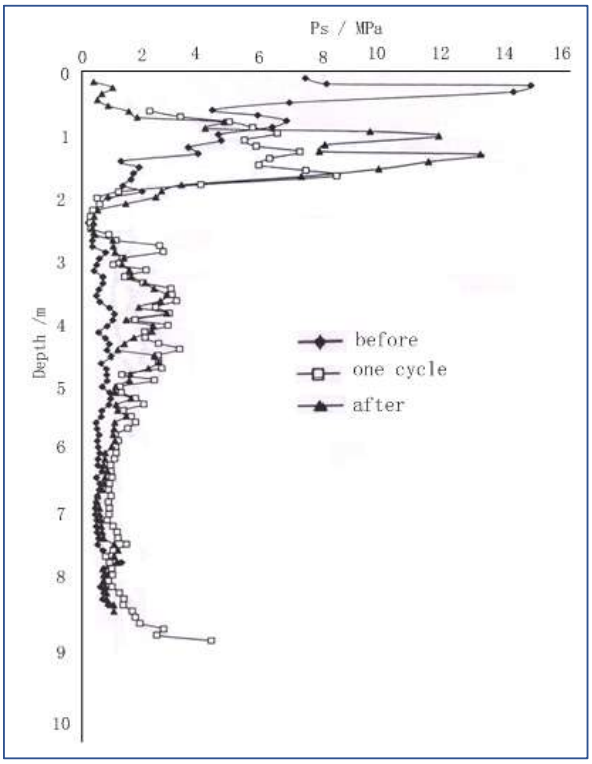
Figure 3.5.c Site Condition after Ground Improvement

3.5.4 Test Results

Bearing Capacity was increased from original 40~50 kPa to 120 kPa by HVDM, and further increased to 210 kPa by Stone Columns.



(a) #1 Oil tank



(b) #8 Oil tank

Figure 3.5.d CPT Cone Resistance Results before, during and after Ground Improvement

4 DYNAMIC COMPACTION AND DYNAMIC REPLACEMENT (DC&DR)

4.1 SOUTH TANK FARMS, SAUDI ARABIA

4.1.1 Project Overview

- Project planning: In South Tank Farm Jazan Refinery & Terminal Project, a total 7 Tanks were to be constructed with tank diameter 106m and 23.5m height. Dynamic Compaction and Dynamic Replacement (DC/DR) method were proposed for two tanks for soil improvement.
- Location: Jazan, Saudi Arabia
- Construction time: 2014
- Design requirements:
  - Bearing Capacity ≥ 250 kPa for tank foundation with 800mm width ring beam at 1m below Finished Grade Level
  - Maximum allowable differential settlement (centre to edge) should be no more than 0.003 R, "where: R=Radius of the Tank"
  - Maximum allowable tank edge settlement should be no more than 100mm
  - Maximum allowable differential settlement along the periphery of the tank should be 13mm per 10m peripheral length

4.1.2 Geological Condition

The top soil layer (especially in top 10m) consisted of loose to medium dense sands, silty sands or partial hard clays, with SPT value varying from 10 to 25. Under the action of large range and high load of tank, it may result in unacceptably high total and differential settlements.

4.1.3 Construction Sequence

- Pre-CPT, Pre-SPT test before soil improvement
- Arrange two trial areas with size 25m×25m for DC and DR, respectively
- Set up positions of DC/DR Point and Mark
- DC/DR Construction
- Post CPT Test and Zone Load Test to verify DC/DR result
- Final Report

Technical Parameters:

- Number of blows: 5
- Pounder weight: 18 ton
- Pounder diameter: 2.5 m
- Dropping height: 20 m
- Single blow Energy: 360 t*m

- Spacing: 4.5 m

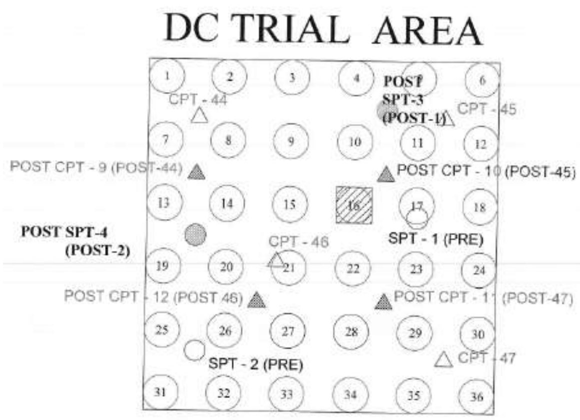


Figure 4.1.a Test Layout in DC Area

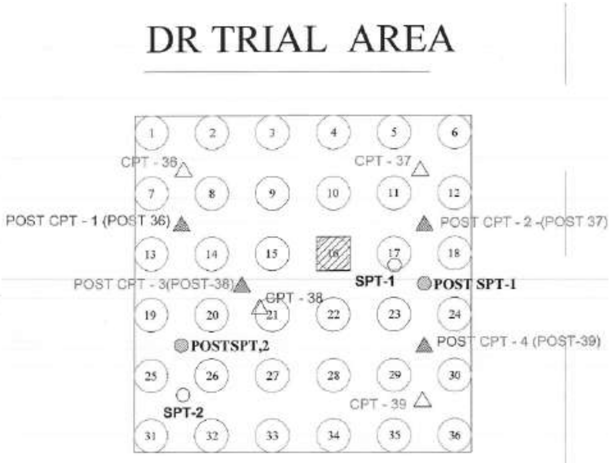


Figure 4.1.b Test Layout in DR Area

4.1.4 Construction Photos

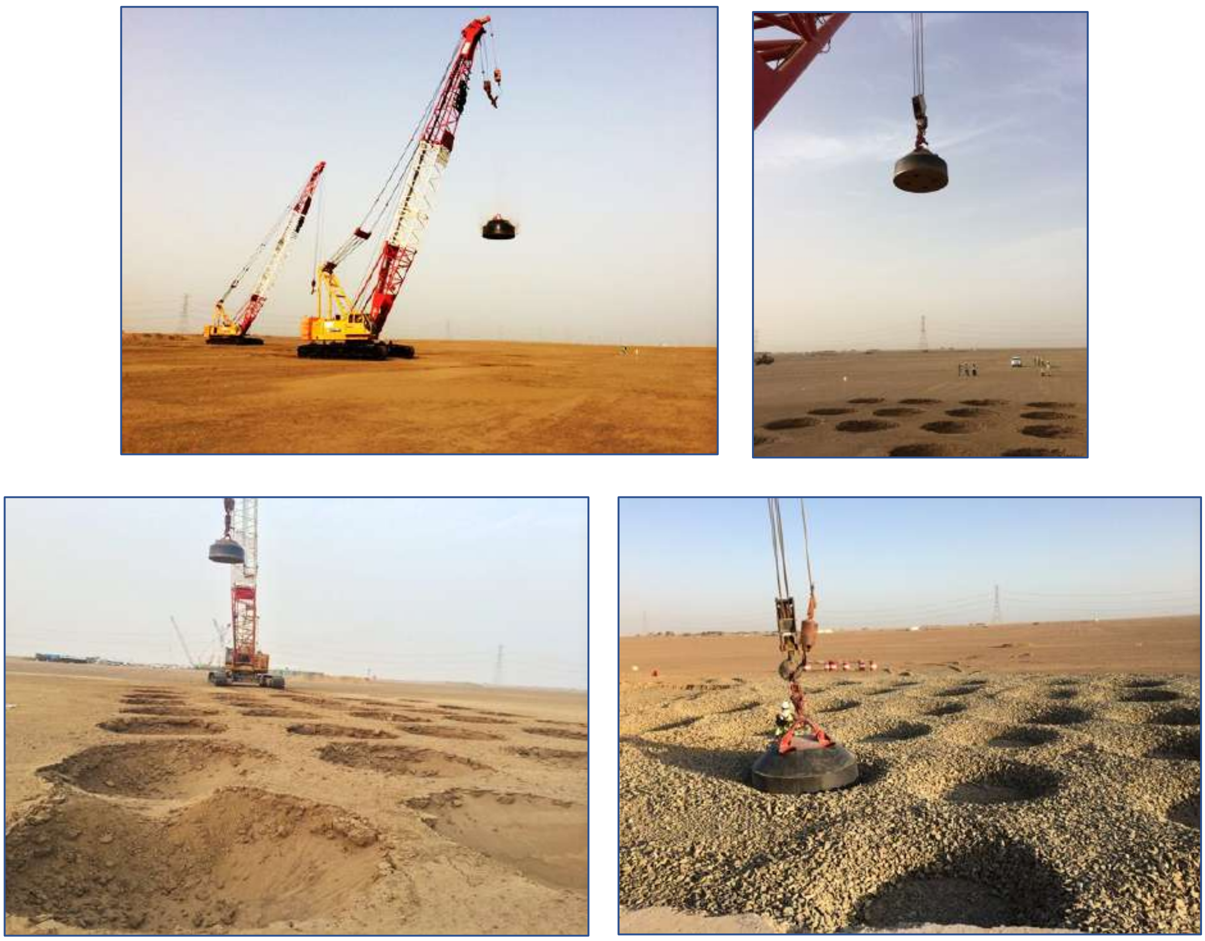


Figure 4.1.c Dynamic Compaction Construction

4.1.5 Test Results

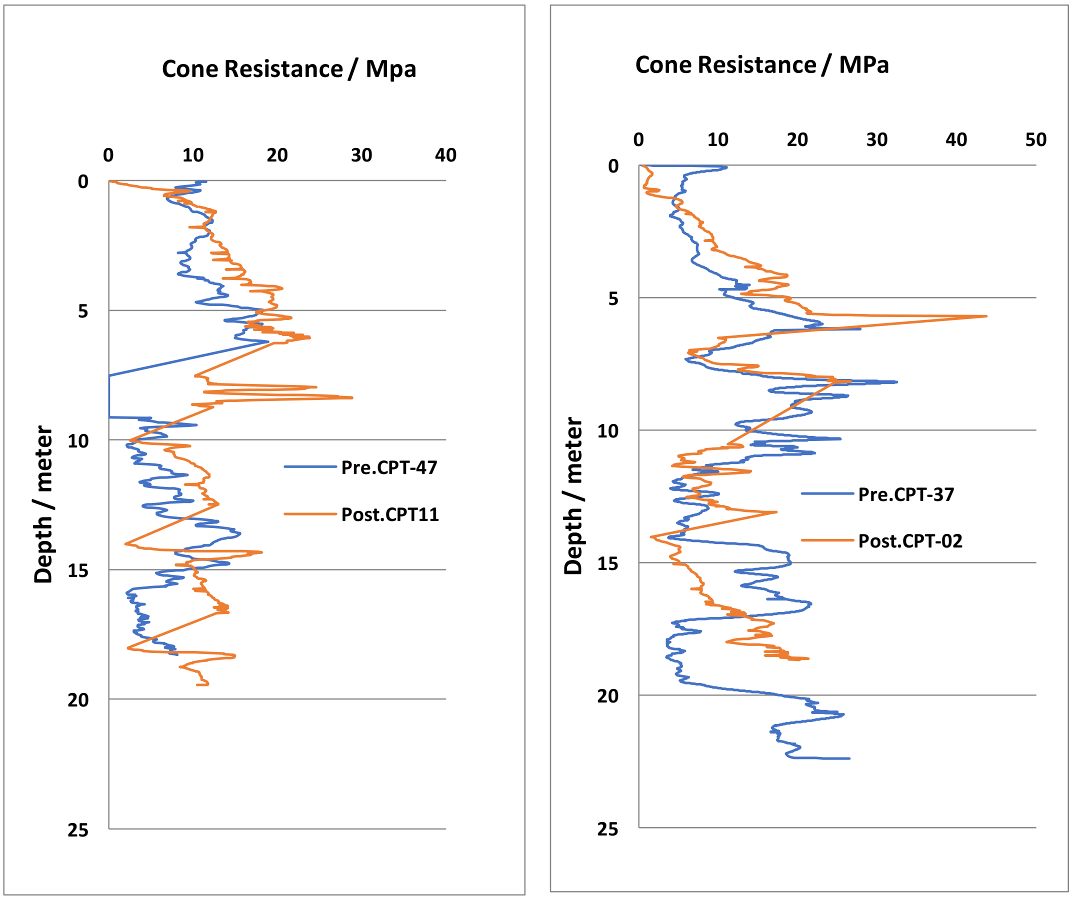
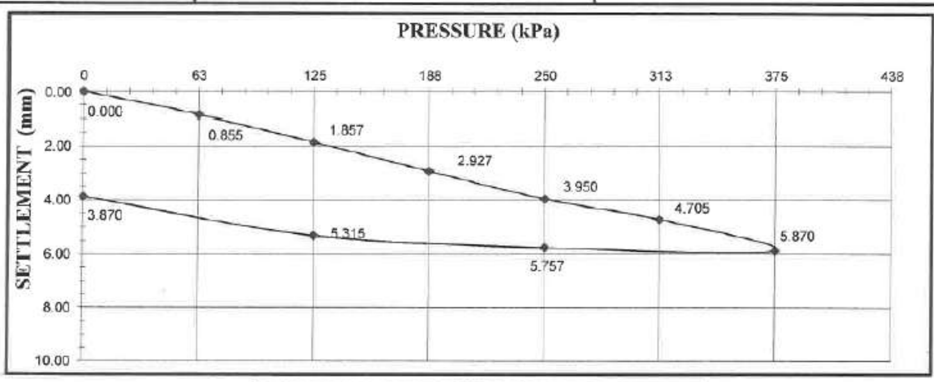


Figure 4.1.d Comparison of CPT Cone Resistance before and after Ground Improvement

% OF DESIGN PRESSURE	0%	25%	50%	75%	100%	125%	150%	100%	50%	0%
APPLIED PRESSURE (kPa)	0	62.5	125.00	187.50	250.00	312.50	375.00	250.00	125.00	0
SETTLE MENT (mm)	0.000	0.855	1.857	2.927	3.950	4.705	5.870	5.757	5.315	3.870

DESIGN PRESSURE = 250 kPa	TEST PRESSURE = 375 kPa	TEST FOOTING SIZE = 2.5 x 2.5 m

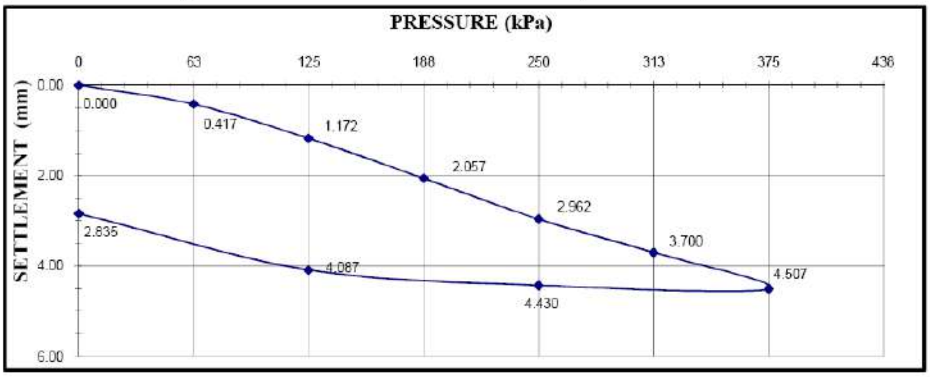


SETTLEMENT @ 100% OF DESIGN PRESSURE	= 3.950mm
SETTLEMENT @ 150% OF DESIGN PRESSURE	= 5.870 mm
SETTLEMENT ON COMPLETE UNLOADING	= 3.870 mm

Figure 4.1.e Load Test Result on DR Area

% OF DESIGN PRESSURE	0%	25%	50%	75%	100%	125%	150%	100%	50%	0%
APPLIED PRESSURE (kPa)	0	62.5	125.00	187.50	250.00	312.50	375.00	250.00	125.00	0
SETTLE MENT (mm)	0.000	0.417	1.172	2.057	2.962	3.700	4.507	4.430	4.087	2.835

DESIGN PRESSURE = 250 kPa	TEST PRESSURE = 375 kPa	TEST FOOTING SIZE = 2.5 x 2.5 m



SETTLEMENT @ 100% OF DESIGN PRESSURE = 2.962 mm
SETTLEMENT @ 150% OF DESIGN PRESSURE = 4.507 mm
SETTLEMENT ON COMPLETE UNLOADING = 2.835 mm

Figure 4.1.f Load Test Result on DC Area

5 DEEP SOIL MIXING

5.1 SARULLA POWER PLANT, TARUTUNG, NORTH SUMATRA, INDONESIA

5.1.1 Project Overview

- Project planning: Sarulla Geothermal Power Plant using geothermal as energy source.
- Location: near Tarutung in North Sumatera, Indonesia
- Construction time: 2016 -
- Design requirement: maximum allowable settlement: 25mm; maximum allowable differential settlement: 1/300.
- Ground Improvement demands: the surface soils were mostly tuff or tuffaceous silts. As a sediment material from volcanic eruption, tuff is highly cemented in natural condition but very dispersive when disturbed. Filling work of this material may cause a loss of strength when encountered with water. The power plant project required flat land which necessitated the filling work. Tuffaceous materials were used because they were handy to source. Solution to the loss of strength due to wetting is soil improvement using deep soil mixing method (DSM) or in other words deep cement mixing (DCM). Fig. 5.1.a gives the layout of this project.

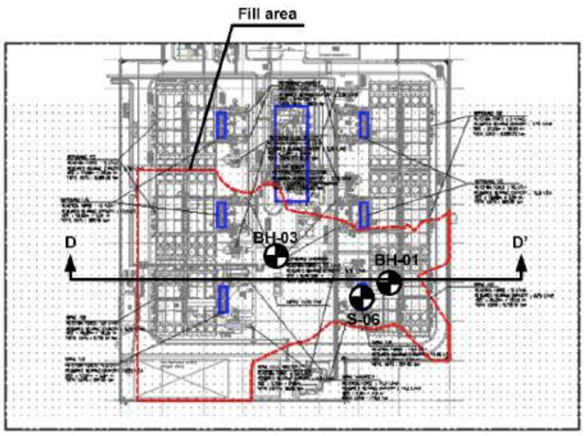


Figure 5.1.a Layout of the Sarulla Power Plant

5.1.2 Geological Condition

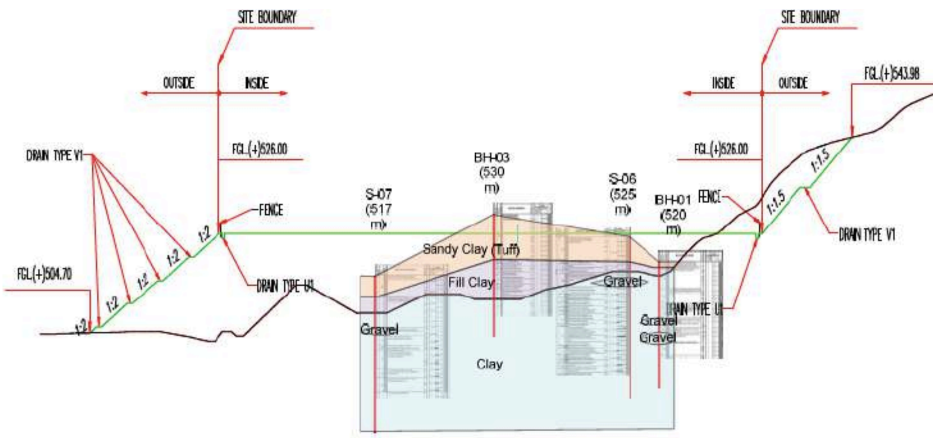


Figure 5.1.b Soil Stratification at Cross Section D-D'

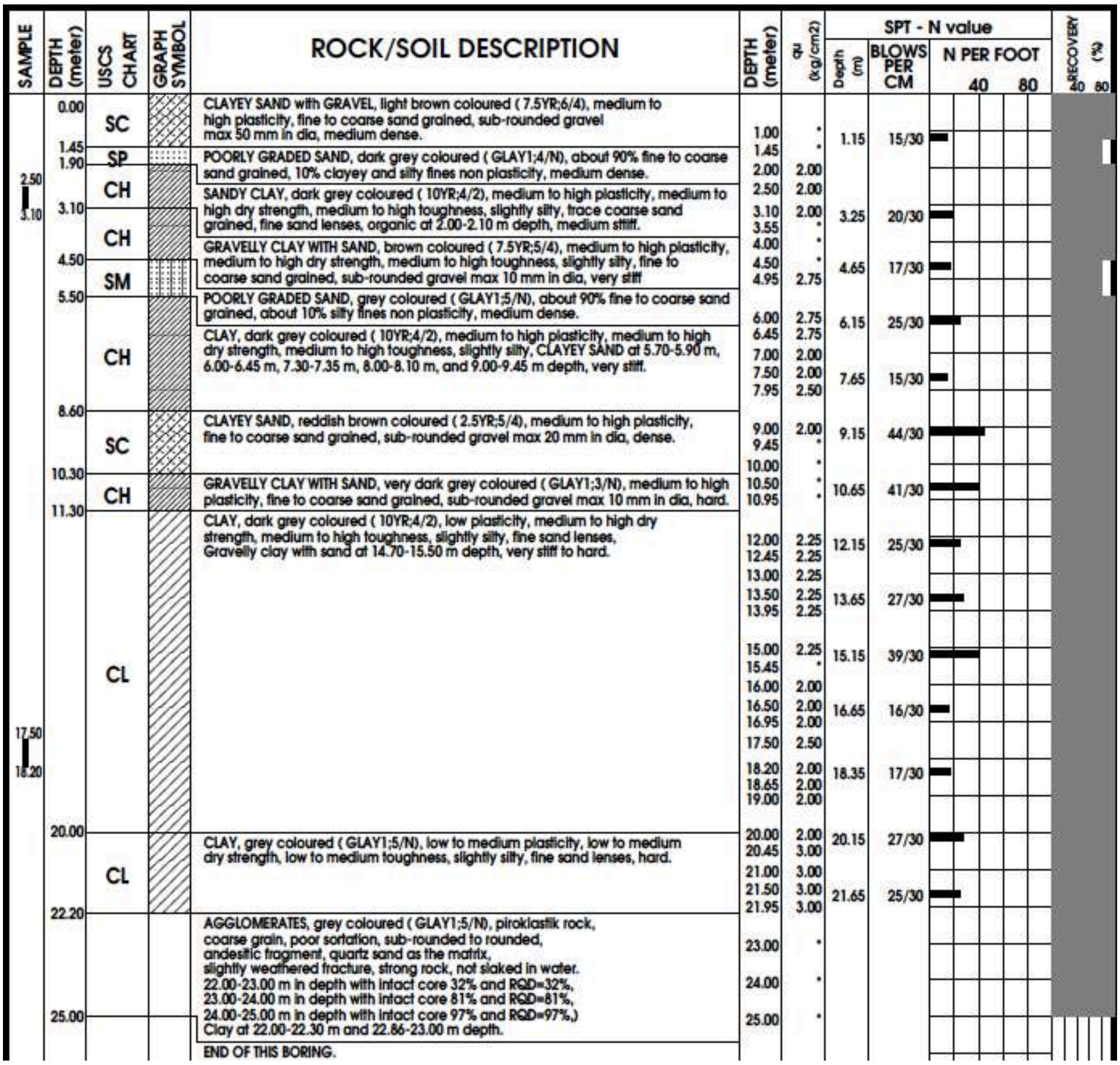


Figure 5.1.c Borehole log at S03

Figures 5.1.b and 5.1.c shows the soil stratification and borehole results respectively.

5.1.3 Cement Mixing

DCM laboratory test was conducted by PT. Soilens. The DCM sample were tested by unconfined compression test method with different cement ratio of 9%, 11%, 13%, 15%, and 17%. Curing period has been selected between 7 days, 14 days, and 28 days. Table 5.1.a shows the results.

Table 5.1.a DCM laboratory test results

Borhole	Depth of sample (m)	Cement Ratio (%)	Curing Time (days)	UCS, qu (kg/cm^2)	Modulus, E (kg/cm^2)	E/qu	Borhole	Depth of sample (m)	Cement Ratio (%)	Curing Time (days)	UCS, qu (kg/cm^2)	Modulus, E (kg/cm^2)	E/qu
BH-1	0.00 - 2.50	9	7	18.50	2000	108	BH-3	0.00 - 3.00	9	7	24.33	2200	90
			14	19.93	1875	94				14	29.68	2000	67
			28	21.25	1875	88				28	30.32	1500	49
		11	7	26.35	3600	137			11	7	33.94	2500	74
			14	32.40	2000	62				14	34.15	1875	55
			28	36.26	1875	52				28	38.99	2500	64
		13	7	29.00	5000	172			13	7	40.67	3125	77
			14	32.28	2750	85				14	42.18	2500	59
			28	41.13	1800	44				28	43.15	3125	72
		15	7	32.25	2500	78			15	7	44.19	2500	57
			14	35.33	2000	57				14	47.29	2750	58
			28	43.64	2400	55				28	52.33	3000	57
		17	7	40.39	3000	74			17	7	45.08	3000	67
			14	44.15	3000	68				14	48.78	2500	51
			28	45.97	2000	44				28	53.99	3250	60
	2.50 - 5.00	9	7	15.37	2000	130		3.00 - 6.00	9	7	20.83	3000	144
			14	17.38	1375	79				14	22.47	2500	111
			28	21.76	1500	69				28	26.51	2000	75
		11	7	28.38	4250	150			11	7	28.70	2250	78
			14	32.40	2500	77				14	32.97	2250	68
			28	38.03	3000	79				28	35.00	3000	86
		13	7	33.49	4000	119			13	7	31.29	1400	45
			14	39.64	3000	76				14	35.73	1500	42
			28	47.43	3000	63				28	46.25	2250	49
		15	7	37.57	3500	93			15	7	33.07	4250	129
			14	45.32	2750	61				14	40.98	2200	54
			28	52.30	3000	57				28	46.58	3250	70
		17	7	40.17	5500	137			17	7	39.02	2750	70
			14	47.94	3250	68				14	46.57	2000	43
			28	54.68	3500	64				28	47.38	2200	46
	5.00 - 7.50	9	7	22.13	2000	90		6.00 - 9.00	9	7	20.69	2250	109
			14	28.52	2250	79				14	27.60	2250	82
			28	30.25	2750	91				28	31.63	3000	95
		11	7	28.98	3000	104			11	7	24.69	3000	122
			14	32.28	2500	77				14	30.63	2000	65
			28	36.25	2500	69				28	33.09	2000	60
		13	7	34.51	3500	101			13	7	33.00	2375	72
			14	36.75	2250	61				14	36.68	2750	75
			28	38.37	3000	78				28	40.91	2500	61
		15	7	35.44	3000	85			15	7	35.07	2500	71
			14	39.00	1875	48				14	38.97	2250	58
			28	47.38	2500	53				28	44.29	2750	62
		17	7	37.64	6000	159			17	7	37.74	2500	66
			14	42.05	2250	54				14	42.52	2000	47
			28	48.78	2500	51				28	53.15	2400	45

5.1.4 Numerical Analysis

Finite element method using Midas GTS NX program with 3D model was used to calculate the capacity of column.

Analysis was divided into two steps as follow:

- Unit Model: to estimate the DCM spacing before applied into full model.
- Full Model: to estimate the settlement for the whole area.

The DCM spacing being analysed varied from 0.8 m, 1.0 m, 1.2 m, to 1.4 m. The DCM diameter was 0.7 m, while the cushion thickness was 0.5 m, and concrete raft thickness was 0.7 m, as shown in Fig. 5.1.d. The cushion was designed to be made by soil mixing with 9% cement and compaction. Figures 5.1.e and 5.1.f show the unit model and full model respectively.

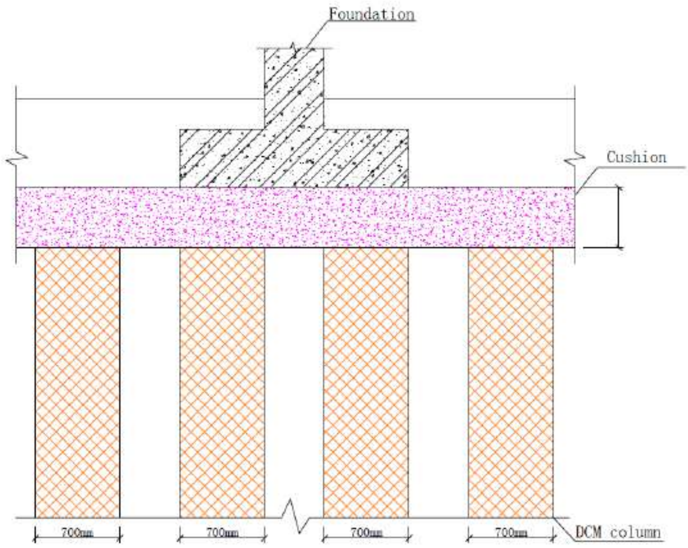


Figure 5.1.d Dimensions of DCM, cushion and concrete raft

(a)

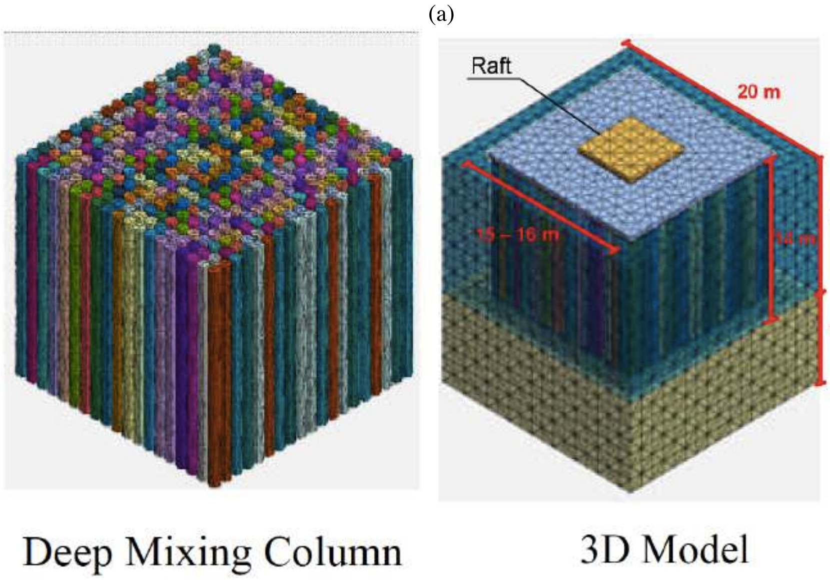


Figure 5.1.e Unit model of the FEM analysis

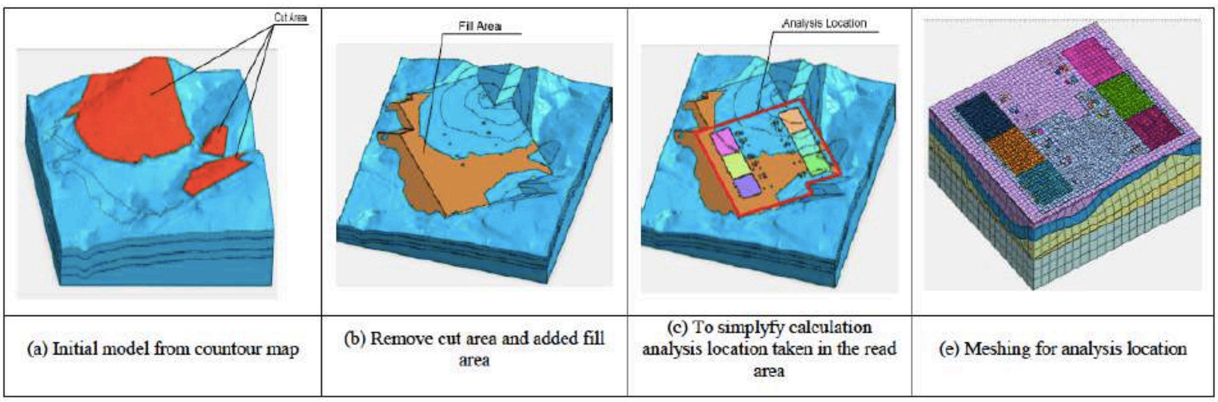


Figure 5.1.f Full model of the FEM analysis

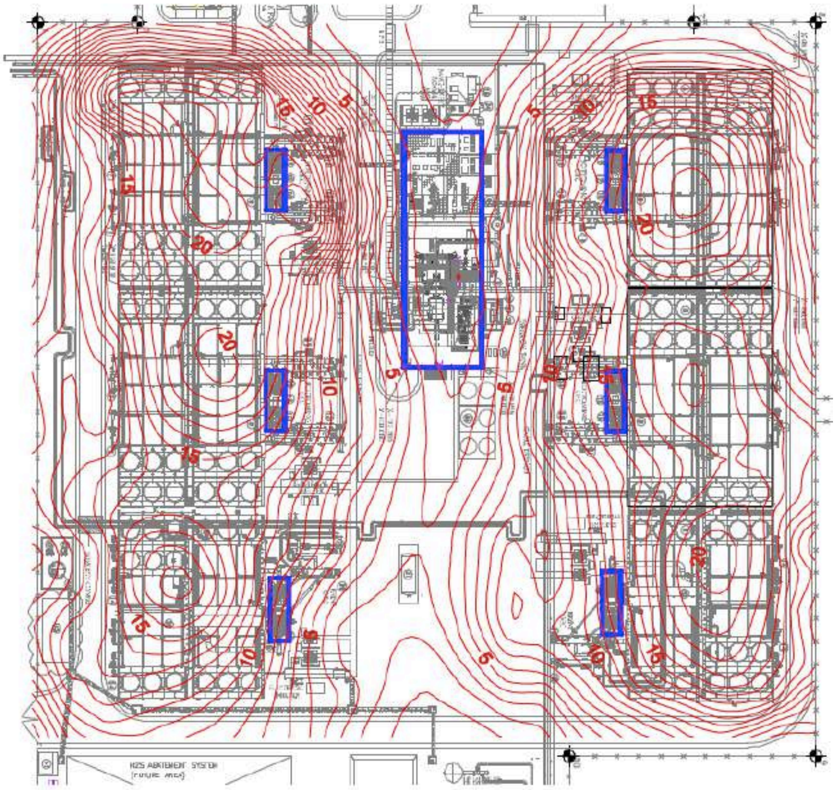


Figure 5.1.g Settlement Contour of the Full model

From the settlement results shown in Fig. 5.1.g, it is observed the maximum settlement was less than 25 mm which met the design requirement. Figure 5.1.f shows the cross section of the largest differential settlement, and it is observed the maximum differential settlement is 1/858, which is less than design requirement 1/300.

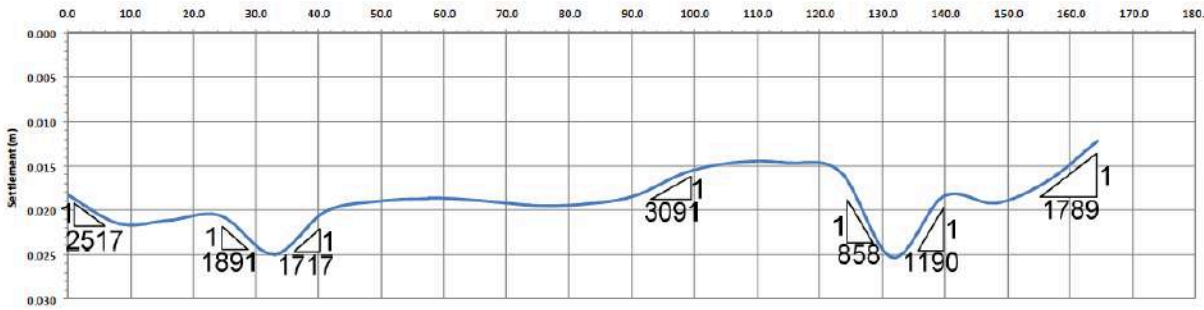
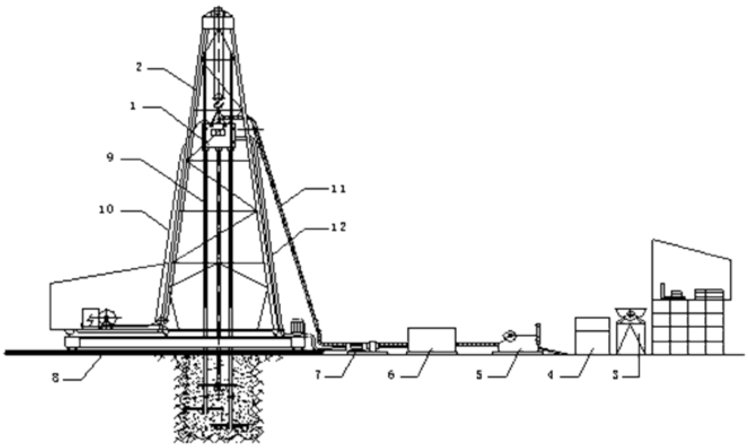


Figure 5.1.h Differential Settlement at Cross Section

5.1.5 Construction Sequence

Figures 5.1.i and 5.1.j schematically show the DCM equipment and construction sequences, respectively.



1- host ; 2 - rack ; 3- mortar mixing machine ; 4- hopper ; 5- mortar pump ; 6- storage tank ;7- cooling water pump ; 8- rail ; 9- guide tube ; 10- cable ; 11- lose slurry pipe ; 12- pipes

Figure 5.1.i DCM equipment

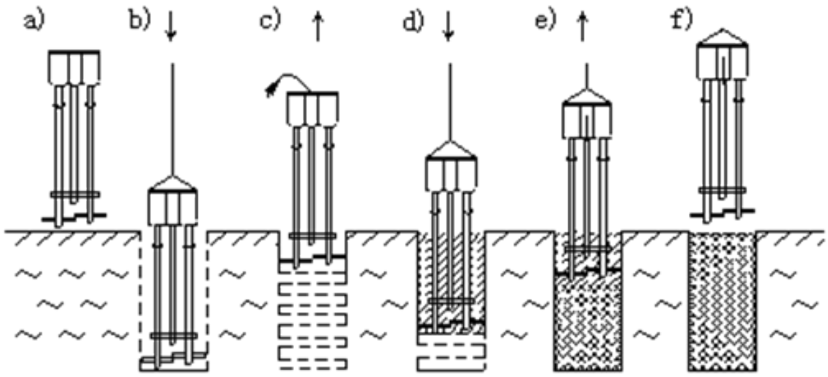


Figure 5.1.j DCM Construction Sequences

5.1.6 Construction Photos

Figure 5.1.k DCM Construction Photos

5.1.7 Test Results

Figure 5.1.l shows the samples taken after the installation of the DCM and Table 5.1.b gives the laboratory test results of these samples.

Figure 5.1.l Sampling after DCM Construction

Table 5.1.b Results of the Laboratory Tests after DCM Construction

LABORATORY TEST TABLE

PT. SOILENS

CORING FOR DCM AT SARULLA, NORTH SUMATERA

PT. GEOTEKINDO

Bor Hole No	Depth in meter	Specific Gravity	Density		Water Content	Atterberg limits			Liquidity Index	Void Ratio	Porosity	Degree of Saturation	Passing No. 200 sieve % finer by weight	Unconfined Compression	
			Wet	Dry		Liquid Limit	Plastic Limit	Plasticity Index						q_u	Strain
		G_s	γ_m	γ_d	w_n	LL	PL	PI	LI	e	n	Sr			
			t/m³	t/m³	%	%	%	%			%	%		kg/cm²	%
BH-1	1.50 - 1.90	2.44	1.62	1.41	14.9	Non Plastic				0.73	42	50	32	49.15	0.80
	4.50 - 4.90	2.54	1.56	1.24	26.1	Non Plastic				1.05	51	63	34	40.22	1.00
BH-2	1.50 - 1.90	2.67	1.54	1.28	20.7	Non Plastic				1.09	52	51	32	29.04	1.40
	4.50 - 5.00	2.59	1.52	1.12	35.7	Non Plastic				1.31	57	70	34	37.20	1.00
	7.50 - 7.90	2.64	1.37	0.94	45.4	Non Plastic				1.81	64	66	33	17.63	1.40
	10.50 - 11.00	2.61	1.43	1.06	34.5	Non Plastic				1.46	59	62	36	18.67	1.20
	13.50 - 14.00	2.63	1.51	1.09	38.1	Non Plastic				1.41	59	71	33	19.22	1.30
	Minimum =	2.44	1.37	0.94	14.9	None Plastic				0.73	42	50	32	17.63	0.80
	Maximum =	2.67	1.62	1.41	45.4	None Plastic				1.81	64	71	36	49.15	1.40
	Average =	2.59	1.51	1.16	30.8	None Plastic				1.27	55	62	33	30.16	1.16

Note : *Test specimens can not be formed or not enough - No Test

5.2 SLURRY WALL, CHANGI AIRPORT, SINGAPORE

5.2.1 Project Overview

- Project planning: Slurry wall using DSM method for vacuum consolidation project at Terminal 5, Changi Airport, Singapore.
- Location: Singapore
- Construction time: 2014
- Design requirements:
  - The width of slurry wall greater than 1000mm
  - The bottom of the slurry wall is 1 m lower than the bottom of the sand layer
  - The permeability of slurry wall should be less than $1*10^{-7}$m/s.

5.2.2 Geological Condition

Figures 5.2.a and 5.2.b show the soil profile and CPT results, which indicated that there was a very thick (about 10 m) sand layer crust at the group surface. A deep soil mixing work was required for a deep impermeable slurry wall because the shallow slurry trench cannot reach to the depth of the clay layer.

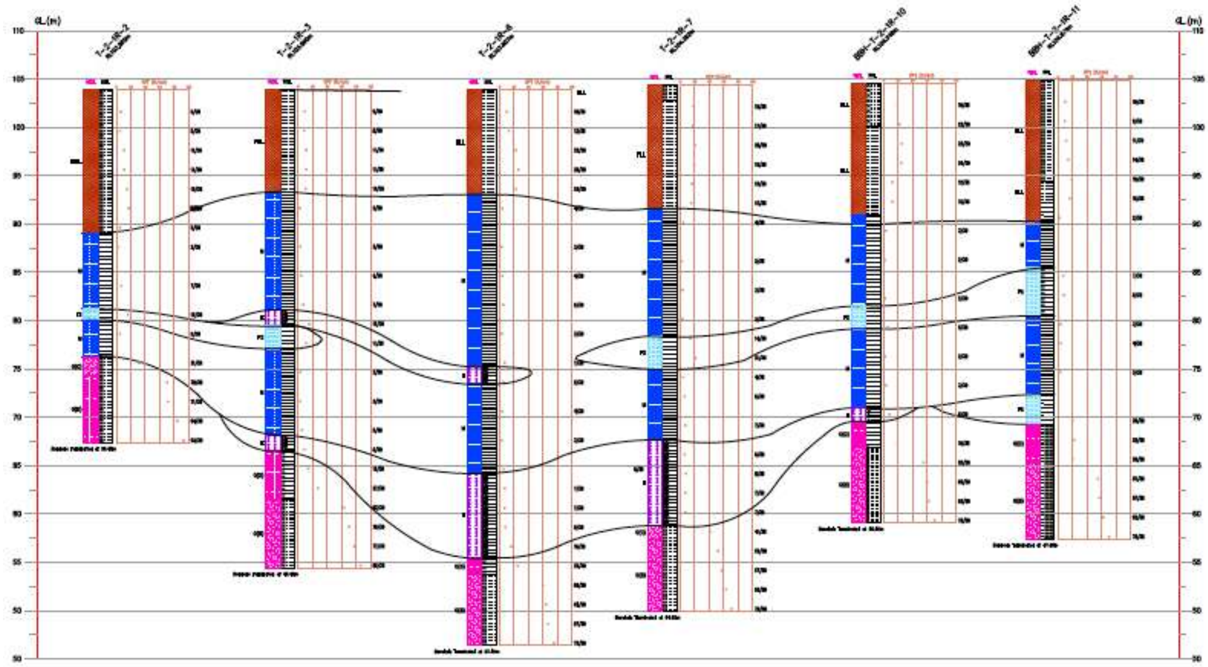


Figure 5.2.a Soil Profile at a Cross Section

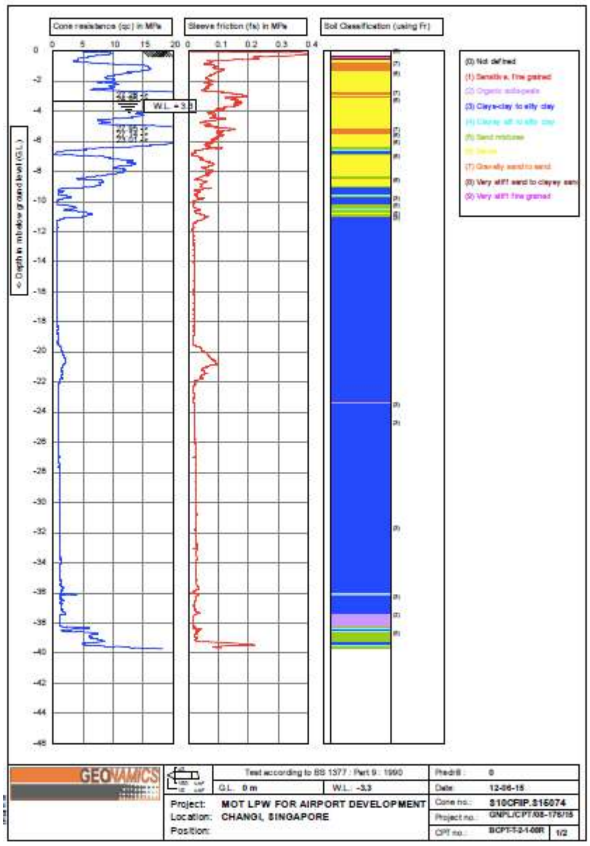


Figure 5.2.b CPT results

5.2.3 Slurry wall design

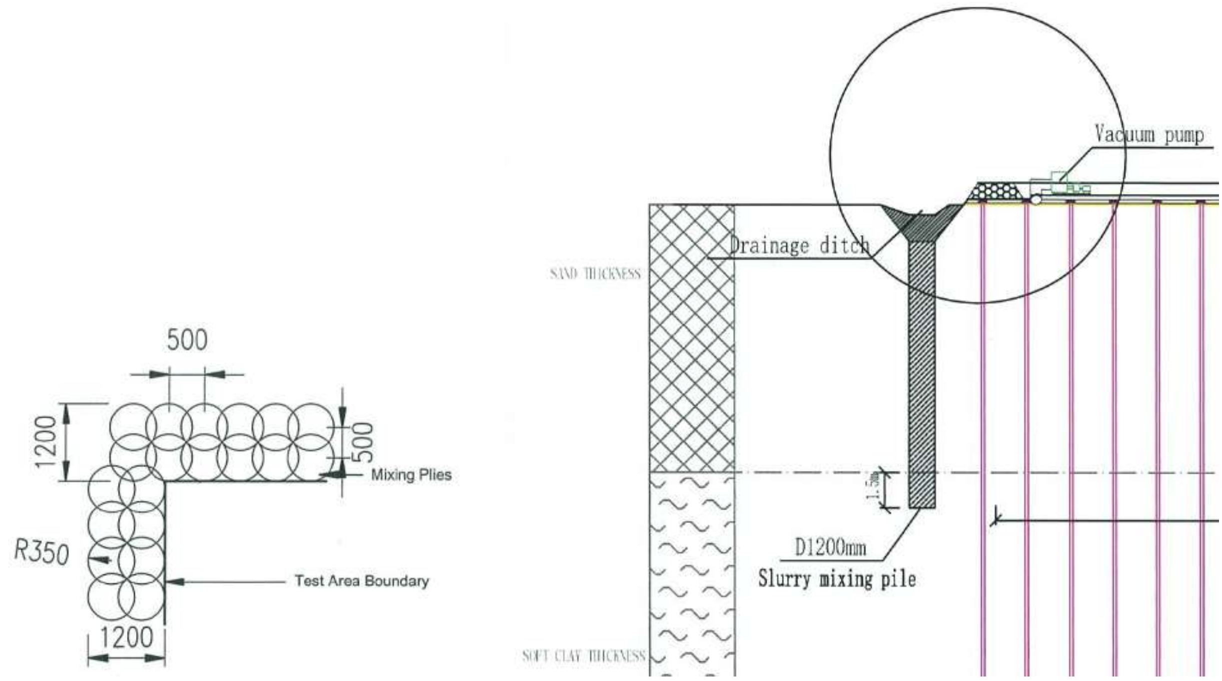


Figure 5.2.c Design of Deep Soil Mixing Slurry Wall

5.2.4 Construction Photos

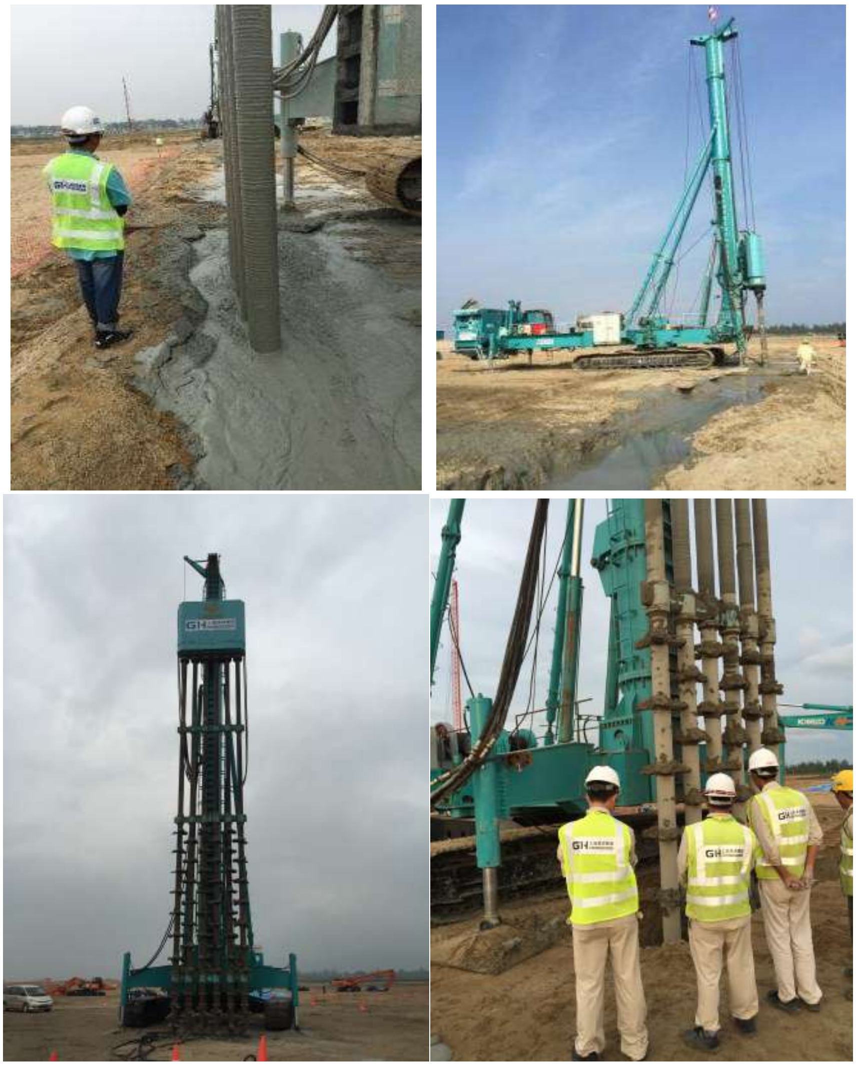


Figure 5.2.d Construction Photos of Slurry Wall

5.3 YANGON INNO CITY DEVELOPMENT PROJECT

5.3.1 Project Overview

- Project planning: Soil Cement Wall for Yangon Inno City Development Project
- Location: South Okkalapa Township, Yangon, Myanmar
- Construction time: July 2017 -
- Site Area: 3 ha
- Scope of work:
  - Soil Cement Wall
  - Method: Mechanical mixing method with wet mixing (slurry type)
  - Cements mixed with existing soils, and H beams inserted
  - Extension length: 750 m
  - Hole quantity: 751
  - Depth: 11.5~18.6 m
  - Total hole length: 13.436 m
- Design requirements:
  - The mixture ratio: about 20%
  - Slurry unit weight: about 1.3~1.4 g/cm^3.
  - Permeability coefficient of soil cement wall: less than 1×10^{-6} cm/s.
  - The Column Diameter: D 1300mm, CTC 1000 mm
  - The Cross Overlap: 300mm
  - The soil cement wall width: 1300mm
  - The row numbers: 1
  - Water and cement mixing ratio: 1:1

5.3.2 Soil Cement Wall Design

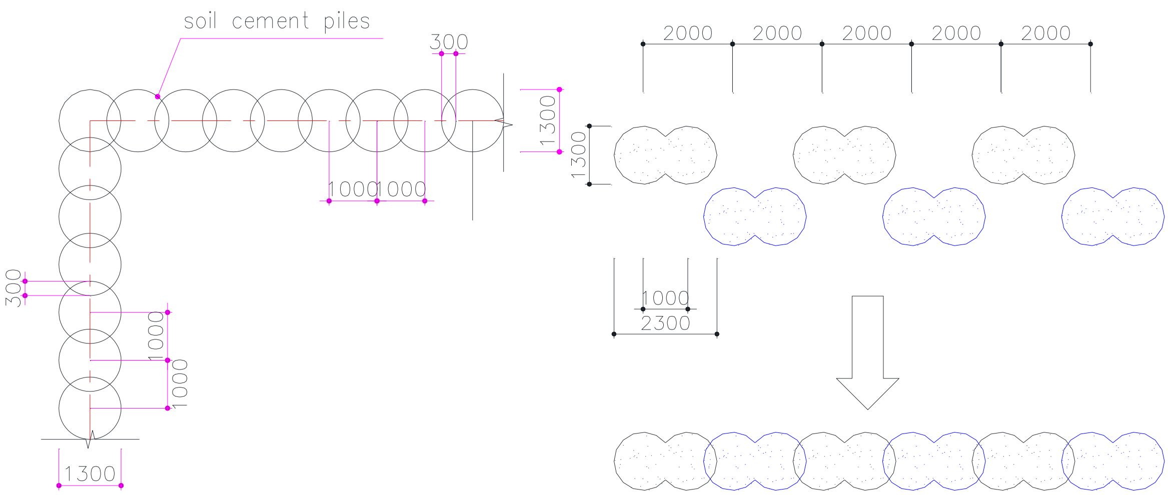


Figure 5.3.a Design of Soil Cement Wall

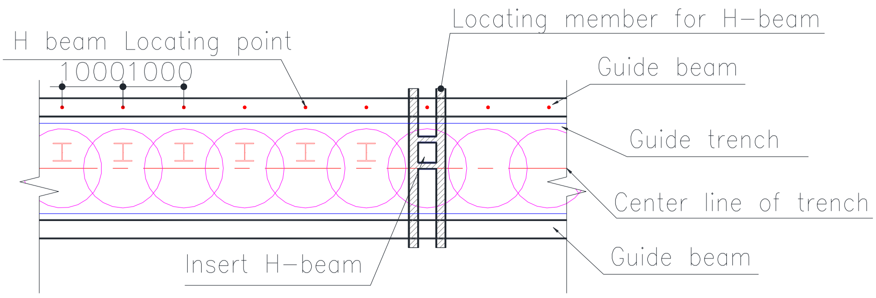


Figure 5.3.b Design of Inserting the H-Beams

5.3.3 Construction Sequences

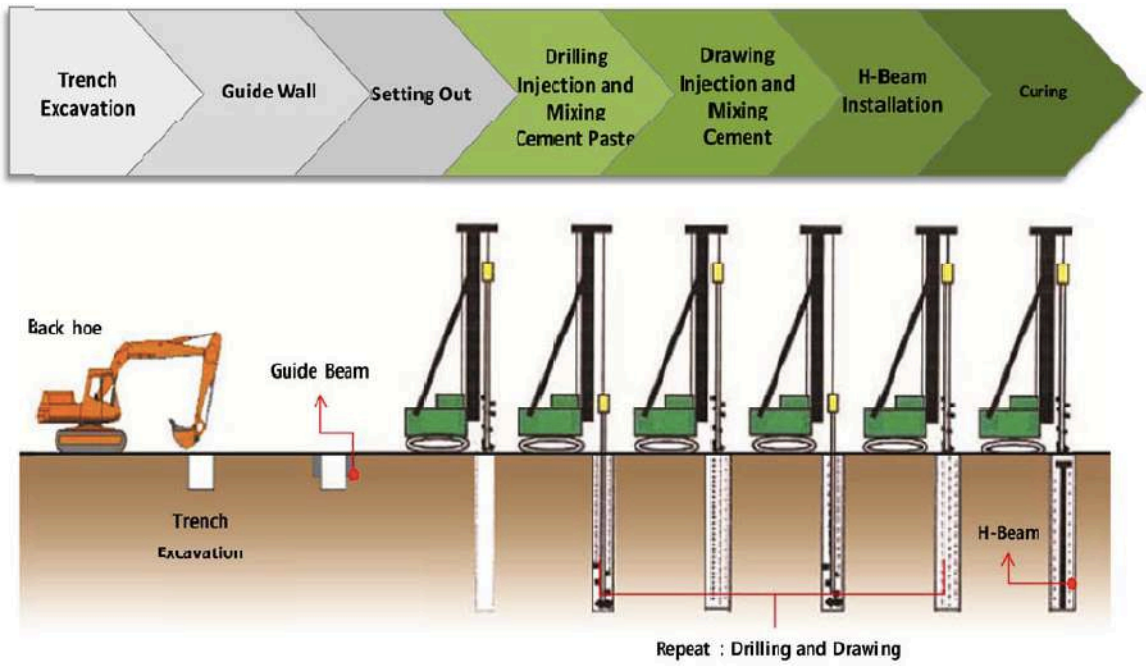


Figure 5.3.c Construction of H-beam reinforced Soil Cement Wall

5.3.4 Equipment

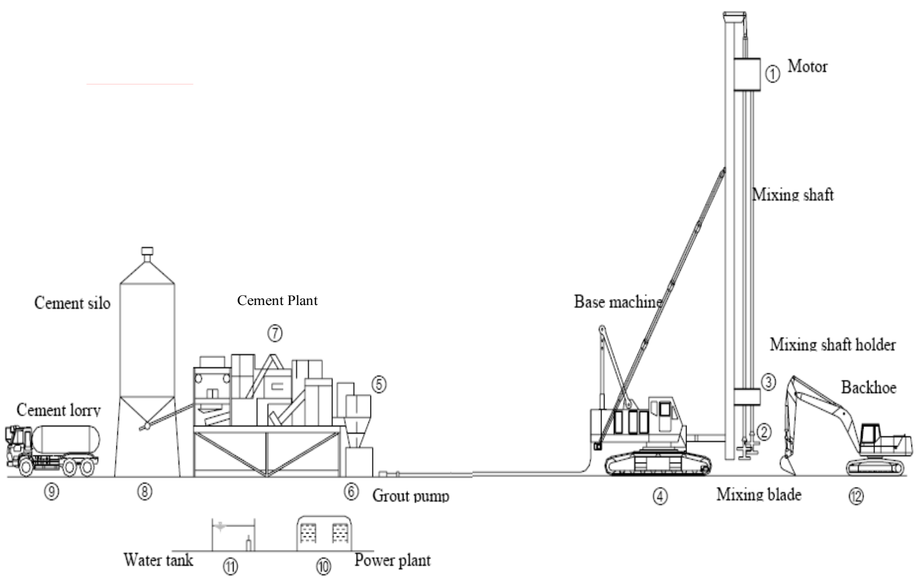


Figure 5.3.d Soil Cement Wall Equipment System

Figure 5.3.e Soil Cement Wall Rigs

5.3.5 Construction Photos

Photos to be provided as construction proceeds.

6 STONE COLUMNS

6.1 PROPOSED SORTING POST OFFICE, BAHRAIN

6.1.1 Project Overview

- Project: Proposed Sorting Post Office
- Location: Hidd Industrial Area, Kingdom of Bahrain
- Construction time: 2016
- Client: Ministry of Transportation, Bahrain
- Main Contractor: Aseeri Construction S.P.C
- Method: Vibro-replacement/stone column
- Design requirements:
    - Bearing Capacity ≥ 150 kPa for strip foundation, and safety factor is 3.0
    - Maximum allowable settlement should be no more than 25mm under design load 150 kPa

6.1.2 Typical Design

Typical profile of stone columns is shown in Fig. 6.1.a, which also indicates the soil profile comprises of: (1) Loose, fine to coarse sand; (2) Medium dense to loose, fine to coarse sand; (3) Sandy silt of low plasticity, very soft; (4) Medium dense, fine to coarse sand; and (4) Sandy silt with intermediate plasticity. Layout of all columns is given in Fig. 6.1.b.

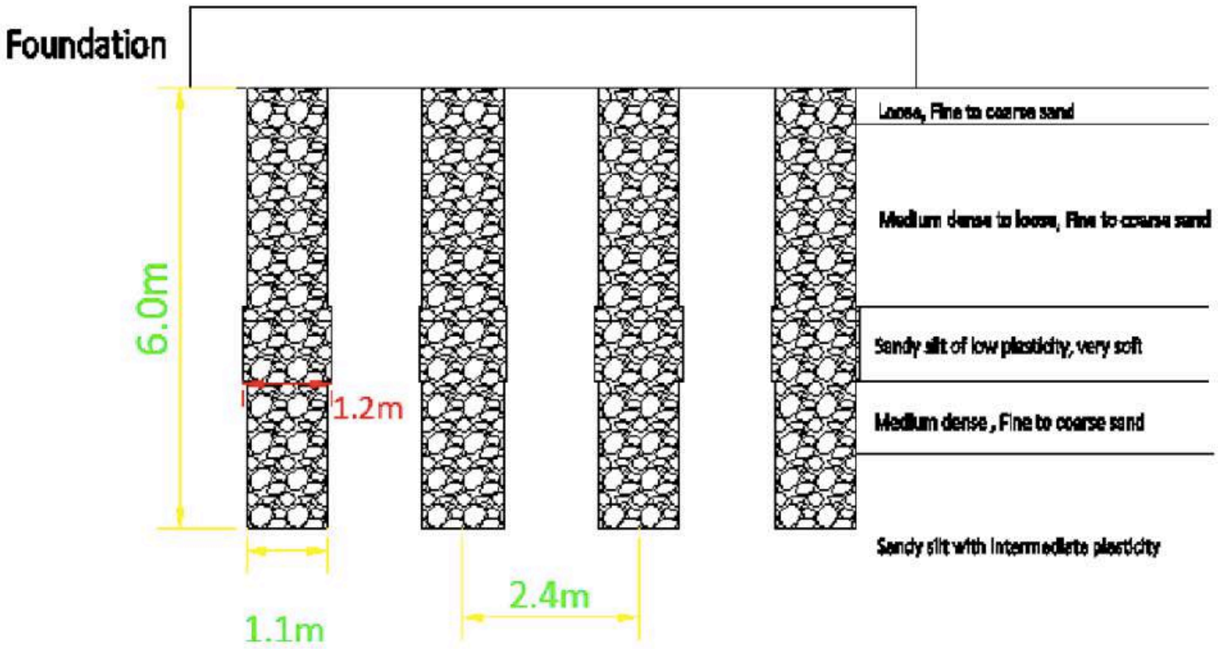


Figure 6.1.a Typical Stone Column Profile

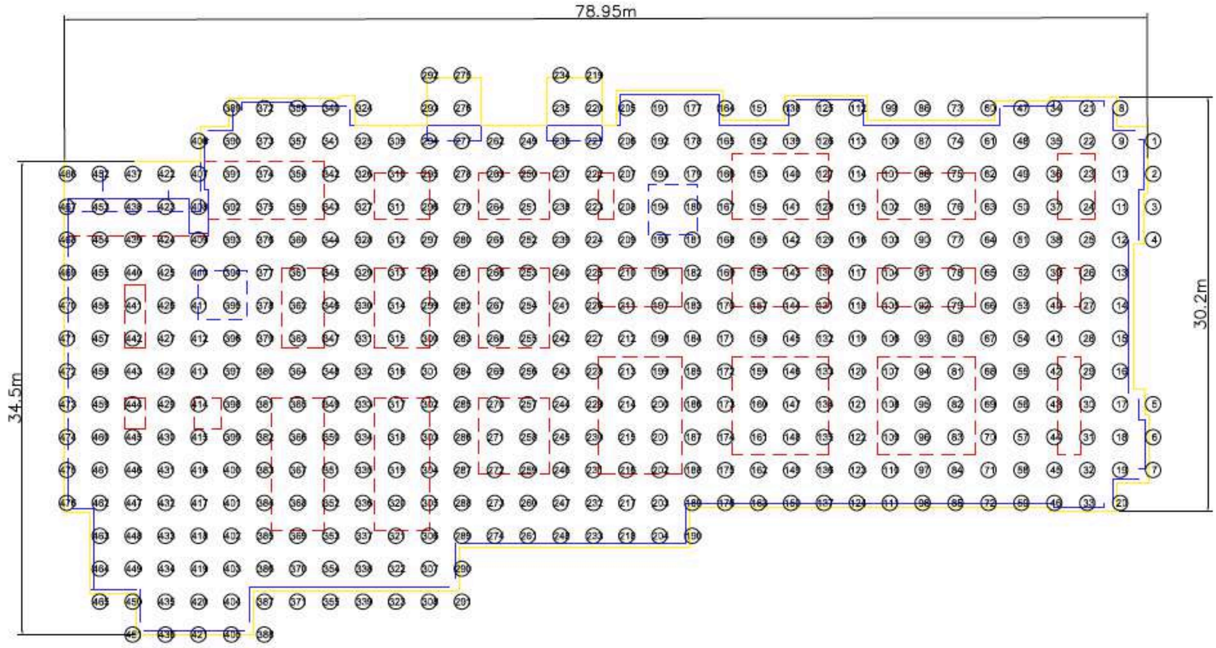


Figure 6.1.b Layout of Stone Columns

6.1.3 Construction Photos

(a) **(b)**

Figure 6.1.c Vibro-replacement work in Bahrain: (a) Vibro, (b) Stone column

6.1.4 Test Results

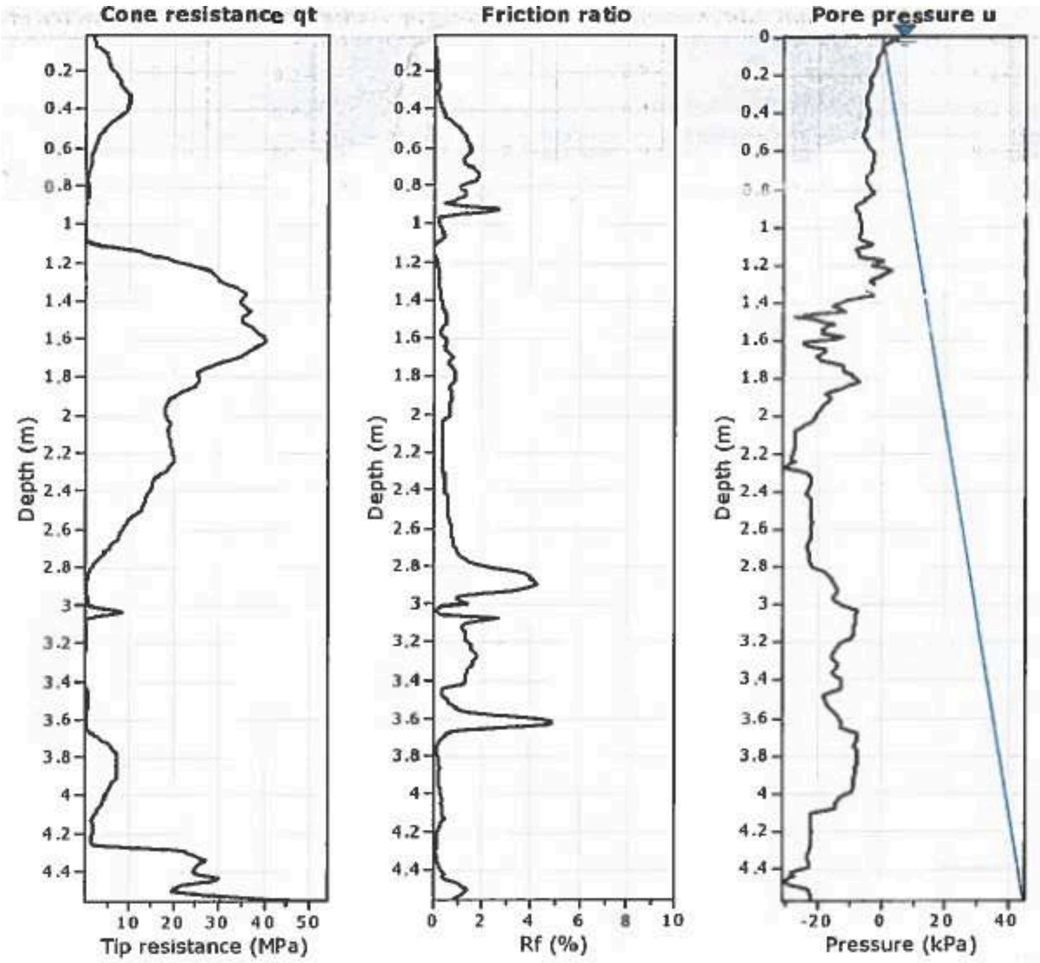


Figure 6.1.d CPT Test Results after Treatment

6.2 HOTEL & SERVICE APARTMENT, DUBAI, UAE

6.2.1 Project Overview

- Project: Hotel & Service Apartment
- Location: Al Barsha 1, Dubai, UAE
- Construction time: 2016
- Client: Deyaar Development
- Consultant: U+A Architects
- Main Contractor: Universal Piling Foundation LLC
- Method: Vibro-replacement/stone column
- Design requirements:
  - Bearing Capacity ≥ 220 kPa for raft foundation, and safety factor is 3.0.
  - Maximum allowable settlement should be no more than 50 mm under design load 220 kPa

6.2.2 Geological Conditions

The backfilled soils above rock layer was compressible layer. Average depth of rock layer is 9 m, and the final average excavation level was 2.1 m. Therefore, the compressible layer thickness was considered as 6.9 m. Below the compressible layer, there underlie the sandstone and siltstone layers. The CPT test results for the top soils are shown in Fig. 6.2.a.

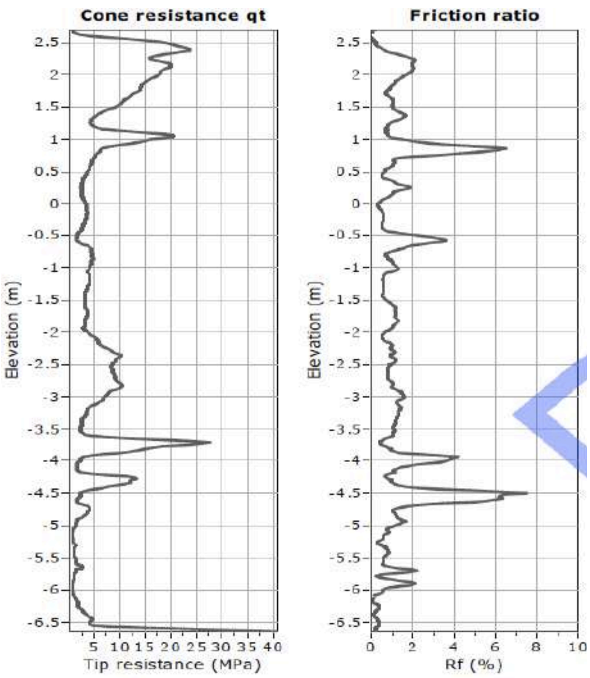


Figure 6.2.a Pre-treatment CPT test results

6.2.3 Typical Design

- Stone column length: 6.9 m
- Stone diameter: 0.9 m
- E_s of soils: 18 MPa
- Grid spacing in rectangular pattern: 2.4 m
- Footing size: 70.3 m by 89.9 m

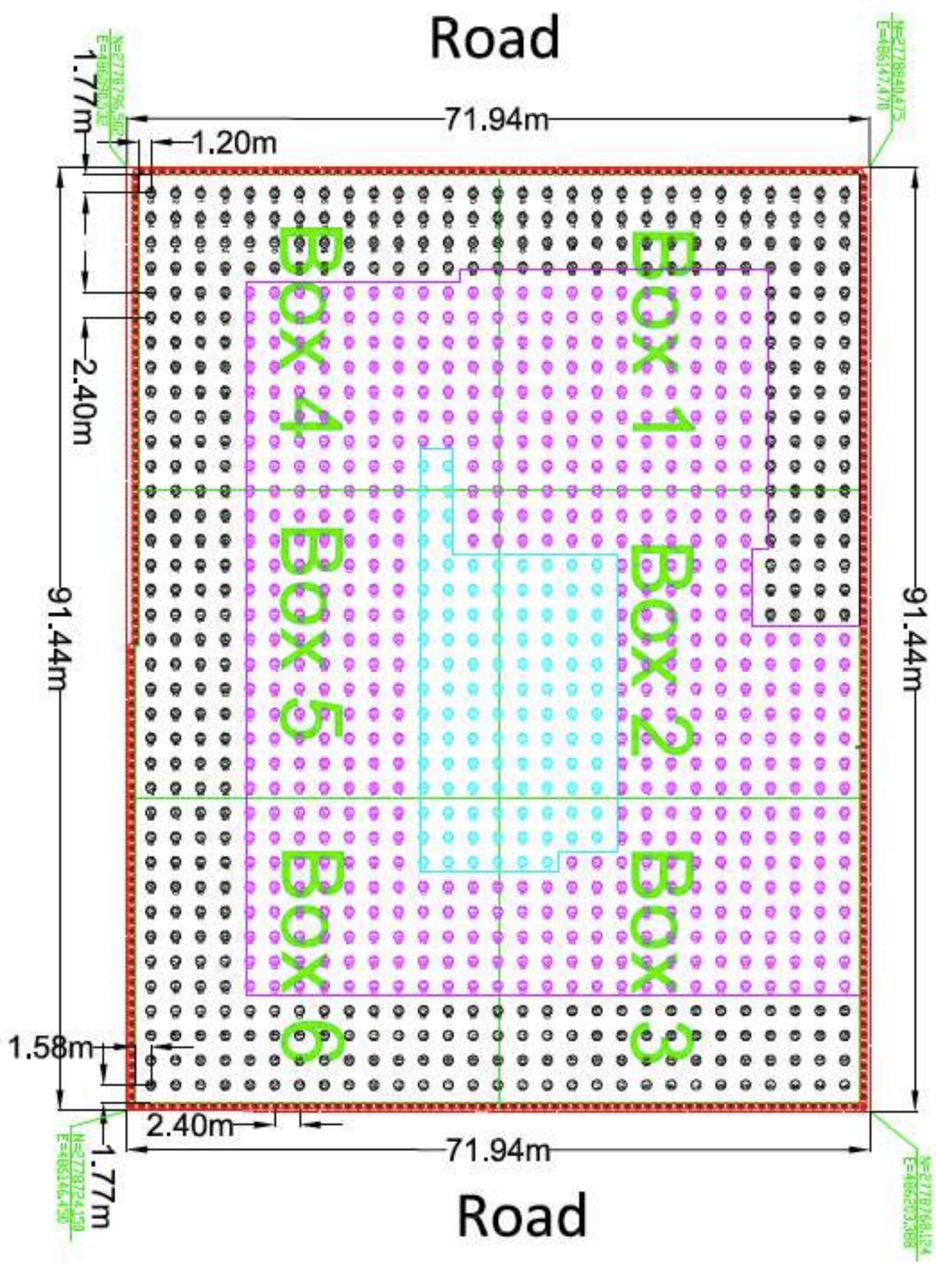


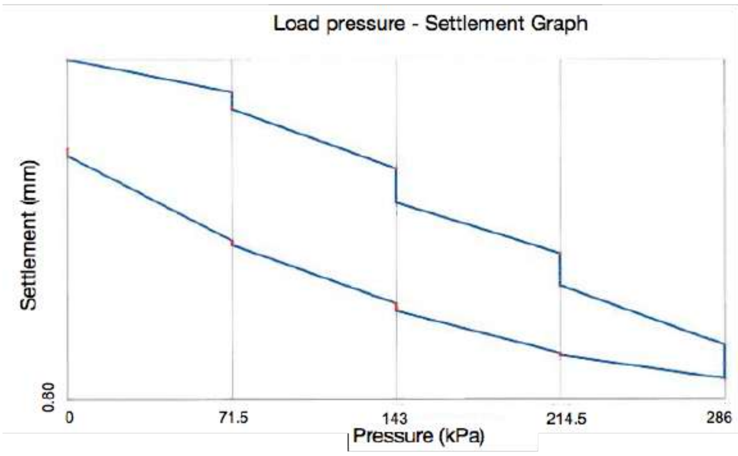
Figure 6.2.b Layout of Stone Columns

6.2.4 Construction Photos

Figure 6.2.c Vibro-replacement/stone column work in Dubai

6.2.5 Test Results

(1) Post-treatment loading test



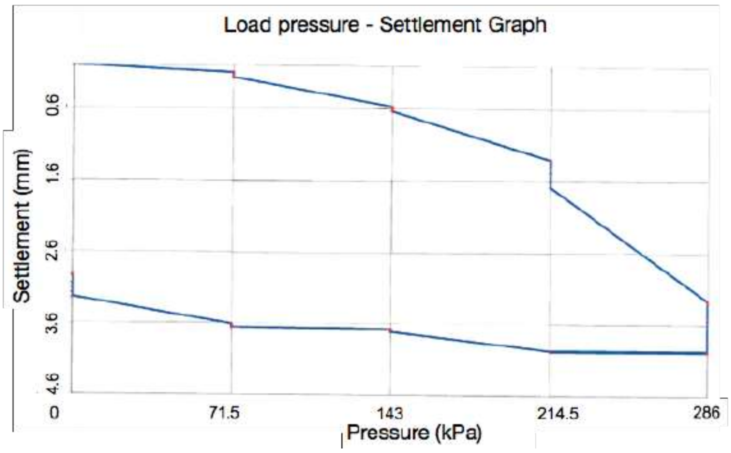
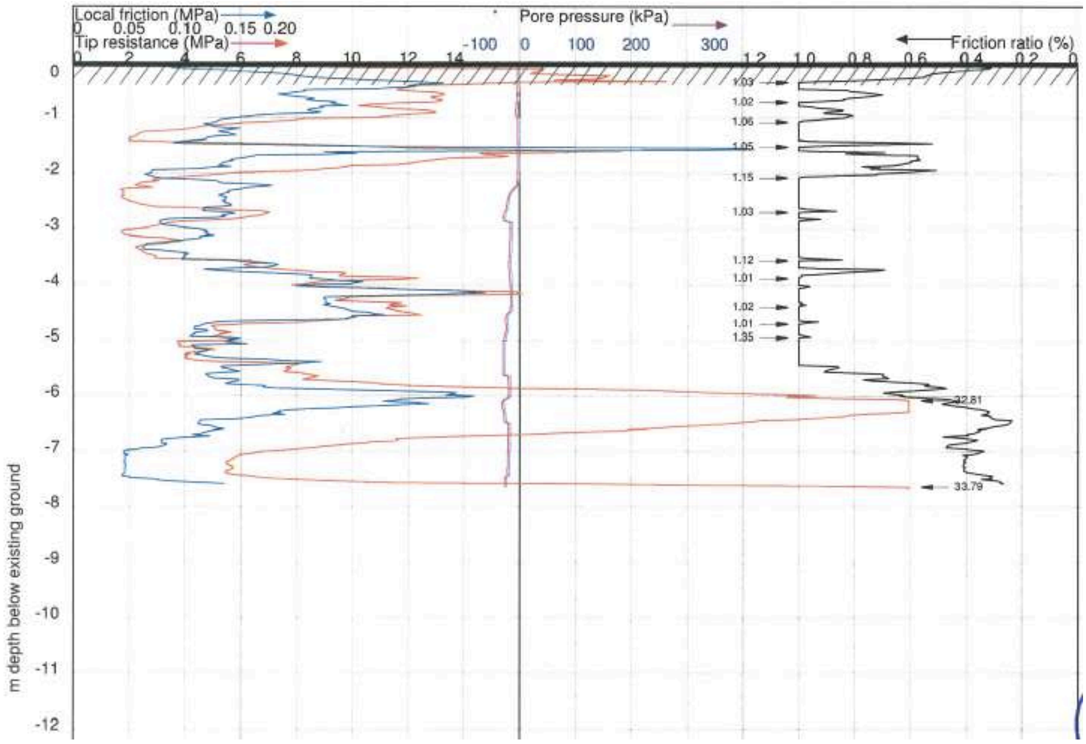


Figure 6.2.d Loading Test Results after Treatment

(2) Post-treatment CPT tests



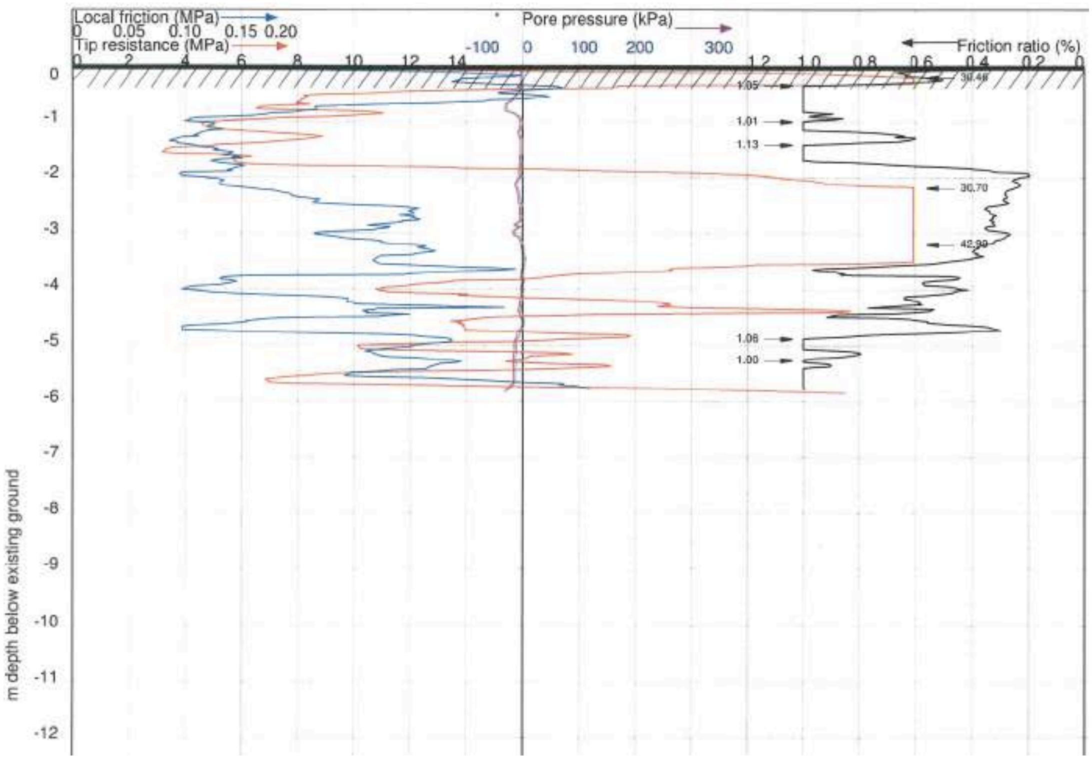


Figure 6.2.e CPT Test Results after Treatment

6.3 BAWABAT AL SHARQ PHASE III VILLAS, ABU DHABI, UAE

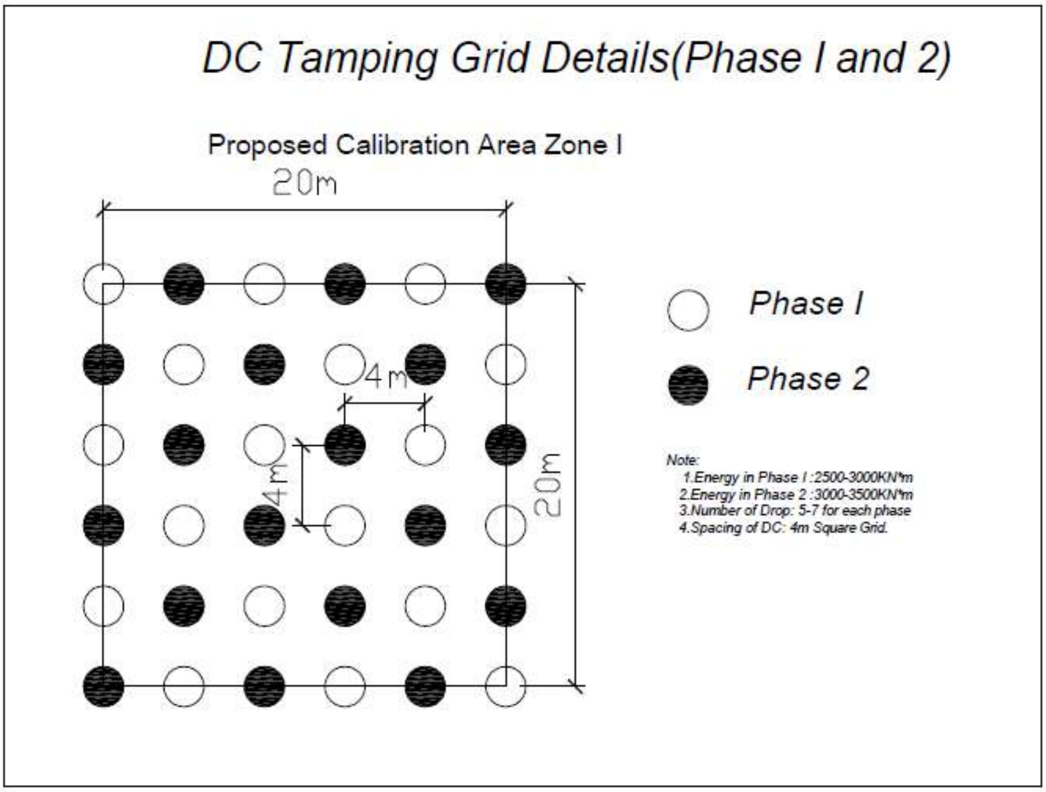
6.3.1 Project Overview

- Project: Bawabat Al Sharq Phase III Villas
- Location: Baniyas, Abu Dhabi, UAE
- Construction time: 2014
- Client: BIDC
- Consultant: AECOM International
- Main Contractor: Royal International Construction
- Main Soil Improvement Contractor: Al Negm Emigrant Foundation llc
- Method: **Dynamic compaction + Stone column**
- Design requirements:
  - Bearing Capacity ≥ 200 kPa
  - Maximum total settlement: 25 mm

6.3.2 Construction Design

According to the soil investigation results and pre-test results, ground improvement to a depth of 9.0m was required for the site preparation. Dynamic compaction was determined to be the major method. In certain areas, due to the existing pipes which might be damaged by dynamic compaction, vibro-replacement/stone column was adopted as an alternative.

(1) Dynamic compaction pattern



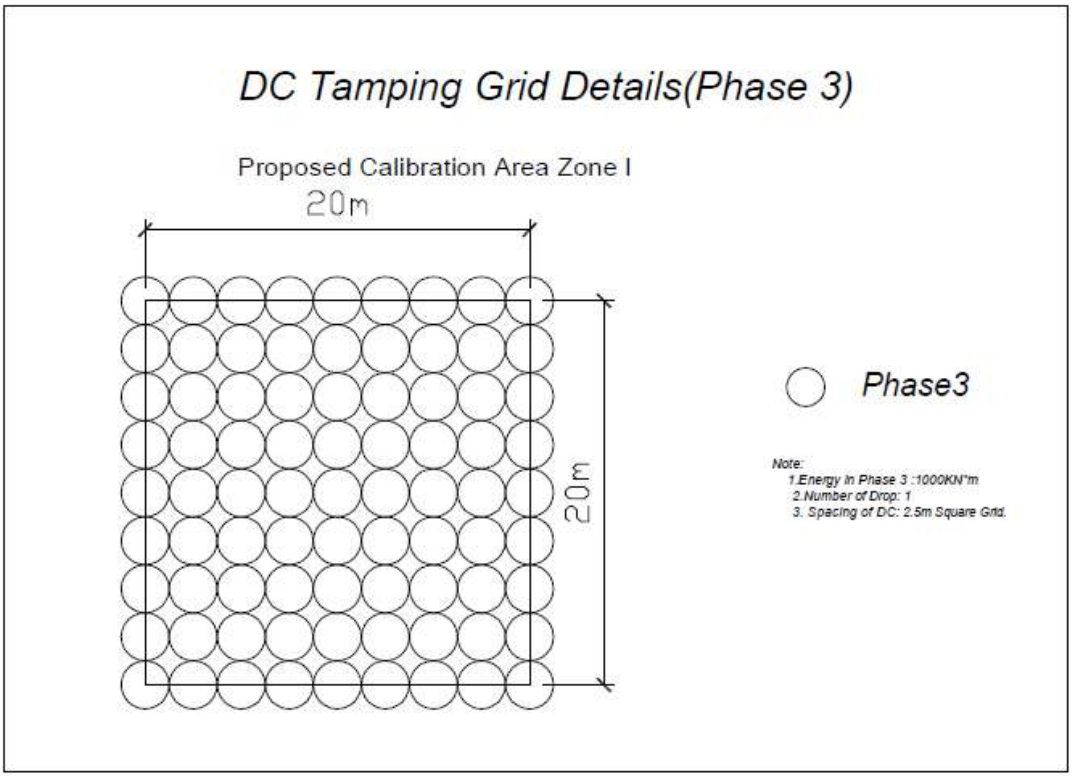


Figure 6.3.a Design of Dynamic Compaction in Abu Dhabi

(2) Vibro-replacement/stone column pattern

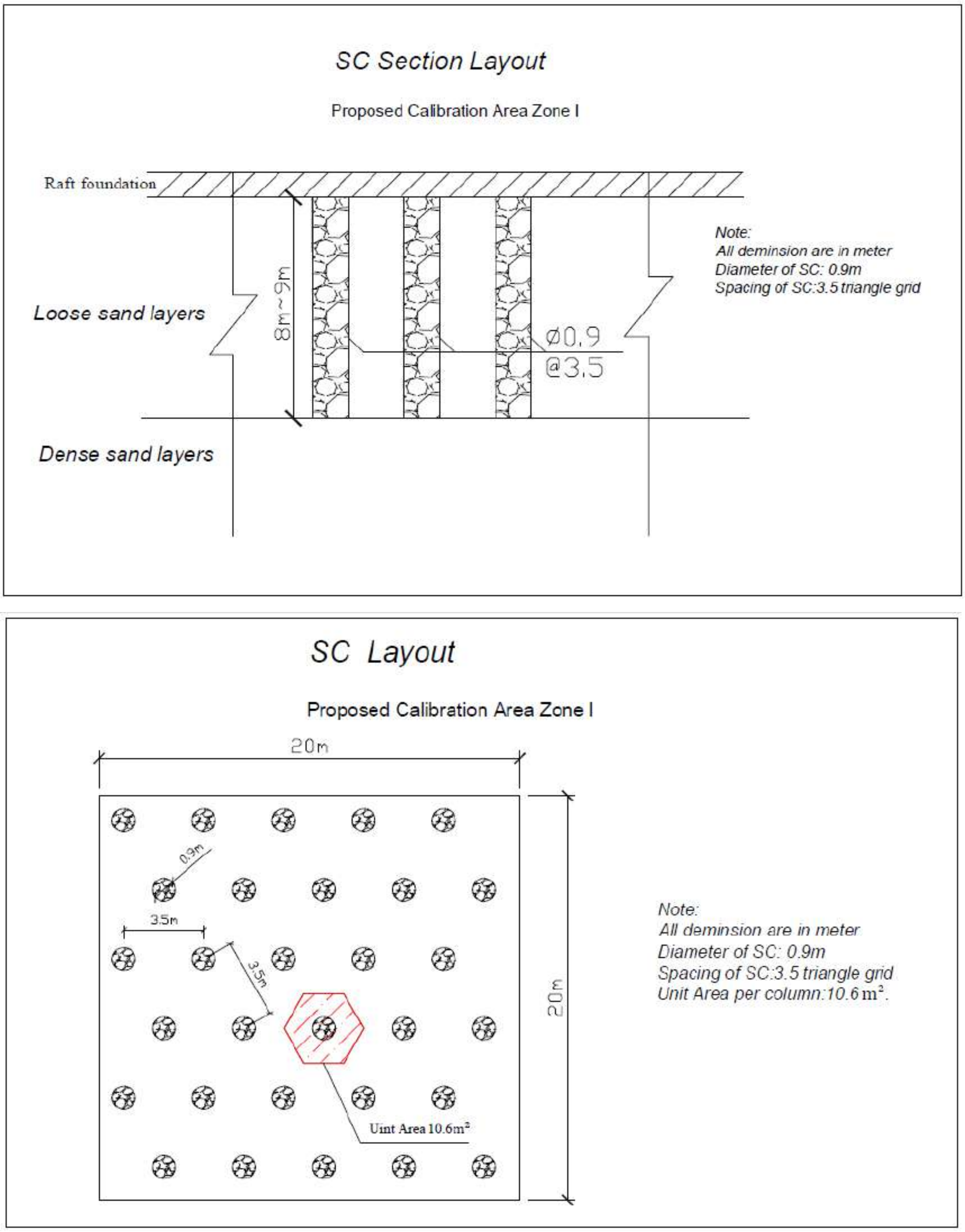


Figure 6.3.b Design of Vibro-replacement/Stone Column in Abu Dhabi

6.3.3 Construction Photos

(1) Dynamic Compaction

Figure 6.3.c Dynamic Compaction Photos in Abu Dhabi

(2) Vibro-replacement/stone column

Figure 6.3.d Vibro-replacement/Stone Column Photos in Abu Dhabi

6.3.4 Test Results

Table 6.3.a Post-treatment test results in Dynamic compaction area

Depth (m)	Post Treatment-SPT (Dynamic Compaction)			Post Treatment-CPT (Dynamic Compaction)				Post Treatment-PLT (Dynamic Compaction)		
	SPT-11 Zone 4 (V3C-75)	SPT-12 Zone 4 (V3C-71)	SPT-7 Zone 3 (V3C-106)	Depth (m)	CPT-V71 Tip Resistance (Mpa)	CPT-V75 Tip Resistance (Mpa)	CPT-V106 Tip Resistance (Mpa)	PLT Test No.	Max. Stress Applied (kN/m2)	Settlement (mm)
+2.0	30	26	25							
+1.5	50	25	25							
+1.0	45	38	45							
+0.5	32	50	27							
0.0	44	50	21	0.0-0.2	10			PLT-C-06 (V3C-75)	644	5.60
-0.5	50	50	23	0.2-0.3	1.0			PLT-C-05 (V3C-71)	644	4.48
-1.0	50	50	22	0.3-1.9	9			PLT-C-08 (V3A-106)	644	5.10
-1.5	33	50	50	1.9-2.9	35					
-2.0	23	50	36							
-2.5	50	50	40	0.0-1.0		1				
-3.0	50	50	50	1.0-2.0		15				
-3.5	50	50	50	2.0-3.0		25				
-4.0	50	50	50	3.0-3.2		1				
-4.5	50	50	50	3.2-4.8		12				
-5.0	50	50	50							
-5.5	50	50	50							
-6.0	50	50	50							
-7.0	50	50	50							
-8.0	50	50	50							
-9.0	50	50	50							
-10.0	50	50	50							

Table 6.3.b Post-treatment test results in Stone column area

Depth (m)	Post Treatment-SPT (Stone Column Compaction)			Post Treatment-CPT (Stone Column Compaction)				Post Treatment-PLT (Stone Column Compaction)		
	SPT- Zone 1 (V3C-42)	SPT-3 Zone 1 (V3A-88)	SPT-1 Zone 1 (V3A-93)	Depth (m)	CPT-V88 Tip Resistance (Mpa)	CPT-V93 Tip Resistance (Mpa)	CPT-V42 Tip Resistance (Mpa)	PLT Test No.	Max. Stress Applied (kN/m2)	Settlement (mm)
+2.0		22	13							
+1.5		21	12							
+1.0		45	44							
+0.5		20	40							
0.0		12	18	0.0-2.0	10			PLT-S-04 (V3C-42)	644	5.23
-0.5		17	17	2.0-3.0	20.0			PLT-S-06 (V3A-88)	644	2.98
-1.0		18	25	3.0-6.0	7			PLT-S-05 (V3A-93)	644	4.87
-1.5		26	20	6.0-9.0	25					
-2.0		28	29							
-2.5		45	49	0.0-0.2		6				
-3.0		34	50	0.2-1.1		10				
-3.5		47	50	1.1-1.7		20				
-4.0		41	50	1.7-1.9		5				
-4.5		47	50	1.9-2.1		45				
-5.0		36	50							
-5.5		42	50							
-6.0		44	50							
-7.0		49	50							
-8.0		50	50							
-9.0		50	50							
-10.0										

APPENDIX: EQUIPMENT LIST

Table A.1 Equipment List of Geoharbour Group

NO.	Equipment	Model	Quantity	Picture
1	Dynamic Compaction Equipment	SQH320	6	
		YTQH450B	3	
		YTQH350B	1	
		QUY50B	2	
2	Equipment for inserting vertical vacuum drainage pipe		30	

NO.	Equipment	Model	Quantity	Picture
3	PVD installation rig	PDB-400	2	
		Static pressure type	35	
		Track type	3	
		Light type	8	
4	Vacuum preloading jet vacuum pump	7.5kW	710	
5	New vacuum preloading pump group	90kW	15	 
6	HVDM pump group	15kW	615	

NO.	Equipment	Model	Quantity	Picture
7	New HVDM pump group	50kW	5	
8	Rotary drilling rig	TR220D	2	
		YTR230D	3	
		YTR280D	1	
		YTR300D	5	
		TR360DF	2	

NO.	Equipment	Model	Quantity	Picture
		TR400DF	2	
9	Circulation drill	STP-10	3	
10	Crawler telescopic boom pile driver	KLB6T-15C	2	
		JZU 90	3	
11	Vibro-Compaction Equipment	BJV180E-426/180kW	74	
		Bottom feed	1	
12	Deep mixing pile machine	SJB-Ⅱ	3	

CONTACT US

We're here to help.

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