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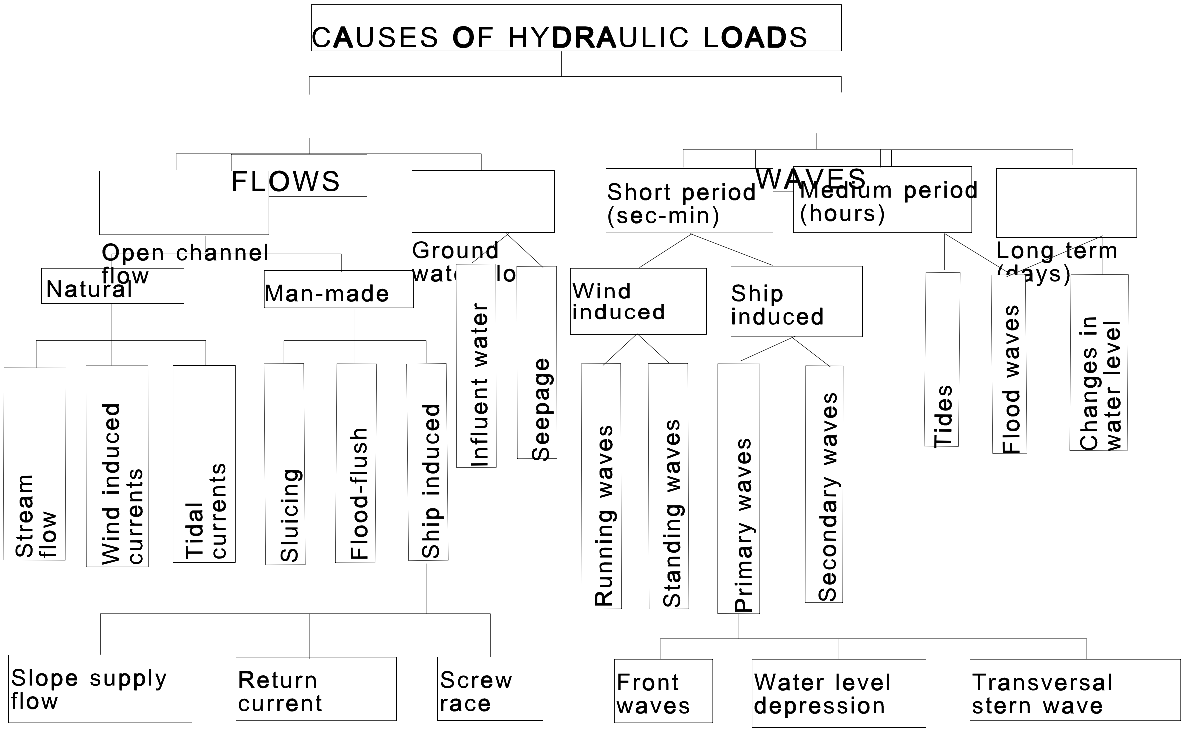
Chapter 1
Introduction

1.1) Background



Waterways either as nature or man made have been used as a means of transportation. Inland navigation, as an example, is increasingly utilized. Banks of waterways, which generally consist of easily erodible materials, are threatened by currents and waves. Figure-1/1 shows main causes of hydraulic loads.

FIGURE-1/1: Main causes of hydraulic loads

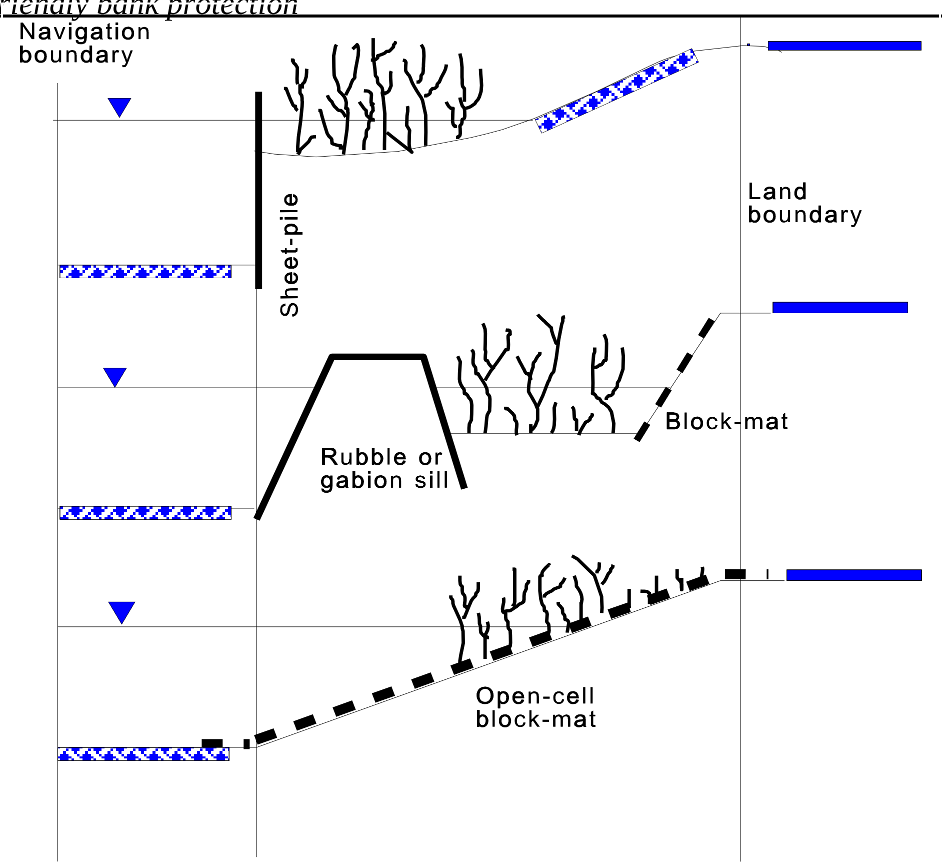
Traditional solutions for bank protection with either rigid or flexible structures are normally practiced. Rigid revetments are made of concrete, cement mortar, stones with mortar, brick work and sheet piles. Flexible revetments are made out of riprap (loose, bound or grouted stones), concrete blocks, fabric mattresses and gabions. In term of bank protection, if properly designed, these “hard” solutions function well. However, such strong protections introduce an abrupt interface between land and water which gives little or no ecological values: loss of vegetation, feeding and spawning grounds.

Instead, banks are transition zones with large variation in exposure, substrate and physical processes. Gradients and border environments are generally rich in natural values. Every reach of the river has its own environmental features with corresponding flora and fauna communities.

Common procedure with hard barrier hinders vegetation, diminishes natural gradients which causes a substantial loss of habitats and degrades its ecosystem. Sustain ability and multi-functionality are keywords for a new approach. Banks are no longer considered as a well defined sharp transition of land and water, but as an integral part of a water system. This leads to the need for a solution of environment-friendly bank protection which not only provides a protective function but also offers a room for nature development as well.

In the Netherlands, the environment-friendly banks have been growing in awareness since 1985. In 1989, this new approach was expressed in the Dutch National Policy Document on Water management. Since then, much research in various related aspects have been carried out, for example :

- Reed as bank protection. Damping of wave attack (1989)



- Influence of soil type on erosion through cellular blocks (1989)
- Prototype inventorization on growth of vegetation in open block-mats (1990)
- Guidelines for vegetation for river dikes (1991)
- Conceptual model on erosion rate of unprotected banks along navigation waterways (1991)

To realize the new approach, not only various materials and solutions need to be investigated but also the scheme for design, construction and management of structures are required. Boeters et al., (1994) provided such a systematic set-up whereby the input of experts in different disciplines with conflicting interests can be achieved.

Some design options for soft bank protection which have been studied and implemented in the Netherlands are :

- construction of longitudinal dikes or fore-shore protections,
- sand or gravel suppletion, and
- vegetation as bank protection such as reed, bulrush and willow.

Figure-1/2 shows some examples of environment-friendly solutions for restricted waterways.

FIGURE-1/2: Examples of environment-friendly banks for restricted waterways

1.2 Statement of the problem

Using vegetation as bank protection provides one of the ecological sound bank protections. Research in this area is very much site specific in term of type of plants and surrounding growing environment. For Dutch waterways, natural vegetation such as reed, bulrush and willow have been studied quite extensively in many aspects, for instance :

- flow velocity in reed stand
- plants penetration ability through geotextiles
- damping and soil stabilization of reed zone plants (reed, bulrush and willow)

Further design formulae and related tests for Dutch vegetation can be referred to references no.4, no.5 and no.10.

Unlike Dutch vegetation, in tropical countries, Thailand for instance, mangrove forests are common and can be found along tidal coasts and further inland lining banks of waterways. Using local mangrove vegetations as natural bank protection is one of a logical solutions. By considering banks as an integral part of a waterway system, the interaction between vegetation and hydraulic loads along this dynamic interface has several effects upon mangrove ecosystem, for example :

- sedimentation process related to wave and current fields
- zonation of micro faunal and floral species related to boundary conditions

Thus, a better understanding in such mechanisms is essential before proper integrated water management utilizing natural mangrove bank protection can be realized. As a result, various aspects and methods of research are required.

Wave damping by mangrove is one of the aspects. Though, literature on mangrove cites on its damping characteristic, hardly any quantitative figure has been investigated. Recently, attempt was made on modeling wave transmission through mangrove forest - Avicennia and Rhizophora - by Schiereck and Booij (1995). In their study, transmission through a forest of 100 m wide was investigated under the following parameters :

- assumed horizontal bottom
- water depth, d = 0.25 - 2.00 m
- wave height is coupled to water depth as Hs = 0.4d
- one wave period, T = 5 sec
- damping by wave breaking, bottom friction and mangrove were considered

Nevertheless, coupling wave height with water depth is quite restricted in making a general conclusion since other ratios have their own dominant damping mechanism. Therefore, to get better understanding, the possible parametric ranges need to be investigated. In addition, it is valuable to investigate bottom slope effect though it is rather gentle. Generally, mangrove forests are abundant in muddy soil. However, they can be found colonized on sandy soil as well. Table-1/1 shows an example of sandy growing environment. This leads to considering the effect of damping by percolation when waves propagate through mangroves over a permeable bed.

TABLE-1/1: Analysis of Jamaica mangrove soils
Source: Chapman, V.J.,“Coastal Vegetation”,1976

soil type	coarse sand %	fine sand %	clay %	silt %	humus %
Jamaica peat					
- surface	1.7-17.3	1.1-27.2	9.0-20	5.1-24.4	19.4-54.4
- subsurface	3.5-13.8	0.7-20.3	12.7-54.7	5.6-44.9	21.8-48.4
Jamaica silicious sand					
- surface	34.7-93.5	0.7-30.93	0.0-2.2	0.03-2.02	0.74-13.8
- subsurface	30.5-93.7	0.8-27.86	0.1-1.42	0.2-1.85	1.21-8.56

1.3) Objective of the study

Environment-friendly bank protection by incorporating mangrove vegetation is a new concept in Thailand. As previously mentioned, various research aspects are essential before any realization can be made. Owing to a broad subject and limited time, this study can only be a primitive study. The objectives of the study, therefore can be described as the following :

- to make an inventory of using a systematic approach on environment-friendly bank protection as a case study with mangrove river bank in Thailand.

- to study on wave damping characteristic by mangrove forest by investigating the realistic parametric ranges.

1.4) Scope of the study and methodology

Along the inventory of case study, DIPRO program (DImensioning PROtection) of Delft Hydraulics will be used. With the existing version, DIPRO can be used for dimensioning only hard structures in the restricted waterways. It is not an aim to design such an environment-friendly bank protection, but rather to make an inventory study. Thus the scopes of this study are:

- DIPRO will be used as a tool for ship induced hydraulic loads calculation.
- Instead of a restricted waterway, application will be made on a natural river (Tha Chin river in Thailand). Therefore, profile schematization is required. However, some basic data are missing and the realistic values will be assumed when necessary.
- Sensitivity of the calculated loads on the input schematization will be investigated.

- Problems arise when making an inventory of using a systematic set-up scheme with mangrove river bank , Tha Chin river, will be examined and summarized.

For wave damping study, CRESS program (Coastal & River Engineering Support System) of IHE will be used. A one dimensional wave energy decay model (ENDEC) which was built in CRESS module 233 will be modified for the purpose of this study. The scopes of this damping study are :

- modification is to include the effect of wave damping by mangroves via roots and trunks, and by percolation via a permeable bed.
- modification is restricted to uni-directional random wave.
- bottom slope is taken into account.
- study intensively on a set of realistic parameters.

1.5) Structure of the report

There are basically two main parts outlined in this report : chapter 3 "case study inventory" and chapter 4 "mangrove wave transmission study" corresponding to the two main objectives respectively. The general knowledge on mangroves as well as an inventory of Thailand mangrove were summarized in chapter 2. This is to provide as a basic information when needed in later chapters. Chapter 5 provides the conclusion and recommendation as a whole.

In this report, the related literature review and discussion were outlined within its own chapter as :

Chapter 3 :

- A review of the integrated scheme used during inventory was provided first under section 3.3. Then, an inventory with a case study was made (section 3.4) followed by discussion.
- A background on ship-induced water motion and a general information of DIPRO program were given under section 3.5.1 and section 3.5.2 respectively. Then, an application of DIPRO with a sensitivity study on profile schematization with a natural river (case study) was discussed under section 3.5.3 and followed by discussion.

Chapter 4 :

- The ENDEC formulation and its modification for mangrove wave dissipation and percolation were discussed under section 4.2 followed by model calibration (section 4.3). Then, the possible realistic parametric ranges were estimated under section 4.4 before a set of tests were carried out (section 4.5). The results and conclusions were summarized under section 4.6 followed by discussion.

Chapter 2
Mangrove in General and Mangrove in Thailand

Mangrove vegetation is the type of plant studied in this research. In later chapters, case study inventory on the mangrove bank in Thailand and the mangrove wave damping characteristic will be discussed. To provide some basic data needed, this chapter gives an overview of mangrove as in general and provides an inventory of mangrove in Thailand.

2.1) Mangrove in General

Mangrove forests occur in the intertidal zones in tropical and sub-tropical countries. Mangroves, defined as complex of salt tolerant communities, are among the most productive of ecosystems. They provide basic services typically required by a coastal community such as storm protection, erosion control, waste water clean up, leisure activities and sources of income generation.

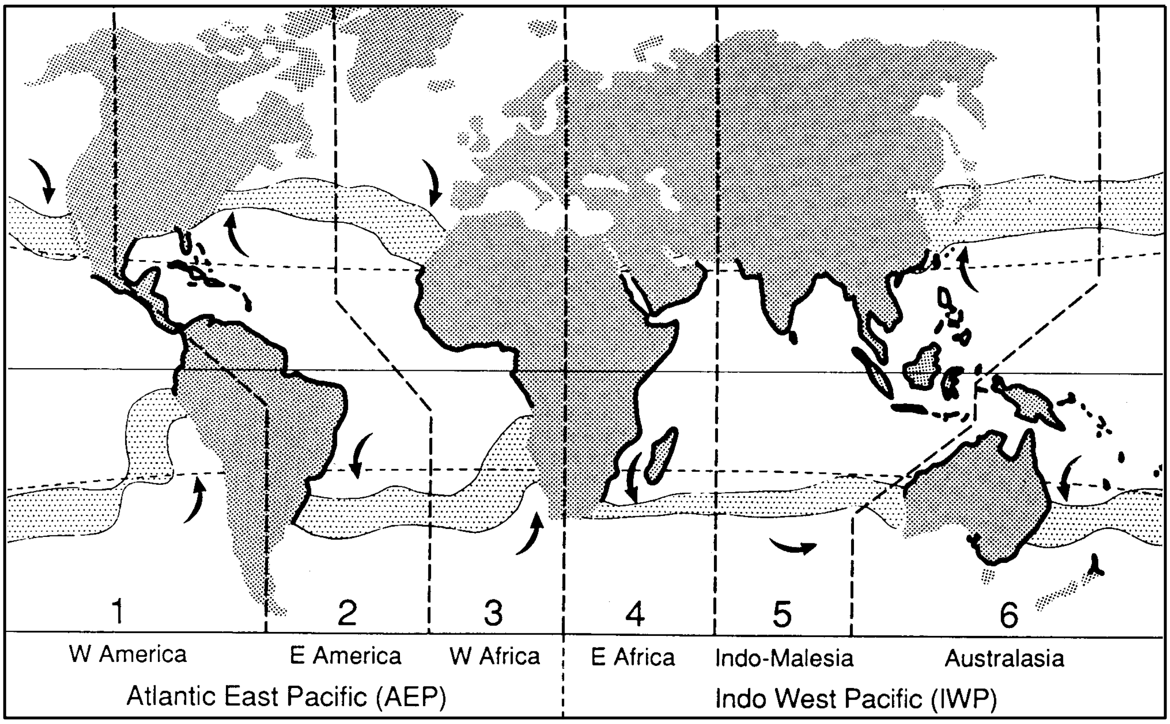
The word "mangrove" is described as obscurely connected with the Portuguese word "mangue", the Spanish word "mangle" and the English word "grove". In the book titled " The Mangroves and Us" by Marta Vannucci, she concluded that the word mangrove is neither Portuguese nor Spanish , but derived from the national language of Senegal. It was probably adopted by the Portuguese , and later modified by the Spanish as a result of their exploration of West African coast. Today, many researchers also use the terms "tidal forest" and "coastal woodland" as synonyms for mangrove forest.

2.1.1) > Geographical distribution

Mangroves are mainly restricted to the tropical areas. However, some are also found in sub-tropical regions such as in Japan and New Zealand. Usually, they are confined to tropical coasts where the water temperatures occasionally drop below 20 ^{o}C in winter. Their lack of tolerance to frost limits their global distribution. The most northern limit is found in Bermuda and Japanese island of Kyushu (approximately 33 ^{o}N). The most southern limit is found in Auckland harbour, New Zealand (approximately 37 ^{o}S).

There are two main centers of mangrove diversity which are associated with the eastern hemisphere (referred as the old word) and the western hemisphere (referred as the new world). Walsh (1974) divided mangrove vegetation by geographical distribution as mentioned into two main areas : the Indo West Pacific (IWP) and the Atlantic East Pacific (AEP).

The IWP includes East Africa, the Red Sea, India, Southeast Asia, Southern Japan, the Philippines, Australia, New Zealand and the South Pacific archipelago as far as Samoa.



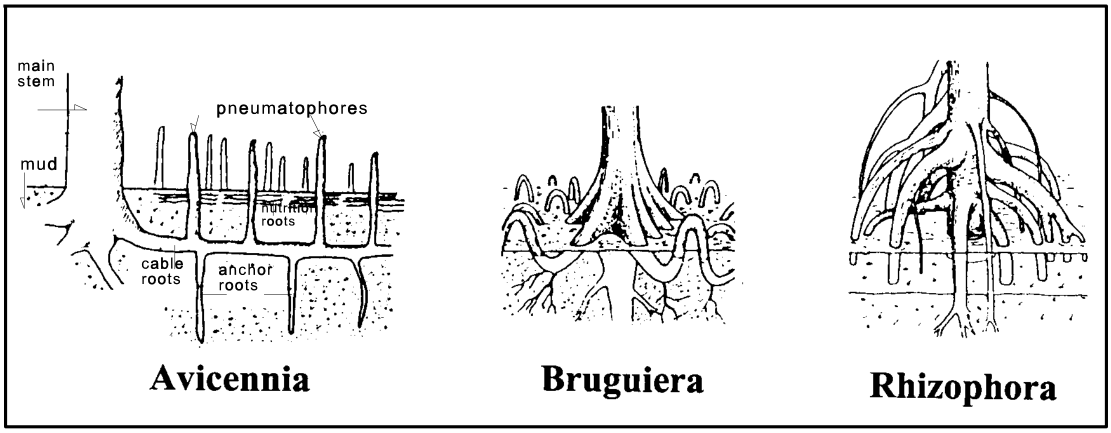
The AEP includes the Atlantic coasts of Africa and the Americas, the Pacific coast of tropical America and the Galapagos Islands. This geographical distribution of mangroves in different regions is illustrated in Figure-2/1 (see also Duke, 1992). On a global scale, mangrove distribution is influenced by the presence of warm and cold oceanic currents.

Mangroves are best developed on tropical shorelines where large areas are available between high and low tide. In addition, they thrive on a good supply of fine sediment and a plentiful amount of fresh water. They are common for muddy areas that are produced by over bank deposition (Cooper, 1993). However, they are able to grow on a variety of substrates, including sand, volcanic lava and carbonate sediments (Woodroffe, 1993).

2.1.2) > Species and root system

There are approximately 70 species of true mangroves of which some 65 contribute significantly to the structure of mangrove forests. There are about 40 species in Southeast Asia, 15 species in Africa, and 10 species in Americas (more detail referred to Walsh, 1974; Duke, 1993 and Field, 1995). It is obvious that, in the eastern hemisphere, there are more species than in the western hemisphere. Among these species, the two most common are species of the genus *Rhizophora* and *Avicennia*. Sometimes, they are named as Red Mangrove for *Rhizophora* and Black Mangrove for *Avicennia*. Species of the genus *Avicennia* are more common in areas with a high salinity range as a result of irregular flooding as *Avicennia* are better able to exclude salt. Since soil aeration is poor in mangroves, root structures are adapted for physical anchoring and aeration. Both species can be easily distinguished from their root structures.

Rhizophora works with prop or stilt roots while *Avicennia* works with "snorkel" type pneumatophores. Stilt or prop roots of *Rhizophora* descend from trunk and anchor into the substrate. If the roots do not reach the soil, they act as aerial roots. The pneumatophores of *Avicennia* are erect peg-like aerial projections which extend horizontally within the subterranean root system. These tips of pneumatophores emerge upwards at regular intervals along the lateral roots. *Avicennia* and *Bruguiera* also posses stilt roots, but there are shorter than *Rhizophora* and arise from the lower parts of the trunk. Figure-2/2 illustrates typical root system.



2.1.3) > Classification of mangrove forest.

Several classifications are used in mangrove literature. The most widely used is developed by Lugo and Snedaker (1974). There are six community types based on forest appearance, geological nature and flow of water through the system. The various functional types of mangrove forests can be listed as shown in Table-2/1 and illustrated in Figure-2/3.

TABLE-2/1: Characteristics of mangrove habitats (after Lugo and Snedaker, 1974)

Class	Characteristic
Overwash	- Frequently over washed. - Small islands covered with mangroves that are frequently washed by the tides. - The dominant species is *Rhizophora mangle.*
Fringe	- Strips of mangrove found along waterways and covered by daily tides. - The dominant species is *Rhizophora mangle*.
Riverine	- Luxuriant stands of mangroves along tidal rivers and creeks with a good input of fresh water. - Mostly daily inundated. - Often composed of *Rhizophora*, *Avicennia* and *Laguncularia*
Basin	- Depressions inland, channeling the terrestrial runoff. - Behind the fringe type forests. - Often dominated by *Avicennia*.
Hammock	- Similar to basin type, but found in more elevated sites.
Scrub	- A dwarfed stand of mangroves found on flat, arid coastal fringes.

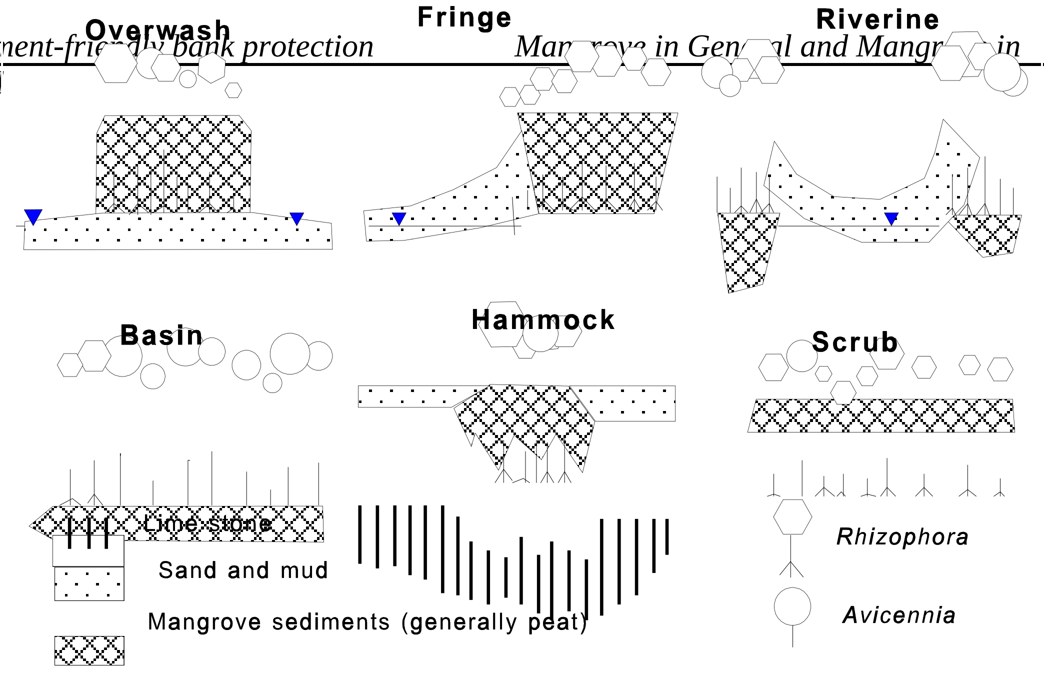


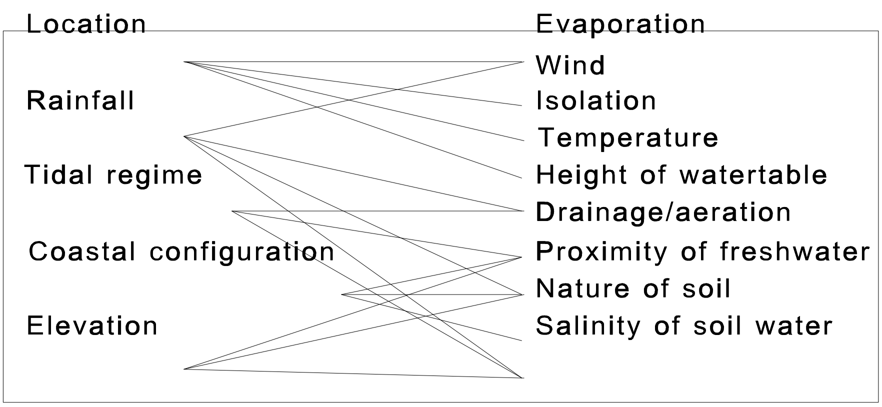
FIGURE-2/3: Classification of mangrove forests (after Lugo and Snedaker, 1974)

2.1.4) > Influence of environment factors

There are many physical and chemical factors affecting the extend and nature of a mangrove forest. A simple diagram, Figure-2/4, shows such factors which are dependent on five environmental aspects: location, rainfall-pattern, tidal regime, elevation and coastal configuration.

FIGURE-2/4: Influence factors on mangrove forests
(after Hutchings and Saenger, 1987)

There are plenty of literature reviewing the effect of environmental factors upon the mangrove forest. Some of these are briefly described as the following :



a) Coastal physiography

Topography is an important factor affecting the characteristics of mangrove structure, especially species composition, distribution, size and extent of the forest. Along the submerged shoreline, a narrow fringe is formed to shelter the narrow coastal plains around mountainous islands. Larger areas of mangrove occur on larger coastal plains. Mud flats and estuaries influenced by river streams are generally, associated with fertile mangrove areas.

b) Climate

> In general, many plants are long-day plants and require high intensity of full sunlight (Macnae, 1968; Du, 1962). This makes tropical coastal zones the ideal habitat. The range of high intensity which is optimal for the growth of mangrove species is 3,000-3,800 Kcal/m^2/day (Lugo and Snedaker, 1974; National Academy of Science, 1974). Long hours of shed harm seedings while inadequate light impedes plant growth and increases the death rate (Clarke and Hannon, 1971; Soohhuae, 1978; Aksornkoae, 1975).

> Normally, mangroves thrives in areas with a range of 1,500-3,000 mm of annual rainfall.

> There is little evidence on the relationship between temperature variation and the growth of the mangroves. In general, the average temperature of the tropical zone is the appropriate temperature for fresh leaf production of mangroves.

> Wind influences waves and currents in the coastal areas. It can also increase evaporation of plants. Strong winds are capable of impeding plant growth.

c) Soil

Mangrove soils are formed by the accumulation of sediment derived from coastal or river bank erosion, eroded soils from upstream and decomposition of organic matter. Numerous studies on mangrove soils indicate that soil characteristics are major factors limiting growth and distribution of plants and animals in mangroves (Gledhill, 1963; Aksornkoae, 1975; Giglioli and King, 1966). For instance, Steenis (1958) reported that *Rhizophora mucronata* could grow well in muddy and relatively deep soils. Gledhill (1963) found that *Avicennia marina* and *Bruguiera* spp. could grow well in muddy-sandy soils. *Rhizophora* soil of range pH 4.6 to 4.9 under dry and nearly dry conditions was recorded (Aksornkoae et al.,1978). Hesse (1961) reported soil pH 6.6 to 6.2 in the *Rhizophora* spp. and *Aegialites* spp. communities. Piyakarnchana (1986) reported that a large numbers of potamid gastropods were found in clayey areas. Sander (1958) found that deposit feeders were usually found on fine clay, while filter feeders were abundant on sandy soil.

d) Salinity and interstitial water salinity are important to growth rate, survival rate and zonation of mangrove species. Mangroves are usually thrive in an area with a range of salinity between 10-30 ppt. (De Haan, 1931; Aksonkoae et al.,1989). Table-2/2 shows an overview of salinity tolerance for a number of mangrove species of eight families. There is no clear evidence indicating the maximum interstitial water salinity that mangroves can withstand. The optimal range is 28-34 ppt. (Aksornkoae et al.,1989).

TABLE-2/2: Salinity tolerance of mangrove (after Smith, 1993)

Species	Max. Salinity (ppt.)

Aegialitis annulata	85
Aegiceras corniculatum	67
Avicennia marina Avicennia officianalis Avicennia germinans Avicennia bicolor	85 63 100 90
Bruguiera exaristata Bruguiera gymnorrhiza Bruguiera sexangula Bruguiera parviflora	72 50 33 66
Ceriops decandra Ceriops austrials Ceriops tagal	67 80 45
Excoecaria agallocha	85
Rhizophora mangle Rhizophora racemosa Rhizophora apiculata Rhizophora stylosa Rhizophora mucronata Rhizophora harrisonii	70 40 65 74 40 65
Sonneratia alba Sonneratia caseolaris	44 35

e) In coastal areas, waves are mostly caused by wind ,while inland waterways, waves are mostly caused by ships. Currents usually occur in associated with tides, winds and waves. Waves and currents in mangroves can directly or indirectly change the structural characteristics and functions of the mangrove ecosystem. For instance, plants in the *Rhizophora* family have seedings which are carried to distance areas by waves and currents (direct influence).
Indirectly, they effect coastal sedimentation of sand bars, dunes at river mount and river banks.

f) Dissolved oxygen is important in the processes of respiration and photosynthesis. It also plays a role in the decomposition of litter in the mangrove forests. Oxygen concentration is the lowest during night and is the highest during day. Mangrove plants, especially those with pneumatophores need dissolved oxygen for their respiration.

g) An adequate supply of nutrients is essential in maintaining the balance of mangrove ecosystem. Inorganic nutrients are nitrogen, phosphorous, potassium, calcium, magnesium and sodium. They are derived from rain, river runoff, sediment, sea water and degraded organic matter. Organic detritus are derived from biogenic materials through several stages in the microbial degradation process

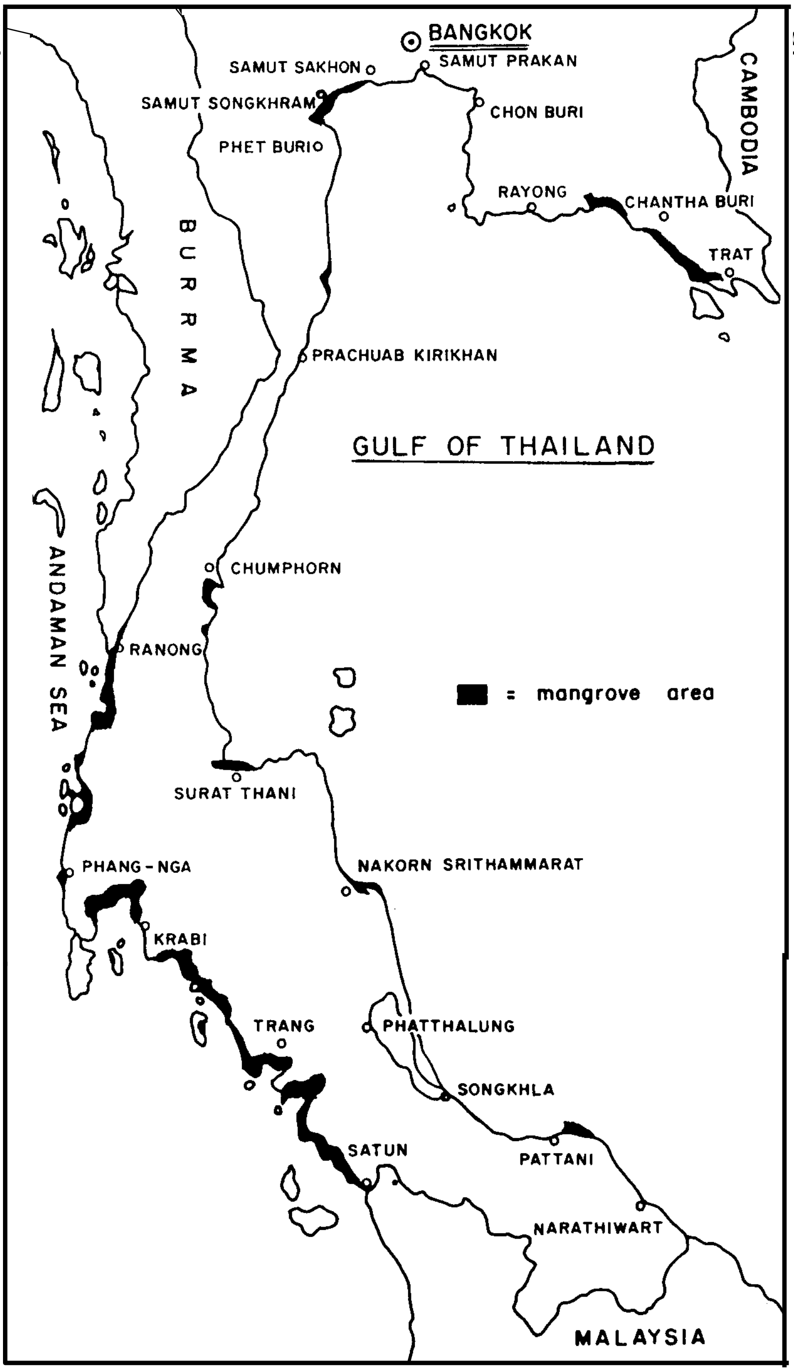
h) Tides determine the zonation of vegetation and animal communities within the mangroves. Tidal duration has a great influence on salinity changes which limit species distribution, especially horizontal distribution. This is evident by difference in structure and fertility of mangroves caused by diurnal, semi-diurnal and mixed tides. Tidal range which is suitable for mangroves is 0.5-3.0 metre (Mitch and Gosselink, 1986).

2.2) Inventory in Thailand.

It is impossible to describe a typical mangrove forest since the variation is immense from place to place. Therefore, the inventory of mangrove distribution, flora and fauna distribution in Thailand are summarized in this section.

2.2.1) > Distribution

Mangroves in Thailand occur on the sheltered muddy shores and low-lying bogs of river and estuaries between low and high tides. Figure-2/5 shows the mangrove distribution in Thailand along the banks of the Gulf of Thailand and on the west and east coasts of the peninsula. The heavy developed natural mangrove forests remain only along the west coast of the peninsula, especially in the provinces of Ranong, Phang-Nga and Trang. On the other hand, due to heavy felling for many years, mangroves along the coast of the Gulf of Thailand are mainly classified as young growth, especially along the upper part of the Gulf in the provinces of Phetchaburi, Samut Prakarn, Samut Sakhon and Samut Songkhram.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SAMUT SONGKHRAM
CHON BURI
PHET BURI
CAMBODIA
RAYONG
CHANTHA BURI
TRAT
BURRMA
PRACHUAB KIRIKHAN
GULF OF THAILAND
CHUMPHORN
ANDAMAN SEA
RANONG
= mangrove area
SURAT THANI
PHANG - NGA
NAKORN SRITHAMMARAT
KRABI
TRANG
PHATTHALUNG
SONGKHLA
SATUN
PATTANI
NARATHIWART
MALAYSIA

The Remote Sensing Division, National Research Council of Thailand estimated the existing mangrove forests from data recorded by LANDSAT-MSS in 1986-1987 to be approximately 196,429 ha. Table-2/3 shows the distribution by provinces.

TABLE-2/3: Mangrove forest in Thailand (1986-1987 from LANDSAT-MSS)
(1 ha = 6.25 rai)

No.	**Provinces**	**Mangrove forest area**		**Percentage**
		Square Km.	**Rai**	
Eastern region				
1	Chachoengsao	7.40	4,625.00	0.38
2	Chonburi	14.98	9,362.50	0.76
3	Rayong	24.18	15,112.50	1.23
4	Chanthaburi	145.07	90,668.75	7.39

5 Trat	88.18	55,112.50	4.49
Total	*279.81*	*174,881.25*	*14.25*
Central region			
6 Samut Prakarn	1.03	643.75	0.05
7 Samut sakhon	1.42	887.50	0.07
8 Samut Songkhram	0.49	306.25	0.02
Total	*2.94*	*1,837.50*	*0.14*
Eastern coast of Peninsula			
9 Phetchaburi	5.77	3,606.25	0.30
10 Prachuap Khiri Khan	1.45	906.25	0.07
11 Chumphorn	36.26	22,662.50	1.84
12 Surat Thani	42.84	26,775.00	2.18
13 Nakhon Sri Thammarat	88.36	55,225.00	4.50
14 Phatthalung	1.05	656.25	0.05
15 Songkhla	9.65	6,013.25	0.50
16 Pattani	18.28	11,425.00	0.93
Total	*203.66*	*127,287.50*	10.37
Western coast of peninsula			
17 Ranong	216.05	135,037.50	11.00
18 Phang Nga	364.20	227,625.00	18.54
19 Phuket	19.35	12,093.75	0.99
20 Krabi	303.12	189,450.00	15.43
21 Trang	262.76	164,225.00	13.38
22 Satun	312.39	195,243.75	15.90
Total	*1,477.88*	*92,367.75*	*75.24*
Grand total	***1,964.29***	***1,227,681.25***	***100.00***

2.2.2 > Climate condition

The coastal area in Thailand can be classified into 4 zones as follow :

- Zone 1: Coastline along the east of the Gulf of Thailand from, Trat to Chonburi.
- Zone 2: Coastline along the south of the great plain of the Chao Phraya river, from Samut Prakarn to Samut Sakhon.
- Zone 3: Coastline along the west of the Gulf of Thailand from, Phetchaburi to Narathiwat.
- Zone 4: Coastline along the east of the Andaman Sea, from Ranong to Satun.

Based on 30 years statistics from the Department of Meteorology (1956-1985), the climate characteristics in each zone can be summarized as shown in Table-2/4.

TABLE-2/4: Statistic climate in the coastal zones in Thailand

Characteristic	Zone 1	Zone 2	Zone 3	Zone 4
Rainfall: (mm)				
- annual average	2,663.70	1,555.90	2,003.30	3,014.80
- monthly max.	Sep.(505.50)	Sep.(378.30)	Nov.(409.90)	Sep.(510.30)
- monthly min.	Dec.(6.10)	Dec.(4.60)	Mar.(52.50)	Feb.(22.30)
Temperature: (^{o}c.)				
- annual average	27.60	27.70	27.60	27.30
- highest	Apr.(29.40)	Apr.(29.90)	May(28.60)	Apr.(28.70)
- lowest	Dec.(26.10)	Jan.(25.30)	Dec.(25.50)	Dec.(26.40)
Relative humidity: (%)				
- annual average	78.50	76.10	80.70	81.70
- highest	Sep.(84.70)	Oct.(81.40)	Nov.(84.80)	Oct.(87.30)
- lowest	Jan.(69.80)	Jan.(70.00)	Apr.(77.90)	-

Climate of coastal zones dominated by mangroves can be classified into 3 types as :

1) tropical savanna climate with little rainfall and some drought during winter and summer,
2) tropical monsoon climate with high rainfall throughout the year and a short dry period, and
3) tropical rain forest climate with high humidity and rainfall throughout the year.

According to these three major climate types, each coastal zone has its climate characteristic as follow :

Zone 1: Coastline from Rayong to Chanthaburi and all the way to Trat has tropical monsoon climate; coastline from Rayong and Chanthaburi up to Chonburi has tropical savanna climate.

Zone 2: All areas have tropical savanna climate.

Zone 3: The area from Phetchaburi to Prachuap Khiri Khan has tropical savanna climate; further south from Prachuap Khiri Khan to Chumphorn and Surat Thani has tropical monsoon climate, and from this area down to Narathiwat is mostly tropical rain forest climate.

Zone 4: All areas have tropical monsoon climate.

Climate characteristics of coastal areas inhabited by mangroves provide a basic information for any study related to plants and animals and functions of the mangrove ecosystem.

2.2.3) > Flora diversity

Santisuk (1983) listed 53 genera and 74 species belonging to 35 families of trees and shrubs in the mangrove of Thailand (Table-2/5). The dominant species are in the family *Rhizophoraceae,* genera *Rhizophora, Ceriops* and *Bruguiera*, the family *Sonneratiaceae* with *Sonneratia* and the family *Avicenniaceae* with many species of *Avicennia*.

Besides mangrove shrubs and trees, some epiphytes are also found in Thailand, Sahavacharin and Boonkerd, 1976 reported the important epiphytic plants total of 18 species, 13 genera and 3 families. Lewmanomont, 1976 reported 46 species, 28 genera and 16 families of the important and common algae in the mangrove community in Thailand.

Mangrove species dominate certain zones from the edge of the estuary to inland sites. These zones are clearly differentiated. They are effected by many physical and chemical factors such as, type of soil, salinity, drainage, tidal and frequency of inundation.

In Thailand, Aksornkoae (1975) described the plant community structure of Chanthaburi province from the edge of the estuary to inland. He reported that *Rhizophora apiculata* and *R. mucronata* were dominant species along estuary and river banks. *Avicennia* and *Bruguiera* formed a distinct zone further inland. Adjacent to this, the area was dominated by *Xylocarpus,* followed by *Ceriops* and *Lumnitzera.*

TABLE-2/5: List of recorded tree and shrub species in the mangrove formation in Thailand

Scientific Name	**Vernacular Name**	**Family Name**
Acanthus ebracteatus 1	Ngueak plaamo dok muang	Acanthaceae
A.illcifiolius 1	Ngueak plaamo dok khao	Acanthaceae
Acrostichum aureum 2	Prong thale	Pteridaceae
A.speciosum 2	Prong nuu	Pteridaceae
Aegialitus rotundifolia 1	Samae	Plumbaginaceae

Allophyllus cobbe 1	To sai	Sapindaceae
Amoora cucullata 2	Daeng nam	Meliaceae
Ardisia littoralis 2	Raamyai	Myrsinaceae
Avicennia alba 1	Samae khao	Avicenniaceae
A.marina 1	Samae thale	Avicenniaceae
A.officinalis 1	Samae dam	Avicenniaceae
Barringtonia asiatica 2	Chik le	Barringtoniaceae
B.racemosa 2	Chik suan	Barringtoniaceae
Browlowia tersa 2	Nam nong	Tiliaceae
Bruguiera cylindrica 1	Thua khao	Rhizophoraceae
B.gymnorrhiza 1	Pangka hua sum dok daeng	Rhizophoraceae
B.parviflora 1	Thua dam	Rhizophoraceae
B.sexangula 1	Pangka hua sum dok khao	Rhizophoraceae
Cerbera manghas 2	Teenped saai	Apocynaceae
C.odollam 2	Teenped thale	Apocynaceae
Ceriops decandra 1	Prong khao	Rhizophoraceae
C.tagal 1	Prong daeng	Rhizophoraceae
Clerodendrum inerme 2	Sam ma ngaa	Verbenaceae
Cycas rumphii 2	Prong	Cycadaceae
Derris indica 1	Yee thale	Leguminosae
Diospyros ferrea 2	Lambit thale	Ebenaceae
Dolichandrone spathacea 2	Khae thale	Bignoniceae
Excoecaria agallocha 1	Taatum thale	Euphobiaceae
Ficus microcarpa 2	Sai yoi bai thuu	Moraceae
Heritiera littoralis 2	Ngonkai thale	Sterculiaceae
Hibiscus tiliaceus 2	Po thale	Malvaceae
Horsfieldia irya 2	Kruai	Myristicaceae
Kandelia candel 1	Rang ka thale	Rhizophoraceae
Lumnitzera littorea 1	Faad daeng	Combretaceae
L.racemosa 1	Faad khao	Combretaceae
Melaleuca leucadendra 2	Samed	Myrtaceae
Melastoma villosum 2	Khlong kleng khon	Melastomaceae
Nypa fruticans 1	Chaak	Palmae

TABLE-2/5: Continued

Scientific Name	Vernacular Name	Family Name
Oncosperma tigillaria 2	Laao cha own	Palmae
Pandanus odoratissimus 2	Toei thale	Pandanaceae
Peltophorum pterocarpum 2	Non see	Leguminosae
Pemphis acidulata 2	Thian le	Lythraceae

Phonix paludosa 1	Peng	Palmae
Planchonella obovata 2	Ngaa sai	Sapotaceae
Pluchea indica 2	Khluu	Compositae
Premma obtusifolia 2	Chaa luead	Verbenaceae
Rhizophora apiculata 1	Kongkaang bai lek	Rhizophoraceae
R.mucronata 1	Kongkaang bai yai	Rhizophoraceae
Sapium indicum 2	Samo thale	Euphorbiaceae
Scaevola taccada 2	Rak thale	Goodinaceae
Scyphiphora hydrophyllaceae 1	See ngam	Rubiaceae
Sonneratia alba 1	Lampoo thale	Sonneratiaceae
S.caseolaris 1	Lampoo	Sonneratiaceae
S.griffithii 1	Lampaen thale	Sonneratiaceae
S.ovata 1	Lampaen	Sonneratiaceae
Sueda maritima 1	Cha khraam	Chenopodiaceae
Thespesia populnea 2	Pho thale	Malvaceae
Xylocarpus gangeticus 2	Ta buun	Meliaceae
X.granatum 1	Ta buun khao	Meliaceae
X.moluccensis 1	Ta buun dam	Meliaceae

Source: Santisuk, 1983

Note: 1) Tree and shrubs absolutely bound to salt or brackish water (true mangrove species)

2) Tree and shrubs belonging to the littoral vegetation and/or inland vegetation which regularly make their appearance in the back-mangroves (mangrove associates)

Miyawaki and Suzuki (1980) and Sabhasri et al.,(1987) investigated mangrove pattern in different areas of Thailand and found that the species zonation varies from place to place as follow :

Chumphorn : Mangrove vegetation exists along the edge of the sea to the fringe of inland forest. *Sonneratia-Avicennia* are predominant along the coast. Next is *Rhizophora mucronata* followed by *R.apiculata* and *Bruguiera*. Adjacent to the *R.apiculata-Bruguiera* zone are *Ceriops-Xylocapus* associations while *Excoecaria* and *Phoenix* grow further inland.

Surat Thani : Along the coast area are *Rhizophora-Avicennia* associations followed by *Ceriops-Xylocarpus*, *Excoecaria* and *Lumnitzera*.

Nakhon sri thammarat : *Rhizophora apiculata* is predominant along the shoreline. Further inland are *Ceriops-Xylocarpus* associations followed by *Lumnitzera* and *Ceriops* respectively.

Pattani : *Rhizophora apiculata* thrives along the coast. *R.apiculata-Bruguiera* and *Xylocarpus-Acrostichum aureum* associations are found in areas further inland.

Ranong : From the sea inward there are communities of *Aegiceras-Kandelia, Sonneratia-Avicennia, Ceriops-Xylocarpus, Avicennia, Lumnitzera* and *Phoenix* respectively.

Pang-Nga : Along the sea coast *Sonneratia-Avicennia* and *Rhizophora mucronata* are found and followed by *R.apiculata-Bruguiera* associations. Toward the mainland are *Ceriops, Ceriops-Xylocarpus* and *Excoecaria-Phoenix* communities.

Krabi : along the shoreline and extending into the mainland are *Rhizophora mucronata, R.apiculata, Ceriops, Ceriops-Xylocarpus, Lumnitzera* and *Phoenix.*

Trung : The fringe coast consists of *Sonneratia-Avicennia* associations. Adjacent to this area are *Rhizophora* and *Ceriops-Xylocarpus*.

Satun : along the coast are *Sonneratia-Avicennia* associations, followed by *Ceriops-Xylocarpus* and *Lumnitzera*. The last region adjacent to the inland forest is covered by *Melaleuca* and *Acrostichum aureum* thriving on disturbed sites.

2.2.4) > Fauna diversity

The diversity of fauna within mangrove is high due to ample food resources and a wide range of micro habitats. In Thailand, there are four major families of shrimp, namely *Penaeidae*, *Palaemonidae*, *Alpheidae* and *Ogyridae*. There are approximately 15 important shrimp species in the mangrove of Thailand (Chaitiamwong 1976,1983). Monkolprasit et al.,(1983) classified the mangrove fish into four groups: true residents, partial residents, tidal visitors and seasonal visitors. They reported 72 important fish species found in the mangrove of Thailand.

Naiyanetr (1985) listed approximately 30 species of mangrove crabs in Thailand. Most crabs are belong to the four predominant families: *Grapsidae, Ocypodidae, Portunidae* and *Gecarcinidae*. Molluscs, snails and bivalves are commonly found in mangrove forest. The predominant snail species include *Littorina, Cerithidea, Telescopium, Terebralis* and *Nerita*. Bivalves such as oysters and cockles are found buried in the mud or attached to the roots and stems of plants.

Other animals also make mangrove as their habitat. Lekakul and Mcneely (1976) summarized the vertebrates and found 35 species of mammals, including monkeys, otters, wild cats, bats, wild boar and deer. Vivanijakul (1976) found 38 species of insects such as, moths, beetles, bugs and flies. Nabhitahata (1982) reported more than 88 species of birds in Songkhla lake, souther Thailand.

In general, mangrove fauna are horizontally distributed in accordance with mangrove plant zonation. They are vertically distributed along the mangrove floor, roots, stems and canopy.

A basic knowledge on mangrove forests as in general is summarized in this chapter. It also provides an inventory data on Thailand’s mangroves. This information will be used as a reference in the next chapters when needed.

Chapter 3
Case Study Inventory

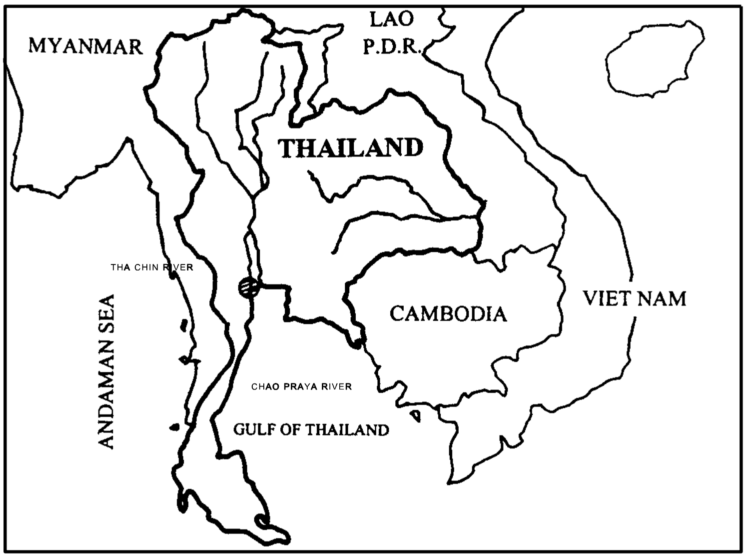
3.1) Introduction

This chapter is devoted to making a case study inventory with mangrove river bank in Thailand. The available scheme set-up (Boeters et al.,1994) for ecological sound bank type and DIPRO program for determining ship-induced hydraulic load were used along the inventory. The description of the study area will be given first. Then, an inventory of case study will be discussed followed by sensitivity of DIPRO on profile schematization with natural river.

3.2) Description of the study area

3.2.1) > Site location

Figure-3/1 shows the location of the study area, Tha Chin river in Thailand. It was

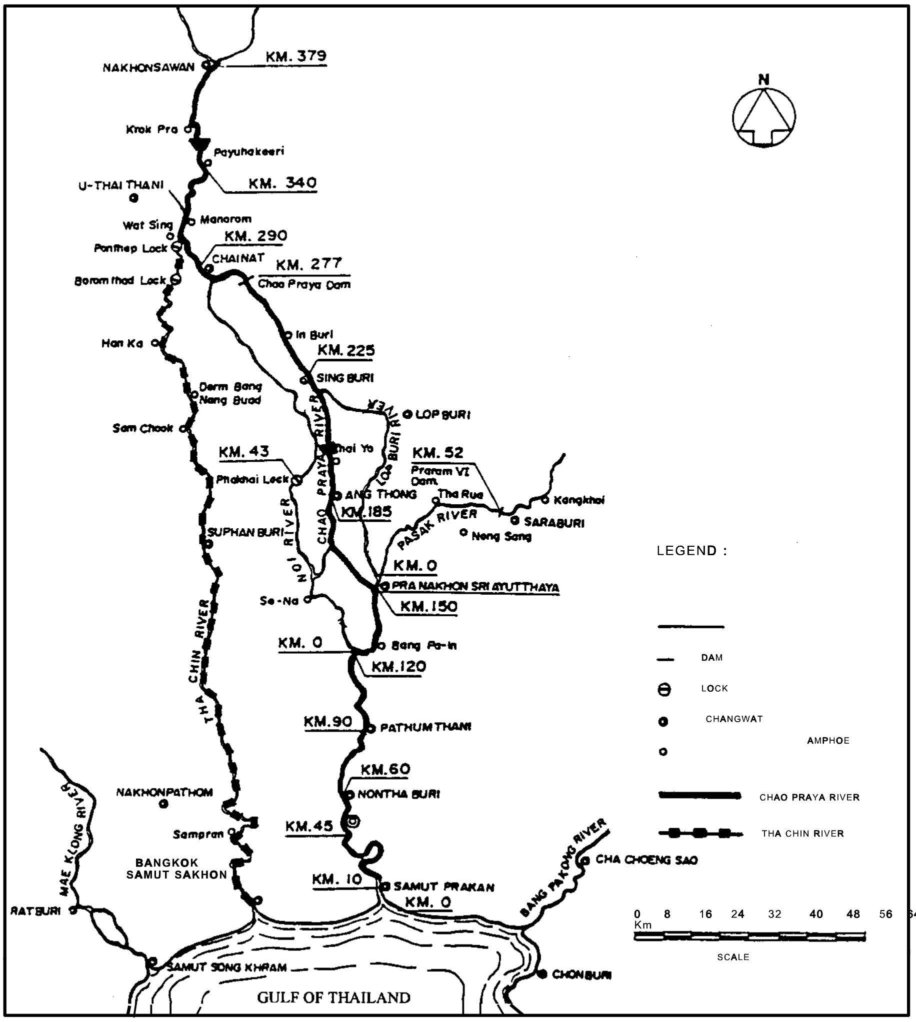


selected as a site for investigation due to the following reasons :

- It has been used as an inland waterway : ship-induced hydraulic load is present.
- It has gentle bank slope which is appropriate for vegetation along the bank.
- Natural banks still exist.

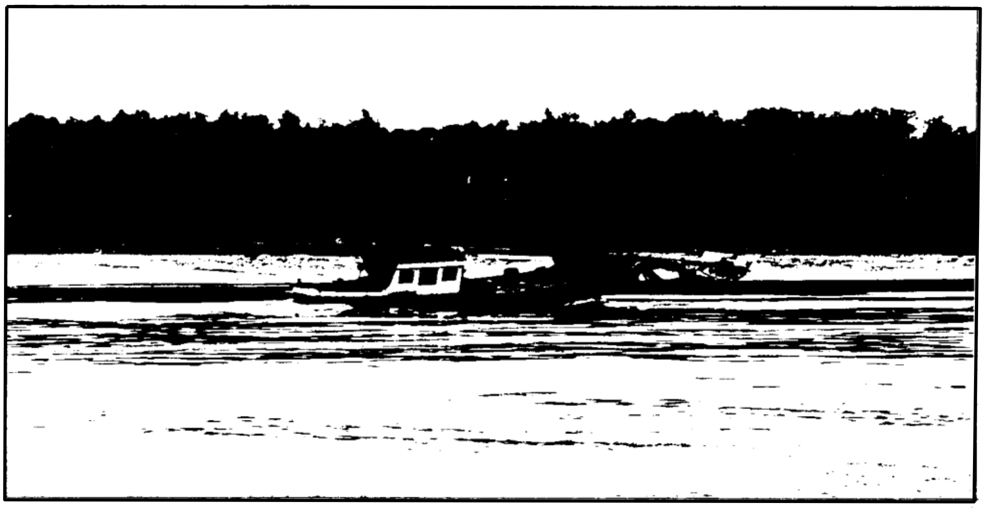
At the present time, the feasibility study on the aspect of improving inland navigation on this river is being studied by SEATEC and NEDECO consulting groups under the supervision of the Harbour Department. Therefore, in the future, it is expected to be used more intensively, especially by barges as inland navigation further upstream.

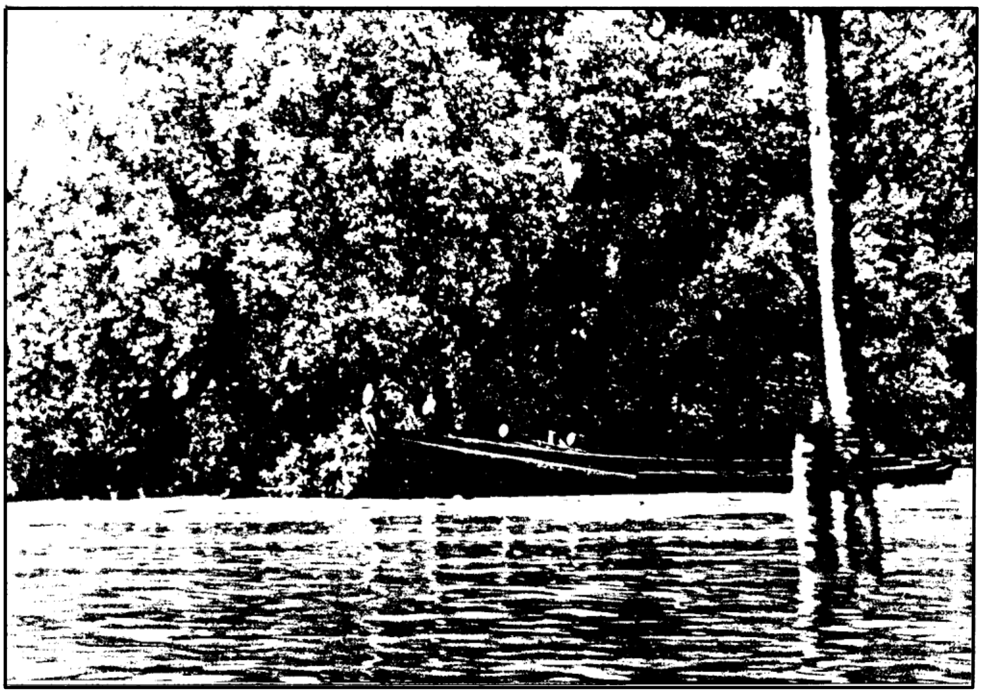
Figure-3/2 illustrates two main rivers in the Gulf of Thailand namely, Chao Praya river and Tha Chin river. Tha Chin river branches out from Chao Praya river approximately at Km 320 from Chao Praya river mouth where Km 0.00 is located. Tha Chin river flows into the Gulf of Thailand forming a delta in the province of Samuth Sakhon. In this study, the study area is about 9 km from Tha Chin river mouth.


KM. 379
NAKHONSAWAN
Krok Pra
Payuhakeeri
KM. 340
U-THAI THANI
Manorom
Wat Sing
KM. 290
Ponthep Lock
CHAINAT
KM. 277
Borom that Lock
Chao Praya Dam
In Buri
Han Ka
KM. 225
SING BURI
Derm Bang Nang Buad
LOP BURI
Sam Chook
KM. 43
Thai Yo
KM. 52
Praram VI Dam
Phakhai Lock
ANG THONG
Tha Rua
Kengkhoi
KM. 185
PASAK RIVER
SARABURI
SUPHAN BURI
Nong Sang
NOI RIVER
CHAO PRAYA RIVER
LOP BURI RIVER
KM. 0
PRA NAKHON SRI AYUTTHAYA
Se-Na
KM. 150
THA CHIN RIVER
KM. 0
Bang Pa-In
KM. 120
KM. 90
PATHUM THANI
KM. 60
NAKHONPATHOM
NONTHA BURI
KM. 45
Sampran
MAE KLONG RIVER
BANGKOK
SAMUT SAKHON
BANG PAKONG RIVER
CHA CHOENG SAO
KM. 10
SAMUT PRAKAN
KM. 0
RATBURI
SAMUT SONG KHRAM
CHONBURI
GULF OF THAILAND
LEGEND :
DAM
LOCK
CHANGWAT
AMPHOE
CHAO PRAYA RIVER
THA CHIN RIVER
0 8 16 24 32 40 48 56 64
Km
SCALE
N

3.2.2) > Geography and land use

Mangroves thrive along Tha Chin estuary. According to the classification and inventory described in chapter 2, it is classified as a riverine mangrove type with savanna climate. They can be found along the coastline and the river banks (Figure-3/3).





The tide at the estuary mouth is of a mixed type. Near spring tide, it is predominantly diurnal ,while near neap tide, it is predominantly semi-diurnal. Tidal range varies from 2.3-2.8 m at spring tide and 1.3-1.8 m at neap tide. It is approximately 2.0 m range. Its bank full flow is about 130 m^3/s (AIT, 1978; NEDECO and ILACO, 1987).

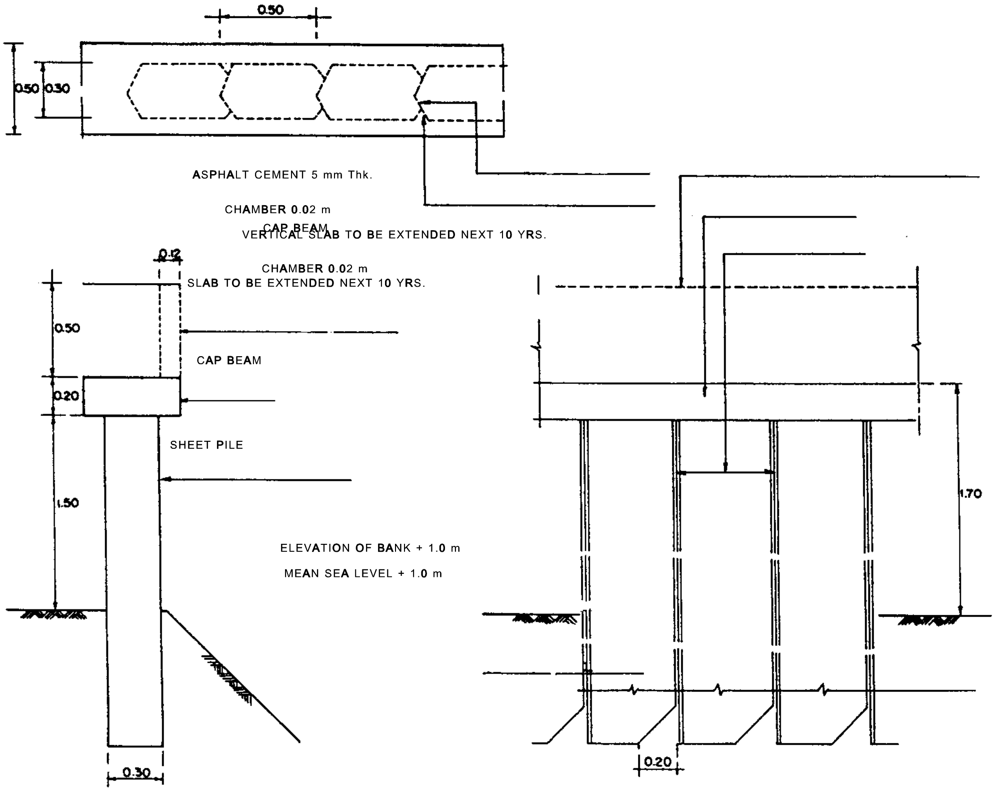
A site visit was made on 29 September 1996. However, due to a heavy raining day, it was not possible to carry out a hydrographic survey. Therefore, in this study, its bathymetry was derived from the recently available data. The hydrographic maps produced by the Engineering Section of Harbour Department in 1995 were used as shown in Figure-3/4.

The maintenance dredging is executed yearly from the entrance and upstream to about 9 km from the river mouth. The depth presented on the maps are referred to lowest low water (LLW). Along this 9 km stretch, the following descriptions can be drawn :

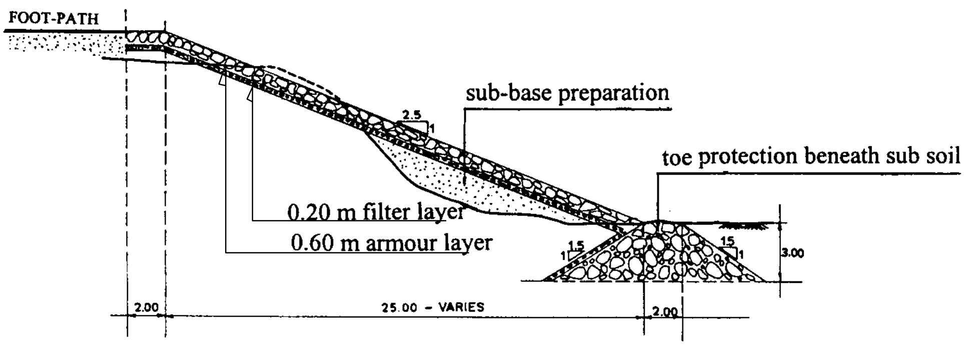
- The width of the river ranges from 600 m at the mouth to 200 m at the inner section.
- The channel is maintained at 5 m depth below LLW with 60 m bottom width.
- Natural deeper parts are along the outer bends of the s-curve shape. The toe depths along the outer bends (20-30 m from bank) are between 4 to 8 m (LLW). Hard structures (rip-rap or sheet-piles) were built to protect bank erosion. The typical hard bank protections are shown in Figure-3/5.
- Along the s-curve inner bends, sedimentation occurs. There are 4 sections approximately as :

  - Section I: between Km 1+000 - Km 2+000
  - Section II: between Km 3+200 - Km 4+000
  - Section III: between Km 5+000 - Km 5+500
  - Section IV: between Km 6+200 - Km 8+300

- Along the right bank (by looking down stream), the bank is generally densely populated by various communities. There are ports, terminals, housewares, ship yards, factories, churches, temples, residential and official buildings. Between Km 2+000 and Km 7+000, it is the business area where rail and road transportations are accessible. The mangrove vegetation exists as a narrow intermittent spots.
- Along the left bank, the business area on this side is between Km 4+000 and Km 6+000. There are ferry piers, terminals, factories, temples, residential and official buildings. Loading and unloading fish, marine product and logs are mainly taken place between Km 6+000 and Km 8+000 where a lot of small piers and ports are available. A distance of about 100 m from the bank into the river of this stretch is used for anchoring and log-storage area. The portions of Km 8+000 to Km 9+000 and Km 4+000 to Km 0+000 are moderately populated with intermittent fringe of mangrove vegetation.



CANTILEVER SHEET-PILE TYPE



RIP-RAP TYPE

3.2.3) > Navigation

Inland navigation is intensive in the section of 9 km from its mouth. There are fishing boats, reefers, general cargo ships and barge carrying vessels. At the present time, beyond this section upstream, only small fishing boats and towing barges are able to use the waterway.

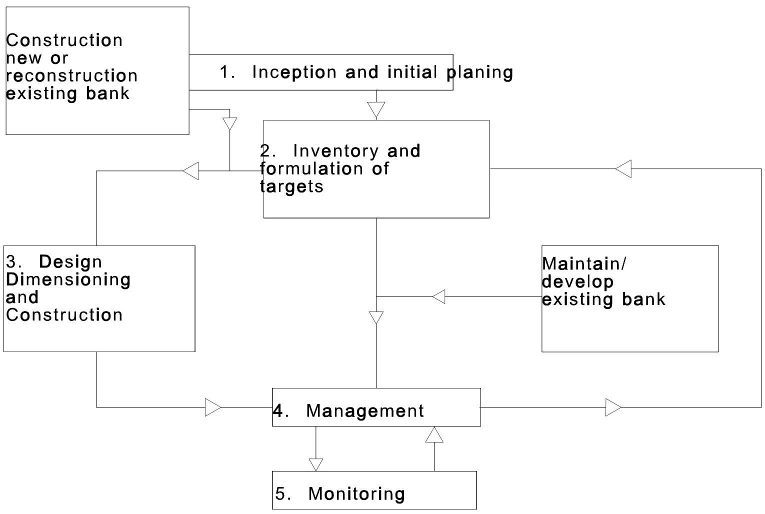
Data on the various type of vessels using this river was tabulated in Table-A1 to Table -A4 (Appendices). According to the interim report on the feasibility study on the navigability improvement of Mae Klong and Tha Chin rivers (January, 1997), the feasible expected barges convey system is still a towing system. This is composed of :

- 1 towing unit with BxWxH = 5x15x2 m, and
- 2 to 6 barges, each of 5x25x3 m.

As the maneuverability of the towing system is not good, the sailing speed was estimated in reality as about 5 km/hr or 1.4 m/s.

3.3) Integrated scheme set-up

This section summarizes a systematic set-up scheme whereby the input of experts in different disciplines with conflicting of interests can be achived (Boeters et al.,1994). This systematic approach will be used for making an inventory of the study area, Tha Chin river in the next section. Figure-3/6 shows such a scheme



There are five main steps related to each other which can be described in detail as following :

1) > Inception and initial planing

In this stage, the problem is recognized and a decision is made to tackle it. Next a team is formed to handle the problem. In this team, experts in several fields and members of local authorities who are responsible for the problem site are represented. The task of this group is to analyze the problem, to define the boundary conditions imposed by nature, the use of the fairway, legal and administrative restrictions, and to come up with possible solutions, which are mostly compromise between all interests involved. In order to do so, activities are planned. This requires the planning of actions according to the above-presented scheme.

The planning procedure successively describes:

- the necessity of developing a management plan,
- the outline of the related objectives,
- supervision of the process (who is responsible for what and how, when and by whom decisions will be taken),
- the design of the organization and how cooperation is arranged,
- the way external decision-making is arranged,
- procedures for lodging objections and appeals,
- the financial organization for the river bank management plan.

2) > Inventory and formulation of targets

In this stage, the following questions must be answered.

Inventory:
a) Which functions do the river, bank or catchment fulfil?
b) What are the decisive factors for the present erosion of the bank?
c) What are the present vegetation and fauna?
d) What are the potentials for vegetation and fauna? (ecological reference situations)

Formulation of targets:
e) Which are the primary functions to be fulfilled?
f) What final situation is aimed at?

a) Functions

The functions of a bank are closely related to the functions of the water and land. They may be described as:

- a dividing line and a transition between water and land,
- a means of protecting the land against the water: it affords protection against high water levels, waves and currents,
- a means of protecting water against the land: it affords protecting against caving and the formation of shallows,
- a habitat for specific (aquatic) plants and animals (ecological role),
- an environment through which specific bank-related plants may spread, and animals move across the land, thus forming part of the ecological infrastructure,
- a scenic element influencing the overall recreational enjoyment of the landscape,

- an element in water-related activities, such as shipping, fishing and recreation,
- an element in land-related activities, such as agriculture and recreation.

b) Decisive factors and erosion

Hydraulic loads caused by wind and shipping are the main reason for erosion of banks. These loads can act directly on the bank, thereby causing its withdrawal, but they can also affect existing vegetation that provides protection of the bank. In that case, the vegetation will gradually disappear and lose its protective function, resulting in a bare bank. Another important cause for erosion may be grazing by cattle, resulting in loss of protective vegetation, and trampling by cattle, thus destroying root layers and subsoil structure.

In Figure-3/7, the effects of navigation on riparian vegetation are presented.

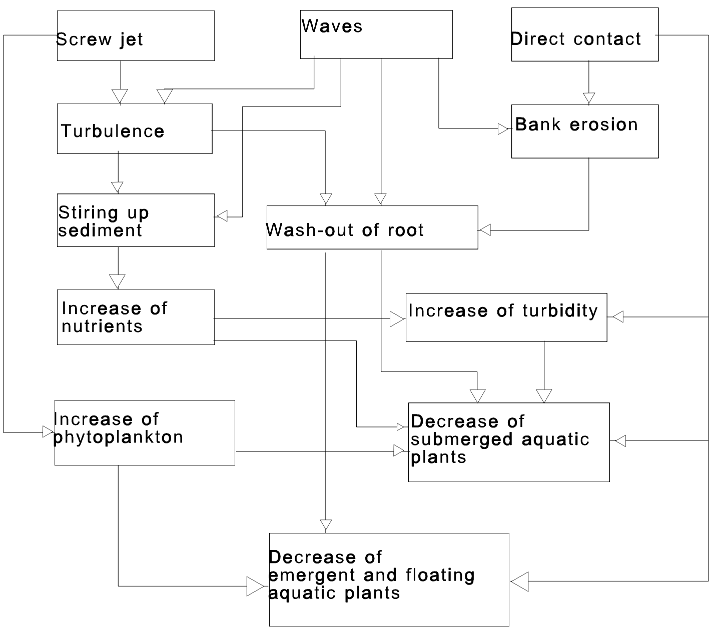


FIGURE-3/7 : Effects of navigation on riparian vegetation

c) Present and potential vegetation and fauna

A site investigation offers insight in the vegetation and fauna that is present.

d) Ecological reference situation

Ecological reference situations are descriptions of the bank as ecosystem under natural conditions without human interference. When drawing up reference situations, many aspects and factors play a part, such as physical-geographical aspects (morphology, hydrology, soil), biology (vegetation, fauna) and landscape (historical, visual) aspects.

With an inventory of the current situation in similar water types under more natural conditions and collecting (sometimes scanty) data from the past combined with generally accepted ecological insights, it is possible to draw up a reference situation. In fact, what is described in natural values of banks can be regarded as the description of a very broad and ideal reference situation. In practice, most of the time only parts of this description are applicable. Sometimes, it is not possible or not desirable to design ecological reference situations by going back in time. It is more useful in the ecological reference situation to describe what habitats might look like under the present circumstances if they were allowed to develop undisturbed. Ecological theories from literature may assist here.

e) Choice of functions

At this stage, the functions have to be chosen which the bank has to fulfil. This choice determines the framework for the design of the bank protection. A long stretch of a bank may be divided into several sections. It should be decided which sections should be adjusted first within the term of the river bank management plan. For each section, emphasis can be laid on a specific function (e.g. one section where recreational is possible, another where nature is preserved).

f) The final situation, the formulation of the targets

Based on the chosen functions and the boundary conditions, a description can be made of the desired final situation, a so-called target situation. The development of various alternatives with different approaches towards achieving the target and/or improving the condition of the surrounding land and water increases the number of options and will give insight into the opportunities of the river bank section involved.

Example of nature development alternatives:

- emphasis on types of ecosystems or habitats which are typical for land or water ecosystems or for the specific river bank ecosystems
- emphasis on high-dynamic or low-dynamic ecosystems
- emphasis on certain types of animal or plant habitats
- combination of nature with other interests such as recreation, fishing or water purifying helophyte zones
- choice for an experimental approach in which variations in river bank design and maintenance can be applied if, for example, the development of the sections is hard to assess.

Naturally, an important criterion for making this choice is a location’s potential for developing a certain habitat or for a specific ecological objective. Besides the chances of success and the money , staff availability will be determining factors in the process of choice. A multi-criteria analysis may be of help here.

It is important to include knowledge about the natural development (succession of the vegetation, land formation) when formulating the target situations. Reference and target situations may be used to control developments, since they provide insight into the stages to be expected in these developments. The necessary management can be tuned to these stages.

3) > Design and construction

In this stage, we are able to make several design alternatives, combining targets and available techniques. Various alternative designs can be drawn up, e.g. by using different widths for the river bank, different types of bank protection and different materials. The biologists and engineers should work closely at this phase. The space necessary for the proper function of habitats and various activities need to be taken into account. The alternatives should as much as possible take into account the following technical demands regarding implementation and maintenance:

- equipment for construction and maintenance should reach the location without damaging the river bank and the surrounding land
- it must be possible to inspect the construction
- in case of damage, it must be relatively easy to carry out repair works
- the work should be carried out with minimal interference of other functions.

It is advised to limit the use of materials as much as possible, to use area-specific materials as much as possible, to use the materials that do not endanger the environment, to use materials that allow the establishment of plants and animals. The best design alternative is the one that has the largest probability to achieve the target situation.

After the choice of design has been made and approved, if necessary, the specifications will need to be drawn up and the work put out for tender. These specifications consequently function as a contract for parties involved as well as the basis for price-setting.

4) > Management

It is essential that bank protection works are adapted as much as possible to the expected natural process that will lead to equilibrium situations. During the design a maintenance plan has to be established concerning all the activities aimed at the achievement of the (ecological) target situation. The target situation may be used to control developments since they provide insight into the stages to be expected in these developments. The necessary management can be tuned to these stages. In order to achieve optimum utilization of the bank as a habitat for flora and fauna, use can be made of nature engineering measures. Nature engineering measures are purposeful actions aimed at the creation, restoration, development or conservation of the living conditions of the local flora and fauna and ecological communities in their mutual relations.

5) > Monitoring and evaluation

After realization of an environment-friendly bank construction, flora and fauna have the opportunity to settle down in and around the bank. As the bank also consist of living materials, in most cases, it will take several years before a stage of equilibrium will be reached. If the stage of equilibrium corresponds to the target image for that bank, it can be stated that the construction functions well. Before this, it is necessary to carry out an evaluation of the condition of the environment-friendly bank. Usually the development of nature on the bank is observed during several years. This is done by means of repeated observations on one or more appropriate parameters and with a method, constant during the year. This monitoring means that one tries to answer the question whether the developments in the bank are going well. If this is not the case, one may change the direction of development by, for example, a change in management, in such a way that the target image will be reached. Besides, another advantage of such a procedure is that, by early observation any undesired bank development can be avoided that might lead to a future damage to the bank. It is impossible to give a standard recipe for the monitoring plan because the total number of possible structures and imaginable situations are too large. The most important parts of monitoring plan are the measuring objectives, the parameters which must be monitored and the method of monitoring. The following aspects must be accounted for within the scope of environment-friendly banks:

- Constructive aspects. Especially, during the first year, the vegetation is very sensible to erosion and damage. Possible monitoring parameters are the stability of the bank protection, the penetration of plants into the filter or protection layer (rip-rap, block mattresses, gabions).
- The bank shape. The inventory of erosion walls. Measurements of bank slopes, etc.
- The hydrology. Particularly the variation in water level as well as the biological and chemical water quality are important parameters.
- The ecology. The vegetation and aquatic macro-fauna may give a good indication of the state and the value of the nature-friendly bank. In most cases, the monitoring can be limited to these parameters, unless one or other species or group of animals has been mentioned explicitly in the objectives.

3.4) Inventory investigation

A stepwise approach towards the design, construction and management of an environmental-friendly bank protection is presented in the previous section. A team of various experts and involving authorities in the development of the project area needs to be set up before the inventory process can be done. However, it is not possible for doing such a step. Therefore, in this section, only several steps of the scheme will be inventoried on the study site, Tha Chin river.

3.4.1) > Project necessity

The navigability improvement of Tha Chin river is being studied under Harbour Department supervision. It is likely that the river will be used more intensively, especially by barges as inland navigation in the future. Within the available data, it is, therefore assumed in this study to make an inventory of the solution of environment-friendly bank protection along 9 km reach from its mouth.

3.4.2) > Function

The following aspects should be taken into account when the function of Tha Chin river is considered :

- Tha Chin river is a natural diverge discharge tributary of Chao Praya river. Any development on the river or its banks should not significantly reduce the discharge capacity of the river.
- The navigation should be maintained, especially along the 9 km reach from its mouth.
- The remaining forests along the river banks should not be degraded but promoted if possible as a room for nature.
- As mangroves are sensitive to tidal range and frequency of inundation, the river course should not be changed without a detailed study : A change in river course may lead to the die-back of the fringing mangroves.

3.4.3) > Decisive factor of erosion

At the present, there is no erosion problem along the study area. The erosive outer bends have been protected. Along the shallow inner bends, there is neither erosion nor vegetation.

The main hydraulic loads, which are regularly acting upon the banks, are caused by vessels. Wind-waves are not significant due to a short fetch length and a shielding effect by buildings. Ocean waves are not relevant for inland waterway.

Ship-induced hydraulic loads can be calculated by using DIPRO program with some necessary schematizations. This aspect including its sensitivity are demonstrated in the next section (section 3.5).

3.4.4) > Present vegetation and fauna

There is no data, neither species diversity nor zonation, available on the present vegetation and fauna in this particular river. The surveys on species of flora and fauna within mangroves of Thailand are summarized in chapter 2. Generally, mangrove species and zonation vary from place to place. In Thailand, mangrove zonation has been investigated for many estuaries, especially along the southern coastlines as summarized in chapter 2. This information should be used carefully and not for interpolation the findings from one mangrove forest to another without consulting the expert.

If required, site investigation on the present vegetation and fauna can be done by a team of experts as have been done in other areas. This is an important step for making a promising target situation.

3.4.5) > Ecological reference situation

Tracing back in time, the information on the natural bank condition without human disturbance is also not available for this river. Even though it would exist, due to the tremendous development of the river bank communities, it might not possible to develop such a reference situation. Therefore, it is more useful in the ecological reference situation to describe what habitats might look like under the present circumstances without disturbance. In this stage, it will be necessary that experts in different disciplines cooperate in order to obtain a realistic idea about the possibilities for the development of nature.

3.4.6) > Target situation

Considering of 9 km reach, although there is no erosion problem, it is possible to promote mangrove vegetation where it is appropriate.

Along the outer bends, the toe depth is about 4 to 8 m (LLW). It is close to the navigation channel which follows the natural deep channel. Moreover, land use behind the bank is mostly occupied. Hence, it is not appropriate or even not possible to promote a vegetation bank.

As discussed under section 3.2.2, along the 9 km reach, the deep outer bends have been protected by hard elements. There are four sections of sedimentation banks along the inner bends. Among these sections, section I (between Km 1+000 and Km 2+000) was selected for this study due to the most promising for implementation : wider section and non hindering to other marine activities. It was examined that the portion between Km 1+150 and Km 1+500 was appropriate for vegetation. There is about 150 m width with bottom slope of 1 to 250 between LLW water line and the left bank where mangroves can be planted.

3.4.7) > Design and construction

Several aspects related to design and construction need to be investigated for the project area. These are as follow :

a) boundary conditions

Besides hydraulic loads, there are other boundary conditions imposed by physical characteristics and by law which need to be considered as :

- by physical characteristics
  As previously described, the vegetated area is a muddy soil with a natural slope of about 1 to 250. The width available for vegetation is about 100 to 150 m. It is inundated by mainly diurnal tide of about 2 m of tidal range. The safety accessibility to and from marine facilities around the vegetation site need to be maintained.

- by law
  In Thailand, the Harbour Department is responsible for safe and efficient river navigation. It has therefore, defined criteria for the dimensions and shape of the river profile to meet navigational requirement. One of the requirements is that, in any circumstance, construction in the waterway should at least be 15m apart from the maintenance dredging profile.

b) possible vegetation

Without the relevant experts, it is not possible to draw out a suitable possible vegetation. Therefore, in this section, it is intended to make use of the available information to draw out the possible vegetation in the study area as a primary investigation.

The informative data are :

- The pioneer species of mangroves should posses strong prop roots (Chaptman, 1975).
- The study area has a savanna climate. In Thailand, the investigation on flora zonation of the estuary with savanna climate was carried out in the nearby province, Chanthaburi province. This was studied by Aksornkoae in 1975 as described under section 2.2.3. He reported that *Rhizophora apiculata* and *R.mucronata* were dominant species along the estuary and river banks. *Avicennia* and *Bruguiera* formed a distinct zone further inland.
- The genus of *Rhizophora*, especially *R.mucronata*, generally, grows well on mud flats while *R.apiculata* prefers moderately soft mud (Ding How, 1958)
- In Thailand, the most widely planted mangrove species are *Rhizophora apiculata* and *R.mucronata*. Muddy area with frequent tides along the coastlines or river banks are the most suitable sites for *Rhizophora* planting. Under this condition, the planting of *Rhizophora* is quite successful as the *Rhizophora* seedlings can grow quickly and show little mortality (Aksornkoae, 1975).

Hence, as of a primary investigation, the species of *Rhizophora apiculata* and

R.mucronata or plants in this genus are probably the suitable and promising in implementation.

c) possible alternative layouts

Environment-friendly bank protection by mangrove vegetation is a new research area. As of a broad subject, various research aspects are essential before any realization can be made. Hence, in this section, it is not intended to dimension such a bank protection, but rather to investigate the proper material or layouts.

The various considerations on the vegetation bank are as follow :

- The cellular blocks type is not possible due to the type of plant and root system which can not thrive throughout the blocks.
- The shallow pool for vegetation is possible. At the present time, the interaction between load and mangrove strength is not well understood. Therefore, it is assumed that a kind of parallel protective structure is required at the interface between vegetation and river, especially for the first few years of plantation (3-5 years). The structure should be able to withstand the hydraulic loads for the design period.
- Wooden piles are not appropriate due to the decay caused by water level fluctuation.
- Concrete piles or steel sheet-piles are possible material but might not blend well into the surrounding environment.
- Fiber or synthetic tube (or sack) filled with aggregates is possible. However, it is subjected to vandalism.
- Rubble mound or gabion type is more appropriate.
- With the low crest structures, sedimentation of the sub-soil is expected as acceptable (incorporate geotextile, if required).
- The mangroves may be killed within a few days, if suffer constant impoundment (Snedaker, 1984). They are also vulnerable to tidal regulation (Lugo et al.,1988). Moreover, drainage is an important factor upon its characteristics. Hence, the dimensions of the protective structures such as crest height and gap width need to be carefully designed. These are also include the consequences of the design structures on frequency of inundation, wave transmission and water quality behind the pool.
- In Thailand, construction material of gabion and rubble mound are common with a reasonable price.
- The accessibility and construction technique are feasible for the study area.

Therefore, The suitable layout seems to be a mangrove vegetation associated with a foreshore protective structure of gabion or rubble mound. In the vicinity of the planting area along the bank, there are some facilities such as slipways and piers. Hence, the safety of the vessels in accessibility to and from those structures have to be maintained. The navigation aids are necessary for the safety reason as well.

d) Management and monitoring

The management and monitoring plan has to be established during the design process concerning all the activities aimed at the achievement of the target situation. For mangrove bank as mentioned, the following activities are for instance :

- It might need to set up a limit speed of vessels for certain sections of waterways.
- Dumping of dredging materials in the area where it can be vulnerable to the propagules or mangrove root system should be avoided.
- Accessibility by local people and officers can damage vegetation. Thus, designed path ways and fencing system are required.
- Some parameters behind the pool which effect the vegetation need to be monitored such as, wave transmission and water quality. This includes the performance of the structures as well such as, opening size, crest height, stability and navigation aids system.
- The growing rate of the plants need to be monitored and evaluated. Pests, diseases and weeding need attention as well.
- The evaluation of flora and fauna is required as a comparison with the target situation.
- As it is a new kind of development along this waterway, trial sections might be useful. The management direction might be changed or adapted to the present situation if necessary in order to achieve the target situation

3.4.8) > Discussion

A systematic set-up scheme whereby the various disciplines with different interests can be incorporated is available (Boeters et al.,1994). It summarizes all related concerns as a stepwise approach towards the design, construction and management for the ecologically sound bank protection. This stepwise approach was followed during the inventory on the case study, Tha Chin river. Basically, the scheme can be applied to any project area, though nature is different from place to place : physical configurations, type of vegetation.,etc. The scheme provides a framework for a study team. However, each study area has its own administration and its unique configuration, thus there are different problems and regulations arising during the inventory process.

The problems hindering towards such an environment-friendly bank protection for Tha Chin river and for Thailand as a general can be grouped into two aspects as follow :

1) administration aspect :
- There is a lack of public and government awareness on the ecological role of the bank, especially on a national level.

- Without national policy or plan on this aspect, it is very difficult for the responsible authority to initiate, to set up the expert team, to get budget and to implement successfully.
- There are many federal and local authorities who are responsible for coastal and river bank protection works. For instance, there are the Public Work Department, Harbour Department, Royal Irrigation Department and provincial authorities. By law, it is dependent on the project area, type of waterway (natural or man made), land-water boundary ,etc., which define the active authority. However, in practice, it is often that the responsible authority is the one to which local people make their request. Moreover, among different laws, the ambiguity on the definitions and active authorities who responsible for protection work and/or approvement of public project still exists. This effects budget and management policy as a whole. For example, each authority has its own strategy and design preference : one may consider the navigability as a main aspect in the design while other may consider the national security as a main reason in its layout.
- In practice, after the common hard structures have been built, hardly any monitoring process has been followed. This is not only because of a costly operation but also the severe lacking in man power in the government sectors. A dynamic system as a vegetation bank need more attention and requires a good monitoring program after plantation. It is very unlikely that this can be established under the present circumstances of the government administration.

2) design aspects :

- Environment-friendly bank protection by mangrove vegetation is a new research area. As of a broad subject and complex system, various research aspects are essential before any realization can be made. At this stage, it is still not possible to make a design of a purely mangrove bank protection, as many physical behaviors of mangroves on hydraulic loads have not been studied and understood, for example, the response of the mangrove root system to long waves, to tide and to current (permissible shear stress under the root-soil system). Moreover, strength of the mangrove vegetation itself due to seasonal variation and frequency of wave loading has not been studied as well. Therefore, the possible design is rather a compromising between the common hard structures practice and the ecological sound bank type within the available tools and knowledge.

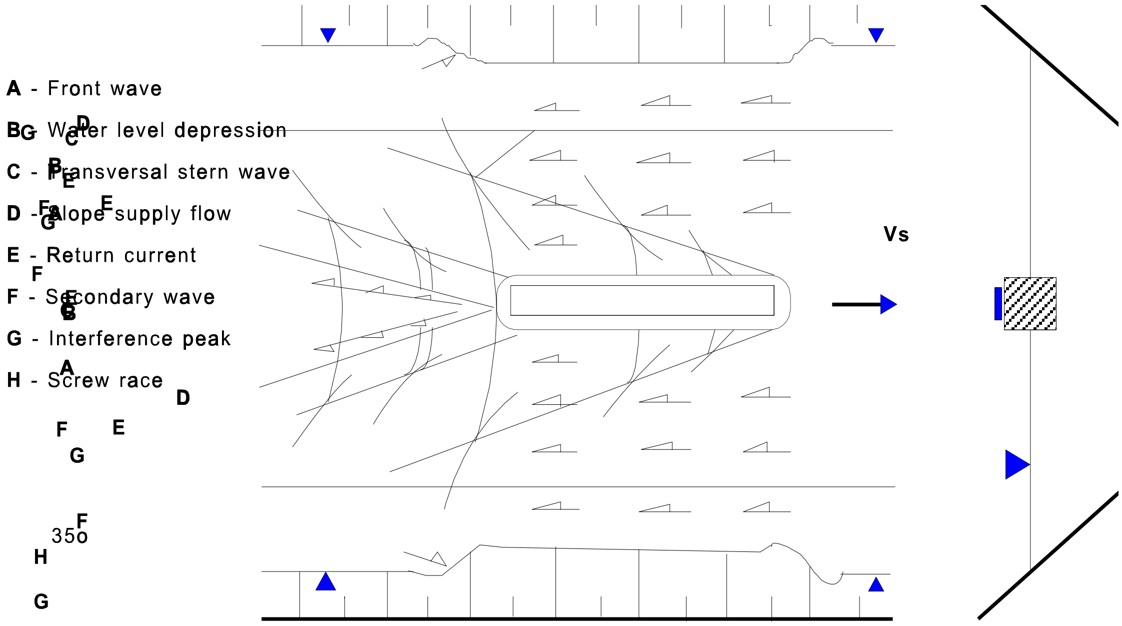
3.5) Sensitivity of ship-induced hydraulics load calculation

In this section, sensitivity of DIPRO program on the schematization with natural river, Tha Chin river will be investigated in detail.

First, the basic definitions and background on ship-induced hydraulic loads will be provided. Second, the general description of DIPRO program and the notations used will be described. Finally, schematization processes and results will be followed and discussed.

3.5.1) > Background on ship-induced water motion

Ship-induced hydraulic loads can be described in terms of waves, currents and change in water level. Their magnitude and occurrence depend on the characteristics of the navigation channel as well as the type and velocity of the vessel. Figure-3/8 demonstrates the components of ship-induced water motions.



A typical profile of water surface adjacent to a moving ship is shown in Figure-3/9.

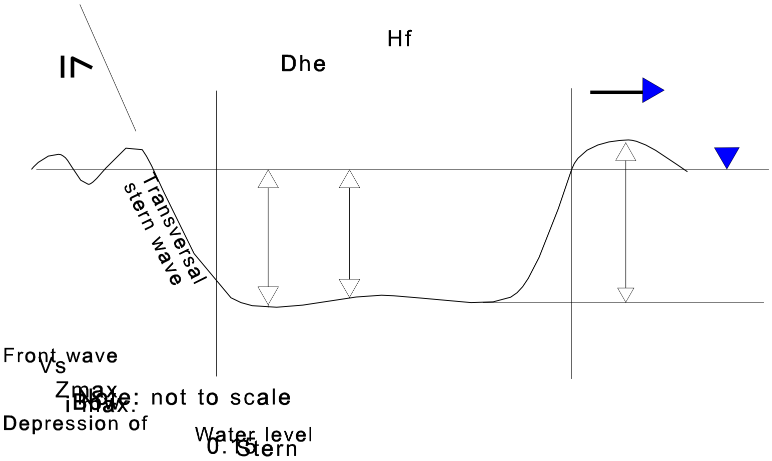


FIGURE-3/9 : Profile of water surface adjacent to a moving ship

The following definitions of ship-induced hydraulic loads are referred to PIANC (1987).

a) Front wave

This is defined as the transition between the undisturbed water level in front of the vessel and the water depression behind it. The water surface immediately ahead of the vessel is elevated by the approaching ship. Therefore, the total height of the front wave is slightly greater than the water level depression. The gradient of the front wave is important in relation to water pressure in the subsoil and underneath the top layer.

b) Water level depression

The velocity head of the water flowing past the vessel causes the water level in that region to fall to maintain the total head constant. The water level around the vessel is thus lowered as a function of the local velocity of the return current.

c) Transversal stern wave and slope supply flow

The transversal stern wave is the transition between the water level depression and the normal water level behind the ship. It may take the form of a breaking wave, depending upon the vessel speed and the channel depth. The local current velocities at the side slopes are associated with the transversal stern wave. The sloping bank causes the make-up water to have a perpendicular to the canal axis component. This results in a local high velocity current called the slope supply flow.

d) Return current

When a ship is moving along a restricted waterway, a return current is set up in the channel parallel but opposite to the direction of the ship. The return current exists for the period it takes the vessel to pass by and produces high shear stress at the waterway boundaries.

e) Secondary waves and interference peaks

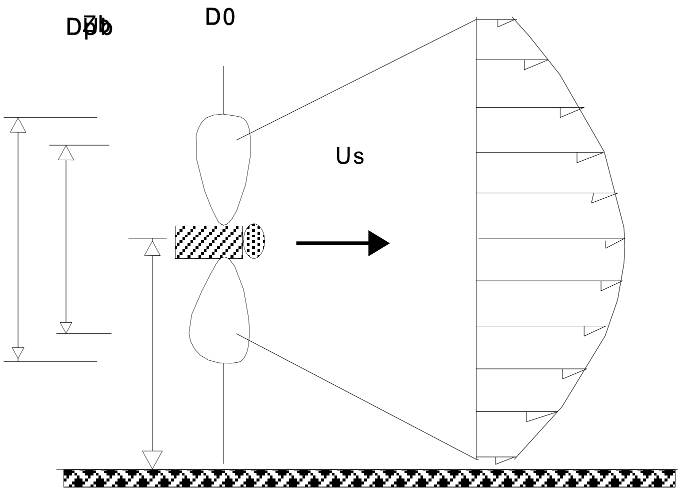
Secondary ship waves are generated particularly at the bow and stern of the vessel and at any discontinuity along the ship hull. The waves comprise transverse and diverging waves. They are together form interference peaks which can cause significant forces on the revetment.
The interference peaks propagate at the angle approximately 35 ^{o}C from the axis of the vessel.

f) Screw race

The propeller generates a high velocity jet of water which may impinge on the bed or bank of the waterway. Usually, load caused by screw race or bow-thruster are significant when vessel is at mooring or near lock gates or on bends. Figure-3/10 shows velocity distribution behind a propeller.

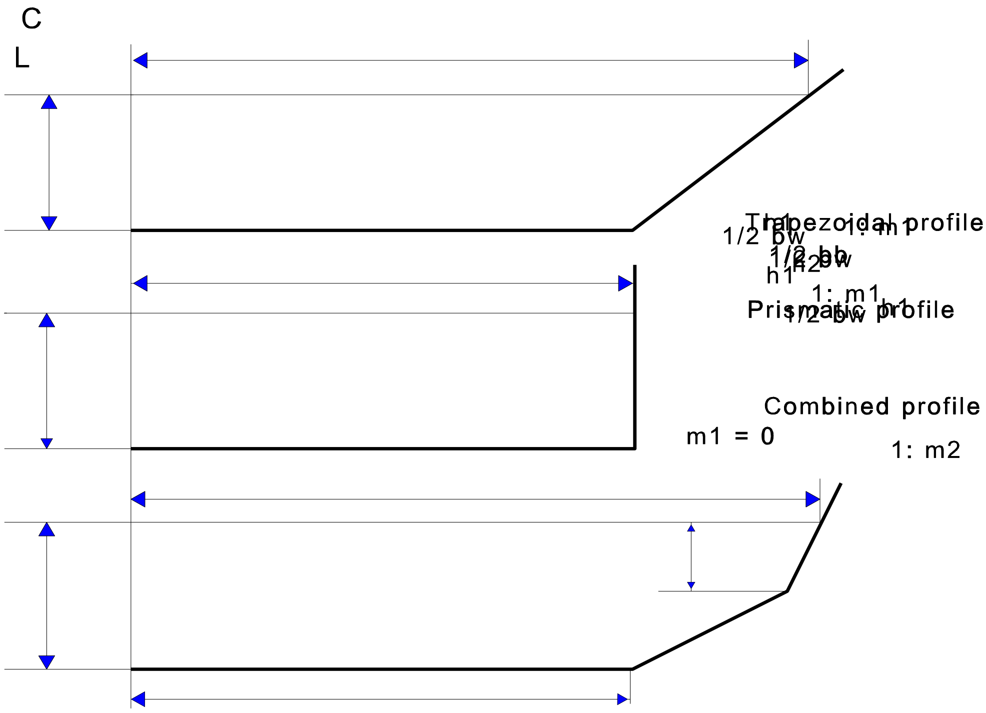
3.5.2) > DIPRO program

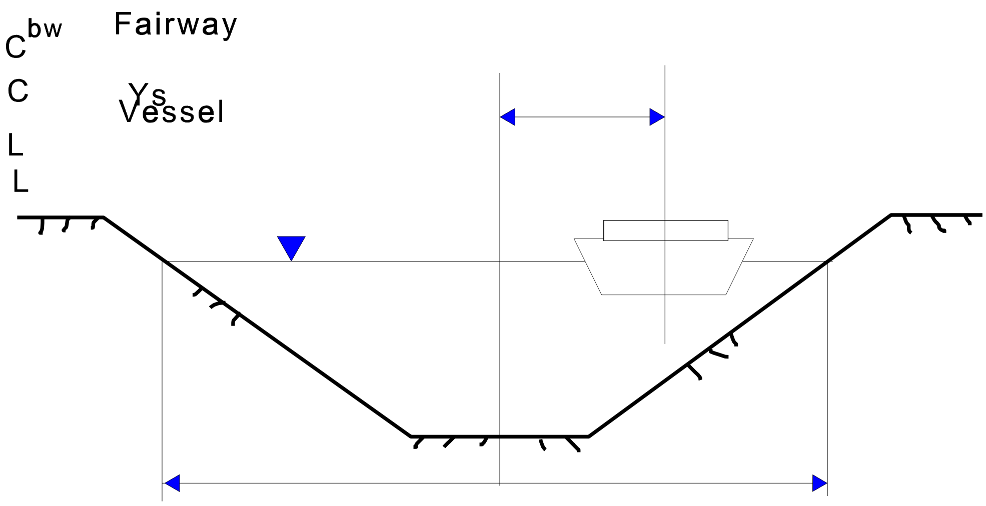
DIPRO program (DImensioning PROtection) of Delft Hydraulics is a program for designing bank protection along the waterway. The program emphasizes on the relationship between the ship-induced water motions and the stability of the top layer of a bank protection and the underlying filter layers. With the existing version, DIPRO can be used for hard structures design of bank protections in the restricted waterways. The formulae used in DIPRO are based on Report M1115 part XIX (Laboyrie and Verheij, 1988).



Basically, all water displacement vessels can be treated with DIPRO except surfing vessels. Standard cross sections of waterways that are recognized by DIPRO are trapezoidal, prismatic and combined profiles (Figure-3/11).

Other cross sections should be schematized into one of the standard profiles. It is important that the wetted perimeter A_c for the schematized section is the same as for the real waterway. The ratio between the cross section of the waterway, A_c and the mid-ship cross section, A_m should not be smaller than about 4. Figure-3/12 demonstrates the typical waterway and vessel geometry.





DIPRO can not calculate the following :

- the water movement for distances between ship and bank smaller than 0.1 times the ship width (due to bank suction),
- the water movement above the berms (berm profiles) or above flats (gully profiles),
- the water movement between the groynes of a river, and
- the water movements in waterway with natural current larger than 1 m/s.

The notations for ship-induced hydraulic loads used in DIPRO are :

- V_L = limit velocity (m/s)
- U_{rm} = mean return current (m/s)
- U_{re} = maximum return current (m/s)
- D_{hm} = mean water level depression (m)
- D_{he} = maximum water level depression (m)
- Z_{max} = transversal stern wave (m)
- I_{max} = maximum slope of Z_{max} -
- I_{gem} = mean slope of Z_{max} -
- H_f = front wave (m)
- I_f = slope of front wave -
- H_i = interference peak (m)
- T_i = wave period of H_i (sec)
- L_{wi} = wave length of H_i (m)
- H_t = transversal wave (m)
- T_t = wave period of H_t (sec)
- L_t = wave length of H_t (m)
- U_{max} = transversal stern wave current (m/s)
- U_s = mean bottom velocity caused by main screw (m/s)
- U_{bs} = mean bottom velocity caused by bower screw (m/s)
- U_c = natural current (m/s)

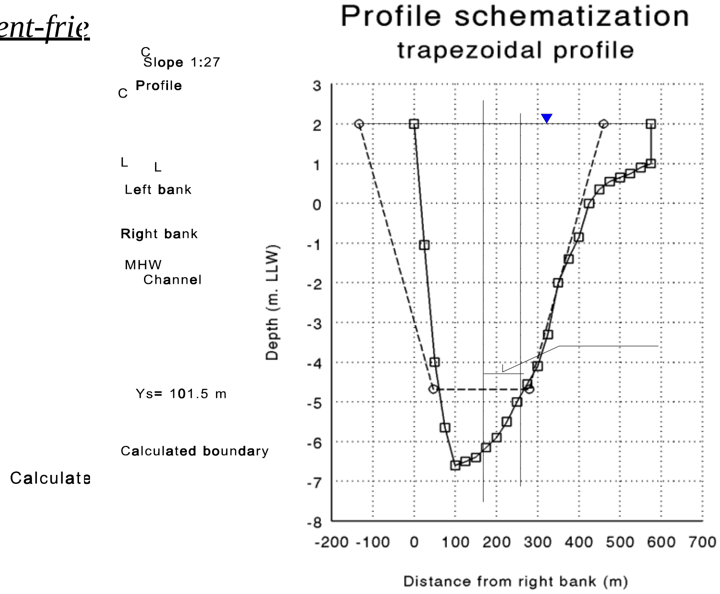
3.5.3) > Profile schematization and results

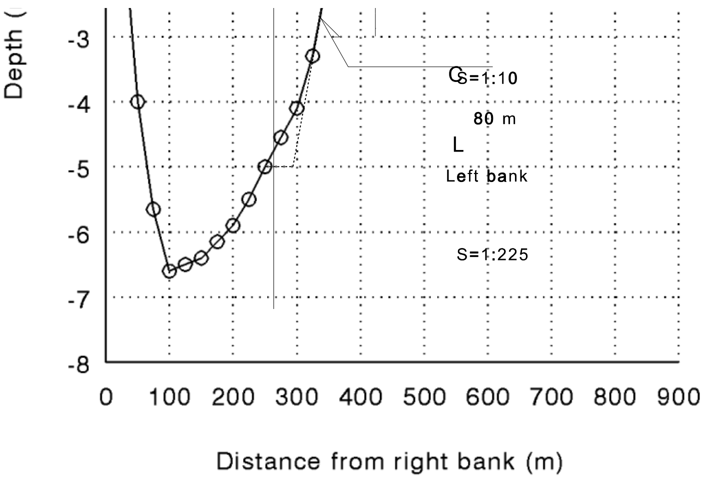
As described under section 3.2.2, along the 9 km reach, the deep outer bends have been protected by hard elements. There are four sections of sedimentation banks along the inner bends. Among these sections, section I (between Km 1+000 and Km 2+000) was selected for this study due to the most promising for implementation : wider section and non hindering to other activities. An appropriate portion of this section was examined. Based on the hydrographic maps (Figure-3/4), two cross sections were mapped out at Km 1+150 and Km 1+500 as shown in Figure-3/13. The wetted cross sectional areas, A_c, for both sections were calculated as 2750 m^2 and 2747 m^2 respectively. These were based on the water line at about mean high water (MHW) which is about 2 m above LLW. The representative cross section of this portion was drawn by using the average values between the two sections (Figure-3/13). Its wetted cross sectional area is 2760 m^2. This representative cross section was used and schematized for DIPRO. Figure-3/14 shows the configuration of the section. This reveals that there is about 150 m width between the LLW water line and the left bank where mangroves can be vegetated. Therefore, the use of DIPRO was to calculate the ship-induced hydraulic loads on this boundary (at LLW water line 150 m from the left bank, Figure-3/14).

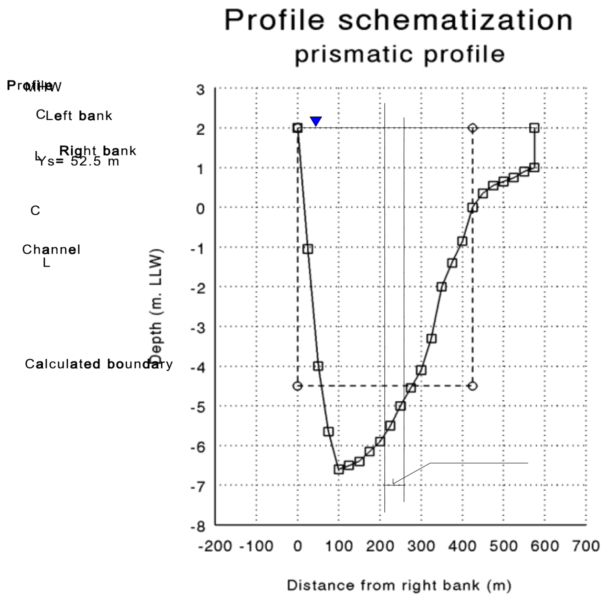
In this case, there are two possibilities for schematization namely, prismatic and trapezoidal profiles. According to the DIPRO manual, schematization should be done by keeping the wetted cross sectional area, A_c, the same as the real cross section.

The real cross section has $A_c = 2760\ m^2$. The prismatic profile has the value of 2762.5 m^2 while the trapezoidal profile has the value of 2761.3 m^2.

The schematization profiles are shown in Figure-3/15 and Figure-3/16 for prismatic and trapezoidal profiles respectively.


Profile schematization
trapezoidal profile
Slope 1:27
Profile
Left bank
Right bank
MHW
Channel
Ys= 101.5 m
Calculated boundary
Calculate
Depth (m. LLW)
Distance from right bank (m)


S=1:10
80 m
Left bank
S=1:225
Depth (
Distance from right bank (m)



According to the type of vessels using this waterway and the expected barges convoy as described under section 3.2.3, the realizations of the testing vessels are as follow :

1) fishing boat, 5x20x4 m (loaded draft = 3 m, unloaded draft = 1.5 m)
2) barges convoy
   - towing unit of 5x15x2 m (normal draft = 1.2 m)
   - 6 barges, each of 5x25x3 m (loaded draft = 2.8 m, unloaded draft = 0.8 m)

Fishing boat was schematized as a tug boat with a block coefficient, C_m, as 0.75. The maximum towing speeds of the towing unit were carried out with DIPRO by schematization as a tug boat for both prismatic and trapezoidal profiles. In appendices, Figure-A1 and Figure-A2 show the maximum speeds as 4.36 m/s and 4.34 m/s respectively. However, the practicing speed of 5 km/hr was used as a sailing speed for the towed convoy. A set of six barges convoy was schematized as a motor ship with C_m= 0.9.

Based on the bank full discharge of 130 m^3/s with tidal discharge, the natural current was estimated as 0.8 m/s. This value was used throughout the calculation.

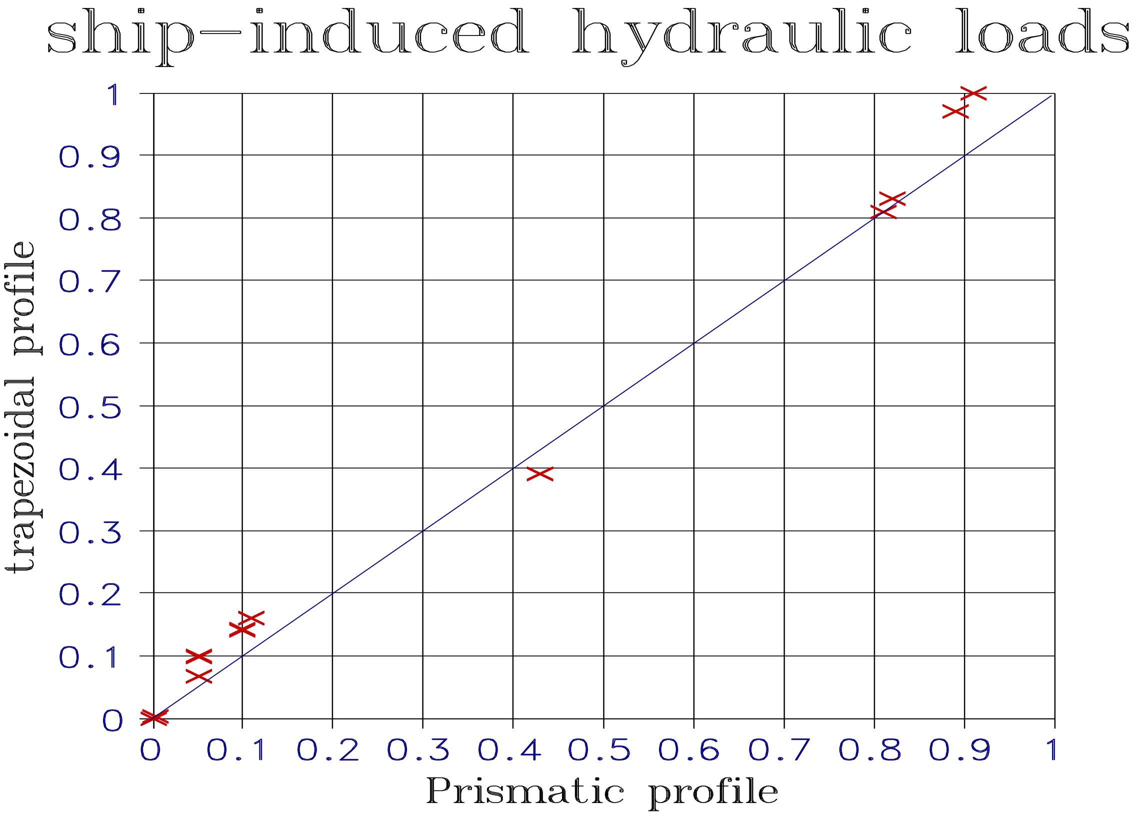
The investigation on the sensitivity of ship-induced hydraulic loads on the schematization profiles was carried out with DIPRO. Both prismatic and trapezoidal profiles were tested with loaded and unloaded fishing boat and six barges convoy. The calculated hydraulic loads were summarized in appendices (Figure-A3 to Figure-A10). Only the main hydraulic loads namely, U_{rm} , Z_{max}, H_f and H_i were summarized and tabulated as shown in Table-3/1.

TABLE-3/1 : Main calculated ship-induced hydraulic loads with DIPRO

Type of vessel And loads	LOADED		UNLOADED	
	Prismatic prof.	Trapezoidal prof.	Prismatic prof.	Trapezoidal prof.
1) fishing boat				
- U_{rm} (m/s)	0.91	1.00	0.89	0.97
- Z_{max} (m)	0.11	0.16	0.10	0.14
- H_f (m)	0.11	0.16	0.10	0.143
- H_i (m)	0.43	0.39	0.43	0.39
2) six barges				
- U_{rm} (m/s)	0.82	0.83	0.81	0.81
- Z_{max} (m)	0.052	0.10	0.051	0.098
- H_f (m)	0.052	0.067	0.051	0.066
- H_i (m)	0.003	0.002	0.001	0.000

3.5.4) > Discussion

Figure-3/17 shows the plot of 16 loads calculated with different schematization



profiles, prismatic and trapezoidal profiles.

The figure reveals that the main hydraulic loads calculated by either prismatic profile or trapezoidal profile are in the same order of magnitude. Hence, the way of schematization using DIPRO with the natural river is not so sensitive provided that the wetted cross sectional areas, A_c, are the same as prototype's.

Chapter 4
Mangrove wave transmission study

4.1) Introduction

ENDEC (an acronym for energy decay) is a one-dimensional model for determining wave energy decay during its propagation towards a shoreline. This was encoded within CRESS program (Coastal & River Engineering Support System) module 233. The formulae in this module are based on Delft Hydraulics report number M 1882 titled "Calibration and verification of a one-dimensional wave energy decay model" by M.J.F. Stive and M.W. Dingemans, December 1984.

The model configurations are as follow :

- one dimensional-model,
- for straight parallel depth contours,
- unidirectional random wave with Rayleigh distribution,
- include refraction due to bottom variation and current variation, and
- energy source and sink terms include :
  - energy gain by constant current wind field
  - energy loss by wave breaking (Battjes and Janssen, 1978)
  - energy loss by bottom friction (Putnam and Johnson, 1949)

4.2) ENDEC formulation and modification

In this study, CRESS module 233 was modified by including the effect of dissipation due to mangrove forests. The formulae developed for ENDEC and its modification will be shortly described in the next section.

4.2.1) > Energy and momentum equations

The wave action conservation equation for a stationary wave field in two horizontal dimensions can be written as :

Error!

where E: mean wave energy density (N/m)
D: mean dissipated power (N/m/s or watt/m^2)
c,_g : wave group speed (m/s) = ∂w,_r / ∂k,_
u,_ : mean current field (m/s)
w_r : relative or intrinsic wave frequency (1/s)

$$w = w_r + k \cdot U$$

with
where w : representative wave frequency of the spectrum (1/s)

and

$$w_r = gk \tanh(kh) : k = |k,\_|$$

Define x-axis as an axis normals to the coastline with positive in the shore ward direction. Let the angle between the ray and the positive x-axis be θ, and the angle between u,_ and the positive x-axis be β, locally. Equation-(1) can be written as :

Error!

where $C_g = |c,\_{g}|$ and $U = |u,\_|$

with straight and parallel depth contours : h = h(x), one has :

Error!

It follows that Equation-(3) reduces to :

Error!

The change in mean water level, _,_, due to change in radiation stress is taken into account in the model. The momentum equation reads :

Error!

with h = d + _,_

Error!

and
where S_{xx} : radiation stress component (N/m)
_,_ : wave induced mean water level above the horizontal reference level (m)
d : local depth of the bottom below the reference level (m)
h : local mean depth (m)
E : wave energy per unit surface area (J/m^2)

The effect of current field and bottom friction are not included in the momentum equation, as this is considered as a third order effect on the energy decay.

Energy balance Equation-(5) and momentum Equation-(6) form a system of two ordinary, first order differential equations. Two independent variables namely, H_{rms} and _,_ are derived numerically by using Runge-Kutta of the fourth order algorithm.
4.2.2) > Dissipation functions

The dissipation power terms, D of Equation-(1), included in CRESS module 233 are dissipation due to wave breaking, D_b and dissipation due to bottom friction, D_f. In this research, wave damping by mangrove forest and by percolation process are also included in the modification version as :

- dissipation due to mangrove root schematized as a set of cylinder rods, D_c, and schematized as bottom friction.
- dissipation due to wave percolation, D_p, when waves propagate over a permeable bed.

All of these dissipation terms will be shortly described as follows :

a) damping by wave breaking

Dissipation by wave breaking for unidirectional random waves was first proposed by Battjes and Janssen (1978). A wave height distribution of non breaking waves is Rayleigh distribution. It takes the form :

Error!

where H^* is some reference wave height. The maximum wave height, H_m, was proposed by Miche as :

Error!

The broken height coefficient, γ, is dependent on the incident wave steepness and bottom profile. The fitted line with the tested data in the laboratory (Delft Hydraulics) and field measurement has the form :

$$\gamma = 0.5 + 0.4 \tanh(33\, S_0)$$

where S_0 : deep water wave steepness (-)

The dissipated power per unit area due to breaking, D_b, can be written as :

Error!

Error!

or
where α : proportionality coefficient = 1 (-)

The probability, Q_b, that at some location x, a wave height is associated with a breaking or broken wave ($H \geq H_m$) is of the form :

Error!

where $b = H_{rms} / H_m$

b) damping by bottom friction

For regular wave, Putnam and Johnson (1949) proposed the bottom friction dissipation per unit area of the form :

Error!

where f_w : bottom friction coefficient (-)

By considering unidirectional random waves with Rayleigh distribution, the corresponding modification of Equation-(14) reads :

Error!

where F(H) is a probability density function of Rayleigh distribution : Equation-(8).

By performing an integration, one obtains :

Error!

c) damping by mangrove forest

The typical mangrove root systems have a stick shape like as shown in Figure-2/2. The dissipation by the root systems can be derived from the instantaneous rate of work done by drag forces on cylinder as :

Error!

where C_D : drag coefficient (-)
D : diameter of cylinder (m)
u_b : fluid velocity at the bottom (m/s)

By integration over depth and over wave period, the energy dissipation per unit area for a regular wave train (Ippen, 1962) has the form :

Error!

where n : number of piles or cylinders per unit area ($1/m^2$)
a : wave amplitude (m)
w : wave frequency (1/s)

Equation-(18) is a model for energy dissipation taken out by mangrove trunks. This can be extended for unidirectional random wave with Rayleigh distribution as done for the bottom friction term as :

Error!

By performing an integration, one obtains :

Error!

The effect of mangrove roots which penetrate the boundary layer can be treated as a bottom friction term. The bottom shear stress is proportional to the square of the fluid velocity at the bottom (same as Equation-(16)). The bottom friction coefficient, f_w, of Equation-(16) for damping caused by root systems can be derived with the above mentioned cylinder approach.

By integration Equation-(17) over the root (cylinder) height, L, one has the bottom

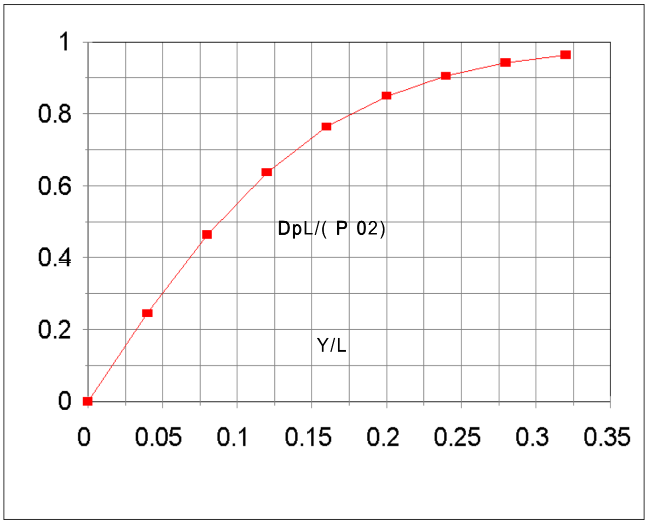
Error!

friction coefficient, f_w, for mangrove roots damping as :

Thus, the modification of CRESS module 233 including the dissipation by mangrove forests can be formulated as :

- damping by mangrove trunks via Equation-(20), and
- damping by mangrove roots as bottom friction term via Equation-(16) with friction coefficient, f_w, of Equation-(21).

d) damping by percolation



According to Putnam (1949), for regular wave, the amount of energy dissipation by viscous forces in the permeable bed per unit area per unit time (average over a wave length), D_p, is given by:

where Φ_0 : potential function = g H/ (cosh kh)
Y : thickness of permeable bed (m)

Error!

L : wave length (m)
v : kinematic viscosity of water (m^2/s)
P : intrinsic permeability coefficient of Darcy's Law (m^2)

or,

Equation-(23) reveals that percolation damping has an effective permeable depth as related to wave length. This is illustrated in Figure-4/1 which is a plot of both sides of Equation-(23).

Figure-4/1 shows that for ratio Y/L larger than about 0.3, the permeable depth is no

$$D_p = \pi g^2 over À\_\_\_,\_\_H^2$$

longer has any significant effect on the percolation dissipation. Thus, in such case, Equation-(22) can be reduced as :

For wave approaching the banks of inland waterway, wave length is in the order of 10 m. Therefore, the permeable bed can be reasonably assumed as greater than 0.3 L (about 3 m). Hence, Equation-(24) was used in the formulation in this study. This equation can be extended for unidirectional random wave with Rayleigh distribution as :

Error!

By performing an integration, one obtains :

Error!

Error!

The intrinsic permeability, P, is related to the hydraulic permeability, k_h, as :
where k_h : hydraulic permeability (m/s)

Therefore, Equation-(26) can be rewritten as :

Error!

Equation-(28) was used in modification of CRESS module 233 for wave damping by percolation process.

4.3) Model calibration

In this section, the dissipation models developed for damping by mangrove forests (via trunks and roots) and by percolation process in the previous section will be calibrated. The calibration of the models are as follows:

- For damping caused by mangroves, the model will be used for hindcasting and compared with the laboratory flume data.
- For damping by percolation process, the model computation will be compared with other computation methods (no test data is available).

4.3.1) > Mangrove damping calibration

As discussed under section 4.2.2, the dissipation by mangrove forests can be modeled with two categories as :

- dissipation by mangrove trunk, Equation-(20), and
- dissipation by mangrove roots, Equation-(16) with bottom friction, f_w, of Equation-(21).

A set of data available for calibration was done in the laboratory flume (Delft University of Technology, R.A. Groen, 1983). In the tests, cylinders of 0.3 m height with 0.9 cm diameter were placed in an array with density of about 200 and 400 rods/m^2 in the flume. A set of wave parameters was generated. The wave heights after passing the cylinder array of about 4 m in distance were measured. Then, the transmission coefficient, K_t, (which is a ratio between the measured wave height after damping and the incident wave height) was calculated for each test.

There were two sets of flume tests. The first test was a test on 0.25 m water depth. This is comparable to the dissipation by mangrove trunks since the water depth is lower than the cylinder height. This set of data was used to compared with the hindcasted values by

Equation-(20). The second test was a test on 0.50 water depth. This is comparable to the dissipation by mangrove roots since the water depth is larger than the cylinder height. This set of data was used to compared with the hindcasted values by Equation-(16) and Equation-(21).

In hindcasting, both dissipation terms require a drag coefficient, C_D . A C_D value depends on the Keulegan Carpenter number, K_C and the spacing of the cylinders. A K_C value is dependent on a wave period, T, a cylinder diameter, D, and a mean bottom orbital velocity, u_b as :

$$K_C = (U_b T) / D$$

Figure-4/2 shows the relationship between C_D and K_C with various cylinder spacing (Heideman et al, 1985). The C_D values from this Figure were used in hindcasting.

It was noted that the regular waves were used in the flume while the random Rayleigh distribution waves were used in the CRESS modified model. Thus, during calibration, the probability of breaking wave, Q_b ,due to wave height distribution in CRESS was imposed as zero. The flume data and the computed data are compared and tabulated as :

- The first data set and the results predicted from Equation-(20) as a model for dissipation by mangrove trunks are summarized as shown in Table-4/1 to Table-4/2.
- The second data set and the results predicted from Equation-(16) and Equation-(21) as a model for dissipation by mangrove roots are summarized as shown in Table-4/3 and Table-4/4.

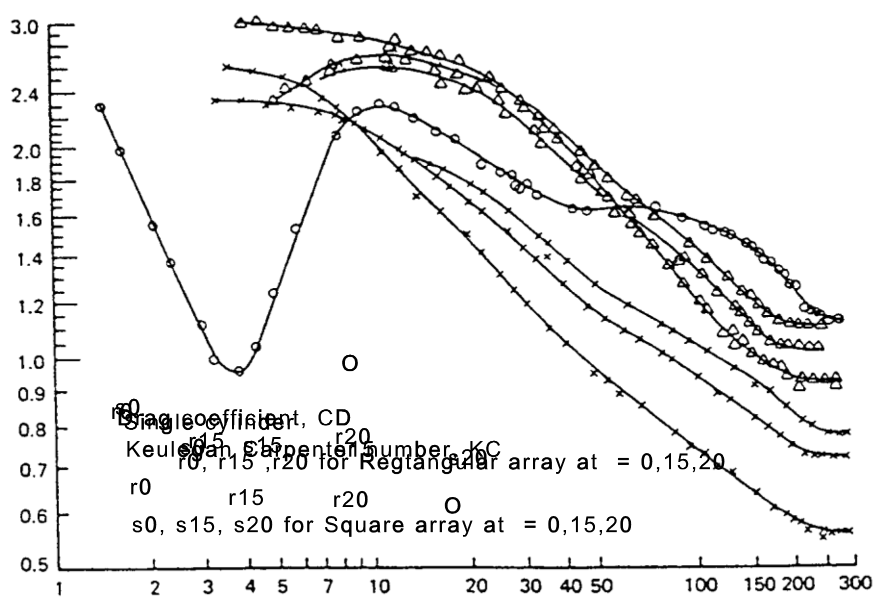


FIGURE-4/2 : K_C number and C_D value relationship (Heideman et al, 1985)

TABLE-4/1 : Calibration of damping by mangrove trunks

wave period	wave height	K_C	C_D	f_w	K_t	
(sec)	(m)	(-)	(-)	(-)	Flume	CRESS
0.80	0.068	26	2.40	-	0.46	0.47
1.00	0.087	37	2.05	-	0.44	0.47
1.20	0.096	47	1.82	-	0.48	0.49

1.50	0.096	56	1.65	-	0.40	0.52

Note : 1) n = 400 rods/m^2 : water depth = 0.25 m
2) $f_w = 0$

TABLE-4/2 : Calibration of damping by mangrove trunks

wave period	wave height	K_C	C_D	f_w	K_t	
(sec)	(m)	(-)	(-)	(-)	Flume	CRESS
0.80	0.065	24	2.47	-	0.60	0.65
1.00	0.079	34	2.15	-	0.60	0.66
1.20	0.077	38	2.05	-	0.67	0.67
1.50	0.068	40	2.00	-	0.79	0.72

Note : 1) n = 200 rods/m^2 : water depth = 0.25 m
2) $f_w = 0$

TABLE-4/3 : Calibration of damping by mangrove roots

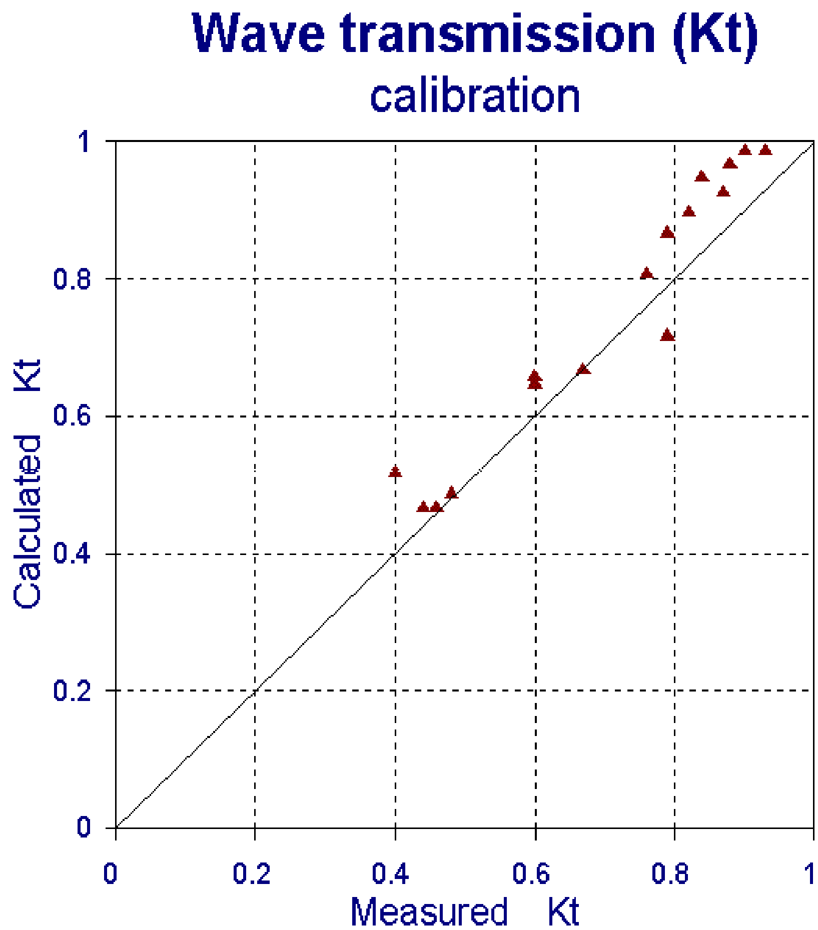
wave period	wave height	K_C	C_D	f_w	K_t	
(sec)	(m)	(-)	(-)	(-)	Flume	CRESS
0.80	0.108	38	2.05	1.107	0.93	0.99
1.00	0.160	58	1.60	0.864	0.84	0.95
1.20	0.182	70	1.50	0.810	0.79	0.87
1.50	0.175	78	1.40	0.756	0.76	0.81

Note : 1) n = 400 rods/m^2 : water depth = 0.50 m
2) f_w from Equation-(21)

TABLE-4/4 : Calibration of damping by mangrove roots

wave period	wave height	K_C	C_D	f_w	K_t	
(sec)	(m)	(-)	(-)	(-)	Flume	CRESS
0.80	0.109	38	2.05	0.554	0.90	0.99
1.00	0.156	56	1.65	0.446	0.88	0.97
1.20	0.179	69	1.50	0.405	0.87	0.93

1.50	0.164	73	1.45	0.392	0.82	0.90



Note : 1) n = 200 rods/m^2 : water depth = 0.50 m
2) f_w from Equation-(21)

Figure-4/3 illustrates the calibration of the mangrove dissipation models by plotting the measured values from flume tests versus the calculated values by CRESS (from Table-4/1 to Table 4/4). It can be seen that both data sets are close to the 45 degree line. Therefore, The dissipation models are quite reasonable.

4.3.2) > Percolation calibration

The dissipation by percolation process is taken into account in CRESS program via Equation-(28) as mentioned under section 4.2.2. There is no laboratory data available. Therefore, the numerical computation of Equation-(28) within CRESS will be compared with the following computation methods as :

1) Putnam (1949) proposed the dissipation function for regular wave train as shown in Equation-(24). Wave dissipation was calculated during wave transformation toward a shore. This was done by first approximation a wave height by neglecting bottom friction using the expression derived by O'Brien et al, (1942). The successive computations were performed until the solutions were matched during the iteration. Such tedious computation was computed for each step of distance interval.

2) C.L. Bretschneider and R.O. Reid (1954) worked out a general solution of the steady state wave height transformation equation (wave energy equation) which takes into account the effects of friction, percolation and refraction. The percolation dissipation takes the form proposed by Putnam (1949). The general solution requires the evaluation of an integral along the wave rays. They provided a set of graphs for various composition of bottom configurations and the friction terms taken into account.

Putnam demonstrated a numerical example of wave transformation from deep water to the theoretical frictionless breaker line. This was calculated for :

- deep water wave height, H_0 , 5 ft with 12 second period,
- beach slope 1 to 300 with straight and parallel depth contours, and
- bed permeability 100 Darcys (corresponds to a sand diameter of 0.104 mm and 35 % porosity.

The computations were calculated for two cases. First, it was computed by neglecting bottom friction as a base case (only shoaling effect was considered). Second, it was computed by including percolation dissipation and shoaling effect. The wave heights were calculated during propagation to a shore for both cases. The percentage of wave reduction effected by percolation process was carried out. This is defined as a ratio, R_e , between the wave height calculated from percolation effect to the wave height calculated from the base case.

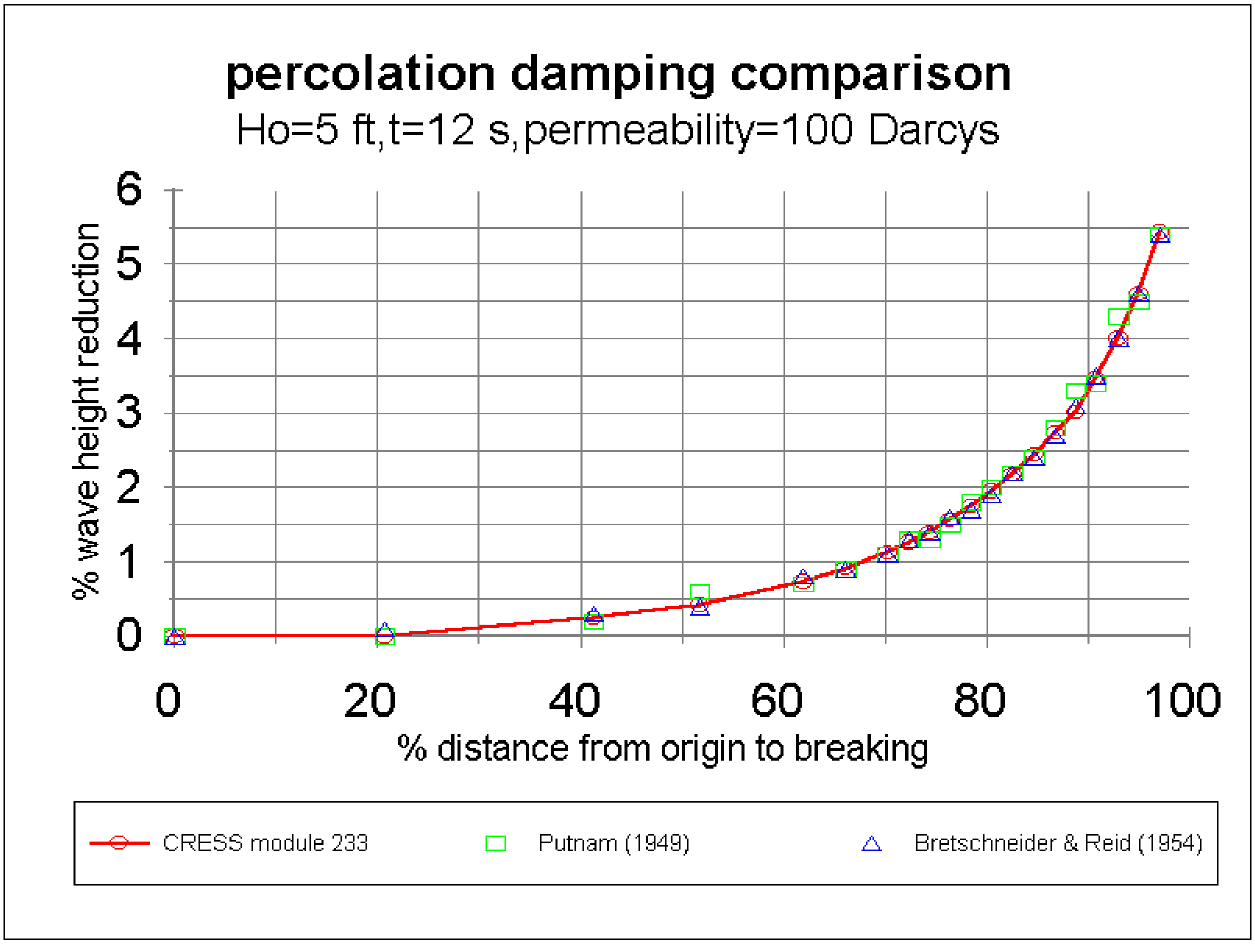
The numerical computation for different methods were summarized and compared in Table-4/5. In case of Bretschneider et al, only the reduction ratio is shown as it is only available in the reference. For comparison purpose, again, the probability of breaking wave, Q_b, due to Rayleigh wave height distribution in CRESS was imposed as zero.

TABLE-4/5 : Percolation damping comparison

distance	depth	Putnam (1949)			Bretschneider et al,(1954)			CRESS module 233		
(m)	(m)	H_{nf} (ft)	H_{wp} (ft)	R_e %	H_{nf} (-)	H_{wp} (-)	R_e %	H_{nf} (m)	H_{wp} (m)	R_e %
32,688	112.36	5.00	5.00	-	nav	nav	-	1.525	1.525	-
25,906	89.97	4.90	4.90	-	nav	nav	0.1	1.503	1.502	0.1
19,176	67.59	4.68	4.67	0.2	nav	nav	0.3	1.461	1.458	0.2
15,779	56.18	4.63	4.60	0.6	nav	nav	0.4	1.436	1.430	0.4
12,414	44.77	4.60	4.57	0.7	nav	nav	0.8	1.414	1.403	0.8
11,075	40.47	4.58	4.54	0.9	nav	nav	0.9	1.408	1.395	0.9
9,703	35.95	4.55	4.50	1.1	nav	nav	1.1	1.406	1.390	1.1
9,016	33.71	4.55	4.49	1.3	nav	nav	1.3	1.406	1.389	1.2
8,363	31.47	4.55	4.49	1.3	nav	nav	1.4	1.408	1.389	1.3
7,710	27.04	4.58	4.51	1.5	nav	nav	1.6	1.417	1.395	1.6
7,024	26.95	4.58	4.50	1.8	nav	nav	1.7	1.418	1.393	1.8
6,370	24.71	4.60	4.51	2.0	nav	nav	1.9	1.426	1.398	2.0
5,684	22.47	4.63	4.53	2.2	nav	nav	2.2	1.436	1.405	2.2
4,998	20.23	4.68	4.57	2.4	nav	nav	2.4	1.451	1.415	2.5
4,312	17.99	4.73	4.60	2.8	nav	nav	2.7	1.470	1.430	2.7
3,659	15.71	4.83	4.67	3.3	nav	nav	3.1	1.496	1.450	3.0
3,005	13.47	4.95	4.78	3.4	nav	nav	3.5	1.530	1.477	3.5
2,287	11.24	5.10	4.90	4.3	nav	nav	4.0	1.575	1.512	4.0
1,633	8.99	5.30	5.06	4.5	nav	nav	4.6	1.639	1.564	4.6
947	6.76	5.60	5.30	5.4	nav	nav	5.4	1.733	1.639	5.4
294	4.47	6.10	5.70	6.6	nav	nav	6.6	*	*	*
0	3.47	6.40	5.93	7.3	nav	nav	7.3	*	*	*

Note : 1) distance : referred to a theoretical frictionless breaker line
2) H_{nf} : wave height calculated with shoaling excluding friction effect
3) H_{wp} : wave height calculated with shoaling and percolation effect
4) % R_e : 100 x (1 - H_{wp}/H_{nf})
5) nav : no data available
6) * : no data due to breaker line calculated with CRESS is different from Putnam's theoretical frictionless breaker line

Figure-4/4 demonstrates the percolation damping comparison . All of the computation



methods are comparable.

4.4) Investigated parametric ranges

Wave transmission through mangroves is dependent on many parameters such as wave and mangrove characteristics, bottom slope, water depth and soil permeability. Therefore, a set of realistic parametric ranges need to be set up for investigation. In this study, such realistic parametric ranges were carried out as the following :

1) wave characteristics

The typical values of the main ship-induced hydraulic loads are shown in Table-4/6.

TABLE-4/6 : Typical values of ship-induced hydraulic load

Type of waterways	return current	water level depression		secondary waves	
	(m/s)	H (m)	T (sec)	H (m)	T (sec)
- small rivers and restricted navigation channels	1-2	0.5-0.75	20-60	0.5	2-5
- large navigation channels	2	1.0	20-60	1.0	2-5
- large rivers & estuaries	3-4	1.0	20-60	1.0	2-5

Source : PIANC, 1987 (reference no.19)

By considering the typical values from Table-4/6, wave heights of 0.2, 0.5 and 1.0 m will be used for examination. Generally, locally generated waves have a wave steepness ratio, H/L, in the order of 4 to 5 percent. The ratio of 4 percent will be used in this study. Thus, the corresponding wave length, L, and wave period, T, for each wave height can be calculated as tabulated in Table-4/7. It is noted that wave period is not significantly influence the damping effect caused by mangroves (Schiereck and Booij, 1995).

TABLE-4/7 : Study wave characteristics

H_s (m)	L (m)	T (sec)
0.2	5.0	1.80
0.5	12.5	2.80
1.0	25.0	4.00

2) mangrove characteristics

As described under section 4.2.2, dissipation by mangrove forests can be modelled as dissipation by trunks and dissipation by roots.

Equation-20 is a model for energy dissipation taken out by mangrove trunks. This is dependent on mangrove characteristics of n, C_D and D values.

where n : number of trunks per unit area ($1/m^2$)
C_D : drag coefficient (-)
D : trunk diameter (m)

These parameters for a natural mangrove forests need to be estimated before computations. There is very limited quantitative information available. Hence, only rough estimates can be made. In this study, the estimation mostly referred to Schiereck and Booij, 1995 study which can be described as the following.

According to Snedaker and Snedaker, 1985, the relationship between trunk diameter, D (m), and density, n ($1/m^2$), can be approximated with,

$$n = 0.007 D^{-1.50}$$

Practically, the standardize measurement of the stem diameter is taken at 1.3 m above ground level. This diameter is called diameter at breast-height, d_{bh} . Unless specified, d_{bh} is assumed to include the thickness of the bark. Equation-30 was derived from various mangrove locations in the new world (Snedaker, 1985). The field measurement carried out by Bambang Sarwono in 1993 on three mangrove plots along the Kalibuntu coastline, Indonesia was proved to be satisfied with Equation-30 as well.

It has been reported that trunk diameter ranges from 0.05 m to 0.25 m. By using Equation-30, the corresponding nD values can be computed as 0.03 and 0.015 respectively. Based on Equation-29 and Figure-4/2, it can be drawn out that C_D value for the small trunk diameter will not much differ from unity, while for a large trunk, it can vary between 1 and 3 depending on the wave period. Thus, the product of nC_DD can be calculated as,

$$nC_DD = (0.03)(1) = 0.03$$
and $$= (0.015)(1) = 0.015$$
and $$= (0.015)(3) = 0.045$$

Hence, a possible range of the product of nC_DD is assumed between 0.01 and 0.05.

Equation-21 represents a bottom friction coefficient, f_w, for mangrove roots dissipation. This is dependent on mangrove characteristics of n, C_D, D and L values.

where n : number of roots per unit area ($1/m^2$)
C_D : drag coefficient (-)
D : root diameter (m)
L : root height (m)

The possible values of these parameters for *Avicennia* and *Rhizophora* root systems will be estimated. The field measurement on the root systems is very scanty. Only rough estimates can be done as follow.

- *Avicennia* roots

Near the trunk, the density of pneumatophores of *Avicennia* of about 400-500 roots/m^2 has been reported (Spenceley, 1977). Outside a distance of 3 m from the trunk, he reported a spacing of about 6 cm corresponding to about 250 roots/m^2. Bird (1980) reported a value of less than 100 roots/m^2. The pneumatophore diameters are estimated as 0.5 cm while the height can reach values between 0.15 m and 0.25 m. The C_D values for these small pnuematophores in real waves can be assumed as unity.

With the assumed root height of 0.2 m and a density varying between 50/m^2 and 400 /m^2, this leads to a range of coefficient, f_w, values as,

$$0.5\, nC_DDL = (0.5)(50)(1)(0.005)(0.2) = 0.025$$

and

$$= (0.5)(400)(1)(0.005)(0.2) = 0.20$$

- *Rhizophora* roots

There is hardly any quantitative information on *Rhizophora* stilt roots. Sato (1989) has done some measurements on these parabolically shaped roots (Figure-2/2). The stilt roots reach up about 0.5 m to 1 m above the ground. The average diameter varies from 2-3 cm while the average number of roots in the first 0.5 m above ground varies from 10-200 roots. The C_D values for these small diameter of stilt roots in real waves can be considered as unity.

Given the upper limit of large trees with diameter of 0.25 m, the number of trees per unit area is 0.056/m^2 (Equation-30). The total root areas (vertical cross section against the flow) is calculated as 6 m^2 per tree (nDL = 200x0.03x1 = 6 m^2). This gives the bottom friction coefficient, f_w, calculated per square metre as,

$$0.5\, nDLC_D = (0.5)(6)(1) = 3 \quad (1/\text{tree})$$

or

$$= (3)(0.056) = 0.168$$

Given the lower limit of small trees with diameter of 0.05 m, the number of trees per unit area is 0.626/m^2 (Equation-30). The total vertical root areas per tree is calculated as 0.1 m^2 (nDL = 10x0.02x0.5 = 0.1 m^2). This gives the bottom friction coefficient, f_w, calculated per square metre as ,

$$0.5\ nDLC_D = (0.5)(0.1)(1) = 0.05 \quad (1/\text{tree})$$

or

$$= (0.05)(0.626) = 0.031$$

Therefore, the bottom friction coefficient, f_w, representing the dissipation caused by mangrove roots of the genus *Avicennia* and *Rhizophora* ranges from 0.025-0.20.

The preliminary study done by Schiereck and Booij (1995) indicated that within the possible ranges, the dissipation by trunks is much less effective than the dissipation by roots via the bottom friction term. Thus, in this study, only one value of the product of nC_DD as 0.03 representing the damping by trunks will be used with Equation-20 throughout the study.

The dissipation caused by root system through bottom friction coefficient, f_w, is classified into four catagories as 0.025, 0.05, 0.10 and 0.15 corresponding to the density of the mangrove root system defined as sparse, average, dense and very dense respectively. These four values of bottom coefficient will be used for investigation in this study via Equation-16 and Equation-21.

3) bottom slope

Generally, bottom slope in the vicinity of mangrove vegetation is a gentle slope, especially in the pioneer zone (the lowest and most seaward part of a mangrove forest). This is dependent on the amount of sediment supply into the area. It has been reported that for little sediment supply, the bottom slope is about 1 to 200, while for abundant sediment supply, the bottom slope is much flatter as 1 to 1000. (Chappell and Grindrod, 1984).

Bird, 1972 reported a mud flats in front of mangrove of slope 1 to 1000 or less. He reported slope between 1 to 50 and 1 to 300 for *Avicennia* area and 1 to 500 for *Rhizophora* area.

Thus, in this study, the bottom slope of 1 to 200 and 1 to 1000 will be investigated.

4) water depth

As described under section 2.1.4, the suitable tidal range for mangroves is between 0.5 to 3.0 metre. The water depth in this study is defined as a depth at the beginning of the incident waves where mangrove forests are vegetated : at the frontal line of vegetation. The water depth of 1 m, 2 m and 3 m will be investigated in this study.

5) soil permeability

The percolation damping caused by a permeable sub soil will be included in the study via a hydraulic permeability coefficient, k_h, of Equation-28. Table-4/8 illustrates the typical values of k_h for different types of soil.

TABLE-4/8 : Typical values of k_h for various soils

Type of soil	Hydraulic permeability (cm/sec)	Relative permeability
Coarse gravel	Exceed 10^{-1}	High
Sand, clean	10^{-1} to 10^{-3}	Medium
Sand, dirty	10^{-3} to 10^{-5}	Low
Silt	10^{-5} to 10^{-7}	Very low
Clay	Less than 10^{-7}	Impervious

Source : (reference no.26)

Damping by percolation process is of interest with a relatively high permeability soil. However, mangroves are hardy found in a gravel soil type. Therefore, in this study, the value of k_h of a sandy soil as 10^{-2} cm/sec will be used in the computations.

6) Mangrove width

The transmission coefficient, K_t, (defined as the ratio between the transmitted wave height and the incident wave height) at some distance from the frontal vegetation line will be calculated. In practice, the width of the mangrove belt as a coastal protection is between 50-200 m (Gan Boon Keong, 1995). In this study, a width of about 500 m will be investigated.

For non trivial solutions, the computation of transmission coefficient, K_t, across the mangrove width during wave propagation will not be carried out up to the intersection between water line and the sub soil, but up to a certain depth. Thus, the transmission coefficient, K_t, will be calculated every 50 m from the frontal line following the slope landward until the water depth of 0.25 m is reached or until the mangrove width of 500 m is reached depending on which criteria is met first.

4.5) Mangrove wave transmission tests

Given the realistic possible parametric ranges as described in the previous section, a number of tests was set up as shown in Table-4/9. The plots of transmission coefficient, K_t, versus mangrove width are shown in Figure-4/5 to Figure-4/16 corresponding to the test number 1 to 12 respectively.

TABLE-4/9 : Configurations of the mangrove wave transmission tests

Test No.	Slope	Water depth (m)	Wave characteristics		Figure	Investigated mangrove width (m)
			H (m)	T (sec)		
1	1:200	3	1.0	4.0	4/5	50-500
2	1:200	3	0.5	2.8	4/6	50-500
3	1:200	3	0.2	1.8	4/7	50-500
4	1:200	2	0.5	2.8	4/8	50-350
5	1:200	2	0.2	1.8	4/9	50-350
6	1:200	1	0.2	1.8	4/10	50-150
7	1:1000	3	1.0	4.0	4/11	50-500
8	1:1000	3	0.5	2.8	4/12	50-500
9	1:1000	3	0.2	1.8	4/13	50-500
10	1:1000	2	0.5	2.8	4/14	50-500
11	1:1000	2	0.2	1.8	4/15	50-500
12	1:1000	1	0.2	1.8	4/16	50-500

Note : 1) damping by mangrove trunks via the product of nC_DD as 0.03
2) damping by mangrove root system via bottom coefficient, f_w, varying with the root density as,
- $f_w = 0.025$ for sparse : $f_w = 0.10$ for dense
- $f_w = 0.05$ for average : $f_w = 0.15$ for very dense

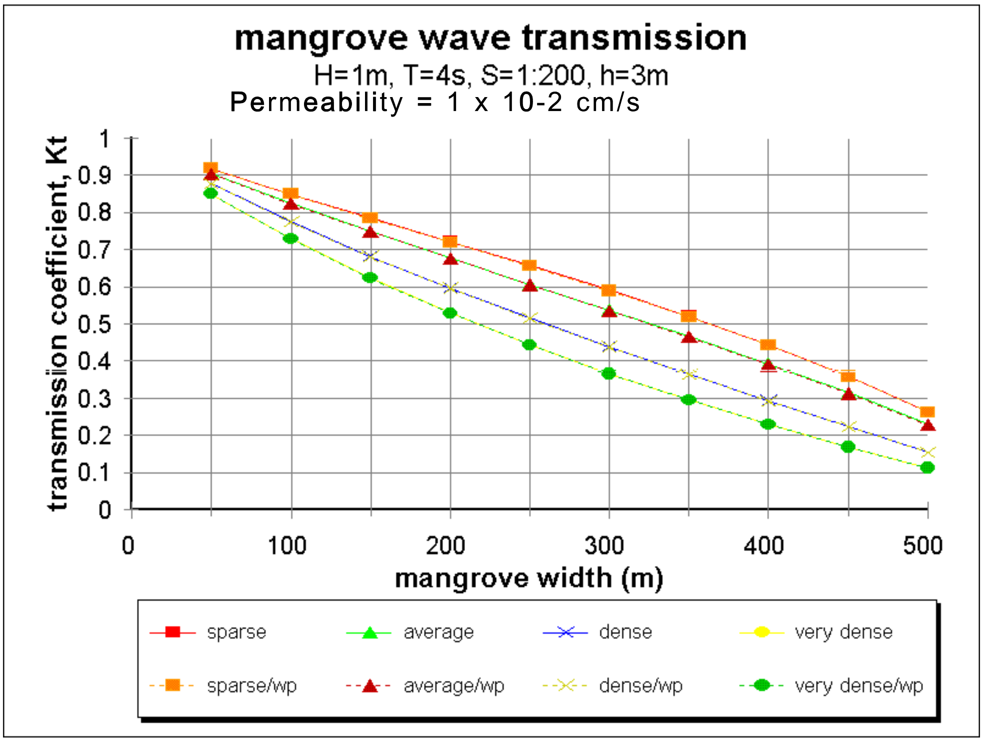
3) damping by percolation process with permeability, k_h, as 10^{-2} cm/s

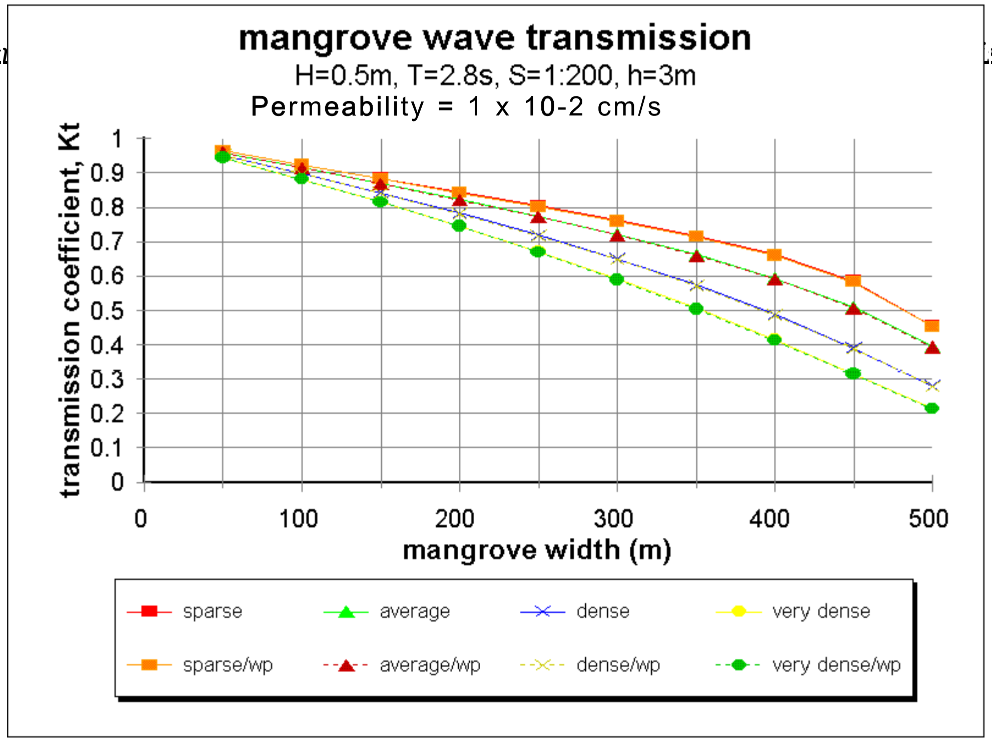
All tests were carried out with two sets of computations as follow :

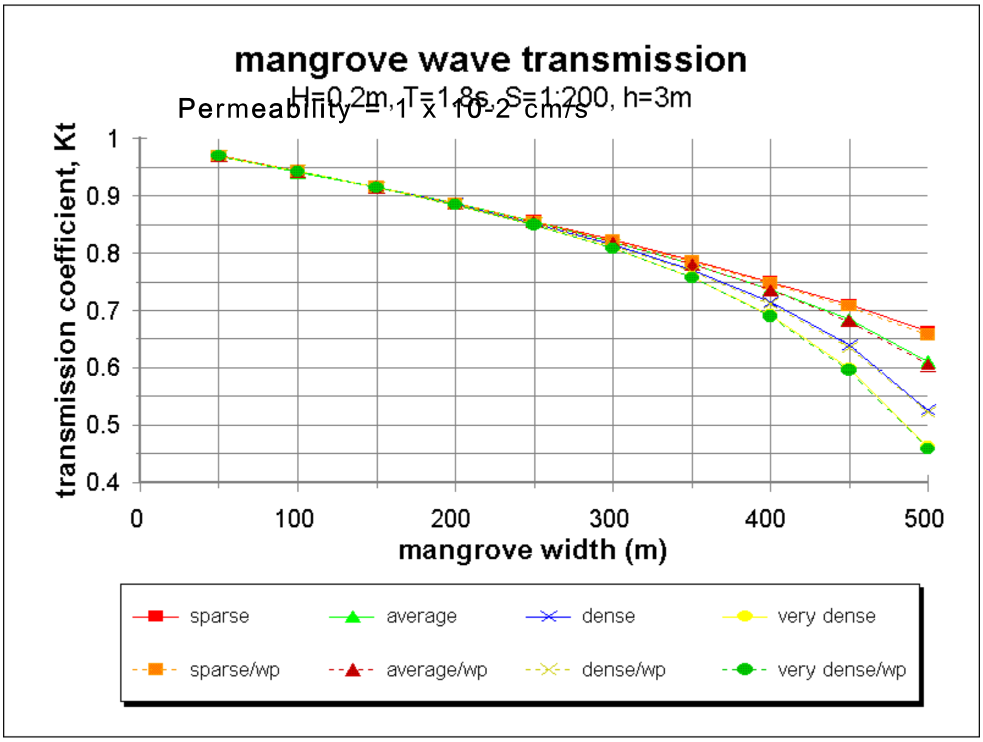
1) First, a set of computations on mangrove wave transmission, K_t, via trunks and

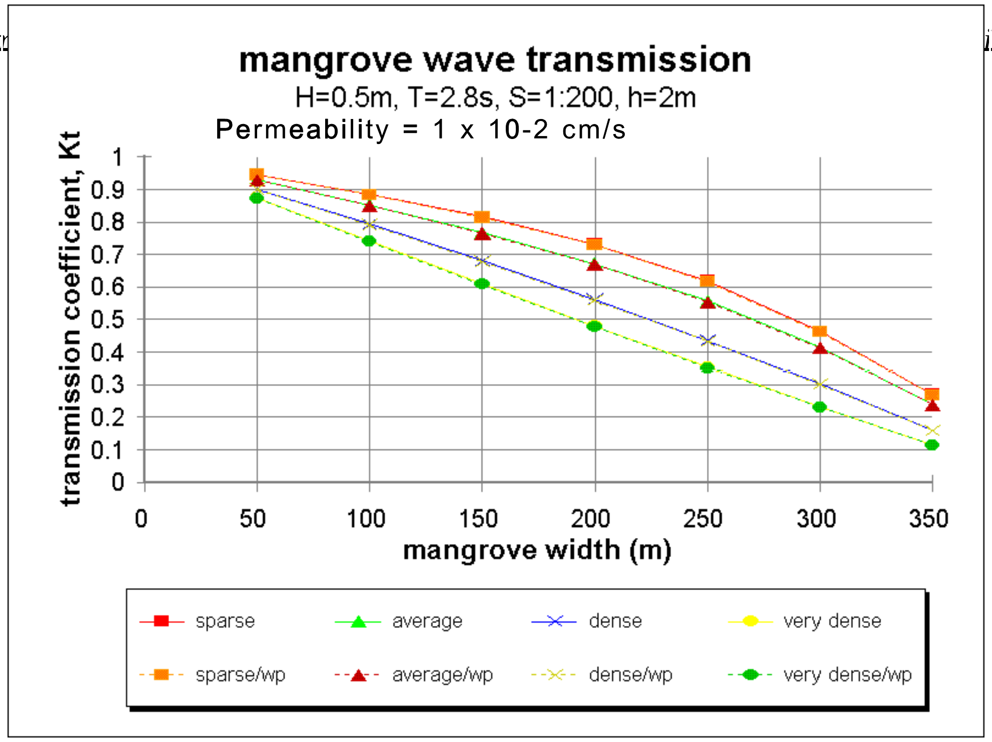
roots without percolation effect was carried out as shown with a set of solid lines in the Figures. There are four lines in each set corresponding to different density of mangrove root system as previously mentioned (sparse, average, dense and very dense).

2) When it was appropriate, the second set of computations was carried out by taken into account the percolation effect as well. These were shown as a set of dotted lines and labelled as sparse/wp, average/wp, dense/wp and very dense/wp in the Figures.

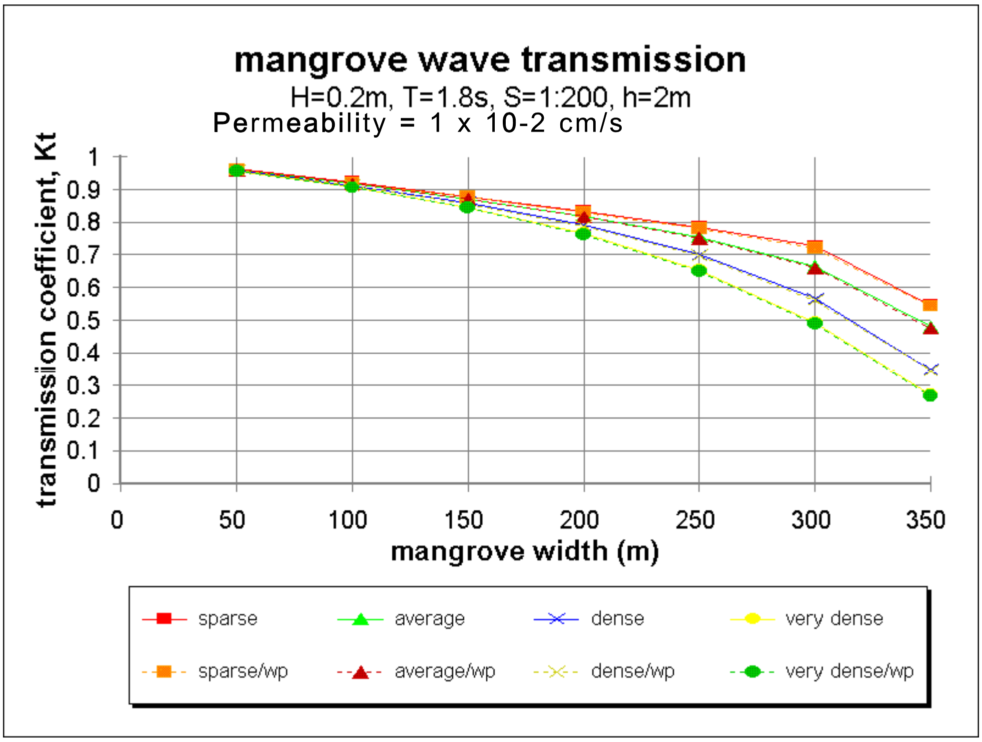


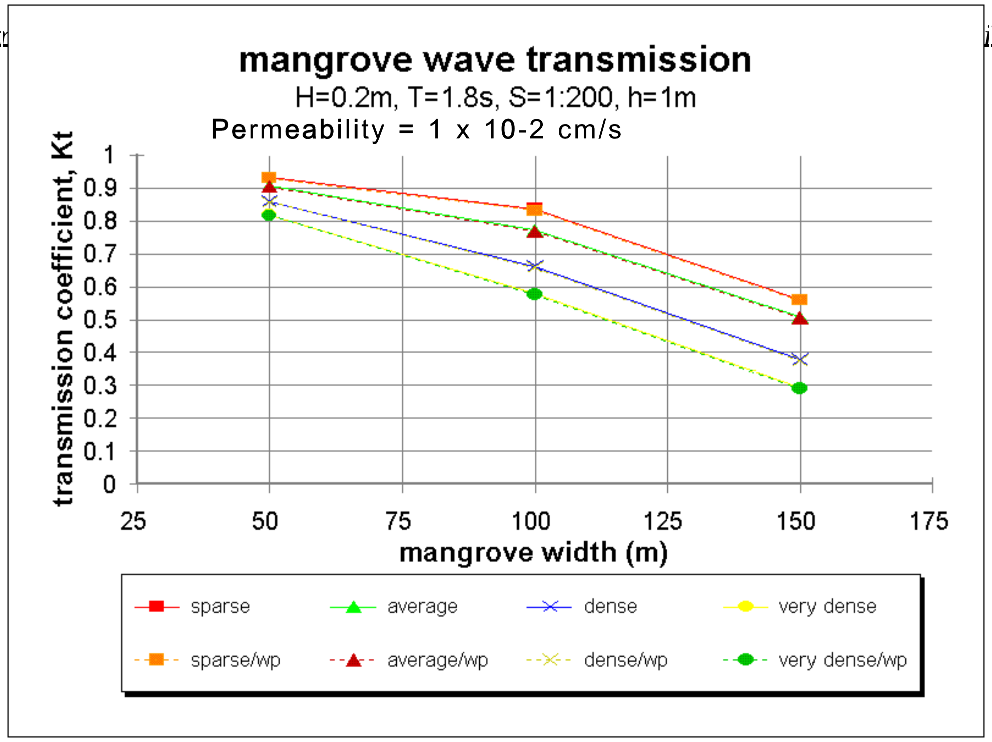

mangrove wave transmission
H=0.5m, T=2.8s, S=1:200, h=3m
Permeability = 1 x 10-2 cm/s
transmission coefficient, Kt
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
100
200
300
400
500
mangrove width (m)
sparse
average
dense
very dense
sparse/wp
average/wp
dense/wp
very dense/wp

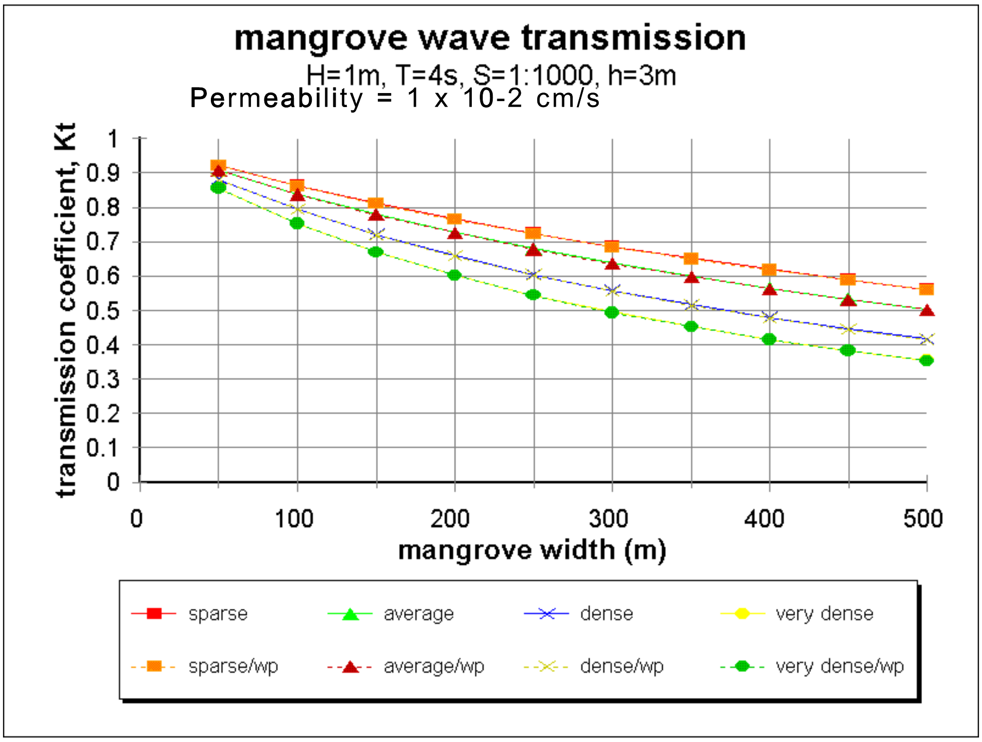

mangrove wave transmission
H=0.2m, T=1.8s, S=1:200, h=3m
Permeability = 1 x 10-2 cm/s
transmission coefficient, Kt
1
0.9
0.8
0.7
0.6
0.5
0.4
0
100
200
300
400
500
mangrove width (m)
sparse
average
dense
very dense
sparse/wp
average/wp
dense/wp
very dense/wp

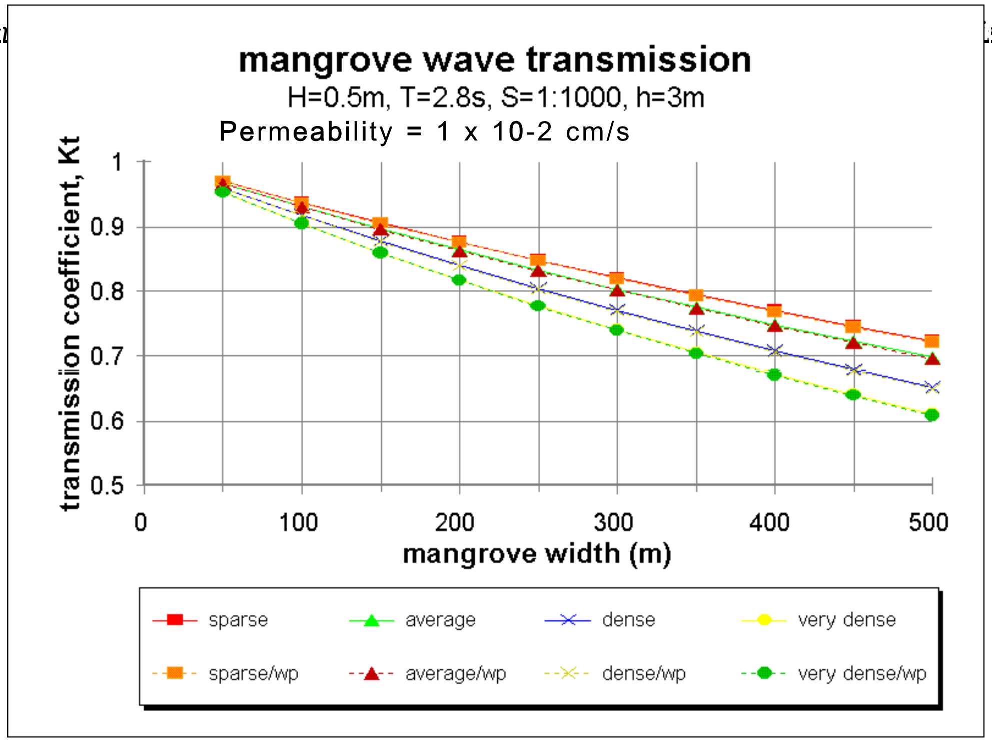


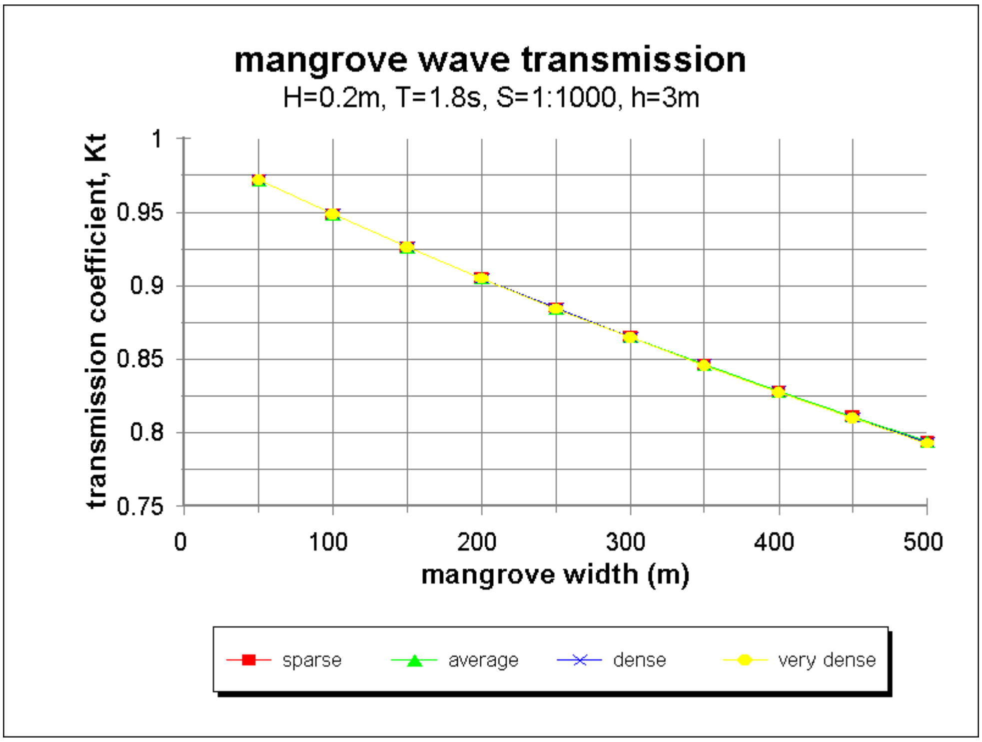
mangrove wave transmission
H=0.5m, T=2.8s, S=1:200, h=2m
Permeability = 1 x 10-2 cm/s
transmission coefficient, Kt
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
250
300
350
mangrove width (m)
sparse
average
dense
very dense
sparse/wp
average/wp
dense/wp
very dense/wp

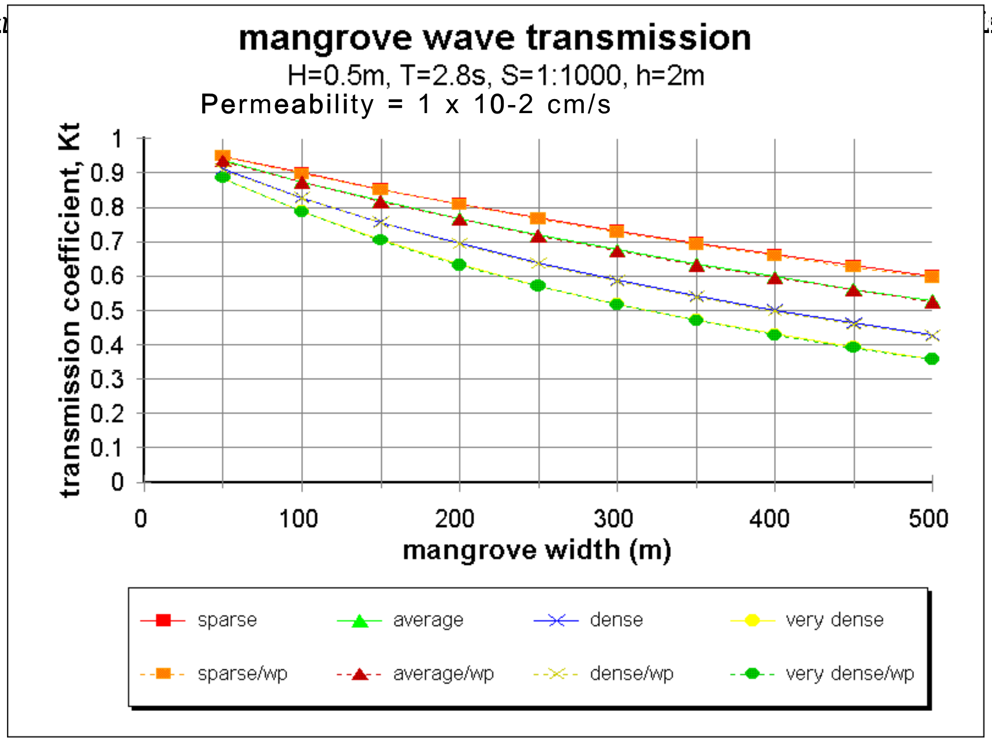

mangrove wave transmission
H=0.2m, T=1.8s, S=1:200, h=2m
Permeability = 1 x 10-2 cm/s
transmission coefficient, Kt
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
250
300
350
mangrove width (m)
sparse
average
dense
very dense
sparse/wp
average/wp
dense/wp
very dense/wp

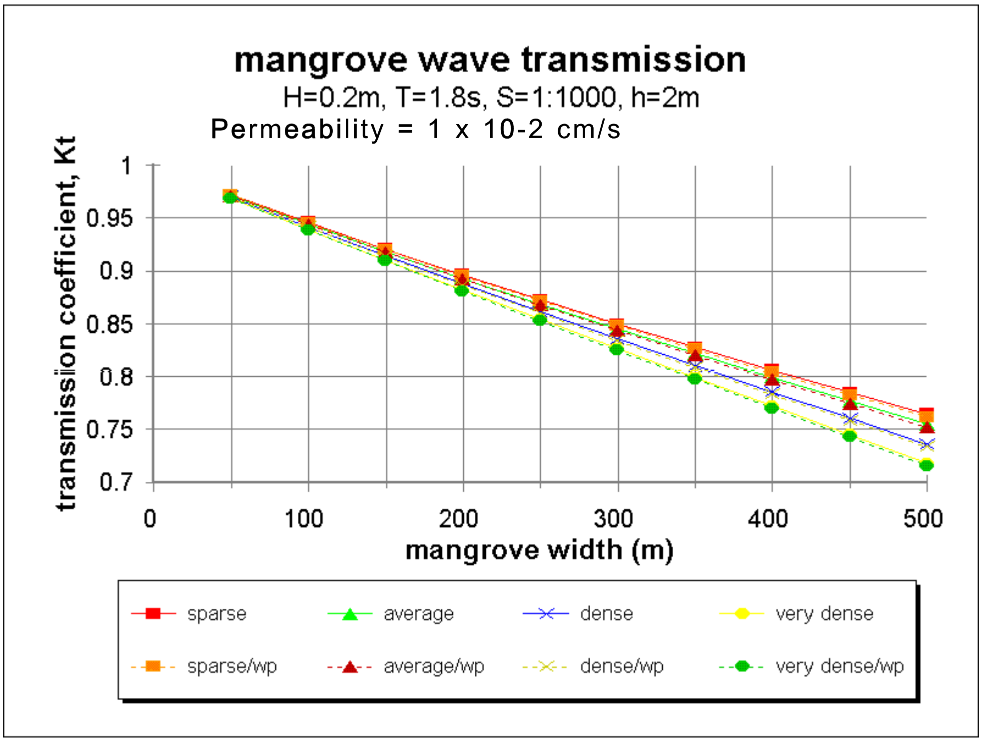

mangrove wave transmission
H=0.2m, T=1.8s, S=1:200, h=1m
Permeability = 1 x 10-2 cm/s
transmission coefficient, Kt
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
25
50
75
100
125
150
175
mangrove width (m)
sparse
average
dense
very dense
sparse/wp
average/wp
dense/wp
very dense/wp

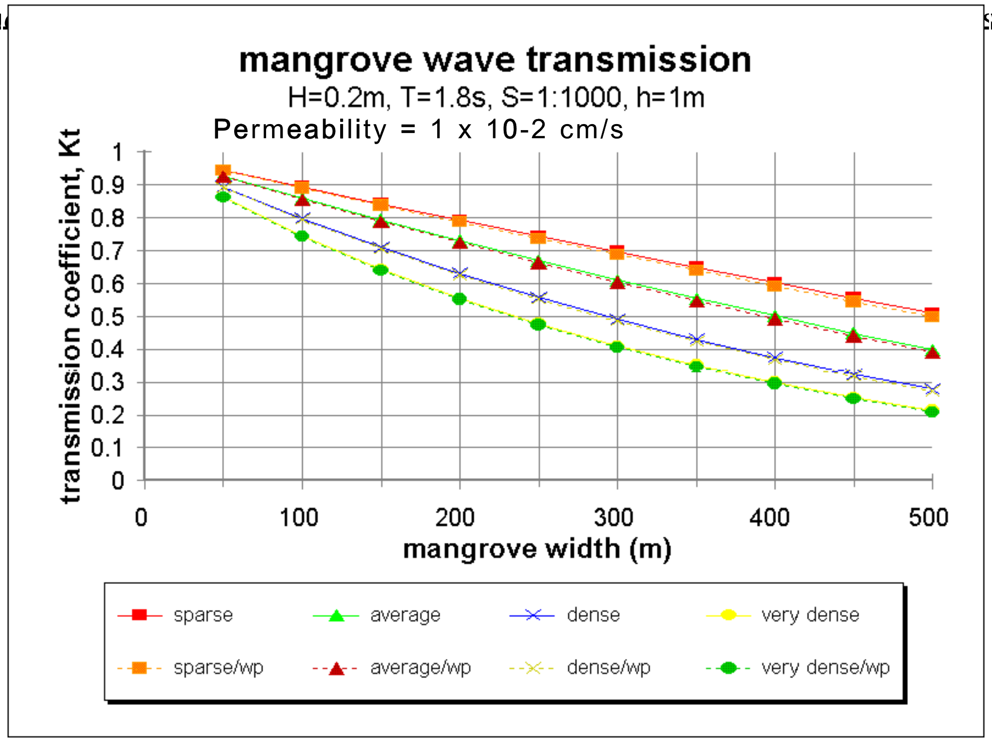

mangrove wave transmission
H=1m, T=4s, S=1:1000, h=3m
Permeability = 1 x 10-2 cm/s
transmission coefficient, Kt
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
100
200
300
400
500
mangrove width (m)
sparse
average
dense
very dense
sparse/wp
average/wp
dense/wp
very dense/wp


mangrove wave transmission
H=0.5m, T=2.8s, S=1:1000, h=3m
Permeability = 1 x 10-2 cm/s
transmission coefficient, Kt
1
0.9
0.8
0.7
0.6
0.5
0
100
200
300
400
500
mangrove width (m)
sparse
average
dense
very dense
sparse/wp
average/wp
dense/wp
very dense/wp


mangrove wave transmission
H=0.2m, T=1.8s, S=1:1000, h=3m
transmission coefficient, Kt
1
0.95
0.9
0.85
0.8
0.75
0
100
200
300
400
500
mangrove width (m)
sparse
average
dense
very dense


mangrove wave transmission
H=0.5m, T=2.8s, S=1:1000, h=2m
Permeability = 1 x 10-2 cm/s
transmission coefficient, Kt
mangrove width (m)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
100
200
300
400
500
sparse
average
dense
very dense
sparse/wp
average/wp
dense/wp
very dense/wp


mangrove wave transmission
H=0.2m, T=1.8s, S=1:1000, h=2m
Permeability = 1 x 10-2 cm/s
transmission coefficient, Kt
1
0.95
0.9
0.85
0.8
0.75
0.7
0
100
200
300
400
500
mangrove width (m)
sparse
average
dense
very dense
sparse/wp
average/wp
dense/wp
very dense/wp



4.6) <u>Results and conclusions</u>

The possible ranges for combination of various realistic parameters were tested in the previous section. According to the tests, the following results can be drawn as :

1) The denser the mangrove forests is, the smaller the wave transmission. This is obviously due to the larger bottom friction.

2) Given the same bottom slope and water depth, the higher the wave height is, the smaller the wave transmission. This is because of the larger orbital velocity at the bottom. A comparison among Figure-4/7, Figure-4/6 and Figure-4/5 is an example : the transmission coefficients, K_t, after passing 500 m width are in the order of 0.46-0.67, 0.2-0.47 and 0.1-0.26 for the wave height of 0.2, 0.5 and 1.0 m respectively.

3) Provided the same wave characteristics and bottom slope, the lower the water level is, the smaller the wave transmission. This is due to the larger bottom orbital velocity. A comparison among Figure-4/13, Figure-4/15 and Figure-4/16 is for instance : the transmission coefficients, K_t, after passing 500 m width are in the order of 0.78, 0.72-0.77, and 0.2-0.5 for the water depth of 3, 2, and 1 m respectively.

4) Given the same wave characteristics and water depth, the steeper the bottom slope is, the smaller the wave transmission. Again, this is due to the larger bottom orbital motion. A comparison between Figure-4/11 and Figure-4/5 is an example : the transmission coefficients, K_t, after passing 500 m width are in the order of 0.35-0.58 and 0.10-0.26 for the bottom slope of 1:1000 and 1:200 respectively.

By considering the tested results as a whole, the general conclusions can be drawn as :

1) In nature, a mangrove forest has its own damping characteristics depending upon wave scenario and boundary conditions locally (as shown in Figure-4/5 to Figure-4/16).

2) Within the combinations of various realistic parameters, it has been shown that wave and mangrove characteristics, bottom slope and water depth have a significant effect on the mangrove wave dissipation, while the percolation process can be neglected.

3) The density of mangrove forest has less influence on wave damping characteristic when the incident wave height is small (Figure-4/7 and Figure-4/9), especially, when propagates over a gentle slope (Figure-4/13 and Figure-4/15).

4.7) Discussion

The simple models for energy taken out via mangrove trunks and roots (modelled as work done by an array of rigid cylinders) were used in this study. The following discussion can be drawn as:

- Due to a very complex and random nature of the growth of mangrove stems and roots, it is very difficult to make a field measurement and assess the representative values of the stem and root characteristics: dimensions and density, especially for a root systems. For stem , it has been established a common diameter measurement which is called the diameter at breast-height, d_{bh} ,(Snedaker,S.C. and Snedaker,J.C., 1984). The statistical analysis on the data either from field or laboratory is required to asses a better representative values.

- A relationship between drag coefficient, C_D, for an array of cylinders and Keulegan Carpenter number, K_C, is shown in Figure-4/2. This means for a rigid cylinders. However, in reality, mangrove stems and roots are flexible. Therefore, an error in computation exists which is dependent on the degree of flexibility in the nature. For rigid cylinders, strong vortices are formed resulting in a strong damping. Hence, the model computation is more likely to overestimate the damping effect caused by mangrove trunks and root system.

Chapter 5
Conclusions and Recommendations

5.1) Conclusions

Environment-friendly bank protection provides not only a protective function but also offers room for nature development. This is quite a new concept in Thailand. Owing to its broad subject, this study can only be a primitive study. As far as the study is concerned, the following conclusions can be drawn :

- Lack of public and government awareness, and ambiguity among various laws cause difficulty in implementation of such an environment-friendly bank protection.

- It is possible to use DIPRO program for ship-induced hydraulic loads computation with a natural river by performing an appropriate schematization : provided the wetted cross sectional areas are the same as in reality.

- Though, a simple model was developed and used in this study, it provides as a primary tool for investigation of mangrove wave damping characteristics taken into account a percolation process.

- It was found that mangrove forests can significantly dissipate wave energy : reduce wave transmission. Therefore, they protect the land against erosion and promote the sedimentation. This is in line with the view increasingly accepted that their establishment leads to a rapid accumulation (Thom, 1967; Carlton, 1974: Zimmermann and Thom, 1982).

- Due to the flexible roots and stems in reality instead of rigid behavior modelled, the computed damping effects are more likely overestimated.

- It was found that, within the possible realistic parametric ranges, wave dissipation through mangrove forests over a permeable bed via percolation process can be neglected.

- At this stage, it is still not possible to make a design of a purely mangrove bank protection, as many physical behaviors of mangrove strength and hydraulic loads have not been studied and well understood. Therefore, the possible solution is a compromise between the common practice of hard structures and the ecological sound bank protection within the available tools and knowledge.

5.2) Recommendations

Along the inventory study and mangrove wave transmission study, the following are the recommendations :

- To advance the practice state of an environment-friendly bank protection, the following climate should be created.
  - developing a better understanding of the ecological values of the natural banks.
  - promoting policy from national to local levels.
  - establishing the unambiguous terms among various laws and regulations.
  - setting up a national data base on banks information.

- To assess the better representative values of natural mangrove characteristics : dimensions and density, the statistical analysis of the measurement data either from field or laboratory is required.

- Before a further realization of environment-friendly bank protection incorporating mangrove vegetation can be made, various researches are needed, for instance :
  - flow velocity through the tortuous root shape,
  - the permissible shear stress of the root-soil systems,
  - seasonal strength of mangrove vegetation variation, and
  - strength of mangrove vegetation due to frequency of wave loading, etc.

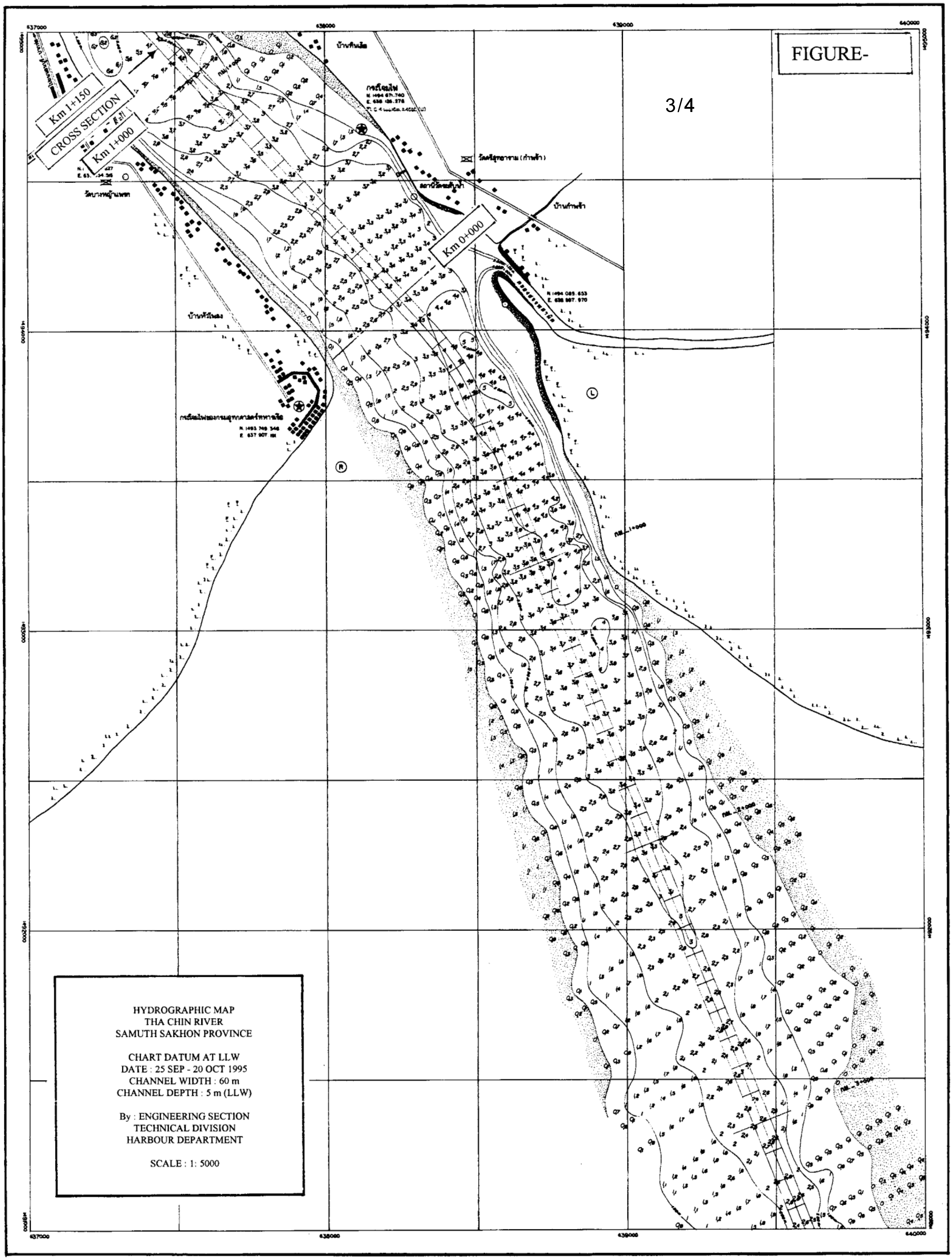


FIGURE-
3/4
Km 1+150
CROSS SECTION
Km 1+000
Km 0+000
637000
638000
639000
640000
HYDROGRAPHIC MAP
THA CHIN RIVER
SAMUTH SAKHON PROVINCE
CHART DATUM AT LLW
DATE : 25 SEP - 20 OCT 1995
CHANNEL WIDTH : 60 m
CHANNEL DEPTH : 5 m (LLW)
By : ENGINEERING SECTION
TECHNICAL DIVISION
HARBOUR DEPARTMENT
SCALE : 1: 5000

FIGURE-

3/4

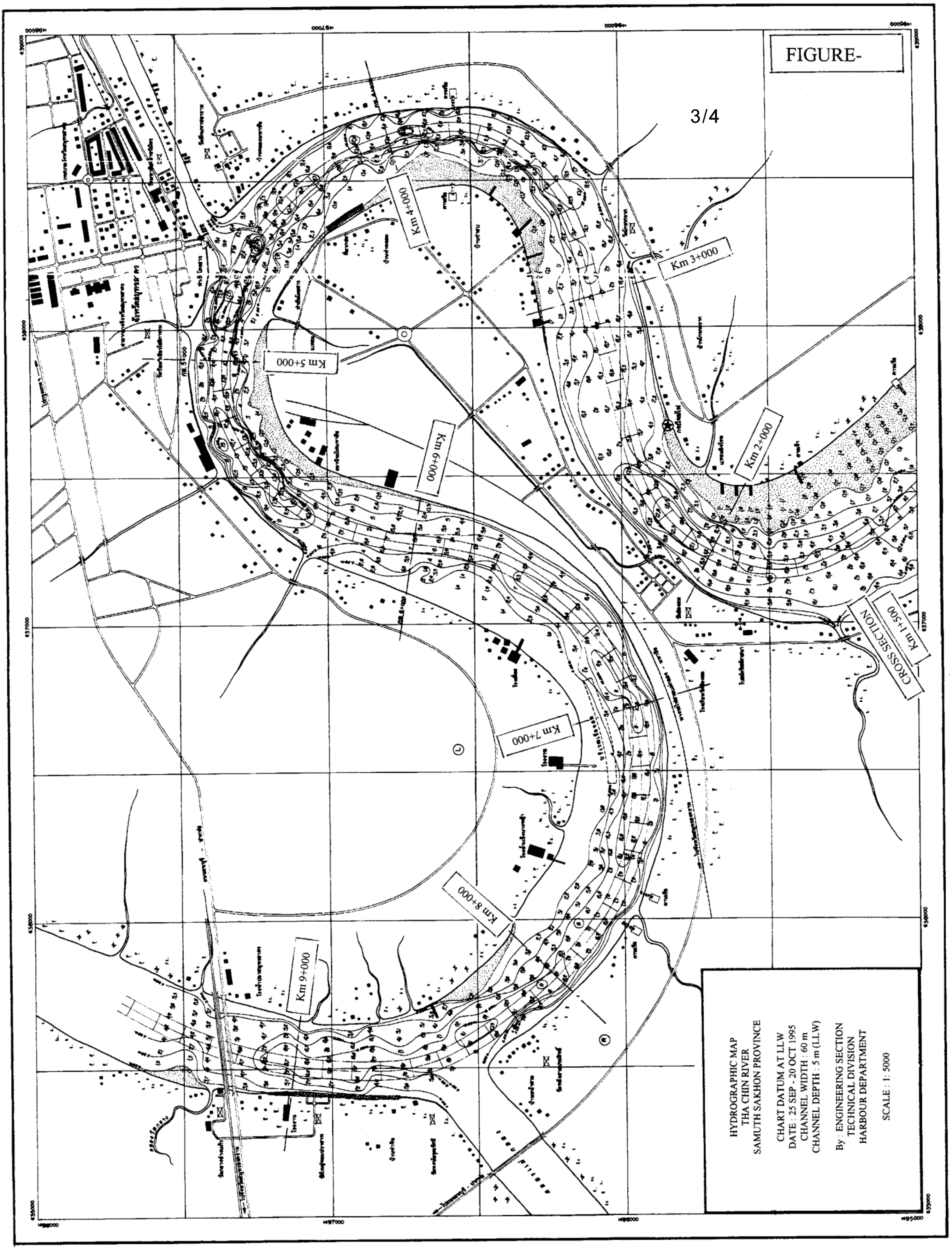

Km 1+500
CROSS SECTION
Km 2+000
Km 3+000
Km 4+000
Km 5+000
Km 6+000
Km 7+000
Km 8+000
Km 9+000
HYDROGRAPHIC MAP
THA CHIN RIVER
SAMUTH SAKHON PROVINCE
CHART DATUM AT LLW
DATE : 25 SEP - 20 OCT 1995
CHANNEL WIDTH : 60 m
CHANNEL DEPTH : 5 m (LLW)
By : ENGINEERING SECTION
TECHNICAL DIVISION
HARBOUR DEPARTMENT
SCALE : 1: 5000

TABLE-A1: Vessels using Tha Chin river, Samuth Sakhon province, based on width
(Source : Harbour Department, 1996)

width of vessel	0.01-1	1.01-3	3.01-5	5.01-8	8.01-10	10.01-15	> 15	total
type of vessel								
1) fishing	15	851	905	966	77	5	1	2,820
2) general cargo	216	885	57	8	3	4	0	1,173
3) river barge	1	60	483	36	1	0	0	581
4) sea-going barge	0	0	1	0	1	0	0	2
5) passenger-cargo	38	485	4	0	1	0	0	528
6) passenger	8	88	3	3	0	0	0	102
7) cruise	0	3	2	0	0	0	0	5
8) tanker	0	0	1	6	0	0	0	7
9) mining	0	1	2	8	0	0	0	11
10) towing boat	0	5	7	1	0	0	0	13
11) tug boat	0	9	1	0	0	0	0	10
12) reefer	0	0	0	5	2	7	0	14
13) others	3	148	14	0	0	0	2	167

TABLE-A2 : Vessels using Tha Chin river, Samuth Sakhon province, based on length
(Source : Harbour Department, 1996)

length of vessel	0.01-4	4.01-8	8.01-14	14.01-18	18.01-24	24.01-45	> 45	total
type of vessel								
1) fishing	3	146	756	461	1,170	278	6	2,820
2) general cargo	2	530	614	10	8	2	7	1,173
3) river barge	1	2	429	139	4	5	1	581
4) sea-going barge	0	0	0	1	0	1	0	2
5) passenger-cargo	0	54	467	6	1	0	0	528
6) passenger	0	11	86	2	1	2	0	102
7) cruise	1	0	3	0	1	0	0	5
8) tanker	1	0	1	0	0	5	0	7
9) mining	0	0	1	5	3	2	0	11
10) towing boat	0	1	5	3	3	1	0	13
11) tug boat	0	0	9	0	1	0	0	10
12) reefer	0	0	0	0	3	2	9	14
13) others	0	14	141	6	4	0	2	167

TABLE-A3: Vessels using Tha Chin river, Samuth Sakhon province, based on depth
(Source : Harbour Department, 1996)

depth of vessel	0.01-0.5	0.51-1	1.01-2	2.01-3	3.01-4	4.01-5	> 5	total
type of vessel								
1) fishing	60	695	913	863	192	69	28	2,820
2) general cargo	722	390	49	5	0	2	5	1,173
3) river barge	3	272	295	10	1	0	0	581
4) sea-going barge	0	0	1	0	1	0	0	2
5) passenger-cargo	235	284	9	0	0	0	0	528
6) passenger	43	54	2	3	0	0	0	102
7) cruise	1	1	2	1	0	0	0	5
8) tanker	0	0	1	0	6	0	0	7
9) mining	0	2	9	0	0	0	0	11
10) towing boat	1	5	6	1	0	0	0	13
11) tug boat	2	6	2	0	0	0	0	10
12) reefer	0	0	0	4	0	1	9	14
13) others	13	138	14	0	0	0	0	167

TABLE-A4 : Vessels using Tha Chin river, Samuth Sakhon province, based on gross tonnage
(Source : Harbour Department, 1996)

length of vessel	0.1-5	5.1-20	20.1-50	50.1-100	100.1-200	200.1-400	> 400	total
type of vessel								
1) fishing	536	545	765	706	175	81	12	2,820
2) general cargo	1,035	122	4	5	0	2	5	1,173
3) river barge	20	476	76	0	9	0	0	581
4) sea-going barge	0	0	1	0	0	1	0	2
5) passenger-cargo	502	26	0	0	0	0	0	528
6) passenger	92	6	1	2	0	1	0	102
7) cruise	1	3	0	1	0	0	0	5
8) tanker	0	1	0	0	6	0	0	7
9) mining	0	5	6	0	0	0	0	11
10) towing boat	3	5	4	1	0	0	0	13
11) tug boat	4	5	1	0	0	0	0	10
12) reefer	0	0	0	4	0	1	9	14
13) others	103	59	3	0	0	0	2	167