No.

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)
THE GOVERNMENT OF LAO P.D.R.

THE STUDY ON MEKONG RIVERBANK PROTECTION AROUND VIENTIANE MUNICIPALITY IN THE LAO PEOPLE'S DEMOCRATIC REPUBLIC

FINAL REPORT

VOLUME 3
MANUAL FOR RIVERBANK PROTECTION

DECEMBER 2004

NIKKEN Consultants, Inc.
NEWJEC Inc.

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Before Construction (Oct. 2002)

After Construction (Jan. 2004)

DECEMBER 2004

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NEWJEC Inc.

COMPOSITION OF FINAL REPORT

VOLUME 1 EXECUTIVE SUMMARY

VOLUME 2 MAIN REPORT

VOLUME 3 MANUAL FOR RIVERBANK PROTECTION
- **SECTOR A PLANNING & DESIGN**
- **SECTOR B CONSTRUCTION**

VOLUME 4 SUPPORTING REPORT
- **SECTOR A PRESENT CONDITION IN THE STUDY AREA**
- **SECTOR B PREPARATORY STUDY FOR PILOT WORKS**
- **SECTOR C FIELD SURVEY FOR PILOT WORKS**
- **SECTOR D EXECUTION OF PILOT WORKS**
- **SECTOR E TEST OF SIMPLE VEGETATION RIVERBANK PROTECTION**
- **SECTOR F MONITORING OF PILOT WORKS**
- **SECTOR G MONITORING SURVEY FOR PILOT WORKS**
- **SECTOR H RIVERBANK PROTECTION MASTER PLAN**
- **SECTOR I ENVIRONMENTAL CONSIDERATION**
- **SECTOR J TRANSFER OF TECHNOLOGY**

VOLUME 5 DATA BOOK

The cost estimate in this study is based on the price level at the beginning of February 2004 and the applied foreign currency exchange rates are as stated below:

EXCHANGE RATE

US Dollar (US$) 1.00 = Lao Kip (Kip) 10,420
Japanese Yen (¥) 100 = Lao Kip (Kip) 9,750
Middle rate as of February 1, 2004

ABBREVIATIONS

(1) Organization

Lao P.D.R.	Lao People's Democratic Republic
GOL	Government of Lao P.D.R.
GOJ	Government of Japan
JICA	Japan International Cooperation Agency
MCTPC	Ministry of Communication, Transport, Post and Construction
DOR	Departments of Roads, MCTPC
DCTPC	Department of Communication, Transport, Post and Construction
VUDAA	Vientiane Urbane Development and Administration Authority
LNMC	Lao National Mekong Committee
ADB	Asian Development Bank
IUCN	International Union for the Conservation of Nature and Natural Resource
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNDP	United Nations Development Programme
UNCHS	United Nations Centre for Human Settlements
FITA	Flanders International Technical Agency
RTSB	Rancang Timur Sdn. Bhd., Malaysia

(2) Place Name, Geographical Name or Project Name

VUISP	Vientiane Urban Infrastructure and Services Project
NBCA	National Biodiversity Conservation Area

ABBREVIATIONS OF MEASUREMENT

Length

mm = millimeter
cm = centimeter
m = meter
km = kilometer
ft = foot
yd = yard

Area

cm^2 = square centimeter
m^2 = square meter
ha = hectare
km^2 = square kilometer

Volume

10^6 = million
cm^3 = cubic centimeter
l = litre
kl = kilolitre
m^3 = cubic meter
gal= gallon

Weight

Gwh = Gigawatthour
mg= milligramk
g = gram
kg = kilogram
ton = metric ton
lb. = pound

Time

s = second
min = minute
h = hour
d = day
y = year

Electrical Measurement

V = Volt
A = Ampere
hz = Hertz (cycle)
Ghz = Gigahertz
W = Watt
kW = kilowatt
MW = Megawatt
GW = Gigawatt
pr = pair

Other Measures

% = percent
PS= horsepower
o = degree
‘ = minute
“ = second
10^3 = thousand
10^9 = billion

Derived Measures

m^3/s = cubic meter per second
cusec = cubic feet per second
mgd = million gallon per day
kWh = Kilowatthour
Mwh = Megawatthour
Wh/y = Killowatthour per year
kVA = kilovolt ampere
BTU = British Thermal Unit
psi= pound per square inch
Icd= litre per capita per day
Kb/s = Kilobot/second
Mb/s = Megabit/second

Currency

US$ = US Dollar
Kip = Laotian Kip

SECTOR A

PLANNING & DESIGN

THE STUDY ON MEKONG RIVERBANK PROTECTION AROUND VIENTIANE MUNICIPALITY IN THE LAO PEOPLE'S DEMOCRATIC REPUBLIC

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SECTOR A

PLANNING & DESIGN

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SECTOR A

PLANNING & DESIGN

1 PLANNING

1.1 Introduction

1.1.1 The Manual

This manual presents simply and concisely the background information and terms to be considered in planning, designing and implementation of the Bank Protection Master Plan prepared as an output of the Study on Mekong Riverbank Protection around Vientiane Municipality in the Lao People's Democratic Republic.

1.1.2 Bank Protection Master Plan

Application of Master Plan: The Bank Protection Master Plan (the M/P) sets forth bank protection activities around Vientiane City toward the target year 2020. During the M/P period, conditions of the object riverbank may change and the coping measure would also be improved. Therefore, the sites and measures stated in the M/P should be reviewed and modified if necessary, complying with the changes of the situation, and based on the experience and technical know-how to be accumulated.

Principles for Bank Protection: As a basis for the M/P formulation, the following principles were introduced.

1) Bank protection is planned for the riverbanks, which are now suffering from erosion, since the changes in plan-form are small in the past.
2) The cliffy riverbanks are now suffering from erosion and are anticipated to suffer from active erosion sooner or later. Erosions of the cliffy banks are of large scale and the sites extend to wide stretch. Stretch of the cliffy bank was focused for the mechanical measures to be taken under the M/P.
3) The mild-slope riverbanks are not suffering from active erosions and are not large in scale and seem local and intermittent. The coping measures to the mild-slope riverbank should be taken locally by the direct beneficiaries depending on their safety levels required.

High Priority Stretches nominated for M/P: Through a series of screenings from physical and social aspects, the following riverbanks were nominated for the high priority stretches for the M/P. For the implementation of the M/P by the year of 2020, the high priority stretches were further divided into two project groups, i.e., Urgent Projects to be implemented immediately and Second Priority Projects to be implemented after the completion of the Urgent Projects. The riverbanks extending 2.70 km in total were proposed as the Urgent Projects. (see Table 1.1.1, Figures 1.1.1 and 1.1.2).

Table 1.1.1 High Priority Stretches nominated for Master Plan

Site Name	Location by KM post	High Priority Stretches nominated for M/P	Length (meter)	Priority	
				Urgent	2nd Priority
Sithantai	From KM-1553+0.85km	Sithantai (1)	1,280	✓	
	To KM-1555+1.28km	Sithantai (2)	2,040		✓
Ban Hom	From KM-1563+1.15km	Ban Hom (1)	760	✓	
	To KM-1565+1.14km	Ban Hom (2)	50	✓	
		Ban Hom (3)	760		✓
		Ban Hom (4)	880		✓
Hatdokkeo	From KM-1571+0.97km To KM-1571+1.74km	Hatdokkeo	770		✓
Bo O	From KM-1575+0.10km To KM-1575+0.21km	Bo O	200	✓	
Sibounheuang - Muang Wa	From KM-1587+1.80km To KM-1589+0.28km	Sibounheuang - Muang Wa	410	✓	
Upper Sibounheuang	From KM-1589+0.56km	Upper Sibounheuang (1)	810		✓
	To KM-1591+0.00km	Upper Sibounheuang (2)	190		✓
	excluding existing BP	Upper Sibounheuang (3)	350		✓
		Upper Sibounheuang (4)	40		✓
		Upper Sibounheuang (5)	230		✓
Total			8,770	2,270	6,070

Proposed M/P:

The M/P is proposed as shown in Figure 1.1.1 taking into consideration not only technical aspect but also financial condition (refer to Volume 2, Main Report in detail):

- Project cost (national budget in principle): US$4.89 million
- Total length of 10 Master Plan projects: 7.38km
  - ✧ Five (5) stretches for Urgent Projects: 2.70km
  - ✧ Five (5) stretches for 2nd Priority Projects: 4.68km

  (the remaining four(4) stretches of 2nd Priority Projects with 1.39km in total will be implemented after 2020)

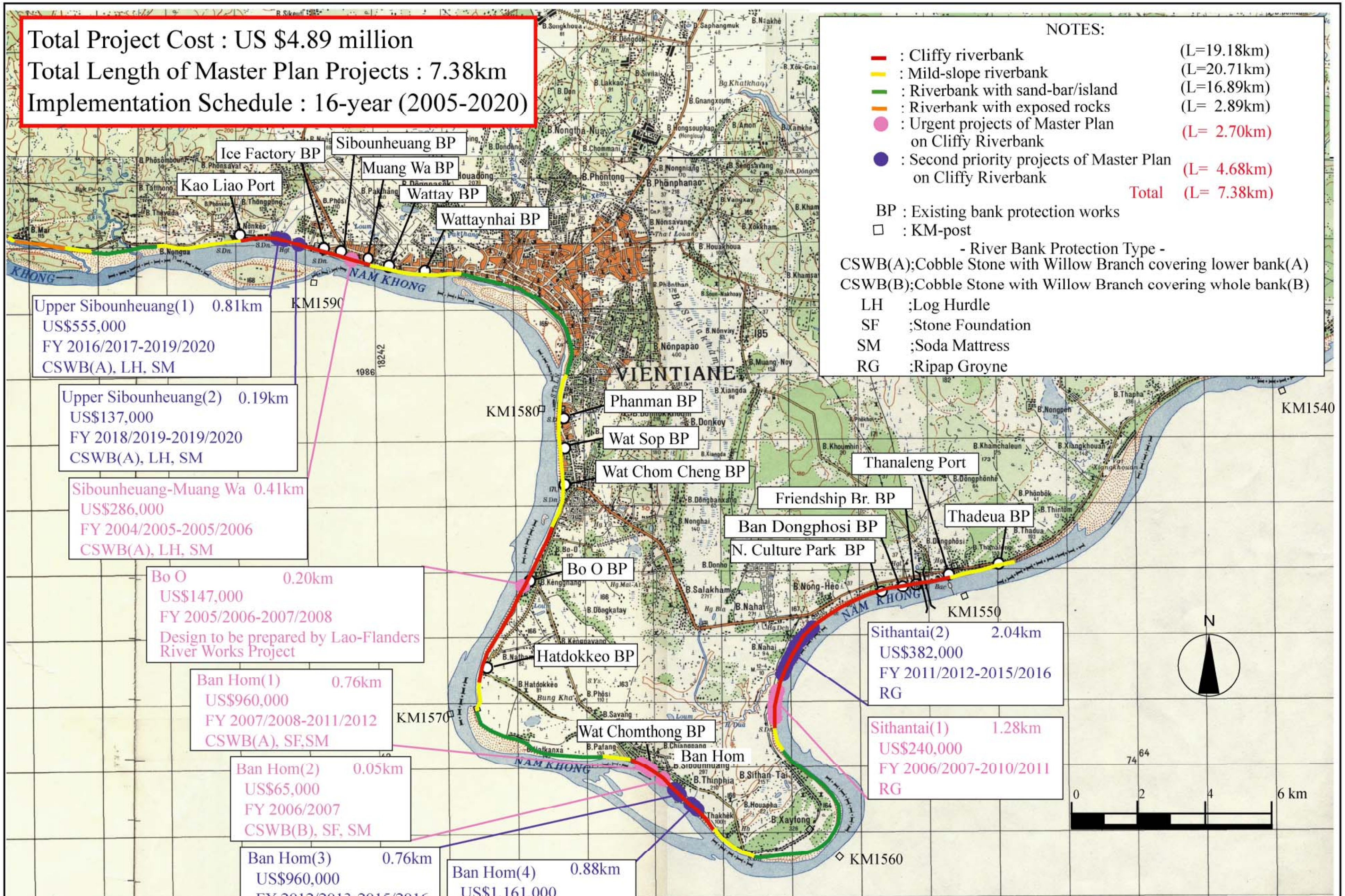
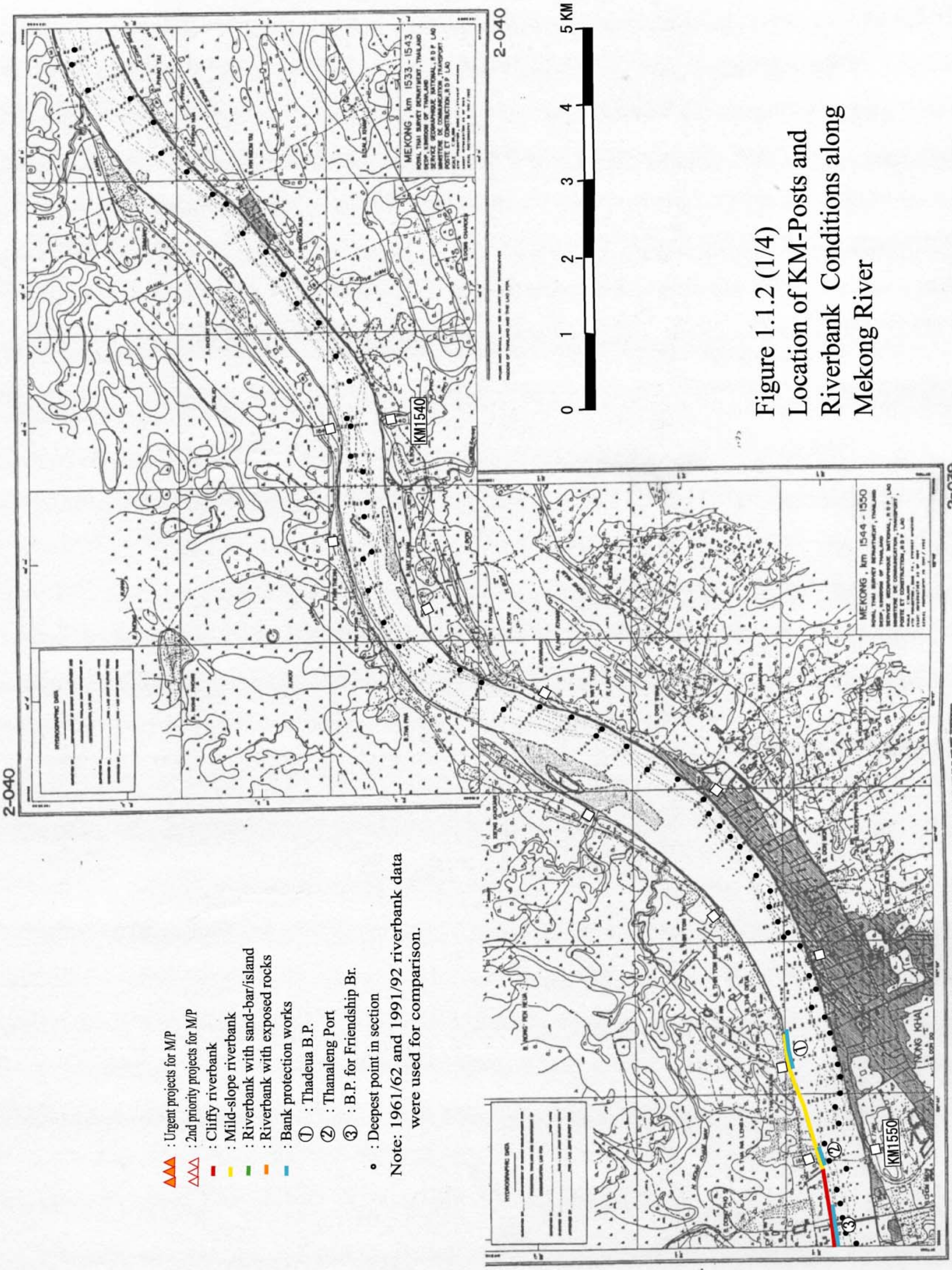


Figure 1.1.1 General Layout of Riverbank Protection Master Plan



: Urgent projects for M/P
: 2nd priority projects for M/P
: Cliffy riverbank
: Mild-slope riverbank
: Riverbank with sand-bar/island
: Riverbank with exposed rocks
: Bank protection works
① : Thadeua B.P.
② : Thanaleng Port
③ : B.P. for Friendship Br.
• : Deepest point in section

Note: 1961/62 and 1991/92 riverbank data were used for comparison.

Figure 1.1.2 (1/4)
Location of KM-Posts and Riverbank Conditions along Mekong River

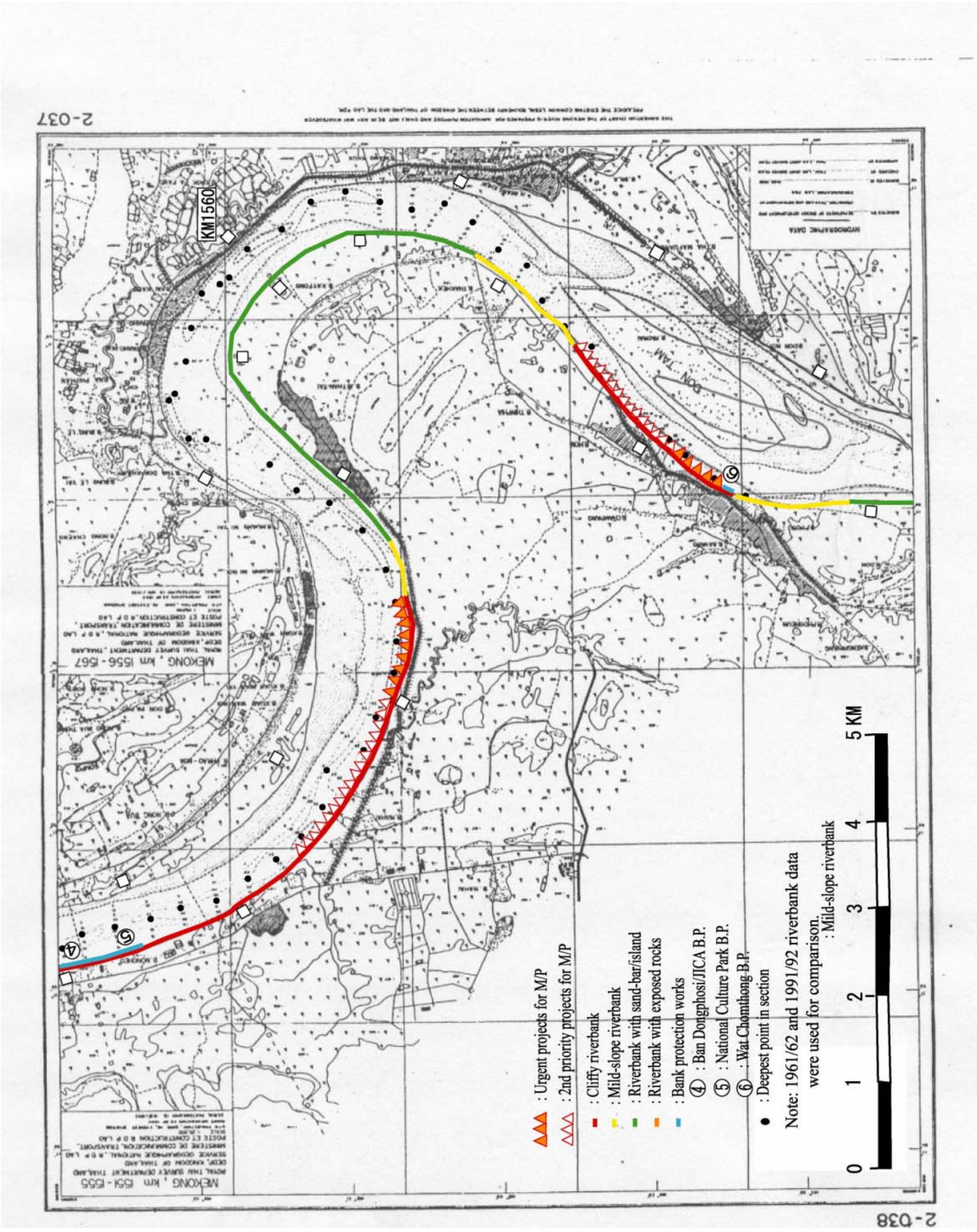


Figure 1.1.2(2/4) Location of KM-Posts and Riverbank Conditions along Mekong River

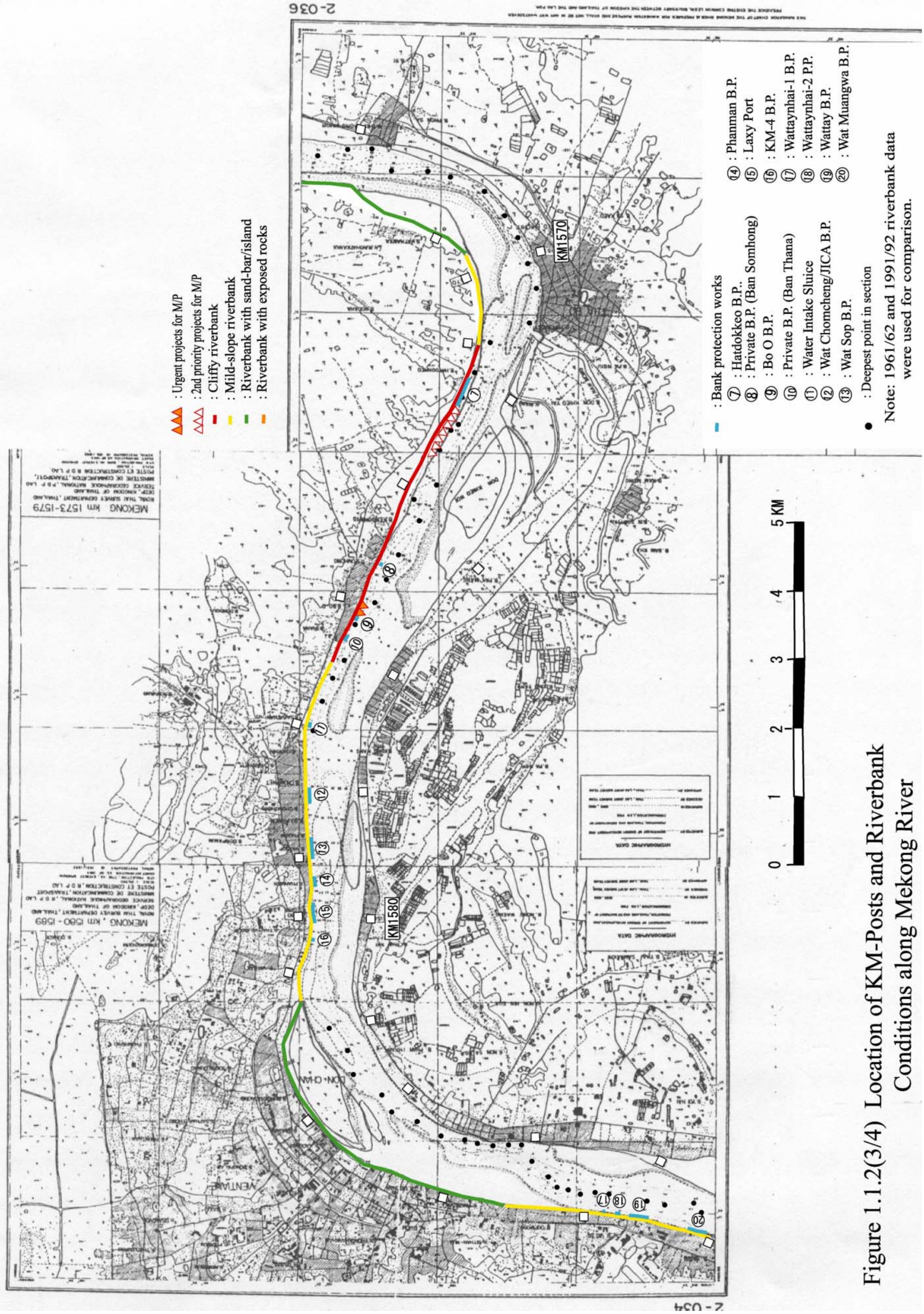


Figure 1.1.2(3/4) Location of KM-Posts and Riverbank Conditions along Mekong River

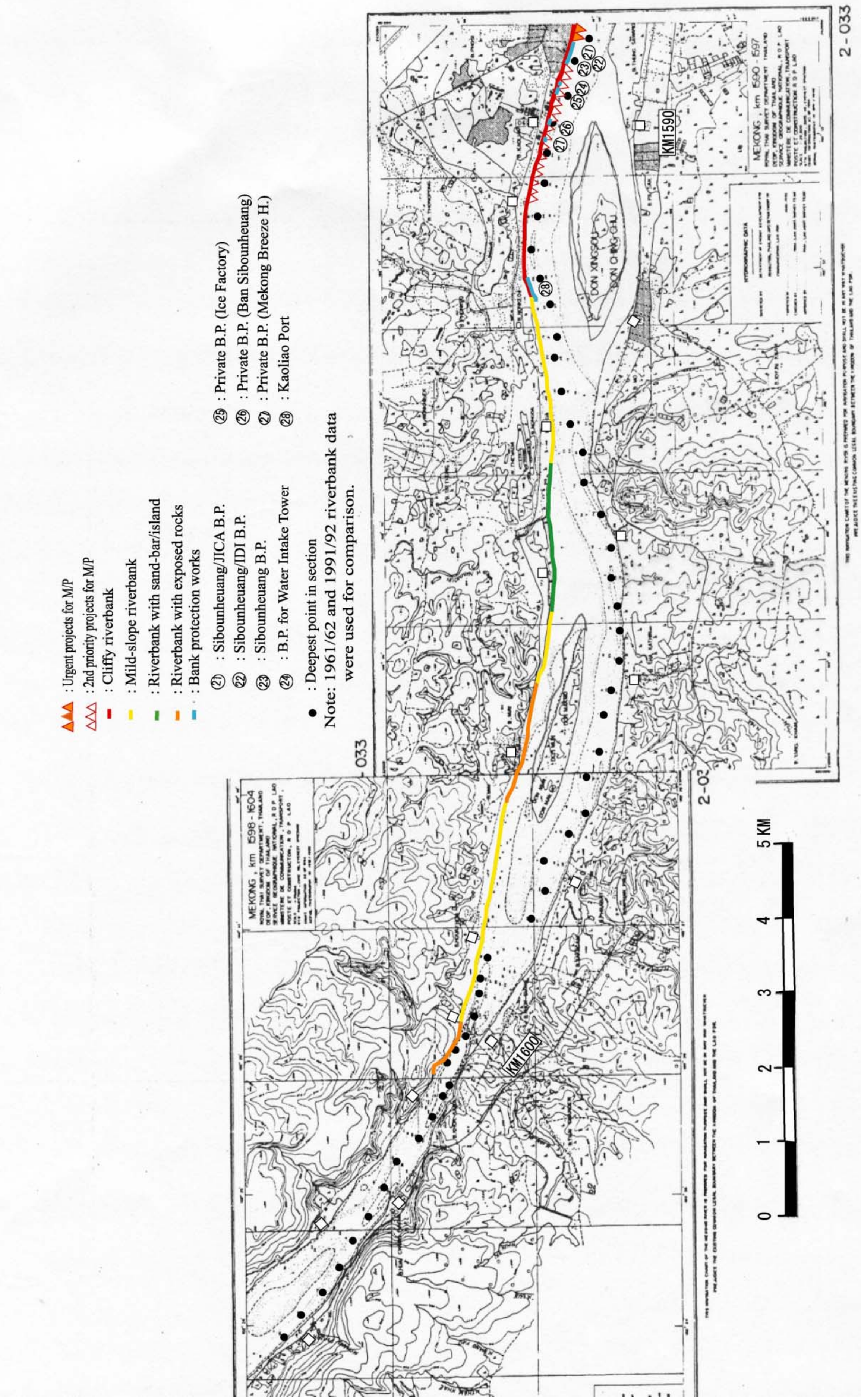


Figure 1.1.2(4/4) Location of KM-Posts and Riverbank Conditions along Mekong River

1.2 Riverbanks around Vientiane City

1.2.1 Geological and Geomorphologic Features

The Vientiane Plain lies on the continental stable plane that is in the process of gently sinking since some tens of thousand years ago. A gravel layer deposited on the basement plane covered with a sand layer on its surface. The gravel layer called as Vientiane gravel is a fan-deposit transported from the Himalayas by the Mekong River during the Glacier Age. The silty sand is a recent alluvial deposit of the Mekong River. The thickness of the silty sand layer ranges from 6 m to 15 m around Vientiane City, which generally becomes thicker toward downstream.

The materials forming the river channel of the Mekong come from mainly two different sources, i.e., Vientiane gravel and silty sand. The gravel is said to be transported during Glacier Age. This gravel hardly be transported by the present flood flows, since the grain size of the gravel (ranging around 5 to 10 cm) exceeds the critical tractive force of the flows. On the other hand the silty sand (d_{60} = 0.44 mm) is transported by the present river flows as suspended loads forming riverbed of dune to transition states on the gravel bed.

Riverbed during the flood is basically formed with the gravel and the depth to the gravel layer is a ruling factor of floodwater depth of the river. The sand is a substantial sediment load closely related to the formation of riverbank and bars.

1.2.2 Mechanism of Bank Erosion

Causes of Bank Erosion: According to the observation and considerations during field reconnaissance of the whole Mekong River in Lao P.D.R. and that around Vientiane City, three major causes could be pointed out for the riverbank erosion. They are bank erosion due to (1) scouring at the foot of riverbank, (2) excess pore pressure during lowering period of river water level, and (3) slope failure.

Erosion due to Scour at Foot of Riverbank: Primary factors of the riverbank erosion are the force of river flow acting on riverbank and the resistance to the flow of riverbank soil. The riverbanks of the Mekong River in the Study Area generally consist of sandy gravel layer below 6 m to 8 m deep clayey soil. Since the sandy gravel layer is mostly unconsolidated and the shear stress of river flow is bigger with longer period of flow attack at the foot of riverbank, the scours take place at the foot of riverbank. When the weight of soil mass exceeds the shearing stress of the bank soil, masses of bank soil fall down and cliffy riverbank are formed. Most of the eroded riverbanks in the Study Area are of this type.

Erosion due to Excess Pore Pressure: High water period last long during the flood season and groundwater table in riverbank is kept high during the period. When the flood season ends, the river water level is lowered rapidly but the groundwater table gradually. In case the riverbank materials are fine and the permeability is low, pore pressure acting on the bank slope may cause failure. Changes of water levels in flood and dry seasons amount to 10 m or more in the Mekong River.

Erosion due to Slope Failure: Slope failure of riverbank may occur at the cliffs newly created. This could happen when additional loads such as earth embankment and buildings were placed on the riverbank.

1.2.3 Hydrological Features of Mekong River around Vientiane City

1) Basin area of Mekong River: 299,000 km^2 at Vientiane (Laxy Port/KM-4)
2) Average riverbed slope: 1/8,100 (The riverbed slope becomes steeper markedly in the upstream reaches of Ban Ang near KM-1620).
3) Average depth to lowest riverbed from riverbank: 14.9 m
4) Average river width: 773 m excluding islands (856 m including. island)
5) Water level (1960-2001):
   - Annual maximum: 10.68 m on average ranging from 6.67 to 12.71 m
   - Annual minimum: 0.43 m on average ranging from 0.28 to 0.93 m
6) Discharge (1960-2001):
   - Annual maximum: 16,000 m^3/s on average ranging from 7,500 to 22,900 m^3/s
   - Annual minimum: 1,000 m^3/s on average ranging from 598 to 1,220 m^3/s

1.3 Planning Riverbank Protection

1.3.1 Planning Works to be Required

The M/P has already been formulated. However, for the implementation of the works in each year, the works should be designed in consideration of the actual situation of the sites adopting reasonable measures. Beside the works for reviewing and materializing the M/P, effective and economical bank protection works fit well with the Mekong River should also be developed based on the monitoring results of the works constructed at sites.

1.3.2 Collection of Data and Information

Collection of Data: Following data should be collected from all the possible government agencies and private organizations in and out of the country, and they should be kept ready for use for the planning the bank protection works and relevant activities.

1) Hydrological observation records
2) Topographic data such as topographic maps and aerial photographs
3) River survey results
4) Study reports of the Mekong River on geology and soil, river morphology, sediment transport, etc.

Survey and Investigation: In order to monitor the changes of river and riverbank, and effects of the structures constructed, survey and investigation should be conducted periodically.

1) **River Survey:** Installation of KM-posts and periodical survey sections along the Mekong River are the first works to be done. Then, the surveys for longitudinal

river profile and river sections should be conducted periodically. River survey data during the flood season are also required to confirm the riverbed movement during flood. These data are required for the analyses of river water and sediment flows.

2) **Riverbank Survey:** Riverbank conditions should be surveyed for such as bank erosion, riverbank materials, riverbank slope, etc. in quantifiable manner as much as possible, and the result of survey should be kept as a survey report specifying the locations linked with the KM-posts along the river. These data are duly necessary to evaluate of erosion damages and to determine the priority site for bank protection.
3) **Monitoring Survey of Bank Protection Works:** In order to verify the effects of the bank protection works, monitoring survey should be conducted specifying works for monitoring. The monitoring may include flow conditions (distributions of flow velocities and directions) and sediment movements (scour/deposition of sediment and their spatial distributions on riverbed). These survey results contribute as the basic data for the improvement and development of the effective protection works.
4) **Investigation of Sand and Gravel Mining:** Sand and gravel mining is carried out in places along the Mekong River. In order to evaluate its influence to riverbank conservation, annual quantities of mining should be investigated. This will contribute to regulate and normalize the mining activities.

1.3.3 Selection of Sites for Protection

Evaluation Items: Considering the limited budget available for bank protection works, sites for the bank protection were selected in the Master Plan Study, through three stages of screenings based on general bank conditions, vulnerability to erosion, and social importance follows:

1) Initial screening based on general bank conditions:
   - Cliffy bank (1A)
   - Mild-slope bank (1B)
   - Bank with sand-bar/island (1C)
   - Bank with exposed rocks (1D)
   - Bank with protection works (1E)

2) Secondary screening based on vulnerability to erosion:
   - Active river shifting (2A)
   - Recent active erosion (2B)
   - Out-curved bank (2C)
   - Close to main flow (2D)
   - Bank with little vegetation (2E)

3) Tertiary screening based on social importance:
   - Settlements including road on bank (3A)
   - Public roads on bank (3B)
   - Temples on bank (3C)

Confirmation of Priority Sites of M/P: Based on the evaluation items mentioned above, the priority sites selected for the M/P should be confirmed and reviewed if necessary according to the latest data and information. For the screening purpose, the left riverbank in the Study Area was divided into numerous segments of 10-m long each, and respective evaluation items were marked for every segment riverbanks based on the study results made so far and supplementary field survey results. As an example, results of marking for the present riverbank as of 2004 are shown in Table 1.3.1. Screenings for the M/P have been made based on the Table.

Review and Revision of the M/P: The M/P is formulated targeting the year 2020, the plan is not unchangeable one, though. There are many uncertainties about the estimate of the conditions of 10 years, 15 years from now. Therefore, it is advisable that the M/P be reviewed and revised by GOL if necessary in 2010 and 2015, in accordance with the national development plans, taking the following factors in consideration:

1. Financial factors(Unforeseen change in financial condition of GOL), and
2. Technical factors.
   a) The result of the long-term monitoring of the Pilot Works
   b) Unforeseen change in the conditions of riverbank erosion

Further Selection of Priority Sites: Considering the budget allocated for the bank protection, the work sites for the respective year should be specified according to the urgency of work implementation judging from the current site conditions as follows:

1. Sites where serious bank-erosion damages took place during these flood seasons,
2. Sites where important building and/or facilities were newly constructed on the erosion-vulnerable bank, and
3. Sites which are anticipated to induce serious erosion damages in near future.

Table 1.3.1(1/5)   Selection of Priority Sites for Bank Protection Works

Distance	Initial screening 1A	1B	1C	1D	1E	Passed	Secondary screening 2A	2B	2C	2D	2E	Passed	Tertiary screening 3A	3B	3C	Passed	Stretch length	2005/6 -2009/10	2010/11 -2019/20	Location (KM-post)	High Priority Stretches nominated for M/P
(km)																	(km)				
0.00		1			1	0						0		1		0	0.50			KM- 1547 + 1.83 km	
0.50		1				0						0	1			0	1.03			KM- 1549 + 0.04 km	
1.53		1				0						0	1		1	0	0.05			KM- 1549 + 1.07 km	
1.58		1				0						0	1			0	0.05			KM- 1549 + 1.12 km	
1.63		1			1	0						0	1			0	0.21			KM- 1549 + 1.17 km	
1.84	1					1						0	1			0	0.50			KM- 1550 + 0.10 km	
2.34	1					1					1	0	1			0	0.11			KM- 1550 + 0.60 km	
2.45	1				1	0						0	1			0	0.21			KM- 1550 + 0.71 km	
2.66	1				1	0						0	1			0	0.22			KM- 1550 + 0.92 km	
2.88	1				1	0					1	0	1			0	0.65			KM- 1550 + 1.14 km	
3.53	1				1	0						0	1			0	0.42			KM- 1551 + 0.58 km	
3.95	1					1			1		1	0	1			0	2.08			KM- 1551 + 1.00 km	
6.03	1					1		1	1	1	1	1	1			1	2.04		2.04	KM- 1553 + 0.85 km	Sithantai (2)
8.07	1					1		1	1	1	1	1		1		1	1.28	1.28	0.00	KM- 1555	Sithantai (1)
9.35		1				0			1			0		1		0	0.72			KM- 1555 + 1.28 km	
10.07			1			0						0				0	6.47			KM- 1555 + 2.00 km	
16.54		1				0	1					0		1		0	0.74			KM- 1561 + 1.41 km	
17.28		1				0	1					0		1	1	0	0.05			KM- 1563 + 0.27 km	
17.33		1				0	1					0		1		0	0.83			KM- 1563 + 0.32 km	

(NOTES)

1. Initial screening: General bank conditions
1A: Cliffy bank
1B: Mild-slope bank
1C: Bank w/bars
1D: Bank w/rocks
1E: Bank w/protection works

2. Secondery screening: Vulnerability to erosion:
2A: Active river shifting
2B: Recent active erosion
2C: Out-curved bank
2D: Close to main flow
2E: Bank w/little vegetation

3. Tertiary screening: Social importance:
3A: Settlements (incl. roads)
3B: Roads
3C: Temples

1 1 1 1 1   1 1 1 1 1   1 1 1

* Riverbank marked as "1" passed the screening and that marked as "0" was screened out.

Table 1.3.1(2/5) Selection of Priority Sites for Bank Protection Works

	Initial screening						Secondary screening						Tertiary screening				Stretch	2005/6	2010/11		High Priority Stretches
Distance	1A	1B	1C	1D	1E	Passed	2A	2B	2C	2D	2E	Passed	3A	3B	3C	Passed	length	-2009/10	-2019/20	Location (KM-post)	nominated for M/P
(km)																	(km)				
18.16	1					1	1	1	1	1	1	1		1		1	0.88		0.88	KM- 1563 + 1.15 km	Ban Hom (4)
19.04	1					1	1	1	1	1	1	1	1			1	0.76		0.76	KM- 1563 + 2.03 km	Ban Hom (3)
19.80	1					1	1	1	1	1	1	1	1		1	1	0.05	0.05	0.00	KM- 1565 + 0.33 km	Ban Hom (2)
19.85	1					1	1	1	1	1	1	1	1			1	0.76	0.76	0.00	KM- 1565 + 0.38 km	Ban Hom (1)
20.61	1				1	0	1	1	1	1	1	0	1			0	0.16			KM- 1565 + 1.14 km	
20.77		1				0	1		1			0				0	1.29			KM- 1565 + 1.30 km	
22.06			1			0	1					0				0	3.43			KM- 1565 + 2.59 km	
25.49		1				0	1					0				0	1.39			KM- 1569 + 0.57 km	
26.88	1					1	1	1		1	1	1				0	0.54			KM- 1571	
27.42	1				1	0	1	1		1		0		1		0	0.43			KM- 1571 + 0.54 km	
27.85	1					1	1	1		1	1	1		1		1	0.77		0.77	KM- 1571 + 0.97 km	Hatdokkeo
28.62	1					1	1					0				0	1.34			KM- 1571 + 1.74 km	
29.96	1					1	1					0	1			0	0.47			KM- 1573 + 0.78 km	
30.43	1				1	0	1					0	1			0	0.05			KM- 1573 + 1.25 km	
30.48	1					1	1					0	1			0	0.59			KM- 1573 + 1.30 km	
31.07	1					1	1	1	1	1	1	1	1			1	0.20	0.20	0.00	KM- 1575 + 0.01 km	Bo O
31.27	1				1	0	1	1	1	1	1	0	1			0	0.01			KM- 1575 + 0.21 km	
31.28	1				1	0	1	1	1	1	1	0	1		1	0	0.05			KM- 1575 + 0.22 km	
31.33	1					1			1	1		0	1			0	0.20			KM- 1575 + 0.27 km	
31.53	1				1	0			1	1		0	1			0	0.09			KM- 1575 + 0.47 km	
31.62	1					1			1	1		0	1			0	0.38			KM- 1575 + 0.56 km	
32.00		1				0			1	1		0	1			0	0.98			KM- 1575 + 0.94 km	

(NOTES)

1. Initial screening: General bank conditions
1A: Cliffy bank
1B: Mild-slope bank
1C: Bank w/bars
1D: Bank w/rocks
1E: Bank w/protection works

2. Secondery screening: Vulnerability to erosion:
2A: Active river shifting
2B: Recent active erosion
2C: Out-curved bank
2D: Close to main flow
2E: Bank w/little vegetation

3. Tertiary screening: Social importance:
3A: Settlements (incl. roads)
3B: Roads
3C: Temples

1 1 1 1 1 1 1 1 1 1 1 1 1

* Riverbank marked as "1" passed the screening and that marked as "0" was screened out.

Table 1.3.1(3/5) Selection of Priority Sites for Bank Protection Works

Distance	Initial screening						Secondary screening						Tertiary screening				Stretch length	2005/6 -2009/10	2010/11 -2019/20	Location (KM-post)	High Priority Stretches nominated for M/P
	1A	1B	1C	1D	1E	Passed	2A	2B	2C	2D	2E	Passed	3A	3B	3C	Passed					
(km)																	(km)				
32.98		1			1	0			1	1		0	1			0	0.03			KM- 1577	
33.01		1				0			1	1		0	1			0	0.82			KM- 1577 + 0.03 km	
33.83		1				0						0	1			0	0.09			KM- 1577 + 0.85 km	
33.92		1			1	0						0	1			0	0.04			KM- 1577 + 0.94 km	
33.96		1			1	0						0	1		1	0	0.05			KM- 1577 + 0.98 km	
34.01		1			1	0						0	1			0	0.15			KM- 1577 + 1.03 km	
34.16		1				0						0	1			0	0.47			KM- 1577 + 1.18 km	
34.63		1			1	0						0	1			0	0.22			KM- 1577 + 1.65 km	
34.85		1			1	0						0	1		1	0	0.05			KM- 1577 + 1.87 km	
34.90		1			1	0						0	1			0	0.05			KM- 1579 + 0.02 km	
34.95		1				0						0	1			0	0.18			KM- 1579 + 0.07 km	
35.13		1			1	0						0	1			0	0.15			KM- 1579 + 0.25 km	
35.28		1				0						0	1			0	0.24			KM- 1579 + 0.40 km	
35.52		1			1	0						0	1			0	0.29			KM- 1579 + 0.64 km	
35.81		1				0						0	1			0	0.12			KM- 1580 + 0.08 km	
35.93		1				0			1	1		0	1			0	0.12			KM- 1580 + 0.20 km	
36.05		1			1	0			1	1		0	1			0	0.07			KM- 1580 + 0.32 km	
36.12		1				0			1	1		0	1			0	0.90			KM- 1580 + 0.39 km	
37.02			1			0			1			0	1			0	1.80			KM- 1581 + 0.42 km	
38.82			1			0						0	1			0	3.19			KM- 1583	
42.01		1				0						0	1			0	1.30			KM- 1585 + 0.96 km	
43.31		1			1	0						0	1			0	0.04			KM- 1587 + 0.25 km	

(NOTES)

1. Initial screening: General bank conditions
1A: Cliffy bank
1B: Mild-slope bank
1C: Bank w/bars
1D: Bank w/rocks
1E: Bank w/protection works

2. Secondery screening: Vulnerability to erosion:
2A: Active river shifting
2B: Recent active erosion
2C: Out-curved bank
2D: Close to main flow
2E: Bank w/little vegetation

3. Tertiary screening: Social importance:
3A: Settlements (incl. roads)
3B: Roads
3C: Temples

1 1 1 1 1 1 1 1 1 1 1 1 1

* Riverbank marked as "1" passed the screening and that marked as "0" was screened out.

Table 1.3.1(4/5) Selection of Priority Sites for Bank Protection Works

Distance	Initial screening						Secondary screening						Tertiary screening				Stretch length	2005/6 -2009/10	2010/11 -2019/20	Location (KM-post)	High Priority Stretches nominated for M/P
	1A	1B	1C	1D	1E	Passed	2A	2B	2C	2D	2E	Passed	3A	3B	3C	Passed					
(km)																	(km)				
43.35		1				0						0	1			0	0.14			KM- 1587 + 0.29 km	
43.49		1			1	0						0	1			0	0.02			KM- 1587 + 0.43 km	
43.51		1				0						0	1			0	0.23			KM- 1587 + 0.45 km	
43.74		1			1	0						0	1			0	0.25			KM- 1587 + 0.68 km	
43.99		1				0						0	1			0	0.62			KM- 1587 + 0.93 km	
44.61		1			1	0						0	1			0	0.07			KM- 1587 + 1.55 km	
44.68		1			1	0						0	1		1	0	0.05			KM- 1587 + 1.62 km	
44.73		1			1	0						0	1			0	0.13			KM- 1587 + 1.67 km	
44.86	1					1		1	1	1	1	1	1			1	0.41	0.41	0.00	KM- 1587 + 1.80 km	Sibounheuang-Muang Wa
45.27	1				1	0		1	1	1	1	0	1			0	0.16			KM- 1589 + 0.28 km	
45.43	1				1	0		1	1	1	1	0	1			0	0.01			KM- 1589 + 0.44 km	
45.44	1				1	0		1	1	1	1	0	1		1	0	0.05			KM- 1589 + 0.45 km	
45.49	1				1	0		1	1	1	1	0	1			0	0.02			KM- 1589 + 0.50 km	
45.51	1				1	0		1	1	1	1	0	1			0	0.04			KM- 1589 + 0.52 km	
45.55	1					1		1	1	1	1	1	1			1	0.23		0.23	KM- 1589 + 0.56 km	Upper Sibounheuang (5)
45.78	1				1	0		1	1	1	1	0	1			0	0.08			KM- 1589 + 0.79 km	
45.86	1					1		1	1	1	1	1	1			1	0.04		0.04	KM- 1589 + 0.87 km	Upper Sibounheuang (4)
45.90	1				1	0		1	1	1		0	1			0	0.11			KM- 1589 + 0.91 km	
46.01	1					1		1	1	1	1	1	1			1	0.35		0.35	KM- 1589 + 1.02 km	Upper Sibounheuang (3)
46.36	1				1	0		1	1	1	1	0	1			0	0.06			KM- 1589 + 1.37 km	
46.42	1					1		1	1	1	1	1	1			1	0.19		0.19	KM- 1590 + 0.02 km	Upper Sibounheuang (2)
46.61	1				1	0		1	1	1	1	0	1			0	0.04			KM- 1590 + 0.21 km	

(NOTES)

1. Initial screening: General bank conditions
1A: Cliffy bank
1B: Mild-slope bank
1C: Bank w/bars
1D: Bank w/rocks
1E: Bank w/protection works

2. Secondery screening: Vulnerability to erosion:
2A: Active river shifting
2B: Recent active erosion
2C: Out-curved bank
2D: Close to main flow
2E: Bank w/little vegetation

3. Tertiary screening: Social importance:
3A: Settlements (incl. roads)
3B: Roads
3C: Temples

1 1 1 1 1 1 1 1 1 1 1 1 1

* Riverbank marked as "1" passed the screening and that marked as "0" was screened out.

Table 1.3.1(5/5) Selection of Priority Sites for Bank Protection Works

Distance	Initial screening						Secondary screening						Tertiary screening				Stretch length	2005/6 -2009/10	2010/11 -2019/20	Location (KM-post)	High Priority Stretches nominated for M/P
	1A	1B	1C	1D	1E	Passed	2A	2B	2C	2D	2E	Passed	3A	3B	3C	Passed					
(km)																	(km)				
46.65	1					1		1	1	1	1	1	1			1	0.81		0.81	KM- 1590 + 0.25 km	Upper Sibounheuang (1)
47.46	1					1			1	1	1	0	1			0	0.70			KM- 1591	
48.16	1					1			1			0	1			0	0.34			KM- 1591 + 0.70 km	
48.50	1				1	0			1			0	1			0	0.30			KM- 1591 + 1.04 km	
48.80		1				0						0				0	1.89			KM- 1591 + 1.34 km	
50.69			1			0						0				0	2.00			KM- 1593 + 0.56 km	
52.69		1				0						0				0	0.72			KM- 1595 + 0.54 km	
53.41		1				0						0		1		0	0.30			KM- 1595 + 1.26 km	
53.71				1		0						0		1		0	1.63			KM- 1595 + 1.56 km	
55.34		1				0						0		1		0	0.14			KM- 1597 + 0.71 km	
55.48		1				0						0				0	0.13			KM- 1597 + 0.85 km	
55.61		1				0					1	0				0	0.58			KM- 1597 + 0.98 km	
56.19		1				0						0				0	2.06			KM- 1597 + 1.56 km	
58.25		1				0				1		0				0	0.16			KM- 1599 + 1.02 km	
58.41				1		0				1		0				0	0.83			KM- 1599 + 1.18 km	
59.24				1		0				1		0				0				KM- 1600 + 0.77 km	
Total (km)						16.02						9.31				8.77	59.24	2.70	6.07		

(NOTES)

1. Initial screening: General bank conditions
1A: Cliffy bank
1B: Mild-slope bank
1C: Bank w/bars
1D: Bank w/rocks
1E: Bank w/protection works

2. Secondery screening: Vulnerability to erosion:
2A: Active river shifting
2B: Recent active erosion
2C: Out-curved bank
2D: Close to main flow
2E: Bank w/little vegetation

3. Tertiary screening: Social importance:
3A: Settlements (incl. roads)
3B: Roads
3C: Temples

1 1 1 1 1   1 1 1 1 1   1 1 1

* Riverbank marked as "1" passed the screening and that marked as "0" was screened out.

1.3.4 Selection of Types of Works

Classification of Types of Riverbank: The left (Lao side) bank for the study is 59.2 km from Thadeua to Wat Thamphat. Out of the left bank, the cliffy riverbank extends to about 19.18 km in total, and the mild-slope riverbank to 20.71 km. The mild-slope riverbank (Type-M) seems to be in the state between erosion and deposition. The cliffy riverbanks are found in the reaches where erosion prevails, and the cliffy banks are in most critical conditions for bank erosion. The cliffy riverbanks are further classified into three, i.e., cliffy riverbanks with silty sand (Type-C1), silty sand on loose gravel bed (Type-C2), and silty sand on consolidated gravel bed (Type-C3). The above classification is not always definite and various geological formations thrust locally in each type of riverbank.

Coping Measures to Erosion: Bank protection works of the Mekong River mainly consist of following component works in general:

1) **Foot Protection Works:** To protect the foundation and slope pavement from the riverbed scour, flexibly adjusting to the riverbed changes.
2) **Foundation Works:** To support slope pavement works, firmly fixing the foot of slope.
3) **Lower Slope Protection Works:** To protect lower part of slope (the most erosion-vulnerable part of slope) by covering the slope surface.
4) **Upper Slope Protection Works:** To protect upper part of slope from erosion due to flood flows and floating materials by covering the slope surface.

Types of Riverbank and Advisable Measures: Types of riverbank and advisable coping measures for bank protection are summarized in Table 1.3.2 for reference. The types of works and their coping measures are not limited to those mentioned in the Table, and they should be improved and developed based on the monitoring results of the works constructed. Considering effective use of the limited fund, it is also advisable to construct small-scale works of lower safety at the initial stage, and enforce the works stage-wise depending on the requirement of the monitoring results.

Table 1.3.2 Type of Riverbank and Protection Measures

Items	Type-C1 bank	Type-C2 banks	Type-C3 bank
Physical Conditions			
Shape of bank	Cliffy bank	Cliffy bank	Cliffy bank
Bank materials	Silty sand (gravel bed is not seen above water surface)	Silty sand on loose gravel bed	Silty sand on consolidated gravel bed
River flows	Facing or contacting to the main flow of the Mekong R.	Facing or contacting to the main flow of the Mekong R.	Facing or contacting to the main flow of the Mekong R.
Mechanism of Bank Erosion/Failure	Scour of bank toe and erosion of slope due to attacks of river flows.	Scour of loose gravel bed at the toe of slope and erosion of slope due to attacks of river flows.	Erosion of bank slope due to attacks of river flows.
Typical Riverbanks in Study Area	- Upstream reaches of Ice Factory B.P. - Ban Hom	- Hatdokkeo B.P. to Bo O B.P. - Wat Muangwa B.P. to Sibounheuan B.P.	- Ban Dongphosi to Sithantai, though Type-C2 banks are found in places.
Coping Measures	- To protect foot of bank-slope from scour. - To protect bank-skope from erosion. - To reduce flow velocity near riverbank.	- To protect foot of bank-slope from scour. - To protect bank-skope from erosion. - To reduce flow velocity near riverbank.	- To protect bank-slope from erosion. - To reduce flow velocity near riverbank.
Advisable Component Works			
Foot protection works (FP)	- Rip-rap groin work - Soda mattress work - Rip-rap work	- Rip-rap groin work - Gabion work - Soda mattress work - Rip-rap work	- Rip-rap groin work - Gabion work - Soda mattress work - Rip-rap work
Foundation works (F)	- Frame work filled w/rip-rap - Rip-rap work	- Frame work filled w/rip-rap - Rip-rap work	- Frame work filled w/rip-rap - Rip-rap work
Lower slope protection works (LS)	- Gabion work - Rip-rap work - Cobble with willow branch work - Soda mattress work - Willow work	- Gabion work - Rip-rap work - Cobble with willow branch work - Soda mattress work - Willow work	- Gabion work - Rip-rap work - Cobble with willow branch work - Soda mattress work - Willow work
Upper slope protection works (US)	- Gabion work - Cobble with willow branch work - Sand bag work	- Gabion work - Cobble with willow branch work - Sand bag work	- Gabion work - Cobble with willow branch work - Sand bag work
Advisable Protection Works			
Important protection sites of higher safety	- Soda mattress (FP) + Rip-rap (F) + Cobble w/willow branch (LS & US)	- Soda mattress (FP) + Rip-rap (F) + Cobble w/willow branch (LS & US)	- Soda mattress (FP) + Rip-rap (F) + Cobble w/willow branch (LS & US)
Other protection sites	- Soda mattress (FP) + Rip-rap (F) + Cobble w/willow branch (LS)	- Soda mattress (FP) + Rip-rap (F) + Cobble w/willow branch (LS)	- Rip-rap groin (FP)

2 DESIGN

2.1 Design Parameters

Here, the method of determining the hydraulic parameters that are necessary for designing revetment structures, namely design water level, design water depth, and design velocity are presented.

2.1.1 Design Water Level and Design Water Depth

Design water level (HWL) in Mekong River around Vientiane City shall be defined as the water level equal to the left bank elevation as shown in Figure 2.1.1.

Low water level is set as a water level corresponding to the annual minimum discharge with return period of 5 years.

As shown in Figure 2.1.2, the annual minimum discharge with return period of 5 years at KM4 port is estimated as approximately 910m^3/s, based on the series of annual minimum discharge observed at Laksi Port in 1960 – 2003.

Design water depth (H_d) is defined as the difference between HWL and the bottom of revetment structure as shown in Figure 2.1.1.

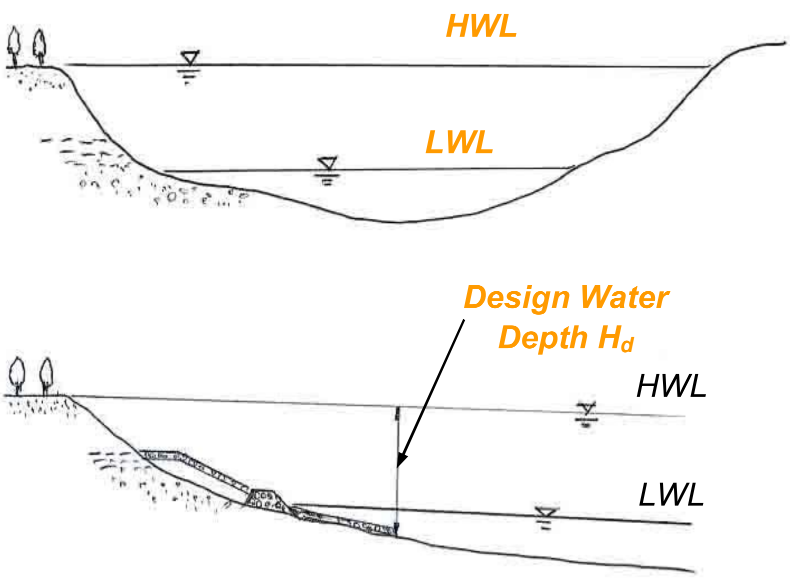


Figure 2.1.1 Design Water Level (HWL) and Design Water Depth (H_d)

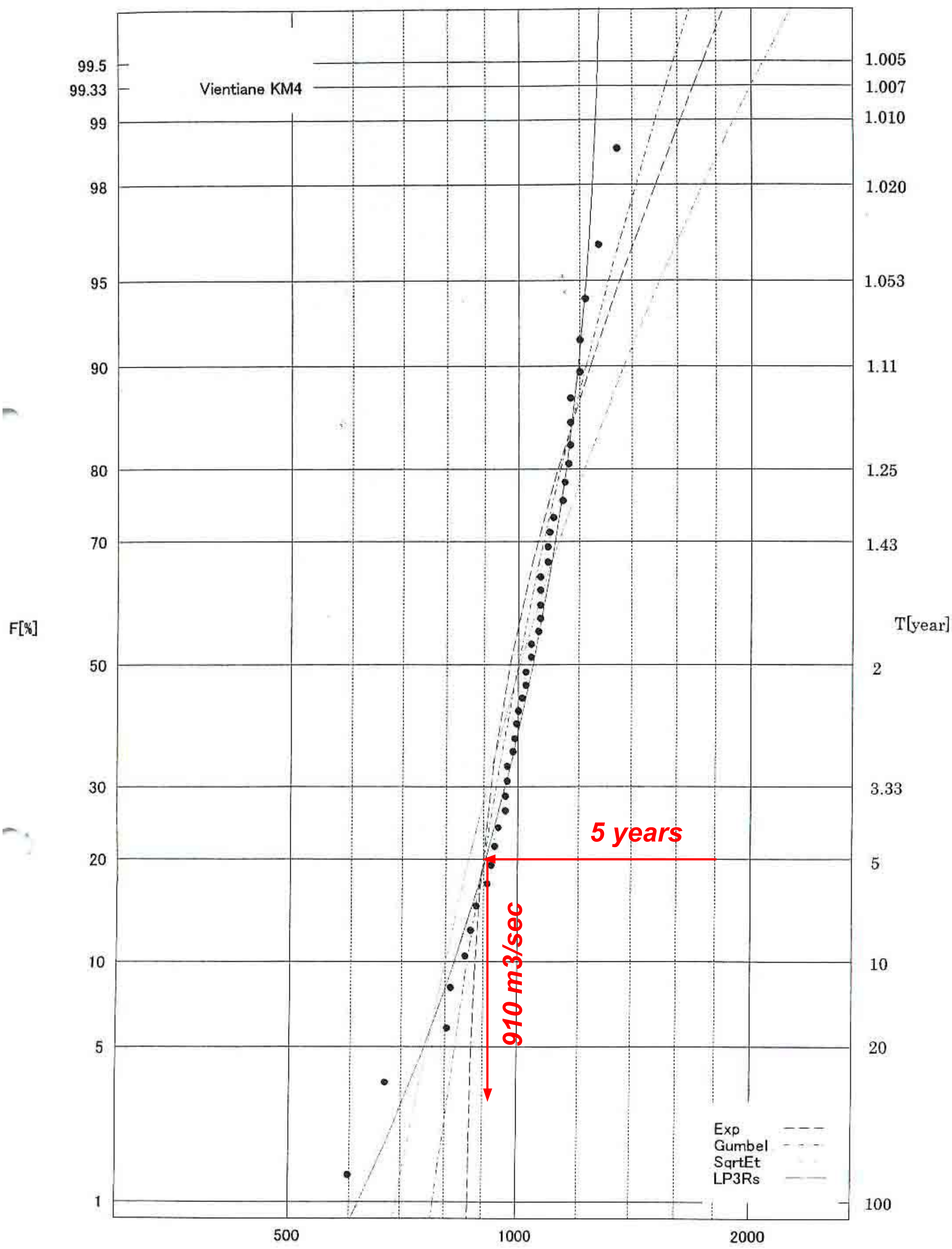


Figure 2.1.2 Probability Analysis on Annual Minimum Discharge at Vientiane KM4

2.1.2 Design Velocity

The typical design velocity calculation procedure is as shown in Figure 2.1.3.

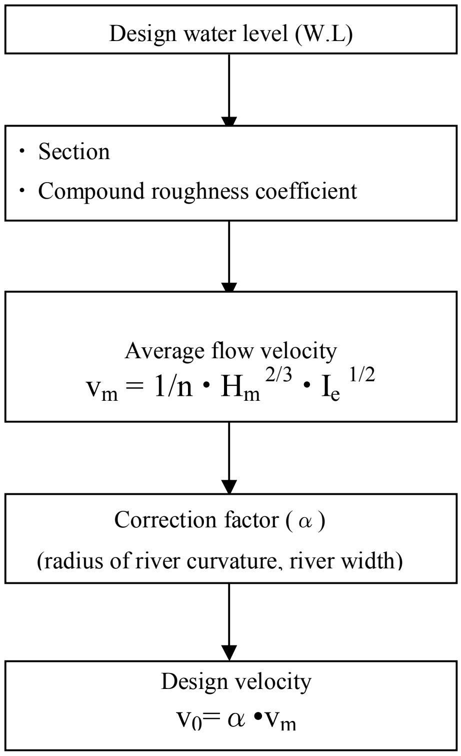


Figure 2.1.3 Procedure of Design Velocity Calculation

a) Average Flow Velocity

Average flow velocity v_m is derided from Manning Formula as described below

$$v_m = 1/n \cdot H_m^{2/3} \cdot I_e^{1/2} \qquad (2\text{-}1\text{-}1)$$

v_m : Average flow velocity (m/s)
I_e : Energy gradient (≒ 1/8,400, the longitudinal river bed slope around Vientiane City)
H_m : Average water depth (m) corresponding to the water level of HWL (= A/B, where A :Section area, B : Channel width)
n : Manning's coefficient of roughness

As for Manning's coefficient of roughness, Figure 2.1.4 shows the comparison of the rating curve of water level and discharge at Vientiane KM4 based on the field measurement and the uniform flow calculation result.

Manning's coefficient of roughness (n) of Mekong River around Vientiane City is evaluated as about 0.025 roughly according to this figure.

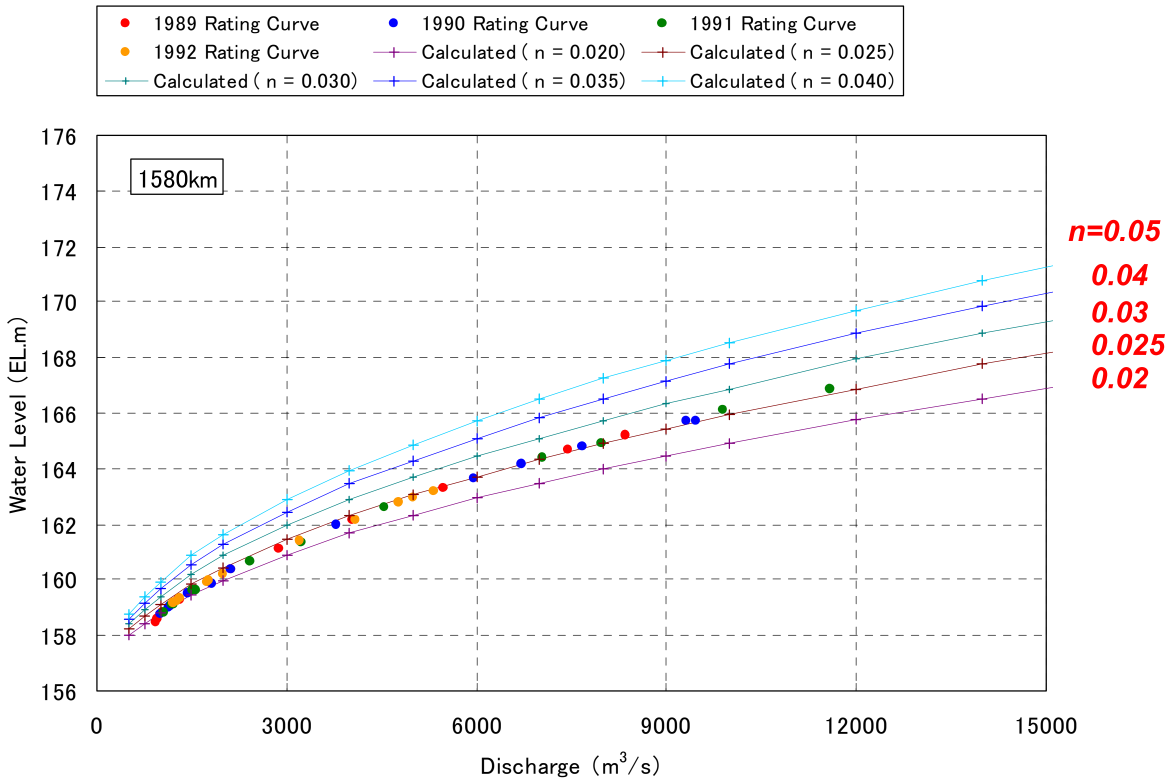


Figure 2.1.4 Measured and Calculated Rating Curve at Vientiane KM4
(Water level is indicated as above M.S.L. Ko Lak Datum.)

Average flow velocity can be calculated by above-mentioned method, or if available, a non-uniform flow calculation and/or field measurement of flow velocity so as to obtain a rating curve of water level and discharge at each project site, and Manning's coefficient of roughness around each area.

(b) Correction Factor and Design Velocity

Design velocity v_0 is calculated by correction factor α and average velocity v_m as below.

$$v_0 = \alpha \cdot v_m \qquad (2\text{-}1\text{-}2)$$

Correction factor is defined as velocity concentration ratio (v_{toe} / v_m) in bending reach. Where v_{toe} = riverside part average velocity,

According to Thorne, Bat, Abt Maynold*), for calculating the design velocity, v_{toe} / v_m of outer bank in a bend immediately downstream of straight channel in natural river is presumed by the equation as shown below,

$$\alpha = v_{toe} / v_m = 1.66 - 0.42 \log (r / B) \qquad (2\text{-}1\text{-}3)$$

where r = radius of channel curvature, B = width of channel for the bend. This relation is adopted for r/B values equal to or greater than 2.

Though α is calculated by above-mentioned equation, the value of α should be set greater than unity.

*) Colin R.Thorne, S.R.Abt, S.T.Maynold : Prediction of Near-Bank Velocity and Scour Depth in Meander Bends for Design of Riprap Revetments, River, Coastal And Shoreline Protection, Edited By Colin R.Thorne…et.al., John Wiley & Sons Ltd, 1995

2.1.3 Hydraulic Condition of Mekong River around Vientiane City

Here, the hydraulic parameters that are necessary for designing revetment structures, namely average flow velocity, river width, radius of curvature, and water depth around Vientiane city are roughly estimated.

This information is useful to determine the design flow velocity according to the procedure shown in Figure 2.1.3 as one of alternatives.

a) Average Flow Velocity

Average flow velocity, which is used as a basic parameter of determining the design flow velocity would be defined as the one when the water level is equal to the bank elevation.

Figure 2.1.5 shows the longitudinal profiles of water surface obtained by several conditions of the non-uniform flow calculations indicated with the left bank elevation based on the topographical map. Left bank elevation can be applied to design water level (HWL).

The non-uniform flow calculation was executed under some conditions of discharge Q intended for the region between 1548km and 1593km in Mekong River. Channel section shape was read based on the plan of the river and the distribution of depth based on L.LWL, which had been recorded in it.
Uniform flow depth to the longitudinal slope of L.LWL (1/8,400) was calculated and the water level of the downstream edge was given.

Estimated discharge when the water level is equal to the left bank elevation at each section is derived from this figure respectively.

Figure 2.1.6 shows the longitudinal distribution of the section average velocity v_m corresponding to Figure 2.1.5. The legend of latter figure is the same as former one.

With these two figures, estimated discharge and section average velocity when the water level is equal to the left bank elevation at each section is derived as shown in Figure 2.1.7.
b) Design Water Depth

As shown in Figure 2.1.1, design water depth H_d is defined as below.

$$H_d = HWL - Z \tag{2-1-4}$$

Z : Bottom height of revetment structure

When Z is assumed as nearly equal to the water level corresponding to the annual minimum discharge with return period of five years (LWL), about 900m^3/s, minus the height of structures, H_d is derived from the difference between HWL and LWL as shown in Figure 2.1.8.

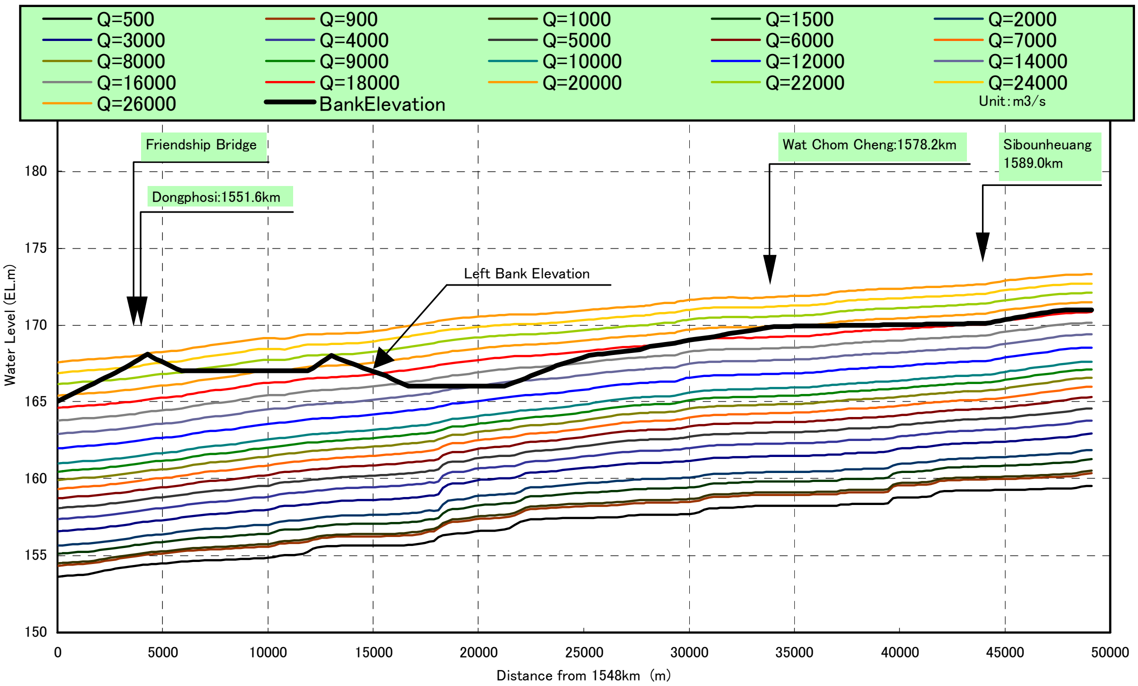


Figure 2.1.5 Left Bank Elevation and Result of Non-Uniform Flow Calculation from 1548km to 1593km

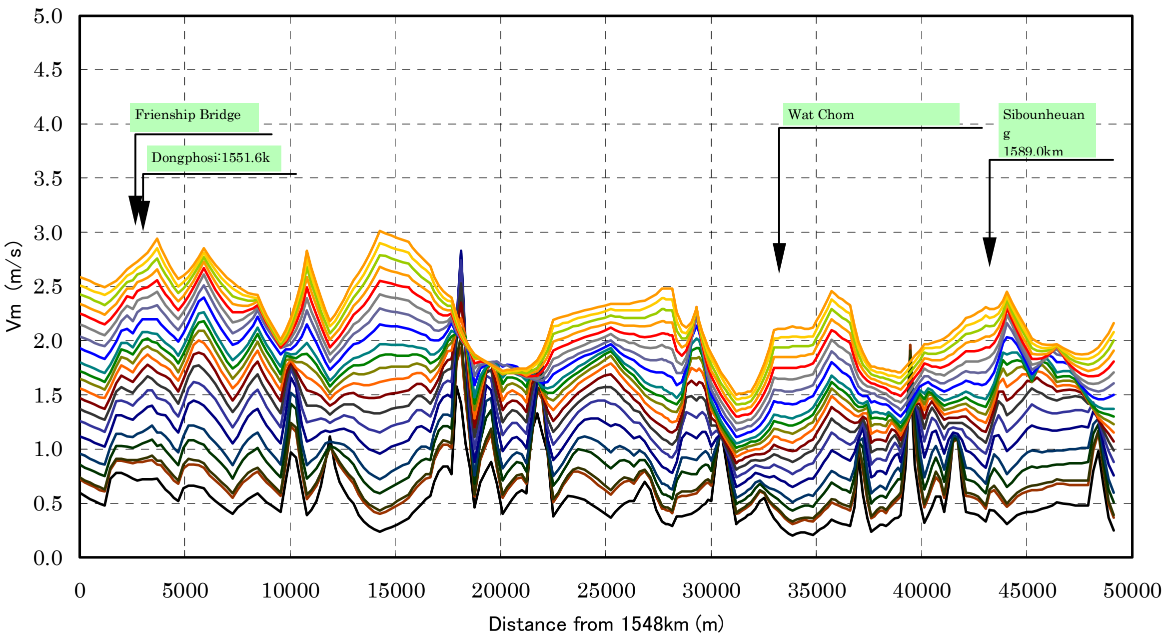


Figure 2.1.6 Longitudinal Distribution of the Section Average Velocity (Calculated)

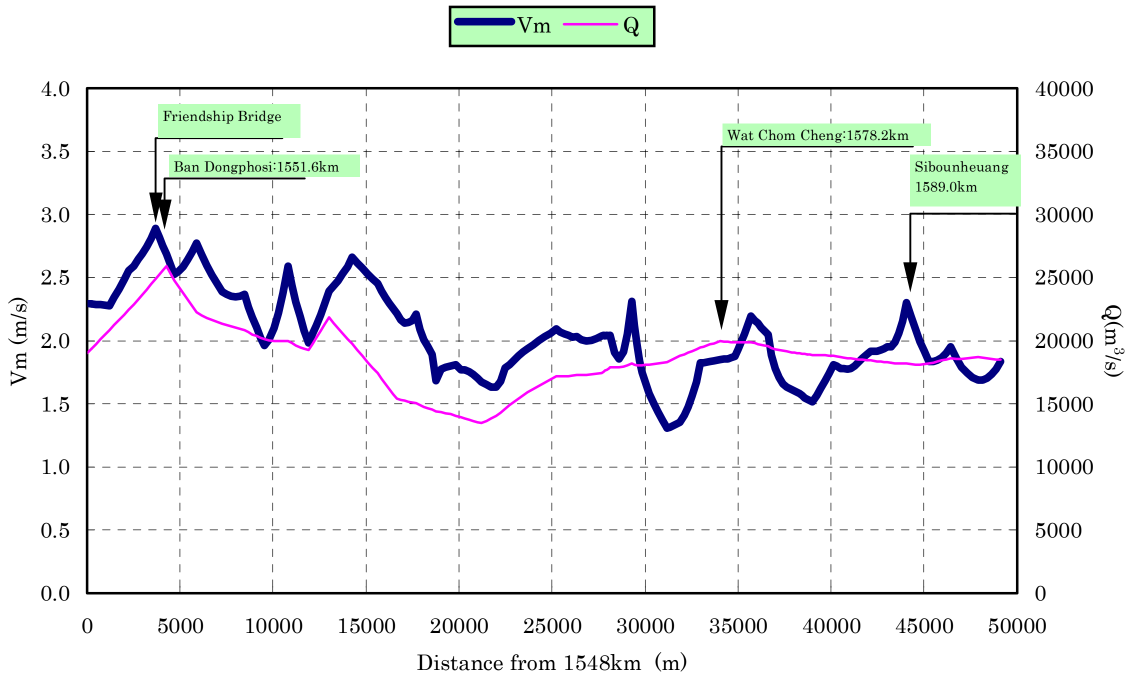


Figure 2.1.7 Estimated Discharge and Section Average Velocity when the Water Level is Equal to the Left Bank Elevation

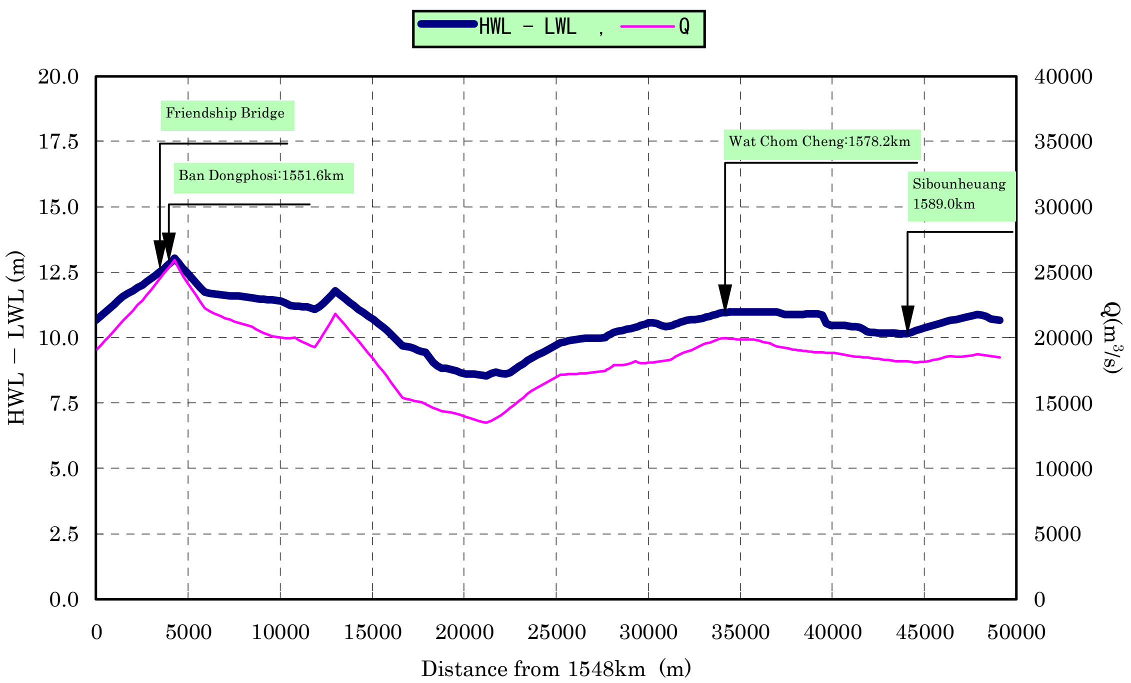


Figure 2.1.8 Estimated Discharge when the Water Level is Equal to the Left Bank Elevation and Assumed Design Water Depth

c) Radius of River Curvature and Channel Width

As shown in equation (2-1-3), correction factor α depends on radius of river curvature r and channel width.

Table 2.1.1 shows the radius of channel curvature at bending reaches of Mekong River derived from Figure 2.1.9, and channel width for bend based on the topographical map. In evaluating the channel width, the widths of islands and big bars have been excluded.

Additionally, the longitudinal distribution of above mentioned parameters are shown in Figure 2.1.10.

Table 2.1.1 Radius of Channel Curvature and Channel Width

Distance from river mouth (km)	Radius of channel curvature r (m)	Average Channel width B_m (Without islands and big bars) (m)
1,550 to 1,556	4,000	540
1,563 to 1,567	3,500	470
1,575 to 1,578	3,500	430
1,580 to 1,585	3,000	440
1,588 to 1,593	8,000	450

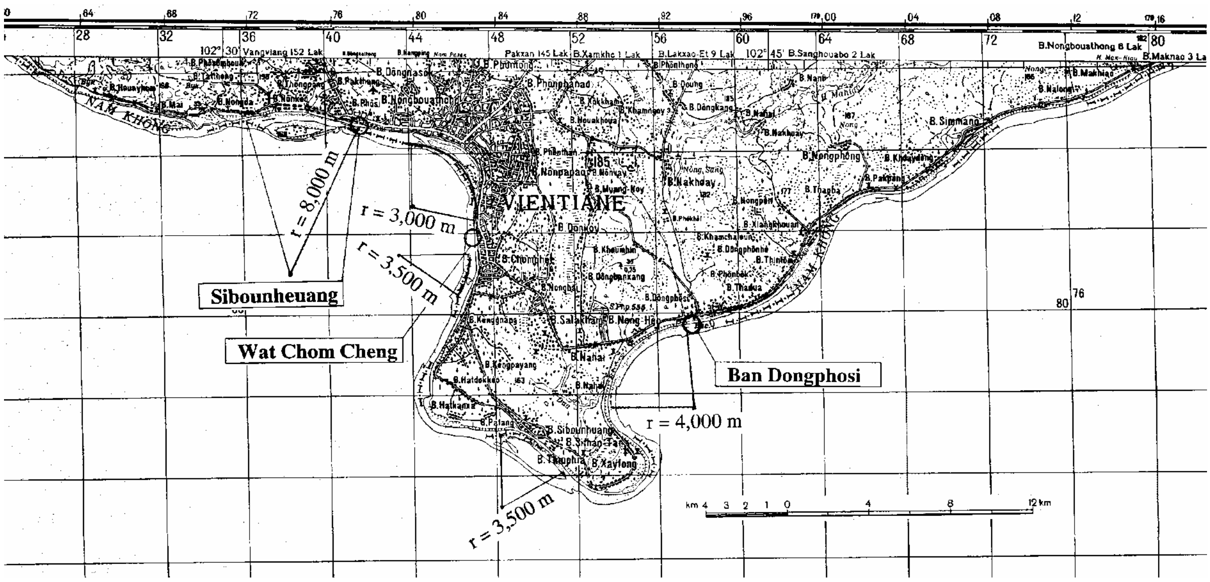


Figure 2.1.9 Evaluation of Radius of Channel Curvature (r)

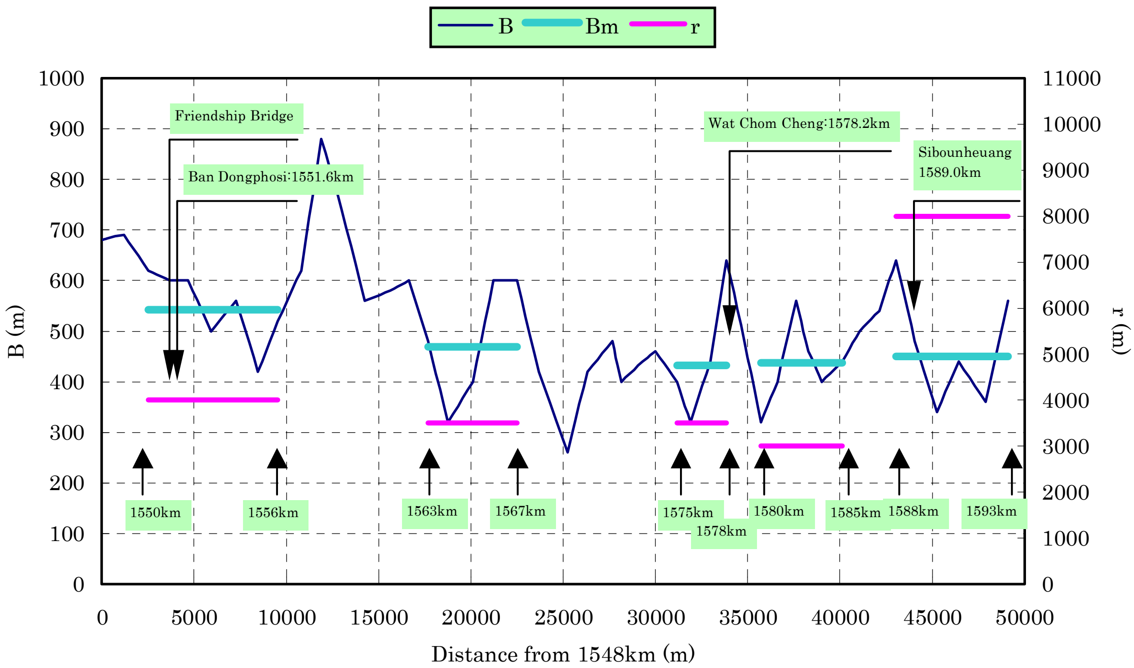


Figure 2.1.10 Radius of River Curvature (r) and Channel Width (B,B_m)

d) Range Of Design Velocity At Bending Reaches

With the above-mentioned values of hydraulic parameters (Figure 2.1.7 and Figure 2.1.10), using equation (2-1-3) for calculating α, ranges of design velocity at bending reaches are shown as Table 2.1.2.

Table 2.1.2 Range of Design Velocity at Bending Reaches

Distance from river mouth (km)	r (m)	B_m (m)	r/B_m	α	v_m (m/s)	v_0 (m/s)
1,550 to 1,556	4,000	540	7.4	1.29	1.96～2.89	2.53～3.73
1,563 to 1,567	3,500	470	7.4	1.29	1.63～2.21	2.10～2.85
1,575 to 1,578	3,500	430	8.1	1.28	1.31～1.84	1.68～2.36
1,580 to 1,585	3,000	440	6.8	1.31	1.52～2.19	1.99～2.87
1,588 to 1,593	8,000	450	17.8	1.13	1.69～2.30	1.91～2.60

2.2 Design of Riverbank Protection Work

2.2.1 General

Riverbank protection work is a revetment work for protecting riverbank and /or dyke.
In the course of designing riverbank protection work, the following items are to be studied:
- Reason of erosion of riverbank or near riverbank and scoring of riverbed.
- Mechanism of riverbank erosion
- Riverine environment / Nature-friendliness
- Easiness of construction work
- Economical view point
- Maintenance and repair

Additionally, not only to pay attention to materials for the bank protection work such as stone, wood, vegetation, but also to strength and durability against actual external forces are important.

Philosophy of design
- Using local construction material as much as possible.
- Construction work can be done by people of Lao P.D.R. as much as possible.
- To pay attention to keep riverine environment

In this context, this manual dose not deal with gabion-type riverbank protection work.
Location of the construction of revetments
It is generally economical to put priority on constructing revetments on the water impingement parts of the shoreline, but because changes in the river flow discharge are accompanied by a certain degree of change in the locations of the water impingement parts of the shoreline, it is necessary to make these decisions by thoroughly investigating the actual state of the shoreline on each river.
Generally, the larger a flood discharge, the water flows straighter and the water impingement part move downstream. And it is necessary to note that the water impingement part is moved by the installation of a revetment or groyne. Consequently, a method of determining an execution location that is often applied is to begin the execution from the water impingement part or other location susceptible to scouring or erosion, and at the same time, perform a monitoring survey of its effects on the scene, and gradually increase the number of locations with revetments, incorporating the monitoring results.

2.2.2 Structure of revetments

The general structures of revetments are shown in Figure 2.2.1, and consist of the following parts.

a) Slope covering work
b) Girdle work
c) Crown work
d) Crown protection work
e) End protection work
f) Slope-toe protection work (foundation work)

g) Foot protection work

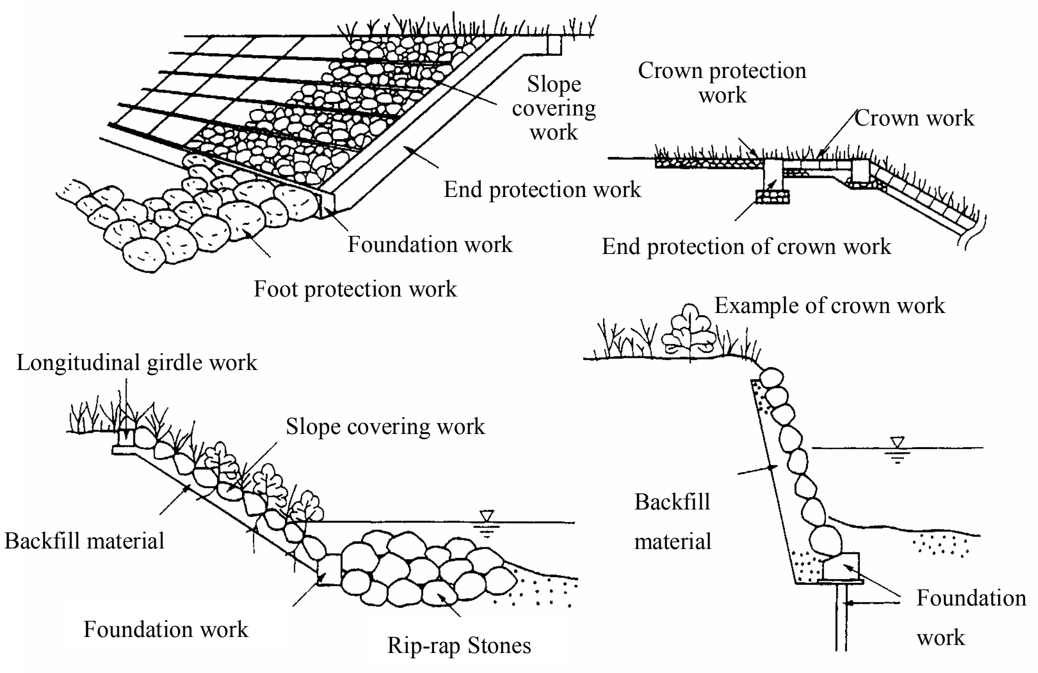


Figure 2.2.1 Structure of Revetments

2.2.3 Slope Protection Work

(1) Safety from Suction of the Back-fill Soil

On revetments in rivers where the recession speed is high during flooding, the residual pore water pressure when the water level is low results in backfill soil flowing from joints in the revetment, forming voids that eventually cause the slope covering work to fail.

The measure generally used to prevent this from happening is to place suction prevention material behind the slope covering work

(2) Safety from Failure caused by Soil Pressure and Water Pressure acting from behind the Revetment

A revetment is subjected to heavy load from behind that includes the residual pore water pressure, in addition to the pressure of the soil behind it. It is necessary to consider these points when designing a particularly steeply graded revetment.

(3) Safety from Failure of the Slope Covering Surface caused by Flowing Water

Slope covering work is subjected primarily to the action of drag force and lift force from flowing water on uneven parts of its front surface, but its self-weight resists these fluid forces. But if the fluid forces are dominant, it will fail. This is a serious problem in rivers where the current is particularly fast, and if it is made of stones or concrete blocks, these must be sufficiently heavy.

(4) Safety from Failure caused by a Gap at the Upstream End

The ends of revetments are often scoured (particularly the downstream end), and in some cases this causes suction of the soil behind the revetment, resulting in its failure. End protection work should be installed by using such as rip-rap arrangement to prevent this.

(5) Safety from Scouring from the Shoulder of the Revetment

If the alignment of a water revetment is curved, the shoulder of the revetment is often scoured by flowing water impacting it directly during large floods. As a countermeasure to prevent this, it is necessary to construct a horizontal folding (crown work) with width between 1 m and 2 m on the crown of the revetment and to put end concrete at the end of the folding as shown in Fig. 2.2.2 (end concrete: on large rivers from 1 m to 1.5 m, and on medium and small rivers, from 0.5 m to 1.0 m). If it is necessary to provide even wider protection, wired mat work, linked blocks, etc. are often used (crown protection work).

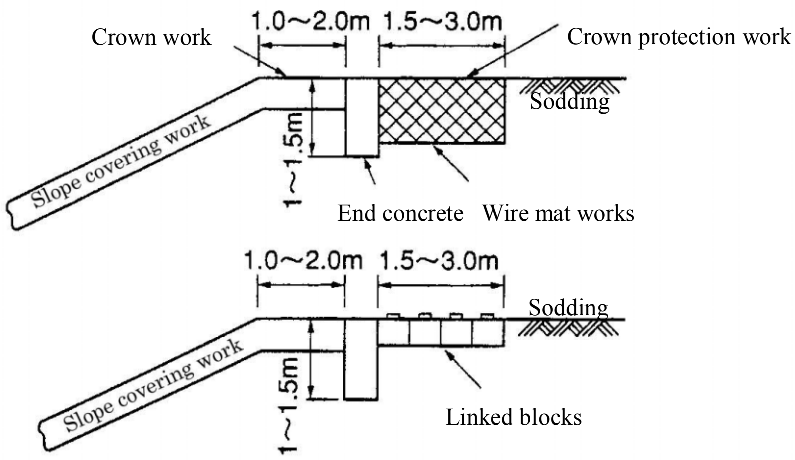


Figure 2.2.2 Crown Work of Revetments

(6) Safety from Failure at a Point of Change of the Revetment Structure

Because the part of a continuous revetment near a point where the work method or the slope gradient changes sharply or the foot protection work is discontinued is a weak section, these abrupt changes are generally to be avoided. When a change in structure on a continuous revetment is unavoidable, it is necessary to change the structure gradually to avoid an abrupt change.

(7) Concern for the Natural Environment

Many revetments are constructed at the shoreline that is a particularly important part of a riverine environment, and at the same time as they protect the riverbank, they must also conserve the ecosystem and scenery at the site. A structure on the shoreline should be as varied as possible and be porous enough in order to conserve a biologically diverse environment. Materials such as rocks (dry pitching and dry masonry work), wood, vegetation, and similar materials are highly suitable as materials for a revetment that protects the environment.

But to design a revetment with such new functions it is necessary to fully study its durability, and perform studies to make sure that it protects the dike or river bank from erosion, and that it is safe from flowing water. It is also important to design it so it is a structure adaptable to long term changes in the river course without imprudently providing excessive allowance for durability and safety, and accounting for the fact that its role as a revetment is, along with the high water channel and groynes, to protect the dike.

(8) Cobble Stone with Willow Branch Work

An example of slope protection work is Cobble Stone with Willow Branch Work.

a) Structure of Cobble Stone with Willow Branch Work
The structure consists of Siki-Soda on the slope of earth embankment, tie-twig hurdle work on them, made of willow branch, covered by pebble stone and sand with willow plantation on them as shown in Figure 2.2.3. After growing up of the willow trees, they give moderate roughness to the flow and act as resistance to protect the structure. Over growing of the willow trees should be stopped by regular cutting maintenance work. Vegetation bank will be realized, to have good environmental aspect. Mild slope river would be preferable for this work, with necessary attention of stability of the slope. This work will be vital for the site, where willow branches and Soda materials and stone material can be obtained easily and economically.

b) Filling Stone
Filling stone for the Cobble Stone with Willow Branch Work is decided according to the following relations, considering tractive force of water not exceeding the critical tractive force:

$$\tau *sd = \tau *d \cdot \cos(1-\tan^2\theta/\tan^2\Phi)^{(1/2)}$$

where; $\tau *d$: Non-dimensional shear force (=0.05 based on Shield's experiment)

$\tau *sd = u*^2/(sgD)$

$u* = Vo/\phi$

$\phi = 6.0 + 5.75 Log_{10}(Hd/ks)$

Φ : Internal critical angel of submerged stone =38° for natural stone, =41° for crushed stone

From those relations, we get:

$$D \geqq Vo^2/((6.0 + 5.75\text{Log}_{10}(H_d/k_s))^2 \cdot \tau{*}sd \cdot s\ g)$$

Assuming $k_s \fallingdotseq D$, and H_d is taken as design water depth, necessary stone size for rip-rap is obtained as shown in Figure 2.2.4. Actual stone size should be 1.3 to 1.5 times of the critical size of stone, considering the incompatibility of stone arrangement and any undulation of the surface might be weak against strong velocity.

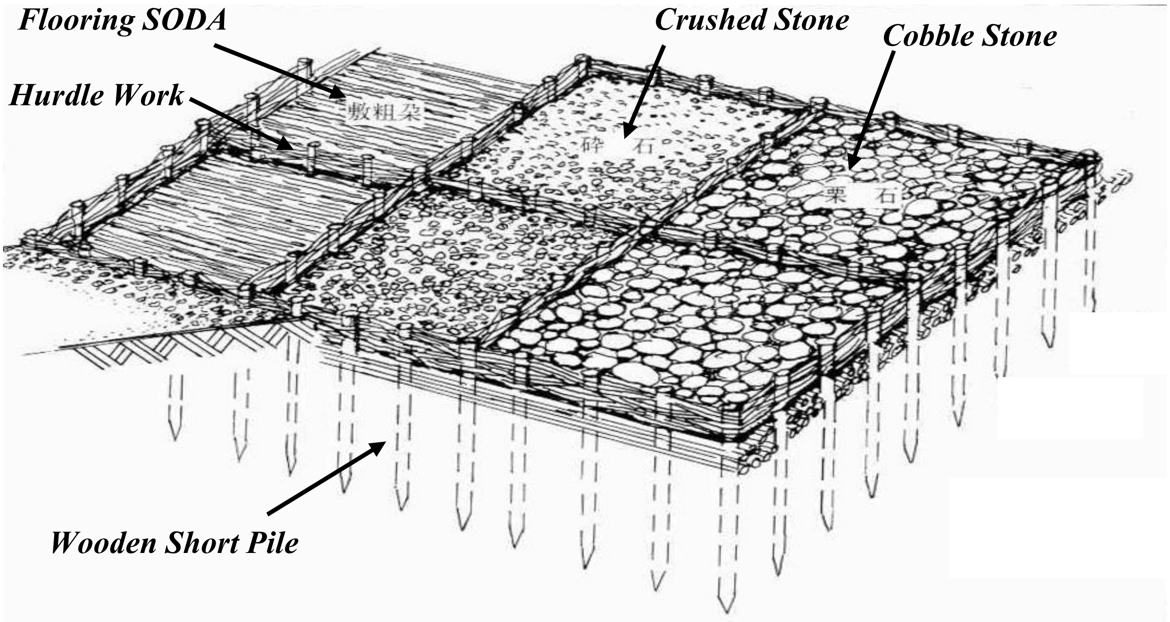


Figure 2.2.3 Structure of Cobble Stone with Willow Branch Work

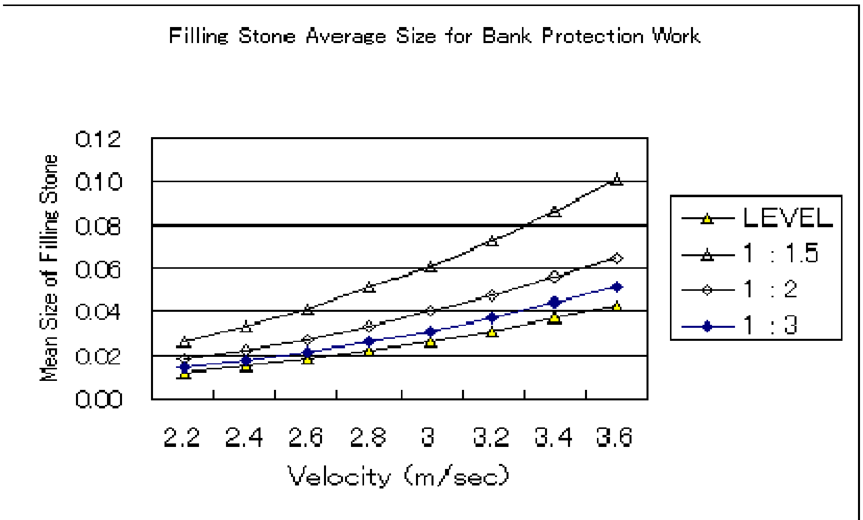


Figure 2.2.4 Stone Size for Bank Protection Work

(9) Vertical Extent of Riverbank Slope Protection Work

As often seen along Mekong Riverbank around Vientiane Municipality, the riverbank shows high vertical cliff. The height of steep natural slope is considered to depend on the soil characteristics of the layer(s) as cohesiveness, internal friction angle and unit weight.

In case of relatively large steep cliff part of riverbank with less dense properties behind it, the riverbank erosion progression could be reduced by stabilizing the lower half part of the cliff with the assist of vegetation expand on the natural riverbank slope on the upper part of the cliff. This trial, therefore, could reduce cost of the riverbank protection work and is considered as one of method adaptable along Mekong River around Vientiane Municipality.

Monitoring of the riverbank change after construction of riverbank protection work is necessary to assure and enhance the design procedure and for maintenance / repair if necessary by feeding back the result of monitoring in the design procedure.

2.2.4 Foundation Work

(1) Making the Foundation Safe from Scouring

The failure of revetments is often caused by scouring of the foundation, so designing a foundation safe from scouring is the most important consideration in revetment design. If scouring of the riverbed at the front surface of a revetment foundation reaches a depth greater than the height of the crown of the foundation work, the foundation rises above the riverbed, resulting in the failure of the unsupported slope covering. To prevent this, it is important to embed the foundation adequately, and as necessary, to take foot protections measures.

The general method of setting the height of a foundation is to consider the temporary scouring during high water of the planned riverbed set in advance in the river course plan.

(2) Rip-rap Foundation Work

a) Rip-rap

Rip-rap size is decided by applying the formula as below:

$D = K \cdot Dm$

Where,

$K = 1/〔\cos\theta\,(1-\tan^2\theta/\tan^2\Phi)^{1/2}〕$

Dm : Minimum average size of rip-rap stone for a horizontal slope of rip-rap work.

$= 1/〔E_1{}^2 \cdot 2g(\rho s/\rho -1)〕\cdot Vo^2$

Vo: Velocity (m/sec)

ρs : Density of stone

ρ : Density of water

θ : Slope of protection work

Φ : Friction angle of submerged stone

E_1 : Coefficient(≒1.2)

Relation between velocity and stone size is as shown in Figure 2.2.5.

Actual stone size should be 1.3 to 1.5 times of the critical size of stone, considering the incompatibility of stone arrangement and any undulation of the surface might be weak against strong velocity

b) Minimum Width of Rip-rap

Minimum width of rip-rap is obtained by the following formula:

$Bsmin = Zs / \sin\Phi s$

Where; Bs : Minimum width of rip-rap

Zs : Height of rip-rap work above assumed locally scored river bed.

Φs : Critical internal angle of rip-rap stone in water

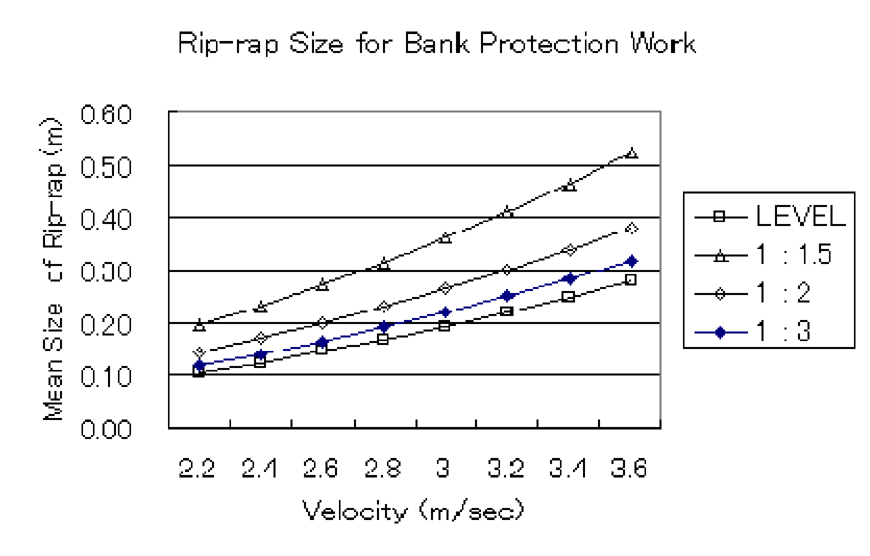


Figure 2.2.5 Rip-rap Stone Size for Bank Protection Work

(3) Log Hurdle Work

Log hurdle work is a kind of hurdle work using wooden log pile and filling stones for a foundation work of revetment structure. The wooden pile appears on the ground is approximately 1m. The log hurdle work is suitable for not only mild slope river but also for the relatively steep river.

Generally, wooden logs are tied by lateral wooden beam fixed by bolts. Parent wooden log piles are arranged in every 2m, and in between them, shorter and thinner wooden piles are arranged vertically and tied with tie-beam as shown in Figure 2.2.6. After setting flooring SODA and vertical SODA, crushed stone/filling stone is filled behind the wooden hurdle work.

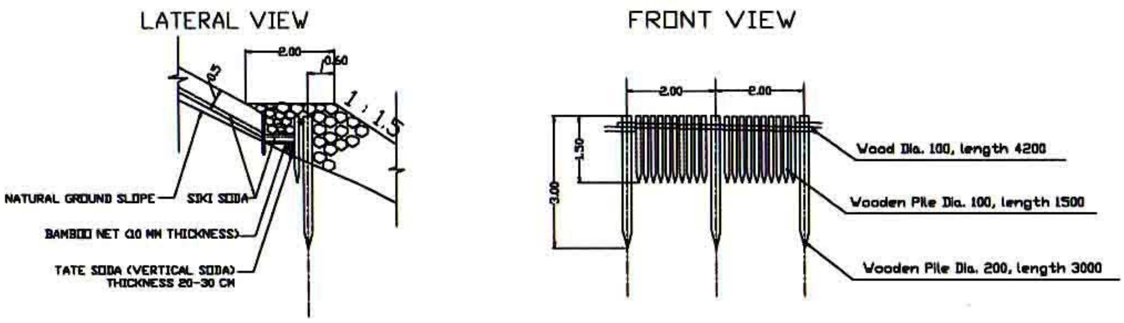


Figure 2.2.6 Structure of Log Hurdle Work

2.2.5 Foot Protection Work

(1) Fundamentals of Foot Protection Work

<u>Necessity of Foot Protection Work</u>

Foot protection work is necessary to resist against erosion and the riverbed decrease at the tip of the foundation work. Riverbed of Mekong River around Vientiane Municipality has a seasonal variation. An example is as shown in Figure 2.2.7, in which the range of riverbed variation attains approximately 4 to 5m.

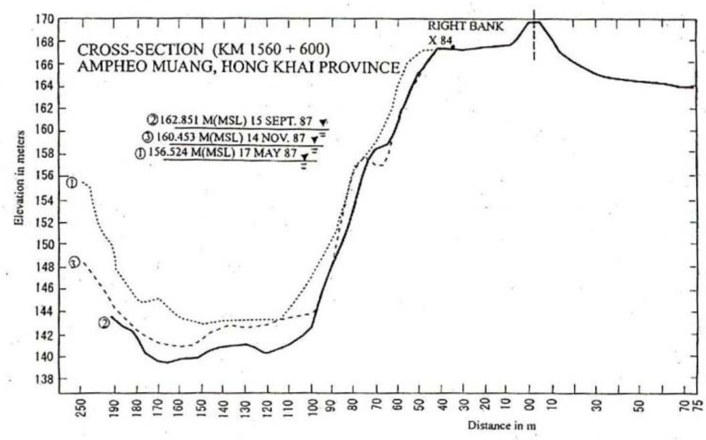


Figure 2.2.7 Sample of Seasonable Variation of Mekong Riverbed (*)

Foot protection work is installed in front of slope-toe work (foundation work); to prevent riverbed scouring, mitigate the flow velocity in front of the revetment, and to protect the slope-toe work and slope covering work.

The following basic points guide its installation.

1) It is constructed at low position accounting for scouring during flood periods and the future degradation of the riverbed.
2) It has flexibility and width sufficient for it to bend accompanying scouring occurring in front of it.
3) It has sufficient weight and strength as a continuous body to permit it to resist the maximum flow velocity and rolling rocks.
4) It prevents suction of the soil beneath.
5) It has long durability.
6) It has roughness suitable for foot protection so that it restricts the flow velocity near the revetment.
7) The space between the foot protection work and the slope-toe work is completely filled with pebbles etc. to keep out the flowing water.

(2) Selection of Foot Protection Work Method

The foot protection work method is selected by comprehensively judging the following points.

1) River course characteristics
2) The natural environment and the surrounding environment
3) Continuity of construction methods with adjoining structures
4) Cost and ease of execution

(3) Types of Foot Protection Work and Their Characteristics

1) Wooden foot protection works

Fascine mattresses are often constructed on gently flowing rivers and wooden mattresses on fast flowing rivers. They must be constructed to prevent suction.

a) SODA mattress and single layer SODA mattress

A SODA mattress consists of a spread SODA (fascine), hurdle work made mainly of Tie-Twig (flexible SODA), wooden short piles and ballast stones as shown in Figure 2.2.8, and it is a type of foot protection work used mainly on gently flowing rivers.

Because SODA mattresses are flexible, they adapt well to sandy riverbeds, effectively preventing suction of the sand by the flowing water. They are used primarily on gently flowing rivers with a riverbed gradient less than 1/2,000.

A single layer SODA mattress as shown in Figure 2.2.9 is either used as foot protection work at locations where the water is slightly shallow, or it is spread under SODA mattresses.

b) Wooden frame mattress

A wooden frame mattress is made by filling the spaces between logs assembled to form a curb-shaped frame with pebbles and rubble as shown in Figure 2.2.10. It is primarily used as foot protection or as groynes at locations where a fascine mattress would be unable to resist the tractive force in the middle reaches of rivers and where rubble for use as fill is available. It is porous and it is suitable as a habitat space for fish and other aquatic life.

2) Stone type foot protection work

Stones are the strongest of all natural materials, and foot protection work made of stones has been used often since ancient times.

Large stones are placed on the front surface. And particularly large stones should be lined up at the toe of the slope. And to prevent suction, the grain diameter should be a mixture of large and small grain diameter material.

(*):Interim Committee for Coordination of Investigations of the Lower Mekong Basin (Lao People's Democratic Republic, Kingdom of Thailand and Socialist Republic of Vietnam), Pilot Project Stage I of Mekong River Bank Protection (Basin-Wide), MKG/R.88032, May 1988.

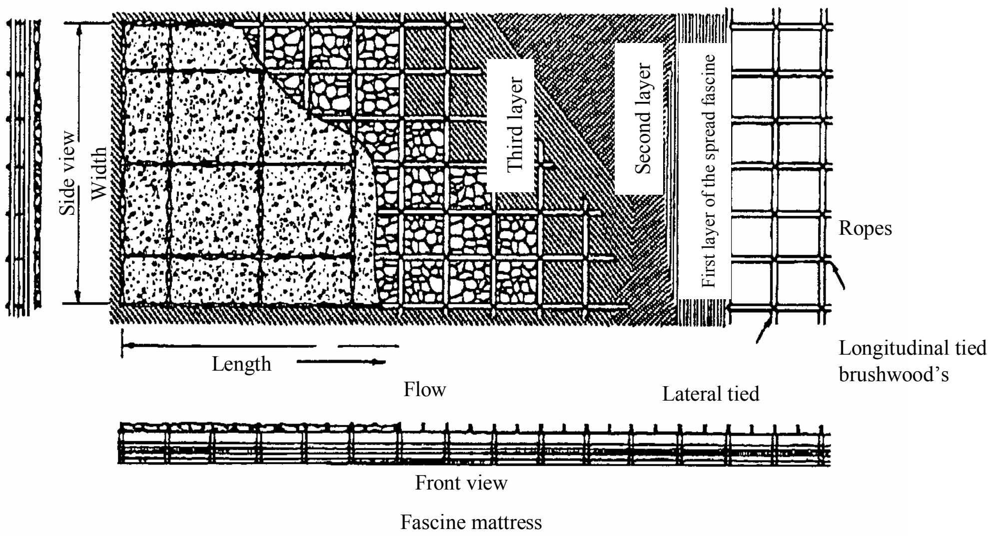


Figure 2.2.8 Soda Mattress

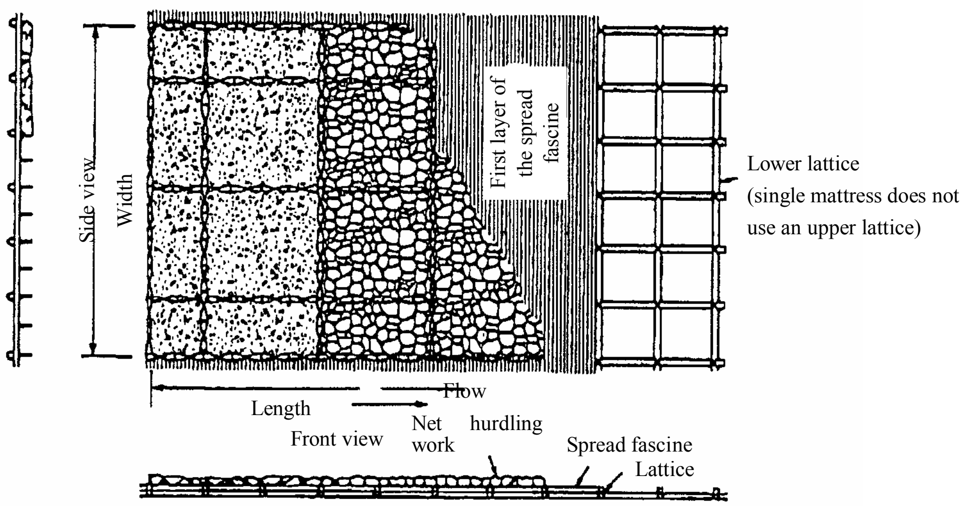


Figure 2.2.9 Single Layer Soda Mattress

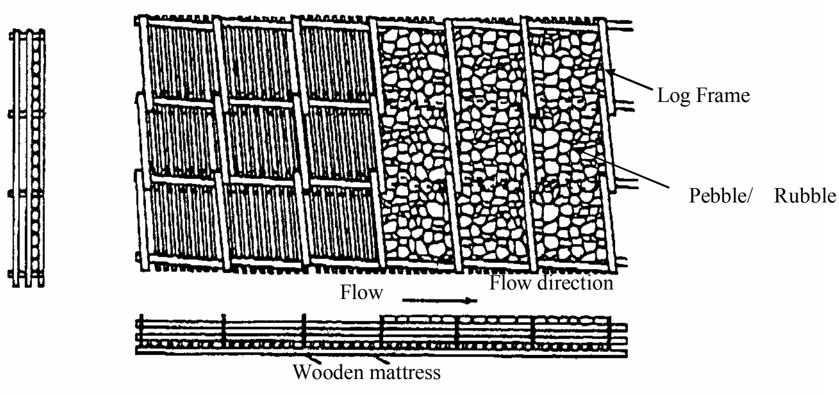


Figure 2.2.10 Wooden Frame Mattress

2.2.6 Groyne Work

(1) Outline of groynes

1) Purpose and function

The purpose of a groyne is to protect dikes or riverbanks from the direct attack of the river flow by reducing the flow velocity and changing the flow direction.

Functions of the groyne are as below:

- Reducing the flow velocity by increasing resistance to the flow (flow velocity reduction action).
- Blocking the flowing water to change its direction so that it does not impact the location that should be protected (water blocking action).

As a result of these actions, the groyne has the following effects:

- Fixing the channel
- Inducing sedimentation
- Guiding the current

2) Types of groynes

Groynes are categorized as shown in Figure 2.2.11 according to the functions and effects of each type. Examples of groynes are as shown in Figure 2.2.12.

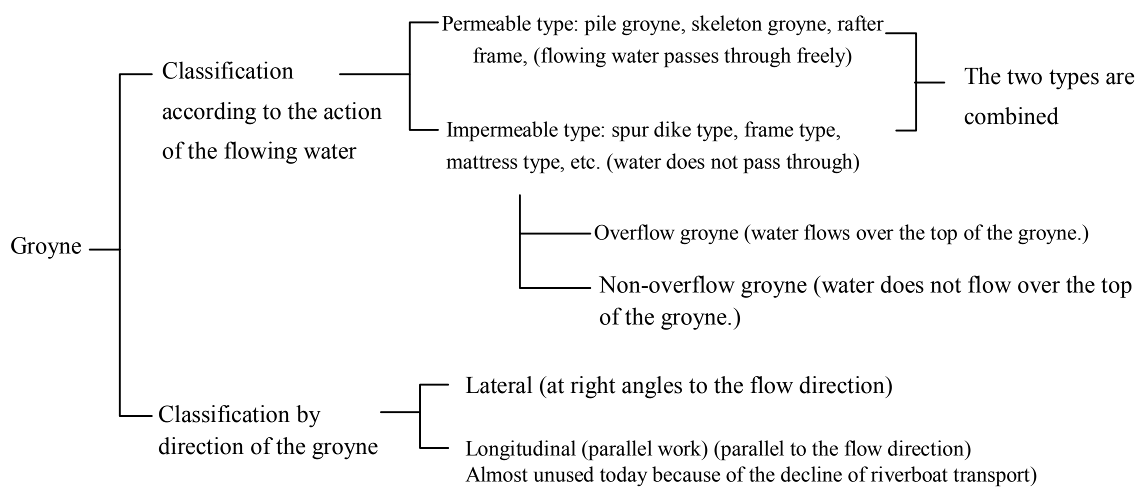
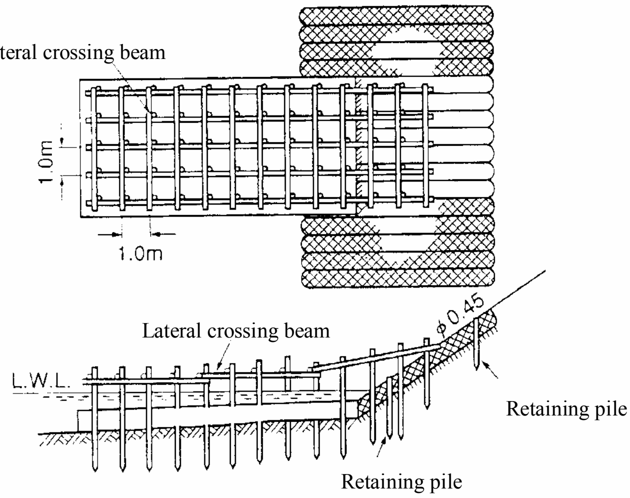
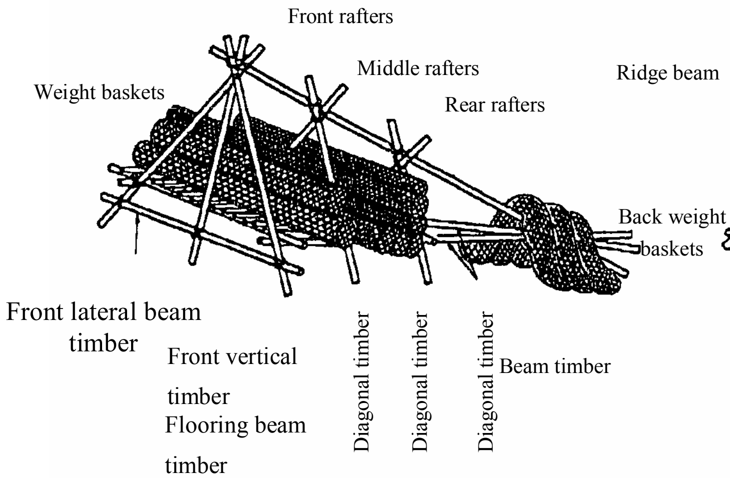


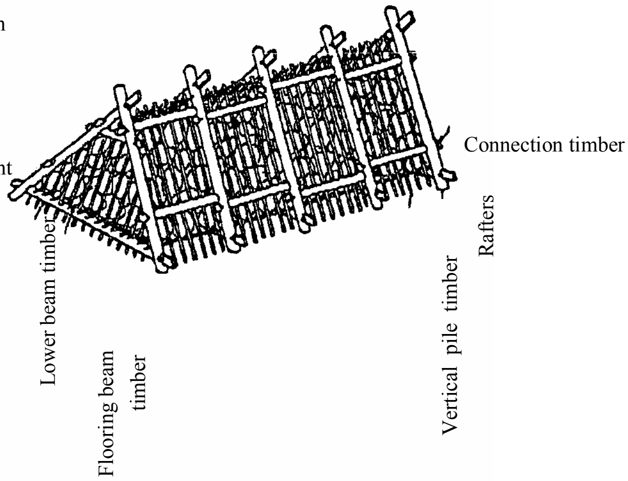
Figure 2.2.11 Types of Groynes



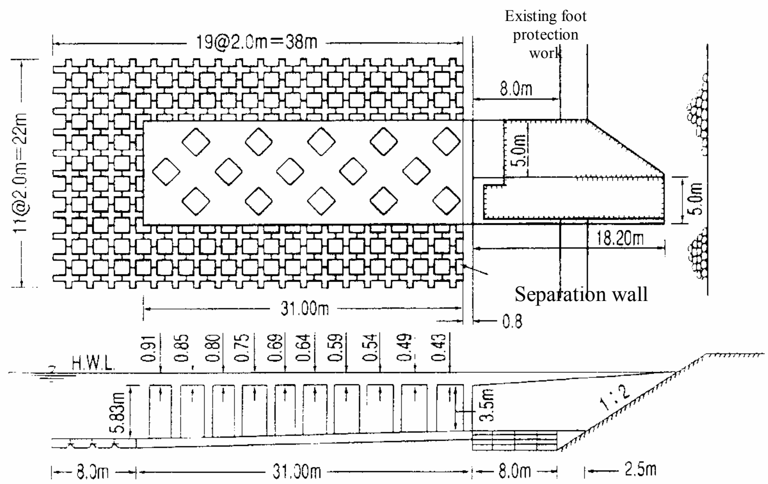
(a) Pile groyne



(b) Typical skeleton work



(c) Typical crib work



(d) Concrete block groyne

Figure 2.2.12 Examples of Typical Groynes

3) Groyne dimensions

a) Direction of groynes

The direction of each groyne should be set according to the purpose of its construction and river conditions as shown in Figure 2.2.13, but they are generally at right angles to the current or angled in the upstream direction. The upstream angle of most channel use groynes or foot protection groynes is between 10° and 15°.

Because floodwaters overflow most foot protection groynes during flood periods, angling the groyne downstream is avoided in order to prevent the overflowing waters from impacting on the bottom of the dike.

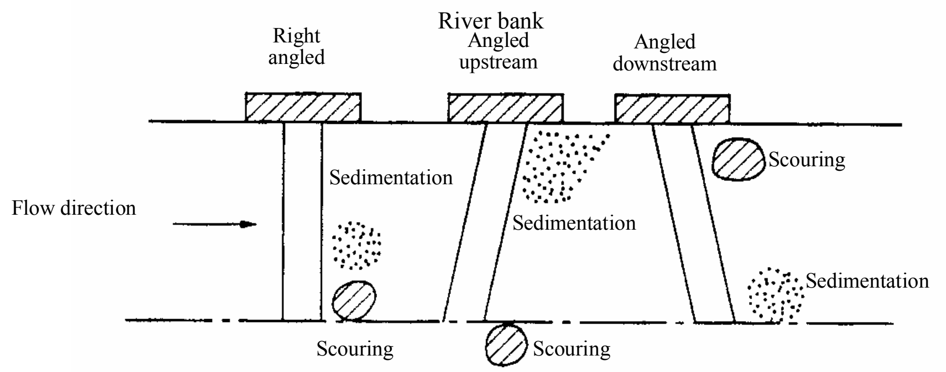


Figure 2.2.13 Relationship of Groyne Direction with Scouring and Sedimentation

b) Installation height of groynes

The height of existing groynes ranges from those as low as 60 cm to those as high as 5 m. Based on a survey of the relationship of the water depth during flooding (*H*: for convenience, water depth at the planned high water level) with the groyne height (h_g), values of (h_g/H) are between 0.1 and 0.4 at more than half, and between 0.3 and 0.4 in most cases.

c) Relationship of groyne length and interval

According to the relationship of groyne length (*L*) with river width (*B*) based on existing facilities, values of *L*/*B* are less 10% in almost all cases, and rarely higher than 25%. The reason for this result is that if it is too short, it will not provide groyne effects, and if it is too long, it will unavoidably affect the opposite bank. The ratio of the groyne interval (*D*) to groyne length (*L*) is an average of 3. The interval is established so that it will be about 3 times the length.

Hydraulic model tests have confirmed that the stream line of the current that has passed the tip of a groyne is displaced by an angle of incidence of about 6° from the main stream line. The streamline of the displaced current reaches the riverbank after moving about 9.5 times the groyne length *L*. Consequently, to prevent scouring at the revetment foundation by the displaced current, the length and interval should be determined so that the displaced current intersects the axis of the groyne at a point about one-third of its length *L* from the riverbank as shown in Figure 2.2.14.

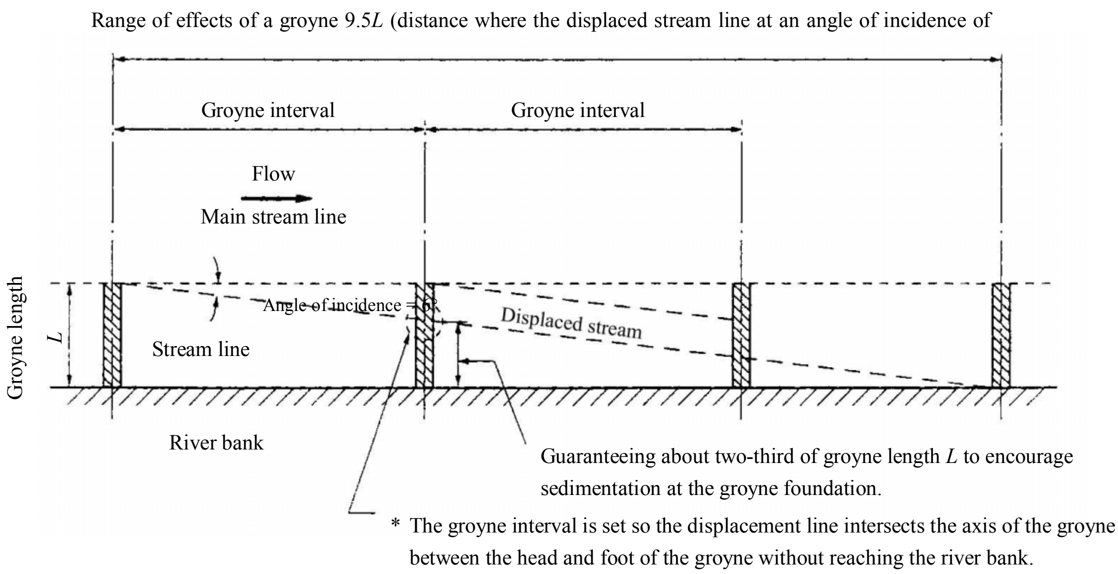


Figure 2.2.14 Groyne Length and Installation Interval

(2) Groyne design

1) Design concept

A groyne is designed to conform with the purpose of its construction and to act as one body with a revetment or similar structure with the high water channel to protect the dike from the action of flowing water below the planned high water level (on an artificially excavated river, safely protect the protected area). It must be designed with reference to past work in similar rivers and nearby sections accounting for various factors such as the characteristics of the river, external force conditions, flood characteristics etc. at the installation location.

2) Attentions to design

Design of a groyne by applying theoretical interpretations is even more difficult than it is in the case of a revetment, because it is difficult to accurately predict the characteristics of the river channel that changes sharply (riverbed height and flow speed during flood periods), and it is even more difficult to predict these factors because installing a groyne will change them.

To design groynes more rationally, it is necessary to carry out full studies, paying attention to the following items, and carry out improvements in accord with post execution conditions through monitoring work with feedbacks to the former design.

a) Local scouring around the groyne
b) Flow velocity reduction effects of the groyne
c) Sedimentation conditions inside the groyne area
d) Critical velocity for movement of the groyne material
e) Groyne work and the riverbank alignment

2.3 Monitoring

Design of riverbank protection works are described in the former sections based on assumptions of the riverbank erosion mechanism.

The assumption on the riverbank erosion mechanism and the design method based on it are to be revised through the monitoring of the riverbank protection works and riverbank condition around them after implementation. The monitoring result is used to feed back to the assumption of riverbank erosion mechanism to enhance the design method that is optimum for the location. The flow chart of the design procedure of riverbank protection work is as shown in Figure 2.3.1.

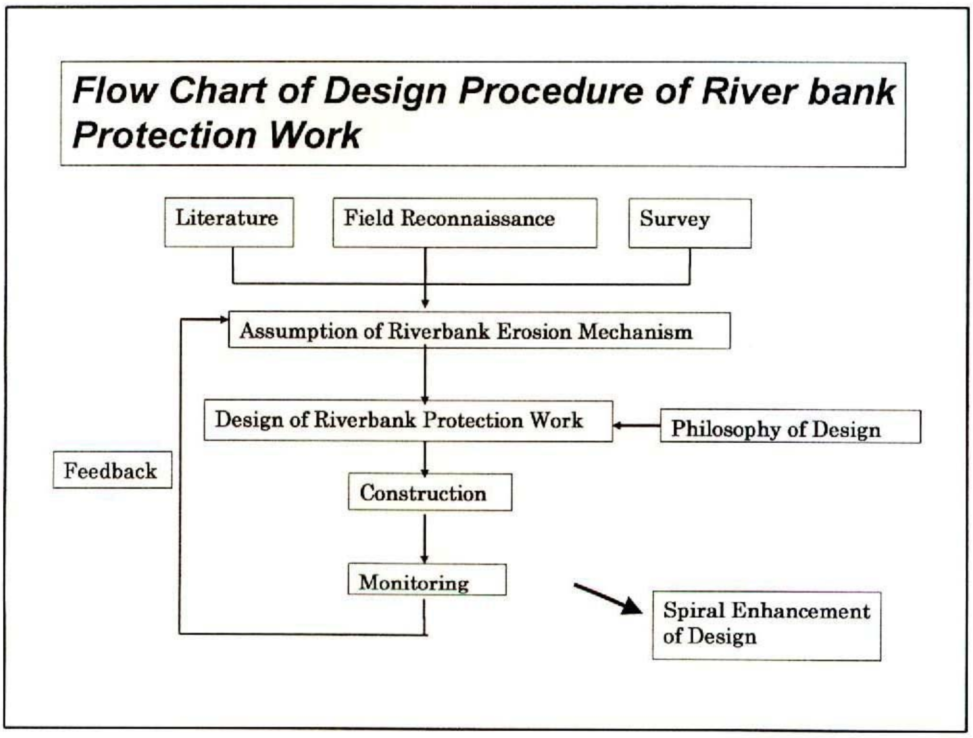


Figure 2.3.1 Flow Chart of Design Procedure of River Bank Protection Work

Items of monitoring are topography, change of river current condition, any slope change of the riverbank protection work, vegetation condition, etc. Example check list of the monitoring is as shown in Table 2.3.1.

Table 2.3.1 List of Monitoring Items (Sample)

Verification Item	Monitoring Item	Method
Cobble Stone with Willow Branch Work	/Deformation /Loss of Cobble Stone /Vegetation situation /Sedimentation	/Visual inspection /Photograph from the fixed point
Rip-rap Foundation Work	/Deformation /Loss of rip-rap stones /Vegetation/Sedimentation	/Visual inspection /Photograph from the fixed point
SODA Mattress	/Deformation/Loss of element/Loss of Stones	/Visual inspection /Photograph from the fixed point
Wooden Groyne	/Deformation/Inclination /Loss of wooden pile /Sedimentation between rows of gyone	/Visual inspection /Photograph from the fixed point
Natural riverbank slope	(Riverbed Protection Part) /Collapse /Development of Gully /Slide Down (Around riverbank protection work) /Riverbank erosion /Collapse /Slide down /Sedimentation /Vegetation situation	/Visual /inspection/Photograph /from fixed point /Topographic survey /Bathymetric survey
Hydraulic Condition	/Water Level /Current speed/Direction /Flow condition	/Water gauge /Current meter /Sketch/Photograph with tracer in the flow

Table 2.3.2 Monitoring Check List (Sample)

Location: xxxxxxxx

(Date: 200x/xx/xx, Inspector: xxxxxx)

Monitoring Item	Check Item	Judgment	Remarks
Natural Riverbank	Collapse of slope	☐Yes ☐No ☐NA	
	Riverbank erosion	☐Yes ☐No ☐NA	
	Seepage	☐Yes ☐No ☐NA	
	Vegetation progress	☐Yes ☐No ☐NA	
	Any other phenomena	☐Yes ☐No ☐NA	
Cobble Stone with Willow Branch Work	Deformation of slope	☐Yes ☐No ☐NA	
	Loss of Cobble Stones	☐Yes ☐No ☐NA	
	Damage of Wooden Material	☐Yes ☐No ☐NA	
	Vegetation progress	☐Yes ☐No ☐NA	
	Sedimentation Progress	☐Yes ☐No ☐NA	
	Any other phenomena	☐Yes ☐No ☐NA	
SODA Mattress	Deformation	☐Yes ☐No ☐NA	
	Loss of Rip-rap Stones	☐Yes ☐No ☐NA	
	Damage of Wooden Material	☐Yes ☐No ☐NA	
	Sedimentation Progress	☐Yes ☐No ☐NA	
	Any other phenomena	☐Yes ☐No ☐NA	
Wooden Pile Groyne	Deformation/Inclination	☐Yes ☐No ☐NA	
	Loss of Wooden Pile	☐Yes ☐No ☐NA	
	Any other phenomena	☐Yes ☐No ☐NA	
Rip-rap Foundation Work	Deformation	☐Yes ☐No ☐NA	
	Loss of Rip-rap Stones	☐Yes ☐No ☐NA	
	Sedimentation Progress	☐Yes ☐No ☐NA	
	Any other phenomena	☐Yes ☐No ☐NA	