Lach Huyen Port Infrastructure Project and Soil Improvement Works

Thi Ha
Port and Airport Department, Nippon Koei Co. Ltd., Tokyo, Japan
E-mail: ha-th@n-koei.jp

ABSTRACT: To cover cargo demand in northern part of Vietnam and to fit large size vessel in marine transportation sector, an international deep sea port for 100,000 DWT size vessel is being constructed in Lach Huyen area situated at south east part of Hai Phong City. In this project, reclamation work is being conducted at Port Terminal Area and Access Road Area. In the construction area, totally 20m to 30m of fine soil (clay, slit and sandy clay) layers are distributed. To accelerate the consolidation and to reduce the residual consolidation settlement during port operation, soil improvement works are being carried out by cement deep mixing method and prefabricated vertical drain method. In this paper, overall construction project will be introduced in briefly and then soil improvement works will be presented.

KEYWORDS: Deep Seaport, Reclamation, Soil Improvement, Cement Deep Mixing Method (CDM), Prefabricated Vertical Drain Method (PVD) with Pre-loading

1. INTRODUCTION

In Vietnam, import and export cargo volume is increased with rapid economic growth by flowing foreign direct investment (FDI) to the country after changing to market economic system in 1990s. Such increase of cargo volume under economic growth, 110- 130 million tons was estimated in the northern part of Vietnam in 2020. However, total cargo handling capacity in main ports of the northern part area, Hai Phong Port and Cai Lang Port, was 75 million tons and so it was found that the cargo handling volume is not enough in that study time of 2007.

Here, an issue for Hai Phong Port, main gateway port of northern Vietnam, water depth of the channel is around -7 m and so the containers from Vietnam to Europe and America are transited from feeder vessels to large size vessel in Hong Kong and Singapore etc. and it leads high transportation costs. Then, as another issue, Hai Phong Port is situated at the river mouth of Red River and huge sedimentation in the channel is a big challenge for the port. Besides, according to some bridge construction projects by Hai Phong new city plan also leads some restriction of large size vessel entering to the Port. Therefore, an international deep seaport for 100,000 DWT maximum size vessel is being constructed in Lach Huyen area situated at southeast part of Hai Phong City, to meet cargo handling capacity and demand cargo volume (Figure 1).

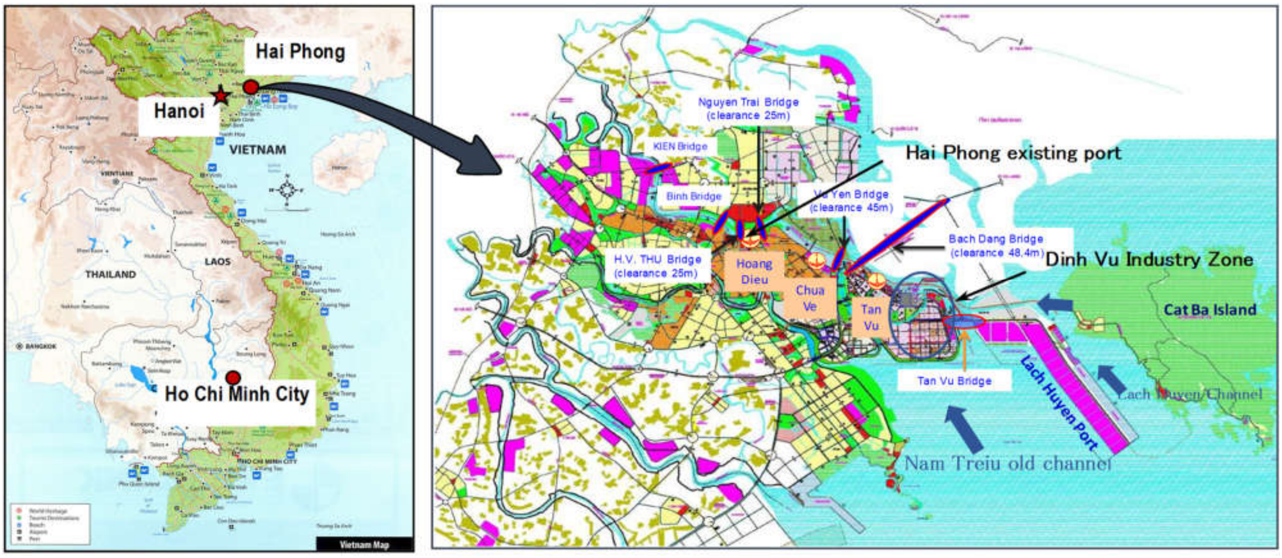


Figure 1 Location of Hai Phong City and Lach Huyen Port Construction Site

2. LACH HUYEN PORT CONSTRUCTION PROJECT

Master Plan of Development of Vietnam Seaport System for 2020-2030 was approved by Ministry of Transport (MOT) under Prime Minister Decision. Based on this master plan, port development in Hai Phong area will be carried out mainly in Lach Huyen Port area and totally 23 berths (16 container berths & 7 general cargo berths) are planned to be constructed in Lach Huyen Port until 2030 (Figure 2). Two container berths were completed in May 2018 and now break water and sand protection dye are under construction and plan to be finished in April 2020. In this project, not only port construction but also surrounding infrastructure such as road and bridge construction are also included. The road and bridge construction were completed and now under operation from September 2017.

Lach Huyen Port construction project is the first Public- Private Partnership (PPP) Japanese ODA loan in Vietnam and Japanese companies are taking part in construction and management of container terminal. Besides, advaced technology and construction manners are being utilized in this project for keeping proper qualities, shortening construction period and safety construction works.

As for demarcation of public and private, basic infrastructures such as reclamation and soil improvement, channel dredging, break water, sand protection dyke, are public component. On the other hand, upper structures such as jetty, crane, building etc. are under private component (Figure 3, port bureau document, MLIT, 2011).

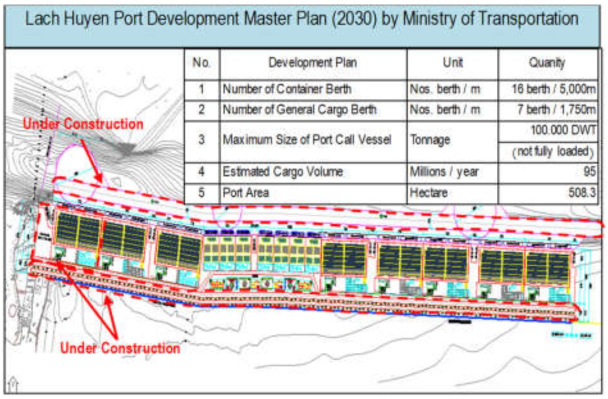


Figure 2 Lach Huyen Port Development Master Plan

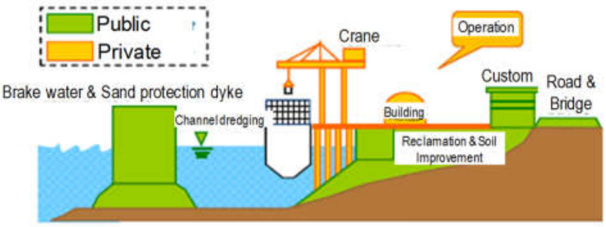


Figure 3 Demarcation of Public and Private Component

Construction of Lach Huyen Port project is composed by 4 packages; PK6 reclamation and soil improvement (port area (750 m ×1000 m), PK8 channel dredging (water depth -14 m, channel width 160 m, length 7.1 km, dredging volume 16 million m^3 including ϕ 660 m turning basin), PK9 (water depth -14 m, channel width 160 m, length 10.3 km, dredging volume 15.7 million m^3) channel dredging, PK10 Breakwater (2.48 km) and sand protection dyke (7.6 km) as shown in Figure 4 and Table 1. Some views of construction works are as shown in Photo 1.

In this project, there are some special considerations in construction works as below.

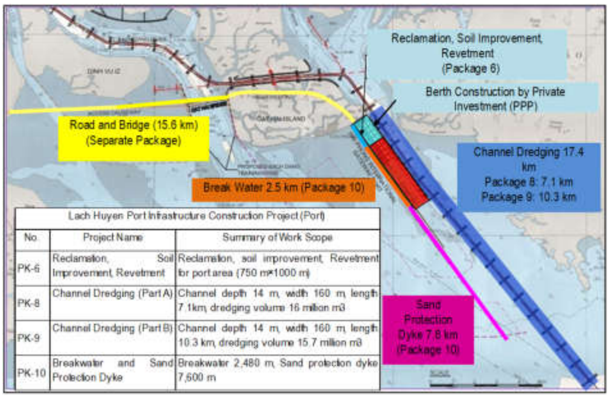


Figure 4 Each Construction Package of L.H. Port Project

Table 1 Contract and Progressive of Each Package

Name	Contractor	Contract Date	Term (Months)	Defect Period	Progressive
PK6	PENTA-TOA JV	2013/04/11	52	2 years	99.5 %
PK8	TOYO Construction	2015/11/30	30	N/A	78.6%
PK9	PENTA-RINKAI JV	2015/11/30	30	N/A	76.8%
PK10	TOA Corporation	2014/12/27	52	2 years	53.4%

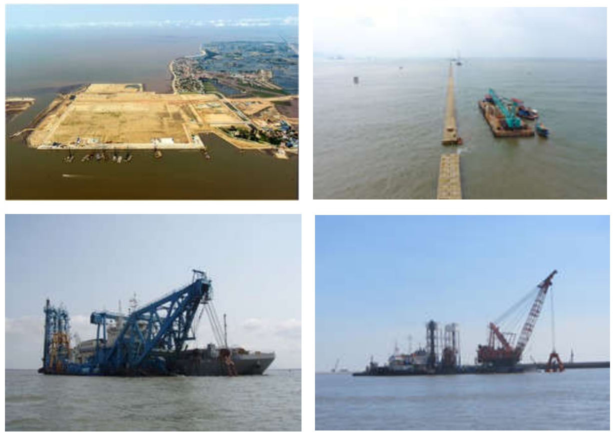


Photo 1 Views of Construction Site

2.1 Dredging Works Under Operation of Commercial Channel

Width of the existing Lach Huyen channel is 100 m and -7 m water depth for 20,000 DWT vessel. In this construction, the existing channel is being extended to 160 m width and -14 m water depth for 100,000 DWT vessel. Since, the existing channel is under operation, not only dredging plan such as schedule and allocation of dredgers beside commercial channel but also change of left side and right side of commercial channel and safety measures for safe navigation by public vessels are also required under this construction. (Figure 5).

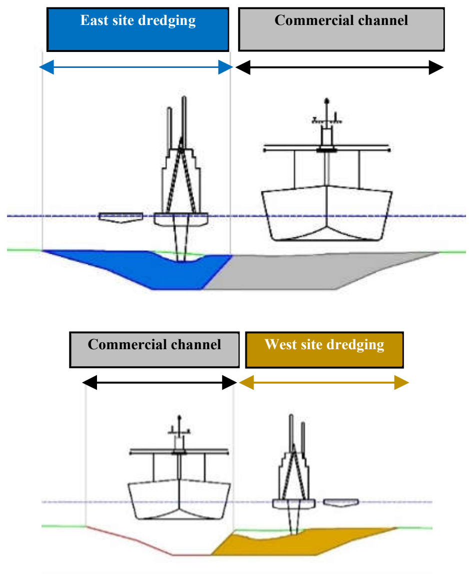


Figure 5 Dredging Works Under Channel Operation (left: east side dredging, right: west side dredging)

2.2 Sand Protection Dyke

Old channel to the existing Hai Phong Port, Nam Trieu channel (Figure 1), had a problem of huge sedimentation from upstream river and drift sand from south-west of offshore, in past years. Therefore, Lach Huyen channel was newly constructed in Hai Phong Port rehabilitation project Phase 2 (Japanese ODA project in 2000). At that time, the Lach Huyen channel was -7m water depth, but dredging works for -14 m depth are now being carried out under this project.

After completion of -14 m dredging works, sedimentation in the channel is expected by sediment supply from upstream river. Therefore, construction of Sand Protection Dyke is included in this project by using cellular block structure (Figure 6).

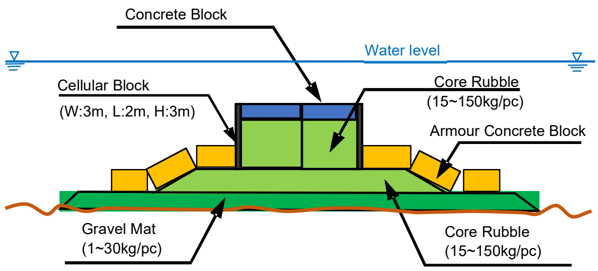


Figure 6 Sketch of Sand Protection Dyke Structure

2.3 Monitoring of Channel Sedimentation

As afore mentioned, channel sedimentation issue is concerned not only in construction stage but also in operation stage of the port. Therefore, periodical bathymetric survey and hydrological survey such as continuous monitoring of current, turbidity and wave are being carried out under this project. By using these data, sedimentation volume and trend, its mechanism will be clarified and maintenance dredging plan will be formulated for Vietnamese Government.

3. RECLAMATION AND SOIL IMPROVEMENT

3.1 Reclamation

Port area construction under PK6 is composed by two areas; container terminal area and public area such as custom building and port management office etc. (Figure 7). Under PK6 construction work, reclamation works were carried out in container terminal area (marine reclamation, +4.5 m elevation but +5.5 m elevation at harbor road part) and public area (land-based reclamation, +4.5 m elevation). The reclamation volume is about 2.20 million m^3 for container terminal area and about 0.23 million m^3 for public area.

Aerial views of progressive of reclamation works are as shown in Photo 2.

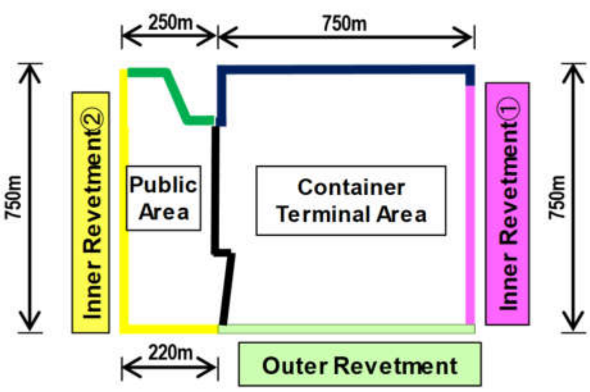
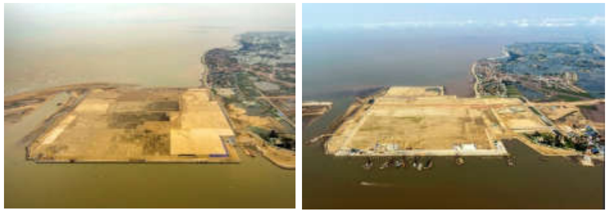


Figure 7 Reclamation Area under PK 6

April 2014 **April 2015**



April 2016 **May 2016**

Photo 2 Aerial View of Reclamation Site

3.2 Soil Improvement

3.2.1 Subsoil condition of port area

Subsoil of the port area is mutual layers of sand and clay layers and the layers with less than SPT *N*-value 10 are distributed until around GL-15 m to -26 m. Soil improvement layers are mainly two layers; upper clay layer and lower clay layer. The upper clay layer is very soft layer with average SPT *N*-value 1.0 and distributed in 6 m to 10 m of thickness. Then, the lower clay layer is medium consistency clay layer with average SPT *N*-value 5.7 and distributed in 8 m to 14 m thickness.

Some physical and mechanical properties of the upper clay layer and lower clay layer are as shown in Table 2.

Table 2 Physical and Mechanical Properties of Clay Layer

Layer	ρ_s (g/cm^3)	γ (kN/m^3)	e_0	c_u (kN/m^2)	C_c	c_v (cm^2/s)
Upper clay layer	2.70$^{1)}$	17.0	1.45	15	0.6	0.001
Lower clay layer	2.70$^{1)}$	17.5	1.20	40	0.6	0.002

Remark: 1) range between 2.64-2.74 g/cm^3

3.2.2 Soil improvement methods

Since soft to medium consistency clay layers are identified in the port area, long term consolidation and stability are concerned. Then, also due to tight schedule of construction work, the residual settlement cannot be retained within required range without any soil improvement works. Therefore, soil improvement is necessary in this project to accelerate the consolidation and to reduce the residual consolidation settlement occurred by the port operation load.

There are several methods for the soil improvement upon natural conditions of site and purpose. For example, replacement method, vertical drain method, deep mixing method, sand compaction pile method, rod compaction method, well point method etc. (Technical Standards and Commentaries for Port and Harbor Facilities in Japan, 2009).

In this project, a comparison study for the following soil improvement methods was carried out in design stage.

- Deep Mixing Method (DMM)
- Prefabricated Vertical Drain Method (PVD) with pre-loading Method
- Sand Compaction Pile Method
- Sand Replacement Method

As the result, Prefabricated Vertical Drain (PVD) with Pre-loading Method was recommended as a main soil improvement method because this method is easy for work, low construction cost, no hazardous impact for natural & social environment and already experiences in Vietnam.

However, Cement Deep Mixing Method (CDM) was also applied to the area right behind the container berth where earth retaining wall is constructed to sustain the reclamation fill under consideration of the following effects (Figure 8).

- Since this project is PPP project and it is necessary to hand over the reclamation area behind the berth to Private component to complete their berth construction during target construction date.
- To reduce active earth pressure acting on the vertical type of earth retaining wall installed behind of container berth.
- To shorten the construction period for soil improvement work by using the combination of PVD and CDM method.

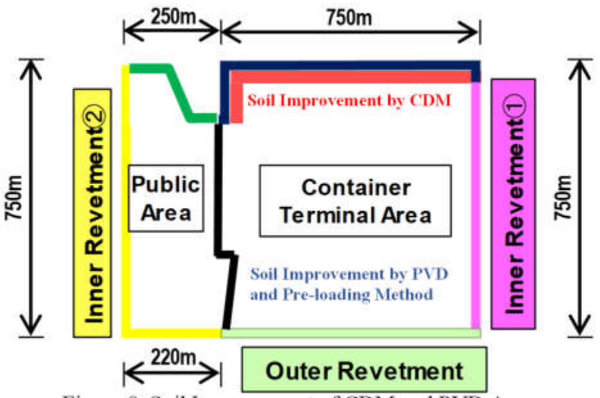


Figure 8 Soil Improvement of CDM and PVD Area

After finishing of CDM soil improvement work, construction works of steel sheet pipe pile (SSPP), rock mound and anchor block will be carried out. Then, after Tie Wire work for the anchor block and SSPP, upper concrete structure at SSPP part will be constructed. Then, the reclamation work on berth area will be started (Figure 9).

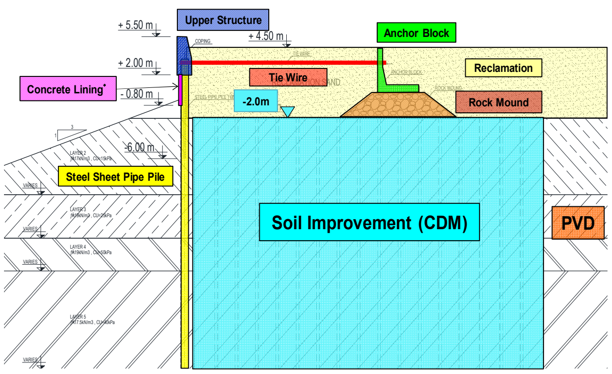


Figure 9 Typical Cross Section of Container Berth Area

3.2.3 Soil improvement by cement deep mixing method

(1) Design condition

Soil improvement by CDM method was designed as below conditions. Then, dimension and a typical arrangement of CDM column is as shown in Figure 10.

- Required design compressive strength of improved column: 600 kN/m^2
- Head of column: CDL -2.0 m
- Bottom end of column: upper end of the hard soil layer
- Diameter of column: φ 1300 mm, Lap type installed by 2 shafts
- Width of CDM 33-40 m
- Improvement ratio: 50%
- Cement content and water cement ratio *W/C*: 180 kg/m^3, 1.0, respectively (determined by results of trial installation at site before permanent installation)
- Layout of improved part: basically wall-shape and lap type are applied to both longitudinal ends of the improved part in order to increase the whole strength of the improved part
- Design load condition: preload fill at back side of CDM improved part

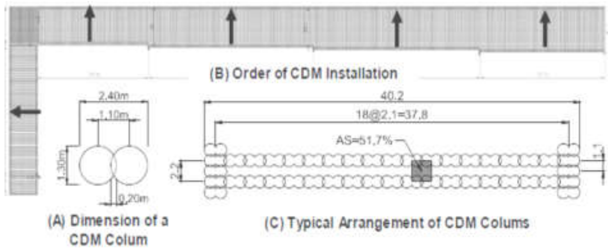


Figure 10 Dimension and typical arrangement of CDM column

(2) Determination of cement content and water cement ratio

1) Laboratory trial mix test

Before, trial installation at site, laboratory trial mix test was carried out in order to determine the suitable cement content and water cement ratio for field trial test. Here, two local ordinary Portland cements (here, express as N-cement and H-cement) were used. Specimens were prepared according to JGS practice (Japanese Geotechnical Society, 2005) and unconfined compression test (JIS A1216) was carried out after 7 days and 28 days curing in temperature controlled box with 20 degrees Celsius.

From a series of test results, unconfined compression strength q_u of 28 days curing specimens was 1.5 times larger than 7 days curing specimens. Figure 11 shows the relationship between q_u and cement content. As afore mentioned, the design strength is 600 kPa. Then, safety factor Fs=2.0 was applied based on past experiences in Vietnam for determining cement content and water cement ratio of slurry. Therefore, required q_u value is 1,200 kPa and cement content of 170 kg/m^3 to 200 kg/m^3 can satisfy this value.

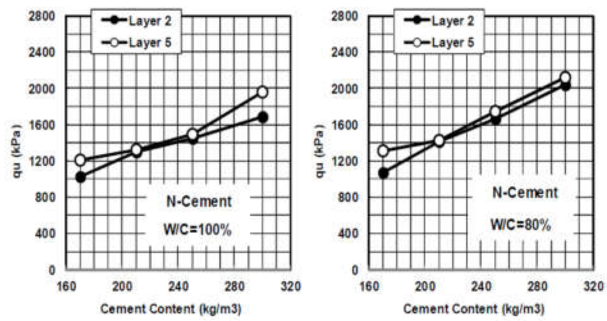
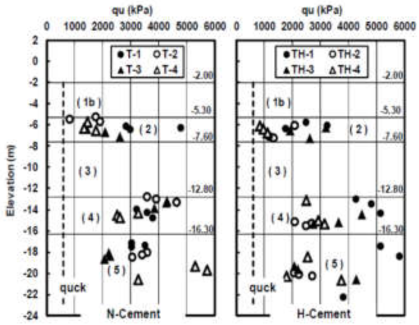


Figure 11 Results of laboratory trial mix test

2) Field trail test

Based on the laboratory trial mix test results, test columns with cement content of 180 kg/m^3 and 200 kg/m^3, *W/C* ratio 80 % and 100 % were installed at site by CDM barge. Then, undisturbed samples were taken by core pack sampler (diameter of sample is 69 mm) and 28-day strength was measured by unconfined compression tests. As shown in Figure 12, all test columns satisfied design strength of 600 kPa.

Since higher *W/C* ratio is more efficient for mixing in the ground, cement content of 180 kg/m^3 with *W/C* ratio of 100% was applied for actual CDM in this project.



Cement	Column No.	Cement Content (kg/m3)	W/C Ratio (%)
N	T-1	200	100
	T-2	200	80
	T-3	180	100
	T-4	180	80
H	TH-1	200	80
	TH-2	200	100
	TH-3	180	80
	TH-4	180	100

Figure 12 Results of field trial tests (28-day strength)

(3) CDM installation

CDM barge shown in Photo 3 was utilized in the installation works. The size of the barge is 55 m long and 16 m wide, And each barge has two 55 m height rigs with two mixing shafts that enable to install two CDM columns simultaneously. As for CDM pile installation procedure, first, excavation of the seabed up to CDL (chart datum level) -2.0 m was carried out (Photo 4). Then, CDM pile installation works were carried out.

Implemented quantity of CDM works in this project; area 42,600 m^2, volume 502,000 m^3, numbers of column 7,589, installation length 23- 25 m.

Photo 3 CDM Installation Work

Photo 4 Dredging work until CDL -2.0 m

(4) Quality assurance tests

To assure the quality of installed CDM piles, undisturbed sampling by using core pack sampler was conducted from 39 columns which is 0.5% of total installed number of column. Then, the specimens were wrapped in plastic film and cured in a temperature controlled box with 20 degrees Celsius for 28-day strength tests.

As shown in Figure 13, the values of q_u in almost all test results exceeded the design strength of 600 kPa which shows the successful implementation of CDM improvement. In here, some results show over 2,000 kPa with extremely large values, and the reason can be considered because of partially existing of sandy soil.

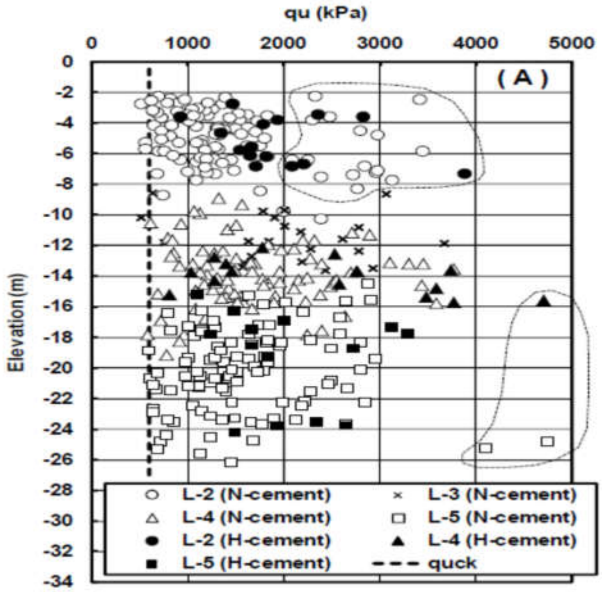


Figure 13 Results of quality assurance test (28-day strength)

(5) Removal of upheaval

According to bathymetric survey results at CDM installation area, ground level uplift around 3m from -2 m of excavated elevation, after CDM columns installation works. The volume of upheaved soil is 107,000 m^3 for the entire area of CDM works. Since the volume of soil targeted to CDM improvement is 462,000 m^3, the ratio of the upheaved soil to the targeted improved soil is 23%.

In this project, removal dredging of CDM upheaval soil was conducted after completion of CDM installation works (Photo 5).

Photo 5 Removal Dredging of CDM Upheaval Soil

3.2.4 Soil Improvement by Prefabricated Vertical Drain (PVD) with Pre-loading Method

(1) Design condition

Soil improvement by CDM method was designed as below conditions.

- Design load
  Terminal area (full container storage area): 30 kN/m^2
  Terminal area (empty container storage area): 10 kN/m^2
  Access road area: 10 kN/m^2
- Target achieved consolidation degree (U)
  Over 80% during surcharge loading period
  Over 90% at access road area
- Horizontal coefficient of consolidation c_h=2c_v
  (c_v: vertical coefficient of consolidation)
- Residual settlement
  Container terminal area: S_r=0 cm (primary consolidation completed, 100%)
  Access road area: 15 years after pavement completed
  S_{15}< 30 cm
  (30 cm= Primary + Secondary consolidation)

- Allowable safety factor for slope stability
  $F_{sa} \geq 1.10$ (construction stage)
  $F_{sa} \geq 1.30$ (operation stage)
- Design Elevation from chart datum (CD)
  Container terminal area and access road area: CD +5.50 m
  Required elevation before preloading: more than CD +4.50 m
  Surcharge removal level: CD +4.50 m

Upon above design conditions, study of preload height is studied upon area separation, first. Then, residual settlement is checked by consolidation settlement analysis results. Then, PVD layout and preload thickness are studied to satisfy allowable settlement. Finally, stability analysis is carried out to check allowable safety factor.

Figure 14 shows schematic view of cross section of reclamation area. And, Figure 15 shows PVD installation interval for each area; full container area d =1.1 m, empty container area d =1.2 m, access road area d =1.6 m. Here, d is distance from center to center of each PVD.

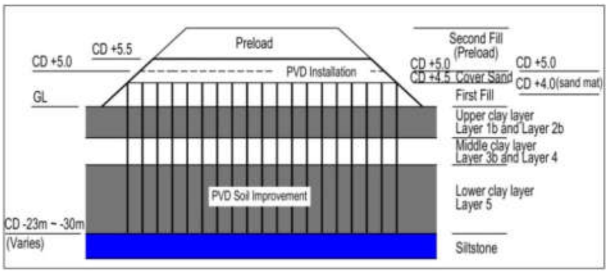


Figure 14 Schematic View of Cross Section of Reclamation Area Improved by PVD and Preload

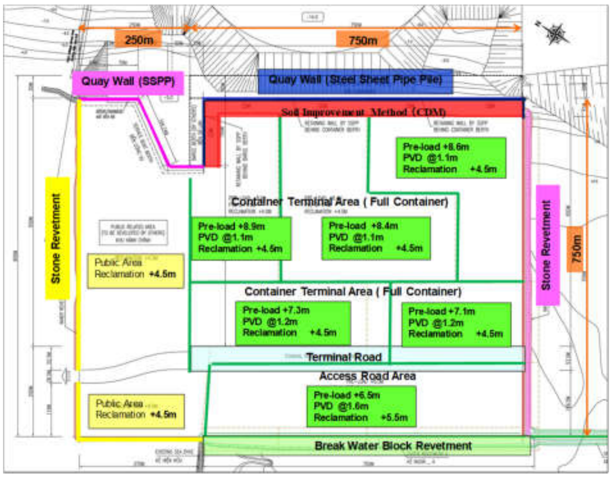


Figure 15 PVD Interval and Elevation of Preload

(2) PVD installation

As for PVD installation procedure, reclamation and fill works from existing elevation to +4.0 m were carried out, first (Photo 6). Then, inclinometer and settlement plate were installed on the finished reclamation elevation and then lower sand mat layer with 0.5 m thickness was filled (Photo 7). Then, as shown in Photo 8, PVD installations were started from lower sand mat layer of elevation +4.5 m. PVD installation depth is controlled by automatic recording system which is set up on PVD installation machine.

Photo 6 Sand barges and pump station (left), reclamation (right)

Photo 7 Sand Mat Filling Works

Photo 8 PVD Installation Work

After PVD installation, some monitoring equipment such as extensometer, piezometer etc. and pumping point were installed. Then, upper sand mat layer with thickness 50 cm was filled. Then, surcharge fill was carried out from elevation +5.0 m to design elevation (Photo 9)

Photo 9 Surcharge Filling Work

After the surcharge fill was constructed, the consolidation settlement was monitored. After achievement of 85% to 90% of the estimated consolidation settlement was confirmed, the surcharge materials were removed to design surcharge removal level.

Implemented quantity of PVD installation in this project is as below.

- Numbers of PVD: 406,705

- Sand mat: 583,319 m^3
- Surcharge fill: 1,642,944 m^3

(3) Field Monitoring during construction period

The monitoring shown in Table 3 were carried out during construction period.

Table 3 Monitoring items and purpose

No.	Item	Purpose
1	Settlement Plate	Evaluation of final settlement, degree of consolidation and the average value of c_h for the ground
2	Magnetic Extensometer	Evaluation of final settlement, degree of consolidation and the value of c_h for individual sub-layers
3	Electric Piezometer	Evaluation of excess pore water pressure and degree of consolidation for individual sub-layers
4	Stand Pipe	Evaluation of hydrostatic pressure in the ground which is necessary to calculate excess pore water pressure from piezometer measurement
5	Inclinometer	Evaluation of stability for surcharge slope
6	Alignment Stakes	Evaluation of stability for surcharge slope excepting

(4) Monitoring related to slope stability

Horizontal displacement of the ground measured by inclinometer meter and settlement data measured by nearby settlement plate will be plotted in Matsuo-Kawamura diagram presented in Figure 16 (Matsuo & Kawamura, 1977). If Matsuo-Kawamura plot shown as white arrows, the slope can be considered as stable because horizontal movement is relatively small when it is compared with settlement. If the plot shown as black arrow and cross q/q_f=0.9, the slope is close to failure because horizontal movement is relatively large when it is compared with settlement.

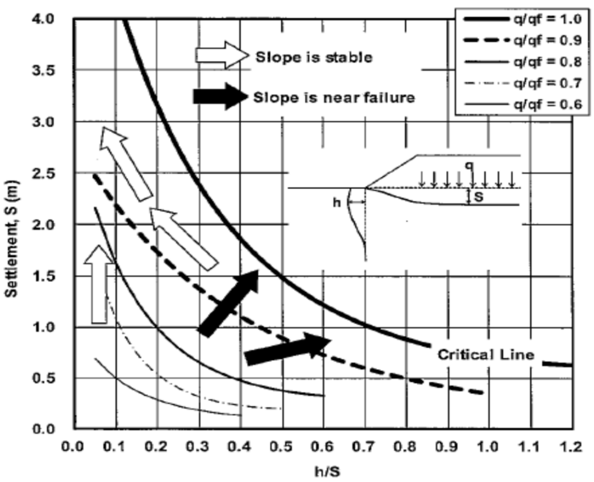
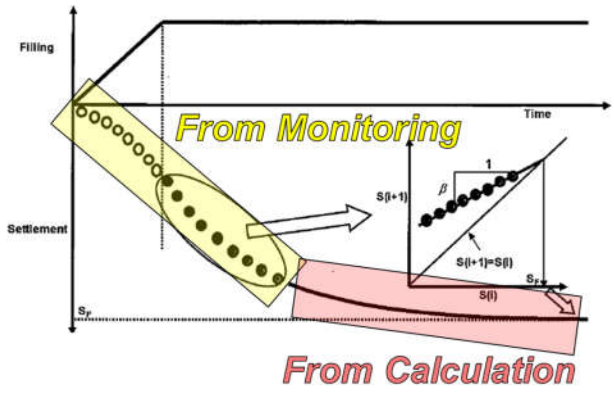


Figure 16 Matsuo-Kawamura Diagram

(5) Monitoring related to consolidation settlement

There are some methods to evaluate consolidation settlement in Japan such as simplified method (hyperbolic method), Asaoka method, Hoshino method etc. (Asaoka, 1978, Hoshino, 1963, Yamaguchi, 1994). In this project, Asaoka Method which is being used widely in Japan was applied to evaluate the consolidation settlement (Figure 17).



$$c_h = -\frac{F\,d_e^{\,2}}{8}\frac{\ln\beta}{\Delta t}$$

$$F = \frac{n^2}{n^2-1}\left(\ln n - \frac{3}{4}\right)\ ,\ \ n = \frac{d_e}{d_w}$$

where c_h: Coefficient of consolidation in horizontal direction

Δt: Constant time interval in Asaoka method

β: Determined from above figure

d_e: Diameter of effective circle

d_w: Diameter of drain well (=5cm for PVD)

Figure 17 Asaoka Method to Predict Consolidation Settlement

Once the values of S_f and c_h are obtained by Asaoka method, theoretical curve of settlement can be determined by Barron's equation Eq.1. as shown in Figure 18. Then, time to reach a certain value of degree of consolidation or settlement can be predicted with the theoretical curve.

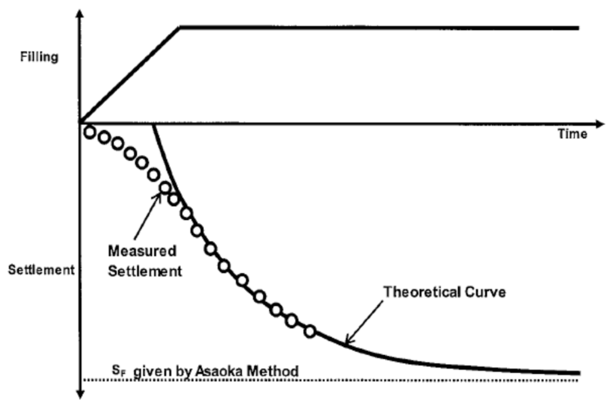


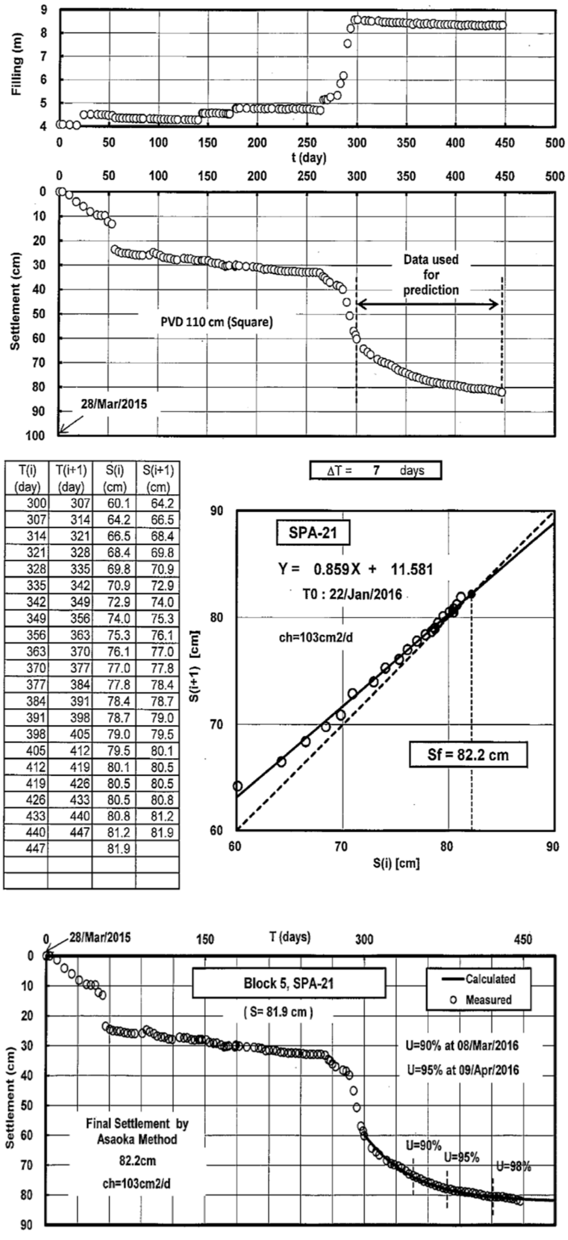
Figure 18 Prediction of future settlement

$$U = 1 - \exp\left(-\frac{8T_h}{F}\right) \qquad (1)$$

$$T_h = \frac{c_h}{{d_e}^2}t \quad , \quad F = \frac{n^2}{n^2-1}\left(\ln n - \frac{3}{4}\right) \quad , \quad n = \frac{d_e}{d_w}$$

where U : Degree of consolidation
T_h : Time factor
c_h : Coefficient of consolidation in horizontal direction
t : Elapsed time
d_e : Diameter of effective circle
d_w : Diameter of drain well (=5cm for PVD)

Before removal of the surcharge fill, the consolidation settlement shall be reached to 90% of the estimated consolidation settlement. Example of monitoring result and evaluation of settlement are shown in Figure 19.



T(i) (day)	T(i+1) (day)	S(i) (cm)	S(i+1) (cm)
300	307	60.1	64.2
307	314	64.2	66.5
314	321	66.5	68.4
321	328	68.4	69.8
328	335	69.8	70.9
335	342	70.9	72.9
342	349	72.9	74.0
349	356	74.0	75.3
356	363	75.3	76.1
363	370	76.1	77.0
370	377	77.0	77.8
377	384	77.8	78.4
384	391	78.4	78.7
391	398	78.7	79.0
398	405	79.0	79.5
405	412	79.5	80.1
412	419	80.1	80.5
419	426	80.5	80.5
426	433	80.5	80.8
433	440	80.8	81.2
440	447	81.2	81.9
447		81.9	

Figure 19 Examples of evaluation for Consolidation Settlement by Asaoka Method

3. CONCLUSION

In this paper, especially a series of soil improvement works in Lach Huyen Port construction project were discussed. In the project, soil improvement design and method by the combination of CDM, PVD with preloading, implementation techniques and construction manners were introduced as one of advanced technologies. By using this method, the construction works of the reclamation and soil improvement for port area were completed successfully during target date without any accidents and technical problems.

According to the port master plan of Vietnamese Government, the next stage construction of the Lach Huyen Port will be continuous in offshore area in future. Because of reclamation and soil improvement works at deeper area, the appropriate design method and technology for soil improvement, suitable materials for reclamation etc. will become necessary in future for success construction during target period. Advanced technologies are expected to apply in future projects of Vietnam especially for such difficult construction site.

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