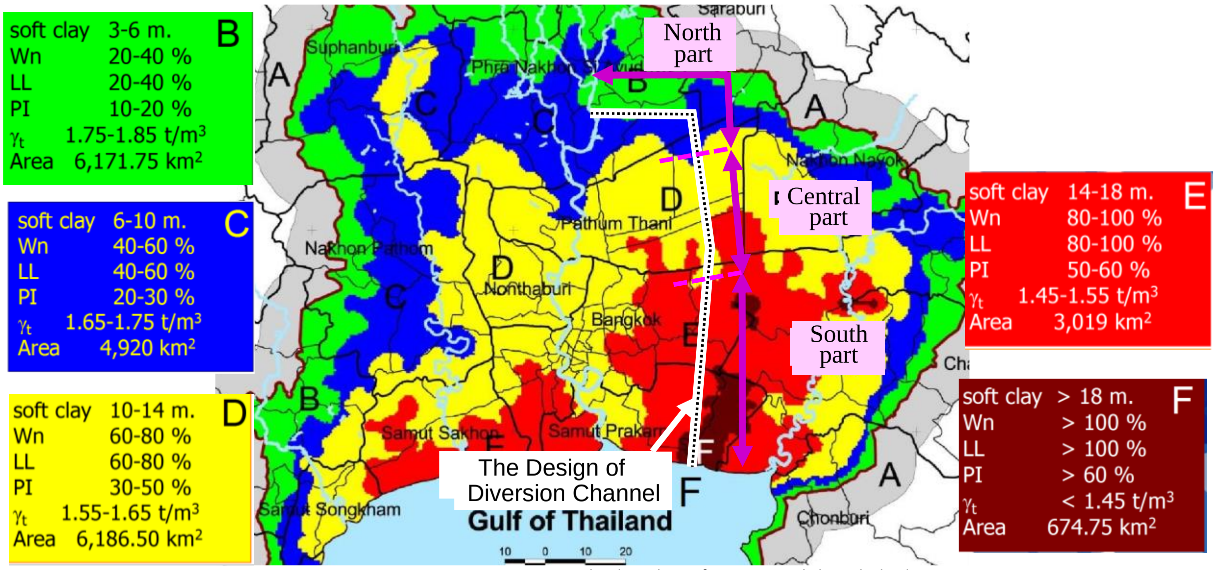
CHAPTER 4 BASIC DESIGN OF THE DIVERSION CHANNEL STRUCTURE

4.1 Study contents

The Diversion Channel combined with the Outer Ring Road is planned to be constructed on a thick layer of soft clay, especially in the southern part, as shown in the horizontal alignment view in Figure 4.1.1 (published by Kasetsart University). This figure shows soft clay planar distribution, classified in six types (A to F) by considering the thickness of the soft clay layer and the water content ratio. The Diversion Channel is planned to be constructed on soft clay type C, which has relatively good soil properties, to soft clay type F, which has relatively poor soil properties.

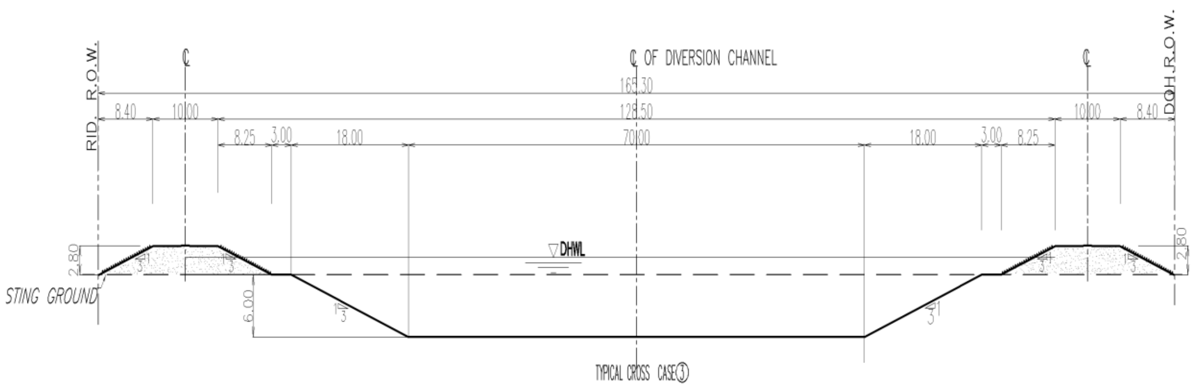


Source:Engineering Subsoil Database of Lower Central Plain, Thailand
Feasibility Study of the 3rd outer Bangkok Ring Road Project

Source : JICA Study Team

Figure 4.1.1 Planar Distribution of soft clay and location of the Diversion Channel

The planned cross section of the drainage channel is shown below. The excavation depth from the local board is 6.0 m, the embankment height is 2.8 m, and the slope is 1:3.0. In addition, the bed width is 70 m and the site width is about 166 m.

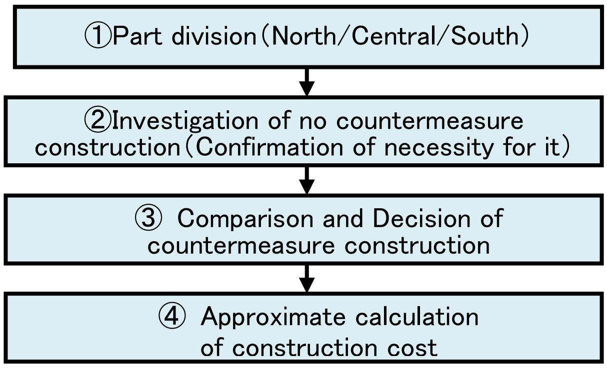


Source : JICA Study Team

Figure 4.1.2 Cross section of the Diversion Channel

The present study flowchart is shown in Figure 4.1.3. Hence, the investigation focuses on the soft clay layer thickness and divides the region into three parts (North, Central and South). The investigation is made for slope stability of the embankment of the Diversion Channel and consolidation settlement at the levee banking. The first investigations is performed to confirm the necessity for countermeasure construction, the second investigation is performed to compare and decide the method for countermeasure construction and the third investigation is performed to calculate the construction cost approximately.

In addition, we conducted a new geological survey on all of the three sections in this work. For the central and southern sections, we used the historical geological survey results from the compatibility with the survey time. Considering the below items ① to ④, based on the results of the new survey, we reviewed ② to ④. However, as for ③Countermeasures, we set the countermeasures items (countermeasure size) in response to the construction method determined from the quality survey results.



Source ：JICA Study Team

Figure 4.1.3 Investigation Flow Chart

4.2 Section division

The region was divided into three parts, North, Central and South in terms of soft clay distribution. The planar distribution of the soft clay shows a thick layer of soft soil in the southern part and medium thickness of the soil layer in the central part. In the Northern part, the soft clay was found only in a few boreholes.

Table 4.2.1 Characteristic parts of soft soil conditions

Part	Classification by Kasetsart University	Soft clay thickness	Comments
North	C（Blue）	Laying up in longitudinal direction discontinuously	
Central	D（Yellow）	Thickness H=12m approximately	
South	E（Red）・F（Brown）	Thickness H=18-25m approximately	

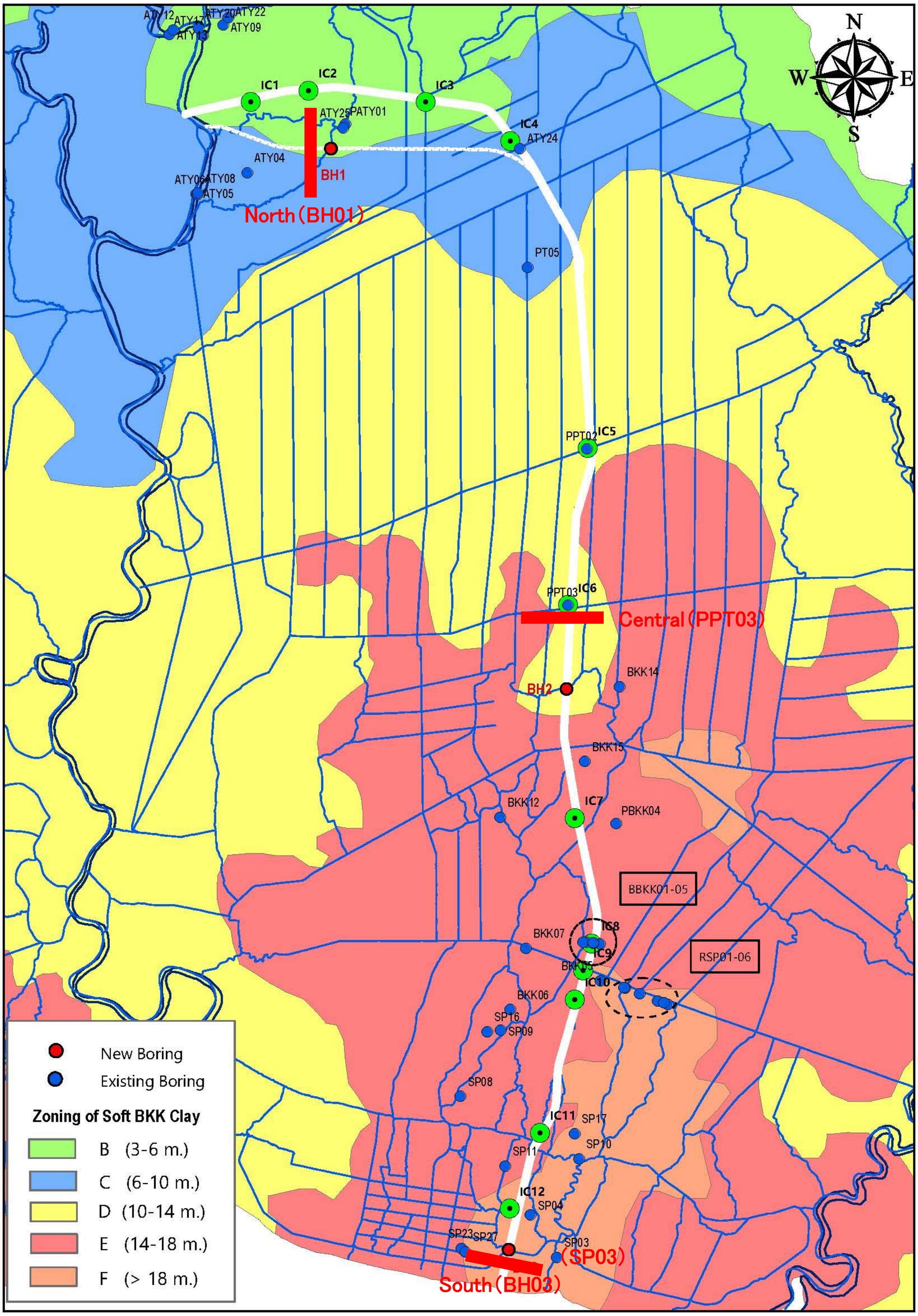
Source ：JICA Study Team

Referring to the existing geological survey result, the areas where the layer of soft clay is the thickest were selected as survey sites. In the investigation after the new geological survey, the examination section was set at the point where the layer thickness is the thickest among the geological survey results on the planned line of the drainage channel.

Table 4.2.2 Cross Section

Part	Phase	Cross-site location	Reason for selection
North	Final study	New point of ground-survey boring(BH1)	Geological features study point on the line of the Diversion channel construction plan
Central	Comparison study	Existing point of ground-survey boring(PPT03)	Moist thick soft clay boring point (PPT03) was adopted based on previous study of geological features.
	Final study	Existing point of ground-survey boring(PPT03)	Moist thick soft clay boring point (PPT03), on the line of the Diversion channel construction plan, was adopted based on the new study of geological features.
South	Comparison study	Existing point of ground-survey boring (SP03)	Moist thick soft clay boring point (PPT03) was adopted based on the previous study of geological features.
	Final study	New point of ground-survey boring(BH03)	Moist thick soft clay boring point (PPT03), on the line of the Diversion channel construction plan, was adopted based on the new study of geological features.

Source ：JICA Study Team



Source : JICA Study Team

Figure 4.2.1 Location map of existing boring and new boring (Boring in this study)

Table 4.2.3 List of laboratory tests for investigation of existing geology

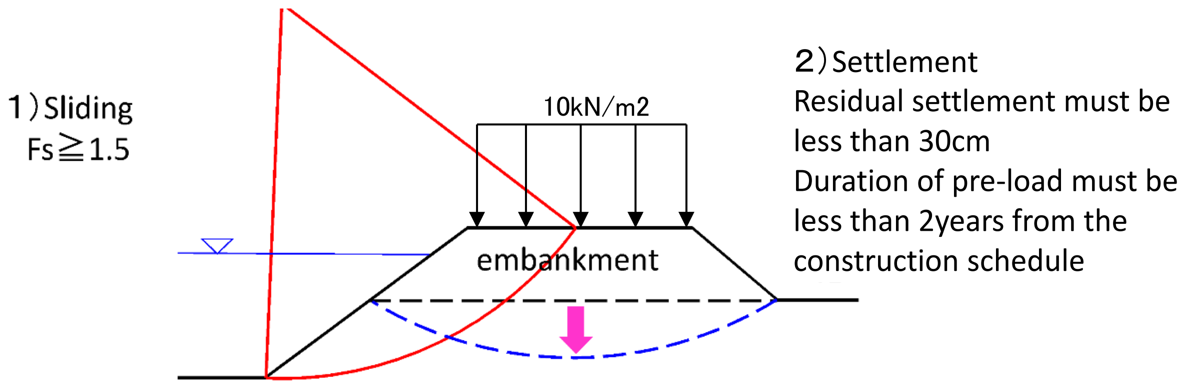
ZONING COLOR	AreaNo	Bor No			Boring (count)	depth	consolidation test	GROUP SYMBOL	ATTERBERG LIMITS (%)				UC.	UP.	UNIT WEIGHT		SPT		VANE SHEAR STRENGTH (TSM)			GRADATION (% PASSING)						Direct Shear Test		PP.	FV.	qu.	gt	SPT-N	Wn
								L	LL.	PL.	PI.	MC.	Ksc.	Ksc.	gt	γd	blows/ft	Sp.Gr.	Ps	Rs	Rd	NO.3/8"	NO.4	NO.10	NO.40	NO.100	NO.200	ksc. c	degree ø	t/m^2	t/m^2	t/m^2	(t/m^3)	(blow/ft)	%
B	ATY12	BH1	~	BH3	3			○	○	○	○	○	○	○	○	○	○						○				○								
B	ATY13	BH1	~	BH4	4			○	○	○	○	○	○	○	○	○	○						○				○								
B	ATY20	BH1	~	BH5	5			○	○	○	○	○	○	○	○	○	○						○				○								
B	ATY27	BH1	~	BH2	2			○	○	○	○	○	○	○	○	○	○				○		○				○								
B	ATY09	BH1	~	BH4	4			○	○	○	○	○	○	○	○	○	○						○				○								
B	ATY025	BH1			1			○	○	○	○	○	○	○	○	○	○						○				○								
B	PATY01	BH1			1			○	○	○	○	○	○	○	○	○	○																		
C	ATY22	BH1	~	BH7	7			○	○	○	○	○	○	○	○	○	○	○					○				○	○	○						
C	ATY05	BH1	~	BH4	4			○	○	○	○	○	○	○	○		○						○				○	○	○						
C	ATY06	BH1	~	BH2	2			○	○	○	○	○	○	○	○	○	○		○		○			○			○	○	○						
C	ATY08	BH1	~	BH5	5			○	○	○	○	○	○	○	○		○		○				○				○								
C	ATY24	BH1			1			○	○	○	○	○	○	○	○	○	○						○				○								
C	PT05	BH1	~	BH8	8				○	○	○	○	○	○	○	○	○																		
D	PPT02	BH6			1		○	○	○	○	○				○								○	○	○	○	○					○		○	○
D	PPT03	BH6			1		○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○		
E	BKK14	BH1	~	BH4	4			○	○	○	○	○	○	○	○		○						○				○								
E	BKK15	BH1			1			○	○	○	○	○	○	○	○	○	○																		
E	BKK12	BH1			1			○	○	○	○	○	○	○	○	○	○						○				○								
E	PBKK04	BH1	~	BH2	1																														
E	BBKK01	BKCS BH-40			1		○	○	○	○	○					○						○	○	○	○	○	○			○	○	○		○	○
E	BBKK02	BKCS BH-41			1		○	○	○	○	○					○							○	○	○	○	○			○	○	○		○	○
E	BBKK03	BKCS BH-42			1		○	○	○	○	○					○							○	○	○	○	○			○	○	○		○	○
E	BBKK04	BKCS BH-43			1		○	○	○	○	○					○							○	○	○	○	○			○	○	○		○	○
E	BBKK05	BKCS BH-44			1		○	○	○	○	○					○						○	○	○	○	○	○			○	○	○		○	○
E	BBKK06	BKCS BH-45			1		○	○	○	○	○					○						○	○	○	○	○	○			○	○	○		○	○
E	BKK07	BH1			1			○	○	○	○	○	○	○	○	○	○																		
E	BKK06	BH1	~	BH2	2			○	○	○	○	○	○	○	○	○	○						○				○								
E	SP09	BH1			1			○	○	○	○	○	○	○	○	○	○		○				○				○								
E	SP16	BH1	~	BH2	2			○	○	○	○	○	○	○	○	○							○				○								
E	SP08	BH1			1			○	○	○	○	○	○	○	○	○	○		○				○				○								
E	SP11	BH1			1			○	○	○	○	○	○	○	○	○	○						○				○								
E	SP23	BH1	~	BH2	2			○	○	○	○	○	○	○	○	○	○		○				○				○								
F	BKK05	BH1			1			○	○	○	○	○	○	○	○	○	○						○				○								
F	RSP01	BH1			1		○	○	○	○	○				○							○	○	○	○	○	○			○	○	○		○	○
F	RSP02	BH2			1		○	○	○	○	○				○								○	○	○	○	○			○	○	○		○	○
F	RSP03	BH3			1		○	○	○	○	○				○							○	○	○	○	○	○			○	○	○		○	○
F	RSP04	BH4			1		○	○	○	○	○				○								○	○	○	○	○			○	○	○		○	○
F	RSP05	BH5			1		○	○	○	○	○				○								○	○	○	○	○			○	○	○		○	○
F	RSP06	BH6			1		○	○	○	○	○				○								○	○	○	○	○			○	○	○		○	○
F	SP17	BH1	~	BH2	2			○	○	○	○	○	○	○	○	○	○		○				○				○								
F	SP10	BH1			1			○	○	○	○	○	○	○	○	○	○		○				○				○								
F	SP04	BH1	~	BH9	9			○	○	○	○	○	○	○	○	○	○		○				○				○								
F	SP27	BH1			1			○	○	○	○	○	○	○	○	○	○						○				○								
F	SP03	BH1	~	BH2	2			○	○	○	○	○	○	○	○	○	○	○	○		○		○				○	○	○						

Source：JICA Study Team

4.3 Discussion of without countermeasure case (confirmation of necessary measures)

4.3.1 Items for the study

The slope stability of the excavation slope without countermeasures was analyzed by using the circular slip surface slope analysis as well as analysis of the consolidation settlement of the embankment after construction. The slip stability calculation was conducted assuming immediately after completion. It was assumed that the increase in the strength of the foundation ground and the soft clay accompanying of the embankment is not expected. The stability calculations were carried out in consideration of equally distributed loads because embankment crest will be shared with service road. And necessary measures were confirmed. In the consolidation settlement calculation, based on the fact that there is a section where the embankment top serves as a service road, we focused on the amount of residual settlement after the start of service and confirmed the necessity of countermeasures. Also, considering an integrated process, the construction period of countermeasures, such as preloading, was set to less than 2 years. In addition, due to the need to satisfy the planned embankment height, we planned to secure surplus height equivalent to the final settlement amount.



Source : JICA Study Team

Figure 4.3.1 Simple Mechanism of Sliding and Settlement

(1) Method of the study

1) Factor of safety against sliding

Factor of safety is obtained by using the following equation.

$$F_s = \frac{\Sigma\{c_i \cdot \ell_i + (W_i - u_i \cdot b_i)\cos\theta_i \cdot \tan\phi_i\}}{\Sigma W_i \cdot \sin\theta_i}$$

where,

Fs : Factor of safety

ci, ϕi : Cohesion (kN/m^2), Internal friction angle (degrees)

li : Slice length (m)

Wi : Total weight of the slice (kN/m)

ui : Pore water pressure (kN/m^2)

bi : Width of slice (m)

θi : Average inclinometer angle of slice piece's slip surface (degrees)

2) Consolidation settlement analysis

i. Settlement

Consolidation settlement of the ground is obtained by using the method of "⊿e".

$$S = \frac{e_0 - e_1}{1 + e_0} \cdot H$$

where,

S : Consolidation settlement (m)

e_0 : Initial void ratio of consolidation settlement layer

e_1 : Void ratio after consolidation settlement

(Use "e" obtained from "P0＋⊿P" in the equation from "e～log(p) curve")

⊿P : Stress increment of vertical stress, caused by embankment load, etc. (kN/m^2)

P_0 : Stress increment of vertical stress, caused by consolidation pre-compression load (kN/m^2)

H : Thickness of consolidation settlement layer (m)

ii. Settlement time

Time required for consolidation was obtained by using the following equation.

$$t = \frac{Tv \cdot d}{Cv}$$

where,

t　: Time required to reach required degree of consolidation “U” (days)

Tv ：Time factor, corresponding degree of consolidation “U” (Following table)

Cv ：Coefficient of consolidation (m^2/day)

d：Maximum drainage length (m)

Two way drainage：d＝H／2

One way drainage ：d＝H／2

H　：Thickness of consolidation layer (m)

U　：Degree of consolidation (%) ＝St/Sc

St　：Settlement at obtained time (m)

Sc　：Final settlement (m)

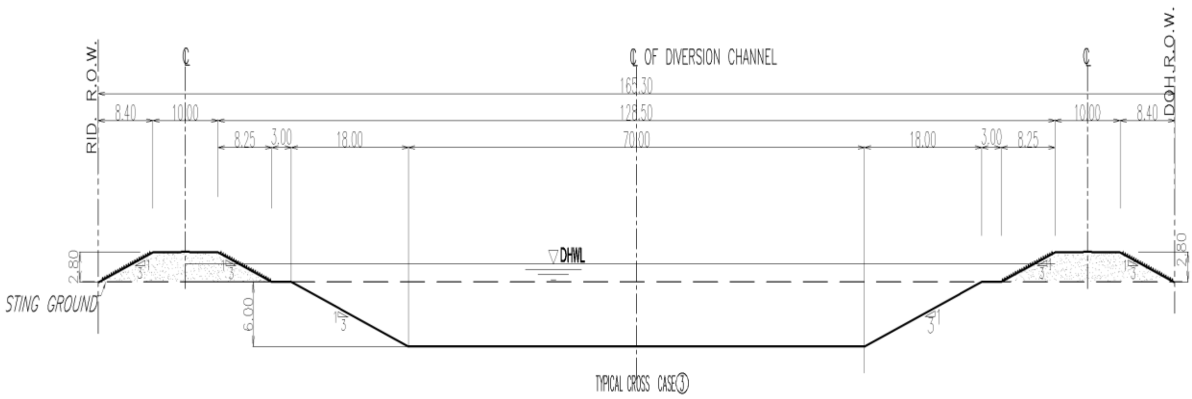
U	10	20	30	40	50	60	70	80	90	95
Tv	0.008	0.031	0.071	0.126	0.197	0.286	0.403	0.567	0.848	1.129

4.3.2 Condition of the Study

(1) Cross section design of the Diversion Channel

Fundamental cross sectional shape of The Diversion Channel is described below.

- Riverbed width：70m
- Slope gradient 1：3.0
- Water depth：8.8m（Excavation depth：6.0m、Embankment height：2.8m）



Source：JICA Study Team

Figure 4.3.2 Cross section of the Diversion Channel (Repeated)

(2) Ground condition

In this work, a geological survey has been done in one location in each of the three areas in order to investigate the soil condition along the planned alignment of the Diversion Channel. On the other hand, for the preliminary discussion and investigation, existing drilling data were used to make initial comparisons of different construction methods. Details of each item are further discussed to select the construction method based on the comparison of new drilling results. For the southern part, the rough comparison result based on the existing geological surveys and discussion result of detail items for the solution method based on the new geological survey is shown in this report. For the central part, the discussion result based on the existing geological survey is shown. And for the northern part, the discussion result is shown, where the strata structure is based on new drilling data while soil properties are based on the existing geological survey. The soil properties were set by using the following method.

●Unit Volume Weight γ_t

According to the soil experimental results, average value, the saturated unit weight γsat is assumed as wet unit weight γt +1.0kN/m3.

●Cohesion C

The cohesion C could be obtained from the average value of the result from laboratory experiment. However, the cohesion obtained from the experiment for the layer near the boundary was assumed to be soil with difficult properties in the perspective of water content, wet weight, and grain size analysis, even though they are evaluated to be the same layer in the soil boring log. For the deep soil layer where laboratory experiments were not performed, the cohesion was predicted based on the empirical data from the literature, based on a representative N-value according to the assumption by Terzaghi and Peck.

$$c = q_u/2 = N/0.16 = 6.25N$$

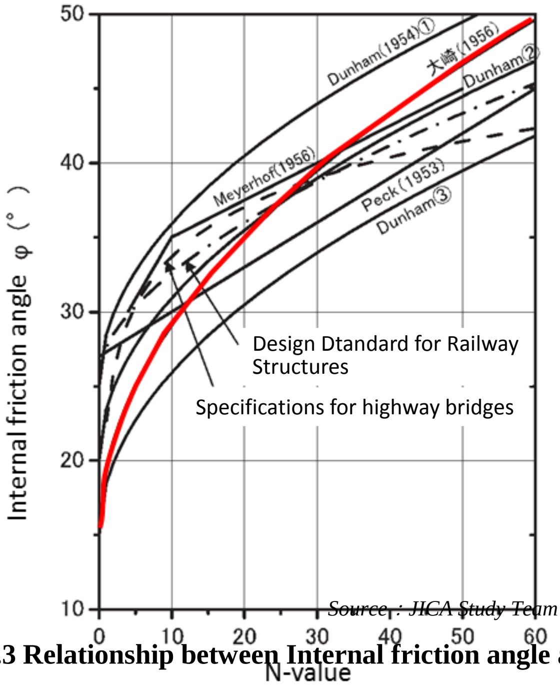
Where, c is cohesion (kN/m2), qu is unconfined compression strength (kN/m2), N is the representative N-value.

(Source：Guideline for temporary structures, road civil engineering, Japan Road Association, 1999.3)

●Internal friction angle ϕ

The Internal friction could be obtained from the average value of the result from laboratory experiment. The predicted value of the internal friction angle was obtained from the representative N-value whenever it was not experimental data and was predicted by using the Oosaki formula.

*The curve of Oosaki formula (red) is relatively in the middle among all the empirical methods.



Source：JICA Study Team

Figure 4.3.3 Relationship between Internal friction angle and N-value

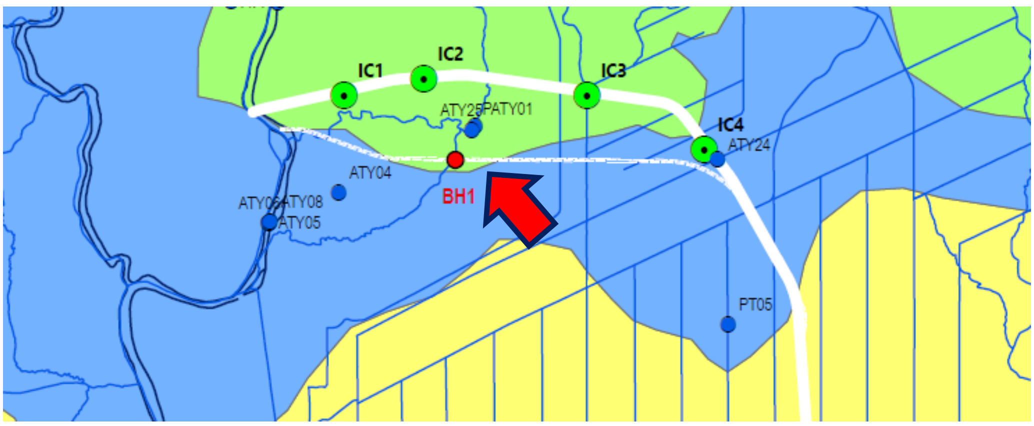
●Consolidation Characteristic

The Consolidation characteristic could be obtained from the average value of the result from consolidation experiment. But, there is no consolidation experiments were performed for the soil from the boring in the northern area, and therefore the results from the experiments on soil from the central area were used. The design quality of soil as a fixed number set after the new borings in every section is as below.

1) Northern Part

●Soil Structure

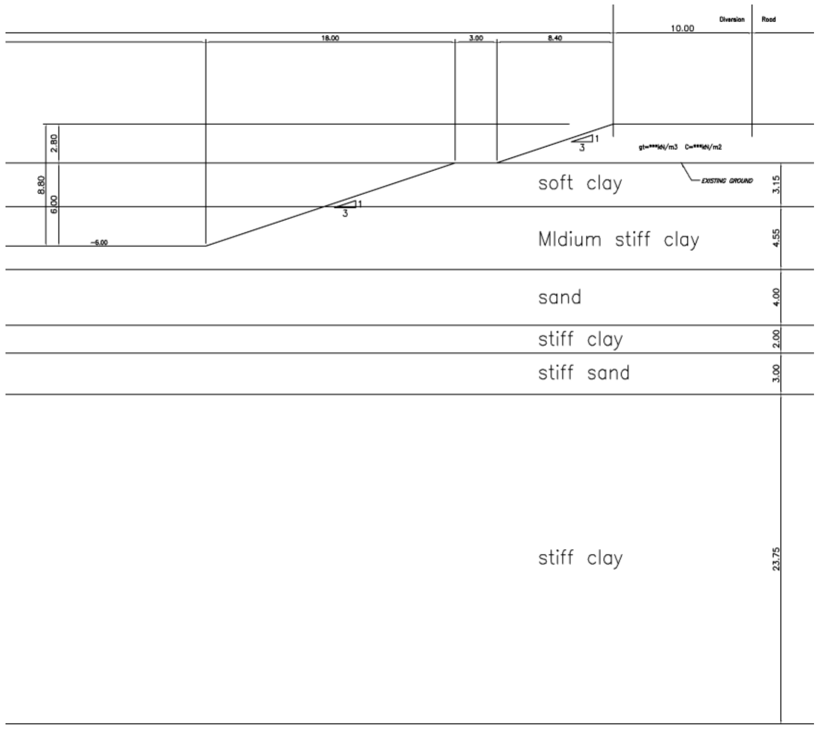
The location of the boring, located in the north part, is shown in the following figure. This boring is located at the center of the northern part. Apparently, there is a soft clay layer in this boring only, but there is not in others borings located around.



Source：JICA Study Team

Figure 4.3.4 Boring Position

The soft clay layer is 3 m in depth from the ground level. Below the soft clay layer, the medium clay, sand and a stiff clay layer were found. In this investigation, the soft clay is considered as a consolidation layer.



Source：JICA Study Team

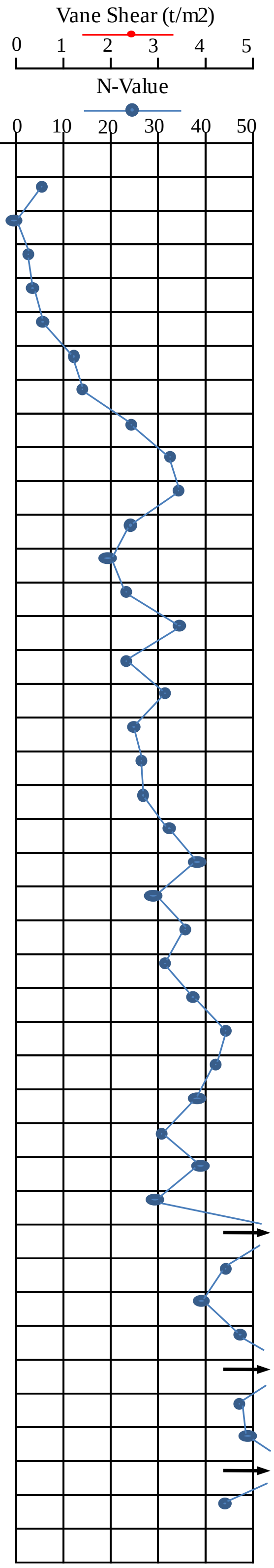
Figure 4.3.5 Strata Map of Northern part (Estimated from Boring (BH1) in this study)

BH1 Coodinates : X=680015. Y=1577587

GWL: GL-1.50m

Depth	Description
0.80	Bank soil, Dark brown
1.20	Humix soil, Black
3.15	Up. part: slighttry stif clay Dark gray. Low. part: Soft clay. Dark gray.
7.70	Medium stiff clay. Yellowish gray. 4.40m - milkey gray. Containing pumice (fai=1mm). 5m - ocher, Water contents: low. 7m Sandy silt (very fine sand is
11.70	Coase sand, brown, unevenness particle. Silt containning. App.10.00m - granule containing.
13.70	Stiff clay, shallow brown. Low water contents.
16.70	Silty sand (wide classification of grain), Brown. Medium sand containing
26.70	Stiff clay, milkey gray. Reddish clay part containing. 19m - homogeneous milkey yellow color 22m - Stiff clay, brown. App.24m milkey brown
27.70	Coase sand, brown
28.70	Stiff silt, milky gray, 28m fine sand seam
29.70	Silty F.sand, Liver.
31.70	Silty clay, gray white. 31m clay, ocher.
32.70	Silty sand
40.45	Stiff clay, Ocher(Khaki)

Depth	15	15	N−Value	
1	3	4	**7**	30
2	0	0	**0**	45
3	1	2	**3**	30
4	2	2	**4**	30
5	3	4	**7**	30
6	6	7	**13**	30
7	7	8	**15**	30
8	8	17	**25**	30
9	15	18	**33**	30
10	17	18	**35**	30
11	12	13	**25**	30
12	12	16	**28**	30
13	10	14	**24**	30
14	14	21	**35**	30
15	13	11	**24**	30
16	15	17	**32**	30
17	12	14	**26**	30
18	12	15	**27**	30
19	12	16	**28**	30
20	15	18	**33**	30
21	16	23	**39**	30
22	15	15	**30**	30
23	17	20	**37**	30
24	13	19	**32**	30
25	15	24	**39**	30
26	17	28	**45**	30
27	18	25	**43**	30
28	17	22	**39**	30
29	16	15	**31**	30
30	17	23	**40**	30
31	12	18	**30**	30
32	27	32	**59**	30
33	21	24	**45**	30
34	17	23	**40**	30
35	22	27	**49**	30
36	30	33	**63**	30
37	21	28	**49**	30
38	25	25	**50**	30
39	24	29	**53**	30
40	21	24	**45**	30



Source ：JICA Study Team

Figure 4.3.6 Result from the Boring Survey in this study (BH1)

●Soil Modulus

The data for the soil modulus of the northern area is shown in the table below.

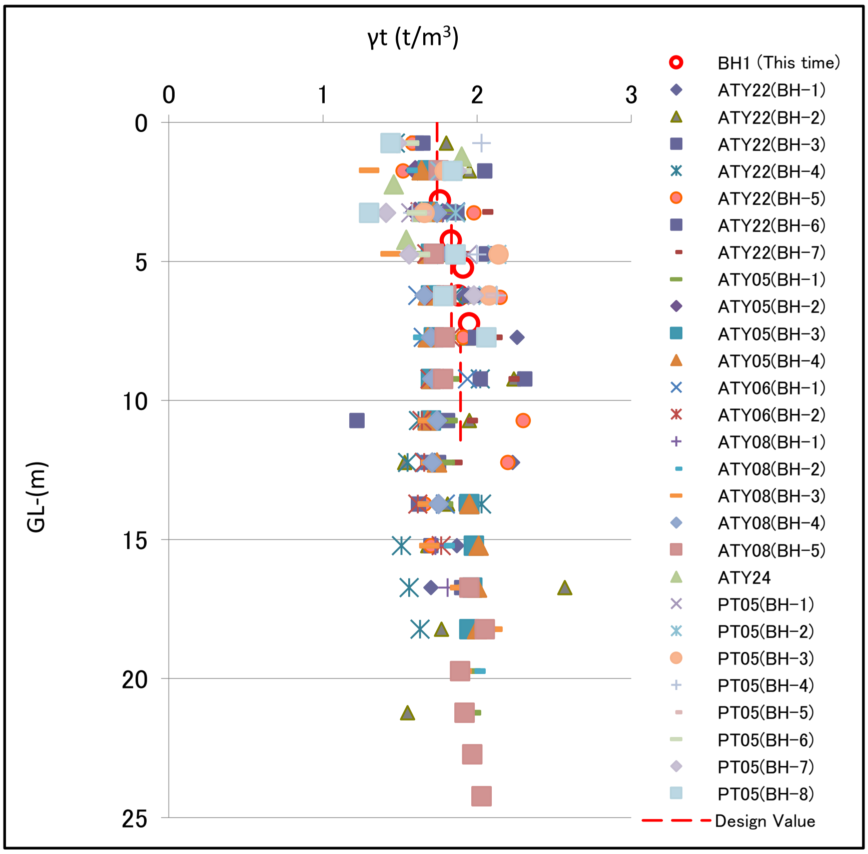
Table 4.3.1 Soil Modulus in Northern Part

Layer	Water Content W (%)	Unit weight γ_t (kN/m^3)	Internal friction φ (°)	Cohesion C (kN/m^2)	Consolidation curve (e-logP, Cv)
Soft clay	33	17.4	0	29.0 (Maximum GL-3.15m)	Set curve1
Medium stiff clay	35	18.3	0	-0.55Z + 27.3 (Z:Depth GL-m)	Set curve2
sand	-	18.9	39	-	Drainagelayer
Very Stiff clay	-	19.8	0	-	Drainagelayer

Source : JICA Study Team

●Unit Volume Weight γ_t

The unit volume weight γt is the average value of the samples of the existing boring and the new boring (BH 01) in the northern part (Kasetsart C classification [blue]).

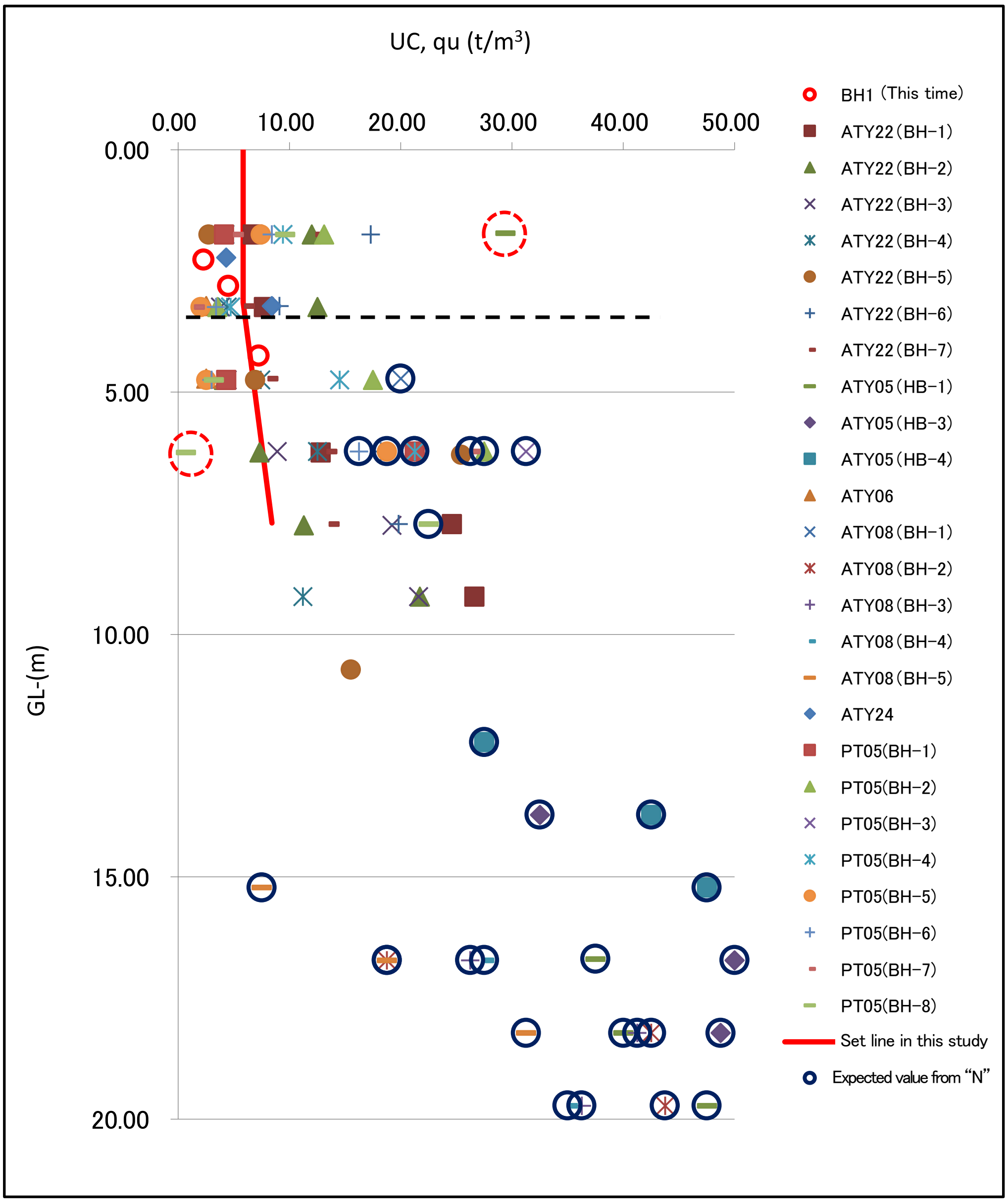


Source : JICA Study Team

Figure 4.3.7 Unit Volume Weight from the existing boring sample

●Cohesion C

Uniaxial Compressive Strength is obtained as an average value based on existing boring data and new boring data (BH01) in the northern area (Kasetsart University, Classification : C (blue)) and the result of the Unconfined Compression Test. The value of the point with the red dashed circle in the figure was omitted since it was an extreme outlier. Average of values obtained from the layer lower than the dashed line drawn at the 3m-deep were calculated as C for this lower layer. In the area deeper than the broken line, an approximate straight line connecting the C value (Cohesion) at the depth indicated by the broken line and the average C value at the depth of 5m was determined. And C value was approximated by this straight line.



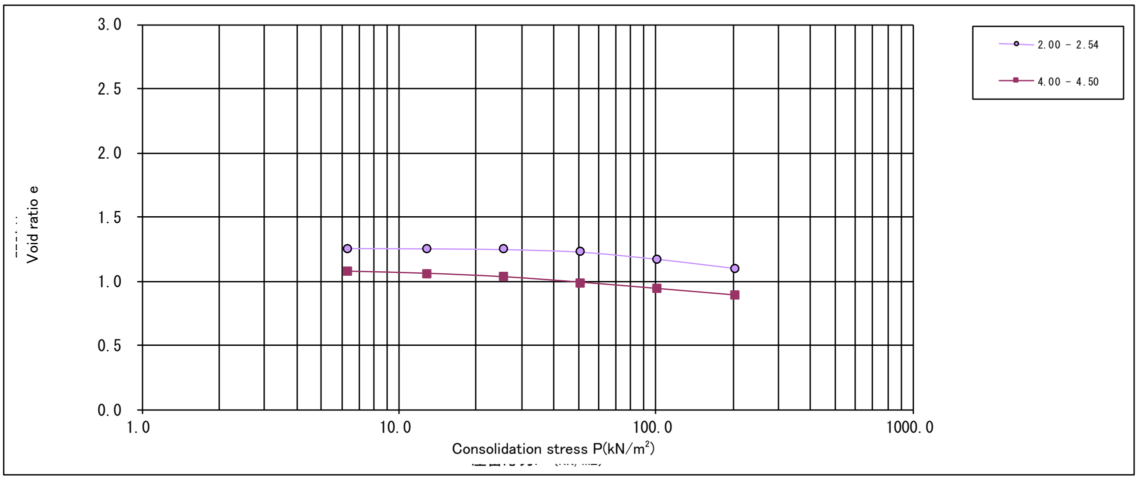
Source : JICA Study Team

Figure 4.3.8 Uniaxial Compressive Strength set with reference to existing boring sample

●Consolidation curve

e-log Curve									
Boring No.	Consolidation stress※ P(kN/m²) Depth	0.0	6.3	12.8	25.5	50.8	101.5	203.0	Note
BH1	2.00 – 2.54	1.266	1.256	1.254	1.248	1.228	1.172	1.101	Set curve1
Boring No.	Consolidation stress※ P(kN/m²) Depth	0.0	10.0	20.0	40.0	80.0	160.0	320.0	Note
BH1	4.00 – 4.50	1.198	1.076	1.059	1.032	0.989	0.939	0.888	Set curve2

※Converted Ksc unit of data sheet to SI

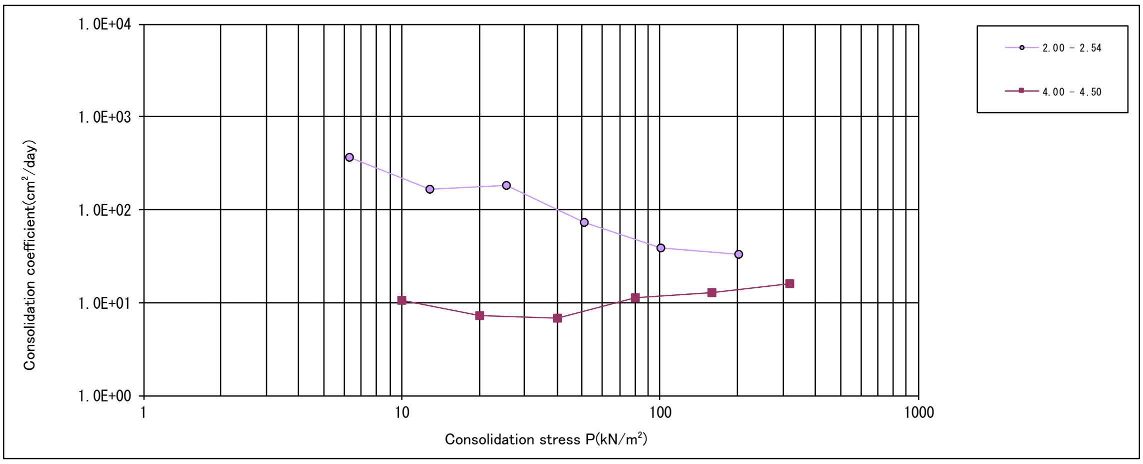


Source ：JICA Study Team

Figure 4.3.9 Relationship between void ratio and consolidation stress, based on boring samples

Cv Curve									
Boring No.	Consolidation stress※ P(kN/m²) Depth	0.00	6.3	12.8	25.5	50.8	101.5	203	Set curve1
BH6	2.00 – 2.54		362.02	164.85	184.55	73.35	38.19	33.00	
Boring No.	Consolidation stress※ P(kN/m²) Depth	0.0	10.0	20.0	40.0	80.0	160.0	320.0	Set curve2
BH7	4.00 – 4.50		10.454	7.171	6.739	11.232	12.960	15.898	

※Converted Ksc unit of data sheet to SI



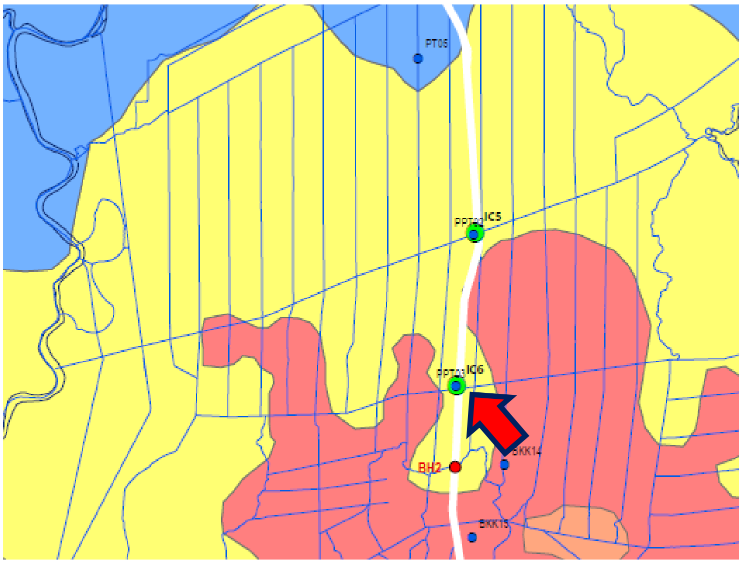
Source ：JICA Study Team

Figure 4.3.10 Relationship between consolidation coefficient and consolidation stress, set based on boring samples

2) Central Part

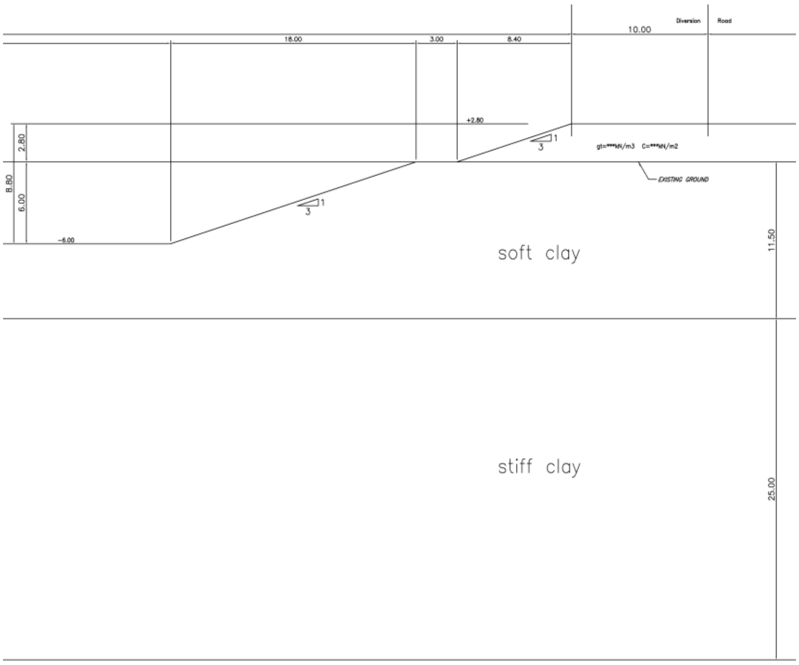
●Soil Structure

The location of the boring in the central part is shown in Figure 4.3.11. Soil boring log obtained from the investigation is shown in Figure 4.3.12. The data from the central part boring were used as representative for the southern area (layer of soft clay is thick).



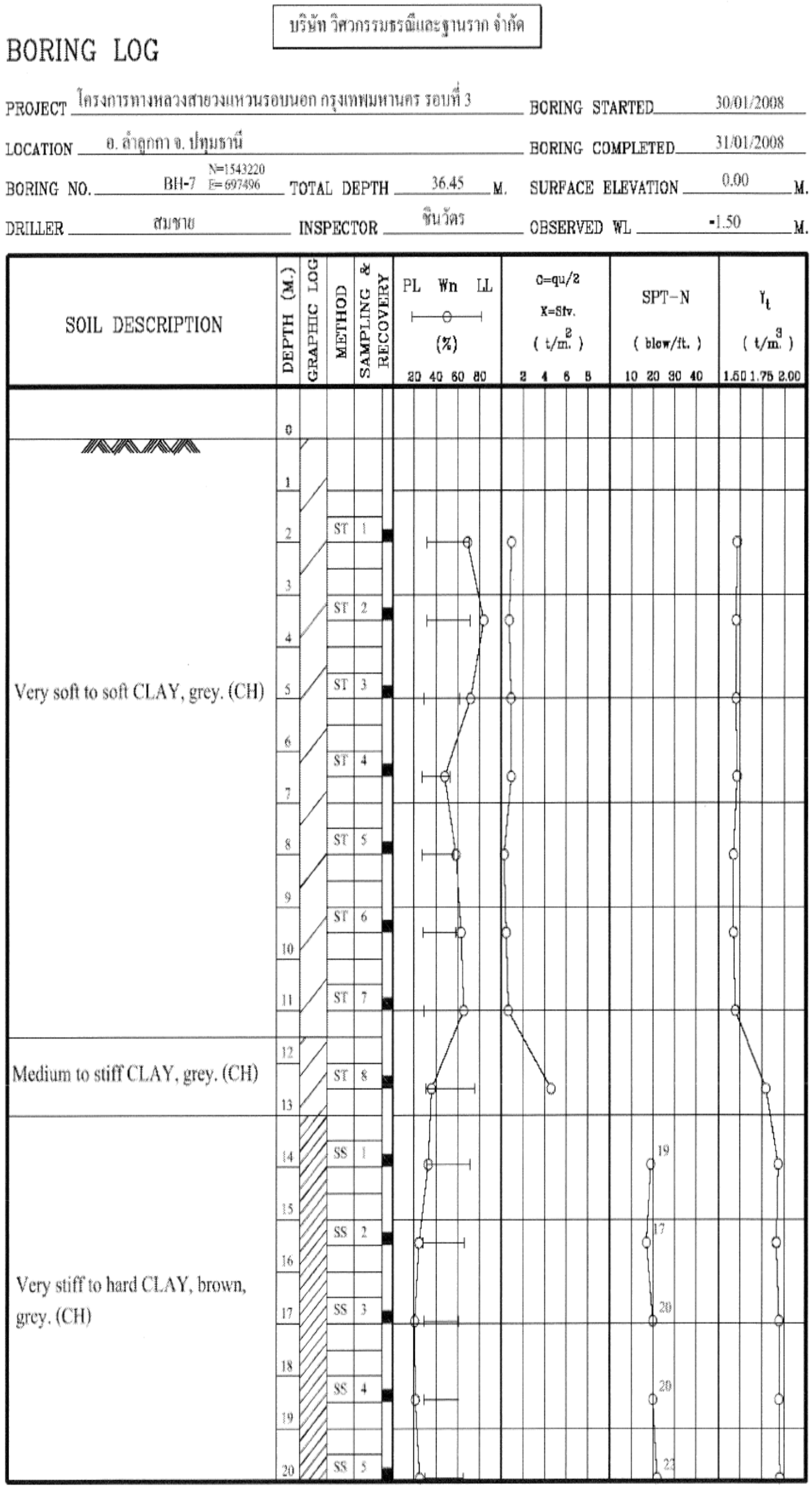
Source：JICA Study Team

Figure 4.3.11 Boring Position



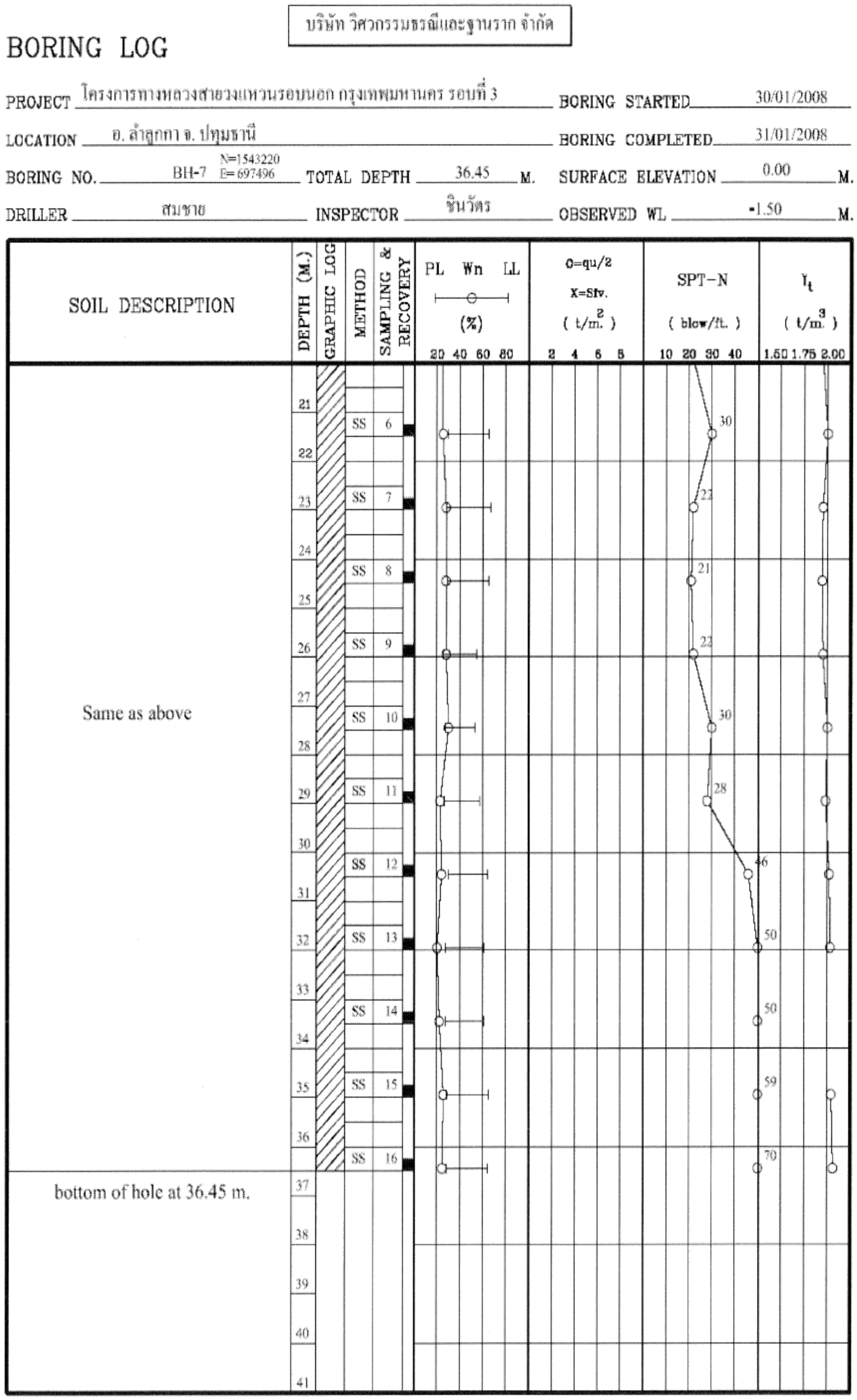
Source：JICA Study Team

Figure 4.3.12 Strata Map of Central part (Estimated from existing Boring)



Source : JICA Study Team

Figure 4.3.13 Result of Existing Boring Survey (PPT03)



Source：JICA Study Team

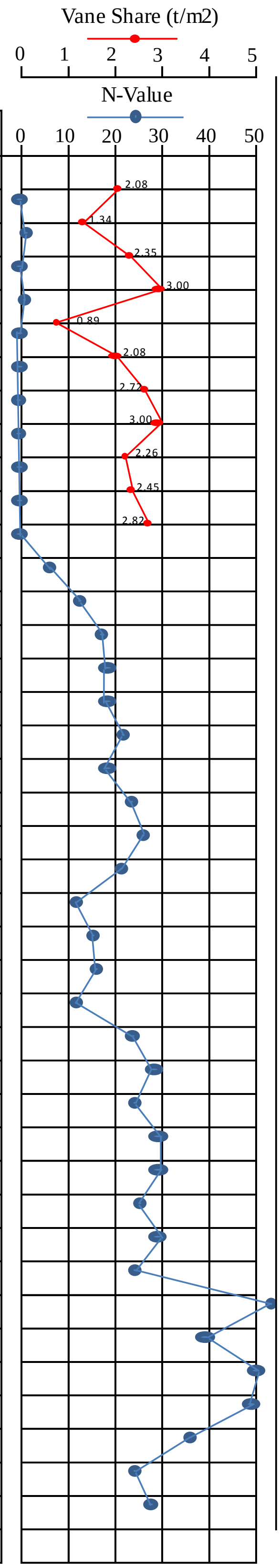
Figure 4.3.14 Result of Existing Boring Survey (PPT03)

BH2 Coodinates : X=698581. Y=1538724

GWL: GL-1.50m

Depth	Description
0.40	Surface soil silty clay brown
11.40	Soft Clay, Dark gray. High moisture contents. 2.20m shell fragment seam (f=3cm). 4.30-4.40m silty sand seam(f=10cm). Silty clay. 5.00m - Moisture contents going to low. Below 6m Silty clay, green gray. 9m low moisture contents.
30.70	Stiff clay, dark yellow gray. Low moisture contents. 14m - 16m : Stiff Sandy silt. Milkey gray 17m - Stiff clay 18m - Dark brown, black particle containing (volcanic?) 20m : Limonite nodule containing (fai 5mm) 21m: red clay and milkey clay admix. Taffaciouse. 22m - Stiff clay milkey gray.
31.70	Silty sand, volcanic.
32.70	Stiff Clay, milkey gray
33.70	Sandy silt, Dark gray. well sorted.
39.70	Fine sand, Dark Brown. 36m - Fine sand to Medium sand. Lower part, going to coas sand.
40.45	Silt. Brown.Homogeneous.

Depth (m)	15	15	N−Value	
1	0	0	**0**	45
2	0	1	**1**	39
3	0	0	**0**	45
4	0	0	**1**	47
5	0	0	**0**	45
6	0	0	**0**	45
7	0	0	**0**	45
8	0	0	**0**	45
9	0	0	**0**	45
10	0	0	**0**	45
11	0	0	**0**	45
12	3	4	**7**	30
13	5	8	**13**	30
14	8	10	**18**	30
15	7	12	**19**	30
16	8	11	**19**	30
17	10	12	**22**	30
18	8	11	**19**	30
19	11	13	**24**	30
20	12	15	**27**	30
21	10	12	**22**	30
22	5	7	**12**	30
23	7	9	**16**	30
24	7	10	**17**	30
25	5	7	**12**	30
26	8	16	**24**	30
27	12	17	**29**	30
28	11	14	**25**	30
29	13	17	**30**	30
30	14	16	**30**	30
31	11	15	**26**	30
32	13	17	**30**	30
33	10	15	**25**	30
34	21	33	**54**	30
35	20	20	**40**	30
36	20	31	**51**	30
37	28	22	**50**	30
38	18	19	**37**	30
39	10	15	**25**	30
40	13	16	**29**	30



Source : JICA Study Team

Figure 4.3.15 Result of New Boring Survey (BH02)

●Soil Modulus

The data for soil modulus of the Central area is shown in the table below.

Table 4.3.2 Soil Modulus in Central Part

Set value reflecting new boring survey: used for final setting of countermeasure work items.

Layer	Water Content W (%)	Unit weight γ_t(kN/m^3)	Internal friction φ (°)	Cohesion C(kN/m^2)	Consolidation curve (e−logP, Cv)
Very soft to soft clay	73	16.1	0	−1.70Z＋10.2 (Z:Depth GL−m)	Set curve
Midium to stiff clay	−	19.4	−	−1.70Z＋30.6 (Z:Depth GL−m)	-

Set value by the existing boring survey: used for comparative study of countermeasure construction method.

Layer	Water Content W (%)	Unit weight γ_t(kN/m^3)	Internal friction φ (°)	Cohesion C(kN/m^2)	Consolidation curve (e−logP, Cv)
Very soft to soft clay	68	16.5	0	−2.10Z＋6.75 (Z:Depth GL−m)	Set curve

●Unit Volume Weight γ_t

Unit volume weight γt is set as average value based on existing borings and new boring (BH02) in the northern area (Kasetsart University, Classification : D (yellow)).

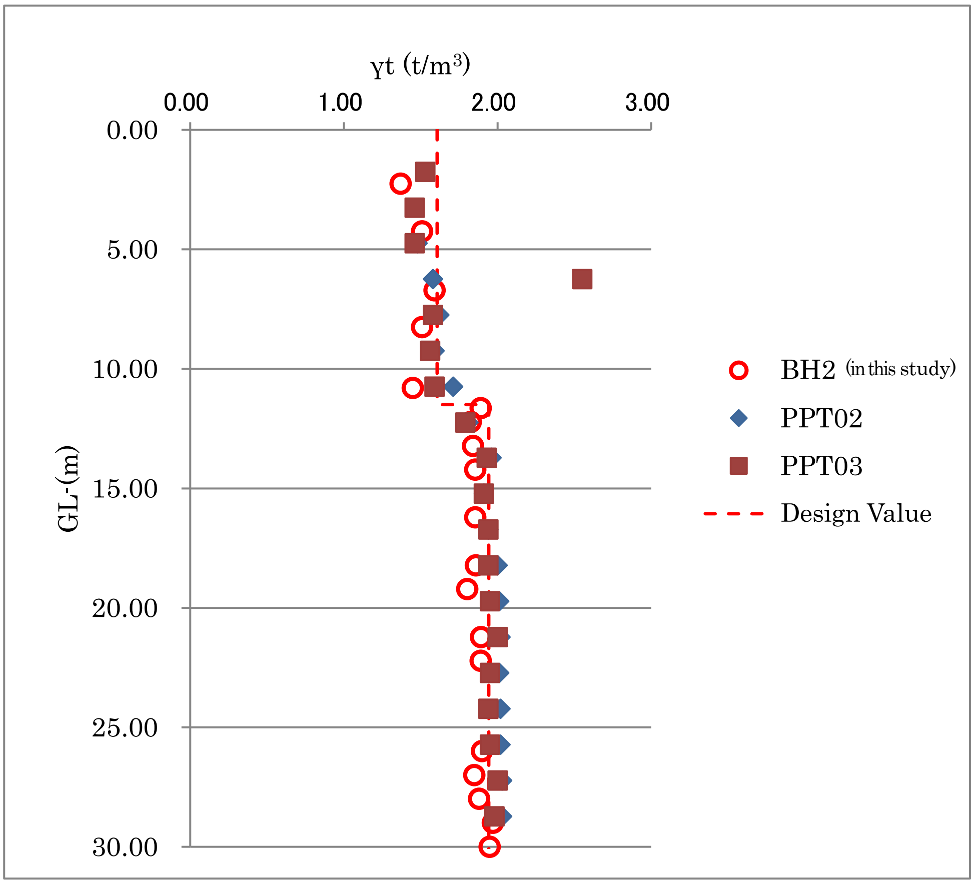
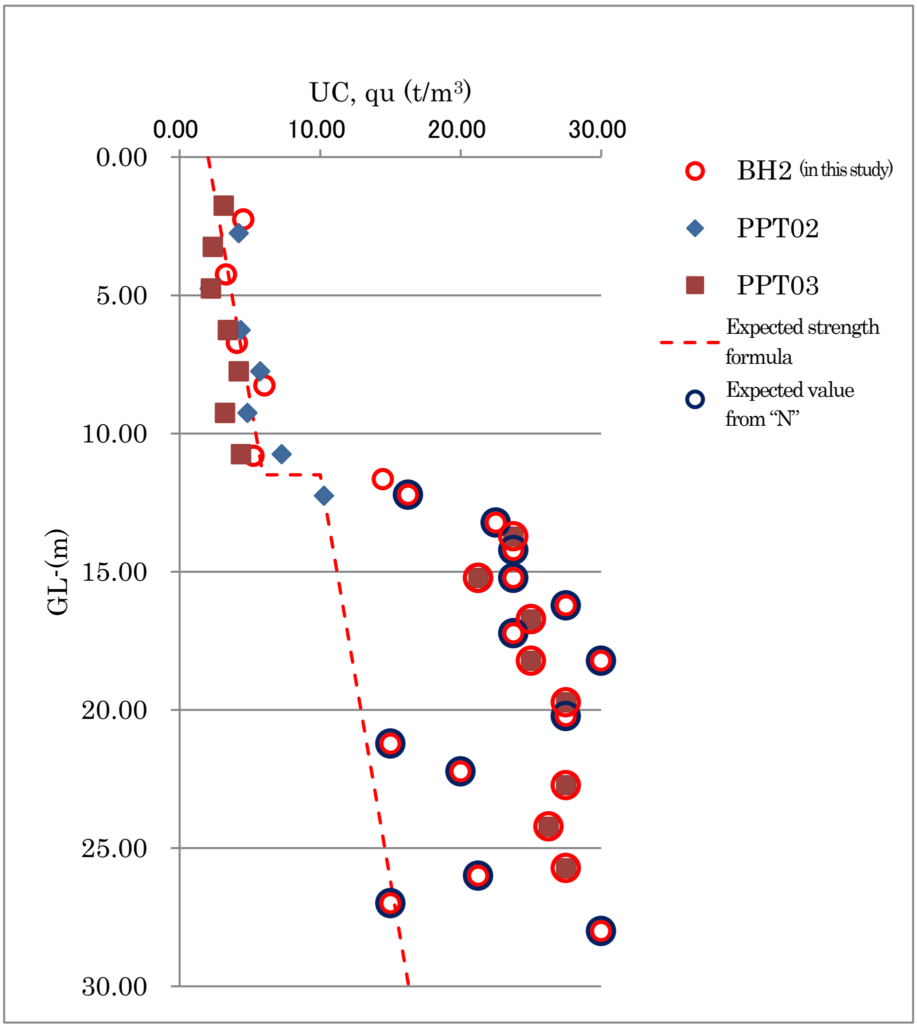


Figure 4.3.16 Unit Volume Weight from the existing boring sample

●Cohesion C

Cohesion was obtained as an average value based on previous data in the central area (Kasetsart University Classification: D (yellow)) and uniaxial / triaxial compressive strength of new boring data (BH02) and the result from the unconfined compression test, with strength increasing with the depth.



Source : JICA Study Team

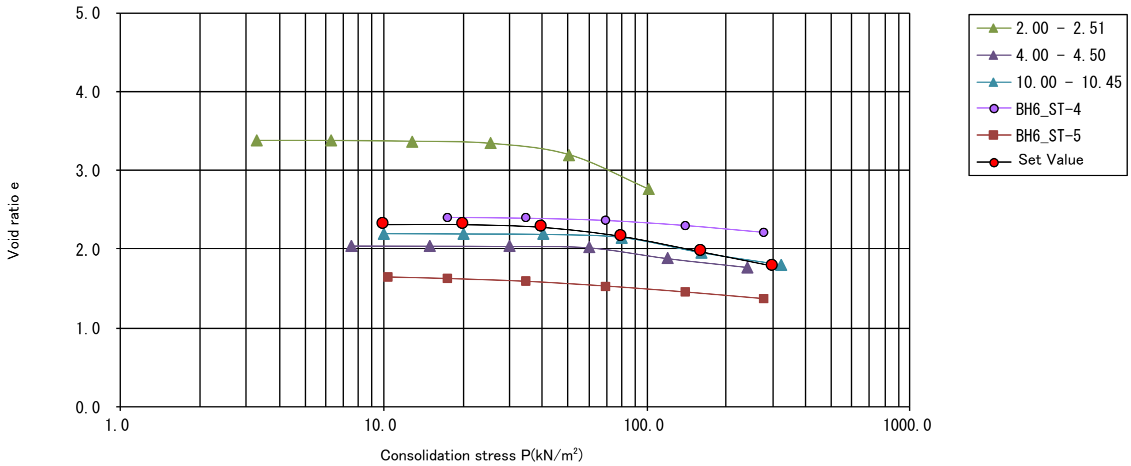
Figure 4.3.17 Uniaxial Compressive Strength set with reference to existing boring sample

●Consolidation curve

Consolidation curve is obtained as an average value based on the data of previous consolidation testing.

e-log Curve									
Boring No.	Consolidation stress※ P(kN/m²) Depth	0.0	3.3	6.3	12.8	25.3	50.6	101.5	
BH2	2.00 – 2.51	3.405	3.379	3.378	3.369	3.343	3.199	2.762	
Boring No.	Consolidation stress※ P(kN/m²) Depth	0.0	7.5	15.0	30.0	60.0	119.5	239.5	
BH2	4.00 – 4.50	2.052	2.042	2.04	2.036	2.019	1.882	1.771	
Boring No.	Consolidation stress※ P(kN/m²) Depth	0.0	10.0	20.0	40.5	80.5	161.0	322.0	
BH2	10.00 – 10.45	2.224	2.205	2.201	2.195	2.154	1.953	1.795	
Boring No.	Consolidation stress※ P(kN/m²) Depth	0.00	10.4	17.4	34.7	69.5	138.9	277.9	138.9
BH6	ST-4	2.424	–	2.406	2.396	2.367	2.303	2.214	2.240
BH7	ST-5	1.906	1.655	1.635	1.597	1.535	1.456	1.366	1.389
	Consolidation stress※ P(kN/m²) Depth ²)※	0.00	10	20	40	80	160	300	Note 号
Set Value 直			2. 320	2. 320	2. 285	2. 167	1. 970	1. 786	Set curve

※Converted Ksc unit of data sheet to SI

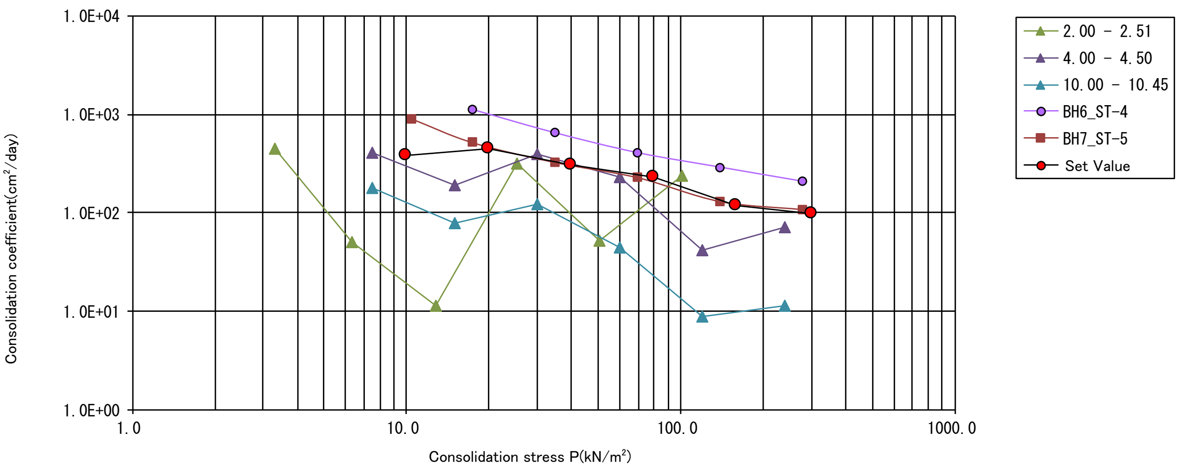


Source : JICA Study Team

Figure 4.3.18 Relationship between consolidation stress and void ratio from the existing boring sample

Cv Curve									
Boring No.	Consolidation stress※ P(kN/m²) Depth	0.0	3.3	6.3	12.8	25.3	50.6	101.5	
BH2	2.00 － 2.51		443.664	50.112	11.5776	320.112	52.7904	237.168	
Boring No.	Consolidation stress※ P(kN/m²) Depth	0.0	7.5	15.0	30.0	60.0	119.5	239.5	
BH2	4.00 － 4.50		407.2896	193.1904	391.9104	227.664	41.5584	71.0208	
Boring No.	Consolidation stress※ P(kN/m²) Depth	0.0	7.5	15.0	30.0	60.0	119.5	239.5	
BH2	10.00 － 10.45		179.0208	78.192	120.7008	44.928	8.8992	11.232	
Boring No.	Consolidation stress※ P(kN/m²) Depth	0.00	10.4	17.4	34.7	69.5	138.9	277.9	138.9
BH6	ST-4	－	－	1127.779	652.579	407.549	289.613	207.360	－
BH7	ST-5	－	908.323	519.178	327.110	229.219	131.069	108.518	－
	Consolidation stress※ P(kN/m²) Depth	0.00	10	20	40	80	160	300	Note
Set Value			376. 553	447. 690	309. 018	229. 306	117. 785	99. 533	Set curve

※Converted Ksc unit of data sheet to SI



Note: Average value of the same pressure load is set as the set value, but some of them were adjusted to make the curve smooth.

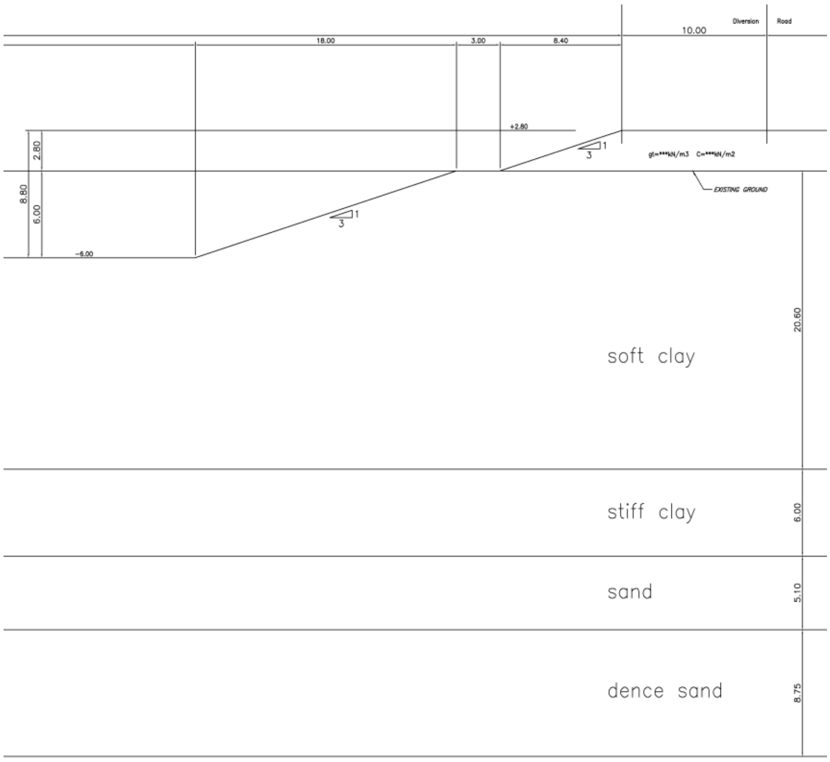
Source : JICA Study Team

Figure 4.3.19 Relationship between consolidation stress and coefficient of consolidation from the existing boring sample

3) Southern part

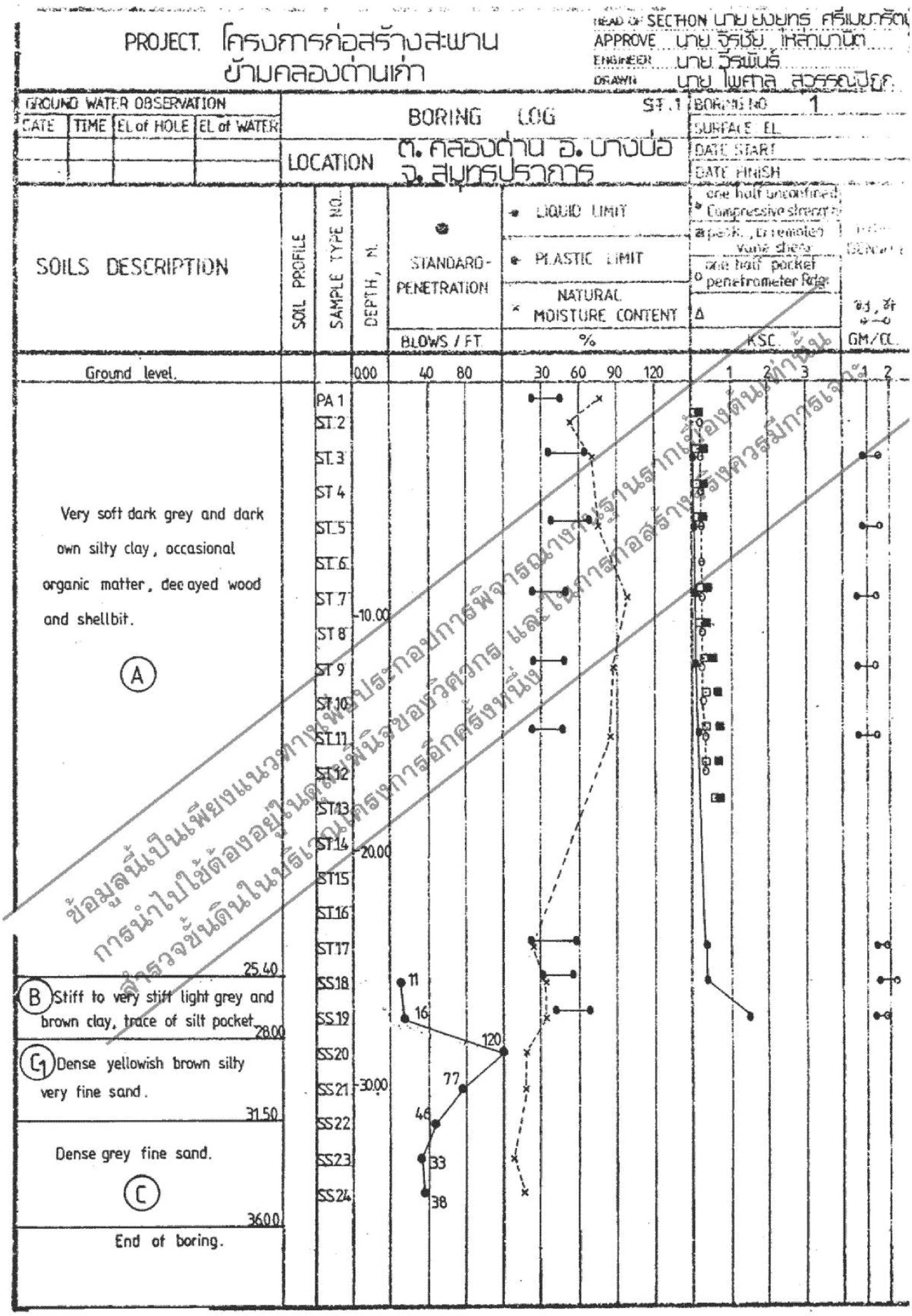
- Soil Structure

Set soil modulus of the central area is shown below. In the southern area, there is no previous data of consolidation test result. Therefore test data of existing borings in the central area is used instead. Investigation of countermeasure construction against soft clay was based on solid modulus data of existing borings (SP03 BH01) in the thickest soft clay area. Then various factors for countermeasures were investigated again by using the data of the new borings (BH3). Investigated cross section is shown below.



Source：JICA Study Team

Figure 4.3.20 Strata Map of North Part (Estimated from Existing New Boring result)



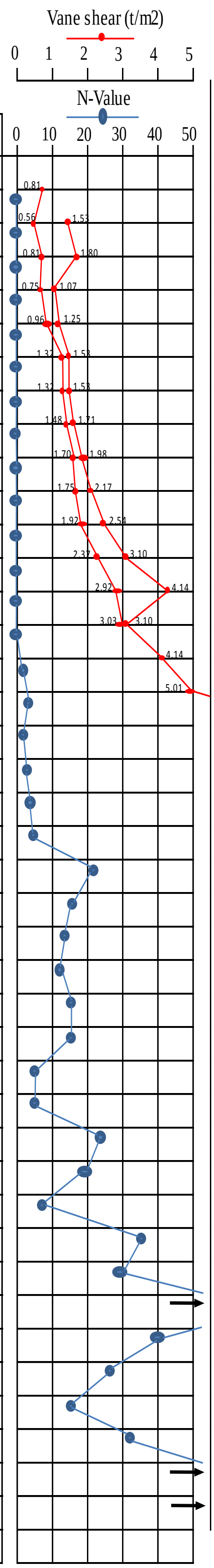
Source : JICA Study Team

Figure 4.3.21 Result of Existing Boring Survey（SP03）

BH3 Coodinates : X=696075. Y=1494944

Depth (m)	Mark	Description
0 – 1.20		Bank Soil: Gravel, sandy silt
1.20 – 16.40		Very Soft Clay. Dark gray - Bluish gray. High moisture contents. Shell fragment containing. Moisture contents reduced. From 10m Dark green gray.
16.40 – 20.60		Clay Green gray. Low moisture contents.
20.60 – 26.60		Stiff clay. Green gray. Consolidated silt fragment containing in upper part. Middle to bottom layer is volcanic and shallow purple white.
26.60 – 30.70		Very fine sand. Yellow gray. High moisture contents. Loose. Below 28.70m silty.Moisture contents decrease.
30.70 – 31.70		Sandy silt dark gray.
31.70 – 36.70		Dence uniformity very fine sand(only upper part). Below 33m medium to coase sand. Yellow brown. 36m granule contents.
36.70 – 38.70		Silty clay.yellow brown.
38.70 – 40.45		Very fine sand. Silty. Yellowish gray.

Depth	15	15	N－Value	
1	0	0	**0**	45
2	0	0	**0**	45
3	0	0	**0**	45
4	0	0	**0**	45
5	0	0	**0**	45
6	0	0	**0**	45
7	0	0	**0**	45
8	0	0	**0**	45
9	0	0	**0**	45
10	0	0	**0**	45
11	0	0	**0**	45
12	0	0	**0**	45
13	0	0	**0**	45
14	0	0	**0**	45
15	0	2	**2**	34
16	1	3	**4**	35
17	0	2	**2**	40
18	1	2	**3**	38
19	2	2	**4**	35
20	2	3	**5**	32
21	10	12	**22**	30
22	7	10	**17**	30
23	7	7	**14**	30
24	6	6	**12**	30
25	8	9	**17**	30
26	8	9	**17**	30
27	3	3	**6**	30
28	3	3	**6**	30
29	13	11	**24**	30
30	9	11	**20**	30
31	6	3	**9**	30
32	18	19	**37**	30
33	12	18	**30**	30
34	30	32	**62**	30
35	24	17	**41**	30
36	16	12	**28**	30
37	7	10	**17**	30
38	15	17	**32**	30
39	30	37	**67**	30
40	27	33	**60**	30



Source : JICA Study Team

Figure 4.3.22 Result of Newly done Boring Survey in this study (BH3)

●Soil Modulus

The data for the soil modulus of the Southern area is shown in the table below.

Table 4.3.3 Soil Modulus in Southern Part

Soil Modulus set with reference to existing boring：used for comparative study of countermeasure construction method.

Layer	Average N-value (SP03)	Unit weight γ_t (kN/m^3)	Internal friction Angle φ（°）	Cohesion C (kN/m^2)	Deformation Coefficient (kN/m2)	Consolidation curve (e-logP, Cv)
embankment	–	16	0	15	–	–
Soft clay	–	15.3	0	GL0～-10m：10kN/m2 GL-10～：C=-1.0Z (Z:Depth GL-m)	500	Set curve 泉
stiff clay	–	20.0	0	140.7	–	–
Dence sand	62.8	18.8	31	0	–	–

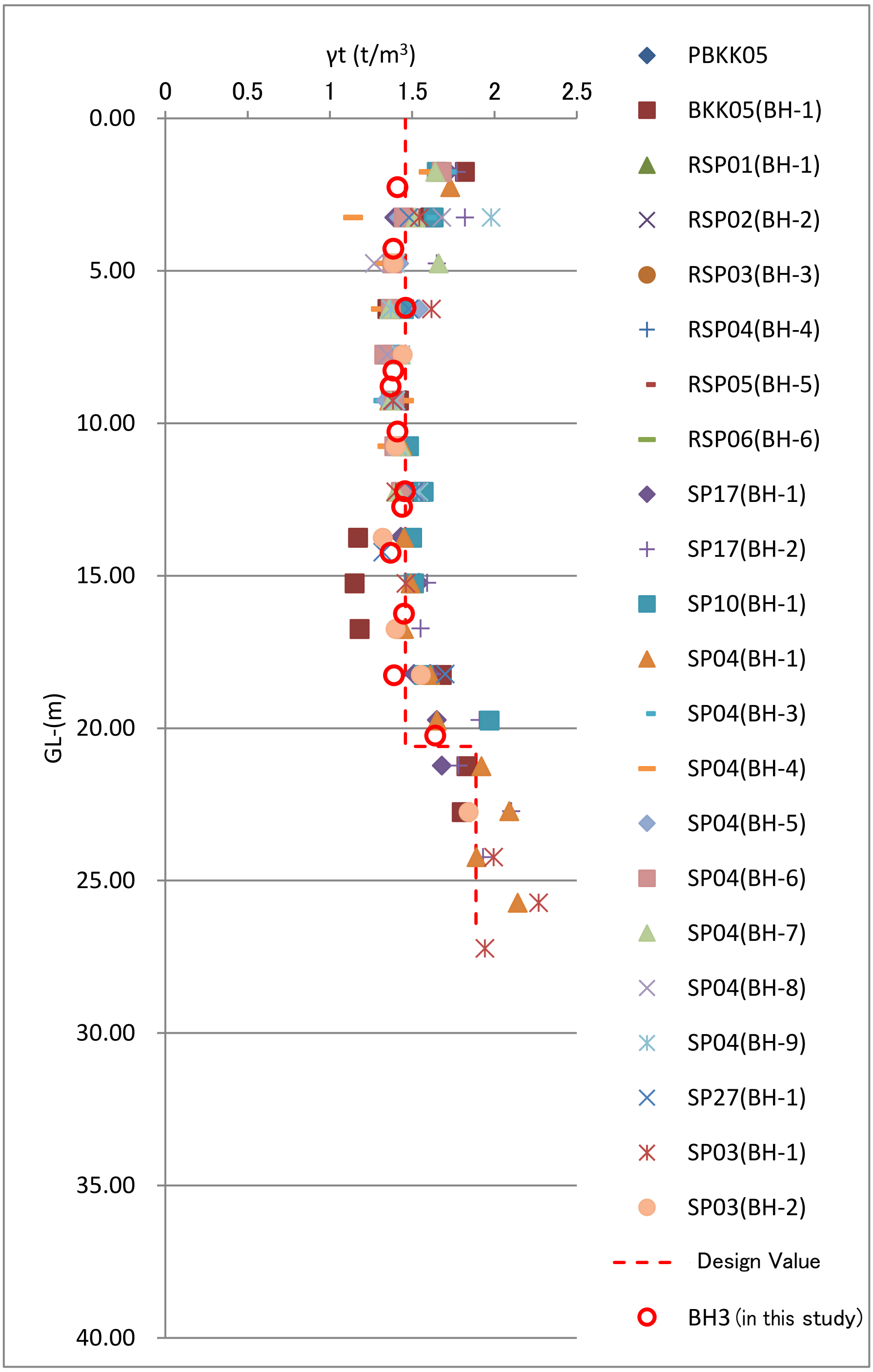
Soil Modulus set with reference to boring in this study：used for final setting of countermeasure work items.

Layer	Average N-value	Depth GL- (m)	Water Content W (%)	Unit weight γ_t (kN/m^3)	Internal friction Angle φ（°）	Cohesion C (kN/m^2)	Consolidation curve (e-logP, Cv)
Very Soft clay ～ Clay	1	0.0 ～ 10.0	93	14.6	0	10.0	Set curve
		10.0 ～ 20.6				-1.00Z (Z:Depth GL-m)	
Stiff clay	16	20.6～26.6	–	18.9	–	130.5	–

Source：JICA Study Team

●Unit Volume Weight γ_t

Unit volume weight, γt, is set as average value based on existing borings and new boring (BH03) in the southern area (Kasetsart University Classification: F (brown)).

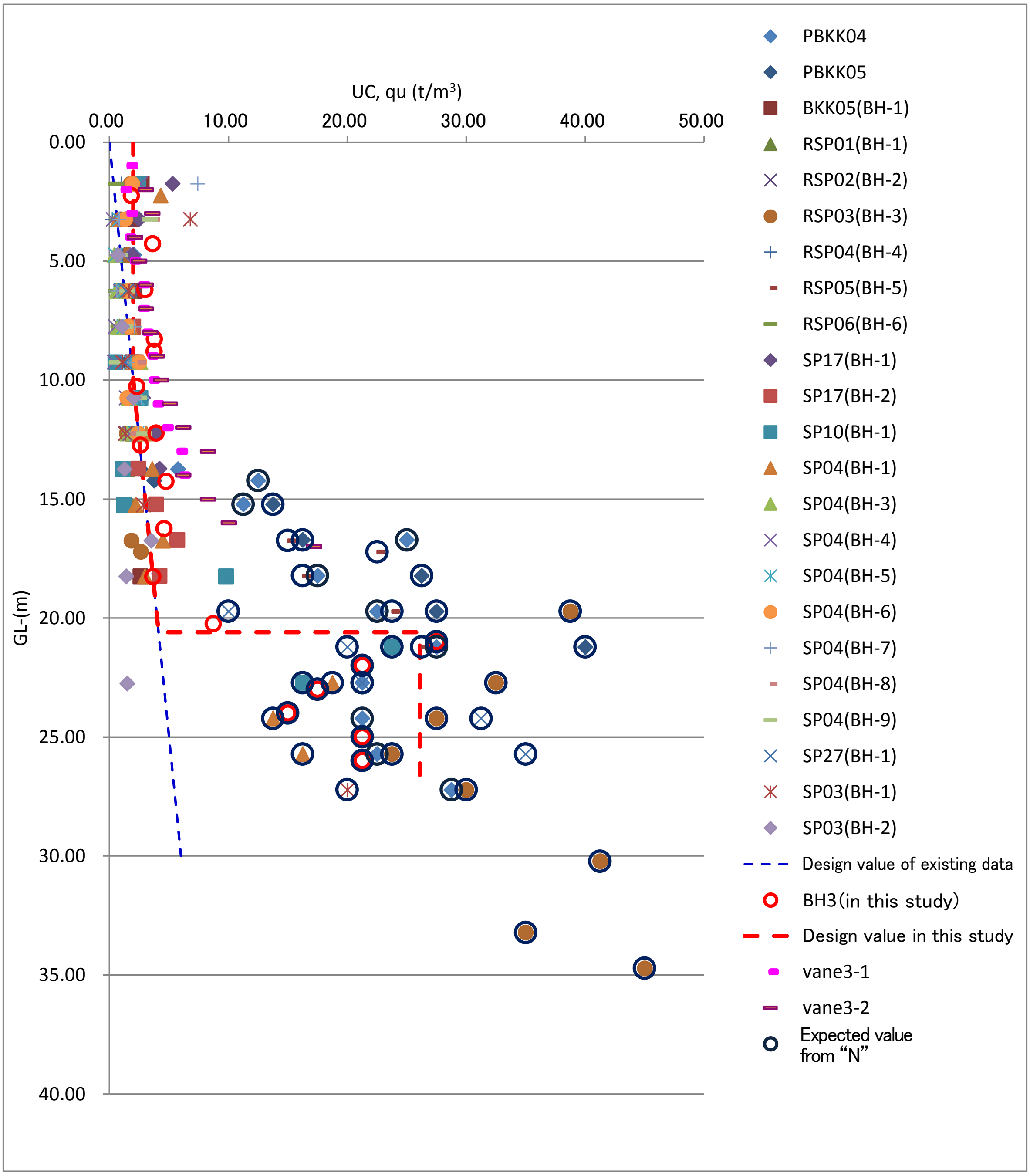


Source ：JICA Study Team

Figure 4.3.23 Unit Volume Weight set with reference to existing boring and boring in this study (Under Consideration)

●Cohesion C

Cohesion was obtained as an average value based on previous data in the southern area (Kasetsart University Classification: F (brown) and the result from the unconfined compression test. Strength increases with depth. Additionally, the data from the new borings from the Triaxial Compression Test (UU: Unconsolidated-Undrained) were used.



Source : JICA Study Team

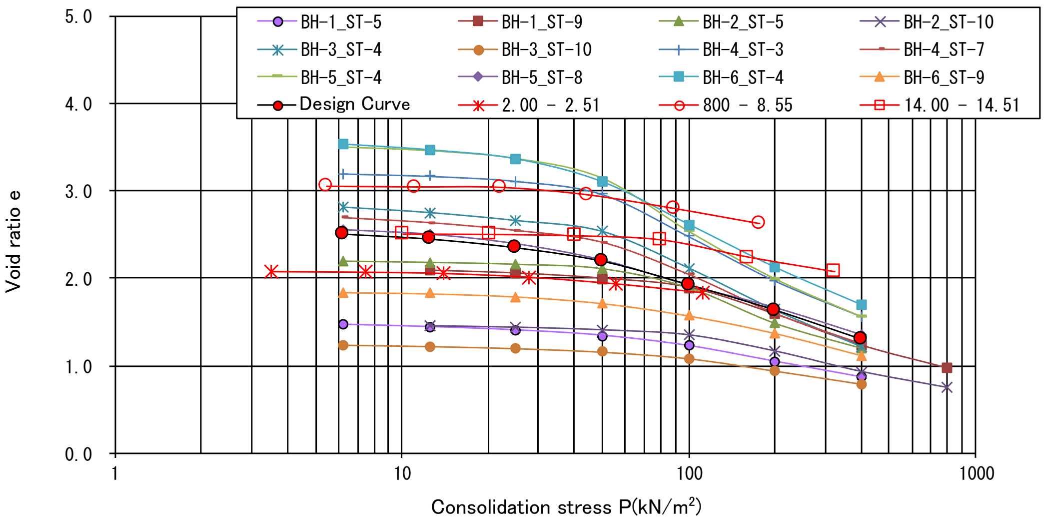
Figure 4.3.24 Uniaxial Compressive Strength set with reference to existing boring and boring in this study

● Consolidation curve

Consolidation curve was obtained as an average value based on the data from existing Consolidation Testing.

Existing data, including this study

e-log Curve									
Boring No.	Consolidation stress $P(kN/m^2)$ Sample No.	6.25	12.5	25	50	100	200	400	800
BH-1	ST-5	1.470	1.444	1.407	1.346	1.230	1.052	0.875	
BH-1	ST-9		2.088	2.056	1.998	1.896	1.594	1.242	0.982
BH-2	ST-5	2.201	2.188	2.166	2.115	1.898	1.491	1.207	
BH-2	ST-10		1.457	1.441	1.411	1.354	1.168	0.934	0.749
BH-3	ST-4	2.812	2.750	2.660	2.536	2.119	1.640	1.224	
BH-3	ST-10	1.243	1.226	1.202	1.161	1.085	0.941	0.789	
BH-4	ST-3	3.198	3.170	3.113	2.962	2.481	1.972	1.565	
BH-4	ST-7	2.687	2.630	2.542	2.407	2.044	1.602	1.260	
BH-5	ST-4	3.502	3.460	3.371	3.146	2.539	1.996	1.565	
BH-5	ST-8	2.550	2.498	2.390	2.205	1.919	1.664	1.355	
BH-6	ST-4	3.534	3.467	3.364	3.102	2.614	2.122	1.692	
BH-6	ST-9	1.844	1.829	1.794	1.715	1.571	1.366	1.108	
Set Value		2. 508	2. 450	2. 350	2. 196	1. 926	1. 634	1. 299	0. 866



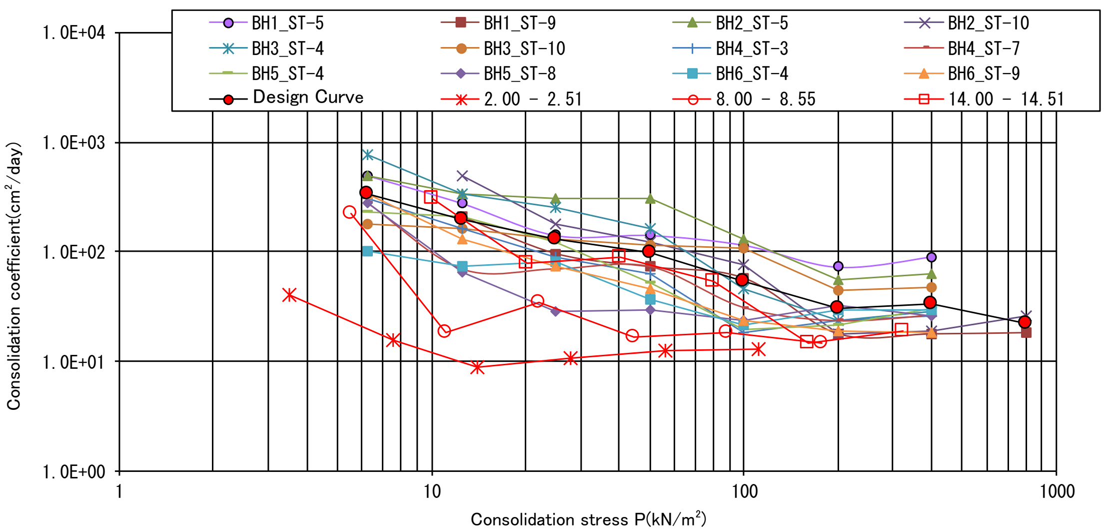
Note: Average value of consolidation pressure is used for each curve but some were adjusted.

Source : JICA Study Team

Figure 4.3.25 Relation between consolidation stress and gap ratio set with reference to boring sample

Existing data, including this study

Cv Curve									
Boring No.	Consolidation stress P(kN/m²) Sample No.	6.25	12.5	25	50	100	200	400	800
BH-1	ST-5	491.869	276.676	141.161	141.161	115.162	72.762	90.343	
BH-1	ST-9		209.207	95.736	72.762	57.165	17.733	17.733	18.190
BH-2	ST-5	491.869	341.576	306.567	306.567	131.594	54.652	62.738	
BH-2	ST-10		491.869	177.073	122.967	76.642	17.733	19.160	26.194
BH-3	ST-4	768.546	341.576	250.954	163.714	46.094	23.245	28.790	
BH-3	ST-10	177.073	163.714	131.594	115.162	108.077	44.268	48.034	
BH-4	ST-3	306.567	163.714	90.343	62.738	18.190	23.245	26.194	
BH-4	ST-7	276.676	69.169	69.169	72.762	30.742	23.245	26.194	
BH-5	ST-4	228.658	209.207	122.967	52.302	19.675	21.348	30.742	
BH-5	ST-8	276.676	65.836	28.790	29.742	23.934	32.899	26.194	
BH-6	ST-4	101.626	72.762	80.840	36.585	21.348	29.742	29.742	
BH-6	ST-9	341.576	131.594	72.762	46.094	23.934	19.160	18.190	
Set Value		331. 201	197. 874	130. 663	97. 519	52. 915	30. 414	33. 907	22. 192



Source : JICA Study Team

Figure 4.3.26 Relation between consolidation stress and gap ratio set with reference to boring sample

(3) Soil constant of fill material

The soil constants of the embankment were set based on indoor soil test results conducted on mixed soil of local soil and sand. The wet density was estimated from the moisture content at which the cone index was 400 kN / m^2 or more, based on the compaction test and cone test results performed on mixed soil. Strength constant, C and Φ were set based on the result of triaxial compression testing (CUB). Regarding the northern part calculation, the soil constant was set based on the soil test result, using soil of the northern part (S1). Regarding the central and southern part calculations, the soil constant was set based on test values, using materials collected from the central area (S2).

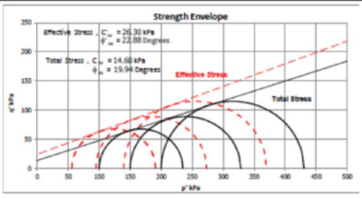
Table 4.3.4 Design soil constant

North		
γt (kN/m^3)	C (kN/m^2)	Φ (°)
16.5	14	19

Central		
γt (kN/m^3)	C (kN/m^2)	Φ (°)
15.5	10	18

North Part (S1)

		CUB				primary compression Hand Mix (For reference) C=1/2qu		
		Hand Mix		Mixer		qu(kN/m2)		
		Ccu (kN/m2)	φcu (°)	Ccu (kN/m2)	φcu (°)	1	2	3
Test Result		14.6	19.94	15.34	19.27	84.07	104.77	133.93
C	Test Result	14.6	–	15.34	–	42.035	52.385	66.965
		(Test)		(Test)				
	Design Value	C=14.6⇒14kN/m2						
φ	Test Result	–	19.94	–	19.27	–	–	–
			(Test)					
	Design Value	φ=19.94⇒19°						



Central Part (S2)

		CUB				primary compression Hand Mix (For reference) C=1/2qu		
		Hand Mix		Mixer		qu(kN/m2)		
		Ccu (kN/m2)	φcu (°)	Ccu (kN/m2)	φcu (°)	1	2	3
Test Result		12.63	17.83	10.34	18.98	84.07	104.77	133.93
C	Test Result	12.63	–	10.34	–	42.035	52.385	66.965
		(Test)		(Test)				
	Design Value	C=10.34⇒10kN/m2						
φ	Test Result	–	17.83	–	18.98	–	–	–
			(Test)		(Test)			
	Design Value	φ=18.98⇒18°						

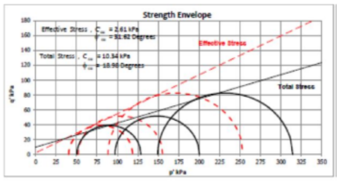
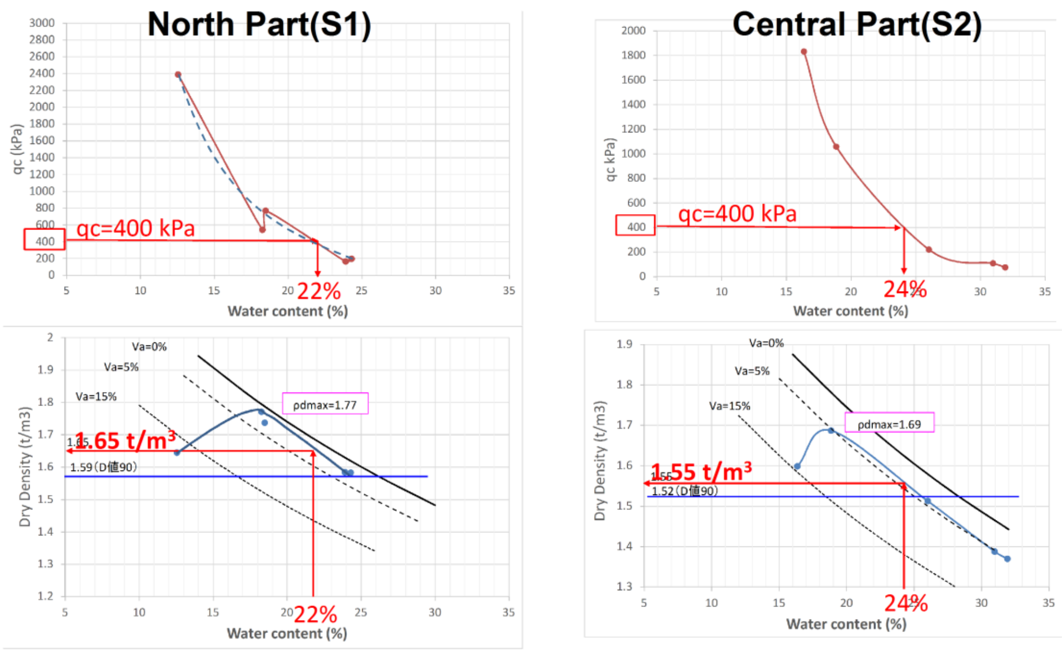


Figure 4.3.27 The result of triaxial compression test



Source ：JICA Study Team

Figure 4.3.28 The result of cone test and compaction test

(4) Surcharge loadings

The surcharge loading is set as q=10kN/m2 on top of the levee when construction is completed.

(5) Design seismic coefficient

Design seismic coefficient is kh=0.04, used for structure design, e.g. for steel sheet pile etc.

(6) Minimum factor of safety against sliding

Minimum factor of safety for circular slip calculation should be 1.3, during construction and 1.5 after construction. In this report, stability under completion was analyzed and countermeasure structure was decided.

4.3.3 Result

The study result of no countermeasure is shown below, using the soil constant, which is the result of the new soil study. At the northern area, it is unnecessary to take countermeasures on slipping or settlement for the northern segment. In the central area, residual settlement after embankment and excavation exceed 30 cm when no countermeasure is conducted. Additionally, slipping stability at excavation slope could not be ensured. In the southern part, slipping stability condition is the same as at the central area. An appropriate additional quantity of banking should be placed considering the final settlement quantity because it is necessary that the dike height is assured. Especially in the southern area, appropriate dike height should be adopted considering the extent of the dike height because the final settlement quantity in the southern area is high (140cm).

Table 4.3.5 Estimated value without countermeasures

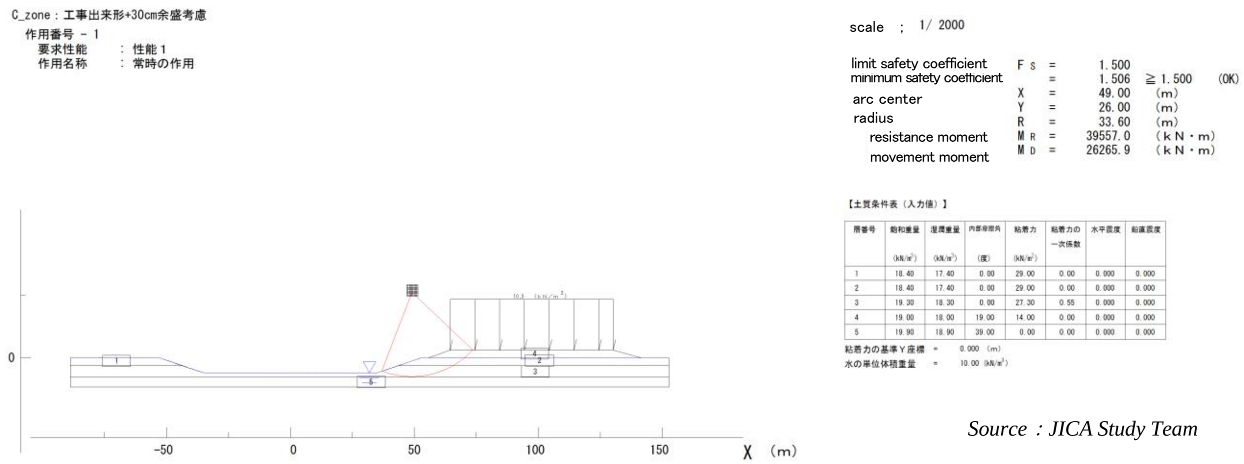
Section	Slipping safety coefficient (after completed)	Residual settlement	Final settlement	Time for settlement until 90% consolidation
North	1.51	9.2cm	17.8cm	3410 days
Middle	**1.11** ×	**30.4cm** ×	58.8cm	4400 days
South	**0.50** ×	20.9cm	**140.0cm**	51000 days

Source ：JICA Study Team

●Calculation result for the northern section

〇Slipping stability

The slipping stability calculation was conducted, assumingly, after the start of road operation (strength is not expected to increase and traffic load on the embankment crest is considered). The condition to ensure safety in the Diversion channel is set as no water in the Diversion channel. Slipping stability ratio exceeded the target value (Fs=1.51<1.5) and a countermeasure was unnecessary.



Source ：JICA Study Team

Figure 4.3.29 The calculation result of circular slip

〇Consolidation settlement

1) final settlement (max)：Sf=17.8cm

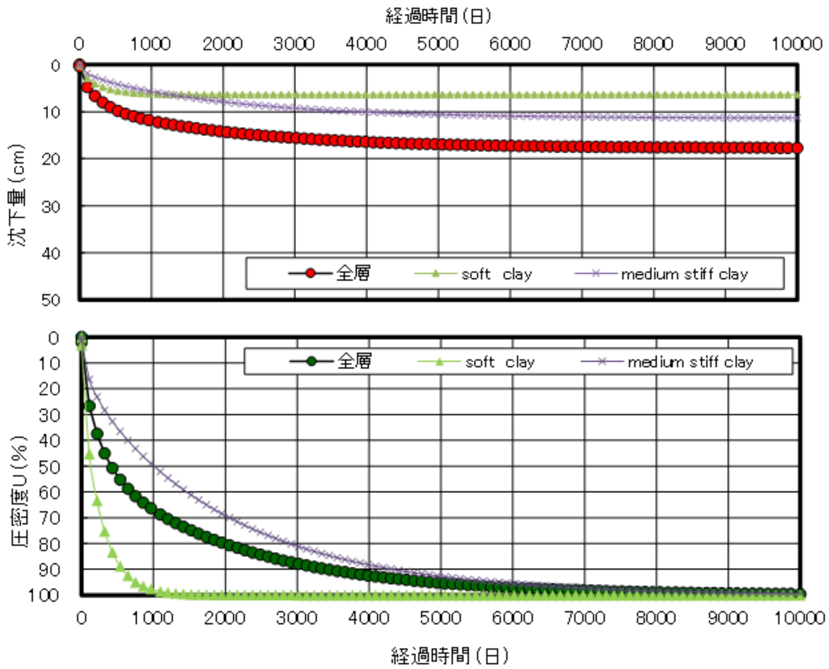
（location： road embankment CL）

2) settlement time

a. time until consolidation U=90%： t ≒3410 days

b. residual settlement：9.2 cm< 30 cm

Countermeasure against settlement is not necessary since residual settlement is less than 30cm. But, in consideration of residual settlement, the height of extra banking was designed to be 30cm.



Source: JICA Study Team

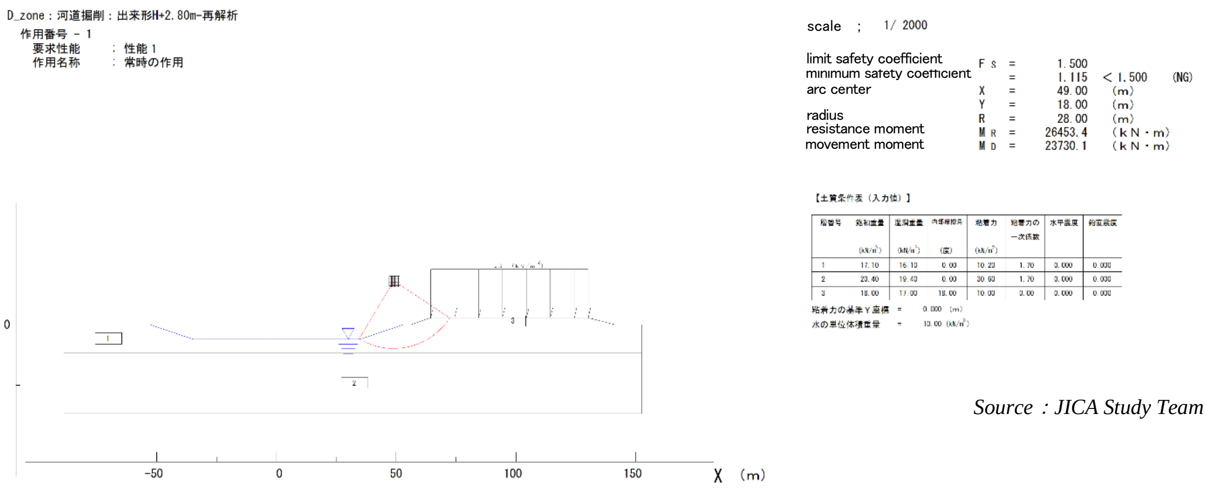
Figure 4.3.30 Relationship between settlement volume and time/degree of consolidation

●Calculation result for the middle section

〇Slipping stability

The slipping stability after the start of road operation was calculated (strength is not expected to increase and traffic load on crest is considered). The condition to ensure safety in the Diversion channel is set as no water in the Diversion channel.

Slipping stability ratio exceeded the target value (Fs=0.5<1.5) and countermeasures were necessary.



Source：JICA Study Team

Figure 4.3.31 The calculation result of circular slip

〇Consolidation settlement

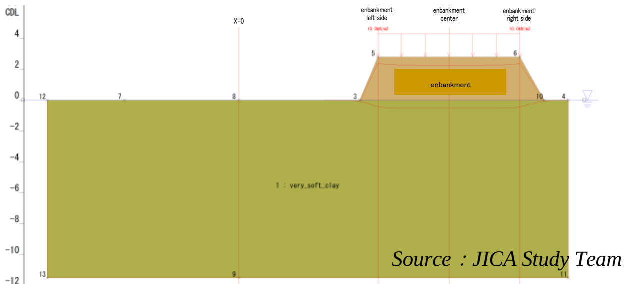
1) final settlement (max) : Sf=58.8cm

(location: road embankment CL)

2) settlement time

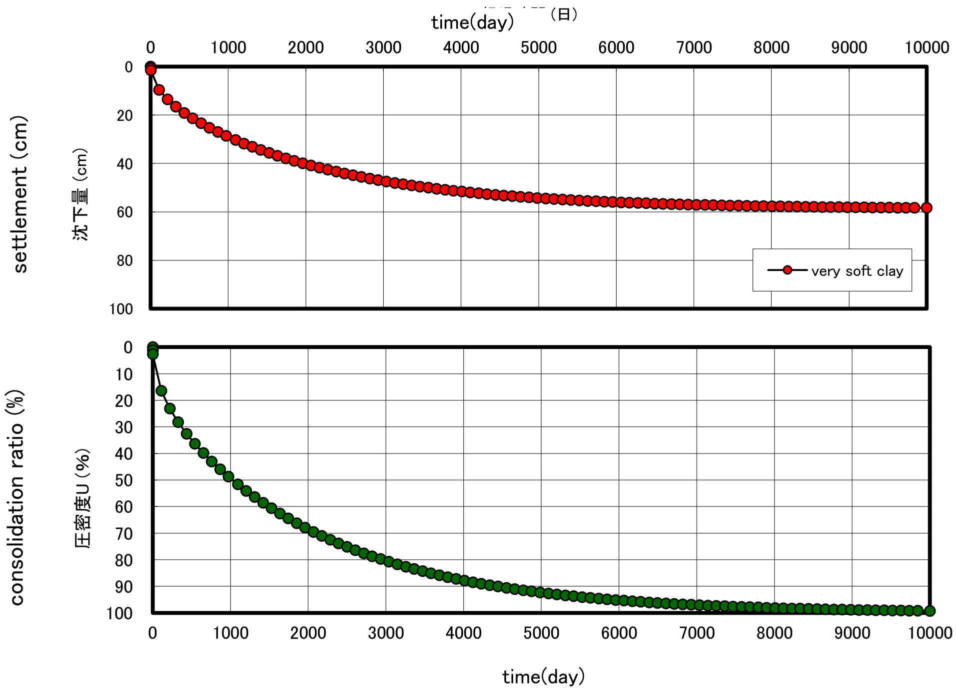
a. time until consolidation ratio U=90%: t ≒4420 day

b. residual settlement : 30.4cm



Source : JICA Study Team

It is necessary to counter the residual settlement since settlement is more than 30 cm.



Source : JICA Study Team

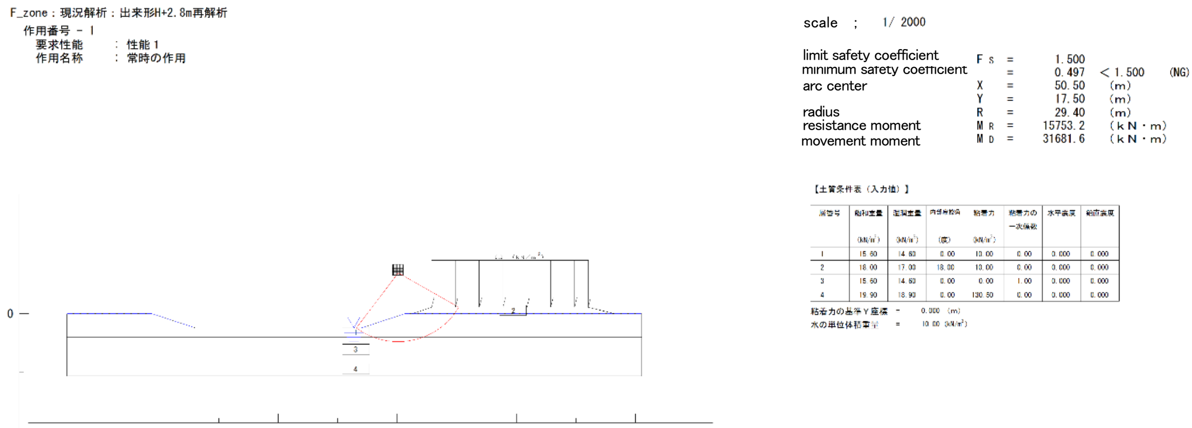
Figure 4.3.32 Relationship between settlement volume and time / degree of consolidation

●Calculation result for the southern section

〇Slipping stability

The slipping stability after the start of road operation was calculated (strength is not expected to increase and traffic load on crest is considered). The condition to ensure safety in the Diversion channel is set as no water in the Diversion channel.

Slipping stability ratio exceeded the target value (Fs=0.50<1.5) and countermeasures were necessary.



Source：JICA Study Team

Figure 4.3.33　The calculation result of circular slip

〇Consolidation settlement

1) final settlement（max）：Sf=140.0cm

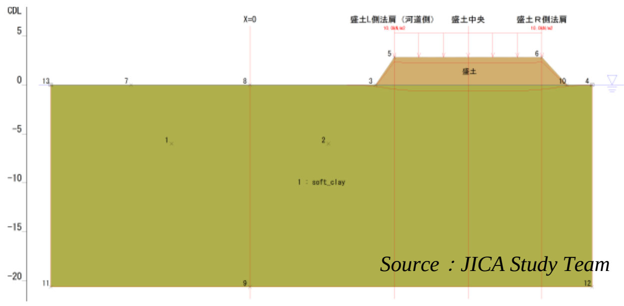
（location: embankment center）

2) settlement time

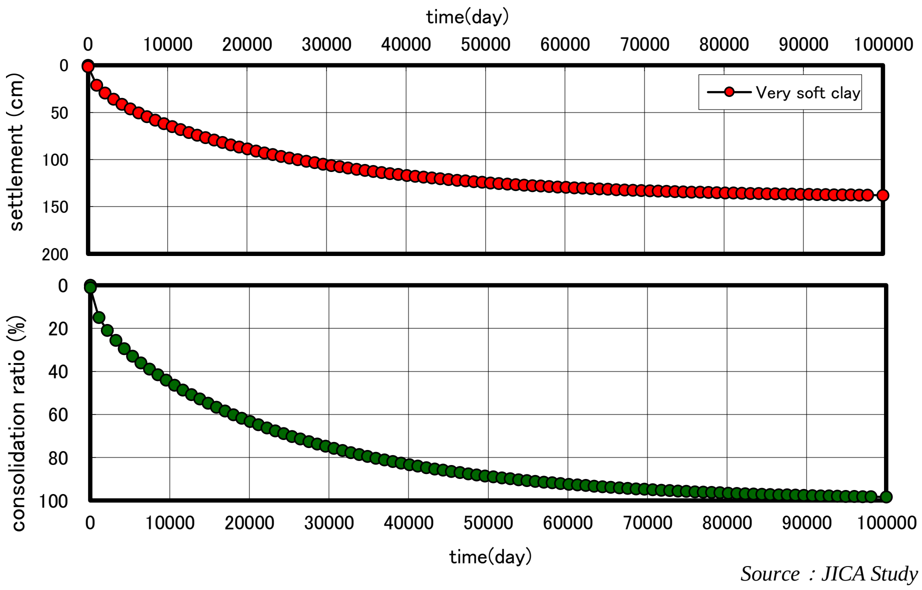
a. time until consolidation ratio U=90%: t ≒51000 days

b. residual settlement：20.9cm

It is necessary to counter the residual settlement to accelerate consolidation settlement and to increase strength since final settlement is 140 cm.



Source：JICA Study Team



Source：JICA Study Team

Figure 4.3.34 Relationship between settlement volume and time / degree of consolidation

4.4 Comparison and decision of the method for countermeasure construction

(1) Primary selection of countermeasure construction

From the current ground investigation results, countermeasure construction against slip and settlement should be implemented. Countermeasure construction was selected from several possible methods (described below) through primary selection and estimated by calculation. The presented second method and third method focus on the stabilization of excavation slope (cross sectional shape). If countermeasure construction against consolidation settlement under embankment is needed, the first method will be done simultaneously. For the central part, the first and second methods were proposed as countermeasure construction against slip of excavation slope. For the south part, first, second and third methods were proposed as countermeasure construction against slip and settlement.

＜Chosen countermeasure methods＞

Countermeasure-1 : Vertical drain method

This method ensures slip stability by accelerating the consolidation settlement and increasing the strength of the soil. If it could not ensure slip stability, the excavation gradient should be lowered and the shape of the slope should be revised. For example, PVD method etc., have been widely used in Thailand.

Countermeasure-2 : Soil Strengthening Method (SCC : Soil Cement Column)

This method ensures slip stability by constructing soil cement columns in the ground. It has been used with some positive results in the drainage project for the airport etc. Based on the lessons learned from accidents in the drainage project at the airport, two conclusions were made. The first one is not to use floating pile in soft clay in order to minimize the impact of uneven settlement. The second one is to use a grid shape pattern of the soil cement columns, not a pile foundation pattern in order to avoid the soft soil slipping between the soil cement columns.

Countermeasure-3 : Steel Sheet Pile Method (for southern part)

In the southern area, the investigation of structural countermeasures was done together with that of ground countermeasures. Concrete sheet pile was adopted since it has a lot of use in Thailand. However, if it could not ensure enough strength, the use of steel sheet piles should be reconsidered.

Table 4.4.1 Primary Selection of Countermeasure against Soft Ground

Principle	Typical countermeasure construction methods		Impact: Settlement – Accelerating consolidation settlement /Reducing settlement	Settlement – Reducing total settlement	Stability – Increasing strength by consolidation	Stability – Increasing landslide resistance	Stability – Reducing sliding force	Deformation – Breaking stress	Deformation – Reducing stress	Liquefaction – Countermeasure against liquefaction – Improvement of sand land property – Increasing density	Improvement of sand land property – Consoli-dation	Improvement of sand land property – Improving grain size	Improvement of sand land property – Reducing saturation	Countermeasure against liquefaction – Increasing Effective stress	Countermeasure against liquefaction – Dissipation pore water pressure	Countermeasure against liquefaction – Reducing shear de-formation	Liquefaction – Reducing suffer by liquefaction	Ensure trafficability
Consolidation /Drainage	Surface drainage method																	○
	Sand mat method		○															○
	Slow loading method				○													
	Embankment loading method		○		○													
	Vertical drain method	Sand drain method	○		○													
		Prefabricated vertical drain method	○		○													
	Vacuum consolidation method		○		○													
	Groundwater level lowering method		○		○								○	○				
	Vibration compaction method	Sand compaction pile method	○	○	○	○			○	○								
		Vibrating rod method		○※)						○								
		Vibroflotation method		○※)						○								
		Vibrotamper method		○※)						○								
		Heavy tamping compaction method		○※)						○								
Compaction	Static compaction method	Static sand compaction method	○	○	○	○			○	○								
		Compaction grouting method								○								
Consolidation	Surface mixing method			○		○		○										○
	Deep mixing method	Deep mixing method (Mechanical mixing method)		○		○		○								○	○	
		High-pressure jet mixing method		○		○		○	○		○					○	○	
	Lime pile method			○		○		○	○		○							
	Chemical grouting method			○		○				○	○							
	Freezing method					○					○							
Replacement by excavation	Replacement by excavation method			○		○		○				○						
Dissipation pore water pressure	Dissipation pore water pressure method														○			
Load alleviation	Lightweight banking	Expanded polystyrol method		○			○		○									
		Foamed cement banking method		○			○		○									
		Foamed beads mixed method		○			○		○									
	Culvert method			○			○		○									
Embankment reinforcement	Embankment reinforcement method					○											○	
Counter-measure by structures	Counterweight fill method					○											○	
	Diaphragm wall method															○	○	
	Sheet pile method					○		○							○※※)		○	
	Pile method			○		○			○								○	
Reinforcement materials laying	Reinforcement materials laying					○												○

①Vertical drain method
(many results for roads, for example PVD)

②Soil Strengthen method
(some results for drainage at airport)

③Steel Sheet Pile method

※)Available for sand ground
※※)Only when with drainage function

Reference : Guideline for countermeasure methods against soft ground, Road earthwork, p191 (2012)

(2) Examination Method

4) Vertical Drain Method (PVD)

It is assumed that the strata alternation of excavated soil and purchased sand will be made evenly for preloading and the embankment height is 3.0m, as high as the crest of the dyke. This method will ensure the stability of the embankment during construction and the details will be discussed in the future. In this report, it is assumed that the strength of the ground under the embankment will be enhanced by the consolidation with loading. Like the nearby road project, it was assumed that the consolidation time will be 2 years, and the residual settlement will be less than 30cm. Installation spacing was assumed to be 1.0m ~ 2.0m according to past cases, and it shall satisfy U=90%. For the consolidated layer under the embankment, strength improvement has been calculated when U=90% in the circular slip calculation. For places where rotational stability is difficult to ensure, the slope of the excavated slope was reduced.

$$\mathrm{t} = \frac{T_h}{C_h} d_e^2$$ Formula 6-1

where,

t is consolidation time (day)

Th is horizontal time coefficient

Ch is horizontal consolidation coefficient (m2/day) (usually the vertical consolidation coefficient CV of the standard consolidation experiment is used)

de is effective diameter, calculated by the following formula

d_e = 1.05d equilateral triangular

d_e = 1.13d square

d is the installation interval of the sand drain

Usually, de is extremely small compared with vertical consolidation drain distance H. If ignoring the vertical drain, the correlation between degree Uh of consolidation and time coefficient Th is shown in Figure 6-54, with the ratio n of effective diameter to sand drain diameter dw, which is approximately given by Formula 6-2.

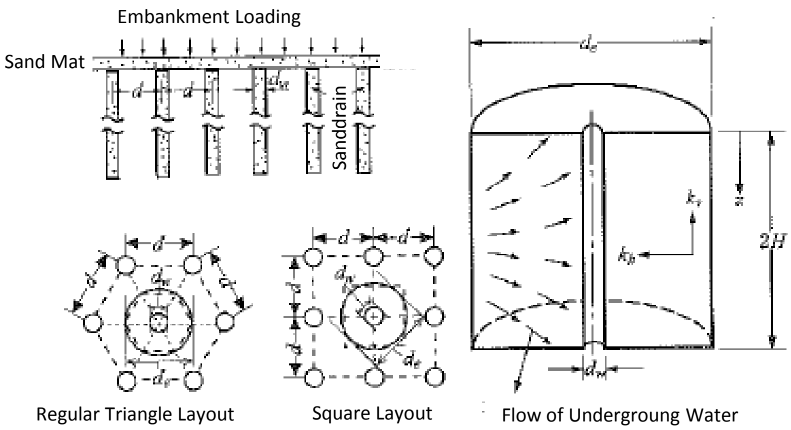
$$\mathrm{U}(T_h) = 1 - \exp\left(-\frac{8T_k}{F(n)}\right)$$ Formula 6-2

Where,

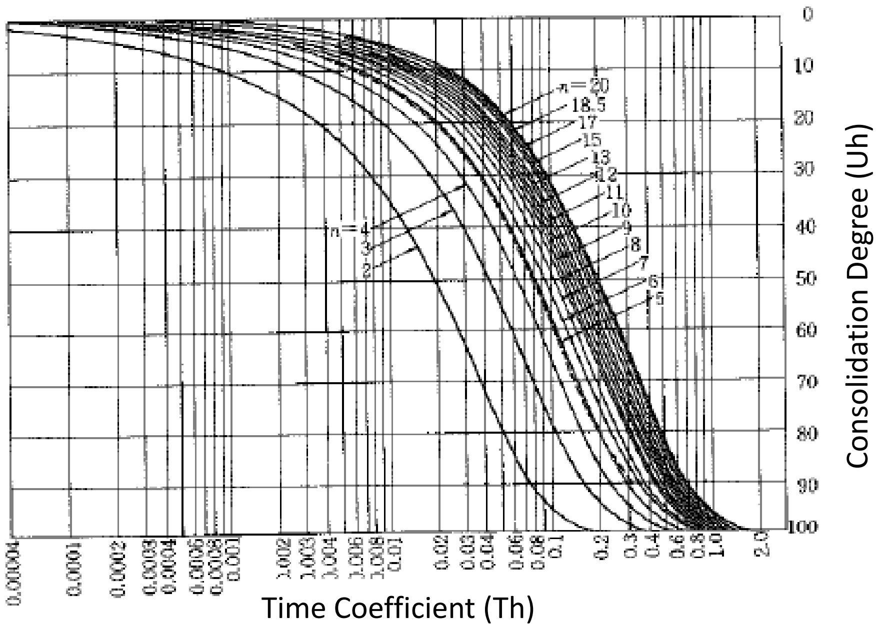
$$\mathrm{F(n)} = \frac{n^2}{n^2-1} log_e n - \left(\frac{3n^2-1}{4n^2}\right) \quad ; \quad n = \frac{d_e}{d_w}$$ Formula 6-3

dw is sand drain diameter

In design of the sand drain, the construction method, drain diameter, installation interval, and improvement range (depth and width) were assumed initially, and then stability and settlement were calculated. Drain installation interval and improvement range should be modified if the result of consolidation degree, safety rate, or residual settlement cannot meet the tolerance in a certain consolidation time.



Layout of Sanddrain and Consolidation situation



Correlation between Consolidation Degree (Uh) and Time Coefficient (Th)

5) Soil Strengthening Method (SCC : Soil Cement Columns)

In this study, considering the SCC method used in Suvarnabhumi Airport Channel and the Japanese Standard as reference, the "Grid-form Ground Improvement" is considered to be applied as the solidification method instead of pile-shape composite soil, from the view of construction cost reduction as well as the judgment that it is necessary to ensure the stability of the structure. The method was planned to satisfy outside and inside stabilities and to ensure circular slip stability.

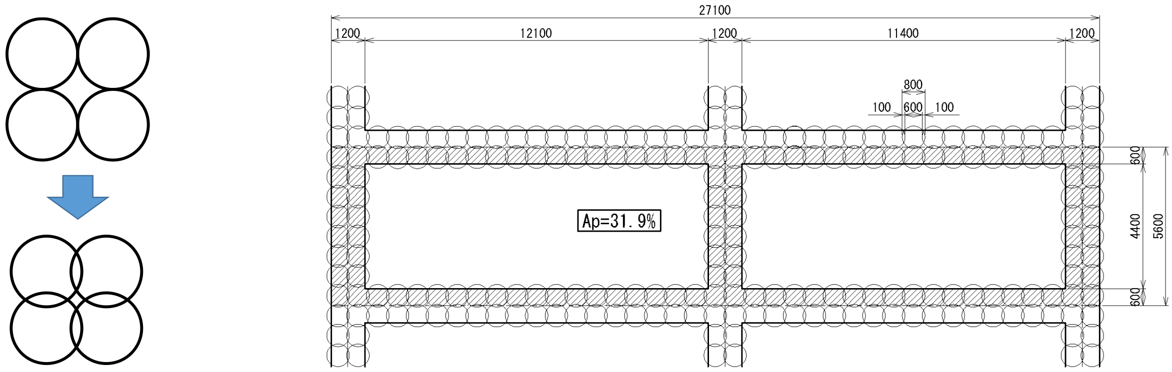


Figure 4.4.1 Arrangement of Grid-form Ground Improvement

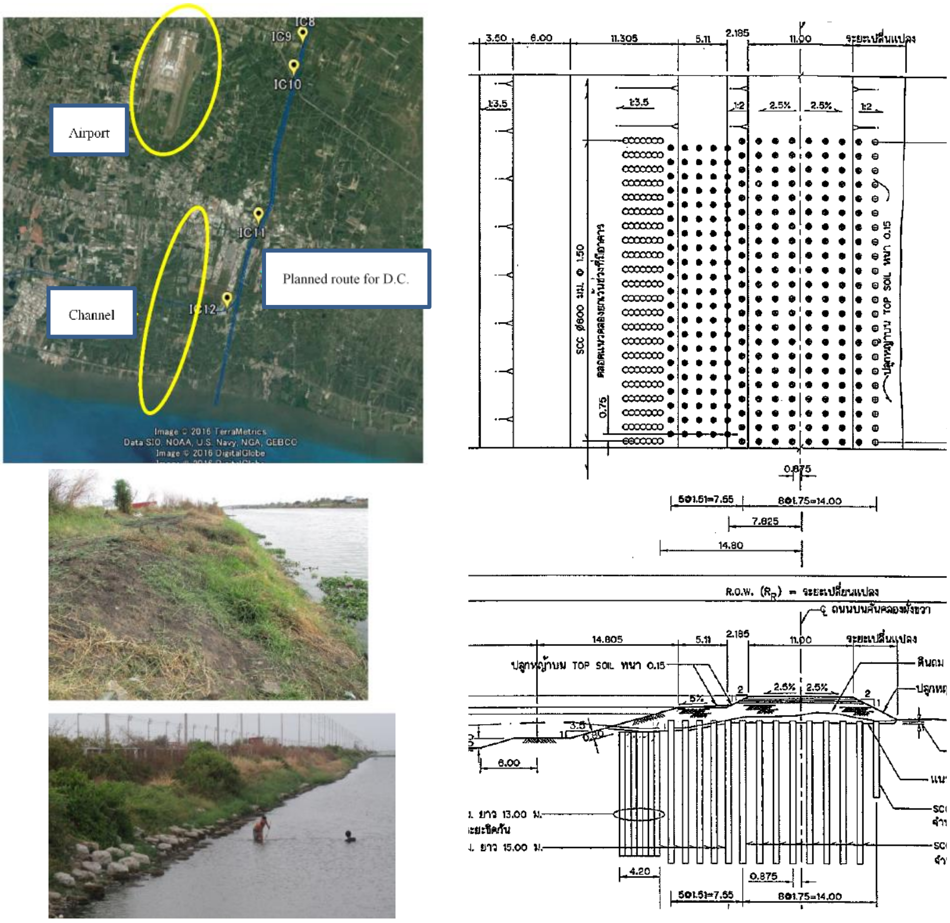
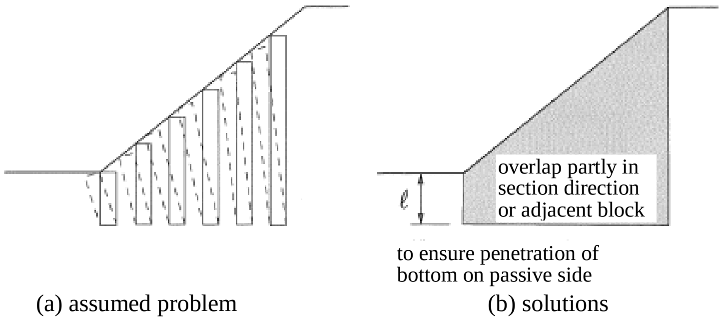


Figure 4.4.2 Example of soil Strengthening Method (Suvanabhumi Airport Channel)

In excavating for the river rebuilding and foundation ground of the structure, a deep mixing method is used to keep the stability of the excavated slope. Circular slip calculation is usually used for ground improvement. Sometimes, the calculation result may indicate that a low or moderate improvement ratio is enough to obtain the target safety rate. In this kind of situation, the pile-shape improved body may lean toward the excavated slope, causing the excavated slope collapse.

This phenomenon happens because the passive side is excavated and the improved bodies collapse one after another like dominos. When using the deep mixing method to keep the excavated slope stable, in order to avoid such phenomenon, it would be discussed whether to overlap them partly in the direction of the excavated section, or to make them adjacent to each other, or to make them like a block mass.

Besides, it is also necessary to analyze the strength decrease caused by the release of internal stress after excavation as well as the underground water table change opposite to the excavation.



Caution when applying deep mixing method to excavation

Source : manual for deep mixing method design and construction in land construction, Public Works Research Center, 2004, P174

i. **Specifications of improvement body**

Soil strength of 500kN/m^2 is used as the design standard strength of the improved ground, which is the largest value of the widely-used range 200～500kN/m^2 in Japan. It has been discussed whether the stability can be ensured if the improvement ratio is lower than 50%. For the circular slip calculation with the above condition, the synthetic ground strength is calculated by using the following formula, based on the "Manual for deep mixing method design and construction in land construction, Public Works Research Center, 2005" and the "Manual for soft peat ground construction, JICA, 2002"

$$C = Cp \times ap + \alpha \times Co(1 - ap)$$

where,

C is composite ground strength (kN/m^2);

Cp is improved body strength (kN/m^2)=$q_{uck}/2$;

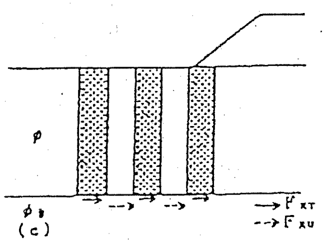
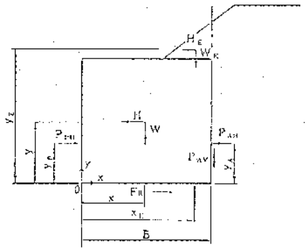
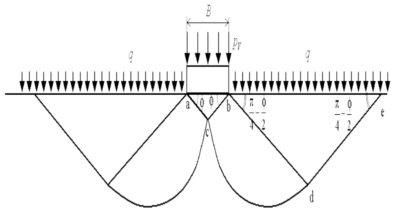
Co is original ground strength (kN/m^2), assumed at $10kN/m^2$ for safety;

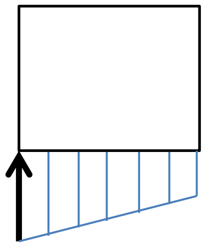
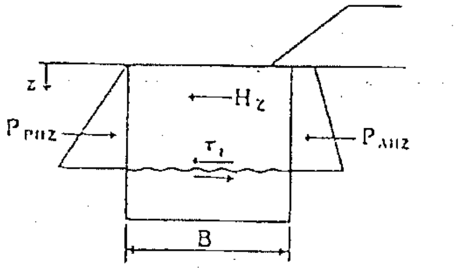
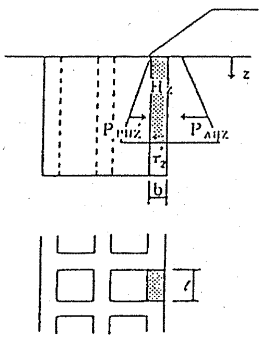
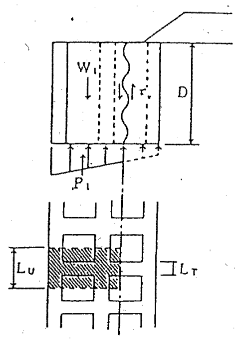
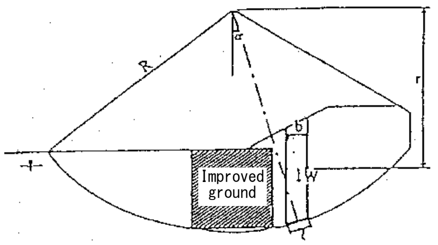
α is strain reduction ratio (usually 1/2 ~ 1/3, here 1/2)

α_p is ground improvement ratio

ii. The internal and external stability of the improved pattern

The check lists are shown below.

Sliding	Over turning	Bearing capacity
		

Toe pressure	Horizontal shearing
	
horizontal shearing	**Vertical shearing**
 図－8.7.2 failure of improved grid pattern	 図－8.7.3 Study of vertical shearing
Slip stability	

source : Construction and design manual for countermeasures against liquefaction (draft)

Figure 4.4.3 Check items for Soil Cement Columns (SCC)

(3) The result of study

The summary results from the analysis are shown in the following table (Under Consideration).

Table 4.4.2 Various Elements of Countermeasures against Soft Ground

Areas	Slope Gradient	Countermeasure	Various elements
Central	1 : 3.0	Vertical Drain Method + Low Pitch Bank	□3.0m×3.0m
	1 : 3.0	Soil Strengthen Method (Soil Cement Columns)	φ800、ap=34%
South	1 : 11.0	Vertical Drain Method + Low Pitch Bank	□1.0m×1.0m
	1 : 3.0	Soil Strengthening Method (Soil Cement Columns)	φ800、ap=34%

1) Central Area

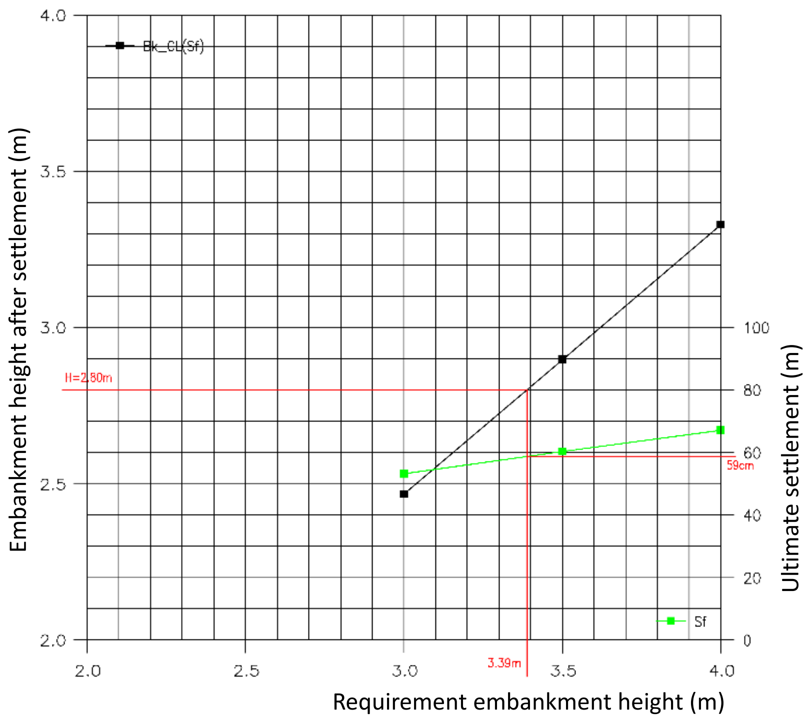
Construction process is as follow.

1. Countermeasure construction is carried out on current ground as formation level.
2. Stockpile is made at the area of embankment. Because of the preload, settlement is accelerated. (Time of consolidation settlement is calculated with Stockpile height =3.0 m and drain pitch is calculated when degree of consolidation is 90% in two years).
3. Remove stockpile. Then embankment is carried out.

The condition of Grid-form Ground Improvement is set to ensure the slip stability of the embankment (considering the height of the top of the embankment), excavation of the Diversion Channel and traffic load effect when the road starts operation. The height of embankment just after construction has determined to be 3.40m (Namely, the extra banking determined to be 60cm) in consideration with the following items.

- The height of embankment after settlement should be design height 2.8m.
- Ultimate settlement height

Regarding this determination, the relation between required embankment height (indicated on the horizontal axis) and embankment height after settlement (indicated on the vertical axis) was referred to.



Source：JICA Study Team

Figure 4.4.4 Setting of essential embankment height

○PVD（□3.0m×3.0m）

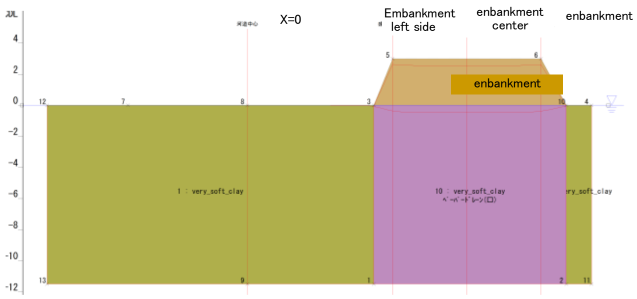
1) Consolidation settlement (U=90%) : St=39.5 cm

(Final settlement : Sf=43.9 cm)

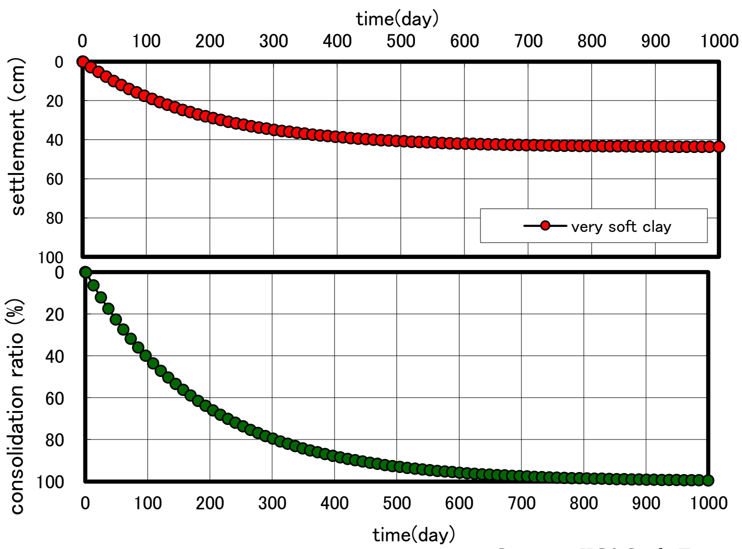
(Location : road embankment CL)

2) Settlement time

- Consolidation (U=90%) ： t≒440 days



Source：JICA Study Team



Source：JICA Study Team

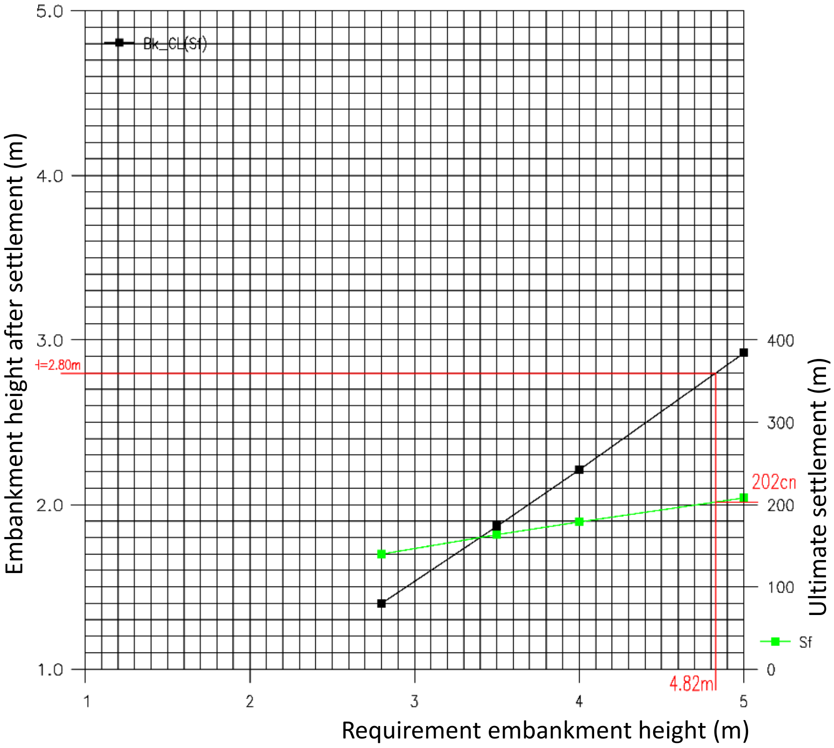
Figure 4.4.5 Relationship between settlement volume and time / degree of consolidation

〇SCC

- The construction study was carried out (The height of extra-banking was set as 60 cm).

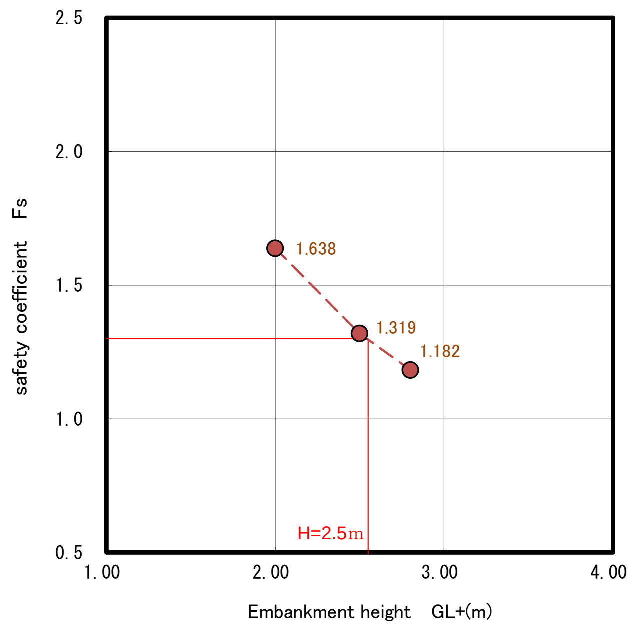
2) Southern Area

The correlation between essential embankment height (as x-coordinate) and embankment height after settlement (as y-coordinate) is shown below, according to the essential embankment which is assumed to be 4.82 m, in order to get embankment 2.8m thick after settlement as designed. Extra-banking is designed as 202cm. And, initial embankment height is designed as 2.5m to provide a safety coefficient larger than 1.3, after checking the height limit of the embankment.



Source ：JICA Study Team

Figure 4.4.6 Setting of essential embankment height

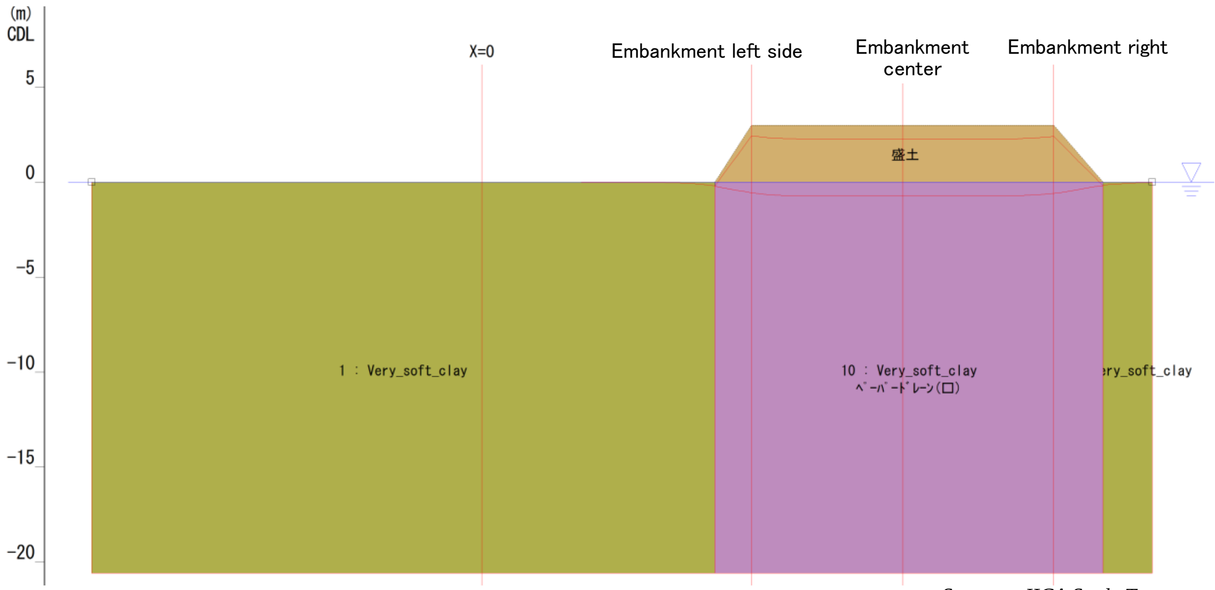


Source：JICA Study Team

Figure 4.4.7 Setting of limit embankment height

On the other hand, the virtual drain method is considered as a countermeasure for consolidation settlement.

- Drain pitch: 1.0m
- Embankment height to be constructed Ｈｔ1=2.50ｍ（initial）, target of strength enhancement is assumed as consolidation ratio U=90%.



Source：JICA Study Team

1) final settlement of Ht1：S=106.0cm　（location：center）
2) settlement time
   a. time until consolidation ratio U=90％： ｔ＝122 days
   b. settlement until consolidation ratio U=90％：S≒95cm

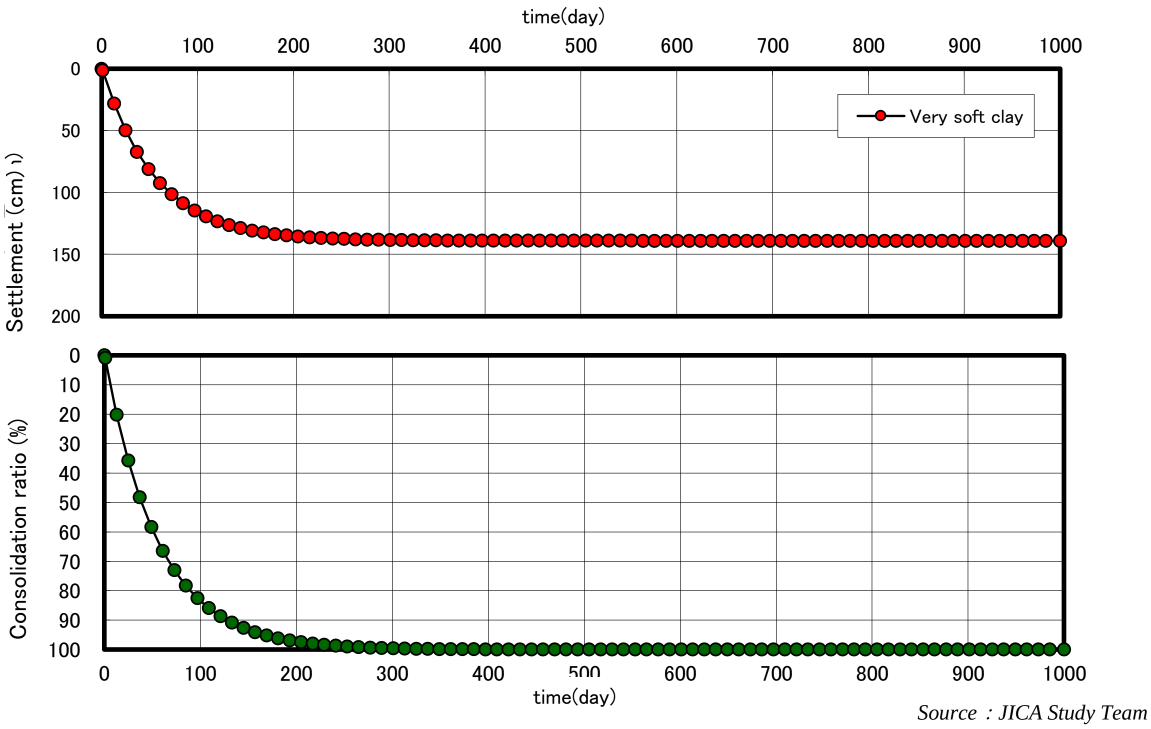


Figure 4.4.8 Relationship between settlement volume and time / degree of consolidation

The soil stabilization by PVD method enhances the strength of foundation ground to the strength under the condition that the consolidation ratio reaches U=90%. An increase in strength due to a load greater than Pc (consolidation yield stress) was assumed. Because it is not appropriate to make the scale of SCC described below too much large.

- consolidation ratio is expected when U=90%
- strength increasing rate (m) is set according to the result of CUB experiment.(m=0.22)

Table 4.4.3 Calculation regarding thr increament of the foundation ground intensity

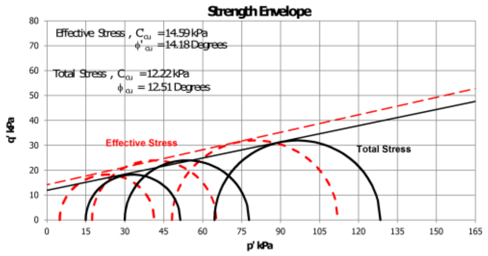
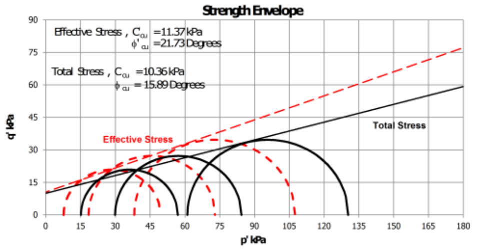
Soil type	Thickness (m)	Initial strength Cuo (kN/m²)	Strength enhancement ratio m※2	Constructed embankment thickness Ht1 (m)	Initial stress Po (kN/m²)	Increased loading (kN/m²)			Uε (%)	⊿Cu (kN/m²)
						Planned embankment ΔP	Consolidation yield stress pc※3	(Po+ΔP-Pc) ΔP'		
soft clay (Upper side)	10.00	10.0	0.22	2.50	28.00	34.25	31.50	30.75	90	6.1
soft clay (Lower side)	10.60	-1.0×Z※1	0.22	2.50	85.68	33.57	80.00	39.25	90	7.8

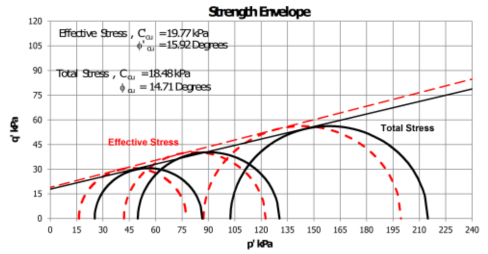
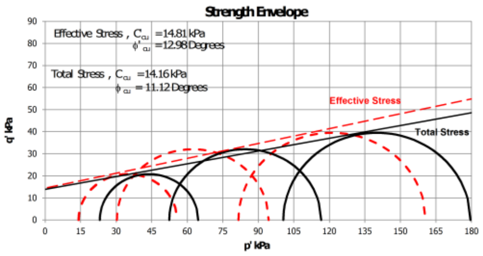
※1　Z means depth (GL=0)

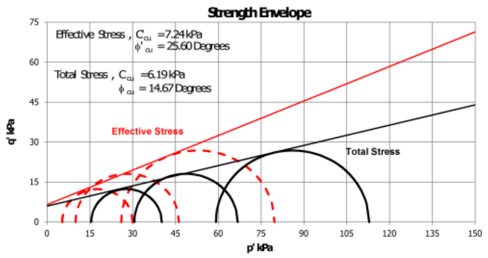
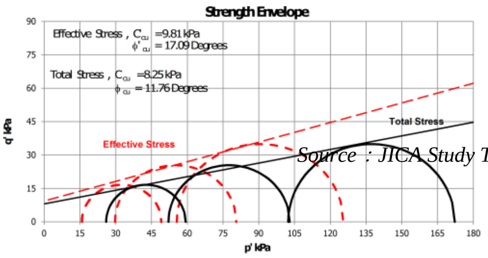
※2　m=22 based on result CUB

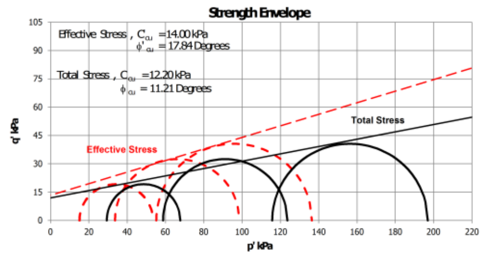
※3　The average value of 2.00m(σ'vm=28.00kN/m^2) and 8.00m(σ'vm=35.0kN/m^2) is used for the upper part as the consolidation yield stress Pc and 14.00m(σ'vm=80kN/m^2) for the bottom part

According to the table, ground strength of soft clay beneath the embankment is set as C=16.1 (kN/m^2) and C=-1.00Z＋7.8 (kN/m^2) for lower and deeper layers.

<table>
<tr><td>BH No</td><td>BH1</td><td>BH2</td></tr>
<tr><td>Depth</td><td>2.54−3.08</td><td>2.51−3.00</td></tr>
<tr><td>Experiment result</td><td>
</td><td>
</td></tr>
<tr><td>φ</td><td>12.51</td><td>15.99</td></tr>
<tr><td>Strength Enhancement rate</td><td>0.22</td><td>0.29</td></tr>
</table>

<table>
<tr><td>BH No</td><td>BH2</td><td>BH2</td></tr>
<tr><td>Depth</td><td>6.94−7.44</td><td>10.54−11.08</td></tr>
<tr><td>Experiment result</td><td>
</td><td>
</td></tr>
<tr><td>φ</td><td>14.71</td><td>11.12</td></tr>
<tr><td>Strength enhancement rate</td><td>0.26</td><td>0.2</td></tr>
</table>

<table>
<tr><td>BH No</td><td>BH3</td><td>BH3</td></tr>
<tr><td>depth</td><td>4.55−4.96</td><td>8.55−9.04</td></tr>
<tr><td>Experiment result</td><td>
</td><td>
</td></tr>
<tr><td>φ</td><td>14.67</td><td>11.76</td></tr>
<tr><td>Strength enhancement rate</td><td>0.26</td><td>0.21</td></tr>
</table>

<table>
<tr><td>BH No</td><td>BH3</td></tr>
<tr><td>Depth</td><td>12.47−13.02</td></tr>
<tr><td>Experiment result</td><td>
</td></tr>
<tr><td>φ</td><td>11.21</td></tr>
<tr><td>Strength enhancement rate</td><td>0.2</td></tr>
</table>

<table>
<tr><td rowspan="4">Strength enhance−ment rate m</td><td>North</td><td>BH1</td><td>0.22</td></tr>
<tr><td>Middle</td><td>BH2</td><td>0.25</td></tr>
<tr><td>South</td><td>BH3</td><td>0.22</td></tr>
<tr><td colspan="2">Total average</td><td>0.23</td></tr>
</table>

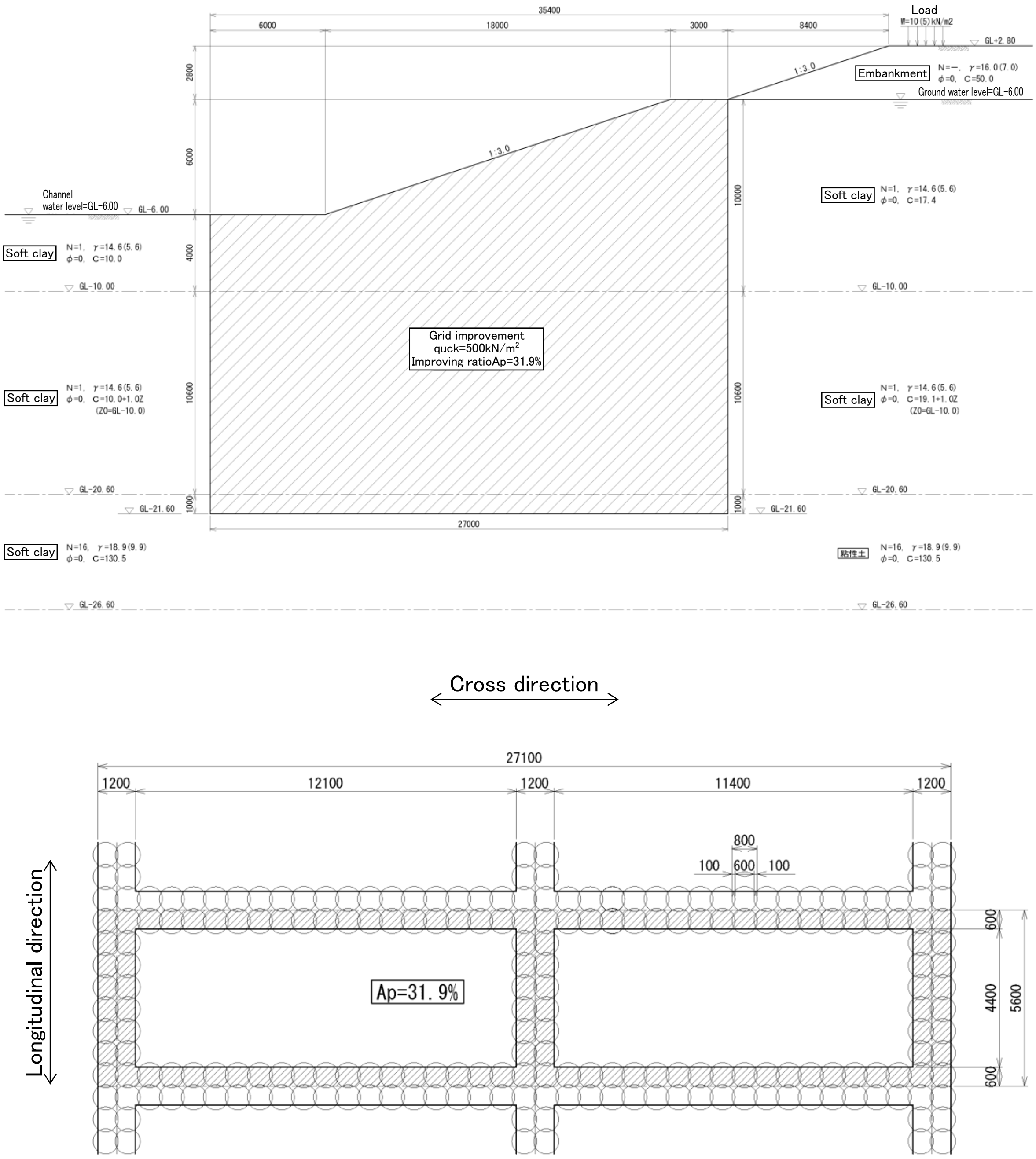
Source ：JICA Study Team

Figure 4.4.9 The floor plan and a cross section plan of improved pillars

●SCC method

SCC is selected to ensure both internal and external stability of the improved body as well as safety regarding arc slipping.

Considering the uncertainty of the quality of construction, the improved body is constructed in a combined way of overlapping each two improved bodies and erecting three lines of improved walls in the crosswise direction.



Source：JICA Study Team

Figure 4.4.10 The floor plan and a cross section plan of improved pillars

		Normal time			Earthquake			Reference
		Calculation result		Limit value	Calculation result		Limit value	
External stability	Arc slip		≦	1.5				Land
	Slide	1.789	≧	1.2	1.563	≧	1.0	Land
	Fall	2.505	≧	1.2	2.223	≧	1.1	Land
	bearing (kN/㎡)	281.76	≦	313.51	418.76	≦	424.44	Land
Internal stability	Toe pressure (kN/㎡)	281.76	≦	500	418.76	≦	750	Liquefaction
	horizontal shear (kN/㎡)	177.50	≦	250	221.68	≦	375	Liquefaction
	Check of thickness of the improved body (kN/㎡)	155.86	≦	250	164.11	≦	375	Liquefaction
	vertical shear (kN/㎡)	211.18	≦	250	271.24	≦	375	Liquefaction

Reference: Land: manual for deep mixing method design and construction in land construction
Liquefaction: Manual for anti-liquefaction design and construction

Figure 4.4.11 The calculation result of outside and inside stability of the improved pillars

Strength of compound ground

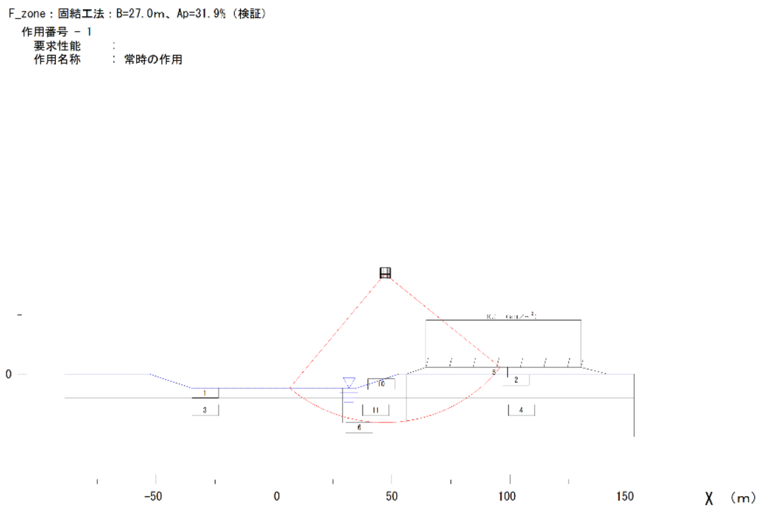
$$C = Cp \times ap + \alpha \times Co(1 - ap)$$

where,
- C : strength of compound ground (kN/㎡)
- Cp : strength of improved body (kN/㎡)=quck/2
- Co : original ground strength(kN/㎡), assume as 10(kN/㎡) for safety
- α : reduction rate of fracture strain
- ap : ground improving ratio

Reference:
Manual for peat soft ground construction, JICA, 2002
(α is partly modified based on manual for deep mixing method design and construction in land construction)

C＝500/2×0.319+0.5×10×(1−0.319)＝83.2 (kN/m2)

<u>**∴ strength of compound ground : C=83.2kN/㎡)**</u>



scale ; 1/ 2000

limit safety coefficient	Fs =	1.500
minimum safety coefficient	=	1.521 ≧ 1.500 (OK)
arc center	X =	47.00 (m)
	Y =	42.50 (m)
radius	R =	63.10 (m)
resistance moment	MR =	225731.5 (kN・m)
movement moment	MD =	148387.4 (kN・m)

【土質条件表（入力値）】

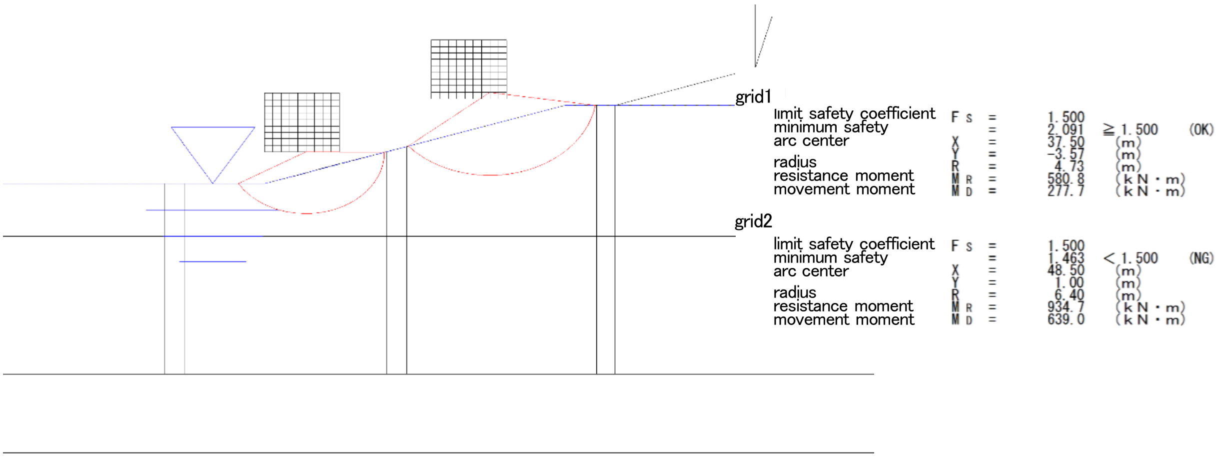
層番号	飽和重量 (kN/m³)	湿潤重量 (kN/m³)	内部摩擦角 (度)	粘着力 (kN/m²)	粘着力の一次係数	水平震度	鉛直震度
1	15.60	14.60	0.00	10.00	0.00	0.000	0.000
2	15.60	14.60	0.00	16.10	0.00	0.000	0.000
3	15.60	14.60	0.00	0.00	1.00	0.000	0.000
4	15.60	14.60	0.00	7.80	1.00	0.000	0.000
5	18.00	17.00	18.00	10.00	0.00	0.000	0.000
6	19.90	18.90	0.00	130.50	0.00	0.000	0.000
10	15.60	14.60	0.00	83.20	0.00	0.000	0.000
11	15.60	14.60	0.00	83.20	0.00	0.000	0.000

粘着力の基準Y座標 = 0.000 (m)
水の単位体積重量 = 10.00 (kN/m³)

Source ：JICA Study Team

Figure 4.4.12 The calculation result for circular slip

The safety coefficient of surface slipping inside the mesh is checked due to its large size. As a result, a safety coefficient larger than 1.4 was confirmed, which is slightly smaller than target value of 1.5.



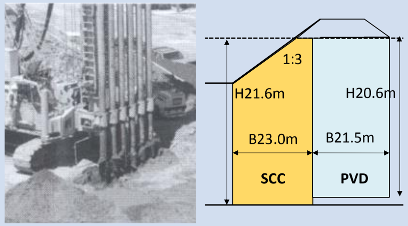
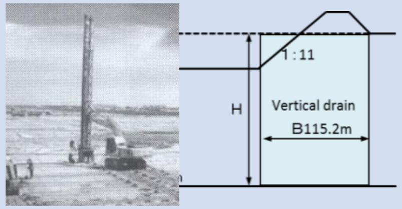
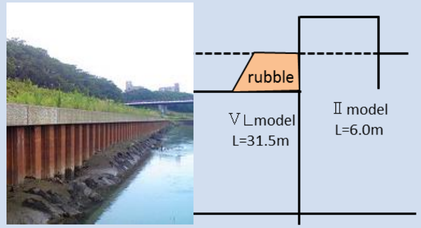
Source：JICA Study Team

Figure 4.4.13 The calculation result regarding circular slip
(Slip happens inside of square pillars)

(4) Overall comparison

The virtual drain method is selected as a solution for consolidation settlement in the middle section. As for the southern section, the SCC method is assumed as the most appropriate one, not only because it is the most cost-friendly one, but also there are many construction cases in Thailand. In addition, as a reinforcement for countering consolidation settlement, the virtual drain method will be also applied beneath the dike embankment.

Table 4.4.4 Method comparison for the southern section

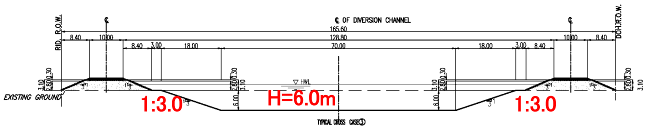
Countermeasure construction		1 Soil strengthening method (SCC) <under the embankment: PVD>	2 Vertical drain method	3 Steel sheet pile method
Image of construction method				
Overview		To construct soil cement columns (SCC) in the ground and arrange them in a grid shape. (37% improved)	To lay vertical drain on in order to accelerate consolidation and increase strength of basic foundation.	To install steel sheet piles doubly and raise the ground level(banking) among steel sheet piles.
Width of land acquisition		160m	238m	139m
Cost performance Thousand TBH/10m	Construction cost	10,933	10,228	18,765
	Land cost	3,952	5,893	3,425
	Total cost	14,885	16,121	22,190
Constraints of construction		Its constraints of construction is better than those of other methods.	It is needed to leave for a year. It takes long time to set pre-road bank and remove them.	No data about installation achievements of steel sheet piles, those width is over 30m
Construction experience		Some achievements for diversion channels	A lot of achievements for road embankment	A lot of achievements for concrete sheet pile
Operation and Maintenance		The risk of its banking deformation is lower than those of other methods.	O&M is needed, viewing from the long term. For example, top end of the foundation, etc.	Countermeasure against settlement is needed for bank among double sheet piles.
Assessment		○	△	△

Source : JICA Study Team

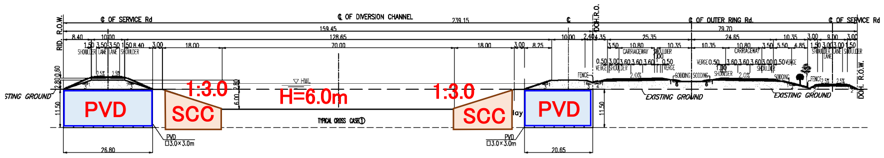
(5) Standard section

A standard section is indicated below.

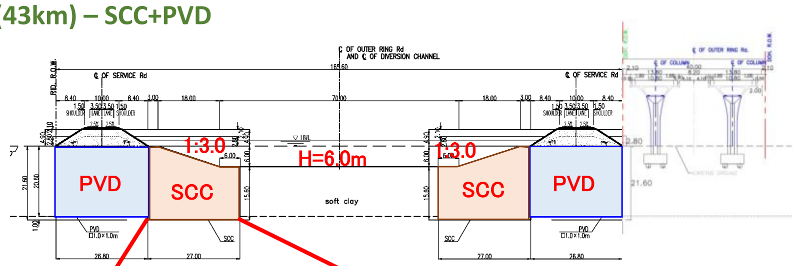
■North part (36km) – No counter measure



■Central part (32km) – SCC+PVD



■South part (43km) – SCC+PVD



Source: JICA Study Team

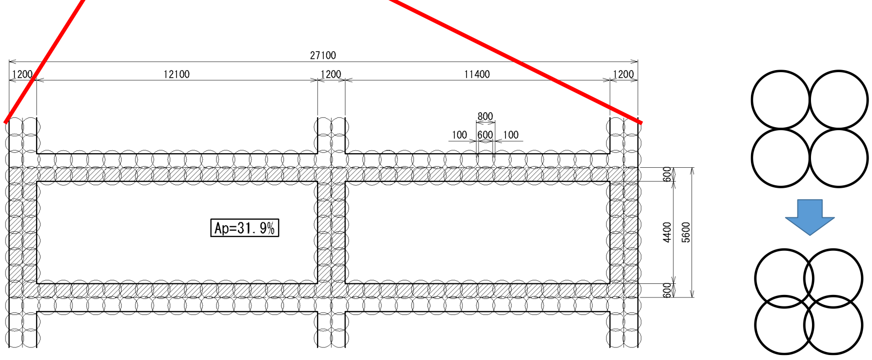


Figure 4.4.14 Standard horizontal projection of the Diversion Channel

4.5 Diversion Channel Project cost

Following table shows the project cost of the Diversion Channel.

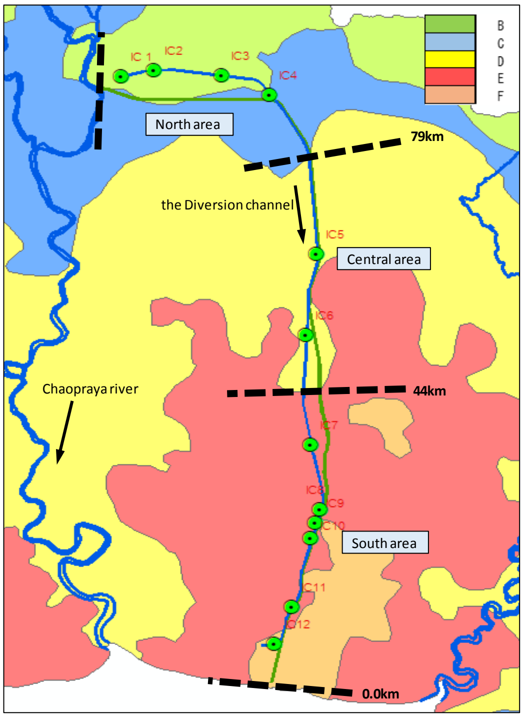
Table 4.5.1 Diversion Channel project cost

	Cost (Include soil disposal cost) Mil. THB
Construction cost	50,627
Facility cost	21,331
Land cost	74,788
Engineering	5,596
Other(EIA/Adm)	9,233
Physical Contingency	7,078
Compensation	563
Project Cost	169,216

Source: JICA Study Team

In the estimation, the conditions shown below are assumed;

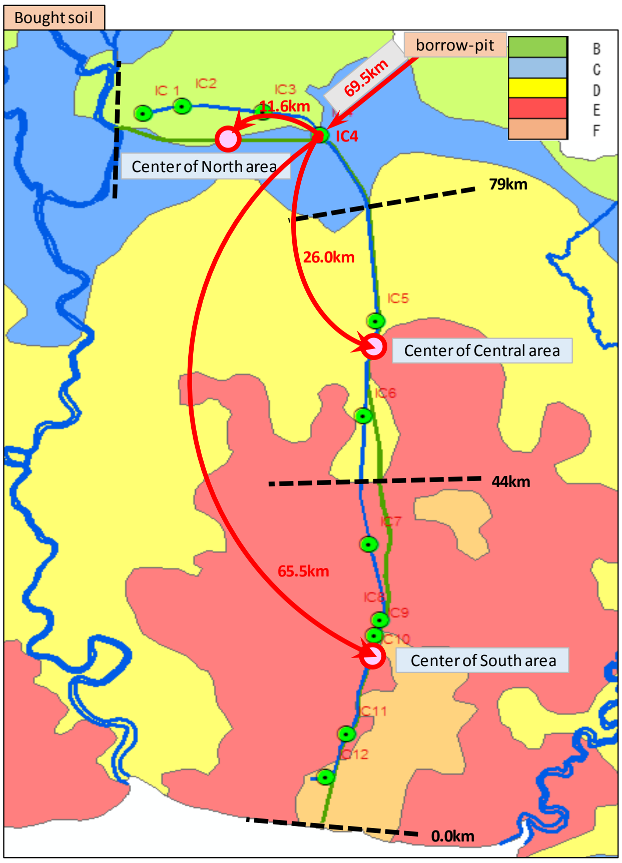
- The project zone is divided into 3 zones (Northern part, Central part and Southern part) by soil condition, and the construction cost in each zone is estimated in line with the necessity of soil strengthening of each zone.
- The construction cost estimation is divided into the estimation of the cost of the Diversion Channel itself and that of facilities: gate, siphon, etc.
- A transportation cost is assumed for the excavated soil from the project site to disposal sites.
- Factor F is set at 13 %
- The land acquisition cost is estimated based on the latest data from the Treasury Department of the Ministry of Finance.
- The other cost items are estimated by multiplying those estimations in the Master Plan in 2013 with the price inflation rate.



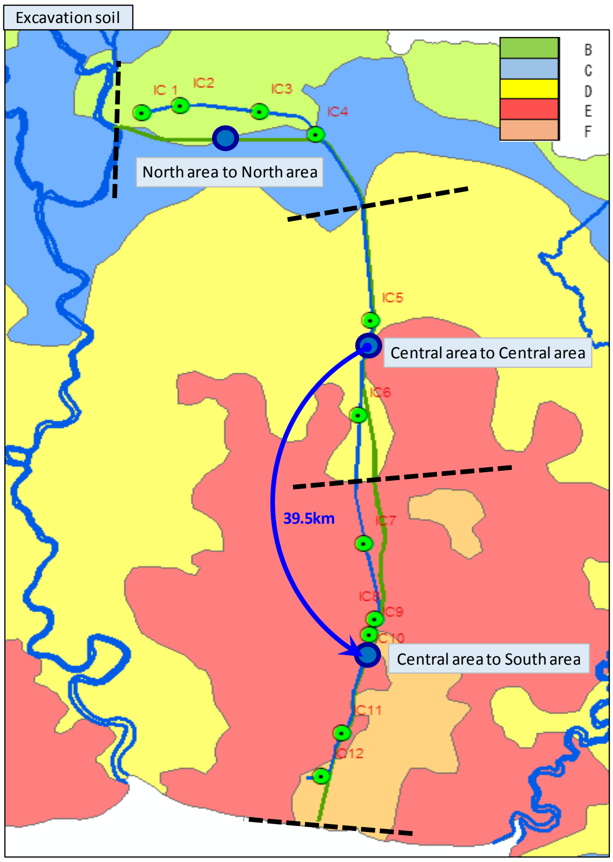
Source: JICA Study Team

Figure 4.5.1 Zone division at the Diversion Channel investment

A transportation cost is assumed by the distance between borrow pit and IC4 and the distance between IC4 and each site. Excavated soil from the northern area is to be used for the Diversion Channel embankment in the northern area. Excavated soil from the central area is to be used for the Diversion Channel embankment in the central area. In the southern area, the transportation cost from the central area to the southern area was totaled. The transportation distance is from the halfway point of the central area to the halfway point of the southern area



Transportation distance of purchased soil



Transportation distance of excavated soil

Source : JICA Study Team

Figure 4.5.2 Transportation distance of bought soil and excavated soil

The breakdown of the construction cost of the Diversion Channel and its facilities is shown in the next page.

Table 4.5.2 Result of estimation of the Diversion Channel

Items			Quantity	Unit	Unit price (THB)	Amount (THB)		Remark
Earthwork	Excavation		58,783,824	m^3	20	1,175,676,480	44,795,262,061	a)
	Embankment	Mixing / Compaction (V)	16,004,910	m^3	292.2	4,676,634,702		
		Purchased sand for mixing (V/3)	5,334,970	m^3	135	720,221,085		
		Purchase sand transportation (Sand pit → Interchange 4)	5,334,970	m^3	240	1,280,393,040		
		Purchased sand transportation (Interchange 4 → Excavation yard)	5,334,970	m^3		995,262,785		
	Remained Soil Disposal	Remained soil disposal	38,231,309	m^3	282	10,781,229,138		
		Excavated soil	*58,783,824*	*m^3*				
		Utilize excavated soil	*-10,669,939*	*m^3*				
		Road embanking material	*-9,882,576*	*m^3*				
Planting Work		Sodding	3,786,795	m^2	65	246,141,675		
Crest Pavement (2 lanes 10m width)		Under layer roadbed T=200mm	437,432	m^3	118.8	51,966,922		
		Upper layer roadbed T=150mm	308,729	m^3	313.6	96,817,414		
		Surface layer t=150mm	292,101	m^3	930.0	271,653,930		
Soil Stabilization		SCC (Soil Cement Column)	16,695,704	m^3	1,200	20,034,844,800		
		PVD (Prefabricated Vertical Drain)	42,938,001	m	90	3,864,420,090		
Boxculvert		Interchange 11 (4 places)	4	sites	150,000,000	600,000,000		
Factor F (Indirect construction cost rate)							5,823,384,068	b)=a)×0.13
Construction cost (Diversion Channel)							50,618,646,129	c)=a)+b)
Facility structure	Road bridge		27,000	m^2	82,000	2,214,000,000	18,876,624,000	d)
	Railway bridge		677,000	m	800	541,600,000		
	Gate	Upstream end, Downstream end	2	place		5,466,000,000		
	Syphon	14 places	1	set		7,429,000,000		
	Lock gate		1	set		2,500,000,000		
	General work	4% of the above				726,024,000		
Factor F (Indirect construction cost rate)							2,453,961,120	e)=d)×0.13
Construction cost (Facility structure)							21,330,585,120	f)=d)+e)
Construction cost							71,949,231,249	g)=c)+f)
Engineering Cost / Construction Control							5,755,938,500	h)=g)×0.08
Project Management Cost / Processing							2,158,476,937	i)=g)×0.03
Value added Tax							0	
Land Cost / Compensation							52,450,447,449	j)
Project cost							132,314,094,135	k)=g)+h)+i)+j)

Source: JICA Study Team

4.6 Recommendation

Followings are recommended as required studies for the promotion of Outer Ring Road and Diversion Channel combined project by RID.

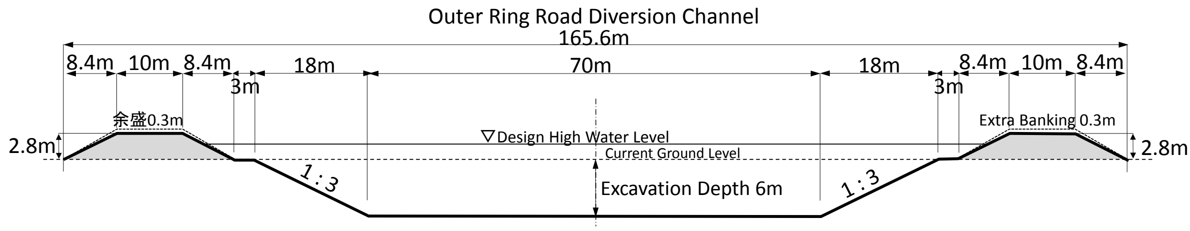
- Recommendation of required items and consideration regarding geological survey that should be conducted
- Consideration regarding detail design and construction of Outer Ring Road Diversion Channel

4.6.1 Required items and consideration regarding geological survey by RID

There is possibility of design change depending on the result of additional geological survey in the future. Design change may affect the project cost as follows;

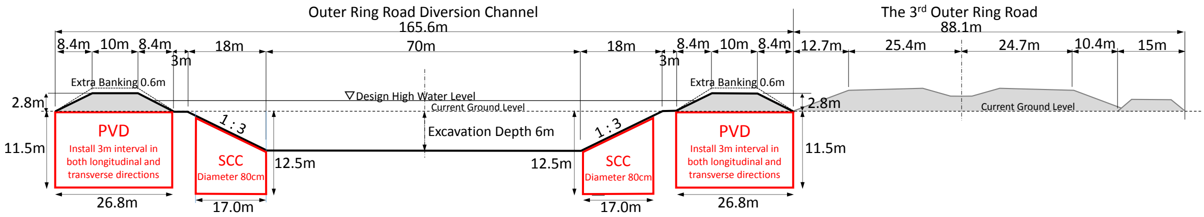
(a) Northern part (Embanking part) 36km length

- By reviewing the settlement, extra-banking may be corrected



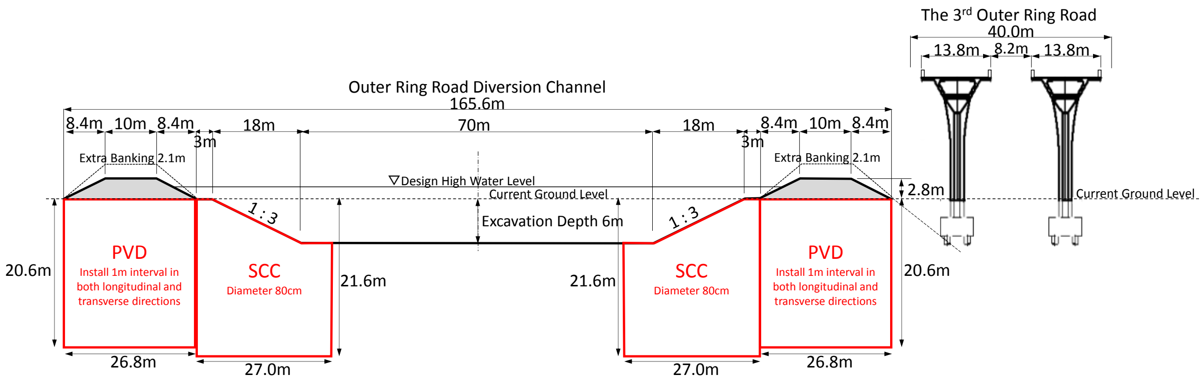
(b) Central part (SCC and PVD will be installed in this part) 32km length

- Required area, installation depth, installation width and installation position of SCC (Soil Cement Column) may be corrected
- Installation depth and installation position of PVD (Prefabricated Vertical Drain) may be corrected
- By reviewing settlement by pre-loading, extra-embanking may be corrected
- Mixing ratio of clay and sand may be corrected



(c) Southern part (SCC and PVD will be installed in this part) 43km length

- Installation depth, installation width and installation position of SCC may be corrected
- Installation depth and installation position of PVD may be corrected
- By reviewing settlement by pre-loading, extra-embanking may be corrected



4.6.2 Recommendation and consideration for the detail design and construction of Outer Ring Road Diversion Channel

1) Necessity of study regarding impact to the channel crossing structures and facilities near the channel

To construct Diversion Channel, 6m depth excavation and 2.8m height embanking are required. In the detail design, studies regarding impacts of excavation and embanking to the neighboring houses, factories, temples and various structures will be required. Especially in Central and Southern part where soil condition is very soft.

2) Necessity of study regarding remained soil disposal

Approximately 60 million cubic meters of excavated soil will be generated by Diversion Channel construction work. Therefore, the measures to reduce costs by using excavated soil in Northern and Central part as material of embankment were considered. On the other hand, excavated soil in Southern part will not be useful for the embankment material. In such a case, excavated soil should be disposed. According to the information in Thailand, excavated soil will be available for sale. However, because the amount of excavated soil is very large, it is necessary to consider how to deal with these large amount of excavated soil.

3) Necessity of determination of irrigation facilities dimension

Diversion Channel will cross with the existing irrigation channels at 14 sites. At the crossing with irrigation channels, syphons are planned to construct. In the detail design, water utilization conditions should be grasped exactly and structural design should be implemented.

CHAPTER 5 STUDY FOR USE OF DIVERSION CHANNEL IN NON-FLOOD TIME

5.1 Case Study

(1) Case Example of Recreational Water Use in Thailand

For the study of the beneficial uses in usual activities, example cases of open water space use in Thailand were studied. In Thailand, there are many example cases of active use of open water space such as riverside restaurants, recreational ground, floating market and floating houses.

[i]Source: Refer to chapter end

Figure 5.1.1 Example case recreational use of open water in Thailand (1)

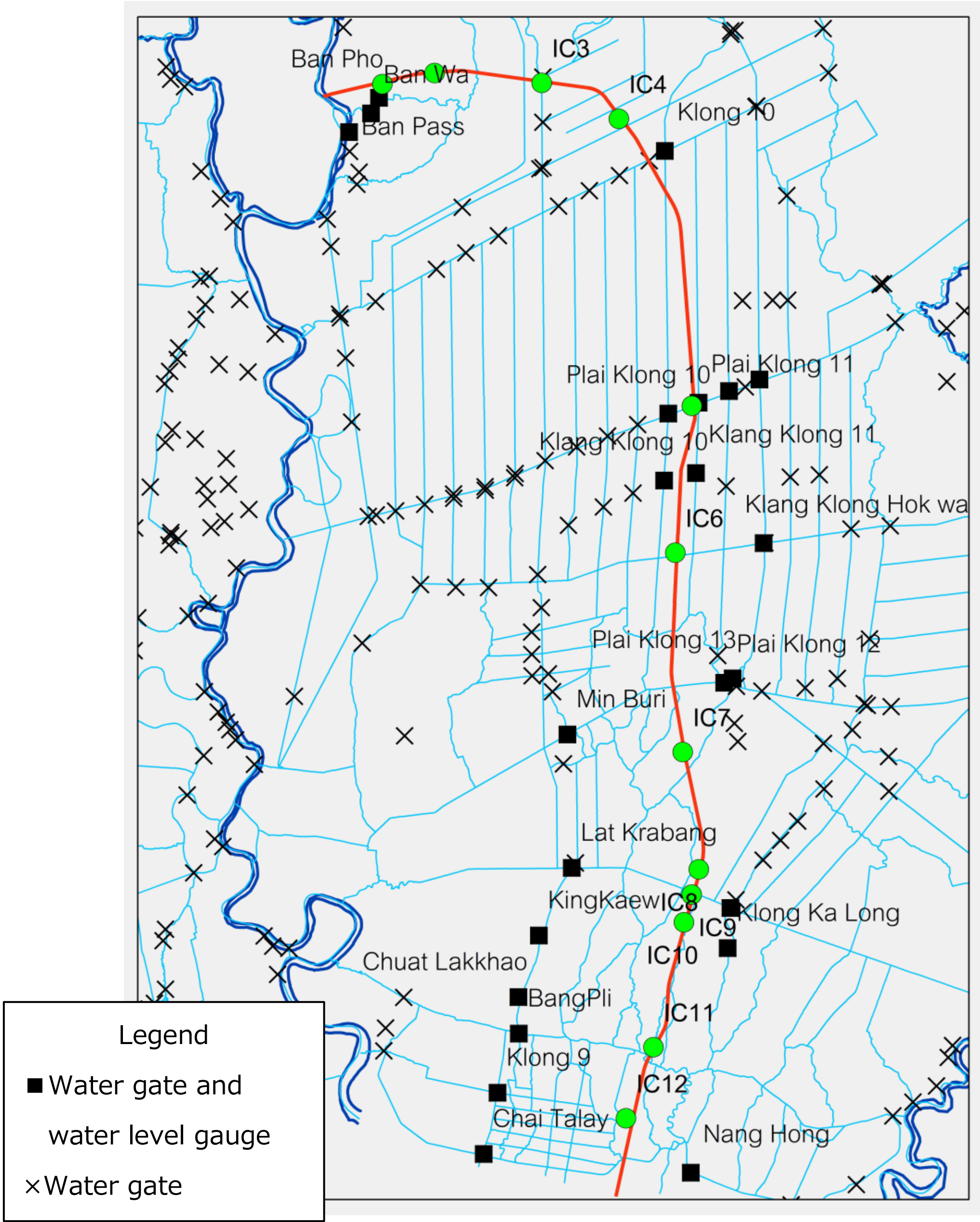
[ii]Source: Refer to chapter end

Figure 5.1.2 Example case recreational use of open water in Thailand (2)

5.2 Study on Irrigation Canal

(1) Current Situation of Installation Position of Water Gates

Figure 5.2.1 shows installation position of water gates in irrigation canals. From this figure it can be seen that the water gates are mainly installed in the north-south canals and upstream of each crossing point of north-south canals and east-west canals.



Source: JICA Study Team

Figure 5.2.1 Location of Existing Water Gates

Source: JICA Study Team

Figure 5.2.2 Location of Existing Water Gate at Channel Crossing

(2) Current Situation of measuring water level

1) Data Collection

In this study, irrigation canal water level data at measuring stations were collected in the period of 2011 to 2016 and shown in Table 5.2.1. There were 42 measuring stations in irrigation canals, however, water level data at only 20 measuring stations were available due to missing observations at 22 measuring stations.

Table 5.2.1 Availability of water level data in each measuring station (1/5)

Chonlaharnphichit Operation and Maintenance project											
Code Number	Name of Gate	Data from RID									
		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
1	Chonlaharnphichit 1	✓	✓	✓	✓	✓	x	□	□	□	✓
2	Chonlaharnphichit 2	✓	✓	✓	✓	✓	x	□	□	□	✓
16	Klang Klong Prawet	✓	✓	✓	✓	✓	x	□	□	□	✓
17	Lat Krabang	✓	✓	✓	✓	✓	x	x	□	✓	✓
19	King Kaew	✓	✓	✓	✓	✓	x	□	□	□	✓
20	Chuat Lakkhao	✓	✓	✓	✓	✓	x	□	□	✓	✓
21	Bang Pli	✓	✓	✓	✓	✓	x	□	□	□	✓
22	Klong 9	✓	✓	✓	✓	✓	x	□	□	□	✓
24	Klong Kha Long	x	x	x	x	x	x	□	□	□	x
25	Min Buri	x	✓	✓	✓	✓	x	□	□	✓	✓
30	Chai Ta Lay	✓	✓	✓	✓	✓	✓	✓	✓	□	✓
35	Chonlaharnphichit	✓	✓	✓	✓	✓	x	□	□	□	✓
36	Suwannaphumi	x	x	x	✓	✓	x	□	□	□	✓
37	Charoen Rat	✓	✓	✓	✓	✓	x	□	□	✓	✓
41	Nong Chok	x	x	✓	✓	✓	x	□	□	□	✓

Note :
✓ Complete data
□ Incomplete data
x No data

Source: JICA Study Team

Table 5.2.2 Availability of water level data in each measuring station (2/5)

North Rangsit Operation and Maintenance project											
Code Number	Name of Gate	Data from RID									
		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
8	Pak Klong 10	x	✓	✓	✓	□	□	✓	✓	✓	✓
9	Pak Klong Prame	□	✓	✓	✓	□	□	✓	✓	✓	✓
11	Plai Klong 12	□	✓	✓	✓	□	□	✓	✓	✓	✓
12	Plai Klong 10	x	✓	✓	✓	□	□	✓	✓	✓	✓
13	Plai klong 11	x	✓	✓	✓	□	□	✓	✓	✓	✓
14	Pradhammaracha	x	✓	✓	✓	□	□	✓	✓	✓	✓
18	Klang Klong Rangsit 8-9	□	✓	✓	✓	□	x	x	x	x	x
32	lang klong rangsit 12-1	□	✓	✓	✓	□	x	x	x	x	x
40	Pra In Taracha	x	✓	✓	✓	□	□	✓	✓	✓	✓

Source: JICA Study Team

Table 5.2.3 Availability of water level data in each measuring station (3/5)

South Rangsit Operation and Maintenance project											
Code Number	Name of Gate	Data from RID									
		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
3	Klang klong 10	x	✓	✓	✓	□	x	✓	✓	✓	✓
4	Plai Klong 13	x	✓	✓	✓	□	□	✓	✓	✓	✓
5	Klang Klong Rangsit 8-9	✓	✓	✓	✓	□	□	✓	✓	✓	✓
6	Klang klong 11	x	✓	✓	✓	□	□	✓	✓	✓	✓
7	Klang klong hok wa	✓	✓	✓	✓	□	□	✓	✓	✓	✓
15	Klang Klong Sansab	Re-check									
23	Klong 20	✓	✓	✓	✓	□	□	□	✓	x	x
26	Plai klong 12	x	✓	✓	✓	□	□	✓	✓	✓	✓
32	lang klong rangsit 12-1	✓	✓	✓	✓	□	□	✓	✓	✓	✓
38	Pak Klong 10 (สายล่าง)	Re-check									
39	Pak Klong 12 (สายล่าง)	Re-check									

Source: JICA Study Team

Table 5.2.4 Availability of water level data in each measuring station (4/5)

Code Number	Name of Gate	Data from RID									
		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
27	Ban Pho	✓	✓	✓	✓	□	x	□	✓	✓	✓
28	Ban Wa	✓	✓	✓	✓	□	x	□	✓	✓	✓
29	Ban pass	✓	x	x	x	x	x	□	✓	✓	✓
33	Uthai	Re-check									
34	Wang Noi	Re-check									

Source: JICA Study Team

Table 5.2.5 Availability of water level data in each measuring station (5/5)

Pra-ong Operation and Maintenance project											
Code Number	Name of Gate	Data from RID									
		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
31	Nang Hong	x	✓	✓	✓	□	x	✓	✓	✓	✓

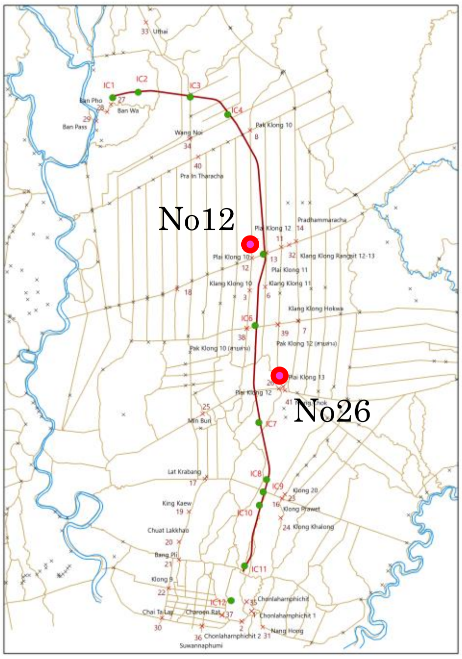
Note :
- ✓ Complete data
- □ Incomplete data
- x No data

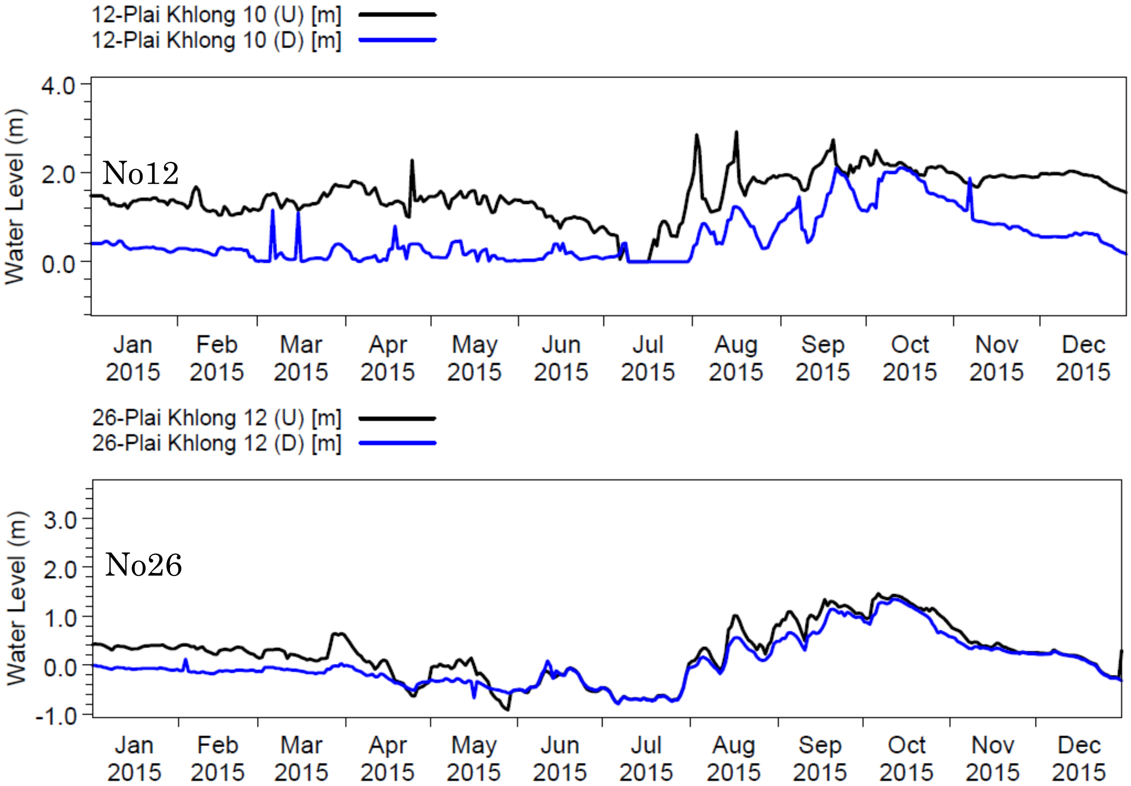
Source: JICA Study Team

2) Water Level Situation of Irrigation Canals

i) Annual Water Level Situation

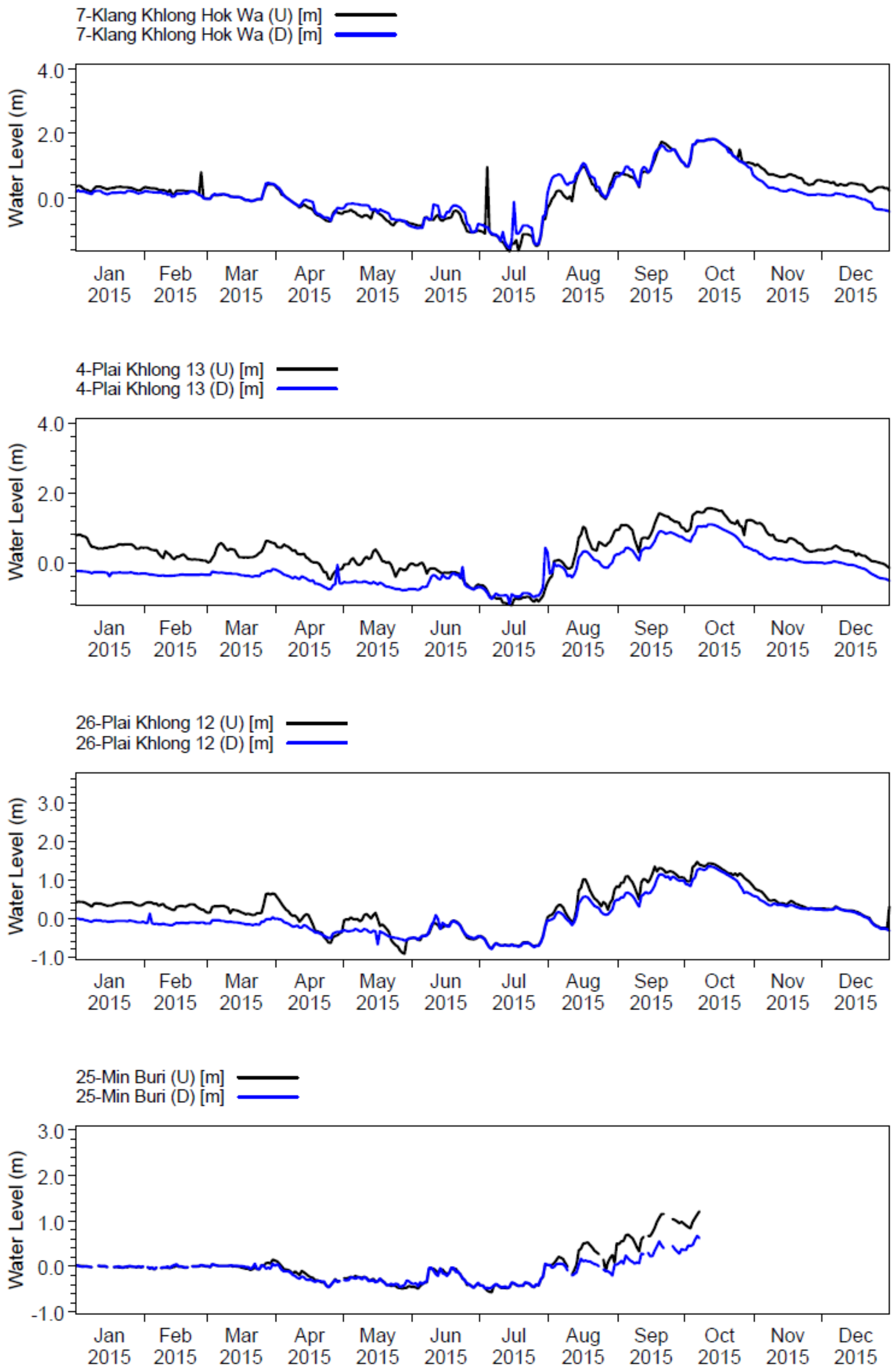
The water level situation of irrigation canals at two representative measuring stations is shown in Figure 5.2.3. For purpose of water gate operation, water levels are measured both upstream (U) and downstream (D) of each water gate. It can be noticed that the water level fluctuation caused by water gate operation depends on the seasonal changes and the location of the water gate. In order to plan appropriate water distribution in the Diversion Channel project, first the water level situation of all the irrigation canals should be analyzed.





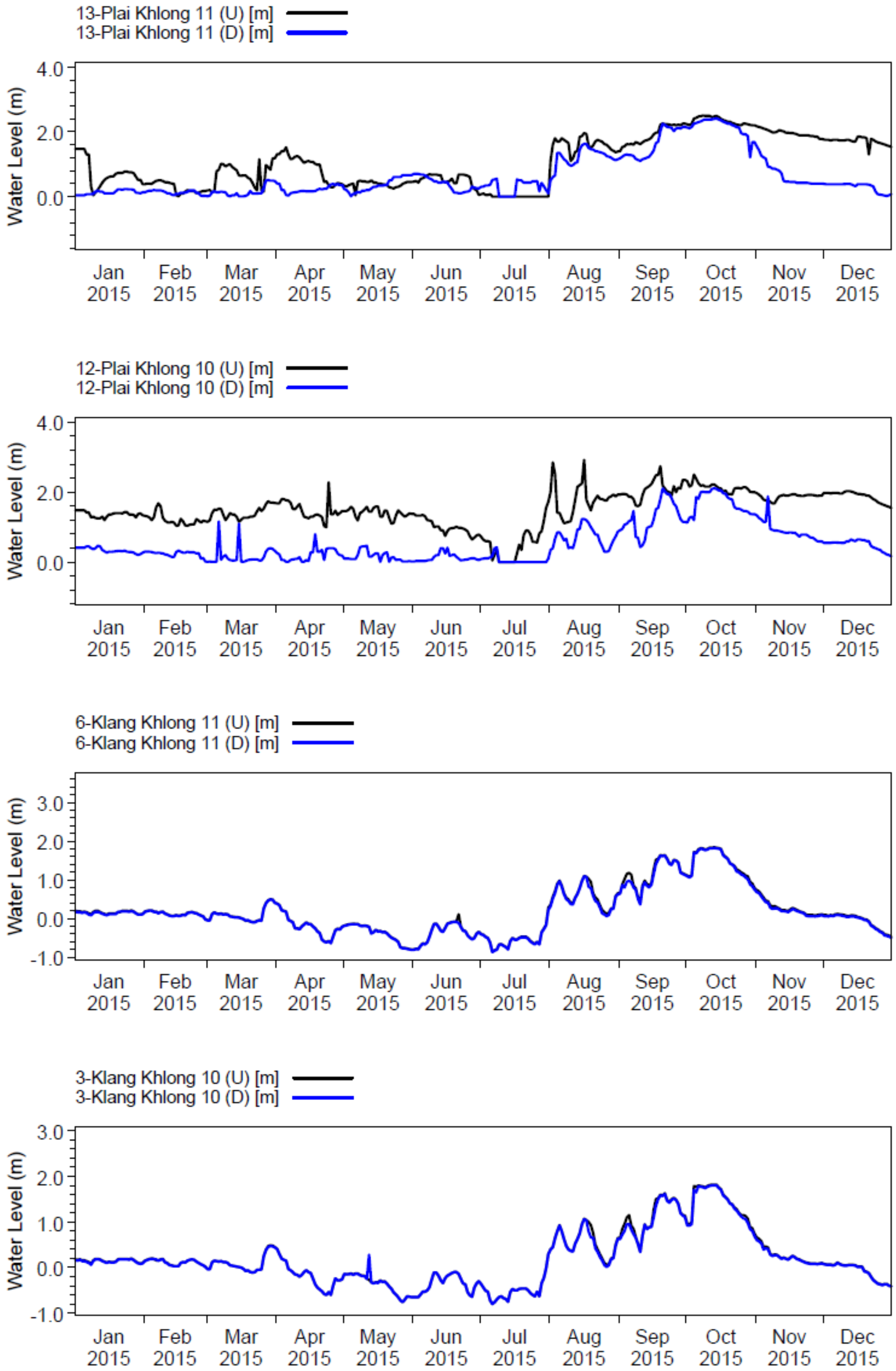
Source: JICA Study Team

Figure 5.2.3 Water level situation at two representative measuring stations in 2015



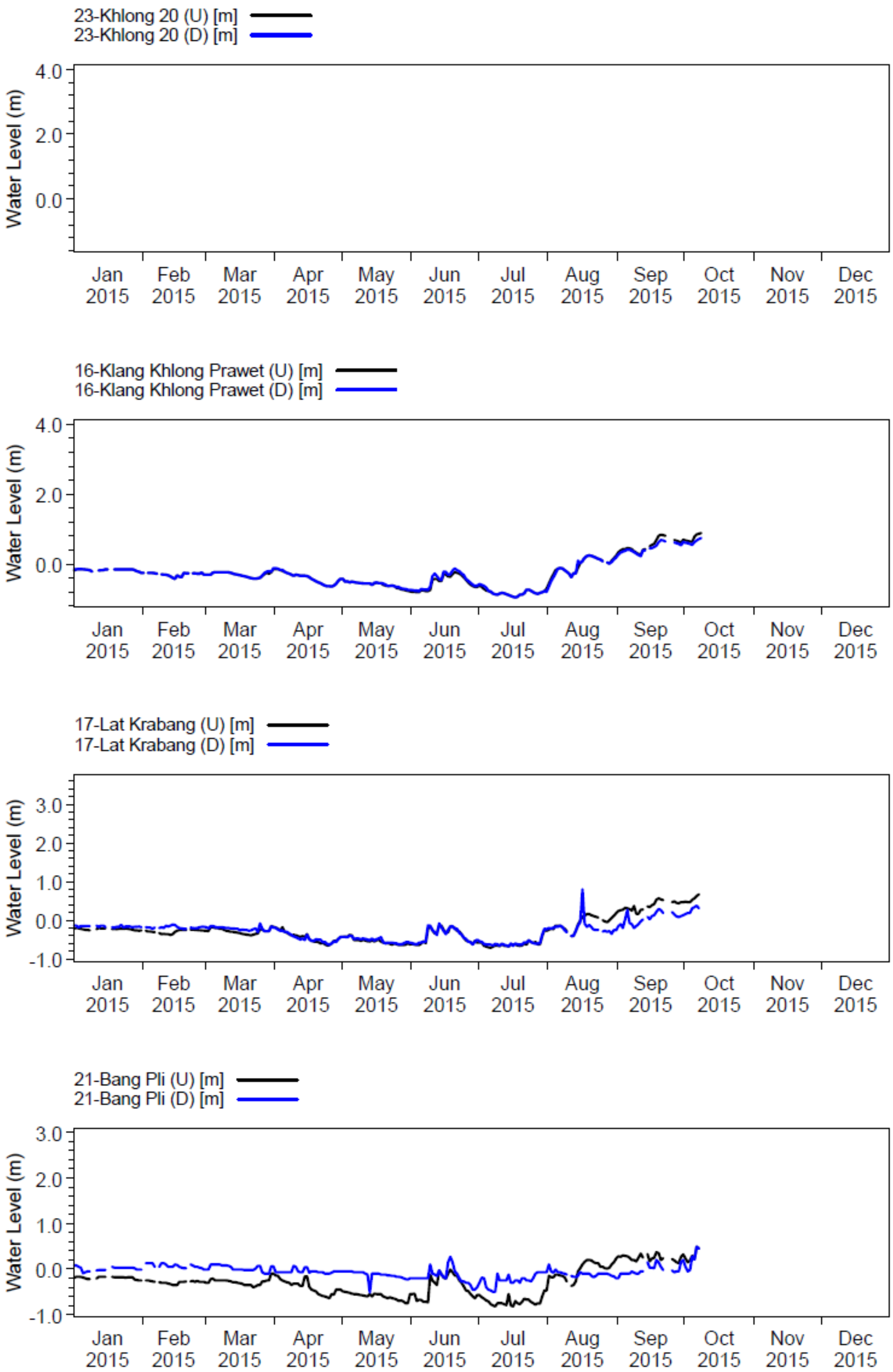
Source: JICA Study Team

Figure 5.2.4 Water level situation at each measuring station in 2015 (1/5)



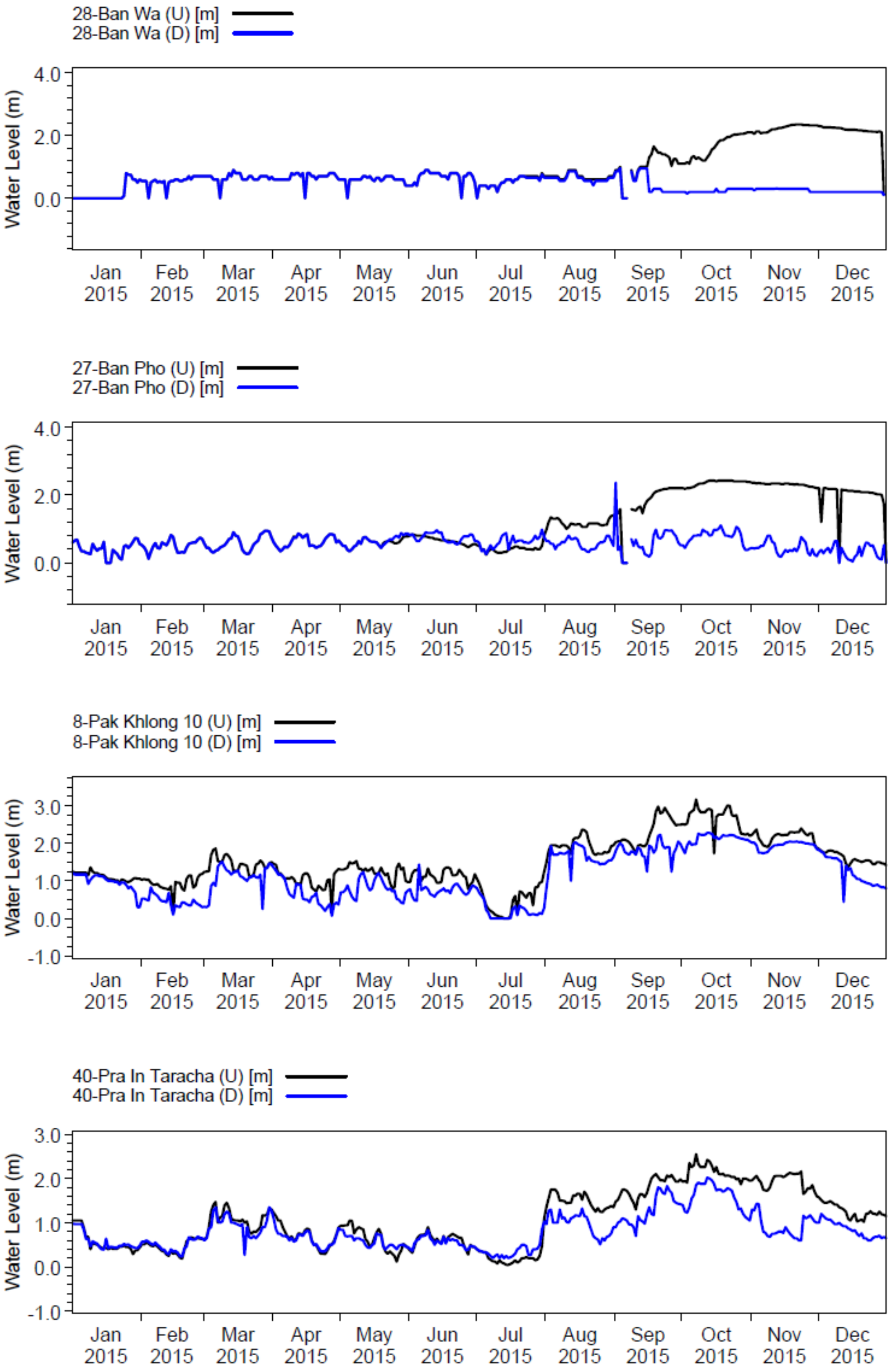
Source: JICA Study Team

Figure 5.2.5 Water level situation at each measuring station in 2015 (2/5)



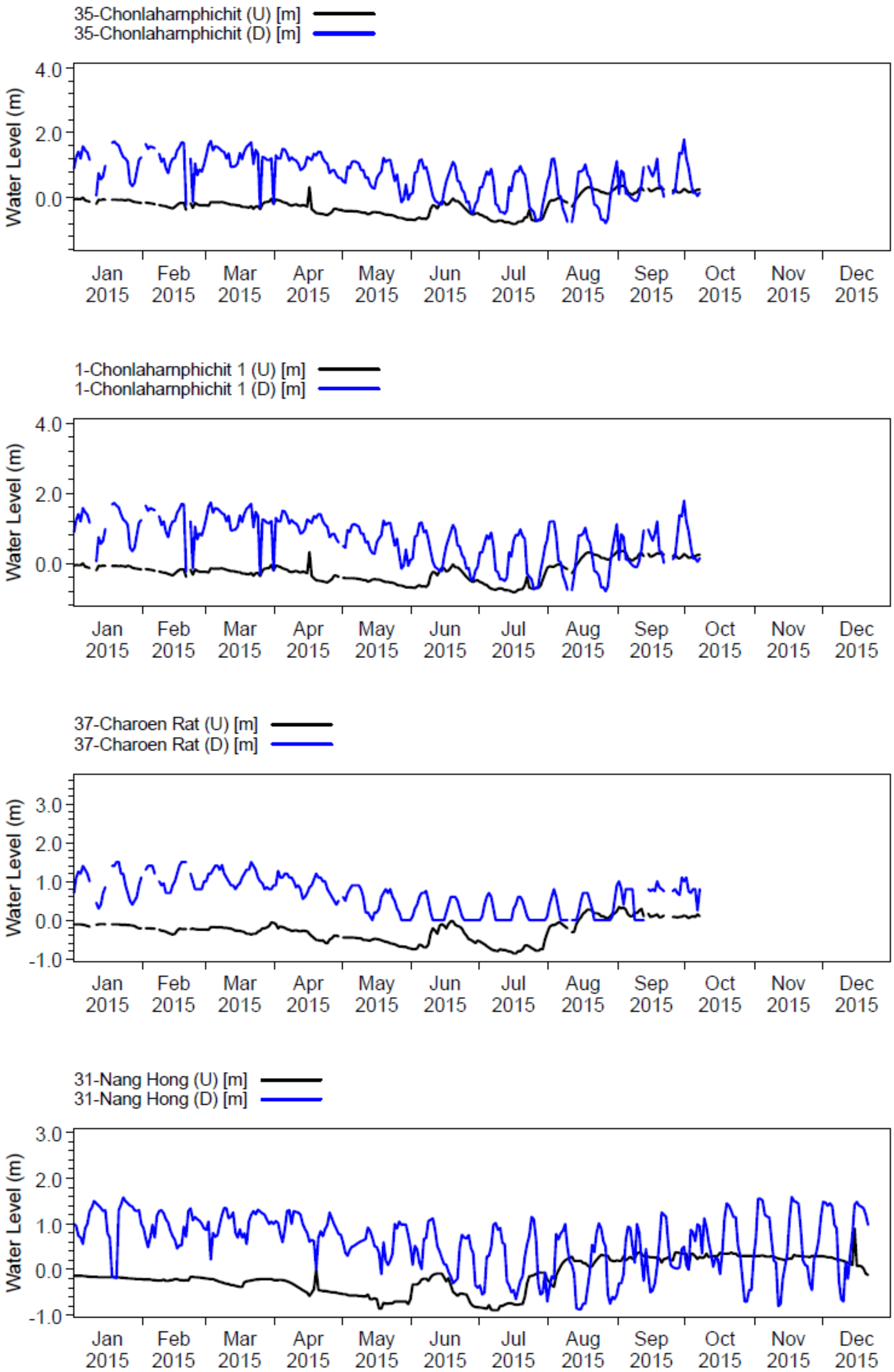
Source: JICA Study Team

Figure 5.2.6 Water level situation at each measuring station in 2015 (3/5)



Source: JICA Study Team

Figure 5.2.7 Water level situation at each measuring station in 2015 (4/5)



Source: JICA Study Team

Figure 5.2.8 Water level situation at each measuring station in 2015 (5/5)

ii) Seasonal Water Level Situation

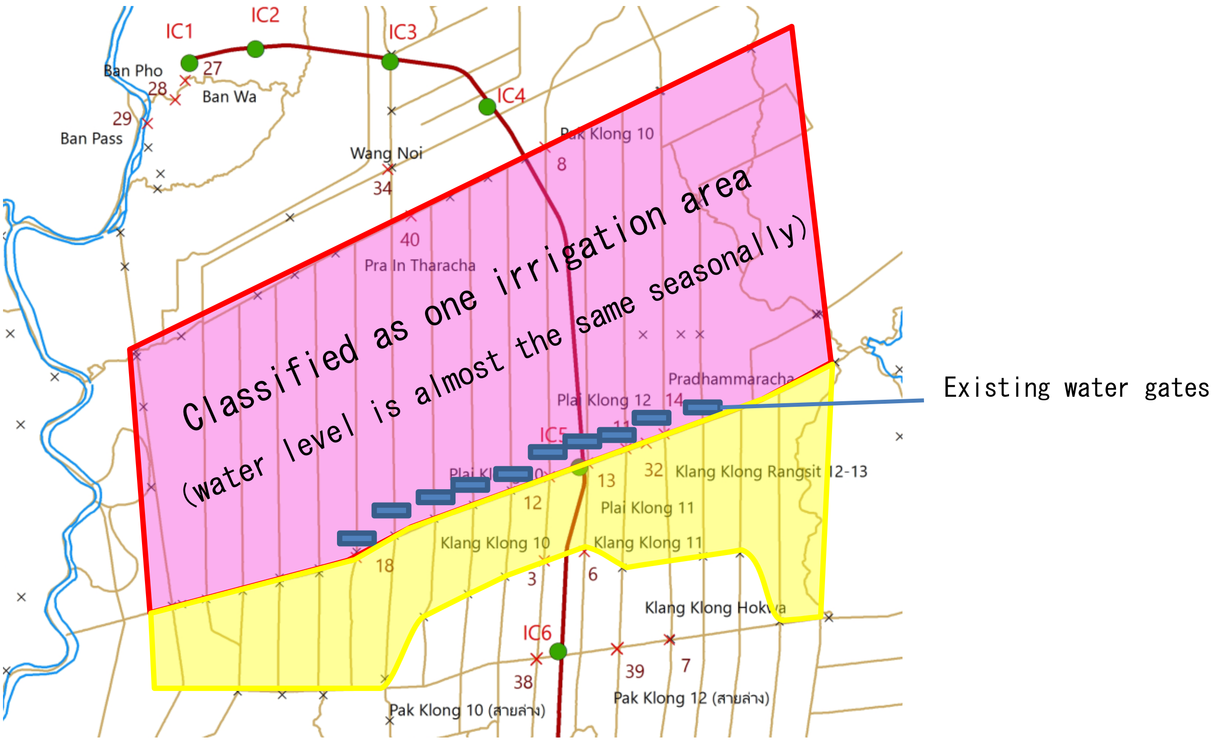
Study of water level distribution in all irrigation canals during the 3 seasons (dry season, hot season and rainy season) was conducted. In consideration of seasonal fluctuation of water use and water flow in each irrigation canal and simultaneous occurrence of seasonal water level situation in the same irrigation area, the study was conducted on the following representative dates in each season.

Approximate end date of season; Dry season: February 1, Hot season: May 1, Rainy season: October 1

The studied period covers 6 years, from 2011to 2016, after the flood in 2011.

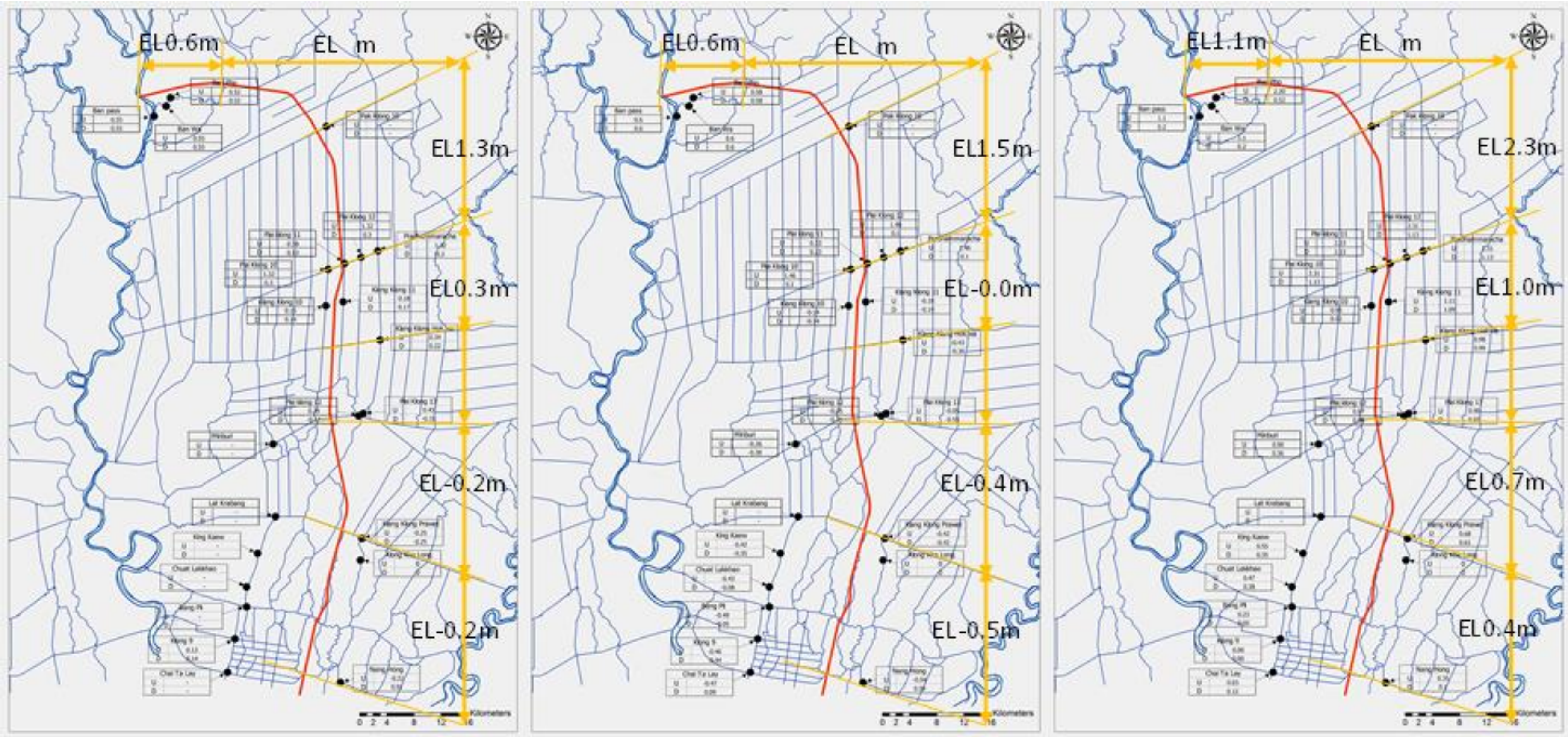
Looking at the water level distribution during the three seasons in 2015, the whole irrigation area can be classified into several irrigation areas in the north-south direction as shown in Figure 5.2.10. Each irrigation area has almost the same water level seasonally, and is divided by the set of water gates.

The conceptual classification of the irrigation areas is shown in Figure 5.2.9. According to the interview with RID, current irrigation canals are operated as an “irrigation block system” (not running water system), and each irrigation block system should be maintained after the completion of the Diversion Chanel.



Source: JICA Study Team

Figure 5.2.9 Classification of irrigation areas in the mesh of irrigation canals



Source: JICA Study Team

Figure 5.2.10 Seasonal water level fluctuation in 2015

5.3 Use of the Diversion Channel in Usual Activities

(1) Functional Maintenance of Existing Irrigation Canals Affected by the Diversion Channel Construction

1) Maintenance of irrigation water distribution function

Existing irrigation canals can be divided by the Diversion Channel construction and the following study was conducted in order to functionally maintain them.

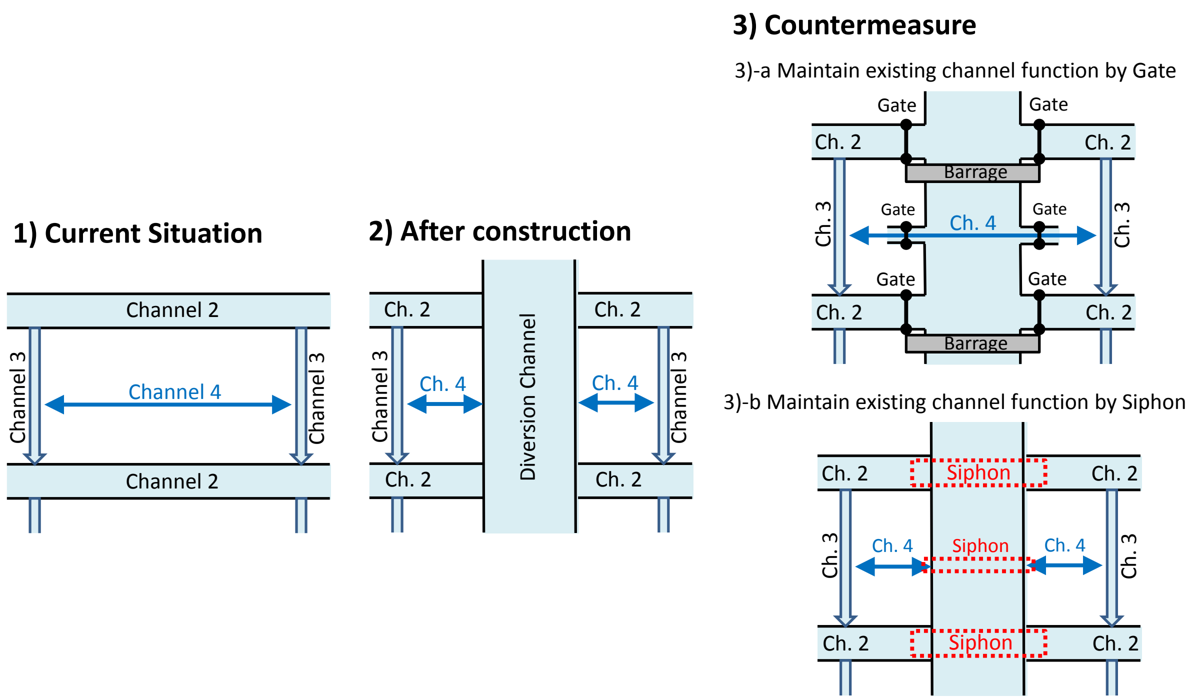
1) Currently, irrigation canals are stretching out in a finely meshed pattern.

2) The irrigation canals can be divided by the construction of the Diversion Channel.

The following actions can be taken to maintain the function of the existing irrigation canals.

3)-a Water gate method・・・Weirs/barrages are installed within the Diversion Channel and the water level upstream of each weir is controlled. Existing irrigation canals and the Diversion Channel are connected at the crossing points.

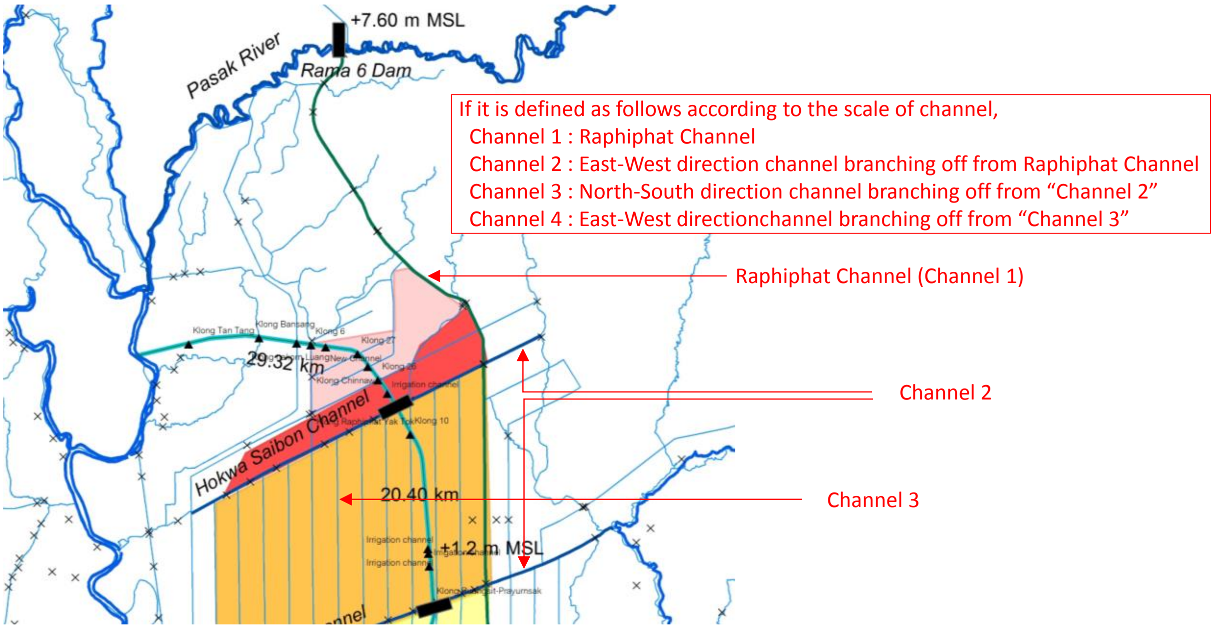
3)-b Siphon method・・・Siphons are installed at the crossing points of existing irrigation canals and the Diversion Channel and existing irrigation canals are not divided.



Source: JICA Study Team

Figure 5.3.1 Image of current functional maintenance of existing irrigation canals

Existing irrigation canals can be classified into Channels l to 4. Because RID governs Channels 1 to 3, and supposedly, Channel 4 is not much affected by the Diversion Channel construction, therefore, only Channels 1to 3 are subject to study the current functional maintenance.



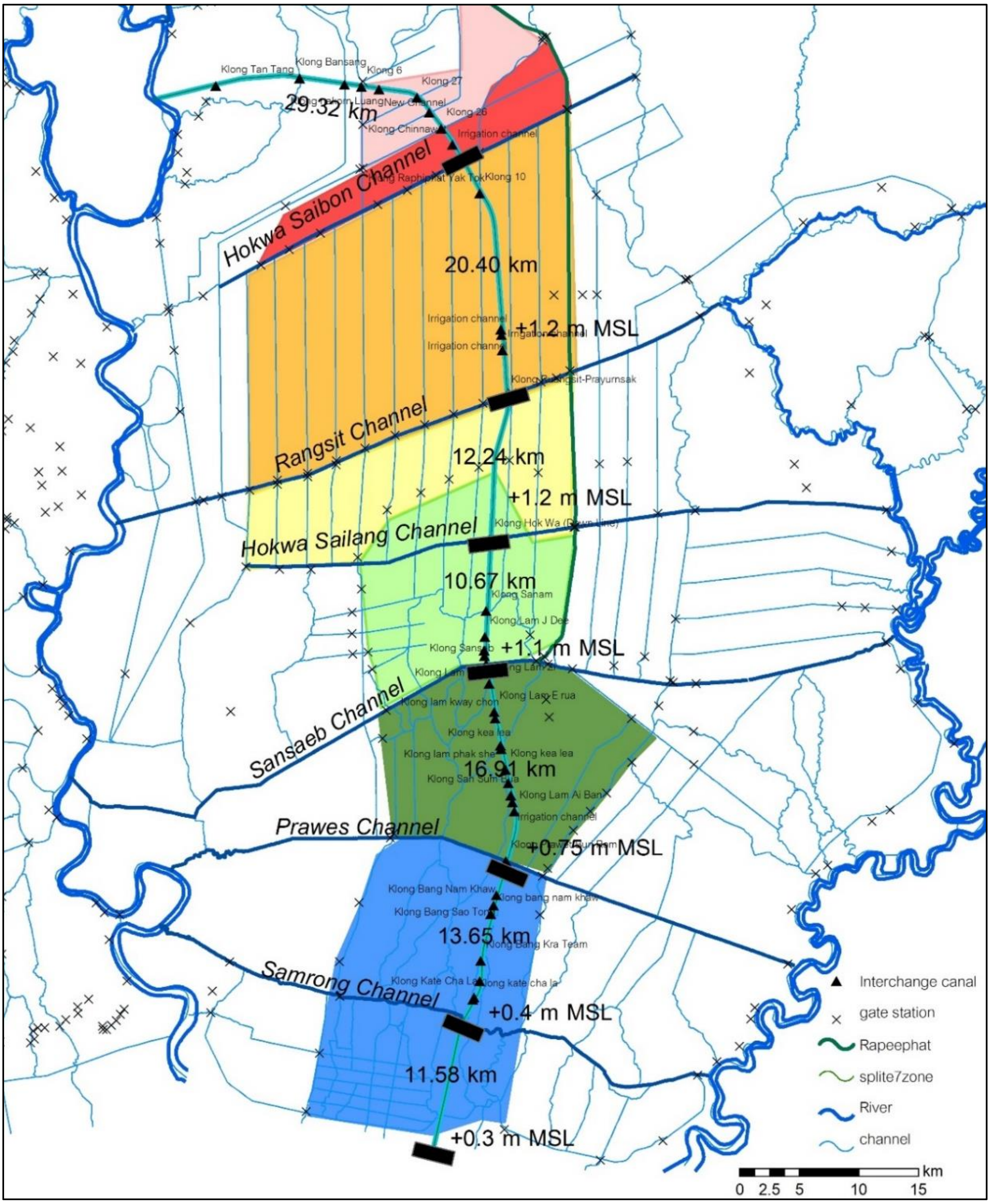
Source: JICA Study Team

Figure 5.3.2 Explanation of Channels 1 ～ Channel 4

Results of confirming the overview of Channels 1 to 4 on site are as follows.

[iii]Source: Refer to chapter end

Figure 5.3.3 Overview of Channels 1 ～ Channel 4 (Result of site visit)



Crossing of existing irrigation channel and diversion channel

▲ 33 (Crossing with existing irrigation channel)

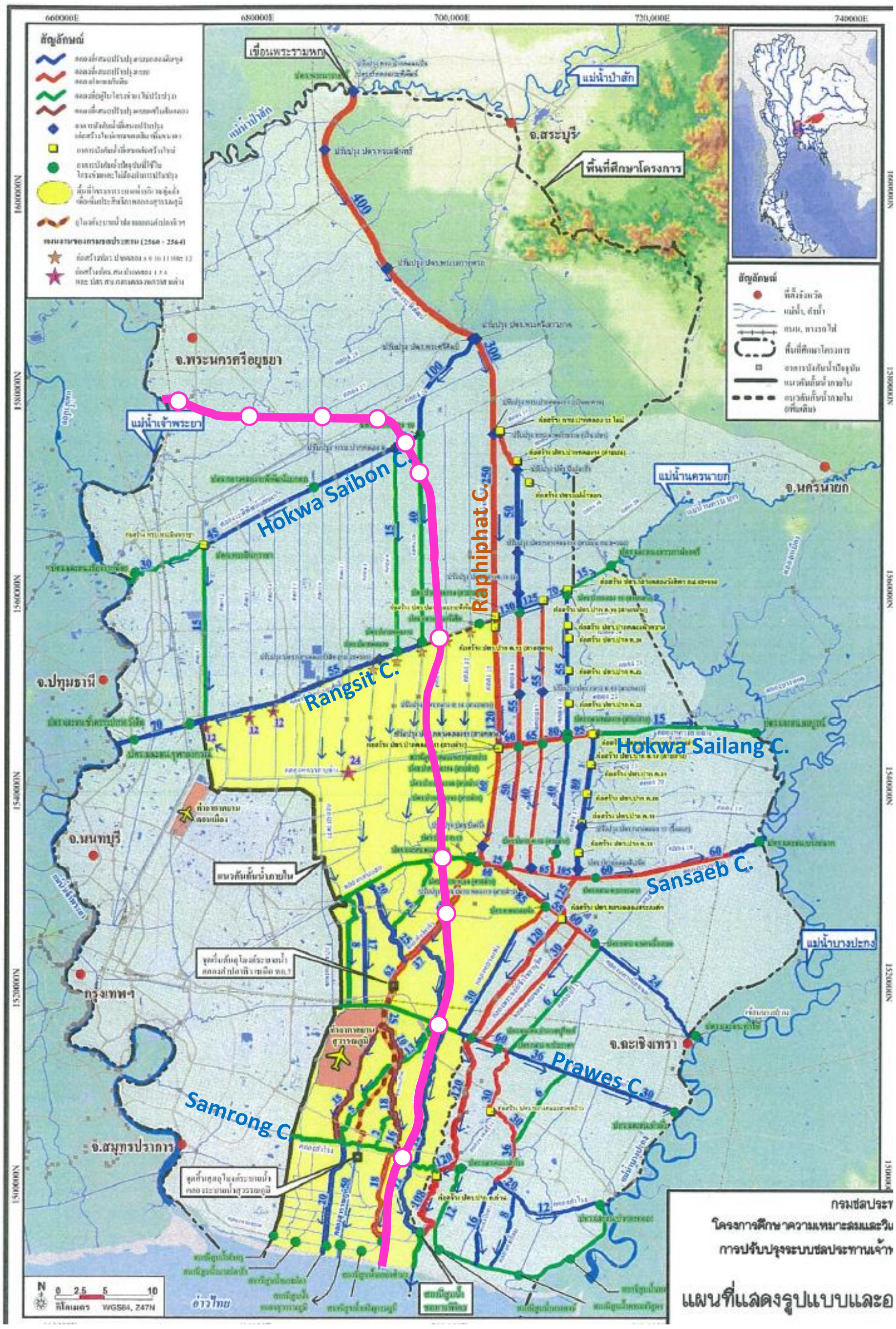
■ 7 (Crossing with Channel 2 etc.)

Source: JICA Study Team

Figure 5.3.4 Crossing points of existing irrigation canals and the Diversion Channel

2) Maintenance of flood drainage function

At the intersection of the Diversion Channel and the existing channel, it is necessary to maintain the flood drainage function. The locations where the Diversion Channel and the channel with flood drainage function intersect are as shown in the figure below.

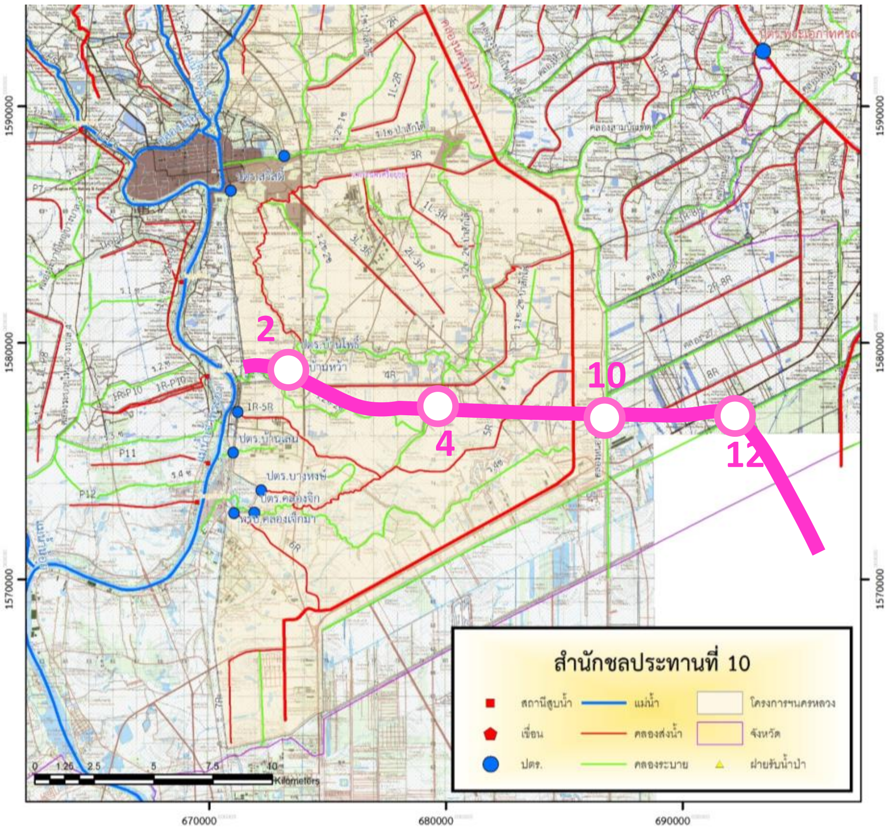


Source: JICA Study Team

Figure 5.3.5 Flood drainage plan with existing channel network

The pink circle indicates the intersection of the Diversion Channel and the existing channel (channel indicated by red, blue, green thick lines) managed by RID as flood drainage channels. Pink thick bold lines indicate Diversion Channel alignment.

In the figure below, the thick pink line indicates the alignment of the Diversion Channel. The pink circle indicates the intersection of the Diversion Channel and the existing flood drainage channel. Red lines indicate irrigation and drainage channels, and green lines indicate flood drainage channels.



Source: JICA Study Team

Figure 5.3.6 Irrigation water distribution / flood drainage system diagram with existing waterway

(2) Opinions from RID regarding use of diversion channel during normal times

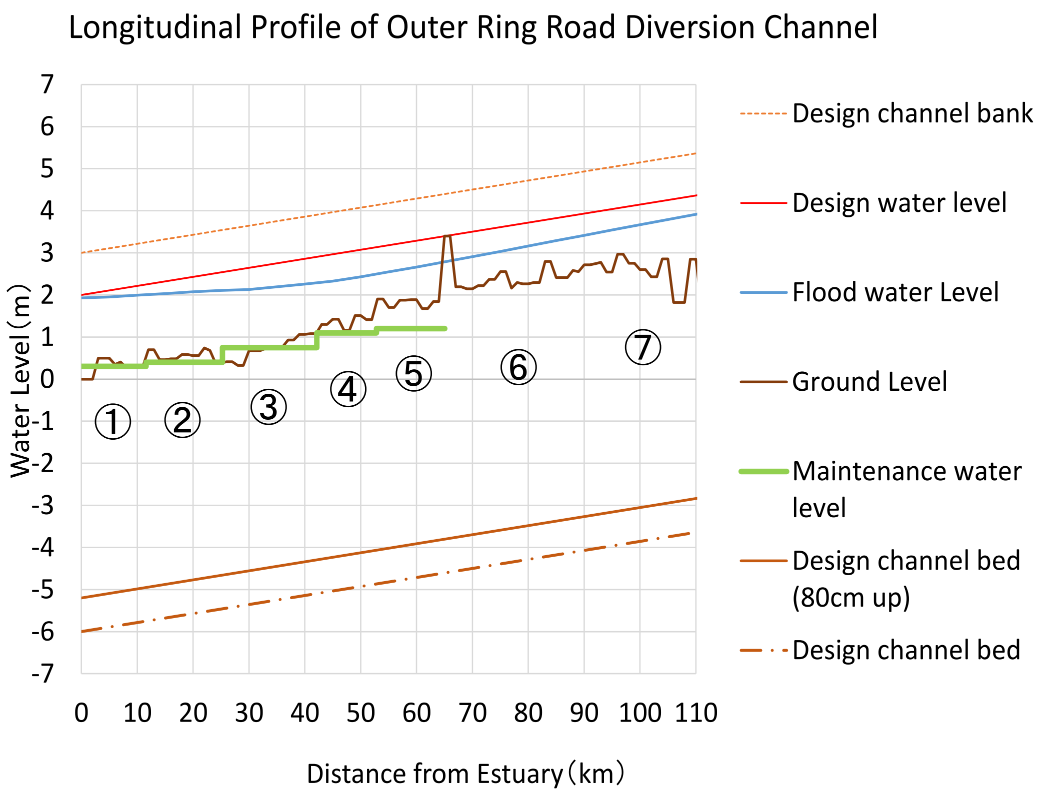
Following opinions regarding the use of diversion channel during normal times were expressed by RID.

- Thai people prefer the situation when water is present in the diversion channel.
- Reserving the water during the normal times for irrigation is expected.
- In case it will be used as facilities for recreation such as boat activities, local governments along the diversion channel will obtain permission from RID and manage it.
- It is possible to use the embankment as a cycling path and jogging course. In this case, the local governments along the diversion channel will be responsible for the maintenance and operation.
- It can be used for fishing, because sometimes the department related to fisheries, stocks fishes into the river and channels.

- The use of the diversion channel during normal times must give consideration to activities such as residential water, protection against saltwater intrusion, boat races etc. Since water for irrigation is used all year round, it is expected to maintain adequate water level throughout the year.
- Since water gates will be installed in the diversion channel, it will be difficult to use the diversion channel for cargo shipment.
- Regarding fish farming, there were many people that set nets near the river bank and farm inside of the net, which is currently prohibited because of the problem with water pollution etc. Therefore, the use of the diversion channel for fish farming is difficult.
- Cultivation of aquatic plants also seems to be difficult.
- It is also difficult to use as a place for solar power generation, because the dry area is small.

(3) Image of Water Level Operation after the Diversion Channel Completion

In the current situation, Maintenance Water Level for irrigation is set in each irrigation area (①～⑦ in the following figure) along the Diversion Channel. Maintenance Water Level is indicated as a green line in the figure below. Under the assumption that this Maintenance Water Level will be maintained after construction of the Diversion Channel, the depth of 5m in the channel will be maintained in each irrigation area.



Source: JICA Study Team

Figure 5.3.7 Image of water level operation after the Diversion Channel completion

[i] Source of Photos in Figure 5.1.1 Example case recreational use of open water use in Thailand (1)

Upper left：http://www.bkkkids.com/listing/amphawa-floating-market/
Upper right：JICA Study Team
Lower left：http://www.chiangmai.bangkok.com/top10/top10-restaurants-chiangmai-riverside.htm
Lower right：http://www.alamy.com/stock-photo/chao-river-activity-in-bangkok.html

[ii] Source of Photos in Figure 5.1.2 Example case recreational use of open water use in Thailand (2)

Upper left：https://www.bangkokpost.com/learning/advanced/589413/what-new-in-business-news-june-11-2015
Upper right：ASTV website
Lower left：http://www.biztosuccess.com
Lower right：http://www.saklektsb.go.th

[iii] Source of Photos in Figure 5.3.3 Overview of Channel 1 ～ Channel 4 (Result of site visit)

google earth