The Kingdom of Thailand
Royal Irrigation Department, Ministry of
Agriculture and Cooperatives

Data collection survey on the outer ring road diversion channel in the comprehensive flood management plan for the Chao Phraya river basin

FINAL REPORT
(Supporting Report)

The Kingdom of Thailand

JUNE 2018

Japan International Cooperation Agency

Pacific Consultants Co., Ltd.
Oriental Consultants Global Co., Ltd.

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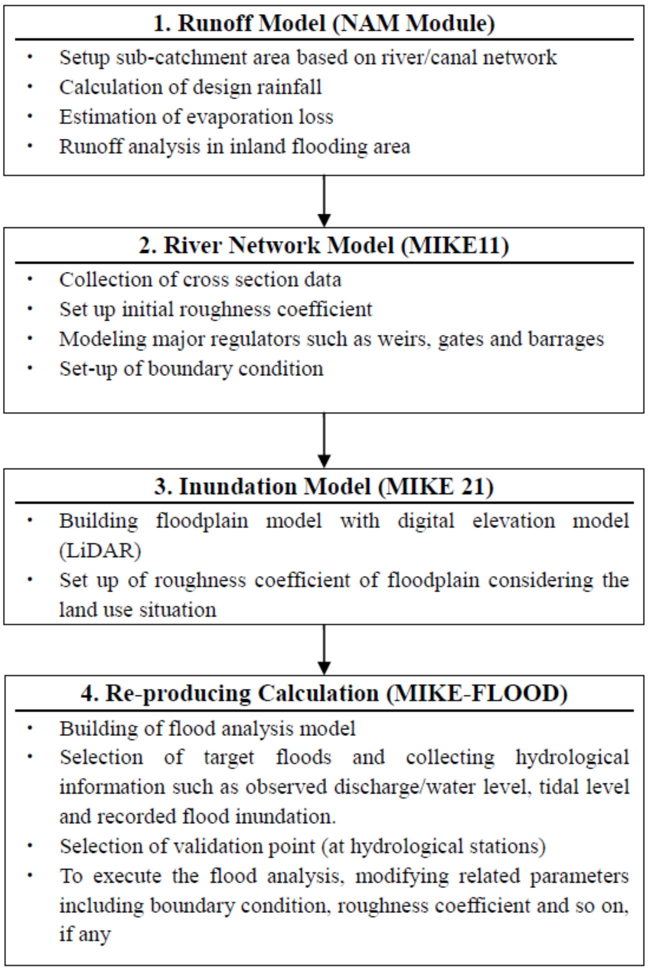
CHAPTER 1 HYDROLOGY・HYDRAULIC ANALYSIS

1.1 Inundation simulation model

1.1.1 Outlines of the inundation simulation model

A 2-dimensional simulation model MIKE FLOOD was used to examine the project effect, and was also used in the Master Plan of the “Project for comprehensive flood management plan for the Chao Phraya river basin: final report, September 2013”, the previous study. The specifications of the model are described as following chart. The data and conditions in the model of this study are the same as those of the previous study, including hydrological data, hydraulic data, river data, elevation data, roughness coefficient, boundary condition, and etc.,



1. Runoff Model (NAM Module)

- Setup sub-catchment area based on river/canal network
- Calculation of design rainfall
- Estimation of evaporation loss
- Runoff analysis in inland flooding area

2. River Network Model (MIKE11)

- Collection of cross section data
- Set up initial roughness coefficient
- Modeling major regulators such as weirs, gates and barrages
- Set-up of boundary condition

3. Inundation Model (MIKE 21)

- Building floodplain model with digital elevation model (LiDAR)
- Set up of roughness coefficient of floodplain considering the land use situation

4. Re-producing Calculation (MIKE-FLOOD)

- Building of flood analysis model
- Selection of target floods and collecting hydrological information such as observed discharge/water level, tidal level and recorded flood inundation.
- Selection of validation point (at hydrological stations)
- To execute the flood analysis, modifying related parameters including boundary condition, roughness coefficient and so on, if any

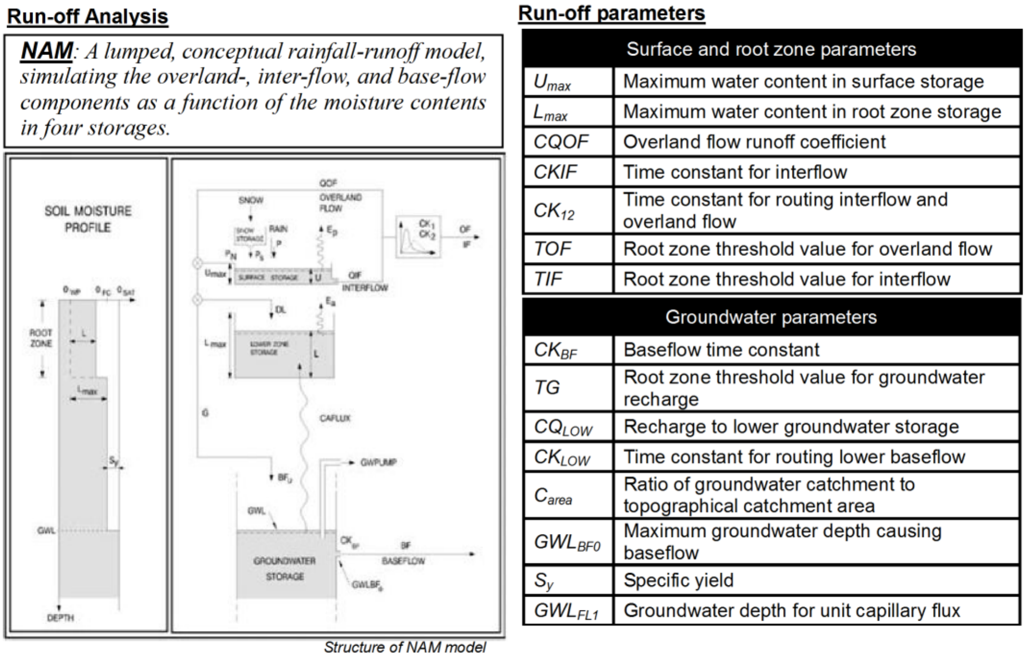
Source : Report of Previous MP

Figure 1.1.1 Procedure of Hydrological and Hydraulic Model Building

Details of each model according to the report on the existing M/P are organized in the following sections

1.1.2 Run-off model

The NAM module is utilized to calculate run-off from each catchment. NAM is a lumped tank model developed by the Technical University of Denmark. This model is composed of four tanks including overland flow, subsurface flow, ground water flow, and soil moisture profile. Moreover, the model is capable to make both short-term and long-term run-off simulations. General specification and parameter definitions of NAM are shown in the following figure.



Run-off Analysis

***NAM**: A lumped, conceptual rainfall-runoff model, simulating the overland-, inter-flow, and base-flow components as a function of the moisture contents in four storages.*

Structure of NAM model

Run-off parameters

Surface and root zone parameters	
U_{max}	Maximum water content in surface storage
L_{max}	Maximum water content in root zone storage
$CQOF$	Overland flow runoff coefficient
$CKIF$	Time constant for interflow
CK_{12}	Time constant for routing interflow and overland flow
TOF	Root zone threshold value for overland flow
TIF	Root zone threshold value for interflow

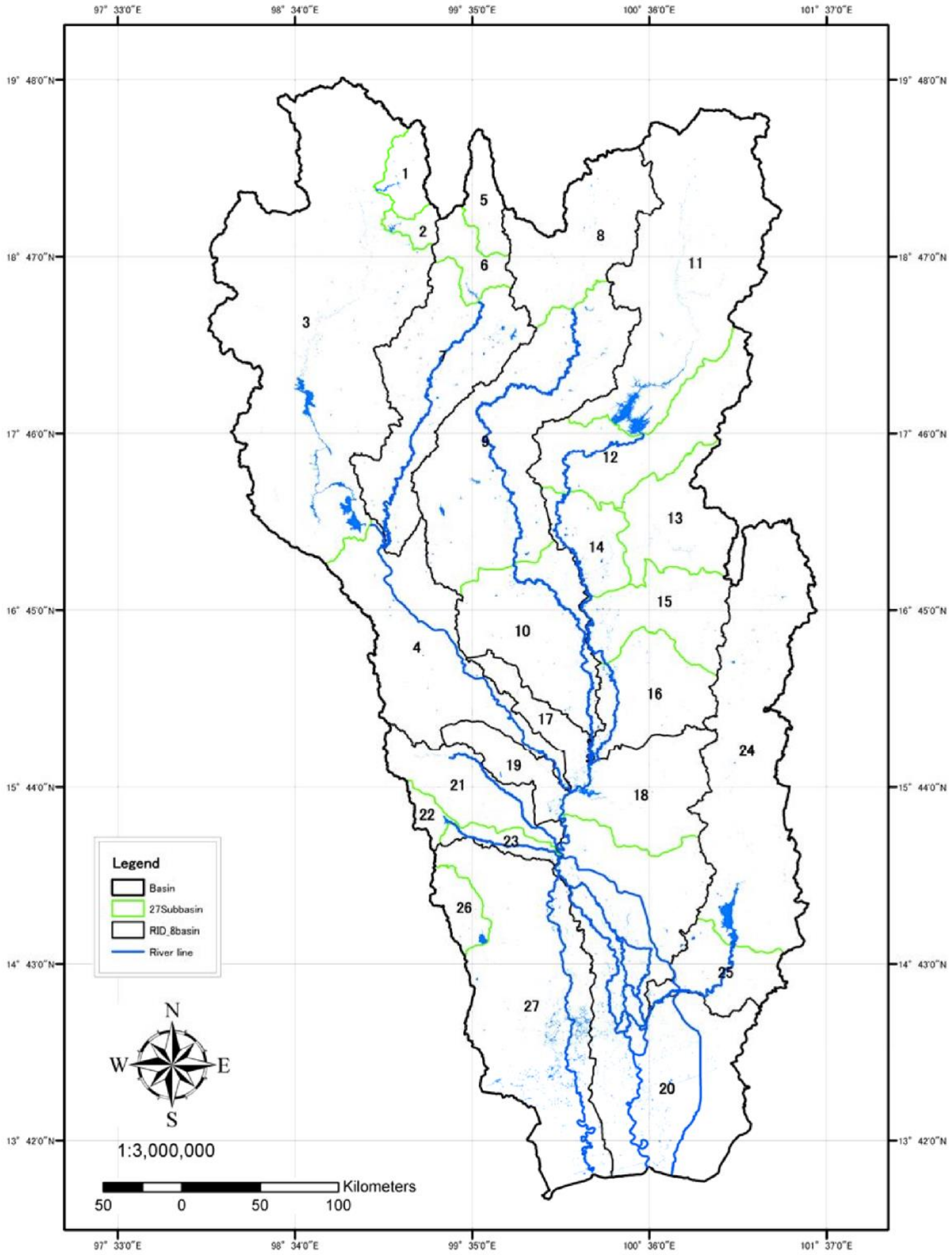
Groundwater parameters	
CK_{BF}	Baseflow time constant
TG	Root zone threshold value for groundwater recharge
CQ_{LOW}	Recharge to lower groundwater storage
CK_{LOW}	Time constant for routing lower baseflow
C_{area}	Ratio of groundwater catchment to topographical catchment area
GWL_{BF0}	Maximum groundwater depth causing baseflow
S_y	Specific yield
GWL_{FL1}	Groundwater depth for unit capillary flux

Source ：Report of Previous MP

Figure 1.1.2 General specifications and parameters of NAM

(1) Catchment

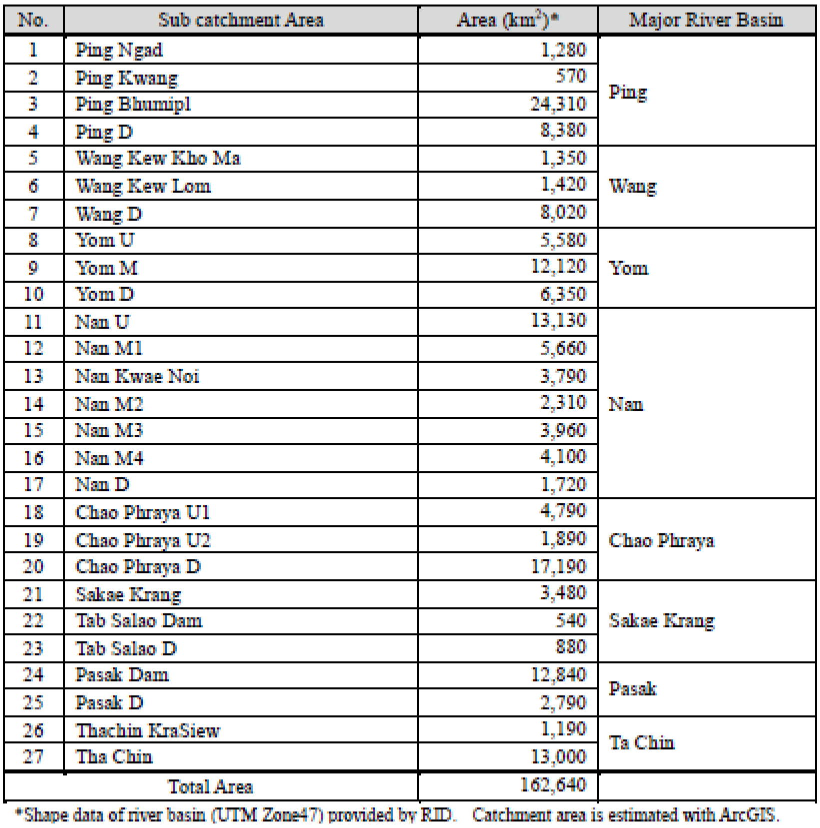
The Chao Phraya River Basin is mainly composed of 8 tributaries. In the previous MP report, the whole basin was divided into 27 catchments for the run-off simulation.



Source：Report of Previous MP

Figure 1.1.3 Catchments of Chao Phraya River Basin in this project

Table 1.1.1 Catchments of Chao Phraya River Basin in this project



No.	Sub catchment Area	Area (km^2)*	Major River Basin
1	Ping Ngad	1,280	Ping
2	Ping Kwang	570	
3	Ping Bhumipl	24,310	
4	Ping D	8,380	
5	Wang Kew Kho Ma	1,350	Wang
6	Wang Kew Lom	1,420	
7	Wang D	8,020	
8	Yom U	5,580	Yom
9	Yom M	12,120	
10	Yom D	6,350	
11	Nan U	13,130	Nan
12	Nan M1	5,660	
13	Nan Kwae Noi	3,790	
14	Nan M2	2,310	
15	Nan M3	3,960	
16	Nan M4	4,100	
17	Nan D	1,720	
18	Chao Phraya U1	4,790	Chao Phraya
19	Chao Phraya U2	1,890	
20	Chao Phraya D	17,190	
21	Sakae Krang	3,480	Sakae Krang
22	Tab Salao Dam	540	
23	Tab Salao D	880	
24	Pasak Dam	12,840	Pasak
25	Pasak D	2,790	
26	Thachin KraSiew	1,190	Ta Chin
27	Tha Chin	13,000	
	Total Area	162,640	

*Shape data of river basin (UTM Zone47) provided by RID. Catchment area is estimated with ArcGIS.

Source : Report of Previous MP

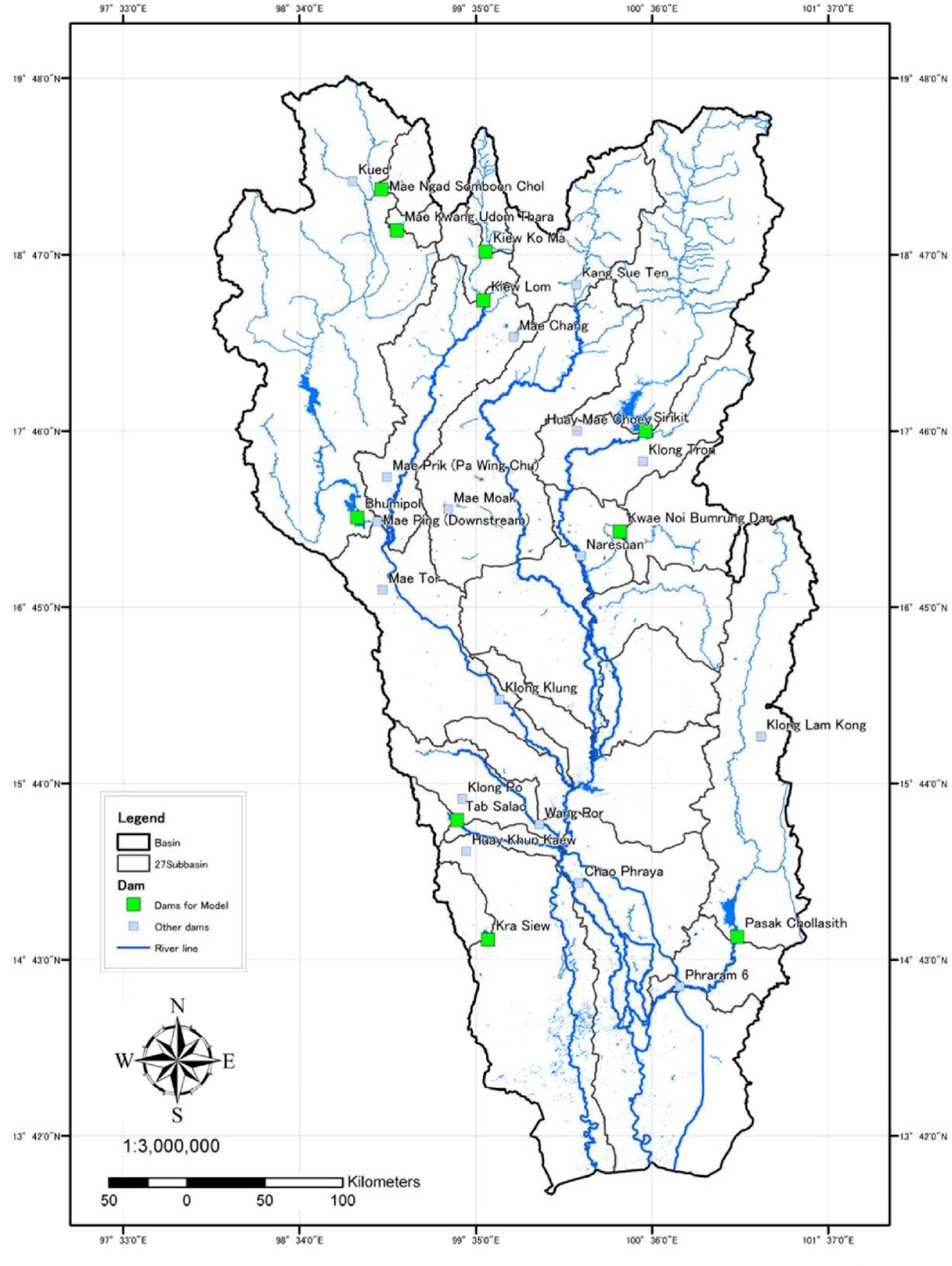
(2) Catchment of Dam

Dams with a large catchment area were included in this model. The list of dams included in the model is shown in the following table. According to the previous MP report, the locations of dams included in the model are shown as the following figure.

Table 1.1.2 List of included dams

No.	Name	River	River Basin	Catchment Area(km^2)	Storage Volume (MCM)	
					Maximum	Retention
1	Mae Ngad Somboon Chol	Ping	Ping_Ngad	1,283	325	265
2	Mae Kwang Udom Thara	Ping	Ping_Kwang	566	263	263
3	Bhumibol	Ping	Ping_Bhumibol	24,305	13,462	13,462
4	Kiew Ko Ma	Wang	Wang_Kiew_Ko_Ma	1,354	209	170
5	Kiew Lom	Wang	Wang_Kiew_Lom	1,422	106	106
6	Sirikit	Nan	Nan_U	13,131	10,640	9,510
7	Kwae Noi Bumrung Dan	Nan	Nan_Kwae_Noi	3,793	1,080	939
8	Pasak Chollasith	Pasak	Pasak_Dam	12,835	960	785
9	Tab Salao	Sakae krang	Tab_Salao_Dam	543	198	160
10	Kra Siew	Tha chin	Thachin_Kra_Siew	1,193	363	240

Source : Report of Previous MP

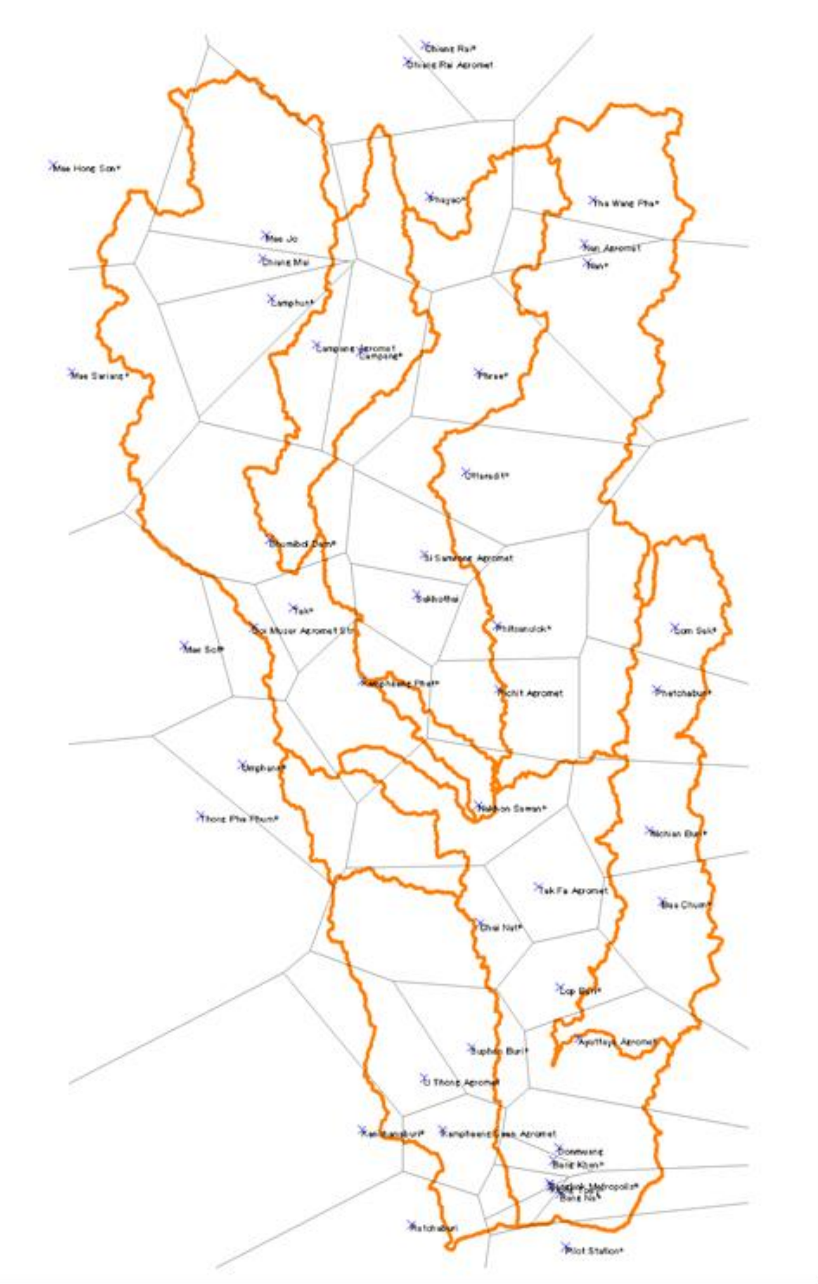


Source：Report of Previous MP

Figure 1.1.4 Location of included dams

(3) Precipitation

Rainfall data observed by RID and TMD (Thailand Meteorological Department) were utilized to calculate the average precipitation for each catchment by using the Thiessen Method. Observed data was directly assigned to flat areas as rainfall input in the 2-dimensional simulation model instead of calculating it through NAM. This is because the flooding in these flat areas is mainly generated by inundation since rainfall is collected and distributed through irrigation channels instead of the river or large canal. Inundation area is set based on topography, elevation, irrigation channels, and inundation record of recent years, as shown in the following figure.



Source : Report of Previous MP

Figure 1.1.5 Location of TND weather stations and Thiessen split view (46 weather stations)

(4) Evaporation

There are 46 TMD synoptic stations observing pan evaporation data and they are divided for each catchment by the Thiessen Method. Input evaporation data for each catchment is set as 80% of the observed value. Pan evaporation is defined as the maximum evaporation (potential evaporation) thus the actual evaporation is calculated by using an evaporation coefficient (actual evaporation/potential evaporation). The evaporation coefficient is calculated by applying Equation (1) using the data of Sirikit Dam, Bhumibol Dam, and C2, the data used including daily rainfall, inflow rate, river flow rate, and evapotranspiration data during 1980~2011. According to the calculation, the evaporation coefficient of Sirikit Dam is 0.82, of Bhumibhol Dam is 0.75, and of C2 is 0.84. The average of coefficient that is 0.80 is applied to the whole basin.

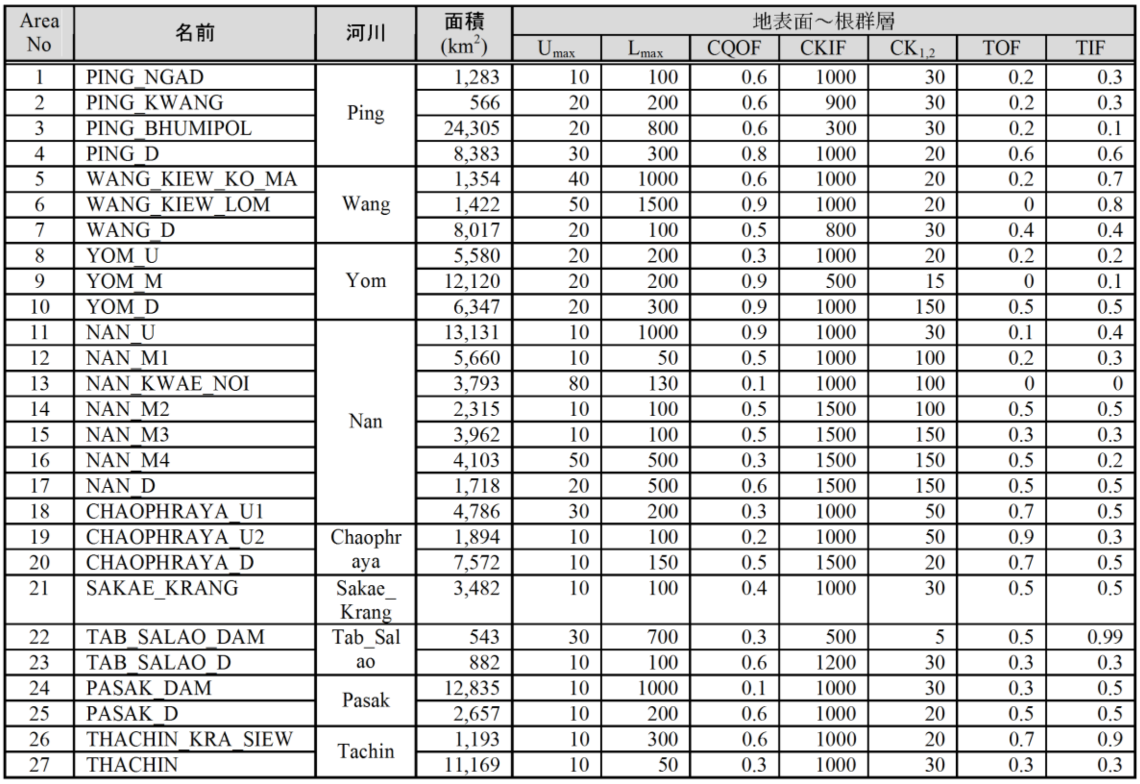
evaporation coefficient = Actual evaporation/maximum potential evaporation (pan evaporation)

$$= \frac{\sum R - \sum Q}{\sum evap} \qquad (1)$$

(5) Model parameters

Parameters of NAM were calibrated with the same data used in the MP survey in 1999 as the initial value. The calibrated value of each parameter is shown in the following tables.

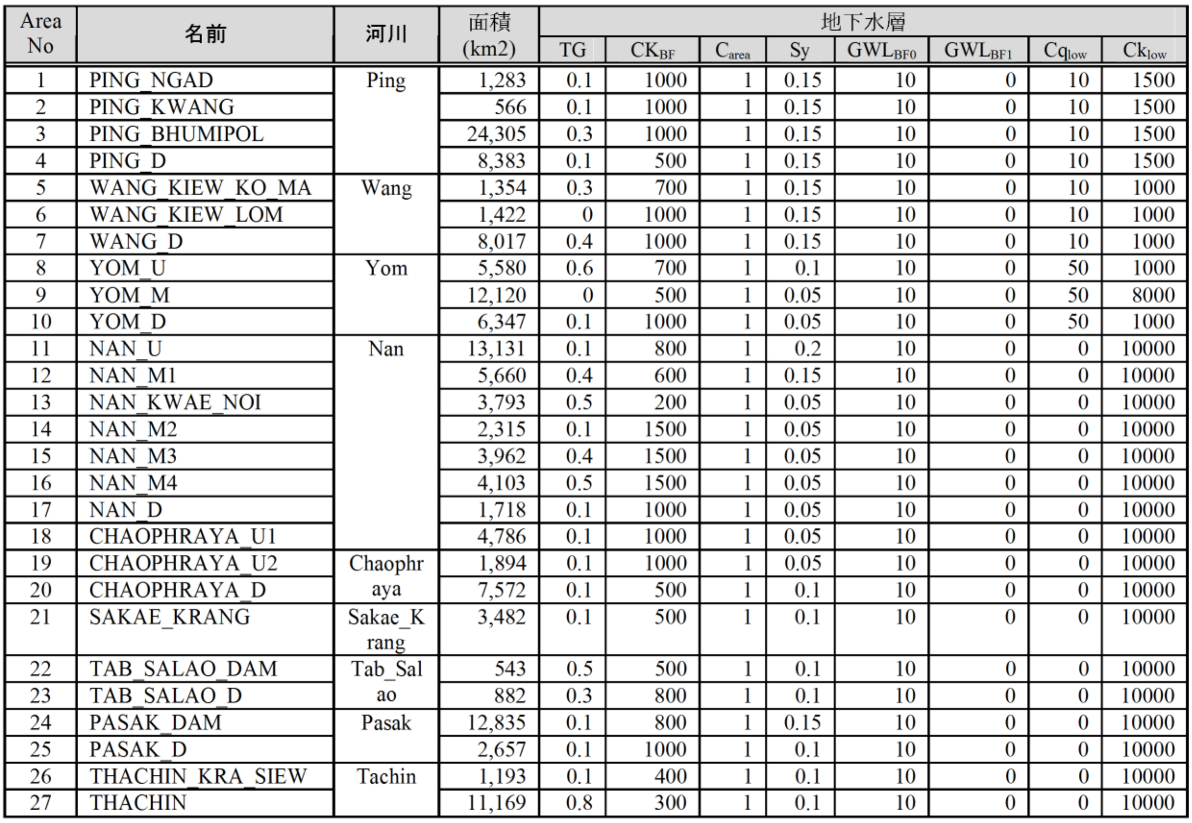
Table 1.1.3 Model Parameters of NAM (Surface～Root zone)



Area No	名前	河川	面積 (km^2)	地表面～根群層						
				U_{max}	L_{max}	CQOF	CKIF	$CK_{1,2}$	TOF	TIF
1	PING_NGAD	Ping	1,283	10	100	0.6	1000	30	0.2	0.3
2	PING_KWANG		566	20	200	0.6	900	30	0.2	0.3
3	PING_BHUMIPOL		24,305	20	800	0.6	300	30	0.2	0.1
4	PING_D		8,383	30	300	0.8	1000	20	0.6	0.6
5	WANG_KIEW_KO_MA	Wang	1,354	40	1000	0.6	1000	20	0.2	0.7
6	WANG_KIEW_LOM		1,422	50	1500	0.9	1000	20	0	0.8
7	WANG_D		8,017	20	100	0.5	800	30	0.4	0.4
8	YOM_U	Yom	5,580	20	200	0.3	1000	20	0.2	0.2
9	YOM_M		12,120	20	200	0.9	500	15	0	0.1
10	YOM_D		6,347	20	300	0.9	1000	150	0.5	0.5
11	NAN_U	Nan	13,131	10	1000	0.9	1000	30	0.1	0.4
12	NAN_M1		5,660	10	50	0.5	1000	100	0.2	0.3
13	NAN_KWAE_NOI		3,793	80	130	0.1	1000	100	0	0
14	NAN_M2		2,315	10	100	0.5	1500	100	0.5	0.5
15	NAN_M3		3,962	10	100	0.5	1500	150	0.3	0.3
16	NAN_M4		4,103	50	500	0.3	1500	150	0.5	0.2
17	NAN_D		1,718	20	500	0.6	1500	150	0.5	0.5
18	CHAOPHRAYA_U1		4,786	30	200	0.3	1000	50	0.7	0.5
19	CHAOPHRAYA_U2	Chaophraya	1,894	10	100	0.2	1000	50	0.9	0.3
20	CHAOPHRAYA_D		7,572	10	150	0.5	1500	20	0.7	0.5
21	SAKAE_KRANG	Sakae_Krang	3,482	10	100	0.4	1000	30	0.5	0.5
22	TAB_SALAO_DAM	Tab_Salao	543	30	700	0.3	500	5	0.5	0.99
23	TAB_SALAO_D		882	10	100	0.6	1200	30	0.3	0.3
24	PASAK_DAM	Pasak	12,835	10	1000	0.1	1000	30	0.3	0.5
25	PASAK_D		2,657	10	200	0.6	1000	20	0.5	0.5
26	THACHIN_KRA_SIEW	Tachin	1,193	10	300	0.6	1000	20	0.7	0.9
27	THACHIN		11,169	10	50	0.3	1000	30	0.3	0.3

Source ：Report of Previous MP

Table 1.1.4 Model Parameters of NAM (Groundwater)



Area No	名前	河川	面積 (km2)	地下水層							
				TG	CK_{BF}	C_{area}	Sy	GWL_{BF0}	GWL_{BF1}	Cq_{low}	Ck_{low}
1	PING_NGAD	Ping	1,283	0.1	1000	1	0.15	10	0	10	1500
2	PING_KWANG		566	0.1	1000	1	0.15	10	0	10	1500
3	PING_BHUMIPOL		24,305	0.3	1000	1	0.15	10	0	10	1500
4	PING_D		8,383	0.1	500	1	0.15	10	0	10	1500
5	WANG_KIEW_KO_MA	Wang	1,354	0.3	700	1	0.15	10	0	10	1000
6	WANG_KIEW_LOM		1,422	0	1000	1	0.15	10	0	10	1000
7	WANG_D		8,017	0.4	1000	1	0.15	10	0	10	1000
8	YOM_U	Yom	5,580	0.6	700	1	0.1	10	0	50	1000
9	YOM_M		12,120	0	500	1	0.05	10	0	50	8000
10	YOM_D		6,347	0.1	1000	1	0.05	10	0	50	1000
11	NAN_U	Nan	13,131	0.1	800	1	0.2	10	0	0	10000
12	NAN_M1		5,660	0.4	600	1	0.15	10	0	0	10000
13	NAN_KWAE_NOI		3,793	0.5	200	1	0.05	10	0	0	10000
14	NAN_M2		2,315	0.1	1500	1	0.05	10	0	0	10000
15	NAN_M3		3,962	0.4	1500	1	0.05	10	0	0	10000
16	NAN_M4		4,103	0.5	1500	1	0.05	10	0	0	10000
17	NAN_D		1,718	0.1	1000	1	0.05	10	0	0	10000
18	CHAOPHRAYA_U1		4,786	0.1	1000	1	0.05	10	0	0	10000
19	CHAOPHRAYA_U2	Chaophraya	1,894	0.1	1000	1	0.05	10	0	0	10000
20	CHAOPHRAYA_D		7,572	0.1	500	1	0.1	10	0	0	10000
21	SAKAE_KRANG	Sakae_Krang	3,482	0.1	500	1	0.1	10	0	0	10000
22	TAB_SALAO_DAM	Tab_Salao	543	0.5	500	1	0.1	10	0	0	10000
23	TAB_SALAO_D		882	0.3	800	1	0.1	10	0	0	10000
24	PASAK_DAM	Pasak	12,835	0.1	800	1	0.15	10	0	0	10000
25	PASAK_D		2,657	0.1	1000	1	0.1	10	0	0	10000
26	THACHIN_KRA_SIEW	Tachin	1,193	0.1	400	1	0.1	10	0	0	10000
27	THACHIN		11,169	0.8	300	1	0.1	10	0	0	10000

Source ：Report of Previous MP

1.1.3 River network model

Water level and flow rate are calculated by using a 1-dimensional unsteady flow model (MIKE11).

Table 1.1.5 Outline of the river channel network model

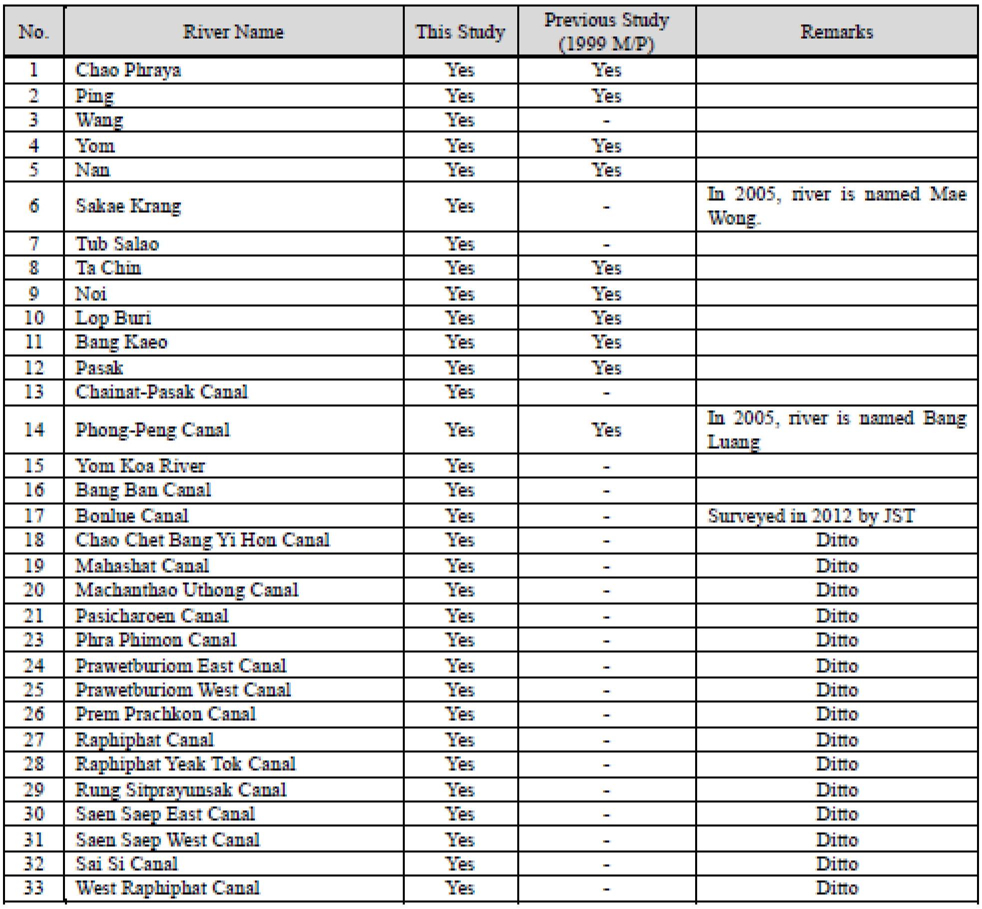
Item	Content
Hydraulic model	1-dimensional unsteady flow (dynamic wave)
River network	Refer to figure
River cross section	Measured data in 2005 and 2006, provided by RID Measured data in 2012 by JST
Structure	Large-scale dam, gate, etc.
Boundary condition	Upstream: hydrograph calculated by run-off model or observed data of dam discharge Downstream: observed data of tide level

Source ：Report of Previous MP

(1) Calculated river flow

Calculated river flows are listed in the following table. Basically, all cross-section-measured rivers are included. However, Chainat-Ayutthaya Channel is excluded since it runs along the west side of Chao Phraya River having little impact on inundation. Besides, Mae Klong River did not show a correlation in water level with Tachin River during the flood in 2006 although they are linked by irrigation channels. Therefore, Mae Klong River and these irrigation channels are also excluded.

Table 1.1.6 Rivers/Canals Built in the River Network Model



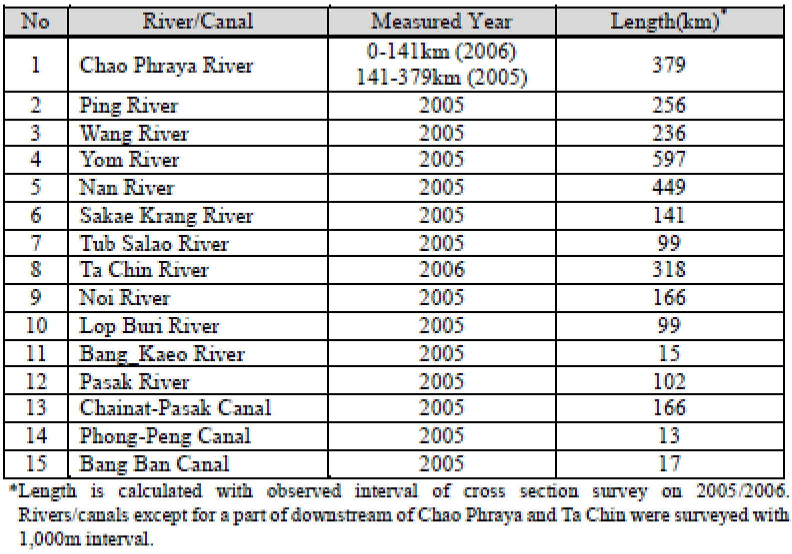
No.	River Name	This Study	Previous Study (1999 M/P)	Remarks
1	Chao Phraya	Yes	Yes	
2	Ping	Yes	Yes	
3	Wang	Yes	-	
4	Yom	Yes	Yes	
5	Nan	Yes	Yes	
6	Sakae Krang	Yes	-	In 2005, river is named Mae Wong.
7	Tub Salao	Yes	-	
8	Ta Chin	Yes	Yes	
9	Noi	Yes	Yes	
10	Lop Buri	Yes	Yes	
11	Bang Kaeo	Yes	Yes	
12	Pasak	Yes	Yes	
13	Chainat-Pasak Canal	Yes	-	
14	Phong-Peng Canal	Yes	Yes	In 2005, river is named Bang Luang
15	Yom Koa River	Yes	-	
16	Bang Ban Canal	Yes	-	
17	Bonlue Canal	Yes	-	Surveyed in 2012 by JST
18	Chao Chet Bang Yi Hon Canal	Yes	-	Ditto
19	Mahashat Canal	Yes	-	Ditto
20	Machanthao Uthong Canal	Yes	-	Ditto
21	Pasicharoen Canal	Yes	-	Ditto
23	Phra Phimon Canal	Yes	-	Ditto
24	Prawetburiom East Canal	Yes	-	Ditto
25	Prawetburiom West Canal	Yes	-	Ditto
26	Prem Prachkon Canal	Yes	-	Ditto
27	Raphiphat Canal	Yes	-	Ditto
28	Raphiphat Yeak Tok Canal	Yes	-	Ditto
29	Rung Sitprayunsak Canal	Yes	-	Ditto
30	Saen Saep East Canal	Yes	-	Ditto
31	Saen Saep West Canal	Yes	-	Ditto
32	Sai Si Canal	Yes	-	Ditto
33	West Raphiphat Canal	Yes	-	Ditto

Source : Report of Previous MP

(2) River cross section data

Information about cross section data provided by RID is shown in following table. Locations of additional cross sections measured in previous MP are shown in the following figure. As mentioned above, the rivers, whose measured data exists, are all included in the 1-dimensional unsteady flow calculation. Additionally, the flow of rivers and channels are important to flood management (according to RID), such as Yom Koa River and Yom Nam Channel, are also calculated.

Table 1.1.7 Utilized river cross section data (provided by RID)

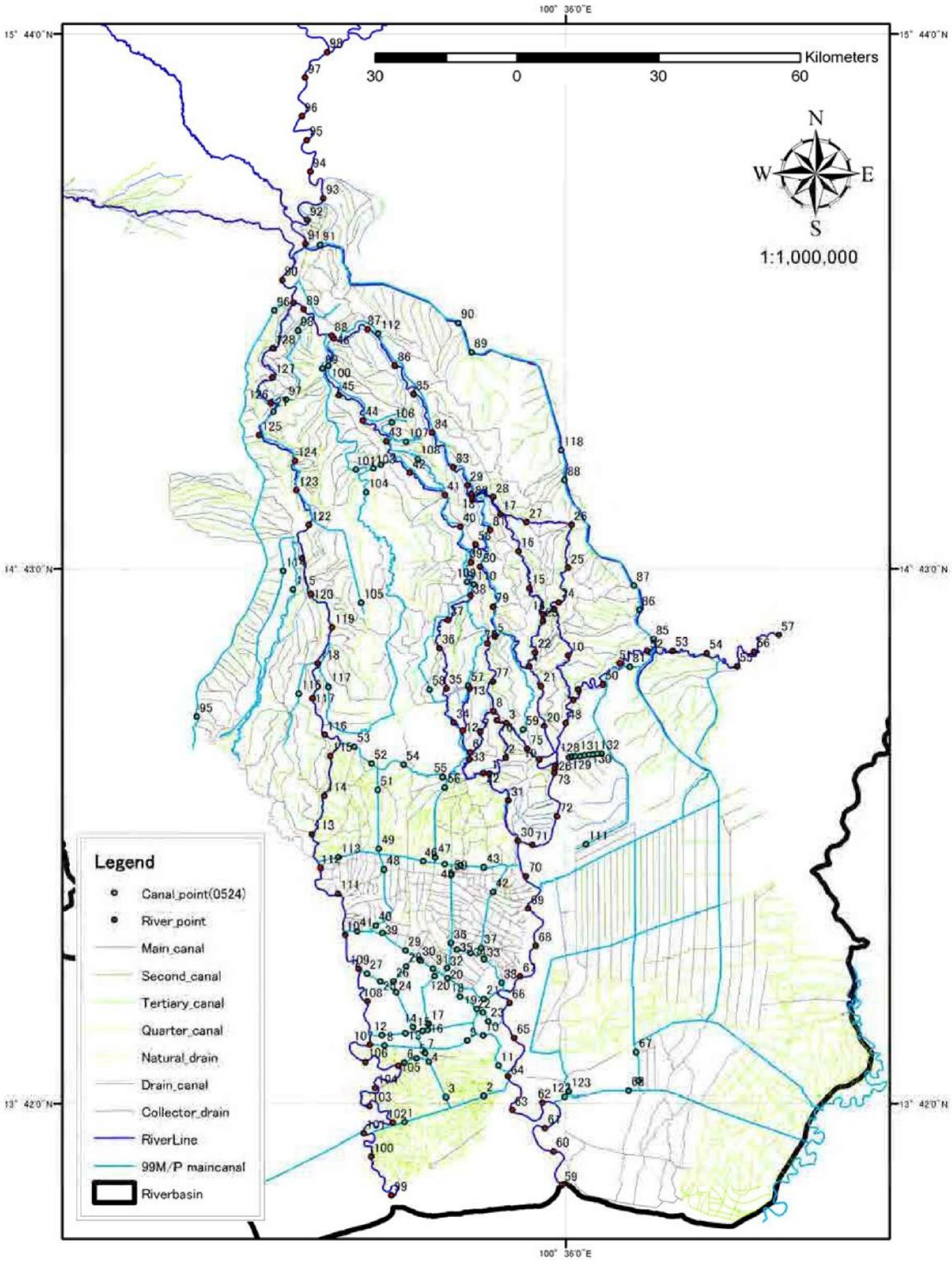


No	River/Canal	Measured Year	Length(km)*
1	Chao Phraya River	0-141km (2006) 141-379km (2005)	379
2	Ping River	2005	256
3	Wang River	2005	236
4	Yom River	2005	597
5	Nan River	2005	449
6	Sakae Krang River	2005	141
7	Tub Salao River	2005	99
8	Ta Chin River	2006	318
9	Noi River	2005	166
10	Lop Buri River	2005	99
11	Bang_Kaeo River	2005	15
12	Pasak River	2005	102
13	Chainat-Pasak Canal	2005	166
14	Phong-Peng Canal	2005	13
15	Bang Ban Canal	2005	17

*Length is calculated with observed interval of cross section survey on 2005/2006. Rivers/canals except for a part of downstream of Chao Phraya and Ta Chin were surveyed with 1,000m interval.

*Distance is calculated based on measure interval in surveys in 2005 and 2006. Measure interval is 1000m except in a part downstream of Chao Phraya River and Tachin River.

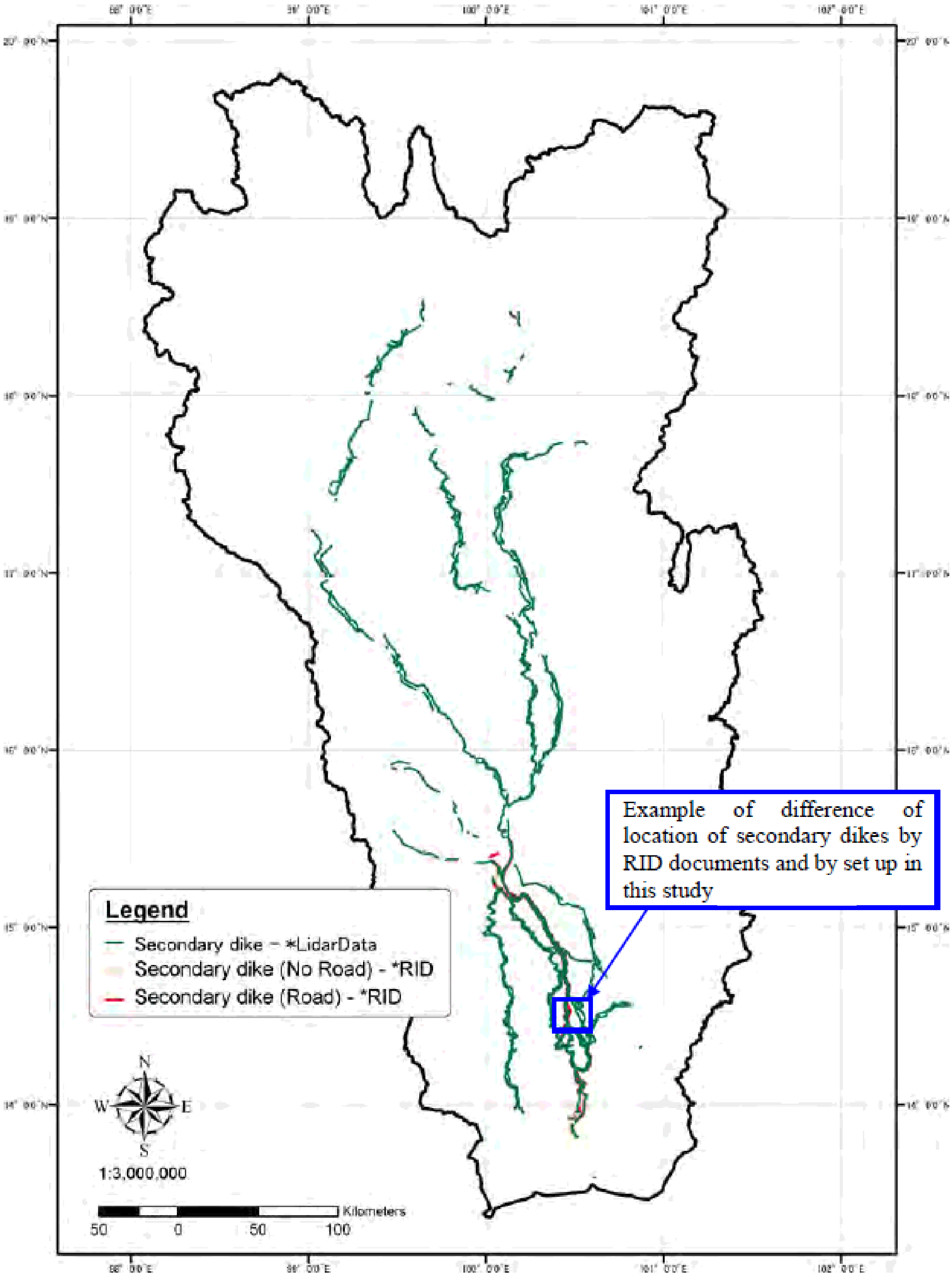
Source : Report of Previous MP



Source：Report of Previous MP

Figure 1.1.6 Location of additional measured cross sections in previous MP survey

There is an embankment road (which functions as a secondary dike) along the natural dike (main dike) and irrigation channels in flat areas. This secondary dike is simulated in the model. Basically, the range of the road is interpolated by using LP data. For segments where LP data is not adequate, the elevations of the road nearby that were calculated in the previous step will be utilized in the next interpolation.



(where the calculated location of the secondary dike differs from documents provided by RID)

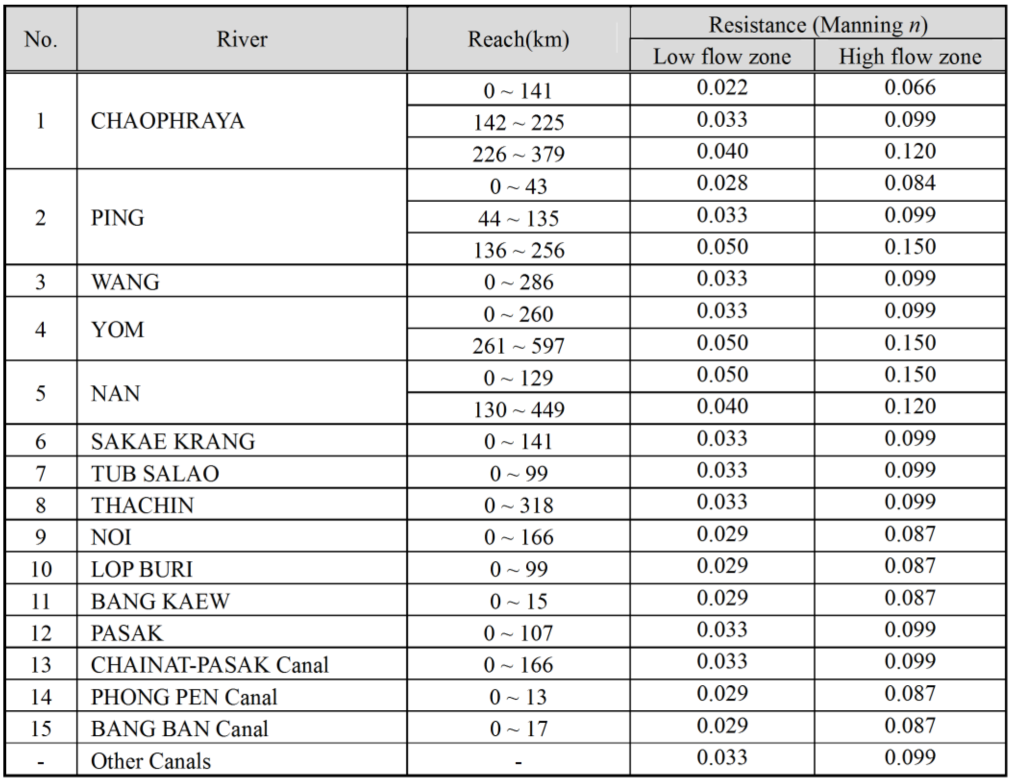
Source：Report of Previous MP

Figure 1.1.7 Location of the secondary dike

(3) Roughness Coefficient

Roughness coefficients were set for low-water channels and the in-channel floodplain of each channel. Coefficients for low-water channels refer to the values used in the previous Master Plan Survey in 1999, while coefficient for the in-channel floodplain was initially set as 3 times of the low-water channel, and then calibrated by reproducing the simulation of the flood in 2011.

Table 1.1.8 Set value of roughness coefficient of each channel



No.	River	Reach(km)	Resistance (Manning *n*)	
			Low flow zone	High flow zone
1	CHAOPHRAYA	0 ~ 141	0.022	0.066
		142 ~ 225	0.033	0.099
		226 ~ 379	0.040	0.120
2	PING	0 ~ 43	0.028	0.084
		44 ~ 135	0.033	0.099
		136 ~ 256	0.050	0.150
3	WANG	0 ~ 286	0.033	0.099
4	YOM	0 ~ 260	0.033	0.099
		261 ~ 597	0.050	0.150
5	NAN	0 ~ 129	0.050	0.150
		130 ~ 449	0.040	0.120
6	SAKAE KRANG	0 ~ 141	0.033	0.099
7	TUB SALAO	0 ~ 99	0.033	0.099
8	THACHIN	0 ~ 318	0.033	0.099
9	NOI	0 ~ 166	0.029	0.087
10	LOP BURI	0 ~ 99	0.029	0.087
11	BANG KAEW	0 ~ 15	0.029	0.087
12	PASAK	0 ~ 107	0.033	0.099
13	CHAINAT-PASAK Canal	0 ~ 166	0.033	0.099
14	PHONG PEN Canal	0 ~ 13	0.029	0.087
15	BANG BAN Canal	0 ~ 17	0.029	0.087
-	Other Canals	-	0.033	0.099

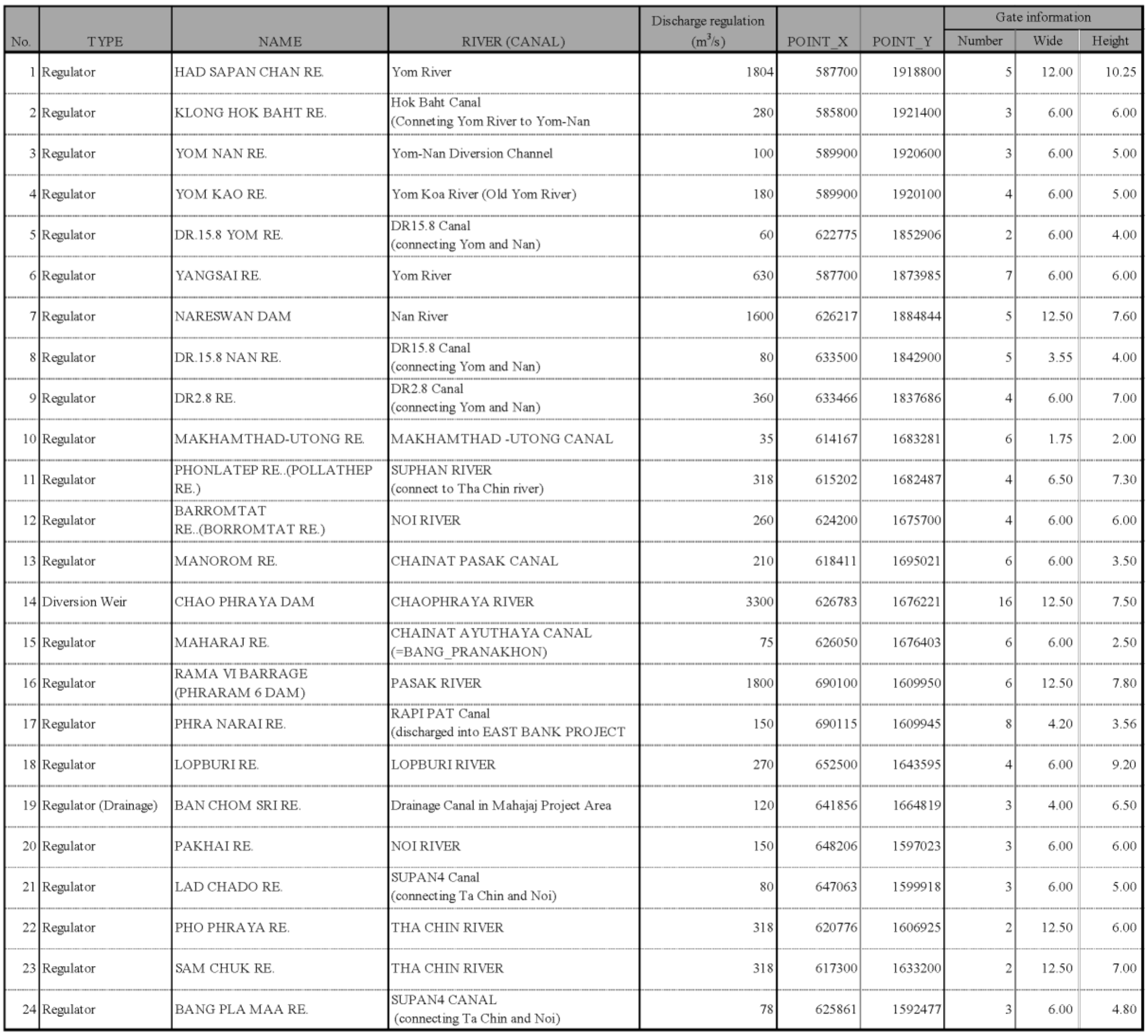
Source : Report of Previous MP

(4) Structures

1) Weir

Weirs included in the model are listed below.

Table 1.1.9 List and specifications of weirs included in model



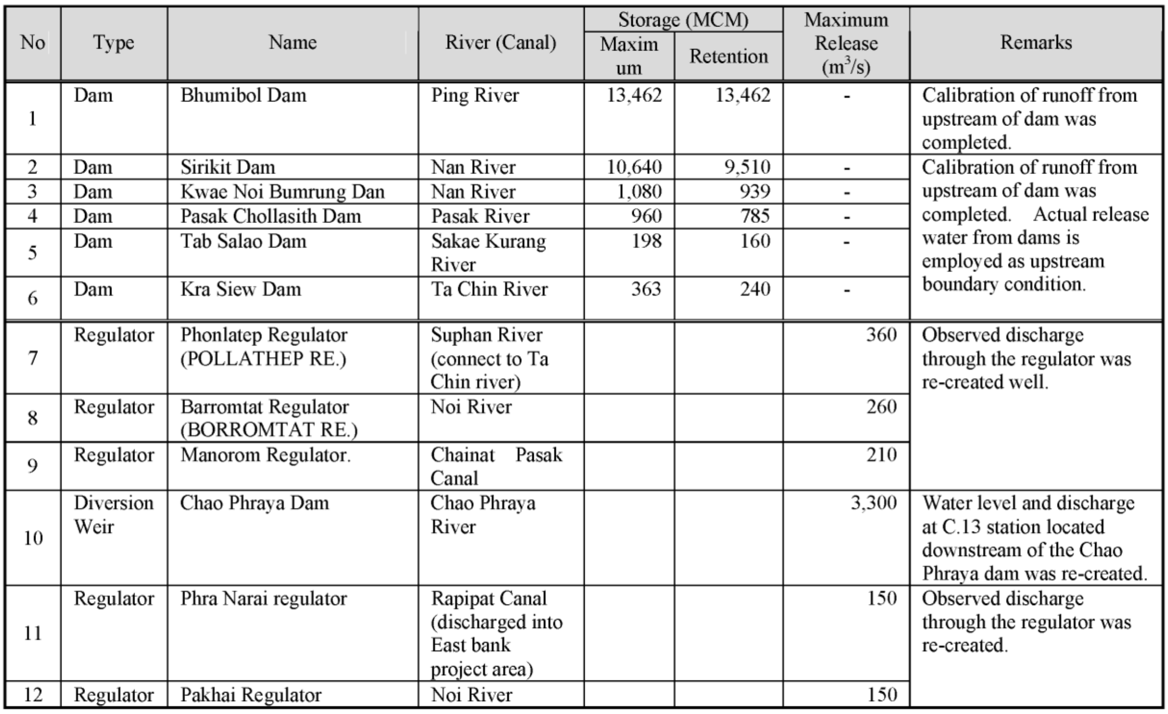
No.	TYPE	NAME	RIVER (CANAL)	Discharge regulation (m^3/s)	POINT_X	POINT_Y	Gate information		
							Number	Wide	Height
1	Regulator	HAD SAPAN CHAN RE.	Yom River	1804	587700	1918800	5	12.00	10.25
2	Regulator	KLONG HOK BAHT RE.	Hok Baht Canal (Conneting Yom River to Yom-Nan	280	585800	1921400	3	6.00	6.00
3	Regulator	YOM NAN RE.	Yom-Nan Diversion Channel	100	589900	1920600	3	6.00	5.00
4	Regulator	YOM KAO RE.	Yom Koa River (Old Yom River)	180	589900	1920100	4	6.00	5.00
5	Regulator	DR.15.8 YOM RE.	DR15.8 Canal (connecting Yom and Nan)	60	622775	1852906	2	6.00	4.00
6	Regulator	YANGSAI RE.	Yom River	630	587700	1873985	7	6.00	6.00
7	Regulator	NARESWAN DAM	Nan River	1600	626217	1884844	5	12.50	7.60
8	Regulator	DR.15.8 NAN RE.	DR15.8 Canal (connecting Yom and Nan)	80	633500	1842900	5	3.55	4.00
9	Regulator	DR2.8 RE.	DR2.8 Canal (connecting Yom and Nan)	360	633466	1837686	4	6.00	7.00
10	Regulator	MAKHAMTHAD-UTONG RE.	MAKHAMTHAD -UTONG CANAL	35	614167	1683281	6	1.75	2.00
11	Regulator	PHONLATEP RE..(POLLATHEP RE.)	SUPHAN RIVER (connect to Tha Chin river)	318	615202	1682487	4	6.50	7.30
12	Regulator	BARROMTAT RE..(BORROMTAT RE.)	NOI RIVER	260	624200	1675700	4	6.00	6.00
13	Regulator	MANOROM RE.	CHAINAT PASAK CANAL	210	618411	1695021	6	6.00	3.50
14	Diversion Weir	CHAO PHRAYA DAM	CHAOPHRAYA RIVER	3300	626783	1676221	16	12.50	7.50
15	Regulator	MAHARAJ RE.	CHAINAT AYUTHAYA CANAL (=BANG_PRANAKHON)	75	626050	1676403	6	6.00	2.50
16	Regulator	RAMA VI BARRAGE (PHRARAM 6 DAM)	PASAK RIVER	1800	690100	1609950	6	12.50	7.80
17	Regulator	PHRA NARAI RE.	RAPI PAT Canal (discharged into EAST BANK PROJECT	150	690115	1609945	8	4.20	3.56
18	Regulator	LOPBURI RE.	LOPBURI RIVER	270	652500	1643595	4	6.00	9.20
19	Regulator (Drainage)	BAN CHOM SRI RE.	Drainage Canal in Mahajaj Project Area	120	641856	1664819	3	4.00	6.50
20	Regulator	PAKHAI RE.	NOI RIVER	150	648206	1597023	3	6.00	6.00
21	Regulator	LAD CHADO RE.	SUPAN4 Canal (connecting Ta Chin and Noi)	80	647063	1599918	3	6.00	5.00
22	Regulator	PHO PHRAYA RE.	THA CHIN RIVER	318	620776	1606925	2	12.50	6.00
23	Regulator	SAM CHUK RE.	THA CHIN RIVER	318	617300	1633200	2	12.50	7.00
24	Regulator	BANG PLA MAA RE.	SUPAN4 CANAL (connecting Ta Chin and Noi)	78	625861	1592477	3	6.00	4.80

Source：Report of Previous MP

2) Dams

Water storage function is considered in modeling dams. In reproducing the simulation of the flood in 2011, a modified flow rate was utilized as a boundary condition. This flow rate is derived from the recorded flow rate with gate manipulation improvement proposed in comparison discussions of countermeasures of previous chapters.

Table 1.1.10 List and specifications of dams included in the model



No	Type	Name	River (Canal)	Storage (MCM)		Maximum Release (m^3/s)	Remarks
				Maximum	Retention		
1	Dam	Bhumibol Dam	Ping River	13,462	13,462	-	Calibration of runoff from upstream of dam was completed.
2	Dam	Sirikit Dam	Nan River	10,640	9,510	-	Calibration of runoff from upstream of dam was completed. Actual release water from dams is employed as upstream boundary condition.
3	Dam	Kwae Noi Bumrung Dan	Nan River	1,080	939	-	
4	Dam	Pasak Chollasith Dam	Pasak River	960	785	-	
5	Dam	Tab Salao Dam	Sakae Kurang River	198	160	-	
6	Dam	Kra Siew Dam	Ta Chin River	363	240	-	
7	Regulator	Phonlatep Regulator (POLLATHEP RE.)	Suphan River (connect to Ta Chin river)			360	Observed discharge through the regulator was re-created well.
8	Regulator	Barromtat Regulator (BORROMTAT RE.)	Noi River			260	
9	Regulator	Manorom Regulator.	Chainat Pasak Canal			210	
10	Diversion Weir	Chao Phraya Dam	Chao Phraya River			3,300	Water level and discharge at C.13 station located downstream of the Chao Phraya dam was re-created.
11	Regulator	Phra Narai regulator	Rapipat Canal (discharged into East bank project area)			150	Observed discharge through the regulator was re-created.
12	Regulator	Pakhai Regulator	Noi River			150	

Source：Report of Previous MP

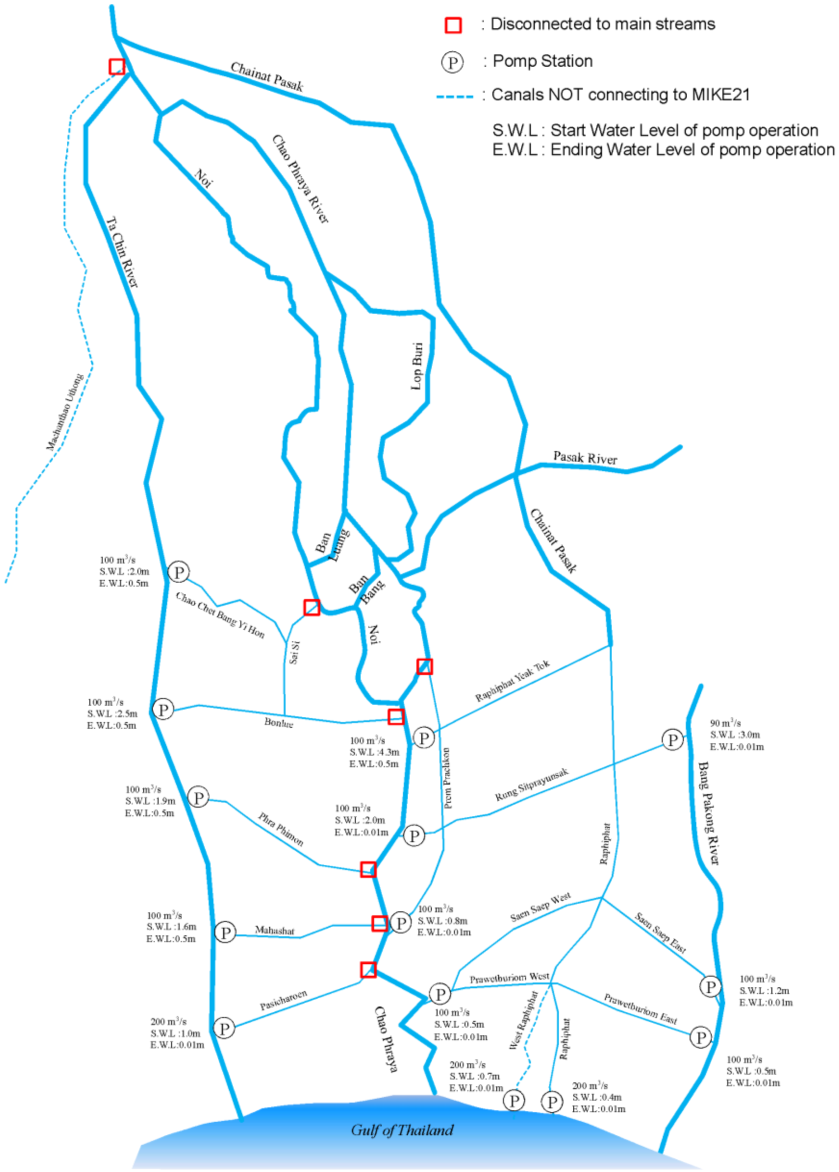
3) Pumps

It is difficult to include all pumps in the simulation, therefore pumps in the same catchment are integrated and the total discharge capacity is assigned to the main channels. Pumps utilized in the model are listed below. However, there is no record of discharge capacity in actual operation, thus pumps are assumed to start when water level is about to reach the vertex and stop when it drops to certain level while discharge capacity is assumed as the maximum.

Table 1.1.11 Specifications of pumps included in the model

No	Outlet	Pump Capacity (m^3/s)			Remarks
		Permanent	Semi-permanent	Total	
East	Chao Phraya R.	167.2	54.0	221.2	
	Nakorn Nayok R.	33.6	54.0	87.6	
	Bang Pakorn R.	101.6	90.0	191.6	
	Gulf	336.8	48.0	384.8	
	Internal drain	136.0	114.0	250.0	
	Subtotal	639.2	360.0	999.2	
West	Chao Phraya R.	53.0	93.0	146.0	
	Tha Chin R.	276.4	267.0	543.4	
	Internal Drain	1.6	-	1.6	
	Sub-total	329.4	360.0	689.4	
Total		968.6	720.0	1,688.6	

Source : Report of Previous MP



Source : Report of Previous MP

Figure 1.1.8 Locations and setting of pumps included in the model

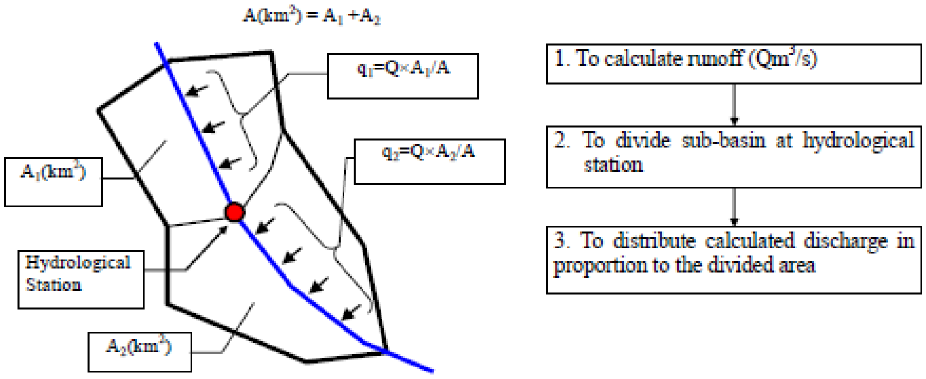
(5) Boundary condition

1) Upstream flow rate

The hydrographs calculated in the run-off simulation or the actual discharge from the dam were set as the flow rates in the river upstream or at the dam sites.

2) Inflow from residual catchments

For channels with inflow from residual catchments, this part is reproduced by having an equivalent inflow along the river.



Source : Report of Previous MP

Figure 1.1.9 Inflow rate from residual catchment

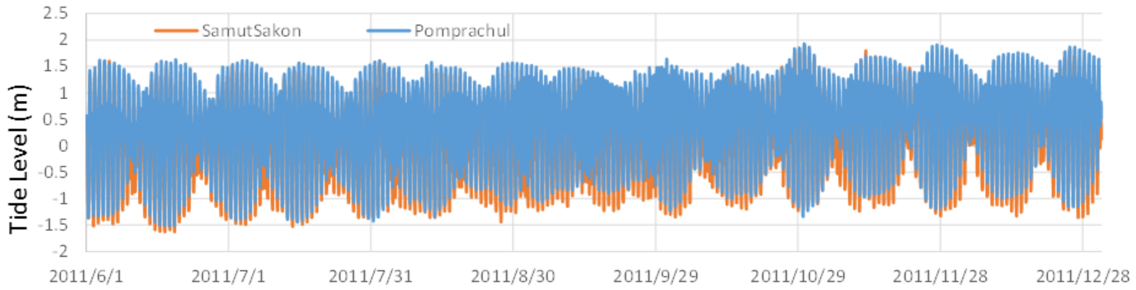
3) Downstream water level

Tide elevation of the Gulf of Thailand is used as the downstream water level. Table 1.1.12 shows the observatories locate the conditions of downstream end of each of Tachin River and Chao Phraya River.

Table 1.1.12 Observatory as the boundary station

Boundary condition	Location	Tide level Observatory
Downstream water level	River mouth of Tachin River	Samut Sakon
	River mouth of Chao Phraya River	Pomprachul

However, observed results from stations are higher than their actual elevation according to the past trace water survey, therefore 16cm and 34cm are subtracted from observed values of Pom Phrachul and Samut Sakon respectively.



Source : JICA study team

Figure 1.1.10 Hydrograph of tide elevations at the downstream end

(6) Dike breaks

Caused by the flood in 2011, dike breaks happened in about 10 places along the Chao Phraya River, the locations of these are shown in the following figure. When flooding occurs, flow to the lower catchment will decrease, therefore, dike breaks are considered in the modeling calculation.

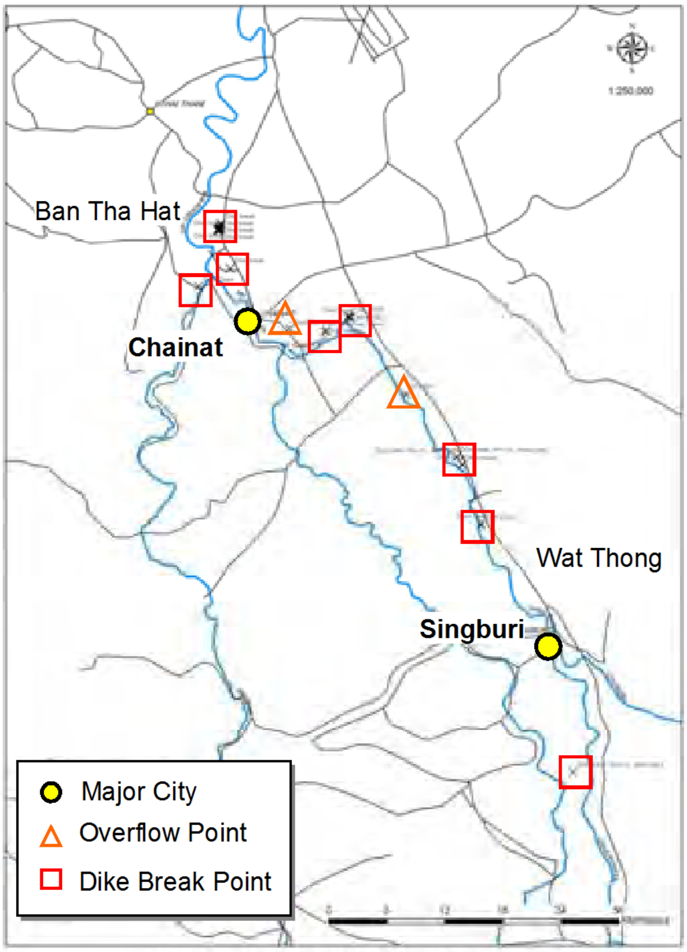
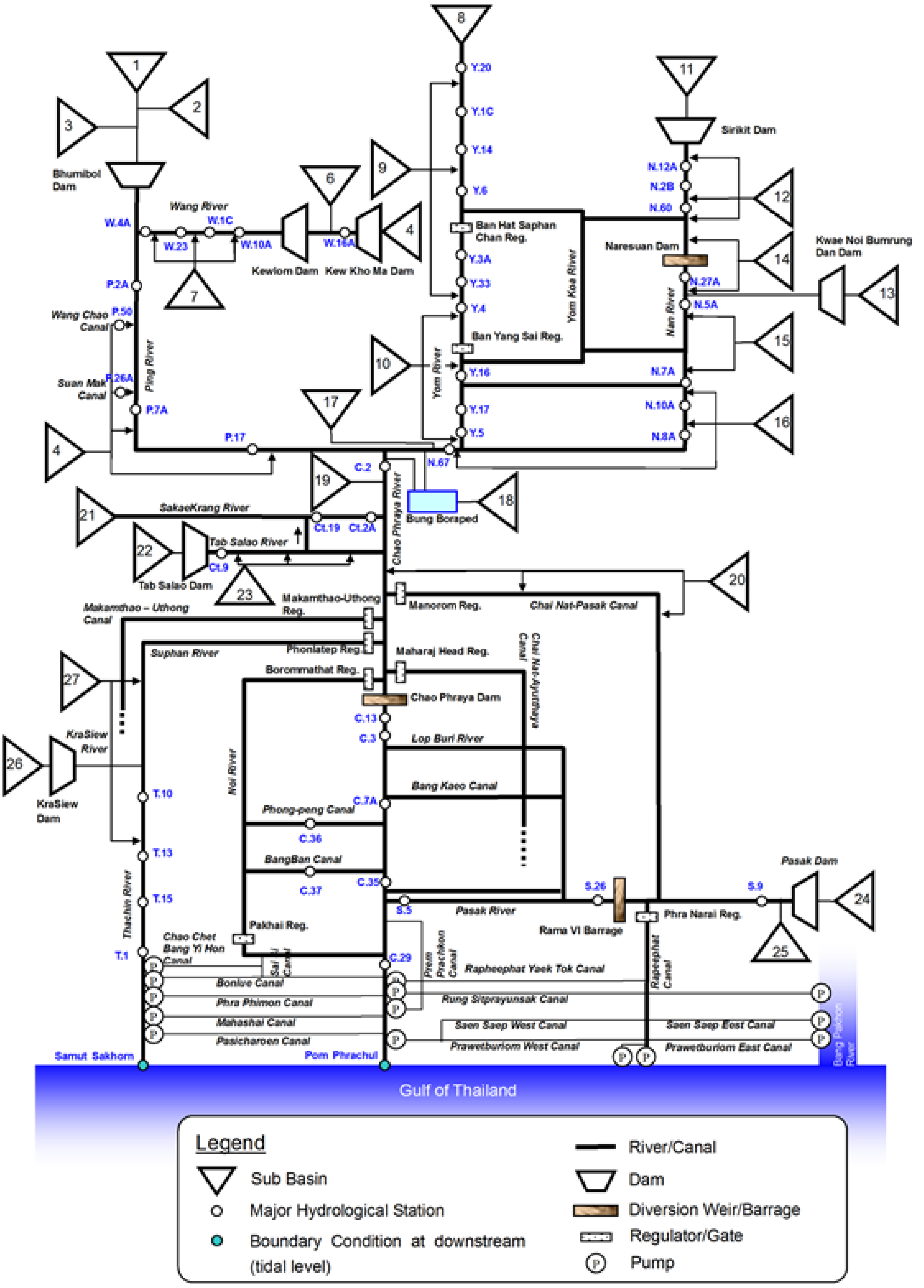


Figure-1 Overflow Points 2011 Flood (Source: RID interview)

Source : Report of Previous MP

Figure 1.1.11 Location of Dike break caused by flood in 2011



Source : JICA Study Team

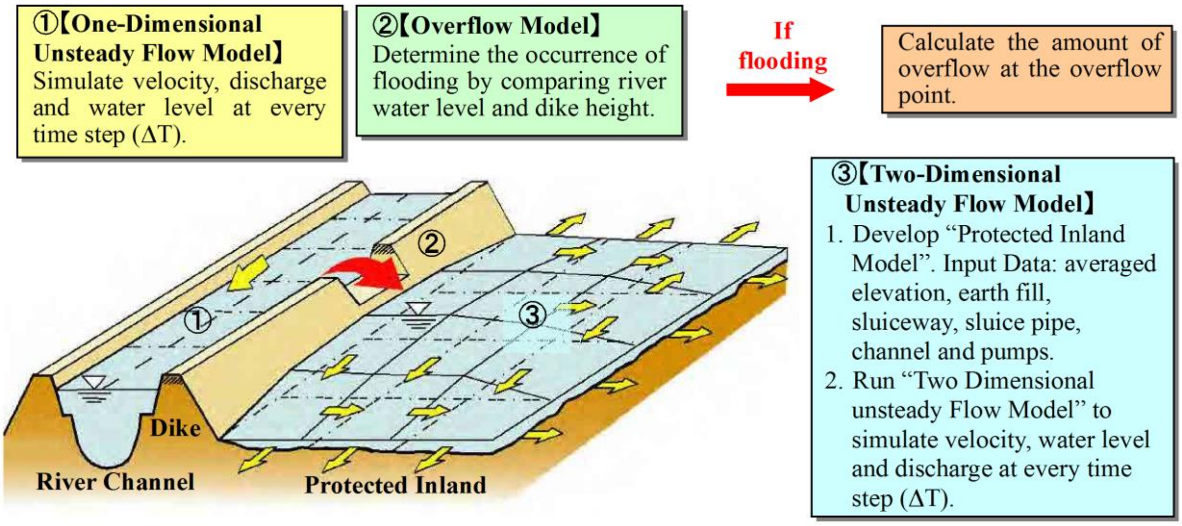
Figure 1.1.12 River network model

1.1.4 Flooding model

A 2-dimensional unsteady flow model is utilized in simulation of the floodplain outside of the dikes. The general description is shown in the following table.

Table 1.1.13 General description of flooding model

Item	Content
Software	DHI-MIKE-FLOOD
Grid size	2000m
Calculation domain	X: 338,000 – 838,000 Y: 1,460,000 – 2,210,000 (coordinate system: WGS84 UTM Zone 47N)
Elevation	Average ground elevation based on aerial observation (LiDAR) in 2012
Roughness coefficient	Set based on land use in 2010 (LANDAST 2009-2010)
Consecutive structure	Main road, King's Dike (Bangkok), Surrounding Dike (main cities). The height of structures is set based on LiDAR.



Source ：Report of Previous MP

Figure 1.1.13 Image of the flooding model

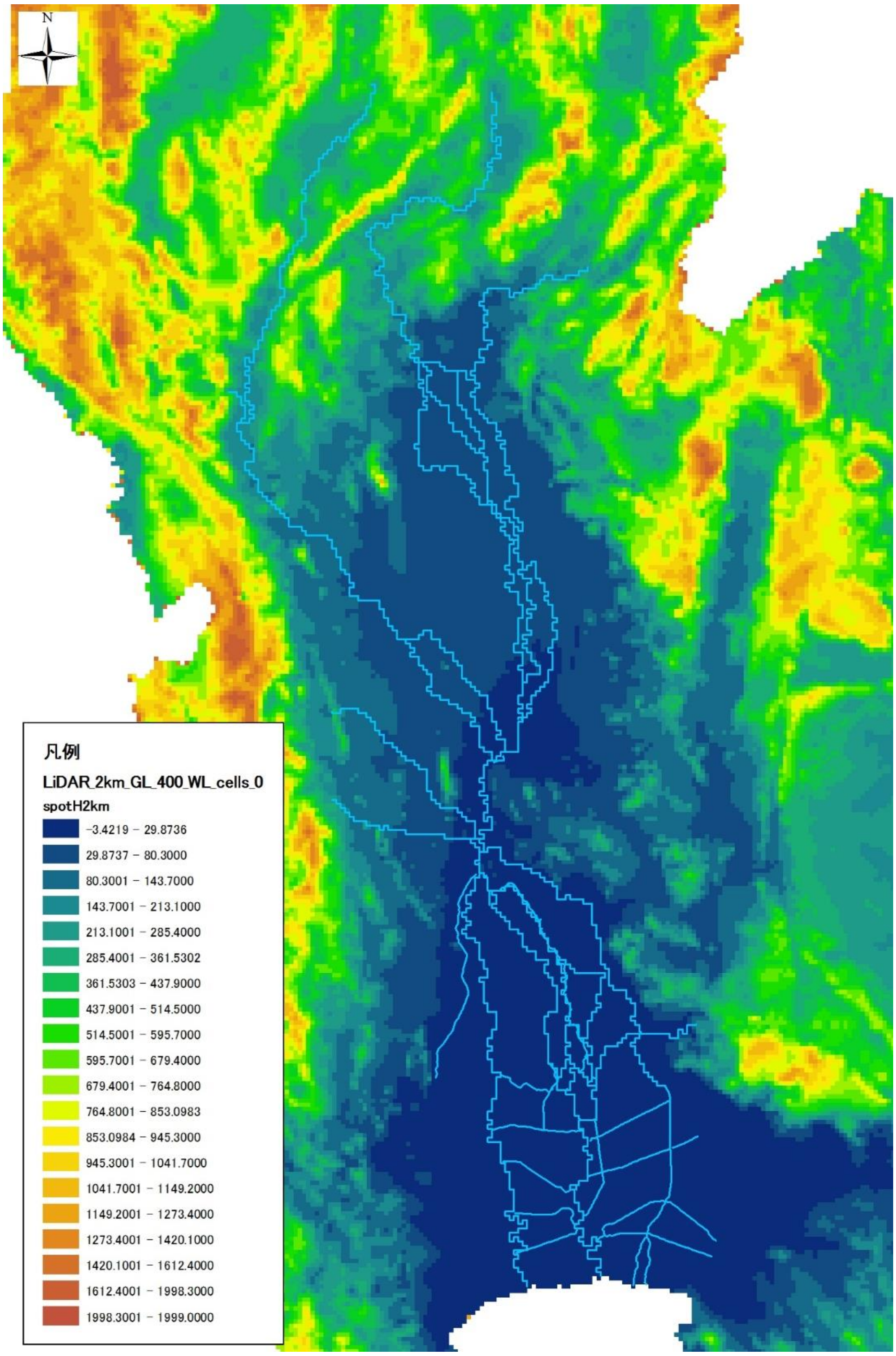
(1) Ground elevation

The result of aerial laser observation made by the JICA LiDAR team is utilized for ground elevations. Point data of topographic map of 1/50,000 scale are used where there is no LiDAR data. Calculation mesh size is 2km since the calculation domain is vast.

Table 1.1.14 Specifications of elevation data

Item	Content	Remark
Observation date	March, 2012	
Resolution	Observation: 4m^2 for 1 point	Grid size is 2km in calculation of this survey
Range (domain)	X: 396,000 – 808,000 m Y: 1,460,000 – 2,044,000 m *coordinate system: WGS84 UTM Zone 47N	Data of military area were not provided due to security. Topographic map is used to complement this area and where there is no LiDAR data.

Source : Report of Previous MP



Source：Report of Previous MP

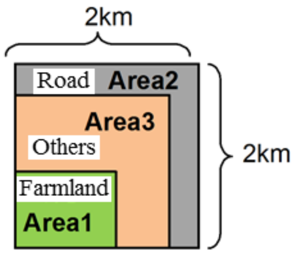
Figure 1.1.14 Ground elevation data based on LiDAR

(2) Roughness coefficient of floodplain

Roughness coefficient is set based on the land use obtained from LANDSAT2011 (2009~2010). For mesh containing multiple types of land use, the roughness value is their area weighted average.

Table 1.1.15 Roughness coefficient of land use (standard value)

Land use	Roughness Value
Farmland	0.060
Road	0.047
Others	0.050



$$n = \frac{0.060 \times Area1 + 0.047 \times Area2 + 0.050 \times Area3}{Area1 + Area2 + Area3}$$

Source：Report of Previous MP

Figure 1.1.15 Calculation method of roughness coefficient

(3) Continuous constructions

Since they affect the flooding flow, the main continuous constructions in urban areas are included in the flooding model.

Table 1.1.16 Continuous constructions included in model

Item	Structure	Detail
Dike	Kings Dike	Total Distance: 156km Height: 0-3 (m MSL)
	Ring Dike	Total Distance: 530km Height: 0-4 (m MSL)
	Economic Zone	Total Distance: 126km Height: 0-3 (m MSL)
Road	Main National Route 1,2,3,4,7,9, etc.	Total Distance: 1,376km Height: 0-4 (m MSL)

Source：Report of Previous MP

(4) Infiltration

Infiltration capacity of each grid is 10mm/day, considering infiltration into soil and discharge from small channels.

(5) Evaporation

Evaporation from the floodplain during flooding and inundation is also included. Evaporation is set for each grid based on the Thiessen Division of observed data from 46 TMD synoptic stations.

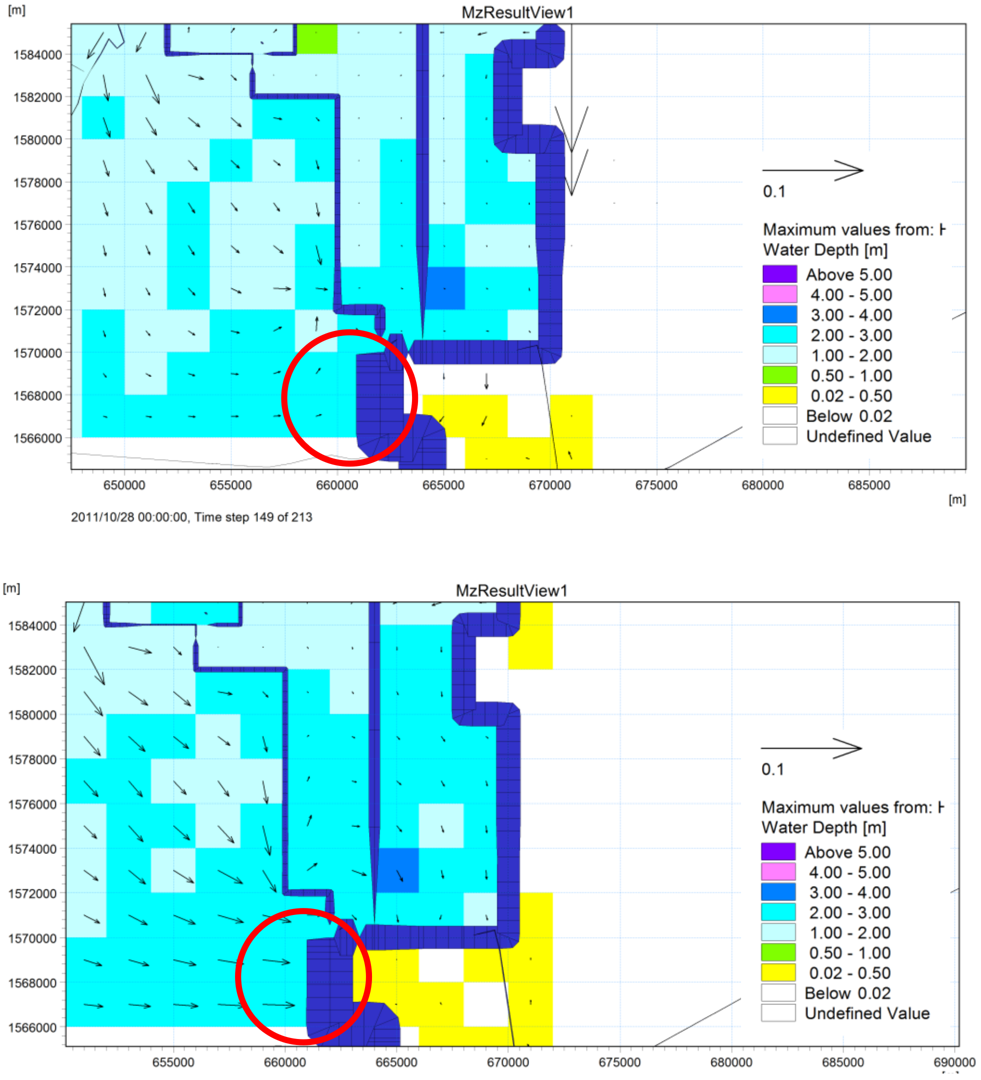
1.1.5 The differences between the versions of the flood analysis models (MIKE FLOOD)

When the previous studies were conducted, the newest MIKE FLOOD, 2011 version, was released, and the flood analysis was conducted with this program. In this study, at first the survey team planned to use the MIKE FLOOD 2016 version which is currently released, the results of inundation range and inundation depth computed by MIKE FLOOD 2016 were widely different from those computed by MIKE FLOOD 2011 version because of the difference of behaviors of overflow and overtopping. For this reason, in this study, MIKE FLOOD 2011 version was used as a flood analysis program. The following shows the difference in stream behavior, inundation range and depth, and longitudinal water level of river channel in computing a simulation of the deluge flood in 2011 between MIKE FLOOD 2011 version and MIKE FLOOD 2016 version.

■Difference in stream behavior in inundation area

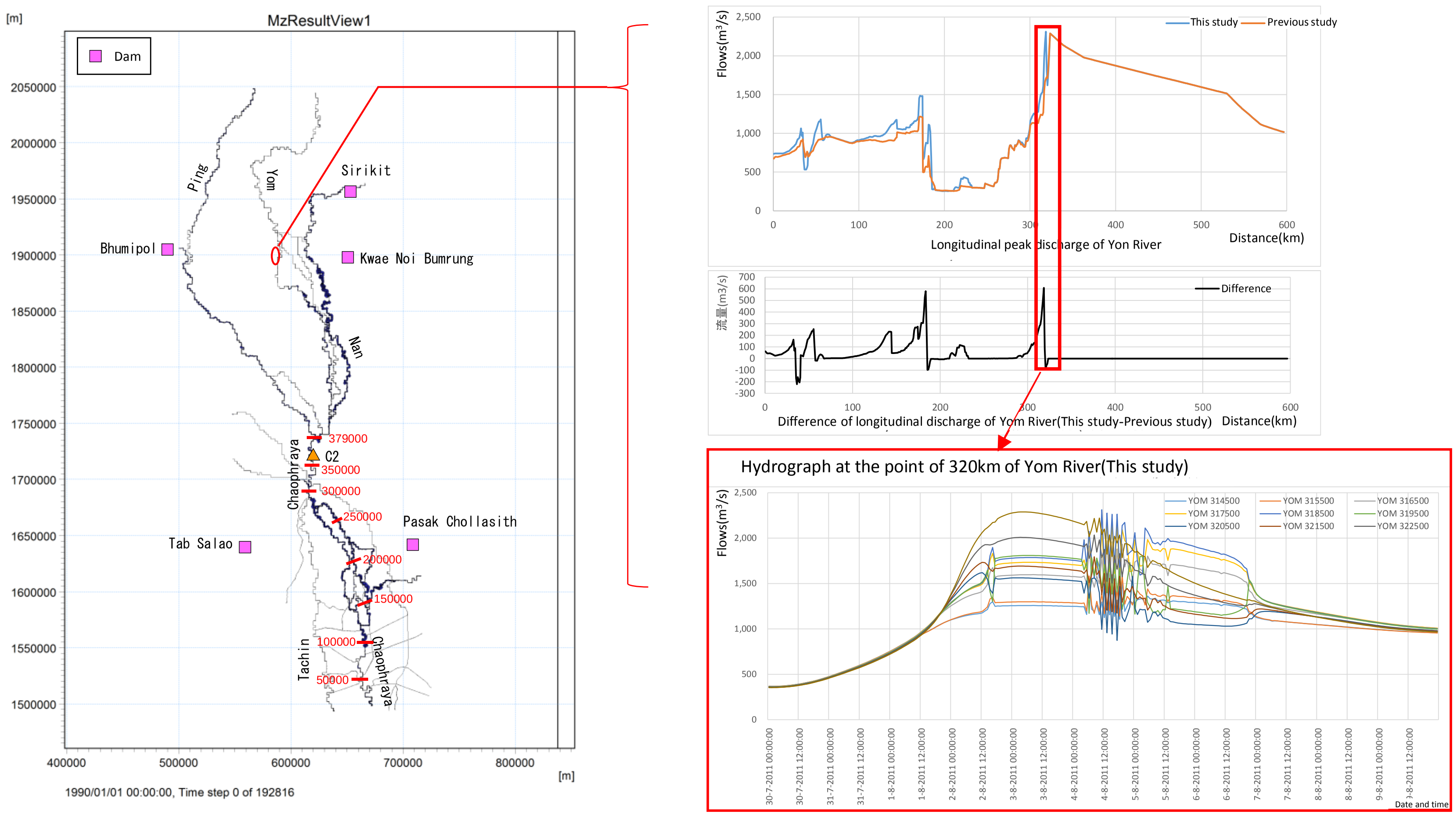
There are some differences of stream behavior in the flood plain between MIKE FLOOD 2011 version and MIKE FLOOD 2016 version such as follows:

- Figure 1.1.16 shows that MIKE FLOOD 2016 version displays that water flows predominantly into the river channel from the flood plain although MIKE FLOOD 2011 version displays that little water flows into the river channel in spite of the same level of inundation depth in the flood plain.
- Figure 1.1.18 shows calculation divergences. The reason for this is estimated to be an instability between the one-dimensional unsteady flow model and the two-dimensional model because of overflow and overtopping from the river channel.



Source : JICA study team

Figure 1.1.16 Differences in behavior in inundation area (Upper: MIKE FLOOD 2011 version, Lower: MIKE FLOOD 2016 version)

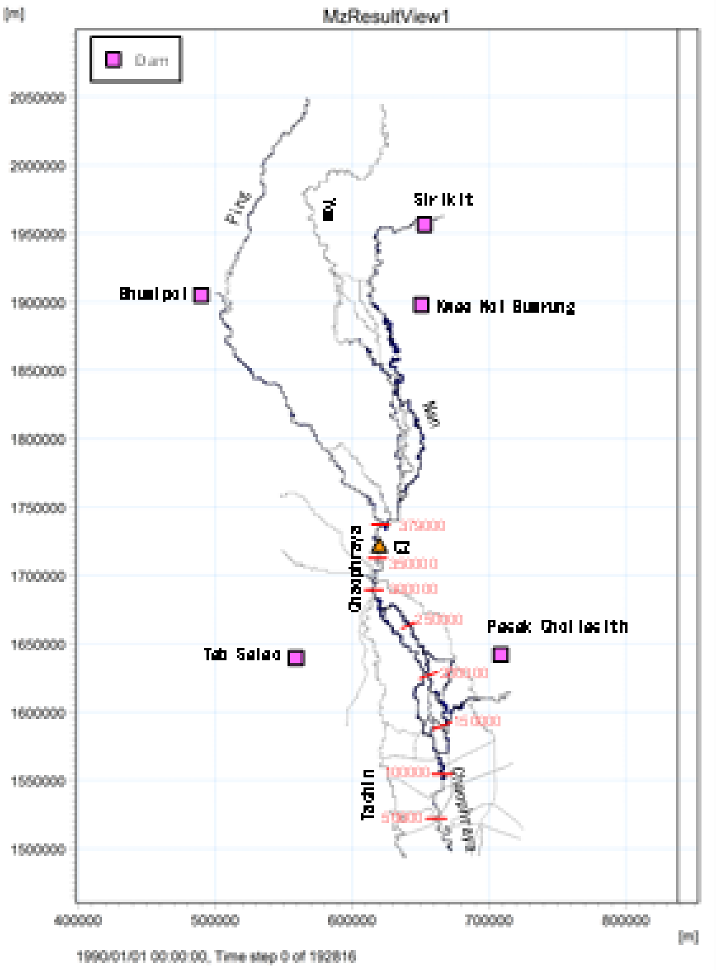


Source：JICA study team

Figure 1.1.17 Calculation divergences in flow rates of Yom River

■Difference in result of analysis

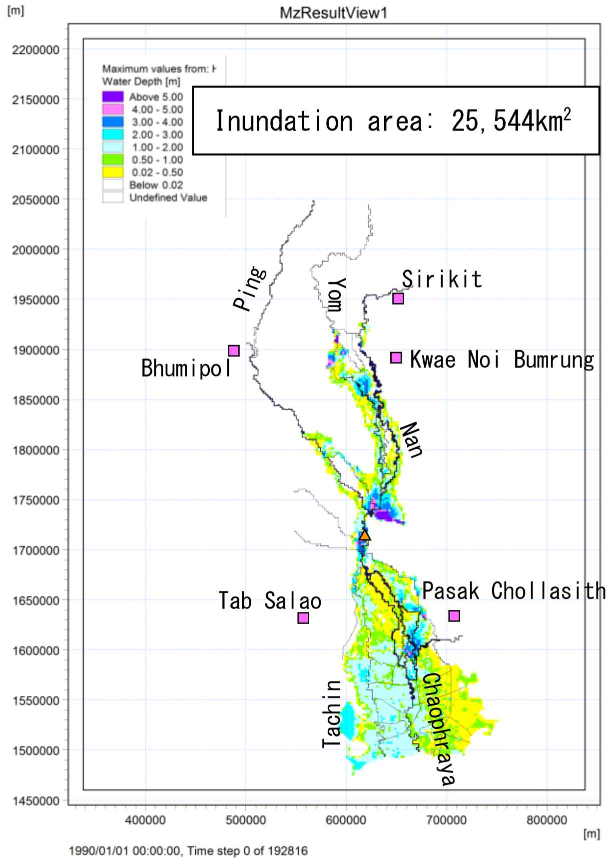
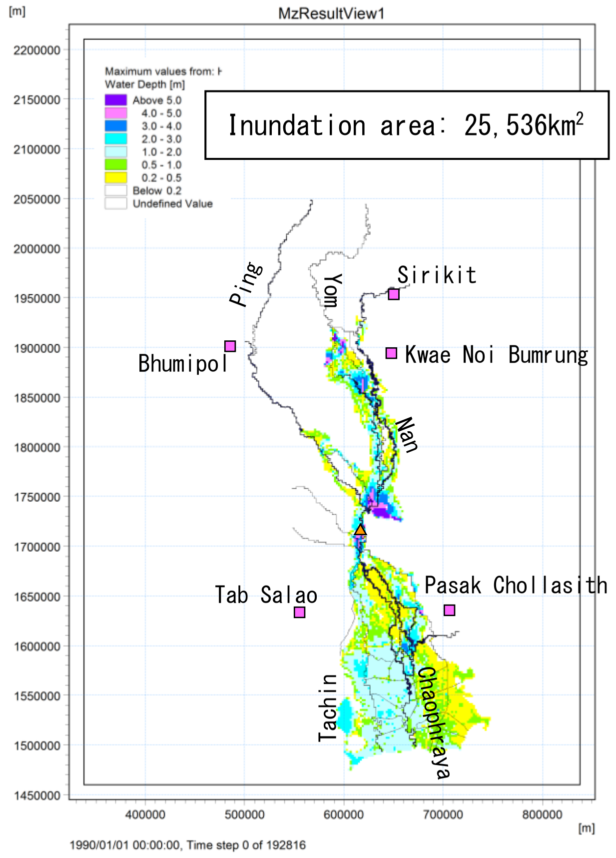
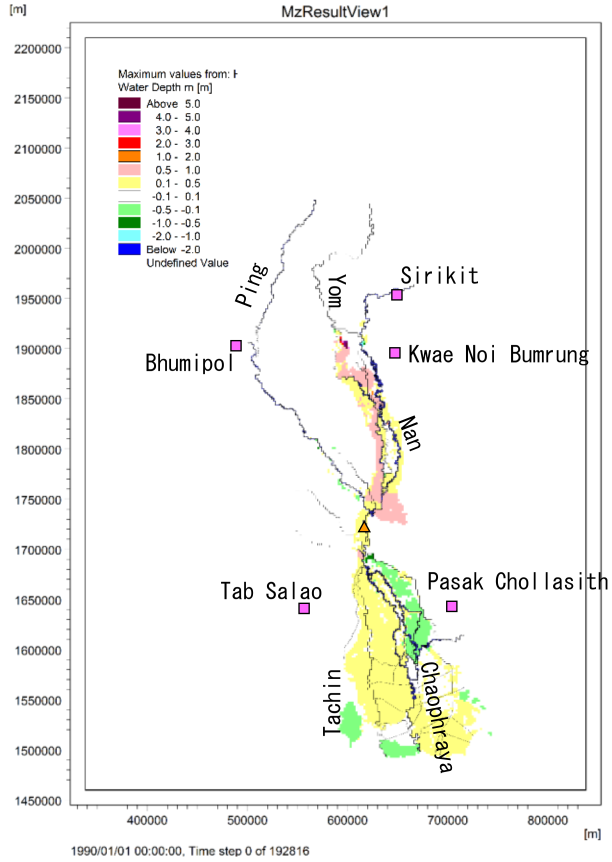
Table 1.1.17 shows the difference in the inundation range and inundation depth depending on the program version. In addition, Table 1.1.18～Table 1.1.23 shows longitudinal water level of the flow of the Chao Phraya River.



Source ：JICA study team

Figure 1.1.18 Relation between the mile-post and the two-dimensional position

Table 1.1.17 Comparison of inundation depth by simulation of the deluge flood in 2011 (Case 0)

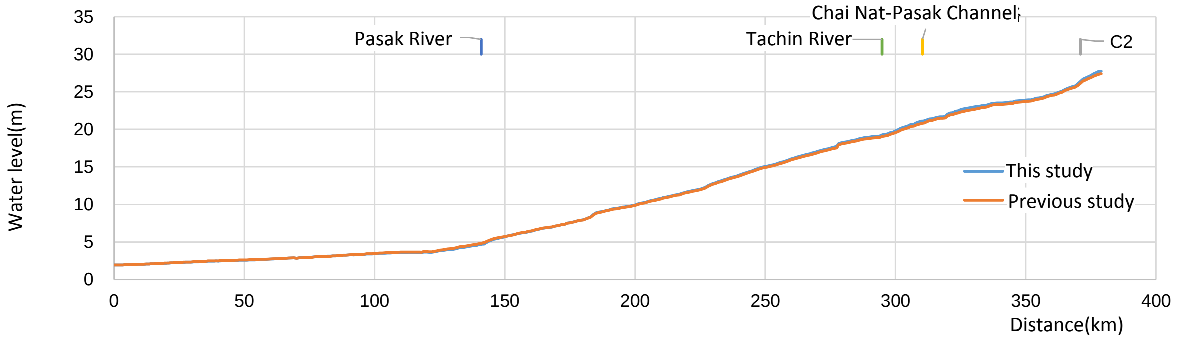
Result of simulation of the deluge flood in 2011 in the previous study	Result of simulation of the deluge flood in 2011 in this study	Difference (<This result>-<The previous result>)
		

Source : JICA study team

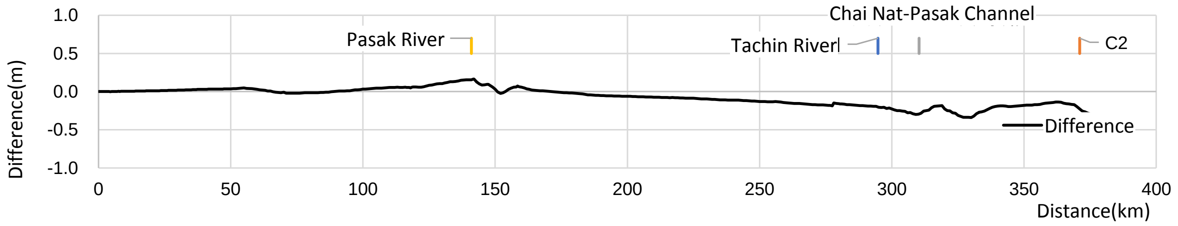
Table 1.1.18 Longitudinal peak water level and discharge of Chao Phraya River

Longitudinal water level

Longitudinal peak water level of Chao Phraya River

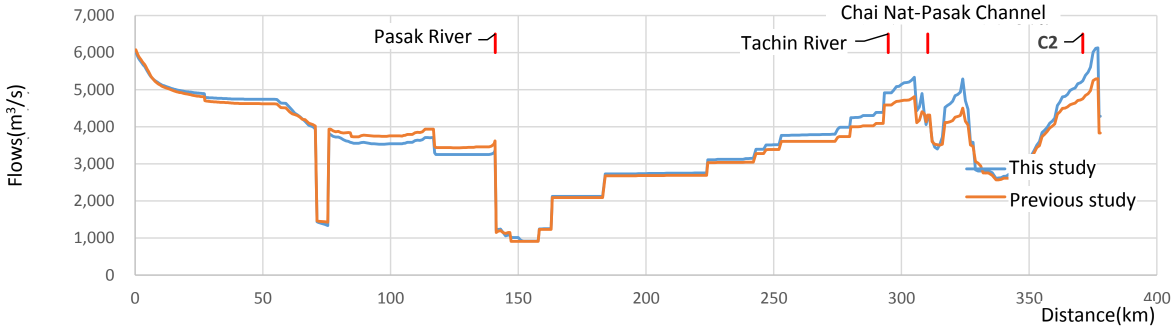


Difference of longitudinal water level of Chao Phraya River(This study- Previous study)

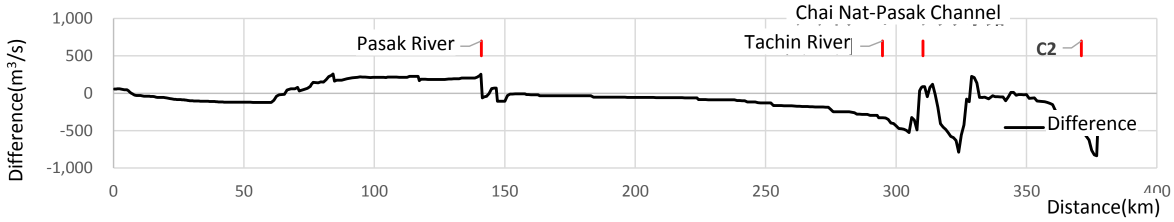


Longitudinal discharge

Longitudinal peak discharge of Chao Phraya River



Difference of longitudinal discharge of Chao Phraya River(This study- Previous study)

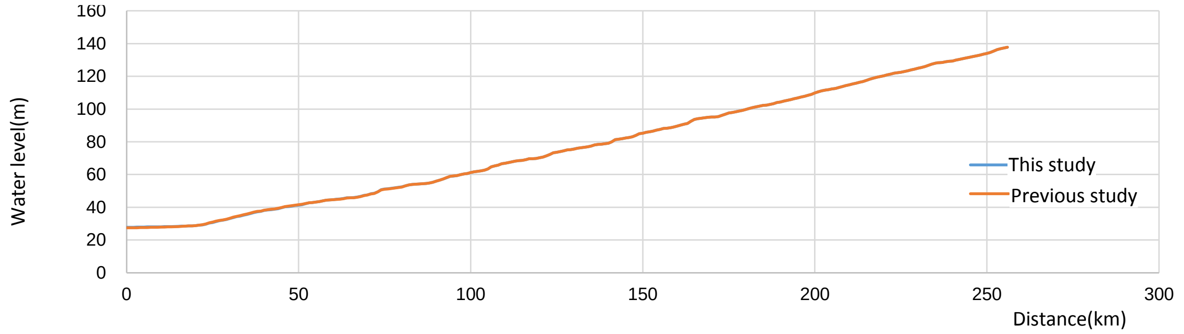


Source : JICA study team

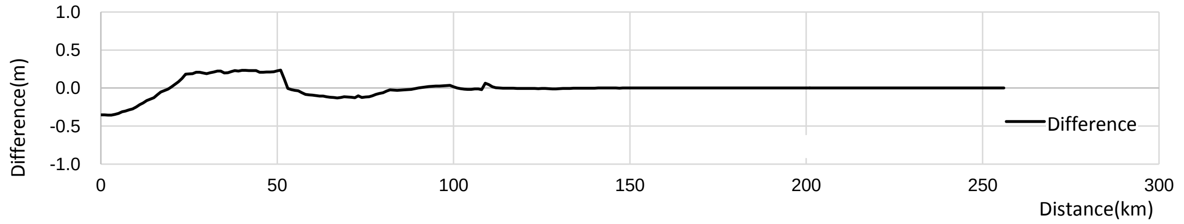
Table 1.1.19 Longitudinal peak water level and discharge of Ping River

Longitudinal water level

Longitudinal peak water level of Ping River

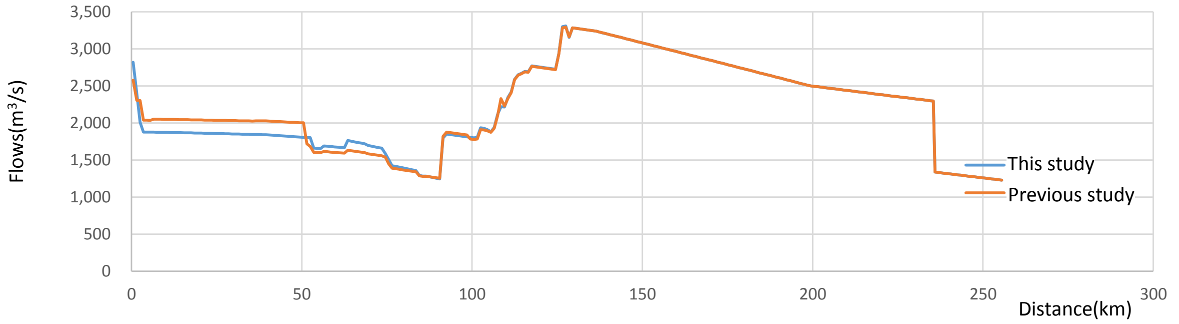


Difference of longitudinal water level of Ping River(This study- Previous study)

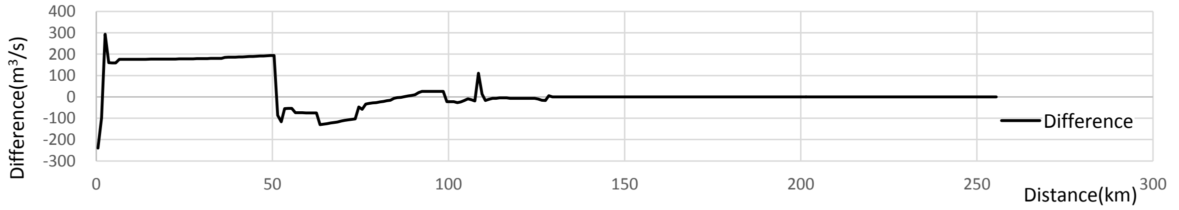


Longitudinal discharge

Longitudinal peak discharge of Ping River



Difference of longitudinal discharge of Ping River(This study- Previous study)

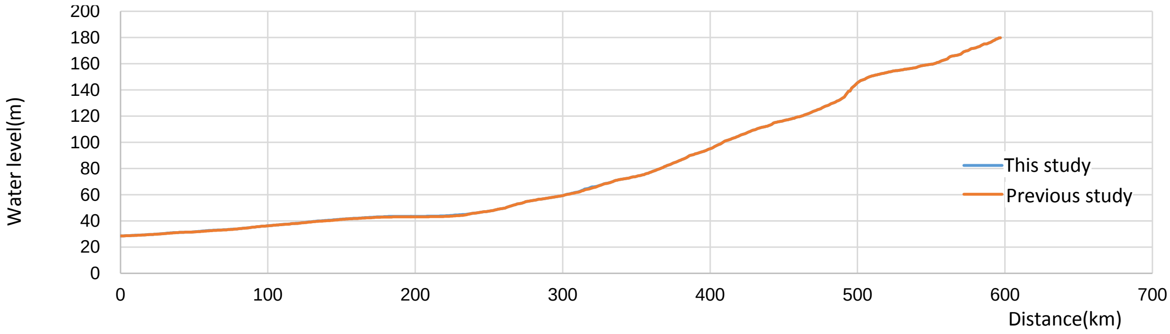


Source : JICA study team

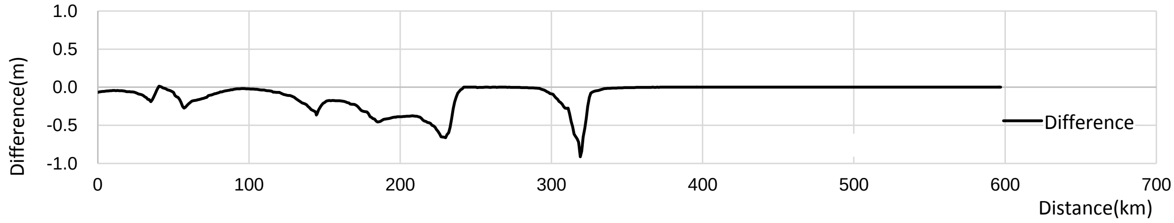
Table 1.1.20 Longitudinal peak water level and discharge of Yom River

Longitudinal water level

Longitudinal peak water level of Yom River

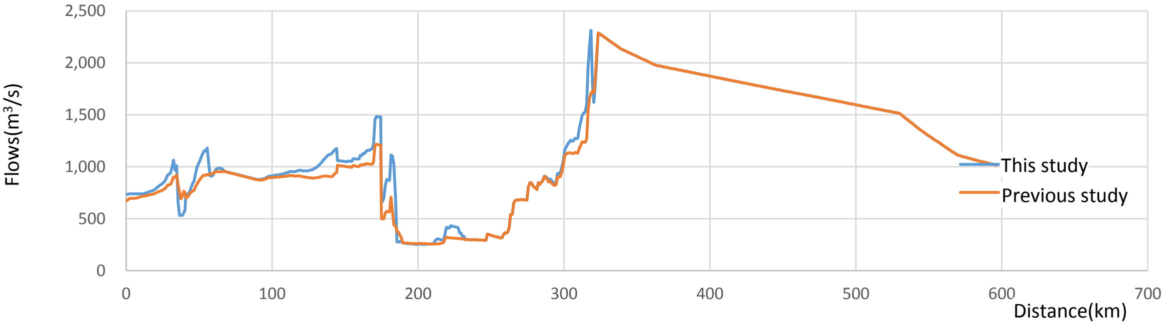


Difference of longitudinal water level of Yom River(This study- Previous study)

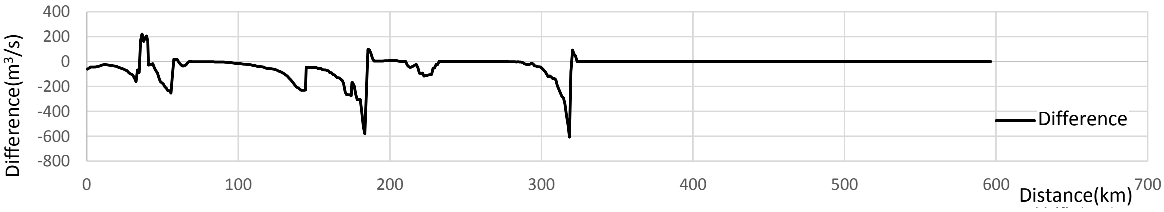


Longitudinal discharge

Longitudinal peak discharge of Yom River



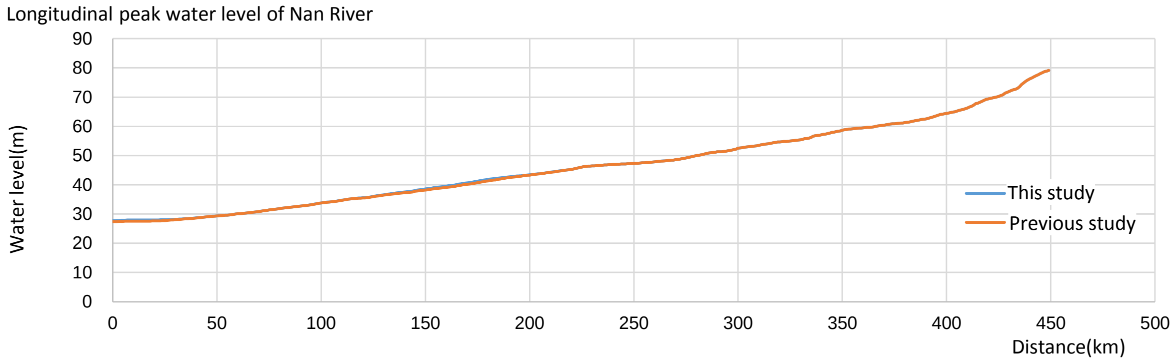
Difference of longitudinal discharge of Yom River(This study- Previous study)

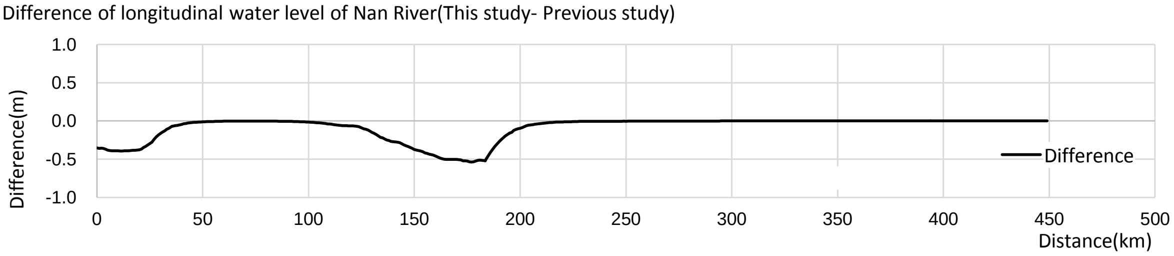


Source：JICA study team

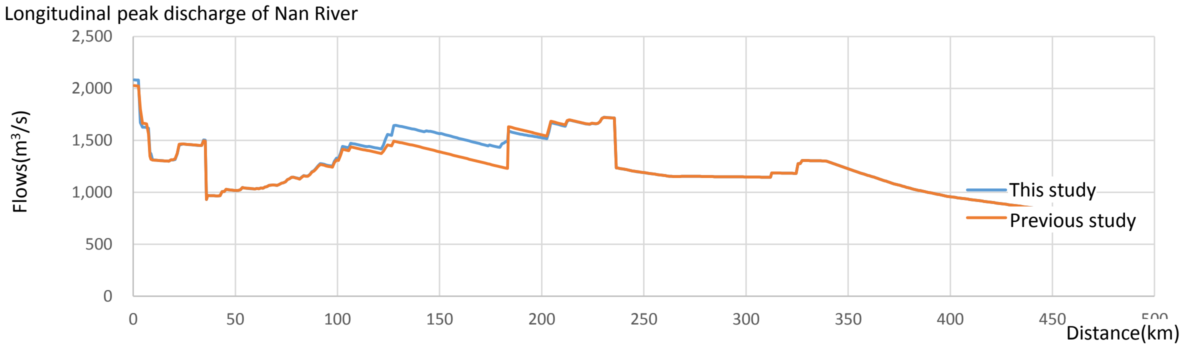
Table 1.1.21 Longitudinal peak water level and discharge of Nan River

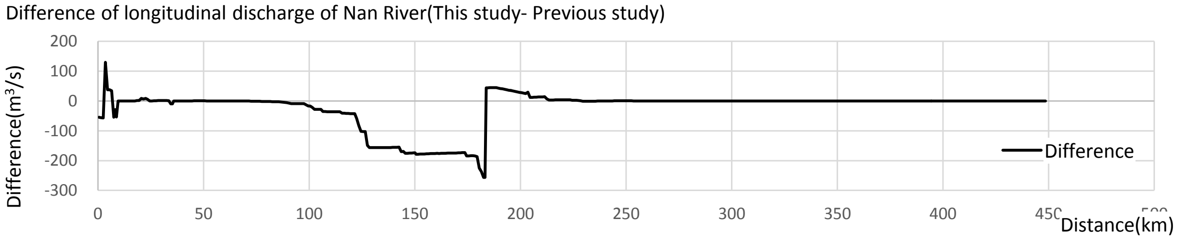
Longitudinal water level





Longitudinal discharge

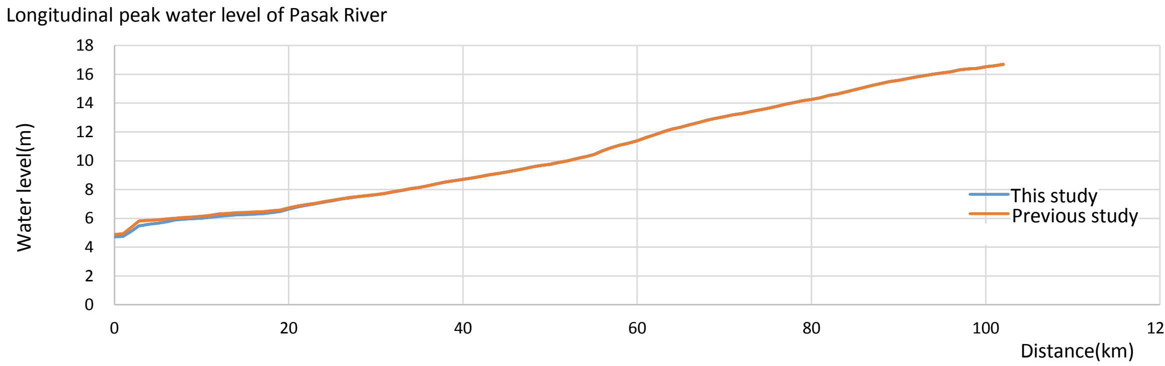


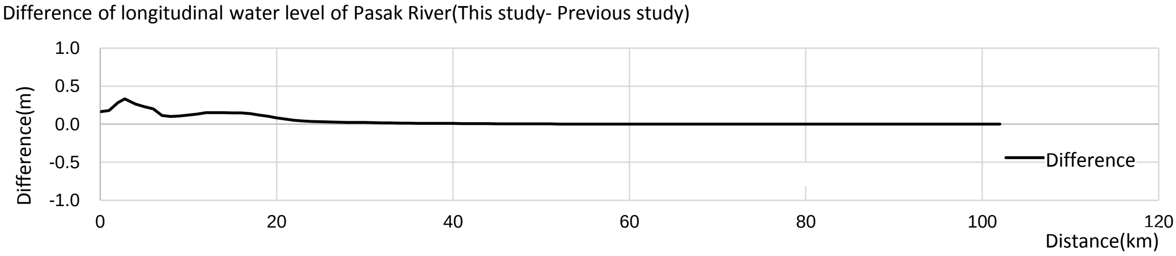


Source : JICA study team

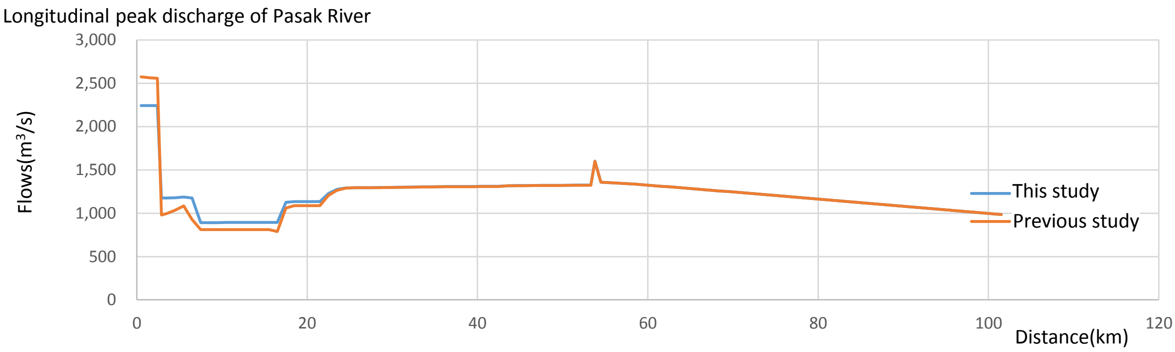
Table 1.1.22 Longitudinal peak water level and discharge of Pasak River

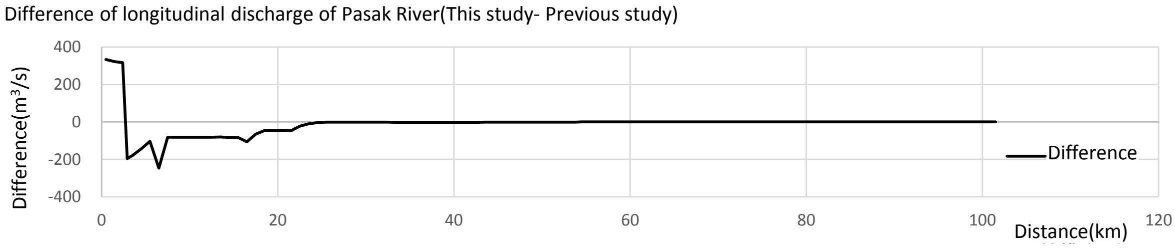
Longitudinal water level


Longitudinal peak water level of Pasak River


Difference of longitudinal water level of Pasak River(This study- Previous study)

Longitudinal discharge


Longitudinal peak discharge of Pasak River

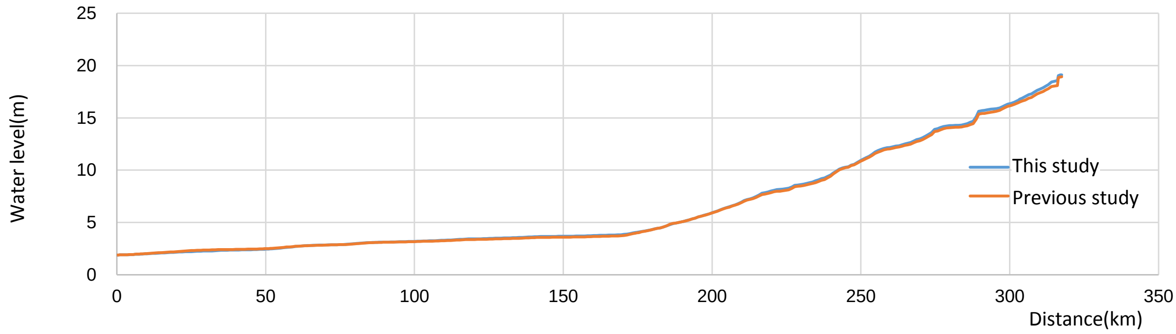

Difference of longitudinal discharge of Pasak River(This study- Previous study)

Source：JICA study team

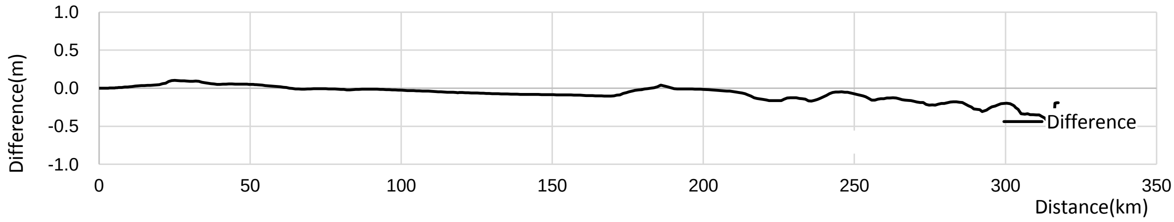
Table 1.1.23 Longitudinal peak water level and discharge of Tachin River

Longitudinal water level

Longitudinal peak water level of Tachin River

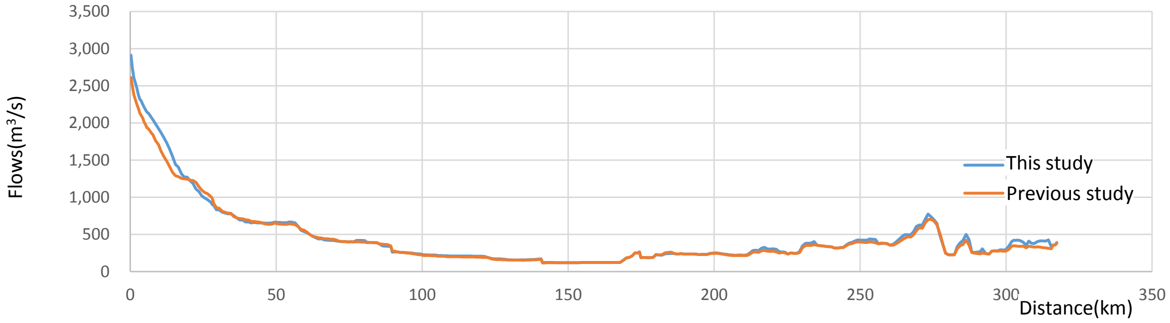


Difference of longitudinal water level of Tachin River(This study- Previous study)

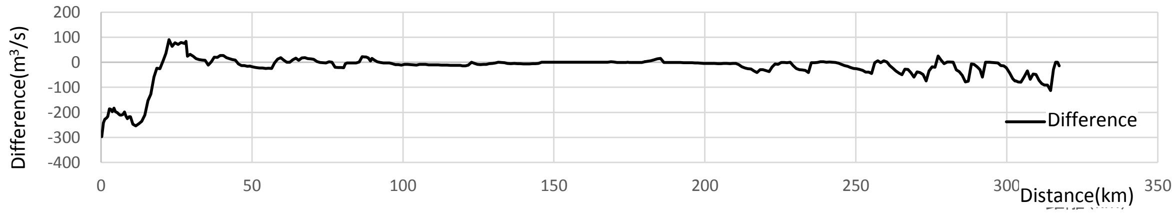


Longitudinal discharge

Longitudinal peak discharge of Tachin River



Difference of longitudinal discharge of Tachin River(This study- Previous study)



Source : JICA study team

1.2 Comparison of flood area reduction with the RID Plan (Impact of prior construction of Ayutthaya Bypass)

RID established a plan to prioritize construction of the Ayutthaya Bypass. If the Ayutthaya Bypass is constructed before the Outer Ring Road Diversion C. is constructed, inundation damage could be worse in the downstream of the Outer Ring Road Diversion C. because in principle, flood control should be implemented from the downstream. Thus, the survey team conducted inundation analysis for the case that only the Ayutthaya Bypass is constructed. The cases are as follows:

Case A：JICA MP

Case B：Only the Ayutthaya Bypass

Case C：Neither the Ayutthaya Bypass nor the Outer Ring Road Diversion C is constructed

Table 1.2.1 List of study cases

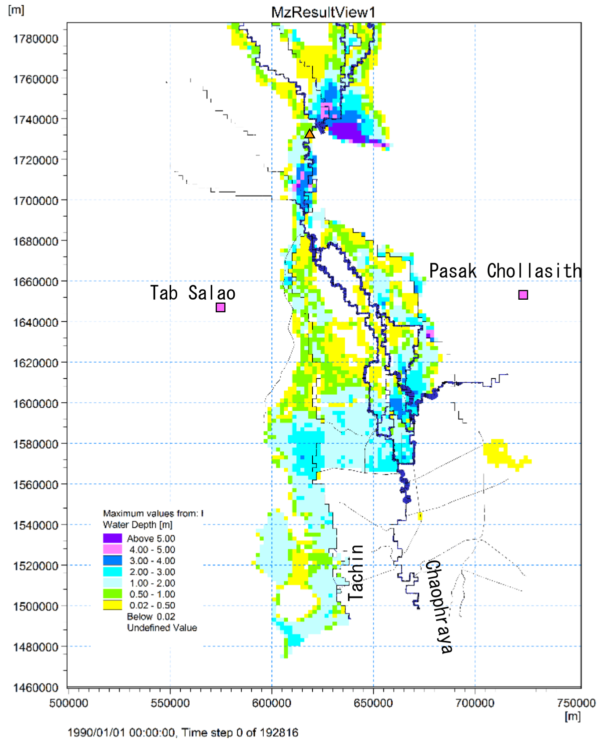
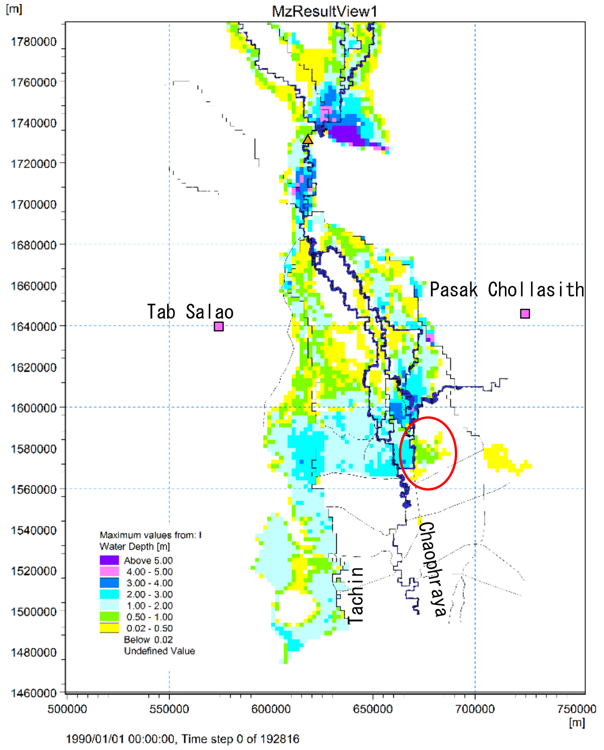
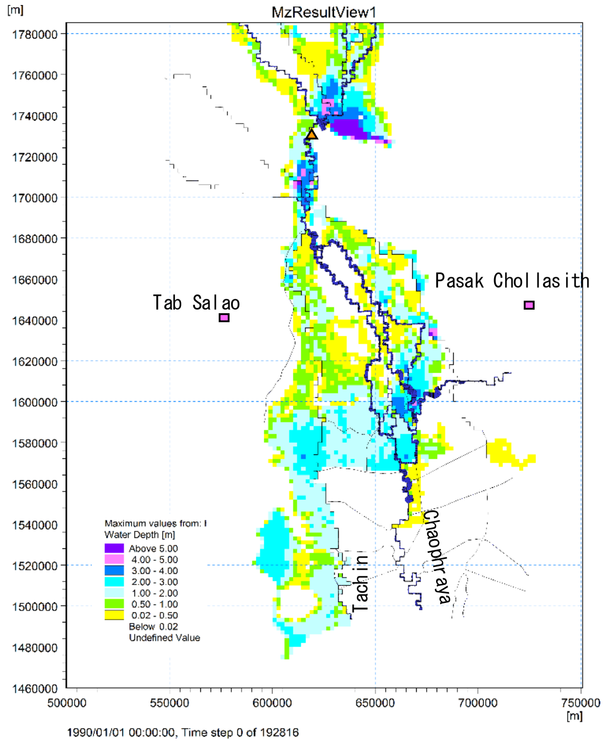
Case A	Ayutthaya Bypass and Outer Ring Road Diversion C.
Case B	Ayutthaya Bypass
Case C	Only common measures
Common measures	・ Heightening the roads surrounding Bangkok and its vicinities ・ Dike construction（downstream of Chao Phraya River） ・ Dike raising（downstream of Tachin River） ・ 4 cutoff channels（downstream of Tachin River） ・ Operating rules improvement for dams

The following are the results of the analysis:

- In Case C, the inundation area is 412 km². With construction of the Ayutthaya Bypass (Case B), the inundation can be reduced by approximately 200 km².
- It should be noted that in Case B, the Ayutthaya Bypass is constructed as the priority, water level of the downstream of the Chao Phraya River would rise to around the DHWL, which is higher than before construction. (This means that if an excess flood occurs, the flood risk in the downstream of the Chao Phraya River could increase due to prior construction of the Ayutthaya Bypass.)
- By construction of the Ayutthaya Bypass and the Outer Ring Road Diversion C., water level of the Chao Phraya River would be lower than DHWL in almost all intervals, and it is possible to avoid inundation in the Protected Area almost completely.

According to the results of the analysis above, it is preferable that the Outer Ring Road Diversion C should be constructed prior to the Ayutthaya Bypass. When the Ayutthaya Bypass is constructed as the priority, inundation can be reduced, however, the flood safety control level in the downstream area declines and the damages in the area could be widen if an excess flood occurs.

Table 1.2.2 Inundation map for the case of constructing only Ayutthaya Bypass

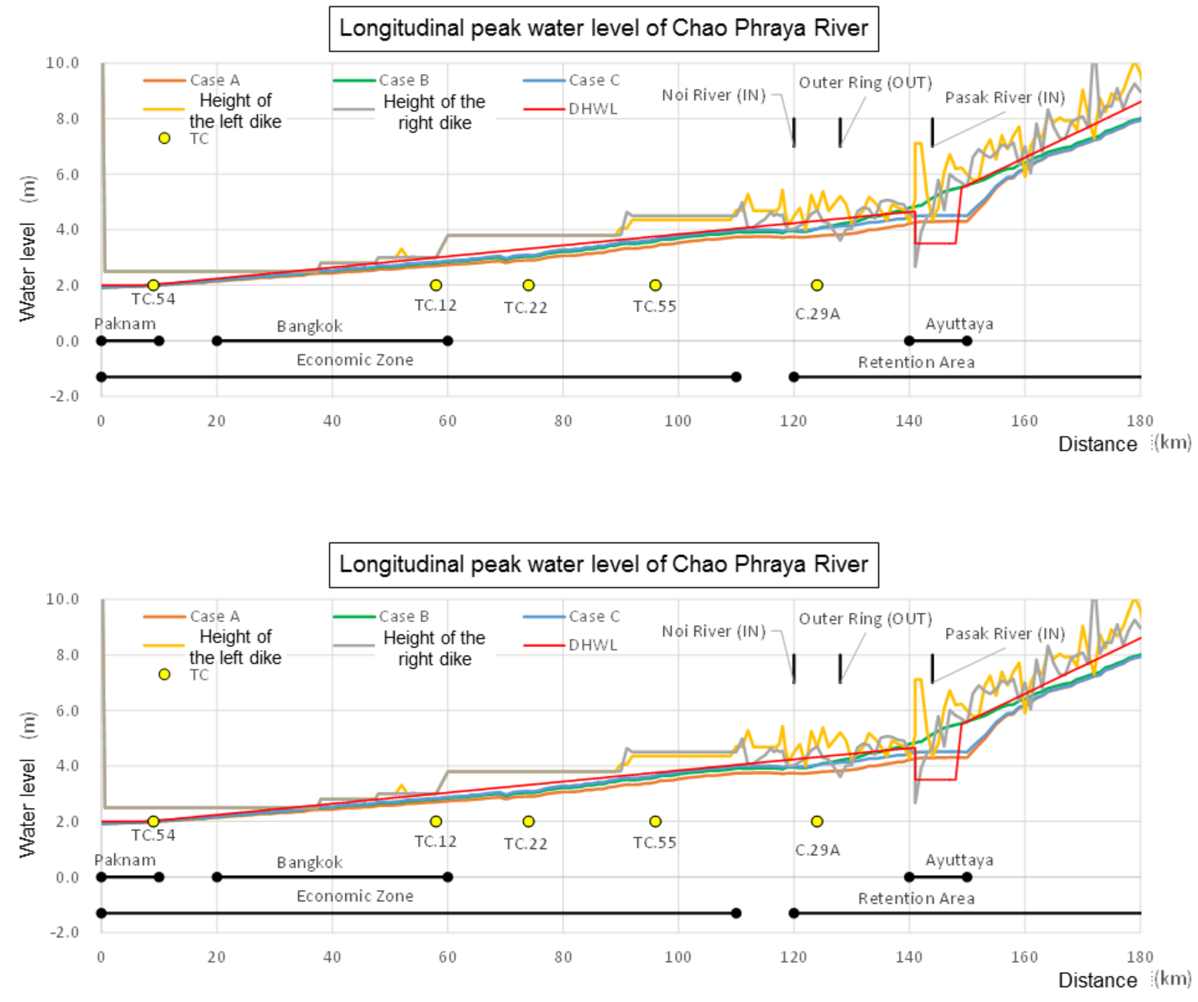
Case A：JICA MP (Both of the Ayutthaya Bypass and Outer Ring Road Diversion C. are constructed)	Case B：Only the Ayutthaya Bypass is constructed	Case C：Neither the Ayutthaya Bypass nor the Outer Ring Road Diversion C is constructed
		

Source：JICA study team

Table 1.2.3 Comparison of the inundation area for the case of constructing only Ayutthaya Bypass

(km^2)	Out of the Protected Area	Protected Area	Whole	Difference to the case of 500m^3/s		
Case A	14,783	13	14,796	Out of the Protected Area	Protected Area	Whole
Case B	14,831	217	15,048	48	204	252
Case C	14,904	412	15,316	121	399	520

Source ：JICA study team



Source ：JICA study team

Figure 1.2.1 Impact to the downstream of the Chao Phraya River by prior construction of the Ayutthaya Bypass

1.3 Cross-Section of the Outer Ring Diversion Channel

1.3.1 Cases for discussion

The longitudinal slope was modified, according to the route designed by DOH, by modifying the total distance and height at diversion points in Chao Phraya River. Then, modification of the river section has been discussed based on the modified longitudinal slope.　Three cases where flow rates were all assumed to be 500m3/s, were studied.

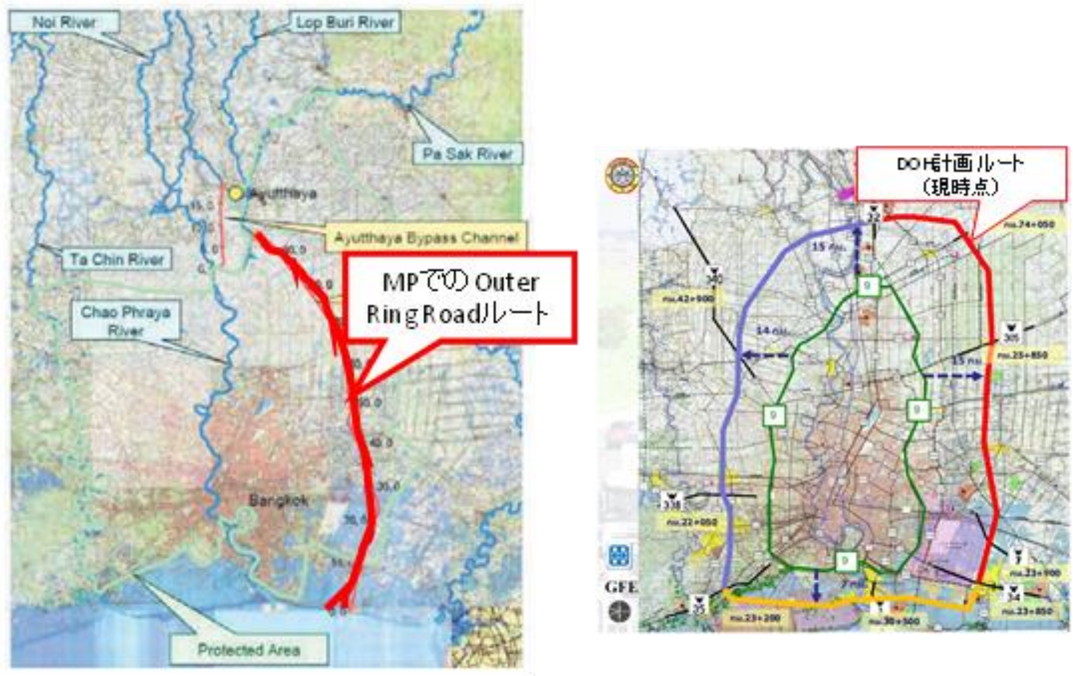


Figure 1.3.1 The route of the Outer Ring Road

Table 1.3.1 List of the changes

Change	MP route	DOH plan route
extension（km）	98.4	114.2
DHWL of upstream（m）	4.2	4.5

Table 1.3.2 List of discussed cases

Case	Discussion point
Case 0： (Original Plan)MP	・ Original designed section when making MP(500m^3/s discharge)
Case 1： Maximal excavation	・ Designed section in MP that was modified ・ Original Designed Water Depth in longitudinal section in MP
Case 2： Maximal width expansion	・ Width of designed section of 1000m^3/s case in MP was used ・ Depth of excavation is low
Case 3： Excavated river channel	① Setting of DHWL ・ In the upstream above the 80km point, water level is planned according to the current height of ground ・ At the point 30km from the river mouth, the height of the dike and planned water level are fixed ・ In the section of 30km to 80km, the height is the same as the height linked linearly between the upstream and the downstream ② Setting of the river bed height ・ River bed slope: 1/68,400, which is as high as the slope of the surface in the upstream ・ Standard height of the river bed: River mouth EL-6.0m

Source：JICA study team

Discussion steps are given as follows.

- Initial section setting: find a river section as initial section by uniform flow assumption, whose capacity is the same as the river section designed in the MP.
- Second setting: use the initial section for varied flow calculations in MIKE11 and modify the river section based on simulation result.

1.3.2 Result

(1) Initial river section with uniform flow assumption

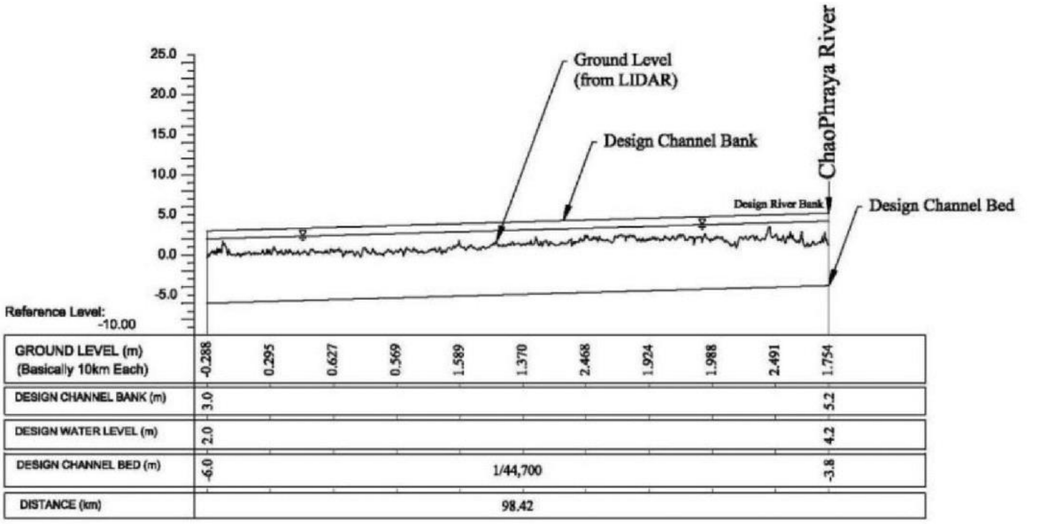
With the amendments of route, the modification of longitudinal design and volume of excavation and embankment calculated with uniform flow assumption are listed as below.

- Total distance increase 16% from 98km to 114km
- No need for significant modification in river section, since river bed slope does not change much as upstream water level rises.
- Volumes of soil increase as the total distance

Table 1.3.3 The results of the initial river section

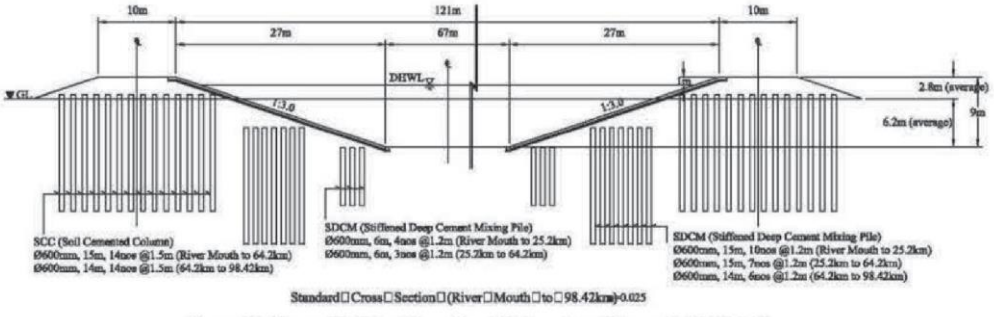
Designed river section in MP(Case 0)

Longitudinal River Section in setting



	Embankment m	Designed water level m	River bed elevation m	Distance km	River bed slope m
Downstream	3.0	2.0	-6.0	0	1/44,700
Upstream	5.2	4.2	-3.8	98.42	

Cross River section in setting



Cross Section of Outer Ring Road Diversion Channel (O500-1)

Target Q m^3	Roughness	River bed slope $(1/I_B)$	Water depth m	Width between banks m	Width of river bed m	Section area m^2	Flow velocity m/s	Flow rate m^3
500	0.025	44,700	8	115	67	728	0.64	464.37

※roughness：fixed value for bottom and side slope n=0.025

Soil volume

Total excavation(m^3)：55,528,564

Total embankment(m^3)：7,385,437

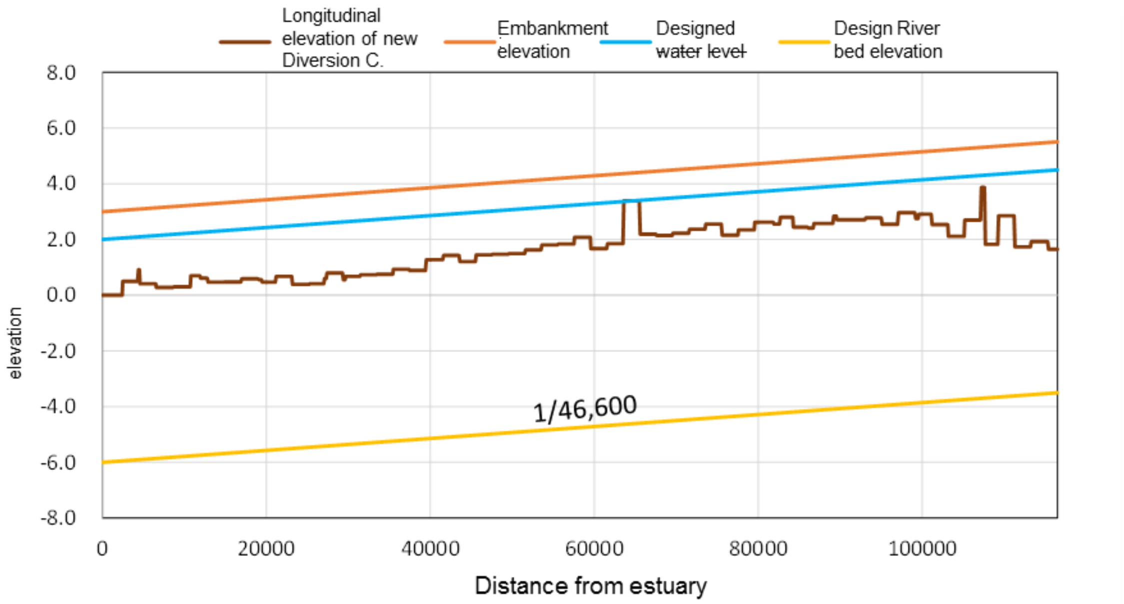
Remaining soil(m^3) : 48,143,127 ※estimated based on excavation and embankment of standard section in report

Source ：JICA study team

Table 1.3.4 The results of the initial river section

Maximal excavation case(Case 1)

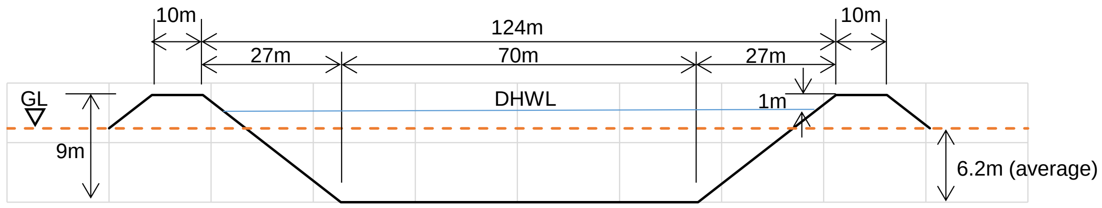
Longitudinal River section in setting



	Embankment m	Designed water level m	River bed elevation m	Distance km	River bed slope m
Downstream	3.0	2.0	-6.0	0	1/46,600
Upstream	5.5	4.5	-3.5	116.50	

※Upstream water level is water level at diversion point of Chao Phraya River (as previous study)

River Cross-section in setting



Target Q m^3	Roughness	River bed slope $(1/I_B)$	Water depth m	Width between banks m	Width of river bed m	Section area m^2	Flow velocity m/s	Flow rate m^3
500	0.025	46,600	8	118	70	752	0.64	480.07

※roughness：same with previous discussion

(roughness of bottom and slope may change necessarily according to actual construction in future)

Soil volume

Total excavation(m^3)：66,541,244(approximately 20% increase)

Total embankment(m^3)：10,975,939(approximately 49% increase)

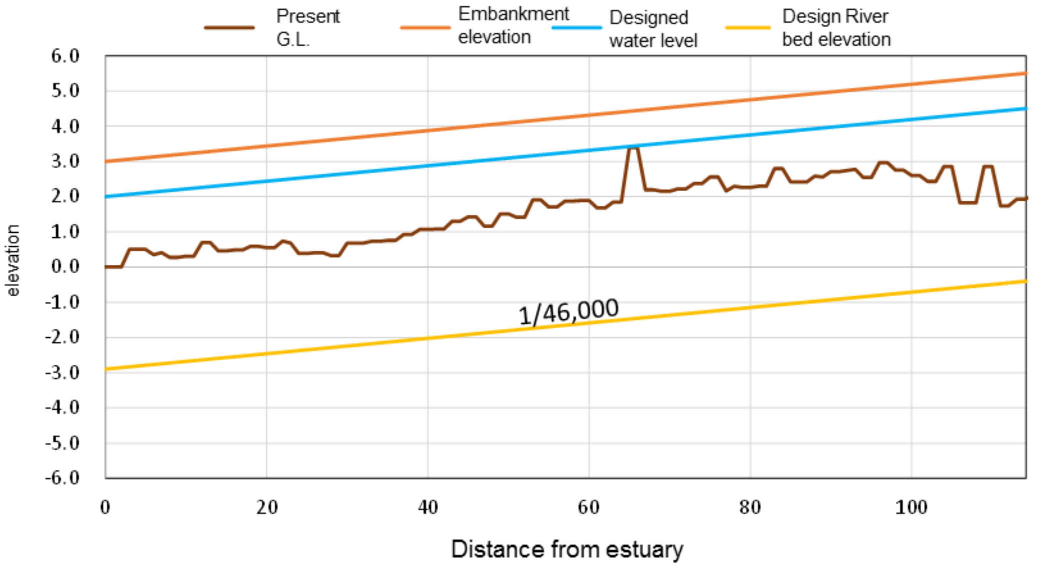
Remaining soil(m^3)：55,565,304(approximately15% increase)　※calculated based on 2km pitch of ground elevation

Source：JICA study team

Table 1.3.5 The results of the initial river section

Maximal width expansion(Case 2)

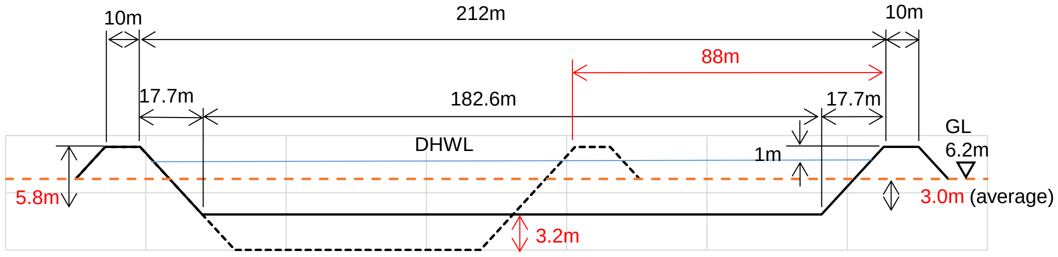
Longitudinal River section in setting



	Embankment m	Designed water level m	River bed elevation m	Distance km	River bed slope m
Downstream	3.0	2.0	-2.8	0.0	1/46,600
Upstream	5.5	4.5	-0.3	116.5	

※Upstream water level is water level at diversion point of Chao Phraya River (as previous study)

Cross River section in setting



Target Q m^3	Roughness	River bed slope $(1/I_B)$	Water depth m	Width between banks m	Width of river bed m	Section area m^2	Flow velocity m/s	Flow rate m^3
500	0.025	46,600	4.8	212	182.6	948.48	0.51	490.18

Soil volume

Total excavation(m^3)：72,304,002(approximately 30% increase)

Total embankment(m^3)：11,233,474 (approximately 52% increase)

Remaining soil(m^3)：61,070,528(approximately 27% increase)

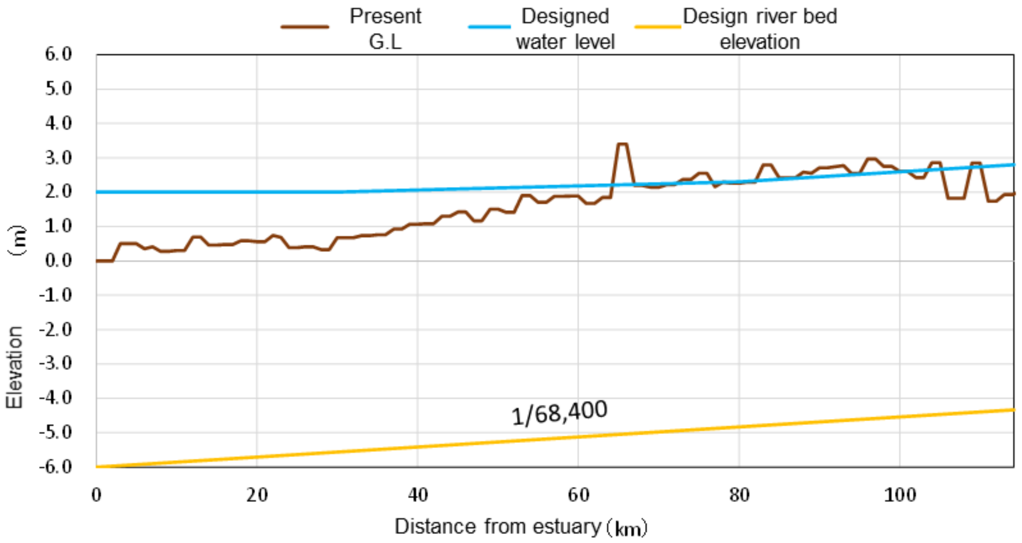
※The comments in “ ( )” means the ratio compared with MP

Source ：JICA Study Team

Table 1.3.6 The results of the initial river section

Excavated river channel(Case 3)

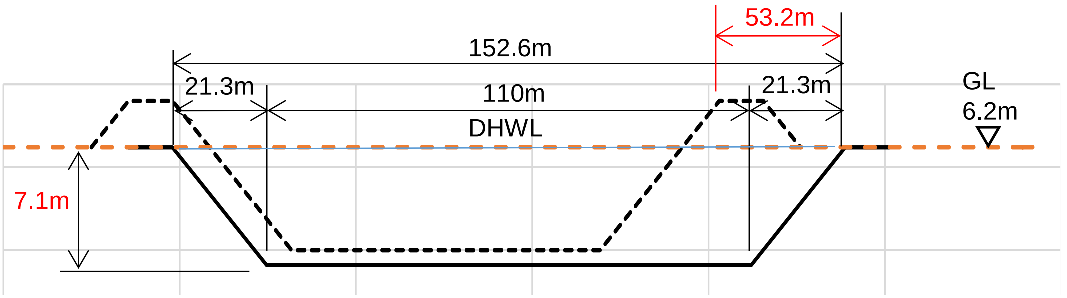
Longitudinal River section in setting



	Embankment m	Designed water level m	River bed elevation m	Distance km	River bed slope m
Downstream end	2.0	2.0	-6.00	0.0	1/68,400
40km	2.0	2.0	-5.56	30.0	
80km	2.3	2.3	-4.83	80.0	
Upstream end	2.8	2.8	-4.33	114.2	

※The water level of the end of the downstream is set by the peak tide, and surface water/ bed slope of the 80km of upstream is set according to the current land height

River Cross section in setting



Target Q m^3	Roughness	River bed slope (1/I_B)	Water depth m	Width between banks m	Width of river bed m	Section area m^2	Flow velocity m/s	Flow rate m^3	Target Q m^3	Roughness
500	0.025	68,400	7.1	152.6	110	932.23	-0.66	1.33	-607.7	850.6

Soil volume

Total excavation(m^3)：106,738,294(approximately 92% increase)

Total embankment(m^3)：6,332,792(approximately14% decrease)

Remaining soil(m^3)：100,405,502(approximately 109% increase)

※Calculated by 2km pitch of the mesh of land height

Source：JICA Study Team

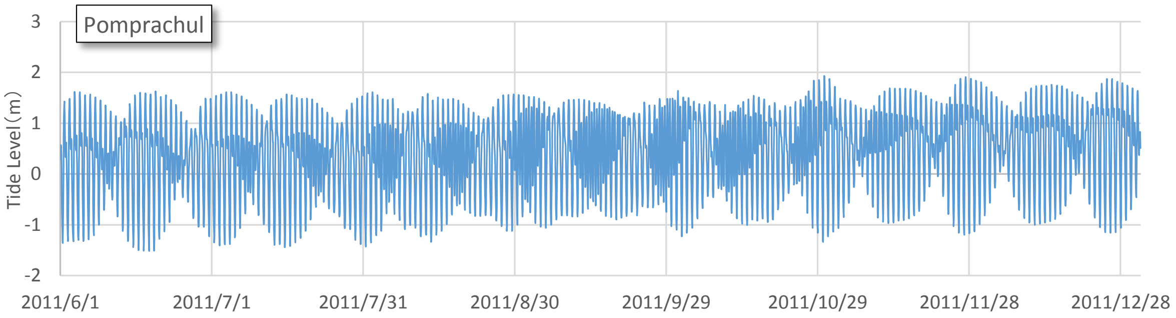
(2) Modification of River section setting by varied flow calculations

1) Boundary Condition

Observed tide level is used as the downstream water level. Salinity concentration is assumed to be 34 psu (the salinity concentration of sea water nearby) and fixed vertically.

＜Downstream Estuary＞

- Previous study :
  Downstream water level is assumed to be 2.0m according to the fluctuation of tide elevation (Figure 1.3.2) at observing point of Pom Prachul near the estuary of Chao Phraya River
- This study：Same as previous study

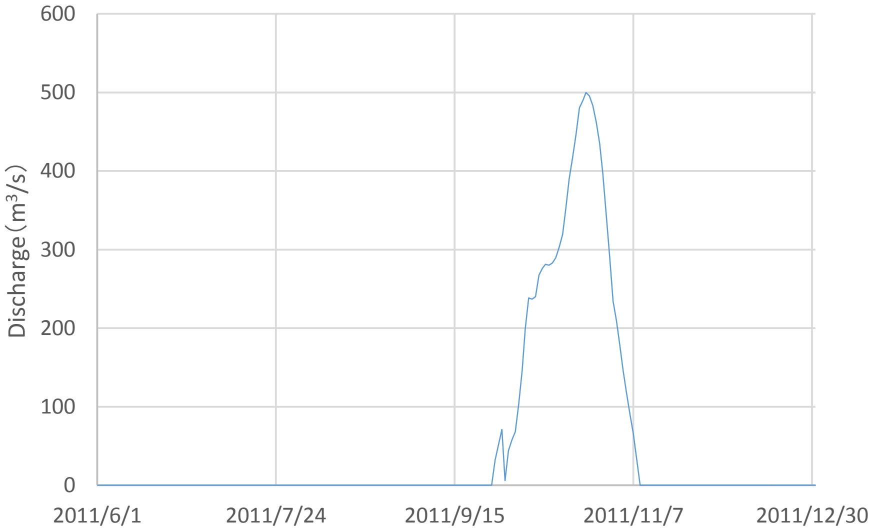


Source ：JICA study team

Figure 1.3.2　Fluctuation of tide elevation at observing point of Pom Prachul

＜Upstream flow rate＞

- Previous study :
  Hydrograph (Figure 1.3.3) of diversion water to Outer Ring Road Diversion Channel is used as the inflow to the diversion Channel, which was also used in the inundation simulation of Chao Phraya River.
- This study：Same as previous study



Source ：JICA study team

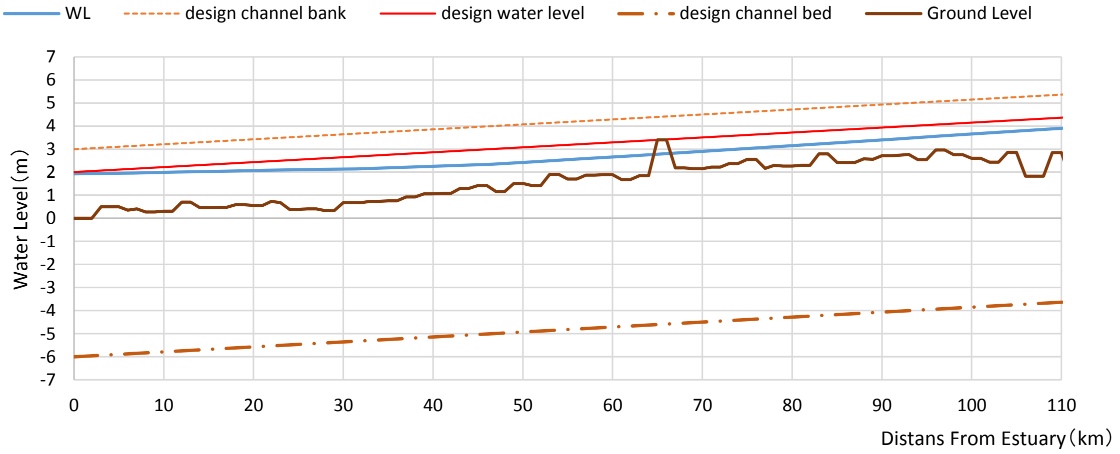
Figure 1.3.3 Discharge to Outer Ring Road Diversion Channel (case of 500m^3/s)

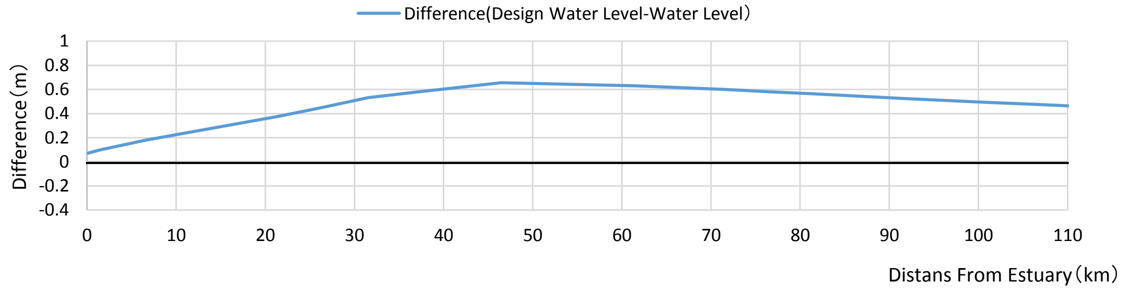
2) Result of Maximal excavation case (the amended case of 500m^3/s case in MP)

i) Calculation result of initial river section

The calculated peak water level, which is calculated based on the initial river section by using a varying flow method, is shown longitudinally in Figure 1.3.4. The peak water level at the diversion point is 0.46 m lower than DHWL according to the figure. Therefore, raising the bottom elevation of the excavation will be discussed in next section.

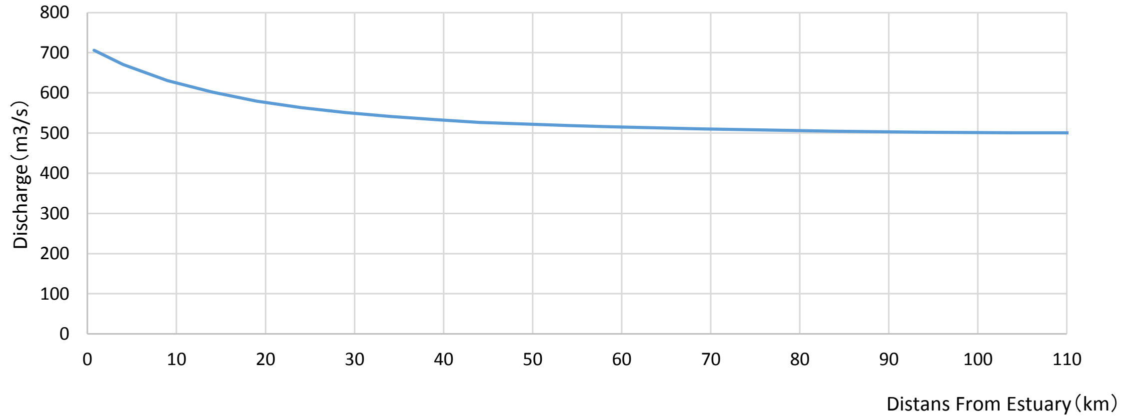
Besides, the slope of the water surface from the estuary to 50km farther is smaller than the slope in its upstream because of the effluence of the downstream water, according to the figure of longitudinal water level peak.





Source ：JICA study team

Figure 1.3.4 Longitudinal water level peak of Outer Ring Road Diversion



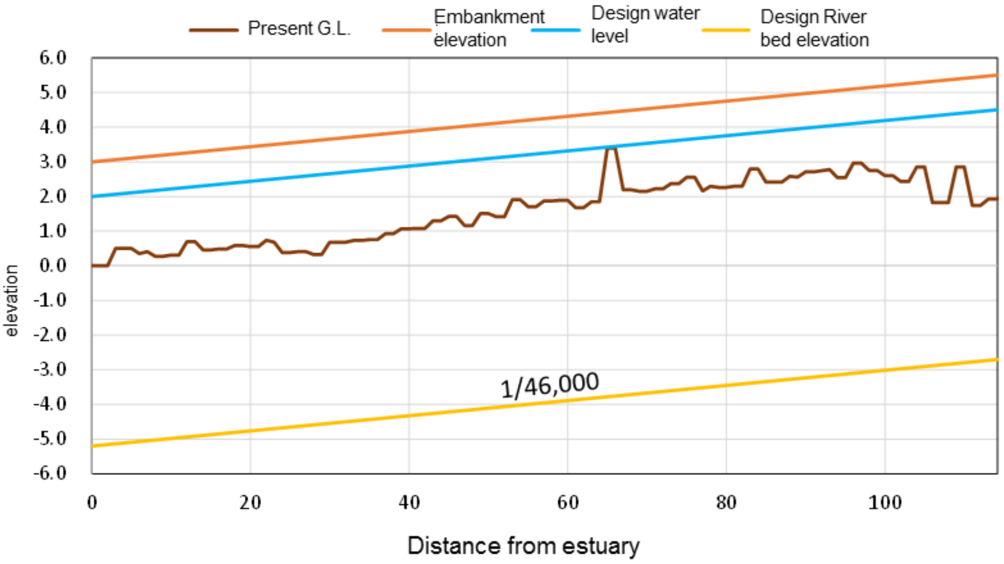
Source ：JICA study team

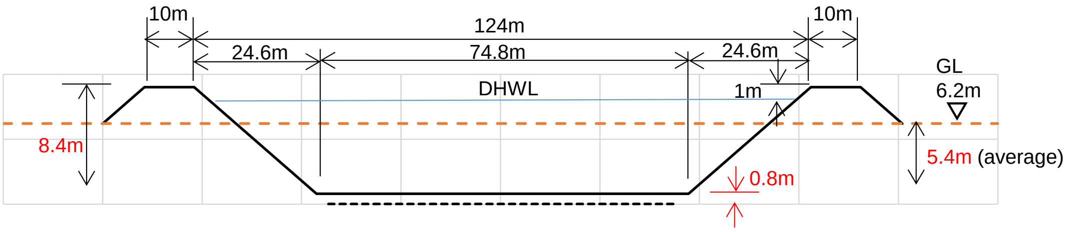
Figure 1.3.5 Longitudinal flow rate peak of Outer Ring Road Diversion

ii) Second setting

In the procedure of the second setting, the increase in the bottom height considers that the calculated water level will still be lower than DHWL even if the bottom of the channel is raised by a fixed height. The longitudinal water level peak before and after the modification of the river section is shown in Figure 1.3.6. Compared with Case1, the river bed elevation can be raised by 0.8m (Case4). Information about the channel after modification (second setting) is listed in Table 1.3.7.

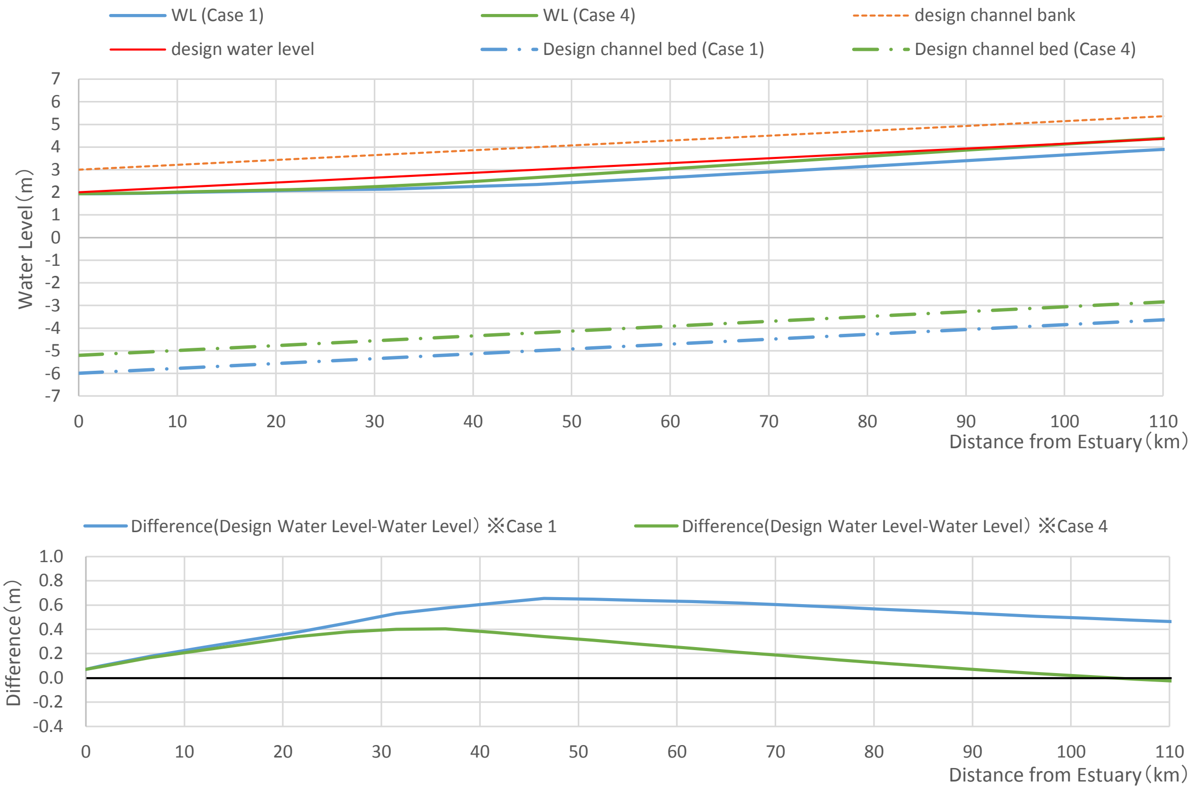
Table 1.3.7 Channel information after Second Setting

<table>
<tr><td></td><td>amendment：Maximal excavation(Case 4)</td></tr>
<tr><td>Longitudinal River section in setting</td><td>


<table>
<tr><th></th><th>Embankment
m</th><th>Designed water level
m</th><th>River bed elevation
M</th><th>Distance
km</th><th>River bed slope
m</th></tr>
<tr><td>Downstream</td><td>3.0</td><td>2.0</td><td>-5.2</td><td>0.0</td><td rowspan="2">1/46,600</td></tr>
<tr><td>Upstream</td><td>5.5</td><td>4.5</td><td>-2.7</td><td>116.5</td></tr>
</table>
</td></tr>
<tr><td>River Cross section in setting</td><td>


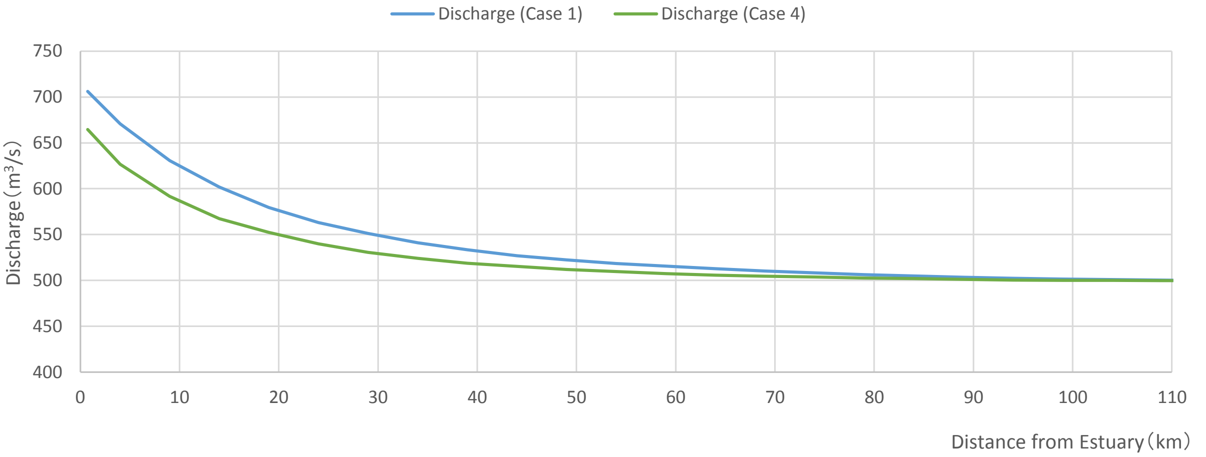
<table>
<tr><th>Target Q
m^3</th><th>Roughness</th><th>River bed slope
(1/IB)</th><th>Water depth
m</th><th>Width between embankments
m</th><th>River bed width
m</th><th>Section area
m^2</th><th>Minimum velocity
m/s</th><th>Maximum Velocity
m/s</th><th>Minimum Q
m^3</th><th>Maximum Q
m^3</th></tr>
<tr><td>500</td><td>0.025</td><td>46,600</td><td>7.2</td><td>124</td><td>74.8</td><td>694.08</td><td>0.23</td><td>1.38</td><td>153.7</td><td>664.5</td></tr>
</table>
</td></tr>
<tr><td>Soil volume</td><td>Total excavation(m^3)：58,791,722(approximately 6% increase)
Total embankment(m^3)：11,233,474(approximately 52% increase)
Remaining soil(m^3)：47,588,247(approximately 1% decrease)
※The comments in (　) means the ratio compared with MP</td></tr>
</table>

Source：JICA study team



Source ：JICA study team

Figure 1.3.6 Longitudinal water level peak of Outer Ring Road Diversion

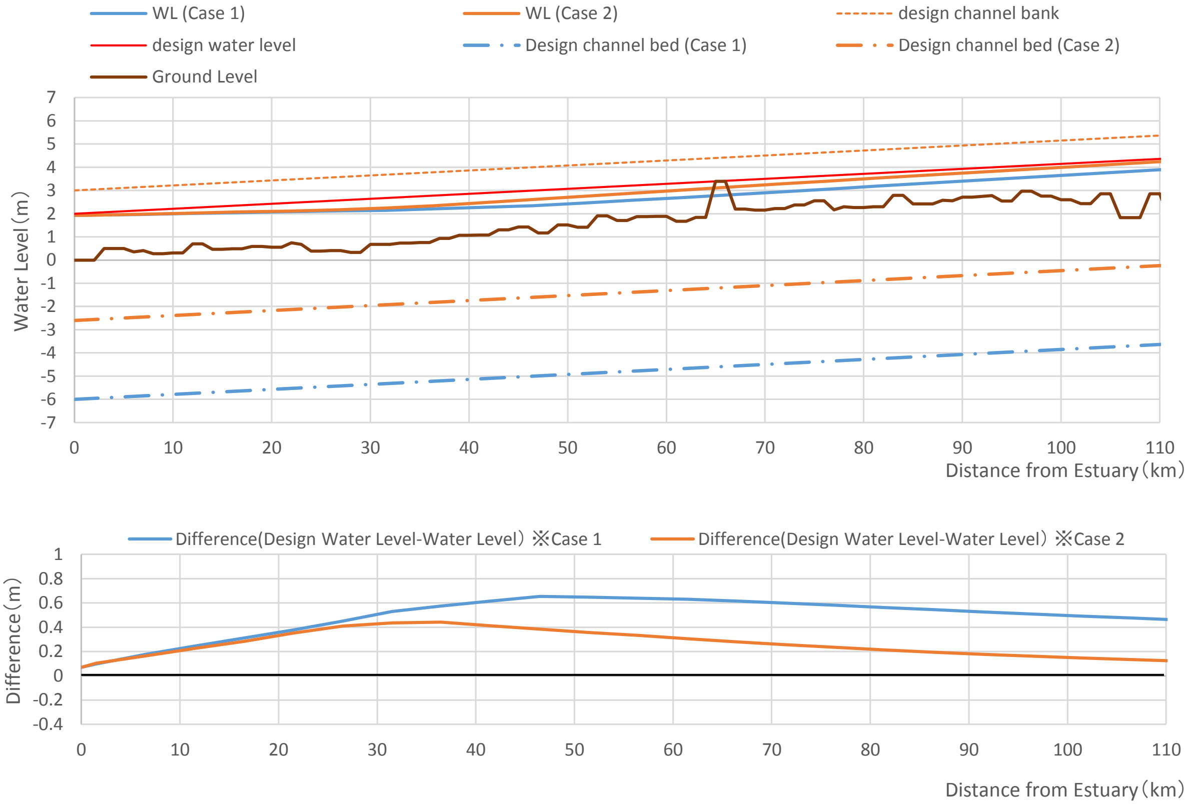


Source ：JICA study team

Figure 1.3.7 Longitudinal flow rate peak of Outer Ring Road Diversion

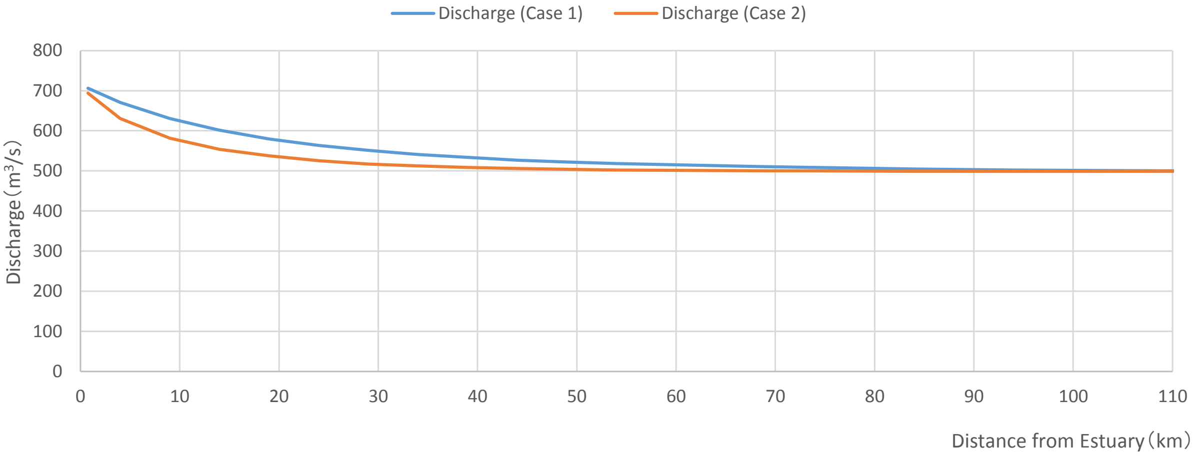
3) Calculate result of Maximal width expansion（designed width in case of 1000m^3/s)

Figure 1.3.8 shows the longitudinal water level peak, where the designed width in case of 1000m3/s in MP is assumed to be the standard width. Calculated water level at diversion point is only 0.065m lower than DWL, thus raising the bottom height is not considered.



Source ：JICA study team

Figure 1.3.8 Longitudinal water level peak of Outer Ring Road Diversion

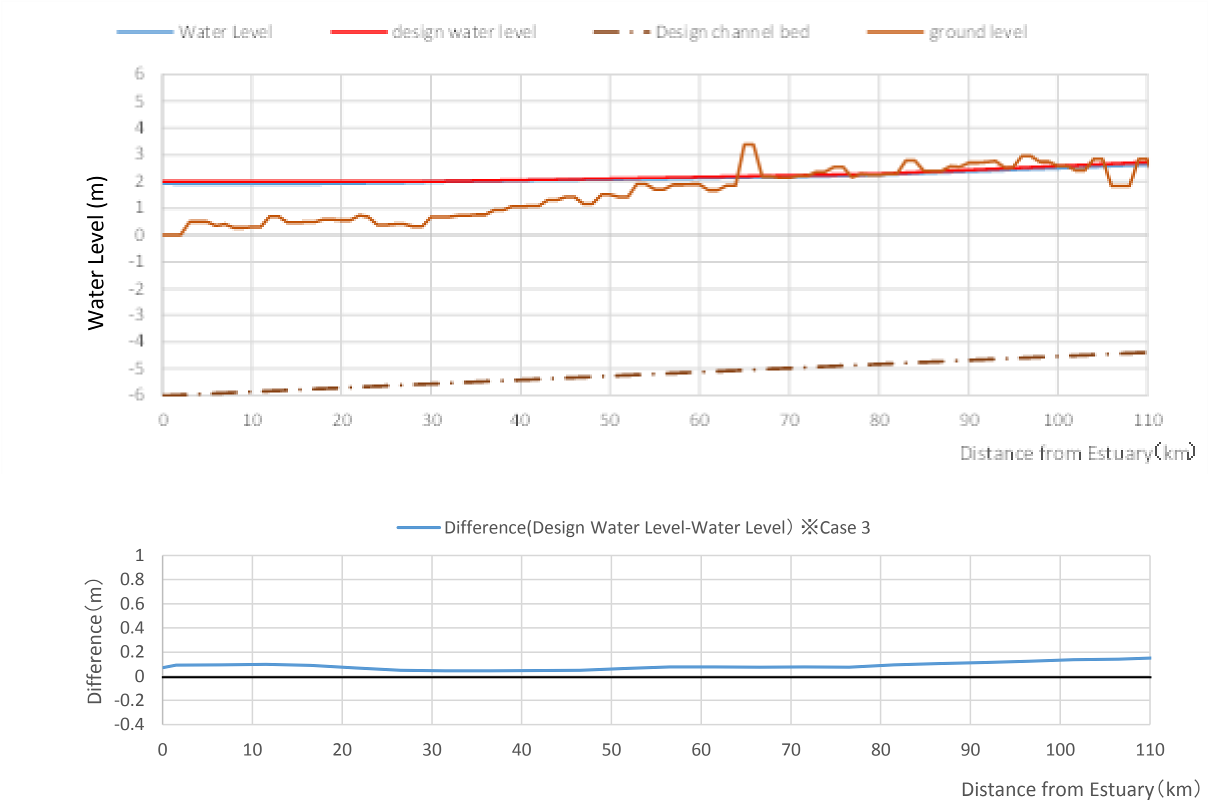


Source ：JICA study team

Figure 1.3.9 Longitudinal water level peak of Outer Ring Road Diversion

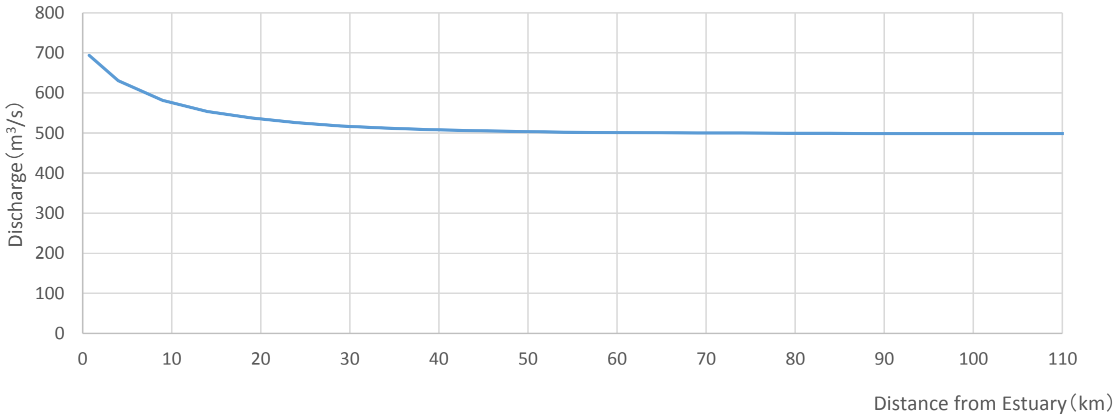
4) Calculate result of excavated river channel

Figure 1.3.10 shows the longitudinal water level peak for the case of the excavated river channel. At the point in the section of which the longitudinal distance is 30-50km, the water level is lower than DWL by 0.1m, which is small. Thus, further modification of the cross-section is not considered.



Source ：JICA study team

Figure 1.3.10 Longitudinal water level peak of Outer Ring Road Diversion



Source ：JICA study team

Figure 1.3.11 Longitudinal water level peak of Outer Ring Road Diversion

1.4 Discussion of river-mouth of the Outer Ring Road Diversion Channel

1.4.1 The points regarding study of river-mouth treatment

Considering the current situation of the river-mouth, the river-mouth treatment was studied in terms of:

- Sediment could occur in the diversion channel because of sand drift from off-island
- Excavation is needed to secure the discharge capacity off-island, which requires maintenance dredging
- Excessive maintenance operation is a challenge in terms of cost-effectiveness and maintenance

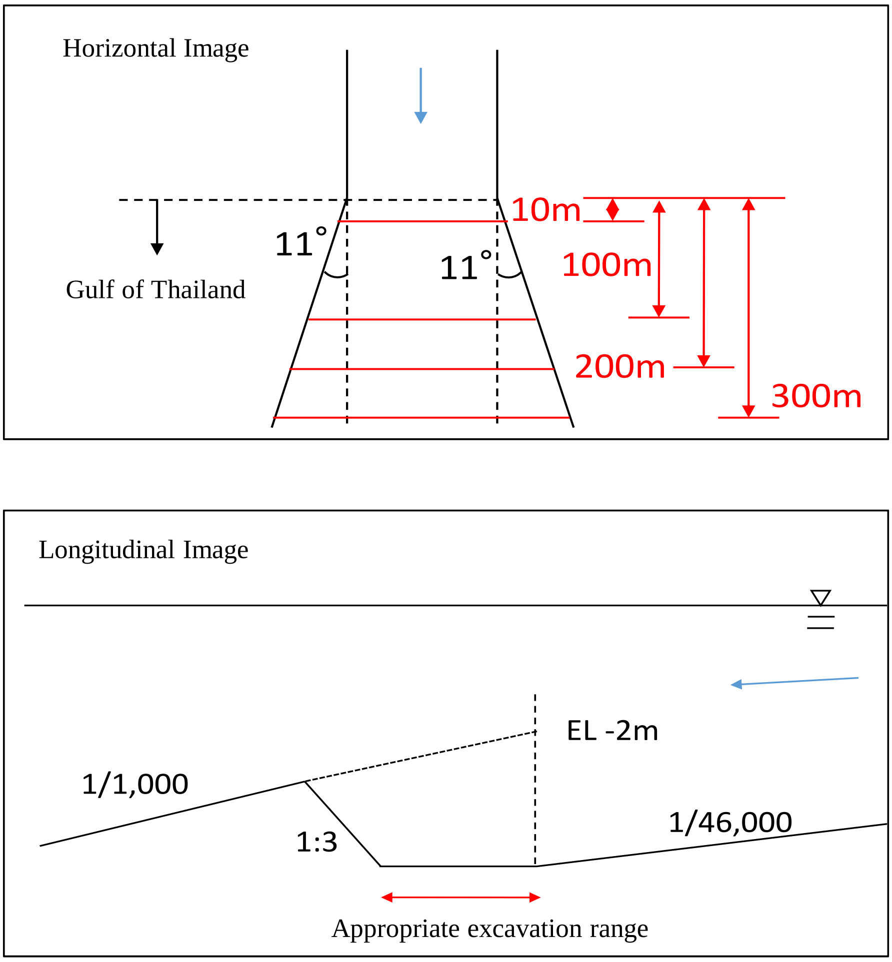
(1) Setting basic excavated shape considering sediment

River mouth treatment methods were compared after setting basic excavated shape (excavation range at offshore and river bed excavation height) considering sediment.

(2) Essential excavation range offshore

1) Excavation method

The excavation range of offshore direction is calculated by assuming a large increase in width with a taper of 11 degrees on each side slope to eliminate the impact on the diversion channel. See drawing below. Meanwhile the slope of the conversion part of the excavation from the channel to the sea floor is designed to be 1:3.



Source ：JICA study team

Figure 1.4.1 Image of excavation in offshore direction

2) Case for discussion

In Japan, there is the case that width of offshore excavation planned as broad as that of rivers (source: Minoru Chida "Planning of Small and Medium Rivers"). Since the width of surface of the diversion channel is approximately 120m, the study was conducted under the cases as follows:

- Toward the offshore: 10m, 100m, 200m, and 300m

3) Conditions in the discussion

- Calculation Range of channel : calculation domain is set to 500m off shore
- Downstream water level : Observed tide level at the point 500m off shore. (same as the condition for the Channel section calculation of the varying flow)
- Upstream flow rate : based on the hydrograph in the 500m3/s discharge case. (same as the condition for the Channel section calculation of varying flow)
- Roughness：same value as the Diversion Channel for extended part, n=0.025

4) Result

Figure 1.4.2 shows the comparison of the water levels calculated by the unsteady flow method, by excavation range in the offshore direction. It indicates that the impact to the diversion channel is negligible because excavation in the offshore direction has little impact on water level during the high-tide because of the large impact of the tides. Therefore, a longitudinal conversion from downstream of the channel to the sea floor is sufficient.

Source ：JICA study team

Figure 1.4.2 Water level calculated by unsteady flow calculation by excavation range in offshore direction

(3) Modification of excavation elevation of estuary

The deeper the excavation of estuary is, the easier it will be for recurrence of sand and silt deposits around the estuary, and the demand for operation maintenance increases. Therefore, the following cases are discussed regarding shallow excavation of the estuary without raising the river bed over the DWL.

1) Excavation method

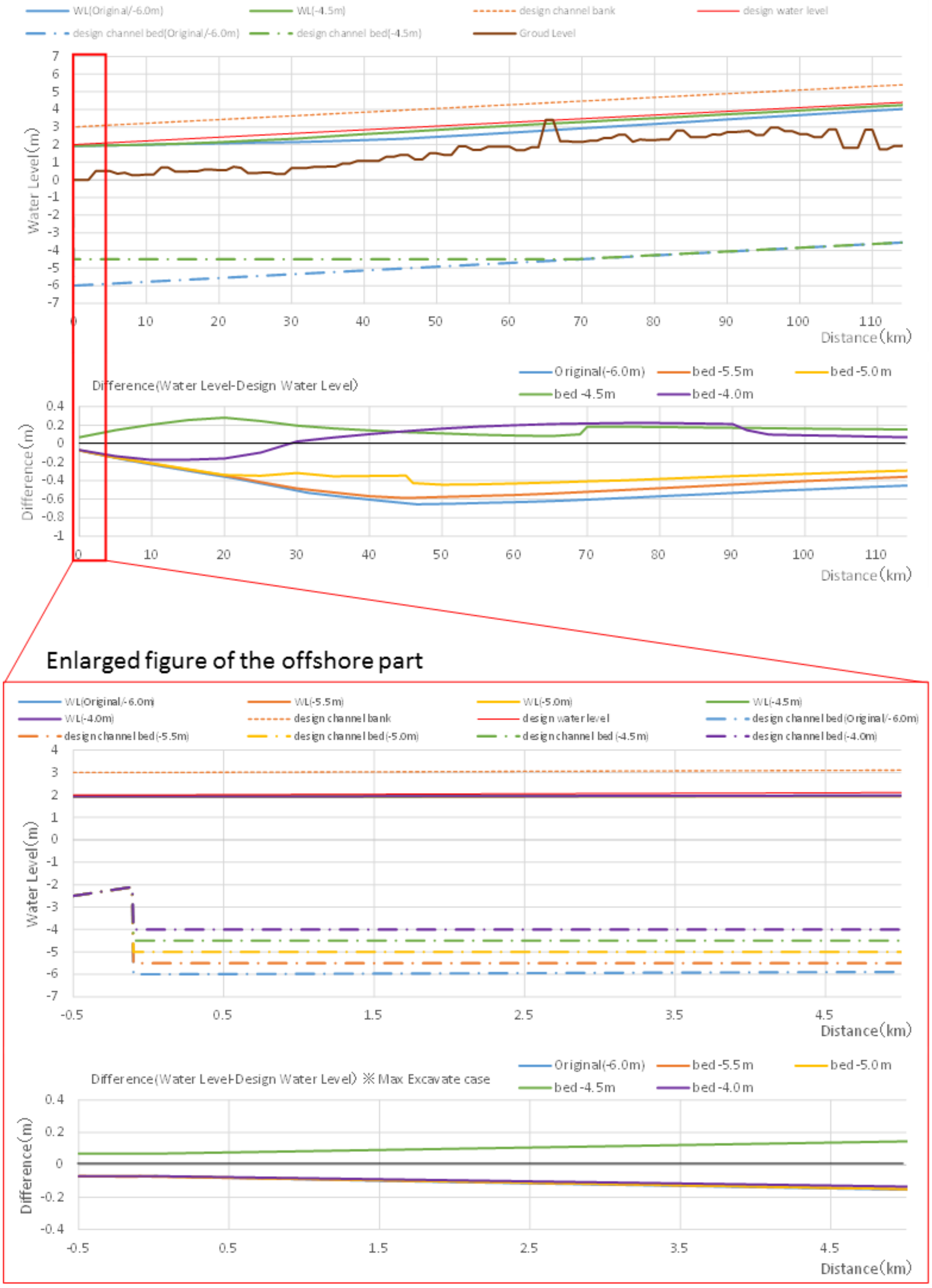
Set the river bed elevation around river mouth as high as possible in the range from EL-6m to EL-4m. At this condition, the water level of the Diversion Channel must not over DHWL

2) Discussion condition

Basic conditions follow the discussion of excavation range, while the limit of excavation in the offshore direction is assumed to be 100m.

3) Result

According to the calculation result of varying flow, it is possible to raise the water level of the river bed of the Diversion Channel to EL-4.5m but no further because DWL will be exceeded if elevating it higher than EL-4.0m.



Source : JICA study team

Figure 1.4.3 Water level calculated by unsteady flow calculation by excavation height

1.4.2 Comparison of river-mouth treatment

Table 1.4.1 shows assumed plans of river-mouth treatment, which include a: Excavation, b: Pumps, c: Gates.

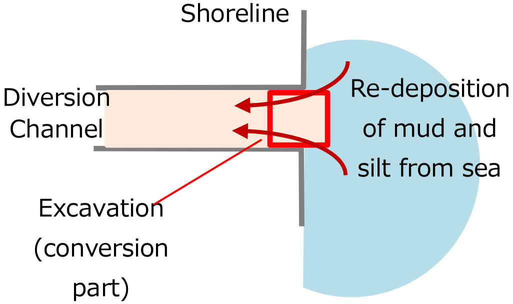
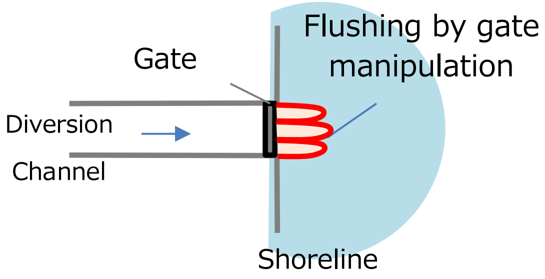
	a. excavation	b. setting pumps	c. setting gate
Concept	Excavation in essential range	Discharge flood water by pumps as Airport Diversion Channel. No need for excavation offshore and prevents re-deposition of sand and silt from offshore	By setting a gate at the estuary to prevent the re-deposition of sand and silt from offshore
Image			
Advantages	Least expensive initial cost ※however, an independent gate is necessary, which is possibly the same scale as alternative c.	Re-deposition of sand is unlikely to happen since excavation is not deeper than present elevation of the estuary	・prevent re-deposition of sand at the estuary ・Sand re-deposition offshore may be prevented by gate manipulation to a certain degree
Disadvantages	・Regular dredging is necessary	・cost is high due to the scale and lift head of the pumps	・dredging of offshore area is necessary
Main initial cost	・excavation (Diversion Channel、offshore)	・excavation(Diversion Channel) ・Pumping Station ・elevated channel ※calculated by referring to cost of Airport Diversion Channel Project	・excavation (Diversion Channel、offshore) ・gate
Operation maintenance	・dredging (Diversion Channel、offshore)	・operation cost of pumps ・renewal of equipment	・dredging(offshore) ※dredging scale can be reduced by gate manipulation ・renewal of gate equipment

Table 1.4.1 Alternatives for estuary of Diversion Channel

Source : JICA study team

1.5 Methodology of diverting the flow of the river into the Outer Ring Road Diversion Channel

1.5.1 Calculation method

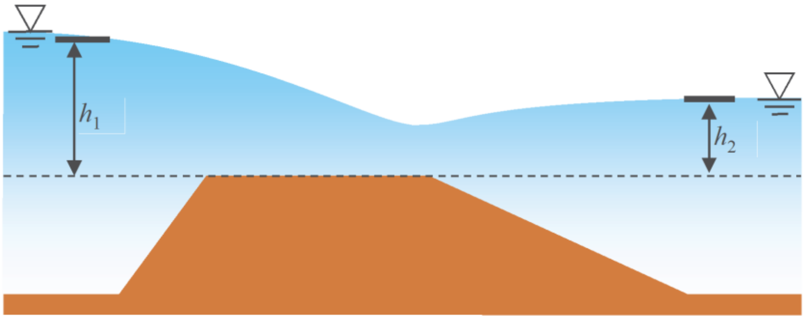
"Frontal overflow formula by Honma" is used for overflow calculation. Lateral flow loss is not considered according to "formula by Kuriki et al." because the river bed slope of Chao Phraya River at the diversion point is approximately 1/50000, although the overflow is a lateral overflow.

i. Front overflow formula (Frontal overflow formula by Honma)

Perfect overflow ($h_2/h_1 < 2/3$) : $Q_0 = 0.35Bh_1\sqrt{2gh_1}$

Submerged overflow ($h_2/h_1 \geqq 2/3$) : $Q_0 = 0.91Bh_2\sqrt{2g(h_1 - h_2)}$

※h_1 and h_2 are depths over the top of the weir, and $h_1 > h_2$. B is width of overflow.

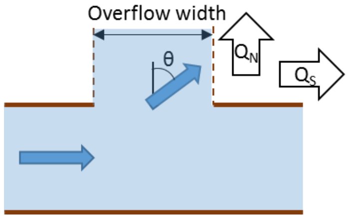


Source : JICA study team

Figure 1.5.1 Relationship between h1 and h2

ii. Lateral overflow formula (by Kuriki et al.)

iii. The formula by Honma is modified as the lateral overflow formula.



$$Q_N = \alpha Q_0 \cos\theta \qquad Q_S = \alpha Q_0 \sin\theta$$

Where, QN、QS is the overflow rate in normal and tangent line direction; and Q0 is the frontal overflow rate of Honma formula. The target of this discussion is the submerged overflow, thus the following formula by Honma is utilized.

Lateral overflow rate is formulated by modifying the overflow rate Q0, the frontal overflow of the formula by Honma, with a vectorial angle θ and a correction coefficient α. The vectorial angle and correction coefficient are determined by River bed slope I as follow.

- I ＞ 1/1,580 : $\alpha = 0.14 + 0.19\log_{10}(1/I), \theta = 48 - 15\log_{10}(1/I)$
- 1/1,580 ≧ I ＞ 1/33,600 : $\alpha = 0.14 + 0.19\log_{10}(1/I), \theta = 0$
- 1/33,600 ≧ I : $\alpha = 1, \theta = 0$

1.5.2 Cases and conditions for discussion

Discussion cases include fixed weir and gate considering the concepts as follows:

- Fixed weir: The height of the weir which can reduce the frequency of the flowing into the diversion channel as much possible. (320m, which secures the longest overflow bank as possible)
- Gate: Minimum necessary river width considering the lateral flow

Cases and calculation conditions are listed in Table 1.5.1.

Table 1.5.1 Calculation condition

		Fixed weir	**Gate**
Flow rate(m^3/s)		500	
Overflow weir length (m)		320 (maximal possible overflow width)	Minimal width by overflow calculation
Water level	River	EL+4.5m(DHWL)	
	Diversion channel	EL+4.4m (water level in varying flow calculation)	
Weir height		Maximal height by overflow calculation	0.05 (assumption, otherwise impossible to execute calculation)

Source ：JICA Study Team

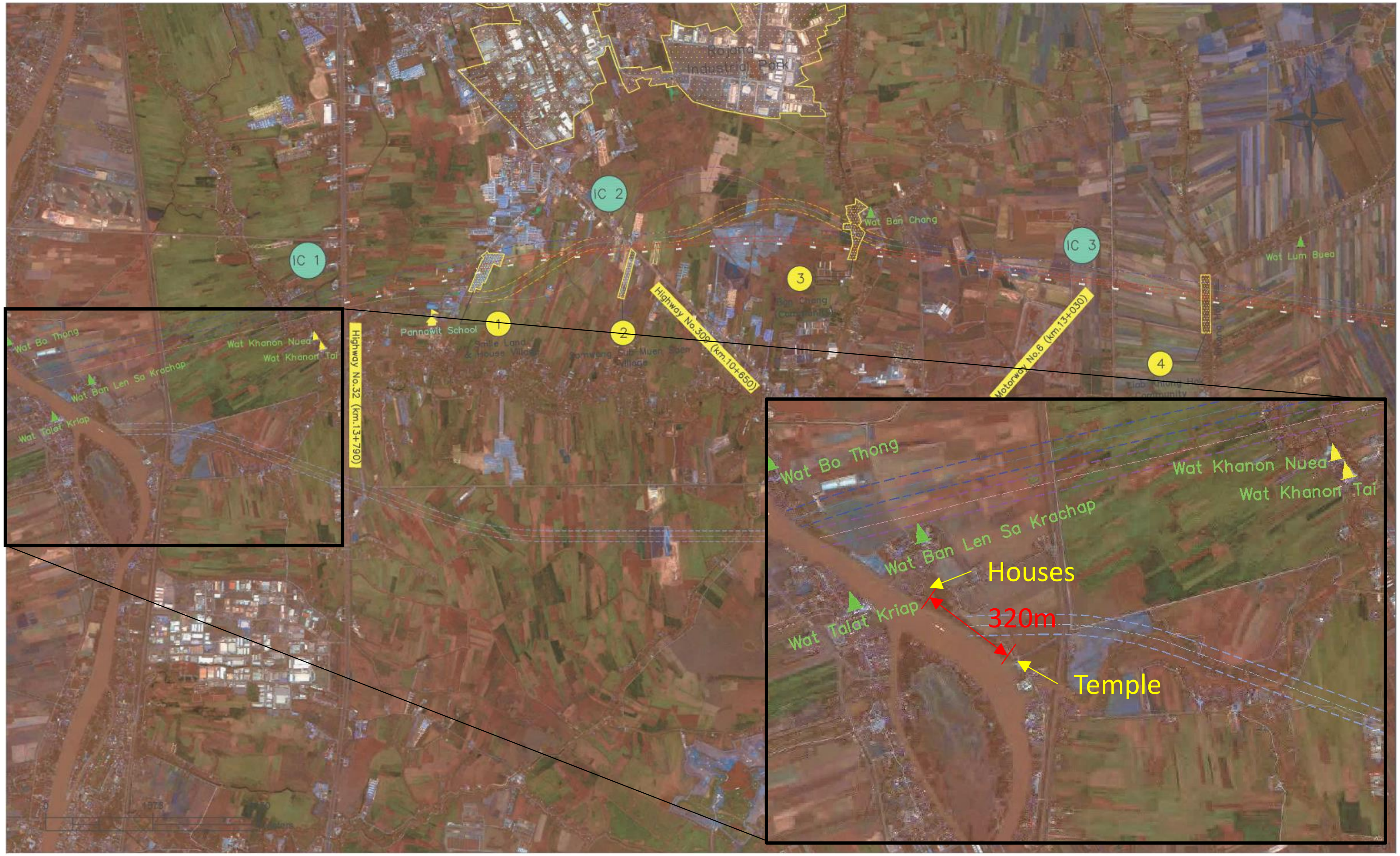


Figure 1.5.2 Local situation at Outer ring road diversion Channel

1.5.3 Results

(1) Fixed weir

Figure 1.5.3 shows the numerical result under the condition that the width of the fixed weir is set to 320m this figure demonstrates the height of the fixed weir is about EL+3.1m under the condition of overflow at 500m^3/s. Figure 1.5.4 shows the comparison of the height of the fixed weir (EL+3.1m) and each probable scale water level. This figure shows that the Inflow frequency from Chao Phraya River to the Outer ring road diversion Channel is about 1/3.

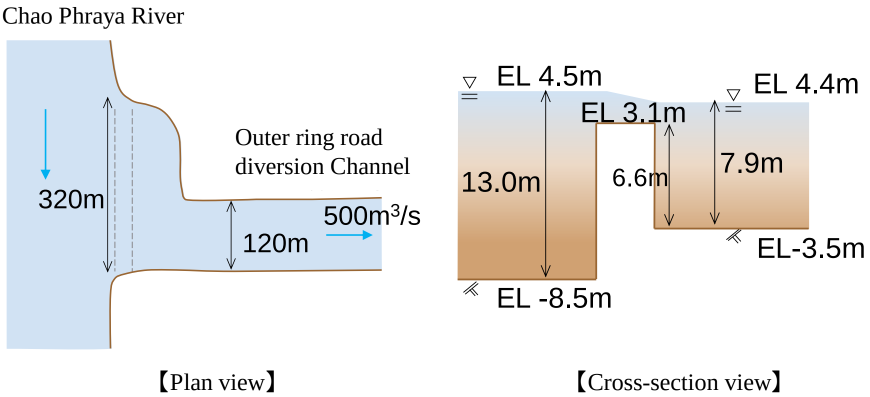


Figure 1.5.3 Result of the Overflow calculation with the fixed weir

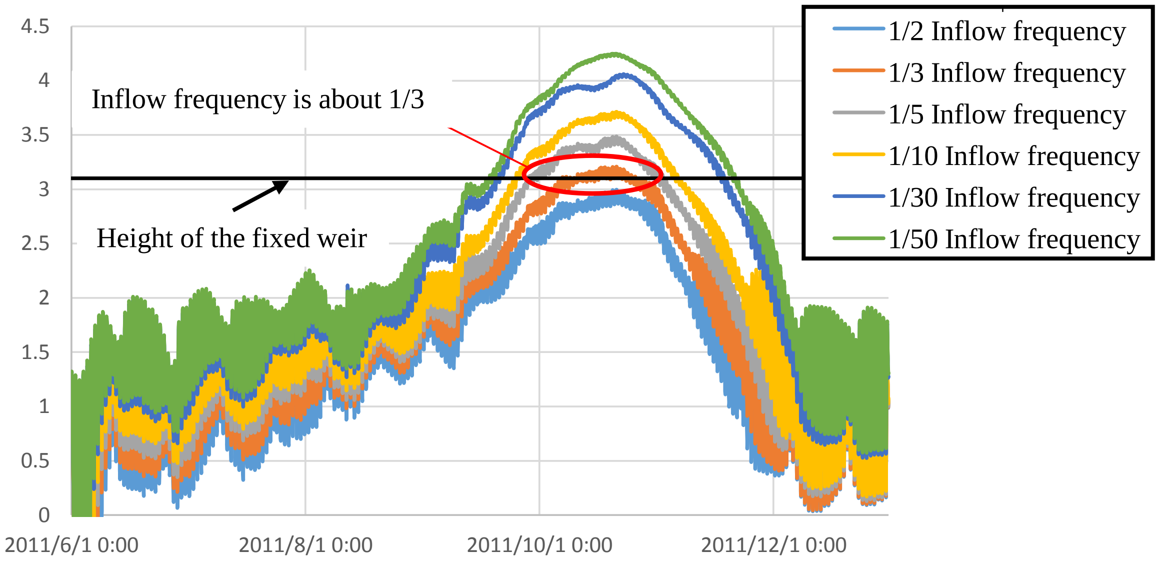


Figure 1.5.4 Hydrograph of the water elevation of Chao Phraya River at flow diversion point

(2) Gate

It is concluded that the width of the gate is about 50m in the Overflow calculation. Therefore the width of the gate is set to 120m the same as the width of the Outer ring road diversion channel.

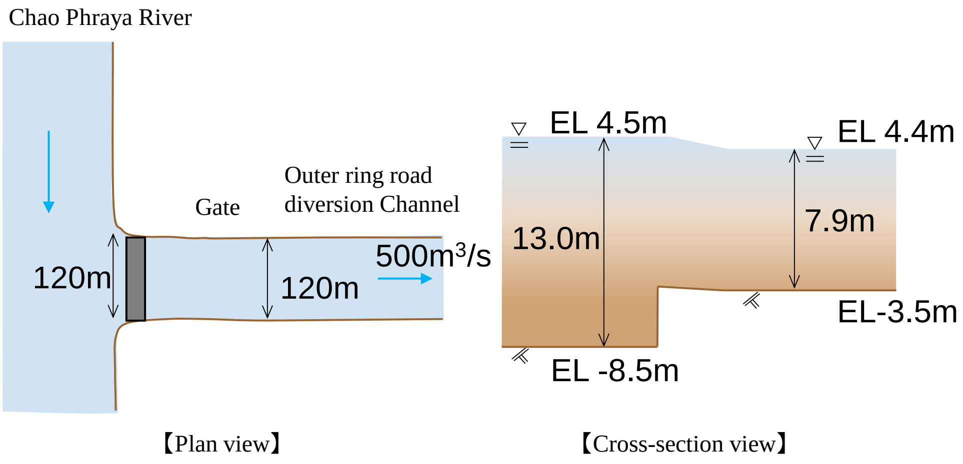


Figure 1.5.5 Result of the Overflow calculation with the gate

(3) Approximate way of the overflow into the Outer ring road channel

The fixed weir needs 320m width under the condition of 1/3 Inflow frequency. Therefore, the gate is better than the fixed weir because the gate can flexibly manage the inflow volume and frequency in normal conditions.

CHAPTER 2 ALIGNMENT OF THE DIVERSION CHANNEL

2.1 Basic Policy for Studying Alignment

The Outer Ring Road (East) is 97 km long running through Ayuttaya Province and Pathum-Thani Province, and finally connecting with The Outer Ring Road (South).

The Outer Ring Road (East) is located about 15 km outside The 2nd Outer Ring Road.

The Outer Ring Road Diversion Channel is planned along with the Outer Ring Road (East), from Ayuttaya to the Gulf of Thailand with a total distance of 110 km. JICA designed the alignment with full attention and respect to DOH’s plan of The Outer Ring Road (East).

The F/S (Feasibility Study) of the Outer Ring Road（East）was finished in August 2009. The road width is 100 m with three main lanes (70 m) and two service roads on both sides (15 m).

Basic policies to study alignment of the diversion channel are considered below.

Function of the diversion channel

- The Outer Ring Road combined Diversion Channel is the most important component of the JICA supported “Comprehensive Flood Management Plan for the Chao Phraya River Basin” of 2013 which carefully considered the balance between mid & upstream agriculture areas and downstream urban areas.
- Design discharge of the Channel capacity is 500 m^3/s and the Channel runs the shortest and smoothest way through the eastern area.
- Intake from the Chao Phraya River is set downstream of Ayutthaya.

Environmental and Social Considerations

- To avoid sensitive and immovable facilities (temple, mosque, hospital, school, etc.)
- To minimize number of relocations (house, factory, etc.)

Project Efficiency

- For prompt realization of the effect, the Outer Ring Road (East) and the Diversion Channel should be constructed through a combined project.

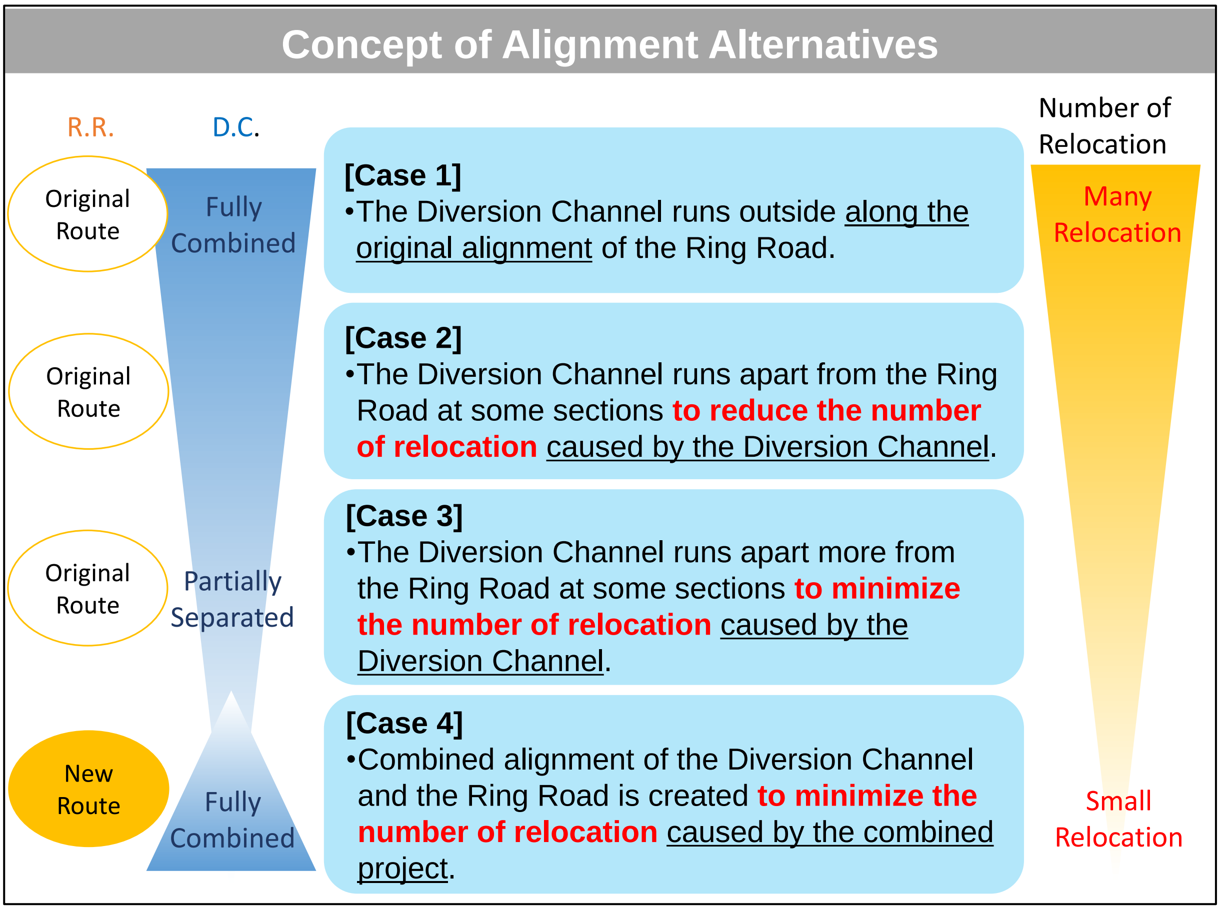
2.2 Concept of Alignment Alternatives

In this comparative study, outlines of the 4 cases of alignment are as below. Details of each case are described in the next pages.

- In the Case 1, the Diversion Channel runs outside along the original alignment of the Ring Road. But the number of relocations may be large, and there are some immovable facilities.
- In the Case 2, the Diversion Channel runs 3~5 km away from the Ring Road at some sections to reduce the number of relocations caused by the Diversion Channel in order to keep the balance

between hydraulic function, structural function and environmental & social impact.

- In the Case 3, the Diversion Channel runs further away from the Ring Road at some sections to minimize the number of relocations caused by the Diversion Channel. However, it may be necessary to review the possibility of integrated construction.
- In the Case 4, combined alignment of the Diversion Channel and the Ring Road is created to minimize the number of relocations caused by the combined project. However, a F/S of the Road and EIA may have to be reviewed.


Concept of Alignment Alternatives

[Case 1]
•The Diversion Channel runs outside along the original alignment of the Ring Road.

[Case 2]
•The Diversion Channel runs apart from the Ring Road at some sections **to reduce the number of relocation** caused by the Diversion Channel.

[Case 3]
•The Diversion Channel runs apart more from the Ring Road at some sections **to minimize the number of relocation** caused by the Diversion Channel.

[Case 4]
•Combined alignment of the Diversion Channel and the Ring Road is created **to minimize the number of relocation** caused by the combined project.

Source: JICA Study Team

Figure 2.2.1 Concept of comparison cases for Diversion Channel

In this study, RID’s project evaluation aspects such as “Engineering”, “Social Impact”, “Environmental Impact” and “Cost & Benefit” are applied to compare the alignment alternatives. By judging the most appropriate alignment in a comprehensive manner, the Case 2 alignment is selected based on each sub-total score of the respective alignment alternatives.

Contents of consideration of each case are described from the next page.

2.3 Evaluation Aspects of Alignment Alternatives

In this comparative study, the evaluation of alignment alternatives are as below.

Table 2.3.1 Evaluation items for Diversion Channel

Evaluation Aspects	Evaluation Items		Description
Engineering	Channel Length (D. C.)		Length of the Diversion Channel
	Road Length (R. R.)		Length of the Ring Road
	Structural Condition		Length of soft clay zone (Structural countermeasures are necessary)
	Hydraulic Condition (D. C.)		Efficiency of the flow of the Diversion Channel
Social Impact	Relocation (House)		Number of possibly relocated houses due to the construction
	Relocation (Factory)		Number of possibly relocated factories due to the construction
Environmental Impact	Environmental Impact**		Environmental Impact caused by the Diversion Channel and the Ring Road.
Cost and Benefit	Total Cost	Land Cost* (D.C. + R.R.)	Land acquisition cost for the Diversion Channel and the Ring Road
		Construction Cost (D.C.)	Construction cost for the Diversion Channel
		Construction Cost (R.R.)	Construction cost for the Ring Road
	Benefit**		Benefit to be provided from the Diversion Channel and the Ring Road.

<Rating Index>
A: Very Good
B: Good
C: Fair

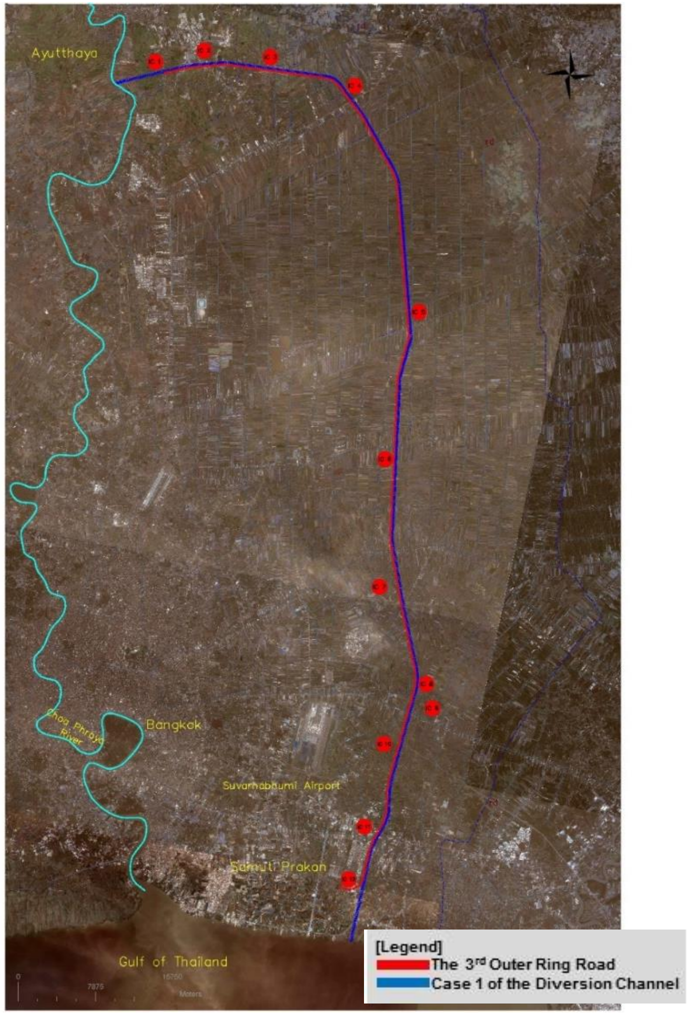
*Note: Relocation cost is not included.

**Note: “Environmental Impact” and “Benefit” are going to be surveyed from July 2017. However, the result is expected to be almost the same in the 4 cases.

Source: Prepared by JICA Study Team based on internal regulation of RID

(1) Case 1

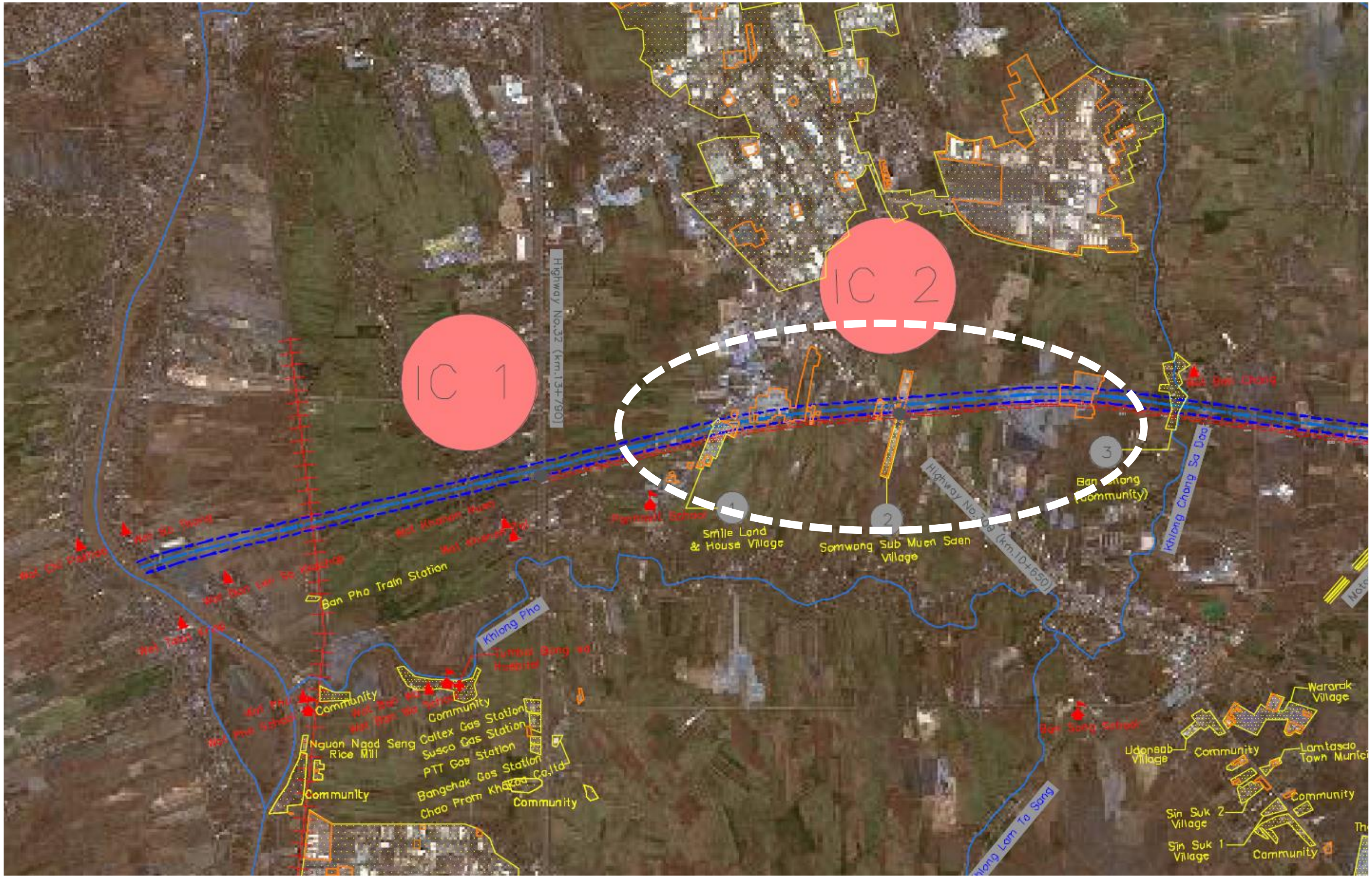
Table 2.3.2 Evaluation of contents of Case 1

<table>
<tr><td rowspan="9">
</td><td colspan="4">◆ The Channel (expected width 160 m) runs side by side outside the Road (expected width 100 m).</td></tr>
<tr><td colspan="2">◆ Channel Length (km)</td><td>114</td><td>B</td></tr>
<tr><td colspan="2">◆ Road Length (km)</td><td>97</td><td>A</td></tr>
<tr><td colspan="3">◆ Structural Condition
・ Length of soft clay zone: 44 km (see “Soil Classification Chart” hereinafter)
・ (Basic design of ICs needs to be changed at all 11 sites).</td><td>A</td></tr>
<tr><td colspan="3">◆ Hydraulic Condition of the Channel
・ From diversion point to north part, securing vertical gradient of the Channel may be difficult.</td><td>B</td></tr>
<tr><td colspan="3">◆ Number of Relocations</td><td rowspan="3">C</td></tr>
<tr><td>・ House</td><td>Many</td><td>(100)*</td></tr>
<tr><td>・ Factory</td><td>Many</td><td>(100)*</td></tr>
<tr><td colspan="3">◆ Environmental Impact</td><td>-</td></tr>
<tr><td></td><td>◆ Land Cost</td><td>Moderate</td><td>(100)*</td><td>B</td></tr>
</table>

*Note: Benchmark index number for comparison

Source: JICA Study Team

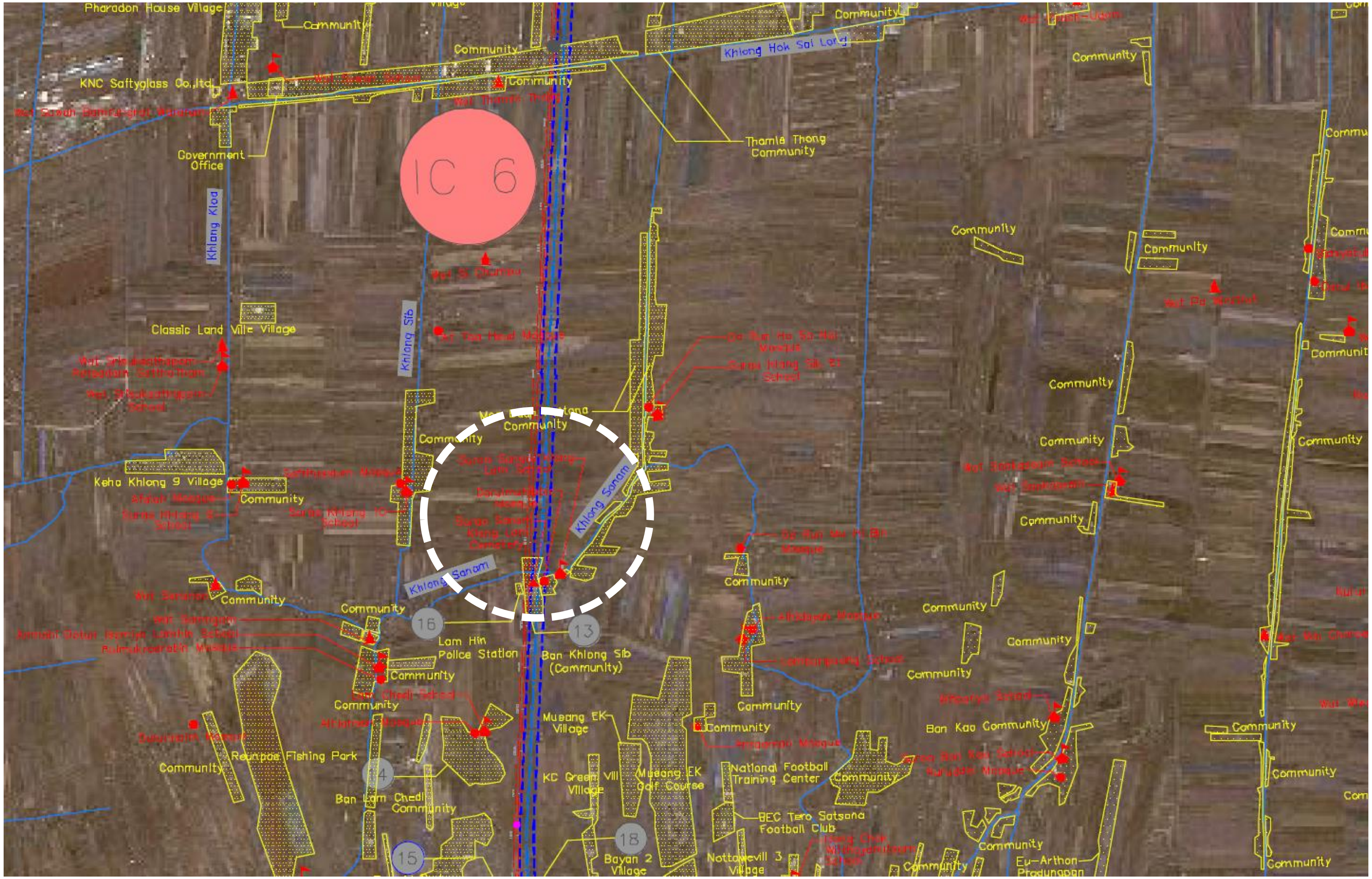
For the Case 1, the number of relocations could become large around IC1 and IC2. And some sensitive facilities could not be passed by.



Source: JICA Study Team

Figure 2.3.1 Alignment of Case 1 (around IC1 and IC2)

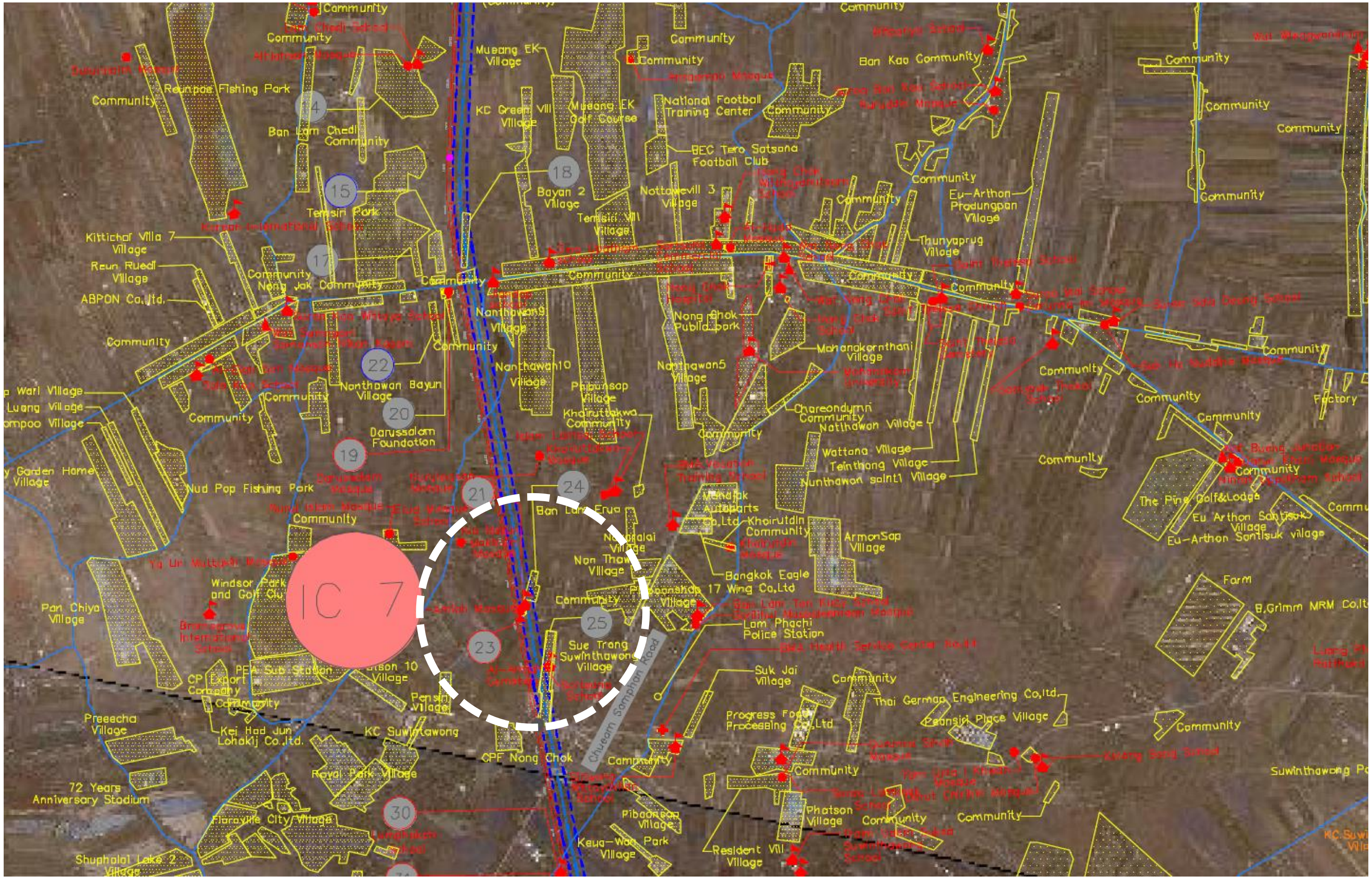
For the Case 1, number of relocations could become large around IC6. And some sensitive facilities could not be passed by.



Source: JICA Study Team

Figure 2.3.2 Alignment of Case 1 (around IC6)

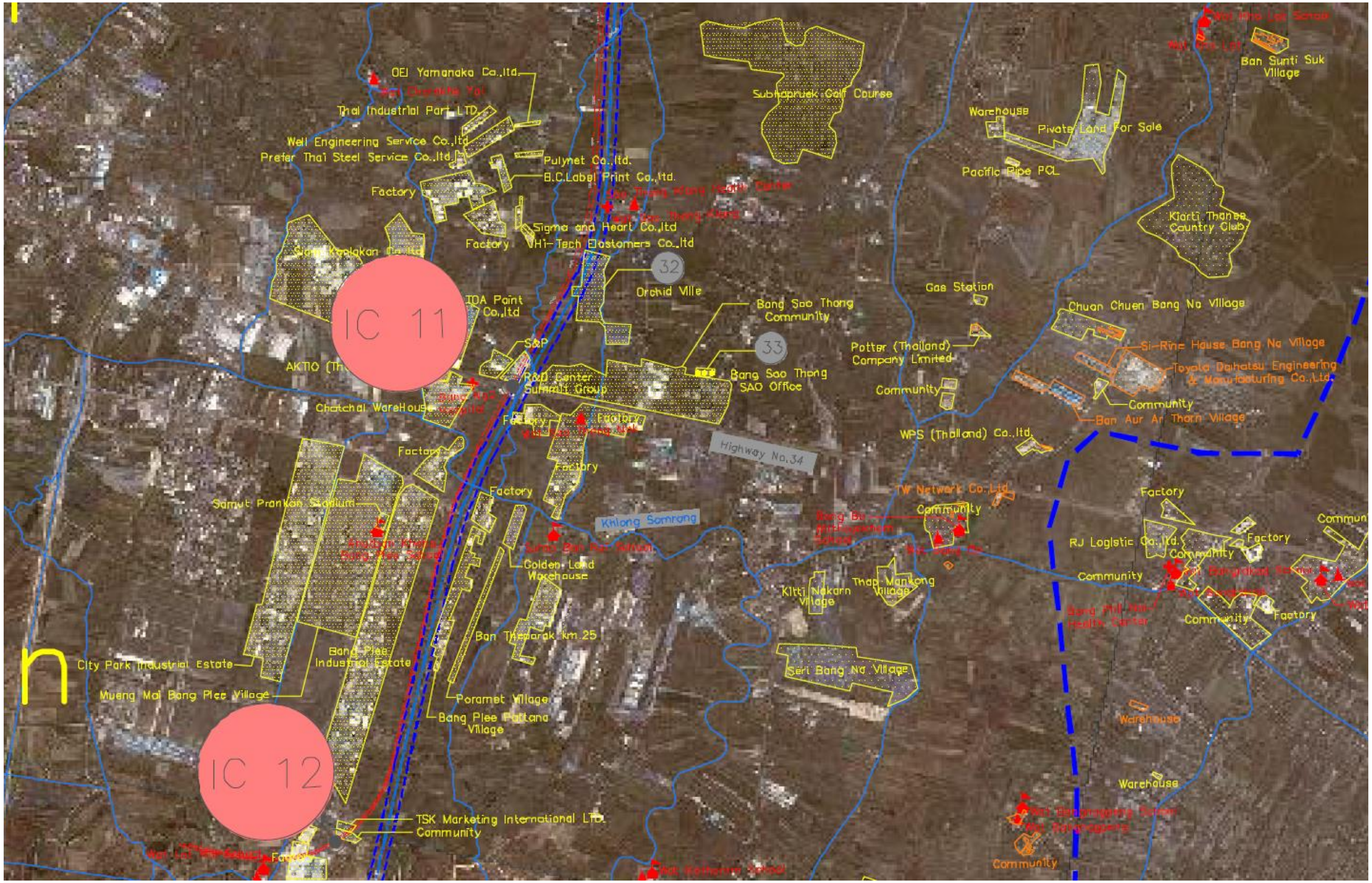
For the Case 1, number of relocations could become large around IC7. And some sensitive facilities could not be passed by.



Source: JICA Study Team

Figure 2.3.3 Alignment of Case 1 (around IC7)

For the Case 1, number of relocations could become large around IC11. However, sensitive facilities could be passed by.

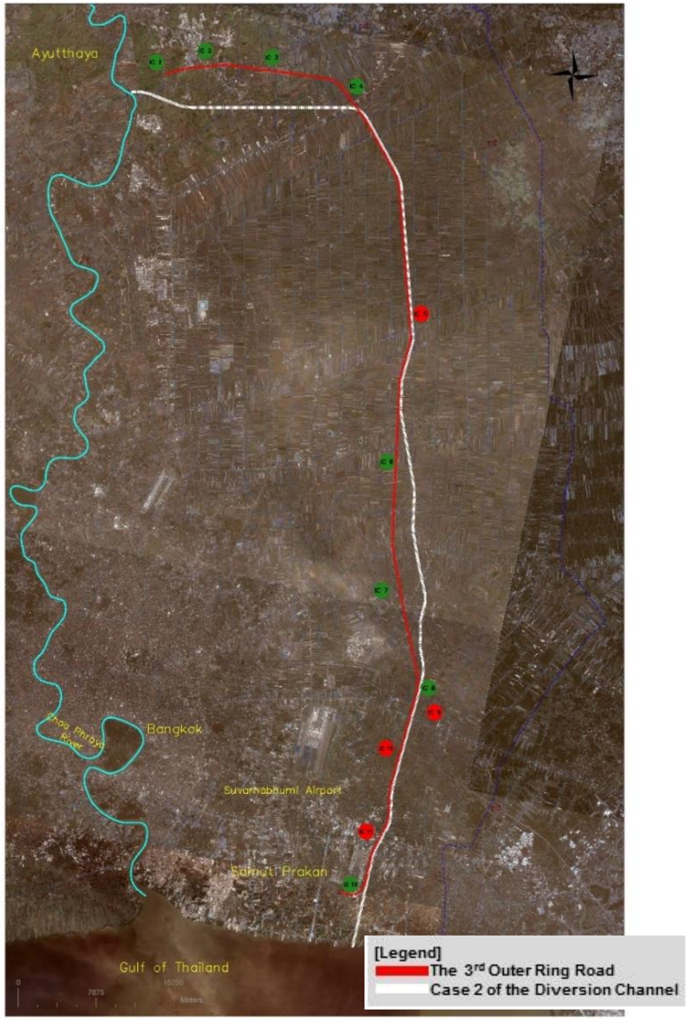


Source: JICA Study Team

Figure 2.3.4 Alignment of Case 1 (around IC11)

(2) Case 2

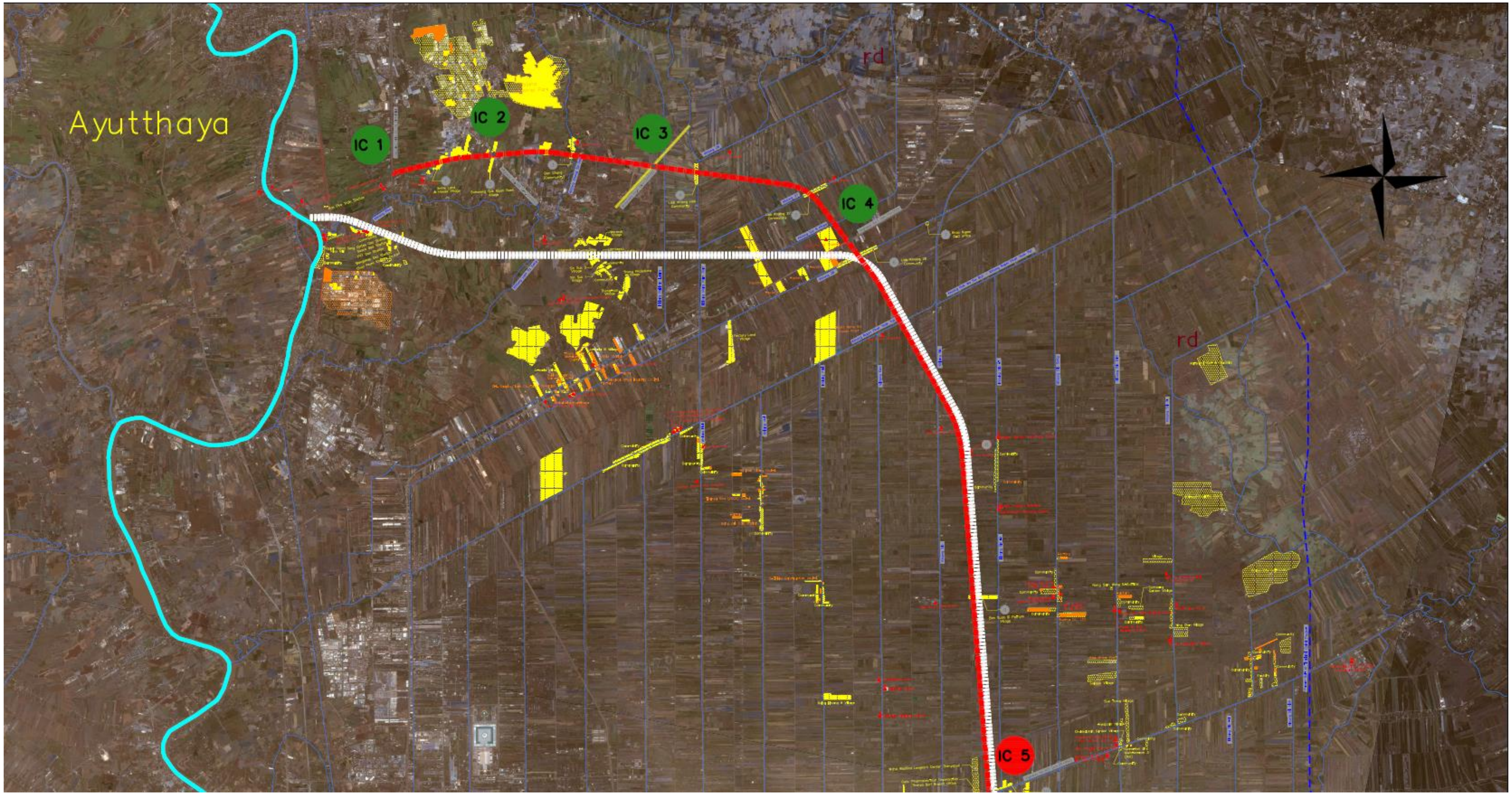
Table 2.3.3 Evaluation of contents of Case 2

<table>
<tr><td rowspan="10">
</td><td colspan="4">From the diversion point to IC4, the Channel is set apart on the south side of the Road by about 5 km.
From IC6 to IC7, the Channel is set apart on the east side of the Road by about 3km to avoid temples and newly developed residences.</td></tr>
<tr><td colspan="2">◆ Channel Length (km)</td><td>111</td><td>A</td></tr>
<tr><td colspan="2">◆ Road Length (km)</td><td>97</td><td>A</td></tr>
<tr><td colspan="3">◆ Structural Condition
・ Length of soft clay zone: 43 km (see “Soil Classification Chart” hereinafter)
・ (Number of design changes of ICs is reduced from 11 sites to 4 sites (IC5, 9, 10, 11)).</td><td>A</td></tr>
<tr><td colspan="3">◆ Hydraulic Condition of the Channel
・ Hydraulically smooth alignment is secured (straight line & gentle curve).</td><td>A</td></tr>
<tr><td colspan="3">◆ Number of Relocations
・ Narrow & isolated areas are not generated between the Channel and the Road.</td><td rowspan="3">B</td></tr>
<tr><td>・ House</td><td>Moderate</td><td>(60)*</td></tr>
<tr><td>・ Factory</td><td>Moderate</td><td>(71)*</td></tr>
<tr><td colspan="3">◆ Environmental Impact</td><td>-</td></tr>
<tr><td>◆ Land Cost</td><td>Low</td><td>(99)*</td><td>A</td></tr>
</table>

*Note: Index number compared to Case 1

Source: JICA Study Team

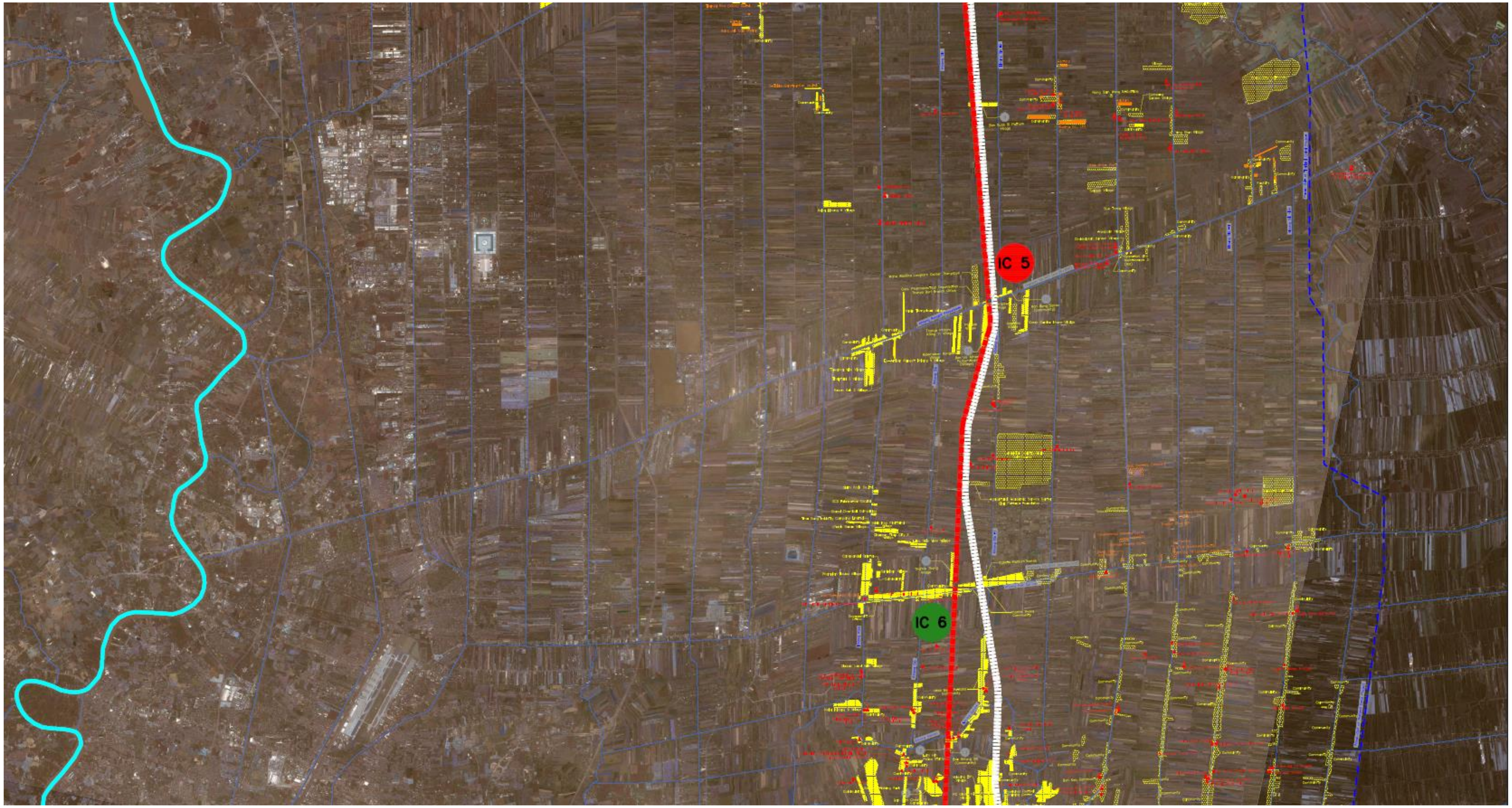
For the Case 2, the number of relocations could become small around IC1 and IC2. And some sensitive facilities could be passed by.



Source: JICA Study Team

Figure 2.3.5 Alignment of Case 2 (from IC1 to IC5)

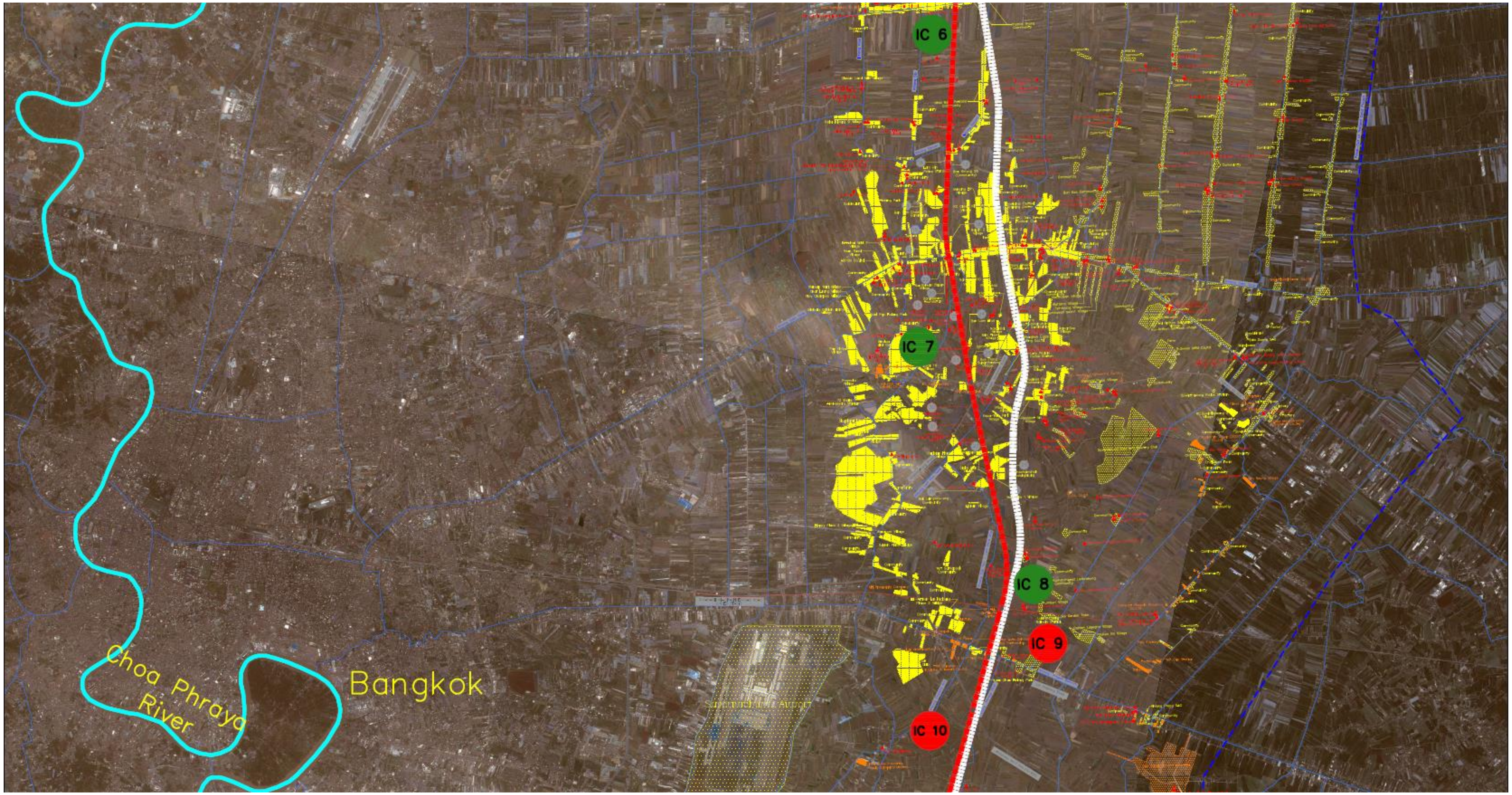
For the Case 2, in order to reduce the number of relocations around IC6, the alignment of the diversion channel is shifted to the east side.



Source: JICA Study Team

Figure 2.3.6 Alignment of Case 2 (around IC5 and IC6)

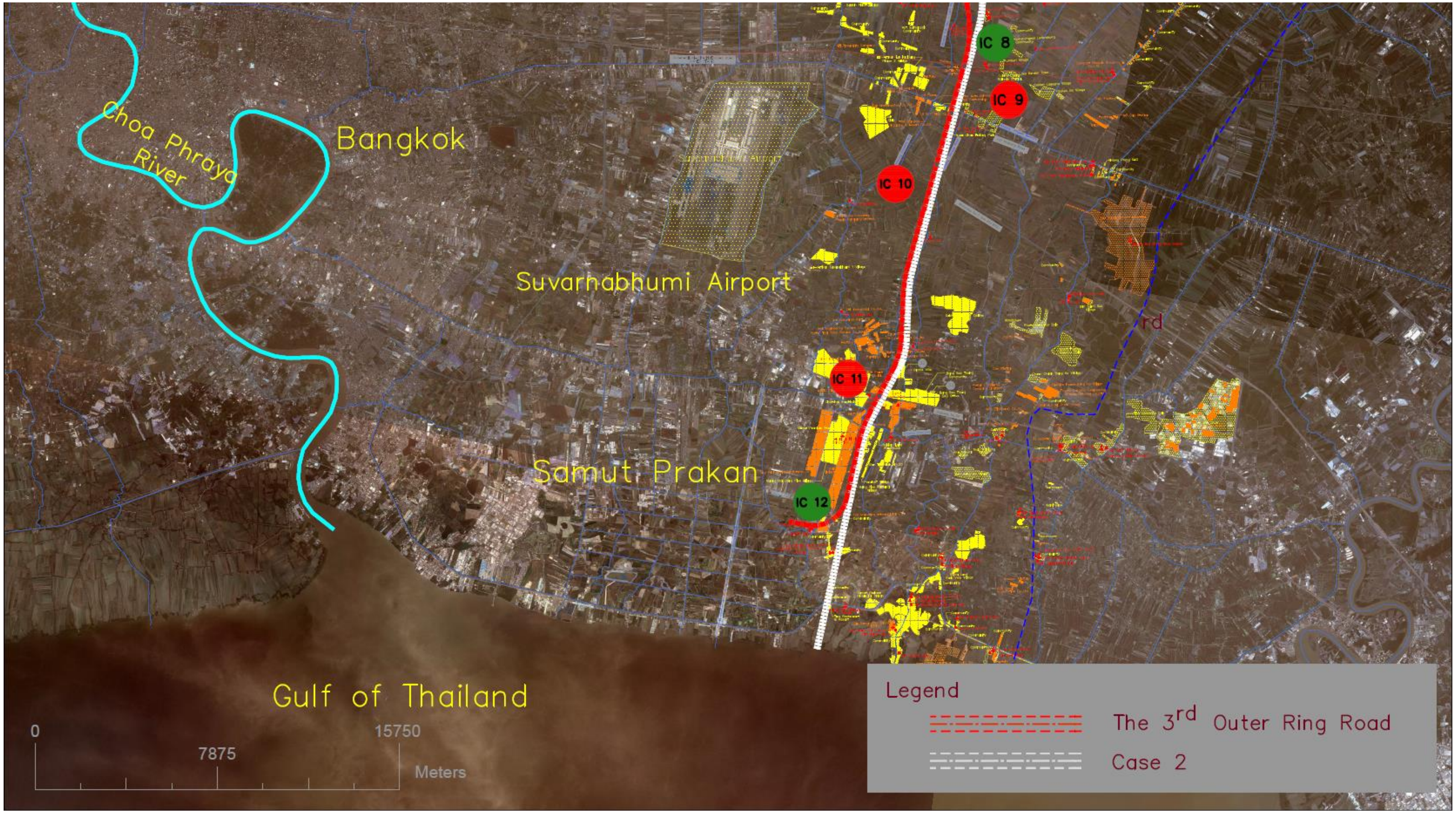
For the Case 2, the number of relocations could be reduced around IC7. And some sensitive facilities could be passed by.



Source: JICA Study Team

Figure 2.3.7 Alignment of Case 2 (from IC6 to IC10)

For the Case 2, the number of relocations could become large around IC11 too. However, sensitive facilities could be passed by.

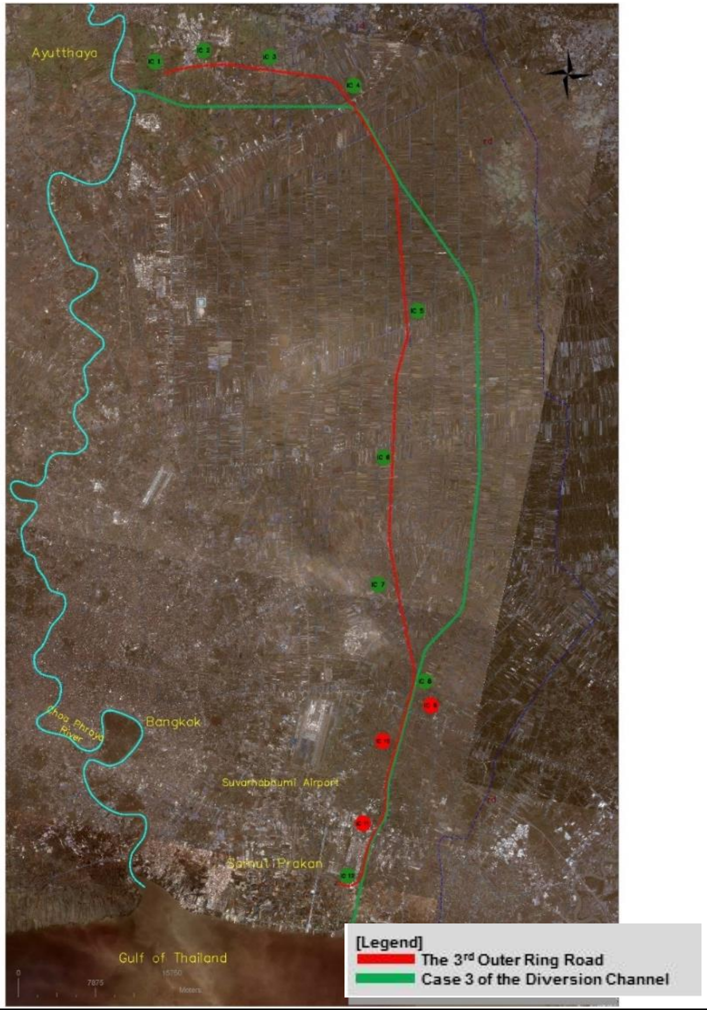


Source: JICA Study Team

Figure 2.3.8 Alignment of Case 2 (South area of IC8)

(3) Case 3

Table 2.3.4 Evaluation of contents of Case 3



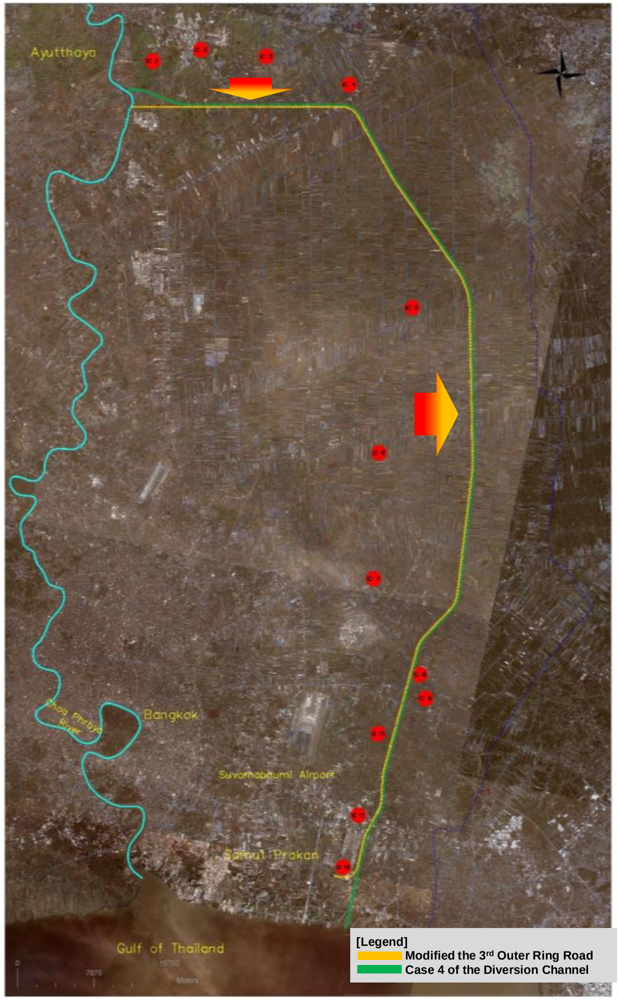
◆ From diversion point to IC4, the Channel is set apart on the south side of the Road by about 5km. ◆ From IC5 to IC7, the Channel shifts to the east side of the road by about 10km. ◆ Possibility of the combined project needs to be checked.			
◆ Channel Length (km)	114		B
◆ Road Length (km)	97		A
◆ Structural Condition ・ Length of soft clay zone: 65 km (see "Soil Classification Chart" hereinafter) ・ (Number of design changes of ICs is reduced from 11 sites to 3 sites (IC9, 10, 11)).			B
◆ Hydraulic Condition of the Channel ・ Hydraulically smooth alignment is secured (straight line & gentle curve).			A
◆ Number of Relocations ・ Narrow & isolated areas are not generated between the Channel and the Road.			A
・ House	Small	(51)*	
・ Factory	Small	(56)*	
◆ Environmental Impact			-
◆ Land Cost	Moderate	(100)*	B

*Note: Index number compared to Case 1

Source: JICA Study Team

(4) Case 4

Table 2.3.5 Evaluation of contents of Case 4



From the diversion point to IC4, the Channel is set apart on the south side of the Road by about 5km. Alignment of the Road is adapted to the Channel.
From IC5 to IC7, the Channel and the Road shift to the east side of the urban area by about 10km.

◆ Channel Length (km)		114	B
◆ Road Length (km)		102	B
◆ Structural Condition ・ Length of soft clay zone: 65 km (see “Soil Classification Chart” hereinafter) ・ (FS of the Road needs to be revised substantially.)			B
◆ Hydraulic Condition of the Channel ・ Hydraulically smooth alignment is secured (straight line & gentle curve).			A
◆ Number of Relocations			A
・ House	Small	(43)*	
・ Factory	Moderate	(67)*	
◆ Environmental Impact ・ (EIA of the Road needs to be revised substantially.)			-
◆ Land Cost	High	(102)*	C

*Note: Index number compared to Case 1

Source: JICA Study Team

2.4 Evaluation of Alignment Alternatives

Table 2.4.1 Result of the evaluation on alignment of the Diversion Channel

Case		Case 1		Case 2		Case 3		Case 4	
Engineering	Channel Length (D. C.)	114 km	B	111 km	A	114 km	B	114 km	B
	Road Length (R. R.)	97 km	A	97 km	A	97 km	A	102 km	B
	Structural Condition (D. C.)	Length of soft clay zone: 44 km	A	Length of soft clay zone: 43 km	A	Length of soft clay zone: 65 km	B	Length of soft clay zone: 65 km	B
	Hydraulic Condition (D. C.)	Not smooth in the north part	B	Smooth	A	Smooth	A	Smooth	A
	Sub-Total Score	**B**		**A**		**B**		**C**	
Social Impact	Relocation of Houses	Many (100)*	C	Moderate (60)*	B	Small (51)*	A	Small (43)*	A
	Relocation of Factories	Many (100)*	C	Moderate (71)*	B	Small (51)*	A	Moderate (67)*	B
	Sub-Total Score	**C**		**B**		**A**		**A**	
Environmental Impact		Almost same in all 4 cases**							
Cost and Benefit	Land Cost (D.C. & R.R.)	(100)*		(99)*		(100)*		(102)*	
	Construction Cost (D.C.)	(100)*		(97)*		(108)*		(108)*	
	Construction Cost (R.R.)	(100)*		(95)*		(94)*		(103)*	
	Total Cost	Moderate (100)*	B	Low (96)*	A	Moderate (101)*	B	High (105)*	C
	Benefit	Almost same in 4 cases							
	Sub-Total Score	**B**		**A**		**B**		**C**	
Total Score				**A**					

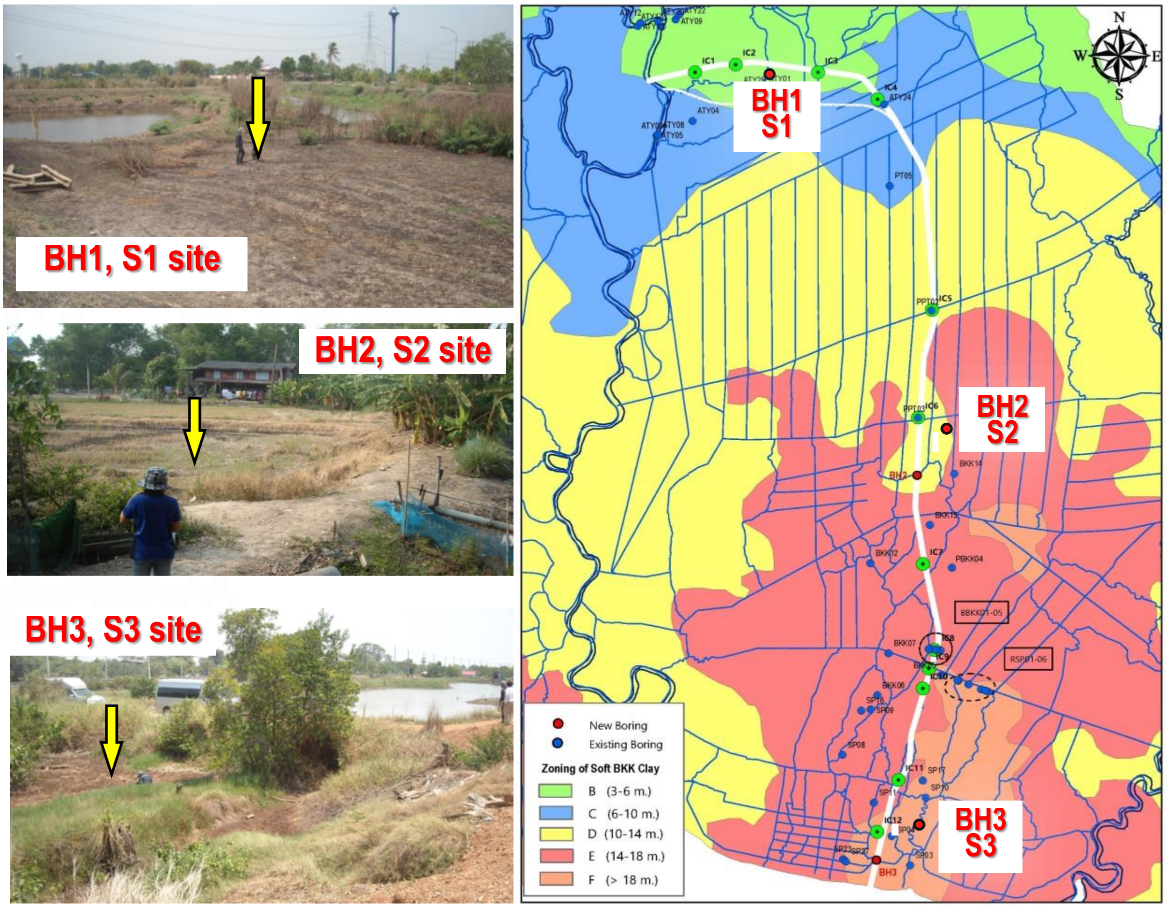
*Note: Index number compared to Case 1, **Note: EIA of the Ring Road needs to be revised in Case 4.

CHAPTER 3 SOIL SURVEY

3.1 Introduction

Soil surveys were carried out in the areas alongside the outer ring road diversion channel in order to study the stability of the ground and the potential for the reuse of the soil (cohesive soil called “Bangkok Clay”) produced from the construction of the diversion channel.

A survey by Kasetsart University divides the construction site into five zones, according to the thickness of the layer of Bangkok Clay (cohesive soil), namely Zone B (3 to 6 m) to Zone F (18 m or thicker) (Figure 3.1.1). In the present survey, these were classified into 3 zones (Zone B-C, Zone D and Zone E-F) and a soil survey was carried out at one location in each zone.



Source: JICA Study Team based on the data made by Kasetsart University

Figure 3.1.1 Thickness of the Bangkok Clay

The survey items and their purpose are listed in Table 3.1.1 below.

Table 3.1.1 Survey Items and their Purpose

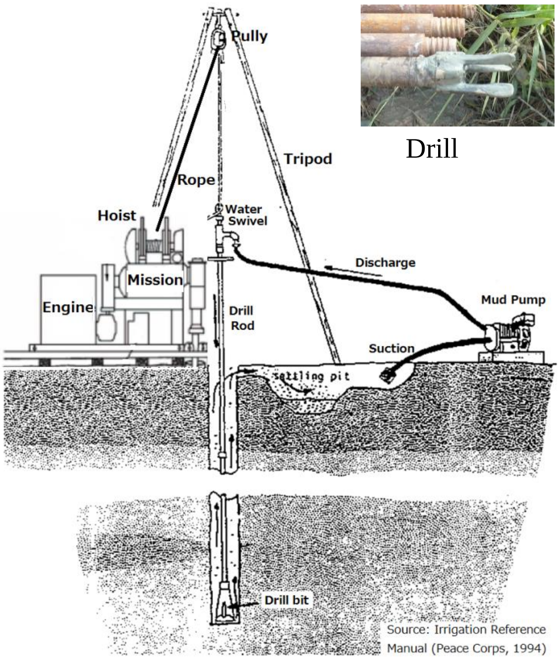
Survey Item		Values Obtained	Purpose	Use
Boring	Standard Penetration Test	N value	Understanding of the strength of the natural ground	Stratigraphic classification and study of ground stability
	Laboratory soil test using disturbed samples	Specific gravity of soil particles Moisture content Liquid/plastic limit Particle size distribution	Soil classification Understanding of soil properties	
	Laboratory soil testing using undisturbed samples	Soil density Unconfined compressive strength Consolidation constant Cohesion/Internal friction angle	Understanding of the mechanical properties of the natural ground	Consideration of the movement/stability of the ground due to construction
Vane test		Soil shear strength		
		Sensitivity	Understanding of soil properties	Study of strength degradation when the soil has been disturbed
Pit excavation and collection of disturbed samples	Compaction test of mixed soil	Compaction curve Optimum moisture content Maximum dry density	Strength of compacted mixed soil Determination of proportion of sand for mixing	Study of the possibility of reuse as fill material
	Cone penetration test of mixed soil	Cone index	Understanding of strength of mixed soil	Study of the possibility of reuse in diversion channel embankment
	Unconfined compression test of mixed soil	Unconfined compressive strength	Understanding of strength properties of mixed soil	Study of stability of diversion channel embankment
	Triaxial compression testing of mixed soil (consolidated undrained)	Viscosity/Shear angle		
	CBR testing of quicklime mix	CBR value	Understanding of strength of improved soil	Study of the possibility of reuse in highway embankment (sub-base / sub-grade material)
	CBR testing of concrete mix	CBR value	Understanding of strength of improved soil	Study of the possibility of reuse in highway embankment (roadbed material)
	Unconfined compression testing of concrete mix	Unconfined compressive strength Viscosity/Shear angle	Understanding of strength of improved soil	

Source: JICA study team

3.2 Survey Method

(1) Exploratory Boring

Exploratory boring uses a rotary-type hydraulic feed boring machine, but the excavation was carried out by the slurry method, percussion drilling. When drilling, standard penetration testing was carried out at intervals of 1 m to gain an understanding of the geological state of the ground and determine the depth for the collection of undisturbed samples; undisturbed samples were taken from a separate borehole. Figure 3.1.1 shows an outline drawing of the drilling method.

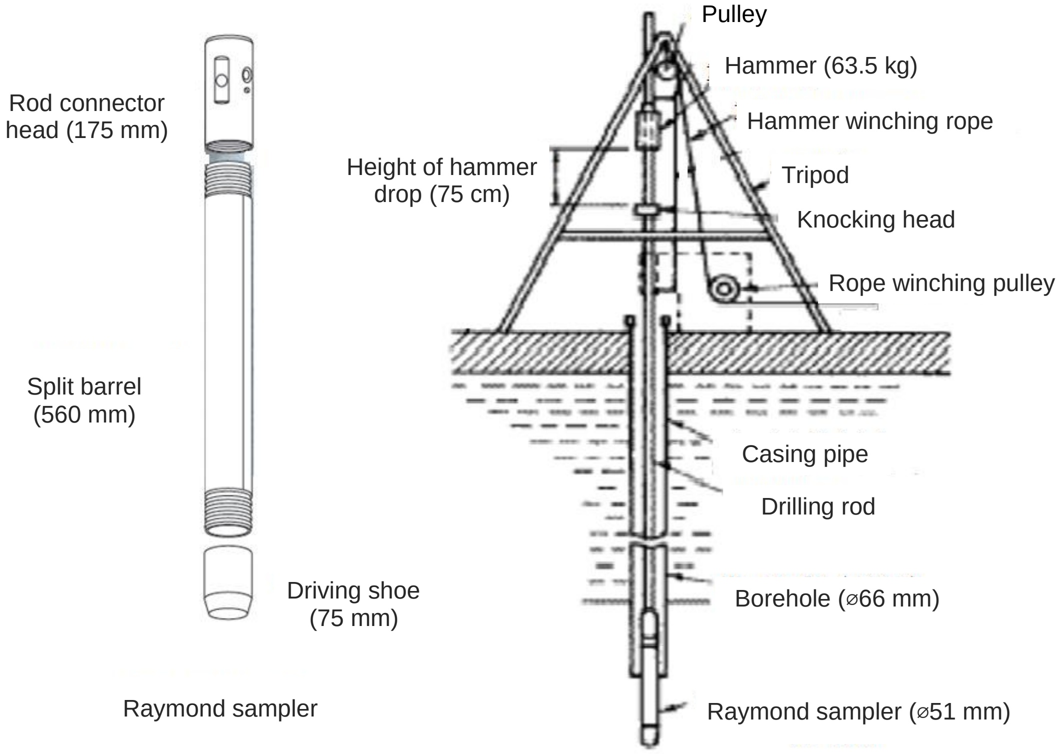


Source: Irrigation Reference Manual (Peace Corps, 1994)

Figure 3.1.1 Boring excavation method

(2) Standard Penetration Test

The standard penetration test is a test in which, in addition to determining the hardness of the ground, samples of the ground are collected; the test is used to understand the stratum structure and to learn the general ground strength. A Raymond sampler is attached to the tip of the drilling rod and lowered to the bottom of the borehole, and a hammer of 140 lbs. (approx. 63.5 kg) is dropped from a height of 75 cm onto a knocking head attached to the upper part of the rod. The number of blows needed to achieve a penetration of 30 cm is recorded as the N value. This test was carried out at intervals of 1 m. The test involved a preliminary penetration of 15 cm, the test penetration of 30 cm and a final penetration of 5 cm. In Thailand, it appears that the custom is not to carry out the test to the soft cohesive soil, but instead to take undisturbed samples and to carry out compression test; nevertheless, in this instance standard penetration tests were carried out at all depths. Figure 3.2.2 shows an outline drawing of the Standard Penetration Test and the Raymond sampler. Physical testing (natural moisture content, specific gravity of soil particles, liquid/plastic limit, soil density, and grain size analysis) was carried out on the samples collected in order to understand their physical properties.



Source: Ground Survey Method (The Japanese Geotechnical Society)

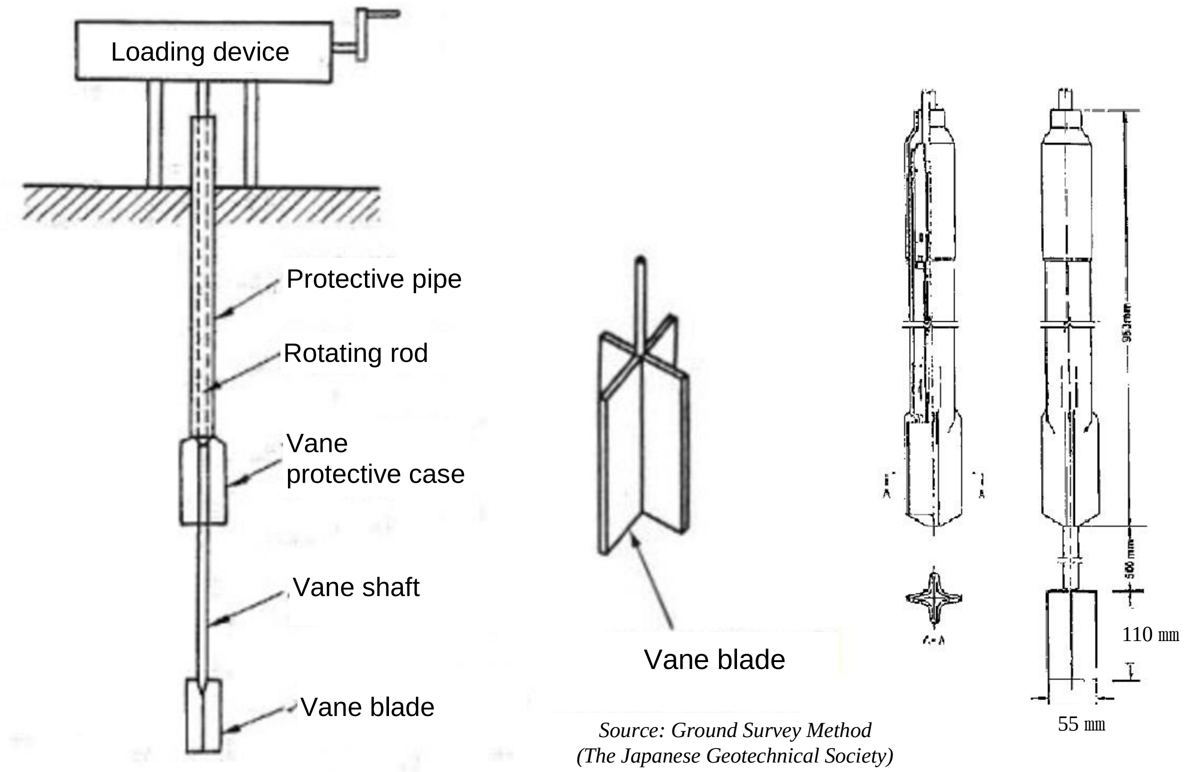
Figure 3.2.2 Outline drawing of standard penetration test

(3) Collection of Undisturbed Samples

Undisturbed sampling is a method of collecting samples of earth in an undisturbed state by pushing statically a metal tube called a thin-walled sampler into the ground to provide samples for laboratory tests in order to learn the mechanical properties of the ground. The thin-walled sampler is made of stainless steel with 60 cm of length and 75 mm of inner diameter. The collection depth was determined by looking at the stratum structure of the borehole in which the standard penetration test was carried out. Thin-wall sampling is a method of sampling used in cohesive soil ground where the soil is soft clay with an N value of no more than 4. In the present survey, this method was used to collect samples of Bangkok Clay. The samples collected were sealed with paraffin wax to prevent the top and bottom ends from drying out and then were carried to the laboratory in an upright position so as to maintain as far as possible the condition they were in while underground. After reaching the laboratory the samples were quickly extracted and tested (consolidation test, unconfined compression test, triaxial compression test (UU and CUB conditions)).

(4) Vane Shear Test

The Vane Shear test measures the strength of the ground in situ. As shown in Figure 3.2.3, the vane blade is pressed into the ground and when it has been pushed to the designated depth the blade is rotated and the torque exerted on the axle is used to calculate the shear strength of the soil.



Source: Ground Survey Method
(The Japanese Geotechnical Society)

Figure 3.2.3 Outline Drawing of the Vane Share Test

(5) Collection of Disturbed Samples

In this study, in order to study the potential of reusing the soil (Bangkok Clay) derived from the excavation of the diversion channel as banking material, soil tests were carried out involving mixing with high-quality soil (sand) and mixing with quicklime and cement. Since large amounts of soil are needed in order to carry out compaction test of mixed soil and strength test of compacted soil (cone penetration test, CBR test, unconfined compression test, triaxial compression test), beside each boring survey location a pit was dug using a backhoe and roughly 1 m^3 of original ground soil was taken from a point between 2 to 3 m below ground level.

(6) Laboratory Soil Tests

The laboratory soil tests were carried out in accordance with ASTM standards. The test items and test methods are listed in Table 3.2.1.

Table 3.2.1 List of soil test methods

Test Item		Testing Standard	Target Soil
Physical test	Specific gravity of soil particles	ASTM D-845	Undisturbed soil/disturbed soil
	Soil moisture content test	ASTM D-2166	Undisturbed soil/disturbed soil
	Liquid/plasticity limit test	ASTM D-4318	Undisturbed soil/disturbed soil
	Grain-size analysis	ASTM D-422	Undisturbed soil/disturbed soil
Mechanical test	Soil density test	ASTM D-7263	Undisturbed soil/disturbed soil
	Unconfined compression test	ASTM D-2166	Undisturbed soil/disturbed soil
	Consolidation test	ASTM D-2435	Undisturbed soil
	Triaxial compression test (UU)	ASTM D-2850	Undisturbed soil
	Triaxial compression test (CUB)	ASTM D-4767	Undisturbed soil/disturbed soil
	Compaction test	ASTM D-698-78	Disturbed soil
	Fall cone test	ISO/TS 117882-6	Disturbed soil
	Simple cone penetration test	JIS A 1228	Disturbed soil
	CBR test of compacted soil	ASTM D-1883	Disturbed soil

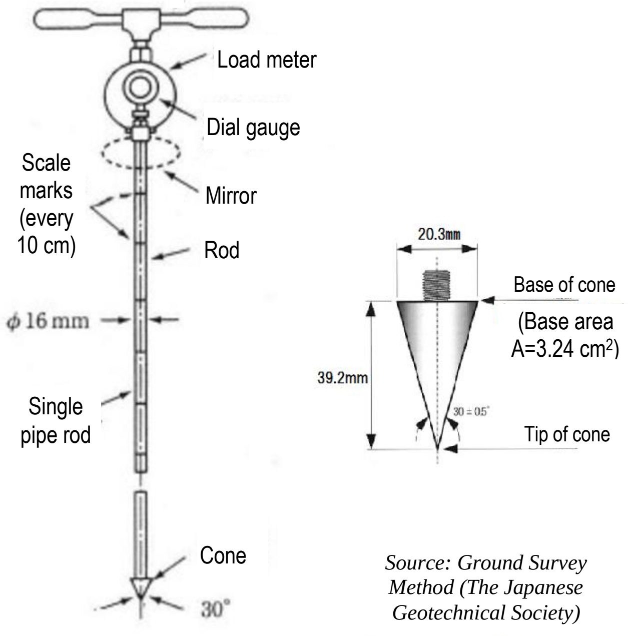
Source: JICA study team

When discussing soil-related construction constraints, the test results from the cone penetration test (cone index: qc (kPa)) are used to determine what kind of heavy machinery can be used. In this study, cone penetration test was carried out on compaction test samples prepared by mixing sand with soil from the site.

However, when it came to carrying out the test it was learned that in Thailand simple cone penetration test apparatus is not generally available, indeed the test itself is not known; and the test was hurriedly switched to a fall cone test, which uses the same cone shape. However, the fall cone test apparatus is used to perform liquid limit testing: the test load is extremely small, and not suitable for testing heterogeneous materials (in this instance, a mixture of sand and soil). For this reason, simple cone penetration test equipment was brought over from Japan, and then, the test was carried out after that using this equipment. Figure 3.2.4 shows an outline drawing of the simple cone penetration test equipment.

With respect to the sample preparation for compaction test, on the other hand, in Thailand a dry method is used, whereby the target soil is first dried out completely and then water is mixed with the soil to obtain the set moisture content. (ASTM D 698).

When cohesive soil is completely dried out the fixed moisture covering the surface of the clay particles is lost, altering the ability of the clay particles to adhere to each other (lowering the viscosity). For this reason, the sample preparation method used in Thailand was disadvantageous and so the samples were prepared by using the wet method (in which a sample with natural moisture content is dried to the target moisture content). In order to prevent parts of the sample from becoming very dry during the drying process, the sample was checked frequently as the moisture content was adjusted.



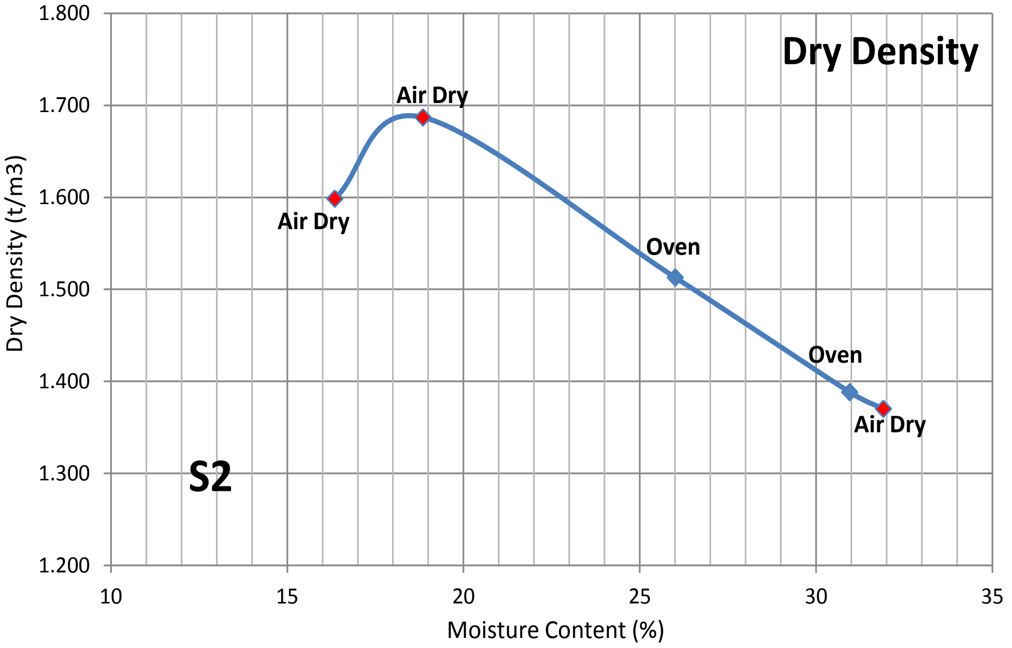
Source: Ground Survey Method (The Japanese Geotechnical Society)

Figure 3.2.4 Outline drawing of simple cone penetration test

The actual procedure is set out below.

i. The target moisture content for the compaction test is established (e.g., 10%, 15%, 20%, 25%, 30% etc.)
ii. The moisture content of the clay and the moisture content of the sand to be mixed with it are measured.
iii. The mixing ratio (by weight) of clay to sand is determined (e.g., clay : sand = 2:1)
iv. From the moisture content of the clay and sand the amounts of water contained in both 2 parts clay and 1 part sand are calculated and the amount of water that needs to be reduced to achieve the target moisture content is calculated.
v. The moisture content of the clay is reduced so as to bring the weight of the clay down to the weight of the clay in its natural state minus the amount of water than needs to be removed.
vi. Once the cohesive soil reaches the designated weight, the designated amount of sand is added using a mixer, and this mixture is the test sample.

Step v, the drying process, is the most important step, and also most time-consuming. In view of this a comparison was made of air-drying and drying in an oven to determine which method to use. As shown in Figure 3.2.5, greater consistency was obtained with the faster method (air-drying) and so this method was used to prepare the samples.

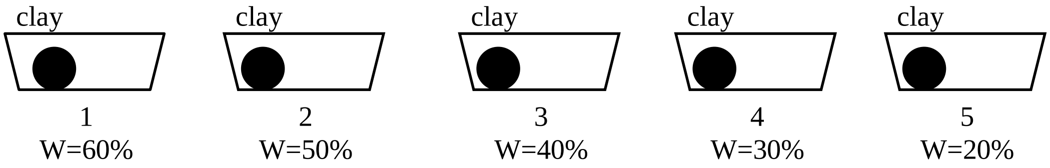


Source: JICA study team

Figure 3.2.5 Comparison of drying methods

During the drying process, it is desirable that the drying should be as even as possible; it is also necessary for measurements to be taken frequently so as to obtain the planned weight. To this end the following method was adopted.

a. 5 trays are prepared; the specified amount of clay is placed in each tray and the weight measured.



b. As the surface of the soil in each tray dries, it is broken into pieces to expose the moister part inside; parts that have become too dry are covered in soil of a higher moisture content to prevent further drying, after which the tray is weighed.

c. The breaking up of the clay and the weighing of the tray is done repeatedly. Repeatedly weighing the tray makes it possible to estimate the time at which the planned moisture content will be reached. If it seems likely that the planned moisture content will be reached overnight or during a holiday, adjustment is made by wrapping the tray to prevent over-drying.

d. When the moisture content has dropped to the required level, it is mixed with the designated amount of sand using a mixer, and compacted.

3.3 Survey Results

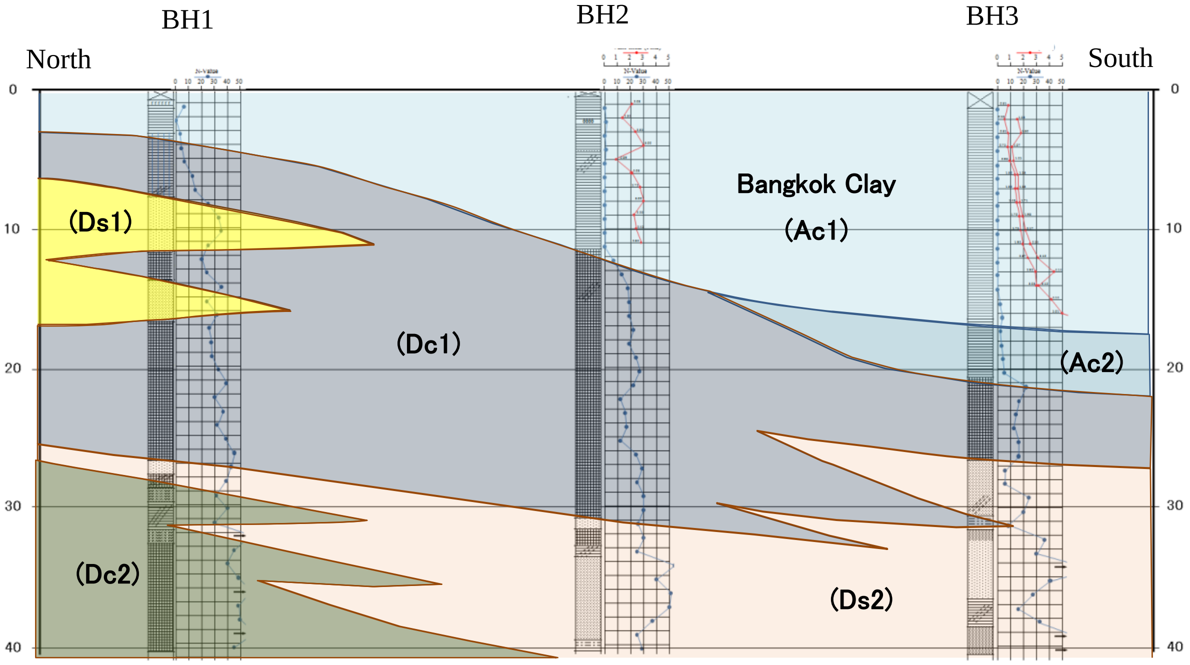
(1) Stratum Structure

With respect to the geology of the survey area, the results of the boring show that the soft Bangkok Clay (Ac1: alluvial cohesive soil) that covers the surface is extremely thin, some area is 2 m, around BH1, with the thickness increasing from the inland area towards the coast, reaching a thickness of some 18 m around BH3. Below the Bangkok Clay are distributed cohesive soil and sandy soil thought to be deposits from the Pleistocene epoch. The estimated geological cross-section surmised from the borings made at the three survey sites is shown in Figure 3.3.1 "Estimated geological cross-section". The distinguishing features of each stratum are set out in Table 3.3.1.

Table 3.3.1 Stratigraphy and Features

Period		Symbol	Features	N value range (average)
Cenozoic Quaternary	Alluvial epoch	Ac1	Extremely soft cohesive soil from dark gray to dark blue-gray in color, with clay as the main component. Also known as Bangkok Clay. Distribution is thin (2 m) at the northern BH-1 site and thick (18 m) at the southern BH-3 site.	0-2 (0)
		Ac2	A green-gray clay rather low in moisture content, lying in a stratum roughly 4 m thick underlying the Ac1 around the BH-3 site.	2-4 (3)
	Pleistocene epoch	Dc1	A cohesive soil distributed widely underlying the Bangkok Clay, low in water content and yellow-gray to milky grayish-brown in color. Has a sandy layer enclosed inside.	3-45 (22)
		Ds1	A brownish-gray sandy layer distributed some 8 to 17 m below ground level around the BH-1 site. The upper part contains coarse sand and the lower part a silty component.	24-35 (30)
		Ds2	A dark brown sandy layer that is thin around the BH-1 site and becomes thicker towards the south. The main component is fine sand. Around 36 m below ground level it alternates with layers of coarse sand to fine gravel.	6-67 (34)
		Dc2	Hard clay, ocher in color, distributed 28 m below ground level at the BH1 site.	39-63 (45.6)

Source: JICA Study Team



Source: JICA Study Team

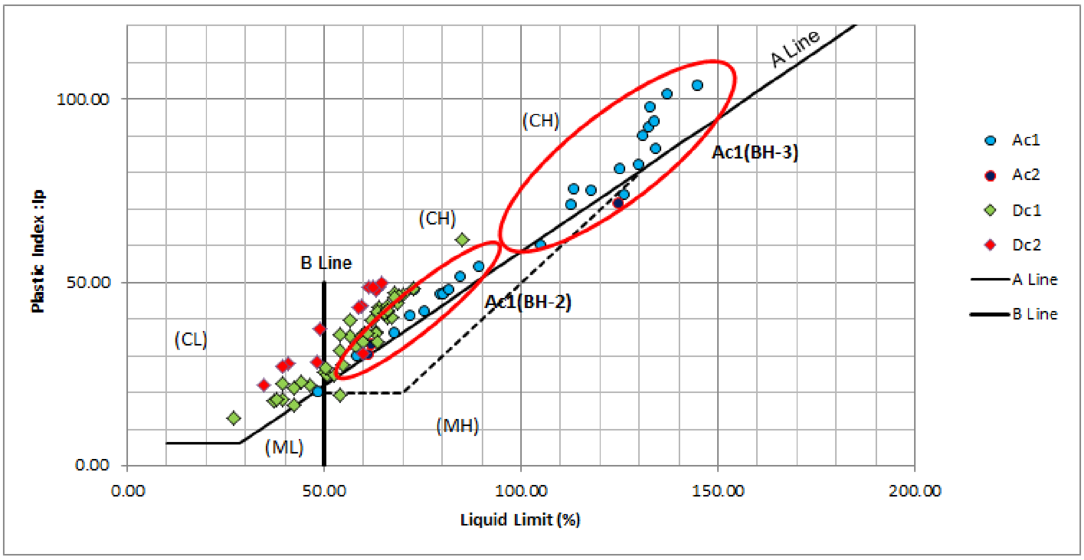
Figure 3.3.1 Estimated geological cross-section

Vane testing was carried out at BH2 and BH3. The results are plotted in red on the graphs shown in Figure 3.3.1 “Estimated geological cross-section”. At BH2 shear strengths of 0.89–3.00 (t/m^2) are shown, and indications can be seen of a tendency to a slight increase at deeper levels. At BH3 values shown are 1.07–8.6 (t/m^2). Around 12 m below ground level, values shown are roughly the same as at BH2 (1–3t/m^2). However, around 13 m bellow, values become higher, and the lowermost part of the Ac1 (Bangkok Clay) level shows a value of 8.6 t/m^2.

The borehole logs and results of the vane share testing are shown in Appendix 3 at the end of this report.

(2) Physical Characteristics of Each Stratum

As shown in the estimated geological cross-section, there are distributions of soft cohesive soil from the alluvial epoch and of hard clay from the Pleistocene epoch. Within the hard diluvial clay are distributing interfingered sandy strata comprising mainly fine sand. The alluvial cohesive soil is called Bangkok Clay (Ac1) which is soft clay with a high moisture content. Consolidation of the diluvial clay is advanced and the strata are stable; in the upper Dc1 layer, the average moisture content is 20% and the N value is 30, while in the lower Dc2 layer, the average moisture content is 17.5% and the N value is 45. Figure 3.3.2 shows the plasticity chart.

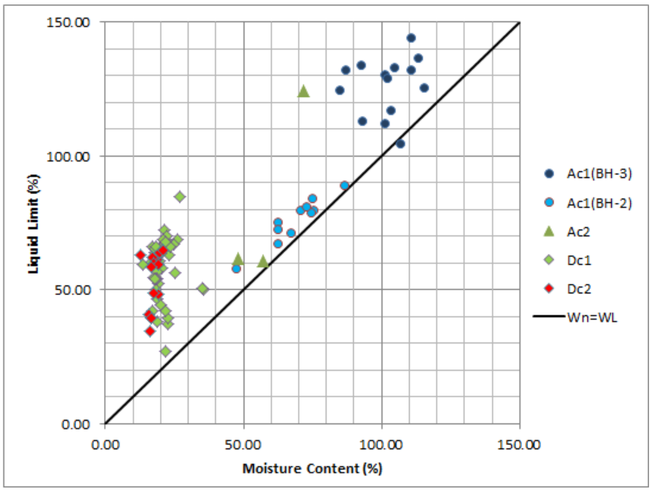


Source: JICA Study Team

Figure 3.3.2 Plasticity chart

In the plasticity chart A is the line separating clay from silt, and Bangkok Clay is classified as clay positioned above the A Line (a high plasticity index). The Bangkok Clay at BH-2 and BH-3 is judged to be the same stratigraphic horizon, but the liquid limit clearly differs; while the Bangkok Clay in the southern area has liquid limit of 100 to 150%, the Bangkok Clay at BH-2 has a liquid limit of 50 to 100%.

B Line is a yardstick indicating greater or lesser compressibility; items to the right of B Line have high compressibility, and items to the left, low compressibility. When the moisture content is high, there is a general tendency for the liquid limit to also be high, so that it can be said that compressibility is high. Dc1 and roughly half of Dc2 are to the right of B Line, but as shown in Figure 3.3.3, the natural moisture content is concentrated in the vicinity of 20% and the soil is already in a state of compression; it can be said that in actual fact the compressibility is not high.



Source: JICA Study Team

Figure 3.3.3 Natural moisture content and liquid limit

(3) Mechanical Properties of Bangkok Clay

As the results of the standard penetration test carried out on Bangkok Clay showed zero (the sampler penetrated the ground with the weight of the rod or hammer) over more or less the whole area, it is not possible to make an assessment using the standard penetration test values. Instead, vane shear testing described elsewhere and mechanical testing using undisturbed samples were carried out.

The strength tests carried out with the unconfined compression tests, and the test results are shown in Figures 3.3.4 and 3.3.5.

Where, qu: Unconfined compressive strength (t/m^2)

C(uu): Viscosity under triaxial compressive strength (UU) conditions: because c = qu/2, comparison with 2*c

Pc: Consolidation yield stress (t/m^2) from consolidation test

Vane Shear: Shear strength is equivalent to viscosity, compared *2 as in triaxial test results

Effective Stress: Effective stress when soil density is 1.5 (t/m^3) average and the groundwater level is 1.5 m below ground level

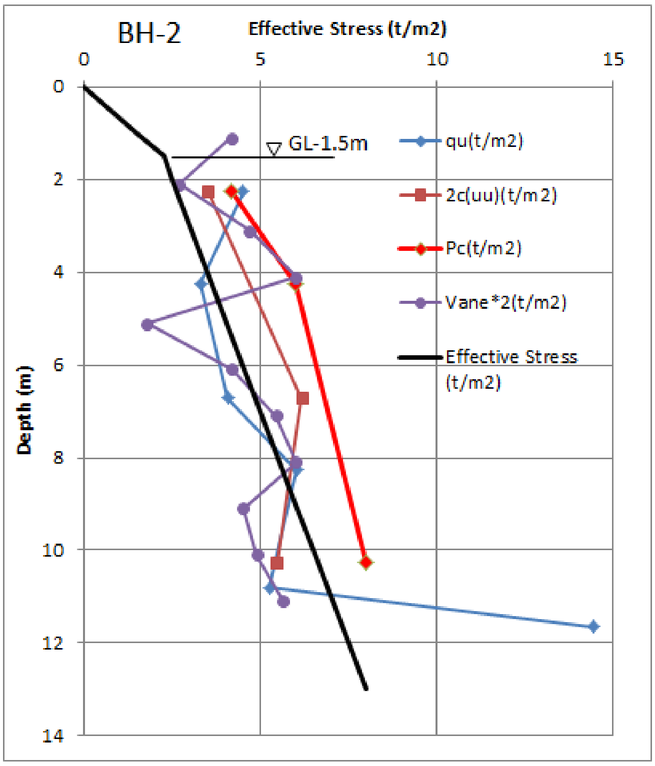


Figure 3.3.4 Results of Bangkok Clay strength testing (BH-2)

Figure 3.3.4 is the graph for the BH-2 site. The Effective Stress is considered to be the stress acting on the soil under current ground conditions, and to have the strength to withstand an equivalent stress. While the adhesive power obtained from the unconfined and triaxial tests and the results of the vane shear test show some variation, it can be said that the values they show do follow the effective stress line. The values for consolidation yield stress are rather high, indicating a state of excessive consolidation.

The soil constants will be determined taking normally compacted soil into account.

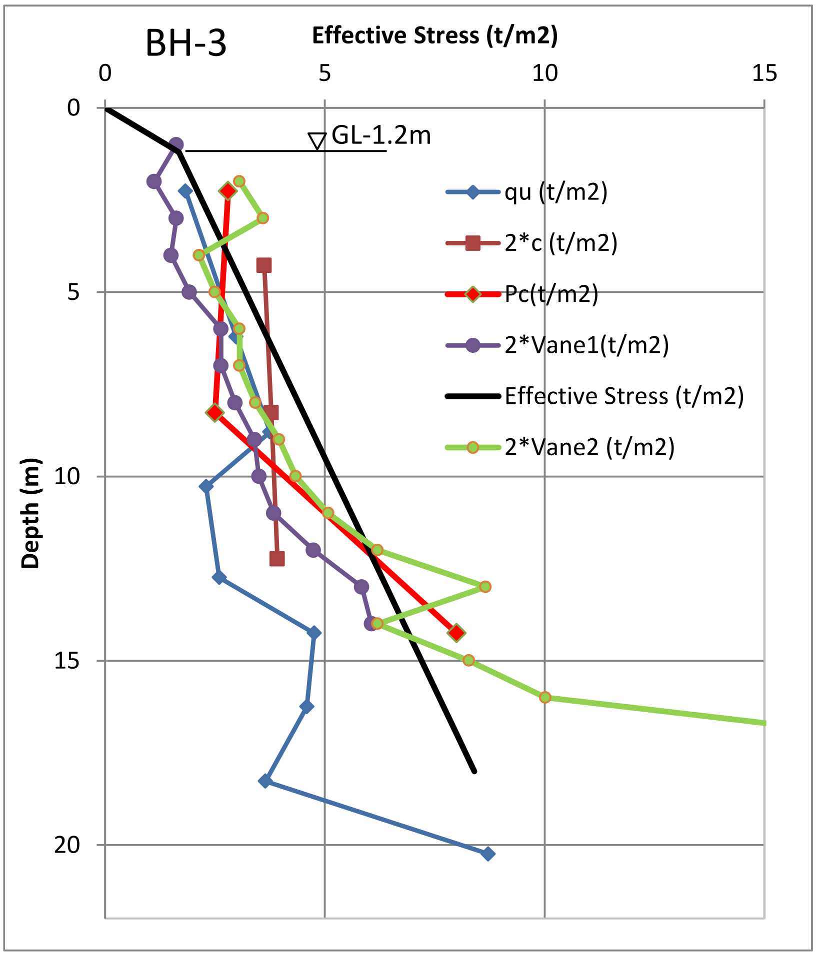


Figure 3.3.5 Results of Bangkok Clay strength testing (BH-3)

Figure 3.3.5 is arranged for BH-3 in the same manner as BH-2. The results of the vane shear test show sharply higher values below 11m, suggesting a change in the geological condition. It clearly shows a weaker Effective Stress than at BH-2. It is thought that the formation of Bangkok Clay at BH-3 is younger than that at BH-2, and it can be said that the 15-m layer of Bangkok Clay at BH-3 is in a state of incomplete consolidation.

The constants to be used in design will be set up taking the above into account.

【Results of reusability testing on excavated soil】

Excavated soil is being considered for use as bank material for the diversion channel or outer ring road embankment material in this study. The exploitation method and criteria are set out in Table 3.3.2.

Table 3.3.2 Criteria of Soil Exploitation Methods Excavated from Diversion Channel

Exploitation Methods		Improvement method	Test method	Criteria	Notes
Diversion channel embankment	Embankment material	Clay: Sand=2:1 D90 ※Mixing by hand also carried out	Cone penetration test	Cone index: qc ≥ 400 kPa	Banking construction by heavy machinery is possible
Outer ring road	Sub-base material	Clay: Sand=2:1	Cone penetration test	Cone index: qc ≥ 400 kPa	Banking construction by heavy machinery is possible
	Subgrade material	Clay: Sand=2:1 Quick Lime 5%, 7%, 9%	CBR	CBE ≥ 4	The higher the CBR value, the thinner the paving can be made
	Roadbed material	Clay: Sand=2:1 Cement 8%	Unconfined compression test	qu ≥ 0.75 MPa	

Source: JICA Study Team

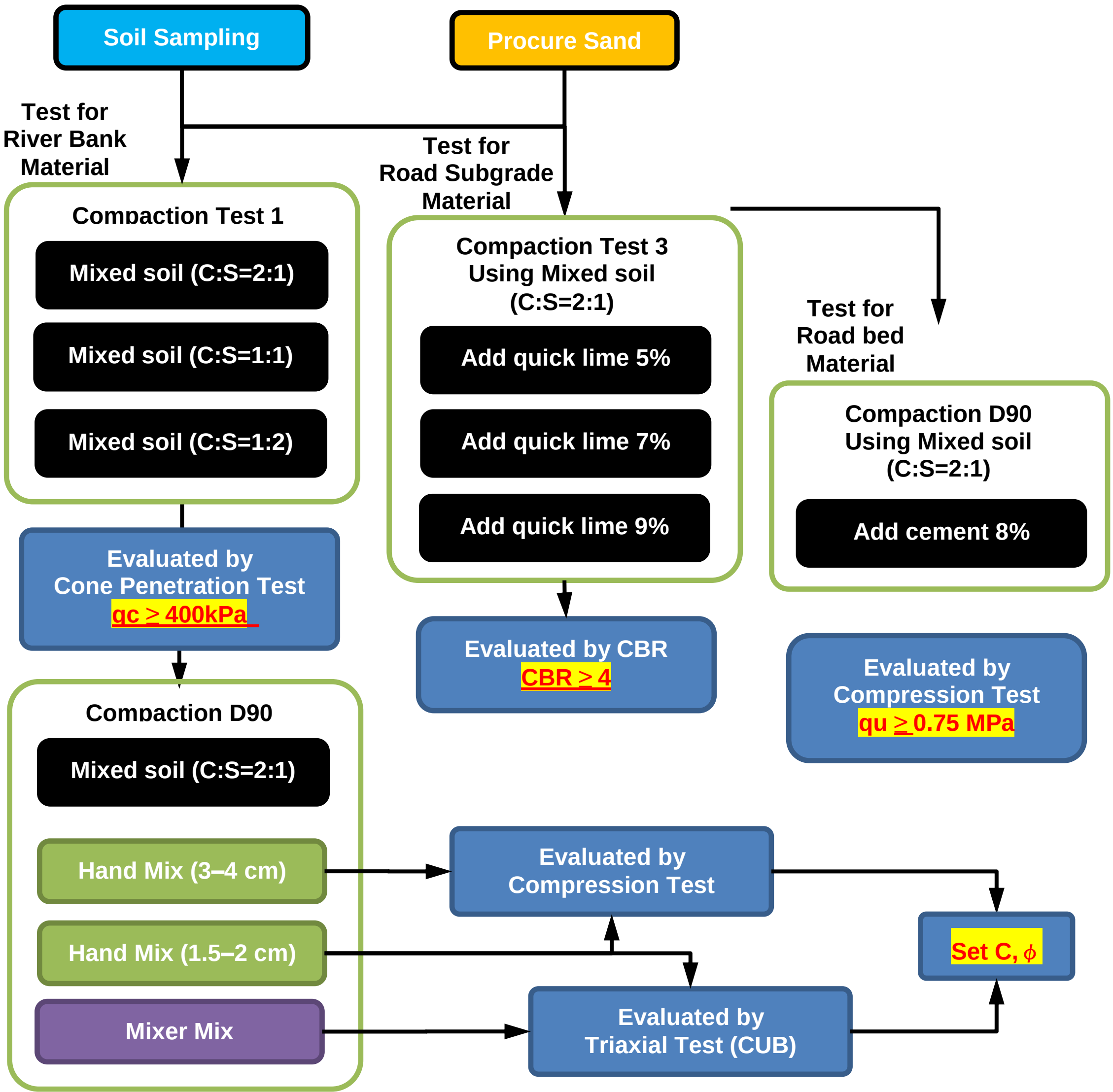
The test procedure was as follows: compaction testing was carried out on samples with proportions of clay: sand at 1:2, 1:1, 2:1 and the cone index (qc) was verified. The minimum ratio of sand required to ensure qc ≥ 400 kPa was determined, and triaxial compression testing (CU conditions) was carried out using that ratio to set the dynamic constant to assess the stability of the diversion channel embankment soil.

For use as embankment material for the outer ring road, however, the use of large amounts of purchased sand would be too costly. Thus, the effects of improving a mixture with a clay-to-sand ratio of 2:1 through the addition of quicklime and cement were verified.

The mixtures of clay and sand were prepared by using a mixer on the assumption that mixing process will be done by using mixing plant, during construction of road embankment. However, testing using specimens prepared by hand mixing were added on the assumption that clay and sand mixing will be done by break stock pile with layered clay and sand using bulldozes (not a mixing plant).

The results of the testing showed that qc ≥ 400 kPa could be ensured with a mixture containing the minimum proportion of sand, all subsequent tests were carried out on mixtures, with a clay-to-sand ratio of 2:1.

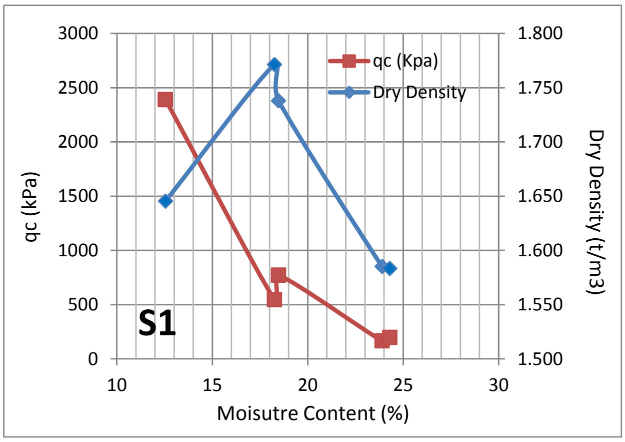
Figure 3.3.6 shows the flow chart for tests relating to the exploitation of soil generated from the construction.



Source: JICA Study Team

Figure 3.3.6 Flow chart for testing relating to reuse of excavated soil

【Compaction test for channel embankment】



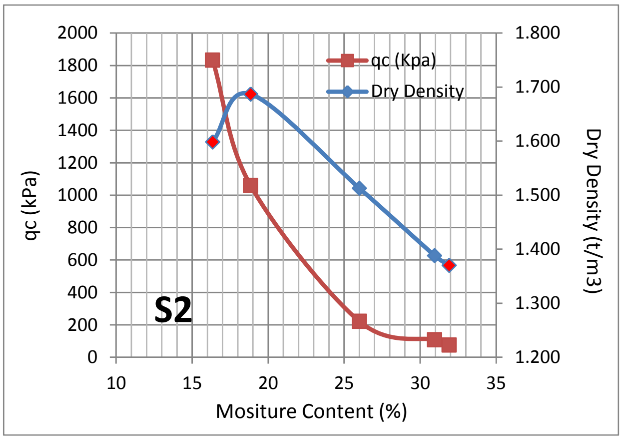
Source: JICA Study Team

Figure 3.3.7 Results of compaction test and cone index (S1)

The results of the compaction test carried out using the clay:sand=2:1 mixture and the cone penetration test carried out on the resulting compacted samples are shown in Figures 3.3.7, 3.3.8, 3.3.9.

The results of the compaction test of the S1 (northern site) samples (blue line) indicate that the optimum moisture content is around 18% and the maximum dry density is 17.7 t/m^3. The qc value at the maximum dry density is 550–770 kPa, values which satisfy qc ≥ 400kPa.

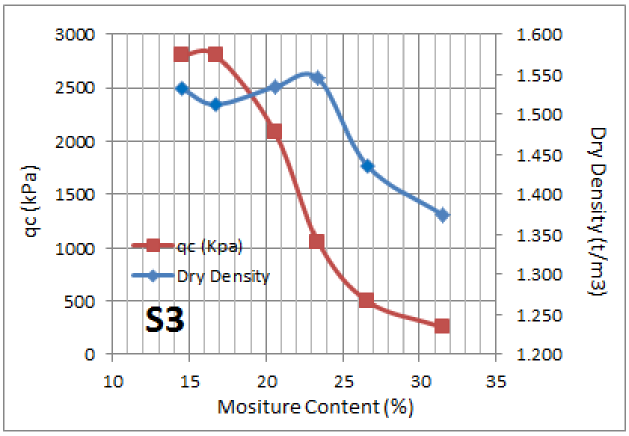
The results of the compaction test of that the S2 (central site) samples (blue line) indicate the optimum moisture content is around 19% and the maximum dry density is 1.69 t/m^3. The qc value at the maximum dry density is 1000 kPa, values which satisfy qc ≥ 400 kPa.



Source: JICA Study Team

Figure 3.3.8 Results of compaction test and cone index (S2)

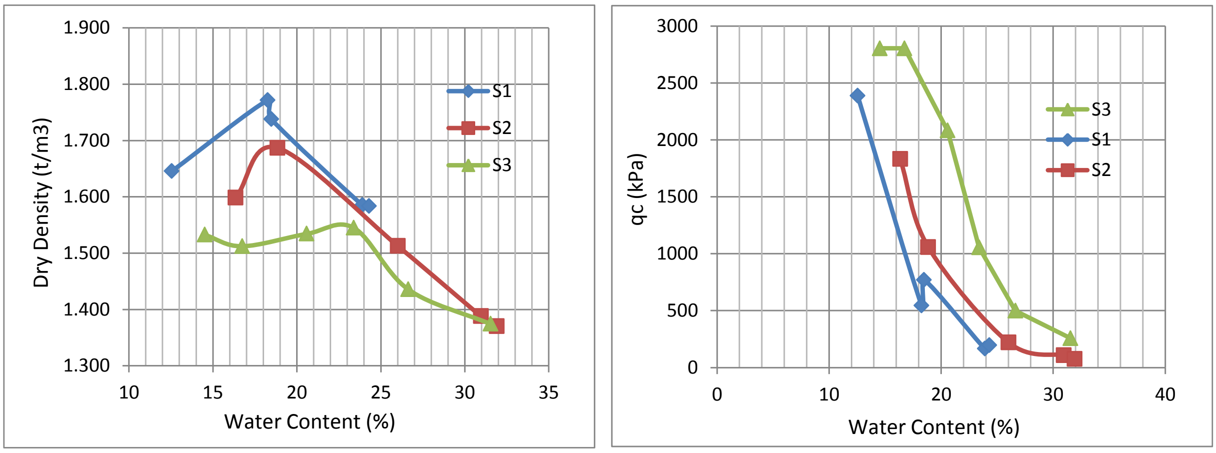
The results of the compaction testing of the S3 (southern site) samples (blue line) indicate the optimum moisture content to be around 22.5% and the maximum dry density to be 1.55 t/m^3. The qc value at the maximum dry density is 1050 kPa, values which satisfy qc ≥ 400 kPa. The highest qc value is around 2800 kPa, but this marks the maximum measurement capacity of the cone penetration test equipment used; the actual value was higher than this.



Source: JICA Study Team

Figure 3.3.9 Results of compaction test and cone index (S3)

A comparison of the characteristics of the three sites is shown in Figure 3.3.10.



(a) Compaction Curve

(b) Cone Index Curve

Source: JICA Study Team

Figure 3.3.10 Comparison of compaction curves and cone indices by site

The maximum dry density is lower at the southern site, and the moisture content is higher. The cone index curves show higher moisture content toward the south (S2 and S3 exhibit a similar strength with a moisture content that is respectively about 1% and 3% higher).

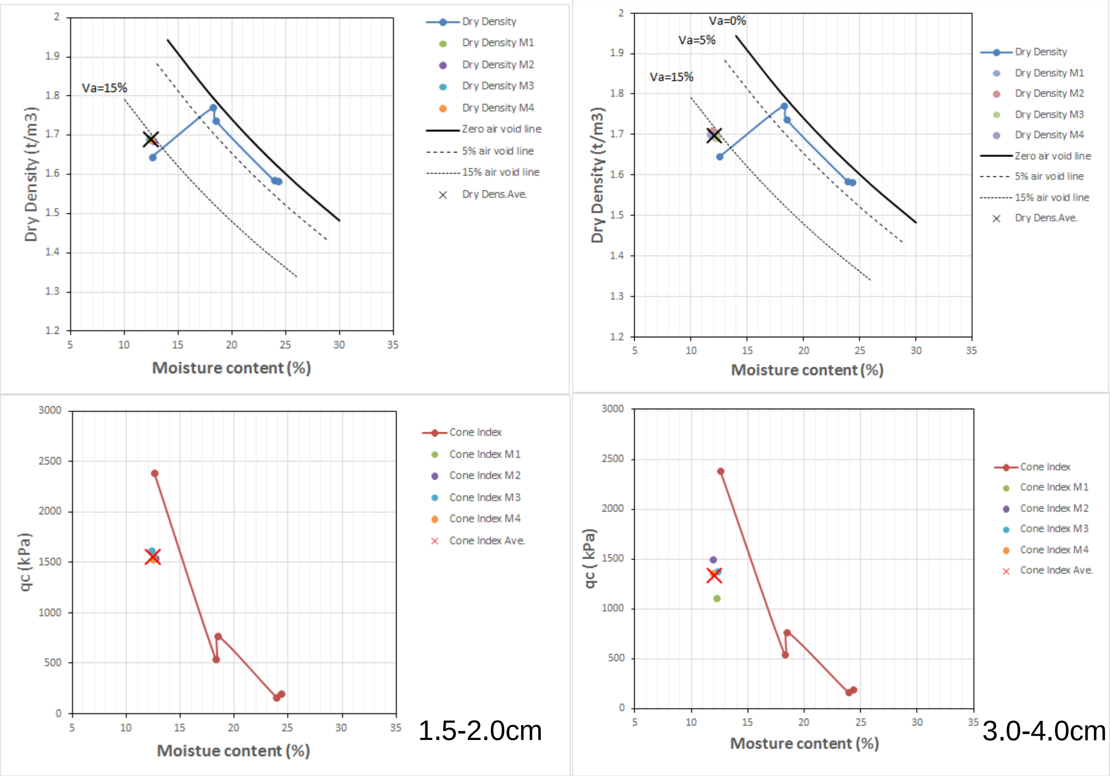
【Evaluation of hand-mixed samples】

The hand-mixed samples were prepared on the assumption that clay and sand mixing will be done by breaking stock pile with layered clay and sand in the construction of the diversion channel the embankment. Two type of samples were prepared, one in which there remained lamps of clay of up to 1.5 to 2 cm in size, and one in which larger pieces of clay, up to 3 to 4 cm, remained.

The moisture content of the sample was the optimum moisture content obtained by mixing in a mixer, and taking into account variations due to the uneven quality of the samples, 4 specimens of each sample were prepared and tested, and the average was calculated.

For the purpose of stability analysis of the diversion channel embankment, triaxial compression testing (CUB conditions) was carried out, but as the diameter of the triaxial compression test specimen was 3.7 cm, packing it with 4 cm lumps of clay would be meaningless. For this reason, only the samples containing blocks of clay measuring 1.5 to 2 cm were used in the triaxial compression testing. As a substitute, the 3 to 4 cm samples were compacted into molds with a diameter of 5 cm and unconfined compression testing was carried out.

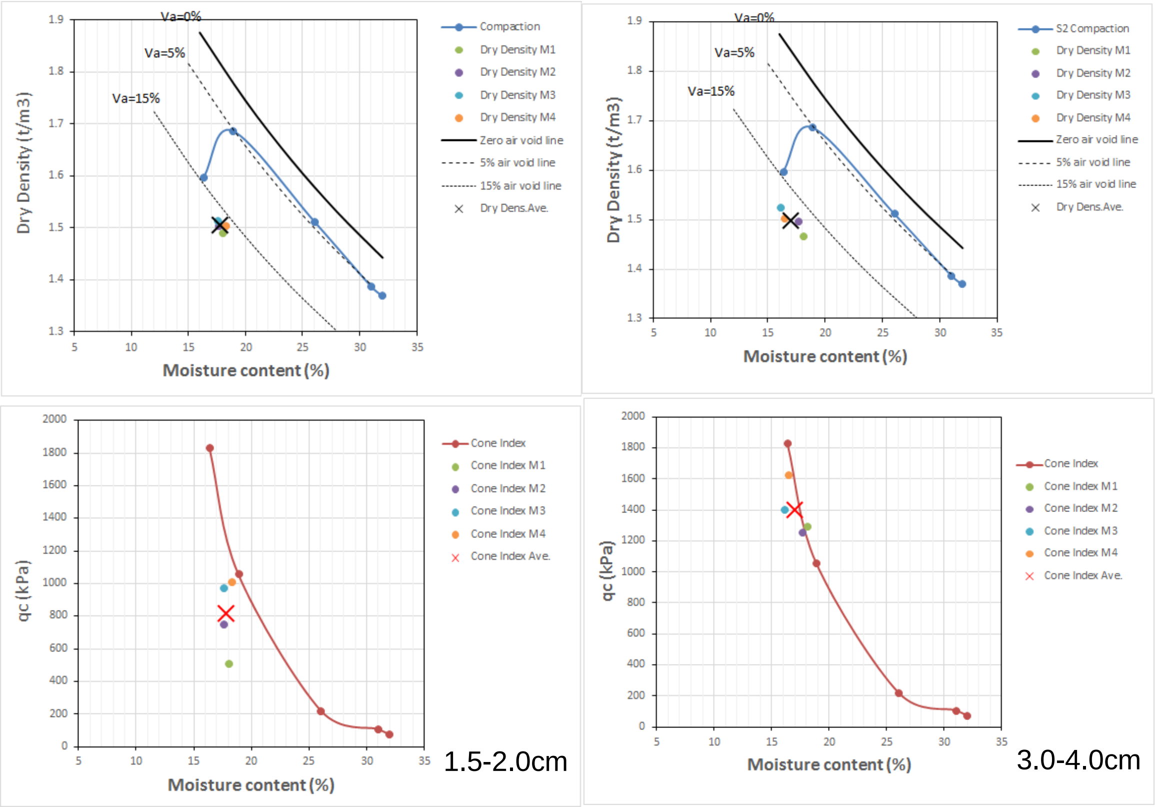
The results of the cone penetration testing carried out on the hand-mixed compacted samples are shown in Figures 3.3.11, 3.3.12, 3.3.13.



Source : JICA Study Team

Figure 3.3.11 Results of compaction and cone penetration testing of hand-mixed samples (S1)

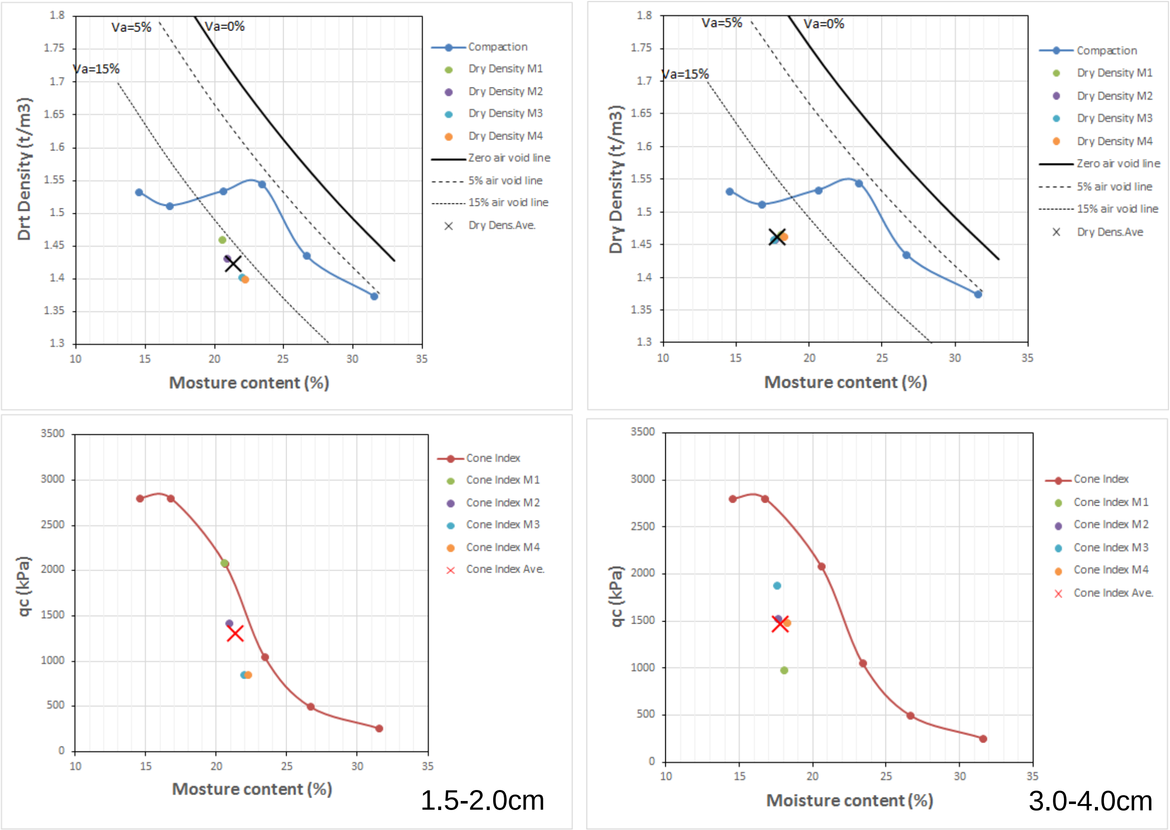
At S1, the same test results were obtained from the 1.5 to 2 cm samples and the 3 to 4 cm samples. In the case of hand-mixed samples, hardening of the sand content means that the gaps between the clay are not filled and larger air voids are formed so that it is considered inevitable that the dry density is greater; in the present testing, a greater dry density was indicated than with samples mixed with a mixer. The natural moisture content at this site is already low, at 30%; it is assumed that even with the mixer, the sand was not well blended. Despite the greater dry density, the cone penetration values are smaller than the values for samples mixed with a mixer. It is anticipated that when the soil is unevenly mixed the qc values will fall; in the case of soil containing 1.5 to 2 cm pieces of clay, a fall of 35%, and in the case of soil containing 3 to 4 cm pieces, a fall of 45%.



Source : JICA Study Team

Figure 3.3.12 Results of compaction and cone penetration testing of hand-mixed samples (S2)

The dry density soil containing 1.5 to 2 cm pieces of clay or 3 to 4 cm pieces are roughly 90% of the value of those obtained with the use of a mixer. Comparing the cone index that hand-mixing produces with that produced using a mixer, the cone value of hand-mixing with 1.5~2.0cm lumps is 70% of mixer mixing, however it is still more than 400kPa. In the case of 3 ~ 4.0cm lumps, cone values are almost the same as with a mixer and are also more than 400kPa.



1.5-2.0cm 3.0-4.0cm

Source : JICA Study Team

Figure 3.3.13 Results of compaction and cone penetration testing of hand-mixed samples (S3)

Comparing to the compaction curve of samples mixed with a mixer, hand-mixed samples containing maximum 1.5 to 2 cm lumps of clay showed some variation but had a dry density of 90 to 95%, and hand-mixed samples containing maximum 3 to 4 cm lumps of clay had a dry density of around 95%. Cone index values were between 55% and 100% for samples containing 1.5 to 2 cm lumps of clay and 40% to 70% for samples containing 3 to 4 cm lumps of clay and all of them showed more than 400kPa. In the testing carried out on the hand-mixed samples, the dry density was plotted around where the void ratio is 15%–20%, and it is thought that this is due to the uneven quality of the mixed sample.

Furthermore, there is a lot of variation in the cone penetration test results, and it is suggested that in the case of low-level mixing a drop in the cone index of around 30% must be expected.

【Evaluation as highway embankment material】

Exploitation of soil which is excavated from the diversion channel for using as the sub-base of the road embankment was confirmed by using mixed samples in the ratio of clay:sand=2:1, the same as the diversion channel embankment.

In exploit of subgrade for road embankment and roadbed material, the addition of quicklime was test to ensure reinforcement through the mixing of cement.

With a minimum CBR of 4 as the target for the sub-base material, testing was carried out on three grades of mix, with quicklime contents of 5%, 7% and 9%. The target for the roadbed material was a minimum unconfined compressive strength of 0.75 MPa, and testing was carried out by mixing with cement content of 8%.

CBR test results of the quick lime mixing test for S2 are shown in below Table 3.3.3

Table 3.3.3 CBR of Quick Lime Mixing for S2 (clay:sand=2:1 and Quick Lime = 5%, 7%, 9%)

Quick lime ratio	5%	7%	9%
Value of CBR	42.42	50.54	63.55

Source : JICA Study Team

It was confirmed that mixing soil (Clay:Sand=2:1) with 5% quick lime can be exploitation as sub-base material.

The results of testing of the cement mix samples are shown in the following table.

Table 3.3.4 Results of unconfined compression testing of cement mix samples (clay 2: sand:1 + cement 8%)

Test Item	S1	S2	S3
Density (t/m^3)	2.02	1.99	1.98
Moisture Contents (%)	17.35	15.27	17.47
Unconfined Consolidation Strength : qu (t/m^2)	18.41	23.61	25.45

Source : JICA Study Team

Expectedly, strength for roadbed material 0.75MPa is approximately 76 t/m^2. From this results it is difficult to use for roadbed material. Besides, there is another way to increase cement or increase sand mixing amount, however, it was considered difficult because it takes much reformation cost.

【Evaluation of the stability of the diversion channel embankment using mixed soil】

In order to evaluate the stability of the diversion channel embankment, consolidated undrained triaxial compression testing was carried out. The test results are shown in Table 3.3.5. The samples were mixed both by hand and mixer in the ratio of clay:sand =2:1.

Table 3.3.5 List of results of triaxial compression testing (CUB)

Test item	S1		S2		S3
Mixing Method	Mixer	Hand	Mixer	Hand	Mixer
Moisture content (%) (Before testing)	13.49	27.01	20.12	35.33	51.85
Density (t/m^3)	2.057	2.01	1.933	1.94	1.627
Effective shear stress C’cu (kPa)	25.86	26.30	2.61	22.97	16.01
Effective shear angle ⌀'cu (°)	19.81	22.88	31.62	18.07	24.68
Shear stress C’cu (kPa)	15.34	14.60	10.34	12.63	7.80
Shear angle ⌀'cu (°)	19.27	19.94	18.98	17.83	20.85

Source: JICA Study Team

With respect to the hand-mixed samples, as the diameter of the triaxial compression test mold is only 3.7 cm, testing was carried out only on samples containing beads of clay no larger than 1.5 to 2 cm.

For reference purposes, with respect to the hand-mixed samples, unconfined compression testing was carried out separately on specimens made in a large (⌀50 mm) mold. The test results are shown in the Table 3.3.6 below. As the specimens contained unevenly mixed clay and sand, the values given are the averages taken from experiments on three specimens.

Table 3.3.6 Results of unconfined compression testing of hand-mixed sample (1.5–2.0 cm)

Test Item	S1			S2			S3		
Density (t/m^3)	1.96	1.94	1.95	1.84	1.98	1.99	1.89	1.88	1.84
	1.95			1.94			1.87		
Moisture Contents (%)	18.48	17.36	17.23	22.06	20.40	18.92	22.59	19.46	21.41
	17.69			20.46			21.15		
Unconfined compressive strength : qu (t/m^2)	21.22	10.60	23.26	8.11	9.87	12.33	12.05	19.33	12.39
	18.36			10.10			14.59		

Source: JICA Study Team

Soil test results are shown in Appendix 3 at the end of this report.

Chapter 3: Appendix

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BORING LOG

PROJECT : **Data Collection Survey on The Outer Ring Road diversion channel in The Comprehensive Flood Management Plan of Chao Phaya River Basin in The Kingdom of Thailand**

LOCATION : **Phra Nakhon Si Ayutthaya**

BORING NO : **BH-1**

TOTAL DEPTH : 40.45 m

N : 1,577,584

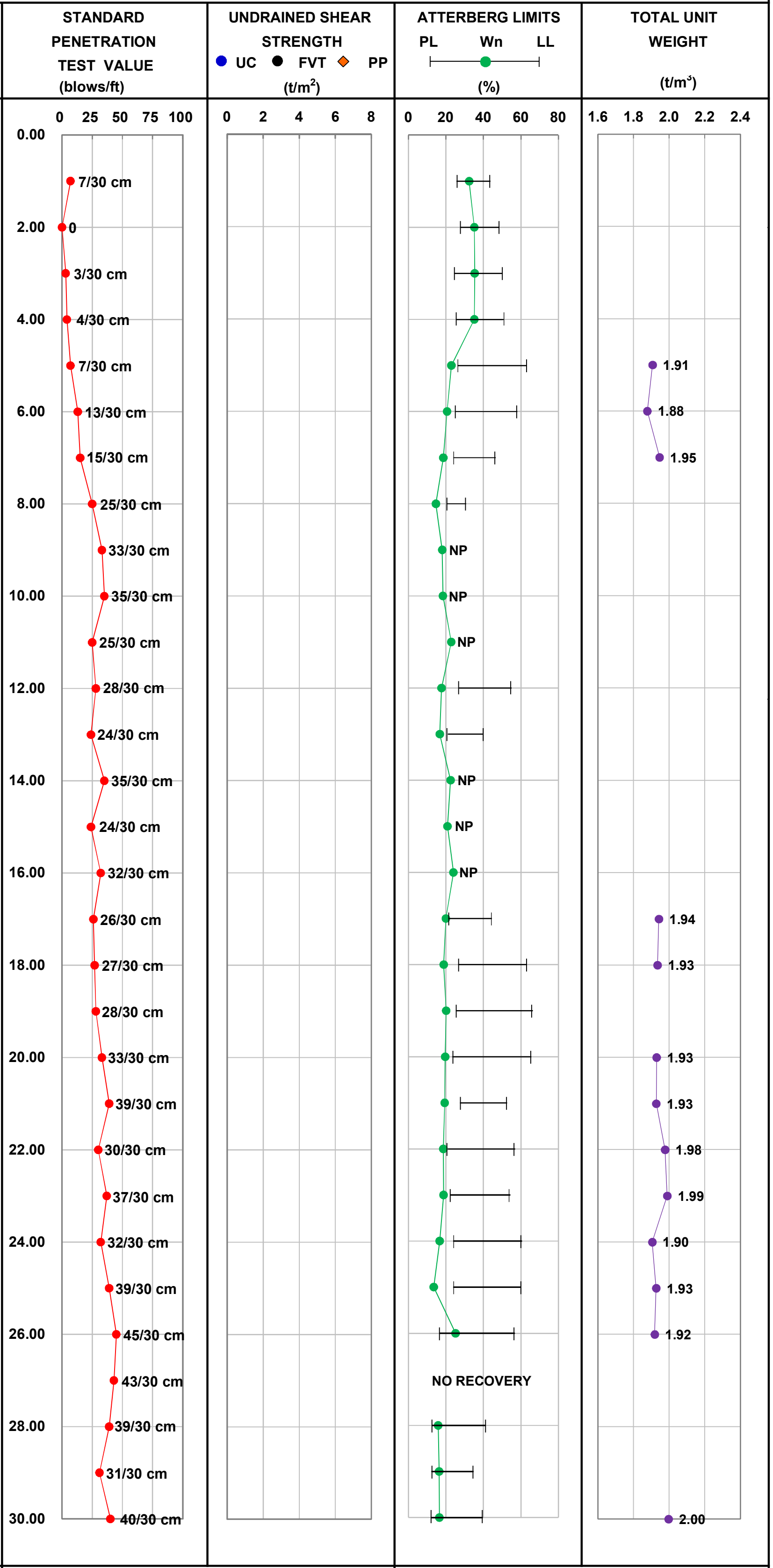
E : 680,016

BORING STARTED : **11/5/2017**

BORING COMPLETED : **12/5/2017**

GROUND WATER LEVEL **-1.50 m**

DEPTH (m)	SOIL DESCRIPTION	METHOD	SAMPLE NO	SPT-N (blows/ft)
0.00-	Ground Surface			
-	**(0.00 - 2.00 m) Silty CLAY (CH)** Grey, medium, high plasticity.	WO		
-		SS	1	7/30 cm
-		WO		
2.00-	**(2.00 - 3.00 m) Silty CLAY (CL)** Grey, very soft, low plasticity.	SS	2	0/45 cm
-		WO		
-	**(3.00 - 5.00 m) Silty CLAY (CH)** Grey, soft, high plasticity. ***SS-4*** is Silty CLAY trace to some gravel (CH)	SS	3	3/30 cm
-		WO		
4.00-		SS	4	4/30 cm
-		WO		
-	**(5.00 - 6.00 m) Silty CLAY (CH)** Grey, medium, high plasticity.	SS	5	7/30 cm
-		WO		
6.00-	**(6.00 - 7.00 m) Silty CLAY (CH)** Brown, stiff, high plasticity.	SS	6	13/30 cm
-		WO		
-	**(7.00 - 8.00 m) Silty CLAY (CL)** Brown, stiff, low plasticity.	SS	7	15/30 cm
-		WO		
8.00-	**(8.00 - 9.00 m) Clayey SAND (SC)** Brown, medium dense, fine to coarse grained.	SS	8	25/30 cm
-		WO		
-		SS	9	33/30 cm
-	**(9.00 - 12.00 m) Silty SAND (SM)** Brown, medium dense to dense, fine to coarse grained.	WO		
10.00-		SS	10	35/30 cm
-		WO		
-		SS	11	25/30 cm
-		WO		
12.00-	**(12.00 - 13.00 m) Silty CLAY (CH)** Brown, very stiff, high plasticity.	SS	12	28/30 cm
-		WO		
-	**(13.00 - 14.00 m) Silty CLAY (CL)** Brown, very stiff, low plasticity.	SS	13	24/30 cm
-		WO		
14.00-	**(14.00 - 17.00 m) Silty SAND (SM)** Brown, medium dense to dense, fine grained.	SS	14	35/30 cm
-		WO		
-		SS	15	24/30 cm
-		WO		
16.00-		SS	16	32/30 cm
-		WO		
-	**(17.00 - 18.00 m) Silty CLAY (CL)** Brown, very stiff, low plasticity.	SS	17	26/30 cm
-		WO		
18.00-	**(18.00 - 28.00 m) Silty CLAY (CH)** Brown, very stiff to hard, high plasticity	SS	18	27/30 cm
-		WO		
-		SS	19	28/30 cm
-		WO		
20.00-		SS	20	33/30 cm
-		WO		
-		SS	21	39/30 cm
-		WO		
22.00-		SS	22	30/30 cm
-		WO		
-		SS	23	37/30 cm
-		WO		
24.00-		SS	24	32/30 cm
-		WO		
-		SS	25	39/30 cm
-		WO		
26.00-		SS	26	45/30 cm
-		WO		
-		SS	27	43/30 cm
-		WO		
28.00-	**(28.00 - 29.00 m) Silty CLAY (CL)** Brown, hard, low plasticity.	SS	28	39/30 cm
-		WO		
-	**(29.00 - 30.00 m) Clayey SAND (SC)** Brown, dense, fine to medium grained.	SS	29	31/30 cm
-		WO		
30.00-		SS	30	40/30 cm



■	Thin Wall Tube	☐	Wash Out
⧗	Split Spoon	⊟	Augering

UC : Unconfined Compression Test
FVT : Field Vane Shear Test
PP : Pocket Penetrometer Test

PL : Plastic Limit
Wn : Natural Water Content
LL : Liquid Limit

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BORING LOG

PROJECT : Data Collection Survey on The Outer Ring Road diversion channel in The Comprehensive Flood Management Plan of Chao Phaya River Basin in The Kingdom of Thailand

BORING STARTED : 11/5/2017

LOCATION : Phra Nakhon Si Ayutthaya

N : 1,577,584

BORING COMPLETED : 12/5/2017

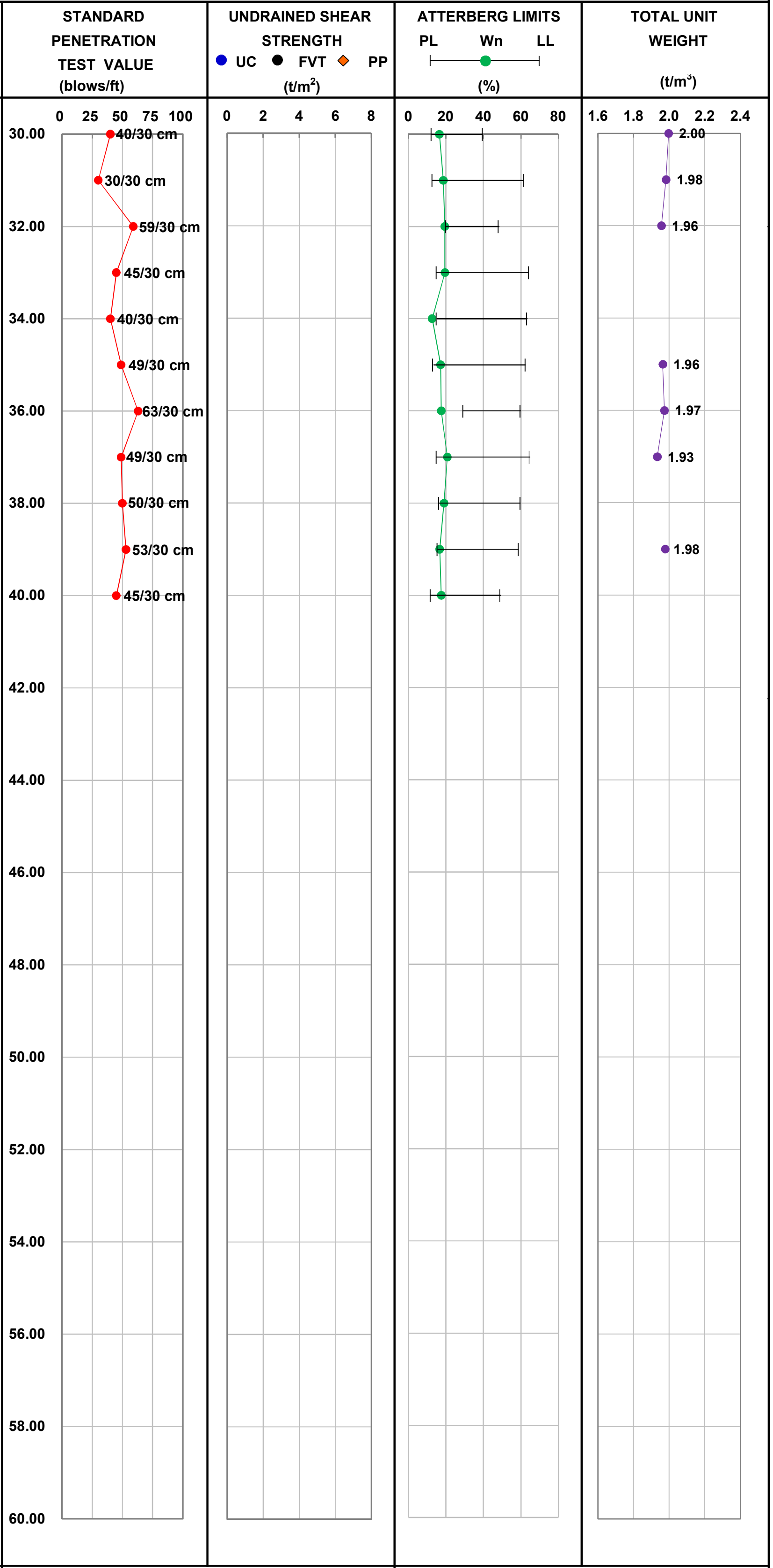
BORING NO : BH-1

TOTAL DEPTH : 40.45 m

E : 680,016

GROUND WATER LEVEL -1.50 m

DEPTH (m)	SOIL DESCRIPTION	SOIL SYMBOL	METHOD	SAMPLE NO	RECOVERY	SPT-N (blows/ft)
30.00	**(30.00 - 31.00 m) Silty CLAY (CL)** Brown, hard, low plasticity.	▨	SS	30	⧗	40/30 cm
			WO			
	(31.00 - 32.00 m) Silty CLAY (CH) Brown, very stiff, high plasticity.	▨	SS	31	⧗	30/30 cm
			WO			
32.00	**(32.00 - 33.00 m) Silty CLAY (CL)** Brown, hard, low plasticity.	▨	SS	32	⧗	59/30 cm
			WO			
	(33.00 - 34.00 m) Silty CLAY (CH) Brown, hard, high plasticity.	▨	SS	33	⧗	45/30 cm
			WO			
34.00	**(34.00 - 35.00 m) Clayey SAND (SC)** Brown, medium dense, fine to coarse grained.		SS	34	⧗	40/30 cm
			WO			
	(35.00 - 40.00 m) Silty CLAY (CH) Brown, hard, high plasticity. ***SS-36*** is Silty CLAY trace gravel (CH)	▨	SS	35	⧗	49/30 cm
			WO			
36.00			SS	36	⧗	63/30 cm
			WO			
			SS	37	⧗	49/30 cm
			WO			
38.00			SS	38	⧗	50/30 cm
			WO			
			SS	39	⧗	53/30 cm
			WO			
40.00	**(40.00 - 40.45 m) Silty CLAY (CL)** Brown, hard, low plasticity.	▨	SS	40	⧗	45/30 cm
	End of boring 40.45 m					
42.00						
44.00						
46.00						
48.00						
50.00						
52.00						
54.00						
56.00						
58.00						
60.00						



■ Thin Wall Tube

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⧗ Split Spoon

⬒ Augering

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BORING LOG

PROJECT : Data Collection Survey on The Outer Ring Road diversion channel in The Comprehensive Flood Management Plan of Chao Phaya River Basin in The Kingdom of Thailand

LOCATION : Nong Chok , Bangkok

BORING NO : BH-2

TOTAL DEPTH : 40.45 m

N : 1,538,721

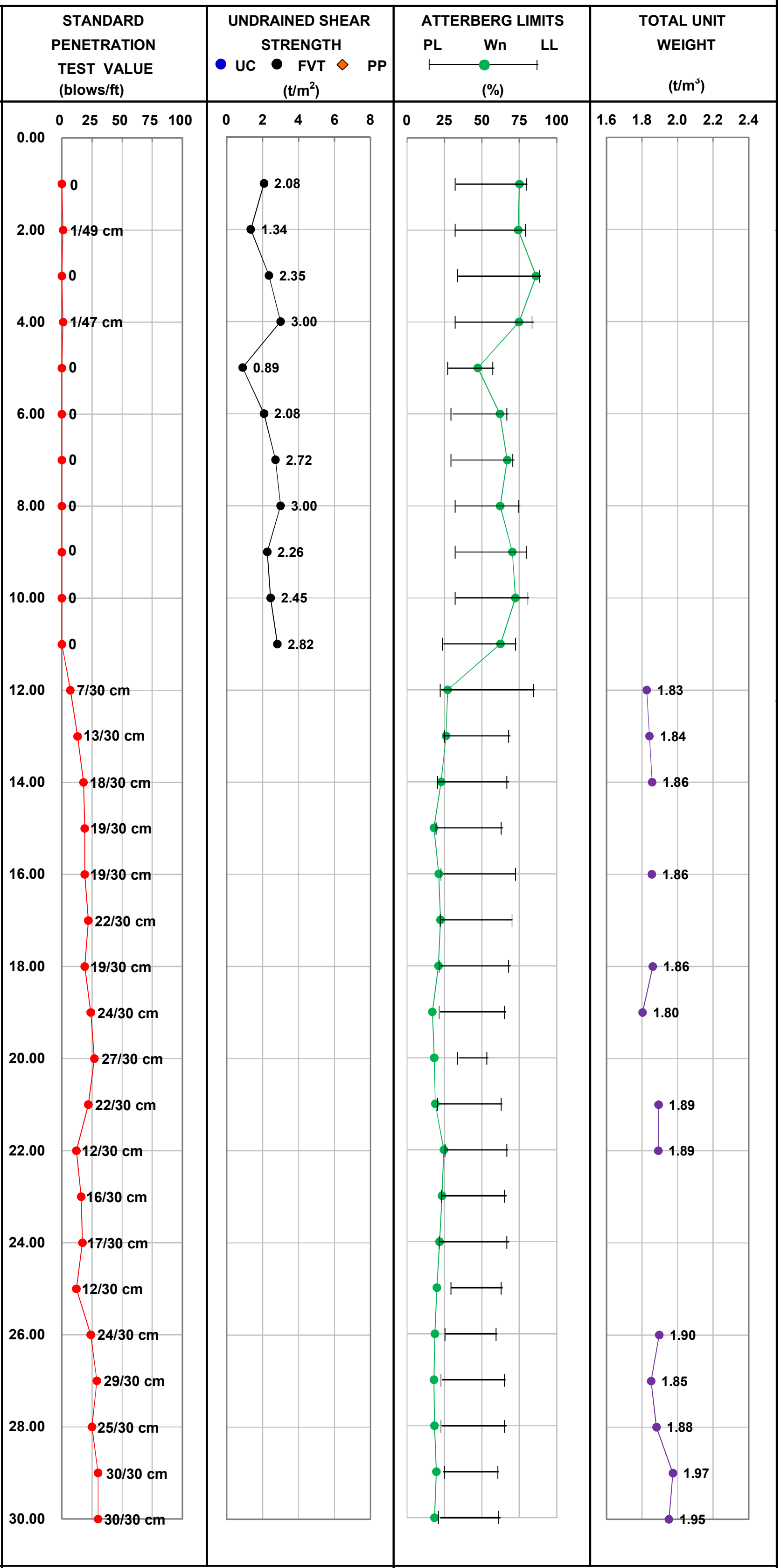
E : 698,582

BORING STARTED : 8/5/2017

BORING COMPLETED : 9/5/2017

GROUND WATER LEVEL : -1.50 m

DEPTH (m)	SOIL DESCRIPTION	SOIL SYMBOL	METHOD	SAMPLE NO	RECOVERY	SPT-N (blows/ft)
	Ground Surface					
0.00-	(0.00 - 12.00 m) CLAY (CH) Grey, very soft, high plasticity.	▨				
			WO			
			SS	1	⧗	0/45 cm
			WO			
2.00-			SS	2	⧗	1/49 cm
			WO			
			SS	3	⧗	0/45 cm
			WO			
4.00-			SS	4	⧗	1/47 cm
			WO			
			SS	5	⧗	0/45 cm
			WO			
6.00-			SS	6	⧗	0/45 cm
			WO			
			SS	7	⧗	0/45 cm
			WO			
8.00-			SS	8	⧗	0/45 cm
			WO			
			SS	9	⧗	0/45 cm
			WO			
10.00-			SS	10	⧗	0/45 cm
			WO			
			SS	11	⧗	0/45 cm
			WO			
12.00-	(12.00 - 13.00 m) CLAY (CH) Grey, medium, high plasticity.	▨	SS	12	⧗	7/30 cm
			WO			
	(13.00 - 20.00 m) CLAY (CH) Grey, stiff to very stiff, high plasticity.	▨	SS	13	⧗	13/30 cm
			WO			
14.00-			SS	14	⧗	18/30 cm
			WO			
			SS	15	⧗	19/30 cm
			WO			
16.00-			SS	16	⧗	19/30 cm
			WO			
			SS	17	⧗	22/30 cm
			WO			
18.00-			SS	18	⧗	19/30 cm
			WO			
			SS	19	⧗	24/30 cm
			WO			
20.00-	(20.00 - 21.00 m) Clayey SILT (MH) Brown, very stiff, high plasticity.	▥	SS	20	⧗	27/30 cm
			WO			
	(21.00 - 25.00 m) Silty CLAY (CH) Brown, grey, stiff to very stiff, high plasticity.	▨	SS	21	⧗	22/30 cm
			WO			
22.00-			SS	22	⧗	12/30 cm
			WO			
			SS	23	⧗	16/30 cm
			WO			
24.00-			SS	24	⧗	17/30 cm
			WO			
	(25.00 - 26.00 m) Clayey SILT (MH) Grey, stiff, high plasticity.	▥	SS	25	⧗	12/30 cm
			WO			
26.00-	(26.00 - 33.00 m) Silty CLAY (CH) Brown, greyish brown, very stiff, high plasticity. *SS-31* is Sandy CLAY (CH)	▨	SS	26	⧗	24/30 cm
			WO			
			SS	27	⧗	29/30 cm
			WO			
28.00-			SS	28	⧗	25/30 cm
			WO			
			SS	29	⧗	30/30 cm
			WO			
30.00-			SS	30	⧗	30/30 cm



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BORING LOG

PROJECT : Data Collection Survey on The Outer Ring Road diversion channel in The Comprehensive Flood Management Plan of Chao Phaya River Basin in The Kingdom of Thailand

LOCATION : Nong Chok , Bangkok

BORING NO : BH-2

TOTAL DEPTH : 40.45 m

N : 1,538,721

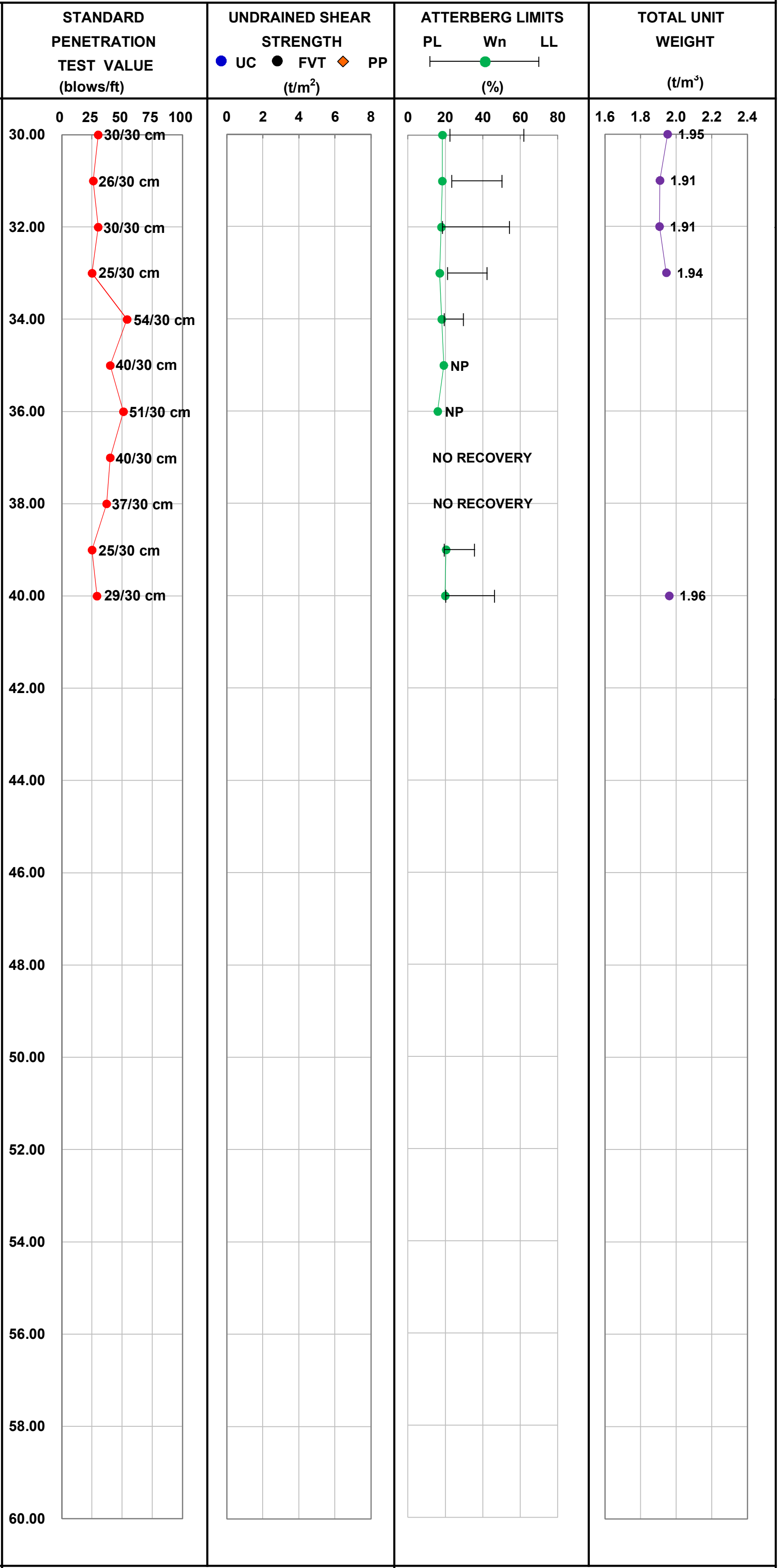
E : 698,582

BORING STARTED : 8/5/2017

BORING COMPLETED : 9/5/2017

GROUND WATER LEVEL : -1.50 m

DEPTH (m)	SOIL DESCRIPTION	SOIL SYMBOL	METHOD	SAMPLE NO	RECOVERY	SPT-N (blows/ft)
30.00		▨	SS	30	⧗	30/30 cm
			WO			
			SS	31	⧗	26/30 cm
	Same As Above		WO			
32.00			SS	32	⧗	30/30 cm
			WO			
	(33.00 - 34.00 m) Silty CLAY (CL) Brown, very stiff, low plasticity.	▨	SS	33	⧗	25/30 cm
			WO			
34.00	(34.00 - 35.00 m) Clayey SAND (SC) Brown, very dense, fine grained.	▨	SS	34	⧗	54/30 cm
			WO			
	(35.00 - 39.00 m) Silty SAND (SM) Brown, dense to very dense, fine to medium grained.	▨	SS	35	⧗	40/30 cm
			WO			
36.00			SS	36	⧗	51/30 cm
			WO			
			SS	37		40/30 cm
			WO			
38.00			SS	38		37/30 cm
			WO			
	(39.00 - 40.45 m) Silty CLAY (CL) Brown, very stiff, low plasticity.	▨	SS	39	⧗	25/30 cm
			WO			
40.00			SS	40	⧗	29/30 cm
	End of boring 40.45 m					
42.00						
44.00						
46.00						
48.00						
50.00						
52.00						
54.00						
56.00						
58.00						
60.00						



■ Thin Wall Tube

☐ Wash Out

⧗ Split Spoon

▤ Augering

UC : Unconfined Compression Test

FVT : Field Vane Shear Test

PP : Pocket Penetrometer Test

PL : Plastic Limit

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BORING LOG

PROJECT : Data Collection Survey on The Outer Ring Road diversion channel in The Comprehensive Flood Management Plan of Chao Phaya River Basin in The Kingdom of Thailand

BORING STARTED : 5/5/2017

LOCATION : Bang Bo, Samut Prakan

N : 1,494,868

BORING COMPLETED : 6/5/2017

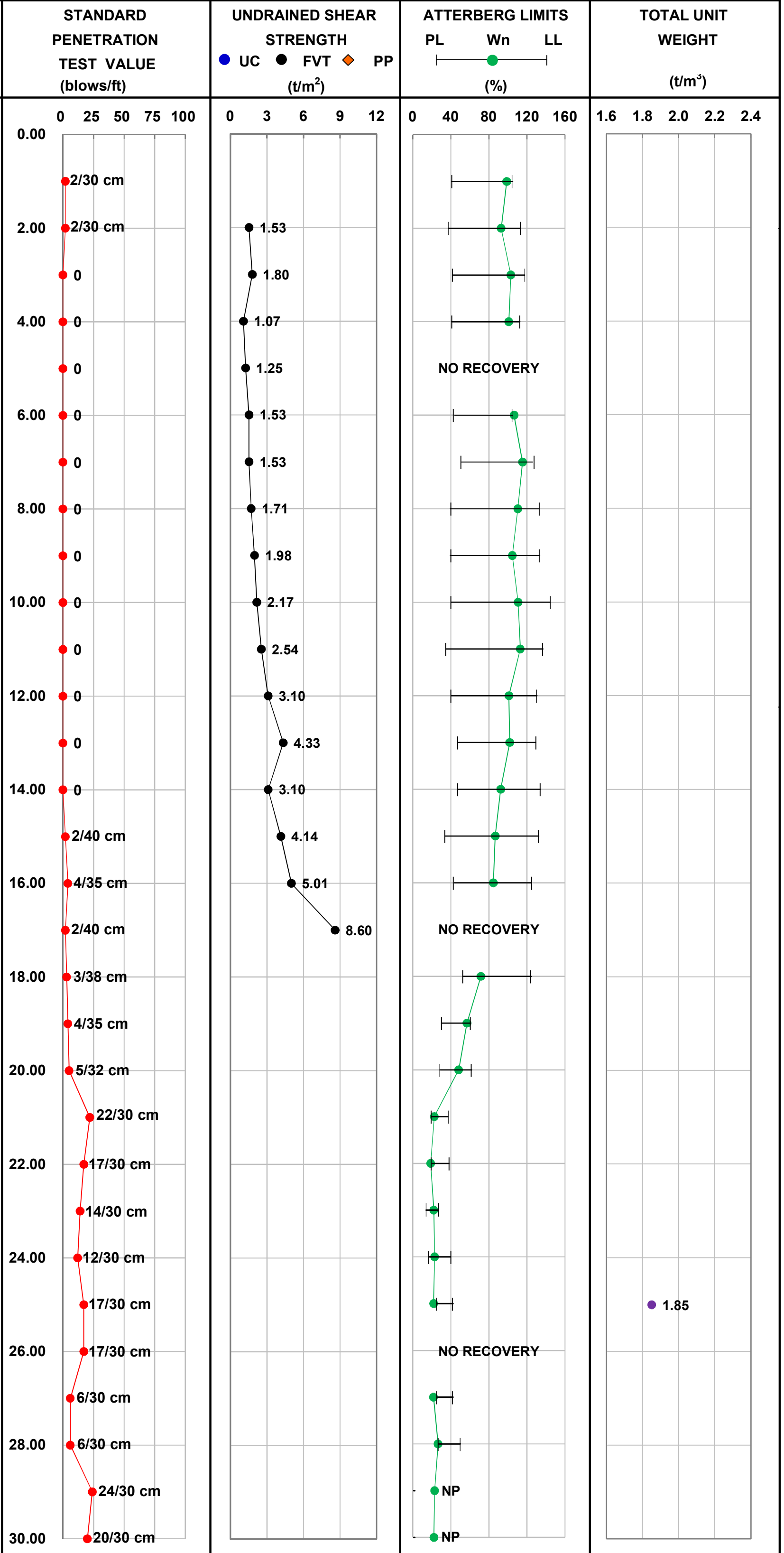
BORING NO : BH-3

TOTAL DEPTH : 40.45 m

E : 696,090

GROUND WATER LEVEL -1.20 m

DEPTH (m)	SOIL DESCRIPTION	SOIL SYMBOL	METHOD	SAMPLE NO	RECOVERY	SPT-N (blows/ft)
0.00	Ground Surface					
	(0.00 - 6.00 m) CLAY (CH) Grey, very soft, high plasticity. *SS-2* is Silty CLAY trace to some gravel (CH)		WO			
			SS	1	⧗	2/30 cm
			WO			
2.00			SS	2	⧗	2/30 cm
			WO			
			SS	3	⧗	0/45 cm
			WO			
4.00			SS	4	⧗	0/45 cm
			WO			
			SS	5	-	0/45 cm
			WO			
6.00			SS	6	⧗	0/45 cm
	(6.00 - 8.00 m) SILT (MH), Clayey SILT trace gravel (MH) Grey, very soft, high plasticity.		WO			
			SS	7	⧗	0/45 cm
			WO			
8.00			SS	8	⧗	0/45 cm
	(8.00 - 18.00 m) CLAY (CH) Grey, very soft to soft, high plasticity.		WO			
			SS	9	⧗	0/45 cm
			WO			
10.00			SS	10	⧗	0/45 cm
			WO			
			SS	11	⧗	0/45 cm
			WO			
12.00			SS	12	⧗	0/45 cm
			WO			
			SS	13	⧗	0/45 cm
			WO			
14.00			SS	14	⧗	0/45 cm
			WO			
			SS	15	⧗	2/40 cm
			WO			
16.00			SS	16	⧗	4/35 cm
			WO			
			SS	17	-	2/40 cm
			WO			
18.00			SS	18	⧗	3/38 cm
	(18.00 - 19.00 m) SILT (MH) Grey, soft, high plasticity.		WO			
	(19.00 - 20.00 m) Silty CLAY (CH) Grey, soft, high plasticity.		SS	19	⧗	4/35 cm
			WO			
20.00			SS	20	⧗	5/32 cm
	(20.00 - 21.00 m) Silty CLAY (CH) Grey, medium, high plasticity.		WO			
	(21.00 - 22.00 m) Sandy CLAY (CL) Grey, very stiff, low plasticity.		SS	21	⧗	22/30 cm
			WO			
22.00			SS	22	⧗	17/30 cm
	(22.00 - 24.00 m) Clayey SAND (SC) Brown, medium dense, fine to coarse grained.		WO			
			SS	23	⧗	14/30 cm
			WO			
24.00			SS	24	⧗	12/30 cm
	(24.00 - 27.00 m) Silty CLAY (CL) Brown, stiff to very stiff, low plasticity.		WO			
			SS	25	⧗	17/30 cm
			WO			
26.00			SS	26	-	17/30 cm
			WO			
	(27.00 - 29.00 m) Silty CLAY (CL) Brown, medium, low plasticity.		SS	27	⧗	6/30 cm
			WO			
28.00			SS	28	⧗	6/30 cm
			WO			
	(29.00 - 31.00 m) Silty SAND (SM) Grey, medium dense, fine grained.		SS	29	⧗	24/30 cm
			WO			
30.00			SS	30	⧗	20/30 cm



■ Thin Wall Tube

☐ Wash Out

⧗ Split Spoon

⬒ Augering

UC : Unconfined Compression Test
FVT : Field Vane Shear Test
PP : Pocket Penetrometer Test

PL : Plastic Limit
Wn : Natural Water Content
LL : Liquid Limit

BORING LOG

PROJECT : Data Collection Survey on The Outer Ring Road diversion channel in The Comprehensive Flood Management Plan of Chao Phaya River Basin in The Kingdom of Thailand

LOCATION : Bang Bo, Samut Prakan

BORING NO : BH-3

TOTAL DEPTH : 40.45 m

N : 1,494,868

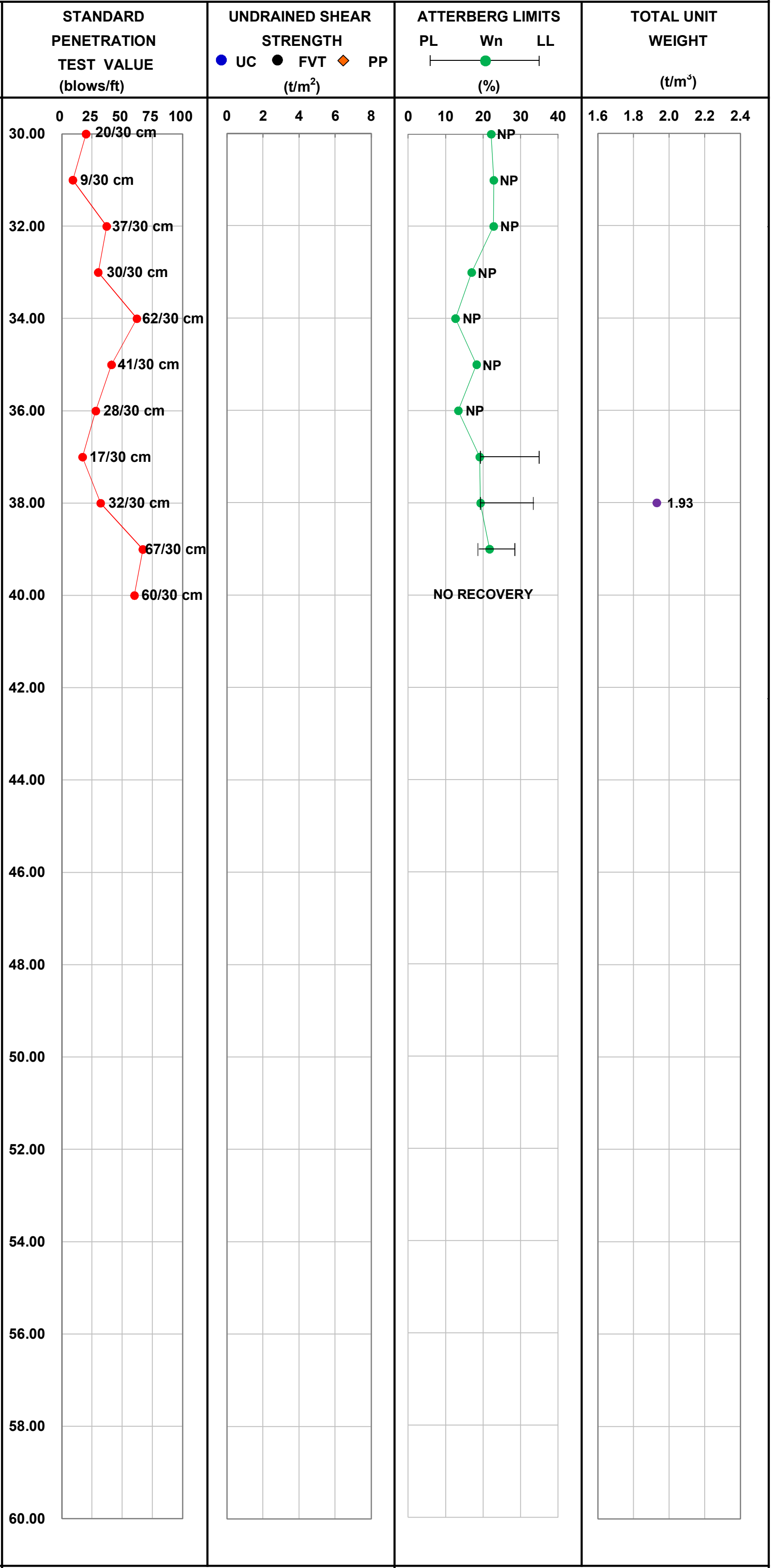
E : 696,090

BORING STARTED : 5/5/2017

BORING COMPLETED : 6/5/2017

GROUND WATER LEVEL -1.20 m

DEPTH (m)	SOIL DESCRIPTION	METHOD	SAMPLE NO	SPT-N (blows/ft)
30.00	Same As Above	SS	30	20/30 cm
		WO		
	(31.00 - 32.00 m) Silty SAND (SM) Grey, loose, fine grained.	SS	31	9/30 cm
		WO		
32.00	(32.00 - 33.00 m) Poorly Graded Silty SAND (SP-SM) Brown, dense, fine graine	SS	32	37/30 cm
		WO		
	(33.00 - 35.00 m) Silty SAND (SM) Brown, medium dense to very dense, fine to coarse grained.	SS	33	30/30 cm
		WO		
34.00		SS	34	62/30 cm
		WO		
	(35.00 - 37.00 m) Poorly Graded Silty SAND (SP-SM), Well Graded Silty SAND (SW-SM) Brown, medium dense to dense, fine to coarse grained.	SS	35	41/30 cm
		WO		
36.00		SS	36	28/30 cm
		WO		
	(37.00 - 38.00 m) Clayey SAND some gravel (SC) Brown, medium dense, fine to coarse grained.	SS	37	17/30 cm
		WO		
38.00	(38.00 - 39.00 m) Sandy CLAY (CL) Brown, hard, low plasticity.	SS	38	32/30 cm
		WO		
	(39.00 - 40.45 m) Clayey SAND (SC) Brown, very dense, fine grained.	SS	39	67/30 cm
		WO		
40.00		SS	40	60/30 cm
	End of boring 40.45 m			
42.00				
44.00				
46.00				
48.00				
50.00				
52.00				
54.00				
56.00				
58.00				
60.00				



■ Thin Wall Tube

☐ Wash Out

⧗ Split Spoon

▬ Augering

UC : Unconfined Compression Test
FVT : Field Vane Shear Test
PP : Pocket Penetrometer Test

PL : Plastic Limit
Wn : Natural Water Content
LL : Liquid Limit

FIELD VANE SHEAR TEST RESULTS

Project : Data Collection Survey on the Outer Ring Road Diversion Channel

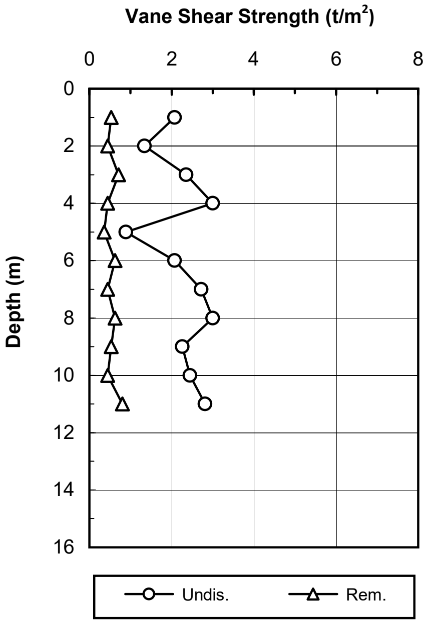
Location : Nong Jok District, Bangkok **Job no.:**

Station : VS-2 **Serial Geonor no. :** 2593 **Date :** 10-May-17

Co-ordinate by handheld GPS : E 698585 N 1538725

Depth(m)	Su_{FV} (undis)	Su_{FV} (rem)	S_t	Vane Size ,mm
1.0	2.08	0.53	3.9	55x110
2.0	1.34	0.44	3.0	55x110
3.0	2.35	0.71	3.3	55x110
4.0	3.00	0.44	6.8	55x110
5.0	0.89	0.35	2.5	55x110
6.0	2.08	0.62	3.3	55x110
7.0	2.72	0.44	6.1	55x110
8.0	3.00	0.62	4.8	55x110
9.0	2.26	0.53	4.2	55x110
10.0	2.45	0.44	5.5	55x110
11.0	2.82	0.80	3.5	55x110
11.4	Can't push below this level.			

Note: 0.00 - 0.50 m Silty CLAY, li-greyish brown. (Top Soil)



Notes:

(i) Su_{FV} (Undis) = Undisturbed Field Vane Shear Strength

(ii) Su_{FV} (Rem) = Remolded Field Vane Shear Strength

(iii) Su_{FV} (Undis) and Su_{FV} (Rem) are in t/m^2

(iiii) Sensitivity , S_t = Su_{FV} (Undis) / Su_{FV} (Rem)

STS Instruments Company Limited

FIELD VANE SHEAR TEST RESULTS

Project : Data Collection Survey on the Outer Ring Road Diversion Channel

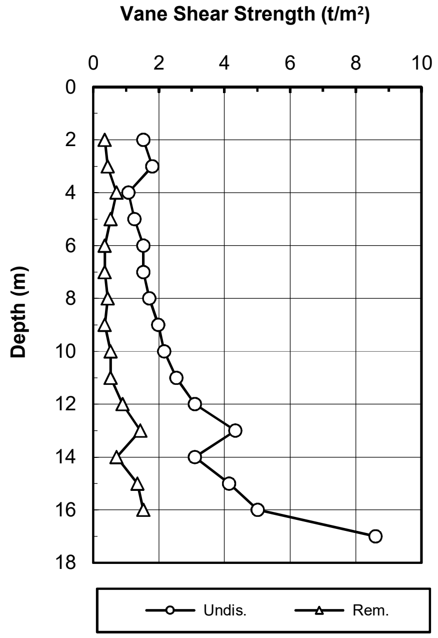
Location : Bang Bo District, Samutprakarn Province **Job no.:**

Station : VS-3 **Serial Geonor no. :** 2593 **Date :** 26-May-17

Co-ordinate by handheld GPS : E 696088 N 1494868

Depth(m)	Su_{FV} (undis)	Su_{FV} (rem)	S_t	Vane Size ,mm
2.0	1.53	0.35	4.3	55x110
3.0	1.80	0.44	4.1	55x110
4.0	1.07	0.71	1.5	55x110
5.0	1.25	0.53	2.4	55x110
6.0	1.53	0.35	4.3	55x110
7.0	1.53	0.35	4.3	55x110
8.0	1.71	0.44	3.8	55x110
9.0	1.98	0.35	5.6	55x110
10.0	2.17	0.53	4.1	55x110
11.0	2.54	0.53	4.8	55x110
12.0	3.10	0.89	3.5	55x110
13.0	4.33	1.43	3.0	55x110
14.0	3.10	0.71	4.3	55x110
15.0	4.14	1.34	3.1	55x110
16.0	5.01	1.53	3.3	55x110
17.0	8.60			
17.9	Can't push below this level.			

Note: 0.00 - 1.50 m Fine Sandy Clay, Lateritic Soil (Fill)



Notes:

(i) Su_{FV} (Undis) = Undisturbed Field Vane Shear Strength

(ii) Su_{FV} (Rem) = Remolded Field Vane Shear Strength

(iii) Su_{FV} (Undis) and Su_{FV} (Rem) are in t/m^2

(iiii) Sensitivity , S_t = Su_{FV} (Undis) / Su_{FV} (Rem)

STS Instruments Company Limited

SUMMARY OF TEST RESULTS

Project : Data Collection Survey on The Outer Ring Road diversion channel
in The Comprehensive Flood Management Plan of Chao Phaya River
Basin in The Kingdom of Thailand

Date of Boring : 11-12/5/2017
Boring No : BH-1
Location : Phra Nakhon Si Ayutthaya

Ground Water Level (m): -1.50
North : 1,577,584 **East :** 680,016

Sample	Depth ,m		Wn	Atterberg Limits (%)			Grain Size Analysis						USCS	γ_t	S_U	SPT-N ,(blows/inch)			N value
No.	From	To	(%)	LL	PL	PI	3/8"	#4	#10	#40	#100	#200	Group	(t/m^3)	(t/m^2)	1st	2nd	3rd	
SS-1	1.00	1.45	32.46	43.56	25.93	17.63	100.00	100.00	99.80	99.38	99.10	98.75	CL			0/15	3/15	4/15	7/30
SS-2	2.00	2.45	35.18	48.33	28.02	20.31	100.00	100.00	98.90	97.05	91.42	85.47	CL			-	-	-	0/45
SS-3	3.00	3.45	35.37	50.09	24.65	25.44	100.00	100.00	98.34	97.75	96.86	94.84	CH			0/15	1/15	2/15	3/30
SS-4	4.00	4.45	35.15	50.56	25.78	24.78	89.58	89.22	87.32	85.62	84.19	82.22	CH			0/15	2/15	2/15	4/30
SS-5	5.00	5.45	22.93	62.97	26.45	36.52	100.00	100.00	99.87	99.44	99.23	98.26	CH	1.91		0/15	3/15	4/15	7/30
SS-6	6.00	6.45	20.69	57.93	25.43	32.50	100.00	100.00	100.00	99.63	99.10	96.73	CH	1.88		0/15	6/15	7/15	13/30
SS-7	7.00	7.45	18.63	46.37	24.37	22.00	100.00	100.00	100.00	99.54	93.48	77.63	CL	1.95		0/15	7/15	8/15	15/30
SS-8	8.00	8.45	14.66	30.55	20.56	9.99	100.00	96.23	89.92	53.12	43.33	34.84	SC			5/15	8/15	17/15	25/30
SS-9	9.00	9.45	18.04	NP	NP	NP	100.00	96.84	90.69	45.87	31.13	26.70	SM			13/15	15/15	18/15	33/30
SS-10	10.00	10.45	18.40	NP	NP	NP	100.00	95.40	87.55	26.83	17.34	14.65	SM			16/15	17/15	18/15	35/30
SS-11	11.00	11.45	22.89	NP	NP	NP	100.00	100.00	98.37	52.36	22.38	18.53	SM			12/15	12/15	13/15	25/30
SS-12	12.00	12.45	17.68	54.80	27.14	27.66	100.00	100.00	100.00	99.75	92.95	87.54	CH			6/15	12/15	16/15	28/30
SS-13	13.00	13.45	16.76	39.51	21.24	18.27	100.00	100.00	100.00	97.92	84.71	72.16	CL			7/15	10/15	14/15	24/30
SS-14	14.00	14.45	22.50	NP	NP	NP	100.00	100.00	100.00	92.28	58.56	32.44	SM			7/15	14/15	21/15	35/30
SS-15	15.00	15.45	20.86	NP	NP	NP	100.00	100.00	100.00	100.00	88.85	48.69	SM			14/15	13/15	11/15	24/30
SS-16	16.00	16.45	24.06	NP	NP	NP	100.00	100.00	100.00	98.91	24.14	19.55	SM			9/15	15/15	17/15	32/30
SS-17	17.00	17.45	19.99	44.24	21.54	22.70	100.00	100.00	99.28	97.75	95.68	92.59	CL	1.94		9/15	12/15	14/15	26/30

SS-18	18.00	18.45	18.87	62.98	26.87	36.11	100.00	100.00	100.00	99.33	98.21	96.59	CH	1.93		6/15	12/15	15/15	27/30
SS-19	19.00	19.45	20.15	66.08	25.54	40.54	100.00	100.00	100.00	99.36	98.54	97.75	CH			9/15	12/15	16/15	28/30
SS-20	20.00	20.45	19.64	65.38	23.73	41.65	100.00	100.00	98.31	97.30	95.36	93.76	CH	1.93		9/15	15/15	18/15	33/30
SS-21	21.00	21.45	19.39	52.44	27.74	24.70	100.00	98.48	97.25	96.27	95.16	93.92	CH	1.93		10/15	16/15	23/15	39/30
SS-22	22.00	22.45	18.63	56.70	21.26	35.44	100.00	100.00	98.82	98.21	96.55	94.90	CH	1.98		8/15	15/15	15/15	30/30
SS-23	23.00	23.45	18.76	54.06	22.64	31.42	100.00	100.00	99.45	98.82	97.83	96.18	CH	1.99		13/15	17/15	20/15	37/30
SS-24	24.00	24.45	16.69	60.29	24.22	36.07	100.00	100.00	100.00	99.04	96.43	93.59	CH	1.90		7/15	13/15	19/15	32/30
SS-25	25.00	25.45	13.55	59.63	24.26	35.37	100.00	100.00	100.00	99.65	98.76	97.91	CH	1.93		10/15	15/15	24/15	39/30
SS-26	26.00	26.45	25.16	56.57	16.91	39.66	100.00	100.00	99.87	99.27	92.67	82.47	CH	1.92		9/15	17/15	28/15	45/30
SS-27	27.00	27.45	NO RECOVERY										(CH)			10/15	18/15	25/15	43/30
SS-28	28.00	28.45	15.88	40.93	12.83	28.10	100.00	100.00	100.00	99.56	89.39	75.72	CL			9/15	17/15	22/15	39/30
SS-29	29.00	29.45	16.39	34.51	12.60	21.91	100.00	100.00	98.23	95.66	49.19	38.31	SC			16/15	16/15	15/15	31/30
SS-30	30.00	30.45	16.57	39.50	12.43	27.07	100.00	96.95	94.70	92.36	89.15	84.49	CL	2.00		12/15	17/15	23/15	40/30
SS-31	31.00	31.45	18.66	61.31	12.74	48.57	100.00	100.00	97.31	94.81	90.43	87.72	CH	1.98		8/15	12/15	18/15	30/30
SS-32	32.00	32.45	19.41	48.22	19.73	28.49	100.00	100.00	97.30	96.16	94.49	92.88	CL	1.96		13/15	27/15	32/15	59/30
SS-33	33.00	33.45	19.50	63.93	15.13	48.80	100.00	98.01	93.86	92.43	90.78	89.55	CH			15/15	21/15	24/15	45/30
SS-34	34.00	34.45	12.70	63.24	15.31	47.93	100.00	100.00	98.82	76.82	45.17	42.88	SC			10/15	17/15	23/15	40/30
SS-35	35.00	35.45	17.19	62.33	13.55	48.78	100.00	98.21	94.34	92.79	90.66	89.28	CH	1.96		12/15	22/15	27/15	49/30
SS-36	36.00	36.45	17.59	59.85	29.09	30.76	100.00	90.38	84.42	80.21	78.07	76.91	CH	1.97		8/15	30/15	33/15	63/30
SS-37	37.00	37.45	20.79	64.77	15.00	49.77	100.00	100.00	100.00	99.04	97.93	96.95	CH	1.93		13/15	21/15	28/15	49/30
SS-38	38.00	38.45	19.01	59.63	16.14	43.49	100.00	98.83	96.28	94.86	93.56	91.78	CH			15/15	25/15	25/15	50/30
SS-39	39.00	39.45	16.72	58.72	15.63	43.09	100.00	100.00	98.35	96.50	94.79	93.44	CH	1.98		17/15	24/15	29/15	53/30
SS-40	40.00	40.45	17.59	49.02	11.71	37.31	100.00	100.00	100.00	100.00	97.28	91.80	CL			15/15	21/15	24/15	45/30

SUMMARY OF TEST RESULTS

Project : Data Collection Survey on The Outer Ring Road diversion channel
: in The Comprehensive Flood Management Plan of Chao Phaya River
: Basin in The Kingdom of Thailand

Date of Boring : 8-9/5/2017
Boring No : BH-2
Location : Nong Chok , Bangkok

Ground Water Level (m): -1.50
North : 1,538,721 **East** : 698,582

Sample	Depth ,m		Wn	Atterberg Limits (%)			Grain Size Analysis						USCS	γ_t	S_U	SPT-N ,(blows/inch)			N value
No.	From	To	(%)	LL	PL	PI	3/8"	#4	#10	#40	#100	#200	Group	(t/m^3)	(t/m^2)	1st	2nd	3rd	
SS-1	1.00	1.45	75.09	80.13	32.74	47.39	100.00	100.00	100.00	100.00	99.64	99.61	CH			-	-	-	0/45
SS-2	2.00	2.45	74.29	79.20	32.22	46.98	100.00	100.00	100.00	99.91	99.77	99.71	CH			0/15	0/15	1/34	1/49
SS-3	3.00	3.45	86.17	89.19	34.49	54.70	100.00	100.00	100.00	100.00	99.59	99.53	CH			-	-	-	0/45
SS-4	4.00	4.45	74.79	84.28	32.50	51.78	100.00	100.00	100.00	100.00	99.81	99.78	CH			0/15	0/15	1/32	1/47
SS-5	5.00	5.45	47.22	58.05	27.77	30.28	100.00	100.00	100.00	100.00	99.44	98.42	CH			-	-	-	0/45
SS-6	6.00	6.45	62.06	67.50	30.92	36.58	100.00	100.00	100.00	100.00	98.51	96.79	CH			-	-	-	0/45
SS-7	7.00	7.45	66.95	71.58	30.21	41.37	100.00	100.00	100.00	100.00	99.74	99.58	CH			-	-	-	0/45
SS-8	8.00	8.45	62.29	75.36	32.74	42.62	100.00	100.00	100.00	99.98	99.25	95.36	CH			-	-	-	0/45
SS-9	9.00	9.45	70.31	79.87	32.77	47.10	100.00	100.00	100.00	100.00	99.52	99.39	CH			-	-	-	0/45
SS-10	10.00	10.45	72.41	81.40	32.92	48.48	100.00	100.00	100.00	99.97	99.92	99.90	CH			-	-	-	0/45
SS-11	11.00	11.45	62.44	72.72	24.53	48.19	100.00	100.00	98.82	98.77	98.75	98.68	CH			-	-	-	0/45
SS-12	12.00	12.45	27.16	84.90	23.04	61.86	100.00	100.00	100.00	100.00	99.91	99.88	CH	1.83		0/15	3/15	4/15	7/30
SS-13	13.00	13.45	26.02	68.75	24.39	44.36	100.00	100.00	100.00	100.00	99.95	99.91	CH	1.84		0/15	5/15	8/15	13/30
SS-14	14.00	14.45	22.85	68.02	21.01	47.01	100.00	100.00	100.00	100.00	100.00	99.94	CH	1.86		5/15	8/15	10/15	18/30
SS-15	15.00	15.45	17.96	63.82	20.41	43.41	100.00	100.00	100.00	100.00	94.02	88.06	CH			5/15	7/15	12/15	19/30
SS-16	16.00	16.45	21.24	72.58	24.17	48.41	100.00	100.00	100.00	99.97	99.92	99.90	CH	1.86		5/15	8/15	11/15	19/30
SS-17	17.00	17.45	22.42	70.11	23.19	46.92	100.00	100.00	100.00	99.99	99.85	99.83	CH			7/15	10/15	12/15	22/30

SS-18	18.00	18.45	20.99	68.97	22.50	46.47	100.00	100.00	100.00	100.00	99.62	99.50	CH	1.86		4/15	8/15	11/15	19/30
SS-19	19.00	19.45	16.90	65.96	22.16	43.80	100.00	100.00	95.75	94.77	94.29	93.49	CH	1.80		7/15	11/15	13/15	24/30
SS-20	20.00	20.45	18.16	53.96	34.77	19.19	100.00	98.69	98.09	97.00	96.48	93.26	MH			6/15	12/15	15/15	27/30
SS-21	21.00	21.45	18.90	63.40	21.47	41.93	100.00	100.00	99.64	98.26	96.71	96.19	CH	1.89		8/15	10/15	12/15	22/30
SS-22	22.00	22.45	24.64	67.12	26.46	40.66	100.00	100.00	100.00	99.47	99.15	99.10	CH	1.89		3/15	5/15	7/15	12/30
SS-23	23.00	23.45	23.35	66.09	23.94	42.15	100.00	100.00	99.87	96.23	93.25	92.43	CH			5/15	7/15	9/15	16/30
SS-24	24.00	24.45	21.75	67.93	22.12	45.81	100.00	100.00	100.00	99.97	98.20	95.82	CH			4/15	7/15	10/15	17/30
SS-25	25.00	25.45	20.00	63.52	29.75	33.77	100.00	100.00	100.00	99.99	95.22	92.42	MH			4/16	5/15	7/15	12/30
SS-26	26.00	26.45	18.58	59.98	26.00	33.98	100.00	100.00	99.93	99.72	98.68	97.99	CH	1.90		4/17	8/15	16/15	24/30
SS-27	27.00	27.45	18.00	65.39	23.72	41.67	100.00	100.00	99.97	99.69	99.50	99.46	CH	1.85		8/15	12/15	17/15	29/30
SS-28	28.00	28.45	18.35	66.14	23.60	42.54	100.00	100.00	100.00	99.74	99.57	99.53	CH	1.88		9/15	11/15	14/15	25/30
SS-29	29.00	29.45	19.57	60.83	24.57	36.26	100.00	100.00	100.00	98.64	91.42	90.41	CH	1.97		10/15	13/15	17/15	30/30
SS-30	30.00	30.45	18.37	62.07	22.43	39.64	100.00	100.00	100.00	100.00	99.45	99.22	CH	1.95		12/15	14/15	16/15	30/30
SS-31	31.00	31.45	18.29	50.36	23.56	26.80	100.00	99.11	84.94	75.92	70.60	68.16	CH	1.91		10/15	11/15	15/15	26/30
SS-32	32.00	32.45	17.75	54.13	18.45	35.68	100.00	100.00	100.00	99.44	98.79	96.17	CH	1.91		12/15	13/15	17/15	30/30
SS-33	33.00	33.45	16.92	42.35	21.19	21.16	100.00	100.00	100.00	99.45	89.71	76.00	CL	1.94		8/15	10/15	15/15	25/30
SS-34	34.00	34.45	17.97	29.66	20.05	9.61	100.00	100.00	100.00	99.93	43.91	30.18	SC			17/15	21/15	33/15	54/30
SS-35	35.00	35.45	19.06	NP	NP	NP	100.00	100.00	100.00	91.52	25.63	20.78	SM			15/15	20/15	20/15	40/30
SS-36	36.00	36.45	15.85	NP	NP	NP	100.00	100.00	100.00	88.33	27.22	21.40	SM			16/15	20/15	31/15	51/30
SS-37	37.00	37.45	NO RECOVERY										(SM)			16/15	0/15	22/15	40/30
SS-38	38.00	38.45	NO RECOVERY										(SM)			12/15	18/15	19/15	37/30
SS-39	39.00	39.45	20.30	35.67	19.40	16.27	100.00	100.00	100.00	100.00	97.75	80.38	CL			9/15	10/15	15/15	25/30
SS-40	40.00	40.45	19.84	46.20	20.24	25.96	100.00	100.00	99.45	99.42	99.23	99.17	CL	1.96		9/15	13/15	16/15	29/30

SUMMARY OF TEST RESULTS

Project : Data Collection Survey on The Outer Ring Road diversion channel
: in The Comprehensive Flood Management Plan of Chao Phaya River
: Basin in The Kingdom of Thailand

Date of Boring : 5-6/5/2017
Boring No. BH-3
Location : Bang Bo , Samut Prakan

Ground Water Level (m): -1.20
North : 1,494,868 **East** : 696,090

Sample	Depth ,m		Wn	Atterberg Limits (%)			Grain Size Analysis						USCS	γ_t	S_U	SPT-N ,(blows/inch)			N value
No.	From	To	(%)	LL	PL	PI	3/8"	#4	#10	#40	#100	#200	Group	(t/m^3)	(t/m^2)	1st	2nd	3rd	
SS-1	1.00	1.45	98.73	104.95	40.77	64.18	100.00	100.00	100.00	100.00	98.91	98.54				-	-	-	0/45
SS-2	2.00	2.45	92.81	113.23	37.40	75.83	87.56	85.34	84.28	82.11	80.90	80.32				-	-	-	0/45
SS-3	3.00	3.45	103.08	117.37	41.83	75.54	100.00	100.00	100.00	98.50	97.84	97.42				-	-	-	0/45
SS-4	4.00	4.45	100.83	112.48	40.88	71.60	100.00	100.00	100.00	98.96	98.51	98.17				-	-	-	0/45
SS-5	5.00	5.45	NO RECOVERY													-	-	-	0/45
SS-6	6.00	6.45	106.51	104.67	44.08	60.59	100.00	91.84	88.47	85.29	83.92	83.16				-	-	-	0/45
SS-7	7.00	7.45	115.38	125.73	51.35	74.38	100.00	100.00	100.00	98.11	96.83	96.30				-	-	-	0/45
SS-8	8.00	8.45	110.32	132.27	39.55	92.72	100.00	100.00	100.00	100.00	99.35	99.10				-	-	-	0/45
SS-9	9.00	9.45	104.62	133.44	39.37	94.06	100.00	100.00	100.00	100.00	99.74	99.59				-	-	-	0/45
SS-10	10.00	10.45	110.63	144.43	40.41	104.01	100.00	100.00	100.00	100.00	98.50	98.19				-	-	-	0/45
SS-11	11.00	11.45	113.01	136.79	35.25	101.54	100.00	100.00	100.00	100.00	99.52	99.03				-	-	-	0/45
SS-12	12.00	12.45	101.00	130.58	40.45	90.12	100.00	100.00	100.00	100.00	98.47	96.88				-	-	-	0/45
SS-13	13.00	13.45	101.89	129.39	47.01	82.38	100.00	100.00	100.00	100.00	99.01	97.76				-	-	-	0/45
SS-14	14.00	14.45	92.44	134.09	47.36	86.73	100.00	100.00	100.00	95.75	95.08	92.89				-	-	-	0/45
SS-15	15.00	15.45	86.69	132.38	34.32	98.06	100.00	100.00	100.00	97.17	96.59	93.90				0/24	1/8	1/32	2/40
SS-16	16.00	16.45	84.61	124.89	43.73	81.16	100.00	100.00	100.00	92.68	92.22	89.55				1/15	1/10	3/25	4/35
SS-17	17.00	17.45	NO RECOVERY													0/15	0/15	2/25	2/40

SS-18	18.00	18.45	71.59	124.53	52.66	71.86	100.00	100.00	100.00	100.00	96.86	93.01				0/15	1/15	2/23	3/38
SS-19	19.00	19.45	56.93	60.86	30.28	30.58	100.00	100.00	100.00	100.00	97.63	91.78				0/15	2/15	2/20	4/35
SS-20	20.00	20.45	48.21	61.75	28.44	33.31	100.00	100.00	100.00	100.00	98.94	93.10				0/15	2/15	3/17	5/32
SS-21	21.00	21.45	22.53	37.07	19.20	17.87	100.00	100.00	98.95	97.93	85.97	70.90	CL			0/15	10/15	12/15	22/30
SS-22	22.00	22.45	18.76	38.05	20.03	18.02	100.00	100.00	100.00	98.30	66.90	35.44	SC			4/15	7/15	10/15	17/30
SS-23	23.00	23.45	21.96	27.01	14.08	12.93	100.00	100.00	100.00	100.00	76.88	42.97	SC			6/15	7/15	7/15	14/30
SS-24	24.00	24.45	22.85	39.42	16.91	22.51	100.00	100.00	99.66	98.95	89.97	73.28	CL			5/15	6/15	6/15	12/30
SS-25	25.00	25.45	21.89	42.32	25.90	16.42	100.00	100.00	100.00	99.36	93.22	77.32	CL	1.85		5/15	8/15	9/15	17/30
SS-26	26.00	26.45	NO RECOVERY										(CL)			7/15	8/15	9/15	17/30
SS-27	27.00	27.45	21.73	42.29	25.90	16.39	100.00	100.00	100.00	99.55	83.46	72.02	CL			2/15	3/15	3/15	6/30
SS-28	28.00	28.45	26.41	49.79	27.15	22.64	100.00	100.00	100.00	99.32	88.48	78.74	CL			4/15	3/15	3/15	6/30
SS-29	29.00	29.45	22.95	NP	NP	NP	100.00	100.00	100.00	100.00	49.95	33.21	SM			6/15	13/15	11/15	24/30
SS-30	30.00	30.45	22.12	NP	NP	NP	100.00	100.00	100.00	100.00	49.28	32.33	SM			8/15	9/15	11/15	20/30
SS-31	31.00	31.45	22.78	NP	NP	NP	100.00	100.00	100.00	100.00	76.00	47.61	SM			3/15	3/15	6/15	9/30
SS-32	32.00	32.45	22.76	NP	NP	NP	100.00	100.00	100.00	99.08	16.62	11.46	SP-SM			12/15	18/15	19/15	37/30
SS-33	33.00	33.45	16.91	NP	NP	NP	100.00	96.92	93.62	40.90	22.86	17.55	SM			10/15	12/15	18/15	30/30
SS-34	34.00	34.45	12.59	NP	NP	NP	100.00	96.72	82.13	37.42	16.96	12.69	SM			10/15	30/15	32/15	62/30
SS-35	35.00	35.45	18.22	NP	NP	NP	100.00	100.00	97.68	51.19	16.52	10.80	SP-SM			22/15	24/15	17/15	41/30
SS-36	36.00	36.45	13.33	NP	NP	NP	100.00	92.84	74.79	26.02	9.25	6.14	SW-SM			15/15	16/15	12/15	28/30
SS-37	37.00	37.45	19.05	34.90	19.40	15.50	90.67	75.82	65.59	52.36	41.23	35.97	SC			13/15	7/15	10/15	17/30
SS-38	38.00	38.45	19.26	33.50	19.29	14.21	100.00	100.00	100.00	99.11	87.93	63.91	CL	1.93		17/15	15/15	17/15	32/30
SS-39	39.00	39.45	21.68	28.44	18.87	9.57	100.00	100.00	100.00	100.00	58.71	24.93	SC			16/15	30/15	37/15	67/30
SS-40	40.00	40.45	NO RECOVERY										(SC)			25/15	27/15	33/15	60/30

Location S1

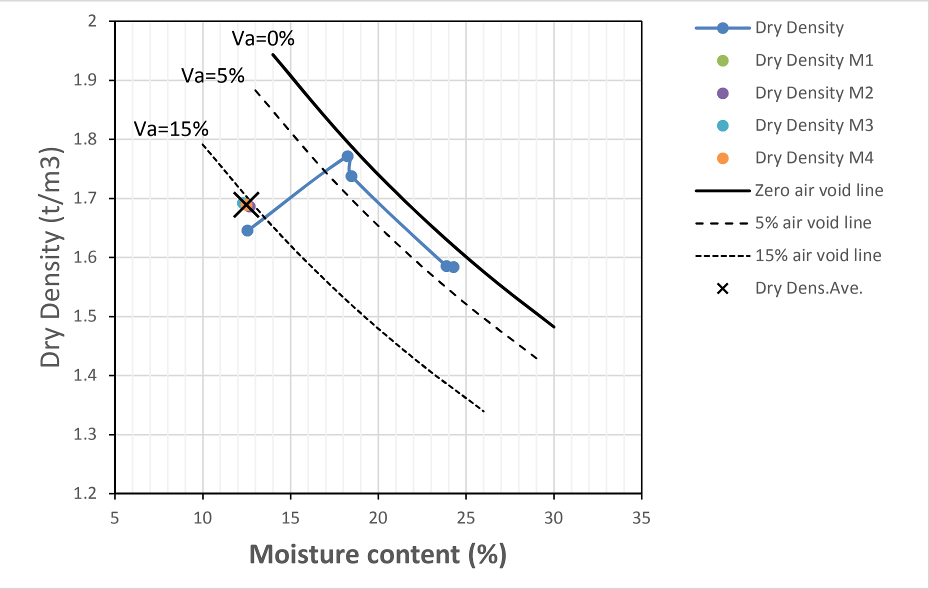
Diameter 1.5–2 cm
Ratio Clay 2: Sand 1

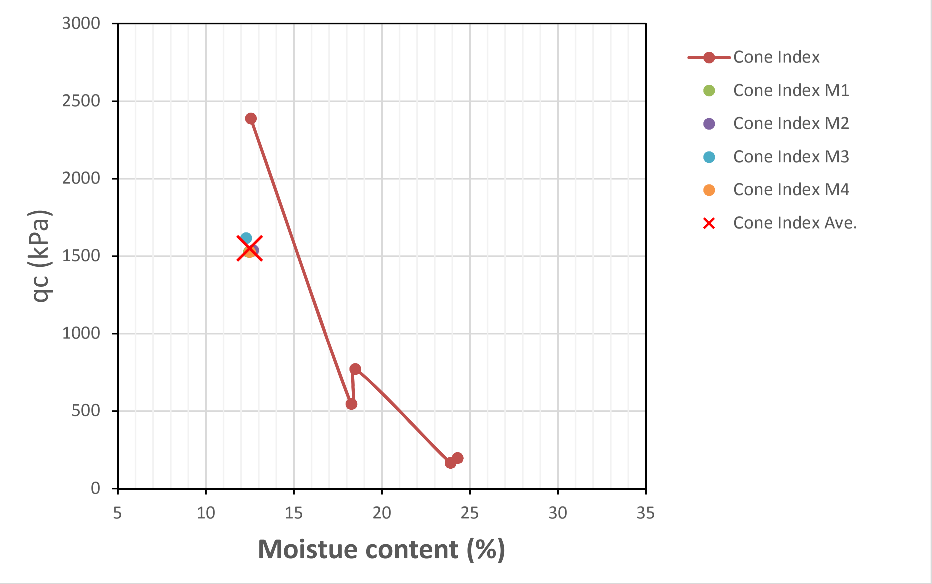
Cone Index Caluculation

qc = 1527.36 (Qc/A)	A : 0.000323 m2
Qc = 0.493337 (Qrd+(m0+n*m1)*gn)/1000	Qrd : 484.704 kN m0 : 0.1 kg n : 1 pcs m1 : 0.78 kg gn : 9.81 m/s2
Qrd = 484.704 (K*D)	K : 4.488 N D : 108 Reading
qc = 1527.35 (Simplified formula)	

Coen Penetration Data Sheet

Mold No		1	2	3	4	Average	
Reading	5cm	86	102	85	96		
	7.5cm	110	102	130	104		
	10cm	128	122	128	124		
	Average	108.0	108.7	114.3	108.0		
Corn Index :qc (kPa)		1527	1537	1615	1527	1551.7	
Water Content (%)							
Dry Density (t/m3)							
Adjust Water Content (%)		12.45	12.69	12.29	12.50	12.5	
Adjusted Dry Density		1.690	1.686	1.692	1.689	1.689	





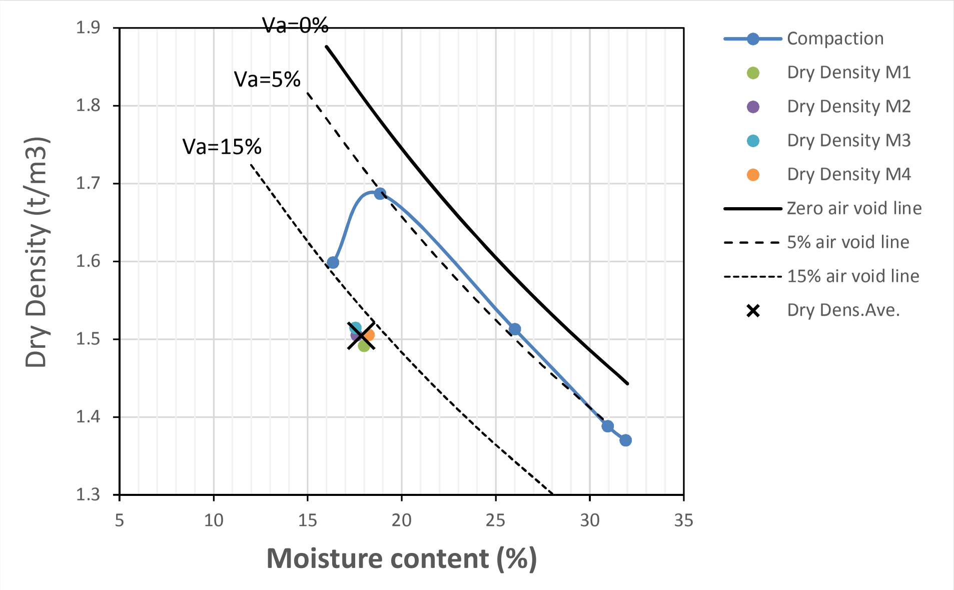
Location S2
Diameter 1.5–2.0 cm
Ratio Clay 2: Sand 1

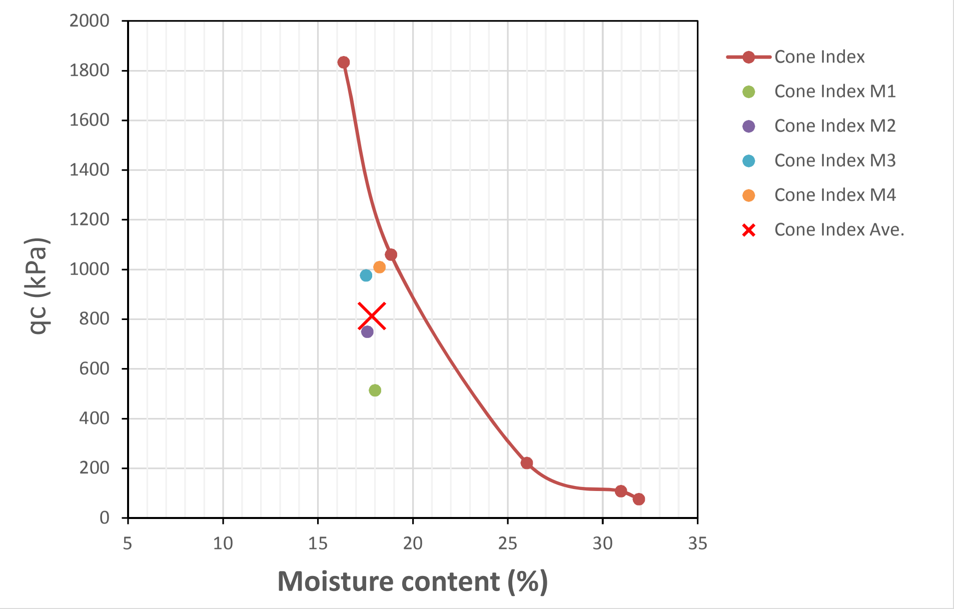
Cone Index Caluculation

qc = 2805.67 (Qc/A)	A : 0.000323 m2
Qc = 0.906233 (Qrd+(m0+n*m1)*gn)/1000	Qrd : 897.6 kN m0 : 0.1 kg n : 1 pcs m1 : 0.78 kg gn : 9.81 m/s2
Qrd = 897.6 (K*D)	K : 4.488 N D : 200 Reading
qc = 2805.67 (Simplified formula)	

Coen Penetration Data Sheet

Sample No		1	2	3	4	Average	
Reading	5cm	35	60	50	57		
	7.5cm		46	75	75		
	10cm		50	80	80		
	Average	35.0	52.0	68.3	70.7		
Corn Index :qc (kPa)		513	749	976	1009	811.8	
Water Content (%)		33.41	32.67	32.55	33.86		
Dry Density (t/m3)		1.32	1.34	1.34	1.33		
Adjust Water Content (		18.00	17.60	17.54	18.24	17.8	
Adjusted Dry Density		1.49	1.51	1.51	1.51	1.5	





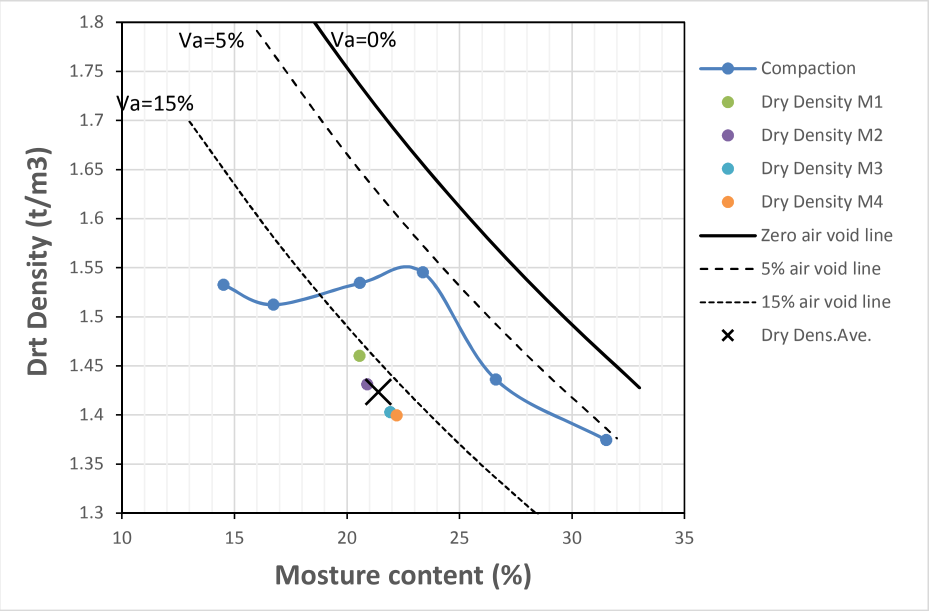
Location S3
Diameter 1.5–2 cm
Ratio Clay 2: Sand 1

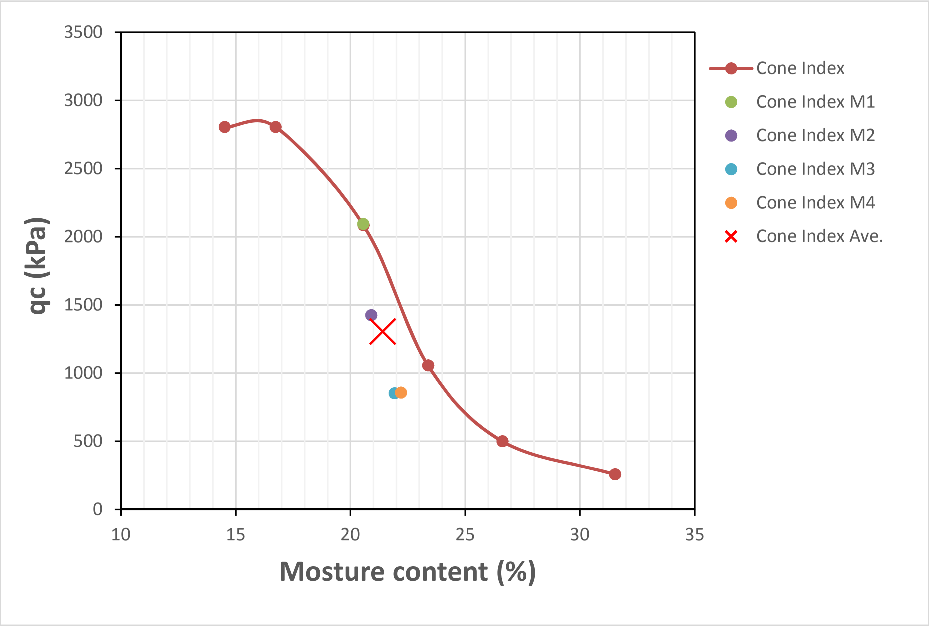
Cone Index Caluculation

qc = 2805.67 (Qc/A)	A : 0.000323 m2
Qc = 0.906233 (Qrd+(m0+n*m1)*gn)/1000	Qrd : 897.6 kN m0 : 0.1 kg n : 1 pcs m1 : 0.78 kg gn : 9.81 m/s2
Qrd = 897.6 (K*D)	K : 4.488 N D : 200 Reading
qc = 2805.67 (Simplified formula)	

Coen Penetration Data Sheet

Sample No		1	2	3	4	Average	
Reading	5cm	148	78	48	45		
	7.5cm	146	104	64	66		
	10cm	152	120	66	68		
	Average	148.7	100.7	59.3	59.7		
Corn Index :qc (kPa)		2092	1425	851	856	1306	
Water Content (%)							
Dry Density (t/m3)							
adjust Water Conten		20.56	20.91	21.93	22.21	21.40	
Adjusted Dry Density		1.46	1.43	1.40	1.40	1.42	





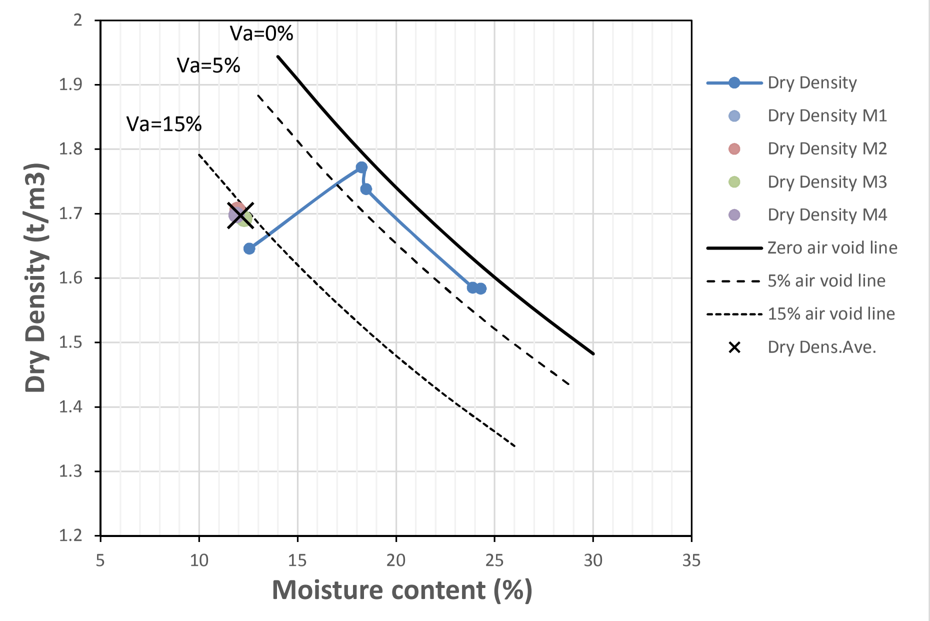
Location S1
Diameter 3–4 cm
Ratio Clay 2: Sand 1

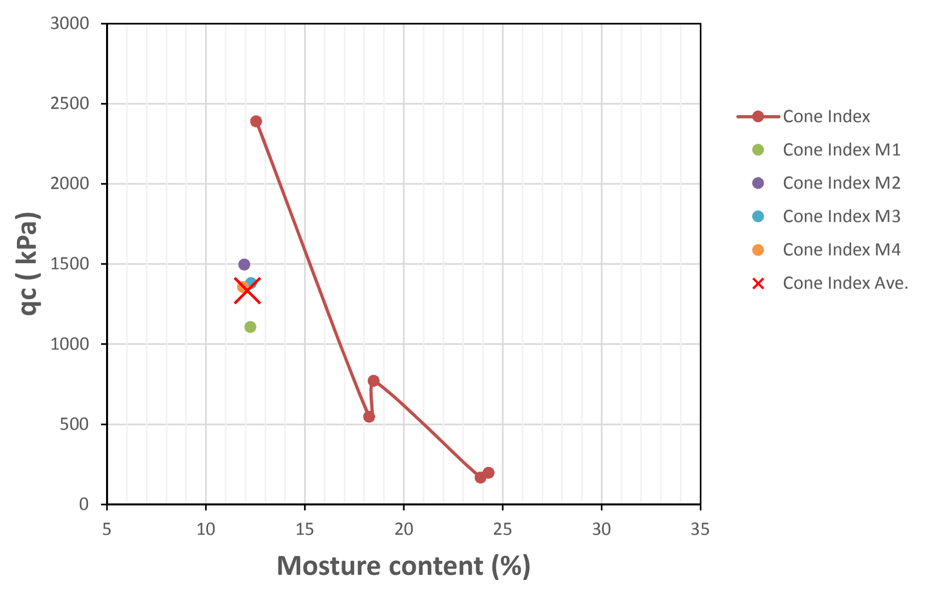
Cone Index Caluculation

qc = 2805.67 (Qc/A)	A : 0.000323 m2
Qc = 0.906233 (Qrd+(m0+n*m1)*gn)/1000	Qrd : 897.6 kN m0 : 0.1 kg n : 1 pcs m1 : 0.78 kg gn : 9.81 m/s2
Qrd = 897.6 (K*D)	K : 4.488 N D : 200 Reading
qc = 2805.67 (Simplified formula)	

Coen Penetration Data Sheet

Mold No		1	2	3	4	Average	
Reading	5cm	75	92	92	62		
	7.5cm	78	105	95	95		
	10cm	80	120	105	130		
	Average	77.7	105.7	97.3	95.7		
Corn Index :qc (kPa)		1106	1495	1379	1356	1334.0	
Water Content (%)							
Dry Density (t/m3)							
Aadjust Water Content (%)		12.26	11.94	12.28	11.88	12.1	
Adjusted Dry Density		1.69	1.71	1.69	1.70	1.70	





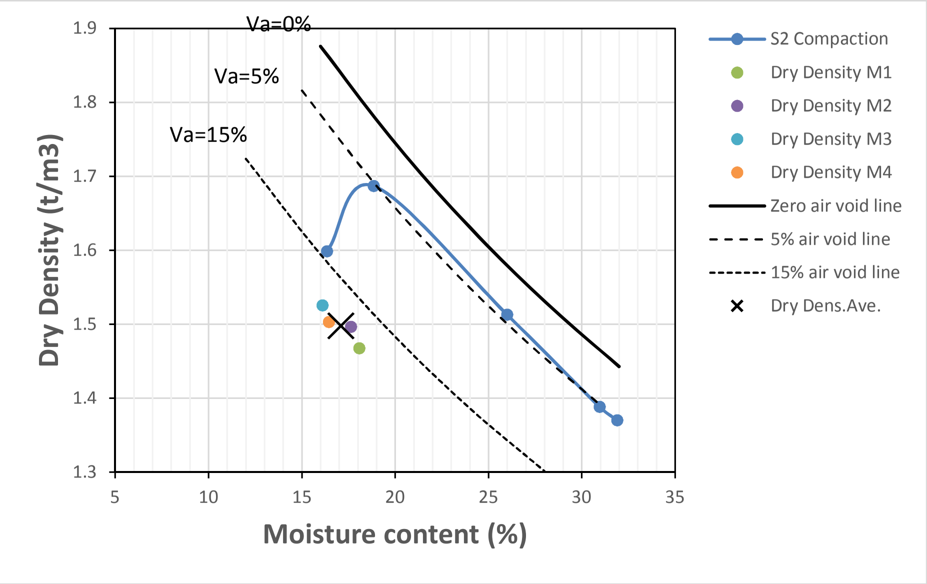
Location S2
Diameter 3–4 cm
Ratio Clay 2: Sand 1

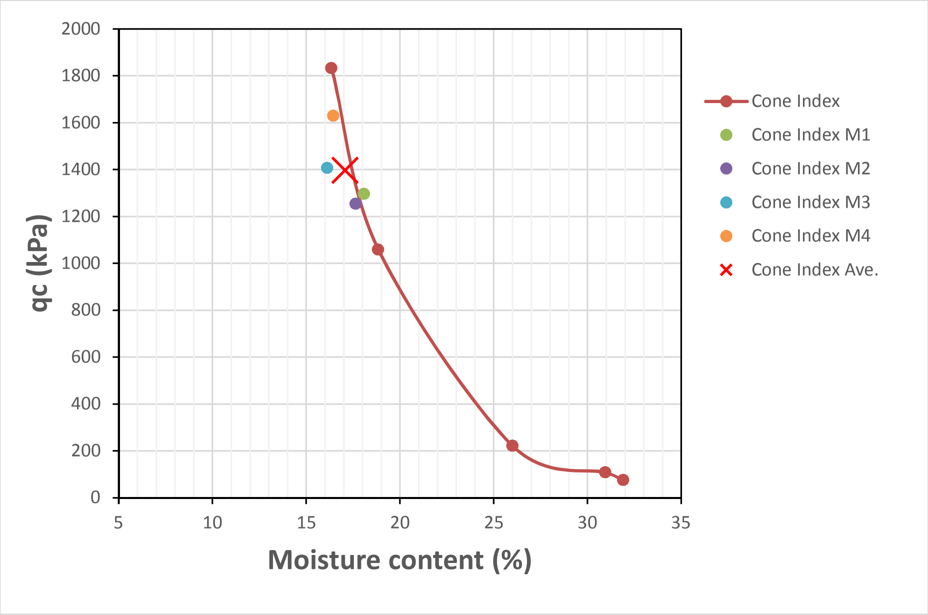
Cone Index Caluculation

qc = 2805.67 (Qc/A)	A : 0.000323 m2
Qc = 0.9062328 (Qrd+(m0+n*m1)*gn)/1000	Qrd : 897.6 kN m0 : 0.1 kg n : 1 pcs m1 : 0.78 kg gn : 9.81 m/s2
Qrd = 897.6 (K*D)	K : 4.488 N D : 200 Reading
qc = 2805.67 (Simplified formula)	

Coen Penetration Data Sheet

Sample No		1	2	3	4	Average	
Reading	5cm	100	75	54	125		
	7.5cm	78	95	104	100		
	10cm	96	95	140	121		
	Average	91.3	88.3	99.3	115.3		
Corn Index :qc (kPa)		1296	1254	1407	1629	1397	
Water Content (%)		33.58	32.75	29.92	30.53		
Dry Density (t/m3)		1.3	1.33	1.36	1.34		
Adjust Water Content (%)		18.09	17.64	16.12	16.45	17.08	
Adjusted Dry Density		1.47	1.50	1.53	1.50	1.50	





Location	S3
Diameter	3-4 cm
Ratio	Clay 2: Sand 1

Cone Index Caluculation

qc = 2805.67 (Qc/A)	A : 0.000323 m2
Qc = 0.9062328 (Qrd+(m0+n*m1)*gn)/1000	Qrd : 897.6 kN m0 : 0.1 kg n : 1 pcs m1 : 0.78 kg gn : 9.81 m/s2
Qrd = 897.6 (K*D)	K : 4.488 N D : 200 Reading
qc = 2805.67 (Simplified formula)	

Coen Penetration Data Sheet

Sample No		1	2	3	4	Average	
Reading	5cm	63	145	100	100		
	7.5cm	73	90	150	110		
	10cm	70	90	150	106		
	Average	68.7	108.3	133.3	105.3		
Corn Index :qc (kPa)		981	1532	1879	1490	1471	
Water Content (%)							
Dry Density (t/m3)							
Adjust Water Content (%)		18.00	17.60	17.54	18.24	17.85	
Adjusted Dry Density		1.47	1.46	1.46	1.46	1.46