Chapter 3. Survey Results

3.1. Wind Direction, Wind Speed and Rainfall

Meteorological data, such as wind direction, wind speed, humidity, fog, and rainfall that were used in the other future analysis were collected from the "Department of Meteorology and Hydrology" of Myanmar (hereafter Meteorological Agency).

(1) Observation Point

The collected data have been observed inside the area of the Meteorological Agency. The following figure shows the position of the Meteorological Agency.

Source: Google Earth, JICA Study Team

Figure 3.1.1. Position of Myanmar Department of Meteorology and Hydrology

(2) Observation Period

The collection period was from 2010 to 2014 (total five years).

(3) Observation Results

Typical data of the available data for wind direction, wind speed, humidity, fog, and rainfall are described below.

1) Wind Direction

Wind direction has been observed four times a day at 6:30, 9:30, 12:30, and 18:30. The collected data are summarised by the Study Team. The results are shown in the following table.

Table 3.1.1. Data of Wind Direction (2014)

Station : KABA-AYE | Year :2014

Daily Wind Direction at (18:30) hrs M.S.T

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	NW	S	Calm	SE	SW	SE	SW	SW	W	NW	N	SE
2	NW	SW	SW	SE	SW	SW	SW	S	SW	S	SW	SW
3	SW	SE	SW	SW	SW	SW	SW	SE	SW	NE	NW	SE
4	W	SW	SW	SW	SW	N	NW	SW	SW	SW	SE	NW
5	S	SE	NW	SE	SW	SW	SW	N	SW	NW	SW	SE
6	NE	SW	SW	SW	SW	SW	SW	SW	SW	Calm	NE	SE
7	NW	SE	SW	NW	SW	SW	SW	SW	N	SE	SE	SW
8	NW	SE	SE	SE	W	SW	SW	SW	NE	SE	NW	SE
9	W	SE	W	SW	Calm	NW	SW	SW	SW	SE	W	SW
10	SW	SW	SW	NW	SW	NW	SW	SW	SW	SW	SW	SW
11	W	SE	SW	SE	SE	SW	SW	S	SW	SW	Calm	SW
12	NW	SW	S	SW	SW	NW	NW	SW	SW	SW	W	NE
13	NW	SW	SW	N	S	S	NW	SW	NE	S	W	SW
14	SE	NW	NW	S	SW	SW	SW	SE	SW	W	NW	NW
15	SE	SW	SW	SW	SW	SE	S	NW	SE	Calm	NW	SW
16	SW	SW	Calm	NW	SW	SE	SW	SW	NW	NW	NW	NW
17	SE	SW	SW	S	SE	SW	SW	S	SW	NE	W	SE
18	SW	NW	SW	NW	SW	SE	SE	SE	SW	Calm	SE	NW
19	SE	SW	SW	SW	SW	NW	SW	SW	SW	N	SW	W
20	W	S	S	SW	SW	SW	SW	S	SW	SE	SW	SW
21	SE	SW	SW	SW	SE	SE	SE	SE	SE	SE	SE	NE
22	SE	NE	SW	NE	SW	SE	SW	SW	SE	SW	SW	SE
23	W	NW	SW	SW	SE	SW	SW	SW	SE	W	NW	Calm
24	W	W	SW	SE	SW	SW	NW	SW	SW	SW	NW	NW
25	SW	SE	SW	SW	SW	SW	SE	SW	NW	SW	NW	NE
26	E	SW	SE	SW	SW	SW	SW	W	SW	NW	W	Calm
27	SW	SW	SE	SW	SW	NW	NW	SW	SW	SW	NE	NW
28	NW	S	SE	S	SW	NW	SW	W	SW	NE	NE	SW
29	W		SW	SW	NW	SW	SE	W	NW	SW	NE	SW
30	Calm		SW	SW	SE	NW	S	SW	SE	SE	NE	NW
31	NW		SW		S		SW	SW		NW		S

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Source: Myanmar Department of Meteorology and Hydrology, JICA Study Team

2) Wind Speed

Wind speed has been observed four times a day at 6:30, 9:30, 12:30, and 18:30 in same manner as wind direction. Wind speed during a year is about 1m / s ~ 3m / s. The collected data are summarised by Study Team and shown in the following table.

Table 3.1.2. Data of Wind Speed (2014 year: Daily Wind Speed at 18:30)

Unit: m/sec

Station : KABA-AYE　　Year :2014

Daily Wind Speed (mph) At (18:30) hrs M.S.T

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	1.2	1.2	0.0	2.4	1.2	2.4	1.2	1.2	1.2	1.2	1.2	2.4
2	2.4	1.2	2.4	3.6	2.4	1.2	1.2	2.4	2.4	2.4	1.2	1.2
3	1.2	4.8	2.4	1.2	1.2	1.2	1.2	2.4	1.2	1.2	1.2	1.2
4	1.2	1.2	1.2	2.4	1.2	1.2	2.4	1.2	1.2	1.2	1.2	1.2
5	1.2	2.4	2.4	1.2	3.6	1.2	2.4	2.4	2.4	1.2	1.2	1.2
6	1.2	1.2	2.4	1.2	2.4	1.2	1.2	1.2	2.4	0.0	2.4	1.2
7	1.2	3.6	1.2	2.4	3.6	3.6	2.4	1.2	1.2	2.4	1.2	1.2
8	2.4	1.2	1.2	2.4	1.2	1.2	1.2	2.4	2.4	2.4	1.2	1.2
9	1.2	2.4	2.4	2.4	0.0	1.2	1.2	2.4	1.2	1.2	1.2	2.4
10	1.2	1.2	1.2	1.2	2.4	1.2	2.4	1.2	2.4	1.2	1.2	1.2
11	1.2	3.6	2.4	1.2	2.4	1.2	1.2	2.4	2.4	2.4	0.0	1.2
12	1.2	3.6	2.4	2.4	1.2	1.2	2.4	1.2	1.2	1.2	1.2	1.2
13	1.2	1.2	1.2	1.2	2.4	2.4	2.4	1.2	2.4	1.2	1.2	1.2
14	3.6	1.2	2.4	1.2	2.4	1.2	1.2	2.4	2.4	1.2	1.2	1.2
15	1.2	1.2	2.4	1.2	1.2	1.2	1.2	2.4	1.2	0.0	1.2	1.2
16	1.2	1.2	0.0	2.4	3.6	3.6	1.2	1.2	1.2	1.2	1.2	1.2
17	2.4	1.2	1.2	2.4	2.4	1.2	1.2	1.2	1.2	1.2	1.2	1.2
18	1.2	2.4	2.4	1.2	3.6	3.6	3.6	1.2	1.2	0.0	1.2	1.2
19	2.4	1.2	2.4	1.2	1.2	3.6	2.4	1.2	3.6	2.4	1.2	1.2
20	1.2	1.2	3.6	6.0	2.4	1.2	2.4	2.4	1.2	1.2	1.2	1.2
21	2.4	1.2	1.2	2.4	1.2	3.6	2.4	2.4	1.2	1.2	1.2	1.2
22	2.4	2.4	1.2	2.4	2.4	2.4	1.2	2.4	2.4	1.2	1.2	1.2
23	1.2	1.2	2.4	2.4	3.6	3.6	2.4	1.2	2.4	1.2	1.2	0.0
24	1.2	1.2	2.4	2.4	1.2	2.4	2.4	1.2	1.2	1.2	1.2	1.2
25	1.2	2.4	1.2	2.4	1.2	2.4	1.2	1.2	1.2	1.2	1.2	2.4
26	1.2	1.2	1.2	2.4	1.2	2.4	2.4	1.2	1.2	1.2	1.2	0.0
27	1.2	1.2	2.4	3.6	2.4	1.2	2.4	2.4	1.2	1.2	2.4	1.2
28	1.2	2.4	2.4	3.6	2.4	1.2	2.4	1.2	1.2	1.2	1.2	1.2
29	1.2		2.4	2.4	1.2	1.2	1.2	2.4	1.2	1.2	1.2	1.2
30	0.0		6.0	1.2	1.2	1.2	1.2	1.2	2.4	1.2	1.2	1.2
31	1.2		3.6		1.2		7.2	2.4		1.2		1.2

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Source: Myanmar Department of Meteorology and Hydrology, JICA Study Team

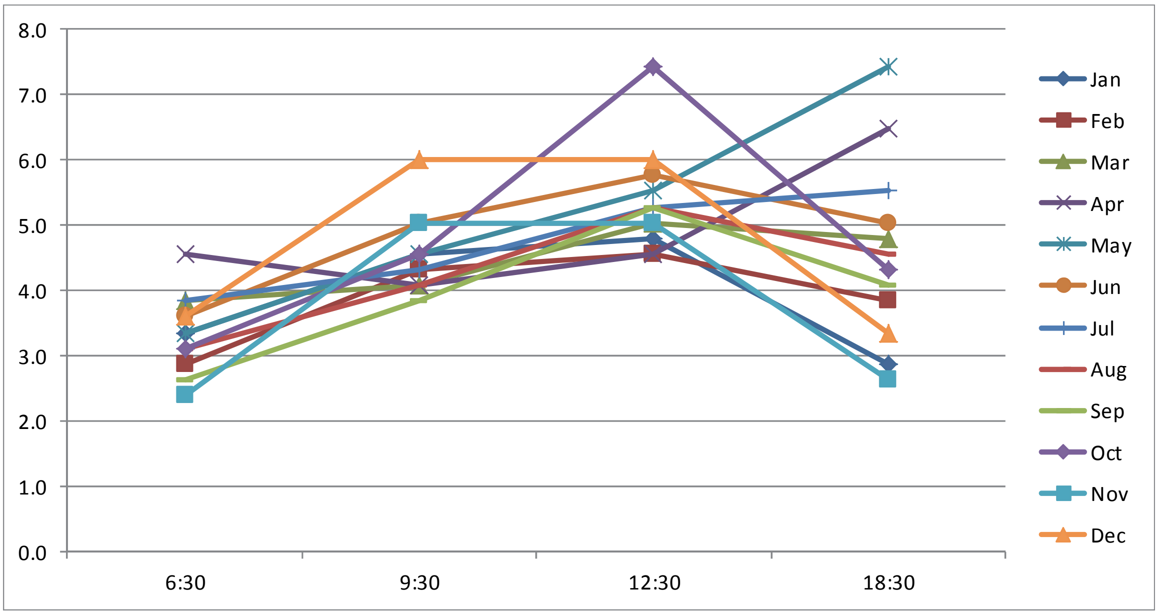
Monthly maximum wind speeds are collected in Table. 3.1.3, and the tendency of wind speed at each collected time was confirmed. In some cases wind speed increased by the occurrence of cyclone, but it can be seen that the largest wind speeds are observed at 12:30 for each month. From the results of the wind direction, daytime strong wind speeds in Yangon are from the south.

Table 3.1.3. Data of Wind Speed (2014 Year: Monthly Maximum Value)

Unit: m/sec

year	time / mon	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2010	6:30	3.6	2.4	3.6	2.4	2.4	2.4	2.4	2.4	1.2	2.4	2.4	6.0
	9:30	2.4	4.8	2.4	3.6	4.8	4.8	2.4	4.8	2.4	4.8	4.8	4.8
	12:30	3.6	3.6	2.4	3.6	6.0	4.8	6.0	3.6	6.0	12.0	6.0	6.0
	18:30	2.4	4.8	4.8	6.0	9.6	4.8	6.0	4.8	4.8	7.2	2.4	4.8
2011	6:30	2.4	2.4	7.2	2.4	1.2	3.6	2.4	2.4	2.4	3.6	2.4	2.4
	9:30	3.6	2.4	7.2	3.6	3.6	7.2	2.4	3.6	2.4	4.8	2.4	8.4
	12:30	4.8	4.8	6.0	3.6	3.6	6.0	3.6	7.2	3.6	4.8	3.6	7.2
	18:30	2.4	2.4	4.8	3.6	6.0	7.2	6.0	4.8	3.6	2.4	2.4	2.4
2012	6:30	3.6	2.4	2.4	12.0	3.6	3.6	3.6	2.4	3.6	2.4	2.4	3.6
	9:30	3.6	3.6	2.4	3.6	3.6	3.6	3.6	3.6	4.8	3.6	9.6	9.6
	12:30	3.6	3.6	3.6	3.6	6.0	6.0	6.0	3.6	4.8	6.0	7.2	6.0
	18:30	2.4	3.6	2.4	9.6	7.2	4.8	3.6	4.8	3.6	3.6	3.6	4.8
2013	6:30	3.6	3.6	3.6	3.6	6.0	3.6	4.8	6.0	3.6	3.6	2.4	3.6
	9:30	6.0	7.2	4.8	6.0	6.0	6.0	8.4	4.8	6.0	6.0	4.8	3.6
	12:30	6.0	7.2	7.2	6.0	7.2	6.0	7.2	8.4	8.4	8.4	4.8	6.0
	18:30	3.6	3.6	6.0	7.2	10.8	4.8	4.8	6.0	4.8	6.0	2.4	2.4
2014	6:30	3.6	3.6	2.4	2.4	3.6	4.8	6.0	2.4	2.4	3.6	2.4	2.4
	9:30	7.2	3.6	3.6	3.6	4.8	3.6	4.8	3.6	3.6	3.6	3.6	3.6
	12:30	6.0	3.6	6.0	6.0	4.8	6.0	3.6	3.6	3.6	6.0	3.6	4.8
	18:30	3.6	4.8	6.0	6.0	3.6	3.6	7.2	2.4	3.6	2.4	2.4	2.4
Maximum average	6:30	3.4	2.9	3.8	4.6	3.4	3.6	3.8	3.1	2.6	3.1	2.4	3.6
	9:30	4.6	4.3	4.1	4.1	4.6	5.0	4.3	4.1	3.8	4.6	5.0	6.0
	12:30	4.8	4.6	5.0	4.6	5.5	5.8	5.3	5.3	5.3	7.4	5.0	6.0
	18:30	2.9	3.8	4.8	6.5	7.4	5.0	5.5	4.6	4.1	4.3	2.6	3.4

Source: Myanmar Department of Meteorology and Hydrology, JICA Study Team



Source: JICA Study Team

Figure 3.1.2. Plot of Monthly Maximum Wind Speed at Measured Time

3) Temperature

Temperature has been collected one time a day at 12:30. Collected data were summarised by the Study Team and shown in Table 3.1.4.

Table 3.1.4. Data of Temperature (2014 Year)

Unit: %

Station : KABA-AYE   Year :2014

Daily Relative Humidity (%) at (12:30) hrs M.S.T

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	51	42	31	54	46	72	93	79	84	100	66	41
2	53	29	43	53	46	72	75	88	75	66	70	42
3	53	42	27	46	38	69	82	85	79	66	62	37
4	57	34	26	54	46	78	96	85	78	64	62	38
5	54	32	40	41	46	66	78	93	68	62	100	52
6	53	41	37	54	36	82	72	96	66	64	100	55
7	53	37	39	48	42	85	74	79	88	58	82	63
8	55	41	32	53	44	78	71	78	75	55	58	51
9	42	47	29	48	48	85	79	85	96	84	66	52
10	91	47	30	51	52	93	75	100	75	84	62	52
11	47	47	32	41	56	93	85	82	79	66	61	51
12	44	45	33	51	56	96	82	71	71	71	56	56
13	46	43	39	43	68	82	89	79	75	66	61	50
14	47	38	36	46	56	85	85	71	71	55	61	53
15	36	38	29	51	56	92	88	88	69	55	66	51
16	64	45	24	47	69	85	79	84	88	58	58	49
17	41	46	36	48	66	79	75	75	78	51	64	45
18	51	53	24	48	72	82	82	92	100	55	58	46
19	95	37	26	48	71	92	96	64	84	55	54	55
20	90	38	51	44	74	78	96	71	74	64	53	48
21	35	39	33	46	100	69	96	92	88	68	56	39
22	66	46	42	46	75	73	88	92	61	70	59	43
23	30	39	38	46	68	65	84	68	55	65	56	38
24	37	32	38	50	64	100	82	66	65	64	50	41
25	42	18	40	50	62	82	96	85	68	64	51	38
26	50	41	40	53	66	71	85	68	96	66	82	38
27	53	34	57	50	62	77	93	64	61	66	49	44
28	91	31	47	50	64	72	79	100	64	71	50	78
29	47		47	92	64	81	100	80	78	65	47	49
30	47		48	48	72	92	85	81	72	65	42	42
31	37		42		56		96	71		66		49

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Source: Myanmar Department of Meteorology and Hydrology, JICA Study Team

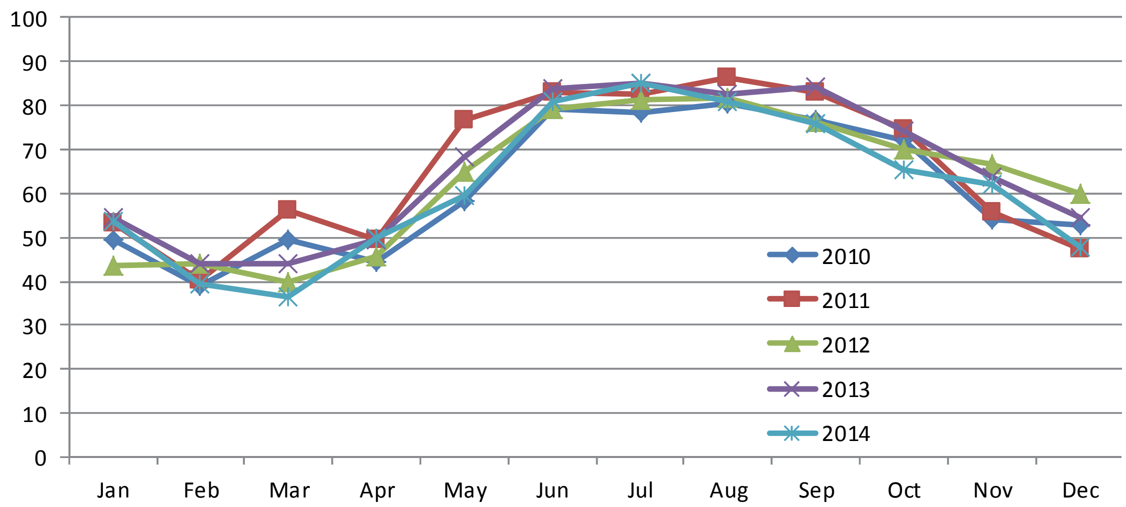
The average humidity of each month was organised (see the following table). Humidity in the dry season from December to April is around 50%. However, humidity in the rainy season from June to September is about 80%.

Table 3.1.5. Monthly Average Humidity

Unit: %

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2010	49	39	50	44	58	79	78	80	76	72	54	53
2011	53	40	56	49	77	83	83	86	83	74	56	47
2012	43	44	40	46	65	79	81	82	76	70	66	60
2013	55	44	44	49	68	84	85	83	84	74	64	55
2014	53	39	37	50	59	81	85	81	76	65	62	48

Source: JICA Study Team



Source: JICA Study Team

Figure 3.1.3. Graph of Monthly Average Humidity Unit: %

4) Fog

Collected data were summarised by the Study Team and shown in the following table. According to the collected data, fog is hardly generated throughout the year.

Table 3.1.6. Fog Data (2014 Number of Foggy Days)

Station : KABA-AYE   Year :2014

Daily Fog Frequency

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0	0	3	0	0	0	0	0	0	0	0	0
2	0	0	3	0	0	0	0	0	0	3	0	0
3	0	3	0	0	0	0	0	0	0	4	0	0
4	0	0	4	0	0	0	0	0	0	3	0	0
5	0	4	0	0	0	0	0	0	0	0	0	0
6	1	2	0	0	0	0	0	0	0	0	0	0
7	0	5	0	0	0	0	0	0	0	0	0	0
8	0	7	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	1
10	0	0	0	0	0	0	0	0	0	0	0	0
11	0	7	0	0	0	0	0	0	0	0	0	0
12	0	7	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	3	0	0	0	0	0	0	0	0	0
15	3	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0
17	1	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	3	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0
24	2	0	0	0	0	0	0	0	0	1	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0
28	3	0	0	0	0	0	0	0	0	0	0	0
29	3		0	0	0	0	0	0	0	0	0	0
30	0		0	0	0	0	0	0	0	0	0	0
31	0		0		0		0	0		0		0

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Source: Myanmar Department of Meteorology and Hydrology, JICA Study Team

5) Rainfall

Precipitation has been measured at 6:00 every day. Daily rainfall is the cumulative total of precipitation observed from 6:00 to 24:00. Collected data were summarised by the Study Team and shown in the following table.

Table 3.1.7. Rainfall Data (2014)

Station : KABA-AYE Year :2014

Daily Rainfall (mm)

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0	0	0	0	0	3	21	55	8	0	0	0
2	0	0	0	0	0	0	17	7	3	25	0	0
3	0	0	0	0	0	0	26	14	45	68	29	0
4	0	0	0	0	0	30	24	47	16	20	2	0
5	0	0	0	Trace	0	45	8	39	0	0	68	0
6	0	0	0	0	0	0	9	36	3	2	154	0
7	0	0	0	0	Trace	14	Trace	26	9	0	47	0
8	0	0	0	0	0	2	7	1	17	0	0	0
9	0	0	0	0	15	8	45	13	0	Trace	0	0
10	0	0	0	0	19	16	10	58	4	17	0	0
11	0	0	0	0	0	49	23	23	Trace	1	0	26
12	0	0	0	0	16	162	31	Trace	0	Trace	Trace	0
13	0	0	0	0	0	7	23	Trace	25	3	0	0
14	0	0	0	0	0	2	43	0	1	0	0	0
15	0	0	0	0	6	5	10	17	17	0	Trace	0
16	0	0	0	0	0	7	23	41	5	0	0	0
17	0	0	0	Trace	0	18	0	1	1	0	Trace	0
18	0	0	0	0	0	16	27	0	0	0	0	0
19	0	0	0	0	101	5	14	9	14	0	0	0
20	0	0	0	0	8	5	127	Trace	0	17	0	0
21	0	0	0	0	22	17	75	21	0	0	0	0
22	0	0	0	0	35	58	36	29	Trace	Trace	0	0
23	0	0	0	0	10	57	Trace	33	0	21	0	0
24	0	0	0	0	62	81	5	2	2	0	0	0
25	0	0	0	0	0	38	43	Trace	5	0	0	0
26	0	0	0	0	0	2	38	3	5	18	0	0
27	0	0	0	0	0	10	39	Trace	6	5	0	0
28	0	0	0	0	0	42	17	30	0	1	0	0
29	0		0	0	0	2	Trace	34	0	21	0	0
30	0		0	0	1	Trace	53	30	11	0	0	0
31	0		0		0		24	6		5		0

"Trace" The amount of rainfall which cannot be measured.

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Source: Myanmar Department of Meteorology and Hydrology, JICA Study Team

From the results of the total rainfall of the past five years, it can be understood that the annual average rainfall of Yangon city is about 2800 mm, i.e. about 1.5 times the average annual rainfall of Japan (1800 mm).

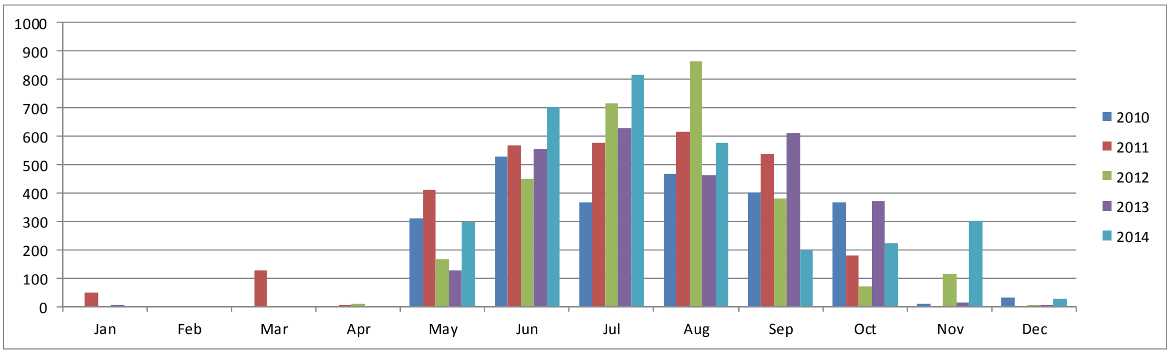
In addition, from the below annual rainfall in the 2010 ~ 2014 period, it can be said that Yangon has a clearly tropical monsoon climate with rainfall that is very different between the rainy season and the dry season.

Table 3.1.8. Monthly Precipitation (2010- 2014)

Unit: mm

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	total
2010	0	0	0	0	308	529	367	467	402	367	7	33	2480
2011	48	0	127	5	412	567	574	615	538	178	0	0	3064
2012	0	0	0	8	167	450	717	864	379	69	115	2	2771
2013	6	0	0	0	125	556	630	464	612	371	13	3	2780
2014	0	0	0	0	295	701	818	575	197	224	300	26	3136

Source: JICA Study Team



Source: JICA Study Team

Figure 3.1.4. Monthly Rainfall Graph (2010 ~ 2014)

3.2. Water Depth along the Navigation Channel

As a derived product, 1 m depth contour interval bathymetric maps covering the whole survey area were prepared based on the results of the 1st bathymetric survey which was executed during May and June 2015 (refer to Volume 3 Drawings Figure 1.1.1.).

Also, 1 m depth contour interval bathymetric maps along the Transit Line (300 m width and approx. 72.0 km length) were prepared based on the results of the 2nd bathymetric survey, which was executed during November and December 2015 (refer to Volume 3 Drawings Figure 1.6.2.).

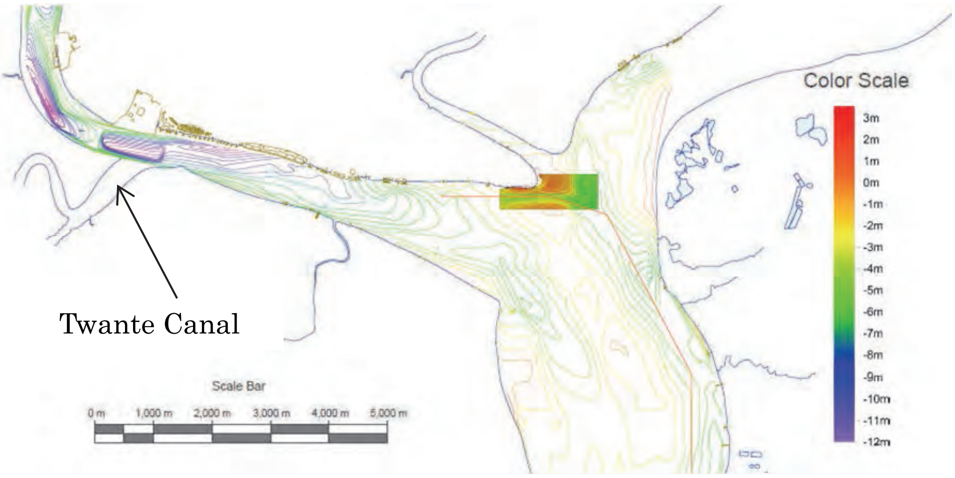
According to the above-mentioned bathymetric survey results, the outline of the riverbed topography of the Yangon River, the river mouth and the offshore area of the Yangon River area are as follows.

3.2.1. From Upper Stream Survey Area of the Yangon River to Monkey Point

The water depth of the area from the upper stream survey area of the Yangon River to Monkey Point is relatively deep.

The deepest point in this area is around the merging point of the Yangon River and the Twante Canal, and the water depth around this area is deeper than 20.0 m.

From this merging point of the Yangon River and the Twante Canal to Monkey Point, the water depth at the centre of the Yangon River becomes shallow gradually, from approx. -12 m to approx. -5 m. The shallowest point in this area is the centre of the merging point of the Yangon River and the Bago River, and the water depth around this area is approx. -1 m.



Source: JICA Study Team

Figure 3.2.1. Survey Result from Yangon Port to Monkey Point

3.2.2. Dredged Navigation Channel at Monkey Point

The water depth of the dredged navigation channel at Monkey Point is approx. -4.0 m and the width of the dredged navigation channel is approx. 150.0 m. The shape of this dredged navigation channel at Monkey Point is maintained well by the periodic maintenance dredging by the MPA.

The water depth of the southern side of the navigation channel of Monkey Point is approx. -1 m and it is difficult for large ships to pass this area, especially at low tide.

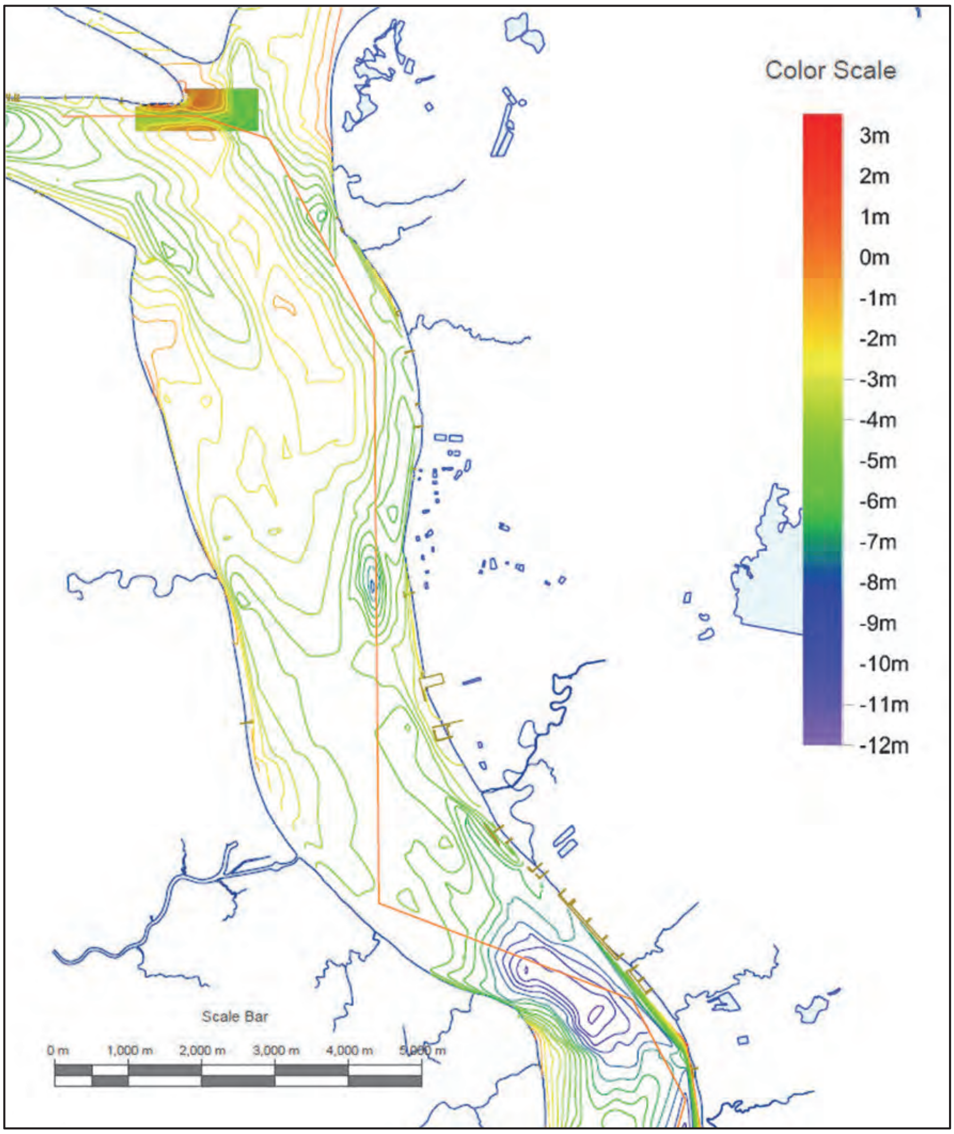
3.2.3. The Area from Monkey Point to Thilawa

Basically, in this area, the water depth on the left side of the Yangon River is deeper than the water depth of the right side of the Yangon River.

The shallow-depth water area (approx. -1 m water depth) exists at the centre of the merging point of the Yangon River and the Bago River. This shallow water area is approx. 2 ~ 3 km in length and 700 ~ 800 m in width.

In this area, two (2) deep water depth points exist and the water depths at these two (2) points are as follows:

a) In front of the New Admiralty Jetty — The water depth is approx. -12 m
b) In front of Thilawa — The water depth is approx. -16 m



Source: JICA Study Team

Figure 3.2.2. Survey Result from Monkey Point to Thilawa Area

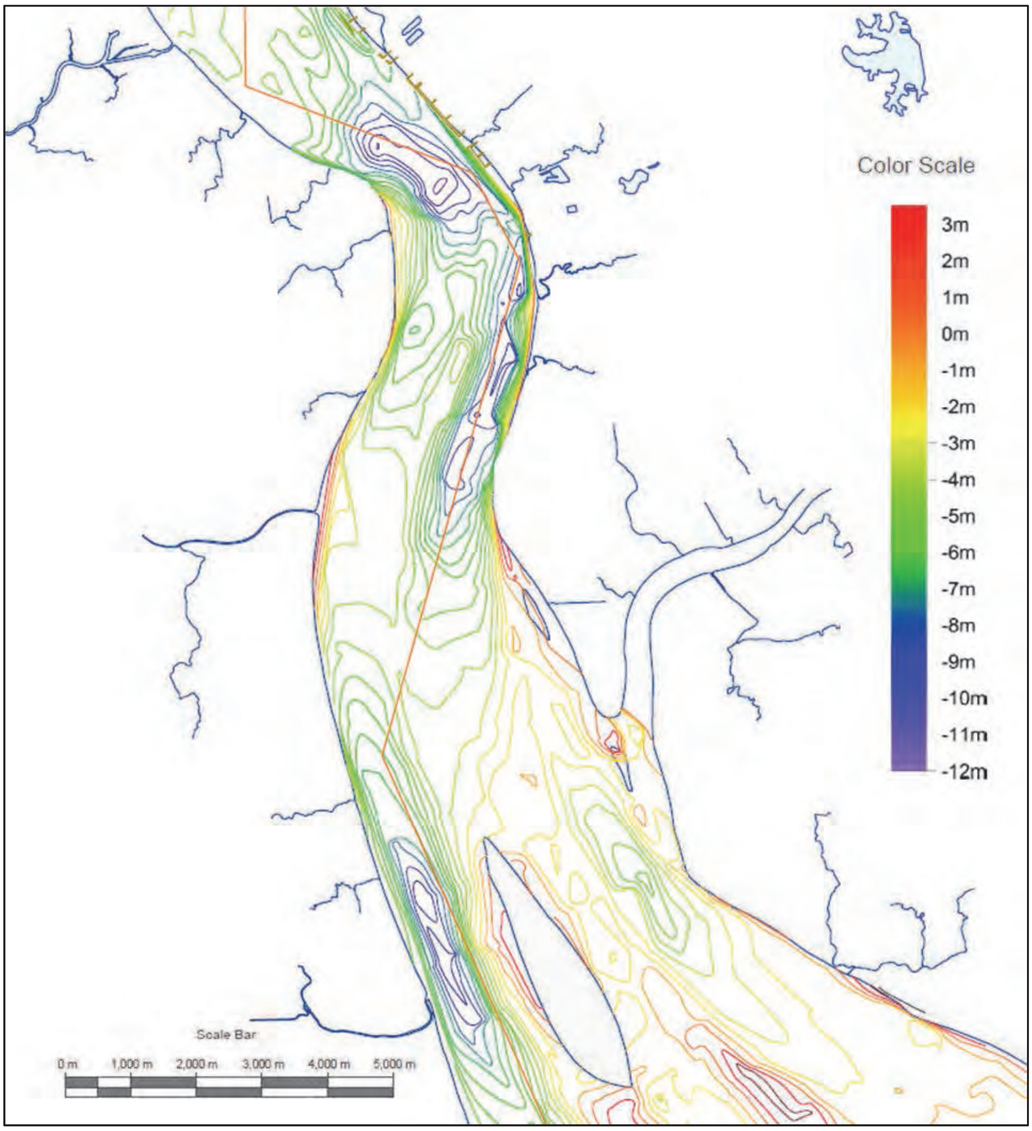
3.2.4. The Area from Thilawa to the Upstream Area of the Island (Myet Sein Kyun)

Basically in this area, the water depth on the left side of the Yangon River is deeper than the right side of the Yangon River.

The Transit Line of the MPA in this area is established from the left side of the Yangon River (Thilawa) to the right side of the Yangon River (upstream area of the island, Myet Sein Kyun).

Therefore, in this area, the water depth upstream of this area along the Transit Line (around Thilawa, left side of the Yangon River) is deeper than downstream of this area along the Transit Line (upstream area of the island, right side of the Yangon River).

The water depth around the upper stream of this area is approx. -13 m ~ -14 m. The water depth around the lower stream of this area is approx. -10 m. The water depth at the centre of the Yangon River in this area is approx. -5 m ~ -6 m.



Source: JICA Study Team

Figure 3.2.3. Survey Result from Thilawa to the Upstream Area of the Island (Myet Sein Kyun)

3.2.5. The Area from the Upstream of the Island (Myet Sei Kyun) to Elephant Point

The water depth on the right side of the island (Myet Sei Kyun) is relatively deep and the water depth on the left side of the island is shallow compared to the right side of the island.

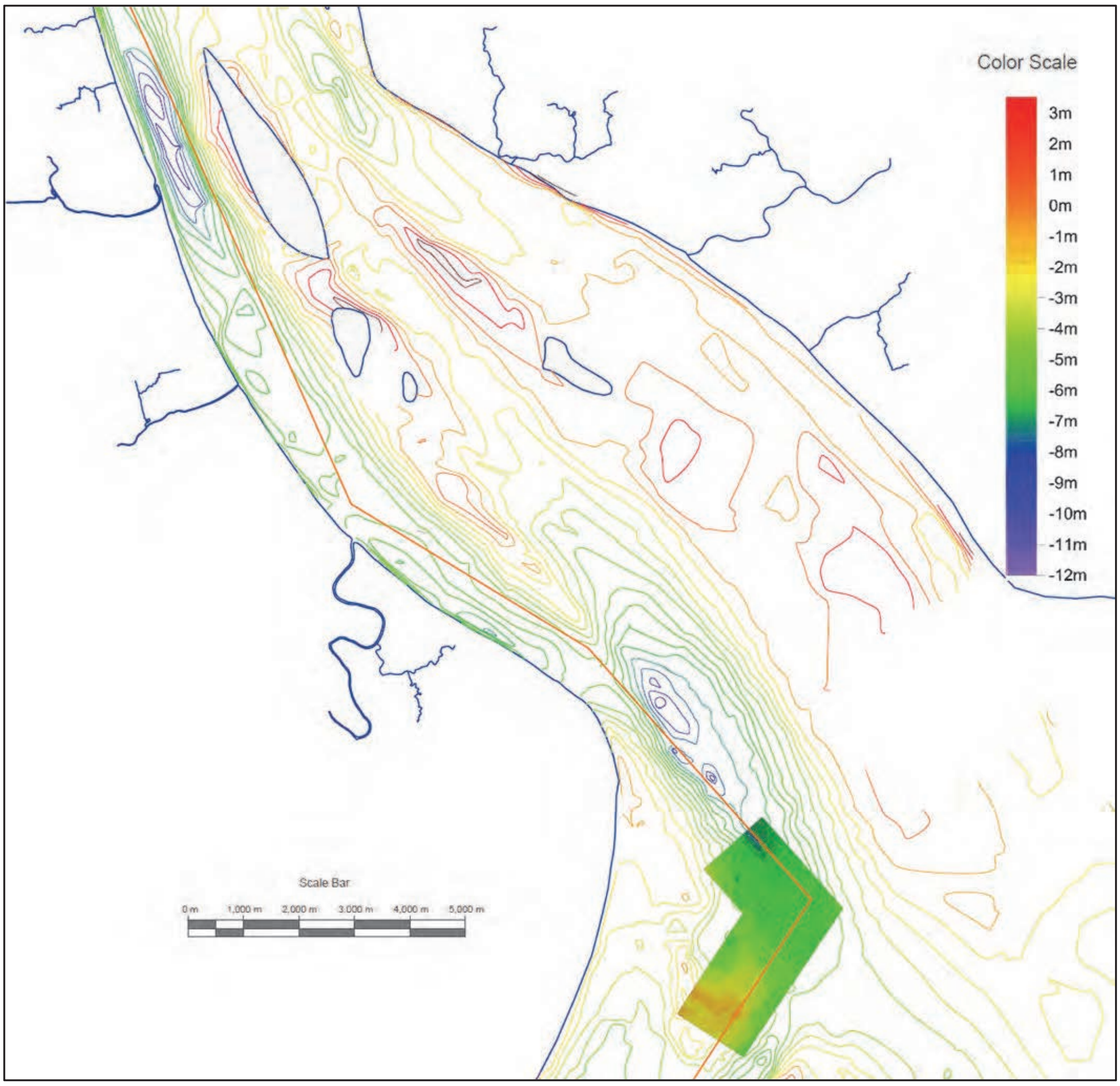
The area with relatively deep water depth is located between the right bank of the Yangon River and the island. The area of relatively deep water depth is running in parallel with the right bank and the distance from the right bank is approx. within 1,000 m.

The water depth between island and the right bank is approx. -10 m ~ -14 m.

The Transit Line of the MPA from the island to the river mouth of the Yangon River in this area is running in parallel with the right bank of the Yangon River (approx. 800 ~ 900 m from the right bank) and the water depth in this area is approx. -7 m ~ -10m.

The Transit Line of the MPA in this area does not coincide with the deepest area of the Yangon River. Especially, the Transit Line between the right bank and island (Myet Sei Kyun) is recommended to be sifted approx. several hundred metres from the present Transit Line of the MPA to the west from the viewpoint of the water depth in this area.

The water depth of the upstream area of Elephant Point is relatively deep and the maximum water depth in this area is approx. -14 m and approx. 1,200 m from the right bank of the Yangon River.



Source: JICA Study Team

Figure 3.2.4. Survey Result from the Upstream of the Island (Myet Sei Kyun) to Elephant Point

3.2.6. Elephant Point

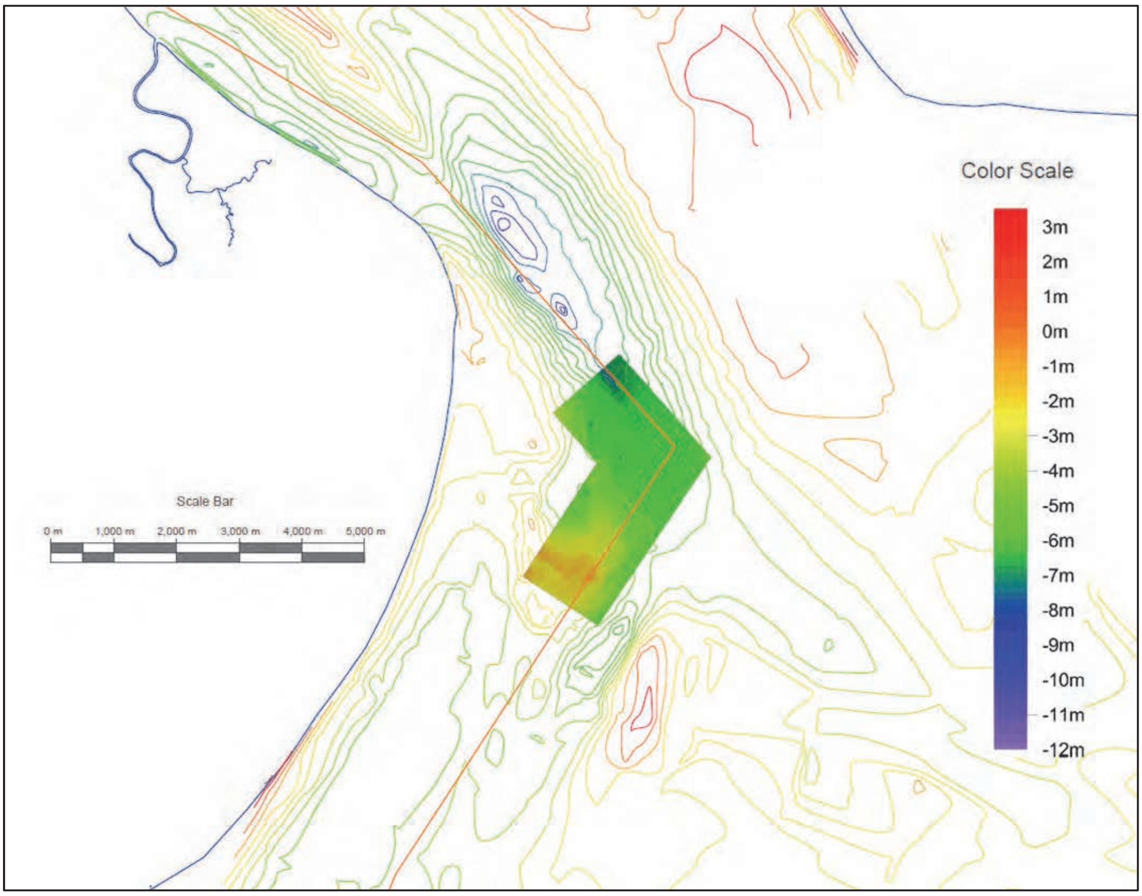
According to the bathymetric survey results at Elephant Point, it is considered that the Transit Line of the MPA does not coincide with the deepest water depth area at Elephant Point (refer to Volume 3 Drawings 1.5.2. and 1.5.3.).

The distance between the Transit Line and the deepest point at Elephant Point is approx. 700 m.

The characteristics of the riverbed topography at Elephant Point are as follows:

1) The shallowest water depth at Elephant Point is approx. +1 m.
2) The deepest water depth at Elephant Point is approx. -9 m.

3) The width of area deeper than -8 m at Elephant Point is approx. 300 m.
4) The eastern side of the deepest area becomes shallow drastically.
   (from -8 m to 0 m within the distance of approx. 450 m)

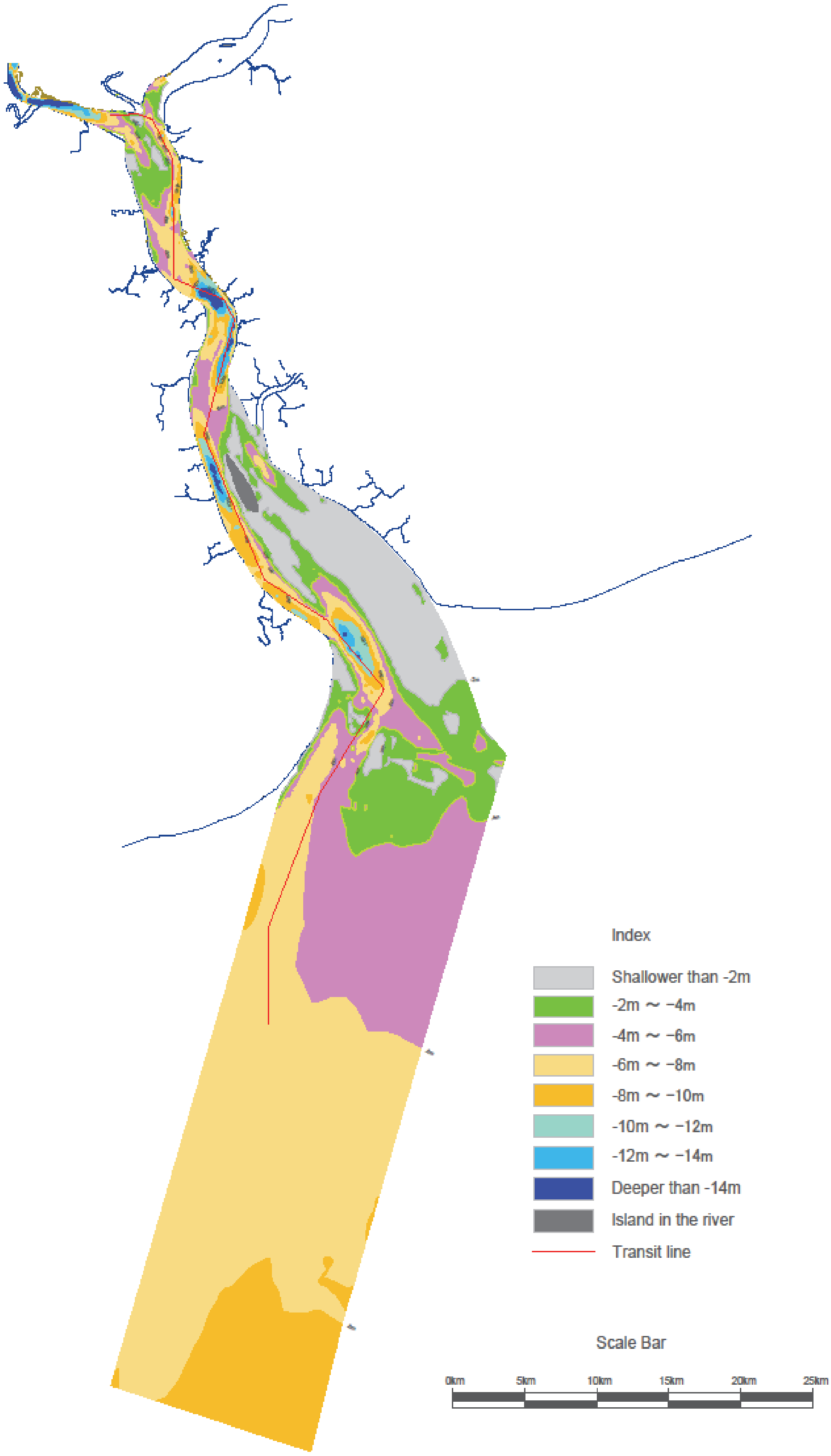


Source: JICA Study Team

Figure 3.2.5. Survey Result at Elephant Point

3.2.7. From Elephant Point to Pilot Station

The sea bottom topography from Elephant Point to the Pilot Station is gentle and the water depth in this area is approx. -5 m ~ -6 m. The following drawing shows the result of the whole survey area including offshore with 2m interval.



Source: JICA Study Team

Figure 3.2.6. 2 m Interval Coloured Bathymetric Map Covering Whole Survey Area before Rainy Season

3.3. Water Depth Change at Monkey Point

3.3.1. Water Depth Change at Monkey Point from the Viewpoint of the Bathymetric Survey Results

Figure 3.3.1. shows the colour maps at Monkey Point before and after the rainy season, and the difference of water depth at Monkey Point between before and after rainy seasons.

Figure 3.3.2. shows the cross sections at Monkey Point before and after rainy seasons based on the 1st and 2nd bathymetric survey by multi-beam sounding system. The blue line is the cross section prepared by the 1st bathymetric survey results before the rainy season (observation during May and June 2015). The red line is the cross section prepared by the 2nd bathymetric survey results after the rainy season (observation during November and December 2015).

The navigation channel at Monkey Point is maintained by the periodical dredging by the MPA. Therefore, the water depth change in the navigation channel at Monkey Point shown on Figure 3.3.1. does not indicate an inartificial difference of water depth between before and after rainy seasons.

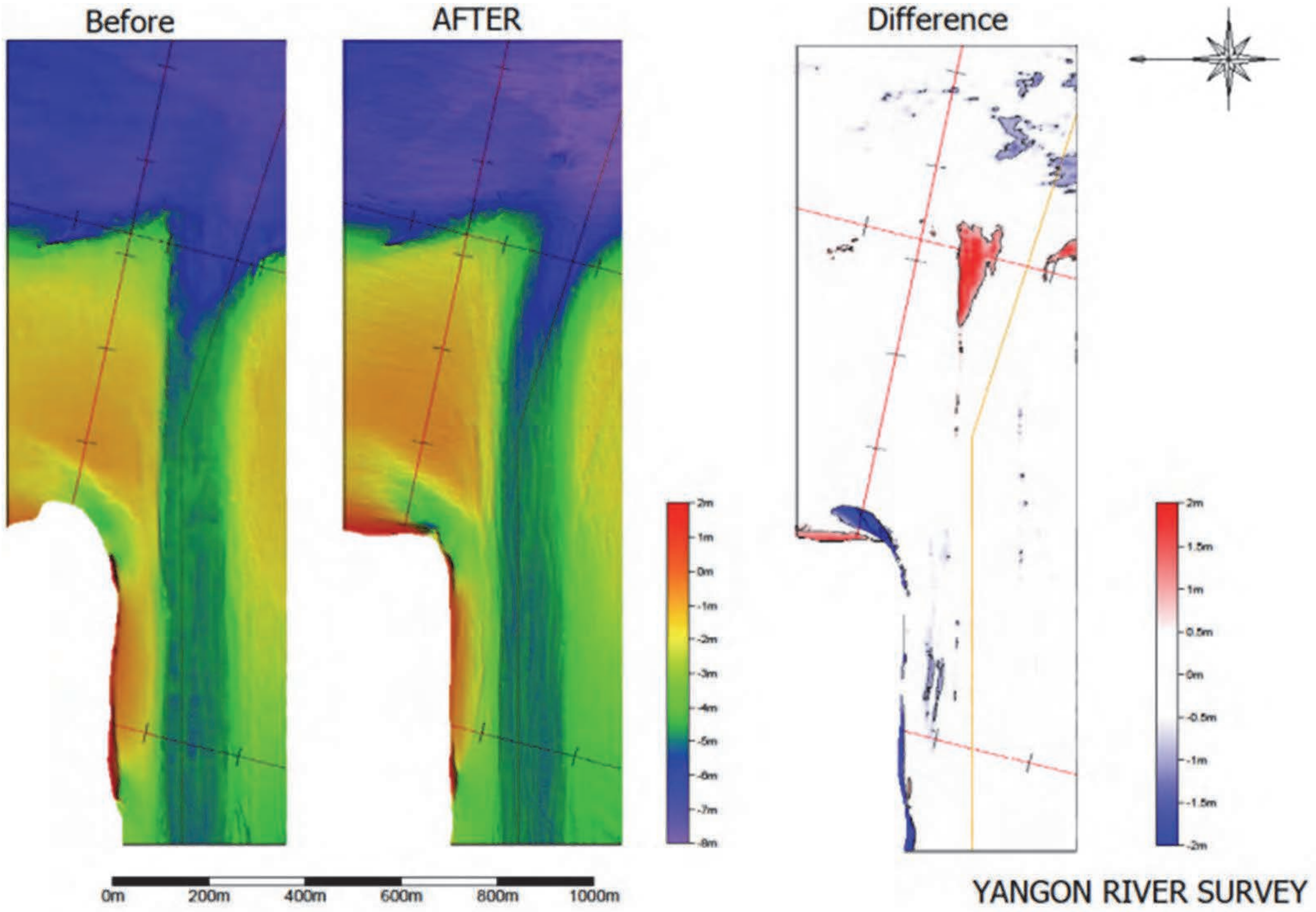
From the viewpoint of the bathymetric survey results, the characteristics of riverbed topography change in the navigation channel at Monkey Point are as follows:

1) The navigation channel at Monkey Point is well maintained by the MPA and the -4 m water depth in the navigation channel at Monkey Point is kept both before and after rainy seasons.
2) An approx. 1.5 m ~ 2.5 m sedimentation between before and after rainy seasons is found at the lower stream area of the navigation channel (both sides of the outlet of the navigation channel) at Monkey Point.
3) At the area connecting Pazundaung Creek, which has the survey line P-01 in the following Figure 3.3.2., and the navigation channel at Monkey Point, the water depth after the rainy season becomes approximately 1.0 m ~ 1.5 m deeper than the water depth before the rainy season.
4) No significant water depth changes were found in other areas of the navigation channel at Monkey Point.

Cross section Y-39 and Y-37 show that for most of the area around the merging point between the Yangon River and the Bago River, the water depth after the rainy season becomes deeper than the water depth before the rainy season.

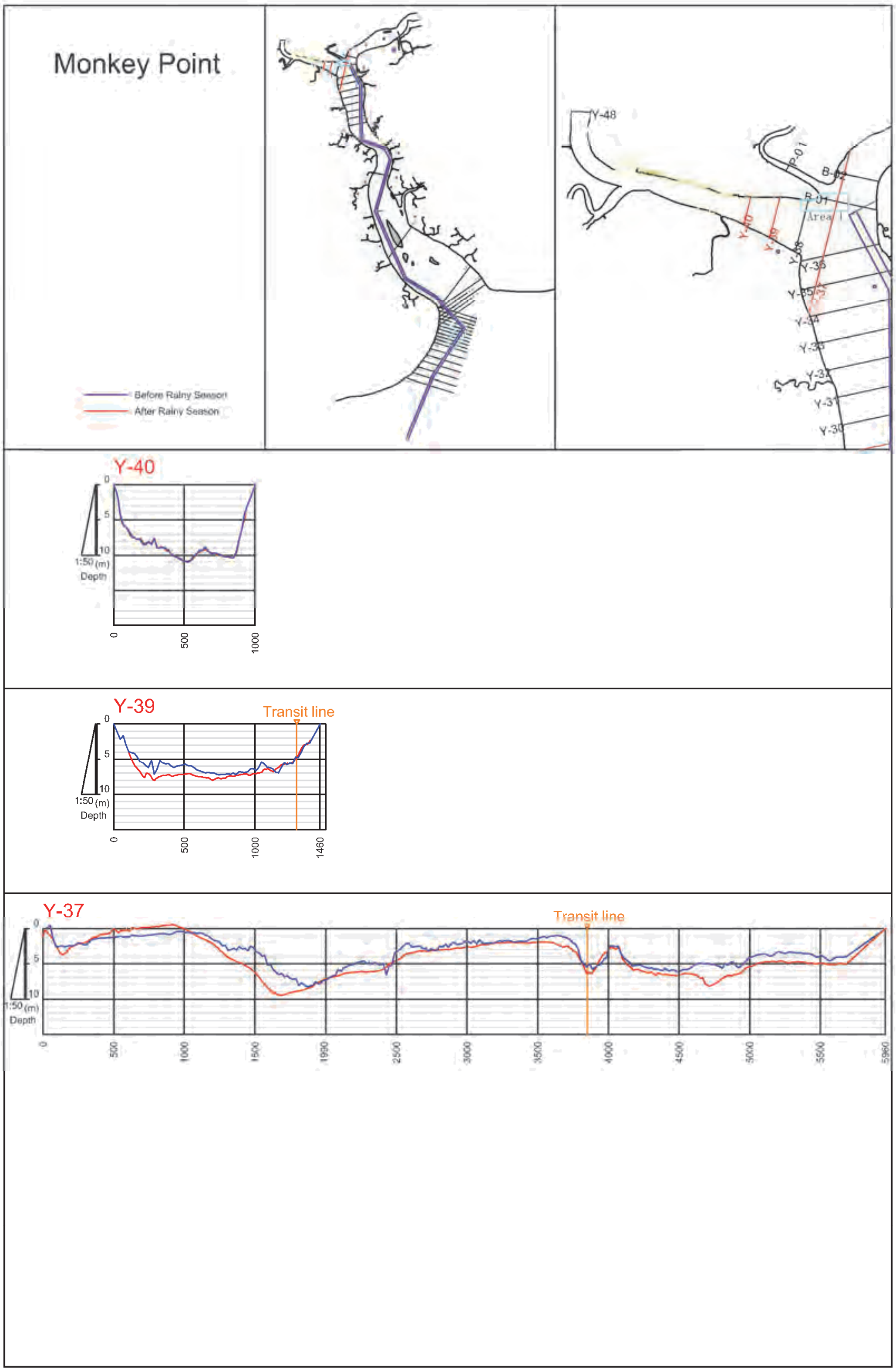
Therefore, it is considered that the sedimentation around Monkey Point occurs in the dry season. The sediments are washed away by the strong river flow during the rainy season.

However, to verify this phenomenon, it is necessary to execute a bathymetric survey at the next dry season again.



Source: The JICA Study Team

Figure 3.3.1. Water Depth Change at Monkey Point between Before and After Rainy Season



Source: The JICA Study Team

Figure 3.3.2. Comparison of Cross Sections at Monkey Point between Before and After Rainy Season

3.4. Water Depth Changes at Elephant Point

3.4.1. Water Depth Changes at Elephant Point from the Viewpoint of Past Bathymetric Maps of the MPA

The MPA executes a bathymetric survey at Elephant Point periodically. The following bathymetric maps at Elephant Point were collected from the MPA.

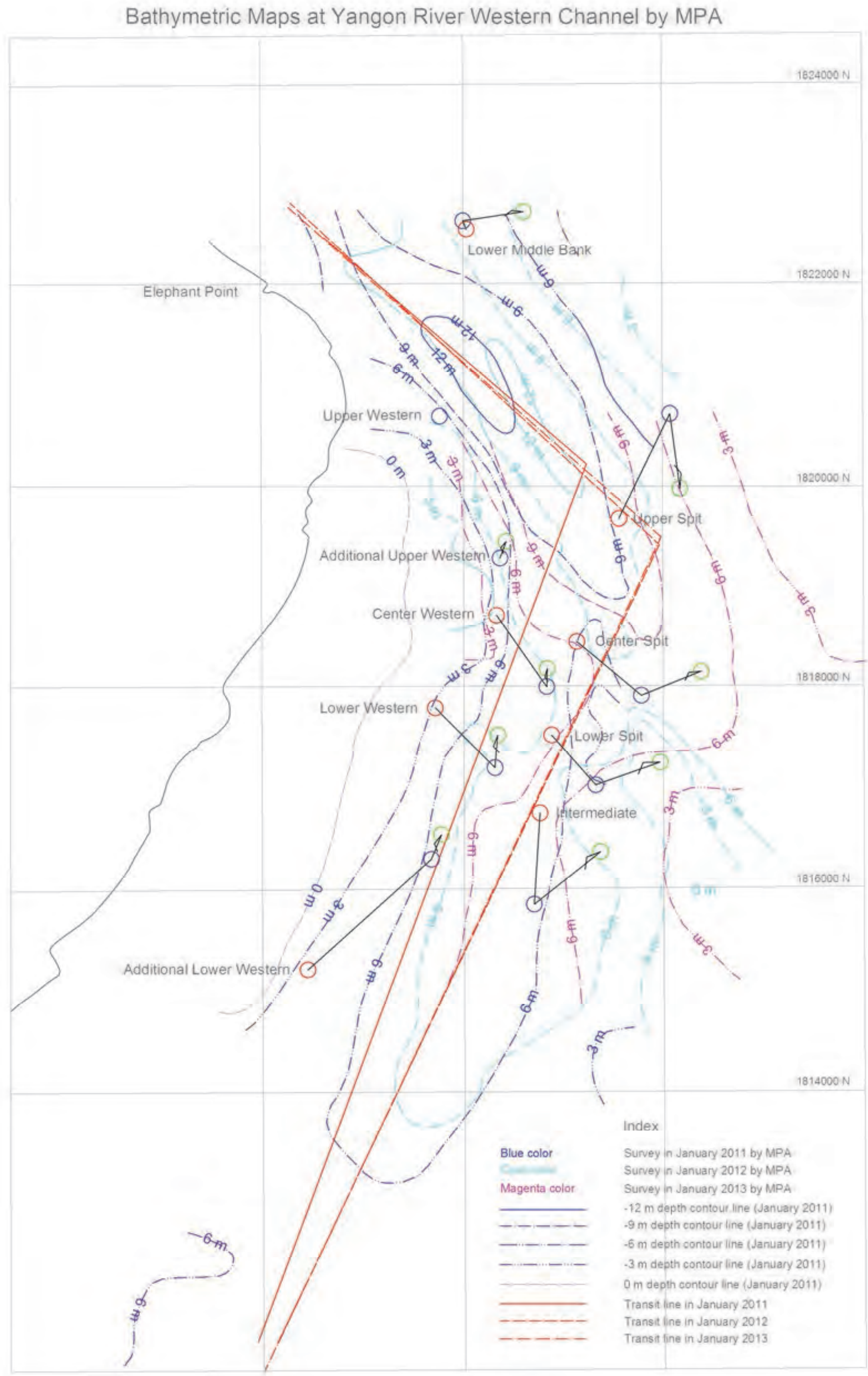
1) 1/35,000-scale bathymetric map from January 2011
2) 1/35,000-scale bathymetric map from January 2012
3) 1/35,000-scale bathymetric map from January 2013
4) 1/35,000-scale bathymetric map from January 2015
5) 1/35,000-scale bathymetric map from May 2015
6) 1/35,000-scale bathymetric map from August 2015

Figure 3.4.1. shows the water depth change at Elephant Point based on the bathymetric maps from January 2011, January 2012 and January 2013 of the MPA. It is possible to grasp the water depth change at Elephant Point horizontally among these three years by this figure.

Figure 3.4.2. shows a comparison of cross sections based on the bathymetric maps of the MPA from January 2011, January 2012 and January 2013. It is possible to grasp the water depth change at Elephant Point vertically among these three years by this figure.

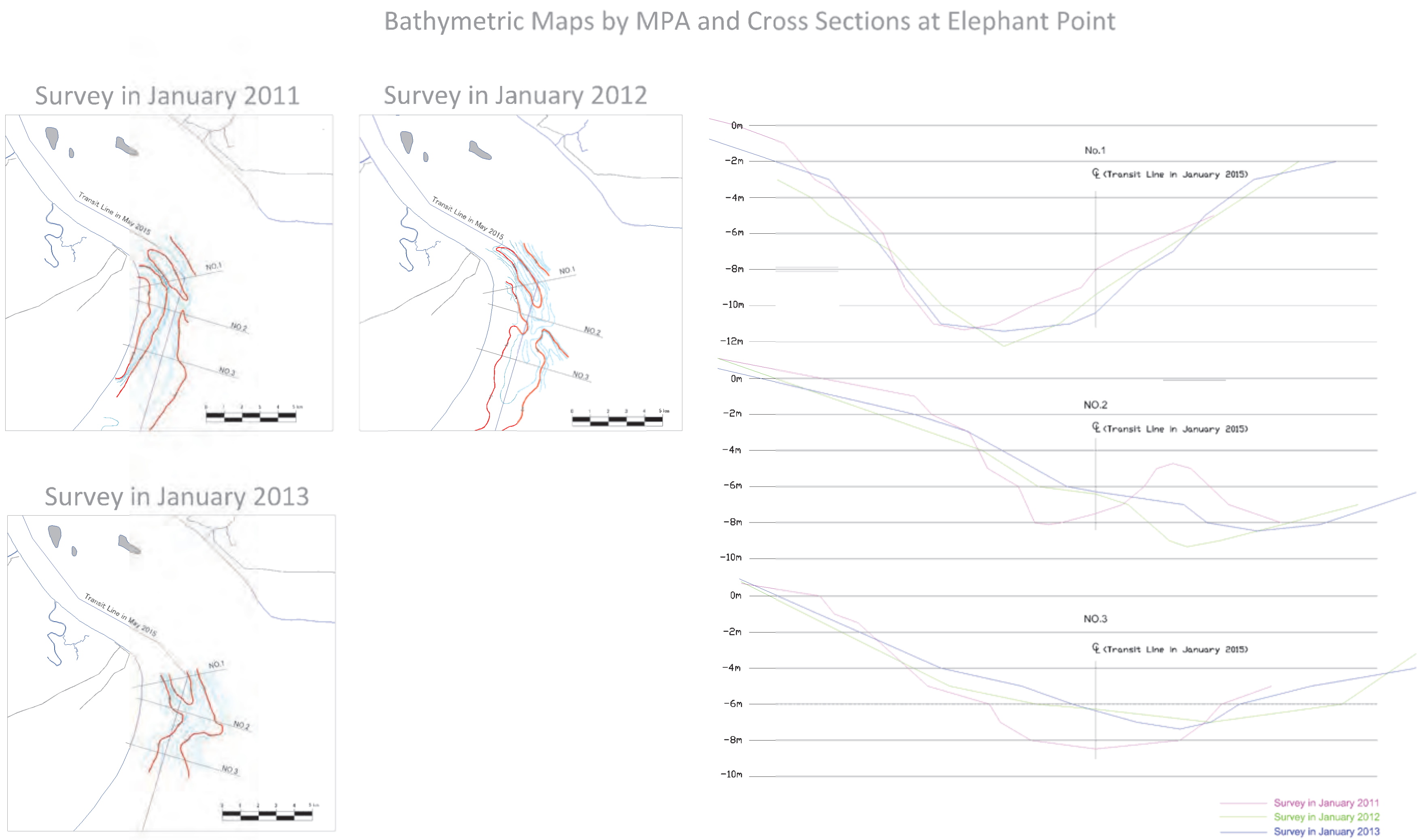
Based on these two figures, the characteristics of water depth change at Elephant Point are considered as follows:

1) The deepest point at Elephant Point moves south-eastward.
2) Both sedimentation and erosion occur within a comparatively narrow area at Elephant Point and the river bed topography at Elephant Point changes drastically.
3) It is considered that the water depth change upstream of Elephant Point is larger than the downstream area of Elephant Point.
4) The Transit Line and locations of navigation buoys at Elephant Point were shifted southeast according to the shifting of the deepest point at Elephant Point.



Source: The JICA Study Team

Figure 3.4.1. Water Depth Change at Elephant Point Based on Bathymetric Maps from January 2011, January 2012 and January 2013 of MPA



Source: The JICA Study Team

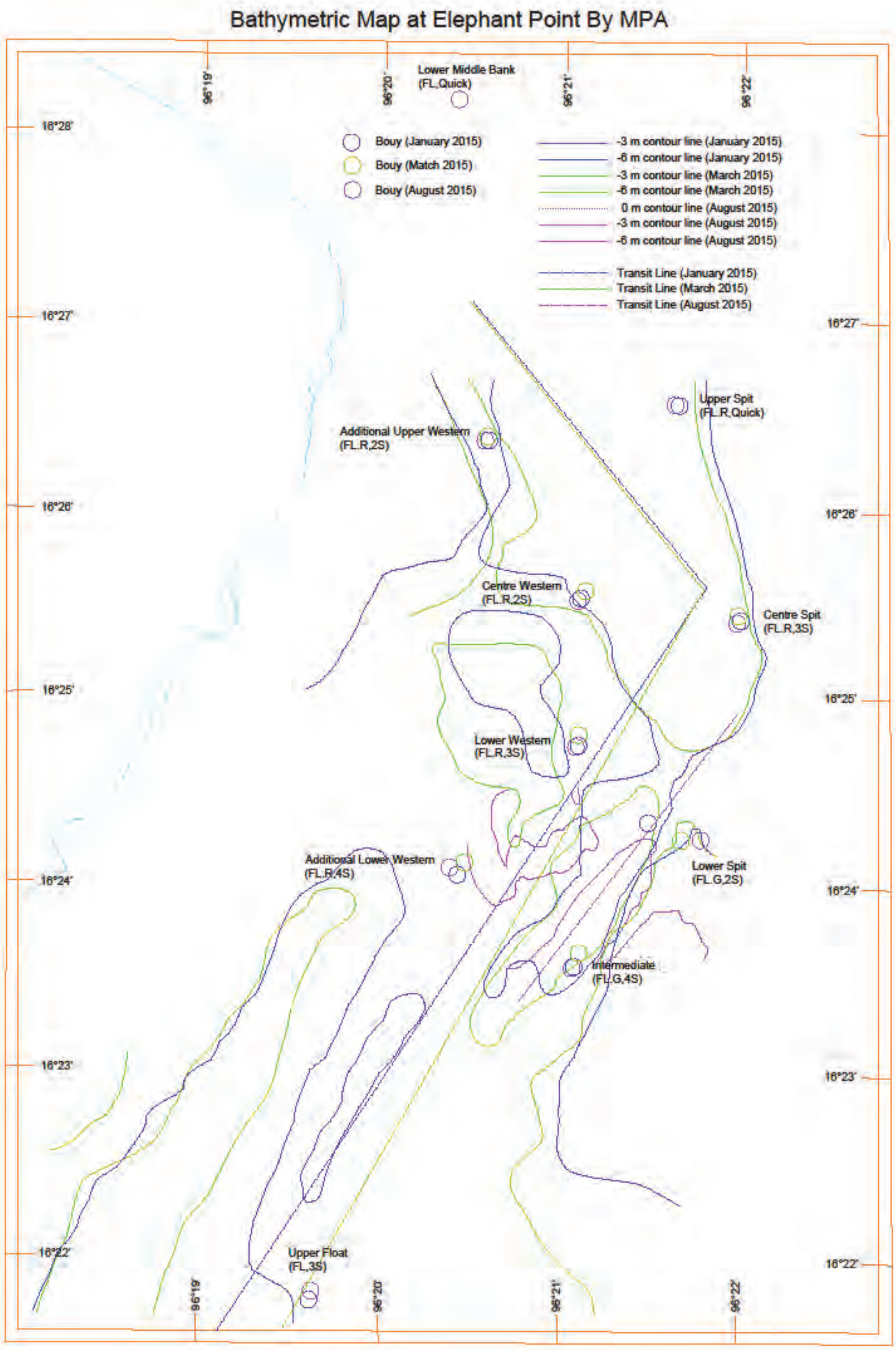
Figure 3.4.2. Cross Sections at Elephant Point Based on the Bathymetric Maps from January 2011, January 2012 and January 2013 of MPA

Figure 3.4.3. shows the water depth change at Elephant Point based on the bathymetric maps of the MPA from January, May and August 2015.

The area of the bathymetric survey from August 2015 is very narrow compared to the area of the bathymetric survey from January and May 2015. Therefore, it is considered that the bathymetric survey from August 2015 was not a periodic bathymetric survey executed ordinarily by the MPA. It is considered that the bathymetric survey from August 2015 was executed to urgently identify the deepest location at Elephant Point.

The Transit Line shown on the bathymetric map from August 2015 of the MPA shifted approximately 700 m east from the location of the Transit Line shown on the bathymetric map from May 2015. Therefore, it is considered that the bathymetric map from August 2015 was executed to identify the deepest location at Elephant Point and to modify the alignment of the Transit Line at Elephant Point.

Based on this figure, it is judged that the deepest point at Elephant Point moves southeast.



Source: The JICA Study Team

Figure 3.4.3. Water Depth Change at Elephant Point Based on January, May and August 2015 of MPA

3.4.2. Water Depth Change at Elephant Point from the Viewpoint of the Bathymetric Survey Results

Figure 3.4.4. shows the water depth change at Elephant Point based on the results of the bathymetric survey by multi-beam sounding system before and after the rainy season.

Figure 3.4.5. shows the comparison of cross sections at Elephant Point based on the results of cross section surveys before and after the rainy season. A blue line is the cross section prepared by the 1st bathymetric survey results before the rainy season (observation during May and June 2015). A red line is the cross section prepared by the 2nd bathymetric survey after the rainy season (observation during November and December 2015).

The two sets of bathymetric survey results show that the change of river bed topography at Elephant Point is very big, and the areas of sedimentation and erosion exist within a relatively narrow area of Elephant Point.

At the location approximately 1,000 m west from the Transit Line on the cross section number E-10 and E-9, the water depth after the rainy season becomes approximately 4.0 m ~ 4.5 m shallower than the water depth before the rainy season. Therefore, in this area, approximately 4.0 m ~ 4.5 m of sedimentation occurred during the rainy season, and the river bed topography after the rainy season in this area looks like a cliff with approximately 4.0 m ~ 4.5 m height.

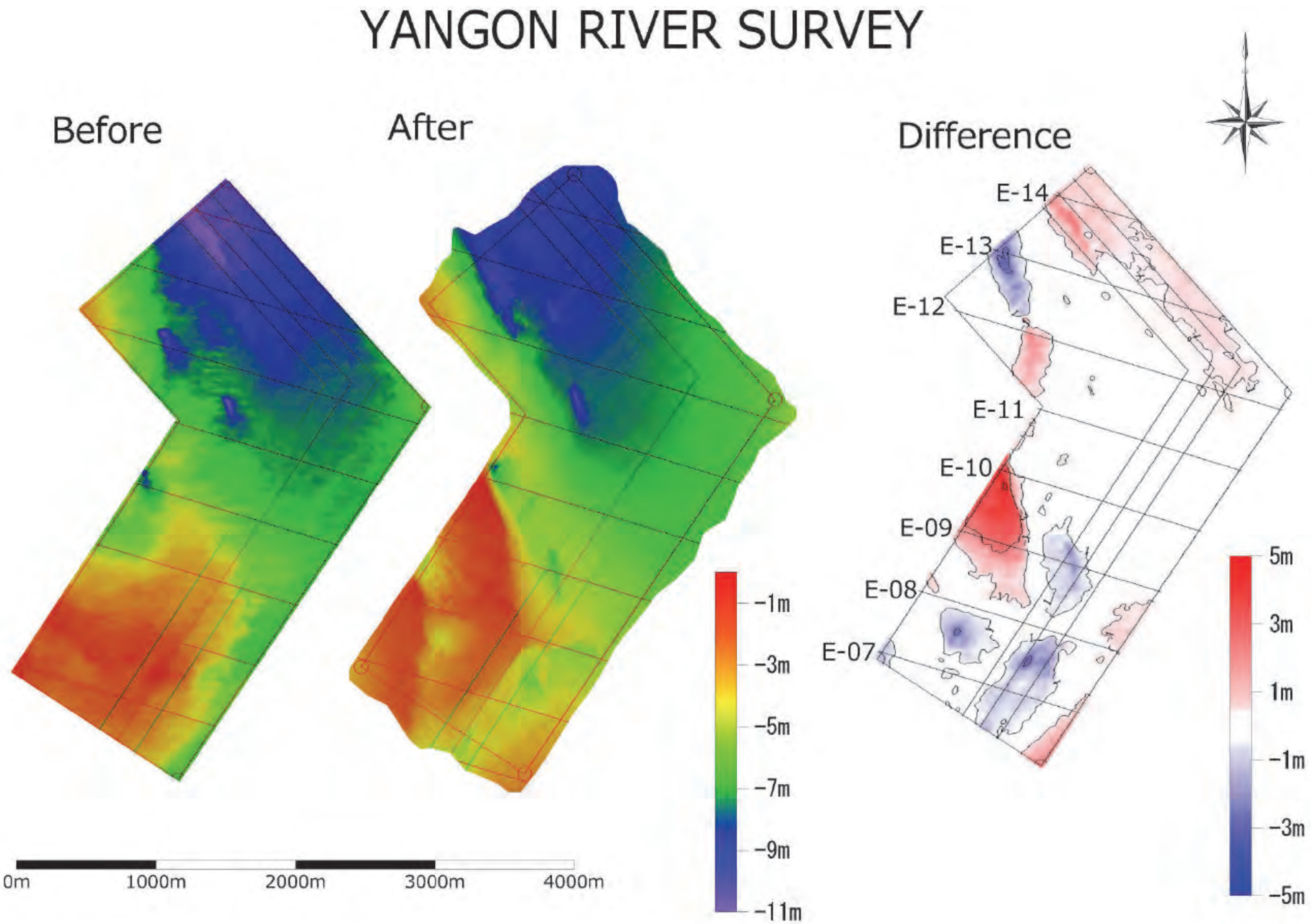
It is uncertain whether the river bed topography, after the rainy season, like a cliff with an approximately 4.0 m ~ 4.5 m height will become a relatively flat river bed topography, shown on the bathymetric survey before the rainy season, at the end of coming rainy season, or if this cliff-like river bed topography will persist after the coming rainy season. To identify this issue, it is necessary and essential to execute continual and periodic bathymetric surveys at Elephant Point.

According to the results of the bathymetric survey, the Transit Line around the upstream area of Elephant Point (cross section line number E-16, E-14 and E-12) coincides with the deepest area of Elephant Point in general.

However, around the downstream area of Elephant Point, the results of the bathymetric surveys both before and after the rainy seasons (cross section line number E-8) show that the Transit Line does not coincide with the deepest area of Elephant Point.

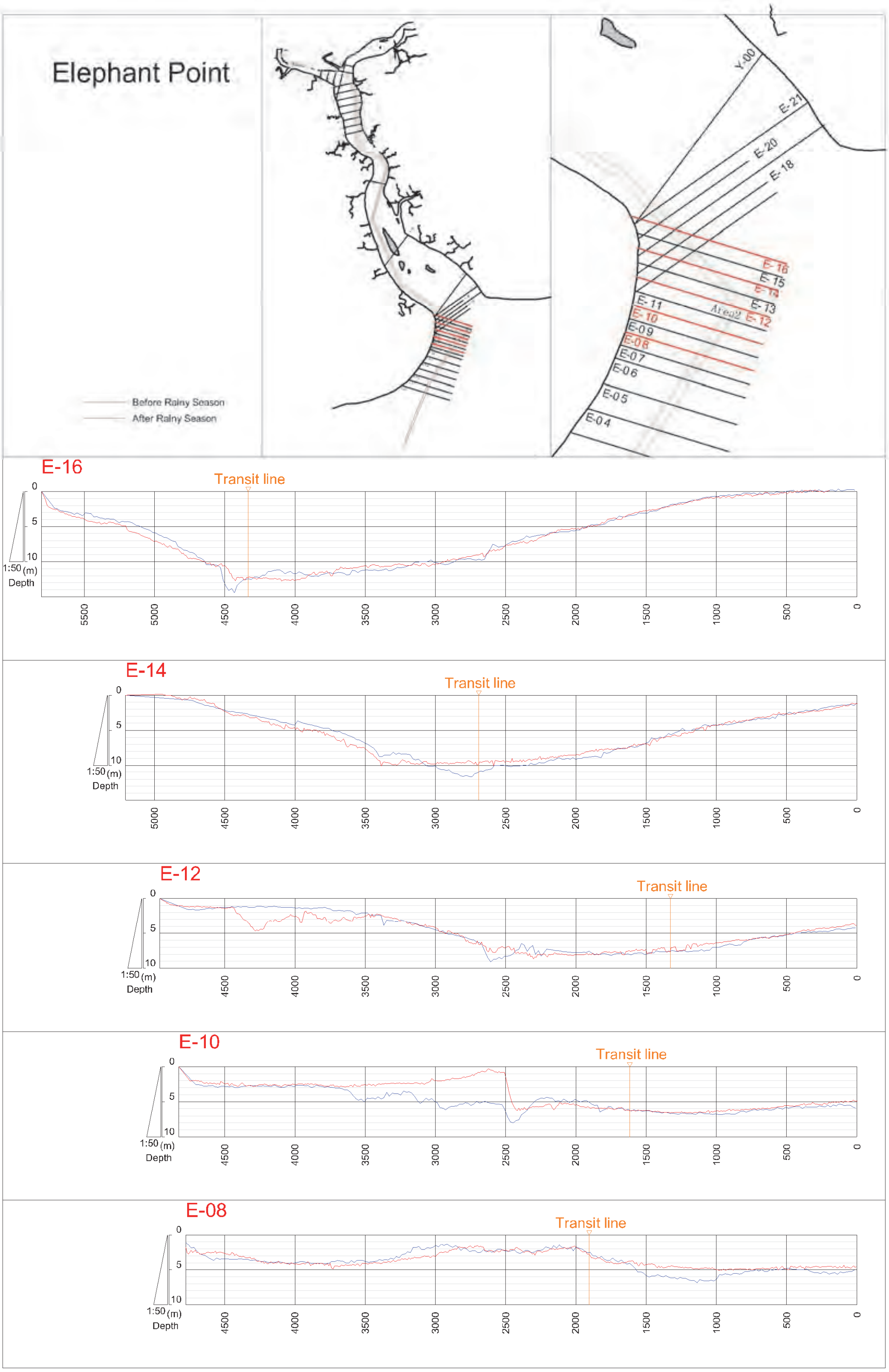
Furthermore, the results of the bathymetric surveys after the rainy season (observation during November and December 2015) shows that the deepest point at Elephant Point shifted east from the deepest point before the rainy season.

The deepest point after the rainy season (observation during November and December 2015) locates at approximately 700 m ~ 800 m east of the Transit Line provided by the MPA.



Source: The JICA Study Team

Figure 3.4.4. Water Depth Change at Elephant Point between Before and After Rainy Seasons



Source: The JICA Study Team

Figure 3.4.5. Comparison of Cross Sections at Elephant Point between Before and After Rainy Seasons

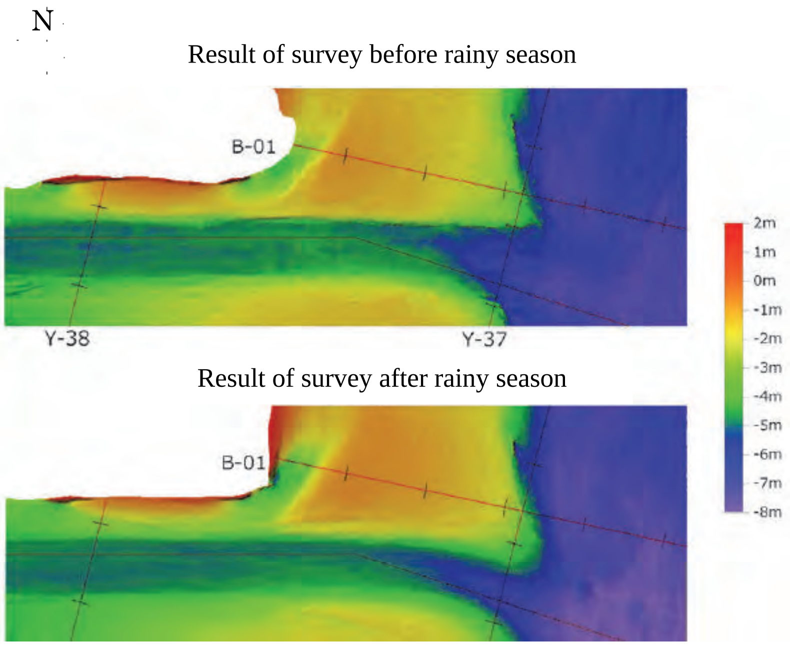
3.5. Status of Maintenance Dredging

The MPA carries out maintenance dredging with the aim of ensuring a water depth of the ship course of the Yangon River. The maintenance dredging has been conducted mainly at Monkey Point (confluence) where navigation becomes most difficult in the channel, and will also be done around the district of Thilawa, etc., as needed. Hearing interviews with the MPA were conducted to understand the status of the maintenance dredging in the channel and to reflect its feedback into consideration of countermeasures for future course maintenance and to use it as a reference. The results of the interviews are given below.

3.5.1. Maintenance Dredging

Maintenance dredging at Monkey Point is conducted almost every day. Such dredging is done around low tide for the working efficiency of the dredgers. Depending on tide levels or anchorage/navigation and other conditions of a large ship, nighttime dredging is also done. Maintenance dredging at Monkey Point, which aims to ensure the shape of the channel at a water depth of CD-4.2 m, is done by a 1000 m^3-class TSHD clamshell dredger owned by the MPA. The shape of the course is monitored through sounding by the survey division of the MPA.

In this study, a multi-beam survey was conducted at Monkey Point in two dry seasons, before and after the rainy season. The results of the survey are shown below as a colour map.



Source: The JICA Study Team

Figure 3.5.1. Results of Multiple Surveys at Monkey Point

As shown in the above figure, it is understood that a refined dredging section with a width of about 500 m is formed while a water depth of about CD-5 m is ensured. The MPA's dredging work at this point maintains a target shape to ensure a safe course to the Port of Yangon.

3.5.2. Annual Volume of Maintenance Dredging

The MPA performs dredging at Monkey Point almost every day throughout the year. The workload of a dredging workboat is said to be some 500 m^3 per dredging. Such work is repeated 10 times (equivalent to 5,000 m^3) during the dry season and about 7 times (equivalent to 3,500 m^3 during the rainy season). The low frequency of dredging during the rainy season is due to the effect of the increase in water level of the river. Annual availability of the dredger is about 90% a year. The dredger is forced to operate at a very high frequency.

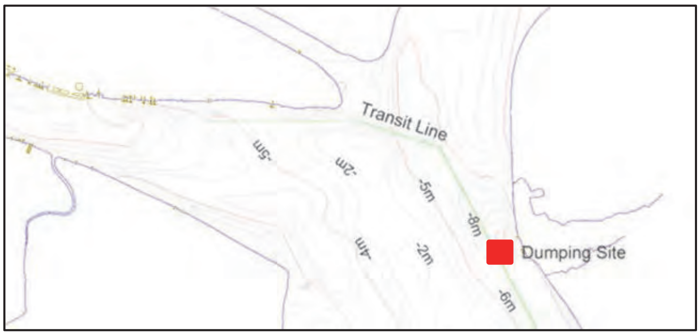
Based on the above discussion, assuming that the dry season is 6 months from November to April next year and the rainy season is 6 months, an annual level of dredging for maintenance of the route can be estimated below.

Rainy season: 5,000 m^3/d × 183 days × 90% = 821,250 m^3/y
Dry season 3,500 m^3/d × 183 days × 90% = 574,875 m^3/y
Total = 1,396,125 m^3/y ≈ **1,400,000 m^3/y**

Hence, an annual level of maintenance dredging at Monkey Point can be estimated to be up to 1.4 million m^3 and the volume of annual maintenance dredging at Monkey Point is quite huge.

3.5.3. Present Dumping Area of Dredged Material

The Dredged material is disposed of at the designated area 2 km downstream of the junction point between the Yangon River and the Bago River. According to the results surveyed in this Study, the point is deeper, having stronger clean flow. So the disposed material would be easily flushed out downstream, therefore the MPA chose that place for their disposal area.



Source: JICA Study Team

Figure 3.5.2. Present Dumping Site of the Dredged Material

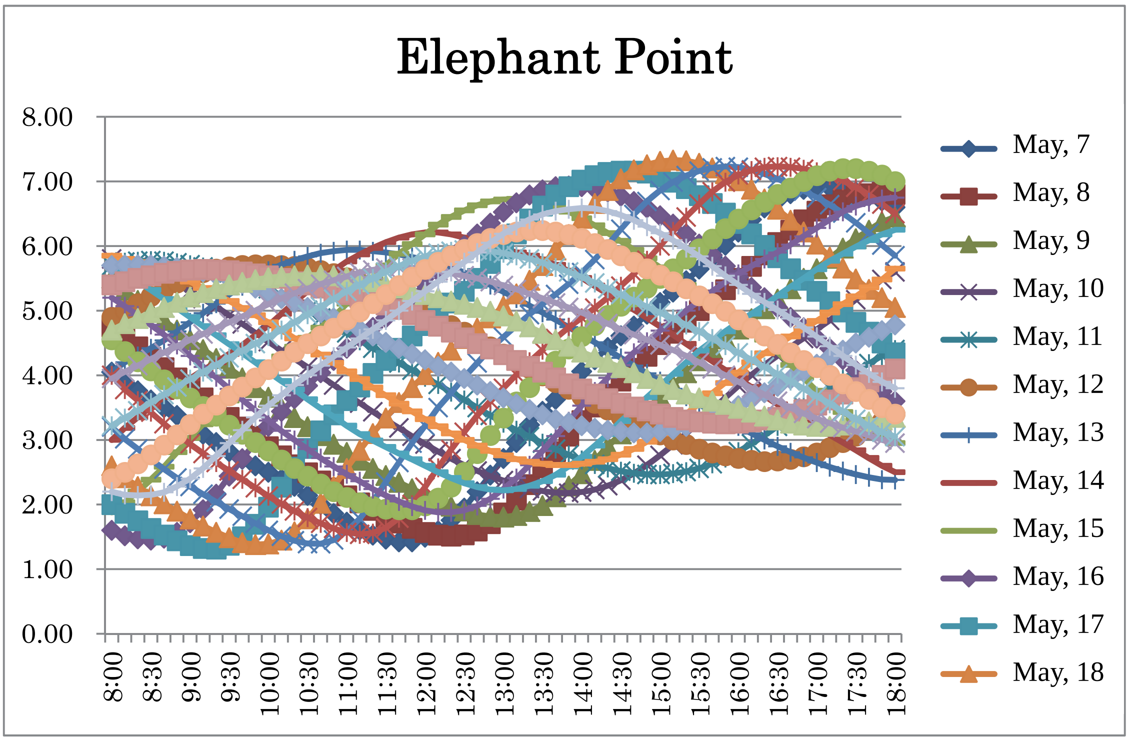
3.6. Fluctuation of Water Level in the Yangon River

In this Study, tide observations were conducted for the bathymetric surveys in pre/post-rainy season. The observations were conducted at 3 points: at Elephant Point, at the MITT berth in the Thilawa Area, and at Monkey Point. The following discussions are continued with the limited observation results collected from the Study.

Basically, the tide observation period in the Study was too short to discuss the fluctuation of the water level in the Yangon River exactly. And the tide observation for consecutive 24 hours by automatic recorder was at Elephant Point only and the data collected at the Thilawa Area and Monkey Point was for 12 hours in the daytime only. Therefore, the following discussions are only for reference. Data accumulation for a long time in years is essential to compute the accurate value.

3.6.1. Collected Tide-Observation Data at Monkey Point, MITT Berth in the Thilawa Area, and Elephant Point

The tide fluctuations at Monkey Point, MITT berth in the Thilawa Area and Elephant Point have 2 cycles in a day, that is, there are two times of high tide in a day, and low tide as well. These three locations have small diurnal inequality and relatively regular tide fluctuation. The following Figure is the tide record at Elephant Point observed in this Study.



Source: The JICA Study Team

Figure 3.6.1. Tide Record at Elephant Point (Before Rainy Season) (Unit: m)

3.6.2. Time Lag of the Tide Fluctuation at Monkey Point, MITT Berth in the Thilawa Area, and Elephant Point

Elephant Point is located at the river mouth of the Yangon River, the Thilawa Area is located about 16 km upstream of the river mouth, and Monkey Point is located about 16 km upstream of the Thilawa Area, that is, Monkey Point is located about 32 km upstream of the river mouth. Therefore, such distances between the above three points creates time lags on the tide fluctuation.

In 2008, a JICA study, "Yangon Port Bathymetry Project in Myanmar," was conducted. In the study, bathymetric surveys were conducted on the Yangon River, and at that time, the time lags of tide fluctuations in the 2 intervals were confirmed as follows.

1) An interval between MIP at Yangon Port and the War War Win Jetty, about 4.5km:
   About 10 minutes of time lag on tide fluctuation
2) An Interval between MIP and Monkey Point, about 7.0km:
   About 20 minutes of time lag on tide fluctuation

On the other hand, the tide observations were conducted at the 3 points in this Study; Monkey Point, the Thilawa Area and Elephant Point. The time lags of tide fluctuation at the following 3 intervals were calculated on trial bases.

1) Time lag of the tide fluctuation between Elephant Point and the Thilawa Area
   - In pre-rainy season: time lag in low tide: about 77 minutes
     : time lag in high tide: about 45 minutes
   - In post-rainy season: time lag in low tide: about 63 minutes
     : time lag in high tide: about 26 minutes
2) Time lag of the tide fluctuation between the Thilawa Area and Monkey Point
   - In pre-rainy season: time lag in low tide: about 25 minutes
     : time lag in high tide: about 17 minutes
   - In post-rainy season: time lag in low tide: about 39 minutes
     : time lag in high tide: about 19 minutes
3) Time lag of the tide fluctuation between Elephant Point and Monkey Point
   - In pre-rainy season: time lag in low tide: about 98 minutes
     : time lag in high tide: about 62 minutes
   - In post-rainy season: time lag in low tide: about 99 minutes
     : time lag in high tide: about 45 minutes

As shown in the above results, the time lag in high tide is about 50~60% that of low tide. The trend, being time lag in high tide is smaller than low tide, was seen in the results of the above study in 2008.

There is a time lag between the results in pre-rainy season and post-rainy season, however, there cannot be seen any regular trend from them and it is impossible to describe further engineering opinions because the collected data were too few and the observation period too short.

3.6.3. Difference of the Water Level Between Before and After Rainy Season

The Yangon River is largely affected by the influence of tide fluctuation and the influence reaches not only the Thilawa Area but also Monkey Point and further upstream of Yangon Port. Besides, the water level of the Yangon River changes depending on the volume of rainfall and it is generally said that the water level in the rainy season would be higher than the one in the dry season.

In the Study, the tide observation in pre-rainy season was conducted in the dry season and the observation in the post-rainy season was executed from November to December in 2015 just after the rainy season, therefore the river water level at the time was still influenced by the rise of the river water in the rainy season. The next table shows differences of the water levels between pre- and post-rainy seasons.

Table 3.6.1. Differences of the Water Levels between Before and After Rain Season

(Unit: m)

Item		Elephant Point	Thilawa Area (MITT)	Monkey Point
Average High Tide	Pre-rainy season	6.25	5.95	5.60
	Post-rainy season	5.96	5.44	5.16
	Difference	0.29	0.51	0.44
Average Low Tide	Pre-rainy season	1.97	1.43	1.15
	Post-rainy season	1.81	1.26	0.99
	Difference	0.16	0.17	0.16

Source: The JICA Study Team

As shown in the above table, the average high tide at the Thilawa Area has about 50 cm difference between pre- and post-rainy season and the difference at Elephant Point is about 30 cm. As for the difference of the average low tide, all points show almost the same difference of about 15 cm.

However, the above figures for the post-rainy season were not collected in the peak of the rise of river water and those figures were collected just after the rainy season. Considering that fact, the water level at the peak of the rainy season would be higher than the above values and it should be carefully noted.

3.6.4. Tide Height Ratios for Elephant Point, Thilawa Area, and Elephant Point

Based on the results of the difference of water level shown in the above table, tide height ratio was calculated. The values at Elephant Point were set as 1.00 and the other values were compared. The results are shown in the following table.

Table 3.6.2. Tide Height Ratios for Elephant Point, Thilawa Area and Monkey Point

	Elephant Point	Thilawa Area (MITT)	Monkey Point
Before Rainy Season	1	1.056	1.039
After Rainy Season	1	1.006	1.006
Average	1	1.031	1.022

Note: the ratio was calculated assuming the level at Elephant Point is 1.0

Source: JICA Study Team

There is not a big difference between Elephant Point, Thilawa Area and Monkey Point and it would be said that the tide difference among the three points is not big.

As mentioned in the beginning of this discussion, basically those examinations should be based on the data accumulation of many years and the above result is a trial result due to the very short observation period.

3.7. Offshore Wave Conditions

3.7.1. Necessity of Wave Observation

The ocean area of Bengal Bay and the Yangon River estuary has relatively calm wave conditions throughout the year, except several times of high waves caused by cyclones. Therefore, quantitative data for wave conditions do not exit and the characteristics of occurred waves, such as wave height and wave periods, are not clear. However, understanding wave characteristics is not only important for the analysis of channel sedimentation but also for future improvement and expansion of the access channel.

In this Study, wave observation was carried out using the hydraulic wave height meter at a location 15 km offshore from the Yangon River mouth. The design offshore wave height needs to be set for the examination of the planning of a deep-sea port in the future. To set the design wave height, data accumulation for a long period is essential, so continuous wave observation is expected with this as the first opportunity.

As will be described in next part of this report (Section 4.4), the reproduction of the current state by numerical value simulation and prediction of the future with a work plan considering countermeasures are the fundamentals to examine the issue of the channel siltation problem. The numerical value simulation should be a multilayered level model in consideration of the flow, floating, diffusion and sedimentation of the bottom mud by waves, and it is thought that an advection, diffusion and the reproduction of the sedimentation flux are particularly important. In that time, a problem is to reproduce the sedimentation flux (quantity of hoist and sedimentation flux) and the condition of the wave is more necessary when the re-surfacing by the wave will be considered. Therefore, it is very significant to acquire the wave height and period of the sea area.

Considering the above discussions, the wave observation should collect data in both dry and rainy seasons and it should be continued as long as possible in years to contribute to our grasp of the tendencies of annual surge appearances. As one piece of past evidences, the number of cyclones in Bengal Bay during the past approximately 100 years has recorded by the Indian Meteorological Department. According to the record, the peak season for cyclones is in May and from October to December.

Cyclone Nargis attacked Myanmar in 2008. In this way, a high tide level and a high surge may attack the country once a year. Therefore, the appearance of high waves can be seen occasionally, and long-term consecutive observation is desirable from such a point of view. Also, wave observation for several decades helps the setting of design waves for the further development of the Yangon River Channel.

Table 3.7.1. Number of Cyclones in Bengal Bay

Month	The Bay of Bengal	
	Cyclonic Storm	Severe Cyclonic Storm
1	4	2
2	0	1
3	2	3
4	11	11
5	15	34
6	33	6
7	33	7
8	27	3
9	24	15
10	44	35
11	40	54
12	23	20
Total	256	192

Source: Indian Meteorological Department, New Delhi

According to the US military's Joint Typhoon Warning Center (JTWC), the number of cyclones closing to Myanmar is 6 times during the past 58 years, although the total number of cyclones observed in Bengal Bay is 556 times during the same period. Also, 3 times within 6 times of cyclones closer to Myanmar occurred in April, including Nargis, and it can be said that April has a high frequency of cyclones close to Myanmar. According to the JTWC, the seasonal stream, which usually occurs in / around April and directs to the east at north latitude of 20-30 degrees, would be a reason for the high frequency.

3.7.2. Wave Observation Method

In general, there are several wave observation methods, as shown in the following, and each method requires a different type of observation equipment.

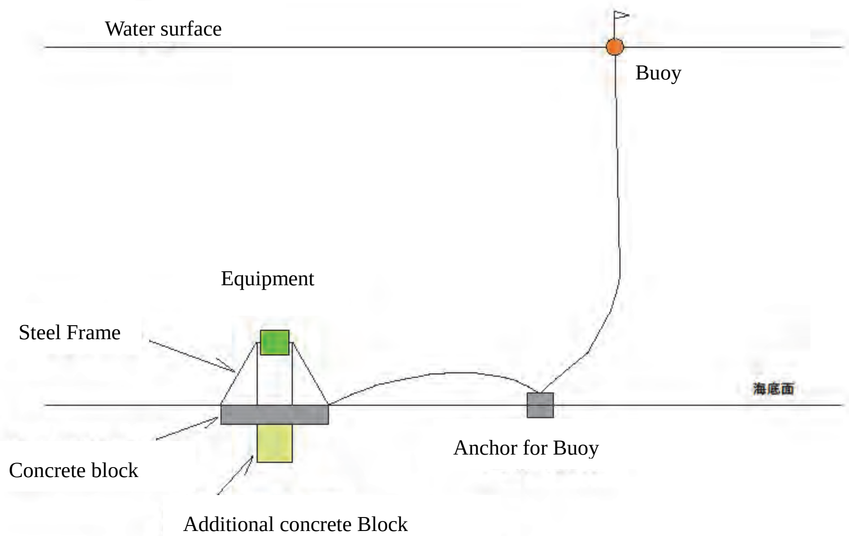
Table 3.7.2. Wave Observation Method and Observation Equipment

The Direct Observation Method	**Optical Method**	**Leveling Pole Method, Stereoscopic Photography Methods**
	Acoustic method	Supersonic wave-style wave height meter
	Mechanical method	Float type
	Electrical method	Step-style wave height meter
The Indirect Observation Method	Method using an acceleration change	Buoy-style wave height meter
	Method using a buoyancy change	Buoyancy-style wave height meter
	Method using a water pressure change	Various water pressure-style wave height meter

Source: JICA Study Team

Most of the wave observation methods are suitable for observation in water depth around 30 m. The wave height meter, which can detect the change of water pressure related to the movement of waves, is relatively easy to use. So this type of equipment is used often. The wave observation scheduled for this Study is a kind of experimental observation whose easiness of installation, lower maintenance cost and lower initial cost within a limited budget should be noted. Besides, considering the accidental loss and damage, the water pressure detection type was selected.

In the beginning, the wave observation for the Study was commenced from June 2015, however the installed equipment was destroyed 1 month after the installation. New equipment was procured in August and it was installed at the location shown in the following table. The observation was continued for 4 months from October 2015 to January 2015. Prior to installing the equipment onto the designated seabed, the site inspection for the seabed conditions was conducted by professional divers. As the result, the concrete foundation to stabilise the equipment and the steel frame to protect the equipment, as shown in the following, were prepared. The total weight of the equipment set was quite heavy and therefore a crane barge was needed to install the set. It was necessary to change the battery every month so data collection was conducted at the same time as the battery change, and maintenance of the equipment was also done as needed.



Source: JICA Study Team

Figure 3.7.1. Installation of the Wave Observation Equipment

Table 3.7.3. Overview of Wave Observation

Wave observation position	**Offshore from Elephant Point 18 km** **N 16°16' 48,43" E 96°19' 11.90"**
Observation period	2015/10/17 ~ 2016/1/31
Observation equipment	Underwater pressure type wave meter INFINITY-WH
Sampling time	Δt = 0.5 s
The number of the sampling data	Observation 20 minutes in every plus N = 1/0.5 × 20 × 60 = 2,400 (The number of the data of one measurement)

Source: JICA Study Team

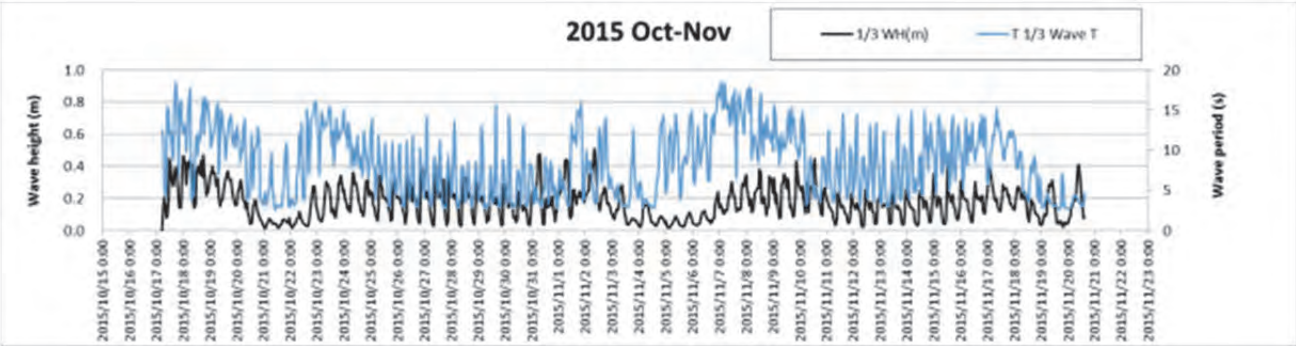
3.7.3. Analytical Method of the Collected Surge Data from the Observation

The collected surge data could be converted into statistics like significant wave height (existence significant wave height, existence significant wave period). The names of the statistics and their definitions are shown in the following.

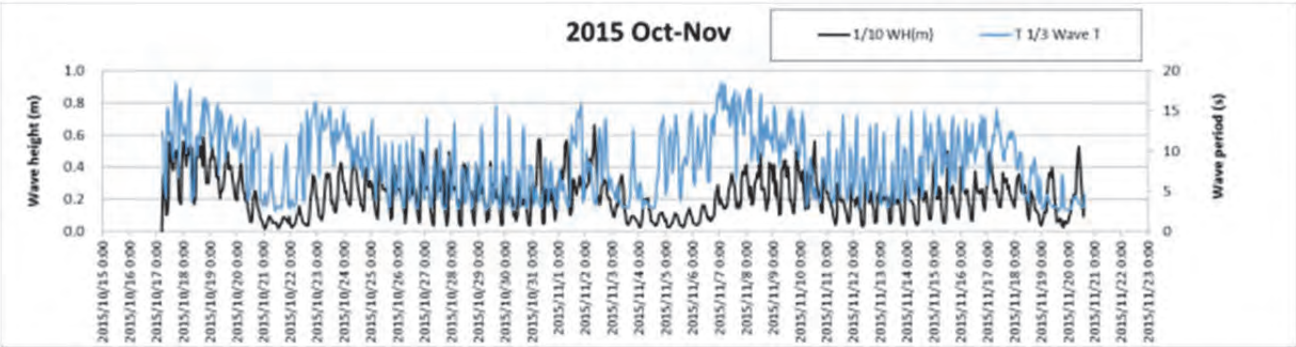
1/3WH : Higher 1/3 maximum wave height by zero up cross method, $H_{1/3}$
1/10WH : Higher 1/10 maximum wave height by zero up cross method, $H_{1/10}$
Max.WH : Maximum wave height by zero up cross method, H_{max}
MeanWH : Mean wave height by zero up cross method, H_{mean}
Sig.WH : Significant wave height by spectrum analysis, H_{sig}
MeanWP : Mean wave period by zero up cross method, T_{mean}
MaxWP : Maximum wave period by zero up cross method, T_{max}
PeakWP : Peak wave period by spectrum analysis, T_{peak}
MeanWP : Mean wave period by spectrum analysis, T_{mean2}
CrossWP : Cross zero wave period by spectrum analysis, T_{cross}
Depth : Mean depth
1/3WP : Higher 1/3 maximum wave period by zero up cross method, $T_{1/3}$
1/10WP : Higher 1/10 maximum wave period by zero up cross method, $T_{1/10}$

3.7.4. Results of the Wave Observation

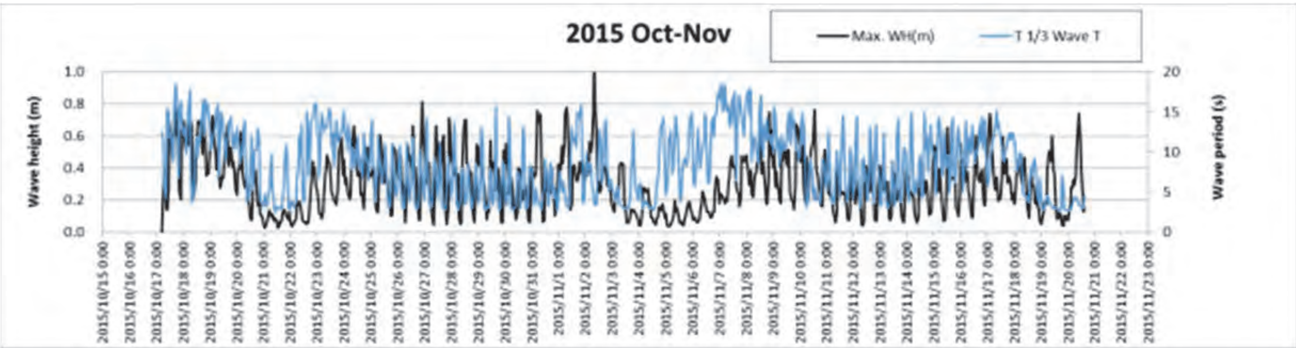
The following graphs are the partial result of the wave observation in this Study and the wave heights and periods from 2015/10/17 5:00 to 2016/1/21 12:00 are shown. Here, the representative value of the wave height is $H_{1/3}$ by the surface water level change conversion, namely the zero up cross method, $H_{1/10}$, H_{max} and $T_{1/3}$.



$H_{1/3}$ (left), $T_{1/3}$ (right)



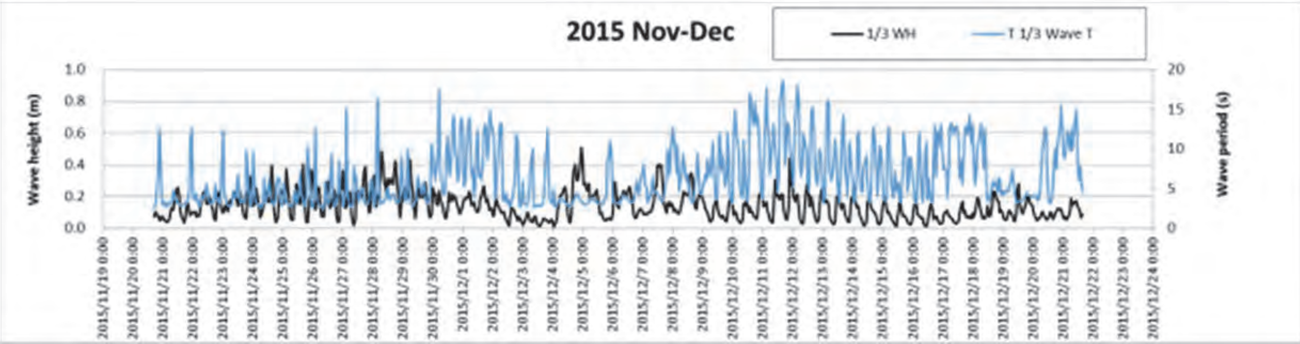
$H_{1/10}$ (left), $T_{1/3}$ (right)



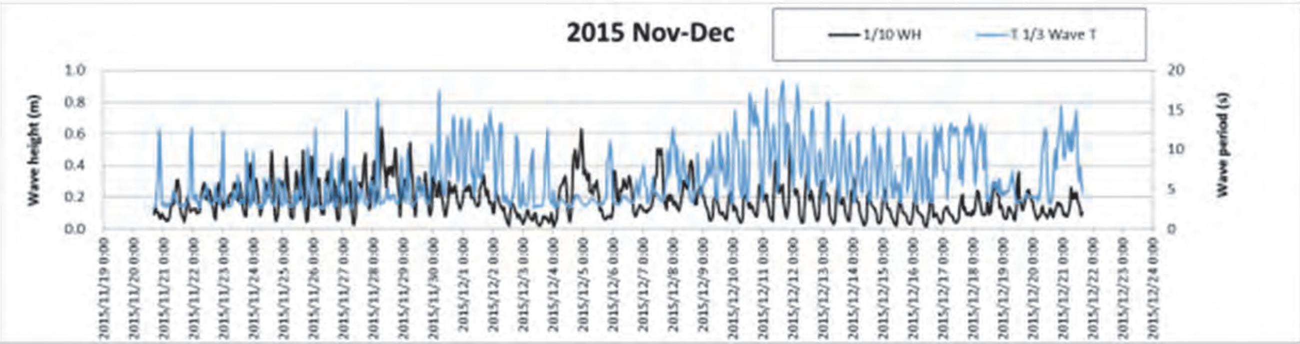
H_{max} (left), $T_{1/3}$ (right)

Source: The JICA Study Team

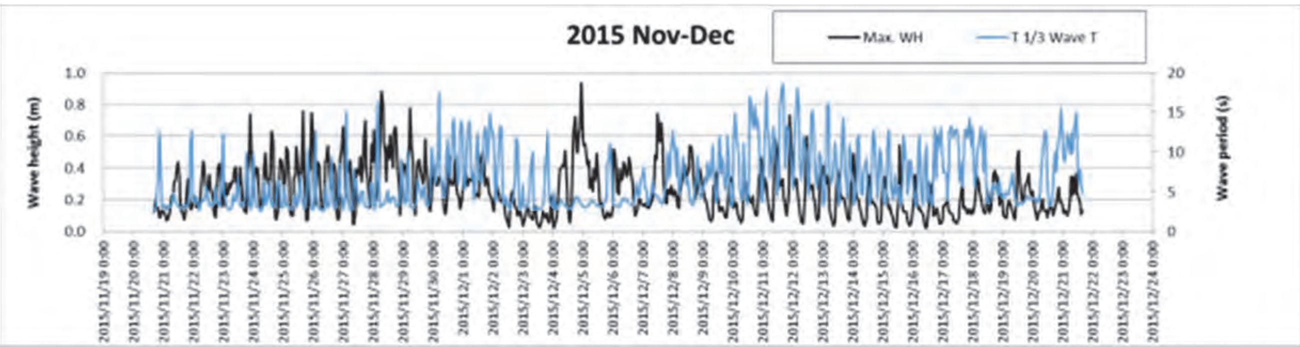
Figure 3.7.2. Wave Observation Result (2015/10/17 5:00 ~ 11/20 15:00)



$H_{1/3}$ (left), $T_{1/3}$ (right)



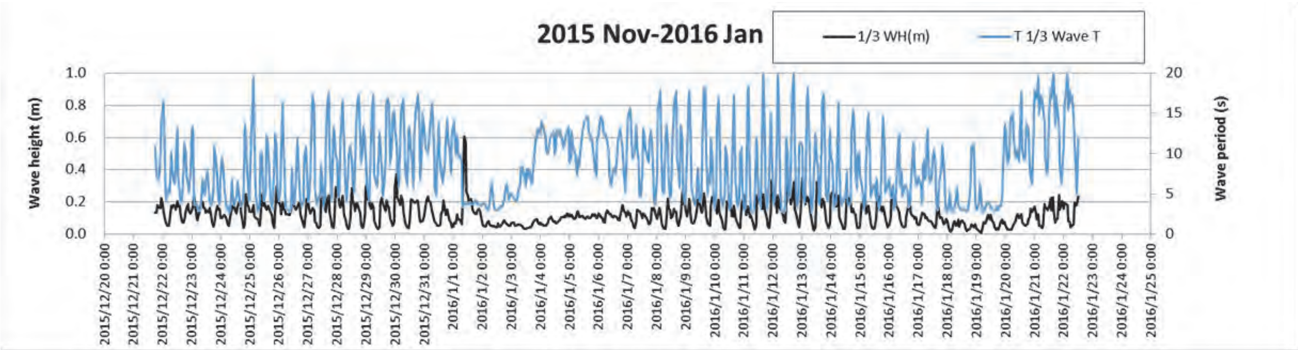
$H_{1/10}$ (left), $T_{1/3}$ (right)



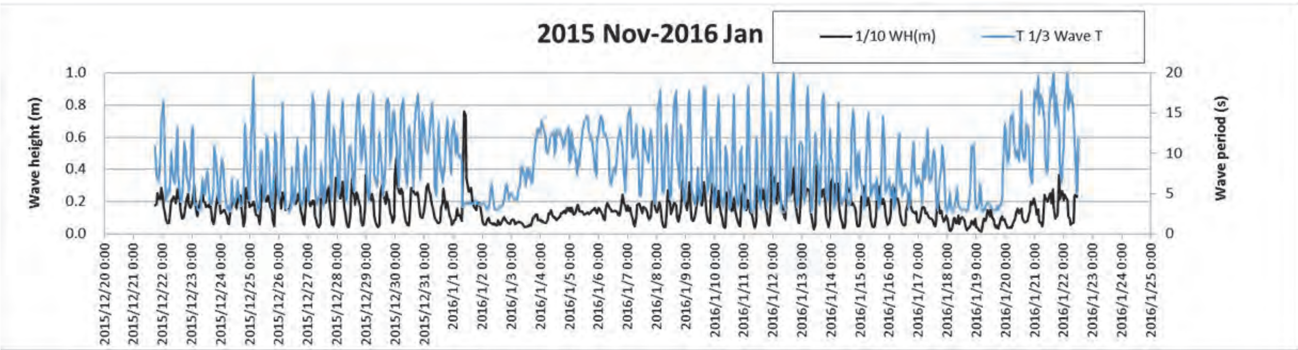
H_{max} (left), $T_{1/3}$ (right)

Source: The JICA Study Team

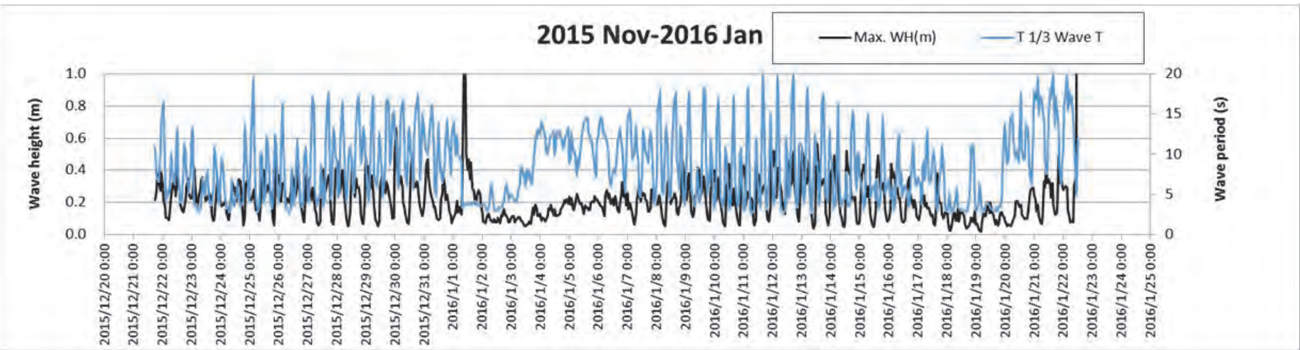
Figure 3.7.3. Wave Observation Result (2015/11/20 17:00 ~ 12/21 16:00)



$H_{1/3}$ (left), $T_{1/3}$ (right)



$H_{1/10}$ (left), $T_{1/3}$ (right)



H_{max} (left), $T_{1/3}$ (right)

Source: The JICA Study Team

Figure 3.7.4. Wave Observation Result (2015/12/21 18:00 ~ 2016/1/22 12:00)

According to the results observed from 5:00, October 17, 2015 to 12:00 January 22, 2016, the wave height in the observation period is small generally, and it is guessed that the big wave height caused by the cyclone did not occur. The following table shows the top 5 high waves. The maximum of the observation period became $H_{1/3}$ = 0.61 m, $H_{1/10}$ = 0.76 m, H_{max} = 1.06 m, and it was very calm.

According to the overall average during the observation period, it is just $H_{1/3}$ = 0.16 m, $H_{1/10}$ = 0.20 m, H_{max} = 0.28 m, and it was very calm.

Table 3.7.4. Top 5 High Waves (2015/10/17 5:00 ~ 2016/1/22 12:00)

Rank	Time	$H_{1/3}$(m)	$H_{1/10}$(m)	H_{max}.(m)	$T_{1/3}$(s)
1	2016/1/1 9:00	0.61	0.76	1.06	3.67
2	2015/11/2 8:00	0.51	0.66	1.11	3.64
3	2015/12/4 23:00	0.51	0.63	0.94	3.42
4	2015/11/28 7:00	0.48	0.64	0.88	3.21
5	2015/10/31 7:00	0.48	0.58	0.72	3.47

Source: The JICA Study Team

Table 3.7.5. Wave Observation Results (2015/10/17 5:00 ~ 2016/1/22 12:00)

Average of $H_{1/3}$ (m)	Average of $H_{1/10}$ (m)	Average of H_{max} (m)	Average of H_{mean} (m)	Average of $T_{1/3}$ (s)
0.15	0.19	0.26	0.09	7.85

Source: The JICA Study Team

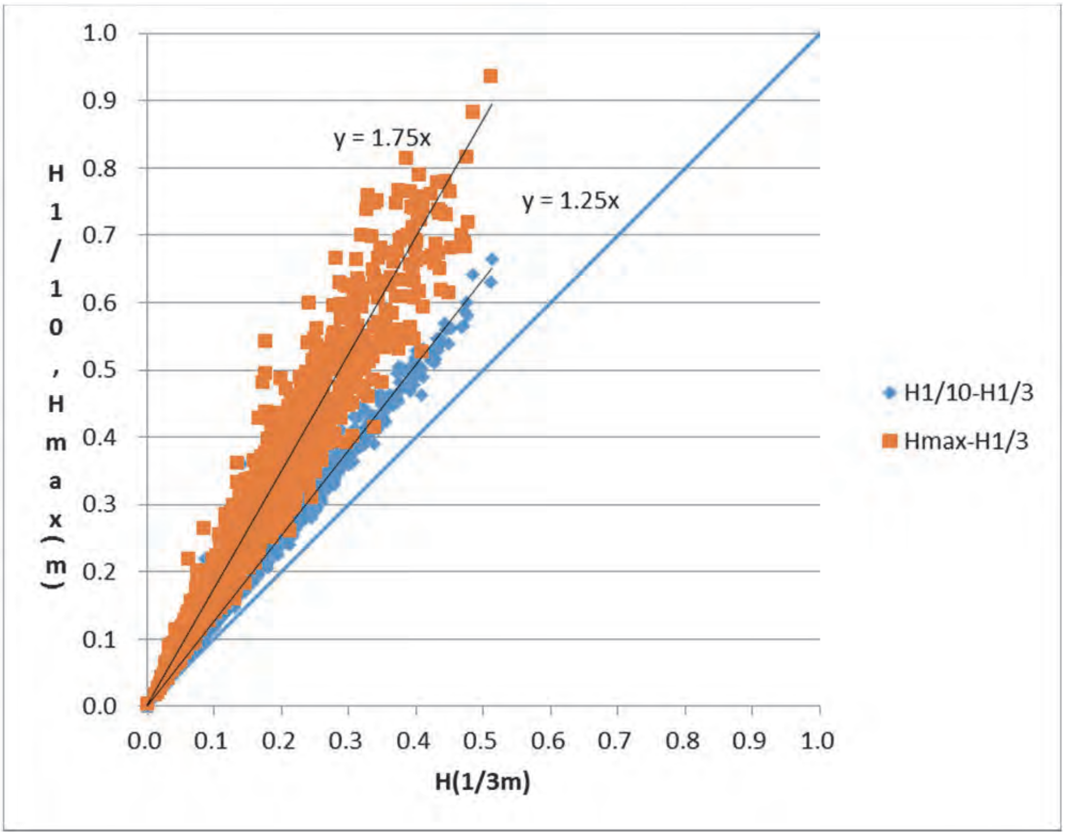
The relations between the representative wave heights, H_{max} /$H_{1/3}$, $H_{1/10}$ /$H_{1/3}$ were clarified as shown in the following table and figure. According to the results, H_{max} /$H_{1/3}$ = 1.75, $H_{1/10}$ /$H_{1/3}$ = 1.25 are confirmed and the situation would be not under the wave breaking. So, any disturbance due to bad weather, which creates big wave heights and long wave periods, did not occur during the observation period.

Table 3.7.6. Results of H_{max} / $H_{1/3}$, $H_{1/10}$ / $H_{1/3}$ and Hmean/ $H_{1/3}$

H_{max} /$H_{1/3}$	$H_{1/10}$ /$H_{1/3}$	H_{mean}/$H_{1/3}$
1.75	1.25	0.63

Note: results from the Wave Observation Results (2015/10/17, 5:00 ~ 2016/1/22, 12:00)

Source: The JICA Study Team



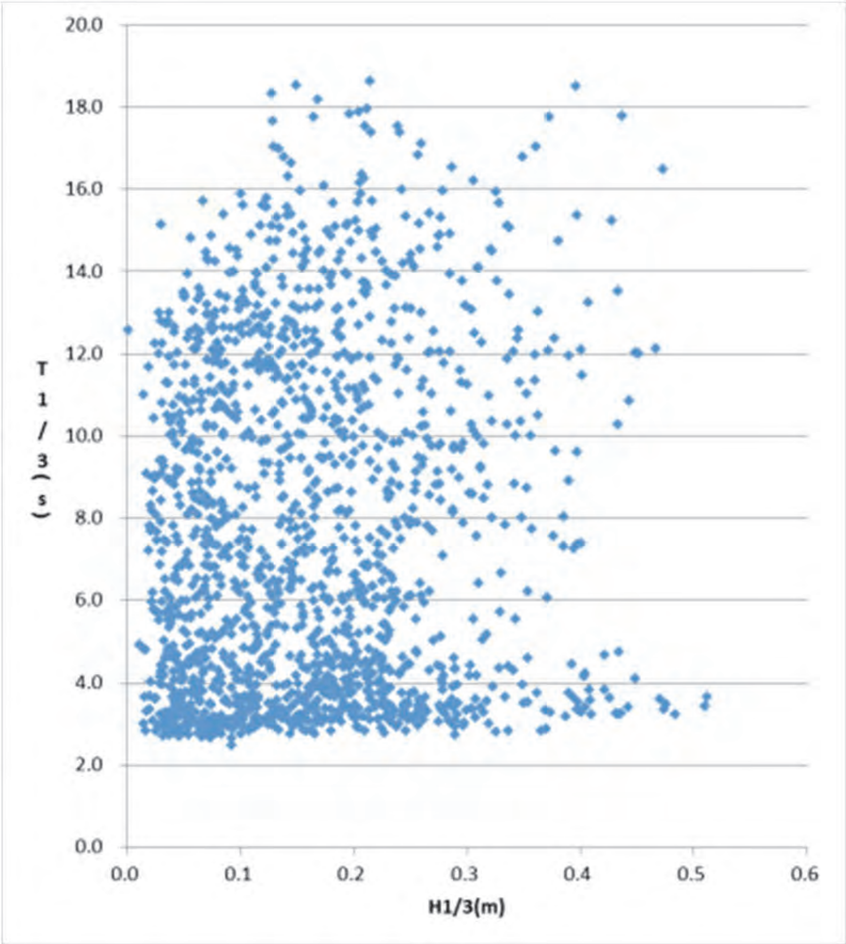
Source: The JICA Study Team

Figure 3.7.5. Relations between Representative Wave Heights and Periods

According to the results, the most characteristic event is that the wave period is quite long, although the wave height is small at the time. The following figure shows the relations between wave height and period. H1/3 shows from 0 m to 3 m. And the wave period is from 2 to 18 seconds. As shown in the above table, $T_{1/3} = 7.85$ s ($H_{1/3} = 0.15$ m) on average, and if the sea depth was set as H = 10 m, the wave length would be L = 69.2 m ($T_{1/3} = 7.85$ s) when it was converted into the wave height gradient:

$$H_{1/3}/L = 0.15/69.2 = 0.0022$$

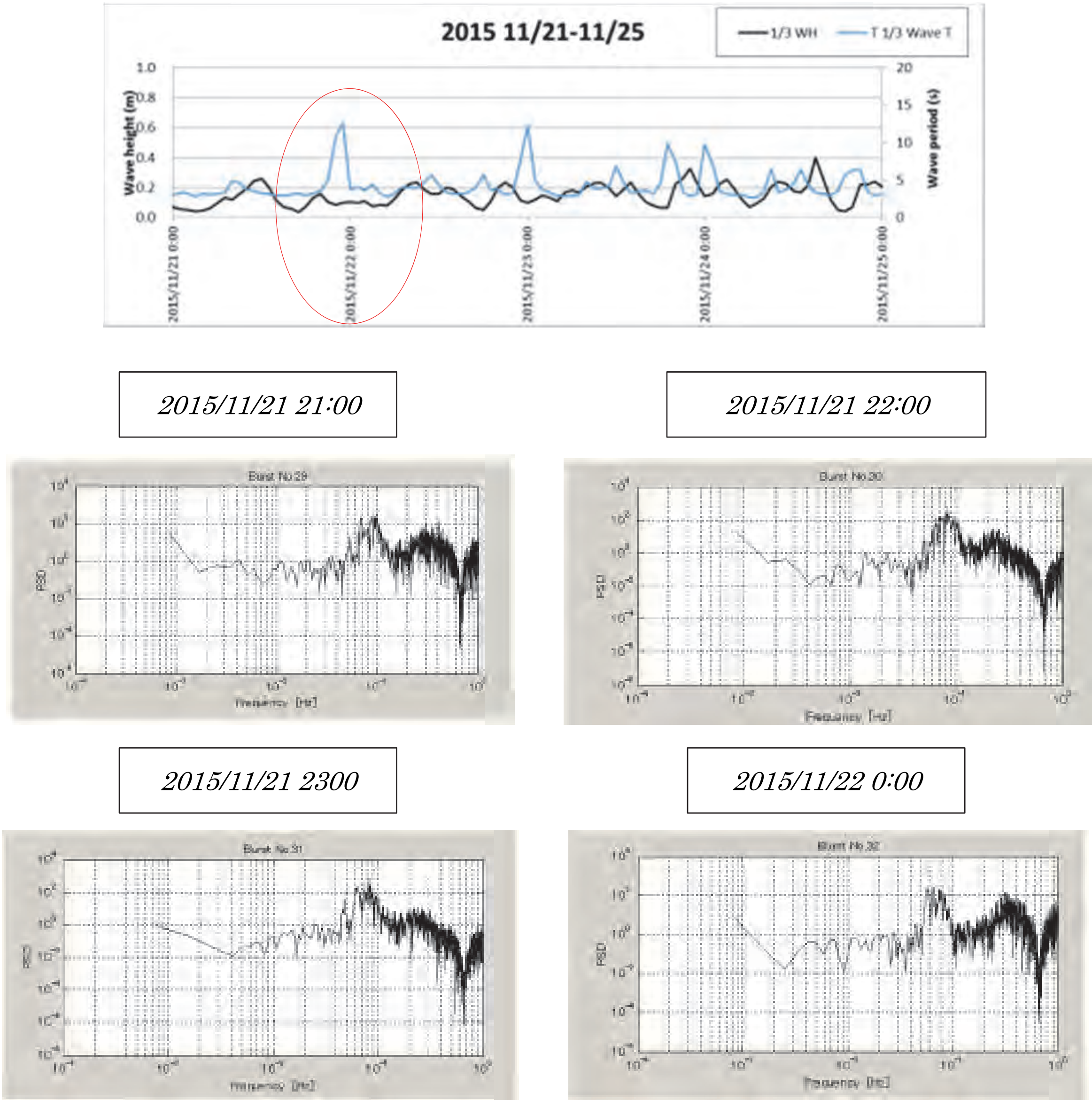
So, it is the swell having very small wave height gradient. To see further details of this phenomenon, the relation among the wave height, a period and the power spectrum were checked.



Source: The JICA Study Team

Figure 3.7.6. Relations between Wave Height and Period

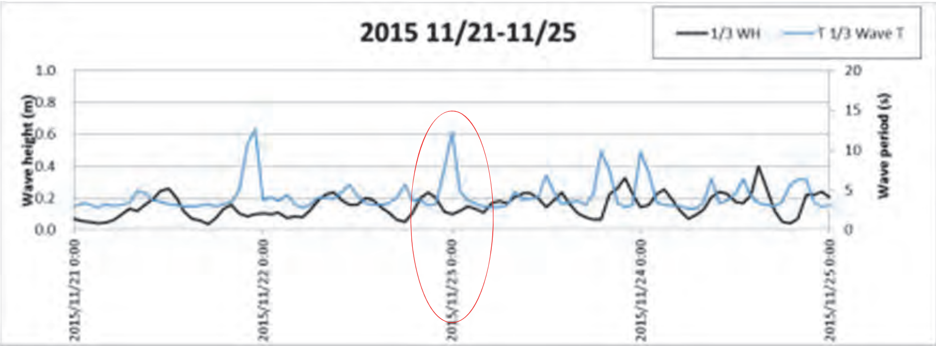
Although wave heights were only around 0.1 m from 22:00 to 23:00 on November 21, the wave period was over 10 seconds during this time. It developed for up to 12.6 seconds at 23:00 but suddenly it was attenuated after the peak. During the same period, the spectrum had the peak clearly with a period of over 10 seconds from 21:00 to 23:00 on November 21, and after that, the other period with around 8 seconds gradually developed.



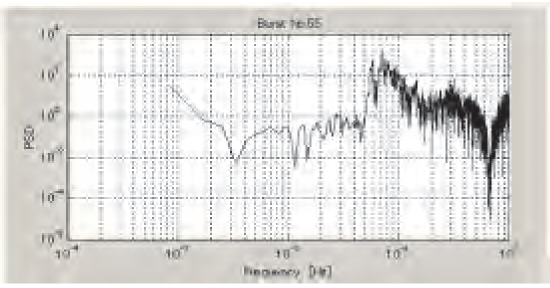
Source: The JICA Study Team

Figure 3.7.7. Wave Observation Result (2015/11/21 ~ 11/25) and Spectrum

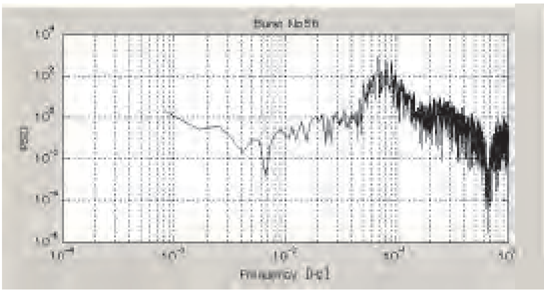
The following other data also show a trend similar to the above result. Although the wave height was only around 0.1 m from 23:00 on November 22 to 0:00 on November 23, the wave period was quite long, over 10 seconds during that time. It developed to the peak but suddenly it attenuated after the peak. During the same period, the spectrum had the peak clearly with a period of over 10 seconds, and after that, the other period with around 8 seconds was gradually developing.



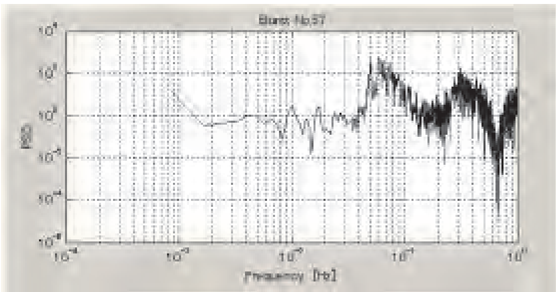
2015/11/22 23:00



2015/11/24 0:00



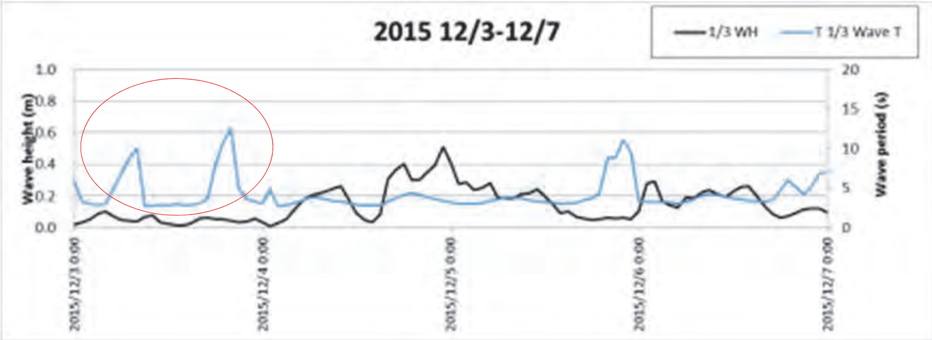
2015/11/24 1:00



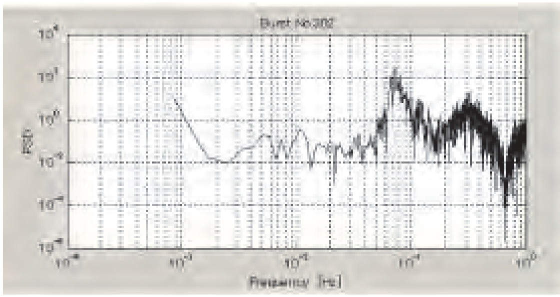
Source: The JICA Study Team

Figure 3.7.8. Wave Observation Result (2015/11/21 ~ 11/25) and Spectrum

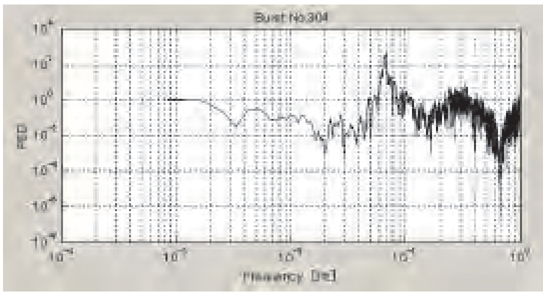
The following wave height is only around 0.1 m from 4:00 to 6:00, but the wave period is over 10 seconds during that time like the above records. After the first peak, it was attenuated but developed again up to 12 seconds at 20:00.



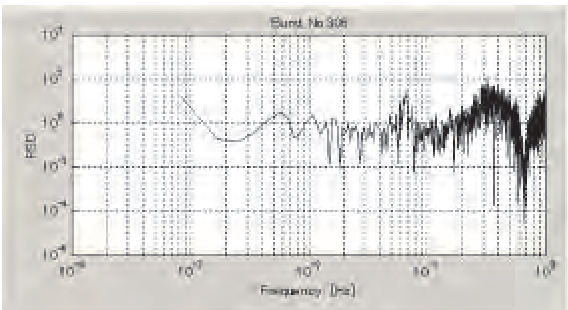
2015/12/3 6:00



2015/12/3 8:00



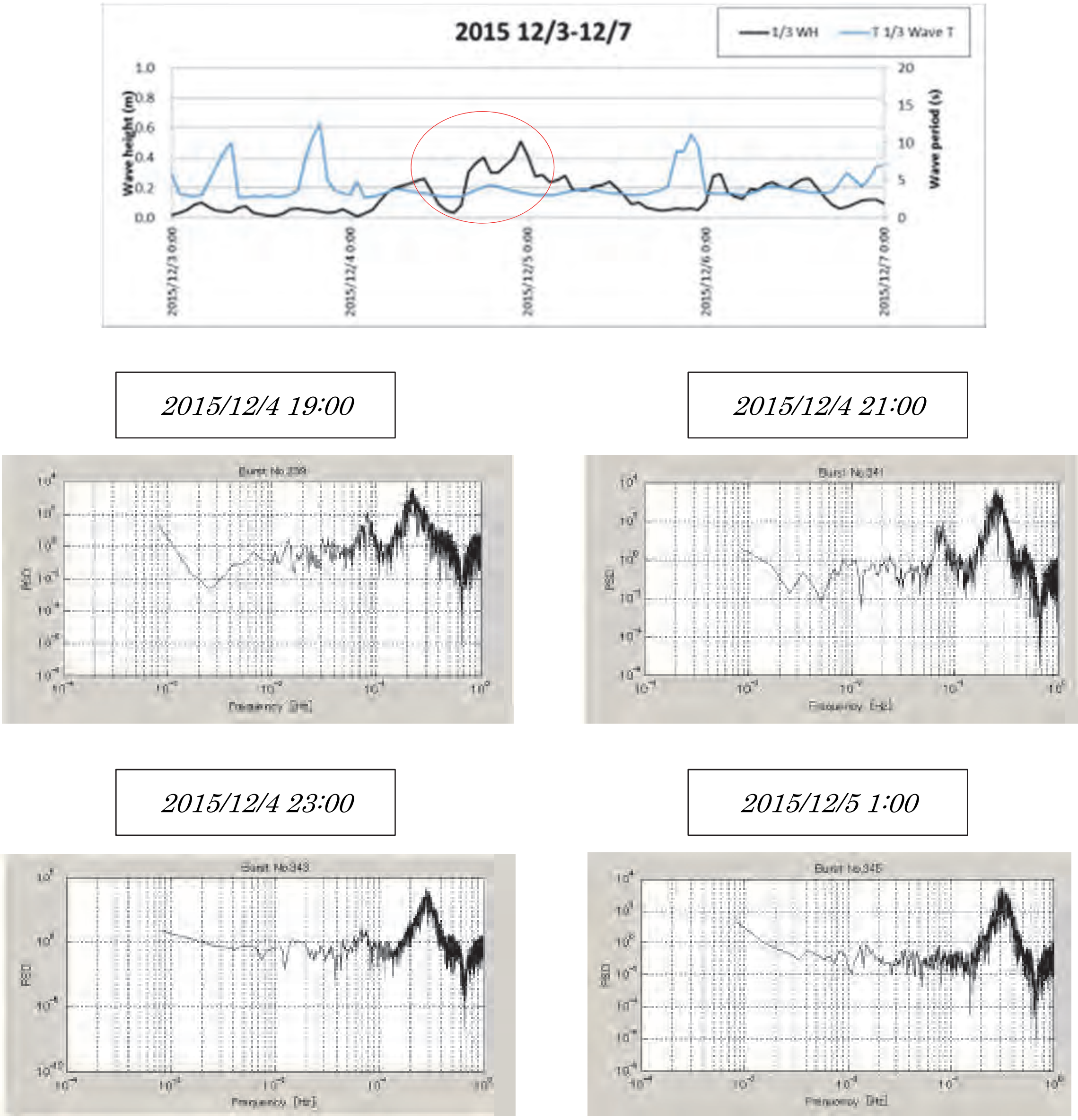
2015/12/3 10:00



Source: The JICA Study Team

Figure 3.7.9. Wave Observation Results (2015/12/3 ~ 12/7) and Spectrum

The following result is a particular case compared to the above results. Only wave height develops from about 14:00 December 4 and it reaches over 0.5 m but the wave period during the same time stays approximately 3 seconds. But from the peak of the spectrum, there is the biggest peak having around 8-9 seconds, and the peak of around 3 seconds is smaller than it. The cause of this is unclear at the moment.



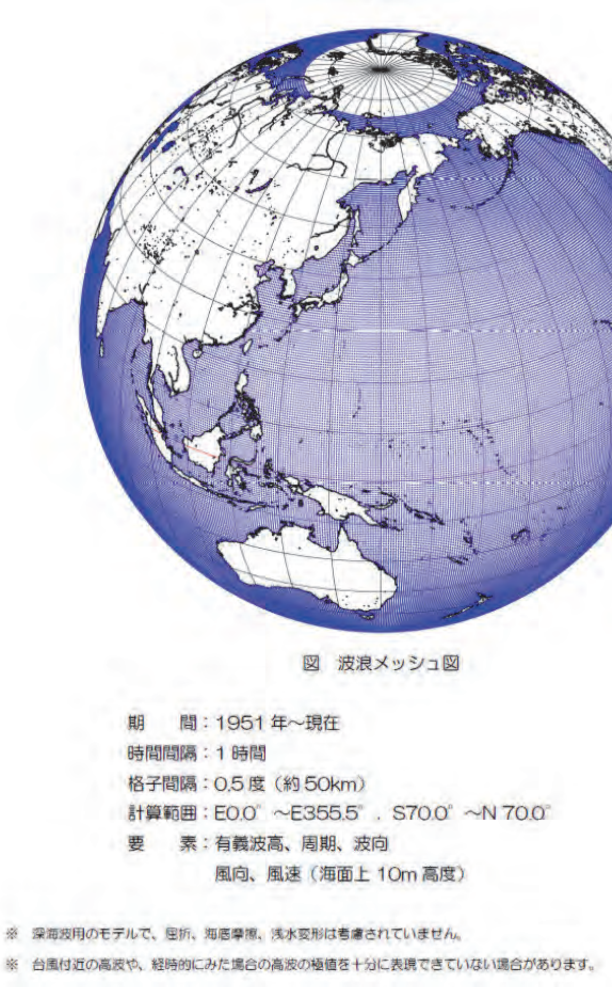
Source: The JICA Study Team

Figure 3.7.10. Wave Observation Results (2015/12/3 ~ 12/7) and Spectrum

Considering the above phenomenon confirmed in the observations, it can be said that 2 types of waves exist around the survey point. That is, waves that occur and develop at / around the observation point, and, the other waves coming from open sea, having a long wave period. To confirm the mechanism of the wave, further investigation and long-term observation are necessary to determine whether or not the long period waves are generated from the influence of the open sea or if it was created by the shape of the seabed of Bengal Bay or other reasons.

3.7.5. Wave Forecasting and Hindcasting

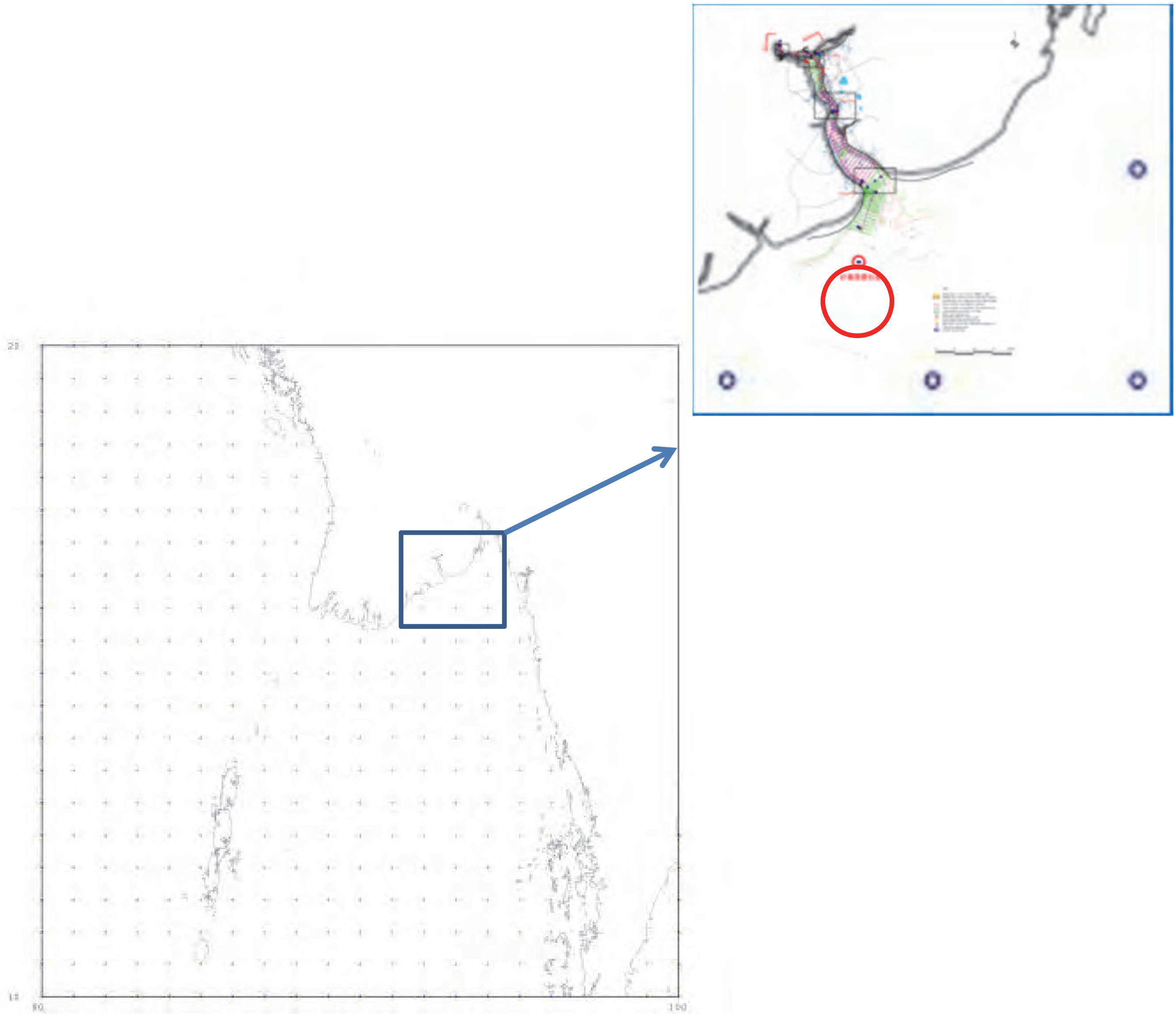
As explained in the beginning of this chapter, wave observation was postponed due to the destruction of the observation equipment. So, the data for wave forecasting and hindcasting was purchased and compared with the surveyed data for the sake of supplementing the survey data and verifying the validity of the surveyed data. The data of wave forecasting and hindcasting was procured from the Japan Weather Association. The wave estimation model of the data is based on the WAM model, and the influence of refraction, shoaling, breaking, and bottom friction are not included.



Source: General Foundation, Japan Weather Association

Figure 3.7.11. Summary of Global Weather Wave Estimation Databases

The objective point of the acquired data is shown in the following. The coordinates are N16°, E96.5°.



Source: The JICA Study Team

Figure 3.7.12. Extraction Position of Global Weather Wave Estimation Databases

The following table shows monthly wave height and period. The model of wave forecasting and hindcasting is based on the WAM model and the base is deep-water waves. So, the influences of refraction, shallow water, breaking and friction of the waves are not included, therefore the wave height from the model would be calculated slightly higher than the actual waves.

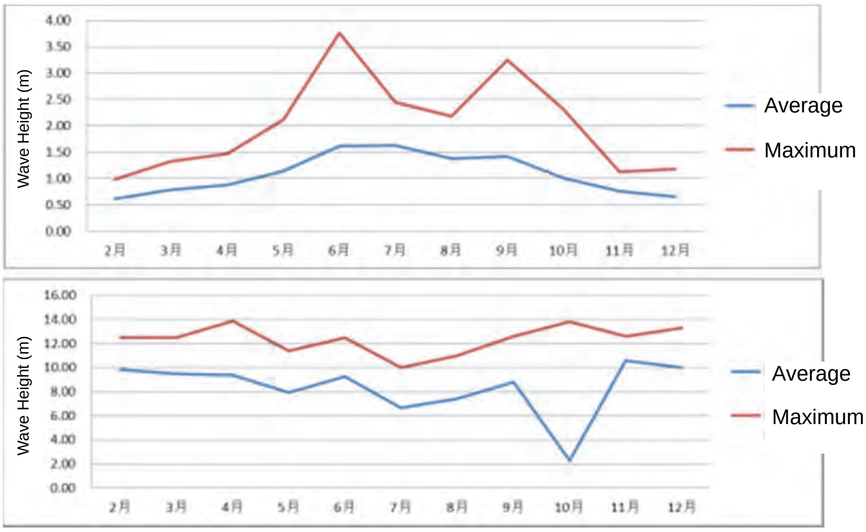
In this time, the data of the wave forecasting and hindcasting is from February 1, 2015 to December 31, 2015. According to the data, the wave height is from about 0.5 m to 1.0 m from February to May. although it repeats bigger and smaller, it grows gradually bigger during the period

Relatively higher waves having height over 1.5 m to 2.0 m can be seen from the end of June to the end of August and especially the waves at the end of June can achieve heights over 3.5 m. The wave height tends to calm gradually after September but sudden high waves of over 3.0 m can be seen on September 19. Although the wave height after October is around 0.5 m ~1.0 m, the wave period is getting remarkable with a long period of 10~15 seconds.

Table 3.7.7. Data from Wave Forecasting and Hindcasting

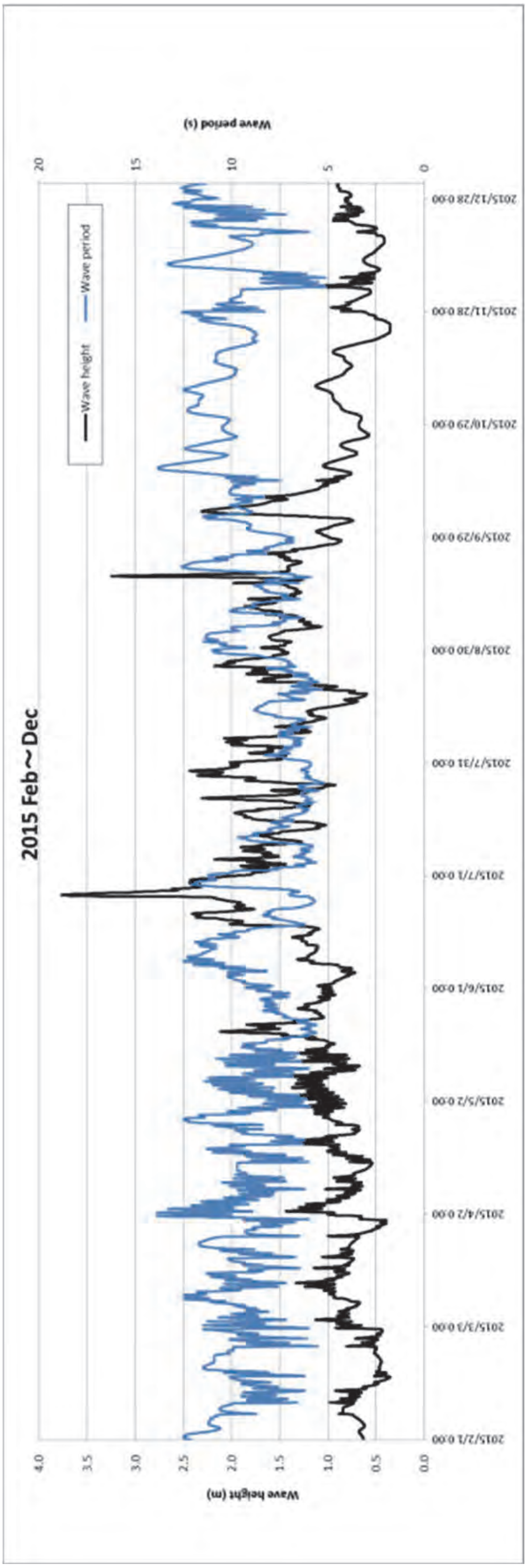
	Average Wave height (m)	Maximum Wave height (m)	Average Wave period (m)	Maximum Wave height (m)
Feb.	0.61	0.98	9.84	12.50
Mar.	0.79	1.33	9.52	12.50
Apr.	0.88	1.47	9.40	13.90
May	1.14	2.12	7.94	11.40
Jun.	1.62	3.77	9.27	12.50
Jul.	1.63	2.44	6.70	10.00
Aug.	1.38	2.18	7.44	11.00
Sep.	1.42	3.25	8.82	12.60
Oct.	1.02	2.31	2.31	13.80
Nov.	0.76	1.13	10.61	12.60
Dec.	0.65	1.18	10.03	13.30

Source: The JICA Study Team



Source: The JICA Study Team

Figure 3.7.13. Transitional Graph of Wave Forecasting and Hindcasting Data



Source: The JICA Study Team

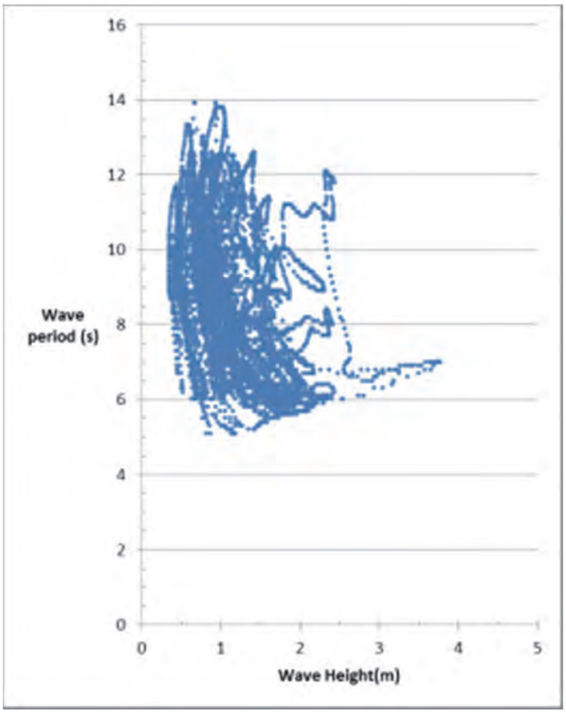
Figure 3.7.14. Wave Height and Period by Surge Estimation (2015/2/1 ~ 12/31)

The following table shows the top 10 high waves in the data of wave forecasting and hindcasting. High waves over 3.0 m can be seen in June and September. The relation between the wave height and period is shown in the following figure. The wave height is distributed within a range from 0.5 m to 4.0 m and the period is from 5 seconds to 14 seconds. Although the below wave periods are a little shorter than the observation results, it is still recognised as a long period wave.

Table 3.7.8. Top 10 High Waves in the Data of Wave Forecasting and Hindcasting

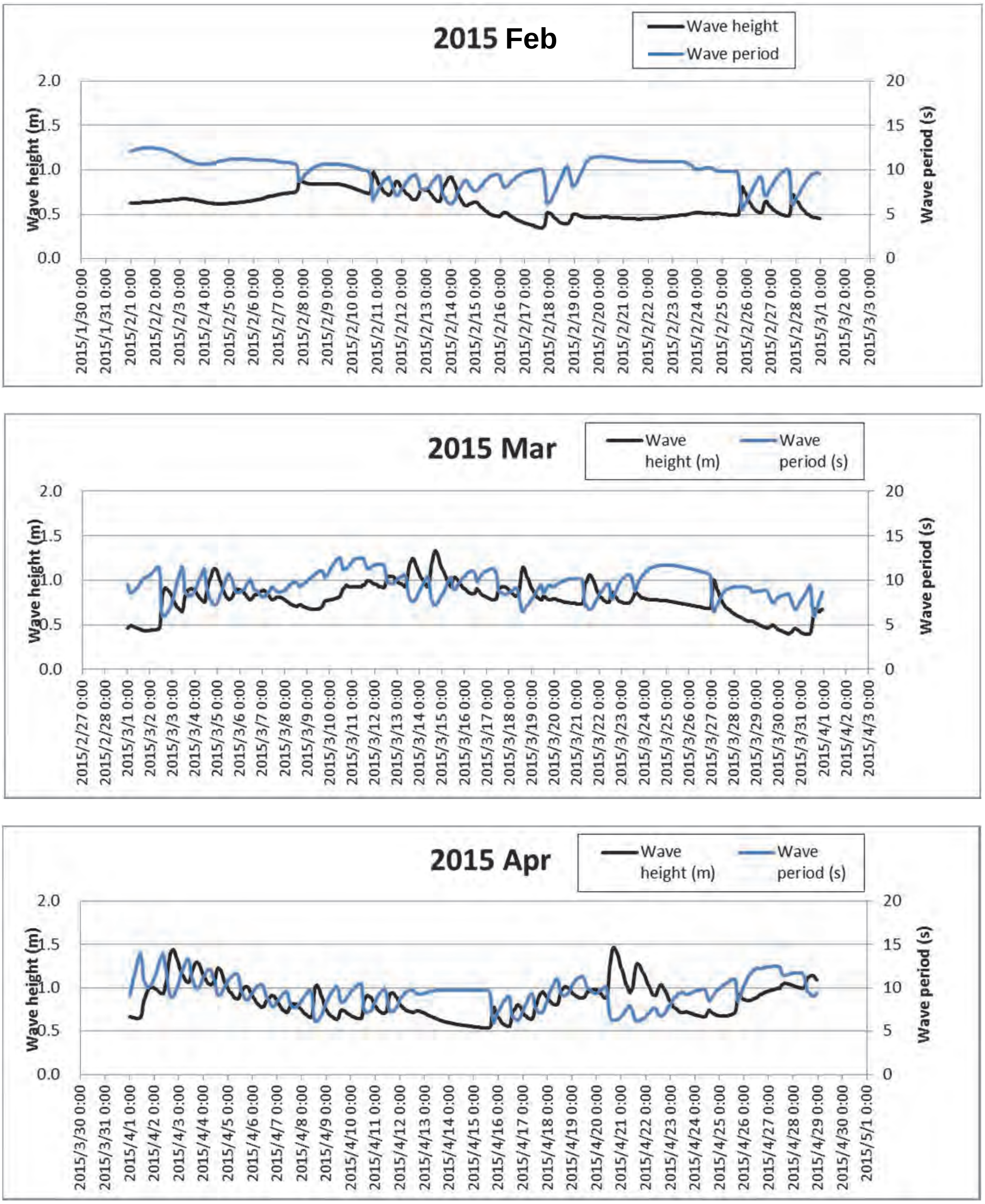
No	Date and time	Waveheight (m)	Waveperiod (s)	Wave direction
1	2015/6/25 20:00	3.77	7.00	230.90
2	2015/9/18 15:00	3.25	6.70	192.90
3	2015/7/28 21:00	2.44	6.20	210.10
4	2015/6/20 20:00	2.41	8.00	212.70
5	2015/7/21 14:00	2.31	6.00	213.80
6	2015/10/5 20:00	2.31	8.90	206.40
7	2015/7/29 2:00	2.30	6.40	212.00
8	2015/7/5 8:00	2.18	6.00	231.30
9	2015/8/25 19:00	2.18	6.70	217.60
10	2015/5/20 12:00	2.12	5.80	228.00
11	2015/8/6 13:00	2.08	6.40	230.60

Source: The JICA Study Team



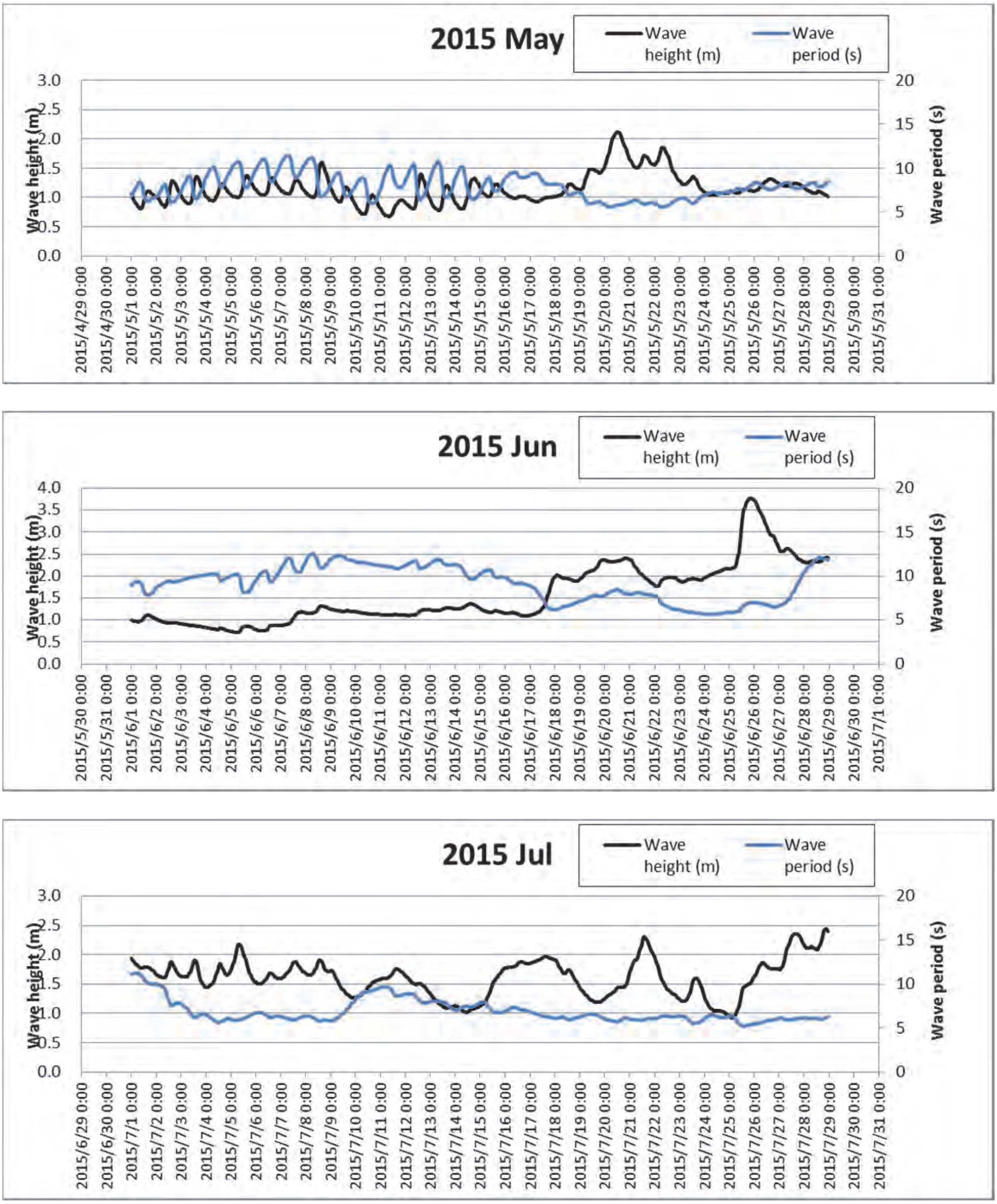
Source: The JICA Study Team

Figure 3.7.15. Relation of Wave Height and Period by Wave Forecasting and Hindcasting (2015/2/1 ~ 12/31)



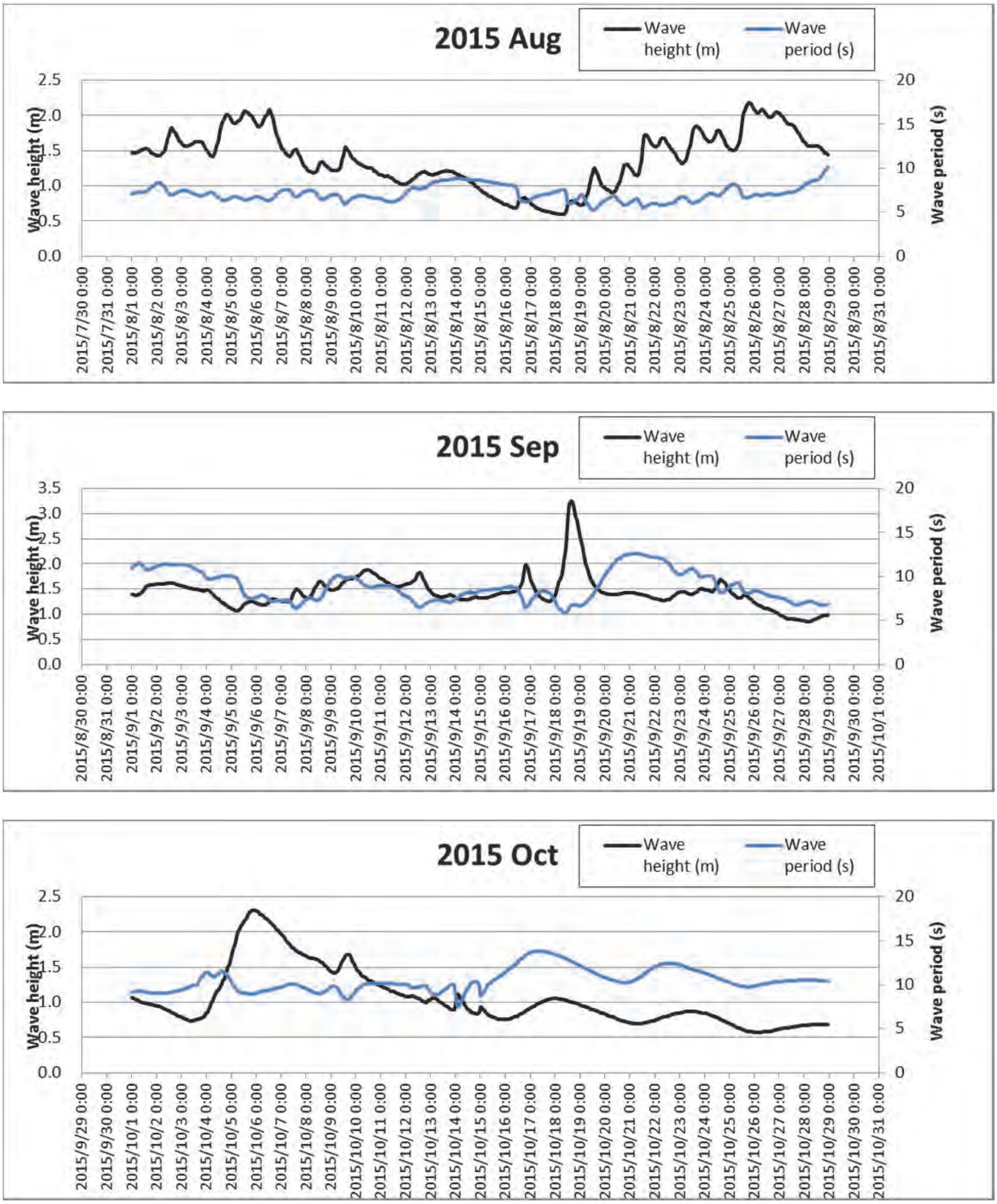
Source: The JICA Study Team

Figure 3.7.16. Wave Height and Period by Wave Forecasting and Hindcasting (2015/2/1 ~ 4/30)



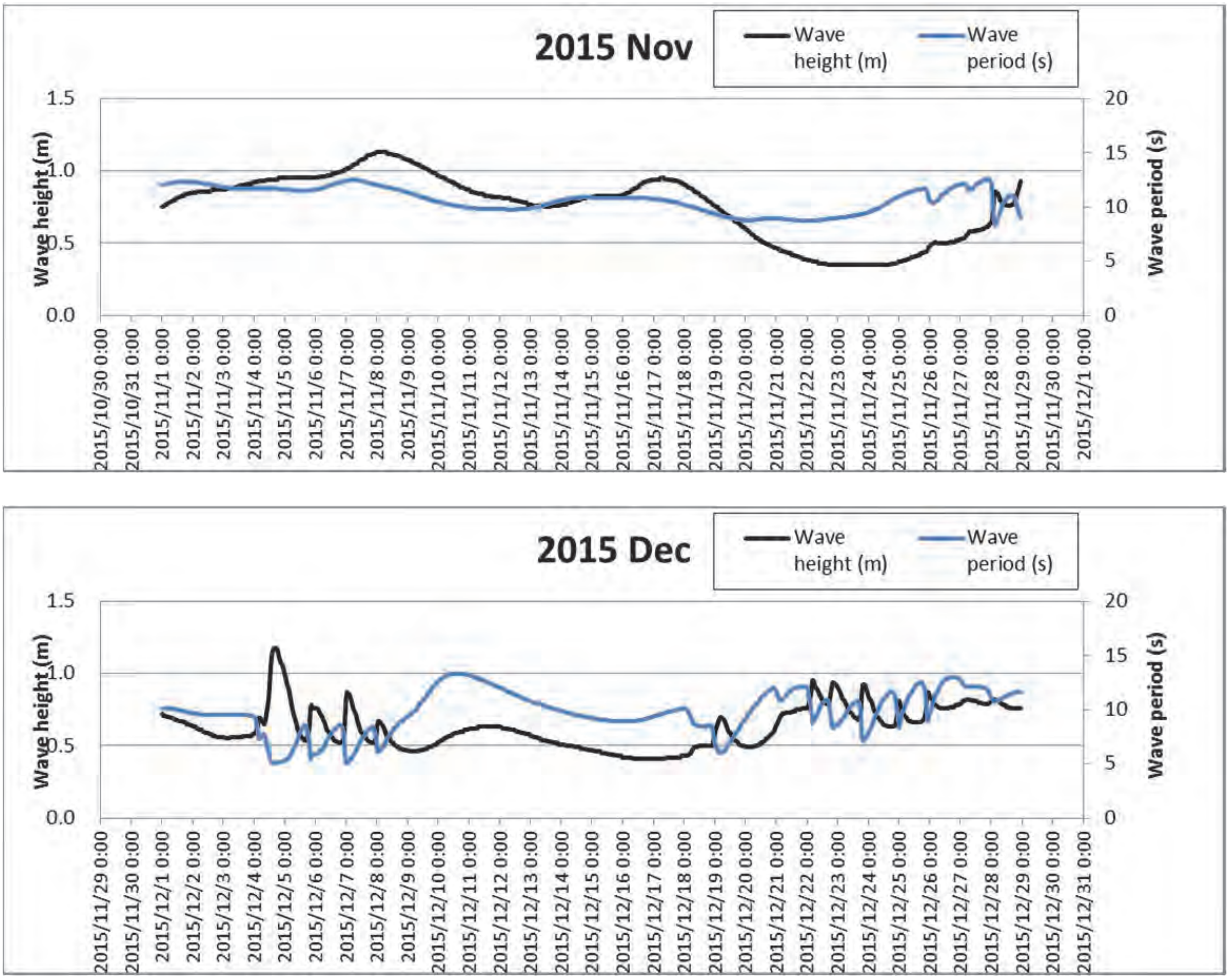
Source: The JICA Study Team

Figure 3.7.17. Wave Height and Period by Wave Forecasting and Hindcasting (2015/5/1 ~ 7/31)



Source: The JICA Study Team

Figure 3.7.18. Wave Height and Period by Wave Forecasting and Hindcasting (2015/8/1 ~ 10/30)

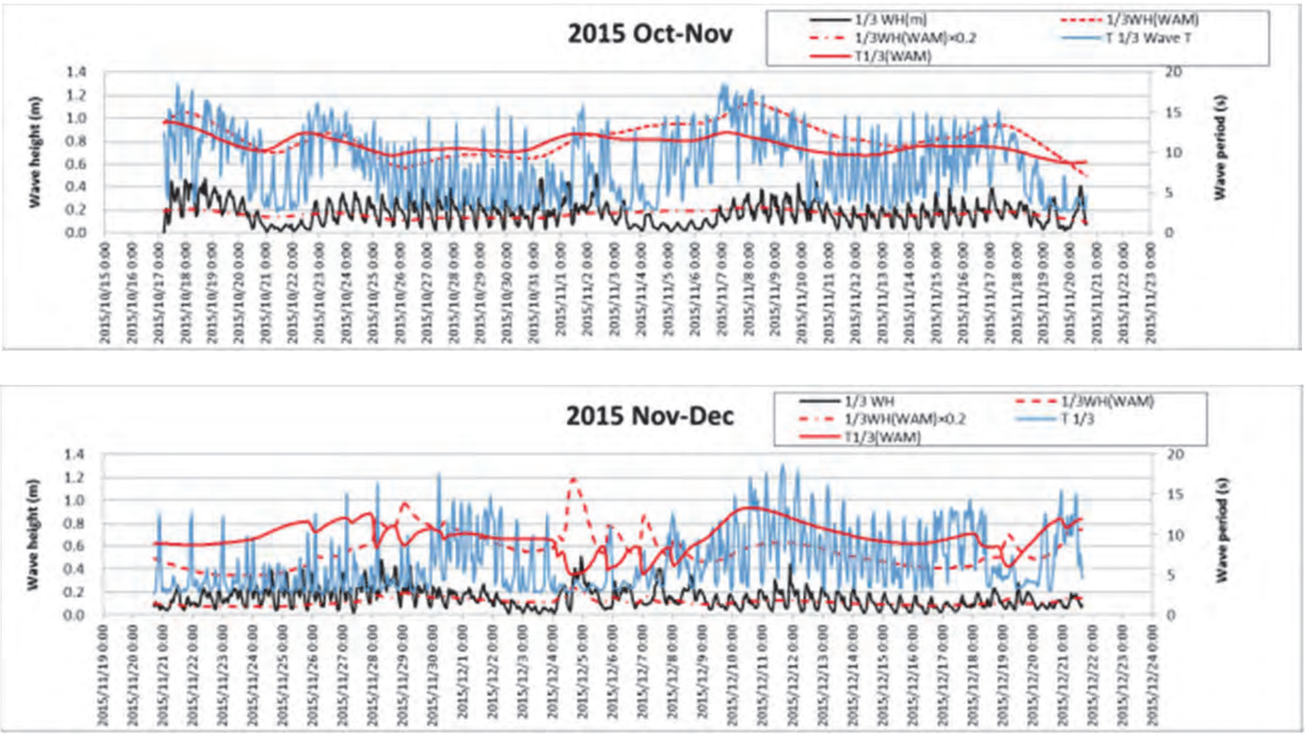


Source: The JICA Study Team

Figure 3.7.19. Wave Height and Period by Wave Forecasting and Hindcasting

On the point of the relation between wave height and period, the above data has the same trend as the observed data in the Study and 2 types of wave are recognised: waves occurring and developing in/around the survey point and other waves coming from open sea having a long period. Although the observed data has frequently repeating developing and attenuating daily, the general trend of the observed data is similar to the data of wave forecasting and hindcasting.

On the other hand, when the wave height of the observed data is compared to the above, the former is about 1/5 of the latter’s. The following figure shows the comparison. Probably the reason for this phenomenon is that the observed data includes the influence of refraction, shallow water, breaking and friction of the waves but the data of wave forecasting and hindcasting includes none of them, as mentioned before. Therefore, these would be a main reason of the difference. However, both show similar tendencies. Although continuous wave observation and data accumulation for a long time, in years, are important, the data of wave forecasting and hindcasting is also effectively usable for the objective area as supplemental.



Source: The JICA Study Team

Figure 3.7.20. Comparison between the Observed Data and Wave Forecasting and Hindcasting Estimation (2015/10/17−12/21)

3.7.6. Summary of Wave Observation

In this opportunity, it was gradually revealed that 2 types of waves exist at Bengal Bay: one is the wave that occurrs and develops in / around the sea area of the survey point and the other wave is coming from the open sea having a certain long wave period.

The long period wave found in this Study would have a possibility of influencing the changing of the bottom shape of the seabed in / around the access channel even if the wave height is small. Further continuous wave monitoring, including observations of current speed, wind, tidal change, weather and so on, shall commence in the near future and those data will be usable for the building of the numerical value simulation. Besides, the bathymetry including the area of the river mouth should be reproduced in detail and a predictive calculation should be conducted for the future development of the access channel considering countermeasures like a groin construction and / or deepening of the access channel.

However, if the long period wave influences the change of bathymetry beyond a certain expectation, such countermeasures would not be effective enough even though the results of simulations could have reproducibility. There was rare case to conduct a plan, design, and construction of the groin work and the deepening channel subjected to such a long period wave in the past and further knowledge would be necessary to build up.

3.8. Flow Velocity of River Channel

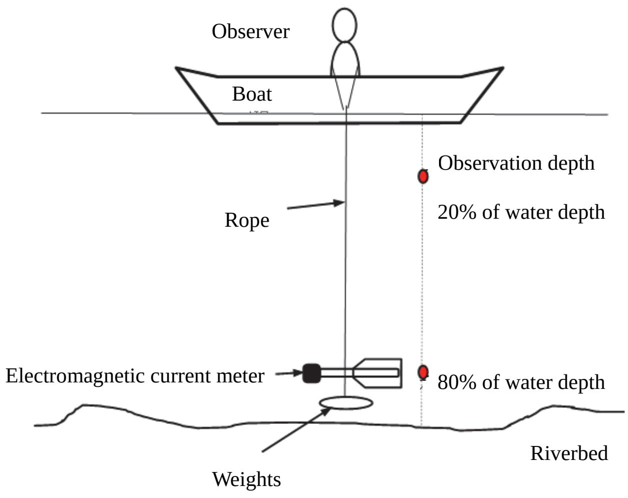
3.8.1. Necessity of Flow Velocity Observation

In this Study, the flow velocity observation for the Yangon River was executed. The purpose of the observation was to acquire materials for the calculation of the river flow rate for the riverbed variation analysis and materials for the vessel traffic analysis. Both analyses are not included in the Study and only collection of basic materials is the purpose of the Study.

The observation for the riverbed variation analysis should compare river flow velocity in the dry season and the rainy season, therefore, it was necessary to conduct the data collection in low tide which has less influence from sea water. However, unfortunately, the commencement of the survey was delayed so the observation in the rainy season was canceled. On the other hand, the observation for the ship traffic analysis was executed on time in the rainy season, so the collected data would be used for the riverbed variation analysis as well. The observation for the ship traffic analysis was necessary to collect the data for the examination of the keel clearance of large cargo vessels so it was done in spring and neap tide for 12 consecutive hours in each survey at 1-hour intervals.

3.8.2. Method for Flow Velocity Observation

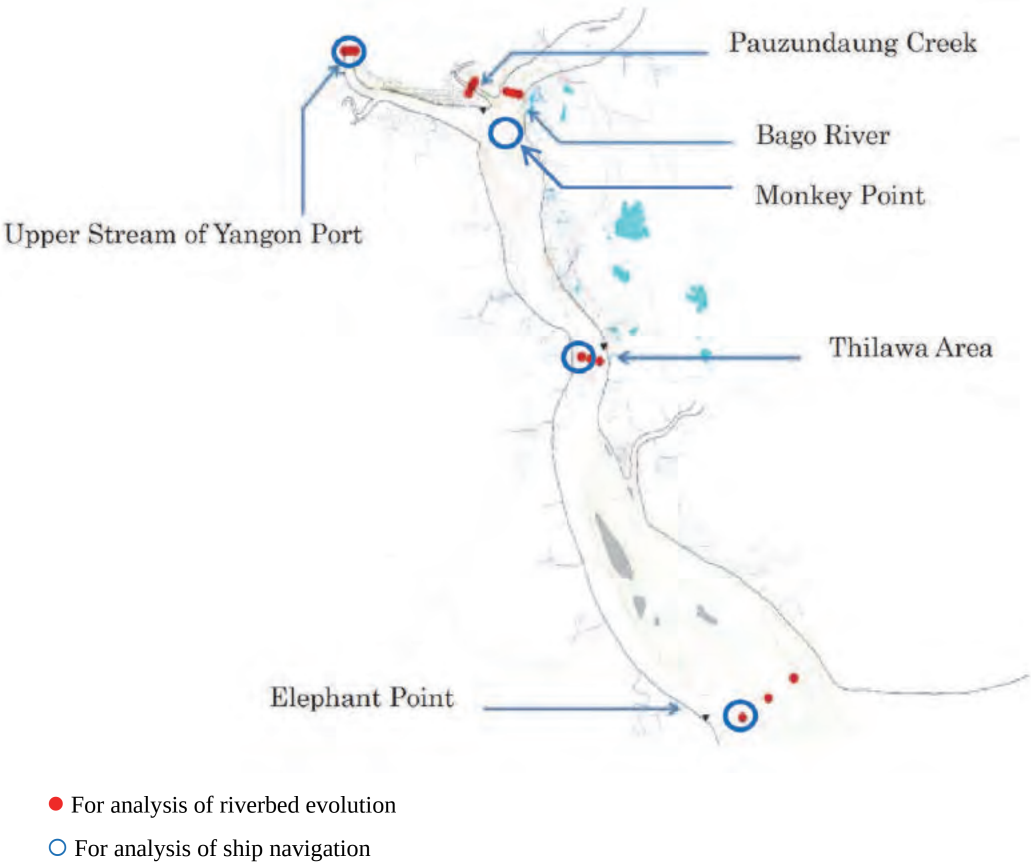
The flow velocity observation was conducted in 2 layers: the surface (about 20% water depth) of the river flow and a lower (80% water depth) layer, with an electromagnetic current meter. The observation length for one time is at least 20 seconds and it was repeated at least 3 times, and then the average flow velocity and flow direction were confirmed. Also, water depth was measured at the start and the completion of the observation.



Source: The JICA Study Team

Figure 3.8.1. Method for Flow Velocity Observation

The observations for the riverbed variation analysis were at 3 points in a river section and for the ship traffic analysis was at 1 point in a section of the channel, as shown in the following.



Source: The JICA Study Team

Figure 3.8.2. Locations of Flow Velocity Observation and Points

The following table shows the points and the dates of the observations.

Table 3.8.1. Observation Points and Dates

Purpose	Time	Point	Date
Analysis of riverbed evolution (3 points)	Low tide	Upper Stream of Yangon Port	2015/6/12
		Pauzundaung Creek	2015/6/11
		Bago River	2015/6/11
		Thilawa Area	2015/6/12
		Elephant Point	2015/6/12, 18
	12-hour continuation (Every one hour)	Upper Stream of Yangon Port	2015/10/20
		Bago River	2015/10/21
		Thilawa Area	2015/10/22
Analysis of ship navigation (1 point)	12-hour continuation (Every one hour at spring tide)	Upper Stream of Yangon Port	2015/10/12
		Monkey Point	2015/10/12
		Thilawa Area	2015/10/12
		Elephant Point	2015/10/12
	12-hour continuation (Every one hour at neap tide)	Upper Stream of Yangon Port	2015/10/23
		Monkey Point	2015/10/23
		Thilawa Area	2015/10/23
		Elephant Point	2015/10/23

Source: The JICA Study Team

3.8.3. Results of the Flow Velocity Observation

The river flow velocity observation in October was conducted at 3 points and the data collection was done consecutively for 12 hours so the data in low tide was picked up and compared with the data in June.

Table 3.8.2. Observation Points and Observations

Point	June Date (low tide)	October	
		Date	Low-tide time
Upper Stream of Yangon Port	2015/6/12	2015/10/20	15:58,03:22
Bago River	2015/6/11	2015/10/21	17:01,04:14
Thilawa Area	2015/6/12	2015/10/22	18:36,05:26

Source: The JICA Study Team

Based on the comparison, it is found that June had a higher flow rate than October.

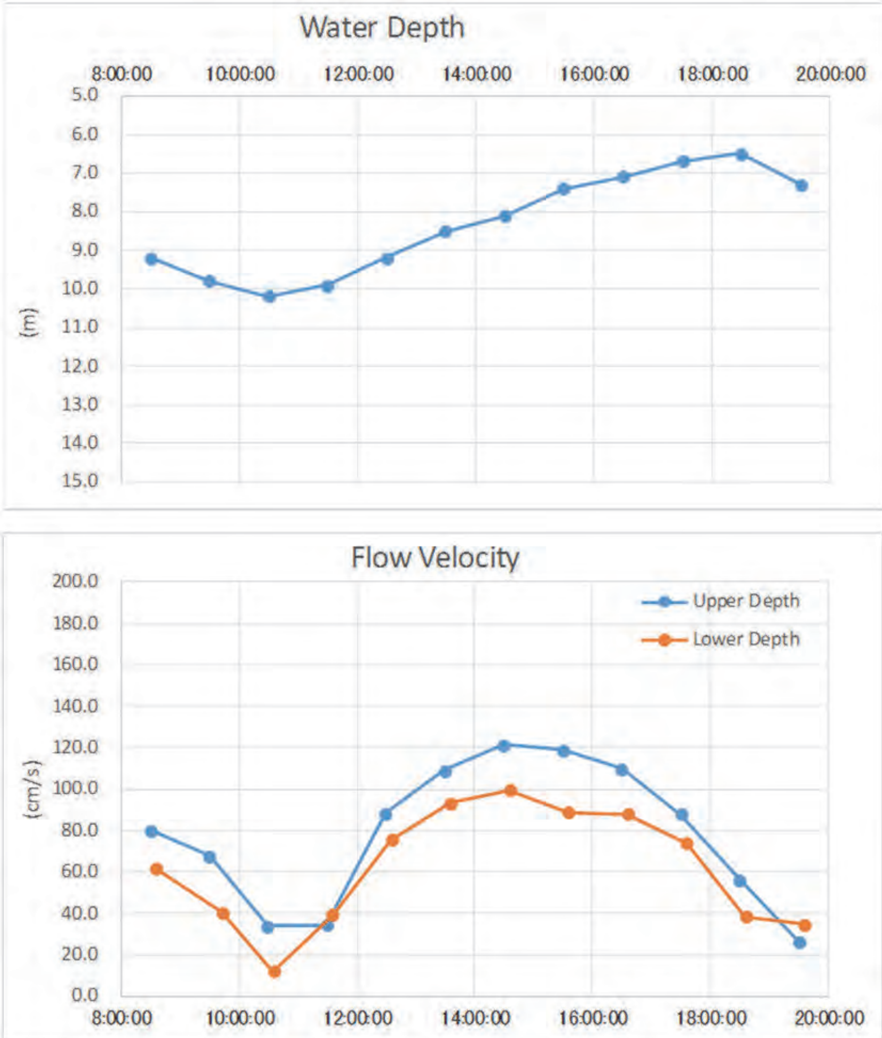
Table 3.8.3. Comparison between the Results of Flow Velocities in June and October

Locaton Name	Point	dry season (Low tide)			rainy season (12h)		
		Water Depth (m)	average Velocity (m/s)	Flow rate	Water Depth (m)	average Velocity (m/s)	Flow rate
Upper Stream of Yangon Port	Right	11.3	0.74	8.3	8.0	0.58	4.7
	Center	14.5	1.20	17.4	11.3	1.21	13.7
	Left	21.8	0.85	18.4	15.3	1.05	16.0
Total Flow rate				44.2			34.4
Bago River	Right	5.6	1.07	6.0	6.3	0.15	0.9
	Center	4.3	0.70	3.0	6.6	0.59	3.9
	Left	4.2	0.27	1.2	4.5	0.24	1.1
Total Flow rate				10.1			5.9
Thilawa Area	Right	16.1	0.82	13.2	6.5	0.47	3.1
	Center	9.1	1.45	13.2	11.2	0.90	10.1
	Left	11.1	1.47	16.3	17.5	0.44	7.7
Total Flow rate				42.7			20.8

Note: The flow rate was calculated on the assumption that the width of the river is 1.

Source: The JICA Study Team

As seen from the results of the 12-hour observation in the following Table 3.8.3, the flow velocities are affected by tide levels to the upper stream of the Port of Yangon. The flow velocities at flood and ebb tides are considered to have a great influence on the cleaning power in the channel. For this reason, it is necessary to conduct an analysis of riverbed variation based on the input of flow velocities generated from tide levels.



Source: The JICA Study Team

Figure 3.8.3. Results of 12-Hour Observation (Thilawa Area)

Table 3.8.4. Results of Flow Velocity Observation (June: At Low Tide)

Locaton Name	Point	Date	Choosen Time of Data collecting	Water Depth (m)	Measurement Depth (m)	Velocity (cm/s)	Direction (°)
Upper Streem of Yangon port	Right	12 June	7:12:00 ~ 7:18:00	11.3	9.0	46.5	172.6
			7:19:00 ~ 7:24:00	11.3	2.3	100.6	182.5
	Center	12 June	6:53:00 ~ 6:59:00	14.5	11.6	106.7	187.6
			7:00:00 ~ 7:06:00	14.5	2.9	133.9	201.5
	Left	12 June	7:45:00 ~ 7:52:00	21.8	17.4	69.5	197.2
			7:54:00 ~ 8:01:00	21.8	4.4	99.5	191.3
Pauzundaung Creek	Right	11 June	17:40:00 ~ 17:46:00	4.5	3.6	45.4	116.1
			17:47:00 ~ 17:52:00	4.5	0.9	56.1	115.5
	Center	11 June	17:12:00 ~ 17:19:00	6.5	5.2	59.4	112.4
			17:19:00 ~ 17:22:00	6.5	1.3	87.4	106.2
	Left	11 June	18:01:00 ~ 18:08:00	5.7	4.6	39.2	110.8
			18:06:00 ~ 18:13:00	5.7	1.1	38.4	120.0
Bago River	Right	11 June	4:23:00 ~ 4:28:00	5.6	4.5	84.6	189.6
			4:30:00 ~ 4:36:00	5.6	1.1	128.7	211.5
	Center	11 June	5:07:00 ~ 5:13:00	4.3	3.4	58.8	186.4
			5:13:00 ~ 5:17:00	4.3	0.9	80.2	198.2
	Left	11 June	5:35:00 ~ 5:41:00	4.2	3.4	8.0	219.6
			5:42:00 ~ 5:47:00	4.2	0.9	46.9	191.1
Thilawa area	Right	12 June	18:21:00 ~ 16:26:00	16.1	12.9	53.5	220.2
			18:27:00 ~ 18:33:00	16.1	3.2	110.4	186.8
	Center	12 June	17:10:00 ~ 17:16:00	9.1	7.3	95.2	178.0
			17:17:00 ~ 17:23:00	9.1	1.8	194.3	202.7
	Left	12 June	19:08:00 ~ 19:14:00	11.1	8.9	127.1	181.4
			19:14:00 ~ 19:22:00	11.1	2.2	167.8	183.7
Elephant Point	Right	12 June	17:57:00 ~ 18:03:00	15.6	12.5	57.1	212.9
			18:06:00 ~ 18:11:00	15.6	3.1	146.1	127.9
	Center	12 June	16:30:00 ~ 16:35:00	4.1	3.3	78.4	195.9
			16:36:00 ~ 16:42:00	4.1	0.8	105.0	183.2
	Left	18 June	19:10:00 ~ 19:16:00	3.5	3.0	55.4	163.1
			19:16:00 ~ 19:22:00	3.5	0.8	72.0	147.9

Source: The JICA Study Team

Table 3.8.5. Results of Flow Velocity Observation (October: 12 hours: Upper Stream of Yangon Port)

Locaton Name	Point	Date	No.	Choosen Time of Data collecting	Water Depth (m)	Measurement Depth (m)	Velocity (cm/s)	Direction (°)
Upper Streem of Yangon port	Right	20 Oct	1-L	6:44:00 ~ 6:49:00	10.6	8.5	39.9	23.6
			1-U	6:49:50 ~ 6:54:50		2.1	30.4	5.1
			2-L	7:45:30 ~ 7:50:30	11.6	9.3	16.8	22.1
			2-U	7:51:30 ~ 7:56:30		2.3	14.7	28.0
			3-L	8:44:45 ~ 8:49:45	13	10.4	36.6	184.2
			3-U	8:50:15 ~ 8:55:15		2.6	48.0	197.0
			4-L	9:45:45 ~ 9:50:45	10.5	8.4	59.3	195.6
			4-U	9:51:30 ~ 9:56:30		2.1	70.9	194.0
			5-L	10:47:00 ~ 10:52:00	10.3	8.2	59.2	195.7
			5-U	10:53:00 ~ 10:58:00		2.1	61.1	191.9
			6-L	11:45:00 ~ 11:50:00	9.5	7.6	26.6	187.0
			6-U	11:51:00 ~ 11:56:00		1.9	39.3	174.4
			7-L	12:45:30 ~ 12:50:30	9.5	7.6	72.5	195.4
			7-U	12:51:30 ~ 12:56:30		1.9	93.2	193.9
			8-L	13:45:30 ~ 13:50:30	9	7.2	66.1	196.8
			8-U	13:51:30 ~ 13:56:30		1.8	70.7	190.7
			9-L	14:45:20 ~ 14:50:20	8.8	7.0	68.0	191.4
			9-U	14:51:20 ~ 14:56:20		1.8	80.4	195.9
			10-L	15:45:20 ~ 15:50:20	8	6.4	50.8	191.9
			10-U	15:51:00 ~ 15:56:00		1.6	66.0	186.7
			11-L	16:45:20 ~ 16:50:20	8.2	6.6	43.9	198.6
			11-U	16:51:30 ~ 16:56:30		1.6	32.5	193.2
			12-L	17:46:00 ~ 17:51:00	8.4	6.7	19.0	350.2
			12-U	17:52:20 ~ 17:57:20		1.7	29.2	2.8

Locaton Name	Point	Date	No.	Choosen Time of Data collecting	Water Depth (m)	Measurement Depth (m)	Velocity (cm/s)	Direction (°)
Upper Streem of Yangon port	Center	20 Oct	1-U	6:50:00 ~ 6:55:00	16	3.2	18.0	344.3
			1-L	6:56:00 ~ 7:01:00		12.8	27.4	23.3
			2-U	7:50:00 ~ 7:55:00	16.8	3.4	14.7	79.4
			2-L	7:56:00 ~ 8:01:00		13.4	9.9	17.3
			3-U	8:50:00 ~ 8:54:30	16.3	3.3	45.1	194.0
			3-L	8:55:00 ~ 9:00:00		13.0	49.6	199.0
			4-U	9:49:00 ~ 9:54:00	15.7	3.1	111.5	194.9
			4-L	9:56:00 ~ 10:01:00		12.6	87.1	193.9
			5-U	10:50:00 ~ 10:55:00	15.5	3.1	118.8	193.5
			5-L	10:57:00 ~ 11:02:00		12.4	79.9	200.4
			6-U	11:50:00 ~ 11:55:00	15.2	3.0	143.6	185.0
			6-L	11:57:00 ~ 12:02:00		12.2	110.3	189.4
			7-U	12:50:00 ~ 12:55:00	14.5	2.9	128.2	191.9
			7-L	12:57:00 ~ 13:02:00		11.6	106.1	193.1
			8-U	13:50:00 ~ 13:55:00	14	2.8	145.1	197.3
			8-L	13:57:00 ~ 14:02:00		11.2	108.9	193.2
			9-U	14:50:00 ~ 14:55:00	11.5	2.3	140.1	192.7
			9-L	14:57:00 ~ 15:02:00		9.2	112.5	191.7
			10-U	15:50:00 ~ 15:55:00	11.3	2.3	133.4	188.8
			10-L	15:58:00 ~ 16:03:00		9.0	109.4	193.8
			11-U	16:50:00 ~ 16:55:00	11.1	2.2	107.7	192.0
			11-L	16:57:00 ~ 17:02:00		8.9	91.8	191.4
			12-U	17:54:00 ~ 17:59:00	13.3	2.7	23.0	136.7
			12-L	18:00:00 ~ 18:05:00		10.6	27.9	83.8

Locaton Name	Point	Date	No.	Choosen Time of Data collecting	Water Depth (m)	Measurement Depth (m)	Velocity (cm/s)	Direction (°)
Upper Streem of Yangon port	Left	20 Oct	1-U	18:41:00 ~ 18:46:00	17.1	3.4	27.0	181.8
			1-L	18:47:00 ~ 18:52:00		13.7	24.9	7.9
			2-U	19:40:00 ~ 19:45:00	19.3	3.9	31.6	10.3
			2-L	19:47:00 ~ 19:52:00		15.4	13.1	14.6
			3-U	20:40:00 ~ 20:45:00	19.7	3.9	6.9	336.8
			3-L	20:47:00 ~ 20:52:00		15.8	10.3	162.2
			4-U	21:44:00 ~ 21:49:00	18.6	3.7	49.8	186.4
			4-L	21:51:00 ~ 21:56:00		14.9	33.2	190.9
			5-U	22:40:00 ~ 22:45:00	18.5	3.7	81.1	188.7
			5-L	22:47:00 ~ 22:52:00		14.8	69.2	189.1
			6-U	23:40:00 ~ 23:45:00	18.4	3.7	95.5	189.3
			6-L	23:47:00 ~ 23:52:00		14.7	87.3	186.2
			7-U	0:40:30 ~ 0:45:30	18.1	3.6	94.0	190.5
			7-L	0:47:00 ~ 0:52:00		14.5	87.6	186.0
			8-U	1:50:00 ~ 1:55:00	16	3.2	104.1	189.4
			8-L	1:56:00 ~ 2:01:00		12.8	94.7	188.0
			9-U	2:41:30 ~ 2:46:30	15.2	3.0	108.5	184.0
			9-L	2:48:10 ~ 2:53:10		12.2	89.2	188.3
			10-U	4:13:00 ~ 4:18:00	15.3	3.1	100.3	185.8
			10-L	4:07:00 ~ 4:12:00		12.2	109.1	186.9
			11-U	4:44:00 ~ 4:49:00	15.4	3.1	101.2	187.3
			11-L	4:54:00 ~ 4:59:00		12.3	86.2	187.8
			12-U	5:40:30 ~ 5:45:30	16	3.2	74.3	185.8
			12-L	5:47:30 ~ 5:52:30		12.8	54.9	186.8

Yellow area: At low tide

Source: The JICA Study Team

Table 3.8.6. Results of Flow Velocity Observation (October: 12 hours: Bago River) Low Tide Hours

Locaton Name	Point	Date	No.	Choosen Time of Data collecting	Water Depth (m)	Measurement Depth (m)	Velocity (cm/s)	Direction (°)
Bago River	Right	21 Oct	1-U	8:34:40 ~ 8:39:40	8.8	1.8	57.8	14.3
			1-L	8:40:40 ~ 8:45:40		7.0	53.2	27.8
			2-U	9:34:40 ~ 9:39:40	9.0	1.8	24.5	20.6
			2-L	9:40:40 ~ 9:45:40		7.2	17.6	41.9
			3-U	10:35:40 ~ 10:39:40	8.8	1.8	15.6	216.1
			3-L	10:40:40 ~ 10:45:40		7.0	19.2	207.1
			4-U	11:34:30 ~ 11:39:30	8.5	1.7	37.9	196.8
			4-L	11:40:30 ~ 11:45:30		6.8	32.6	188.0
			5-U	12:34:10 ~ 12:39:10	8.0	1.6	78.4	203.1
			5-L	12:40:10 ~ 12:45:10		6.4	56.7	186.9
			6-U	13:35:00 ~ 13:40:00	7.5	1.5	67.4	197.8
			6-L	13:40:30 ~ 13:45:30		6.0	56.2	194.8
			7-U	14:34:30 ~ 14:39:30	7.0	1.4	63.5	199.6
			7-L	14:40:30 ~ 14:45:30		5.6	48.2	193.7
			8-U	15:34:30 ~ 15:39:30	6.6	1.3	63.1	202.3
			8-L	15:40:30 ~ 15:45:30		5.3	40.2	190.8
			9-U	16:34:30 ~ 16:39:30	6.4	1.3	42.5	197.6
			9-L	16:40:30 ~ 16:45:30		5.1	27.2	192.7
			10-U	17:34:30 ~ 17:39:30	6.3	1.3	21.2	210.6
			10-L	17:40:30 ~ 17:45:30		5.0	8.0	167.9
			11-U	18:33:30 ~ 18:38:30	6.6	1.3	35.1	11.9
			11-L	18:40:30 ~ 18:45:30		5.3	41.8	23.3
			12-U	19:36:30 ~ 19:41:30	7.5	1.5	61.4	21.0
			12-L	19:42:30 ~ 19:47:30		6.0	55.5	17.6

Locaton Name	Point	Date	No.	Choosen Time of Data collecting	Water Depth (m)	Measurement Depth (m)	Velocity (cm/s)	Direction (°)
Bago River	Center	21 Oct	1-U	18:50:00 ~ 18:55:00	6.6	1.3	67.2	25.5
			1-L	18:56:00 ~ 19:01:00		5.3	71.0	36.9
			2-U	19:50:30 ~ 19:55:30	8.2	1.6	81.1	18.3
			2-L	19:56:30 ~ 20:01:30		6.6	57.7	22.0
			3-U	20:50:00 ~ 20:55:00	8.4	1.7	75.2	21.6
			3-L	20:56:00 ~ 21:01:00		6.7	59.5	27.0
			4-U	21:50:00 ~ 21:55:00	8.8	1.8	50.8	18.2
			4-L	21:56:00 ~ 22:01:00		7.0	34.9	31.1
			5-U	22:50:00 ~ 22:55:00	8.9	1.8	13.2	19.5
			5-L	23:00:00 ~ 23:04:00		7.1	3.7	135.6
			6-U	23:50:00 ~ 23:55:00	8.7	1.7	26.9	214.3
			6-L	23:56:00 ~ 0:01:00		7.0	25.0	198.4
			7-U	0:49:30 ~ 0:54:30	8.3	1.7	62.1	203.8
			7-L	0:55:30 ~ 1:00:30		6.6	48.9	198.4
			8-U	1:50:00 ~ 1:55:00	7.6	1.5	71.5	206.4
			8-L	1:56:00 ~ 2:01:00		6.1	53.2	202.0
			9-U	2:49:30 ~ 2:54:30	7.2	1.4	71.0	203.0
			9-L	2:55:30 ~ 3:00:30		5.8	67.8	201.1
			10-U	3:50:30 ~ 3:54:30	6.6	1.3	68.7	206.2
			10-L	3:55:30 ~ 4:00:00		5.3	49.1	195.0
			11-U	4:50:00 ~ 4:55:00	6.2	1.2	59.8	209.8
			11-L	4:55:30 ~ 5:00:30		5.0	33.3	187.4
			12-U	5:50:00 ~ 5:55:00	6.1	1.2	38.0	210.4
			12-L	5:55:30 ~ 6:00:30		4.9	23.2	189.7

Locaton Name	Point	Date	No.	Choosen Time of Data collecting	Water Depth (m)	Measurement Depth (m)	Velocity (cm/s)	Direction (°)
Bago River	Left	21 Oct	1-U	7:20:00 ~ 7:25:00	6.8	1.4	90.3	18.5
			1-L	7:26:00 ~ 7:31:00		5.4	71.4	27.2
			2-U	8:20:30 ~ 8:25:30	7.4	1.5	68.2	17.7
			2-L	8:26:30 ~ 8:31:30		5.9	52.8	25.6
			3-U	9:22:00 ~ 9:27:00	7.5	1.5	15.2	43.1
			3-L	9:28:00 ~ 9:33:00		6.0	31.2	11.6
			4-U	10:22:00 ~ 10:27:00	7.3	1.5	19.9	203.3
			4-L	10:28:00 ~ 10:33:00		5.8	24.6	202.8
			5-U	11:20:30 ~ 11:25:30	6.9	1.4	59.0	199.4
			5-L	11:26:30 ~ 11:31:30		5.5	43.5	195.1
			6-U	12:21:00 ~ 12:26:00	6.3	1.3	62.1	199.1
			6-L	12:29:00 ~ 12:34:00		5.0	47.5	195.9
			7-U	13:21:30 ~ 13:26:30	5.6	1.1	59.8	199.2
			7-L	13:28:00 ~ 13:33:00		4.5	43.1	195.7
			8-U	14:21:30 ~ 14:26:30	5.2	1.0	54.9	198.3
			8-L	14:27:30 ~ 14:32:30		4.2	36.3	194.9
			9-U	15:21:00 ~ 15:26:00	4.7	0.9	44.3	198.5
			9-L	15:27:00 ~ 15:32:00		3.8	27.3	192.3
			10-U	16:21:00 ~ 16:26:00	4.5	0.9	32.3	199.6
			10-L	16:27:00 ~ 16:32:00		3.6	16.5	190.8
			11-U	17:20:30 ~ 17:25:30	4.0	0.8	6.6	223.7
			11-L	17:26:30 ~ 17:31:30		3.2	7.2	149.2
			12-U	18:19:30 ~ 18:24:30	5.0	1.0	63.6	18.4
			12-L	18:25:30 ~ 18:30:30		4.0	50.5	21.8

Yellow area: At low tide

Source: The JICA Study Team

Table 3.8.7. Results of Flow Velocity Observation (October: 12 hours: Thilawa Area)

Locaton Name	Point	Date	No.	Choosen Time of Data collecting	Water Depth (m)	Measurement Depth (m)	Velocity (cm/s)	Direction (°)
Thilawa Area	Right	22 Oct	1-U	8:29:20 ~ 8:34:20	9.2	1.8	79.9	11.6
			1-L	8:35:20 ~ 8:40:20		7.4	61.4	357.8
			2-U	9:29:20 ~ 9:34:20	9.8	2.0	67.9	10.8
			2-L	9:42:20 ~ 9:47:20		7.8	40.3	4.9
			3-U	10:29:20 ~ 10:34:20	10.2	2.0	33.8	15.0
			3-L	10:35:20 ~ 10:40:20		8.2	11.9	342.8
			4-U	11:29:20 ~ 11:34:20	9.9	2.0	34.2	177.6
			4-L	11:35:20 ~ 11:40:20		7.9	39.1	182.8
			5-U	12:29:20 ~ 12:34:20	9.2	1.8	88.2	181.0
			5-L	12:35:20 ~ 12:40:20		7.4	75.6	187.2
			6-U	13:29:20 ~ 13:34:20	8.5	1.7	109.0	184.4
			6-L	13:35:20 ~ 13:40:20		6.8	93.1	184.7
			7-U	14:29:20 ~ 14:34:20	8.1	1.6	121.4	182.2
			7-L	14:35:20 ~ 14:40:20		6.5	99.3	187.7
			8-U	15:29:20 ~ 15:34:20	7.4	1.5	118.8	183.3
			8-L	15:35:20 ~ 15:40:20		5.9	88.8	185.7
			9-U	16:29:40 ~ 16:34:40	7.1	1.4	109.9	182.7
			9-L	16:35:20 ~ 16:40:20		5.7	87.8	183.7
			10-U	17:29:30 ~ 17:34:30	6.7	1.3	88.0	174.5
			10-L	17:35:20 ~ 17:40:20		5.4	73.9	182.4
			11-U	18:29:20 ~ 18:34:20	6.5	1.3	56.3	180.2
			11-L	18:35:20 ~ 18:40:20		5.2	38.3	182.2
			12-U	19:29:30 ~ 19:34:30	7.3	1.5	26.5	12.9
			12-L	19:35:20 ~ 19:40:20		5.8	34.6	7.2

Locaton Name	Point	Date	No.	Choosen Time of Data collecting	Water Depth (m)	Measurement Depth (m)	Velocity (cm/s)	Direction (°)
Thilwa Area	Center	22 Oct	1-U	20:08:00 ~ 20:13:00	10.7	2.1	44.5	12.6
			1-L	20:14:00 ~ 20:19:00		8.6	39.8	355.5
			2-U	21:08:00 ~ 21:13:00	11.4	2.3	56.5	354.1
			2-L	21:14:00 ~ 21:19:00		9.1	45.7	3.4
			3-U	22:07:30 ~ 22:12:30	12.3	2.5	63.1	359.0
			3-L	22:13:30 ~ 22:18:30		9.8	60.7	4.0
			4-U	23:06:30 ~ 23:11:30	12.7	2.5	58.2	6.3
			4-L	23:12:30 ~ 23:17:30		10.2	43.1	4.5
			5-U	0:07:30 ~ 0:12:30	13.1	2.6	16.2	35.9
			5-L	0:13:30 ~ 0:18:30		10.5	2.7	31.0
			6-U	1:08:00 ~ 1:13:00	12.7	2.5	56.3	177.6
			6-L	1:14:00 ~ 1:19:00		10.2	41.0	184.0
			7-U	2:08:00 ~ 2:13:00	13.3	2.7	94.3	178.5
			7-L	2:14:00 ~ 2:19:00		10.6	73.0	179.4
			8-U	3:08:00 ~ 3:13:00	12.1	2.4	105.8	176.3
			8-L	3:14:00 ~ 3:19:00		9.7	82.9	176.4
			9-U	4:08:00 ~ 4:13:00	11.7	2.3	108.7	173.4
			9-L	4:14:00 ~ 4:19:00		9.4	89.8	177.2
			10-U	5:08:00 ~ 5:13:00	11.2	2.2	110.4	174.6
			10-L	5:14:00 ~ 5:19:00		9.0	69.4	176.7
			11-U	6:08:00 ~ 6:13:00	10.3	2.1	97.9	176.0
			11-L	6:14:00 ~ 6:19:00		8.2	92.6	176.2
			12-U	7:09:00 ~ 7:14:00	10.2	2.0	73.4	174.2
			12-L	7:15:00 ~ 7:20:00		8.2	49.2	175.2

Locaton Name	Point	Date	No.	Choosen Time of Data collecting	Water Depth (m)	Measurement Depth (m)	Velocity (cm/s)	Direction (°)
Thilwa Area	Left	22 Oct	1-U	8:26:00 ~ 8:31:00	19.6	3.9	55.2	8.2
			1-L	8:33:00 ~ 8:38:00		15.7	54.3	352.2
			2-U	9:26:00 ~ 9:31:00	20.5	4.1	57.0	8.7
			2-L	9:33:00 ~ 9:38:00		16.4	42.0	357.1
			3-U	10:26:00 ~ 10:31:00	21	4.2	27.3	3.2
			3-L	10:33:00 ~ 10:38:00		16.8	5.8	18.8
			4-U	11:21:00 ~ 11:26:00	20.6	4.1	7.8	146.1
			4-L	11:28:00 ~ 11:33:00		16.5	20.8	171.5
			5-U	12:26:00 ~ 12:31:00	19.6	3.9	54.3	185.3
			5-L	12:37:00 ~ 12:42:00		15.7	55.0	182.5
			6-U	13:26:00 ~ 13:31:00	19.4	3.9	100.7	184.3
			6-L	13:33:00 ~ 13:38:00		15.5	94.3	187.8
			7-U	14:30:00 ~ 14:35:00	18.8	3.8	86.7	184.5
			7-L	14:37:00 ~ 14:42:00		15.0	85.7	184.9
			8-U	15:26:00 ~ 15:31:00	18.6	3.7	92.7	178.1
			8-L	15:33:00 ~ 15:38:00		14.9	87.0	187.9
			9-U	16:26:00 ~ 16:31:00	18	3.6	91.1	182.3
			9-L	16:33:00 ~ 16:38:00		14.4	78.4	184.2
			10-U	17:25:30 ~ 17:30:30	17.4	3.5	82.9	183.0
			10-L	17:31:00 ~ 17:36:00		13.9	80.8	190.1
			11-U	18:25:30 ~ 18:30:30	17.5	3.5	47.2	187.7
			11-L	18:31:30 ~ 18:36:30		14.0	40.3	175.1
			12-U	19:26:00 ~ 19:31:00	18.5	3.7	14.9	5.1
			12-L	19:32:00 ~ 19:37:00		14.8	20.4	17.1

Yellow area: At low tide

Source: The JICA Study Team

3.9. Survey Results of Suspended Solids

3.9.1. Purpose of Investigation of Suspended Solids

By the siltation analysis, a burying process will be reproduced in consideration of the influence of floating, diffusion, and the sedimentation of the bottom mud by a flow and wave.

The suspended solid (SS) survey was carried out at the time of the flood tide in the dry season and the wet season to perform a comparison of the analysis model.

3.9.2. Current Measurement Method

The water intake, reached with three levels, is shown below in consideration of the depth of the water in each water intake spot.

Water intake at the surface of the water: depth under 1 m from the surface of the water
Water intake in the middle class: depth of 50% of the depth of the water
Water intake of the bottom layer: depth at 1-2 m from the riverbed

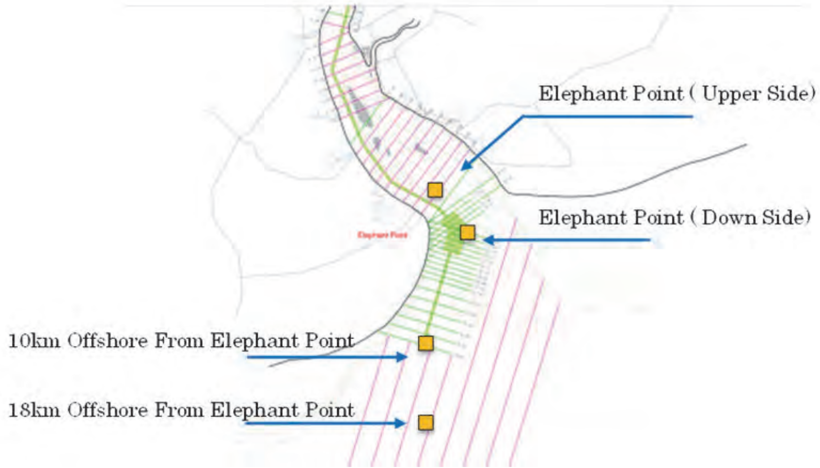
In addition, the water intake was carried out at the time of a flood tide. The measurement of the depth of the water was carried out at the same time, then at the start time at the time of the water intake, and at the end time, too.

Table 3.9.1. Water Intake Interval in One Location, Number of Water Intake Repetitions and Water Intake Date

Water intake interval	Number of water intake repetitions	Water intake date	Remarks
Water intake every one hour	24 times of water intake in total	Dry season: 2016/6/16 ~ 17 Wet season: 2016/10/30 ~ 31	Measured speed at the time of the observation

Source: The JICA Study Team

The observation location for the float density is as shown in the following Figure 3.9.1.



Source: The JICA Study Team

Figure 3.9.1. Suspended Solid Observation Spot

3.9.3. A Float Mass Observation Result and Considerations

As for the sample of collected water, the dry weight, per 1 L, of water including solid material was measured.

As a representative example, observation results from approximately 18 km offshore of Elephant Point will be shown in Table 3.9.2.

Although it was not clear, as for the correlation of speed and float mass, a tendency to have much float mass on the bottom layer was confirmed from Figure 3.9.2.

Table 3.9.2. Float Mass Observation Results (Approximately 18 km Offshore of Elephant Point)

日付	水深(m)	潮位(m)	観測時刻		サンプル No	観測水深 (m)	PH	EC	浮遊物量 (mg/l)	流速 (cm/s)	方向 (°)
			開始	終了							
16.6.2015	7.50	2.36	9:00:00	9:02:20	A1	1.00	7.21	>20.0	300	58.7	131.5
16.6.2015			9:04:16	9:06:23	A2	3.75	7.75	>20.0	1442	59.8	181.1
16.6.2015			9:08:30	9:09:10	A3	6.50	7.76	>20.0	2536	37.6	155.3
16.6.2015	7.20	1.51	10:30:11	10:31:00	A4	1.00	7.77	>20.0	351	69.5	105.8
16.6.2015			10:32:50	10:33.41	A5	3.60	7.72	>20.0	904	67.5	91.0
16.6.2015			10:35:10	10:36:08	A6	6.20	7.75	>20.0	1816	61.7	84.0
16.6.2015	8.10	1.40	11:00:00	11:02:50	A7	1.00	7.73	>20.0	292	172.5	74.6
16.6.2015			11:04:30	11:06:00	A8	4.05	7.73	>20.0	346	198.7	50.9
16.6.2015			11:07:56	11:09:10	A9	7.10	7.72	>20.0	2612	116.1	36.3
17.6.2015	9.20	1.67	12:30:02	12:31:05	A10	1.00	7.77	>20.0	2372	167.0	67.8
17.6.2015			12:33:04	12:34:00	A11	4.60	7.73	>20.0	2396	128.0	32.2
17.6.2015			12:35:16	12:36:12	A12	8.20	7.76	>20.0	2804	88.6	32.4
17.6.2015	9.70	2.08	13:00:00	13:02:30	A13	1.00	7.75	>20.0	1290	105.5	35.9
17.6.2015			13:04:00	13:04:56	A14	4.85	7.77	>20.0	2000	99.8	29.1
17.6.2015			13:06:14	13:07:00	A15	8.70	7.73	>20.0	2408	97.4	24.7

Table 3.9.2., Continued

日付	水深(m)	潮位(m)	観測時刻		サンプル No	観測水深 (m)	PH	EC	浮遊物量 (mg/l)	流速 (cm/s)	方向 (°)
			開始	終了							
17.6.2015			14:20:05	14:21:06	A16	1.00	7.79	>20.0	499	82.2	49.8
17.6.2015	11.00	4.00	14:23:00	14:23:50	A17	5.50	7.77	>20.0	1290	71.2	12.1
17.6.2015			14:25:10	14:26:20	A18	10.00	7.77	>20.0	1438	58.9	13.3
17.6.2015			3:00:00	3:01:45	A19	1.00	7.78	>20.0	420	13.2	286.0
17.6.2015	11.70	4.83	3:04:00	3:05:05	A20	5.85	7.75	>20.0	1318	29.7	266.4
17.6.2015			3:07:10	3:08:00	A21	10.70	7.77	>20.0	1174	34.4	259.9
17.6.2015			4:20:00	4:21:04	A22	1.00	7.70	>20.0	72	124.1	242.3
17.6.2015	11.20	6.01	4:23:00	4:24:03	A23	5.60	7.79	>20.0	718	99.2	238.4
17.6.2015			4:26:30	4:27:50	A24	10.20	7.79	>20.0	1494	96.1	235.1
17.6.2015			5:00:00	5:01:05	A25	1.00	7.77	>20.0	164	156.7	251.6
17.6.2015	10.80	5.99	5:03:10	5:04:05	A26	5.40	7.76	>20.0	364	175.3	235.1
17.6.2015			5:05:03	5:06:06	A27	9.80	7.73	>20.0	1472	134.3	245.1
17.6.2015			6:00:00	6:02:00	A28	1.00	7.75	>20.0	70	166.1	241.9
17.6.2015	10.10	5.60	6:04:10	6:05:02	A29	5.05	7.73	>20.0	1244	144.6	222.5
17.6.2015			6:08:00	6:09:30	A30	9.10	7.74	>20.0	2104	70.7	224.1
17.6.2015			7:30:00	7:31:02	A31	1.00	7.75	>20.0	179	149.4	247.4
17.6.2015	9.10	4.48	7:32:05	7:33:10	A32	4.55	7.74	>20.0	138	140.6	222.5
17.6.2015			7:35:00	7:36:30	A33	8.10	7.74	>20.0	1414	75.1	208.8
17.6.2015			8:01:00	8:03:00	A34	1.00	7.75	>20.0	412	90.4	222.4
17.6.2015	8.40	3.99	8:05:10	8:06:05	A35	4.20	7.76	>20.0	734	74.5	210.6
17.6.2015			8:08:07	8:09:05	A36	7.40	7.74	>20.0	1220	48.1	190.5
17.6.2015			9:23:04	9:24:00	A37	1.00	7.75	>20.0	255	61.7	200.9
17.6.2015	7.70	2.74	9:26:10	9:27:08	A38	3.85	7.76	>20.0	996	61.0	192.4
17.6.2015			9:28:35	9:29:40	A39	6.70	7.74	>20.0	1274	37.0	167.5
17.6.2015			10:28:05	10:29:18	A40	1.00	7.72	>20.0	417	54.0	80.9
17.6.2015	7.40	1.96	10:31:00	10:32:07	A41	3.70	7.73	>20.0	892	66.3	83.7
17.6.2015			10:34:10	10:36:00	A42	6.40	7.80	>20.0	1748	74.3	67.2
17.6.2015			11:27:01	11:28:05	A43	1.00	7.75	>20.0	44	170.8	44.6
17.6.2015	8.40	1.57	11:30:11	11:32:00	A44	4.20	7.74	>20.0	66	176.4	40.2
17.6.2015			11:35:12	11:37:03	A45	7.40	7.75	>20.0	742	114.6	58.7
17.6.2015			12:00:00	12:01:20	A46	1.00	7.72	>20.0	49	165.4	45.7
17.6.2015	9.30	1.52	12:03:00	12:03:50	A47	4.65	7.71	>20.0	244	177.8	16.1
17.6.2015			12:05:00	12:06:13	A48	8.30	7.73	>20.0	2196	76.7	35.1
17.6.2015			13:25:10	13:26:30	A49	1.00	7.76	>20.0	1892	121.3	31.3
17.6.2015	10.80	2.56	13:27:00	13:27:56	A50	5.40	7.72	>20.0	2224	124.0	32.2
17.6.2015			13:29:10	13:30:12	A51	9.80	7.70	>20.0	1804	94.3	35.9
17.6.2015			14:00:00	14:01:15	A52	1.00	7.74	>20.0	1406	66.9	21.6
17.6.2015	11.60	3.44	14:02:20	14:03:00	A53	5.80	7.72	>20.0	1396	50.4	12.6
17.6.2015			14:04:07	14:05:19	A54	10.60	7.77	>20.0	1700	48.3	16.2
17.6.2015			15:22:04	15:23:16	A55	1.00	7.77	>20.0	304	25.3	343.9
17.6.2015	11.80	5.57	15:25:10	15:26:14	A56	5.90	7.76	>20.0	1184	27.9	322.7
17.6.2015			15:28:30	15:29:55	A57	10.80	7.75	>20.0	1122	22.9	306.5
17.6.2015			16:00:00	16:01:20	A58	1.00	7.75	>20.0	284	92.3	242.9
17.6.2015	12.00	6.19	16:02:35	16:03:10	A59	6.00	7.75	>20.0	646	110.5	231.7
17.6.2015			16:04:28	16:06:00	A60	11.00	7.76	>20.0	1160	95.3	227.8
17.6.2015			17:23:13	17:23:00	A61	1.00	7.75	>20.0	236	159.5	252.4
17.6.2015	11.30	6.39	17:25:30	17:26:40	A62	5.65	7.75	>20.0	366	178.3	240.4
17.6.2015			17:28:50	17:30:00	A63	10.30	7.75	>20.0	3340	175.1	251.7
17.6.2015			18:00:00	18:01:00	A64	1.00	7.77	>20.0	200	195.0	234.1
17.6.2015	10.50	6.32	18:02:19	18:03:28	A65	5.25	7.76	>20.0	357	201.8	224.7
17.6.2015			18:05:24	18:06:46	A66	9.50	7.63	>20.0	3970	84.1	226.6
17.6.2015			19:00:00	19:02:25	A67	1.00	7.70	>20.0	479	185.8	231.8
17.6.2015	9.60	6.11	19:03:10	19:05:00	A68	4.80	7.77	>20.0	664	192.6	240.1
17.6.2015			19:05:55	19:07:20	A69	8.60	7.74	>20.0	3450	149.1	253.2
17.6.2015			20:00:00	20:03:20	A70	1.00	7.75	>20.0	652	98.8	227.9
17.6.2015	8.70	5.79	20:04:00	20:07:36	A71	4.35	7.75	>20.0	1066	95.3	205.3
17.6.2015			20:08:00	20:11:00	A72	7.70	7.75	>20.0	1940	47.6	193.9

Note: Tide level calculated by a tide table (the mean of the observation time)

Source: The JICA Study Team

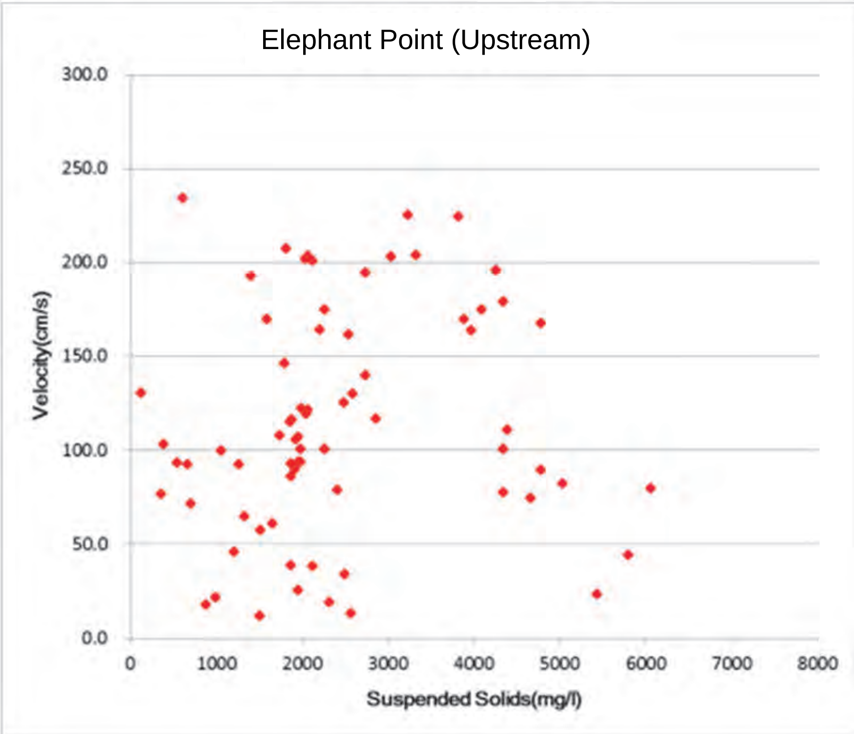
Source: The JICA Study Team

Figure 3.9.2. Float Mass Observation Results (Approximately 18 km Offshore of Elephant Point)

The graph, which shows correlation of speed (velocity, a vertical axis) and float density (SS, a cross axis), is shown in below.

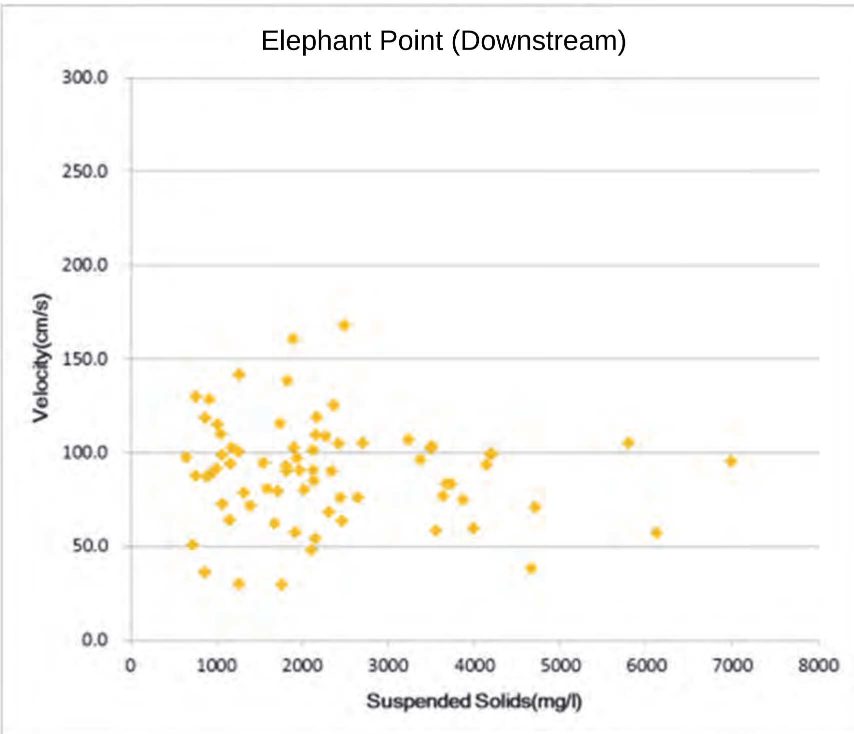
The difference in float density SS in each the collection place is very small. Although the correlation between density SS and river flow speed would be not strong, the density SS at 18km offshore has less density than the one at 10km offshore, so the observation result would be appropriate.

Comparing the float data of October with the float data of June, it was revealed that the October float data grew big with speed and float density.



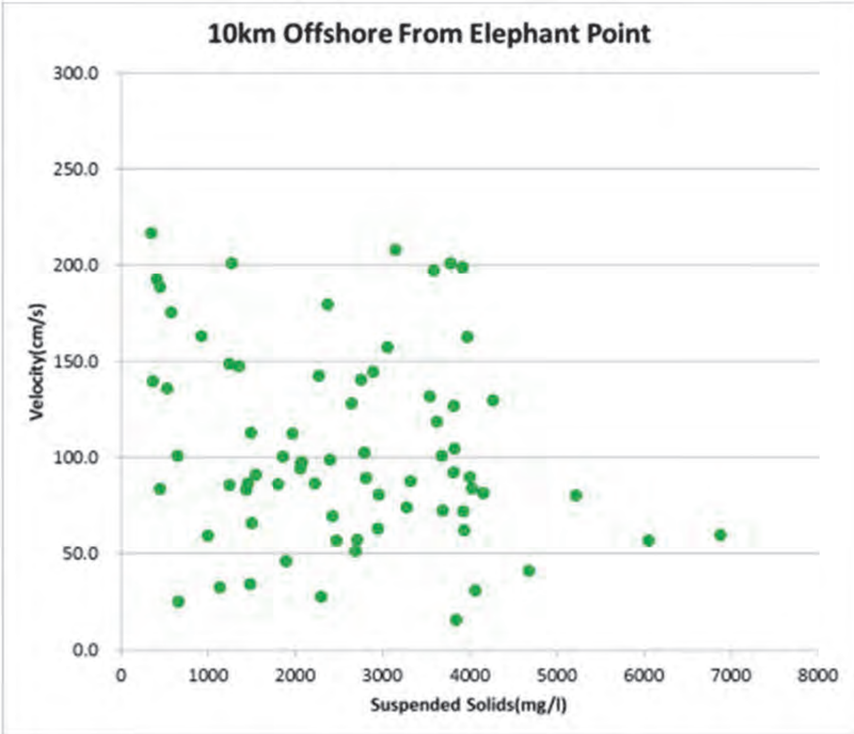
Source: The JICA Study Team

Figure 3.9.3. Correlation of SS-Velocity (Elephant Point (Upper Side)) (June)



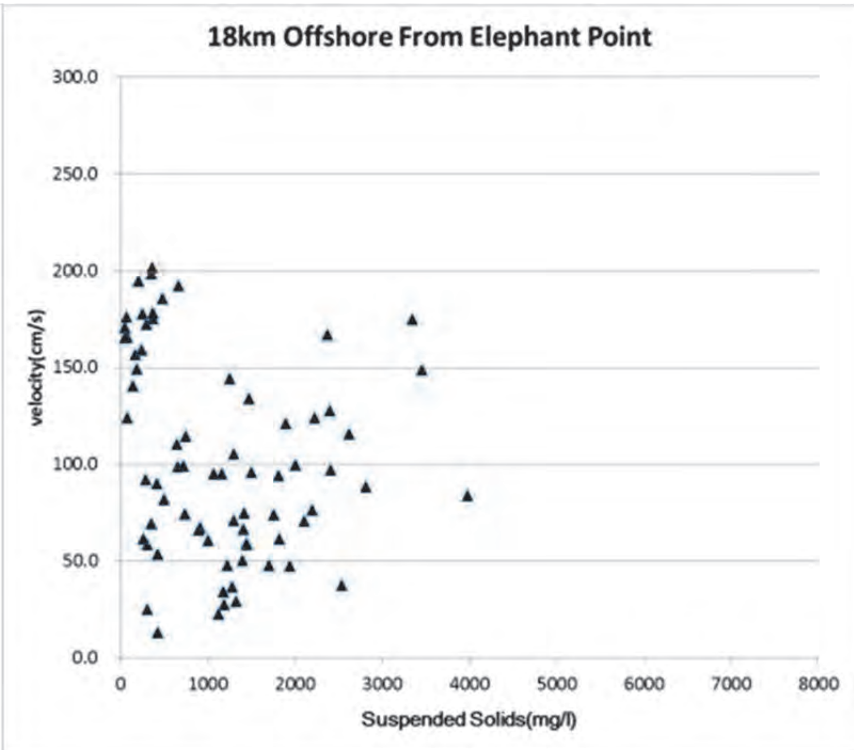
Source: The JICA Study Team

Figure 3.9.4. Correlation of SS-Velocity (Elephant Point (Down Side)) (June)



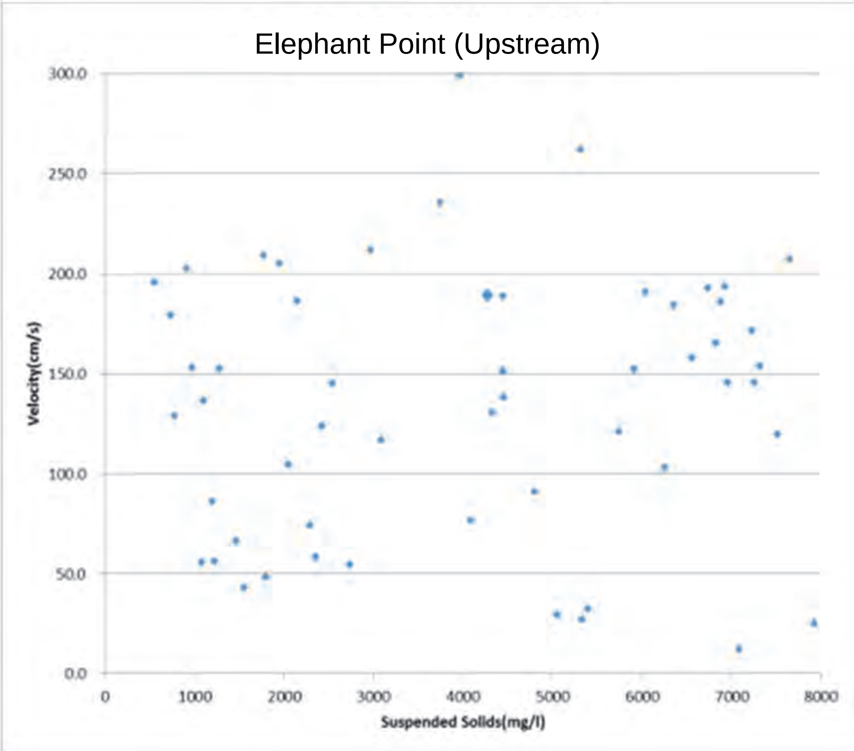
Source: The JICA Study Team

Figure 3.9.5. Correlation of SS-Velocity (10 km Offshore From Elephant Point) (June)



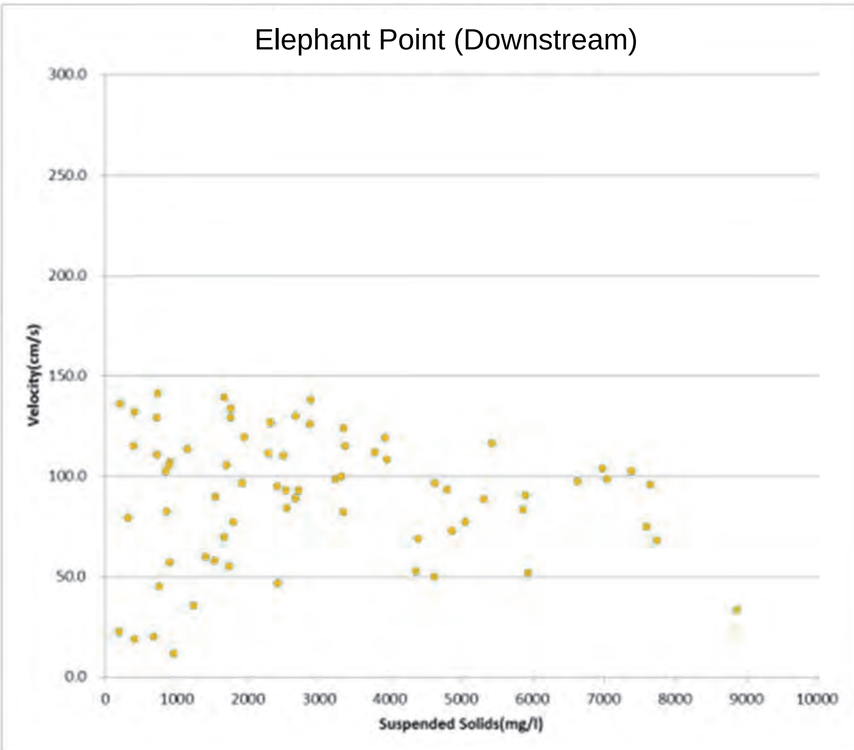
Source: The JICA Study Team

Figure 3.9.6. Correlation of SS-Velocity (18 km Offshore From Elephant Point) (June)



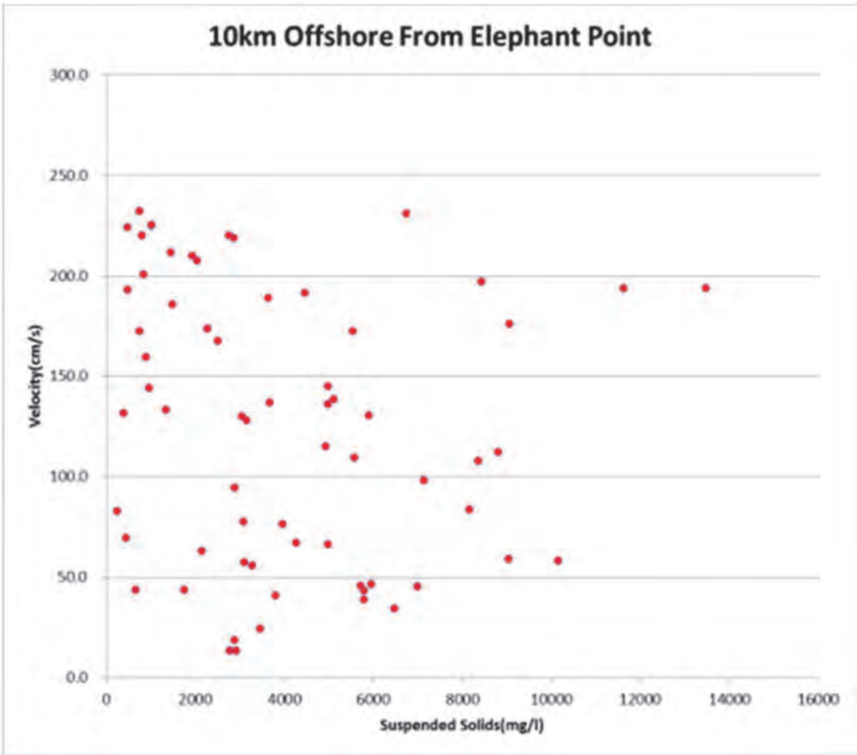
Source: The JICA Study Team

Figure 3.9.7. Correlation of SS-Velocity (Elephant Point (Upper Side)) (October)



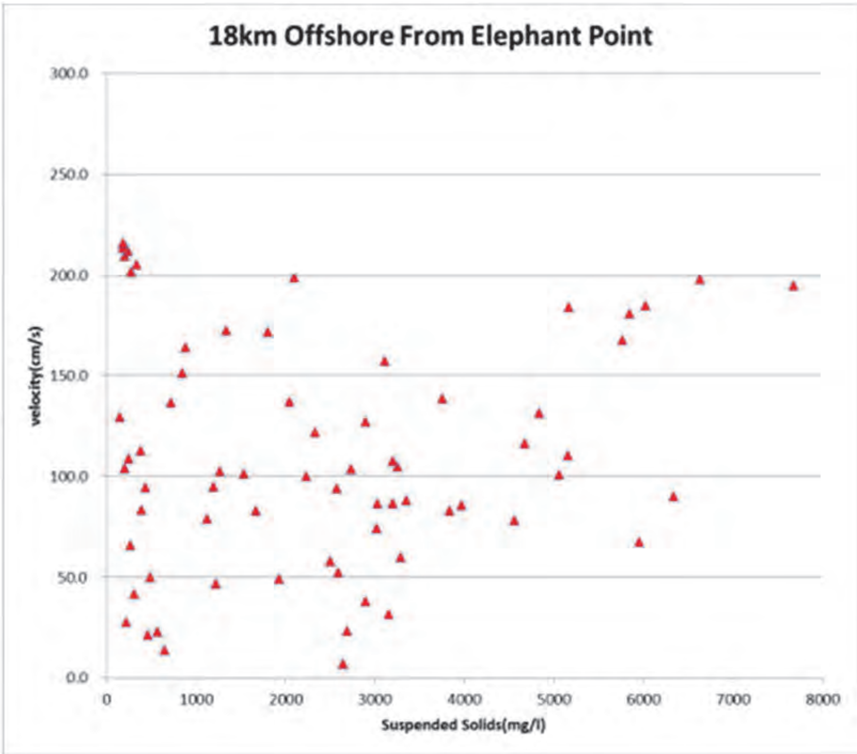
Source: The JICA Study Team

Figure 3.9.8. Correlation of SS-Velocity (Elephant Point (Down Side)) (October)



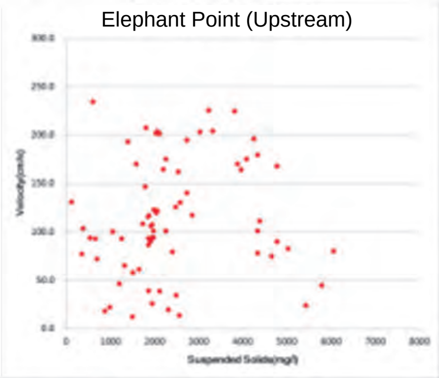
Source: The JICA Study Team

Figure 3.9.9. Correlation of SS-Velocity (10 km Offshore From Elephant Point) (October)

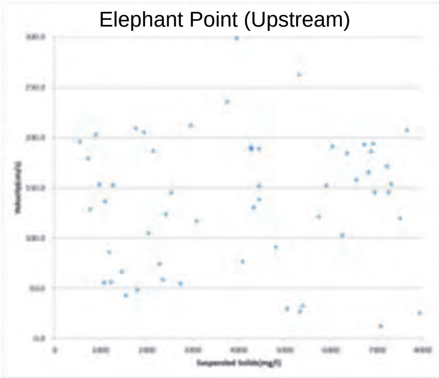


Source: The JICA Study Team

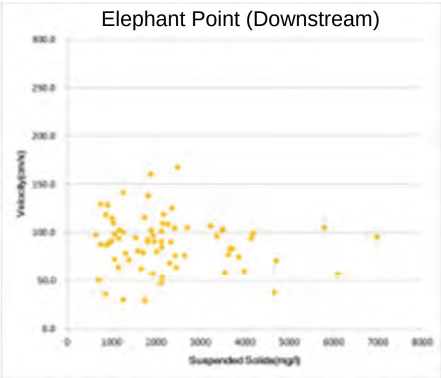
Figure 3.9.10. Correlation of SS-Velocity (18 km Offshore From Elephant Point) (October)



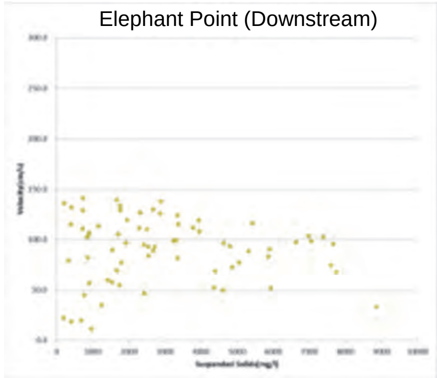
(June)



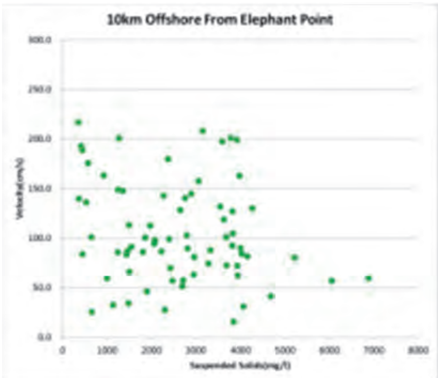
(October)



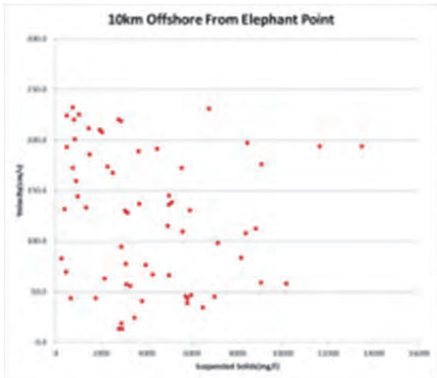
(June)



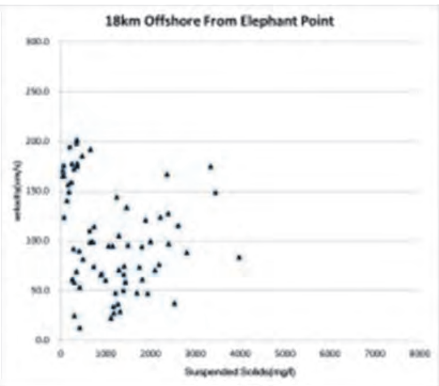
(October)



(June)



(October)



(June)

(October)

Source: The JICA Study Team

Figure 3.9.11. Correlation of SS-Velocity (Comparison of June and October)

3.10. Sediments Survey

3.10.1. Purpose of Sediments Survey

In order to identify the grain size distribution of riverbed materials that provide input conditions for the analysis of riverbed evolution, bottom-sampling surveys in the river and sea were conducted.

3.10.2. Method of Sediments Survey

For sampling of riverbed and sea floor materials, sediments at a depth of about 10 cm under the surface of the bottom materials were taken by an EKMAN = BERGE bottom sampler or equivalent bottom sampler three times or more, and blended to form a sample. Sampling dates, points (coordinate values shall be described) and methods (type of bottom sampler used, size, etc.), and the states of sediments (identification of deposit, sand, silt, etc., colour, odor, etc.), were immediately observed and measured, and recorded.

The points of sampling of riverbed and sea floor materials are shown in Figure 3.10.1.

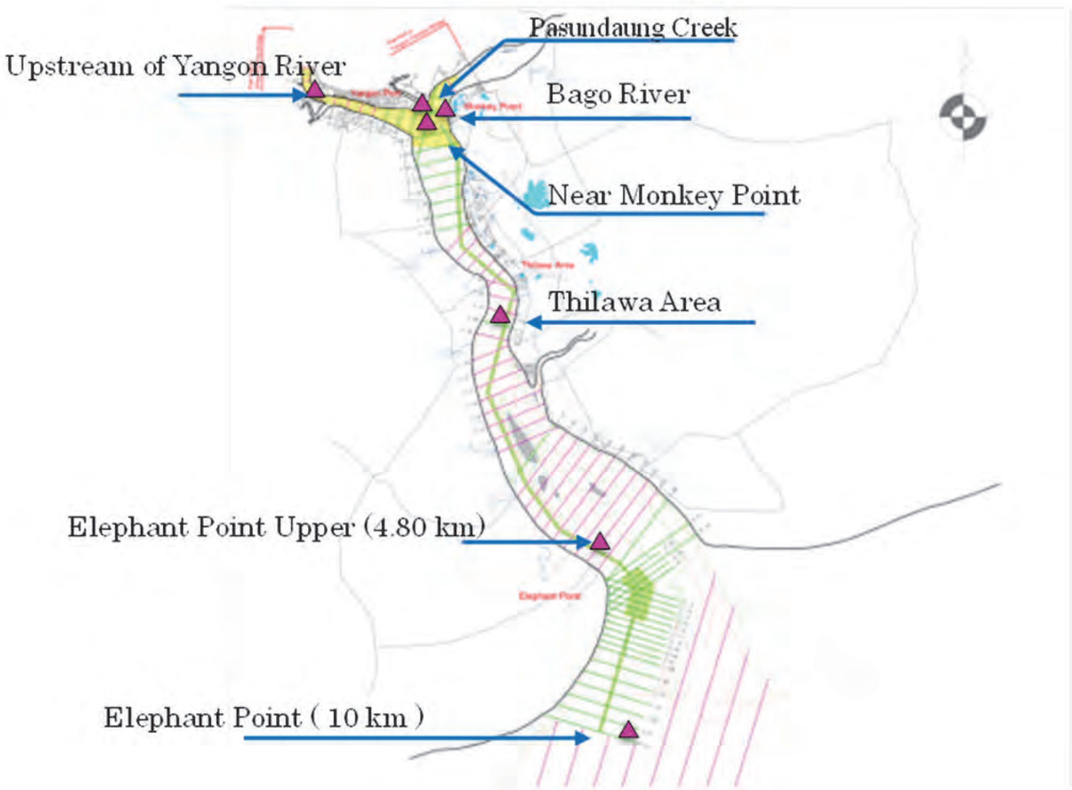


Figure 3.10.1. Points of Sampling of Riverbed and Sea Floors

Source: The JICA Study Team

Table 3.10.1. Points of Sampling of Riverbed and Sea Floor Materials, Observation Point, and Sampling Frequency

	Sampling points	Observation location	Sampling date	Sampling frequency
1	Upstream of Yangon River	1	2015/8/21	1
2	Pasundaung Creek			
3	Bago River			
4	Near Monkey Point			
5	Thilawa Area			
6	Elephant Point Upper (4.80 km)			
7	Elephant Point (10 km)			

Source: The JICA Study Team

3.10.3. Results of Sediments Survey and Discussion

A grain-size analysis of sampled materials was conducted to determine a representative grain size and gradation of each sample.

In the results, it was found that there were similar grain-size distributions of the samples upstream of the Yangon River, Monkey Point and the Thilawa Area and that most of the samples consisted of sand of 4.75 mm or less, and their representative grain size (dm60R) was about 0.3 mm. In addition, there were also similar grain-size distributions of the samples in Pasundaung Creek and the Bago River. Most of the samples consisted of silt or clay, and their representative grain size (dm60R) was about 0.02 mm (See Table 3.10.3 and Figure. 3.10.2).

In the analysis of riverbed evolution, a critical friction velocity is calculated based on the input of these representative grain sizes (see the following Table 3.10.2), from which the movement of the riverbed materials can be identified.

Table 3.10.2. Representative Grain Sizes of Riverbed and Sea Floor Materials

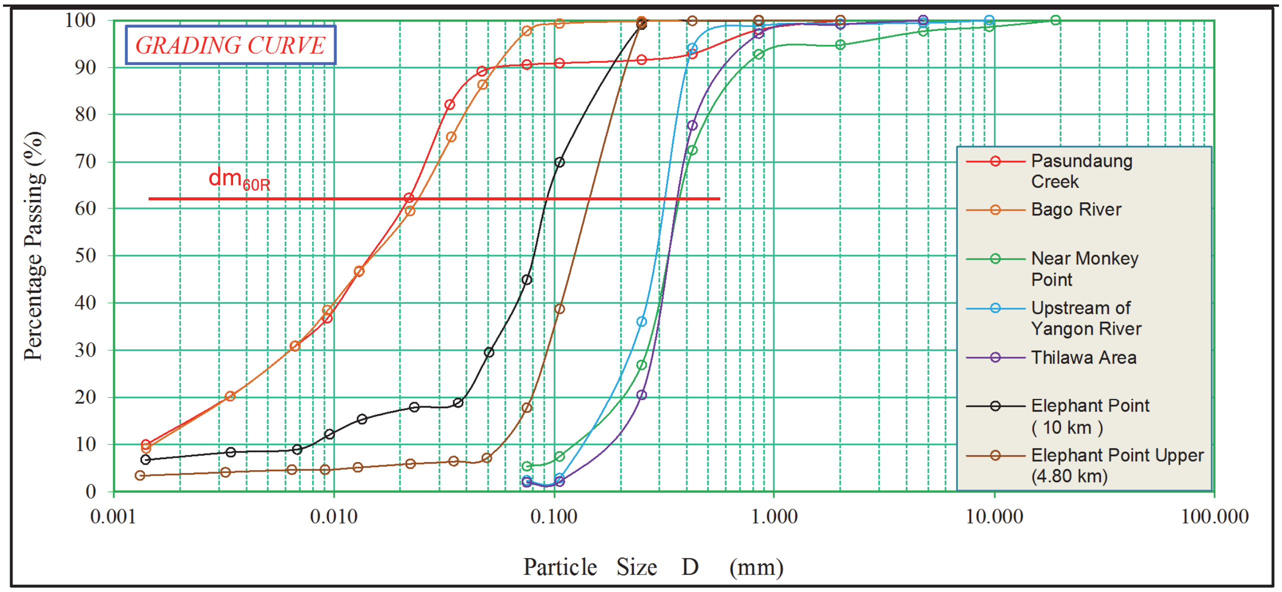
Survey points	Grain size dm(mm)
Pasundaung Creek	0.020
Bago River	0.022
Near Monkey Point	0.350
Upstream of Yangon River	0.310
Thilawa Area	0.350
Elephant Point	0.090
Elephant Point Upper	0.015

Source: The JICA Study Team

Table 3.10.3. Results of Sampling Survey of Riverbed and Sea Floor Materials

Sample No. & Depth	Pasundaung Creek	Bago River	Near Monkey Point	Upstream of Yangon River	Thilawa Area	Elephant Point (10 km)	Elephant Point Upper (4.80 km)
Gravel (75.00 ~ 4.75) mm (%)	-	-	2.31	0.55	-	-	-
Sand (4.75 ~ 0.075) mm (%)	9.38	2.28	92.42	97.17	98.10	55.10	82.32
Silt (0.075 ~ 0.005) mm (%)	64.63	71.73	5.27	2.28	1.90	36.40	13.48
Clay < 0.005 mm (%)	26.00	26.00				8.50	4.20
Maximum Particle Diameter (mm)	2.00	2.00	19.00	9.50	4.75	2.00	2.00
Coefficient of Uniformity (Cu)	-	-	2.77	2.38	1.94	-	-
Coefficient of Curvature (Cc)	-	-	1.56	1.20	1.24	-	-
Liquid Limit (WL) (%)	52.70	45.80	-	-	-	29	-
Plastic Limit (WP) (%)	24.76	23.55	-	-	-	23.93	-
Plasticity Index (IP)	27.94	22.25	-	-	-	5.07	-
Classified Soil Name (Group Name)	Fat clay	Lean clay	Poorly graded sand with silt (or) Poorly graded sand with clay (or silty clay)	Poorly graded sand	Poorly graded sand	Silty sand	Silty sand (or) Clayey sand
Classified symbol (Group Symbol)	CH	CL	SP-SM (or) SP-SC	SP	SP	SM	SM (or) SC

Source: The JICA Study Team



Source: The JICA Study Team

Figure 3.10.2. Results of Sampling Survey of Riverbed and Sea Floor Materials (Grain Size Distribution)

Chapter 4. Comments and Recommendation

4.1. How to Use the Survey Output

4.1.1. Numerical Analyses for Hydrographic Behavior and Traffic Capacity of Yangon River Channel

The objective of this survey is the preparation of data that could be utilised to analyse how much ship traffic can be accommodated by the Yangon River channel, and to examine what kind of channel improvement facilities will be effective to improve the channel capacity, under the circumstance of the river that has two bottlenecks for navigation, Monkey Point and Elephant Point. For such a purpose, the natural condition survey works covered not only bathymetric survey but also flow speed, waves, suspended solids, and material sampling and testing, etc., which could be utilised for future numerical analyses for riverbed / coastal configuration deformations. In addition, information regarding cargo statistics and the practical method of navigation in the channel was collected. The way to use the collected data is summarised in the following table.

Table 4.1.1. Relationships between Analyses and Collected Data

		Analyses		
		Coastal Sedimentation	River Bed Movement	Ships Traffic
Survey Data	Bathymetric Survey	○	○	○
	Flow Speed	○	○	○
	Soil Sampling	○	○	
	Suspended Solid	○	○	
	Wave Record	○		○
	Tidal Level	○	○	○
	Cargo Statistics			○
	Ship Size and Navigation Method			○

Source: The JICA Study Team

4.1.2. Use of Bathymetric Survey Data

(1) River / Coastal Bathymetric Survey Data

The survey data obtained by these survey works are not for the purpose of compiling an official nautical chart, it is to be utilised for numerical analyses. However, the collected data could be used as a valuable reference for pilotage and safe navigation, because similar survey data covering all channel routes are not available in recent years.

(2) Survey Data Before and After the Rainy Season

It is possible to figure out the places along the channel that suffered from the seasonal change in water depth, by comparing between the data before and after the rainy season. At present, the MPA are conducting frequent bathymetric surveys at the Elephant Point area where the water depth is always changing. According to the survey output of this study, the water depths upstream and downstream of the Thilawa area were found to be changed during the rainy season. It is recommended to survey these areas more frequently in the future.

(3) Survey Data Obtained by Means of Multibeam Sounding Device

By using a Multibeam Sounding Device, more detailed three-dimensional data were obtained at Elephant and Monkey Points by this study. From these data, very precise geographical features of the riverbed / seabed at these points are visually examined, which is effective for understanding the characteristics of the river. It is recommendeded to utilise these data as reference for the routine survey works in the channel.

4.1.3. Use of Flow Speed Data

Flow speed data was obtained mainly for the purpose of preparing the input data for riverbed deformation analysis, in which the flow rate is calculated by being multiplied by the cross-sectional area of the river flow.

From the flow speed data with 12 hours of continuous recording, the difference between the current speed between flow tide and ebb tide is known. These data will be a reference for the safe navigation of ships.

4.1.4. Use of Soil Sampling Data

From the soil sampling data, the grain size distribution curve is obtained for each sample. It is known that the bed soil particles at Pazundaung Creek and the Bago River are fine and the sample is categorised as silty / cohesive soil, which can easily be suspended in the water and move with the flow. On the other hand, the samples at the Thilawa area and Monkey Point are sandy soil, which has the tendency to accumulate on the river floor.

4.1.5. Use of Suspended Solids Data

The suspended solids (SS) data is how many soil particles are contained in the river’s turbid water. It is known that a water area with high SS is the place where bed soil is moving fluently by river flow disturbances. These data are also used for the input of riverbed deformation analysis.

4.1.6. Use of Wave Observation Records

The wave data obtained by this survey are mainly used as input data for the coastal sedimentation analysis. The recorded data shows that the characteristic of the waves offshore from Elephant Point is that they have generally long period of waves despite the fact that the wave height is not high. In general, long period waves hold higher energy to move seabed materials, thus this characteristic might influence the frequent changes in the geographical features of the seabed around Elephant Point.

4.1.7. Use of Tide Records

In the Yangon Port area, down flow and reverse flow are repeated by turns due to high tidal ebb / flow movement of maximum 6 m. Therefore, the time difference is caused between highest tide at Yangon and at Elephant Point. The tide records obtained by this survey work can be read for the difference in time of high tide and the difference in tidal height between both places. This information is valued data for safe ship navigation.

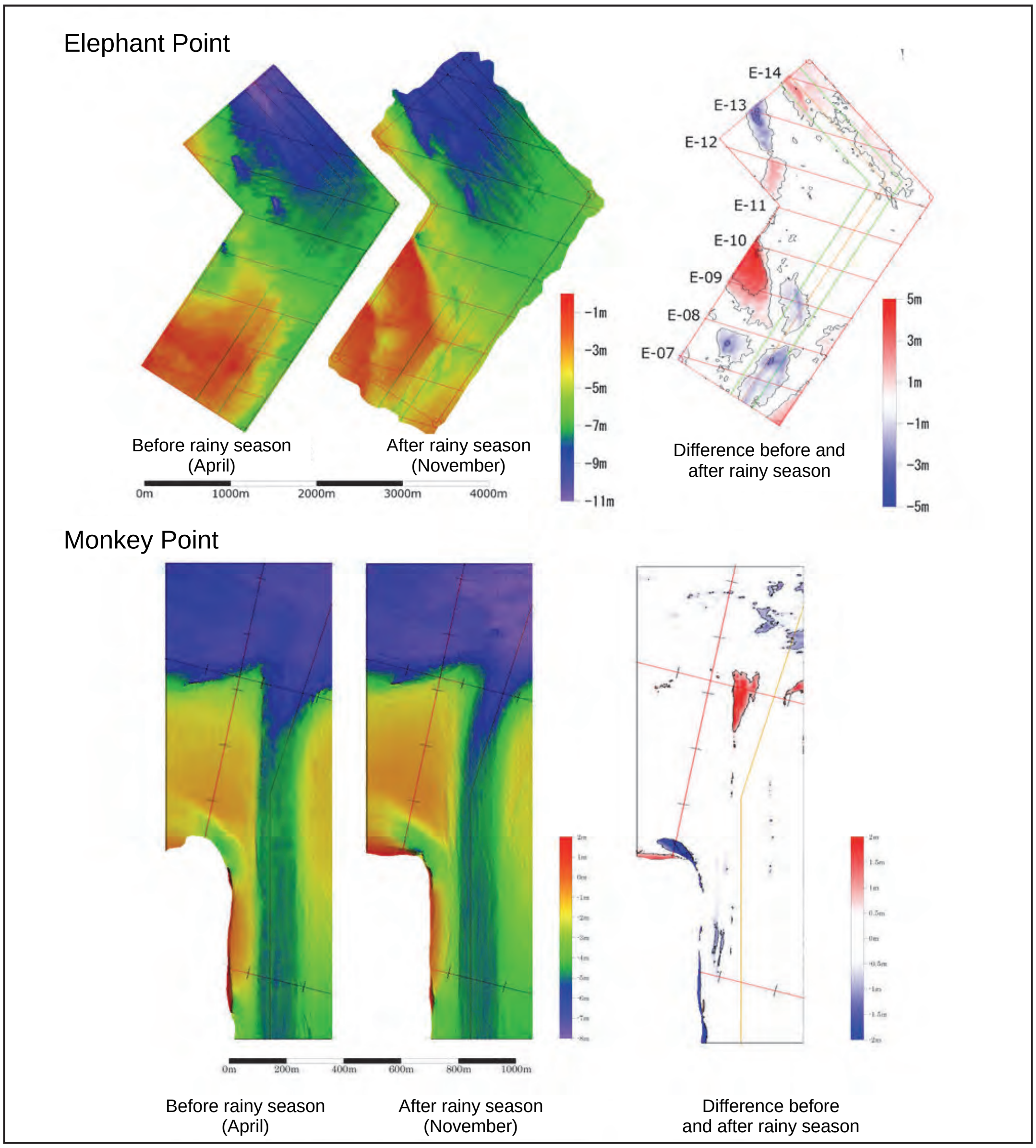
4.1.8. Use of Port Cargo Statistics and Ship Navigation Information

This information is for estimating the port channel’s traffic capacity. As an example of analysis, Appendix 1 shows a case study on the capacity limit of ship traffic for the Yangon Port channel.

4.2. Factor Analysis of Channel Depth Change based on Survey Results

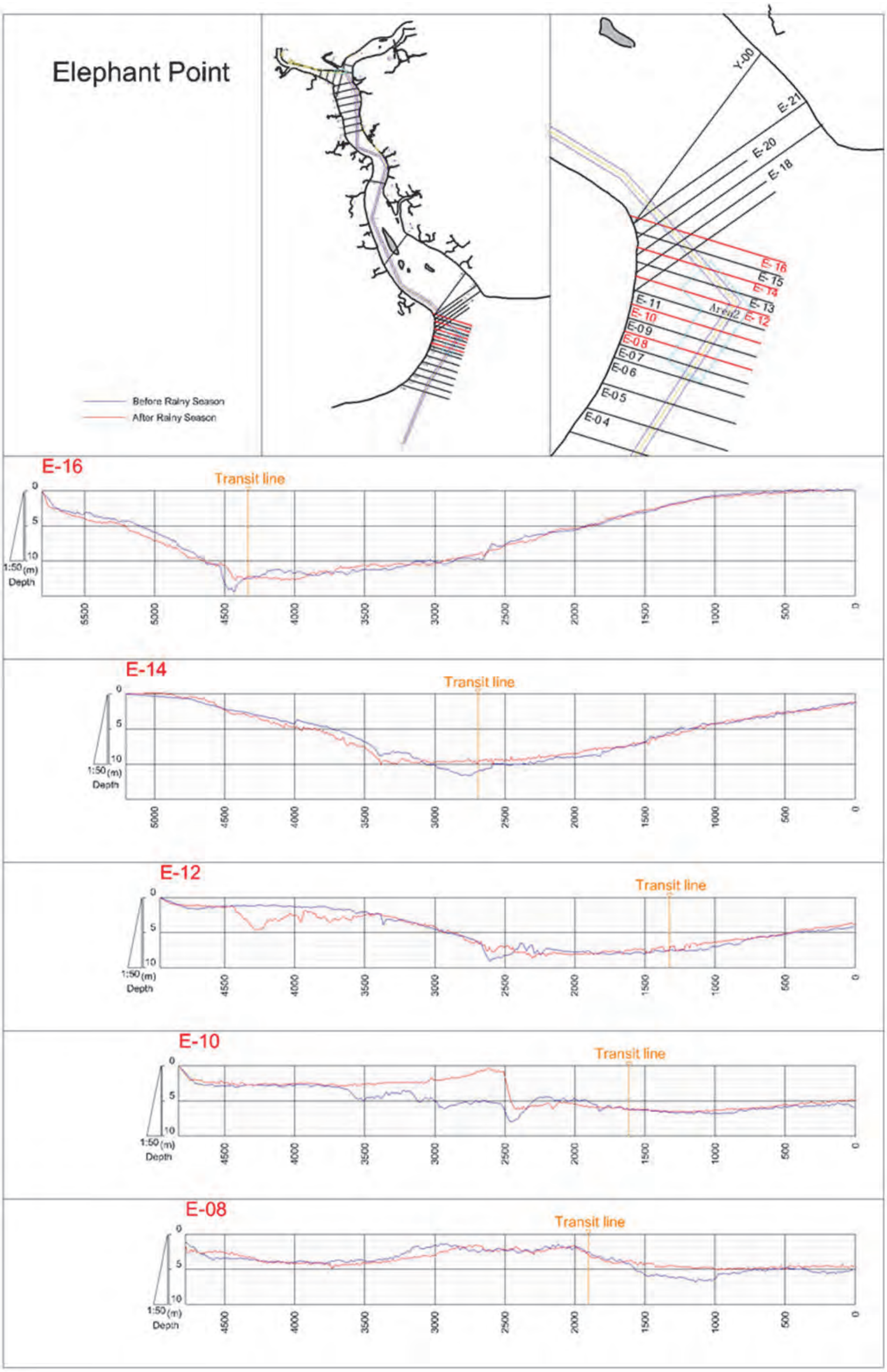
From the reconnaissance survey and the hearing survey at the MPA, it can be understood that the depth of the Yangon river channel proved to be very easy to change.

The following figure shows the multibeam survey results before and after the rainy season. The channel at Monkey Point where MPA maintenance dredging has been implemented was not changed too much. However, in the channel around Elephant Point ±5 m deposit and scour was observed.



Source: The JICA Study Team

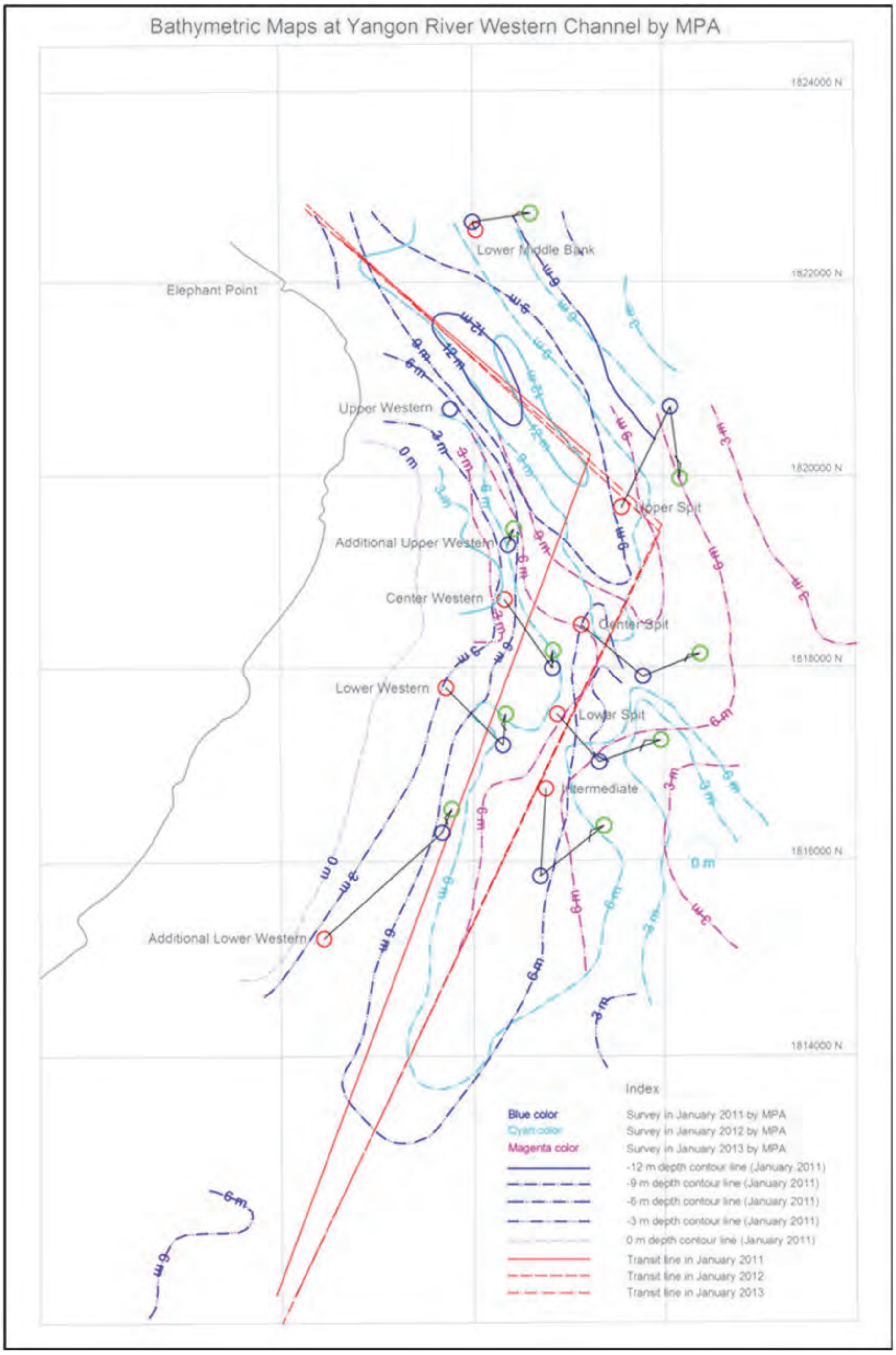
Figure 4.2.1. Change of Channel Bed Before and After Rainy Season



Source: The JICA Study Team

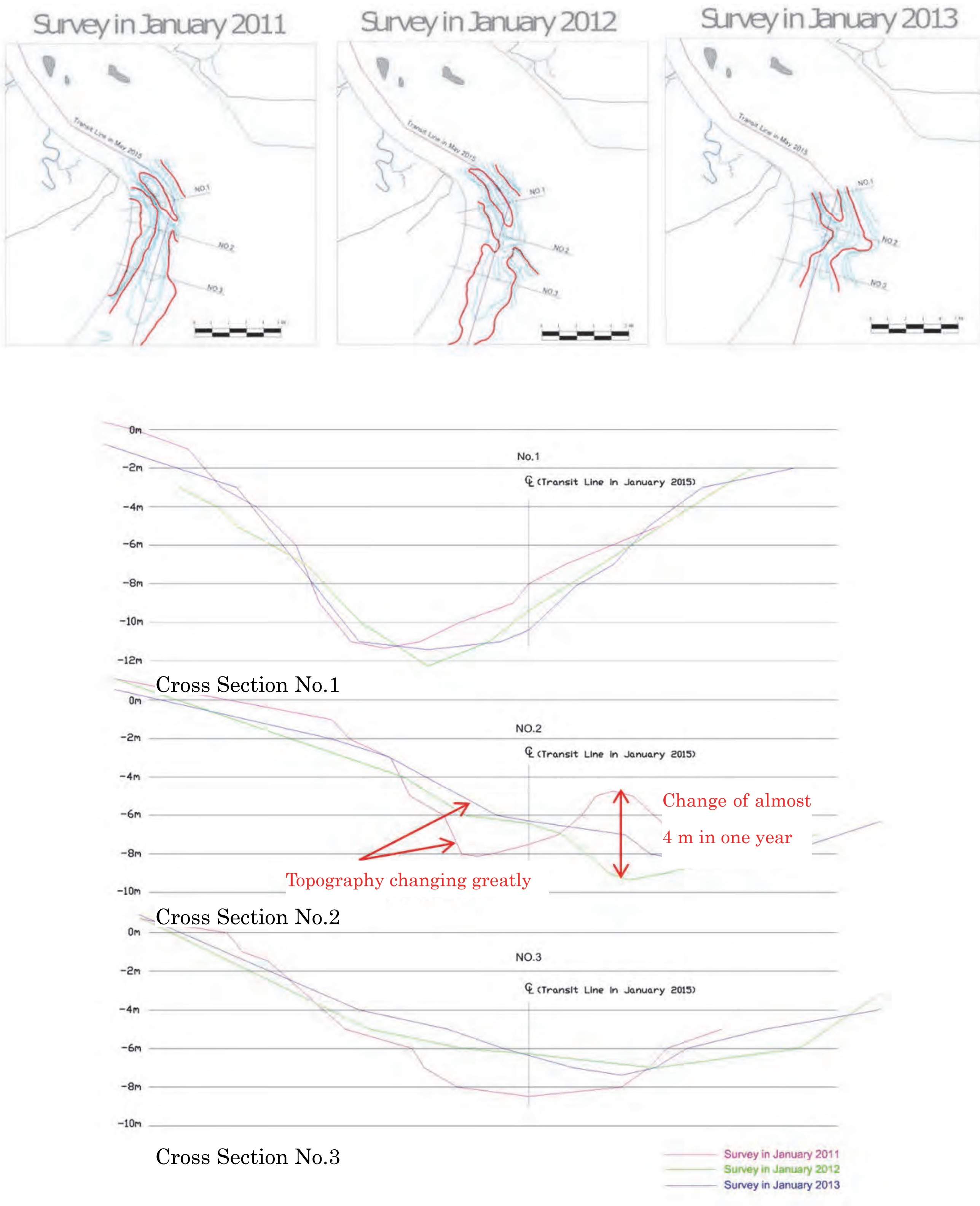
Figure 4.2.2. Change of Channel Bed Before and After Rainy Season at Elephant Point

The following figure shows the change in the navigation channel alignment during 2011 ~ 2013. At Elephant Point where the riverbed easily changes, the MPA has conducted annual monitoring and surveying, then modified the navigation channel alignment for safe navigation.



Source: The JICA Study Team

Figure 4.2.3. Change of Navigation Channel Route at Elephant Point (2011, 2012, and 2013)



Source: The JICA Study Team

Figure 4.2.4. Change of Water Depth at Elephant Point Based on MPA's Survey (2011, 2012, and 2013)

The change of water depth in the channel significantly affects the scale and traffic volume of cargo shipping. In this section, the main drivers of the topography changes in the Yangon River channel are investigated based on the results of local surveying and observation in order to estimate whether the access channel can be stabilised for a safe navigation.

4.2.1. Effect of Easily Moved Bed Materials

(1) Discussion Based on the Survey Results

The critical friction velocities of the materials are investigated based on the results of the riverbed materials survey and the current velocity measurements.

The following equation shows the relationship between representative grain sizes and critical friction velocities (Iwagaki Formula).

$dm \geq 0.303$ cm ; $U_{*c}^2 = 0.050\ dm$

$.118$ cm $\leq dm \leq 0.303$ cm ; $U_{*c}^2 = 134.6\ dm^{31/22}$

$.0565$ cm $\leq dm \leq 0.118$ cm ; $U_{*c}^2 = 55.0\ dm$

$.0565$ cm $\leq dm \leq 0.0565$ cm ; $U_{*c}^2 = 8.41\ dm^{-11/32}$

$dm \leq 0.0065$ cm ; $U_{*c}^2 = 226\ dm$

A comparison of the representative grain sizes, in dm, (D60R) obtained from the riverbed materials survey and the velocity near the riverbed (down) obtained from the flow velocity survey shows that the observed flow velocity exceeds the critical friction velocity at all surveyed locations. Consequently, it can be judged that the riverbed is in a state of easy movement. The river flows can go downstream or upstream under the effects of low tide and high tide, but the riverbed materials might be move downstream and upstream continuously.

Table 4.2.1. Representative Grain Sizes and Flow Velocities

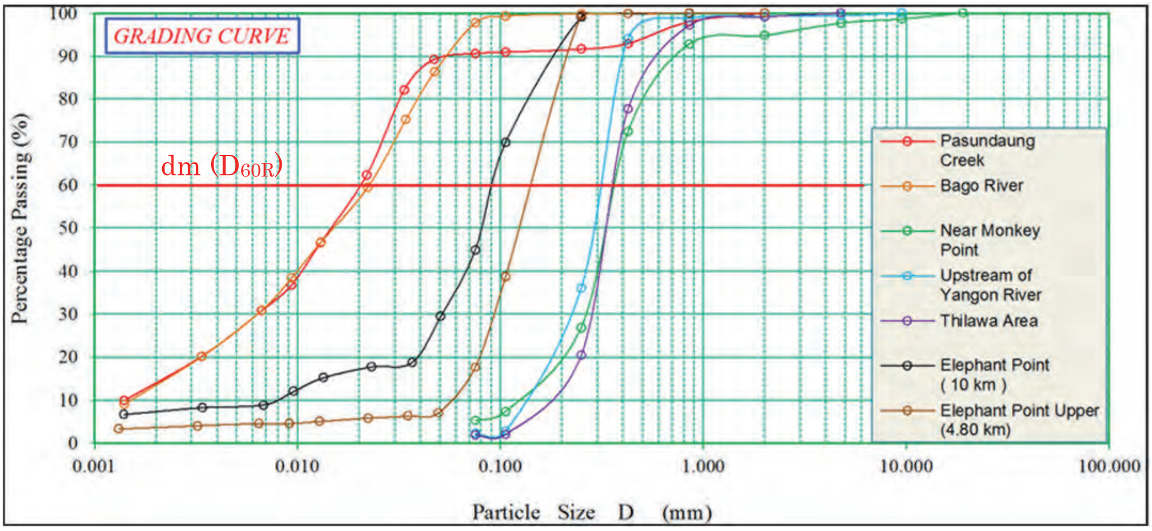
Survey points	Grain size dm(mm)	Grain size dm(cm)	Movement limit friction velocity U_{*c}(cm/s)	判定	Judgment velocity down) V(cm/s)
Pasundaung Creek	0.020	0.00020	0.213	<	87.4
Bago River	0.022	0.00022	0.223	<	128.7
Near Monkey Point	0.350	0.00350	0.889		-
Upstream of Yangon River	0.310	0.00310	0.837	<	133.9
Thilawa Area	0.350	0.00350	0.889	<	167.8
Elephant Point	0.090	0.00090	0.451	<	146.1
Elephant Point Upper	0.015	0.00015	0.184		-

Source: The JICA Study Team

Table 4.2.2. Flow Velocities Near Sampling Points of Bed Material

Locaton Name	Point	Date	Water Depth (m)	Measurement Depth (m)	Velocity (cm/s)
Upper Streem of Yangon port	Right	12 June	11.3	9.0	46.5
			11.3	2.3	100.6
	Center	12 June	14.5	11.6	106.7
			14.5	2.9	133.9
	Left	12 June	21.8	17.4	69.5
			21.8	4.4	99.5
Pauzundaung Creek	Right	11 June	4.5	3.6	45.4
			4.5	0.9	56.1
	Center	11 June	6.5	5.2	59.4
			6.5	1.3	87.4
	Left	11 June	5.7	4.6	39.2
			5.7	1.1	38.4
Bago River	Right	11 June	5.6	4.5	84.6
			5.6	1.1	128.7
	Center	11 June	4.3	3.4	58.8
			4.3	0.9	80.2
	Left	11 June	4.2	3.4	8.0
			4.2	0.9	46.9
Thilawa area	Right	12 June	16.1	12.9	53.5
			16.1	3.2	110.4
	Center	12 June	9.1	7.3	95.2
			9.1	1.8	194.3
	Left	12 June	11.1	8.9	127.1
			11.1	2.2	167.8
Elephant Point	Right	12 June	15.6	12.5	57.1
			15.6	3.1	146.1
	Center	12 June	4.1	3.3	78.4
			4.1	0.8	105.0
	Left	18 June	3.5	3.0	55.4
			3.5	0.8	72.0

Source: The JICA Study Team



Source: The JICA Study Team

Figure 4.2.5. Grain Size Distribution Curve and Representative Grain Size at Different Observation Points

(2) Discussions Based on Reconnaissance Survey

The stages of downstream sediment flow can be roughly classified into wash load, suspended load, and bed load. Among these stages the wash and suspended loads correspond to very fine particles such as clay or silt. Once they are stirred up, they will be floating in the channel. This fact was confirmed during the reconnaissance survey of the Yangon River.

Source: The JICA Study Team

Figure 4.2.6. Stirred-Up Fine Particles

According to the Design Manual for Coastal Facilities 2000, the movement of the riverbed that consists of very fine particulates such as clay and silt is shown to be different from the mechanism of movement of sand particulates. The shear stress of the sand particles is determined only from their internal friction. However, in the case of fine particulates such as clay and silt, it is impossible to ignore their internal viscosity. In the results, the very fine particulates transported to the mouth of the river are deemed to form a floc under the action of positive ions contained in seawater and exhibit a different deposit property.

The phenomenon in which the position of the channel is changing continuously can be explained by the following reason. Fine clay and silt are transported by waves, accumulate in the riverbed, and form a sludge layer. Then this layer repeatedly moving under external force leads to the easy change of the channel.

4.2.2. Effect of River Sand Dredging

With a rapid increase of construction demand in Myanmar, concrete used for infrastructure or house construction and other construction works has increased. Fine aggregates for concrete are collected from the riverbed of the Yangon River. Many private small pump dredgers have been collecting river sand in the area near Monkey Point and Thilawa, then transporting it to nearby concrete factories.

Concrete Refinery

Standby Small Pump Dredgers

Screw Pump Mounted on Small Pump Dredger

Source: The JICA Study Team

Figure 4.2.7. River Sand Collection by Industry

Source: Google Earth, The JICA Study Team

Figure 4.2.8. Private Small Pump Dredgers Collecting Sand (Photography at Low Tide on 4/24/2015 Near Thilawa Area)

These small pump dredgers started to collect sand in low tide when the water level decreases. It seems that large amounts of sand have been dredged. The channel depth is likely significantly affected by sand dredging. Therefore, an interview with the concrete refiner (Mega Mix) and a satellite photo analysis were conducted to estimate the amount of collected sand.

(1) Estimation of Sand Dredging Volume Based on Interview with Concrete Refinery

In the most active zone in the suburb of Yangon (Ayeyar Wun Housing Project: joint development of the Ministry of Housing and several private companies), there are about 10 concrete factories.

Source: Google Earth, The JICA Study Team

Figure 4.2.9. Mega Mix Co. and Location of Estate Development

Two years ago the number of concrete plants along the Yangon River and Bago River was about 30, but it has increased to about 70 now, and is expected to reach 100 in a few years. Most of the plants are moveable style and most of the new entrants often relocate their plants according to development demands.

Source: The JICA Study Team

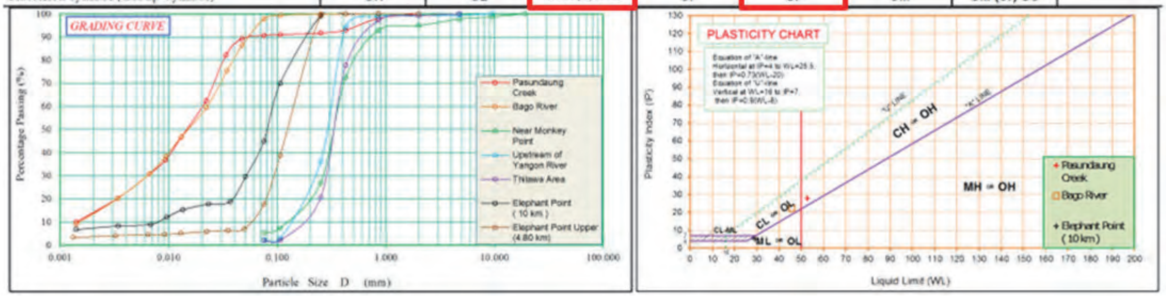
Figure 4.2.10. Concrete Plant at the Place for Estate Development

Sand used for fine aggregate is collected in the Thilawa Area and around Monkey Point. Sand from Thilawa has low content of silt or clay and is said to be excellent for fine aggregate. The riverbed material survey also shows the same conclusion.

SOIL CLASSIFICATION

Project Name: Yangon River Survey Project — Sheet No. 1 of 1 — Date: 21.08.15
Location: — Soil Classification System: Unified Soil Classification System of ASTM D 2487 - 06 — Classified by: P P
Borehole No. — Check by: P P

Sample No. & Depth	Pasundaung Creek	Bago River	Near Monkey Point	Upstream of Yangon River	Thilawa Area	Elephant Point (10 km)	Elephant Point Upper (4.80 km)	
Gravel (75.00 ~ 4.75) mm (%)	-	-	2.31	0.55	-	-	-	
Sand (4.75 ~ 0.075) mm (%)	9.38	2.28	92.42	97.17	98.10	55.10	82.32	
Silt (0.075 ~ 0.005) mm (%)	64.63	71.73	5.27	2.28	1.90	36.40	13.48	
Clay < 0.005 mm (%)	26.00	26.00				8.50	4.20	
Maximum Particle Diameter (mm)	2.00	2.00	19.00	9.50	4.75	2.00	2.00	
Coefficient of Uniformity (Cu)	-	-	2.77	2.38	1.94	-	-	
Coefficient of Curvature (Cc)	-	-	1.56	1.20	1.24	-	-	
Liquid Limit (WL) (%)	52.70	45.80	-	-	-	29	-	
Plastic Limit (WP) (%)	24.76	23.55	-	-	-	23.93	-	
Plasticity Index (IP)	27.94	22.25	-	-	-	5.07	-	
Classified Soil Name (Group Name)	Fat clay	Lean clay	Poorly graded sand with silt (or) Poorly graded sand with clay (or silty clay)	Poorly graded sand	Poorly graded sand	Silty sand	Silty sand (or) Clayey sand	
Classified symbol (Group Symbol)	CH	CL	SP-SM (or) SP-SC	SP	SP	SM	SM (or) SC	



Source: The JICA Study Team

Figure 4.2.11. Results of Survey of Riverbed Materials (collected on 08/21/2015)

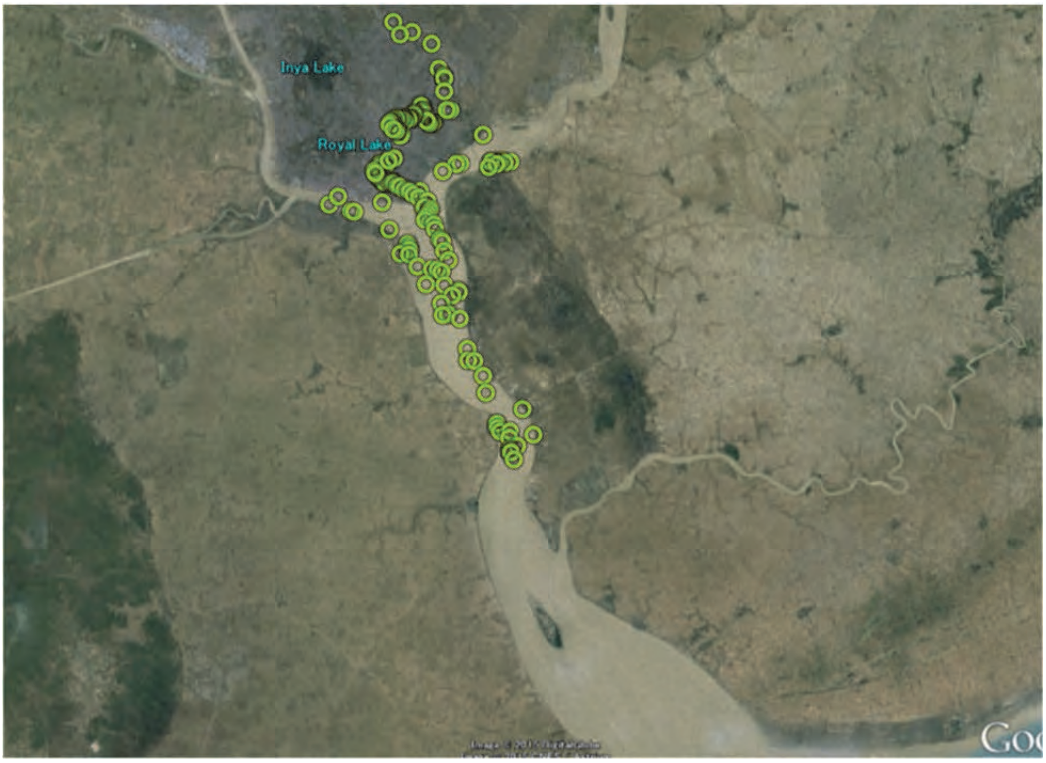
Almost all of the concrete mixers in Yangon City are mobile type and they can produce a daily average of 100 m^3. Assuming that the number of operating days is 300 days/year, it can be estimated that the annual collected sand volume from the Yangon River is about 1.3 million m^3.

Annual sand consumption

$$= 1\ m^3 / 1.6\ kg/m^3 \times 100\ m^3 \times 300\ \text{days (operating days)} \times 70\ \text{plants} = 1.3\ \text{million}\ m^3$$

(2) Estimated Collected Sand Volume Based on Satellite Image Analysis

The circle mark in the following satellite photo (taken on April 29, 2015) indicates the small pump dredgers. It can also be seen from the satellite photo that these small pump dredgers intensively collect sand from Thilawa to the upstream area.



Source: Google Earth, JICA Study Team

Figure 4.2.12. Sand Collection Locations of Small Pump Dredgers (April 29, 2015)

From sailing directions and anchorage directions of the pump dredgers, the operation of sand dredgers can be assumed as follows:

1) The small pump dredgers in Pasundaung Creek navigate upstream and downstream, and are more likely to collect sand around Monkey Point or the Thilawa Area, then transport collected sand to the concrete refiners located along Pasundaung Creek. (Clayey sand in Pasundaung Creek is not collected)
2) The directions of the small pump dredgers in the lower reaches of the Bago River or Monkey Point are dispersed. Consequently, the dredgers are more likely to come to an anchor or operate. At the Bago River, downstream of Monkey Point, and at the Thilawa District the orientation of the small pump boats was sparse, and likely to be anchored or running.
3) Most of the small pump dredgers at the Thilawa Area navigate in the transverse direction of the river. Consequently, most of the collected sand is likely to be used for the development of the Thilawa Area.

The following table shows the number of small pump dredgers assumed to collect sand at Monkey Point and the Thilawa Area, interpreted from the satellite photos.

The small dredgers seem to start collecting sand at low tide and about 200 m^3/boat is collected (as per the interview survey). The five days' worth of data were interpreted. The results show that the average number of boats is about 50 boats a day. Given there are 300 operating days per year, it can be estimated that 3 million m^3 of sand is collected annually.

Annual sand dredging volume = 200 m^3/boat × 50 boats × 300 days (operating days) = 3 million m^3

Table 4.2.3. Number of Sand Dredging Boats by Satellite Image

date	The number of sand up ship		
	Monkey Point	Thilawa	Total
7.1.2015	56	55	111
9.3.2015	12	16	28
10.4.2015	9	13	22
29.4.2015	38	15	53
18.7.12015	57	15	72
average			57

Source: The JICA Study Team

4.2.3. Effect of Riverbank Erosion

The following map illustrates the shoreline of the Yangon River in 2015 as extracted from a satellite image and overlaid on the 1904 topographical map. The riverbank shoreline has clearly retreated. As discussed in "Annex Volume: The initial examination of the trend of annual change of the riverbank in Yangon river" (hereafter called the "Annex Volume"), the shorelines on both banks have retreated since 1930, and in particular, the shoreline on the right bank has retreated significantly.

In the Annex Volume, the volume of annual removed sand due to riverbank collapse was calculated. The amount was determined based on the height that was estimated from the pictures taken during on-site investigation. Consequently, it was roughly estimated that in the area from Monkey Point to the river mouth about 1.8 million m^3 of sand along the right bank and 600,000 m^3 of sand along the left bank (about 1/3 the amount of the right bank) have been removed. The sand that flowed into the channel due to riverbank collapse is assumed to affect the change in the water depth of the Yangon River channel.

Source: JICA Study Team

Figure 4.2.13. Erosion of Riverbank

4.2.4. Effect of Sediment Discharge

As reported in “4.2.1 Effect of Movement of Bed Materials”, wash loads or suspended solids (SS) are stirred up in the Yangon River. As for accurate estimation of sediment discharge, it is desirable to conduct a survey of suspended solids (SS) occurring during flooding in the section where suspended solids (SS) do not move upstream and downstream, i.e. are not affected by tide levels.

The observation points of this study are located at positions where movement of suspended solids (SS) is affected by the tide level. Therefore, it is difficult to estimate sediment discharge. For this reason, only the difference in sediment discharge between the dry season and the rainy season was determined based on the suspended solid (SS) weight concentration.

The average weight concentration reached 2,500 mg/L (0.0025 t/m^3) during the dry season (observed in June), and doubled during the rainy season (5,300 mg/L(0.0053 t/m^3); observed in October). The reason may be the increase of suspended solid (SS) concentration due to the increase of flow velocity and water level or the increase of sediment discharge in the rainy season.

As described in Section 3.8, “Flow Velocity of River Channel”, in this study the water depth measured in October (rainy season) was lower than in June (dry season) and the water discharge was also small. Nevertheless, the average weight concentration in October is higher. Two reasons were considered. The first is that sediment still goes down stream in the later wet season. The second is that the suspended solids (SS) stirred up during the rainy season do not settle down and reveal high weight concentration.

According to the collected report of the United Nations Development Program in 1976 (hereafter UN report) [*1] the annual sediment discharge of the Yangon River was about 100 million m^3. As estimated in the Annex Volume, the deforestation in the catchment area of the Yangon River led to the increasing of water discharge year by year. The increasing of river discharge is considered to promote sediment discharge. Consequently, the development of estate or agriculture in the catchment area would lead to an increase of sediment discharge for the Yangon River.

*1: United Nations Development Program edition, Rangoon Sea Access Channel and Associated Port Improvement Study, March 1976

Table 4.2.4. Results of Suspended Solids Survey at Elephant Point (Upper Side) (June: Dry Season)

Date	Water Depth(m)	Measurement Time		Sample No	Measurement Depth(m)	PH	EC	Suspended Solids (mg/L)
		Start	Finish					
18.6.2015		5:00:00	5:04:25	D1	1.00	7.75	>20.0	1868
18.6.2015	13.00	5:03:13	5:07:03	D2	6.50	7.77	>20.0	2112
18.6.2015		5:05:25	5:08:05	D3	12.00	7.80	>20.0	2316
18.6.2015		6:00:00	6:04:25	D4	1.00	7.81	>20.0	988
18.6.2015	12.60	6:01:50	6:05:40	D5	6.30	7.75	>20.0	1206
18.6.2015		6:02:52	6:05:32	D6	10.60	7.77	>20.0	1324
18.6.2015		7:00:00	7:03:30	D7	1.00	7.76	>20.0	1050
18.6.2015	12.10	7:04:00	7:07:45	D8	6.05	7.70	>20.0	1258
18.6.2015		7:07:00	7:10:55	D9	10.10	7.76	>20.0	1944
18.6.2015		8:00:00	8:04:20	D10	1.00	7.76	>20.0	2044
18.6.2015	10.70	8:03:00	8:05:40	D11	5.35	7.75	>20.0	1976
18.6.2015		8:05:00	8:08:30	D12	8.70	7.76	>20.0	1924
18.6.2015		9:00:00	9:04:50	D13	1.00	7.76	>20.0	1944
18.6.2015	9.70	9:02:00	9:05:55	D14	4.85	7.76	>20.0	1972
18.6.2015		9:02:50	9:07:25	D15	7.70	7.72	>20.0	1864
18.6.2015		10:00:00	10:03:30	D16	1.00	7.72	>20.0	4250
18.6.2015	9.00	10:01:30	10:05:15	D17	4.50	7.70	>20.0	4080
18.6.2015		10:03:40	10:08:09	D18	7.00	7.70	>20.0	3960
18.6.2015		11:00:00	11:04:25	D19	1.00	7.72	>20.0	3880
18.6.2015	8.40	11:01:30	11:05:20	D20	4.20	7.70	>20.0	4340
18.6.2015		11:03:00	11:05:40	D21	6.40	7.71	>20.0	4770
18.6.2015		12:00:00	12:04:25	D22	1.00	7.64	>20.0	5030
18.6.2015	8.20	12:02:40	12:06:30	D23	4.10	7.63	>20.0	5790
18.6.2015		12:04:10	12:06:50	D24	6.20	7.62	>20.0	5430
19.6.2015		1:00:00	1:03:30	D25	1.00	7.64	14.41	4340
19.6.2015	9.20	1:02:50	1:06:35	D26	4.60	7.71	14.95	6050
19.6.2015		1:04:00	1:07:55	D27	7.20	7.63	15.51	4770
19.6.2015		2:00:00	2:04:20	D28	1.00	7.69	>20.0	2532
19.6.2015	10.90	2:01:46	2:04:26	D29	5.45	7.70	>20.0	4340
19.6.2015		2:03:18	2:06:48	D30	8.90	7.69	>20.0	4380
19.6.2015		3:00:00	3:04:50	D31	1.00	7.76	>20.0	2056
19.6.2015	11.30	3:01:32	3:05:27	D32	5.65	7.77	>20.0	3230
19.6.2015		3:03:20	3:07:55	D33	9.30	7.77	>20.0	3810
19.6.2015		4:00:00	4:03:30	D34	1.00	7.76	>20.0	2032
19.6.2015	11.70	4:02:27	4:06:12	D35	5.85	7.78	>20.0	3320
19.6.2015		4:03:50	4:08:19	D36	9.70	7.76	>20.0	1984
19.6.2015		5:00:00	5:04:25	D37	1.00	7.79	>20.0	1860
19.6.2015	12.40	5:02:13	5:06:03	D38	6.20	7.76	>20.0	2404
19.6.2015		5:03:34	5:06:14	D39	10.40	7.76	>20.0	1648
19.6.2015		6:00:00	6:04:25	D40	1.00	7.78	>20.0	872
19.6.2015	12.30	6:02:00	6:05:50	D41	6.15	7.77	>20.0	1496
19.6.2015		6:03:12	6:05:52	D42	10.30	7.78	>20.0	1952
19.6.2015		7:00:00	7:03:30	D43	1.00	7.79	>20.0	698
19.6.2015	11.40	7:02:57	7:06:42	D44	5.70	7.80	>20.0	353
19.6.2015		7:05:50	7:09:45	D45	9.40	7.78	>20.0	658
19.6.2015		8:00:00	8:04:20	D46	1.00	7.72	>20.0	120
19.6.2015	10.50	8:04:00	8:06:40	D47	5.25	7.77	>20.0	383
19.6.2015		8:05:05	8:08:35	D48	8.50	7.74	>20.0	540
19.6.2015		9:00:00	9:04:50	D49	1.00	7.72	>20.0	1732
19.6.2015	9.60	9:05:24	9:09:19	D50	4.80	7.74	>20.0	1856
19.6.2015		9:08:00	9:12:35	D51	7.60	7.75	>20.0	1876
19.6.2015		10:00:00	10:03:30	D52	1.00	7.71	>20.0	1792
19.6.2015	8.80	10:04:40	10:08:25	D53	4.40	7.74	>20.0	2484
19.6.2015		10:06:10	10:10:39	D54	6.80	7.70	>20.0	2850
19.6.2015		11:00:00	11:04:25	D55	1.00	7.71	>20.0	2064
19.6.2015	8.20	11:05:00	11:08:50	D56	4.10	7.72	>20.0	2252
19.6.2015		11:07:14	11:09:54	D57	6.20	7.71	>20.0	4650
19.6.2015		12:00:00	12:04:25	D58	1.00	7.70	>20.0	1512
19.6.2015	9.70	12:03:10	12:07:00	D59	4.85	7.70	>20.0	2560
19.6.2015		12:05:30	12:08:10	D60	7.70	7.67	>20.0	2488
19.6.2015		1:00:00	1:03:30	D61	1.00	7.66	16.50	1912
19.6.2015	9.30	1:01:20	1:05:05	D62	4.65	7.68	16.97	2728
19.6.2015		1:03:00	1:06:55	D63	7.30	7.71	17.55	2580
19.6.2015		2:00:00	2:04:20	D64	1.00	7.75	>20.0	1396
19.6.2015	10.10	2:02:09	2:04:49	D65	5.05	7.75	>20.0	2120
19.6.2015		2:04:01	2:07:31	D66	8.10	7.74	>20.0	2728
19.6.2015		3:00:00	3:04:50	D67	1.00	7.75	>20.0	608
19.6.2015	10.90	3:01:47	3:05:42	D68	5.45	7.77	>20.0	1804
19.6.2015		3:04:39	3:09:14	D69	8.90	7.75	>20.0	1580
19.6.2015		4:00:00	4:03:30	D70	1.00	7.78	>20.0	3030
19.6.2015	11.70	4:02:15	4:06:00	D71	5.85	7.76	>20.0	2260
19.6.2015		4:03:38	4:08:07	D72	9.70	7.76	>20.0	2196
Average	10.49							2447

Source: JICA Study Team

Table 4.2.5. Results of Suspended Solids Survey at Elephant Point (Upper Side) (October: Rainy Season)

Date	Water Depth (m)	Measurement Time		Sample No	Measurement Depth (m)	PH	EC	Suspended Solids (mg/L)
		Start	Finish					
30.10.2015		13:03:30	13:08:00	A1	1.00	7.59	1.24	1188
30.10.2015	7.30	13:09:00	13:14:00	A2	3.65	7.37	1.15	1550
30.10.2015		13:15:30	13:20:30	A3	6.30	7.30	1.08	2040
30.10.2015		14:01:30	14:06:00	B1	1.00	7.64	8.51	6550
30.10.2015	8.60	14:07:00	14:12:00	B2	4.30	7.64	8.36	7220
30.10.2015		14:13:30	14:18:30	B3	7.60	7.65	8.16	7310
30.10.2015		15:05:30	15:10:30	C1	1.00	7.65	8.64	9400
30.10.2015	9.70	15:12:00	15:17:00	C2	4.85	7.52	8.59	11330
30.10.2015		15:18:30	15:23:30	C3	8.70	7.67	8.5	10790
30.10.2015		16:01:00	16:06:00	D1	1.00	7.60	8.91	6950
30.10.2015	10.80	16:07:00	16:12:00	D2	5.40	7.69	8.78	6730
30.10.2015		16:14:00	16:19:00	D3	9.80	7.70	8.57	8870
30.10.2015		17:01:00	17:06:00	E1	1.00	7.68	8.48	6250
30.10.2015	11.80	17:07:00	17:12:00	E2	5.90	7.69	7.97	9160
30.10.2015		17:14:00	17:19:00	E3	10.80	7.68	8.24	7920
30.10.2015		18:01:10	18:06:00	F1	1.00	7.68	8.7	1792
30.10.2015	11.60	18:07:00	18:12:00	F2	5.80	7.69	8.36	7080
30.10.2015		18:13:30	18:18:30	F3	10.60	7.74	8.37	8470
30.10.2015		19:02:30	19:07:30	G1	1.00	7.71	8.71	1078
30.10.2015	11.00	19:08:00	19:13:00	G2	5.50	7.78	8.64	2280
30.10.2015		19:14:30	19:19:30	G3	10.00	7.74	8.63	4320
30.10.2015		20:02:00	20:07:00	H1	1.00	7.72	8.08	1096
30.10.2015	9.80	20:08:00	20:13:00	H2	4.90	7.70	7.94	2536
30.10.2015		20:15:00	20:20:00	H3	8.80	7.71	8.25	4440
30.10.2015		21:01:00	21:06:00	I1	1.00	7.78	8.1	552
30.10.2015	8.60	21:07:00	21:12:00	I2	4.30	7.76	8.13	908
30.10.2015		21:14:00	21:19:00	I3	7.60	7.76	8.23	6820
30.10.2015		22:05:30	22:10:30	J1	1.00	7.72	5.76	4270
30.10.2015	7.50	22:12:00	22:17:00	J2	3.75	4.97	6.74	9290
30.10.2015		22:18:00	22:23:00	J3	6.50	7.63	6.56	8310
30.10.2015		23:00:00	23:05:00	K1	1.00	7.62	4.5	7640
30.10.2015	6.80	23:07:00	23:12:00	K2	3.40	7.65	4.86	9070
31.10.2015		23:13:00	23:18:00	K3	5.80	7.66	4.97	9220
31.10.2015		0:00:00	0:05:00	L1	1.00	7.68	1.34	3740
31.10.2015	6.30	0:07:00	0:12:00	L2	3.15	7.52	1.07	3960
31.10.2015		0:13:00	0:18:00	L3	5.30	7.54	1.07	5310
31.10.2015		1:11:00	1:16:00	M1	1.00	7.56	1.46	1460
31.10.2015	7.80	1:17:00	1:22:00	M2	3.90	7.57	1.98	2344
31.10.2015		1:23:00	1:27:30	M3	6.80	7.57	2.49	3076
31.10.2015		2:02:00	2:06:00	N1	1.00	7.62	8.48	10440
31.10.2015	8.90	2:07:00	2:10:00	N2	4.45	7.67	8.21	10470
31.10.2015		2:13:00	2:18:00	N3	7.90	7.66	8.24	9720
31.10.2015		3:01:00	3:06:00	O1	1.00	7.67	9.19	5740
31.10.2015	10.10	3:07:00	3:12:00	O2	5.05	7.67	8.79	7510
31.10.2015		3:13:00	3:18:00	O3	9.10	7.63	8.97	7250
31.10.2015		4:01:00	4:06:00	P1	1.00	7.66	8.81	5910
31.10.2015	11.30	4:11:00	4:16:00	P2	5.65	7.69	8.65	6030
31.10.2015		4:18:00	4:23:00	P3	10.50	7.66	8.65	9120
31.10.2015		5:01:30	5:05:30	Q1	1.00	7.70	8.91	4450
31.10.2015	11.70	5:07:00	5:11:00	Q2	5.35	7.67	8.89	4800
31.10.2015		5:12:00	5:16:00	Q3	10.70	7.68	8.87	5050
31.10.2015		6:02:00	6:07:00	R1	1.00	7.68	8.89	2730
31.10.2015	11.90	6:08:00	6:13:00	R2	5.95	7.67	8.93	5390
31.10.2015		6:14:00	6:19:00	R3	10.90	7.70	8.98	5320
31.10.2015		7:04:00	7:09:00	S1	1.00	7.71	8.65	1220
31.10.2015	11.50	7:10:00	7:15:00	S2	5.75	7.74	8.71	4080
31.10.2015		7:18:00	7:23:00	S3	10.50	7.73	8.74	2420
31.10.2015		8:01:30	8:06:30	T1	1.00	7.70	8.64	774
31.10.2015	10.60	8:07:00	8:12:00	T2	5.30	7.69	8.65	972
31.10.2015		8:13:00	8:18:00	T3	9.60	7.72	8.53	1268
31.10.2015		9:01:30	9:06:30	U1	1.00	7.70	8.14	724
31.10.2015	9.20	9:07:00	9:12:00	U2	4.60	7.71	8.18	2136
31.10.2015		9:15:00	9:20:00	U3	8.20	7.73	8.21	6340
31.10.2015		10:01:30	10:06:30	V1	1.00	7.64	6.76	1764
31.10.2015	8.00	10:07:00	10:12:00	V2	4.00	7.76	5.95	1940
31.10.2015		10:14:00	10:19:00	V3	7.00	7.69	8.88	6870
31.10.2015		11:01:30	11:06:30	W1	1.00	7.69	5.35	6920
31.10.2015	7.00	11:07:00	11:12:00	W2	3.50	7.68	5.68	8840
31.10.2015		11:14:00	11:19:00	W3	6.00	7.66	5.64	9450
31.10.2015		12:01:00	12:06:00	X1	1.00	7.66	2.28	4270
31.10.2015	6.40	12:07:00	12:12:00	X2	3.20	7.59	2.08	4440
31.10.2015		12:14:00	12:19:00	X3	5.40	7.63	2.04	2964
average	9.27							5273

Source: JICA Study Team

4.3. Comments on the Change of Channel Depth Due to Shore Deformation

As discussed in the previous chapter, it was found that the depth of the access channel near the river mouth fluctuated largely, according to the survey results and hearing interview with the MPA. The following discussion is to seek the main element of the change in channel depth due to shore deformation based on the brief analyses of the influence of waves recorded by the survey.

4.3.1. Influence of Waves

(1) Wave Observation

The overall wave height in the observation period (from 5:00, October 17, 2015 to 12:00, January 22, 2016) is very small, and any remarkably large wave heights caused by weather disturbances such as cyclones did not occur. The following Table 4.3.1 shows the highest five wave heights during the observation period. According to this table, the maximum height becomes $H_{1/3}$ = 0.61 m, $H_{1/10}$ = 0.76 m, and H_{max} = 1.06 m and it is regarded as very calm. Also, when the average figures of the whole data is calculated, $H_{1/3}$ = 0.16 m, $H_{1/10}$ = 0.20 m, and H_{max} = 0.28 m were resulted, and still the wave condition was very calm.

The wave observation period in this Study was in dry season only and the data in rainy season which would have high waves was not collected therefore JICA Study Team procured the data of wave forecasting and hindcasting to verify the collected data.

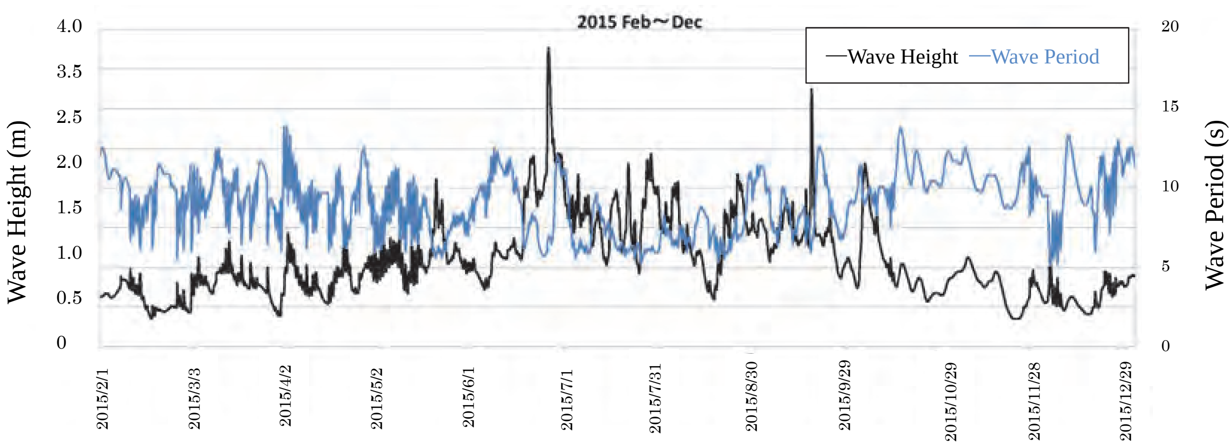
Table 4.3.1. The Highest Five Wave Heights during the Observation Period
2015/10/17 5:00 - 2016/1/22 12:00

Rank	The time	$H_{1/3}$(m)	$H_{1/10}$(m)	$H_{max.}$(m)	$T_{1/3}$(s)
1	2016/1/1 9:00	0.61	0.76	1.06	3.67
2	2015/11/2 8:00	0.51	0.66	1.11	3.64
3	2015/12/4 23:00	0.51	0.63	0.94	3.42
4	2015/11/28 7:00	0.48	0.64	0.88	3.21
5	2015/10/31 7:00	0.48	0.58	0.72	3.47

Source: The JICA Study Team

(2) Wave Forecasting and Hindcasting

Since the observation period was shortened due to the damage of the equipment, wave forecasting and hindcasting data were procured. The purchased wave forecasting and hindcasting data covers from February 2015 to December 2015 and it can be used for verifying the validity of the collected survey data. The model of wave forecasting and hindcasting is based on the WAM model, and the model does not contain the influences of the wave refraction, shoaling, breaking and the bottom friction, because the calculation of the model is based on deep-sea waves.



Source: The JICA Study Team

Figure 4.3.1. Wave Height and Period Derived by Wave Forecasting and Hindcasting (2015/2/1 ~ 12/31)

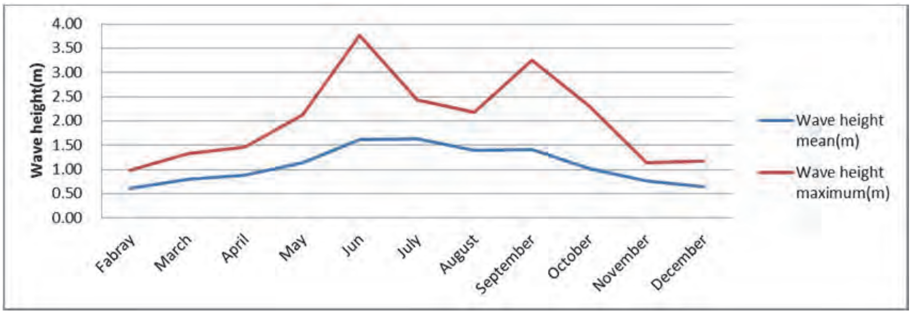
In this time, the wave forecasting and hindcasting data is from February 1, 2015 to December 31, 2015. According to the data, the wave height is from about 0.5 m to 1.0 m from February to May. It repeats bigger and smaller but grows gradually bigger during the period.

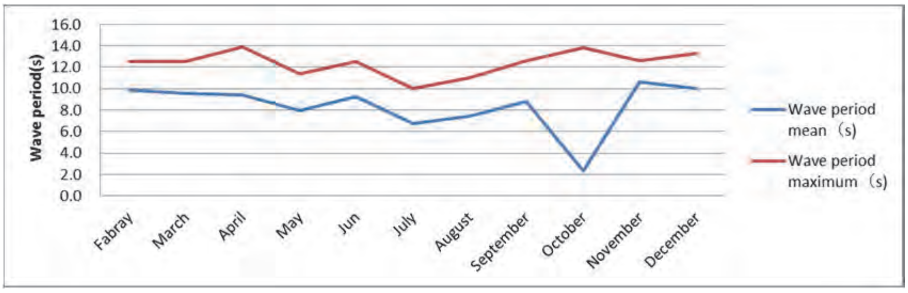
Relatively higher waves, having a height of over 1.5 m to 2.0 m, can be seen from the end of June to the end of August and especially the waves at the end of June have a height over 3.5 m. The wave height tends to calm gradually after September but sudden high waves of over 3.0 m can be seen on September 19. Although the wave height after October is around 0.5 m ~1.0 m, the wave period is getting remarkable with a long period of 10~15 seconds. On the point of the relation between the wave height and the period, the wave forecasting and hindcasting data has the same trend as the observed data in the Study and 2 types of wave are recognised: waves that occur and develop in / around the survey point and other waves coming from open sea having a long period. Averages of the wave height of each month, a maximum of the wave height, the average of the period, and a maximum of the periods are listed in the table below.

Table 4.3.2. Monthly Change in Maximum and Average Values of Wave Height and Wave Period Derived by Wave Forecasting and Hindcasting

	Wave height mean(m)	Wave height maximum(m)	Wave period mean(s)	Wave maximum(s)
Fabray	0.61	0.98	9.84	12.50
March	0.79	1.33	9.52	12.50
April	0.88	1.47	9.40	13.90
May	1.14	2.12	7.94	11.40
Jun	1.62	3.77	9.27	12.50
July	1.63	2.44	6.70	10.00
August	1.38	2.18	7.44	11.00
September	1.42	3.25	8.82	12.60
October	1.02	2.31	2.31	13.80
November	0.76	1.13	10.61	12.60
December	0.65	1.18	10.03	13.30

Source: The JICA Study Team





Source: The JICA Study Team

Figure 4.3.2. Monthly Change in Maximum and Average Values of Wave Height and Wave Period Derived by Wave Forecasting and Hindcasting

The top ten wave heights and wave periods during the observation period are shown in the following lists. In June and September, a high wave of more than 3 m occurs. The highest ten wave heights are concentrated from May to October, namely the wet season.

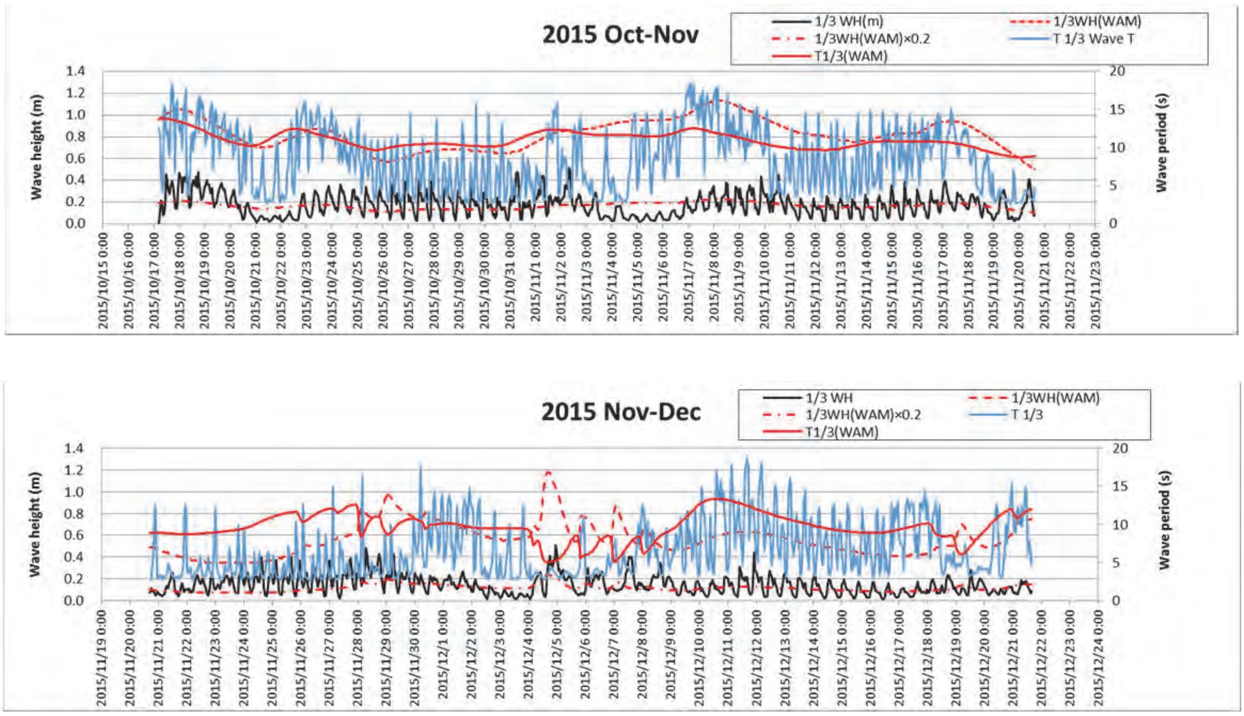
Table 4.3.3. The Highest Ten Wave Heights and Wave Periods during the Observation Period Derived by the Wave Forecasting and Hindcasting

No	The time	Waveheight (m)	Waveperiod (s)	Wavedirection (°)
1	2015/6/25 20:00	3.77	7.00	230.90
2	2015/9/18 15:00	3.25	6.70	192.90
3	2015/7/28 21:00	2.44	6.20	210.10
4	2015/6/20 20:00	2.41	8.00	212.70
5	2015/7/21 14:00	2.31	6.00	213.80
6	2015/10/5 20:00	2.31	8.90	206.40
7	2015/7/29 2:00	2.30	6.40	212.00
8	2015/7/5 8:00	2.18	6.00	231.30
9	2015/8/25 19:00	2.18	6.70	217.60
10	2015/5/20 12:00	2.12	5.80	228.00
11	2015/8/6 13:00	2.08	6.40	230.60

Source: The JICA Study Team

(3) Comparison between Wave Observation and Wave Forecasting and Hindcasting

Although the observed data has frequently repeating developing and attenuating daily, the general trend of the observed data is similar to the wave forecasting and hindcasting data. On the other hand, when the wave height of the observed data is compared to the wave forecasting and hind casting data, the former is about 1/5 of the latter's. The following figure shows the comparison. Probably the reason is that the observed data includes the influence of refraction, shallow water, and the breaking and friction of waves but the wave forecasting and hindcasting data has none of them, as mentioned before. Therefore, this would be a main reason for the difference. However, both show similar tendencies. Although continuous wave observation and data accumulation for a long time (years) are important, the wave forecasting and hindcasting data is also effectively usable for the objective area as supplemental.



Source: The JICA Study Team

Figure 4.3.3. Comparison of Wave Height and Wave Period between Observation and Wave Forecasting and Hindcasting (2015/10/17 ~ 12/21)

(4) Comments

In this opportunity, it was gradually revealed that 2 types of waves exist at Bengal Bay: one is the wave that occurs and develops in / around the sea area of the survey point and the other wave is coming from the open sea having a certain long wave period.

The long period wave found in this Study would have a possibility of influencing the changing of the bottom shape of the seabed in / around the access channel even if the wave height is small. Further continuous wave monitoring, including observations of current speed, wind, tidal change, weather and so on, shall commence in the near future and those data will be usable for the building of the numerical value simulation. Besides, the bathymetry including the area of the river mouth should be reproduced in detail and a predictive calculation should be conducted for the future development of the access channel considering countermeasures like a groin construction and / or deepening of the access channel.

However, if the long period wave influences the change of bathymetry beyond a certain expectation, such countermeasures would not be effective enough even though the results of simulations could have reproducibility. There was no case to conduct a plan, design, and construction of the groin work and the deepening channel subjected to such a long period wave in the past, and further knowledge would be necessary to build up.

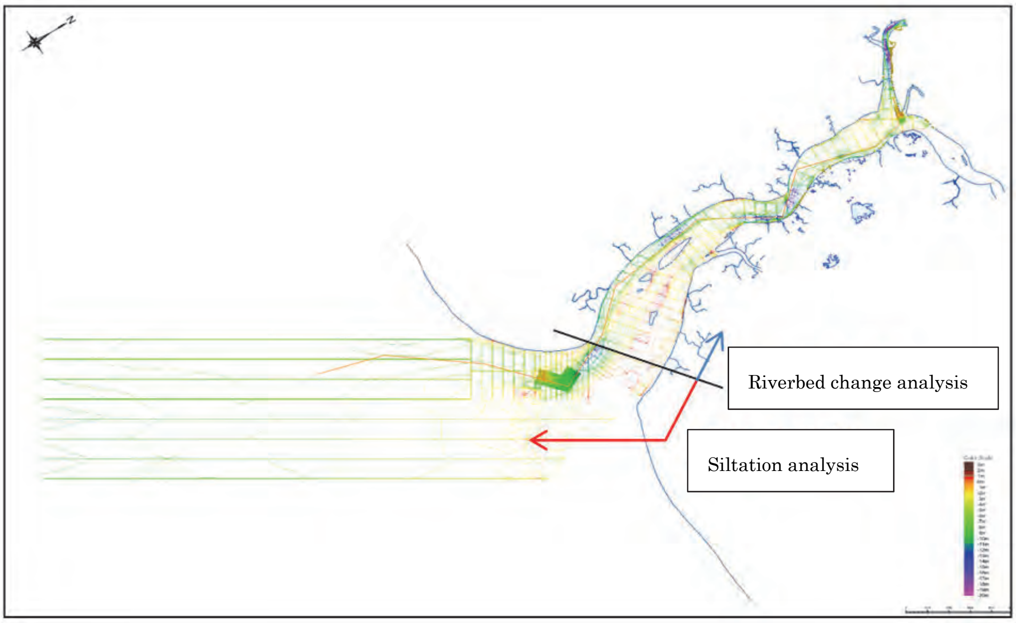
4.4. Proposal of Numerical Simulation Based on Survey Data

In the future river channel improvement, it is important to use the acquired data of this study for analysing / confirming the change of the river topography or the beach topography.

As for the technique of topographic change investigation, there are some existing methods such as hydrological model experiment and examination construction. However, these methods are not favorable in terms of time consumption and cost of implementation. Recently, numerical simulation has become popular due to the improvement of advanced technologies and it is thought to be the most suitable method.

From the results of the riverbed material survey it became clear that the riverbed materials of the upper side of Elephant Point were comprised of sand and the lower side's were comprised of infinitesimal grains such as sand, clay, and silt. Furthermore, the results revealed that under the effect of positive ions included in seawater, the small-size grains form flock and show a manner of accumulation different from sand.

If it is possible to conduct a numerical simulation in the future, a study of riverbed change investigating the scouring and deposition due to bed load sediment transport should be conducted for the upper side of Elephant Point. For the lower side it should be a study about the channel siltation in which the sedimentation situation of the fine particles will be investigated. Furthermore, it is thought to be difficult to analyse and reproduce the topography of some months before and after the rainy season because of the significant change of topography during these periods.



Source: The JICA Study Team

Figure 4.4.1. The Method of Analyses for River Part and Sea Part

4.4.1. Problem in the Riverbed Change Analysis

(1) Overview of the Riverbed Change Analysis

As for the riverbed change, if there is a difference in the quantity of input volume (sediment comes from the upper part) and output volume (sediment out of the lower part), i.e., the amount of input and output volume are unbalanced at vertical or cross section, the elevation of the riverbed will change.

The riverbed change analysis is to analyse elevation change in the vertical and crossing directions. Input data such as flow, riverbed shape, particle size distribution, and the amount of riverbed load are calculated by basic equations. Then, elevation of the riverbed will be calculated by the following equation.

$$\frac{\partial z_B}{\partial t} + \frac{1}{(1-\lambda)}\left\{\frac{\partial q_{Bx}}{\partial x} + \frac{\partial q_{By}}{\partial y}\right\} = 0$$

where

Z_B	: Riverbed height
q_{Bx}, q_{By}	: Volume of bedload sediment in longitudinal direction of the River
λ	: Porosity of riverbed constitution materials
x, k	: River channel vertical section and the coordinate axis of the crossing direction
t	: Time

The calibration of the change in elevation of the riverbed before and after the rainy season will be done by comparing the analysis results with the surveying results. However, it is necessary to analyse the riverbed change considering suspended sediment in case adjustment of the particle size and the diffusion coefficient analysis cannot reproduce well the real phenomenon.

$$\frac{\partial z_B}{\partial t} + \frac{1}{(1-\lambda)}\left\{\frac{\partial q_{Bx}}{\partial x} + \frac{\partial q_{By}}{\partial y} + (q_{su} - c_0 w_0)\right\} = 0$$

Where

q_{su}	: Suspended sediment
C_0	: Concentration of suspended sediment in riverbed
W_0	: Settling velocity of suspended sediment

(2) Validity of the Simulation Model

The wash road and suspension sand in the Yangon River channel move in downstream and upstream directions under the influence of high and low tide currents. The riverbed elevation is thought to change along with the change in quantity of floating volume and deposit volume. Therefore, accumulation will occur when flow velocity is fast, and erosion will occur when flow velocity is low.

A three-dimensional model will be used for numerical analysis. However, because the study area length is about 60 km from river mouth to upstream, the calculation load will be very large. The results of the riverbed sediment survey in four locations on the Yangon River (upstream of Yangon River, near Monkey Point, the Thilawa Area, and Elephant Point Upper (4.80 km)) indicate that the bottom was comprised of sand (SP・SC) . Therefore, the investigation of scour-deposition tendency of bed load will be expected.

However, the analysis using a three-dimensional model in consideration of the quantity of floating sand will be necessary when a local observation result does not accord with an analysis result. In addition, the three-dimensional model for riverbank erosion analysis has been proposed recently. However, the applicability of the model for a large area like the Yangon River needs to be confirmed.

(3) Input Data and Reproducibility

As for the implementation of the riverbed analysis from the river mouth, the data collected from this study, such as riverbed materials, velocity, water level, and external impact factors, are necessary. However, as mentioned before, those data were collected in limited time and space, so is insufficient as the input data.

Therefore, it will become very difficult to reproduce the topography after the wet season even if the analysis carries out with an initial condition of the topography before the wet season.

But it is thought that this analysis model can grasp the tendency of scouring and the deposit of riverbed sand. The measures described in Section 4.5.1 will play an important role for the effect of the installed water system in the river, consideration of other kinds of measures, estimating the deposit time after initial dredging, or the shipping volume and maintenance costs of the transport route.

The follow terms should be noted for the input conditions.

1) Quantities and locations of the sand collecting pump boats: collected volume was estimated from the operational number of sand collecting pump ships
2) The quantity of collapse sediment volume and collapse points of the riverbank were estimated based on the height of the riverbank in the photograph taken in the field work

3) The quantity of maintenance dredging carried out by the MPA was estimated by a hearing with the MPA

【References】

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4.4.2. Problems of Topographic Change Analysis

(1) Overview of Channel Siltation Analysis

As for solving the siltation problem, the basic method is reproducing the present condition and predicting the future stage incorporating engineering measures. The multilayer numerical simulation model is based on floating, diffusion, and sedimentation caused by waves and currents (refer to Tsuruya (1990)). It is an important matter to reproduce advection, diffusion, and sedimentation.

As for the numerical simulation, the multi-level model which considered the floating-diffusion and sedimentation of bottom mud due to flow and waves proposed by Tsurutani, et al (1990) is one option. The reproduction of advection and diffusion or settling flux are thought to be important.

Advection and diffusion can be calculated by the following.

[Tidal current + river flow]

The problem is the reproduction of sedimentation flux (stirred up volume and deposit flux). Furthermore, the wave condition is necessary when considering the resurfacing of the sedimentation flux under the waves' action. In that case, the reproduction scale will be large.

In this survey, although there are some missing periods, field wave observation was conducted (Section 3.7). The sea was in calm condition during the survey period. However, according to the results of additional calculations, which were done for collected data calibration, wave surges of more than 3 m have occurred, and it is thought that further examination is necessary for the consideration of the re-surfacing by the wave for the siltation analysis.

In summary, the goal of the first step is to reproduce the outflow sediment discharge from the Yangon River and that of advection-diffusion, as well as the sediment-accumulating locations. If the main causes of channel sedimentation can be modeled, it can become the means to examine the directional measures.

The main points of the modeling are as below.

1) Multilayer Model

This model is assumed to be a multilayered model along the water depth (2 ~ 3 layers). The reason to use a multilayered model is: it is expected to work well in the case when sediment accumulation is strong, in which the nearby layers will have a high concentration of mud while the upper layers near the water surface will have low sediment concentration. However, a single-layer model can be used if the local observations of suspended solids show that the SS is uniform in the vertical direction.

2) Reproduction Time

As for the reproduction time of this analysis model, because the M2 share tide excels among astronomy tide levels, the 24-hour calculation will be adopted. This analysis model will calculate the advection, diffusion and the sedimentation flux while updating the flow field and the water depth in one hour or 30 minutes. If the quantity of sand flowing down also changes depending on a tide level, it will be considered to include in the model. The river discharge for the dry season and the rainy season will be set to be different.

As for the reproduction calculation and the predictive calculation, the number of days in the dry season as well as the wet season in one year will be defined and advection, diffusion and sedimentation flux will be calculated for one year. Calculation time for one case is about one or two days.

In addition, in cases where the influence of a high surge cannot be ignored, waves and shear stress will be calculated by other wave field, then the time interval of the event will be introduced for considering re-surfacing.

3) Basic Equations

The basics equation of the siltation model is the advection and diffusion equation that can be expressed as below.

$$\frac{\partial}{\partial t}(c_k D_k) + \frac{\partial}{\partial x}(u_k c_k D_k) + \frac{\partial}{\partial y}(v_k c_k D_k) + w_{k-1} C_{k-1} - w_k C_k$$

$$= \frac{\partial}{\partial x}\left(K_x D_k \frac{\partial C_k}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_y D_k \frac{\partial C_k}{\partial y}\right) + \gamma_{k-1}(C_{k-1} - C_k) - \gamma_k(C_k - C_{k+1}) + \omega_0 c_{k-1} - \omega_0 c_k$$

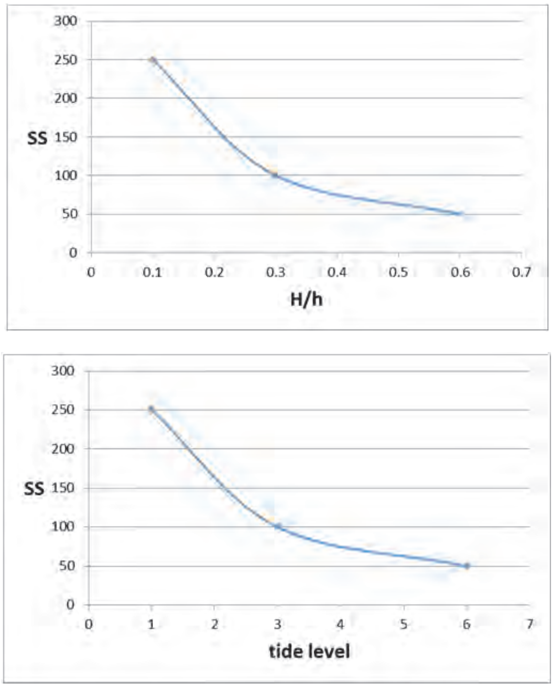
Where

Ck	: Material density
uk, vk	: Flow speed in x and y direction
Dk	: Diffusion coefficient
kx, ky	: Vortex viscosity coefficient

4) Inspection of Plasticity of Calculation Result and Relationship with Reconnaissance Survey

Various kinds of field work results are used for a preliminary calculation stage, this calculation, and the inspection of the calculation results. The results of the channel topographical survey are used for topography data making in simulation. The mesh size of topography data and the water data is about 50

- 100 m. Bottom mud and sand, which are collected by sampling, are used to set the particle sizes, specific gravity and density of the simulation. Measured flow discharge is used as a boundary condition in the simulation model. The float density calculated by simulation is used for reproducible inspection of the simulation by comparing with the measured float value.



Source: The JICA Study Team

Figure 4.4.2. Reproducible Report Image in the Calculation Result

(2) Validity of the Simulation Model

In the present situation, the following two points were found out: the Yangon River channel is constantly changing and the MPA have been carrying out regular maintenance dredging. As for the change of the Yangon River channel, the bottom sediment, such as clay or silt, is carried by flow and waves and deposits in the channel or berthing area, then forms bottom mud. This bottom mud layer then repeatedly moves under external force, and deposits again in the channel and berthing area. This phenomenon is called Siltation.

According to the Design Manual for Coastal Facilities 2000, the movement of the riverbed that consists of very fine particulates such as clay and silt is shown to be different from the mechanism of movement of sand particulates. The shear stress of the sand particles is determined only from their internal friction. However, in the case of fine particulates, such as clay and silt, it is impossible to ignore their internal viscosity. In the results, the very fine particulates transported to the mouth of the river are deemed to form a floc under the action of positive ions contained in seawater and they exhibit a different deposit property. Sedimentation rate is governed by the salt concentration and the collision of fine particles into each other (concentration).

Same as Myanmar, Yangon River siltation that occurred in the harbors or in the river basin has become a serious problem in Southeast Asian countries and Latin America. For example, Bangkok's Port of Chao Phraya River in Thailand (Deguchi et.al (1993)), Pakistan's Qasim Port (Yagi et al. (1985)), Indonesia's Banjarmasin Port (Okabe et al. (1991)). These examination techniques applied in these areas should be analysed as reference.

(3) Input Conditions and Plasticity of the Model

The analysis will be performed for the surrounding river mouth based on various data obtained by field work. The results of this survey show that the scale of the topography change is very big, and the same scale of calibration is necessary. Sufficient attention is necessary for interpretation of the measures, which is carried out on the collected results, and comparison with examples from other countries should be considered.

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4.5. Comments on the Capacity Limit of Ship Traffic for Yangon Port Channel

4.5.1. Recommendation on the Traffic Simulation Analysis

It is recommended to conduct detailed ship traffic simulation analysis to estimate more precise traffic capacity of the port channel, in which meteorological conditions, detailed channel depth and constraints on navigation, etc., should be considered. The following are the recommendations on the analysis based on data collected in this survey work.

1) The simulation should be applied for the time span of at least one month in order to consider the tidal levels of both spring tide and neap tide.
2) The simulation model should be capable of calculating water depth along the channel route changing by movement of tide level, and the keel clearance of each ship should be calculated by applying the draft of the model ships.
3) The simulation model should be capable of calculating the ship's speed vs. water surface, taking into account the changing river flow speed.
4) The suitable model should be created in terms of ship size, draft and frequency of entering / departing of ships, referring to the actual statistics and ships' data collected by this survey work.
5) The model should be capable of assuming the conditions passing through Elephant Point and Monkey Point.
6) For the simulation, future changes in increasing ship-size trends and the rate of containerisation should be considered.

4.5.2. Measures to Increase the Channel Capacity

From the output of this survey work, it was found that more accurate analyses and studies will be required to make the decision about dredging to deepen the channel, taking into consideration the volume of river discharge of sedimentation material and the unknown scale of future maintenance dredging volume. In this report, the following are recommended for increasing channel traffic capacity based on the assumption that the existing channel is not changed.

(1) Installation of Navigation Support System Capable of Night Operation

Looking at the existing pilotage operation, only daylight operation is permitted at Monkey Point, whilst only one high tide per day is used for entering / departing of ships at Elephant Point where nighttime sailing is permitted. In order to achieve night operation and to convince safe navigation, it is recommended to install and operate a VTS (Vessel Traffic Service) system together with radar and GPS (Global Positioning System) capable of monitoring the position and movement of ships in the channel in the central operation room. The seasonal change in channel depth, wave conditions, and river flow speed should be monitored in the system and it is also necessary to train the commanders who can make suitable decisions and send instructions to each ship, communicating with ships by wireless device.

(2) Renewal of Navigation Aids

The existing number of navigation buoys and supporting facilities are not sufficient to enable night operation. According to the interviews with pilot and ship crews in this survey work, the ships in the channel are getting their positions by GPS equipped with the ship, and sailing in accordance with the instructions by the pilot on board. Also, it is said that the leading lights on shore are not clearly visible and not always used for ship navigation. According to the JICA Study Team’s site investigation, visibility in the channel was not good, particularly during rainfall, thus it is assumed that the use of navigation aids is not very effective during night time. Some of the navigation buoys indicated on the nautical chart were not found during the site investigation.

From the viewpoint of safe navigation, the renewal of existing navigation buoys and additional installations are necessary all along the channel route, in parallel with the installation of the above VTS system.

(3) Improvement of Pilotage Service

At present, the number of pilots working for the Yangon Port channel is approximately 30. From the interviews with the pilots, the maximum number of ships with pilotage in a day is about 10 ships for entering. The procedure of pilot’s work and its work shift is described as follows: a pilot leaves Yangon Port by boarding on a sailing ship, passes through Monkey/Elephant Point, and reaches the pilot station, which is located offshore of the river mouth, and on the next day the pilot leaves the pilot station boarding an entering ship and returns to Yangon Port. Looking over this existing operation cycle and available number of pilots, 10 ships receive pilot service for entering plus the same number of outgoing ships is assumed to be the present limit of services. Because the number of ships is increasing, the number of pilots should be increased, as an urgent issue for the MPA.

For the purpose of providing pilot service for an average of 20 entering ships in single-flow tide hours, a minimum of 75 pilots will be required in the near future. When night operation will be commenced, an additional 50 pilots will be required to achieve full pilot service.

In addition, the existing pilot station should also be renewed or a new larger facility should be installed in accordance with the increase of pilots. The existing pilot boats, which are used for docking and boarding the pilot onto the ships, are small and sometimes face danger during rough waves. Larger and safer pilot boats are also required.

4.6. Discussion of Present Channel Dredging Works

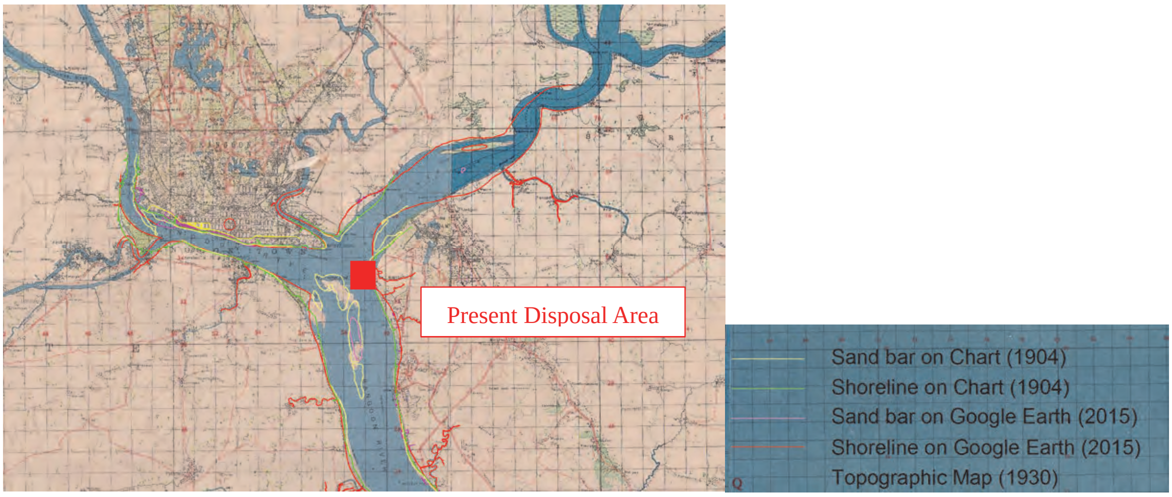
4.6.1. Current Condition of Maintenance Dredging

Basically all dredging works are executed by the MPA. Most of the dredging works are executed at Monkey Point and the total dredged volume is 1.4 million m^3/year. The dredging volume of 1.4 million m^3 is quite a huge volume compared to the deep sea ports in ASEAN countries. For example, Tanjung Priok Port, as the gateway of Indonesia, has the maintenance dredging volume of only 0.6 million m^3/year (referred from the record of PERINDO II). Presently, Tanjung Priok Port handles about 7 million TEU/year, which is over 10 times the amount of Yangon City Port, the total of both Yangon Port and the Thilawa Area.

Although Monkey Point requires such a big volume of maintenance dredging every year, the other part of the international channel in the Yangon River is assumed as about 0.6 million m^3 only. From the viewpoint of maintaining the access channel and reduction of related costs, the Thilawa Area would be much easier than Yangon Port because Monkey Point constrains entering / leaving Yangon Port. However, if present maintenance dredging was completely stopped or reduced, the influence would emerge in other parts of the Yangon River and further investigation and examination are necessary, especially about how big the impact would be on the Thilawa Area.

4.6.2. Current Conditions of Disposal of Dredged Material

It was seen from the survey results of the Study that the shape of the riverbed of the Yangon River largely changes after a rainy season. Also, it was found that the river shape of the Yangon River has fluctuated largely during the past 100 years according to the Separate Volume of the Study Report. The following drawing is one of the examination results of the Separate Volume. The riverbank lines in 1904 and 2015 were superimposed on the old map in 1930 and the secular change of the riverbank line can be seen. Also, the present disposal area of the dredged material designated by the MPA was added. According to the drawing, the riverbank of the downstream side of the disposal area deforms to a large arc gradually to the outside of the river bend by the influence of erosion. The river flow of the Yangon River passes through the junction point with the Bago River and it turns sharply to the left side (southward) almost 90 degrees, and just after the sharp turn, the disposal area exists at the outside of the river flow, where there is stronger clean flow created by the spiral flow and normally such a point shows an erosional trend.



Source: JICA Study Team

Figure 4.6.1. Present Disposal Area and Secular Change of the Riverbanks

It could be said that the present disposal area designated by the MPA has a strong clean flow according to the above figure. Also, the dredged material is liquid formed, therefore the disposed material would be flushed downstream and no bad influence is happening to the cargo vessels for now, although the dumping site is adjacent to the access channel.

4.6.3. Discussion on Present Maintenance Dredging of Access Channel

The river bottom would assumedly fluctuate, complexly intertwined with the related factors in the following.

1) On the river section, the river bottom is mainly comprised of particles of fine sand and silt and such particles are moving up and down in the river due to the influence of tidal change. Also, curling of such particles would happen.
2) At the river mouth around Elephant Point, fluctuation of the sand bank is generated and the alignment of the access channel fluctuates frequently. The main reason would be the accumulation of particles, which are carried by the river flow, tides and waves, and those are curled up not only naturally but also by the force created by vessel navigations. Also, discharged soil caused by riverbank erosion would contribute to the accumulation of sediment.

Basically, the maintenance dredging is comprised of 2 types of work: dredging work and disposal work. The MPA executes maintenance dredging mainly at Monkey Point and the target depth is CD-4.2 m. The dredging work is conducted basically in low tide under the less influence of the river flow. The objective material extracted from the dredging is very soft like a liquid form. Considering these facts, the level of difficulty of the present maintenance dredging work is not high compared to the experiences in other countries.

As for the disposal work as the other component of maintenance dredging, normally, the disposal area is selected for its conditions: the place has no influence on the access channel and the environment, and it has a sea depth of 20~30 m. According to the experiences in nearby countries in ASEAN, the maximum distance from the dredging work place to the disposal area is about 20 km.

The alignment of the access channel in the Yangon River traces its naturally formed deeper points. On the other hand, a natural deeper point indicates a place where there is a stronger clean flow, so the present disposal area was chosen in the same deeper place that accommodates the access channel. Recently, vessel size has been increasing and the traffic is more frequent due to the surging demand of Myanmar. Considering the background, the present disposal activity might influence vessel navigation in the future. Therefore, further detail monitoring surveying of the disposal soil should be conducted.

4.7. Comments on the Practice of Survey Works

Currently the main survey work of the MPA is to conduct bathymetric surveys at Monkey Point and Elephant Point. The frequency of the bathymetric surveys at Monkey Point is weekly. At Elephant Point, it is monthly. Both survey results are handed over to the pilots immediately after the surveys and it contributes to safe pilotage for all vessels passing these constraints. The following are proposals for the surveys of the MPA.

4.7.1. Level Reference Point and Tide Station

There are 2 level reference points within the objective area of this Study. One is located near the headquarters of the MPA and the other is near Elephant Point. The former is positioned in the garden of Pazundaung Wharf and it is protected by a solid steel cover. On the other hand, the latter is on a wooden peg and it is not solid enough as the reference point and it should be replaced by a solid structure like concrete. The Yangon River has complicated river flow and severe natural conditions. So, at least 5 level reference points should be set up and well maintained from Monkey Point to Elephant Point with a view to digitisation of the survey in the near future.

Automatic tide recording commenced at Monkey Point from around October 2015. On the other hand, Elephant Point has no tide station presently since it was lost a long time ago due to riverbank erosion.

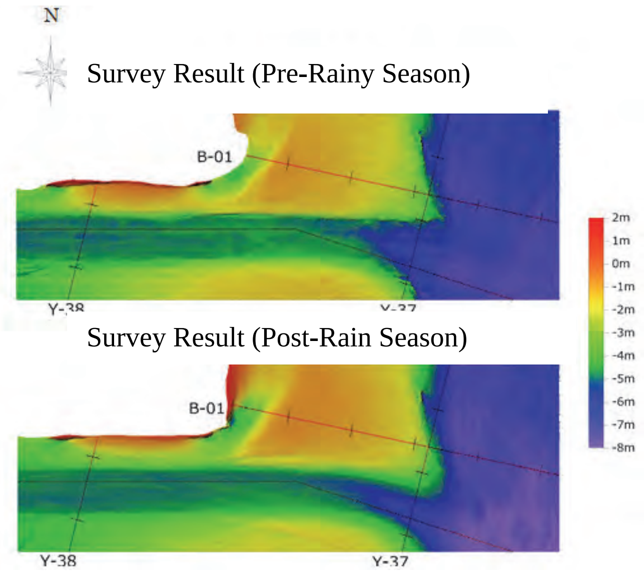
Most of the area of Elephant Point is shallow and its riverbed shape is frequently changing. Related to this change, the deepest point for large cargo vessels is moving frequently as well, so the point is regarded as a big constraint of the Yangon River Channel, therefore, periodic bathymetric surveys at

Elephant Point should be continued to update with higher accuracy and the results should be shared with pilots immediately after the survey.

Considering the situation, firstly, a permanent tide station should be set at Elephant Point. It is desired that an automatic 24-hour observation is introduced sooner. It would contribute greatly to safe navigation to accumulate accurate tide data.

4.7.2. Bathymetric Survey at Monkey Point

Monkey point is the most difficult constraint for larger ship navigation so it requires weekly bathymetric surveys by the MPA. Although the JICA Study Team unfortunately could not get any survey results at Monkey Point executed by the MPA, it was confirmed that the channel shape was trimmed with the target depth of CD-4.2 m and the required width, according to the color maps resulting from the multibeam surveys in both pre- and post-rainy seasons. So, the present survey work of the MPA would have no problem maintaining the current vessel traffic.



Source: The JICA Study Team

Figure 4.7.1. Color Maps of Monkey Point

4.7.3. Bathymetric Survey at Elephant Point

From the comparison of survey results in pre- and post-rainy season in 2015, a part of the large-scale river bottom change could be seen. Presently the bathymetric surveys done by the MPA are mainly focusing on the deepest route for the navigation of larger vessels. However, if the MPA has an eye to examine the improvement of the Yangon River Channel in the future, the present survey area at Elephant Point should be wider. Considering the multibeam survey results done in the Study, the area should be wider in 2 directions: 1 km further upstream and 1 km southwestward.

During the Study, multiple survey results from Elephant Point in 2011, 2012, 2013 and 2015 were provided by the MPA and basically all results have 3-m counter line intervals. As shown in another chapter, a trucking record of a large vessel navigating the Yangon River Channel could be collected. Considering each trucking point with the tide level at the time based on the multibeam results, it was confirmed that the keel clearances at some points were less than 2 m. Considering the severe natural conditions of the Yangon River, e.g. the drastic change of the river flow, the big tidal change of over 6 m, the very long shoring beach from the river mouth and so on, it is normal that large vessels with a draft of about 9 m have to pass the Yangon River Channel with such a small keel clearance, and the such situations will happen more often in the near future due to the sharp increase of demand for larger cargo vessels. For further safe navigation of large vessels, the seabed and riverbed should be confirmed more accurately with at least 2 m interval of contour line, or, preferably, 1 m interval.

4.7.4. Tide Station and Wave Monitoring Offshore of the Yangon River

Presently, the pilot station run by the MPA is located about 20 km offshore from the river mouth of the Yangon River and an anchored vessel is used for the station accommodating pilots and related personnel for the work of pilotage.

Now the MPA is preparing for the renewal of the pilot station. To provide more suitable operation and maintenance of the Yangon River Channel or to improve the Channel, further collection of natural condition data is essential. If the new station is located at the same position as the present one, the following monitoring should be commenced and continued for a long time and that data accumulation is necessary for further examination.

1) Automatic Tide Recorder
2) Ultrasonic Type Wave Observation Equipment
3) Ultrasonic Type Multilayer Current / Flow Speed Monitor
4) Weather Observation（Wind Direction & Speed, Rain, Visibility）

It is effective to get tide records for a long period 20 km offshore where there is less influence of the river flow of the Yangon River compared to Elephant Point, and it is usable especially for sedimentation analysis at the offshore area.

Wave height / current direction and wave speed data also contribute to sedimentation analysis and further safety navigation analysis. In the wave observation of this Study, infragravity waves with relatively small wave height were observed constitutively at the observation point in the Andaman Sea, having very shallow shoring seabed, and the infragravity waves might influence the large change of the sea bottom shape confirmed at Elephant Point in this Study. Also, the nearshore currents might be a reason for the large sea bottom change. Considering these issues, the accumulation of such data would be highly recommended for further examination and analysis of the access channel.

4.7.5. Recommendation on Digitisation of Survey Data

In this Study, some of the bathymetric survey maps for Elephant Point made by MPA were collected. Basically the scale of the maps was 1:35,000, hand-drawn, but the survey result in August 2015 was drawn by AutoCAD. The survey division of the MPA introduced AutoCAD software recently and the digitisation of mapping / drawing is advancing in the MPA. One of the important roles of the survey division of the MPA is to conduct periodic surveys at the constraints with frequent intervals to trace the trend of the big changes happening on the seabed and riverbed of the Yangon River, and the survey results have to be delivered to the pilots as soon as they finish the survey to secure safe vessel navigation. The digitisation of mapping / drawing contributes more accurate and faster transmission of the survey information to the pilots.

Basically the survey field can be divided into 3 works, 1) field survey (data acquisition), 2) data processing, and 3) mapping and drawing. Recently these 3 works have been transitioning to digitisation rapidly even in ASEAN. The MPA starts digitisation of the above 3) so digitisation of 1) and 2) are needed in the near future.

As for the digitisation of 3) mapping / drawing, it is relatively easy to learn the skill by referring to the operation manual book only and it is regarded as easy to introduce. On the other hand, the digitisation of 1) field survey and 2) data processing is relatively difficult to introduce. The main reasons are: A) as a premise for the introduction of digitisation, the number of level reference points should be increased and well maintained; B) the initial cost to procure the digitised equipment and the related software is very expensive and its maintenance cost is also expensive (Basically the updating cycle of the software is within 4~5 years.); and C) it is impossible to learn the operation skill by referring to the manual book only and several training programs to get the skills for both field survey and data processing are needed under skilled instructors.

Also, related to the introduction of digitisation, the required skill, experience, and ability of the personnel would be changed from that in a conventional organisational system and it would produce a surplus workforce. As a result, the conventional organisation could not manage the new digitised system. Such cases have happened in other countries. Therefore, for the introduction of digitisation, the preparations should consider a reform of the organisational system, which would be needed for a smooth transition to the new system.

4.7.6. Utilisation of Multibeam Survey

The present bathymetric survey system in the MPA uses the analogue type single-beam survey. Aiming to the increase accuracy and efficiency of the survey, the MPA should introduce digitised multibeam surveys in the near future for higher safety vessel navigation.

As discussed in the Separate Volume of the Study, the Yangon River has a large change of the river route. Aiming to better maintain and improve the Yangon River Channel, the MPA should confirm Monkey and Elephant Points more accurately, and to do so, the introduction of a multibeam survey system is an answer. However, the initial cost to introduce the new system is very expensive and the maintenance cost is also expensive compared to the single-beam system. Besides, a certain high level of skill and experience for both fieldwork and data processing on the multibeam survey is essential. Therefore, the plan for procurement, operation, maintenance and a training program should be made in advance of the introduction of the new system under skilled instructors.

Appendix 1 Examples of River Training Structures and Comments

In this section, the examples of the river training structures implemented in Japan are introduced. The practice should be carefully examined for the application of these examples to the Yangon River, as the Japanese rivers have generally smaller-scale basins and flow volumes.

A1.1. Training Jetties

In the Design Manual for Coastal Facilities (2000), the ‘training dike’ is defined to be the jetty extended from both or one side of the river mouth toward to the sea. In some cases, the dike is extended from the riverbank inside the mouth, which is connected to the separation levee of the river channel. The main functions of the training dikes are as follows.

- To maintain the existing shape and location of the river mouth
- To maintain the river channel of the river mouth
- To maintain the depth of the river mouth

Similar structures are used not only for river facilities but also as coastal facilities for controlling the volume of drift sand caused by coastal waves. The following figure shows an example of a training dike on the Hikiji-River in Kanagawa Prefecture, Japan. This structure has the functions of reducing the entry of drift sand coming from the sea side and maintaining the river channel water depth by arranging the dikes on both sides and parallel to the river flow.

Source: The JICA Study Team

Figure A1.1. An Example of a Training Dike (the Hikiji-River in Kanagawa Prefecture, Japan)

A1.2. Groins

River training works are generally installed for flood control, water utilisation, or environmental purposes. As Japanese rivers have generally steep-sloped riverbeds downstream, the training facilities in Japan commonly have the function of protecting against erosion. The following example is for maintaining the ships' channel, which is for few cases.

In the past, the Tama River had had the river training structure for the purpose of maintaining the channel. Due to past excavation / dredging for the flood channel, the river training structures were washed out. At present, the channel route is stable due to the dredged flood channel.

Source: The River Environment Research Institute, Material No. 15 - The Layout and the Significance of Art History of Groins at Downstream of Tama River

Figure A1.2.   An Example of River Training (Tama River)

In the Yodo River, the height of the river floor was increased by the influence of the increase in discharge soil in the water due to the decrease of forest in the basin. The river channel became difficult to use for carrying wood logs, thus the river training facilities were installed (1970s)

After the installation of these structures, the sedimentation accumulated inside the training dikes, then the state of the structure changed to the shape of a 'wand'. The channel is still being maintained.

Source: WS of Yodo-River Office MLIT

Source: Google Earth

Figure A1.3. Example of River Training (Yodo-River)

A1.2. Comments

If the river training structures were installed in the Yangon River, the functions to be required are to maintain the river channel and to protect the riverbank from erosion.

Groins are expected to reduce flow velocity and water splashing effects to the riverbank. On the other hand, scouring might occur due to the concentration of water flow around the groin head. As described in the separate volume for the erosion of the riverbank, the local government installed small dikes (1 m high and 1 m wide) for protecting the riverbank from floods and cyclones. These structures were washed out and disappeared every 6 months or 1 year by heavy erosion according to the hearing investigation.

In general, it is necessary to assess the rate of scour, how deep and wide the scour will be in the vicinity of the river training structures, in order to design the river training structures to avoid collapsing from the erosion.

However, the river training structures are usually designed mainly based on past experience, observation data taken from similar rivers, test installation or laboratory model experiments, because the structures usually suffer from unknown factors influenced by erosion.

If the characteristics of the Yangon River are considered, such as the frequent change in channel depth of the river, it should be noted that there are difficulties in estimating or assessing whether the installed river training structures might be impacted by heavy erosion, or if they might be buried by accumulated sedimentation.

It is commented that the installation of river training structures seems difficult for the Yangon River Channel. Even if the design will be required, it is necessary to conduct a careful assessment before the design and installation of the river training structures, because there is a high risk that the structures may be washed out due to river flow, taking into account the output of this survey data, which shows that the river bed had a lot of change during the rainy season and that the bed material has very movable characteristics. In addition, careful attention must be paid to safety precautions for smaller ships in the design, because installed structures might cause obstructions to such ships' movement along the channel route.

According to the results observed from 5:00, October 17, 2015 to 12:00 January 22, 2016, the wave height in the observation period is small generally, and it is guessed that the big wave height caused by the cyclone did not occur. The following table shows the top 5 high waves. The maximum of the observation period became $H_{1/3}$ = 0.61 m, $H_{1/10}$ = 0.76 m, H_{max} = 1.06 m, and it was very calm.

According to the overall average during the observation period, it is just $H_{1/3}$ = 0.16 m, $H_{1/10}$ = 0.20 m, H_{max} = 0.28 m, and it was very calm.

Table 3.7.4. Top 5 High Waves (2015/10/17 5:00 ~ 2016/1/22 12:00)

Rank	Time	$H_{1/3}$(m)	$H_{1/10}$(m)	H_{max}.(m)	$T_{1/3}$(s)
1	2016/1/1 9:00	0.61	0.76	1.06	3.67
2	2015/11/2 8:00	0.51	0.66	1.11	3.64
3	2015/12/4 23:00	0.51	0.63	0.94	3.42
4	2015/11/28 7:00	0.48	0.64	0.88	3.21
5	2015/10/31 7:00	0.48	0.58	0.72	3.47

Source: The JICA Study Team

Table 3.7.5. Wave Observation Results (2015/10/17 5:00 ~ 2016/1/22 12:00)

Average of $H_{1/3}$ (m)	Average of $H_{1/10}$ (m)	Average of H_{max} (m)	Average of H_{mean} (m)	Average of $T_{1/3}$ (s)
0.15	0.19	0.26	0.09	7.85

Source: The JICA Study Team

The relations between the representative wave heights, $H_{max}/H_{1/3}$, $H_{1/10}/H_{1/3}$ were clarified as shown in the following table and figure. According to the results, $H_{max}/H_{1/3}$ = 1.75, $H_{1/10}/H_{1/3}$ = 1.25 are confirmed and the situation would be not under the wave breaking. So, any disturbance due to bad weather, which creates big wave heights and long wave periods, did not occur during the observation period.

Table 3.7.6. Results of $H_{max}/H_{1/3}$, $H_{1/10}/H_{1/3}$ and Hmean/ $H_{1/3}$

$H_{max}/H_{1/3}$	$H_{1/10}/H_{1/3}$	$H_{mean}/H_{1/3}$
1.75	1.25	0.63

Note: results from the Wave Observation Results (2015/10/17, 5:00 ~ 2016/1/22, 12:00)

Source: The JICA Study Team