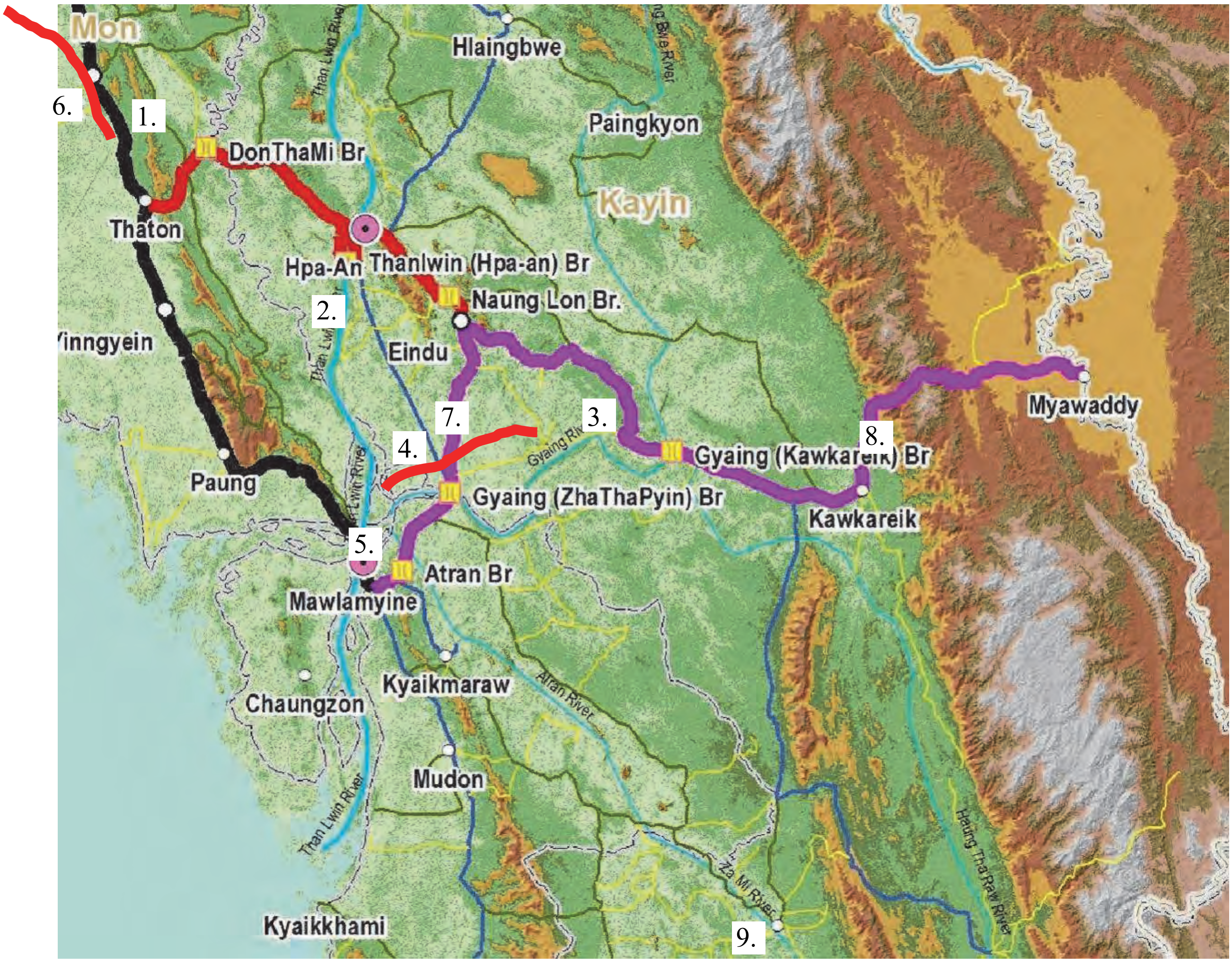
CHAPTER 5 NATURAL CONDITION SURVEYS

5.1 Natural Condition Surveys

The scope of work for aerial natural condition surveys for this project design is as follows:



Source: The Survey Program for the National Transport Development Plan in the Republic of the Union of Myanmar (2014 ICA)

Figure 5.1.1 Position of Natural Condition Surveys

Table 5.1.1 List of natural condition surveys

Survey site	Length
(1) Donthami Bridge	200m
(2) Naung Lon Bridge	115m
(3) Gyaing Kawkareik	400m
(4) Gyaing Zathapyin	870m
(5) Atran Bridge	433m
(6) Thaton Bypass	29km
(7) Kyargalay Bypass	25km
(8) Dawna Bypass	25km
(9) Three Pagoda Pass	105km

Source: JICA Survey Team

5.2 Topographic Survey

5.2.1 Data Acquisition (Aerial Photographs)

(1) Scope of Work

The scope of work for aerial photography for digital mapping area in the southern area in the Republic of the Union of Myanmar is as follows:

- Total area to be covered with digital aerial photo : approx. 250km^2
- Type of aerial camera : Ultra Cam with airborne GPS and IMU or equivalent
- Focal length of camera : 80-120mm
- Charge-coupled device (CCD) : 5-12 microns
- Ground sampling distance : 20cm
- Flight altitude : Approx.3, 000m
- Number of flight lines : Base on flight plan design
- Overlap : 80%±5%
- Sidelap : 40%±5%
- Flying direction : North-South direction

(2) Parameters

Datum and Coordinate System

All mapping deliverables shall be in the following coordinate system:

- Ellipsoid : WGS84 (World Geodetic System 84)
- Projection : Universal Transverse Mercator (UTM) Projection
- Zone : Zone number N47
- Central Meridian origin : 99 degree west of Meridian international
- Latitude origin : Equator
- Scale factor at origin : 0.9996
- False coordinates : (0,500,000) at equator
- Vertical : BM height adopted by Myanmar Survey Department
- Unit of measurement : meter
- EPSG : 3247 (WGS84 UTM coordinates.47)

5.2.2 Ground Surveys

(1) Survey locations

Table 5.2.1 East West Economic Corridor Five (5) Bridge sites

Name of Bridge	Bridge Length	Approach Road
Donthami Bridge	200m	2x100m
Naung Lon Bridge	115m	2x100m
Gyaing Kawkareik Bridge	400m	2x200m
Gyaing Zathapyin Bridge	870m	2x250m
Atran Bridge	433m	2x200m

Source: JICA Survey Team

(2) Scope of Works

The scope of work for Ground Survey areas in the southern part of Myanmar is as follows:

- Mobilization and Demobilization
- Benchmark Installation
- Plane Survey by Total Station
- Centreline / Profile Levelling Survey for Road
- Cross Section Survey for Road
- Centreline / Profile Levelling Survey for River
- Cross Section Survey for River
- Mapping and Reporting

(3) Accuracy of the survey

The survey results shall be kept at the following accuracy:

Survey Type		Accuracy	Remarks
Levelling	Elevation measurement	2cm×√S	S=Surveyed distance of one-way (km)

(4) Plane Survey Result

Table 5.2.2 The execution area of surveying

SITE	GROUND SURVEY (km^2)	ORTHOPHOTO MOSAIC (km^2)	TOPOGRAPHIC MAP (km^2)
(1) Donthami Bridge	0.76	—*1	—*1
(2) Naung Lon Bridge	0.81	3.73	3.73
(3) Gyaing Kawkareik Bridge	0.97	5.83	5.83
(4) Gyaing Zathapyin Bridge	4.00	6.14	6.14
(5) Atran Bridge	0.66	5.40	5.40
(6) Dawna Mountain Site	-	731	167
(7) Thaton Bypass Site	-	323	37.4
(8) Kyargalay Bypass Site	24.4	122	122
(9) Three Pagoda Pass Site	-	655*2	-

*1: Included in Thaton Bypass Site
*2: It is only the Mosaic image data not the Orthophoto.
Source: JICA Survey Team

(5) Area of Ground surveys

➢ <u>Donthami Bridge</u>

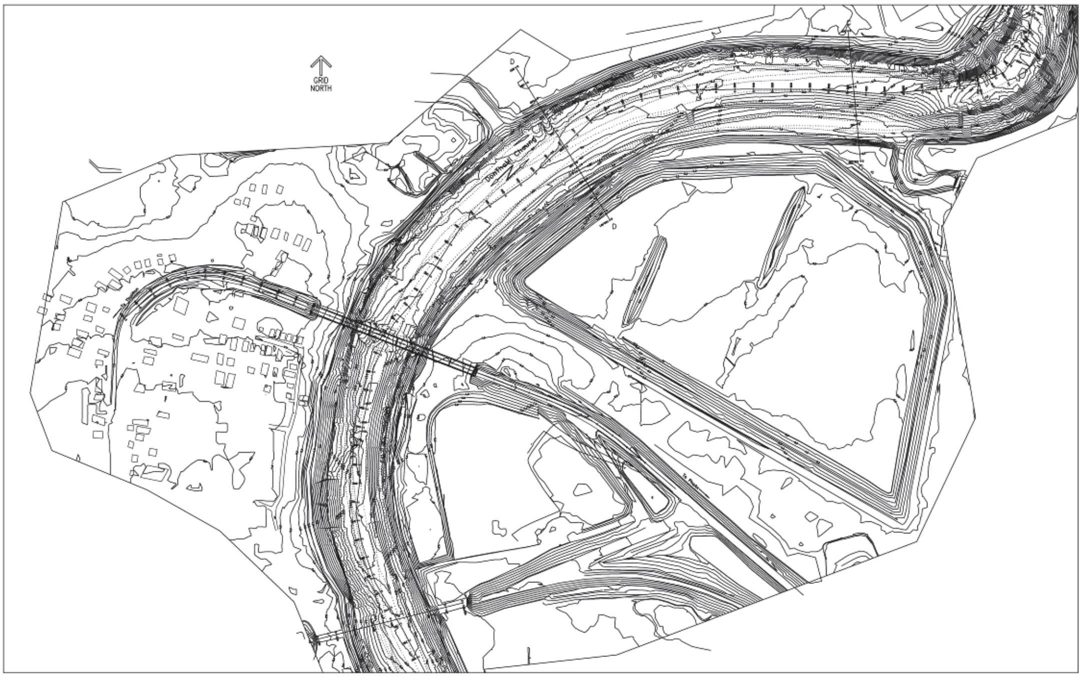
- Naung Lon Bridge

- Gyaing (Kawkareik) Bridge

- Gyaing (Zathapyin) Bridge

- Atran Bridge

(6) Result of Survey



Source: JICA Survey Team

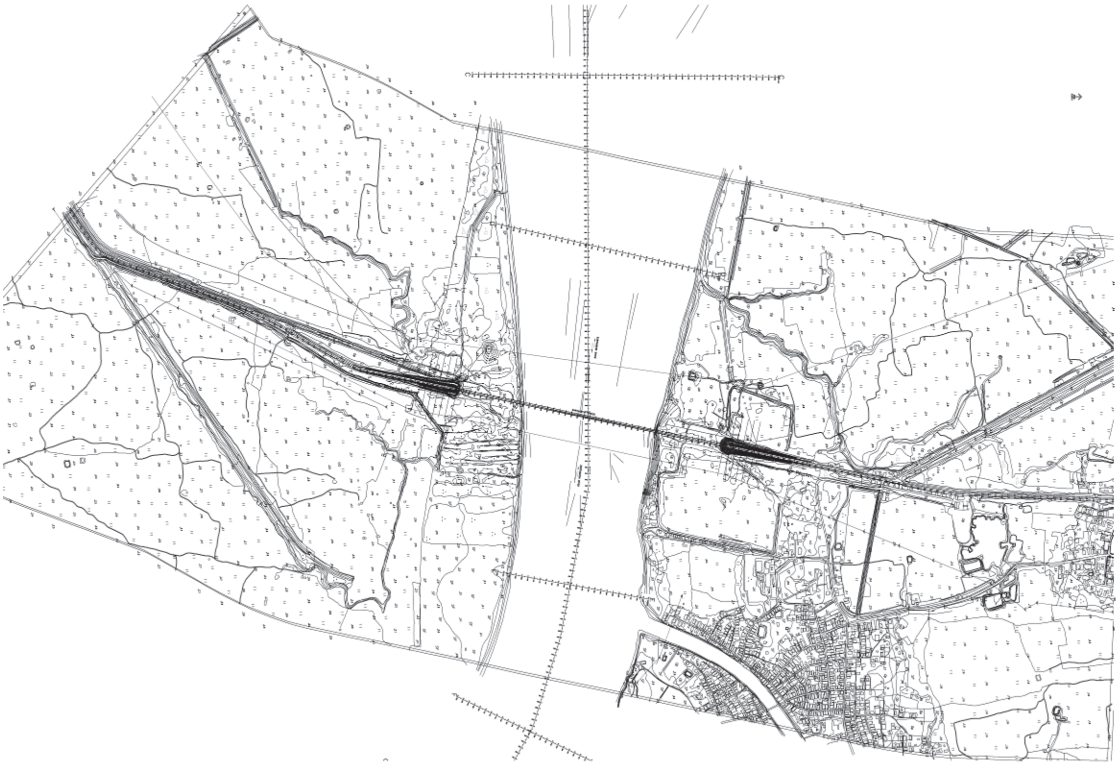
Figure 5.2.1 Donthami Bridge

Source: JICA Survey Team

Figure 5.2.2 Naung Lon Bridge

Source: JICA Survey Team

Figure 5.2.3 Gyaing (Kawkareik) Bridge



Source: JICA Survey Team

Figure 5.2.4 Gyaing (Zathapyin) Bridge

Source: JICA Survey Team

Figure 5.2.5 Atran Bridge

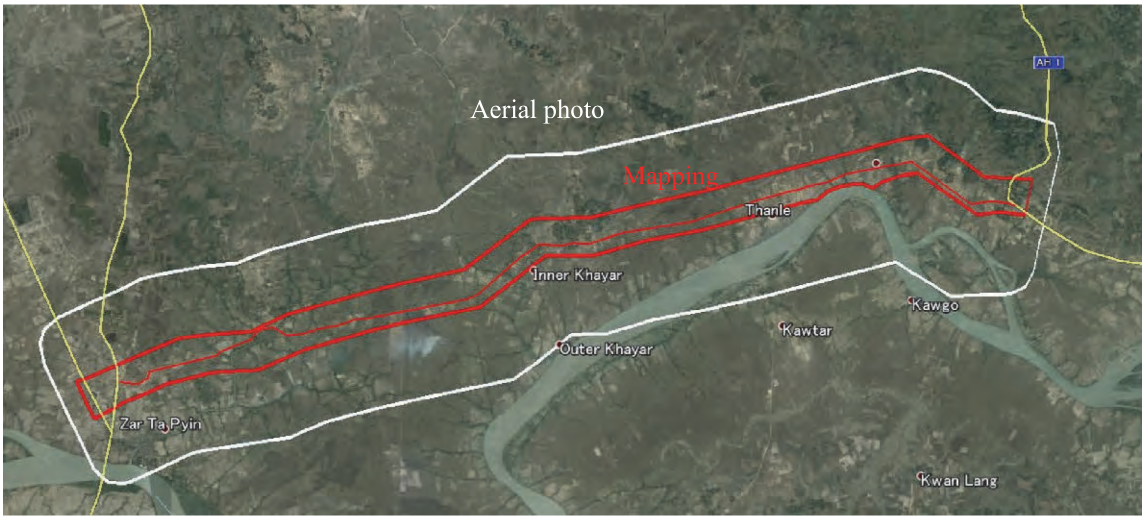
5.2.3 Digital Photogrammetric Mapping

(1) Area and Scale

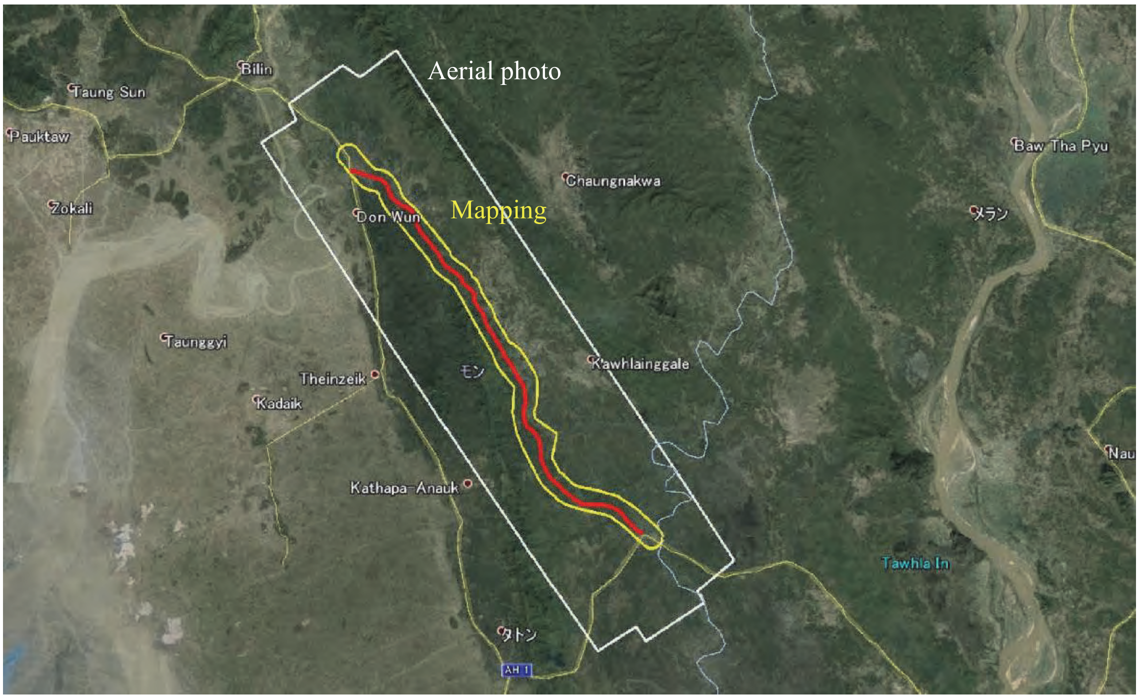
The area to be covered with new aerial photographs and digital topographic maps at a scale of 1:5,000 is approximately 250km^2 in Myanmar, which is used for The Project for Strengthening Connectivity of International Highway in Mekong Region in the Republic of the Union of Myanmar. The location of the aerial photography area and digital topographic mapping is shown in the attached map.

(2) Digital Photogrammetric Mapping Area

- Kyargalay Bypass

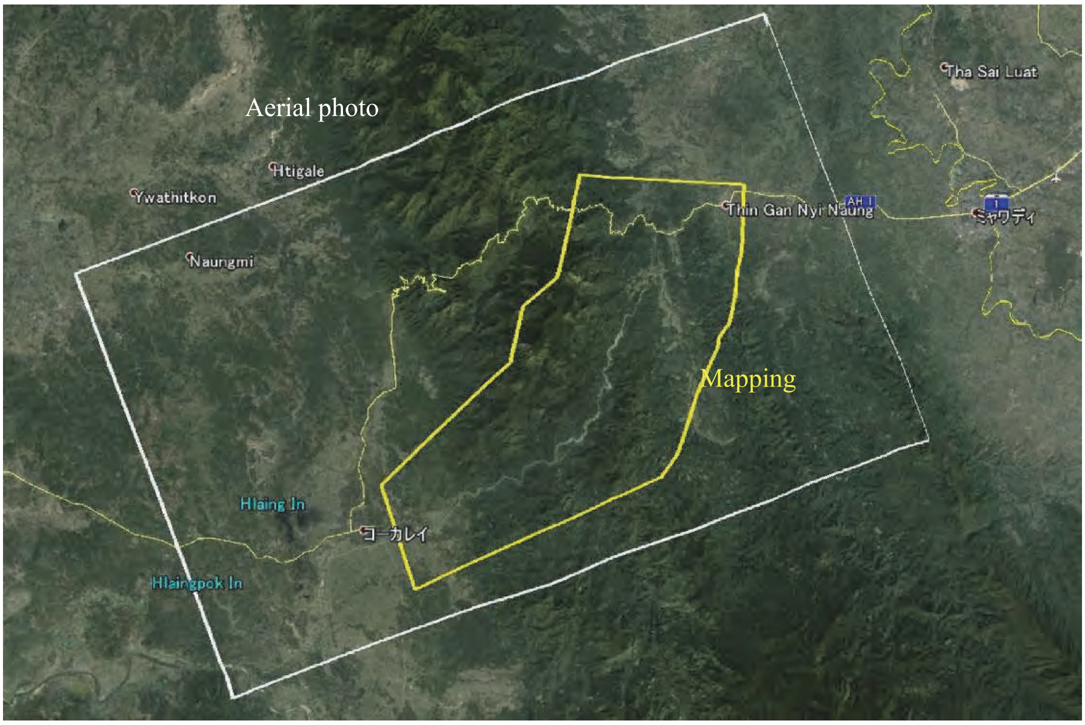


- Thaton Bypass



(3) Aerial Photo and Ortho Data Area

➢ <u>Dawna Bypass</u>



(4) Aerial Photo Area

➢ <u>Three Pagoda Pass</u>

(5) Survey Result

Source: JICA Survey Team

Figure 5.2.6 Thahton Bypass

Source: JICA Survey Team

Figure 5.2.7 Kyargalay Bypass

5.3 Geological Survey

The objective of the Survey is to provide preliminary data regarding the geological formation and geological properties along the Project site. The collected data and information are incorporated into the implementation of road, bridge and tunnel preliminary designs of the Project.

Geological Surveys are undertaken by a sub-contractor selected in accordance with JICA regulations. A detailed survey result is described in a report submitted by the sub-contractor. This section summarizes the geological surveys.

5.3.1 Scope of Work

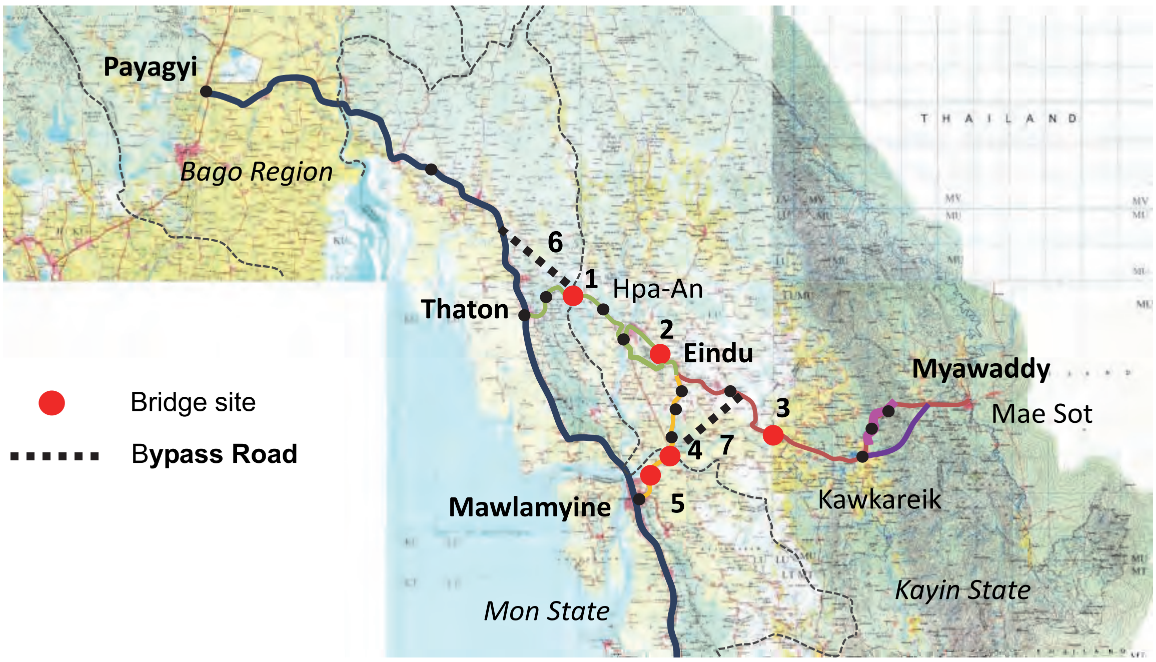
(1) Survey Area

Geological Surveys were carried out for five bridge sites and two bypass road sites (Thaton Bypass, Kyargalay Bypass). The Survey Area is shown in Figure 5.3.1.

Table 5.3.1 Location of survey area

Survey Site	Length	Approach*	Type	Width	Construction
1. Donthami Bridge	200m	2x100m	PC+RC	7.5m	1982
2. Naung Lon Bridge	115m	2x100m	RC	7.5m	1970s
3. Gyaing Kawkareik	400m	2x200m	Suspension	7.5m	1999
4. Gyaing Zathapyin	870m	2x250m	Suspension	8.5m	1999
5. Atran Bridge	433m	2x200m	Suspension	8.5m	1998
6. Thaton Bypass	2,900m	-	-	-	-
7. Kyargalay Bypass	2,500m	-	-	-	-

*Approach length is assumed and might vary depending on proposed new bridge location.
Source: JICA Survey Team



Source: JICA Survey Team

Figure 5.3.1 Location Map of Survey Area

(2) Survey Components

The following work was performed during geological investigation. The method followed was the America Society for Testing and Materials (ASTM). The detailed method is described in the sub-contractor's report.

- Setting up Boring Stage on Land and Water (River)
- Boring (Including Water level measuring and water sampling)
- Drilling with in-situ test (SPT, Pressuremeter) and sampling
- Sampling (Undisturbed, disturbed sampling and fill material test sampling)

Setting up Float Stage on River

Boring Work on Land

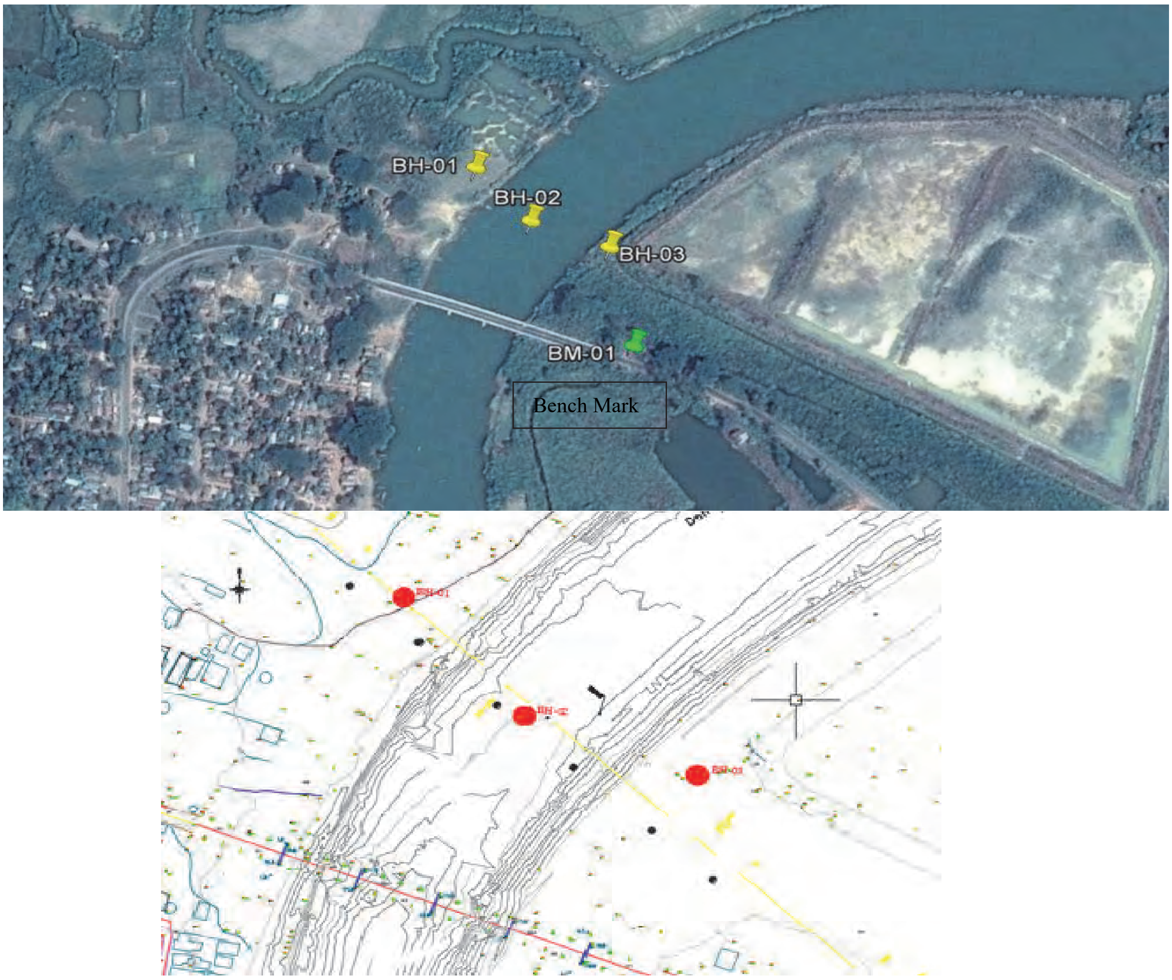
- Laboratory Test
    - Unit weight for undisturbed sample
    - Natural moisture contents
    - Atterberg limits (Liquid Limit/Plastic Limit) for cohesive soil
    - Grain size analysis (sieve + hydrometer)
    - Specific gravity
    - Unconfined compression test
    - Consolidation test
    - Direct Shear Test (UU)
    - CBR Test
    - Water quality test

5.3.2 Results of Survey

(1) Donthami Bridge

1) Soil Profile

The location map of borehole points as well as soil condition distribution under the Donthami Bridge is shown in Figure 5.3.2.

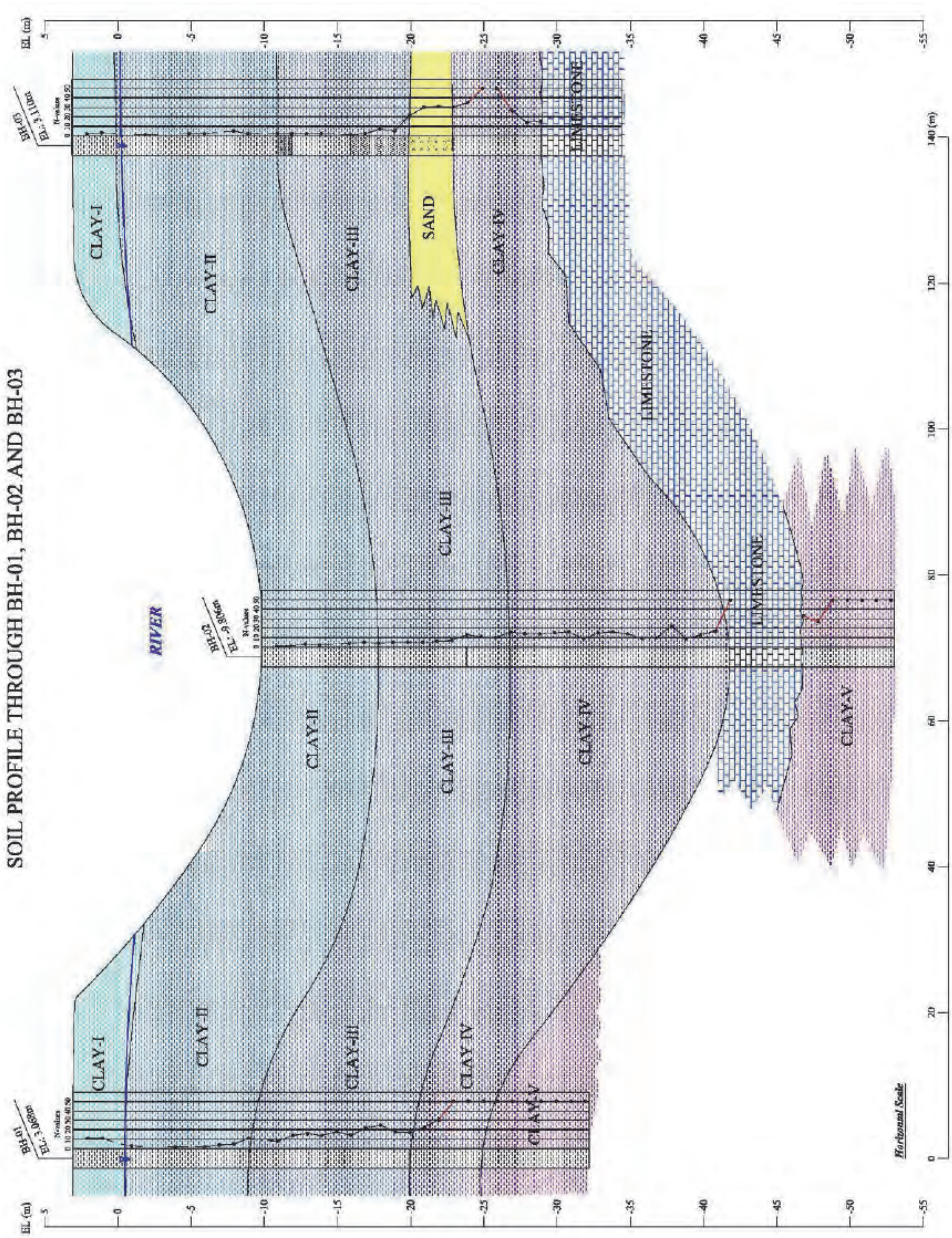


Source: Prepared by JICA Survey Team based on Google Earth

Figure 5.3.2 Location of Boreholes (Donthami Bridge)

Three soil investigations were carried out at the point of abutment and pier for the planned location of bridge construction. The drilling depth is from 35m to 43m. The seven different layers observed in the Project Area are described from top to bottom as follows. CLAY-I and CLAY-II are comparatively soft clay with low N-value and the colour is brown to mottled grey. CLAY-III is comparatively stiff, its N-value ranges widely, and the colour is reddish brown to pinkish brown. SAND is observed partially between the CLAY layers. CLAY-IV and CLAY-V are stiff residual soil. LIMESTONE is confirmed at all area as a basic rock.

① CLAY-I
② CLAY-II
③ CLAY-III
④ SAND
⑤ CLAY-IV (Residual Soil)
⑥ CLAY-V (Residual Soil)
⑦ LIMESTONE



Source: JICA Survey Team

Figure 5.3.3 Soil Profile for Donthami Bridge Area

2) Soil Property

A summary of the soil test results are shown in Figure 5.3.4.

Natural water content, specific gravity, fine content, unconfined compression strength test and consolidation test results are compiled in a graph as a depth distribution figure layer by layer.

The test items are shown in Table 5.3.2.

Table 5.3.2 Soil Test Items and Quantity (Donthami Bridge)

BH-No.	Physical Properties Test of Soil							Engineering Properties Test of Soil		Physical & Enginering Properties Test of Rock		Chemical Properties Test
	Natural Moisture Content Test	Specific Gravity Test	Particle Size Analysis Test		Atterberg's Limit Test		Unit Weight	Unconfined Compression Test	Consolidation Test	Unit Weight (Absolute Density)	Uniaxial Compressive Strength	Water Quality Test
			Sieve Analysis Test	Hydrometer Analysis Test	Liquid Limit Test	Plastic Limit Test						
BH-01	11	11	11	11	9	9	3	3	3	-	-	-
BH-02	10	10	10	10	8	8	1	1	1	-	-	-
BH-03	11	11	11	11	9	9	4	4	3	5	5	1
Total	**32**	**32**	**32**	**32**	**26**	**26**	**8**	**8**	**7**	**5**	**5**	**1**

Source: JICA Survey Team

Each test result is summarized as follows:

① Natural Moisture Content (W_n %)

Natural water content (W_n) for clay ranges from 21% to 55%, W_n for CLAY-II is comparatively high, about 42%. W_n for SAND is 12% on average and W_n for CLAY-IV, CLAY-V ranges from 18% to 23%.

② Specific Gravity (ρ_s)

Specific gravity (ρ_s)ranges from 2.6 to 2.7 in spite of the difference in soil type, sand, clay, gravel etc.

③ Liquid Limit, Plastic Limit test

This test is carried out for clay. The detailed soil classification based on this test result is CL and OL.

④ Particle Size Analysis Test

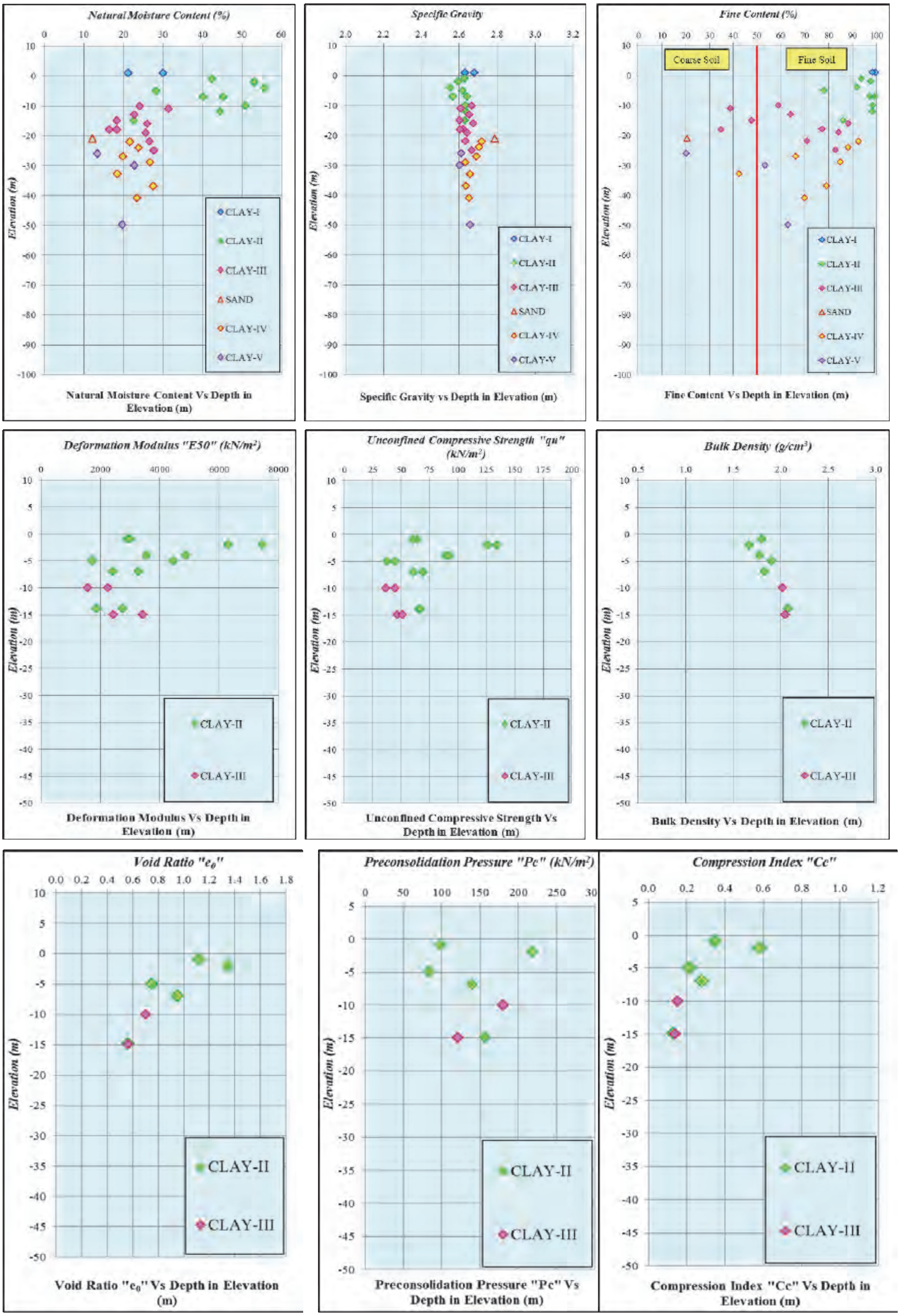
For CLAY-I and CLAY-II, the fine content ratio (<0.075mm) ranges almost over 90%. For CLAY-III, CLAY-IV and CLAY-V, the fine content ratio becomes comparatively low because of mixing with sand and gravel.

⑤ Unconfined Compression Strength Test (q_u kN/m^2)

For CLAY-II, the unconfined compression strength test (q_u kN/m^2) is 75kN/m^2 on average. For CLAY-III, q_u is comparatively low, 44kN/m^2 on average. The unit weight for CLAY-II is about 1.84 and 2.03 for CLAY-III comparatively high.

⑥ Consolidation Test

Pre-consolidation yield stress (P_c) ranges from 139kN/m^2 to 150kN/m^{2,} It indicates the soil is in an over-consolidated condition. And the compression Index (C_c) ranges from 0.14 to 0.31, comparatively low.



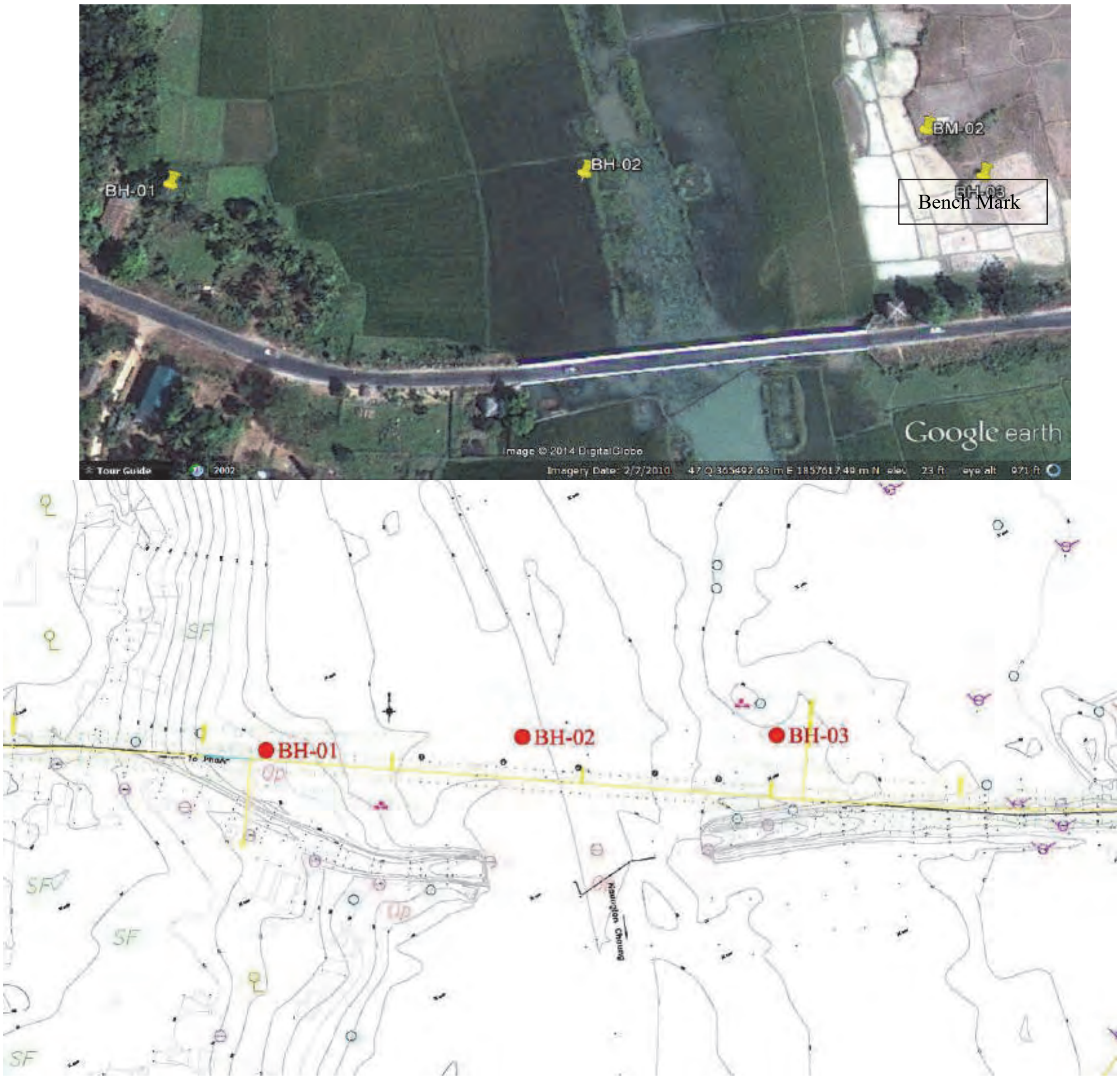
Source: JICA Survey Team

Figure 5.3.4 Summary of Soil Test Results for the Donthami Bridge Area

(2) Naung Lon Bridge

1) Soil Profile

The location map of the boring points is shown in below and soil condition distributed under the ground at Naung Lon Bridge is shown in Figure 5.3.5.

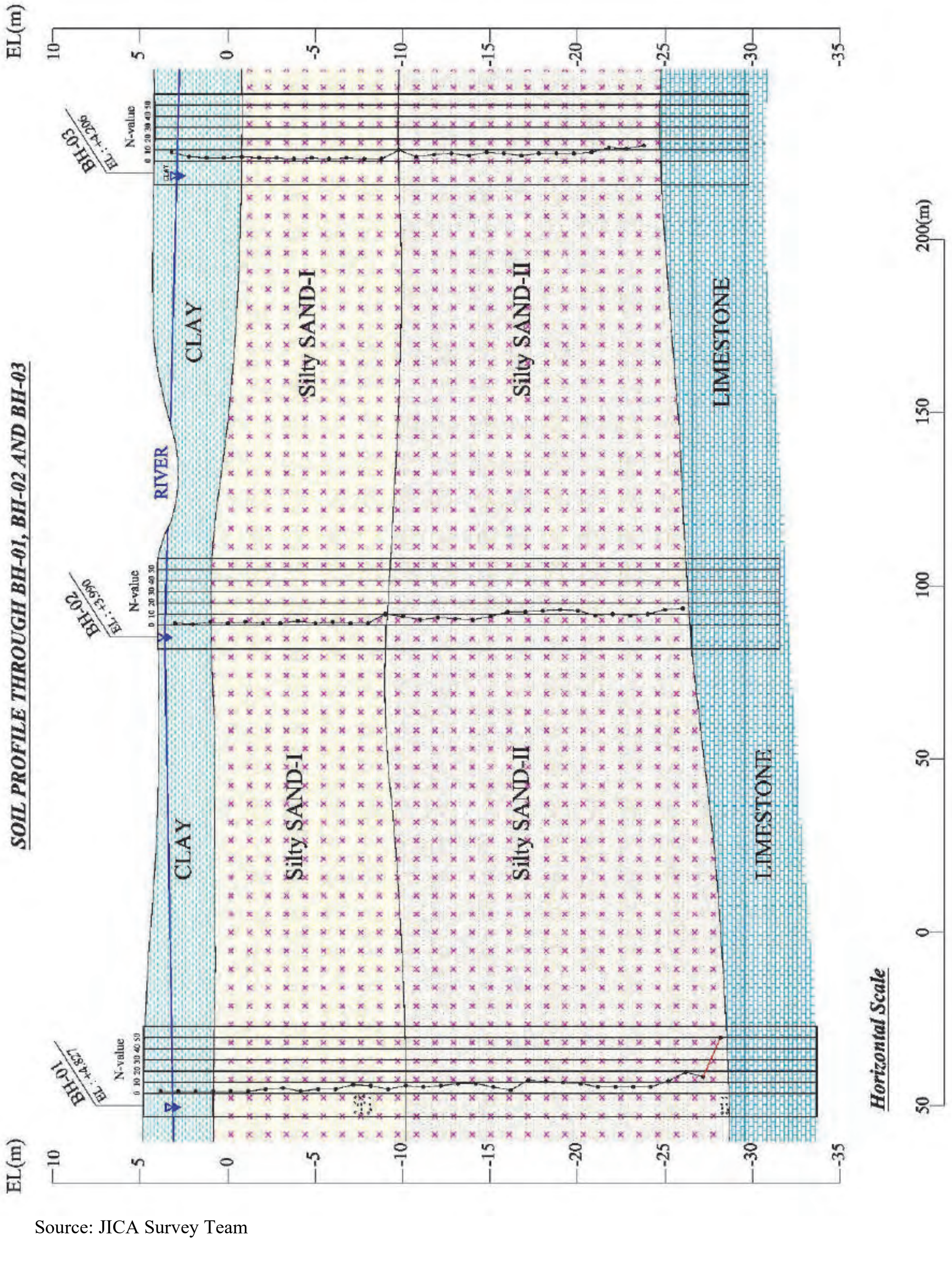


Source: Google, JICA Survey Team

Figure 5.3.5 Location of Boreholes (Naung Lon Bridge)

Three soil investigations were carried out at the point of abutment and pier for the planned location of bridge construction. The drilling depth was from 34m to 38.5m. The four different layers observed in the Project Area are described from top to bottom as follows. The top layer CLAY is soft clay with a thickness of 3m to 5m, and the colour is brown to mottled grey. Reddish brown SAND was found under the CLAY. The SAND is separated into loose SAND-I and medium dense SAND-II. LIMESTONE was found at all area at the bottom layer.

① CLAY
② Silty SAND-I
③ Silty SAND-II
④ LIMESTONE



Source: JICA Survey Team

Figure 5.3.6 Soil Profile for Naung Lon Bridge Area

2) Soil Property

A summary of the soil test results is shown in Figure 5.3.7. The test items are shown in Table 5.3.3.

In this area, a soft clay/silt layer of the upper surface soil was confirmed. Therefore, engineering property tests (unconfined compression strength test, consolidation test) were not carried out. Only physical tests (natural water content, specific gravity, fine content, Atterberg test) were carried out. Test results are compiled in a graph as a depth distribution figure layer by layer.

Table 5.3.3 Soil Test Items and Quantity (Naung Lon Bridge)

BH-No.	Physical Properties Test of Soil Samples						Physical and Mechanical Properties Test of Rock Core Samples				Chemical Analysis Test
	Natural Moisture Content Test	Specific Gravity Test	Particle Size Analysis Test		Atterberg's Limit Test		Unit Weight (Absolute Density)	Specific Gravity Test	Absorption Test	Uniaxial Compressive Strength Test	Water Quality Test
			Sieve Analysis Test	Hydrometer Analysis Test	Liquid Limit Test	Plastic Limit Test					
BH-01	11	11	11	11	3	3	1	1	1	1	1
BH-02	9	9	9	9	3	3	3	3	3	3	1
BH-03	10	10	10	10	2	2	-	-	-	-	1
Total	**30**	**30**	**30**	**30**	**8**	**8**	**4**	**4**	**4**	**4**	**3**

Source: JICA Survey Team

Each test result is summarized as follows:

① Natural Moisture Content (W_n %)

Natural water content (W_n) for clay varies greatly, ranging from 16% to 47%. W_n for silty SAND ranges from 19% to 32%, comparatively high because of contained silt.

② Specific Gravity (ρ_s)

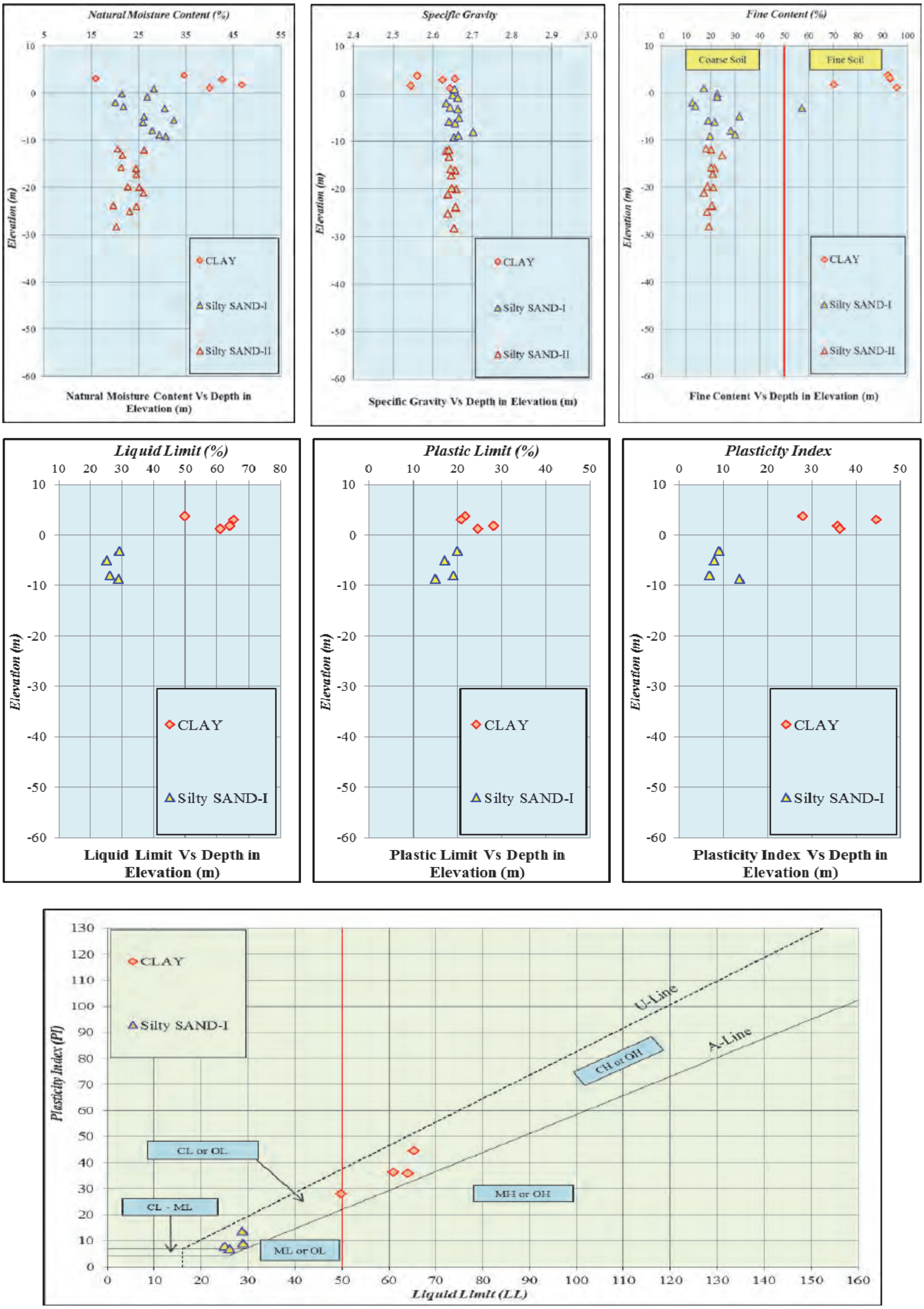
Specific gravity (ρ_s) ranges from 2.60 to 2.65 in spite of the difference in soil type, sand, clay, gravel etc.

③ Liquid Limit, Plastic Limit test

This test is carried out for clay. The detailed soil classification based on this test result is CL and OL for silty SAND, CH and OH for CLAY.

④ Particle Size Analysis Test

For CLAY, fine content ratio (<0.075mm) ranges almost over 90%. For silty SAND, fine content ratio ranges from 10% to 30%, comparatively low because of mixing with sand and gravel.



Condition of Atterberg's Limit Test Results

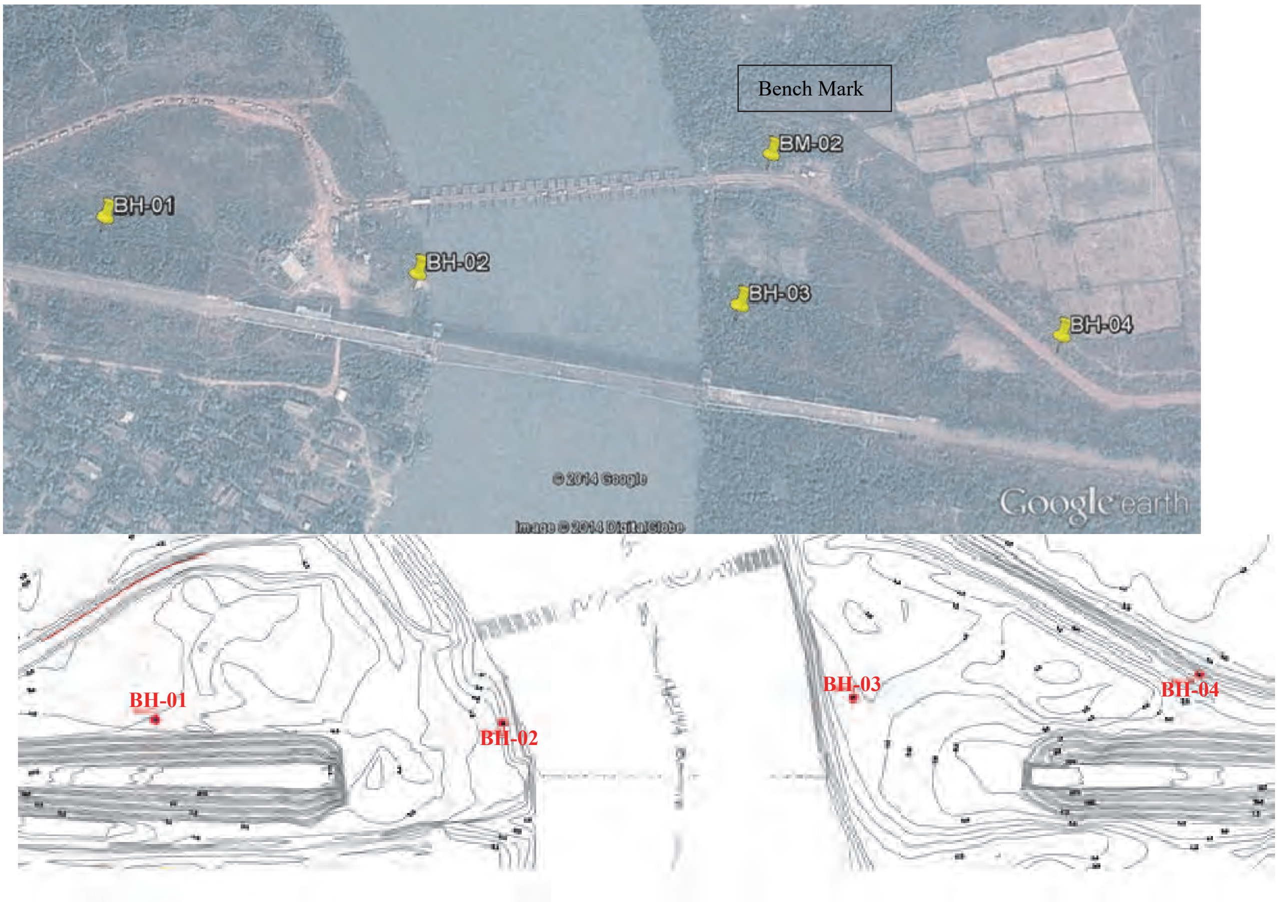
Source: JICA Survey Team

Figure 5.3.7 Summary of Soil Test Results for Naung Lon Bridge Area

(3) Gyaing Kawkareik Bridge

1) Soil Profile

The location map of boring points is shown in Figure 5.3.8 and the soil condition distributed under the ground at Gyaing Kawkareik Bridge is shown in Figure 5.3.9.

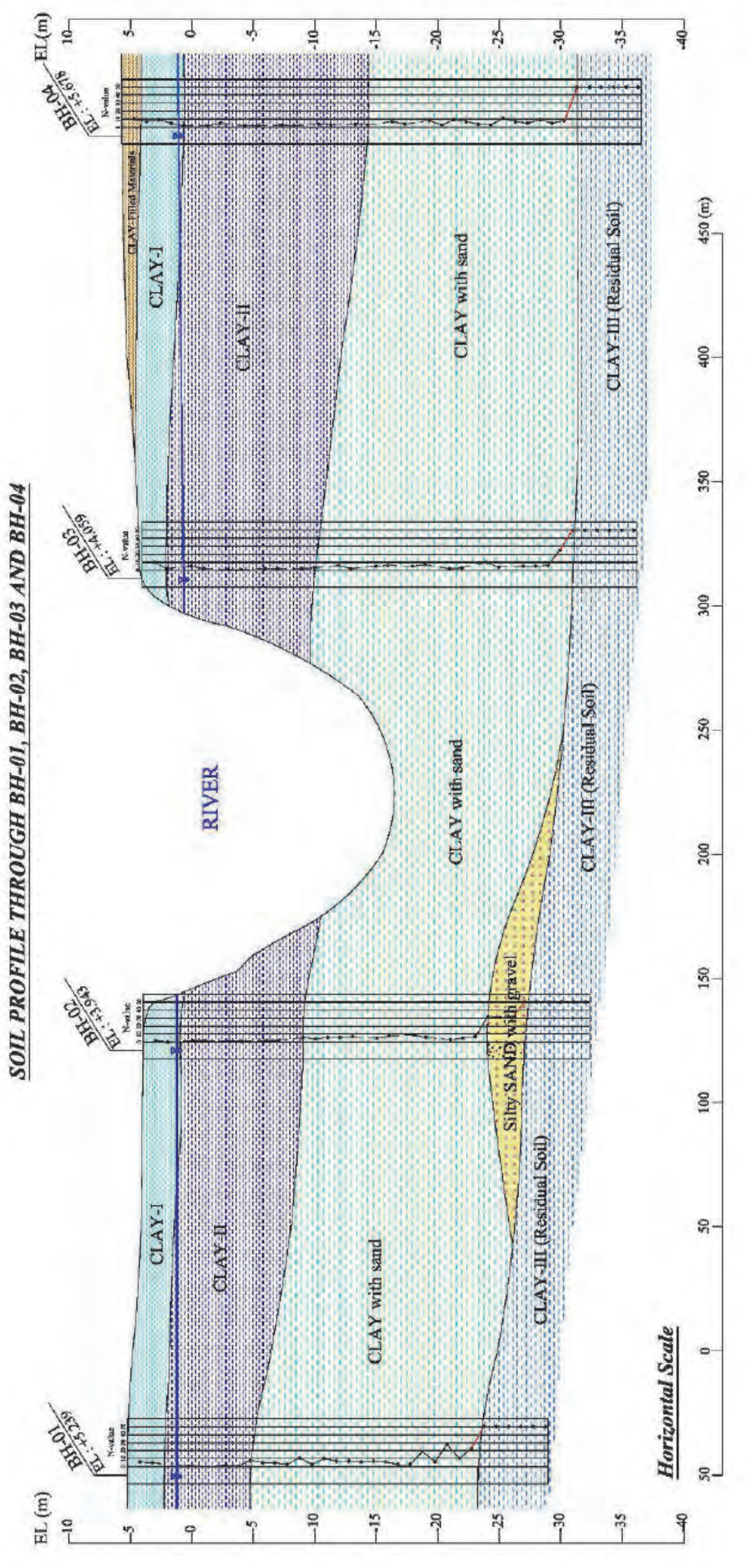


Source: Prepared by JICA Survey Team based on Google Earth

Figure 5.3.8 Loacation of Boreholes (Gyaing Kawkareiki Bridge)

Four soil investigations were carried out at the point of abutments and piers for the planned location of bridge construction. The drilling depth is from 34m to 40m. The six different layers observed in the Project Area are described from top to bottom as follows. The top layer CLAY is thin CLAY-Filled material. And next layer is soft CLAY-I and CLAY-II with a thickness of 2m to 15m. CLAY with sand has N-value from 2 to 19 widely distributing with a thickness of 15m to 21m. Silty SAND with gravel is partially confirmed. The bottom layer is CLAY-III (Residual soil) with N-value over 50 (very hard).

① CLAY-Filled Materials
② CLAY-I
③ CLAY-II
④ CLAY with sand
⑤ Silty SAND with gravel
⑥ CLAY-III (Residual Soil)



Source: JICA Survey Team

Figure 5.3.9 Soil Profile for Gyaing Kawkareiki Bridge Area

2) Soil Property

A summary of soil test results are shown in Figure 5.3.10. The test items are shown in Table 5.3.4.

Natural water content, specific gravity, fine content, unconfined compression strength test and consolidation test results are compiled in a graph as a depth distribution figure layer by layer.

Table 5.3.4 Soil Test Items and Quantity (Gyaing Kawkareik Bridge)

BH-No.	Physical Properties Test							Engineering Properties Test			Chemical Properties Test
	Natural Moisture Content Test	Specific Gravity Test	Particle Size Analysis Test		Atterberg's Limit Test		Unit Weight	Unconfined Compression Test	Consolidation Test	Direct Shear Test (UU)	Water Quality Test
			Sieve Analysis Test	Hydrometer Analysis Test	Liquid Limit Test	Plastic Limit Test					
BH-01	10	10	10	10	5	5	2	2	2	2	1
BH-02	11	11	11	11	8	8	7	7	6	5	-
BH-03	13	13	13	13	12	12	10	10	7	-	-
BH-04	15	15	15	15	14	14	8	8	5	6	1
Total	**49**	**49**	**49**	**49**	**39**	**39**	**27**	**27**	**20**	**13**	**2**

Source: JICA Survey Team

Each test result is summarized as follows:

① Natural Moisture Content (W_n %)

Natural water content (W_n) for clay ranges from 17% to 42%, Wn for CLAY-II is comparatively high, about 43%. W_n for Residual Soil is comparatively low, 12%.

② Specific Gravity (ρ_s)
Specific gravity (ρ_s) ranges from 2.69 to 2.76 in spite of the difference in soil type, sand, clay, gravel etc.

③ Liquid Limit, Plastic Limit test

This test is carried out for clay. The detailed soil classification based on this test result is almost CL and OL.

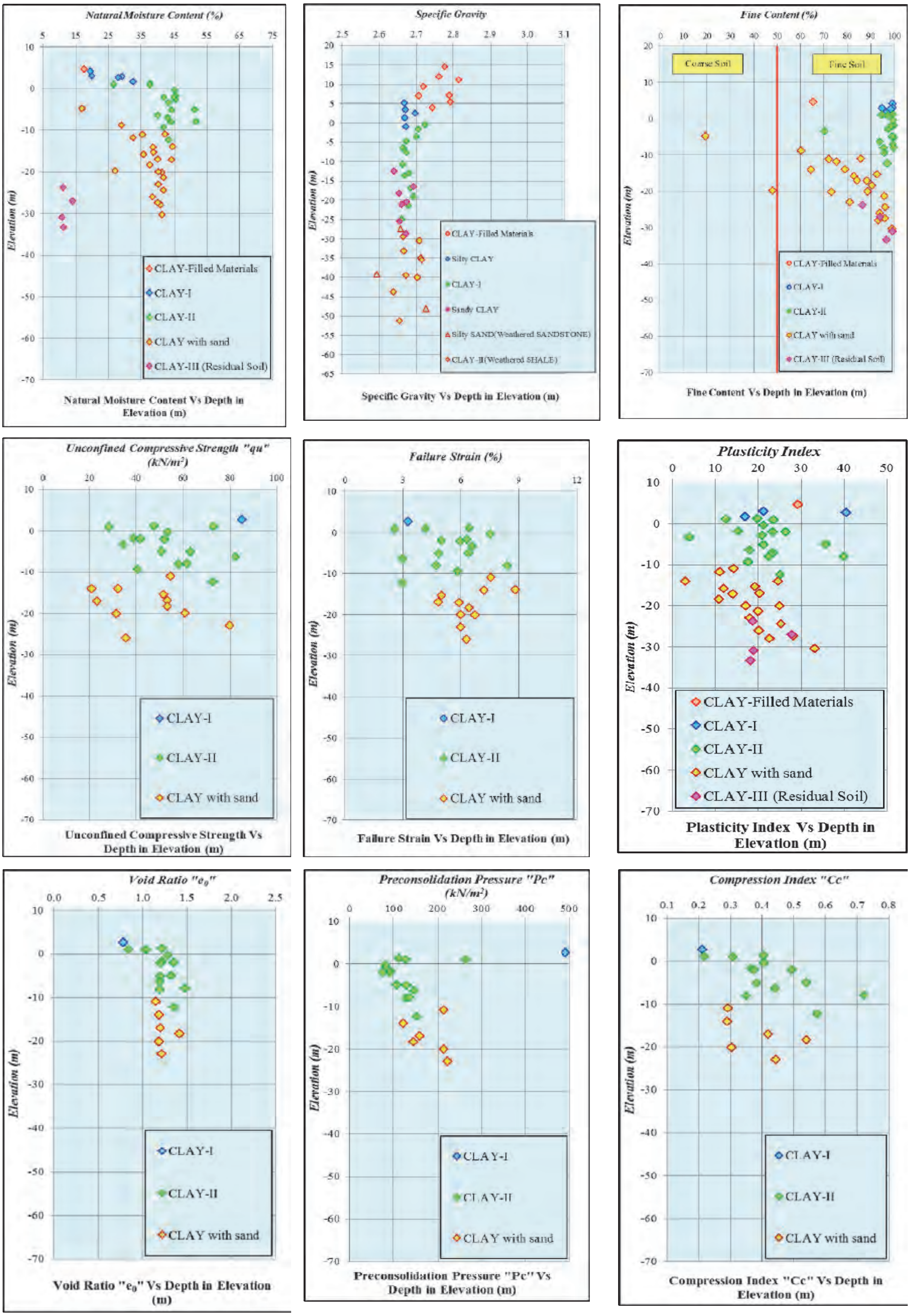
④ Particle Size Analysis Test

For CLAY, fine content ratio (< 0.075mm) ranges almost over 90%. For CLAY with sand, fine content ratio (< 0.075mm) is comparatively low, because of mixing with sand and gravel.

⑤ Unconfined Compression Strength Test (q_u kN/m^2)

For CLAY-I, unconfined compression strength test (qu kN/m^2) is 53kN/m^2 on average. For CLAY with sand, q_u is comparatively low, 45kN/m^2 on average.

⑥ Consolidation Test
Pre-consolidation yield stress (P_c) ranges from 120kN/m^2 to 490kN/m^2, which indicates the soil is in a very over-consolidated condition. And the compression index (C_c) ranges from 0.21 to 0.43, comparatively low.



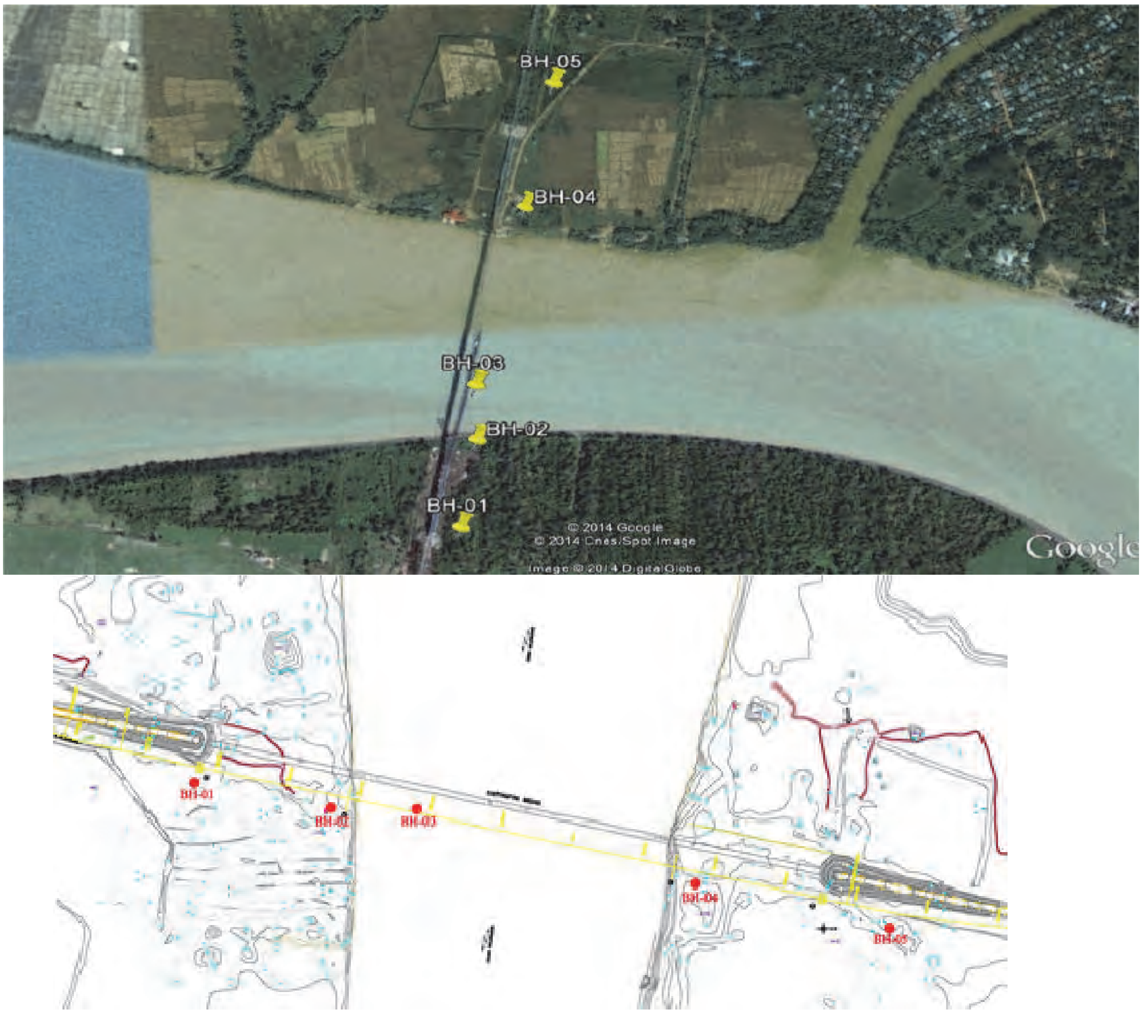
Source: JICA Survey Team

Figure 5.3.10 Summary of Soil Test Results for Gyaing Kawkareik Bridge Area

(4) Gyaing Zathapyin Bridge

1) Soil Profile

The location map of the boring points is shown in Figure 5.3.11 and the soil condition distributed under the ground at the Gyaing Zathapyin Bridge is shown in Figure 5.3.12.

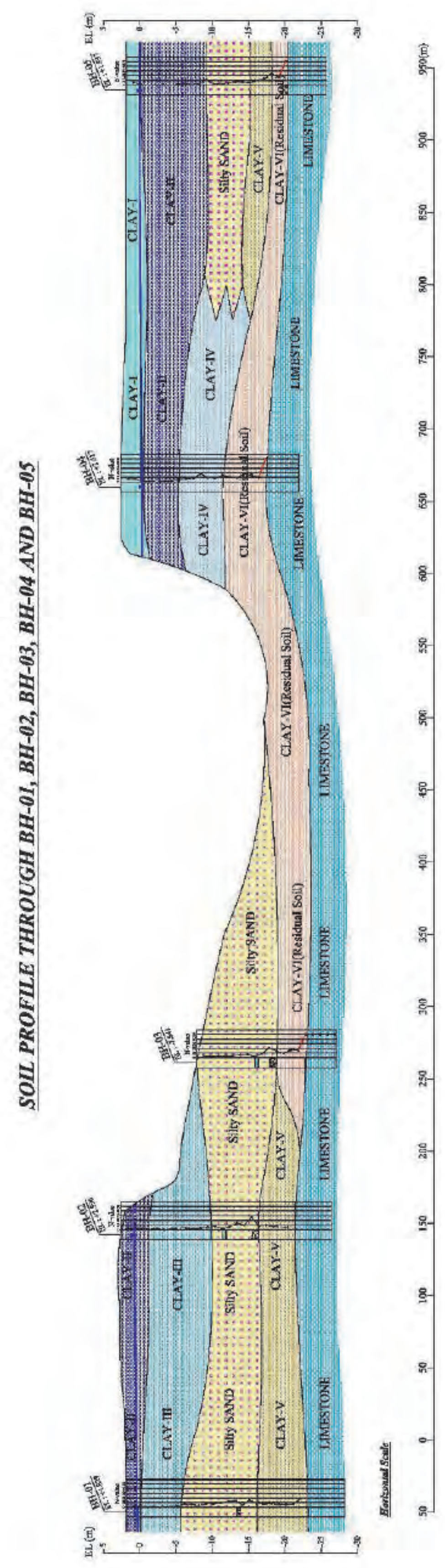


Source: Prepared by JICA Survey Team based on Google Earth

Figure 5.3.11 Location of Boreholes (Gyaing Zathapyin Bridge)

Five soil investigations were carried out at the points of abutments and piers for the planned location of bridge construction. The drilling depth is from 19m to 30m. Eight different layers observed in the Project Area are described from top to bottom as follows. CLAY-I, CLAY-II and CLAY-III are soft clay with brown grey colour. The next layers, CLAY-IV and CLAY-V, are comparatively hard with N-value 5 to 134 with a reddish brown grey colour. Below, silty SAND has a greatly varying N-value of 2 to 21. At the bottom, LIMESTONE is found at all areas as a basic rock.

① CLAY-I
② CLAY-II
③ CLAY-III
④ CLAY-IV
⑤ Silty SAND
⑥ CLAY-V
⑦ CLAY-VI (Residual Soil)
⑧ LIMESTONE



Source: Google, JICA Survey Team

Figure 5.3.12 Soil Profile for Gyaing Zhatapyin Bridge Area

2) Soil Property

A summary of the soil test results are shown in Figure 5.3.13. The test items are shown in Table 5.3.5.

Natural water content, specific gravity, fine content, unconfined compression strength test and consolidation test results are compiled in a graph as a depth distribution figure layer by layer.

Table 5.3.5 Soil Test Items and Quantity (Gyaing Zathapyin Bridge)

BH-No.	Physical Properties Test										Engineering Properties Test				Chemical Properties Test
	Soil							Rock			Soil			Rock	
	Natural Moisture Content Test	Specific Gravity Test	Particle Size Analysis Test		Atterberg's Limit Test		Unit Weight	Unit Weight (Absolute Density)	Specific Gravity Test	Absorption Test	Unconfined Compression Test	Consolidation Test	Direct Shear Test (UU)	Uniaxial Compressive Strength Test	Water Quality Test
			Sieve Analysis Test	Hydrometer Analysis Test	Liquid Limit Test	Plastic Limit Test									
BH-01	12	12	12	10	6	6	1	5	5	5	1	1	1	5	1
BH-02	11	11	11	9	9	9	3	3	3	3	3	3	3	3	1
BH-03	7	6	7	5	4	4	-	-	-	-	-	-	-	-	-
BH-04	8	8	8	8	8	8	1	2	2	2	1	1	-	2	1
BH-05	13	13	13	13	12	12	4	-	-	-	4	4	2	-	1
Total	**51**	**50**	**51**	**45**	**39**	**39**	**9**	**10**	**10**	**10**	**9**	**9**	**6**	**10**	**4**

Source: JICA Survey Team

Each test result is summarized as follows:

① Natural Moisture Content (Wn %)

Natural water content (Wn) for clay ranges from 17% to 49%, Wn for CLAY-II, CLAY-III is comparatively high, about 37%. Wn for residual soil is comparatively low, 27%.

② Specific Gravity（ρs）

Specific gravity（ρs）ranges from 2.63 to 2.72 in spite of the difference in soil type, sand, clay, gravel etc.

③ Liquid Limit, Plastic Limit test

This test is carried out for clay. The detailed soil classification based on this test result is almost CL and OL.

④ Particle Size Analysis Test

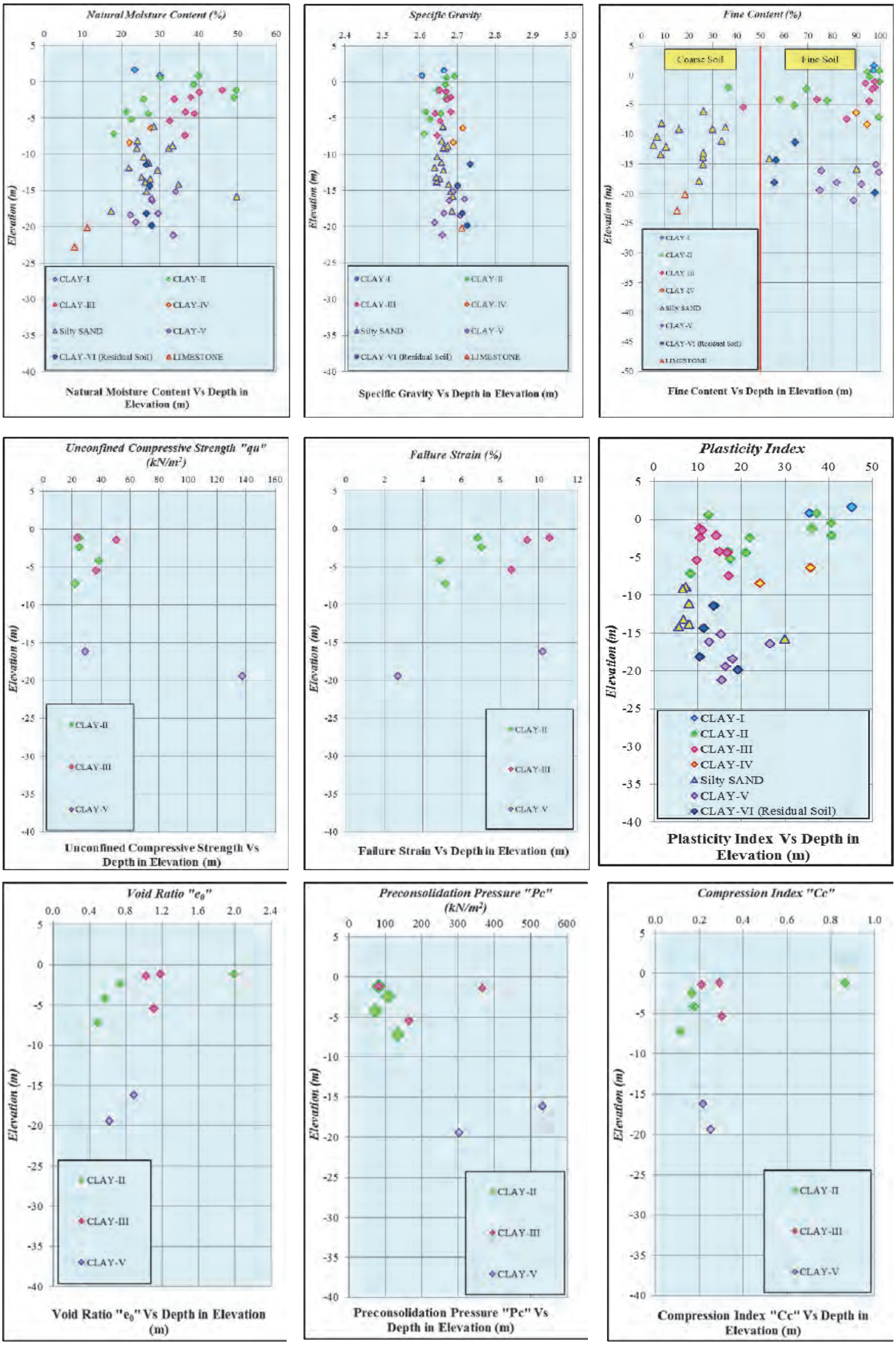
For CLAY, the fine content ratio (<0.075mm) ranges almost over 90%. For other soil, the fine content ratio (<0.075mm) is comparatively low, because of mixing with sand and gravel.

⑤ Unconfined Compression Strength Test (qu kN/m^2)

For CLAY-II, qu is 27kN/m^2 on average and for CLAY-III, qu is 36kN/m^2 on average. For CLAY-V, qu is comparatively high, 83kN/m^2 on average.

⑥ Consolidation Test

Pre-consolidation yield stress (Pc) ranges from 99kN/m^2 to 420kN/m^2, which indicates the soil is in a very over-consolidated condition. And the compression index (Cc) ranges from 0.2 to 0.3, comparatively low.



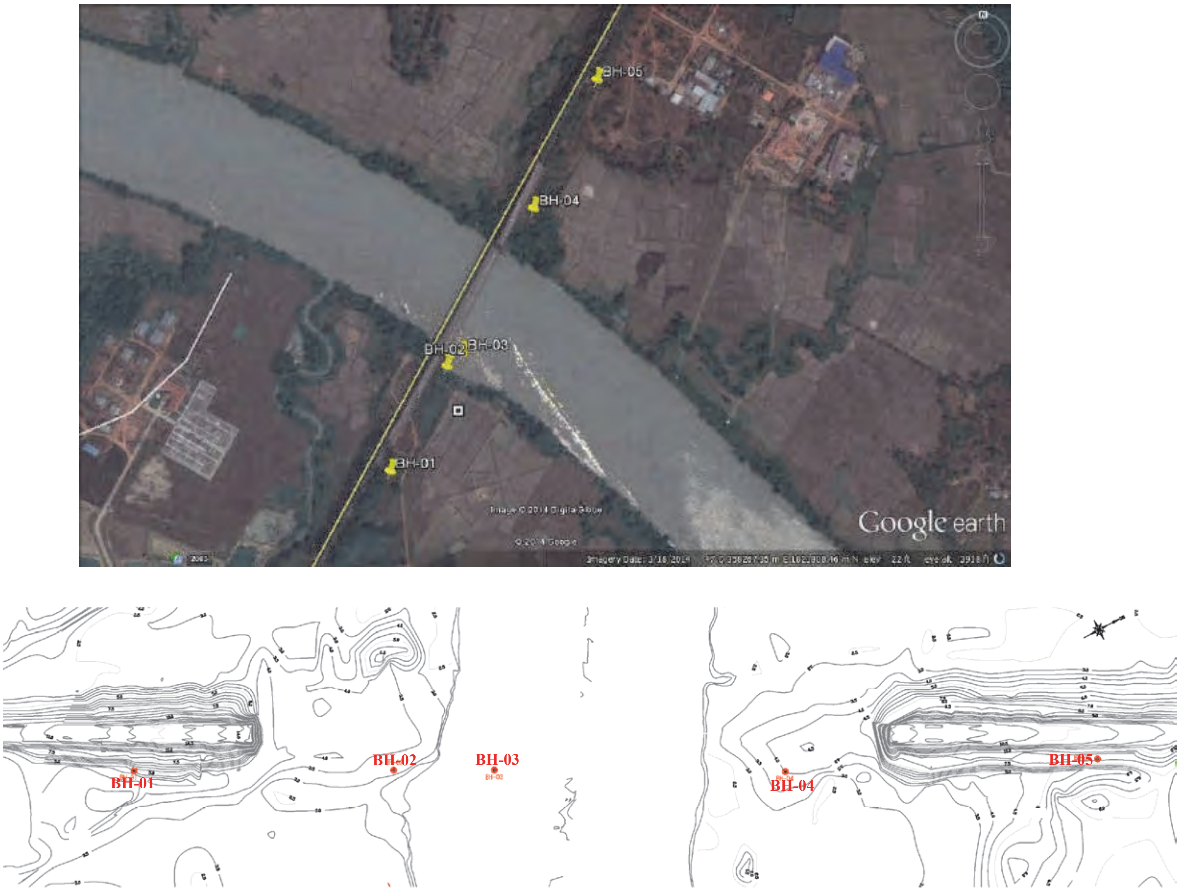
Source: JICA Survey Team

Figure 5.3.13 Summary of Soil Test Results for Gyaing Zhatapyin Bridge Area

(5) Atran Bridge

1) Soil Profile

The location map of the boring points is as shown in Figure 5.3.14 and the soil condition distributed under the ground at the Atran Bridge area is shown in Figure 5.3.15.

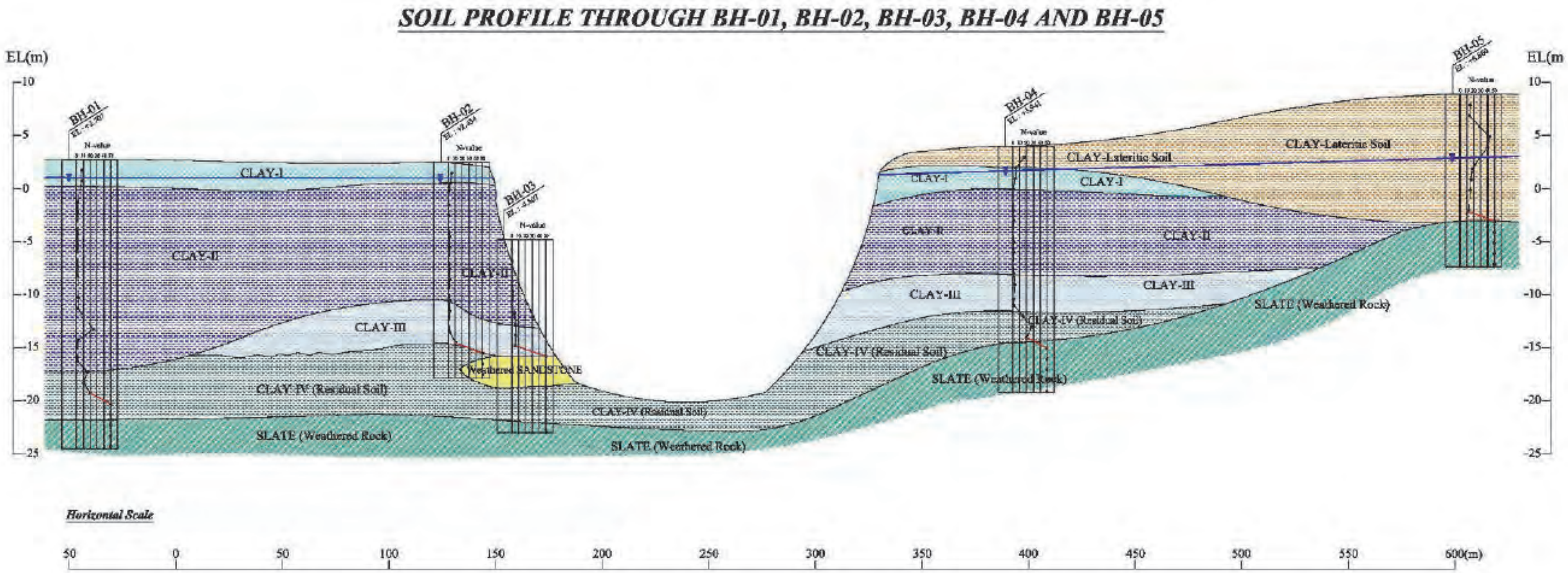


Source: Prepared by JICA Survey Team based on Google Earth

Figure 5.3.14 Loacation of Boreholes (Atran Bridge)

Five soil investigations were carried out at the point of abutment and pier for the planned location of bridge construction. The drilling depth is from 16m to 27m. Seven different layers observed in the Project Area are described from top to bottom as follows. CLAY-Lateritic Soil is a reddish brown colour and mixed with gravel at random. CLAY-I, CLAY-II and CLAY-III are soft clay with a brown grey colour. Next layer CLAY-IV (residual Soil) is hard. SLATE (Weathered Rock) is very hard with N-value over 50, it is estimated to be distributed in all areas as a basic rock.

① CLAY-Lateritic Soil
② CLAY-I
③ CLAY-II
④ CLAY-III
⑤ Weathered SANDSTONE
⑥ CLAY-IV (Residual Soil)
⑦ SLATE (Weathered Rock)



Source: JICA Survey Team

Figure 5.3.15 Soil Profile of Survey Area at Atran Bridge

2) Soil Property

A summary of soil test results are shown in Figure 5.3.16. The test items are shown in Table 5.3.6. Natural water content, specific gravity, fine content, unconfined compression strength test and consolidation test results are compiled in a graph as a depth distribution figure layer by layer.

Table 5.3.6 Soil Test Items and Quantity (Atran Bridge)

BH-No.	Physical Properties Test							Engineering Properties Test			Chemical Properties Test
	Natural Moisture Content Test	Specific Gravity Test	Particle Size Analysis Test		Atterberg's Limit Test		Unit Weight	Unconfined Compression Test	Consolidation Test	Direct Shear Test (UU)	Water Quality Test
			Sieve Analysis Test	Hydrometer Analysis Test	Liquid Limit Test	Plastic Limit Test					
BH-01	15	15	15	15	13	13	6	6	6	6	1
BH-02	12	12	12	12	12	12	5	5	5	5	1
BH-03	6	6	6	6	6	6	2	2	2	2	-
BH-04	10	9	9	9	9	9	4	4	4	4	1
BH-05	7	7	7	7	6	6	-	-	-	1	1
Total	**50**	**49**	**49**	**49**	**46**	**46**	**17**	**17**	**17**	**18**	**4**

Source: JICA Survey Team

Each test result is summarized as follows:

① Natural Moisture Content (Wn %)

Natural water content (Wn) for clay ranges from 22% to 42%, Wn for CLAY-II, CLAY-III is comparatively high, about 39% to 42%. Wn for residual soil is comparatively low, 18%.

② Specific Gravity（ρs）

Specific gravity（ρs）ranges from 2.67 to 2.75 in spite of the difference in soil type, sand, clay, gravel etc.

③ Liquid Limit, Plastic Limit test

This test is carried out for clay. The detailed soil classification based on this test result is CL to OL and CH to OH.

④ Particle Size Analysis Test

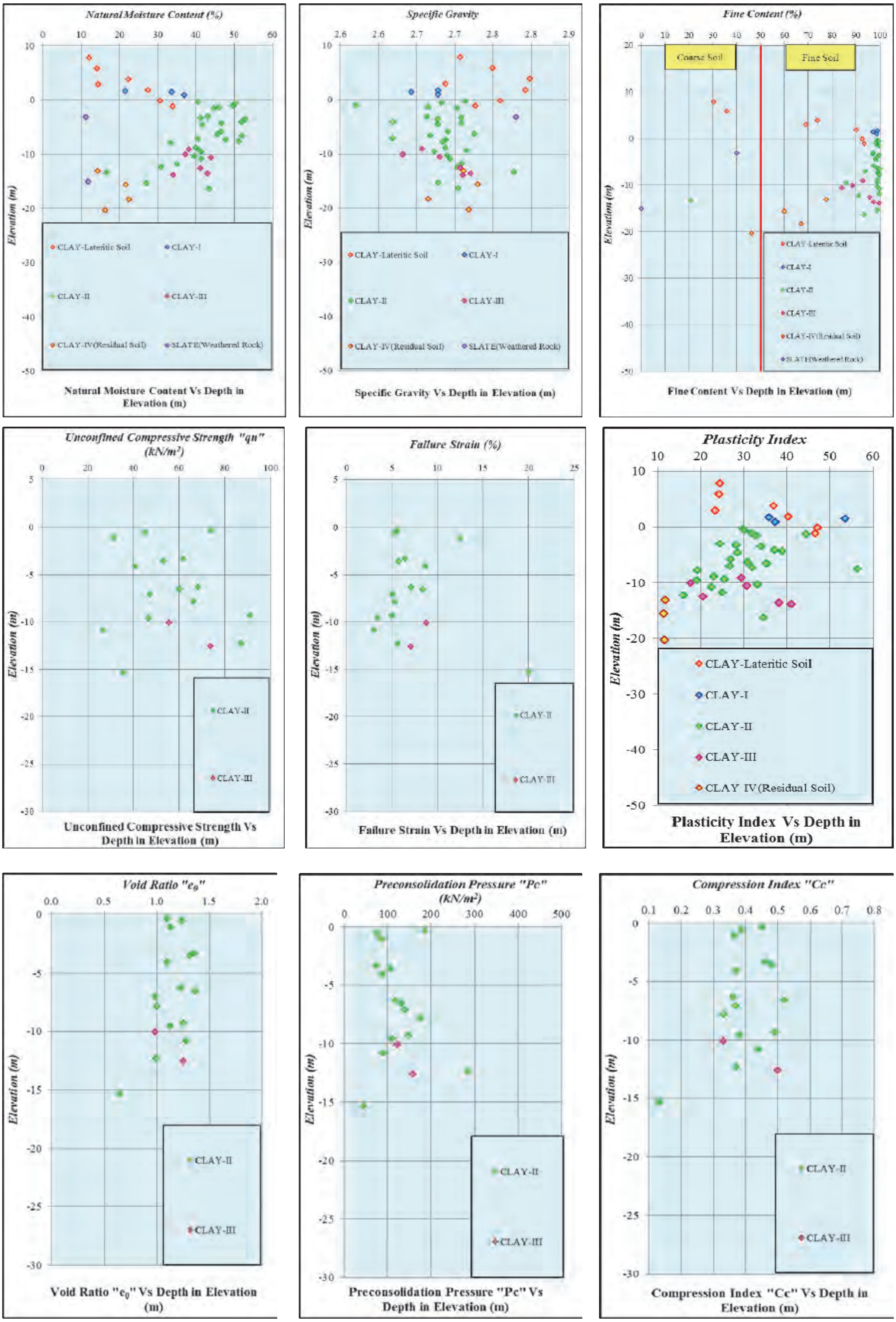
For CLAY, the fine content ratio (<0.075mm) ranges almost over 90%. For other soil, the fine content ratio (<0.075mm) is comparatively low, because of mixing with sand and gravel.

⑤ Unconfined Compression Strength Test (qu kN/m^2)

For CLAY-II, qu is 55kN/m^2 on average and for CLAY-III, qu is 64kN/m^2 on average.

⑥ Consolidation Test

Pre-consolidation yield stress (Pc) ranges from 123kN/m^2 to 139kN/m^2, which indicates the soil is very over-consolidated condition. And the compression index (Cc) ranges from 0.39 to 0.42, comparatively low.



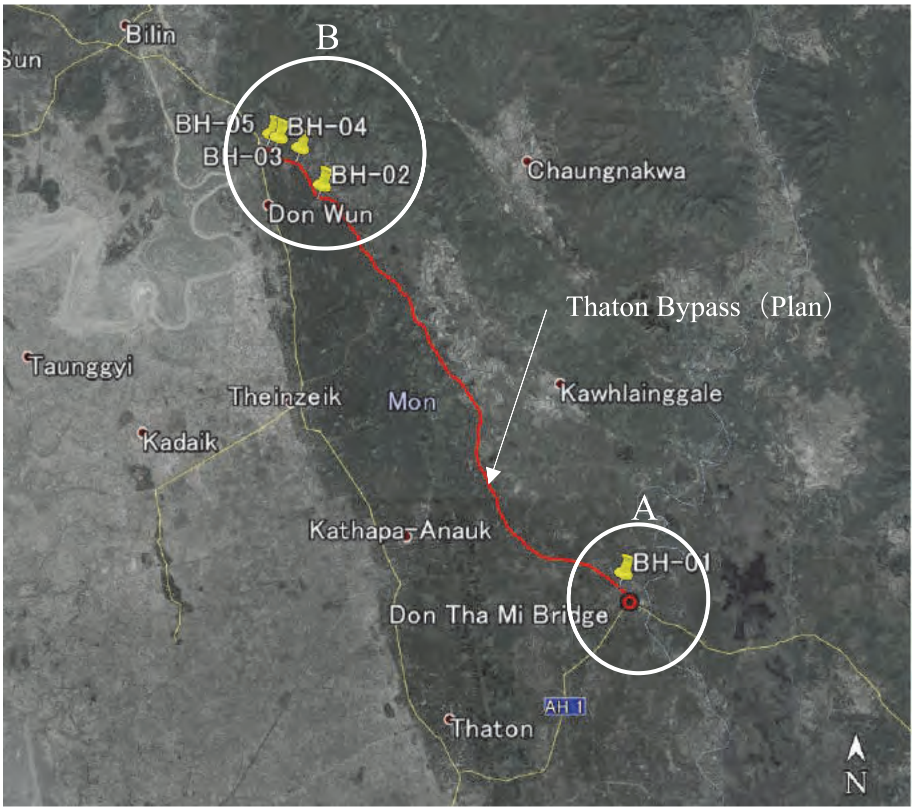
Source: JICA Survey Team

Figure 5.3.16 Summary of Soil Test Results for Atran Bridge Area Area

(6) Thaton Bypass

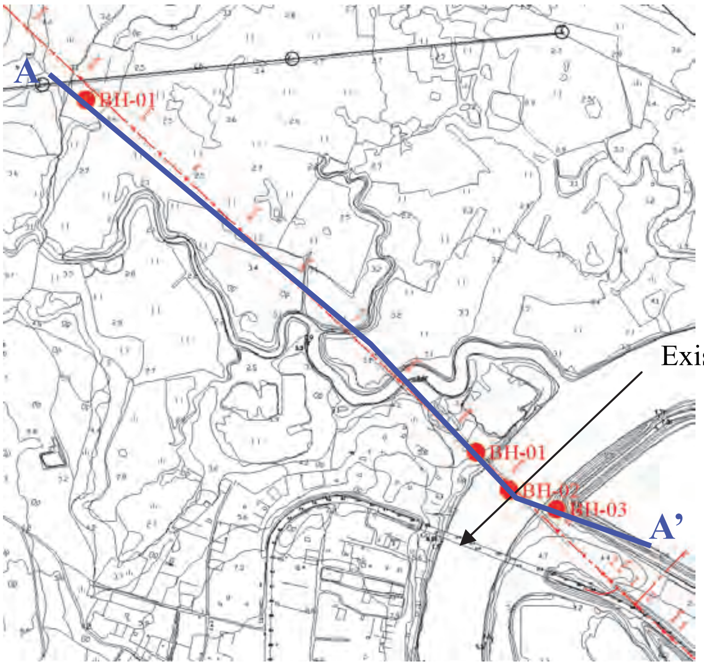
1) Soil Profile

The location map of the boring points is shown in Figure 5.3.17 to Figure 5.3.19.The soil profile is shown in Figure 5.3.20 to Figure 5.3.22.



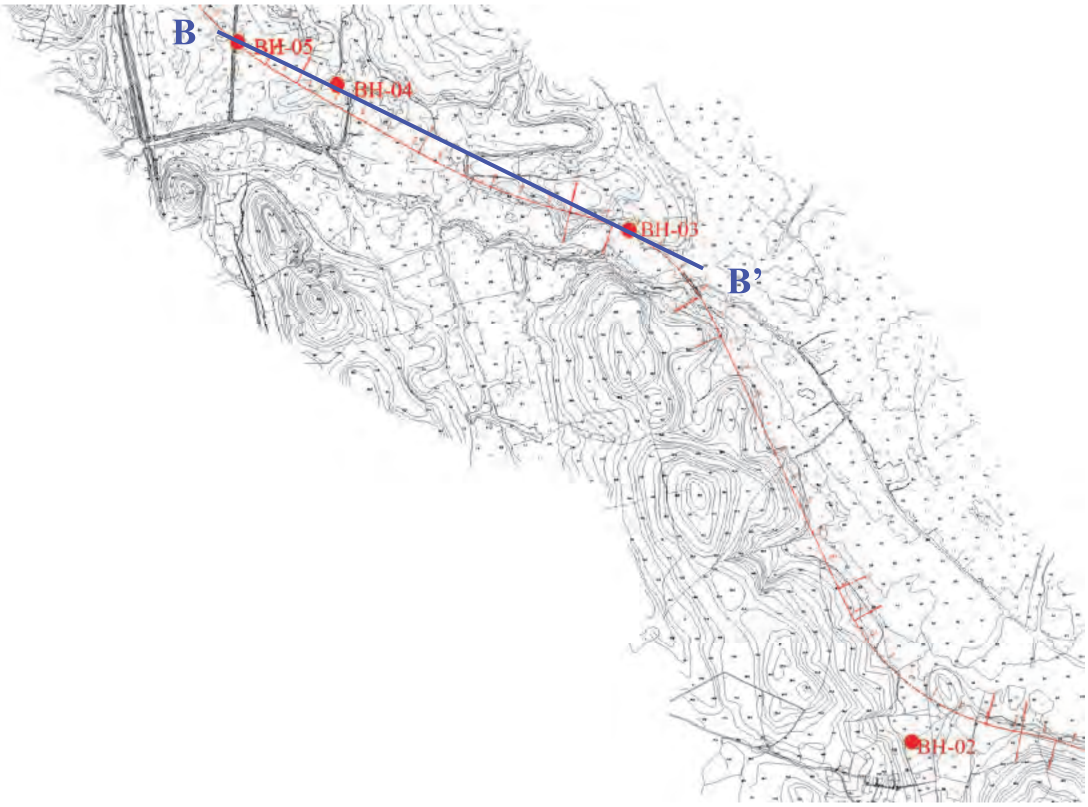
Source: Prepared by JICA Survey Team based on Google Earth

Figure 5.3.17 Location of Boreholes (Thaton Bypass)



Source: JICA Survey Team

Figure 5.3.18 Location of Boreholes (Thaton Bypass / A portion)



Source: JICA Survey Team

Figure 5.3.19 Location of Boreholes (Thaton Bypass / B portion)

Table 5.3.7 Coordinates for Boreholes in Thaton Bypass

No.	Borehole No.	Coordinate (E)	Coordinate (N)	Elevation (m)
1	BH-01	333676.000	1878704.000	3.542
2	BH-02	320404.000	1896355.000	7.262
3	BH-03	319451.000	1898078.000	6.905
4	BH-04	318470.000	1898568.000	6.982
5	BH-05	318136.000	1898711.000	6.447

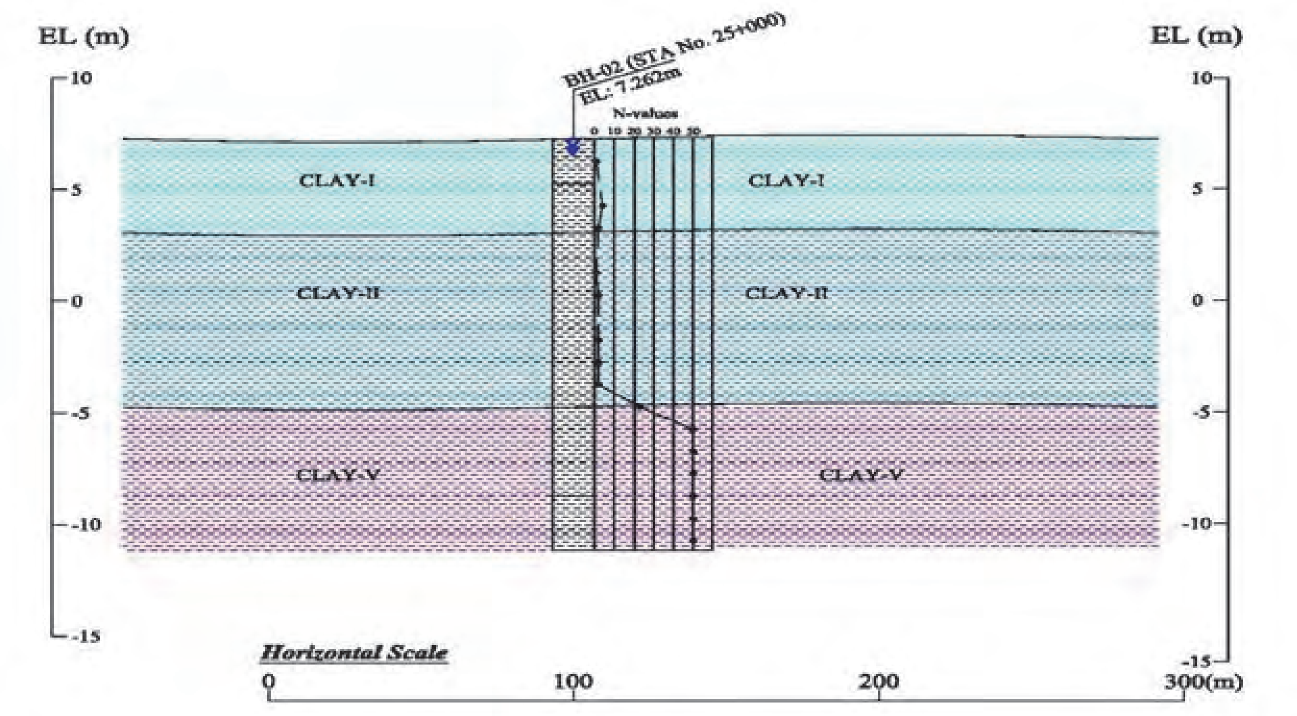
Source: JICA Survey Team

Five soil investigations were carried out along the Thaton Bypass. The ground elevation at the area is almost comparatively high, it means ground condition is good. Therefore, the boring points are only for the low land area which is estimated to be a soft soil distributed area. The drilling depth is from 35m to 43m. Since the length of Thaton Bypass is long, the soil profile is made by dividing into three section as shown in Figure 5.3.13 (1)(2)(3).
Seven different layers were observed in the Project Area are described from top to bottom as follows:

① CLAY-I
② CLAY-II
③ CLAY-III
④ SAND
⑤ CLAY-IV (Residual Soil)
⑥ CLAY-V (Weathered Shale)
⑦ Weathered LIMESTONE

In the top layer, CLAY-I and CLAY-II is confirmed only at Dontham Bridge area and at BH-1, BH-2 and BH-3. N-value ranges from 1 to 10 widely, and it is soft on the whole. CLAY-II is specially very soft with N-value less than 5 and the colour is grey.
For CLAY-III confirmed at BH-1, BH-4 and BH-5, it is comparatively hard with N-value 2 to 28, and the colour is reddish brown.
For SAND confirmed at BH-1, BH-4 and BH-5 with a thickness of 1.5m to 7m, the N-value widely ranges from 4 to 22, and its colour is yellowish brown.
For CLAY-IV (Residual Soil) confirmed at BH-3, it is stiff with N-value 24 to 32, and its colour is grey.
For CLAY-V (Weathered Shale) confirmed at BH-2, BH-3, its N-value is from 23 to 50, very hard.
For Weathered LIMESTONE distributed in the whole Survey Area as basic rock, it is very hard with N-value over 50. Weathered SANDSTONE is confirmed with thin thickness only at BH-3.

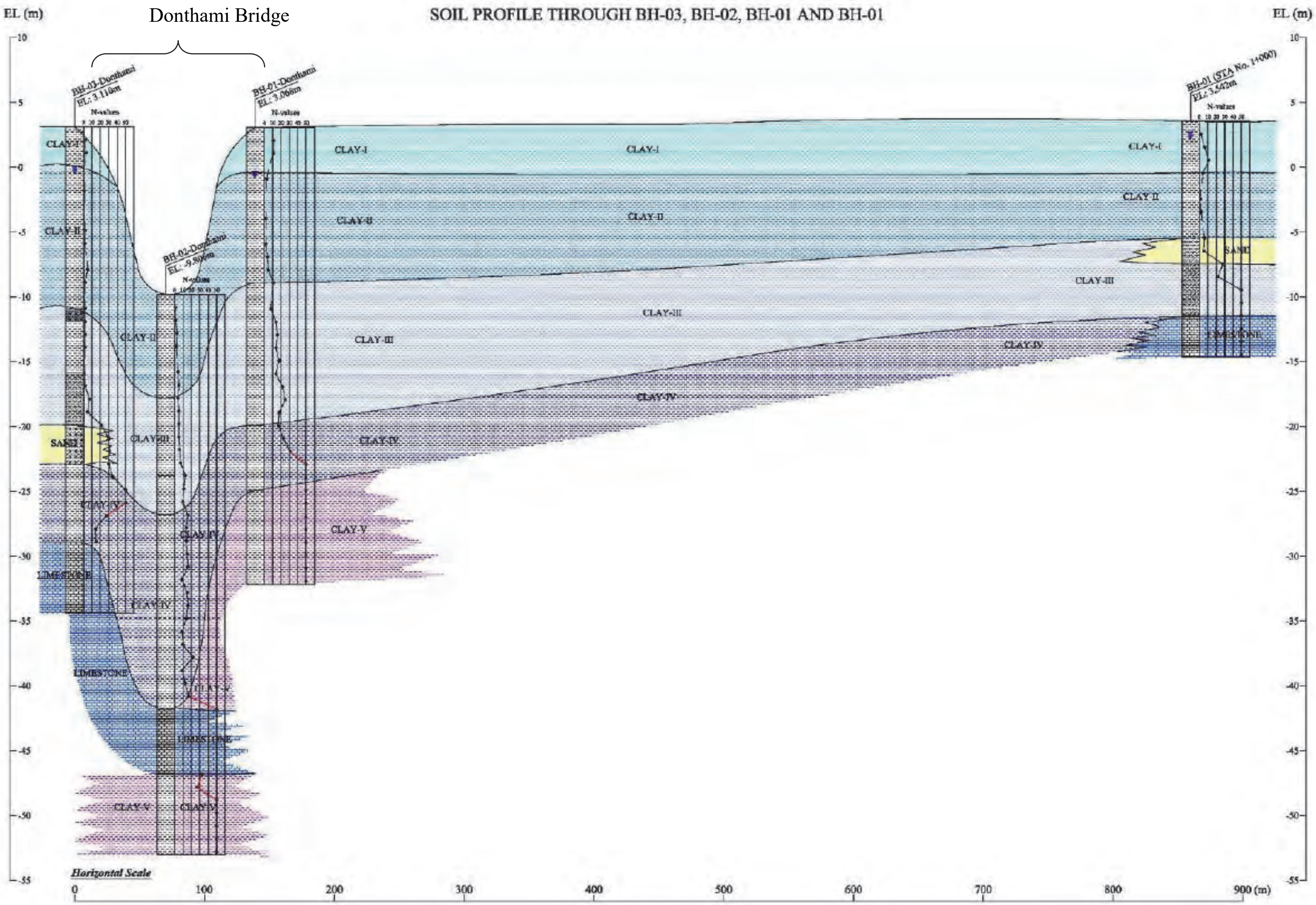
BH-2 (STA No.25)



Source: JICA Survey Team

Figure 5.3.20 Soil Profile in Thaton Bypass (BH-2)

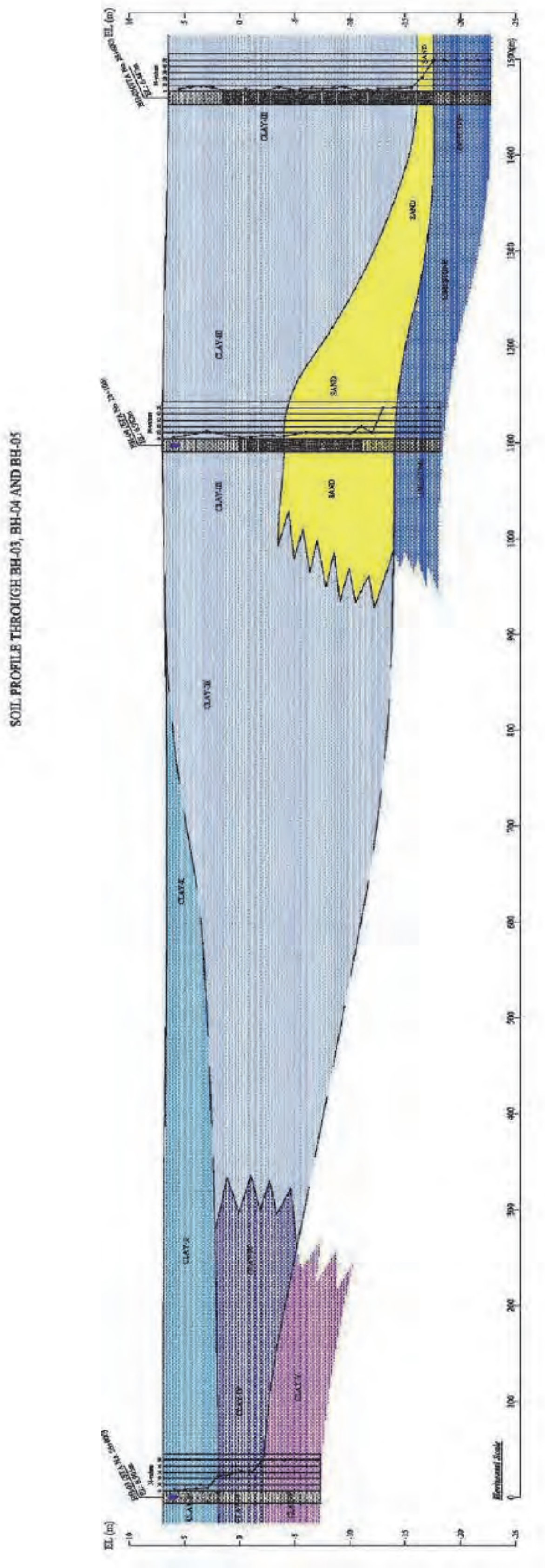
< Section A – A′>



Source: JICA Survey Team

Figure 5.3.21 Soil Profile in Thaton Bypass (Section A-A')

< Section B – B′>



Source: JICA Survey Team

Figure 5.3.22 Soil Profile in Thaton Bypass (Section B-B')

2) Soil Property

A summary of soil test results are shown in Figure 5.3.23. The test items are shown in Table 5.3.8.

Natural water content, specific gravity, fine content, unconfined compression strength test and consolidation test results are compiled in a graph as a depth distribution figure layer by layer.

Table 5.3.8 Soil Test Items and Quantity (Thaton Bypass)

BH-No.	Physical Properties Test							Engineering Properties Test	
	Natural Moisture Content Test	Specific Gravity Test	Particle Size Analysis Test		Atterberg's Limit Test		Unit Weight	Unconfined Compression Test	Consolidation Test
			Sieve Analysis Test	Hydrometer Analysis Test	Liquid Limit Test	Plastic Limit Test			
BH-01	6	6	6	6	5	5	2	2	2
BH-02	7	7	7	7	7	7	3	3	3
BH-03	5	5	5	5	5	5	-	-	-
BH-04	8	8	8	8	7	7	-	-	-
BH-05	7	7	7	7	6	6	-	-	-
Total	**33**	**33**	**33**	**33**	**30**	**30**	**5**	**5**	**5**

Source: JICA Survey Team

Each test result is summarized as follows:

① Natural Moisture Content (Wn %)

Natural water content (Wn) for clay ranges from 30% to 41%, Wn for residual soil is comparatively low, 22%.

② Specific Gravity （ρs）

Specific gravity（ρs）ranges from 2.65 to 2.73 in spite of the difference in soil type, sand, clay, gravel, etc.

③ Liquid Limit, Plastic Limit test

This test is carried out for clay. The detailed soil classification based on this test result is CL to OL and CH to OH.

④ Particle Size Analysis Test

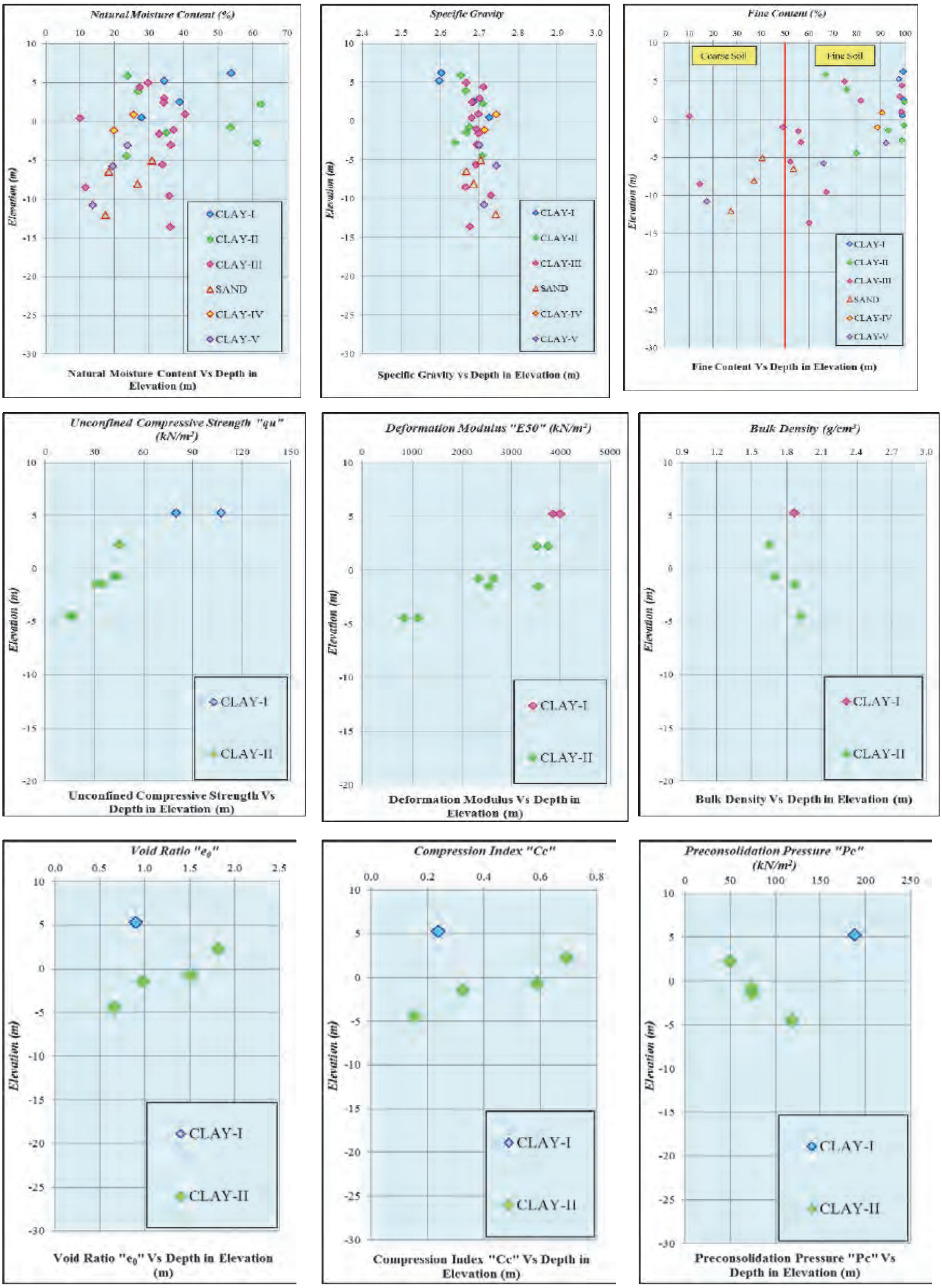
For CLAY, the fine content ratio (<0.075mm) ranges almost over 90%. For other soil, the fine content ratio (<0.075mm) is comparatively low, because of mixing with sand and gravel.

⑤ Unconfined Compression Strength Test (qu kN/m^2)

For CLAY-I, qu is 93kN/m^2 on average and for CLAY-II, qu is 34kN/m^2 on average.

⑥ Consolidation Test

Pre-consolidation Yield Stress (Pc) ranges from 78kN/m^2 to 188kN/m^2, it indicates the soil is in a comparatively over-consolidated condition. And the compression index (Cc) ranges from 0.23 to 0.44, comparatively low.



Source: JICA Survey Team

Figure 5.3.23 Summary of Soil Test Results for Thaton Bypass Area

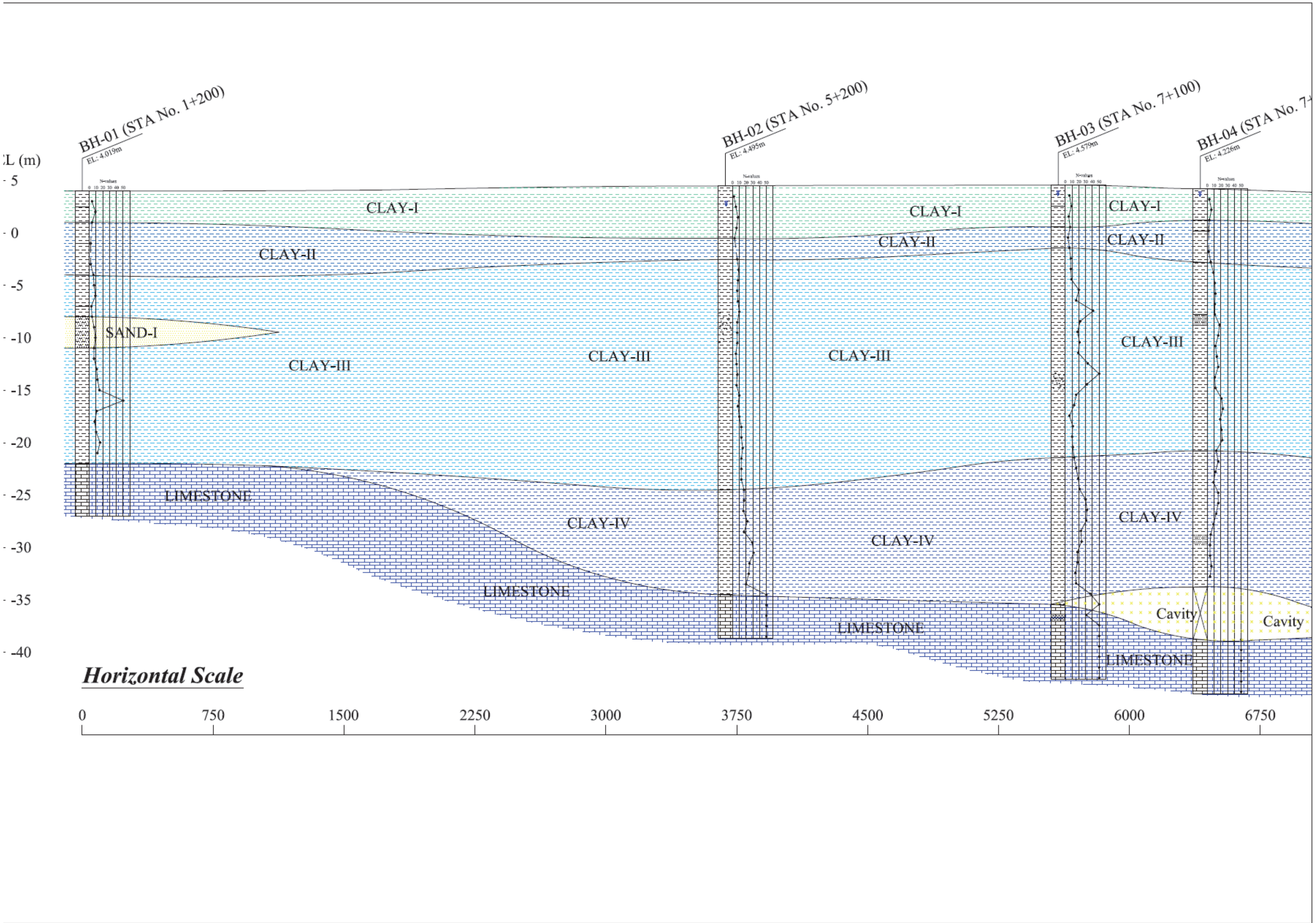
(7) Kyargalay Bypass

1) Soil Profile

The location map of the boring points is shown in Figure 5.3.24. The soil profile is divided into three portions, as shown in Figure 5.3.25 to Figure 5.3.27.

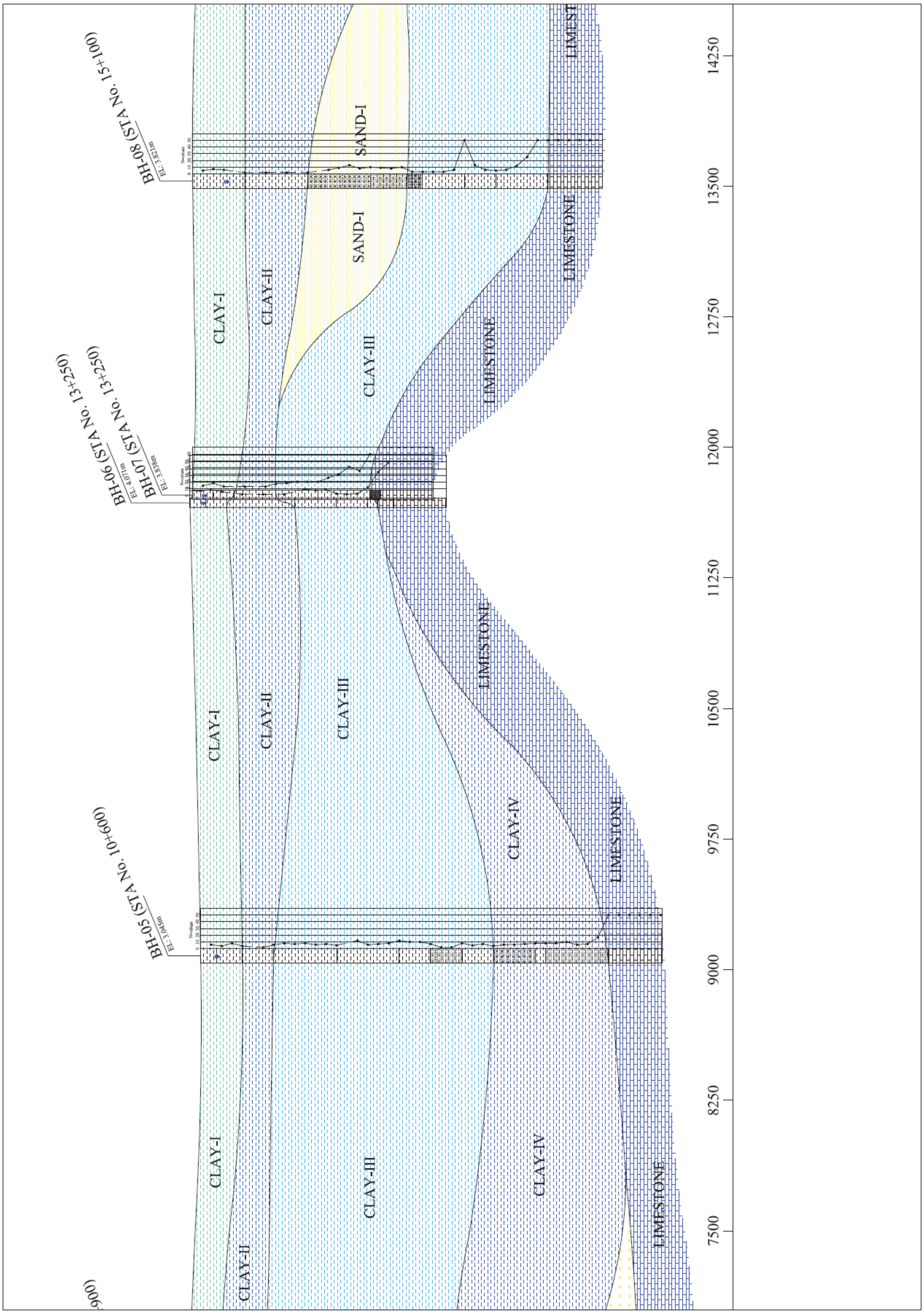
Source: Prepared by JICA Survey Team based on Google Earth

Figure 5.3.24 Location of Boreholes (Kyargalay Bypass)



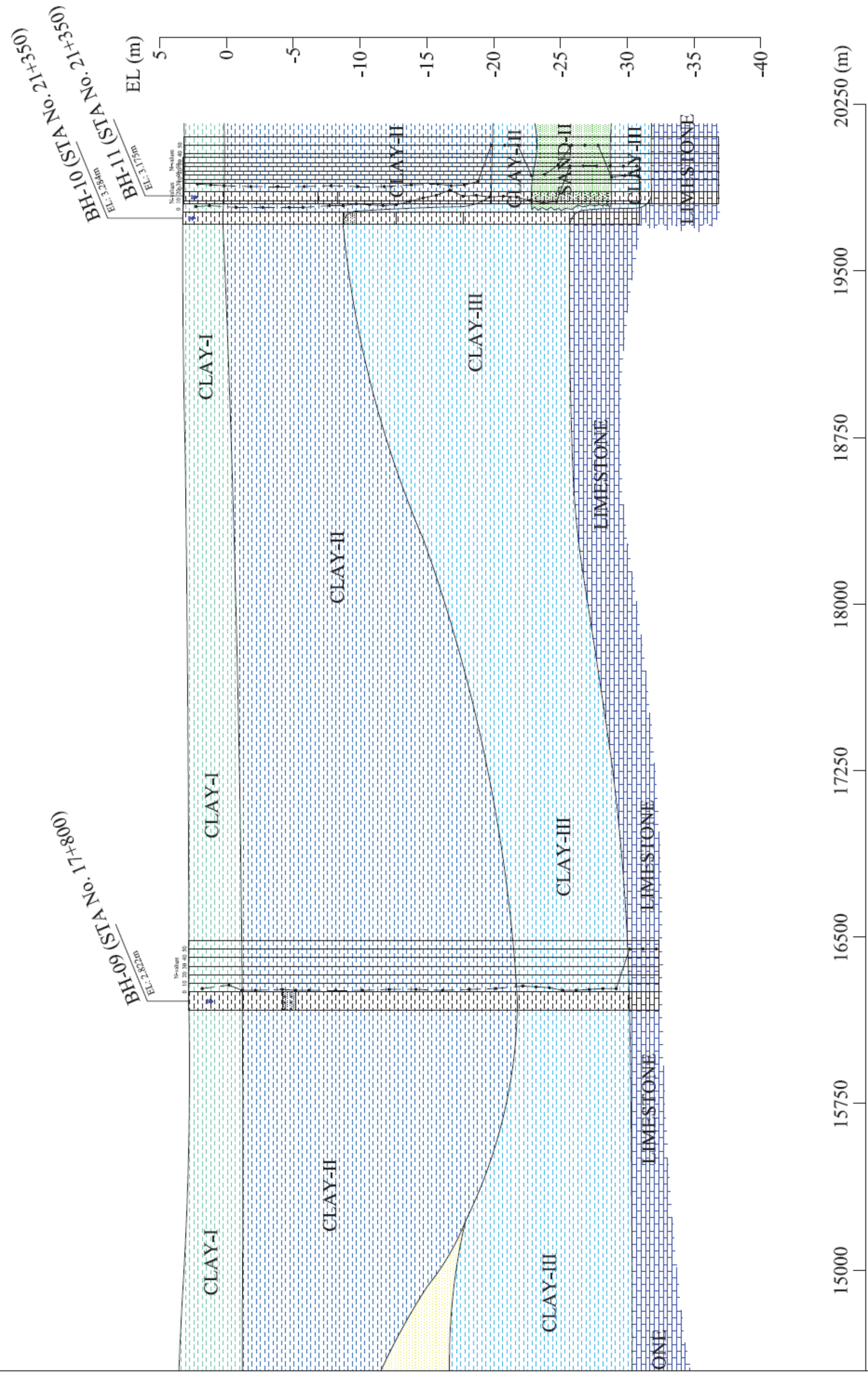
Source: JICA Survey Team

Figure 5.3.25 Soil Profile of Kyargalay Bypass (Section A – A')



Source: JICA Survey Team

Figure 5.3.26 Soil Profile of Kyargalay Bypass (Section B – B')



Source: JICA Survey Team

Figure 5.3.27 Soil Profile of Kyargalay Bypass (Section C – C')

The boring points are planned for the purpose of structure design (box culvert, small bridge) and the soft soil measures as shown in the following table.

Table 5.3.9 Location of Boreholes (Kyargalay Bypass)

Bor No.	STA No.	Purpose
1	1+200	Box
2	5+200	Box
3	7+100	Bridge
4	7+900	Bridge
5	10+600	Bridge
6	13+250	Bridge
7	13+250	Bridge
8	15+100	Bridge
9	17+800	Box
10	21+350	Bridge
11	21+350	Bridge

Source: JICA Survey Team

The drilling depth is 23m to 48m. The soil condition is divided into seven layers as the following. Upper layer, CLAY-I, CLAY-II and CLAY-III is soft clay with a brown grey colour. CLAY-III is not a uniformly clay layer mixed with gravel. Under those layers, SAND-I, CLAY-IV and SAND-II are deposited and weathered LIMESTONE is confirmed in the whole area as basic rock.

① CLAY-I
② CLAY-II
③ CLAY-III
④ SAND-I
⑤ CLAY-IV
⑥ SAND-II
⑦ Weathered LIMESTONE

2) Soil Property

A summary of the soil test results are shown in Figure 5.3.28. The test items are shown in Table 5.3.10.

Natural water content, specific gravity, fine content, unconfined compression strength test and consolidation test results are compiled in a graph as a depth distribution figure layer by layer.

Table 5.3.10 Soil Test Items and Quantity (Kyargalay Bypass)

BH-No.	Physical Properties Test of Soil							Engineering Properties Test of Soil		Engineering Properties Test of Rock		Chemical Properties Test
	Natural Moisture Content Test	Specific Gravity Test	Particle Size Analysis Test		Atterberg's Limit Test		Unit Weight	Unconfined Compression Test	Consolidation Test	Unit Weight (Absolute Density)	Uniaxial Compression Strength Test	Water Quality Test
			Sieve Analysis Test	Hydrometer Analysis Test	Liquid Limit Test	Plastic Limit Test						
BH-01	7	7	7	7	5	5	2	2	2	2	2	1
BH-02	8	7	8	8	8	8	1	1	1	-	-	1
BH-03	9	9	9	9	9	9	-	-	-	-	-	1
BH-04	10	10	10	10	9	9	1	1	1	-	-	1
BH-05	11	11	11	11	6	6	1	1	1	-	-	1
BH-06	7	7	7	7	6	6	3	3	3	2	2	1
BH-07	6	6	6	6	6	6	2	2	2	3	3	1
BH-08	15	15	15	15	14	14	2	2	2	-	-	1
BH-09	15	15	15	15	14	14	10	10	6	-	-	1
BH-10	11	11	11	11	11	11	4	4	3	-	-	1
BH-11	14	14	14	14	14	14	8	8	5	2	2	1
Total	**113**	**112**	**113**	**113**	**102**	**102**	**34**	**34**	**26**	**9**	**9**	**11**

Source: JICA Survey Team

Each test result is summarized as follows:

① Natural Moisture Content (Wn %)

Natural water content (Wn) for clay widely ranges from 17% to 46%, Wn for CLAY-II is comparatively high, about 47%. Wn also for SAND-I and SAND-II is comparatively high, about 30%.

② Specific Gravity（ρs）

Specific gravity（ρs）ranges from 2.67 to 2.73 in spite of the difference in soil type, sand, clay, gravel etc. However, ρs only for CLAY-IV is a little high, about 2.85.

③ Liquid Limit, Plastic Limit test

This test is carried out for clay. The detailed soil classification based on this test result is CL to OL and CH to OH.

④ Particle Size Analysis Test

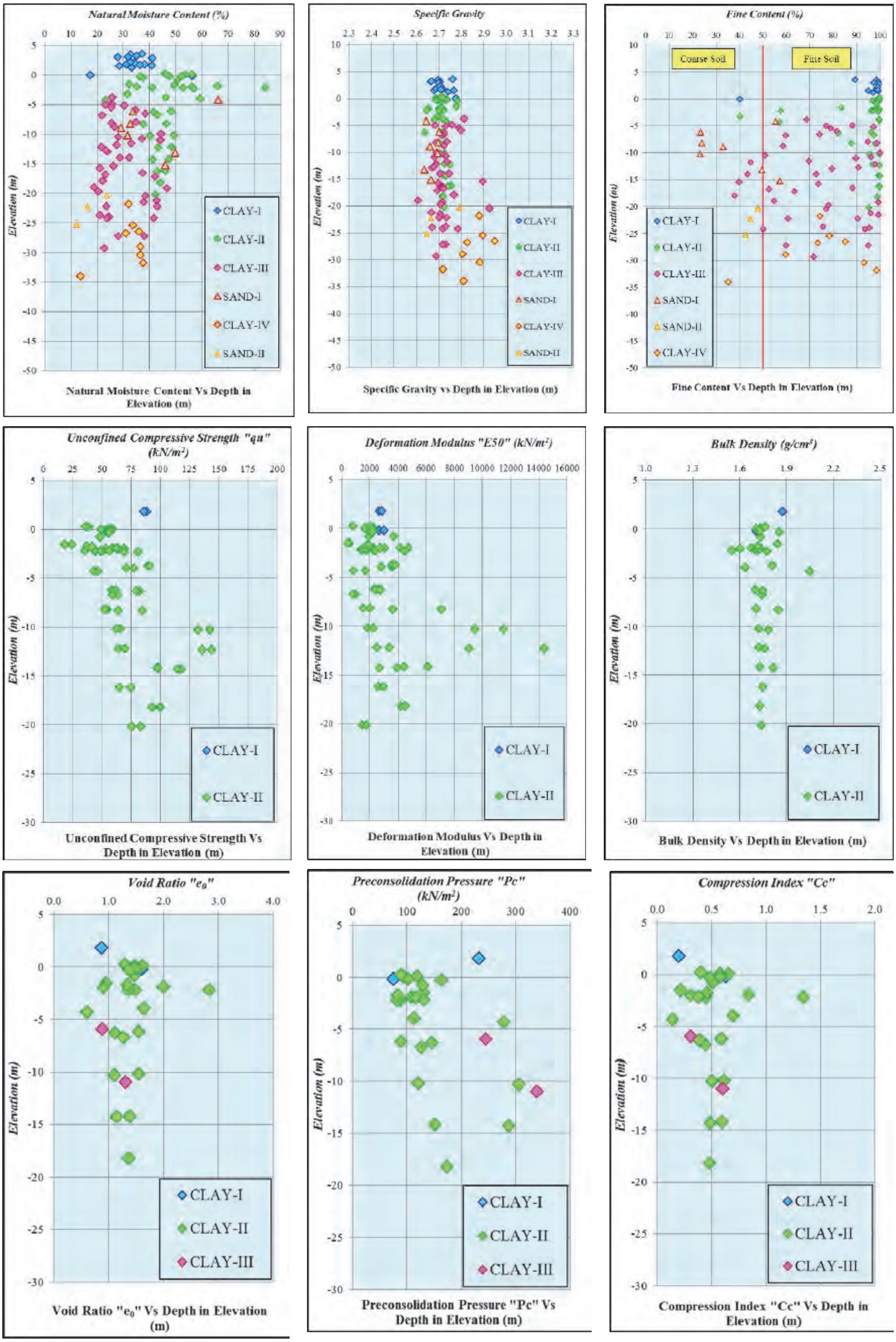
For CLAY, the fine content ratio (<0.075mm) ranges almost over 90%. For other soil, the fine content ratio (<0.075mm) is comparatively low, because of mixing with sand and gravel.

⑤ Unconfined Compression Strength Test (qu kN/m^2)

For CLAY-I, qu is 70kN/m^2 on average and for CLAY-II, qu is 68kN/m^2 on average.

⑥ Consolidation Test

Pre-consolidation yield stress (Pc) ranges from 74kN/m^2 to 305kN/m^2, which indicates the soil is in a comparatively over-consolidated condition. And the compression index (Cc) ranges from 0.42 to 0.57, comparatively low.



Source: JICA Survey Team

Figure 5.3.28 Summary of Soil Test Results for Kyargaly Bypass Area

(8) Material Test

1) Sampling

Soil sampling was carried out at the following borrow pit sites, quarry sites and existing road shoulders:

① Borrow Pit
The following borrow pits were selected for soil sampling:

- Two sites near Kawkareik and Eindu ()
  Soil taken from Kawkareik was previously used as fill material for the current Kawkareik Bridge construction and now the amount of soil that can be taken from the borrow pit is small. However, a large soil amount can be taken from the area near Eindu. The borrow pit is also used for a quarry.

- Three sites from Thaton Bypass ()
  Since the ground elevation for most of the Thaton Bypass is comparatively high, the fill material can be expected to be taken near the Thaton Bypass alignment.

- Three sites from Kyargalay Bypass ()
  Two sites near the starting point of Kyargalay Bypass and one near the end. Two soil samples for the site were taken, for a total of six soil samples.

② Quarry Site
The following quarry sites were selected for soil sampling:

- Quarry near Zathapyin ()
  This quarry produces limestone. The limestone mountain can be seen throughout the Project Area. The stone and soil covering the limestone mountain is weathered rock and soil which can be used for fill materials.

- Quarry near Thaton ()
  This quarry produces granite. The rock quality is fresh and hard. The granite mountain can be seen in some areas between Thaton and Mawlamyine.

Borrow Pit near Kawkareik (Used for present Kawkareik bridge fill material)

Borrow Pit near Eindu (Used for also as Quarry, Good material with Gravel and Sand)

Source: JICA Survey Team

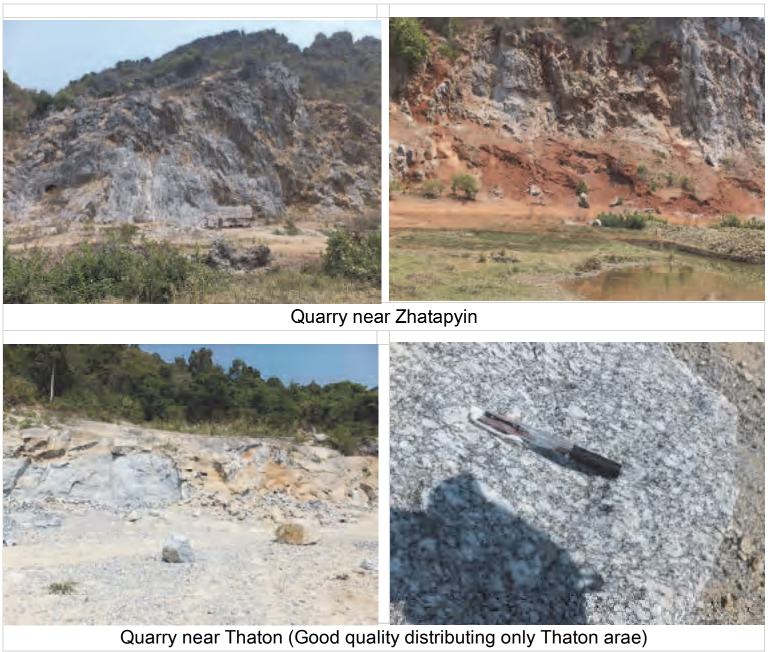
Figure 5.3.29 Borrow Pit near Kawkareik and Eindu

Source: JICA Survey Team

Figure 5.3.30 Borrow Pit near Thaton Bypass

Source: JICA Survey Team

Figure 5.3.31 Borrow Pit near Kyargalay Bypass



Source: JICA Survey Team

Figure 5.3.32 Quarry near Zathapyin and Thaton

③ Existing Road Shoulder

The following road shoulders were selected for soil sampling:

- ➢ Four locations from four bridge sites (,)

  Soil sampling was carried out on both sides (Left and Right side of bridge) at the following four bridge sites.
  - Naung Lon Bridge Site
  - Gyaing Kawkareik Bridge Site
  - Gyaing Zathapyin Bridge Site
  - Atran Bridge Site

- ➢ Six locations from Kyargalay Bypass

  One site at the starting point of Kyargalay Bypass and two sites near the end of the bypass.

<Naung Lon Bridge> Left side sampling
<Naung Lon Bridge> Right side sampling
<Naung Lon Bridge> Left side pavement
<Naung Lon Bridge> Right side pavement
<Kawkareik Bridge> Left side sampling
<Kawkareik Bridge> Right side sampling
<Kawkareik Bridge> Left side pavement
<Kawkareik Bridge> Right side pavement

Source: JICA Survey Team

Figure 5.3.33 Naung Lon and Kawkareik Bridge

<Thatapyin Bridge> Left side sampling
<Thatapyin Bridge> Right side sampling
<Thatapyin Bridge> Left side pavement
<Thatapyin Bridge> Right side pavement
<Atran Bridge> Left side sampling
<Atran Bridge> Right side sampling
<Atran Bridge> Left side pavement
<Atran Bridge> Right side pavement

Source: JICA Survey Team

Figure 5.3.34 Zathapyin and Atran Bridge

2) Material Test Result

CBR test results for soil taken from the borrow pits and existing road shoulders are shown in Table 5.3.11 and Table 5.3.12. Aggregate tests results for the rock samples taken from quarry sites are shown in Table 5.3.13.

Table 5.3.11 CBR Test Results for Borrow Pit

Borrow Pit near Eindu & Kawkareik

Location (Borrow Pit)		CBR (%)			Bulk Density ρ (tf/m^3)			Moisture Content w (%)			Expansion Ratio r_e (%)			Grain size (%)			Remarks
		No1	No2	Mean	No1	No2	Mean	No1	No2	Mean	No1	No2	Mean	Gravel	Sand	Silt/Clay	
Borrow Pit	Near Eindu	50.00	66.70	58.35	1.833	1.904	1.869	0.22	0.21	0.22	0.00	0.00	0.00	70.59	22.36	7.05	Gravel with Silt/Clay and Sand
	Near Kawkareik	8.00	9.00	8.50	1.607	1.614	1.611	3.67	3.54	3.61	3.24	2.91	3.08	65.77	22.64	11.58	Gravel with Silt/Clay and Sand

Borrow Pit for Thaton Bypath

Location (Borrow Pit)		CBR (%)			Bulk Density ρ (tf/m^3)			Moisture Content w (%)			Expansion Ratio r_e (%)			Grain size (%)			Remarks
		No1	No2	Mean	No1	No2	Mean	No1	No2	Mean	No1	No2	Mean	Gravel	Sand	Silt/Clay	
Borrow Pit for Thaton Bypath	Sue Inn Area	2.19	2.76	2.48	2.143	2.144	2.144	24.75	24.82	24.79	0.00	0.00	0.00	32.78	36.58	30.64	ρdmax=1.87g/cm^3, Wopt=16.9%
	Dar Yoe Area	1.52	1.57	1.55	1.919	1.918	1.919	32.44	32.33	32.39	0.00	0.00	0.00	19.22	24.73	56.05	ρdmax=1.73g/cm^3, Wopt=19.9%
	Thee Gone Area	45.71	49.52	47.62	1.968	1.991	1.980	23.33	22.79	23.06	0.07	0.06	0.07	85.08	8.7	6.22	ρdmax=1.68g/cm^3, Wopt=17.1%

Borrow Pit for Kyargalay Bypath

Location (Borrow Pit)			CBR (%)			Bulk Density ρ (tf/m^3)			Moisture Content w (%)			Expansion Ratio r_e (%)			Grain size (%)			Remarks
			No1	No2	Mean	No1	No2	Mean	No1	No2	Mean	No1	No2	Mean	Gravel	Sand	Silt/Clay	
Borrow Pit for Kyargalay Bypath Road	Khayar	－1	1.43	1.57	1.50	2.108	2.122	2.115	19.96	19.44	19.70	0.00	0.00	0.00	20.27	39.34	40.39	ρdmax=2.02g/cm^3, Wopt=11.4%
		－2	1.14	0.90	1.02	2.141	2.147	2.144	18.78	18.01	18.40	0.00	0.00	0.00	23.58	52.2	24.22	Silty/Clayey Sand with Gravel
	Kokapon	－1	14.29	11.90	13.10	2.203	2.227	2.215	20.99	21.23	21.11	0.00	0.00	0.00	42.24	39.18	18.58	ρdmax=1.91g/cm^3, Wopt=16.5%
		－2	2.95	3.24	3.10	2.142	2.148	2.145	22.75	22.81	22.78	0.00	0.00	0.00	35.35	42.82	21.83	Silty/Clayey Sand with Gravel
	Khyuone Phal	－1	18.38	8.57	13.48	2.305	2.297	2.301	17.14	18.45	17.80	0.00	0.00	0.00	72.6	11.87	15.53	ρdmax=2.00/cm^3, Wopt=10.7%
		－2	3.05	2.76	2.91	2.252	2.255	2.254	20.20	18.08	19.14	0.00	0.00	0.00	57.67	16.97	25.36	Gravel with Silt/Clay and Sand

Source: JICA Survey Team

Table 5.3.12 CBR Test Results for Existing Road Shoulder

Existing Bridge (Sampling at both sides of 4 Bridges)

Location			CBR (%)			Bulk Density ρ (tf/m^3)			Moisture Content w (%)			Expansion Ratio r_e (%)			Grain size (%)			Remarks
			No1	No2	Mean	No1	No2	Mean	No1	No2	Mean	No1	No2	Mean	Gravel	Sand	Silt/Clay	
Bridge site	Naung Lon	Left	5.70	5.90	5.80	1.900	1.900	1.900	4.66	4.53	4.60	2.36	2.88	2.62	18.80	37.37	43.83	Silty/Clayey Sand with Gravel
		Right	10.71	10.76	10.74	1.809	1.817	1.813	2.45	2.68	2.57	1.71	1.63	1.67	26.10	40.42	33.48	Silty/Clayey Sand with Gravel
	Kawkareik	Left	5.61	4.95	5.28	1.827	1.827	1.827	9.23	9.48	9.36	3.91	4.49	4.20	54.18	26.44	19.39	Silty/Clayey Gravel with Gravel
		Right	2.10	1.91	2.00	1.881	1.874	1.878	8.56	9.15	8.86	6.16	6.02	6.09	35.69	28.56	35.75	Silty/Clayey Gravel with Gravel
	Zathapyin	Left	0.95	0.67	0.81	1.842	1.830	1.836	7.50	8.12	7.81	5.27	4.83	5.05	19.86	19.15	60.99	Fine-grained Soil
		Right	1.91	1.70	1.80	1.932	1.909	1.921	5.45	5.55	5.50	3.87	3.92	3.90	27.23	35.89	36.88	Silty/Clayey Sand with Gravel
	Atran	Left	3.10	3.20	3.15	1.873	1.876	1.875	8.63	9.20	8.92	4.89	4.38	4.63	21.32	36.94	41.74	Silty/Clayey Sand with Gravel
		Right	1.91	1.70	1.80	1.806	1.803	1.805	11.25	11.26	11.26	4.04	4.30	4.17	27.85	30.63	41.52	Silty/Clayey Sand with Gravel

Kyargalay Bypass

Location (Road shoulder)		CBR (%)			Bulk Density ρ (tf/m^3)			Moisture Content w (%)			Expansion Ratio r_e (%)			Grain size (%)			Remarks
		No1	No2	Mean	No1	No2	Mean	No1	No2	Mean	No1	No2	Mean	Gravel	Sand	Silt/Clay	
Kyargalay Bypass Road	STA No 6+900	6.00	5.70	5.85	1.984	1.981	1.983	24.39	24.50	24.45	1.10	1.29	1.20	0	8.74	91.26	Silt/Clay withSand
	STA No 7+900	4.19	4.00	4.10	1.974	1.971	1.973	25.86	25.97	25.92	0.98	1.09	1.04	0	0.45	99.55	Silt/Clay withSand
	STA No 10+700	5.90	6.00	5.95	2.022	2.039	2.031	21.56	21.48	21.52	1.06	0.94	1.00	0	5.93	94.07	Silt/Clay withSand
	STA No 15+100	3.90	4.00	3.95	2.031	2.035	2.033	23.19	23.36	23.28	1.67	1.76	1.72	0	3.74	96.26	Silt/Clay withSand
	STA No 17+800	3.71	3.24	3.48	2.005	1.995	2.000	24.88	25.34	25.11	1.96	2.02	1.99	0	1.45	98.55	Silt/Clay withSand
	STA No 21+400	1.14	1.14	1.14	1.956	1.968	1.962	25.22	25.16	25.19	0.24	0.04	0.14	0	1.2	98.8	Silt/Clay withSand

Source: JICA Survey Team

Table 5.3.13 Aggregate Test Result for Rock Sample taken from Quarry Site

CONSTRUCTION MATERIAL TEST LABORATORY (CONCRETE)
ITC
IRRIGATION TECHNOLOGY CENTER
IRRIGATION DEPARTMENT

SUMMARY TEST RESULTS SHEET OF AGGREGATE

Project Name -

Date-14.5.2014

Sr. No.	Sample Name	Location	Specific Gravity	absorption (%)	Unit Weight (gm/cc)	Abrasion (%)	5 Cycle Soundness (%)	Remarks
1.	Near Kin Du (Private Co)	Quarry-2 (Crushed Stone)	2.70	0.14	1.32	29.87	5.07	
2.	Thaton (Private Company)	Quarry-3 (Crushed Stone)	2.63	0.40	1.34	28.45	-	

Source: JICA Survey Team

5.3.3 Geotechnical Assessment

(1) Soil Condition at Project Site

At the survey area located at the Eastern Fold Belt of the Myanmar Tectonic Region, the regional topographic feature is distinct in ridge and valley features. The flood plain area is relatively flat, surrounded by low relief mountain ranges. In some areas, limestone stacks are exposed as a high relief mountain. Some survey areas are located beside the river and are therefore covered by river water during the rainy season.

Since the Survey Area is mostly flatland with an elevation of 0m to 10m, soft clay/silt and loose sand (Alluvial soil) are widely deposited with a thickness of approximately 10m to 30m. At all survey areas except for the Naung Lon Bridge site, the soil investigation confirmed that the main layer is clayey/silty soil. Carboniferous Limestone is well exposed as limestone stack, and exists as isolated hills among the alluvial deposit. Weathered rock or limestone as a hard layer was confirmed. The representative soil layer deposited in the Project Area, five bridge sites, Thaton Bypass and Kyargalay Bypass are summarized in Table 5.3.14 to Table 5.3.16.

Table 5.3.14 Soil Condition of Each Layer for Five (5) Bridge Site

Layer Name	Soil Condition
CLAY-Lateritic Soil	This layer is observed in Atran bridge site with a thickness of 2m to 12m. N-value is 14 to 40 and the colour of this layer is grey to reddish brown. The consistency of this layer is stiff.
Clay I	This layer covers most of the area with a thickness of around 2m to 3m. Lateritic soil is observed in some areas. Fine sand, decayed wood and plant root are mixed in this layer. N-value is 1 to 11, very soft to stiff.
Clay II	This layer is confirmed in most of areas, except the Naung Lon Bridge site, with a thickness of 2m to 17m. N value is 1 to 5, very soft to firm. Decayed wood is confirmed at some points; however, this layer consists of homogeneous Clay/Silt.
CLAY with sand	This layer is observed in Gyaing Kawkareik bridge site with a thickness of 15m to 21m. N-value is 2 to 19 and the consistency of this layer is soft to firm.
Clay III	This layer is also observed in most of areas with a thickness of 4m to 11m. N-value is 1 to 25, very soft to very stiff. This Clay III layer includes sand, gravel and decayed wood etc. Therefore, the soil property of this layer is heterogeneous.
SAND	In the Donthami bridge site only, the layer is confirmed with a thickness of 3.0m. N- value is 21 to 31 and relatively dense.
Silty Sand	In the Naung Lon Bridge site and Gyaing Zathapyin site, silty sand layer is mainly composed with a thickness of 6m to 30m; N-value is 2 to 21, very loose to medium.
Silty Sand with gravel	In the BH-03 of Gyaing Kawkareik bridge, the layer is confirmed with a thickness of 3.0m. and relatively dense. N- value is 30 to 32.
Clay IV	This layer is confirmed in some areas with a thickness of 4m to 15m. N-value is 9 to 50, stiff to hard. This layer is residual soil, including weathered rock fragment. The colour of this layer is brown, gray and spotted red.
Clay V	This layer is observed in the Dontami Bridge and Gyaing Zathapyin Bridge sites. The colour of this layer is yellowish brown to grey with a stiff consistency. N-value is more than 27 in the Donthami Bridge site and 5 to 13 in the Gyaing Zathapyin Bridge site.
Clay VI	This layer is observed in Gyaing Zathapyin bridge site with a thickness of 2m to 6m. N-value is 10 to 17 and the consistency of this layer is relatively stiff.
Weathered SAND STONE	This layer is rarely observed at BH-03 in the Atran Bridge site. The strength of rock is very weak and the joint spacing is very close. The thickness is 3.0m and this layer may float from other places.
SLATE (Weathered Rock)	This layer is well observed in the Atran Bridge site. The colour of this layer is grey. N-value is more than 50 though the rock strength is very weak and the weathering grade is highly weathered.
LIMESTONE	For the Donthami Bridge site, Atran Bridge site, and Gyaing Zathapyin site, this layer is observed as bedrock There is partially weathered rock and its extent varies by location and depth. N-value is over 50.

Source: JICA Survey Team

Table 5.3.15 Soil Condition of Each Layer for Thaton Bypass

Layer Name	Soil Condition
Clay I	This layer covers only BH-1 and BH-2 points with a thickness of around 4m. Fine sand, decayed wood and plant root are mixed in this layer. N-value is 1 to 11, very soft to stiff. The colour of this layer is brown to mottled yellow and brownish grey, spotted red.
Clay II	This layer is confirmed at BH-1, BH-2, and BH-3 with a thickness of 5m to 8m. N value is 1 to 5, very soft to firm. Decayed wood is confirmed at some points; however, this layer consists of homogeneous clay/silt.
Clay III	This layer is confirmed at BH-1, BH-4, and BH-5 with a thickness of 4m to 22m. N-value is 2 to 28, very soft to very stiff. This Clay III layer includes sand, gravel and decayed wood etc. Therefore, the soil property of this layer is heterogeneous.
Sand	This layer is confirmed at BH-1, BH-4, and BH-5 with a thickness of 1.5m to 7m. N-value is 4 to 22, very loose to medium dense. Traces of weathered rock fragment are confirmed at BH-5. The colour is yellowish brown to greenish grey.
Clay IV	This layer is only observed at BH-03. The colour of this layer is brownish grey. The thickness is about 4.0m. N-value varies from 24 to 32, and the consistency is very stiff to hard. Moreover, traces of weathered rock fragments are observed in this layer
Clay V (Weathered Shale)	This layer is only observed at BH-02 and BH-03. The colour of this layer is greenish grey and bluish grey, and dark grey. N-value range varies from 23 to over 50, very stiff to hard in consistency. Moreover, this layer is a weathered portion of shale bedrock.
Weathered Rock (Weathered Limestone)	Weathered limestone is confirmed at BH-1, BH-4, and BH-5. It is characterized as highly weathered and highly jointed. The strength of rock is very weak, and calcite veins can be seen witin the limestone. N-values of this layer are over 50, very dense.

Source: JICA Survey Team

Table 5.3.16 Soil Condition of Each Layer for Kyargalay Bypass

Layer Name	Soil Condition
Clay I	This layer is well observed in all boreholes. The thickness of this layer is 3m to 5m. N-value is varies from 2 to 9, soft to stiff. Moreover, traces of decayed wood and plant roots fragments, fine lateritic gravel are observed in this layer.
Clay II	This layer is also observed at all boreholes. According to the investigation results, the thickness of this layer is very thin at BH-01, and very thick at BH-09, BH-10 and BH-11. The thickness of this layer is 2m to 21m. N-value is from 2 to 8, soft to firm in consistency. Moreover, traces of fine sand, decayed wood fragments, fine lateritic gravels are found at some boreholes.
Clay III	This layer is also observed at all boreholes. The thickness of this layer is 8m to 21m. N-value is from 2 to 50, and the consistency is soft to hard. Moreover, traces of fine sand and fine gravel are included in this layer. N-values are very high at some depths because of a fine lateritic gravel layer is lying at intercalated layer
Sand I	This layer is rarely observed at BH-01 and BH-08. The thickness of this layer is around 3m. The grain size of sand is fine grained. N-value is from 2 to 13, very loose to medium dense. Moreover, traces of decayed wood fragments are observed at BH-08, and traces of fine gravel are observed at BH-01.
Clay IV	This layer is only observed at BH-02, BH-03, BH-04 and BH-05. The thickness of this layer is 10m and 14m. N-value is from 4 to 37, and the consistency is soft to hard. Moreover, traces of weathered rock fragments are observed in this layer.
Sand II	This layer is rarely observed at BH-11. The thickness of this layer is around 9m. The grain size of sand is fine grained. N-value is from 15 to over 50, medium dense to very dense. Moreover, traces of weathered rock fragments are included in this layer.
Weathered Rock (Weathered Limestone)	The last sub-soil layer is weathered Limestone and this layer is underlying as bedrock. It is characterized as highly weathered and highly jointed. The strength of the rock is very weak in some boreholes and moderately strong at BH-11. Moreover, calcite veins can be seen within the limestone. N-values are over 50, very dense.

Source: JICA Survey Team

(2) Structure Foundation

According to the soil investigation results, as explained above, soft soil, such as loose sand and soft clay/silt, was widely confirmed throughout the Project Area. The thickness varies from around 10m to 30m. Structure foundations generally require an N-value of at least over 30 to 50 for the sand/gravel layer, and an N-value of at least over 15 to 20 for the clay/silt layer.

In this survey, the bearing layer is assumed to be an N-value of at least over 30 for the sand/gravel layer, and an N-value of at least over 15 for the clay/silt layer, which is based on the Japanese Standard. For the soil condition in the Project Area, the limestone and slate layers are expected as a bearing layer. Furthermore, Clay III to V can be expected in some areas since the above conditions are satisfied. However, the depth for the bearing layer needs to be examined carefully in the detail design stage because limestone may have a heterogeneous layer.

However, a suitable structure foundation type shall be selected taking into consideration various conditions, such as design, economical point of view, work efficiency, local characteristics and ground conditions.

As the soft clay layer is confirmed thick in some areas, negative friction by ground settlement shall be considered for the pile foundation design. There are loose sand layer deposits in some areas, so liquefaction also shall be considered for the design.

Since the ground water level rises close to ground level during the rainy season, foundation work should be avoided during the rainy season.

Followings are described for foundation condition for each bridge.

① Donthami Bridge

As the soft clay layer is distributed with a thick thickness in the area, it is considered that a pile foundation installed up to LIMESTONE is suitable.

② Naung Lon Bridge

As a loose sand layer is confirmed at the area with a thick thickness, foundation type is considered to be adopted. The bearing layer is recommended to be the CLAY-IV and LIMESTONE.

③ Gyaing Kawkareik

As the soft clay layer is confirmed with a thick thickness, a pile foundation installed up to CLAY-III (N-value >50) shall be considered to be adopted.

④ Gyaing Zathapyin

As soft clay layer is confirmed with a thick thickness, a pile foundation installed up to LIMESTONE shall be considered to be adopted.

⑤ Atran Bridge

As the soft clay layer is distributed with a thick thickness at the area, it is considered that pile foundation installed up to CLAY-IV and SLATE is suitable.

(3) Fill Materials

Only lateritic soil distributed in large quantities throughout the Project Area can be taken as filling materials. Weathered rock soil taken from quarry sites can be used for filling materials after treating with grain adjustment.

The CBR values obtained from laboratory tests using soil samples taken from sites are mostly less than five as seen in the previous section. On the other hand, some CBR values for soil samples of which gravel and sand content is high tend to be larger.

When lateritic soil is soaked in water, swelling decreases its strength. However, when lateritic soil is in a moderate wet state, it is suitable to be compacted.

The following shall be considered for use of lateritic soil as fill material:

- The soil of which fine content (grain size <0.075mm) is as little as possible at least less than 50% shall be used.
- The weathered soil obtained from quarry should be used after grain size adjustment.
- Road construction work, such as fill soil sampling and fill compaction, shall not be conducted in the rainy season.

(4) Soft Soil Problem

As mentioned in the previous section, soft soil deposits are widely found in the Project Area. This could cause stability problems and foundation ground settlement, and will have to be considered.

The bearing capacity for the planned structure load to the ground foundation and the safety of slope failure for the filling work on the ground shall be examined for any stability problems.

For the settlement problems, consolidation settlement will occur due to fill load and structure load to the ground foundation.

The objective soft layer for stability problem examination is Clay I and Clay II.

The objective soft layer for settlement problem examination is the Clay II layer. Clay I has a comparatively high N-value and is mixed with some gravel and sand, therefore, the settlement of the Clay I layer is not expected to occur.

5.4 Hydrological Survey

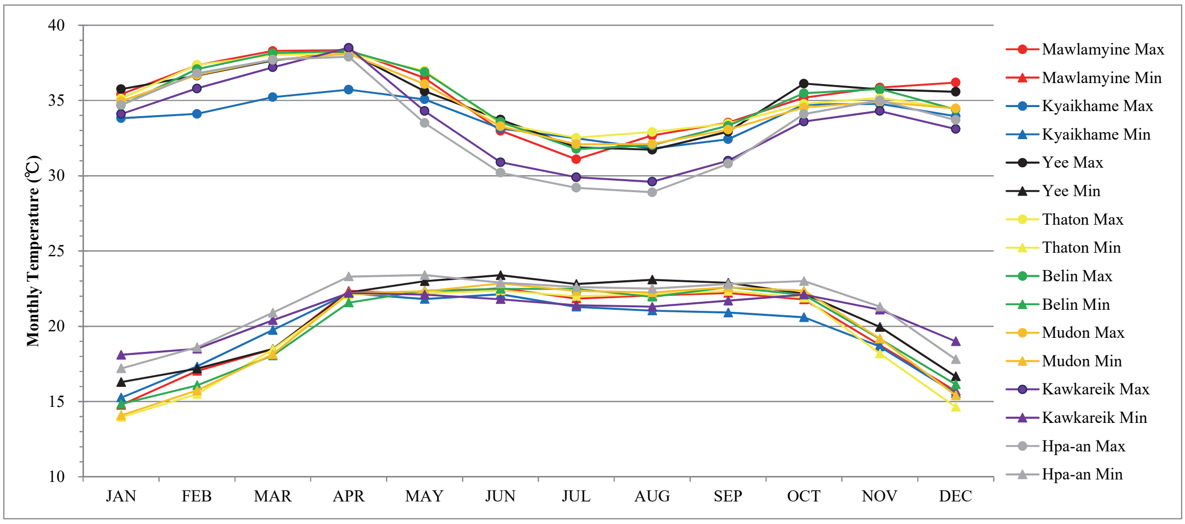
5.4.1 Meteorological Conditions

(1) General Weather Conditions

1) Temperature

The temperature data of eight stations show a similar trend. The monthly mean temperature of southeastern Myanmar ranges between 25℃ and 30℃. According to collected data, the mean monthly maximum temperature 36-38℃ (April) and the mean minimum temperature 14-18℃ (January) in the target area was recorded in the last ten years.

The mean monthly maximum and minimum temperature at eight stations is shown in Figure 5.4.1 and Table 5.4.1.



Source: JICA Survey Team

Figure 5.4.1 Mean Monthly Maximum and Minimum Temperature (2004-2013)

Table 5.4.1 Mean Monthly Maximum and Minimum Temperature (2004-2013)

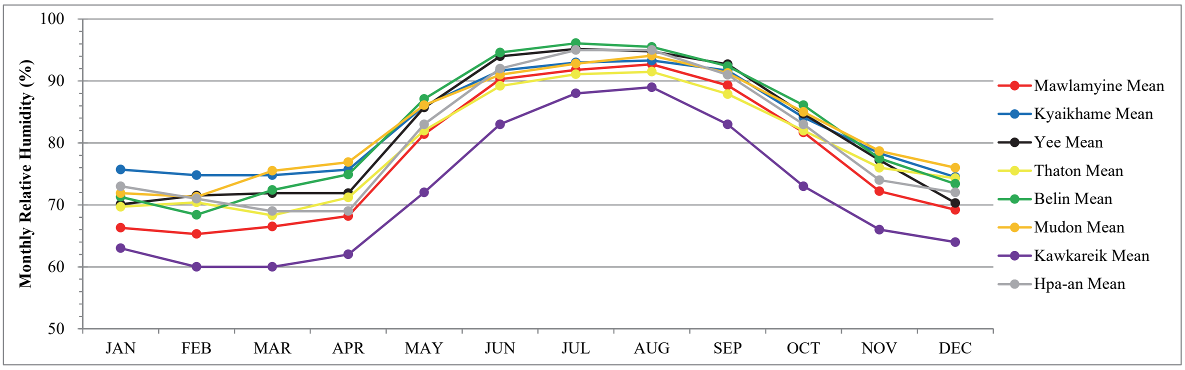
Station		Item	2004-2013 Monthly Temperature in ℃													Remarks
			JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Average	
1	Mawlamyine	Max	35.4	37.3	38.3	38.4	36.5	33.0	31.1	32.7	33.5	35.2	35.9	36.2	35.3	
		Min	14.8	17.0	18.5	22.4	22.2	22.5	21.8	22.0	22.2	21.8	18.7	15.7	20.0	
2	Kyaikhame	Max	33.8	34.1	35.2	35.7	35.1	33.1	32.5	31.8	32.4	34.7	34.8	34.0	33.9	
		Min	15.3	17.3	19.8	22.2	21.8	22.1	21.3	21.0	20.9	20.6	18.7	15.6	19.7	
3	Yee	Max	35.8	36.7	37.7	38.2	35.6	33.7	31.9	31.7	32.9	36.1	35.7	35.6	35.1	
		Min	16.3	17.2	18.5	22.3	23.0	23.4	22.8	23.1	22.9	22.2	20.0	16.7	20.7	
4	Thaton	Max	35.1	37.4	38.0	38.1	37.0	33.4	32.5	32.9	33.5	34.8	35.2	34.5	35.2	
		Min	14.0	15.5	18.5	22.1	22.2	22.4	22.0	22.1	22.3	21.9	18.2	14.6	19.6	
5	Belin	Max	34.7	37.1	38.1	38.3	36.9	33.6	31.8	32.0	33.3	35.5	35.8	34.4	35.1	
		Min	14.8	16.1	18.1	21.6	22.4	22.5	22.5	22.0	22.6	22.1	19.2	16.1	20.0	
6	Mudon	Max	35.0	36.7	37.7	38.1	36.1	33.3	32.1	32.1	33.1	34.5	34.9	34.5	34.8	
		Min	14.1	15.7	18.1	22.2	22.3	22.9	22.4	22.3	22.6	22.4	19.2	15.4	20.0	
7	Kawkareik	Max	34.1	35.8	37.2	38.5	34.3	30.9	29.9	29.6	31.0	33.6	34.3	33.1	33.5	
		Min	18.1	18.5	20.4	22.2	22.1	21.8	21.4	21.3	21.7	22.1	21.1	19.0	20.8	
8	Hpa-an	Max	34.7	36.8	37.7	37.9	33.5	30.2	29.2	28.9	30.8	34.1	35.0	33.7	33.5	
		Min	17.2	18.6	20.9	23.3	23.4	22.9	22.6	22.5	22.8	23.0	21.3	17.8	21.4	

Source: DMH

2) Relative Humidity

The relative humidity is recorded twice a day at 9:30 and 18:30. Although the rainy season is hot-humid, the relative humidity during winter from December to April is low. The mean monthly relative humidity in the target area is between 65 and 95%, except for Kawkareik in the inland area.

The mean monthly relative humidity at eight stations is shown in Figure 5.4.2 and Table 5.4.2.



Source: JICA Survey Team

Figure 5.4.2 Mean Monthly Relative Humidity (2004-2013)

Table 5.4.2 Mean Monthly Relative Humidity (2004-2013)

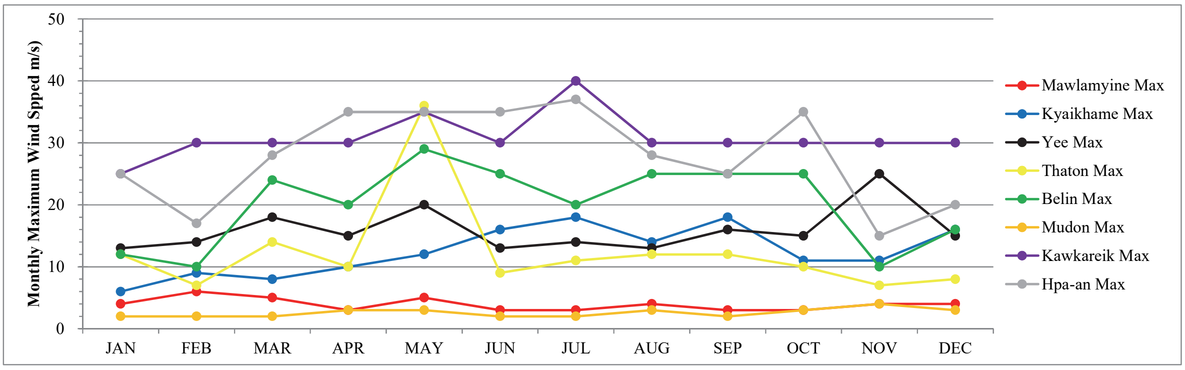
	Station	Item	2004-2013 Monthly Relative Humidity in %													Remarks
			JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Average	
1	Mawlamyine	Mean	66	65	67	68	81	90	92	93	89	82	72	69	77.9	
2	Kyaikhame	Mean	76	75	75	76	86	92	93	93	92	84	78	75	82.8	
3	Yee	Mean	70	72	72	72	86	94	95	95	93	85	77	70	81.7	
4	Thaton	Mean	70	70	68	71	82	89	91	92	88	82	76	74	79.5	
5	Belin	Mean	71	68	72	75	87	95	96	96	92	86	78	73	82.5	
6	Mudon	Mean	72	71	76	77	86	91	93	94	91	85	79	76	82.6	
7	Kawkareik	Mean	63	60	60	62	72	83	88	89	83	73	66	64	71.9	
8	Hpa-an	Mean	73	71	69	69	83	92	95	95	91	83	74	72	80.6	

Source: DMH

3) Wind Speed and Direction

The monthly maximum wind speed at each station is not stable and ranges from two to 40 m/s throughout the year. The wind direction in the target area depends on the influence of the southwest monsoon during rainy season and the northeast monsoon during the dry season. The maximum wind speed of the target area is caused by low-pressure waves (the remnants of typhoons and tropical storms from the South China Sea), and the Bay of Bengal cyclones have never hit the southern coast in Mon State and Tanintharyi Division in Myanmar.

The monthly maximum wind speed at eight stations is shown in Figure 5.4.3 and Table 5.4.3.



Source: JICA Survey Team

Figure 5.4.3 Monthly Maximum Wind Speed (2004-2013)

Table 5.4.3 Monthly Maximum Wind Speed (2004-2013)

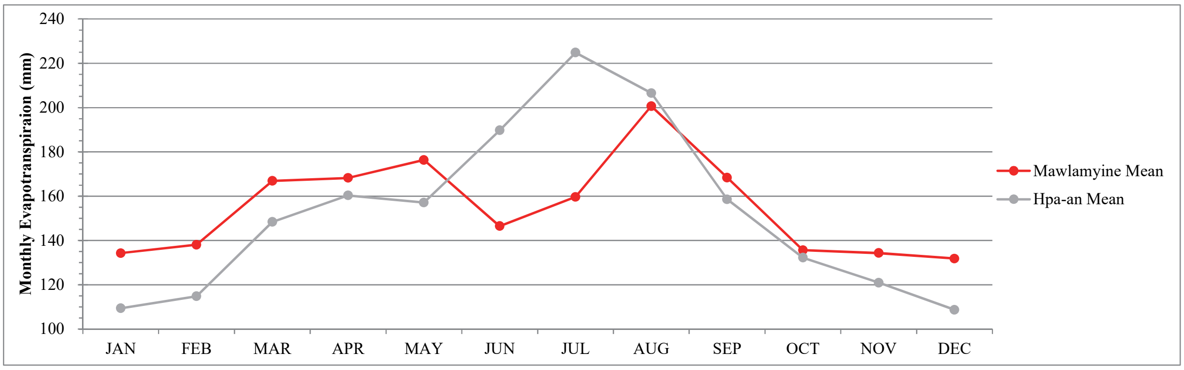
Station		Item	2004-2013 Monthly Wind Speed in m/s													Remarks
			JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Average	
1	Mawlamyine	Max	4	6	5	3	5	3	3	4	3	3	4	4	3.9	
2	Kyaikhame	Max	6	9	8	10	12	16	18	14	18	11	11	16	12.4	
3	Yee	Max	13	14	18	15	20	13	14	13	16	15	25	15	15.9	
4	Thaton	Max	12	7	14	10	36	9	11	12	12	10	7	8	12.3	
5	Belin	Max	12	10	24	20	29	25	20	25	25	25	10	16	20.1	
6	Mudon	Max	2	2	2	3	3	2	2	3	2	3	4	3	2.6	
7	Kawkareik	Max	25	30	30	30	35	30	40	30	30	30	30	30	30.8	
8	Hpa-an	Max	25	17	28	35	35	35	37	28	25	35	15	20	27.9	

Source: DMH

4) Evapotranspiration

Evapotranspiration is not observed at six stations, Mawlamyine and Hpa-an being the two exceptions. The annual mean evapotranspiration is 1,832–1861mm and which accounts for 30% of Mawlamyine and 40% of Hpa-an's annual rainfall.

The mean monthly evapotranspiration at two stations is shown in Figure 5.4.4 and Table 5.4.4.



Source: JICA Survey Team

Figure 5.4.4 Mean Monthly Evapotranspiration (2004-2013)

Table 5.4.4 Mean Monthly Evapotranspiration (2004-2013)

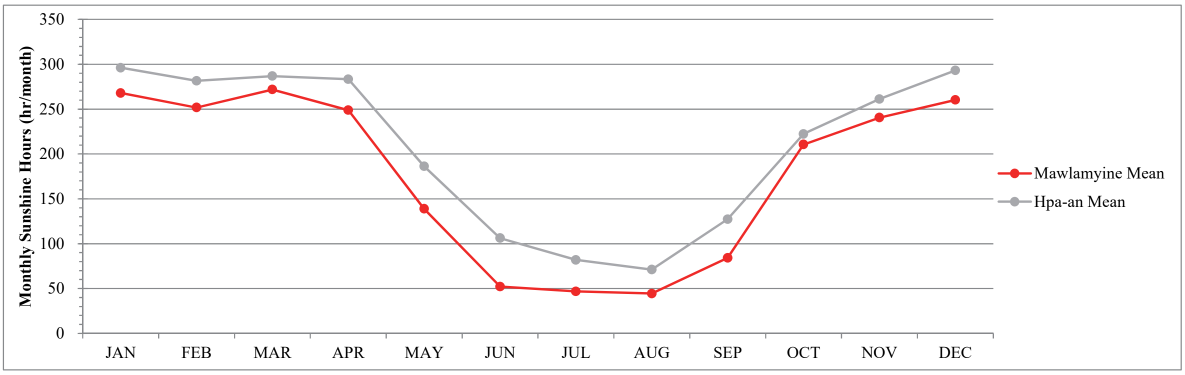
Station		Item	2004-2013 Monthly Evapotranspiration in mm/month													Remarks
			JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total	
1	Mawlamyine	Mean	134.3	138.1	166.9	168.2	176.4	146.5	159.7	200.6	168.4	135.6	134.3	131.8	1860.8	
8	Hpa-an	Mean	109.4	114.8	148.4	160.4	157.2	189.7	224.8	206.6	158.6	132.3	121.0	108.7	1831.7	

Source: DMH

5) Sunshine Hours

The sunshine hours were observed at Mawlamyine and Hpa-an stations. The annual mean sunshine hours are 5.8 hours/day in Mawlamyine and 6.8 hours/day in Hpa-an. Sunshine hours are shorter during the rainy season, and its pattern is shown the opposite of monthly rainfall fluctuation.

The mean monthly sunshine hours at two stations are shown in Figure 5.4.5 and Table 5.4.5.



Source: JICA Survey Team

Figure 5.4.5 Mean Monthly Sunshine Hours (2004-2013)

Table 5.4.5 Mean Monthly Sunshine Hours (2004-2013)

Station		Item	2004-2013 Monthly Sunshine Hours in hr													Remarks
			JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total	
1	Mawlamyine	Mean	267.9	251.7	271.9	248.9	138.8	52.2	46.8	44.4	84.2	210.6	240.6	260.3	2118.4	Gap 2007-2011,5.80 hr
8	Hpa-an	Mean	296.1	281.6	286.9	283.4	186.3	106.2	81.9	71.1	127.3	222.4	261.3	293.1	2497.6	6.84 hr

Source: DMH

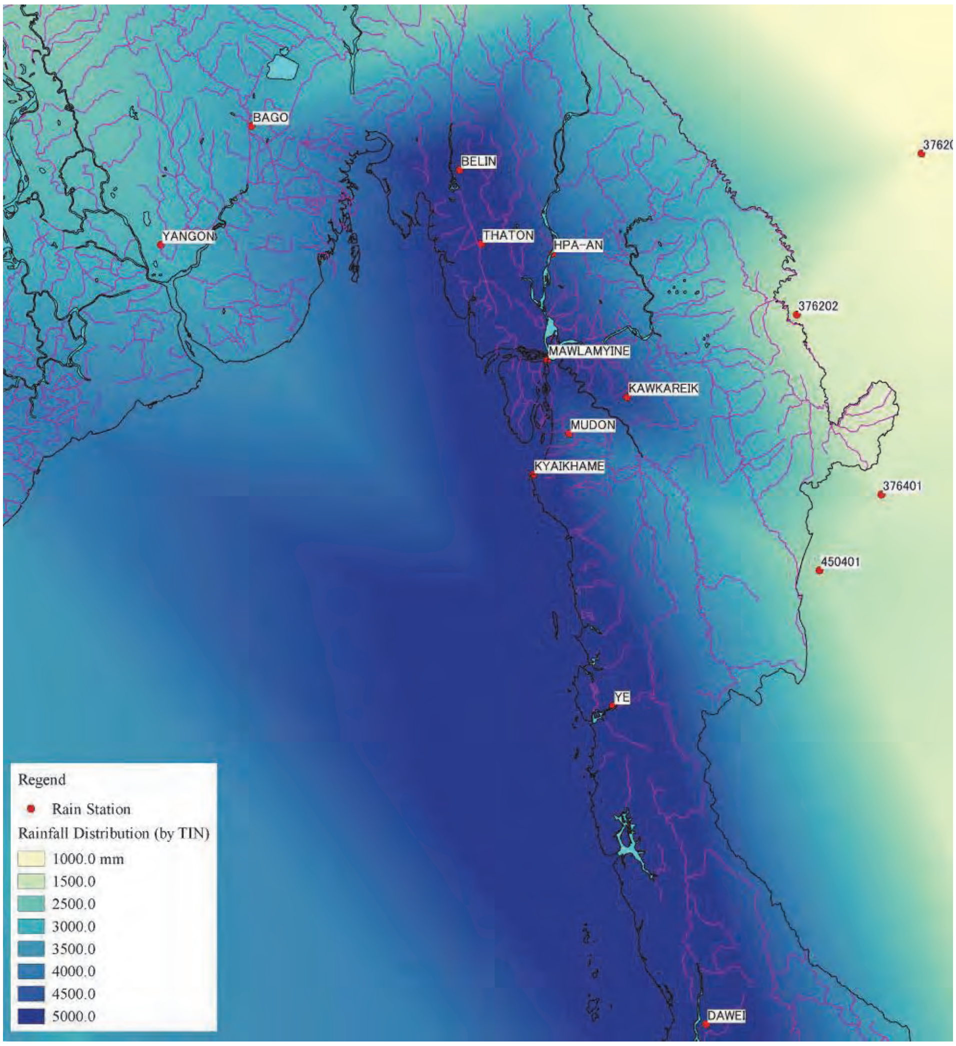
(2) Rainfall

1) Annual Rainfall and Seasonal / Long-term Fluctuation

The target area has abundant precipitation. The areal distribution of annual rainfall, which is predicted based on annual rainfalls during the past ten years or more of observation at stations in and around southeastern Myanmar, is shown in Figure 5.4.6.) The annual mean rainfall during the past ten years ranges from 4,396mm at Mudon to 5,695mm at Yee. The annual rainfall also fluctuates between each station significantly. (e.g. between 4,742 and 6,015mm in Mawlamyine.)

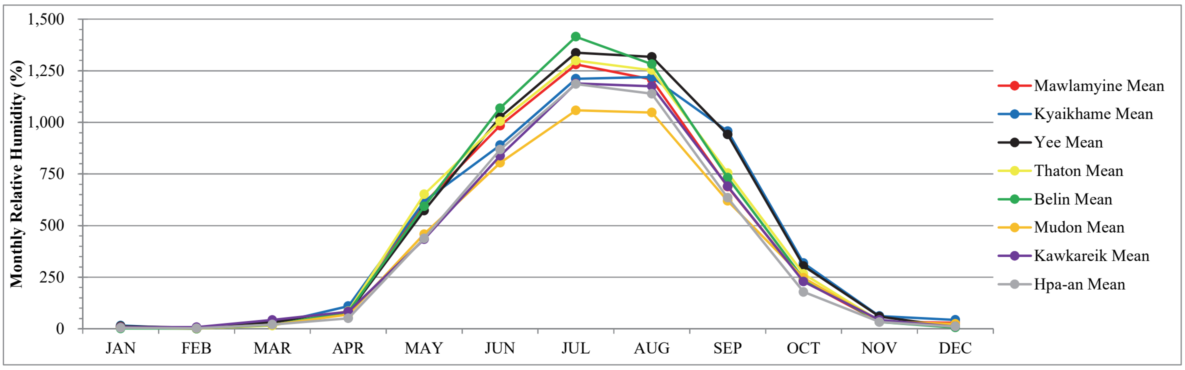
Seasonal variation of the monthly total is similar at each station. Over 95% of annual rainfall is brought by the rainy season from May to October, with the highest amount of rainfall in July or August.

The mean monthly rainfall at eight stations is shown in Figure 5.4.7 and Table 5.4.6.



Source: JICA Survey Team based on the data from DMH, Other JICA Study

Figure 5.4.6 Areal Distribution of Annual Rainfall in Southern Myanmar



Source: JICA Survey Team

Figure 5.4.7 Mean Monthly Rainfall (2004-2013)

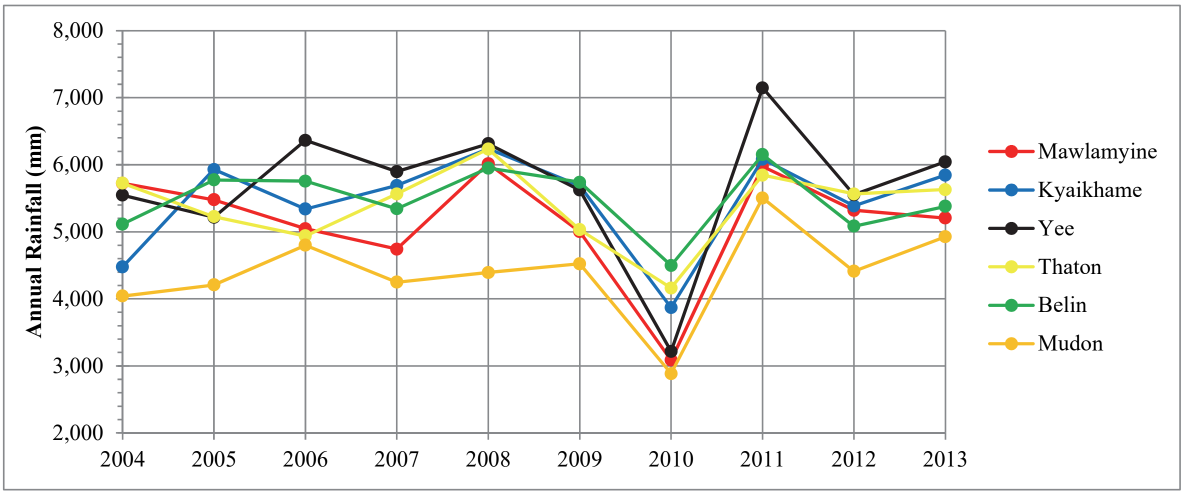
Table 5.4.6 Mean Monthly Rainfall (2004-2013)

	Station	Item	2004-2013 Monthly Rainfall in mm													Remarks
			JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total	
1	Mawlamyine	Mean	7	1	22	74	609	984	1,281	1,208	689	231	34	29	5,168	
2	Kyaikhame	Mean	15	0	24	111	617	889	1,211	1,219	958	318	62	43	5,468	
3	Yee	Mean	12	6	32	78	573	1,026	1,337	1,318	941	304	59	9	5,695	
4	Thaton	Mean	5	1	16	85	652	1,005	1,299	1,253	755	266	39	17	5,392	
5	Belin	Mean	2	1	19	83	593	1,069	1,415	1,282	733	242	34	7	5,480	
6	Mudon	Mean	9	3	19	69	459	804	1,058	1,048	620	247	36	24	4,396	
7	Kawkareik	Mean	8	8	43	83	434	838	1,189	1,175	691	229	43	11	4,752	
8	Hpa-an	Mean	5	3	21	51	438	868	1,186	1,139	635	179	33	11	4,569	

Source: DMH

Figure 5.4.8 shows the long-term fluctuation of annual rainfall at eight stations. Although the cycle of wet and drought periods are not clear, rainfall in 2010 was low at all stations.

While rainfall was low in 2010, a rising trend in annual rainfall can be seen at all stations except for Mawlamyine and Belin.



Source: JICA Survey Team

Figure 5.4.8 Fluctuation of Annual Rainfall (2004-2013)

Table 5.4.7 Fluctuation of Annual Rainfall (2004-2013)

Station		2004-2013 Annual Rainfall in mm											Remarks
		2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average	
1	Mawlamyine	5,722	5,478	5,046	4,742	6,015	5,004	3,085	5,976	5,322	5,205	5,160	
2	Kyaikhame	4,479	5,930	5,339	5,690	6,240	5,688	3,870	6,084	5,386	5,845	5,455	
3	Yee	5,546	5,215	6,363	5,896	6,313	5,623	3,218	7,146	5,552	6,043	5,692	
4	Thaton	5,724	5,226	4,938	5,565	6,233	5,031	4,161	5,844	5,565	5,630	5,392	
5	Belin	5,115	5,773	5,756	5,344	5,950	5,739	4,499	6,151	5,084	5,380	5,479	
6	Mudon	4,043	4,209	4,800	4,248	4,393	4,523	2,885	5,503	4,411	4,926	4,394	

Source: DMH

2) Exceedance Probability and Intensity Curve of Rainfall

The annual maximum daily rainfall (extremal value) data at seven precipitation stations has been collected for the study of road drainage design for Thaton and Kyargalay Bypass Roads. The 24-hour rainfall of 2-500 year probabilities are calculated using these extreme values, as shown in Table 5.4.8 and Figure 5.4.9.

The probability calculation adopts the commonly used Gumbel distribution method.

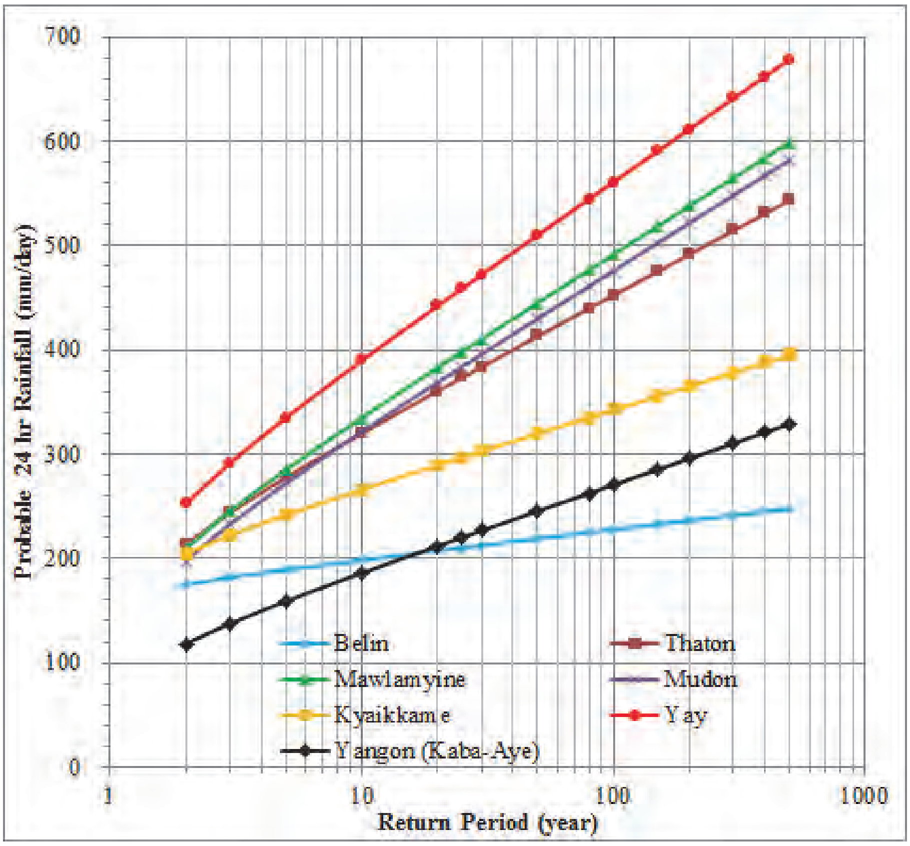
Among these seven stations, Belin and Kyaikkame station results are rejected because the distribution of precipitation samples is estimated to be relatively uniform. The remaining five station results show a relatively good correlation, even if there are differences in the number of samples. Taking into consideration the above reason, and the proximity to the proposed-bypass roads, Thaton Station probability values are used for Thaton Bypass and the Mawlamyine Station probability values are used for Kyargalay Bypass.

As a next step, the correlation between intensity of short time rainfall duration and 24-hour rainfall is estimated in reference to Mononobe's equation. The relationship of IDF (Intensity-Duration-Frequency), namely the rainfall-intensity for Thaton and Kyargalay Bypass roads is shown in Table 5.4.9, Table 5.4.10, Figure 5.4.10 and Figure 5.4.11.

Table 5.4.8 Calculation Results of Probable Daily Rainfall at 7 Precipitation Stations

Return Period (Probability) (Year, %)		Dairy Rainfall: R_{24} (mm/day)						
		Yangon (Kaba-Aye)	Belin	Thaton	Mawlamyine	Mudon	Kyaikkame	Yay
2	50.0%	118.2	175.0	213.7	209.5	197.7	204.8	252.4
3	33.3%	137.5	181.7	243.9	245.2	232.9	222.2	291.4
5	20.0%	159.0	189.1	277.6	285.0	272.1	241.6	334.9
10	10.0%	186.0	198.5	319.8	334.9	321.4	266.0	389.6
20	5.0%	211.9	207.4	360.4	382.9	368.7	289.4	442.0
25	4.0%	220.2	210.3	373.3	398.1	383.7	296.8	458.6
30	3.33%	226.8	212.6	383.7	410.5	395.9	302.9	472.2
50	2.0%	245.5	219.1	412.9	444.9	429.9	319.7	509.9
80	1.25%	262.5	225.0	439.6	476.5	461.0	335.1	544.4
100	1.0%	270.6	227.8	452.2	491.4	475.8	342.4	560.7
150	0.667%	285.3	232.8	475.1	518.6	502.5	355.6	590.4
200	0.5%	295.7	236.4	491.4	537.8	521.5	365.0	611.4
300	0.33%	310.3	241.5	514.3	564.8	548.2	378.2	641.0
400	0.25%	320.7	245.1	530.5	584.0	567.1	387.6	661.9
500	0.2%	328.7	247.9	543.1	598.9	581.8	394.8	678.2
Data No.		45 (years)	10 (years)	10 (years)	10 (years)	20 (years)	10 (years)	20 (years)

Source: JICA Survey Team



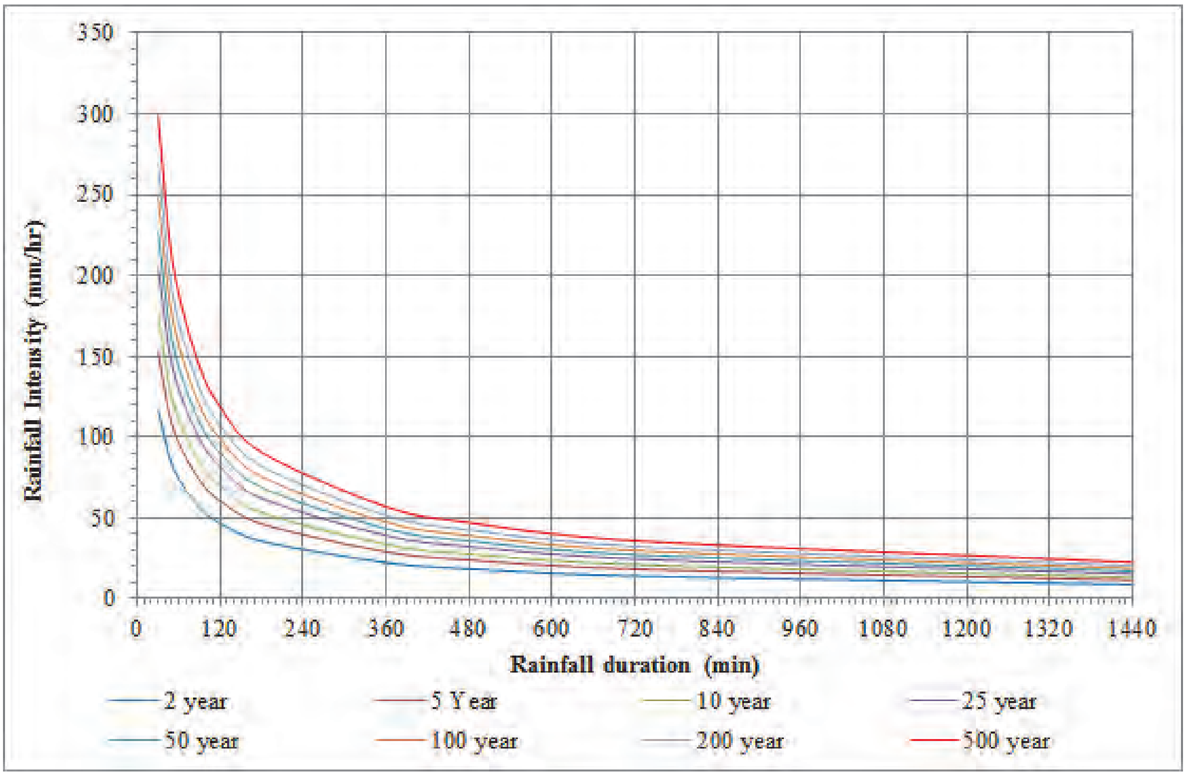
Source: JICA Survey Team

Figure 5.4.9 Correlation of Probable Daily Rainfall at 7 Precipitation Stations

Table 5.4.9 Calculation Results of IDF (Intensity-Duration-Frequency) at Thaton Station for Thaton Bypass

Return Period (Probability) (Year, %)		Dairy Rainfall: R_{24}	Rainfall intensity each rainfall duration (mm/hr): It = $R_{24}/24*(24/t)^m$, m=2/3											Remarks
		24 hour	24	12	8	6	3	2	1.5	1	0.75	0.5	It= $A/t^{2/3}$	
Thaton		1,440 min.	1,440	720	480	360	180	120	90	60	45	30		
2	50.0%	213.7	8.9	14.1	18.5	22.4	35.6	46.7	56.5	74.1	89.7	117.6	A= 74.086	
3	33.3%	243.9	10.2	16.1	21.1	25.6	40.7	53.3	64.5	84.6	102.4	134.2	A= 84.555	
5	20.0%	277.6	11.6	18.4	24.1	29.1	46.3	60.6	73.4	96.2	116.6	152.8	A= 96.239	
10	10.0%	319.8	13.3	21.2	27.7	33.6	53.3	69.8	84.6	110.9	134.3	176.0	A= 110.868	Road Drain
20	5.0%	360.4	15.0	23.8	31.2	37.8	60.1	78.7	95.3	124.9	151.4	198.3	A= 124.944	
25	4.0%	373.3	15.6	24.7	32.4	39.2	62.2	81.5	98.8	129.4	156.8	205.4	A= 129.416	Culvert
30	3.33%	383.7	16.0	25.4	33.3	40.3	64.0	83.8	101.5	133.0	161.1	211.2	A= 133.021	
50	2.0%	412.9	17.2	27.3	35.8	43.4	68.8	90.2	109.2	143.1	173.4	227.2	A= 143.144	Bridge
80	1.25%	439.6	18.3	29.1	38.1	46.2	73.3	96.0	116.3	152.4	184.6	241.9	A= 152.401	
100	1.0%	452.2	18.8	29.9	39.2	47.5	75.4	98.8	119.6	156.8	189.9	248.9	A= 156.769	Main Bridge
150	0.667%	475.1	19.8	31.4	41.2	49.9	79.2	103.8	125.7	164.7	199.5	261.5	A= 164.708	
200	0.5%	491.4	20.5	32.5	42.6	51.6	81.9	107.3	130.0	170.4	206.4	270.4	A= 170.359	
300	0.33%	514.3	21.4	34.0	44.6	54.0	85.7	112.3	136.1	178.3	216.0	283.0	A= 178.298	
400	0.25%	530.5	22.1	35.1	46.0	55.7	88.4	115.9	140.4	183.9	222.8	291.9	A= 183.914	
500	0.2%	543.1	22.6	35.9	47.1	57.0	90.5	118.6	143.7	188.3	228.1	298.9	A= 188.282	
		Calculation formula of 24hr Probable rainfall = Gumbel distribution												

Source: JICA Survey Team



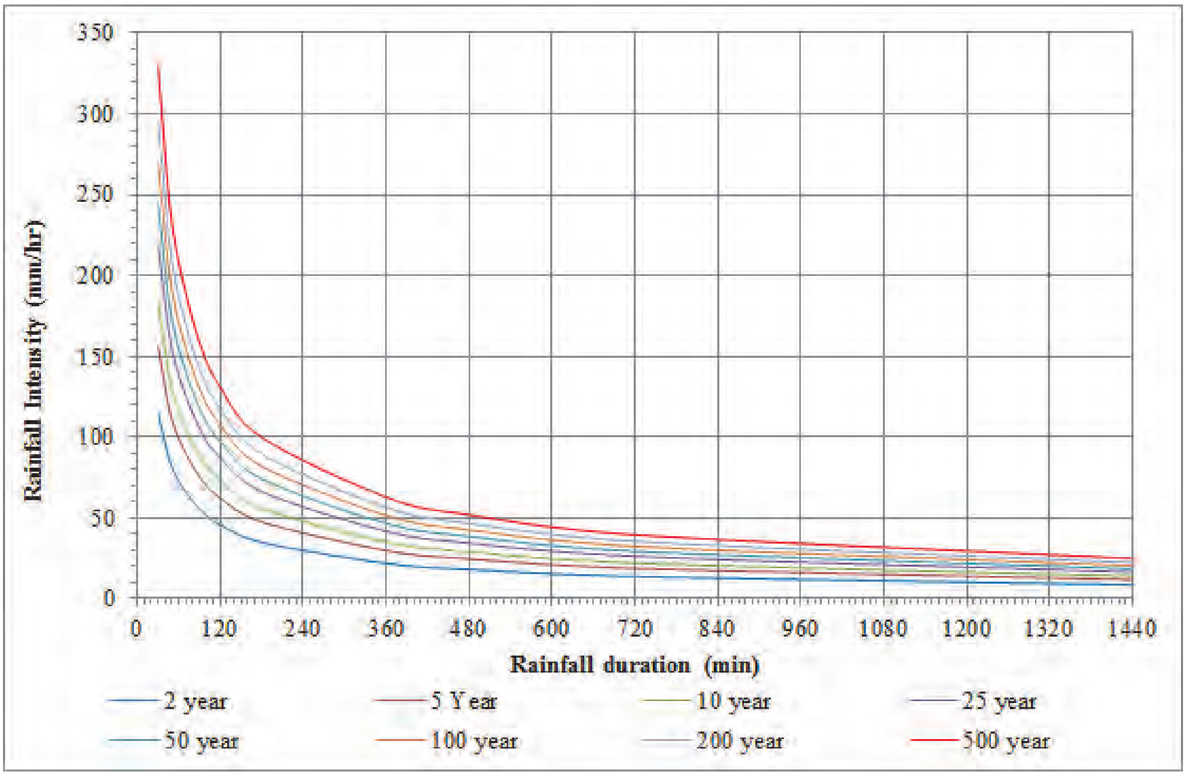
Source: JICA Survey Team

Figure 5.4.10 IDF (Intensity-Duration-Frequency) Curve at Thaton Station for Thaton Bypass

Table 5.4.10 Calculation Results of IDF (Intensity-Duration-Frequency) at Mawlamyine Station for Kyargalay Bypass

Return Period (Probability) (Year, %)		Dairy Rainfall: R_{24}	Rainfall intensity each rainfall duration (mm/hr): It = $R_{24}/24*(24/t)^m$, m=2/3											Remarks
		24 hour	24	12	8	6	3	2	1.5	1	0.75	0.5	It= $A/t^{2/3}$	
Mawlamyine		1,440 min.	1,440	720	480	360	180	120	90	60	45	30		
2	50.0%	209.5	8.7	13.9	18.2	22.0	34.9	45.8	55.4	72.6	88.0	115.3	A= 72.630	
3	33.3%	245.2	10.2	16.2	21.3	25.7	40.9	53.6	64.9	85.0	103.0	134.9	A= 85.006	
5	20.0%	285.0	11.9	18.9	24.7	29.9	47.5	62.2	75.4	98.8	119.7	156.8	A= 98.804	
10	10.0%	334.9	14.0	22.2	29.0	35.2	55.8	73.1	88.6	116.1	140.6	184.3	A= 116.103	Road Drain
20	5.0%	382.9	16.0	25.3	33.2	40.2	63.8	83.6	101.3	132.7	160.8	210.7	A= 132.744	
25	4.0%	398.1	16.6	26.3	34.5	41.8	66.4	86.9	105.3	138.0	167.2	219.1	A= 138.014	Culvert
30	3.33%	410.5	17.1	27.2	35.6	43.1	68.4	89.7	108.6	142.3	172.4	225.9	A= 142.312	
50	2.0%	444.9	18.5	29.4	38.6	46.7	74.2	97.2	117.7	154.2	186.8	244.8	A= 154.238	Bridge
80	1.25%	476.5	19.9	31.5	41.3	50.0	79.4	104.1	126.1	165.2	200.1	262.2	A= 165.193	
100	1.0%	491.4	20.5	32.5	42.6	51.6	81.9	107.3	130.0	170.4	206.4	270.4	A= 170.359	Main Bridge
150	0.667%	518.6	21.6	34.3	44.9	54.4	86.4	113.3	137.2	179.8	217.8	285.4	A= 179.789	
200	0.5%	537.8	22.4	35.6	46.6	56.5	89.6	117.5	142.3	186.4	225.9	296.0	A= 186.445	
300	0.33%	564.8	23.5	37.4	49.0	59.3	94.1	123.3	149.4	195.8	237.2	310.8	A= 195.805	
400	0.25%	584.0	24.3	38.6	50.6	61.3	97.3	127.5	154.5	202.5	245.3	321.4	A= 202.461	
500	0.2%	598.9	25.0	39.6	51.9	62.9	99.8	130.8	158.4	207.6	251.5	329.6	A= 207.627	
		Calculation formula of 24hr Probable rainfall = Gumbel distribution												

Source: JICA Survey Team



Source: JICA Survey Team

Figure 5.4.11 IDF (Intensity-Duration-Frequency) Curve at Mawlamyine Station for Kyargalay Bypass

5.4.2 Hydrological / Hydraulic Conditions

In order to predict the flow rate/water level during the flood season, it is necessary to collect and correlate the collectable hydrological/hydraulic data and conditions of the related rivers surrounding the target area.

(1) Characteristics of River Flow

1) Flow Regime

The discharge-duration curve, which is often used in Japan, is examined in order to understand the potential surface water characteristics of the river through the year. The flow regime shows the annual flow condition using the daily discharge at each hydrological station, and is indicated by the daily discharge and the number of exceeded days. The annual flow regime shows as follows;

- ✓ High Discharge (95th daily discharge from the greatest discharge)
- ✓ Normal Discharge (185th daily discharge from the greatest discharge)
- ✓ Low Discharge (275th daily discharge from the greatest discharge)
- ✓ Drought Discharge (355th daily discharge from the greatest discharge)

The coefficient of river regime is the ratio of the minimum and maximum flow rate at optional river points, and shows the stability of the river flow quantitatively. The magnitude the coefficient of river regime t indicates that the flow fluctuation is large. Large flow fluctuation indicates that the full year water intake is difficult and the flood damage can easily occur. (For example, in Europe: 18 - Rhine River, Basel; 4 - Danube River, Vienna; 34 - Seine River. In Japan: 930 - Tone River: 870 - Kiso River; 5060 - Yoshino River.)

The flow regime calculated at Belin (Belin River) and Hpa-an (Thanlwin River) stations from 2009–2013 is summarized in Table 8.2.2 and Figure 8.2.2.

Although there is a certain level of flow fluctuation in the rainy season, the coefficient of the river regime of both rivers is relatively small and similar, for having delta-specific morphology. The flow-rate during the dry season is relatively stable for both rivers. (However, the difference in the catchment area scale between both rivers is big.)

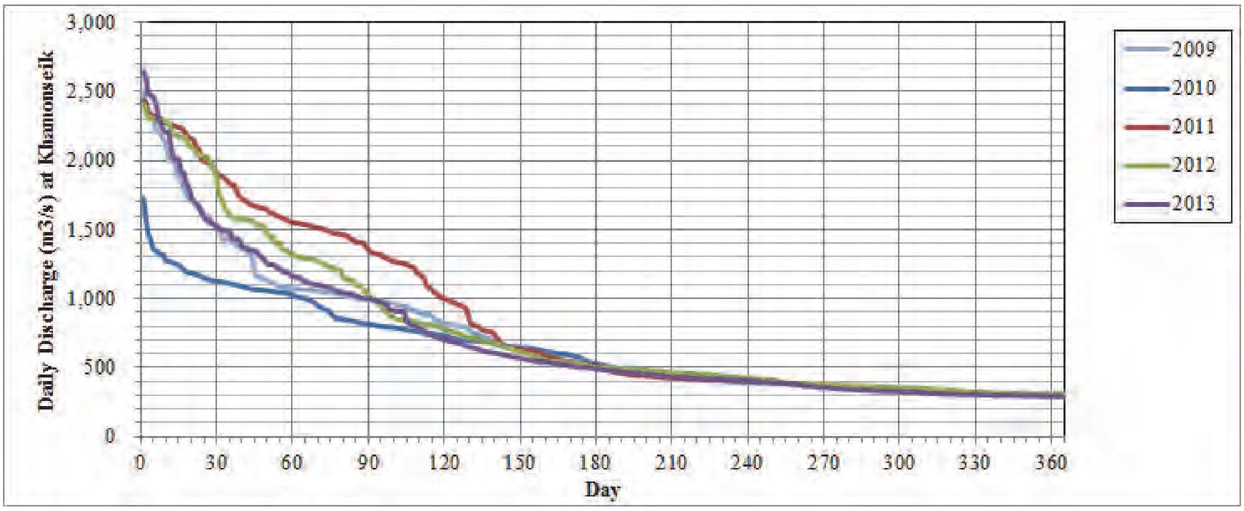
The Thanlwin River is an international river that runs through three countries. The river name is a derivation of "Angry River" in Chinese. Hence, the re-survey by using long-term data is needed to confirm flow regime.

Table 5.4.11 Flow Regime (2009-2013) at Belin of Belin River

River: Belin River
Station: Belin

Year	Drainage Area (km^2)	Daily Discharge (m^3/s)							Coefficient of River Regime	Remarks
		Max.	High Dischage	Normal Discharge	Low Discharge	Drought Discharge	Min.	Mean		
			95th day	185th day	275th day	355th day				
2009	2,518	2,498	977	514	364	312	308	721	8.1	
2010	2,518	1,730	800	502	360	299	293	624	5.9	
2011	2,518	2,426	1,317	480	363	298	290	838	8.4	
2012	2,518	2,411	954	497	372	306	299	769	8.1	
2013	2,518	2,644	974	477	346	292	289	710	9.1	
Mean	2,518	2,342.0	1,004.0	494.0	361.0	301.0	296.0	732.0	7.9	

Source: JICA Survey Team



Source: JICA Survey Team

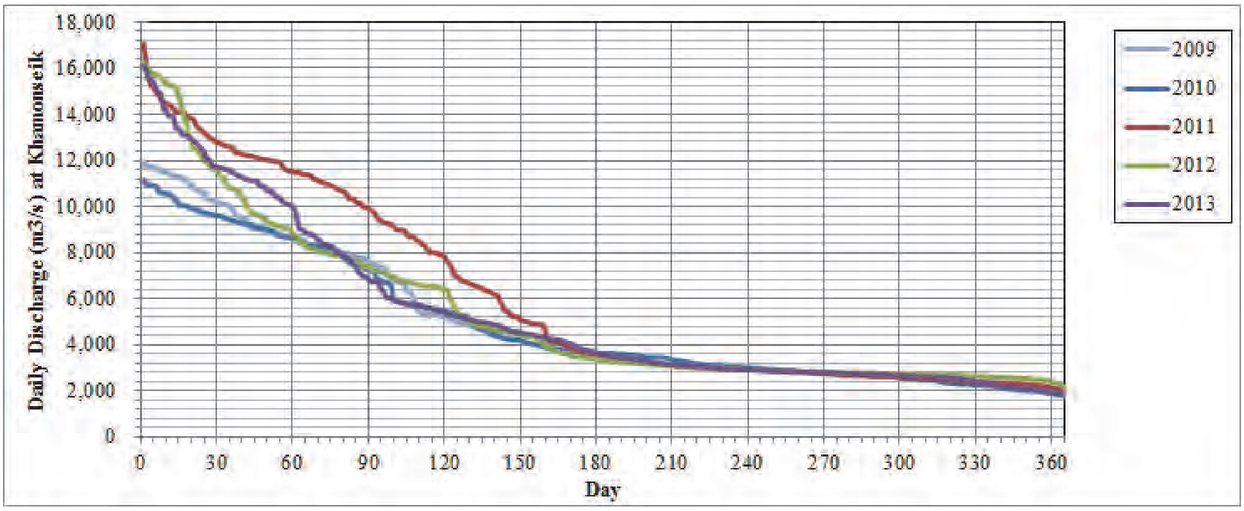
Figure 5.4.12 Discharge-Duration Curve (2009-2013) at Belin of Belin River

Table 5.4.12 Flow Regime (2009-2013) at Hpan Station of Thanlwin River

River: Thanlwin River
Station: Hpaan

Year	Drainage Area (km^2)	Daily Discharge (m^3/s)							Coefficient of River Regime	Remarks
		Max.	High Dischage	Normal Discharge	Low Discharge	Drought Discharge	Min.	Mean		
			95th day	185th day	275th day	355th day				
2009	-	11,937	7,337	3,347	2,716	2,195	2,090	4,938	5.7	
2010	-	11,140	6,785	3,611	2,777	1,943	1,743	4,836	6.4	
2011	-	17,080	9,332	3,451	2,684	2,211	1,927	6,014	8.9	
2012	-	16,227	7,156	3,294	2,798	2,472	2,145	5,312	7.6	
2013	-	16,077	6,386	3,502	2,767	2,033	1,827	5,302	8.8	
Mean	-	14,492.0	7,399.0	3,441.0	2,748.0	2,171.0	1,946.0	5,280.0	7.4	

Source: JICA Survey Team



Source: JICA Survey Team

Figure 5.4.13 Discharge-Duration Curve (2009-2013) at Hpaan of Thanlwin River

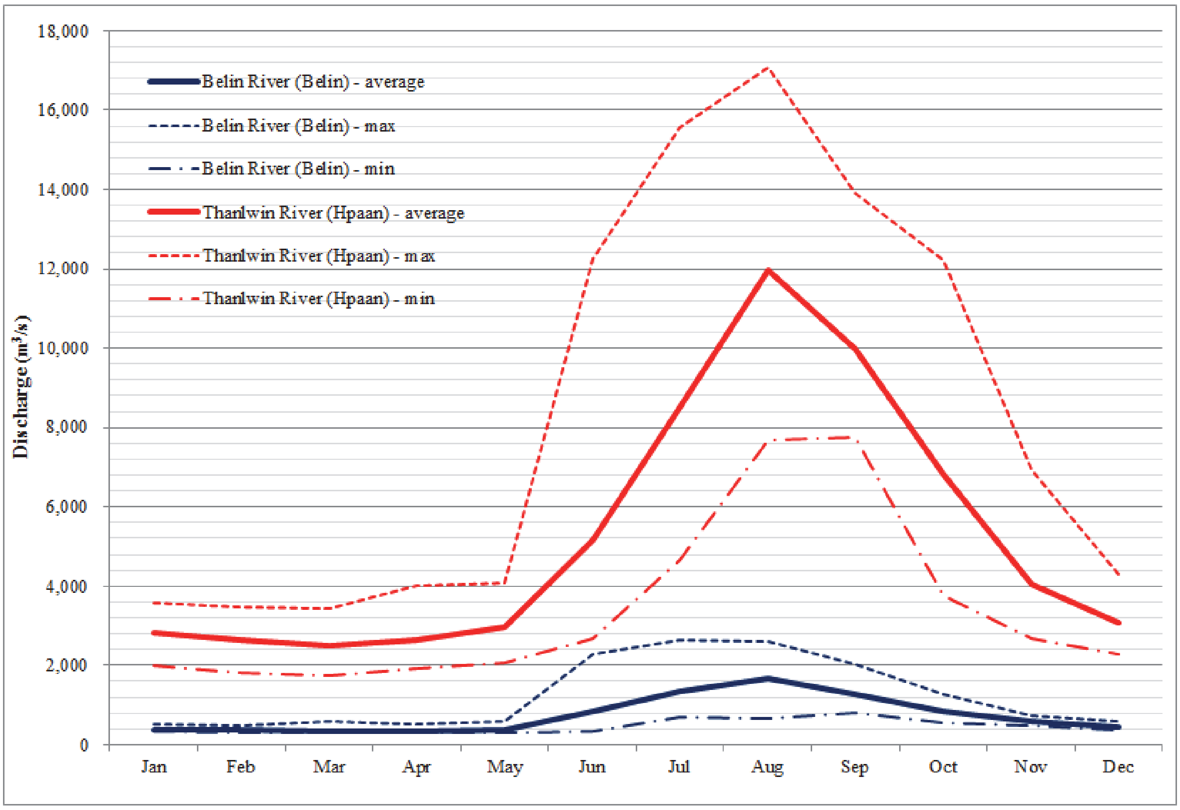
2) Monthly Flow Pattern

The mean monthly flow pattern from the past five years of data at the two river's gauging stations are shown in Table 5.4.13 and Figure 5.4.14. The peak discharge occurs in July and August.

Table 5.4.13 Monthly Flow Pattern at Belin River (Belin) and Thanlwin River (Hpaan) during 2009-2013

River Name	Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Remarks
Belin River	Mean	389	357	345	340	364	843	1,328	1,652	1,256	832	588	460	730	
	Max	503	495	578	508	607	2,280	2,644	2,601	2,016	1,258	736	590	2,644	
	Min	337	301	289	291	289	355	684	679	804	544	464	385	289	
Thanlwin River	Mean	2,833	2,643	2,506	2,630	2,954	5,172	8,497	11,959	10,000	6,808	4,063	3,085	5,262	
	Max	3,580	3,483	3,451	4,016	4,096	12,243	15,550	17,080	13,913	12,203	6,938	4,287	17,080	
	Min	2,007	1,803	1,743	1,913	2,068	2,660	4,656	7,685	7,760	3,747	2,684	2,271	1,743	

Source: JICA Survey Team



Source: JICA Survey Team

Figure 5.4.14 Monthly Flow Pattern at Belin River (Belin) and Thanlwin River (Hpaan) during 2009-2013

(2) Catchment Areas of the Proposed Main 5 Bridges and Roads

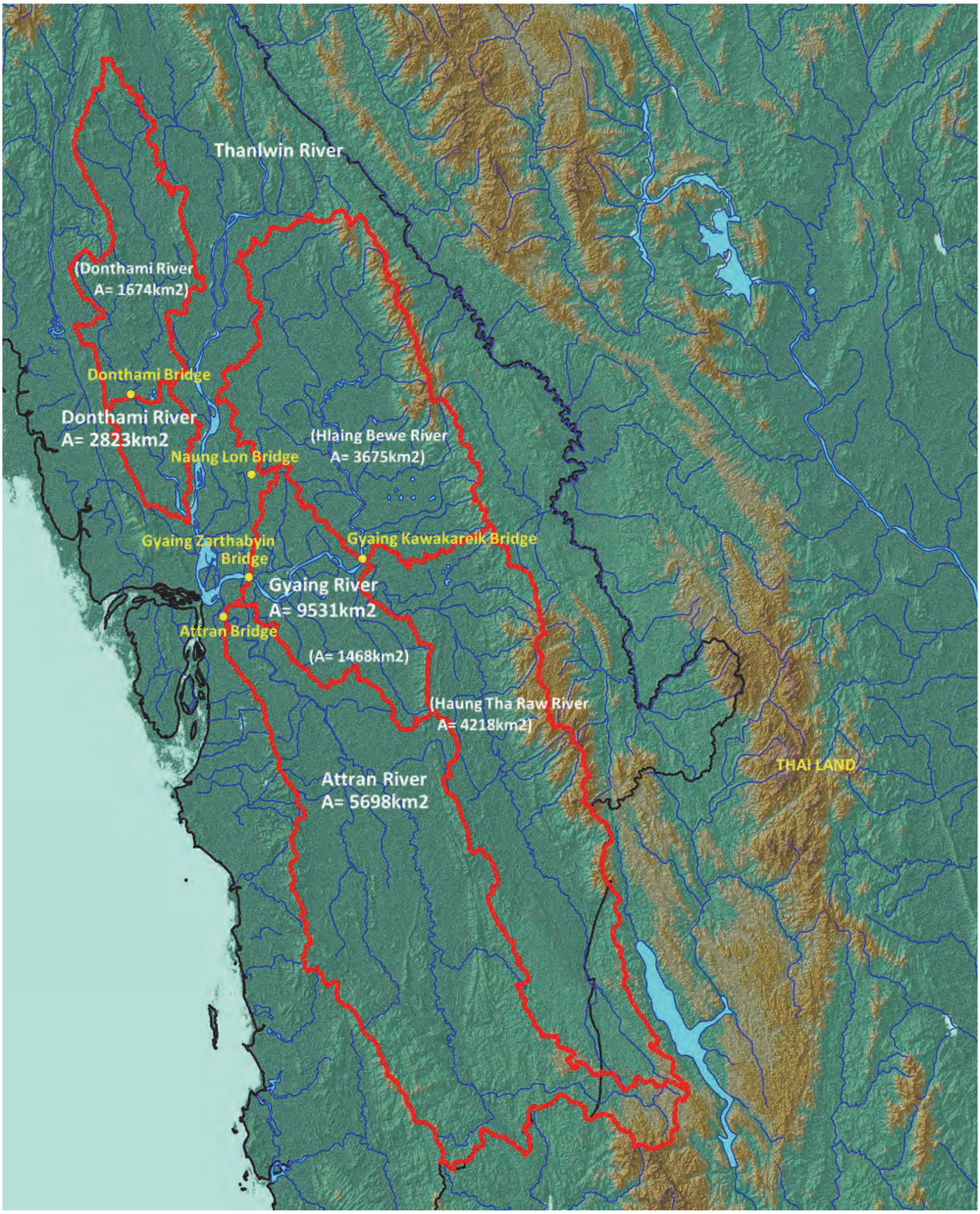
The catchment areas of related rivers at the proposed main bridges are measured using topographic maps, as shown in Table 5.4.14 and Figure 5.4.15. Although the bridges (except Naung Lon Bridge) have the catchment area, Naung Lon Bridge is located at the catchment boundary between Naung Lon and Eindu Creeks.

Table 5.4.14 Catchment Areas at the Proposed Bridges

No.	Bridge Name (River Name)	Riverine system	River / Tributary Name	Catchment Area (km^2)	Remarks
1	Donthami	Thanlwin	Donthami	1,674	
2	Naung Lon		Naung Lon	-	Almost watershed between Naung Lon and Eindu creeks
3	Gyaing (Kawkareik)		Hlaing Bwe (Gyaing)	3,675	
4	Gyaing (Zathapyin)		Gyaing	9,531	
5	Atran		Atran	5,698	-

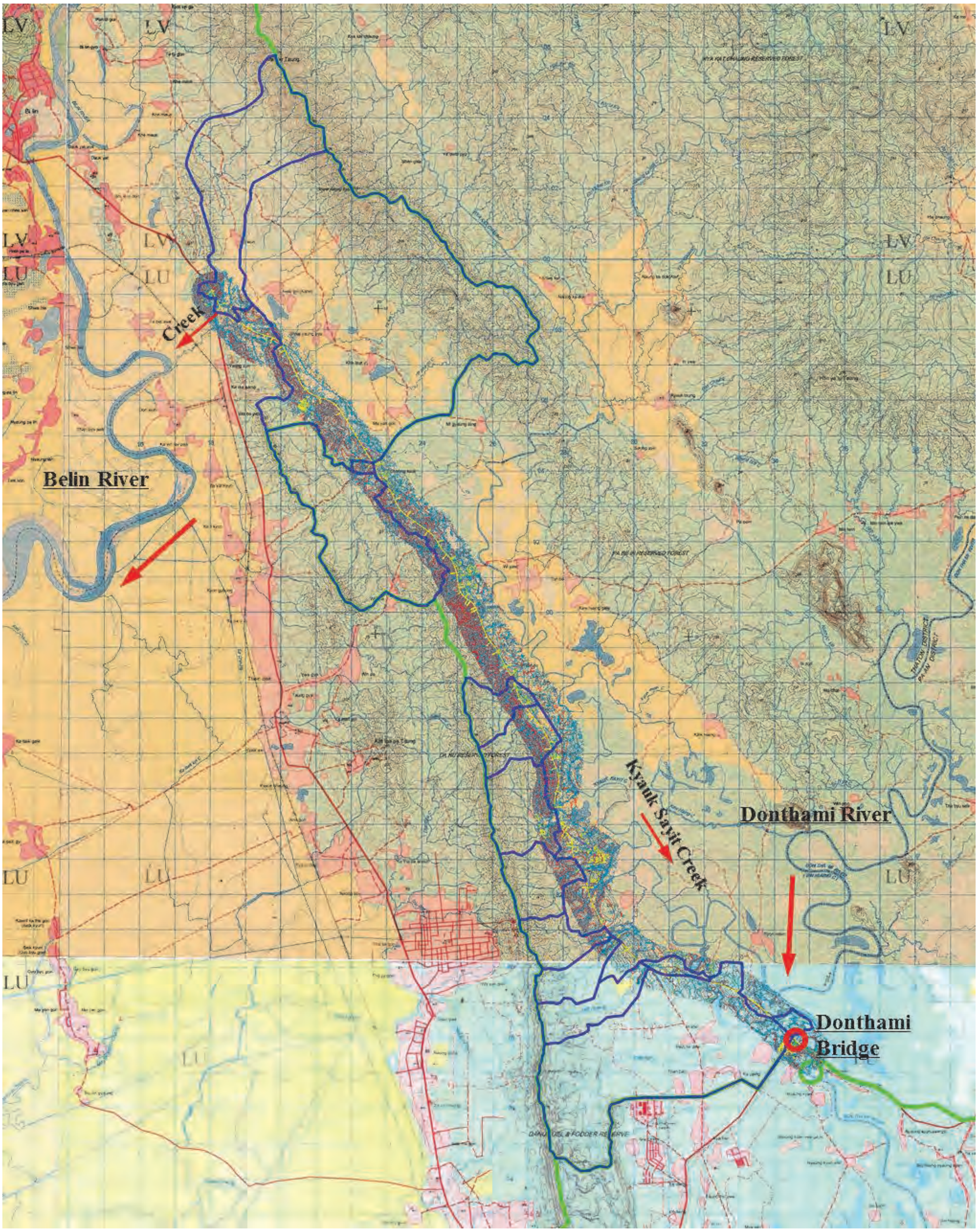
Source: JICA Survey Team

In addition, the catchment areas of Thaton and Kyargalay Bypass Roads are shown in Figure 5.4.16 and Figure 5.4.17. The proposed Thaton and Kyargalay Bypass Roads traverse across several types of terrain, including swamps, waterways, paddy field zones, and low-lying areas. The bypass-road crosses many waterways throughout its alignment, and necessary drainage provisions such as bridges and culverts, are to be provided by the discharge which is calculated from its catchment area. (The catchment area for the bypass road is divided with reference to the past topographic map and the topographic survey results along the road.) However, its topographic information is not detailed and its channel-network is very complicated for flood areas. Therefore, a more detailed survey shall be performed in a future study.



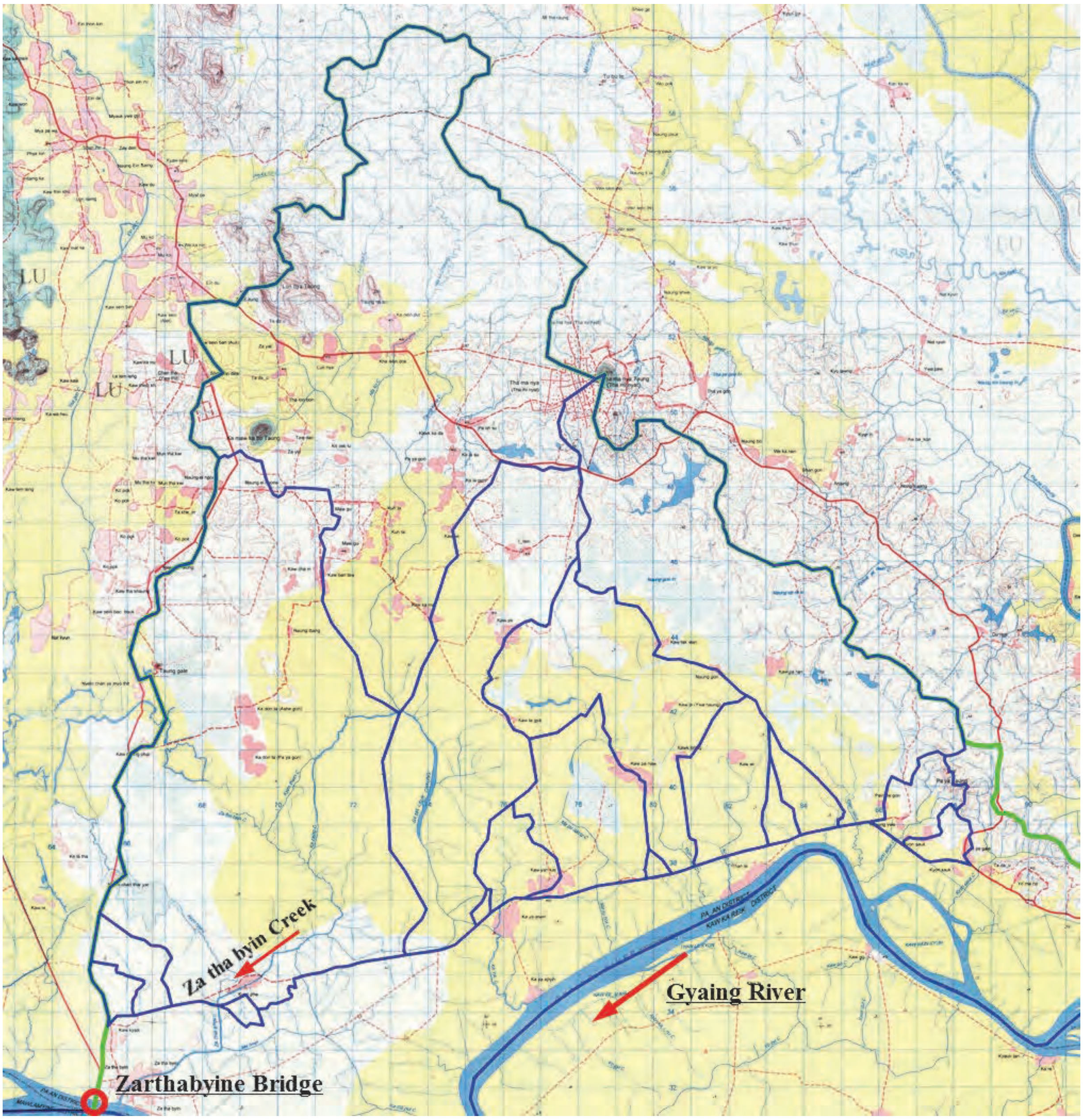
Source: JICA Survey Team based on the data from Topographic Map (Irrigation Dept.) and ASTER-GDEM

Figure 5.4.15 Catchment Area Map at the Proposed Bridges



Source: JICA Survey Team based on the data from Topographic Map (Irrigation Dept.)

Figure 5.4.16 Catchment Area Map at the Thaton Bypass Road



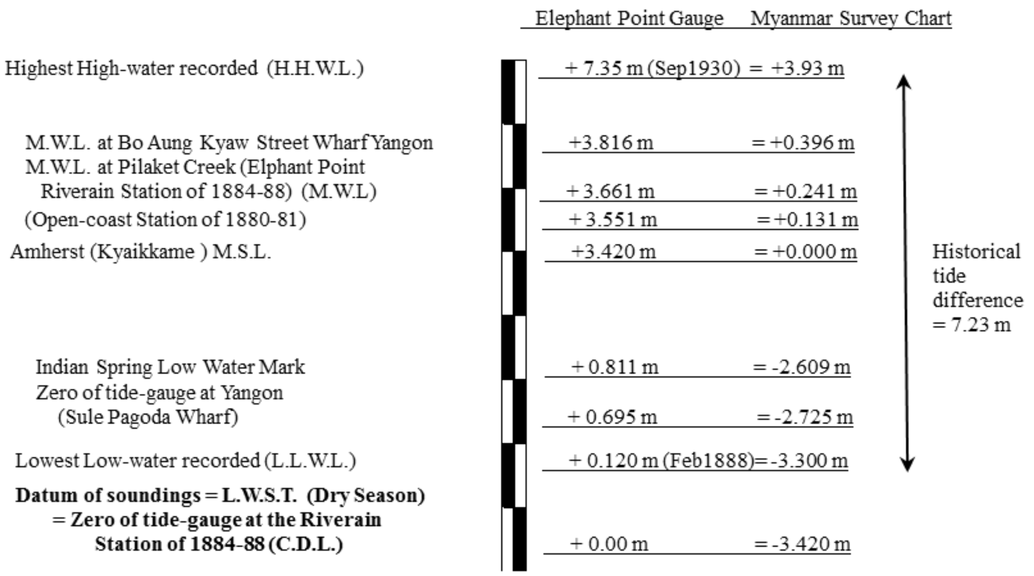
Source: JICA Survey Team based on the data from Topographic Map (Irrigation Dept.)

Figure 5.4.17 Catchment Area Map at the Kyargalay Bypass Road

(3) Tidal Level around Mawlamyine

The nearest tide-gauge station to the Study Area is the Mawlamyine (formerly, Mawlamyine) Port (located near the Andaman Sea). However, its tide chart diagram is difficult to obtain, therefore, the chart diagram at Elephant Point as the same tidal station, is shown in Figure 5.4.18. From it, the difference between historical high and low tide levels is observed as 7.23m.

Zero of Myanmar Survey Datum, namely, zero meters of topographic survey is measured based on Mean Water Level (M.W.L.) at Amherst (Kyaikkame) Tidal Station. Hence, historical high-tide at Elephant Point becomes 3.93 from this Figure.



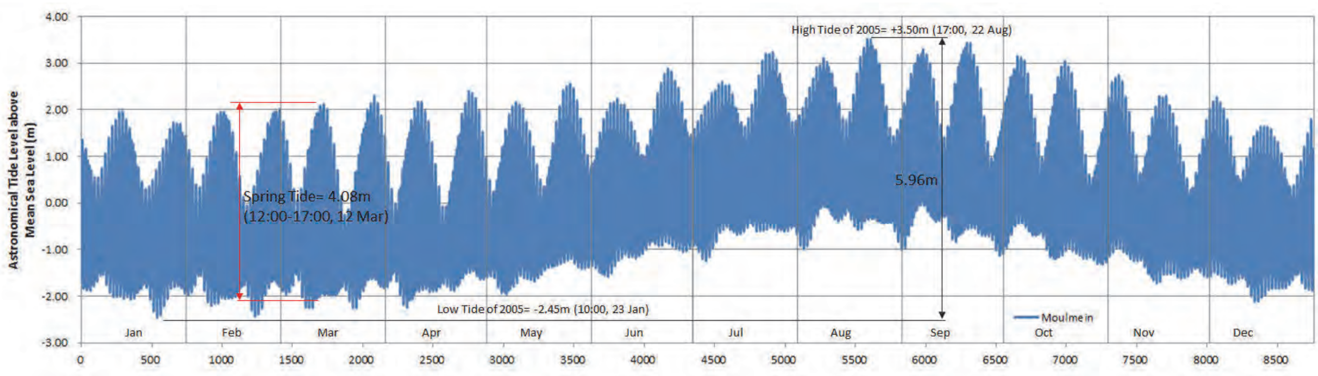
Source: MPA

Figure 5.4.18 Tide Level of Elephant Point (Chart Diagram)

On the other hand, the hourly data of calculated astronomical tide at Mawlamyine Port is available on a University of Tokyo website. The astronomical tide levels in Mawlamyine in 2005 are shown in Figure 5.4.19 and Figure 5.4.20. The season with the highest tide, as seen in this figure, is August to September of the rainy season. Since discharge from the river is added to the astronomical tide, the actual water level of the inland river during the rainy season is even higher.

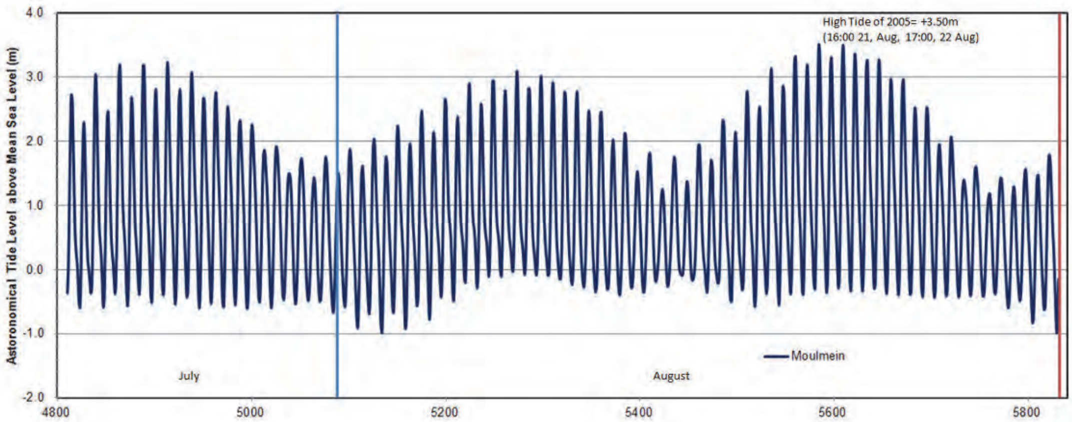
According to DWRIR reference, the maximum difference between past high and low water level at Hpa-an Gauging Station located 48 km upstream Thanlwin River from Mawlamyine Port, is 8.42 meters, as shown in Figure 5.4.21.

As seen above, the water level of the river during rainy-season is closely related to the tidal change.



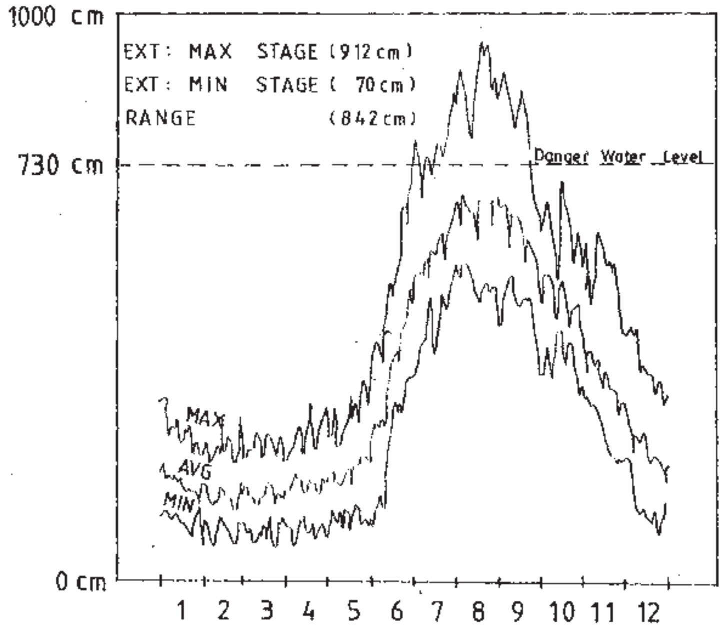
Source: Earthquake Research Institute, the University of Tokyo

Figure 5.4.19 Fluctuation of Annual Astronomical Tide at Mawlamyine station (2005)



Source: Earthquake Research Institute, the University of Tokyo

Figure 5.4.20 Fluctuatuon of (Astronomical) High Tide at Mawlamyine Station (July-August 2005)



Source: Myanmar River Reference (1996, DWRIR)

Figure 5.4.21 Seasonal Fluctuatuon of (Observed) High – Mean - Low Water Level at Hpa-an Station (1983-1992)

(4) Flood Conditions

According to "Hazard Profile of Myanmar, 2009", flooding has always been one of the major hazards in Myanmar, accounting for 11% of all disasters, second only to fire. Floods around the target area can be classified into three types:

- ✓ Riverine floods in the river delta or the lowland;
- ✓ Localized floods in urban areas due to a combination of factors, such as cloudburst, saturated soil, poor infiltration rates and inadequate or poorly built infrastructure (such as blocked drains);
- ✓ Flooding due to storm surges in the coastal areas.

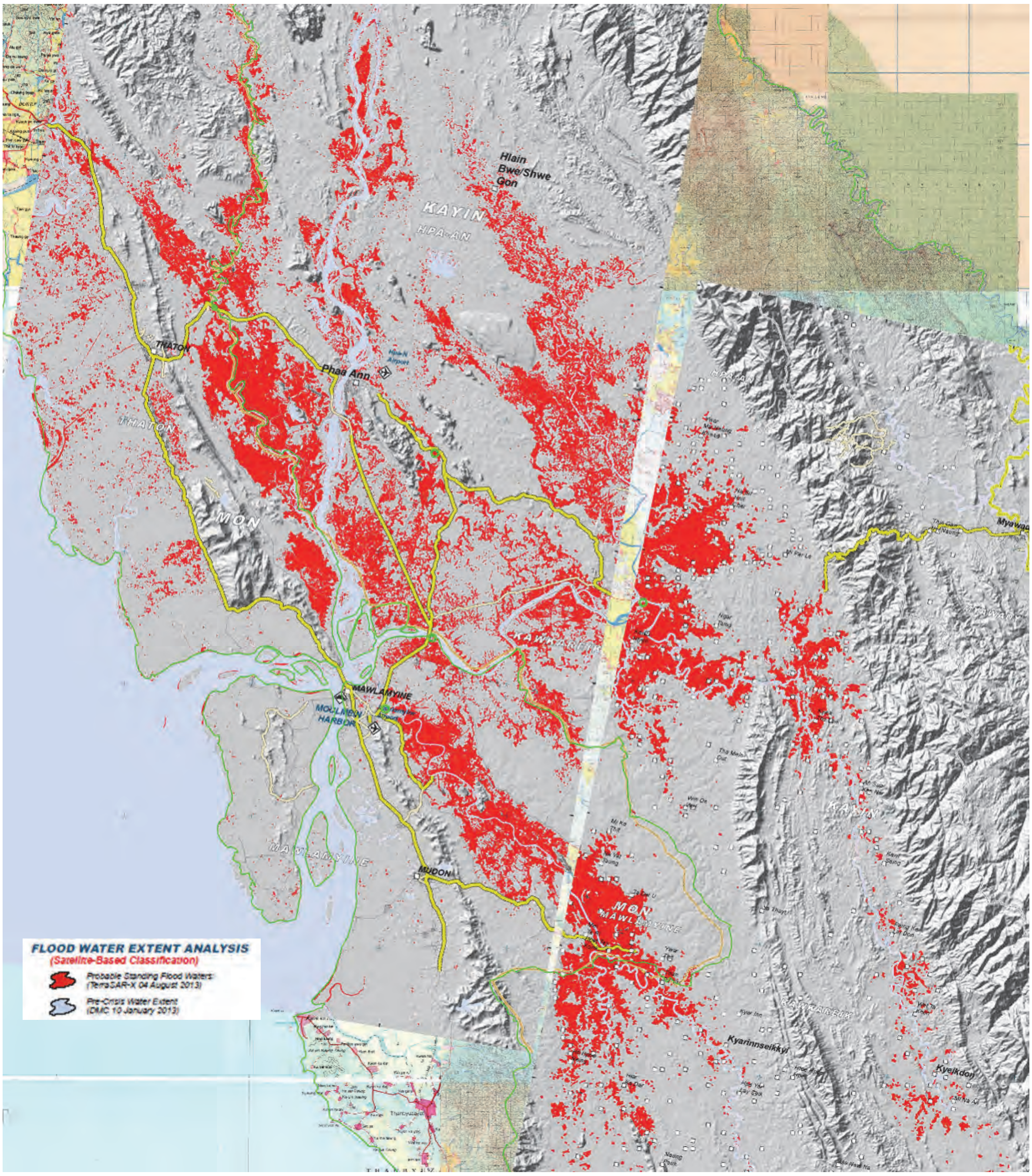
In Sittoung and Thanlwin riverine systems, floods are caused by rainfall associated with low-pressure waves (the remnants of typhoons and tropical storms of South China Sea) moving from east to west. Riverine floods are the most common, and they happen when the monsoon troughs or low-pressure waves or storm-surges superimposes on the general monsoon pattern, resulting in intense rainfall over lowlands of the river catchment areas.

According to DMH reference, flood frequencies during 1966-2009 along Sittoung and Thanlwin Rivers were 88 events in 44 years at Madauk, Sittoung River and 93 events at Hpa-an, Thanlwin River. Four flooding events in the past twelve years that caused substantial damage are shown in Table 5.4.15. Also, Figure 5.4.22 shows the flood inundation areas resulting from heavy rain on 29 July 2013, taken by satellite imagery on 4-5 August 2013.

Table 5.4.15 Major Floods in Past around Targeted Area (1997-2013)

No.	Location	Date	No. of Affected Village Tracts and Villages	No. of Affected Households	No. of Affected Families	Affected Population	Deaths	Loss (x100,000 kyat)
1	Kayin State	1/8/97	All villages in 5 townships	18,804	18,855	109,840	-	-
2	Hpa-an, Kayin State	13/8/97	6 villages	2,669	2,669	14,488	-	-
3	Kyaikmaraw Township, Mon State	19/8/02	-	829	829	4,686	-	414 (37,636USD)
4	Kayin, Mon and other States	29/7/13	7 townships, etc.	8,218	8,218	38,316	3	-

Source: Hazard Profile of Myanmar (Union of Myanmar), OCHA (UN)



Source: UNSAT data (and topographic Map)

Figure 5.4.22 Inundation Hazard Areas based on Satellite Image at the time of 4-5 August 2013 Flood

5.4.3 Estimation of Probable Floods and Water Levels

(1) Probable Floods and Water Level at Gauging Stations

1) Probable Floods at Gauging Stations

Past annual maximum discharges (extremal values) of two stations (Hpa-an, Belin) for the design discharge, are collected as shown in Table 5.4.16. Although both gauging stations are influenced by the tide, accuracy against flow rate in rainy season is not considered a problem since the flow of rainy season is only one-way, from upstream to downstream.)

Table 5.4.16 Collection Data List for Annual Maximum Discharge

Station Name	River Name	Catchment Area (km^2)	Period of record	Collected Data No.	Remarks
Hpa-an	Thanlwin	15,800 in Myanmar	1981-2013	33 (1981-2013)	
Belin	Bilin	2,518	1965-2013	19 (1994-1997, 1999-2013)	Gap 1998-1999

Source: DMH

The probable discharges are calculated according to the following:

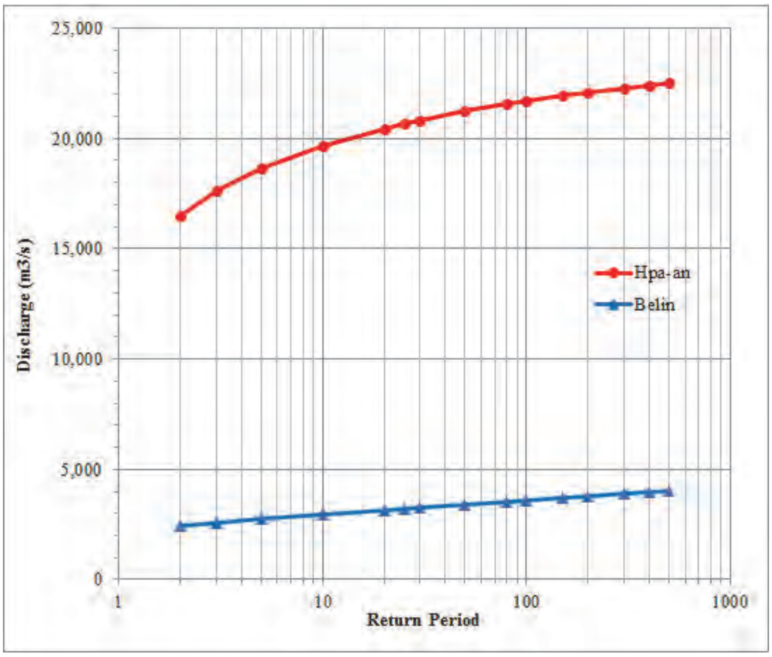
- ✓ To select the appropriate model for probability distribution from the six methods; Exponential distribution, Gumbel distribution, Square Root - Exponential type maximum distribution, Generalized extreme value distribution, Log Pearson type III distribution (Real space method) and Log Pearson type III distribution (Logarithmic space method).
- ✓ In this study, the distribution model is selected in reference to SLSC (Standard Least Squares Criterion) value or adequacy of probability value, etc. (SLSC value of 0.04 or less is desirable.)
- ✓ Calculation return periods are for 2, 3, 5, 10, 20, 25, 30, 50, 80, 100, 150, 200, 300, 400 and 500 year.

The results of probable discharge at two discharge-gauge stations (Hpa-an, Belin) are shown in Table 5.4.17 and Figure 5.4.23.

Table 5.4.17 Probable Flood Calculation at Hpa-an and Belin Stations

Riverine System Name		Thanlwin River	Bilin River	Remarks
River Name		Thanlwin River	Bilin River	
Gauge Station Name		Hpa-an	Belin	
Catchment Area at Station (km^2)		15,800 in Myanmar	2,518	
Probable Discharge (m^3/s) each Return Period	1/2	16,494	2,452	
	1/3	17,632	2,600	
	1/5	18,662	2,765	
	1/10	19,685	2,971	
	1/20	20,459	3,170	
	1/25	20,671	3,233	
	1/30	20,833	3,284	
	1/50	21,241	3,426	
	1/80	21,566	3,557	
	1/100	21,706	3,619	
	1/150	21,940	3,731	
	1/200	22,091	3,810	
	1/300	22,285	3,922	
	1/400	22,411	4,002	
	1/500	22,502	4,063	
Applicable distribution		Log Pearson type Ⅲ distribution (Logarithmic space method)	Gunbel distribution	

Source: JICA Survey Team based on the data from DMH



Source: JICA Survey Team based on the data from DMH

Figure 5.4.23 Probable Flood Calculation at Hpa-an and Belin Stations

2) Probable Water Levels at Gauging Stations

In a similar way, past annual maximum water levels (extremal values) of three stations (Hpa-an, Myawaddy, Belin) for design water level reference, are used as shown in Table 5.4.18. (Regarding the observed water levels of other stations, the observed-year is small, and is not used for the probability calculation.) In this regard, the offset for heights is needed because the observed water-level data at all stations collected are arbitrary.

The results of probable water-level at three discharge-gauge stations (Hpa-an, Myawaddy, Belin) are shown in Table 5.4.19 and Table 5.4.17.

Table 5.4.18 Collection Data List for Annual Maximum Water Level

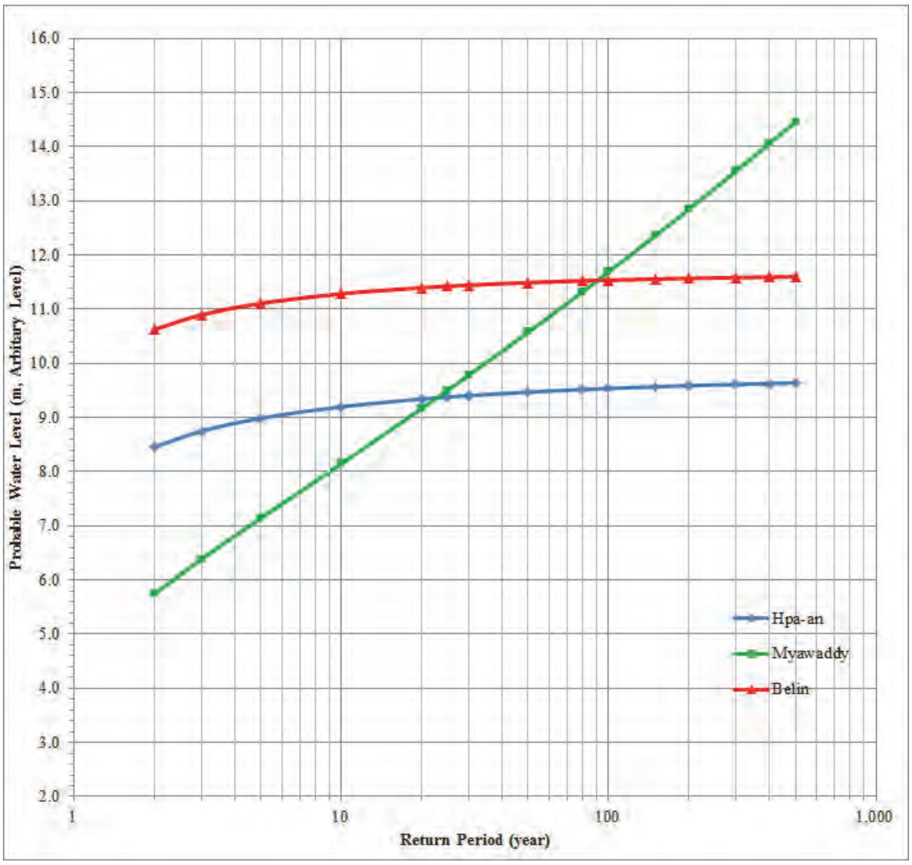
Station Name	River Name	Catchment Area (km^2)	Period of Record	Collected Data No.	Remarks
Hpa-an	Thanlwin	15,800 in Myanmar	1981-2013	30 (1981-2010)	
Myawaddy	(Thanlwin)	-	-	-	
Belin	Bilin	2,518	1965-2013	19 (1994-1997, 1999-2013)	Gap 1998-1999

Source: DMH, ID

Table 5.4.19 Probable Water Level Calculation at 3 Stations

Riverine System Name		Thanlwin River		Bilin River	Remarks
River Name		Thanlwin	Thaungyin	Bilin	
Gauge Station Name		Hpa-an	Myawaddy	Belin	
Catchment Area at Station (km^2)		15,800 in Myanmar	-	2,518	
Datum Level		Arbitrary datum	Arbitrary datum	Arbitrary datum	
Probable Water Level (m) each Return Period	1/2	8.46	5.74	10.63	
	1/3	8.75	6.39	10.90	
	1/5	8.99	7.14	11.11	
	1/10	9.20	8.15	11.29	
	1/20	9.34	9.17	11.40	
	1/25	9.38	9.51	11.43	
	1/30	9.41	9.78	11.45	
	1/50	9.47	10.58	11.49	
	1/80	9.52	11.33	11.53	
	1/100	9.54	11.69	11.54	
	1/150	9.57	12.36	11.56	
	1/200	9.59	12.85	11.57	
	1/300	9.61	13.55	11.59	
	1/400	9.63	14.06	11.59	
	1/500	9.64	14.46	11.60	
Applicable distribution		Log Pearson type III distribution (Real space method)	SQRT-exponential type maximum distribution	Log Pearson type III distribution (Real space method)	

Source: JICA Survey Team based on the data from DMH and ID



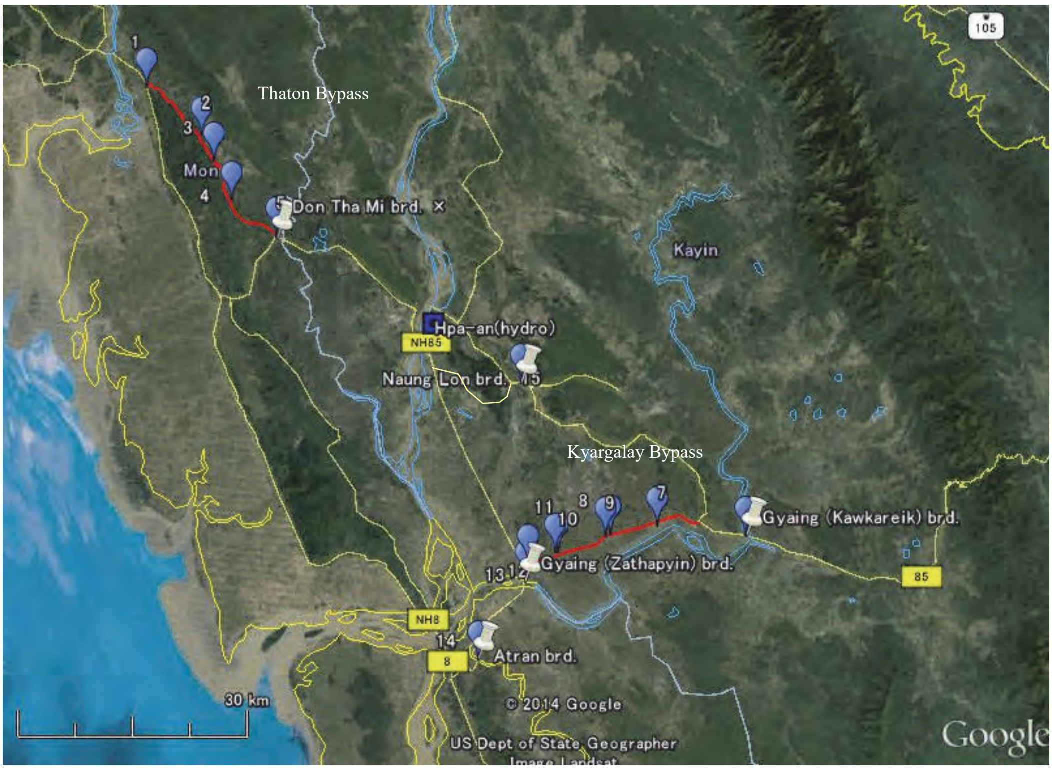
Source: JICA Survey Team based on the data from DMH

Figure 5.4.24 Probable Water-level Calculation at 3 Stations

(2) Interview Survey Result

The water level in the water-level gauging station is an arbitrary elevation value, not the elevation from topographic survey data. Therefore, in order to analogize the correlation between the flood-level at sites and the probability value at the gauging station, inhabitants of the area were interviewed about the actual flood levels. Locations and results of the interview are shown in Figure 5.4.25 and Table 5.4.20.

Historical high flood levels mostly occurred at August 2013 based on interviews with inhabitants. Inhabitants interviewed said the historical flood level (HHWL) at Kawkareik Bridge was 6.50m. The ADB project team interviews said 6.45m.The annual mean highest-flood level (AHWL) was reported as 5.50m, a 1.0 m difference to HHWL.



Source: Prepared by JICA Survey Team based on Google Earth

Figure 5.4.25 Hydrological Interview Survey Locations

Table 5.4.20 Hydrological Interview Survey Results

No.	Bridge / Bypass Name	Longitude	Latitude	Historical High Water Level	Annual (Mean) High Water Level	CA area	Remarks
	1. Thaton Bypass						
1	NH8 Brd.	97.287426	17.162537	8.30	-	Belin	
2	Flood on the road	97.353576	17.102337	8.30	7.70	Donthami	
3	C-17 (Box11)	97.367515	17.072029	8.80	8.25	Donthami	
4	C9 (Brd4)	97.387918	17.025054	8.22	7.77	Donthami	
5	Donthami	97.441531	16.980879	7.29	6.20	Donthami	
6	2. Kawakareik	98.005392	16.606911	**6.50**	**5.50**	Gyaing	flood mark
				6.45			(ADB project measured.)
	3. Kyargalay Bypass						
7	Lunch location	97.897335	16.62277	5.36	-	Gyaing	
8	crossroad	97.839212	16.615288	5.02	4.52	Gyaing	
9	C-6 (Brd-4)	97.833092	16.613177	4.32	-	Gyaing	
10	PW Brd	97.773626	16.596122	4.60	(3.50)	Gyaing	"()" is assumed PW-bridge design level.
11	Shop	97.770166	16.596309	**4.69**	**4.09**	Gyaing	flood mark
12	Near EP	97.736429	16.584354	No flood	-	Gyaing	
13	4. Zathabyin	97.732794	16.565738	2.80	-	Gyaing	
14	5. Attran	97.670281	16.473232	4.20	-	Attran	
15	6. Naunglon	97.736443	16.797243	5.50	-	Naunglon	

Source: JICA Survey Team

(3) Probable Floods and Water Level at Proposed Bridges and Roads

1) Probable Floods at the Proposed Bridges

The discharge (probable floods) of proposed bridges is calculated by multiplying the proportion of each catchment area to the probable discharge of each gauge station upstream ("specific discharge" method). In terms of the magnitude of design discharge, a 100-year flood is adopted for the five main bridges, a 50-year flood for small bridges in the proposed bypass roads.

The probable discharge used for the hydraulic calculation of the five main bridges is shown in Table 5.4.21. (The probable discharge for proposed roads is calculated in another chapter.)

Table 5.4.21 Probable Floods at Proposed Bridges

Bridge Name		-	Donthami	Gyaing Kawkareik			Gyaing Zarthabyin	Attran	Naunglon	Remarks
River Name		Bilin River	Donthami River	Hlaing Bwe River (Bridge point)	Haung Tha Raw River	Gyaing	Gyaing	Attran	Naunglon	
Gauge Station Name / Location		Belin	Bridge	Bridge	Downstream of Brd.	Downstream of Brd.	Bridge	Bridge	Bridge	
Catchment Area at Station (km^2)		2,518	1,674	3,675	4,218	7,893	9,531	5,698	5.8	
Low Discharge		361	240	527	605	1,132	1,366	817	0.8	0.14337 m3/s/km2
Normal Discharge		494	328	721	828	1,549	1,870	1,118	1.1	0.19619 m3/s/km2
Probable Discharge (m^3/s) each Return Period	1/2	2,452	1,630	3,579	4,108	7,687	9,282	5,549	5.7	
	1/3	2,600	1,728	3,795	4,355	8,150	9,841	5,883	6.0	
	1/5	2,765	1,838	4,035	4,631	8,666	10,464	6,256	6.4	
	1/10	2,971	1,975	4,337	4,978	9,314	11,247	6,724	6.9	
	1/20	3,170	2,107	4,626	5,310	9,936	11,997	7,173	7.4	
	1/25	3,233	2,149	4,718	5,415	10,133	12,235	7,315	7.5	
	1/30	3,284	2,183	4,793	5,501	10,294	12,429	7,431	7.6	
	1/50	3,426	2,278	5,001	5,740	10,741	12,969	7,753	8.0	
	1/80	3,557	2,365	5,191	5,959	11,150	13,463	8,049	8.3	
	1/100	3,619	2,406	5,282	6,062	11,344	13,697	8,189	8.4	Design Discharge
	1/150	3,731	2,480	5,445	6,250	11,695	14,122	8,443	8.7	
	1/200	3,810	2,533	5,561	6,383	11,945	14,423	8,623	8.8	
	1/300	3,922	2,608	5,725	6,571	12,295	14,846	8,876	9.1	
	1/400	4,002	2,660	5,841	6,704	12,544	15,147	9,055	9.3	
	1/500	4,063	2,701	5,931	6,807	12,737	15,380	9,195	9.4	

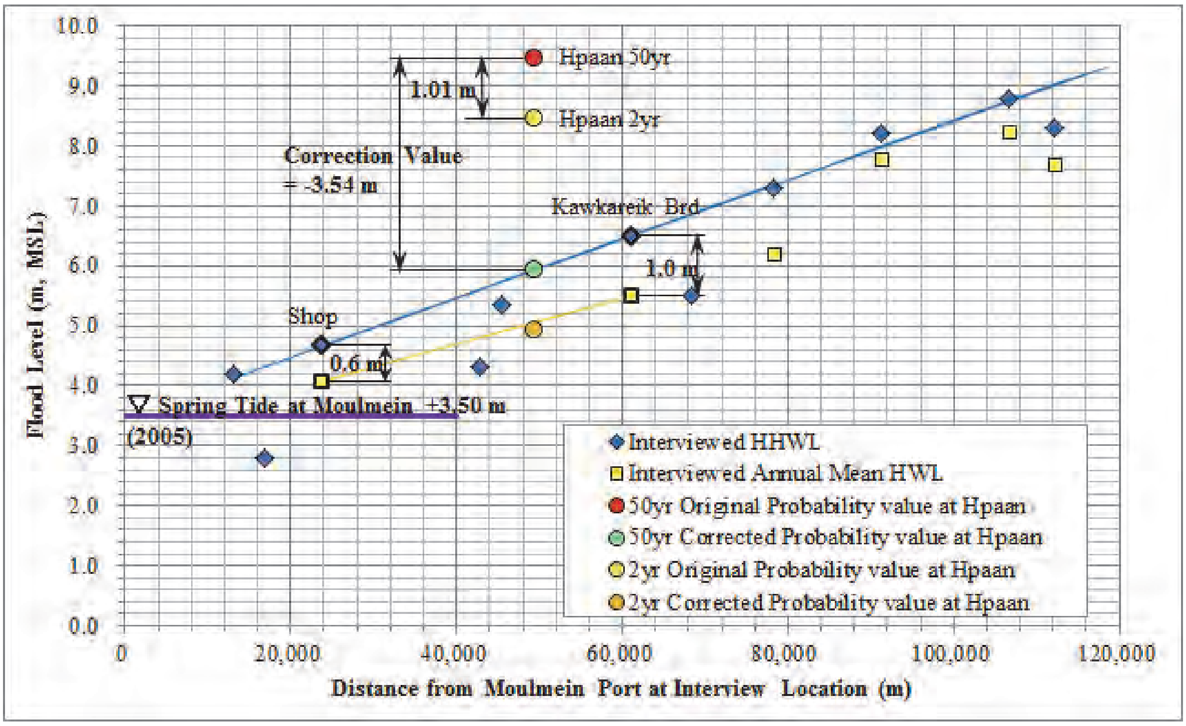
Source: JICA Survey Team

2) Probable Water Levels at Proposed Bridges and Roads

The correlation between the flood-level at sites and the probability value at gauging stations are estimated based on the following assumptions;

- Flood level at each proposed bridge/road site is associated with the distance from outer sea (Mawlamyine Port).
- Water level is based on various inhabitant interviews and is uncertain. However, the flood of 2013 is relatively recent, and the flood marks were left on some buildings. Hence, interview results that have a flood mark are a priority. (Two locations in Kawkareik and a shop.)
- 2-year and 50-year flood levels at Hpa-an Gauging Station (50 km from Mawlamyine Port) are 8.46 m and 9.47m (on an arbitrary datum), with a difference of 1.01m. The average value of annual high flood level during the observation period at Hpa-an is 8.40m, and the equivalent year to probability year is less than two years, from Figure 5.4.24. On the other hand, the difference between the historical high-flood level of 2013 and the annual mean high flood level at Kawkareik Bridge (61km from Mawlamyine port), is 1.0m (on survey datum). In addition, the difference between them at a shop along the Kargaly bypass is 0.6m.
- The annual maximum spring tide at Mawlamyine Port is 3.50m (according to MSL survey data).
- The relationship between the interviewed-historical-high-flood levels and the distance of each interview location from Mawlamyine are shown in Figure 5.4.26. (As seen in this Figure, the correlation between the historical high flood level and the distance from Mawlamyine Port has relatively good linear regression.)
- Although there are some errors are included in this study, the return period of 2013 flood is estimated as 50-year flood with comprehensive consideration of the above.

The probable water levels at the proposed bridge and road sites are estimated based on the above assumptions, as shown in Table 5.4.22.



Source: JICA Survey Team

Figure 5.4.26 Correlation between the interviewed-historical-high-flood levels and the distance to Mawlamyine Port from each interview location

Table 5.4.22 Probable High Water Level at Proposed Bridges and Road Structures

Road Name	Bridge Name	Chainage	Riverine System Name	River Name	High Water Level each Return Period (m, MSL)						Remarks
					2yr	10yr	25yr	50yr	100yr	500yr	
AH-1, Thaton Bypass	Donthami	Km0+300	Thanlwin	Donthami	5.74	6.92	7.20	7.34	7.45	7.61	=BP
	Brd-2	Km0+500		Donthami - Kaw Hlaing C - (Tributary)	5.75	6.94	7.22	7.37	7.48	7.64	
	C-9	Km8+600			6.12	7.49	7.82	7.99	8.12	8.30	
	C-17	Km14+400			6.56	8.16	8.55	8.75	8.89	9.11	
	Brd-3	Km21+900			6.89	8.67	9.10	9.31	9.48	9.72	
	Brd-4	Km26+900	Belin	(Tributary)	7.15	8.07	8.29	8.40	8.49	8.61	
	Brd-5	Km28+600			7.11	8.00	8.22	8.33	8.41	8.53	=EP
AH-1	Naunglon	-	Thanlwin	Naunglon	5.26	6.18	6.40	6.52	6.60	6.73	
	Kawkareik	-		Gyaing - Hlaing Bwe	5.25	6.17	6.39	6.50	6.58	6.71	
Kyargalay Bypass	C-1	Km1+200		(Tributary)	4.98	5.75	5.94	6.04	6.11	6.21	=BP
	Brd-1	Km3+500		Kyonsauk C	4.95	5.71	5.89	5.98	6.05	6.16	
	Brd-2	Km7+100		Kolu C	4.82	5.51	5.68	5.76	5.82	5.92	
	Brd-3	Km7+900		Thanle C	4.81	5.50	5.66	5.75	5.81	5.90	
	Brd-4	Km10+600		Mekobok C	4.74	5.39	5.54	5.62	5.68	5.77	
	C-6	Km13+200		(Tributary)	4.73	5.37	5.53	5.61	5.67	5.76	
	Brd-5	Km14+0		Kaya C	4.72	5.37	5.52	5.60	5.66	5.75	
	Brd-6	Km21+300		Zathabyin C	4.14	4.47	4.55	4.59	4.62	4.67	=EP
-	Zarthabyin	-		Gyaing	3.98	4.24	4.30	4.33	4.35	4.39	
-	Attran	-		Attran	3.88	4.08	4.12	4.15	4.17	4.19	

Source: JICA Survey Team, Datum of water Level is AMSL (Above Mean Sea Level of Amherst station).

(4) Hydraulic Calculation

1) Analysis Software

Hydraulic analysis was carried out to simulate the hydraulic phenomena at the proposed bridges using the Hydrologic Engineering Center - River Analysis System (HEC-RAS) developed by the US Army Corps of Engineers, USA.

HEC-RAS has the capability to compute one-dimensional water surface profiles for both steady and unsteady flow. Sub-critical, supercritical and mix flow regime profiles can be calculated.

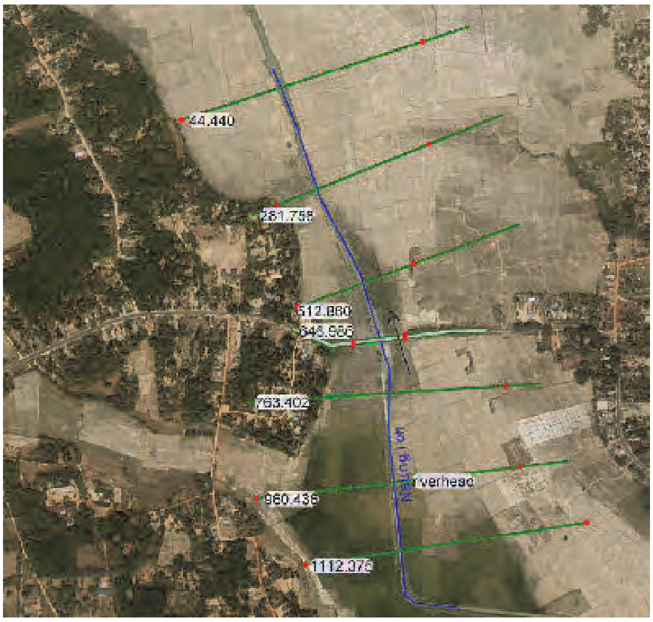
Water surface profiles are computed from one cross section to the next by solving the energy equation using standard-step method. Energy losses are evaluated by friction (Manning's equation) and contraction/expansion coefficients. HEC-RAS requires inputs for boundary conditions of upstream discharge and either downstream water level or known energy gradient.

2) Hydraulic Calculation Model

The hydraulic calculation models at the proposed main bridges are shown in Figure 5.4.27 to Figure 5.4.33. The cross-sections for hydraulic calculation are given by using the topographic and bathymetry survey results.

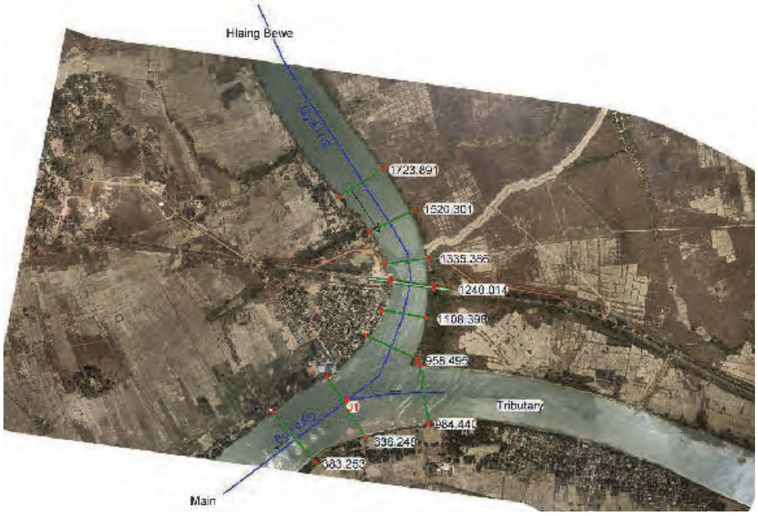
Source: Prepared by JICA Survey Team based on Google Earth

Figure 5.4.27 Hydraulic Calculation Model at Donthami Bridge



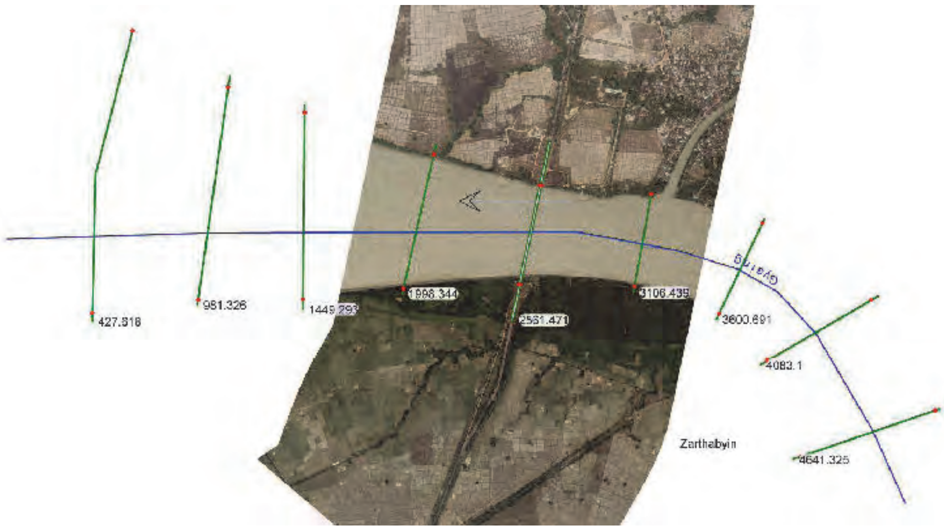
Source: Prepared by JICA Survey Team based on Google Earth

Figure 5.4.28 Hydraulic Calculation Model at Naunglon Bridge



Source: Prepared by JICA Survey Team based on Google Earth

Figure 5.4.29 Hydraulic Calculation Model at Gyaing Kawkareik Bridge

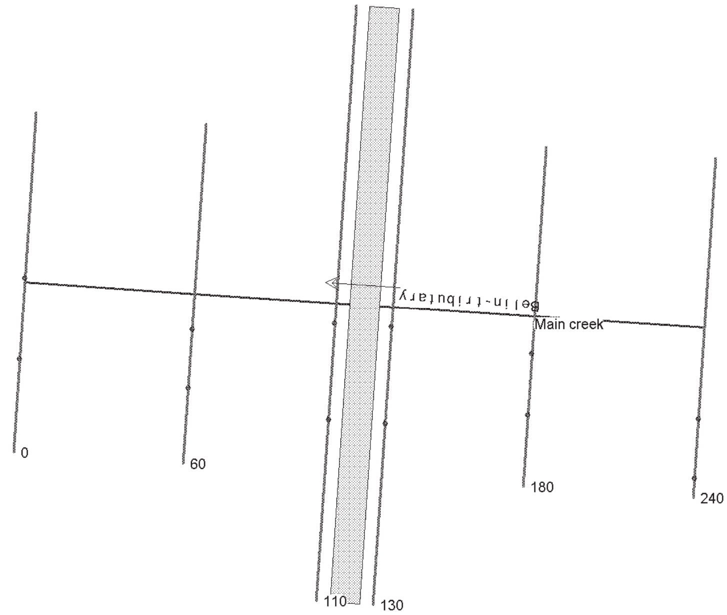


Source: Prepared by JICA Survey Team based on Google Earth

Figure 5.4.30 Hydraulic Calculation Model at Gyaing Zarthabyin Bridge

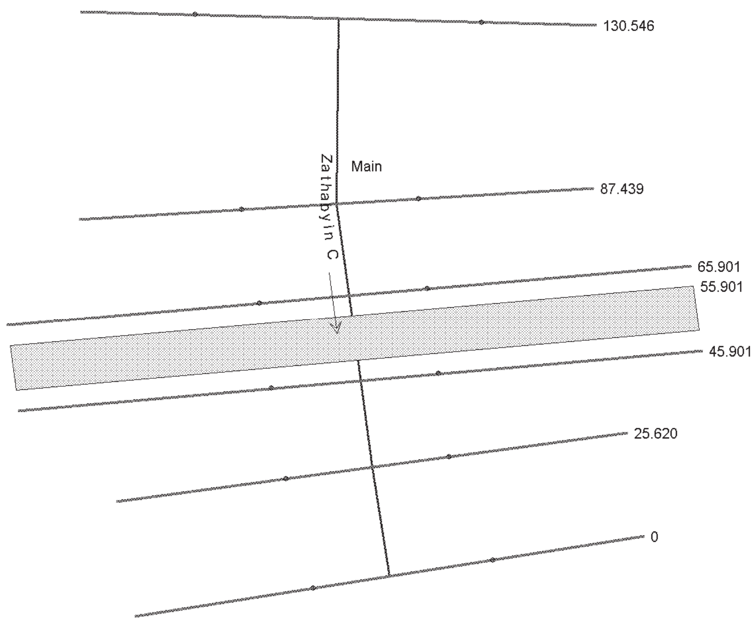
Source: Prepared by JICA Survey Team based on Google Earth

Figure 5.4.31 Hydraulic Calculation Model at Atran Bridge



Source: JICA Survey Team

Figure 5.4.32 Hydraulic Calculation Model at Bridge (km26+900) of Thaton Bypass



Source: JICA Survey Team

Figure 5.4.33 Hydraulic Calculation Model at Bridge (km21+300) of Kyargalay Bypass

3) Hydraulic Analyses and the Results

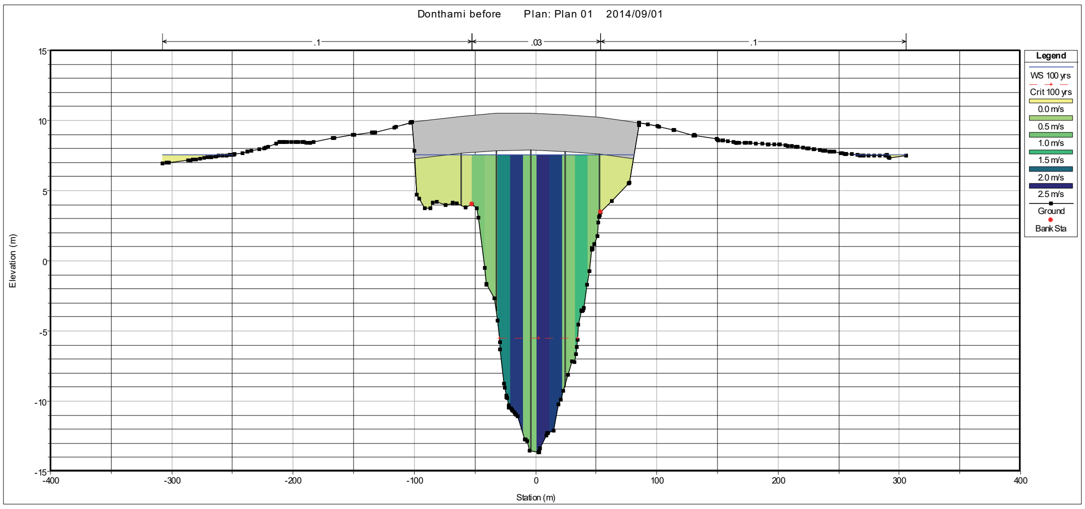
Hydraulic analysis is performed under the following conditions and results are shown in Table 5.4.23, and Figure 5.4.34 to Figure 5.4.45.

- Discharge for main bridges - Low discharge, Normal discharge, 2, 10, 50, 100 years (design scale) and 500 years
- Discharge for small bridges - Low discharge, Normal discharge, 2, 10, 25, 50 (design scale) and 100 years
- Water Level at downstream end of calculation - Above calculated probability high flood level

Table 5.4.23 Results of Hydraulic Analyses

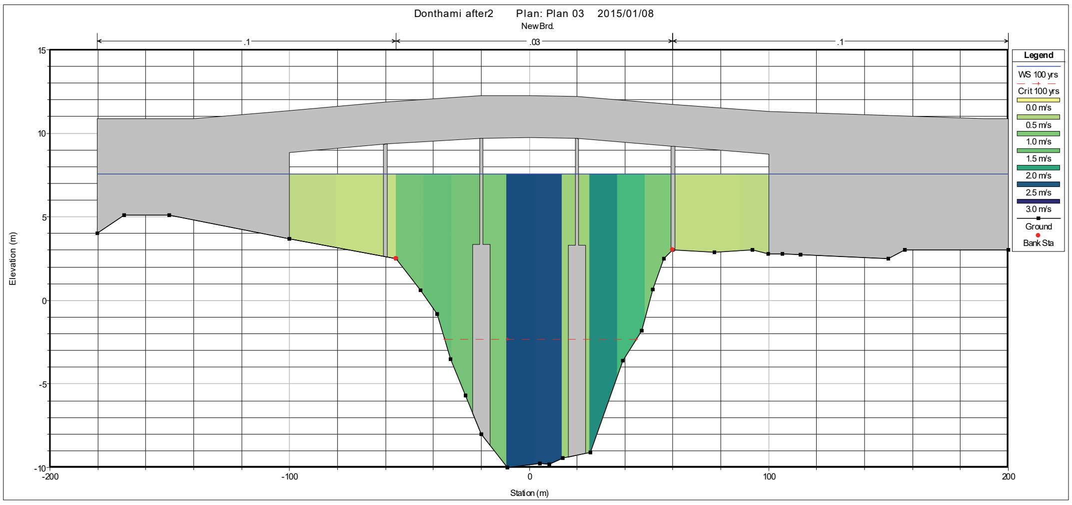
Items \ Bridge Name		unit	Donthami	Naunglon	Kawkareik	Zarthabyin	Attran	Thaton km26+900	Kyargalay Km21+300	Remarks
Return Period	T	year	100 yrs	100 yrs	100 yrs	100 yrs	100 yrs	50 yrs	50 yrs	
Discharge	Q	m^3/s	2406	100	5282	13697	8189	447	697	
Probable Water Level	WL	m	7.45	6.60	6.58	4.35	4.17	8.40	4.59	
Calculated Water Level	WL	m	7.57	6.60	7.20	4.40	4.28	8.42	4.58	
Critical Water Level	WLc	m	-5.53	3.66	-7.92	-8.42	-9.75	7.49	0.7	
Max Channel Depth	Dmax	m/s	21.2	3.74	23.63	22.06	23.26	2.81	9.23	
(Average) Velocity	V	m/s	1.38	0.24	1.66	1.84	2.4	2.16	2.07	
Flow Area	A	m^2	1743.47	424.21	3186.72	7429.44	3406.2	207.31	337.2	
Froude No.	Fr	-	0.11	0.05	0.14	0.16	0.18	0.53	0.31	
Hydraulic Depth	Dh	m	7.84	1.88	9.51	8.86	9.15	2.36	4.31	
Wetted Perimeter	P	m	459.87	287.6	424.47	878.63	397.41	89.24	83.71	
Shear Total	τ	N/mm^2	6.5	0.33	7.19	7.82	10.92	29.34	8.98	
Power Total	P	N/m·s	-14734.58	-9630.97	-8712.91	-20845.62	-10724.98	-5027.17	-3830.23	

Source: JICA Survey Team



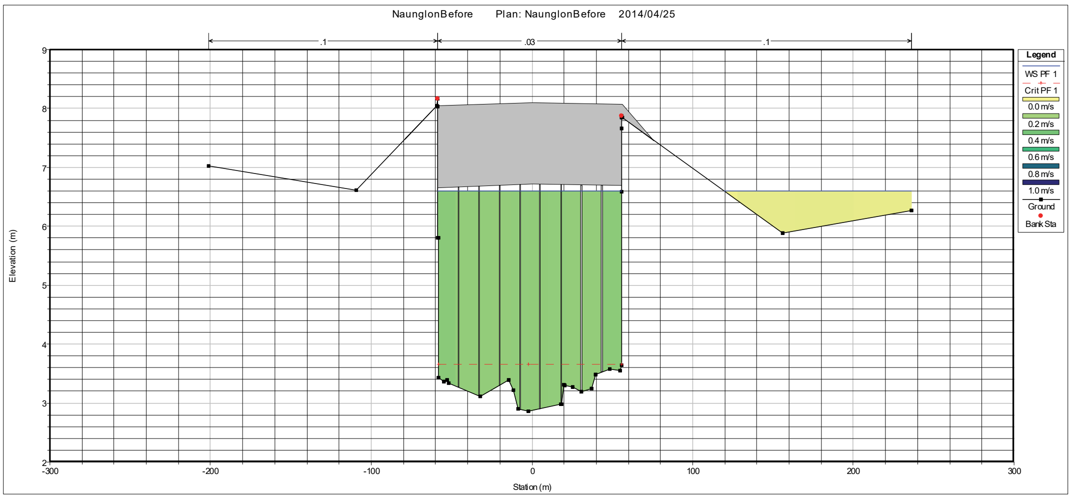
Source: JICA Survey Team

Figure 5.4.34 Hydraulic Cross-sectional profile of Donthami Bridge (Existing)



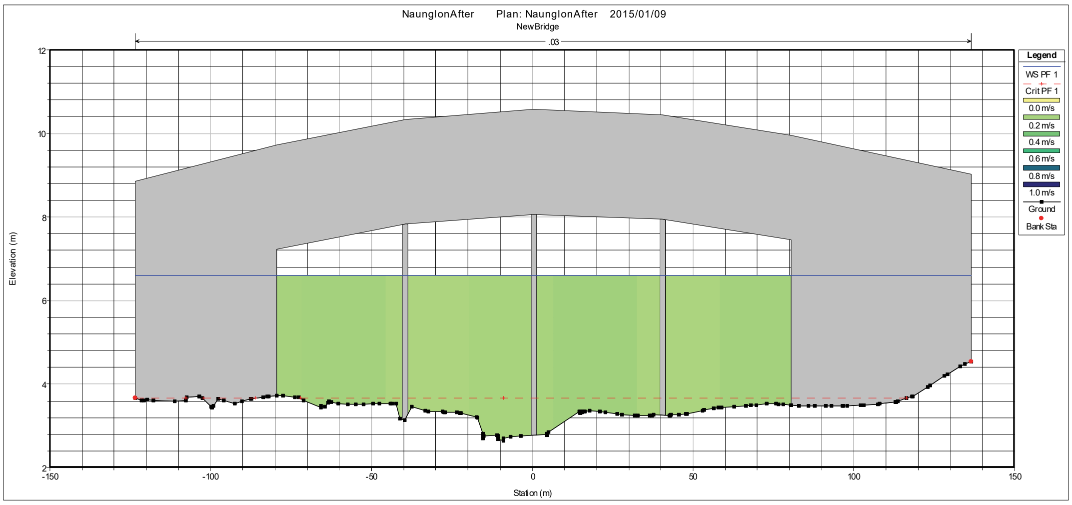
Source: JICA Survey Team

Figure 5.4.35 Hydraulic Cross-sectional profile of Donthami Bridge (New)



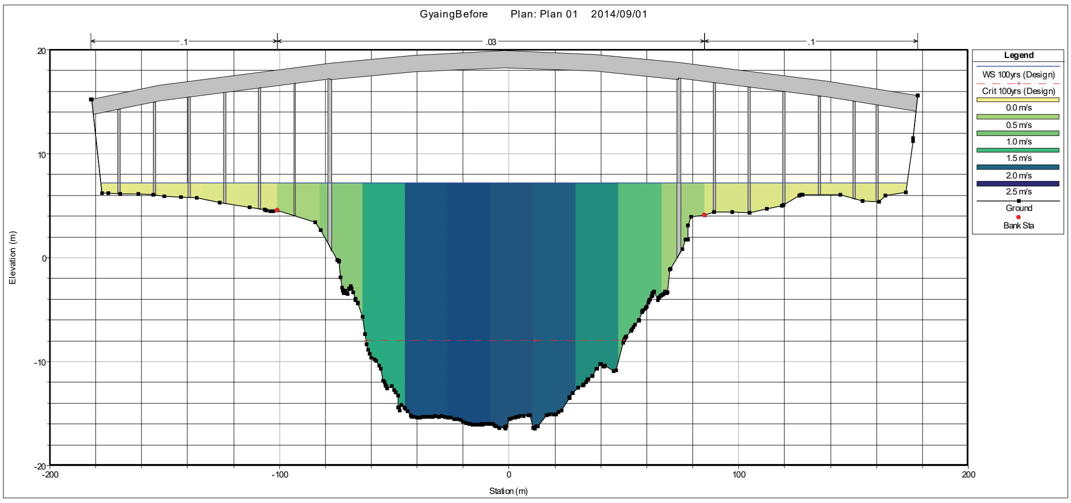
Source: JICA Survey Team

Figure 5.4.36 Hydraulic Cross-sectional profile of Naunglon Bridge (Existing)



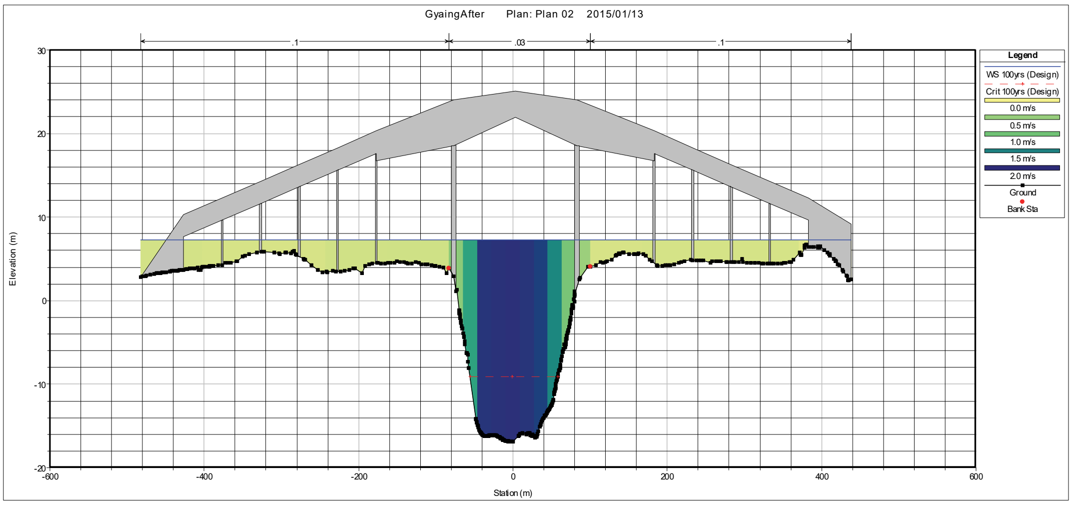
Source: JICA Survey Team

Figure 5.4.37 Hydraulic Cross-sectional profile of Naunglon Bridge (New)



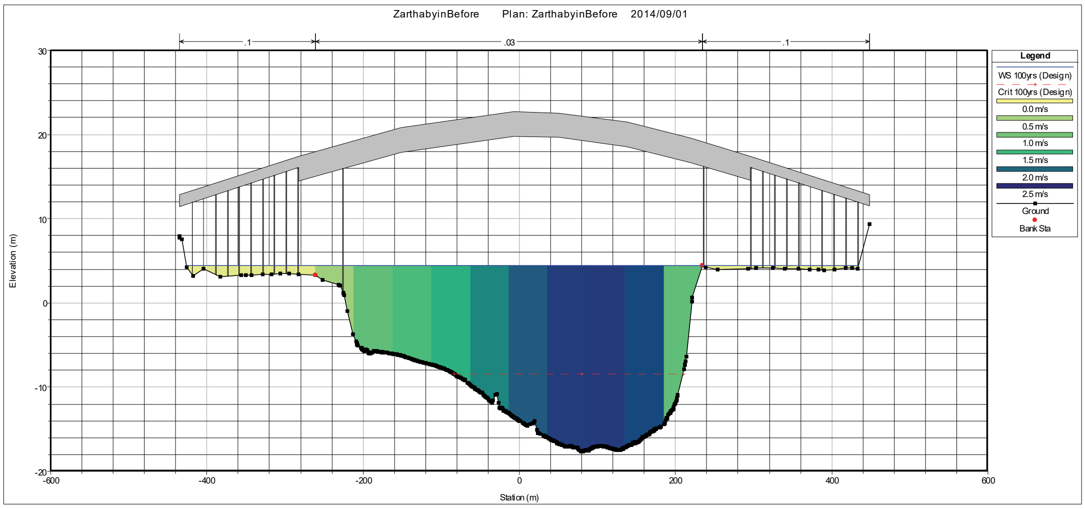
Source: JICA Survey Team

Figure 5.4.38 Hydraulic Cross-sectional profile of Gyaing Kawkareik Bridge (Existing)



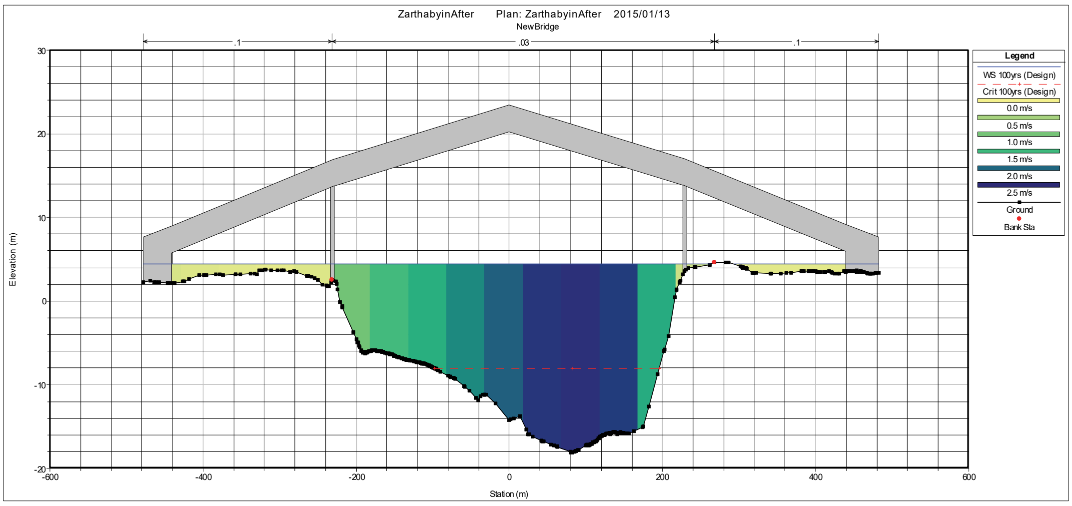
Source: JICA Survey Team

Figure 5.4.39 Hydraulic Cross-sectional profile of Gyaing Kawkareik Bridge (New)



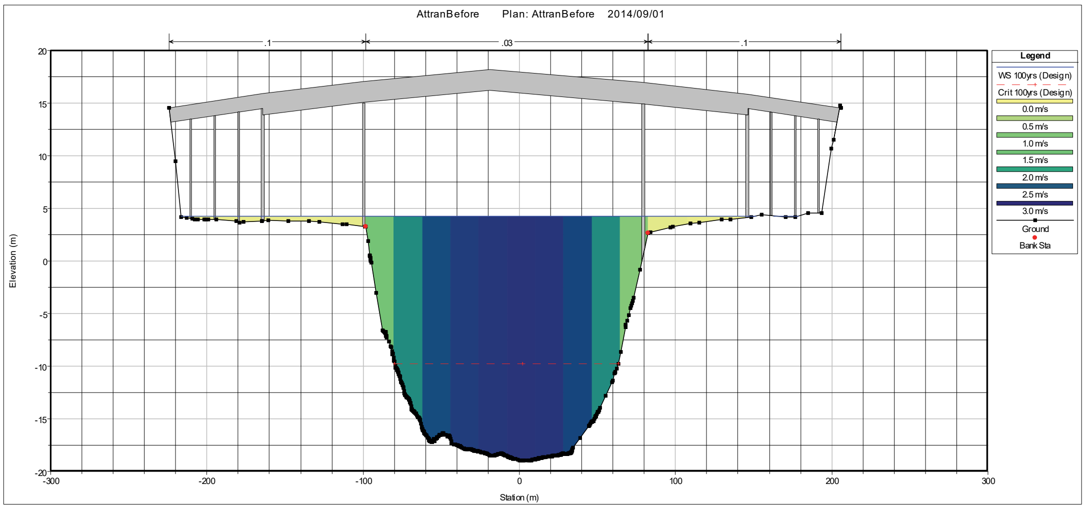
Source: JICA Survey Team

Figure 5.4.40 Hydraulic Cross-sectional profile of Gyaing Zathapyin Bridge (Existing)



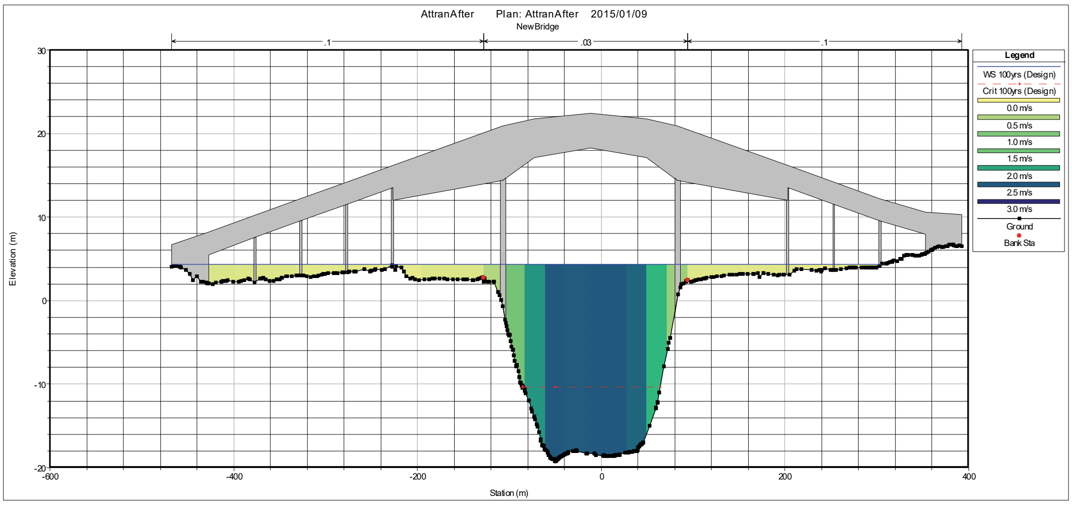
Source: JICA Survey Team

Figure 5.4.41 Hydraulic Cross-sectional profile of Gyaing Zathapyin Bridge (New)



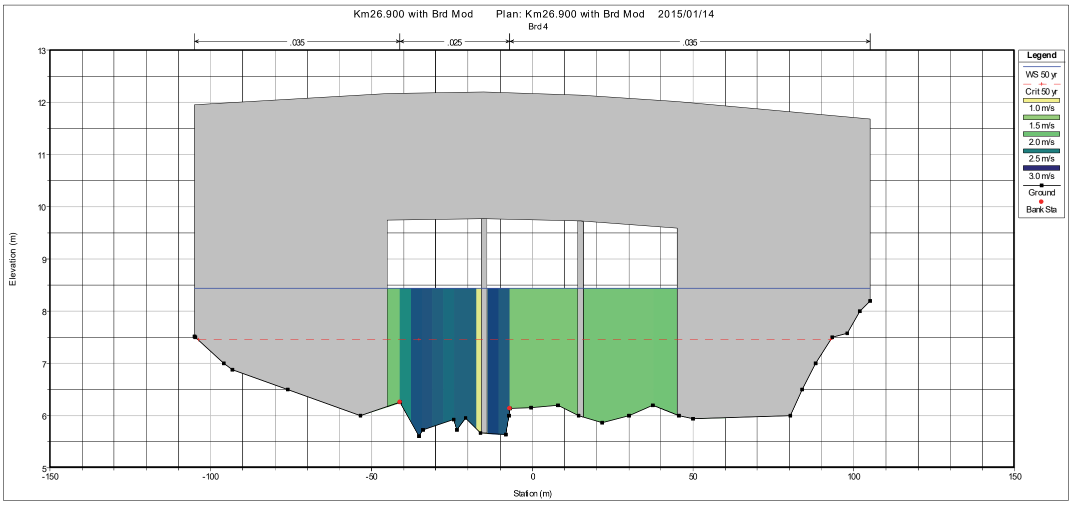
Source: JICA Survey Team

Figure 5.4.42 Hydraulic Cross-sectional profile of Atran Bridge (Existing)



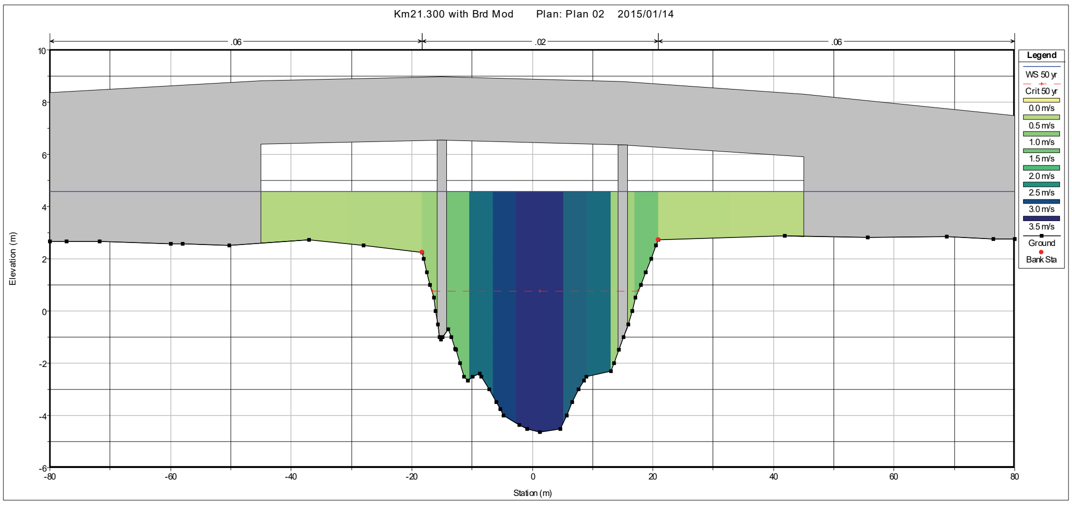
Source: JICA Survey Team

Figure 5.4.43 Hydraulic Cross-sectional profile of Atran Bridge (New)



Source: JICA Survey Team

Figure 5.4.44 Hydraulic Cross-sectional profile of Km26+900 Bridge of Thaton Bypass (New)



Source: JICA Survey Team

Figure 5.4.45 Hydraulic Cross-sectional profile of Km21+300 Bridge of Kyargalay Bypass (New)

5.4.4 Scour Estimation

(1) Basic concept

Bridge scour is caused by the erosive action of flowing water, excavating and carrying away materials from the riverbed and its banks. The scour process is cyclic in nature, which makes determining the magnitude of scour complicated. Scour can be deepest near the peak of a flood, however. Since scour holes refill with sediment during the receding stage of flood, they can be difficult to spot. In general, several floods may be needed to attain maximum scour under typical flow conditions at bridge crossings.

(2) Methodology of Scour Computation

In designing the bridge sub structure, it is very important to evaluate the scour potential at piers and abutments, carefully studying site-specific subsurface information. The total scour at a bridge crossing is comprised of three components:

1. Long-term aggradation or degradation
2. Contraction scour
3. Local scour

1) Aggradation and Degradation

Aggradation and degradation are long-term changes of stream bed elevation due to natural or man-induced causes that can affect the stream bed. Aggradation involves the deposition of material eroded from the stream or watershed upstream of the bridge, and degradation involves the lowering of the stream bed due to the lack of sediment supply from upstream. Basically, it is to be evaluated independently from the hydraulic model. Streams are generally considered to be stable and have a balanced sediment transport if the configuration is not changed long-term. (In this study, the river bed/course fluctuation analysis was not conducted. It shall be conducted during the detailed design stage and the results will be studied after surveying current and past topographic data of rivers.)

2) Contraction Scour

Contraction scour at a bridge crossing, involves the removal of material from the stream bed and banks across the channel width, as a result from a contraction of the flow area and an increase in discharge at the bridge.

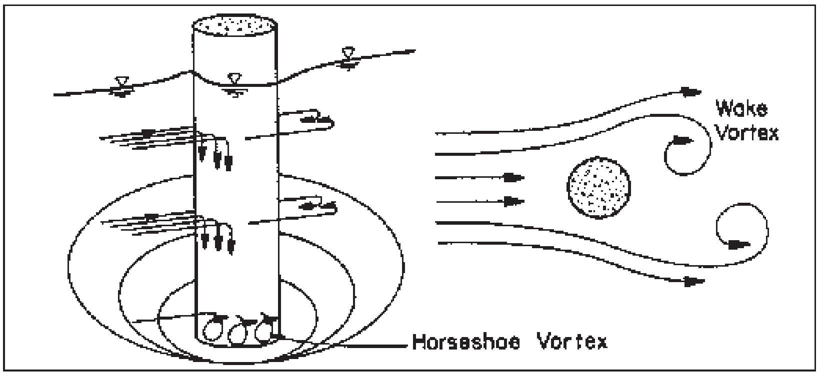
In the case of new bridge construction, common causes for contraction of flows are constriction (encroachment) of road embankment onto the floodplain and/or into the main channel or piers blocking a portion of flow. As a result, flow area decreases cause an increase in velocity and bed shear stress. Hence, more bed material is removed from the contracted reach than transported into the reach. As bed elevation is lowered, the flow area increases, velocity reduces and a situation of relative equilibrium is reached.

3) Local scour

Local scour at piers or abutments is due to the removal of bed material as a result of the formation of vortices known as the horseshoe vortex and wake vortex at their base. The horseshoe vortex results from the pileup of water on the upstream surface of the obstruction and subsequent acceleration of the flow around the nose of the pier or abutment. The action of the vortex removes bed material around the base of the obstruction. In addition to the horseshoe vortex around the base of a pier, there are vertical vortices downstream of the pier called the wake vortex. Both the horseshoe and wake vortices remove material from the pier base region. The intensity of wake vortices diminishes rapidly as the distance downstream of the pier increases. As a result, there is often the deposition of material immediately downstream of a long pier.

Factors which affect the magnitude of local scour depth at piers and abutments are:

1. Velocity of the approach flow
2. Depth of flow
3. Width of the pier
4. Discharge intercepted by the abutment and returned to the main channel at the abutment
5. Length of the pier if skewed to flow
6. Size and gradation of bed material
7. Angle of attack of the approach flow to a pier or abutment
8. Shape of a pier or abutment
9. Bed configuration
10. Ice formation or jams and debris



Source: Evaluating Scour at Bridges (2012 Fifth edition), Hydraulic Engineering Circular No. 18 (HEC 18), FHWA, USA

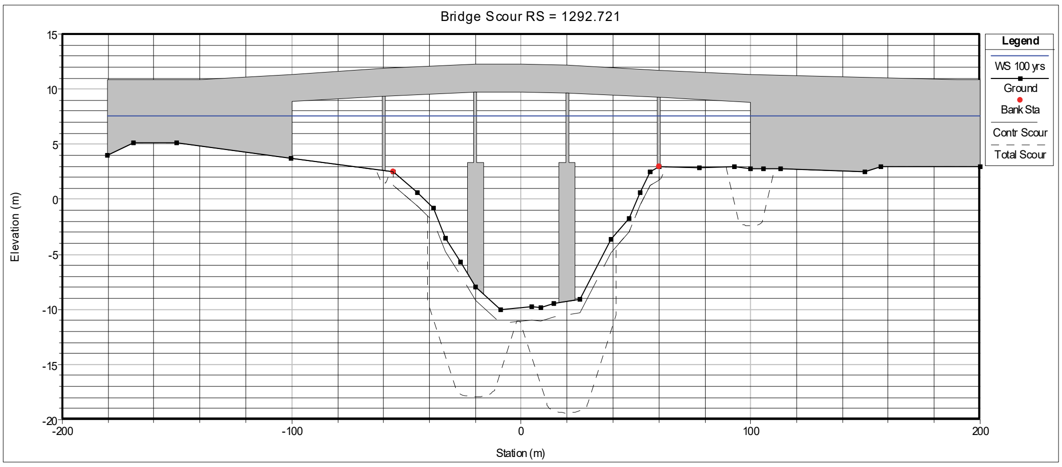
Figure 5.4.46 Simple Schematic Representation of Scour at a Cylindrical Pier

(3) Scour Estimation

All major streams intercepted by the proposed bridge alignment were modelled with the HEC-RAS model developed by Hydraulic Engineering Center, USA. The model reach covered a sufficient length from upstream to downstream from the bridge location. These models were simulated for 100 (or 50) year return period discharges under existing conditions (without bridge), and incorporating the bridge. In Geometric Data, all bridge data, including deck/roadway and piers, are given.

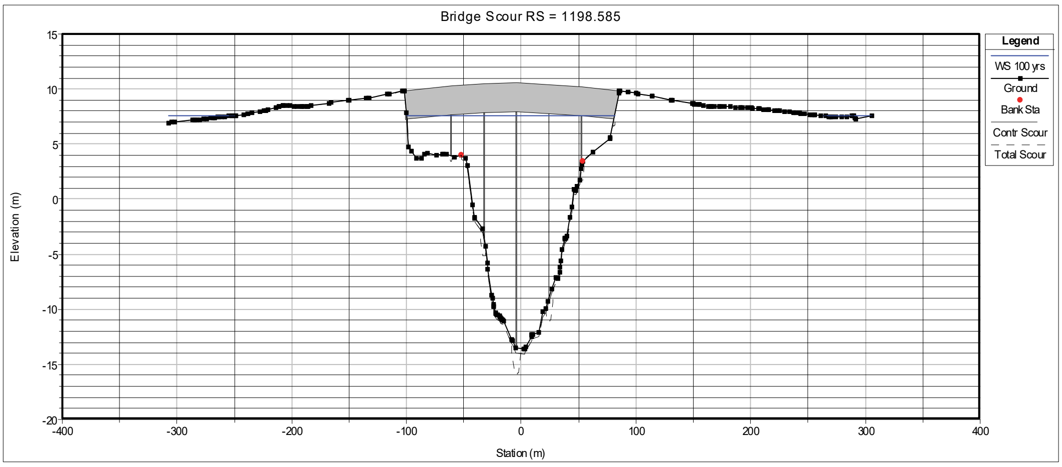
Scour estimation by steady flow analysis of HEC-RAS is conducted based on Hydraulic Engineering Circular No. 18 (HEC 18) of the Federal Highway Administration (FHWA), USA by using the value of probable maximum discharge and probable high water level. The schematic diagram of the scour depth of each bridge is shown in Figure 5.4.47 - Figure 5.4.58.

The results of scour estimation are shown in Table 5.4.24.



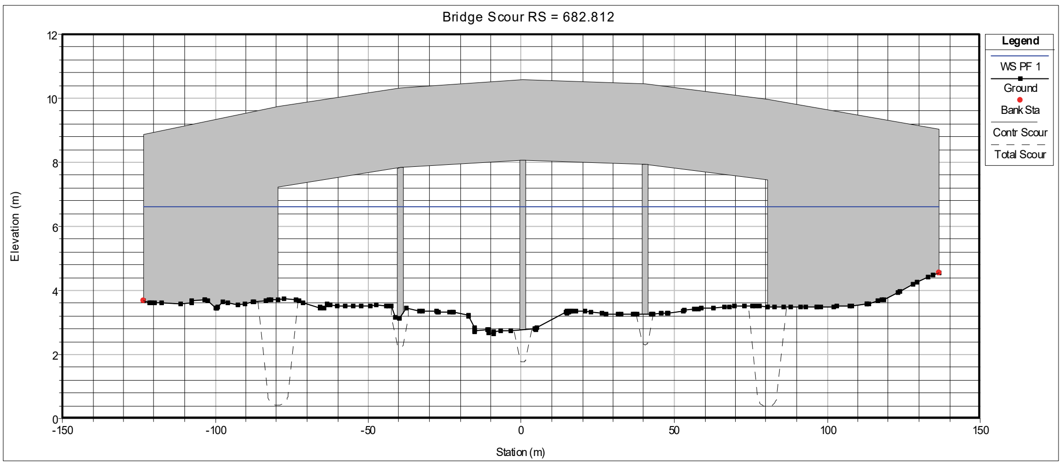
Source: JICA Survey Team

Figure 5.4.47 Schematic Diagram of Scour at Donthami Bridge (New)



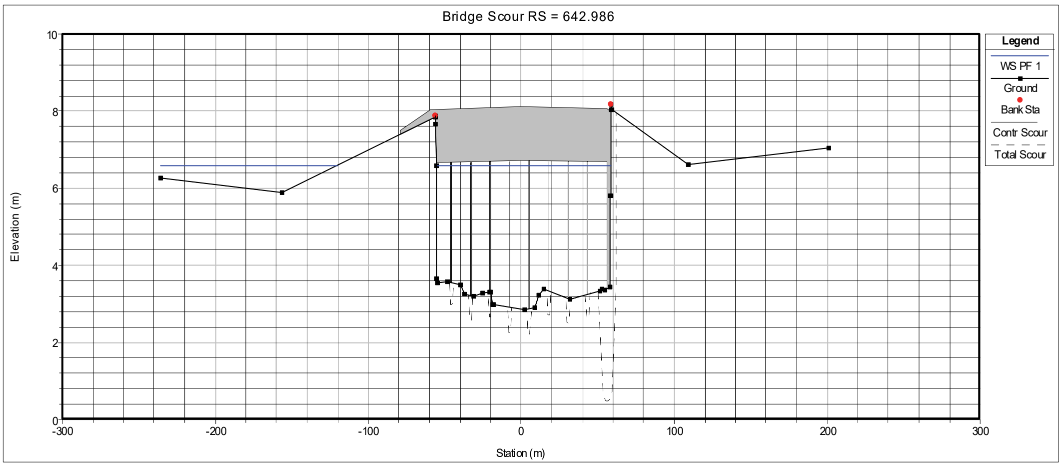
Source: JICA Survey Team

Figure 5.4.48 Schematic Diagram of Scour at Donthami Bridge (Existing)



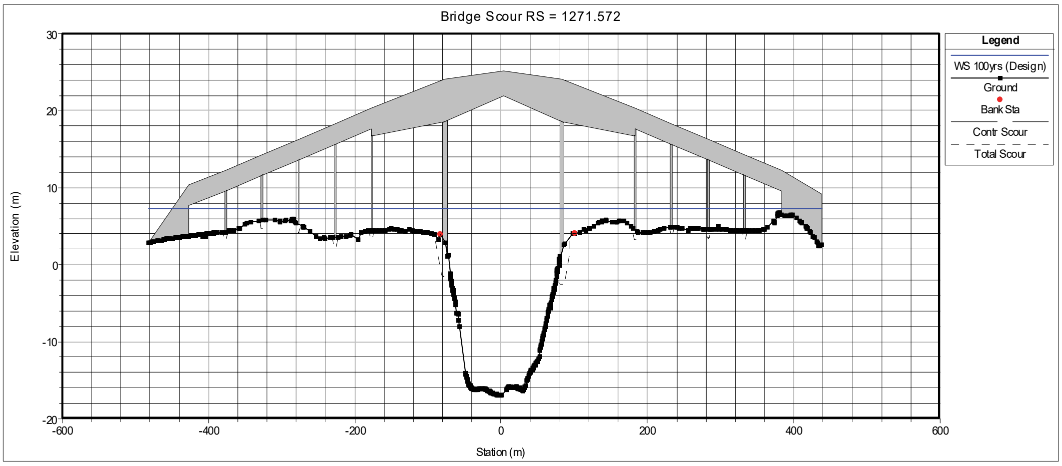
Source: JICA Survey Team

Figure 5.4.49 Schematic Diagram of Scour at Naunglon Bridge (New)



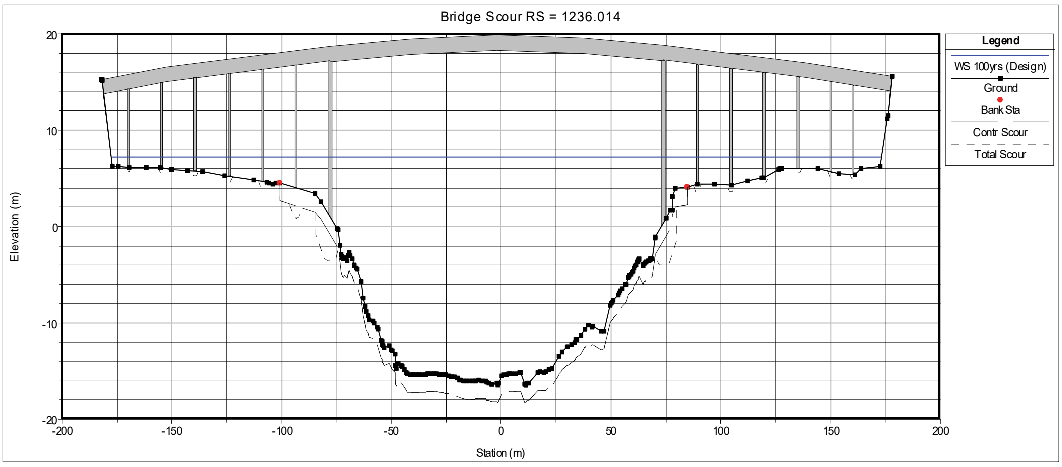
Source: JICA Survey Team

Figure 5.4.50 Schematic Diagram of Scour at Naunglon Bridge (Existing)



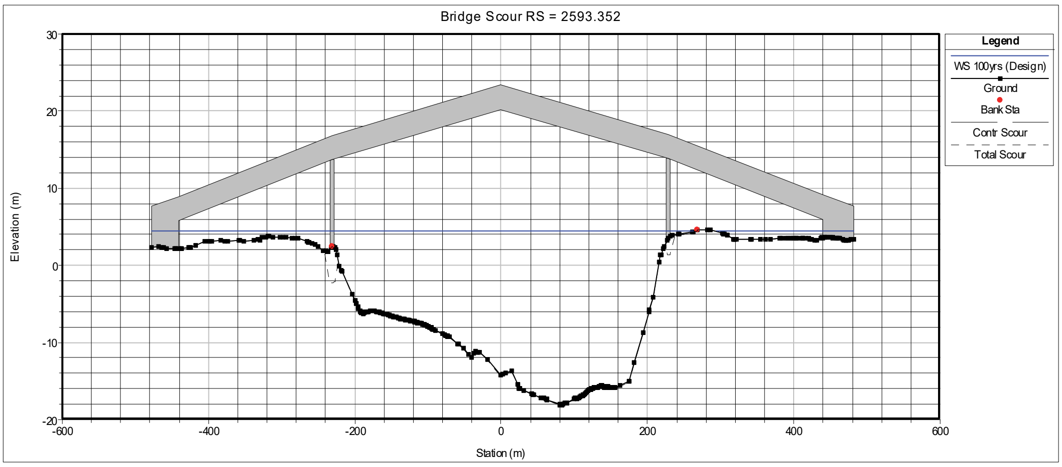
Source: JICA Survey Team

Figure 5.4.51 Schematic Diagram of Scour at Kawkareik Bridge (New)



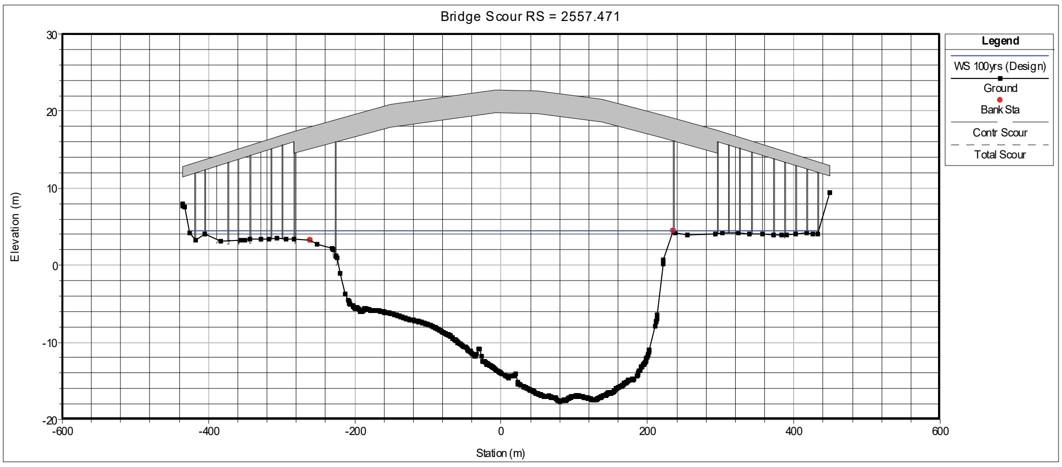
Source: JICA Survey Team

Figure 5.4.52 Schematic Diagram of Scour at Kawkareik Bridge (Existing)



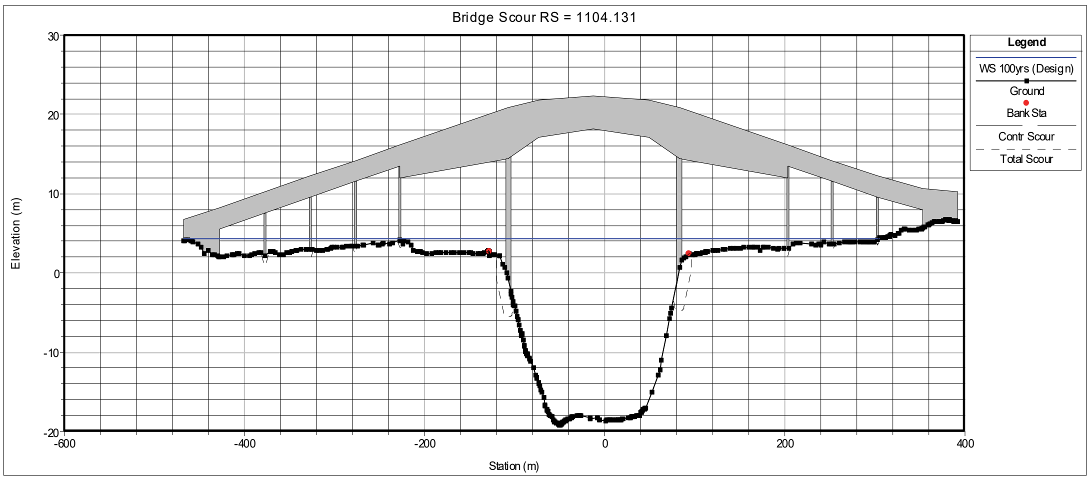
Source: JICA Survey Team

Figure 5.4.53 Schematic Diagram of Scour at Zarthabyin Bridge (New)



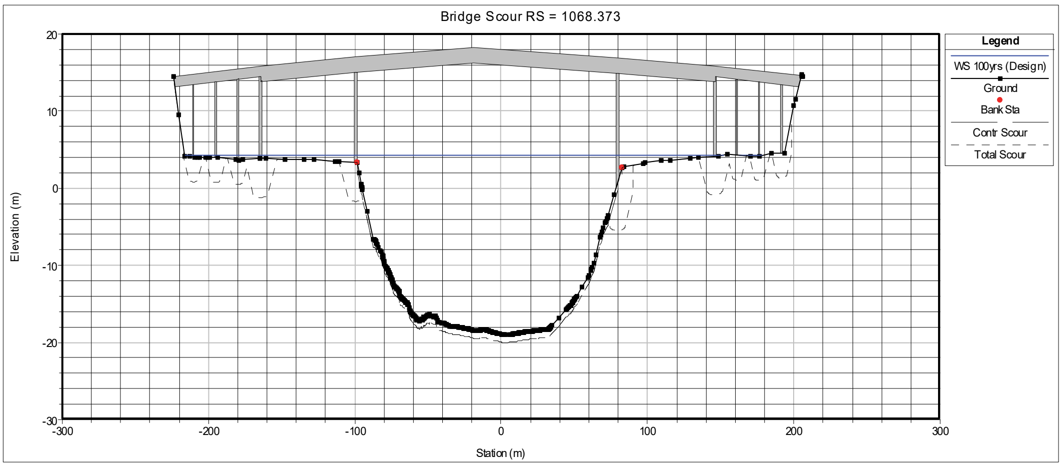
Source: JICA Survey Team

Figure 5.4.54 Schematic Diagram of Scour at Zarthabyin Bridge (Existing)



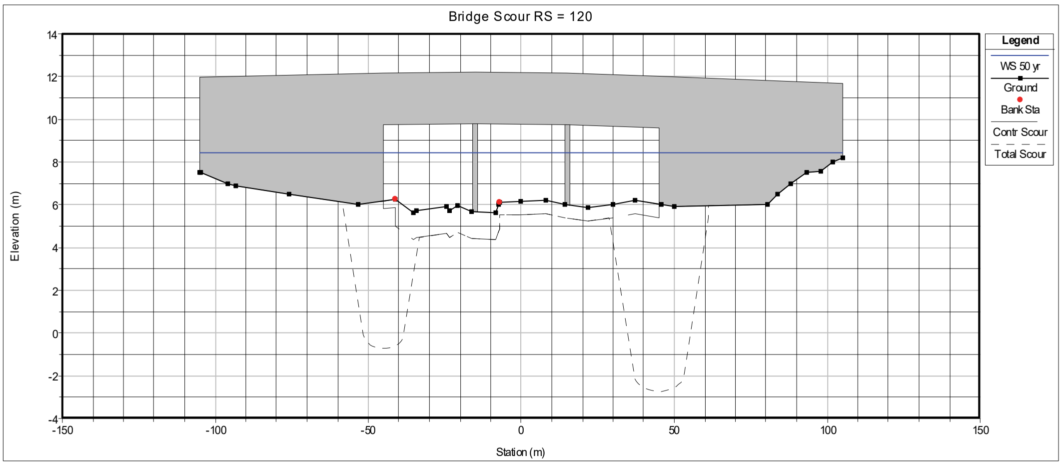
Source: JICA Survey Team

Figure 5.4.55 Schematic Diagram of Scour at Atran Bridge (New)



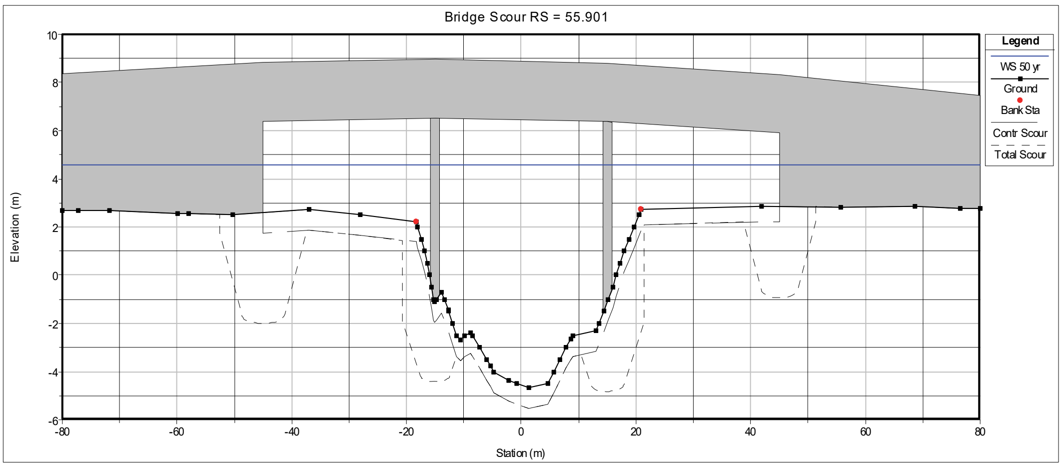
Source: JICA Survey Team

Figure 5.4.56 Schematic Diagram of Scour at Atran Bridge (Existing)



Source: JICA Survey Team

Figure 5.4.57 Schematic Diagram of Scour at Thaton (Km26+500) Bridge



Source: JICA Survey Team

Figure 5.4.58 Schematic Diagram of Scour at Kyargalay (Km21+300) Bridge

Table 5.4.24 Results of Scour Estimation

Sub-structure	Bridge	Donthami		Naunglon		Kawkareik		Zarthabyin		Attran		Thaton	Kyargalay	Remarks
		New	Existing	New	Existing	New	Existing	New	Existing	New	Existing	Km26+500	Km21+300	
	Return Period	100 yrs	100 yrs	100 yrs	100 yrs	100 yrs	100 yrs	100 yrs	100 yrs	100 yrs	100 yrs	50 yrs	50 yrs	
Left Bank Abutment	Contraction Scour	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.37	0.85	
	Local Scour	0.00	0.60	3.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.53	3.75	
	Total Scour	0.00	0.60	3.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.90	4.60	
Pier 1	Contraction Scour	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.00	1.26	0.86	
	Local Scour	1.15	0.56	0.95	0.57	1.19	0.46	4.65	0.44	1.20	3.20	2.30	2.51	
	Total Scour	1.15	0.56	0.95	0.57	1.19	0.46	4.74	0.44	1.20	3.20	3.57	3.37	
Pier 2	Contraction Scour	1.22	0.40	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.00	1.26	0.86	
	Local Scour	8.72	1.39	1.01	0.63	1.08	0.49	2.16	0.37	0.99	3.20	1.85	2.84	
	Total Scour	9.94	1.79	1.01	0.63	1.08	0.49	2.25	0.37	0.99	3.20	2.46	3.70	
Pier 3	Contraction Scour	1.22	0.40	0.00	0.00	0.00	0.00		0.00	0.00	0.00			
	Local Scour	8.92	1.92	0.95	0.65	1.10	0.53		0.50	0.94	3.20			
	Total Scour	10.14	2.32	0.95	0.65	1.10	0.53		0.50	0.94	3.20			
Pier 4	Contraction Scour	0.00	0.40		0.00	0.00	0.00		0.00	0.00	0.00			
	Local Scour	1.15	1.70		0.67	1.35	0.61		0.51	0.77	5.02			
	Total Scour	1.15	2.10		0.67	1.35	0.61		0.51	0.77	5.02			
Pier 5	Contraction Scour		0.40		0.00	0.00	0.00		0.00	0.00	0.00			
	Local Scour		1.07		0.66	1.29	0.68		0.51	4.60	5.02			
	Total Scour		1.47		0.66	1.29	0.68		0.51	4.60	5.02			
Pier 6	Contraction Scour				0.00	0.00	1.87		0.00	0.00	1.04			
	Local Scour				0.63	4.57	1.25		0.51	5.11	5.02			
	Total Scour				0.63	4.57	3.11		0.51	5.11	6.06			
Pier 7	Contraction Scour				0.00	0.00	1.87		0.00	0.00	0.00			
	Local Scour				0.65	4.26	2.68		0.49	0.96	5.02			
	Total Scour				0.65	4.26	4.55		0.49	0.96	5.02			
Pier 8	Contraction Scour				0.00	0.00	1.87		0.00	0.00	0.00			
	Local Scour				0.64	1.22	2.47		0.49	0.73	3.20			
	Total Scour				0.64	1.22	4.34		0.49	0.73	3.20			
Pier 9	Contraction Scour					0.00	0.00		0.00	0.00	0.00			
	Local Scour					1.19	0.72		0.48	0.56	3.20			
	Total Scour					1.19	0.72		0.48	0.56	3.20			
Pier 10	Contraction Scour					0.00	0.00		0.00		0.00			
	Local Scour					1.19	0.69		0.50		3.20			
	Total Scour					1.19	0.69		0.50		3.20			
Pier 11	Contraction Scour					0.00	0.00		0.00					
	Local Scour					1.22	0.66		1.27					
	Total Scour					1.22	0.66		1.27					
Pier 12	Contraction Scour						0.00		0.00					
	Local Scour						0.50		0.23					
	Total Scour						0.50		0.23					
Pier 13	Contraction Scour						0.00		0.00					
	Local Scour						0.55		0.30					
	Total Scour						0.55		0.30					
Pier 14	Contraction Scour						0.00		0.00					
	Local Scour						0.52		0.29					
	Total Scour						0.52		0.29					
Pier 15	Contraction Scour								0.00					
	Local Scour								0.29					
	Total Scour								0.29					
Pier 16	Contraction Scour								0.00					
	Local Scour								0.30					
	Total Scour								0.30					
Pier 17	Contraction Scour								0.00					
	Local Scour								0.30					
	Total Scour								0.30					
Pier 18	Contraction Scour								0.00					
	Local Scour								0.35					
	Total Scour								0.35					
Pier 19	Contraction Scour								0.00					
	Local Scour								0.35					
	Total Scour								0.35					
Pier 20	Contraction Scour								0.00					
	Local Scour								0.34					
	Total Scour								0.34					
Pier 21	Contraction Scour								0.00					
	Local Scour								0.28					
	Total Scour								0.28					
Pier 22	Contraction Scour								0.00					
	Local Scour								0.29					
	Total Scour								0.29					
Right Bank Abutment	Contraction Scour	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.62	0.65	
	Local Scour	5.23	0.59	3.13	2.91	0.00	0.00	0.00	0.00	0.00	0.00	8.12	3.14	
	Total Scour	5.23	0.59	3.13	2.91	0.00	0.00	0.00	0.00	0.00	0.00	8.74	3.80	

Source: JICA Survey Team

5.4.5 Hydrological Assessment of Proposed Bridges and Roads

(1) Hydraulic Design Criteria of Bridge

In order to design the opening of the bridge waterway, the following design criteria for hydraulics are required:

- ✓ The backwater does not significantly increase the flood damage to properties upstream from the bridge.
- ✓ The velocity through the bridge does not damage the road facility or increase the damage to downstream properties.
- ✓ The existing flow distribution is maintained to the extent practicable.
- ✓ The pier and abutment are designed to minimize the flow disruption.
- ✓ Potential local scour is within acceptable limits.
- ✓ Clearance at the structure is adequately designed to safely pass any anticipated debris. (The elevation of the bottom of the bridge girder is higher than "Highest high water level + Navigation channel height".)

The design return period, the clearance from the bridge girder to high water level shall be compliant with authorized standards by the organizations concerned. (In the case of a navigation waterway, the clearance between the bottom girder of the bridge and the water surface will at least secure the same clearance as the existing bridge. In other cases, the freeboard on the hydraulics is in compliance with Japanese Technical Criteria for River Works.)

In this Study, the design return period is adopted as a 100-year return period for the main bridges and 50-year for the small bridges of bypass roads. The design standard is based on the well-used international HEC series standards.

(2) Hydraulic Design Criteria of Culverts and Road Embankments

The design scale (return period) for drains, culverts and road embankments applies to the following:

- ✓ Drains (for road drainage), Small culverts ($A<1km^2$) ----- 10 year return period
- ✓ Culverts ($A\geq 1km^2$) ----- 25 year
- ✓ Road embankments ----- 50 year

Lateral road drainage is mainly through culverts and bridges. The size of the flood opening is determined by the catchment area parameters and consideration of existing nearby structures.

The hydraulic design requires consideration for the following points:

- ✓ Head loss due to contraction at the entry of the culvert.
- ✓ Head loss at the inlet, through the culvert and outlet due to roughness.
- ✓ Tailwater level and downstream conditions

The embankment of roads is made from the earth and sand material, and it is very weak to overtopping and bumping. Therefore, safety countermeasures, such as clearance, must be considered. The freeboard of roads will apply the same criteria as the river embankment. Protection for the embankment shall be ensured using suitable protection work. In addition, all high flood levels shall be shown in the design drawings in order to check whether the high flood level will influence the road embankment.

(3) Hydrological Recommendations

From the above hydraulic study, several challenges and conclusions have been extracted. The following hydraulic issues of the proposed bridge are left as future challenges:

- ✓ The existing Donthami and Naunglon Bridges have not ensured the appropriate clearance (freeboard) with its bridge girder. This means that bridge heights and openings against the flow are small. Therefore, the re-construction or the heightening of the bridge's superstructure shall be performed as soon as possible.
- ✓ In this study, the computation for the contraction and local scouring have been conducted using HEC-RAS. The appropriate bed protections for each bridge have been proposed. However, the appropriate bed protection and revetment work shall be re-studied at the detailed design stage. In addition, the scouring estimation is necessary to for further study in other prediction formulas, including HEC. (The general estimate equation for scouring in HEC-RAS is for the sand layer, but the surface layers of the river-bed at proposed bridges are cohesive soil. Also, the HEC-RAS equation cannot be applied to complex pier shapes, such as the pile-bent pier at the new Donthami Bridge. Hence, the estimate equation for scouring shall be restudied at the detailed design stage.)
- ✓ In order to secure the accuracy of the elevation values and probability values, a check of the difference between gauging stations data and topographic survey datum data shall be performed during the detailed design stage.
- ✓ The rainfall intensity formula at the current stage is predicted from the 24-hour rainfall volume. Rainfall data for a short time has not been used because it was difficult to collect. The rainfall intensity curve equation should be modified after data on short-term rainfall is obtained.
- ✓ The topographic information in this Study Area partially surveyed the surroundings of the proposed bridges and roads only. However, this Study Area is a low-lying, flood area and its channel-network is very complicated. Therefore, a more detailed survey in the range of all of the catchment areas of the drainage structures shall be performed in a future study.