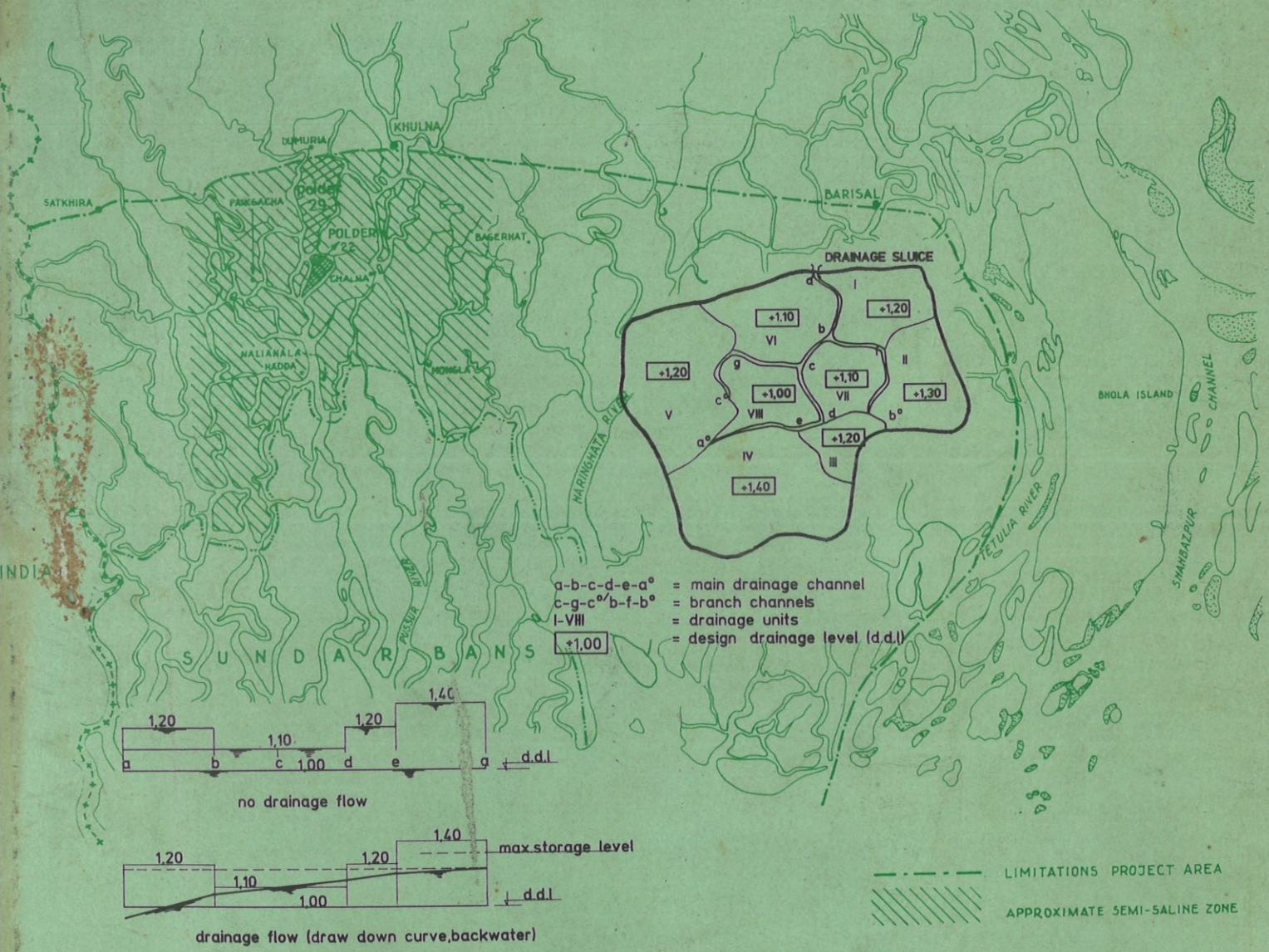
# DESIGN MANUAL

## FOR POLDERS IN SOUTH-WEST BANGLADESH




PART 1, VOL. I-IV


**DELTA DEVELOPMENT PROJECT**
BANGLADESH-NETHERLANDS JOINT PROGRAMME
UNDER BWDB

**DHAKA**
**NOVEMBER 1985**

BELAYET
1986.

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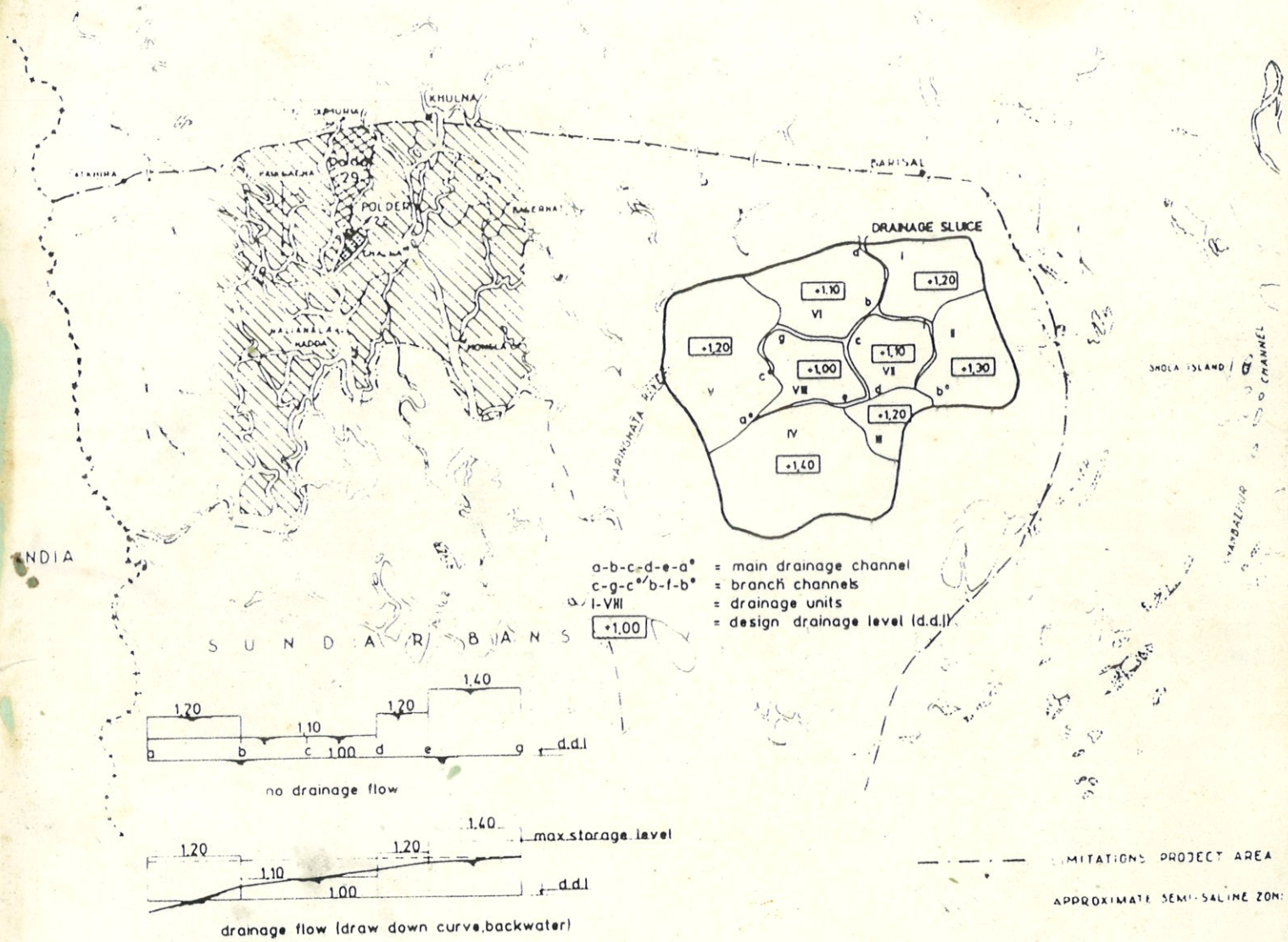


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# FOREWORD

This design manual has been prepared by the Design Team of the Delta Development Project, Bangladesh Water Development Board. In the process of its preparation, help has been taken of the existing documents. Participation of the engineers of the design directorates of BWDB and Khulna and Barisal Water Dev. Circles in the form of discussion played an important role in the preparation of this manual. Although this manual has been prepared for the tidal areas of Bangladesh, most of its chapters would be useful for other areas also.

This manual was finalised jointly by the experts of the BWDB and the expatriate consultants of this Project during August-October 1985.

In comparison with the draft version (1983) of this manual the present final issue has been improved and certain subjects were better clarified after exchange of experiences from two years of applicating the presented design methods within BWDB design directorates.

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THIS DESIGN MANUAL CONSISTS OF THE FOLLOWING PARTS AND VOLUMES :

PART 1

| | |
|---|---|
| VOLUME I | INTRODUCTION AND SUMMARY OF DESIGN PROCEDURES |
| VOLUME II | SURVEY AND MEASUREMENTS |
| VOLUME III | DESIGN OF EMBANKMENTS, CLOSURE DAMS |
| VOLUME IV | IRRIGATION AND DRAINAGE REQUIREMENTS - DESIGN CRITERIA |
| ANNEX PART 1 | COMMENTS ON AND REMARKS OF DESIGN CIRCLE-I |

PART 2

| | |
|---|---|
| VOLUME V | HYDRAULIC COMPUTATIONS |
| VOLUME VI | FOUNDATION DESIGN |
| VOLUME VII | GENERAL AND STRUCTURAL DESIGN ASPECTS |

PART 3

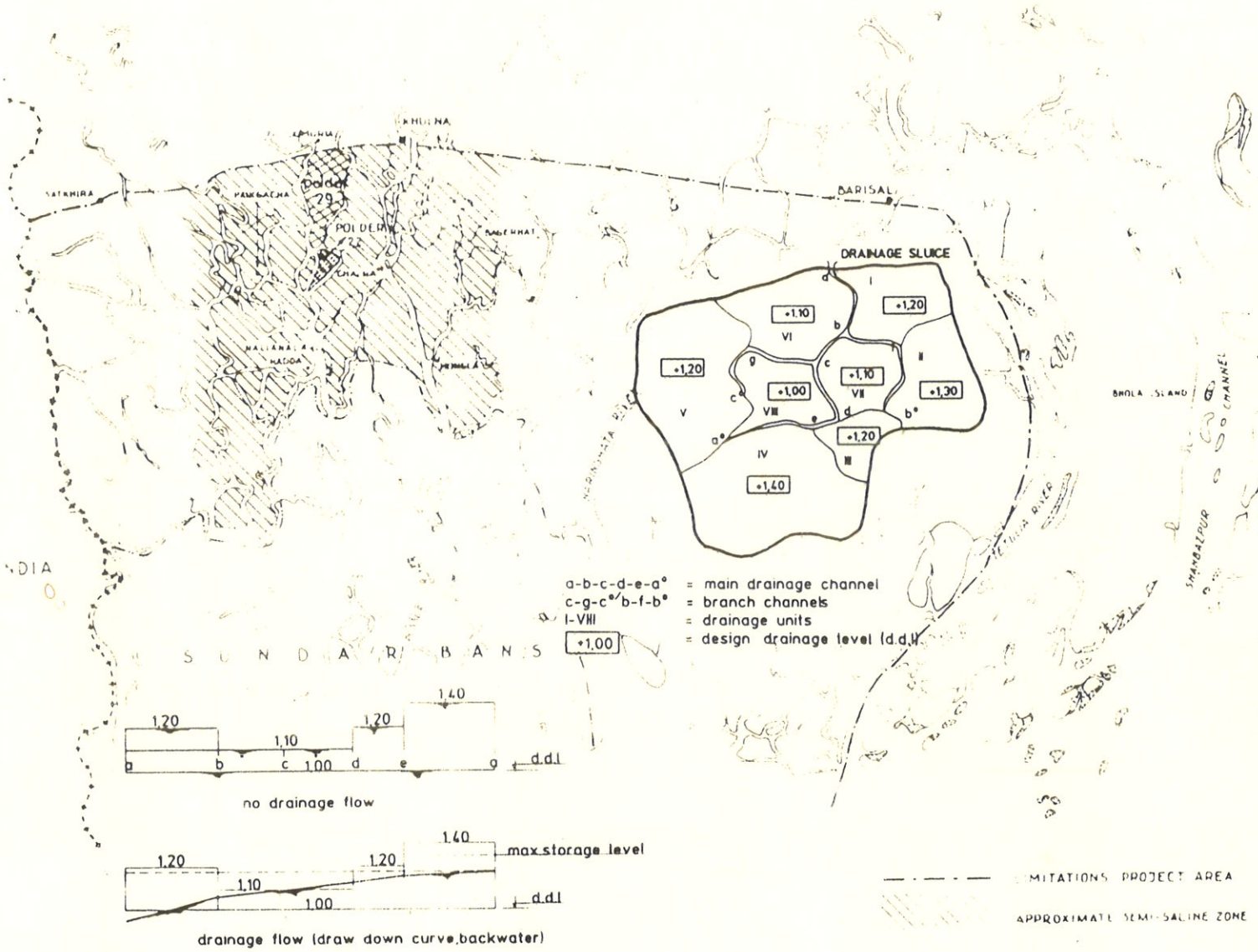
| | |
|---|---|
| VOLUME VIII | BASIC DESIGN DRAWINGS |

PART 4

| | |
|---|---|
| VOLUME IX | WORKED-OUT EXAMPLE. |

# DESIGN MANUAL

## FOR POLDERS IN SOUTH-WEST BANGLADESH




VOL. I


DELTA DEVELOPMENT PROJECT
BANGLADESH-NETHERLANDS JOINT PROGRAMME
UNDER BWDB

DHAKA
NOVEMBER 1985

VOLUME I INTRODUCTION AND SUMMARY OF DESIGN PROCEDURES

Table of Contents


| | Page |
|---|---|
| Chapter 1. Introduction | I-1 |
| Chapter 2. Summary of design steps | I-3 |
| 2.1 General | I-3 |
| 2.2 Design of Embankments | I-4 |
| 2.2.1 Data collection | I-4 |
| 2.2.2 Design of embankment profile | I-5 |
| 2.2.3 Design of alignment | I-6 |
| 2.2.4 Design height of embankment | I-6 |
| 2.2.5 Design revetments (if applicable) | I-6 |
| 2.3 Design of Closuredam | I-7 |
| 2.3.1 Site selection | I-7 |
| 2.3.2 Data collection | I-7 |
| 2.3.3 Design final section of the closuredam | I-7 |
| 2.3.4 Determine method of closure operations | I-7 |
| 2.3.5 Established maximum velocities in closure gap | I-7 |
| 2.3.6 Make scenario for closure operation | I-7 |
| 2.3.7 Design bottom and (if applicable) sill protection | I-8 |
| 2.3.8 Prepare minutious execution schedule | I-8 |
| 2.4 Design of Drainage and Irrigation System | I-9 |
| 2.4.1 Data Collection | I-9 |
| 2.4.2 Data evaluation, design of lay-out | I-10 |
| 2.4.3 Irrigation design of an irrigation unit | I-10 |
| 2.4.4 Drainage design of the polder | I-11 |
| 2.5 Design of Drainage Regulator | I-14 |
| 2.6 Design of tidal inlet structure | I-15 |
| 2.7 Foundation Design | I-16 |
| 2.7.1 Design the construction pit to be excavated | I-16 |
| 2.7.2 Determine the weight of the structure and the additional loads | I-16 |
| 2.7.3 Check the stability of the structure | I-16 |

| | | |
|---|---|---|
| 2.7.4 | Calculate the gross and net foundation pressure | I-16 |
| 2.7.5 | Arrange the soil data | I-16 |
| 2.7.6 | Compute the allowable bearing capacity and check settlements | I-16 |
| 2.7.7 | If settlements are unacceptable | I-17 |
| 2.7.8 | Design of pile foundation | I-17 |
| 2.7.9 | Check seepage | I-17 |

VOLUME I INTRODUCTION AND SUMMARY OF DESIGN PROCEDURES

## Chapter 1. Introduction

The underlying Design Manual has been prepared as per agreement between the Governments of Bangladesh and the Netherlands on the Delta Development Project. The scope of the Manual follows the guideline mentioned the Inception Report of the Project (March 1981).

This manual presents procedures for the designs related to the development of polders in the tidal area of Bangladesh. The regulator structures for the inlet and drainage of water as discussed in this manual are assumed to be operating under gravity only.

In principle, the area in which the presented design procedures are applicable, is bordered by the line of tidal influence. In fact, for a realistic tidal drainage and/or irrigation system the tidal fluctuations should be in the range of 1 meter or more during the time of the year that boundary conditions with respect to water levels are determinant for the design of the system. This means that the area of interest is located south of the line Satkhira-Khulna-Barisal-Noakhali, part of the Meghna basin and a small strip along the Chittagong coast.

Especially the Volume on Hydraulic Computations for regulators is therefore restricted to this area. Other Volumes, like Foundation Design have a much wider application.

At the time of preparation of this manual, there were already existing a number of design manuals prepared by the BWDB in 1962 and 1966-1967. In a number of separate Engineering Manuals, more or less independent aspects of design work as are practised by the BWDB Design Directorates, not necessarily restricted to tidal or no tidal areas, are discussed.

In this new design manual, it was tried to present a complete set of booklets, each Volume dealing with a specific subject of the design work. The Volumes are all related and are dealing with the complete design of embankments, irrigation and drainage systems and structures for the above defined area.

For the preparation of this manual the already existing manuals were duly studied and evaluated on their applicability and practicability. The process resulted in a manual containing a number of new subjects,

which were not yet covered by existing manuals and more elaborated, updated design procedures for subjects that were already covered by the existing manuals.

The existing manuals served as a guidance in many respects and where possible, the already used nomenclature and symbols were maintained. Especially the existing manual on "Earth and Foundation procedures for retaining wall design" was taken as the basis for the related chapter in the new Volume on Foundation Design, since there were no reasons to change the approach in this subject. Furthermore the theories and methods presented are taken from various sources in engineering literature of which references are presented at the end of each Volume.

One Volume consists of a set of basic drawings of a number of structures. On purpose the expression "Standard Design" is not used, because such a design cannot be applied anywhere. Too often book-shelve solutions, or "Standard Designs" are used without considering that each structure has its own specific design criteria which have to be elaborated step by step to arrive at an economical and sound design. In the manual these design criteria are discussed and analysed per Volume dealing with the specific subjects.

It is emphasised that dimensions of the structure presented on the basic drawings should be calculated as indicated in the related Volumes and it never should be allowed just to change measures without looking into the reasons and consequences.

In the process of preparation of this manual extensive contacts were maintained with design engineers from various BWDB design directorates. Contents and approach of all chapters and subjects to be highlighted were discussed and the general out line of the manual was decided in consultation with the concerned BWDB design engineers.

A draft version of the complete manual was distributed in November 82 among all Design Departments and a joint meeting was called by the Chief Engineer Planning in April'83 in which comments from all

Design Departments were discussed and suggestions for modifications and adjustments were made.

During the meeting it was also requested to include in the manual one worked out example of the design of drainage and irrigation system. It was agreed that at first some try-out designs would be made and that on the basis of the results thereof and the comments received in the April'84 meeting, the design manual would be finalised, including the example design.

The present final version of the design manual thus was prepared duly considering the comments of the April'83 meeting and including the worked out example.

The worked out example does only comprise the design processes for drainage and irrigation structures and does not elaborate on design procedures for foundation and structural aspects. Especially the detailing of concrete dimensions and re-inforcements is considered as routine procedures by most BWDB designers and is not considered a major constraint in the design process. The procedures for foundation design were found to have been followed very well in the try-out design made by BWDB and therefore this part is not further elaborated in the example design.

The contribution of engineers from the BWDB Design Directorates and BWDB-Khulna and - Barisal Circle, who have studied and commented on draft issues of this manual and who's advises and recommendations have duly been incorporated, are gratefully acknowledged herewith.

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The contribution of engineers from the BWDB Design Directorates and BWDB-Khulna and - Barisal Circle, who have studied and commented on draft issues of this manual and who's advises and recommendations have duly been incorporated, are gratefully acknowledged herewith.

## Chapter 2. Summary of design steps

### 2.1 General

In order to facilitate the design process, in this chapter a short list of design steps is presented in the right sequence, to be adhered during the design of embankments and drainage and irrigation systems.

The following abreviations are used in the reference column:

| | | |
|---|---|---|
| III - 6.3.2 | means | : Volume III, Chapter 6, paragraph 6.3.2. |
| Figure IV - 3.1 | means | : Figure number 1 in Chapter 3 of Volume IV |
| Tab. VI - 2.2 | means | : Table number 2 of Chapter 2 in Volume VI |
| p-II-34 | means | : page number 34 of Volume II |
| A-III-1 | means | : ANNEX 1 to Volume III |
| Figure A.V-3.1 | means | : Figure 3 in ANNEX 3 to Volume V. |

## 2.2 Design of Embankments

### 2.2.1 Data collection

a) Collect topographic maps of the area, including the surrounding rivers, scale as big as possible — A-II-4

b) Collect aerial photographs of the area of interest and compare shore lines for erosion areas. — A-II-3

c) Mark erosion prone reaches on a map and indicate erosion rate and consequent set back which is necessary for the embankment to be constructed. — III-1.2.7

d) Arrange for a topographic survey to be made of the proposed alignment of the embankment, with cross sections — A-II-1, II-1.2.2, II-1.2.3, II-1.2.4

e) Arrange for bathemetric surveys to be carried out for erosion prone shores and possible river closures to be encorporated in the design of the polder embankment — A-II-5, II-2.2.1, II-2.2.2, II-2.3.4

f) Arrange for current velocities to be taken along the relevant river banks (expected scour) during springtide conditions when upland discharges are at maximum stage. — II-3.3.3

g) Collect tidal and seasonal water level informations from neighbouring gauge-station over as long as possible period. Establish additional temporary gauges at — A-II-7

relevant places along the proposed embankment alignment in order to correlate readings of permanent gauges to the area of interest. II-2.4.1
II-3.1
A-II-6

h) Arrange for auger borings upto 4 m depth to be made along the proposed embankment alignment and borrow pits and establish general soil characteristics of available subsoil (foundation, seepage through permeable layers) and material for embankment construction (quality, settlements) II-6.2
III-2
p-III-2/3

i) Collect information on wind (direction, duration, force, time of the year) in order to evaluate necessity of accounting for wave run-up and wind set-up. A-II-8

2.2.2 Design of embankment profile

a) Determine design flood level from information gathered under 2.2.1-g) above
- required frequency III-1.1, III-1.2.2
- Gumbel frequency analyses III-3.2

b) Determine wind setup from information gathered under 2.2.1-i) above III-3.3

c) Determine wave run-up from information gathered under 2.2.1-i) above III-3.4
for relevant r/s slope, III-5.1,5.2, 5.3
if applicable weigh earthwork and revetment costs against crestheight

d) Determine design crest height from results of 2.2.2-a), b), c) above III-1.2.3, III-3

| | | |
|---|---|---|
| e) | Determine r/s and c/s slopes | III-5.1, 5.2, 5.3<br>III-1.2.4,III-5.4,<br>A-III.1 |
| f) | Determine crest width | III-1.2.5<br>III-4. |

2.2.3 Design of alignment

| | | |
|---|---|---|
| a) | Determine quantity of earthwork per section of embankment, | III-3.5 |
| b) | Establish setback, considering borrowpit at r/s or c/s, erosion rate | III-1.2.6<br>III-6 |
| c) | Consider soil conditions along proposed alignment | III-2<br>III-3.5 |
| d) | Establish alignment | III-2 |
| e) | Re-design embankment profile for sections where setback is insufficient | |

2.2.4 Design height of embankment

| | | |
|---|---|---|
| | Determine design height by adding over-height for shrinkage and settlements | III-3.5 |

2.2.5 Design revetments (if applicable)

| | | |
|---|---|---|
| a) | Determine relevant water levels as indicated in: and depth of river in front of embankment | IV-7.2.3 |
| b) | Determine maximum velocities and waves to be expected and at which stages | III-3.3,3.4 |
| c) | Determine size and weight of the protection layer, considering the slope of the embankment | III-5.5 |
| d) | Design the required filter construction | A-III-3 |
| e) | Check the stability of the embankment slopes | III-5.4<br>A-III-2 |

## 2.3 Design of Closuredam

### 2.3.1 Site selection — III-8.2

### 2.3.2 Data collection

a) Reference to steps a..... b of 2.2.1 for embankment design — I-2.2.1, III-8.3

add:

b) Detailed current velocities over full width of the channel to be closed — II-3.3

c) Tidal discharge measurements — II-3.2,III-8.3

d) Semi-detailed hydrographic survey — A-II-5

e) Core borings with undisturbed sampling and laboratory sample testing — II-6.2, II-6.3

### 2.3.3 Design final section of the closuredam — III-8.4

### 2.3.4 Determine method of closure operations — III-8.5

horizontal, vertical or combination.

### 2.3.5 Established maximum velocities in closure gap

In case of horizontal closure:
determine by flood routing the minimum area of the closure gap.
Use method as indicated in: — III-8.6.1, III-8.6.2

In case of vertical closure: — Fig. III-8.13, III-8.6.3

### 2.3.6 Make scenario for closure operation

and determine detailed dimensions of construction at different phases of the execution. — III-8.6, -8.7

Determine velocities through the final closure gap at springtide conditions with sill completed and during closing operations at neaptide by means of floodrouting — III-8.7

2.3.7 Design bottom and (if applicable) sill protection III-8.8

2.3.8 Prepare minutious execution schedule with detailed description of all procedures and construction methods

## 2.4 Design of Drainage and Irrigation System

### 2.4.1 Data Collection

a) The field office or proposing authority should make a descriptive report on the area, elaborating on present situation of drainage, irrigation, agriculture and other activities, including descriptions of hydraulic features of channels, rivers and any relevant information, illustrated with maps and figures as much as possible.

b) Collect topographical maps of the area, showing elevation details as many as possible, contour-lines at least every foot — A-II.4, IV-7.2.1

c) Collect aerial photographs (the most recent ones), to study the pattern of creeks and ditches that criss crosses through the area and correlate available survey information from the field office with information on maps and photos. — II-A-3

d) Arrange for the carrying out of additional topographic measurements of special areas, like beels, low pockets, areas where additional channels may have to be excavated and cross-sections of the internal channels. — II-2.3.4, A-II-5

e) Collect meteorological data on rainfall, evaporations, temperature, etc. as required to determine the drainage modules and evaporation — II-4, Fig.IV-3.1, III-2.3

f) Collect water level information from neighbouring permanent gaugestations over as long as possible periods and establish temporary gauges at relevant positions around the project area and correlate water level informations. — IV-7.2.3

Collect tidal information from temporary installed gauges over as long as possible periods during the critical time of the year. A-II-7

g) Collect information on the salinity of the waters surrounding the area, with respect to quality and durations. II-A-7

II-3.4

h) After studying above information a field visit should be made to familiarise with the area and the gathered data and resolve any remaining questions.

2.4.2 Data evaluation, design of lay-out

a) Based on existing agriculture use of the land, the topographic conditions and possible improvements and/or development of agriculture potentials, a cropping calender for the different parts of the area should be established and for each part the maximum allowable depth of flooding for the critical months of the year should be determined IV-2.2 Fig.IV_5.1

For each part of the area a design drainage level should be established IV-5.

If differences in surface elevation and resulting differences in maximum permitted water level and the design drainage level are not too big (in the order of 0.5 m) then the combining of irrigation and drainage channels for a part of parts of the area should be considered. IV-5, IV-6.

b) From above information and considerations, the lay-out of the drainage and irrigation units is determined. IV-6

2.4.3 Irrigation design of an irrigation unit

a) The information on water levels (2.4.1 - f) and water quality (2.4.1- g) and rainfall

(2.4.1 - e) should be evaluated with respect to the application possibilities for the crops of the considered area and the time of the year in which there is scope for irrigating the crops. If necessary the cropping calender could be adjusted to optimize the efficiency. IV-3.7

IV-4

b) Determine $ET_{crop}$ (crop water requirement) with $ET_{crop} = k_c \times ET_o \times 1,2$ for critical months of the year. for $k_c$ see ------ --- Tabl IV-3.4

for $ET_o$ see ------ --- IV-3.2.1

IV-3.2.3

c) Determine effective rainfall IV-3.3

d) determine net irrigation requirement (= $ET_{crop}$ - effective rainfall)

e) determine field irrigation requirement and conveyance losses IV-3.4

IV-3.5

f) determine irrigation supply requirement IV-3.6

Tab.IV-3.6

g) proceed with design of irrigation channel system V-2

- For seperate irrigation and drainage system see: V-2.1.2

V-2.3.3

V-2.4

- For combined irrigation and drainage system see: V-2.1.3

V-2.3.3

V-2.4

2.4.4 Drainage design of the polder

a) Determine the drainage modules for the area under consideration according to the procedures mentioned in Volume IV, IV-2.4

considering the maximum allowable storage that can be provided in the lowest parts of the area, as was established above under point 2.4.2 - a). V-2.2

- If rainfall frequency curves of Khulna, Barisal or Patuakhali cannot be used, then new curves have to be calculated according to procedures indicated in — A-V-1, V-2.3
- Determine crop-type corresponding allowable depth of flooding = maximum storage that can be allowed — V-2.2, Fig.IV-2.1, Tab.IV-2.2, IV-5, Fig.IV-5.1

b) With the information of the tidal riverwater and the required design drainage discharge of the total area, the average required sluice discharge during the tidal discharge period T is determined: — IV-2.5, V-4.2.4

The tidal discharge period T is estimated by plotting the maximum allowable storage level (m.a.st.l) and the design drainage level (d.d.l.) in the average tide curve of the critical period of the year. The period T starts where the level of ½[m.a.st.l+d.d.l.] intersects the falling tide curve and ends where the level of [1½ d.d.l.-½ m.a.st.l] intersects the rising tide curve. — A-V-3d)

c) Determine the design discharge in each section of the drainage channel and for the entire drainage area at the sluice. — A-V-3a)

Determine the design drainage discharge by multiplying drainage modules and area. — IV-2.5

If cropping pattern varies considerably in the polder, the area may be split up in parts, with each its own permissable storage criteria and resulting drainage modules.

For the design discharge of channels and the sluice, the different areas times there drainage modules have to be added. — V-2.1, A-V-3a)

d) Determine surface area of the main and secondary drainage channels and of the low pockets of the area at a water level of ½[m.a.st.l.) + (d.d.l.)] and at the level of d.d.l. proper — A-V-3a), p-V-48+49

e) Select suitable location for the drainage sluice V-4.2.2

f) Schematize main drainage channel in sections with constant Q, b, S, n and determine for each section the normal waterdepth at various discharges V-4.2.4 A-V-3a)

For each section:

- determine average bottomslope V-4.2.4
- select roughness coefficient n V-1.2
- define maximum permitted velocity V-1.4
- calculate normal waterdepth $h_n$ with Manning for various discharges ranging from 0,6 to 1.5 times the average design drainage discharge. V-1.1 A-V-2
- plot the information according to Fig.A-V-3.1

g) Calculate backwater curve in the main drainage channel for the design drainage discharge starting at the end of the drainage channel with various water levels ranging from (m.a.st.l) to (d.d.l) or lower level if required V-4.2.4 V-4.2.5 A-V-3.b)

h) Present the calculations as the delivery curves for the drainage channel A-V-3.b) Fig.A-V-3.2

## 2.5 Design of Drainage Sluice — V-4.2

a) Take design drainage discharge for the sluice as determined under 2.4.4-c) for the critical time of the year. — A-V-3a)

b) Determine required water level boundary conditions for the selected site and the required time of the year. — V-4.2.3 / IV-7.2.3

c) Determine invert level of sluice on the basis of maximum permitted velocity in the sluice (3.5 m/s) during extreme drainage conditions. i.e. polderwater level at (m.a.st.l) and riverwater at lowest stage (l.l.w.s). — V-4.2.5 / p-V-45/ 47

d) Determine required sluice width, assuming average drainage discharge through sluice and channel system to be constant at the value determined under 2.5-a) above and calculate backwater effect at the sluice at the beginning and ending of sluice period T, considering the decrease in polderwater level.
Use the drainage channel delivery curves as determined under 2.4.4-i) — V-A-3b)

e) Check sluice discharge at maximum drainage conditions and verify assumptions on flow conditions and velocities — p-V-51, 52

f) Determine the height of the sluice barrel — p-V-52

g) Make a sketch lay-out of the sluice and design connecting channel between sluice and natural drainage channel. — Fig.V-4.10 / p-V-53 / p-V-54

h) Calculate possible maximum velocities through the sluice in case of inlet of water and determine c/s wingwall flaring — V-4.2.6 / p-V-59

i) Design channel transition from apron to drainage channel profile, including protections — III-5.5.4 / V-5

j) Calculate maximum velocities through the sluice in case of maximum drainage — V-4.2.7

k) Design energy dissipating measure — V-4.2.8, V-4.2.9, V-4.2.10

l) Design channel transition from sluice to outfall channel, including energy dissipating measures and bottom/slope-protections — III-5.5.4, Fig.V-4.18, Fig.V-4.22, V-5

m) Check sluice capacity by floodrouting — A-V-3d)

## 2.6 Design of tidal inlet structure — V-4.1

a) Determine irrigation requirements of the considered area as given in point 2.4.3-f) — IV-3
This gives a water volume in $m^3$/ha/month.

b) Determine the tide curve for the specific time of the year that irrigation is required. — IV-7.2.3
Take note of the observations presented in paragraph V-4.1.2, p-V-32.

c) Determine irrigation supply level for the considered area. — V-2.1

d) Determine discharge capacity as a function of inlet structure's wet area and the available head difference. Choose inlet structure's wet area, considering available construction materials, costs, size of the irrigation area. — V-4.1.1, V-4.1.2, Fig.V-4.1, IV-1.3, IV-6.2

e) Select location (s) for the inlet structure(s) — V-4.1.3

## 2.7 Foundation Design VI

### 2.7.1 Design the construction pit to be excavated VI-6.4

Check whether dewatering is possible upto the required level, study results of borings and soil samples taken.

### 2.7.2 Determine the weight of the structure and the additional loads

vertical and horizontal and lateral earth and water pressures that are imposed on it. Consider most unfavourable conditions and highest ground-water level.

a) vertical load by earth on top of structures VI-3
b) lateral earth pressures VI-2
c) uplift pressures VI-6.2

### 2.7.3 Check the stability of the structure VI-2.4

### 2.7.4 Calculate the gross and net foundation

pressure and set criteria for settlements VI-1.7
and safety coefficient. VI-2.5

### 2.7.5 Arrange the soil data from the soil report

in a convenient way, specify characteristics for each layer

### 2.7.6 Compute the allowable bearing capacity of the

soil and compare with the structure foundation pressure and check if settlements are permissible VI-4.2
VI-4.3
A-VI-2

2.7.7 If settlements are unacceptable

Then: re-consider sluice design and check if an alternative design with higher invert level and a wider sluice may give reduced earth pressures — V-4.2.10

or : proceed to "Design of Deep-foundation". — VI-5.4

2.7.8 Design of pile foundation

a) determine resultants of total load imposed on the soil for different loading conditions — VI-5.4

b) design an adequate lay-out of pile system and calculate the load imposed on each pile group — A-VI-3

c) Determine bearing capacity of one pile and establish the number of piles in each group.
   - if adequate layer is present, calculate point bearing with or without skin friction, depending on the soil on top of the foundation stratum.
   - if no specific suitable foundation stratum is present then design pile on skin friction only.

d) Check the group action of the piles and readjust number of piles or pile length — VI-5.2.4

2.7.9 Check seepage under and along the sides of the structure and design appropriate cut-off walls — VI-6.2

2.7.7 If settlements are unacceptable

then: re-consider sluice design and check
if an alternative design with higher
lower level and a wider sluice may
give reduced earth pressures V-4.2.10
or : proceed to "Design of Deep-founda- VI-5.4
tion".

2.7.8 Design of pile foundation

a) determine resultants of total load imposed on
the soil for different loading conditions VI-5.4

b) design an adequate lay-out of pile system and
calculate the load imposed on each pile group A-VI-3

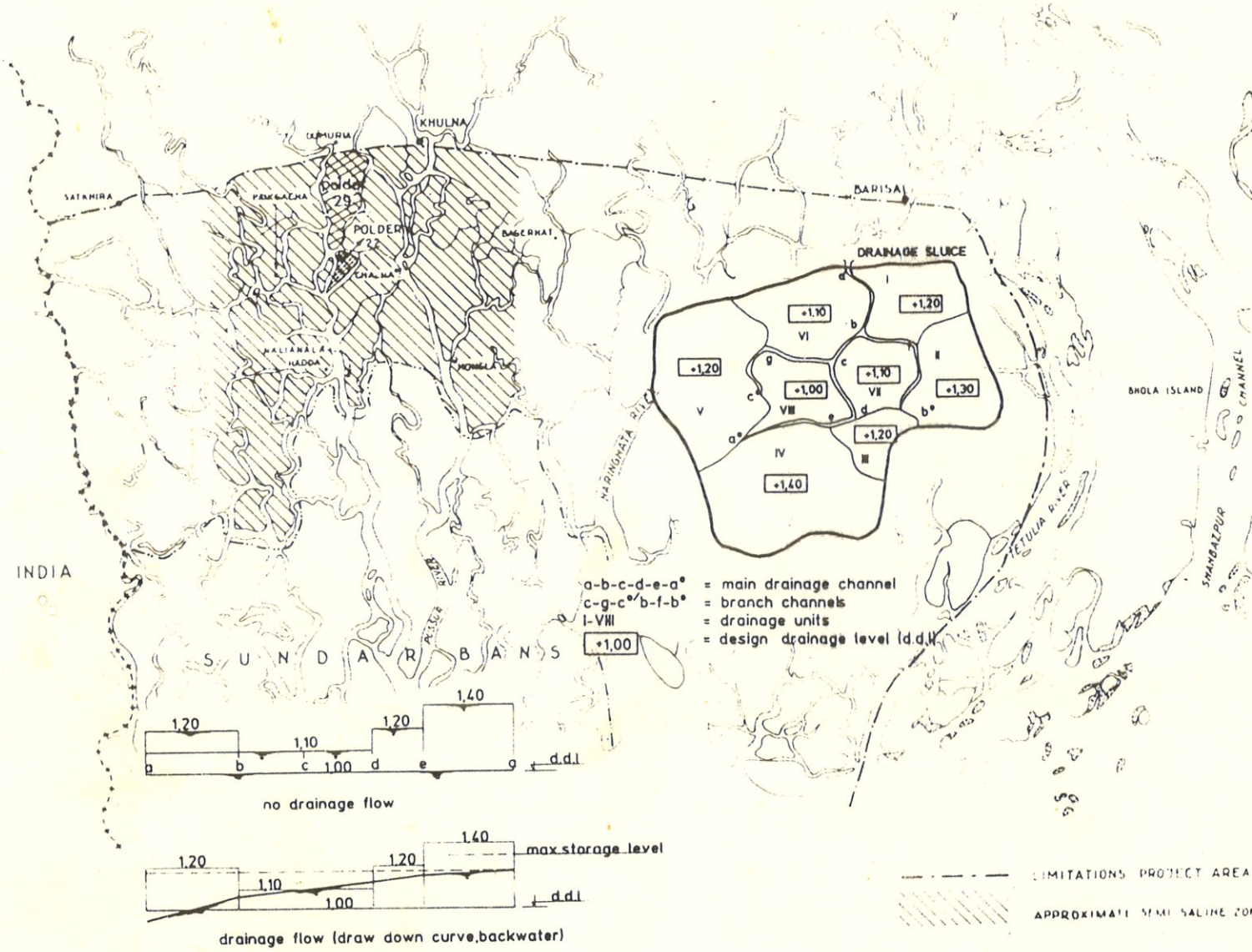
c) Determine bearing capacity of one pile and
establish the number of piles in each group.
- if adequate layer is present, calculate
point bearing with or without skin friction,
depending on the soil on top of the foundation
stratum.
- if no specific suitable foundation stratum is
present then design pile on skin friction only.

d) Check the group action of the piles and readjust
number of piles or pile length VI-5.2.4

2.7.9 Check seepage under and along the sides of
the structure and design appropriate cut-off walls VI-6.2

# DESIGN MANUAL

## FOR POLDERS IN SOUTH-WEST BANGLADESH




VOL. II

DELTA DEVELOPMENT PROJECT
BANGLADESH-NETHERLANDS JOINT PROGRAMME
UNDER BWDB

DHAKA
NOVEMBER 1985

# DESIGN MANUAL

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VOL. II

DELTA DEVELOPMENT PROJECT
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VOLUME II SURVEYS AND MEASUREMENTS

Table of Contents


| | Page |
|---|---|
| Chapter 1. Topographic Surveys | II-1 |
| 1.1 Introduction | II-1 |
| 1.1.1 General | II-1 |
| 1.1.2 Accuracies and reliabilities | II-2 |
| 1.1.3 Methods used in topographic surveying | II-3 |
| 1.2 Levelling Surveys | II-5 |
| 1.2.1 Execution of levellings | II-5 |
| 1.2.2 Errors in levelling | II-6 |
| 1.2.3 Levelling of sections | II-7 |
| 1.2.4 Area-levellings | II-8 |
| 1.2.5 Transportation of a level across rivers | II-8 |
| 1.3 Triangulation Surveys | II-9 |
| 1.3.1 General | II-9 |
| 1.3.2 Methods | II-10 |
| 1.3.3 Execution of triangulation surveys | II-12 |
| 1.3.4 Distance measurements | II-13 |
| 1.3.5 Local grid system, true north bearings, transformations | II-14 |
| 1.4 Mapping | II-15 |
| 1.4.1 Aerial photography | II-15 |
| 1.4.2 Cartography | II-17 |
| 1.5 Topographic surveys for polder development works | II-17 |
| 1.5.1 Organization of the survey work | II-17 |
| 1.5.2 Stations, benchmarks and pillars | II-19 |
| Chapter 2. River Morphology Surveys | II-21 |
| 2.1 Introduction | II-21 |
| 2.2 Methods | II-21 |
| 2.2.1 Bathymetric Surveys | II-21 |
| 2.2.2 River bank alignment surveys | II-22 |
| 2.2.3 Sediment transport measurements | II-22 |
| 2.2.4 Bottom sampling | II-23 |

Page

2.3 Position fixing during surveys II-25
2.3.1 Methods II-25
2.3.2 Positioning by angle measurement II-25
2.3.3 Accuracies in positioning II-28
2.3.4 Required density for surveys II-28
2.4 Water levels and Tides II-29
2.4.1 Datum for soundings II-29
2.4.2 Tides II-30
2.4.3 Definitions of tidal levels presented in Tide Tables II-33

Chapter 3. Hydrological Measurements II-35

3.1 Waterlevels II-35
3.2 Discharges II-36
3.3 Velocities II-38
3.3.1 General II-38
3.3.2 The velocity profile II-38
3.3.3 Float observations II-39
3.4 Salinity measurements II-40

Chapter 4. Meteorological Observations II-43

Chapter 5. Groundwater Surveys II-44

5.1 Introduction II-44
5.2 Preparatory study II-45
5.3 Observation network II-45
5.4 Additional observations II-46
5.5 Groundwater level readings II-48
5.6 Groundwater quality determination II-48
5.7 Remarks II-48

Chapter 6. Soil Investigation for Foundation Purpose II-51

6.1 General II-51
6.2 Field tests, soil identification, soil sampling II-51

Page


6.3 Laboratory tests II-55

6.3.1 Index properties II-55

6.3.2 Atterberg limits test II-56

6.3.3 Compression test II-56

6.3.4 Direct shear test II-58

6.3.5 Triaxial Test II-59

6.3.6 Permeability test II-61

Chapter 7. Agricultural Surveys II-63

7.1 General II-63

7.2 Soils II-65

7.3 Land use and land evaluation II-66

Chapter 8. Socio-economic surveys II-68

8.1 Introduction II-68

8.2 The role and contents of socio-economic surveys II-68

8.2.1 The fundamental goals of development projects II-68

8.2.2 The uses of socio-economic surveys II-70

8.2.3 The contents of socio-economic surveys: a general over view II-72

8.3 Survey design and implementation II-75

8.3.1 General observations II-75

8.3.2 Stages in survey design and implementation II-77

8.4 Some difficulties and limitations of socio-economic surveys II-81

ANNEX II - 1 BASIC STANDARDS FOR LEVELLING SURVEYS II-87

ANNEX II - 2 BASIC STANDARDS FOR TRIANGULATION SURVEYS II-88

ANNEX II - 3 AVAILABLE AERIAL SURVEYS OF THE DELTA AREA SINCE 1961 II-89

ANNEX II - 4 AVAILABLE TOPOGRAPHICAL MAPS II-90

ANNEX II - 5 DENSITY REQUIREMENTS OF BATHYMETRIC SURVEYS II-91

ANNEX II - 6 PLOTTING OF REDUCTION CURVE FOR HYDROGRAPHIC SURVEYS FROM TIDAL INFORMATION OF TWO GAUGE STATIONS II-92

ANNEX II - 7 LOCATIONS OF WATER LEVEL GAUGE STATIONS

ANNEX II - 8 LOCATIONS OF METEOROLOGICAL OBSERVATION STATIONS

See part 3

ANNEX II - 9 SOIL PROPERTIES, SYMBOLS, TESTS AND APPLICATIONS II-95

Page

6.3 Laboratory tests II-55
6.3.1 Index properties II-55
6.3.2 Atterberg limits test II-56
6.3.3 Compression test II-56
6.3.4 Direct shear test II-58
6.3.5 Triaxial Test II-59
6.3.6 Permeability test II-61

Chapter 7. Agricultural Surveys II-63

7.1 General II-63
7.2 Soils II-65
7.3 Land use and land evaluation II-66

Chapter 8. Socio-economic surveys II-68

8.1 Introduction II-68
8.2 The role and contents of socio-economic surveys II-68
8.2.1 The fundamental goals of development projects II-68
8.2.2 The uses of socio-economic surveys II-70
8.2.3 The contents of socio-economic surveys: a general over view II-72
8.3 Survey design and implementation II-75
8.3.1 General observations II-75
8.3.2 Stages in survey design and implementation II-77
8.4 Some difficulties and limitations of socio-economic surveys II-81

ANNEX II - 1 BASIC STANDARDS FOR LEVELLING SURVEYS II-87
ANNEX II - 2 BASIC STANDARDS FOR TRIANGULATION SURVEYS II-88
ANNEX II - 3 AVAILABLE AERIAL SURVEYS OF THE DELTA AREA SINCE 1961 II-89
ANNEX II - 4 AVAILABLE TOPOGRAPHICAL MAPS II-90
ANNEX II - 5 DENSITY REQUIREMENTS OF BATHYMETRIC SURVEYS II-91
ANNEX II - 6 PLOTTING OF REDUCTION CURVE FOR HYDROGRAPHIC SURVEYS FROM TIDAL INFORMATION OF TWO GAUGE STATIONS II-92
ANNEX II - 7 LOCATIONS OF WATER LEVEL GAUGE STATIONS } see part 3
ANNEX II - 8 LOCATIONS OF METEOROLOGICAL OBSERVATION STATIONS } see part 3
ANNEX II - 9 SOIL PROPERTIES, SYMBOLS, TESTS AND APPLICATIONS II-95

VOLUME II SURVEYS AND MEASUREMENTS

## Chapter 1. Topographic Surveys

### 1.1 Introduction

#### 1.1.1 General

Topographic surveys, comprising triangulation surveys and levellings, are part of the geodetic science that is dealing with the projection of the physical earth surface on a horizontal reference plan, according to the direction of the vertical. The more comprehensive geodetic engineering however uses the earth ellipsoide as a reference plane.

The horizontal reference plane used in basic topographic surveys covers an area of approximately 50 x 50 sq. km. in order to keep inaccuracies, resulting from the projections along the vertical, within limits, i.e. the verticals or projection lines can still be considered parallel within the area.

For levellings a reference plane is used that has a convex shape and is always perpendicular to any vertical or projection line (see Figure II - 1.1).

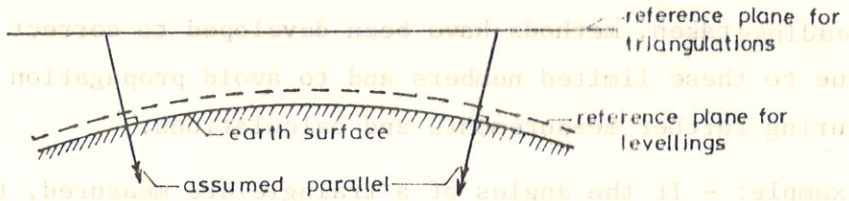



Figure II - 1.1. Reference planes

If triangulations have to be carried out over areas exceeding the 50 x 50 sq. km limit, and survey results are plotted on a horizontal reference plane, distortions resulting from the convex earth surface will show. The bigger the area, the bigger the distortion. Although these distortions can be eliminated with correcting calculations, it

is easier to divide the area into smaller parts that are within the 50 x 50 $km^2$ limit.

This is what generally is done, by covering the area with a fundamental net-work of triangulation stations, at distances that are in concert with the above named area limit condition. The area in between these major triangulation stations (G.T.S.) (= Grid Triangulation Station) can be considered as a horizontal plane, to be used as a reference plane for further detailed triangulation works as may be necessary for embankment alignment and drainage and irrigation works.

It should be kept in mind that due to the different reference planes, there is always a distinction between triangulation surveys and levelling surveys, although often triangulation stations are also main benchmarks for levelling.

### 1.1.2 Accuracies and reliabilities

Taking measurements is a process in which inaccuracies occur. If the same angle or distance is measured 10 times, the result might be different all the ten times.

Since only the mean of an infinit number of measurements will yield the exact value, and measurements only comprise a limited number of readings taken, methods have been developed to correct inaccuracies due to these limited numbers and to avoid propagation of inaccuracies during further measurements and calculations.

example: - If the angles of a traingle are measured, the summation of the result will never be 180°. To make it 'fit', a correction method has to be applied, yielding the "most probable value" of the three angles.

- A new triangulation station (T.S.) has been established and coordinates are calculated from measurements taken from two known points. The measurement-results will introduce inaccuracies, and the calculated position of the new T.S. will be not completely correct. If from this new T.S. the measurements and calculations are further extended, the "incorrectness" of the next T.S. increases.

One of the methods to reduce fault propagation is the division of all measurements in consecutive phases or orders, so that influences of inaccuracies are isolated. The major grid of triangulation stations (G.T.S.) is of a primary order, all inaccuracies are corrected/ eliminated as good as possible and the coordinates of such a station will serve as the absolute right basis for the calculation of next order of stations. These next series of triangulation stations (T.S.) is thus of a second order,etc., etc.

### 1.1.3 Methods used in topographic surveying

- Triangulation surveys. A group of points (stations) is connected in such a way that a network of triangles is formed. If in every triangle, two angles and one of the sides is measured, all other values can be calculated. This method is used for primary and secondary order measurements as well as for lower order measurements.

- Section method. From two known points a third new point is being measured by measuring both angles (see Figure II - 1.2). Section surveys are done for fourth and lower order measurements.

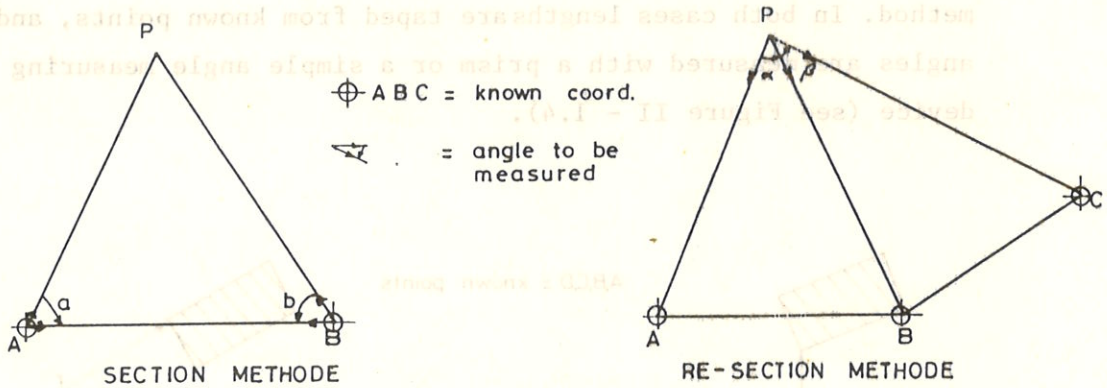



Figure II - 1.2. Section and re-section measurement.

- Resection method. From a new station, of which the position has to be calculated, three known stations are measured and coordinates of the new station can then be calculated with Snellius (see Figure II - 1.2). The method is used for third and lower order measurements.
- Traverse measurement. The polygone consists of a chain of lines, connecting two known stations. All lengths and angles have to be measured (see Figure II - 1.3). Traverses are only used for lowest order measurements.

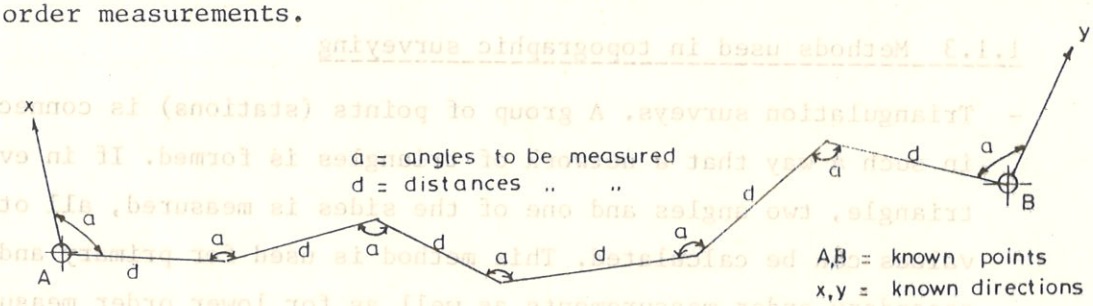



Figure II - 1.3. Traverse measurement

- Coordinates methods, lowest order of measurement, to determine location of buildings and other features of landscape. One can distinguish polar coordinates method and rectangular coordinates method. In both cases lengths are taped from known points, and angles are measured with a prism or a simple angle measuring device (see Figure II - 1.4).

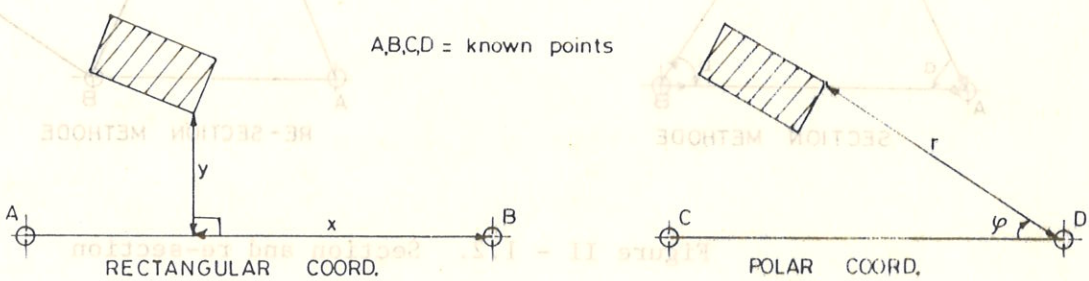



Figure II - 1.4. Coordinates method.

- Plane table survey. Directions and distances are directly plotted on a levelled table. This survey method is of the lowest order.
- Levelling surveys. Method is the same for every order of accuracy, depending mainly on the capabilities of the instrument that is available.

## 1.2 Levelling Surveys

### 1.2.1 Execution of levellings

To determine the difference in height between two points the levelling instrument has to be positioned at equal distance to the two points, to eliminate any remaining instrument adjustment errors. The distance to the two objects is limited by the enlargement factor of the level's telescope. With the instruments available to the BWDB - surveyors the the maximum distance between two consecutive points should be about 60 m. During adverse weather conditions, distances should be reduced.

Whether levelling has been executed upto the standards, can thus be checked by dividing the actual distance between start and end point of a continuous levelling by the number of instrument locations. The number of instrument locations equals the number of back sight and fore sight readings and should be within the instruments range (see Figure II - 1.5).

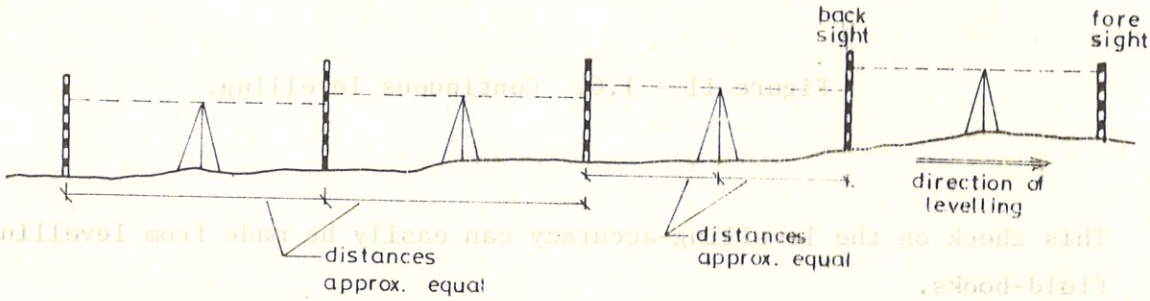



Figure II - 1.5. Execution of levelling.

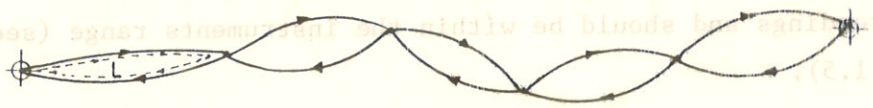
### 1.2.2 Errors in levelling

During levelling three kinds of errors can be made, two of which will not be discussed because they result direct from the instrument or from external circumstances, like convex earth surface, ondulations, refractions. Errors made by the observer will be further elaborated.

If levelling is done along a route from one known level to another, mistakes will appear but the chance of a mis-reading of one meter or decimeter that has been made twice in opposite way, is still present.

Therefore levelling along an elongated route is to be split up in loops of 1000 - 1500 m, beginning and ending in the same point. The difference between beginning and ending should then not exceed $v = a\sqrt{L}$ mm, when L is distance in kilometre, (see Figure II - 1.6) and v = closing error in mm. Coefficient a depends on accuracy order of the measurement.

a = 3 for primary order levellings
a = 5 for secondary order levellings
a = 10 for third order levellings
a = 20 for lower order levellings

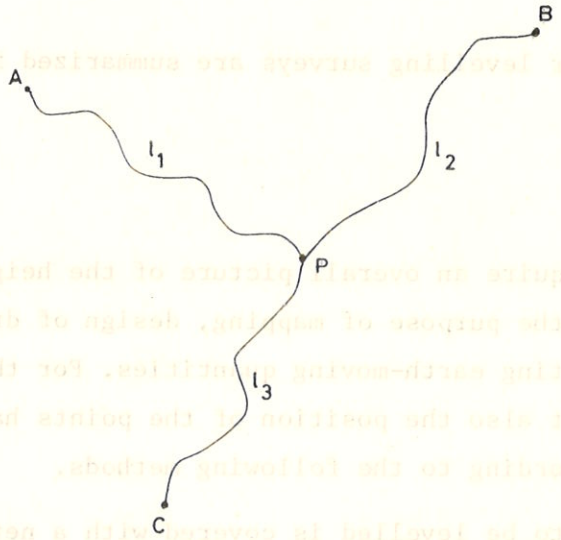



for every loop: $v \leqslant a\sqrt{L}$

Figure II - 1.6. Continuous levelling.

This check on the levelling-accuracy can easily be made from levelling field-books.

The closing difference v has to be spread over all the readings, provided that the lengths of the strokes (distance between two instrument positions) are more or less equal. If the new point is levelled from three known benchmarks then the new height has to be calculated, weighing the levels found from the three points respective to their distances. (see Figure II - 1.7.).




$$h_P = \frac{\frac{1}{l_1}H_{AP} + \frac{1}{l_2}H_{BP} + \frac{1}{l_3}H_{CP}}{\frac{1}{l_1} + \frac{1}{l_2} + \frac{1}{l_3}}$$

$h_P$ = level of P

$H_{AP}$ = level of P measured from A

Figure II - 1.7. Spreading differences.

### 1.2.3 Levelling of sections

Levellings of longitudinal and cross-sections are executed to measure elongated routes for embankments, canals, roads, railways, to establish the alignment in detail end to calculate earthmoving quantities. Longitudinal sections are plotted in a distorted scale. Normally applied are 1:100 vertical and 1:2500 horizontal. Cross-sections are plotted in right proportion. Normally scales of 1:100 and 1:200 are used.

The density of spot levels to be taken along a section and the intermediate distances of cross-sections depends on the type of detail required.

Longitudinal sections are measured along a line of pegs that show the centre line of the route. Also fixed points like benchmarks, bridges and firm buildings close to the centre line are included in the level--ling. A tape or a line with knots is used to establish distances between spotlevels. Cross-sections along the centre line are set out with a pentagonal prism. For all levellings sketches should be made in the field showing the instrument positions and special features along the levelling track, like road crossings, waterway and ditch crossings, embankments.

For the plotting of the levelling results, always the P.W.D. should be used as a reference plane.

Basic standard requirements for levelling surveys are summarized in ANNEX II - 1.

### 1.2.4 Area-levellings

Area levellings are made to acquire an overall picture of the height distribution of a terrain for the purpose of mapping, design of drainage and irrigation system, calculating earth-moving quantities. For this purpose not only the height but also the position of the points has to be known. This can be done according to the following methods.

*Method of squares; the area to be levelled is covered with a network of squares and at each corner a rangepole is placed. All range pole positions are measured and a map is prepared. The disadvantage is that the corners of the sections are arbitrary and will not always represent a true picture of the surrounding terrain. Interpolating the level between the corners for the construction of contour maps is allowed, provided that the density of the network is high and the features of landscape are smooth.

*Method of sections. In stead of a square network, a system of parallel lines is set out in the area to be levelled. The intermediate distance is depending on the terrain and the extent of detail required. Along every line levels are taken and the results are plotted. For checking purposes a few cross lines are also levelled, the number depending on the size and shape of the area. Sections for levelling should be taken as much as possible perpendicular to the estimated global contour lines of the area to be surveyed.

*Plane table, is used for detailed survey work in small areas. Distances and levels are directly plotted on a map, placed on top of the plane table.

### 1.2.5 Transportation of a level across rivers

If a level has to be transferred from one bank to the other, the telescope of a normal levelling instrument will not give a sharp image of the levelling staff at the other bank if the distance is over 100-150 m. (depen-

ding of course on the instrument). In such cases, the reading of the levelling staffs can be done with the help of a theodolite.

Measurements have to be repeated from both sides of the river, to be able to even out the inaccuracies due to unequal levelstaff distances, refraction and earth-surface curvature.

In case the distance between the bank is more than 3 km and even the theodolite does not give reliable readings, the water level has to be measured simultaneously from gauges at both banks during slackwater at neap tides, preferably during very calm weather conditions, in order to exclude wind-effects.

## 1.3 Triangulation Surveys

### 1.3.1 General

Triangulation surveys have to be carried out to establish a system of fixed points (Triangulation Stations) to which other surveys, like levellings, alignment surveys, cross-sections, can be tied up. If the T.S.'s are connected to the main G.T.S. - system, maps can be prepared that fit into the existing system. For the measuring of a network of triangles it is necessary to measure the angles of the triangles. Standing in one point the bearings of the surrounding points are determined with a theodolite and the differences of these bearings give the angles between the different points (see Figure II - 1.8).

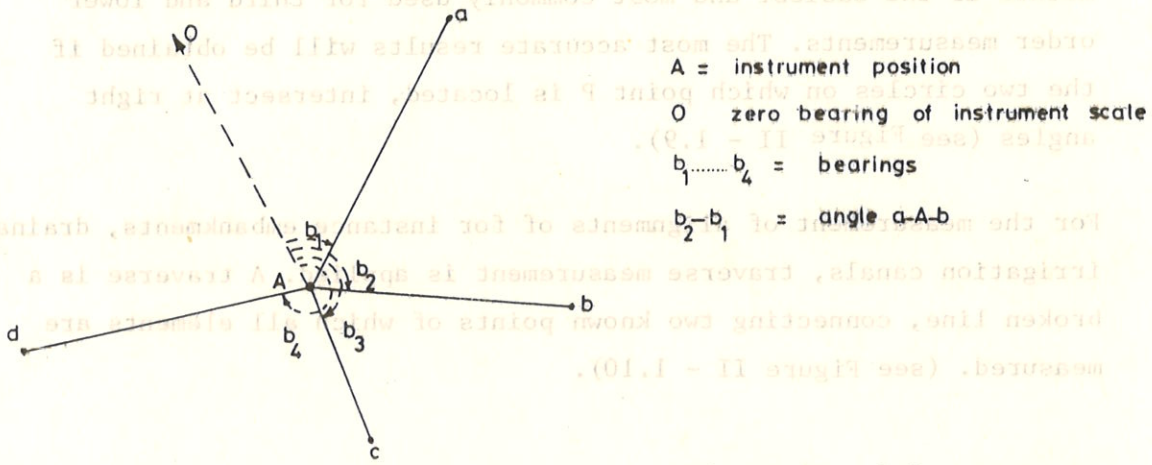



Figure II - 1.8. Measuring bearings.

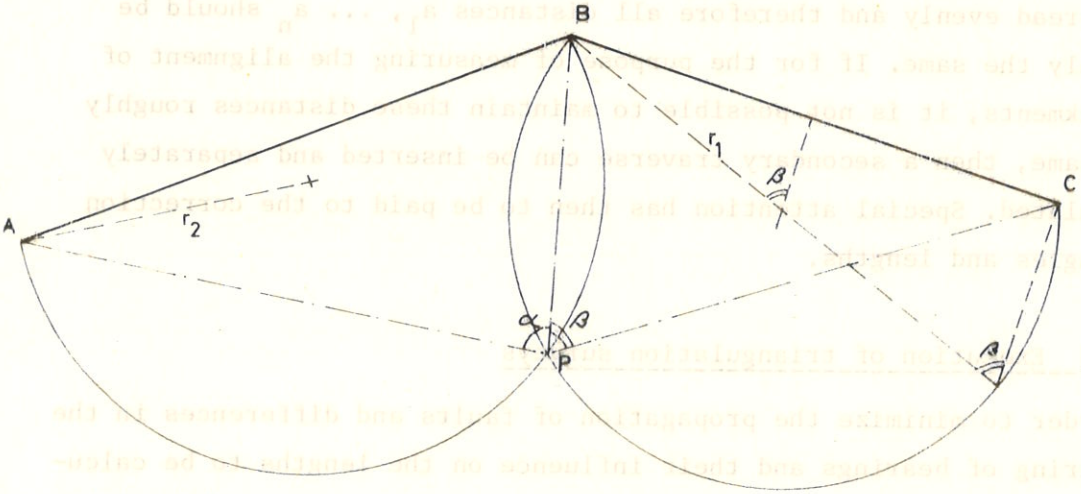
The measurements in such a rosette have to be repeated and averages to avoid mistakes in reading and to compensate for instrument related inaccuracies.

All bearings are measured four times according to Bessel's method. These Bessel-series are measured as follows. The rosette of the Figure II-1.8 is measured starting with the reading of $b_1, b_2, b_3$ and $b_4$. Then the scale of the theodolite is turned $\pi/4$ radians and the bearings are read again, now from $b_4 - b_3 - b_2 - b_1$. Then the telescope of the instrument is reversed and toppled. The same series of measurements is repeated, including the turning of the theodolite scale over $\pi/4$ rad, at $b_4$. In this way every bearing is measured 4 times. Four angles can be calculated and averaged to obtain the most probable value.

### 1.3.2 Methods

For the extension of a triangulation network, two methods are used. With the section method the position of a new point P is determined from two known points A and B by measuring the bearings to P from A and B. In Figure II - 1.2 angles a and b are calculated from the bearing measurements AP, AB, BP and BP. Then P - coordinates can be calculated from A and B - coordinates. The determination of the position of a new point P by measuring the bearings to three known point A,B & C is called the resection method. The coordinates of P can be calculated with Snellius method (see Figure II - 1.2). This method is the easiest and most commonly used for third and lower order measurements. The most accurate results will be obtained if the two circles on which point P is located, intersect at right angles (see Figure II - 1.9).

For the measurement of alignments of for instance embankments, drainage/irrigation canals, traverse measurement is applied. A traverse is a broken line, connecting two known points of which all elements are measured. (see Figure II - 1.10).




$$r_1 = \frac{\frac{1}{2}\,\overline{AB}}{\text{sinus } \alpha}$$

$$r_2 = \frac{\frac{1}{2}\,\overline{BC}}{\text{sinus } \beta}$$

* from all points on circle APB, the angle A-P-B = $\alpha$
* from all points on circle BPC, the angle B-P-C = $\beta$

Figure II - 1.9. Snellius circles.

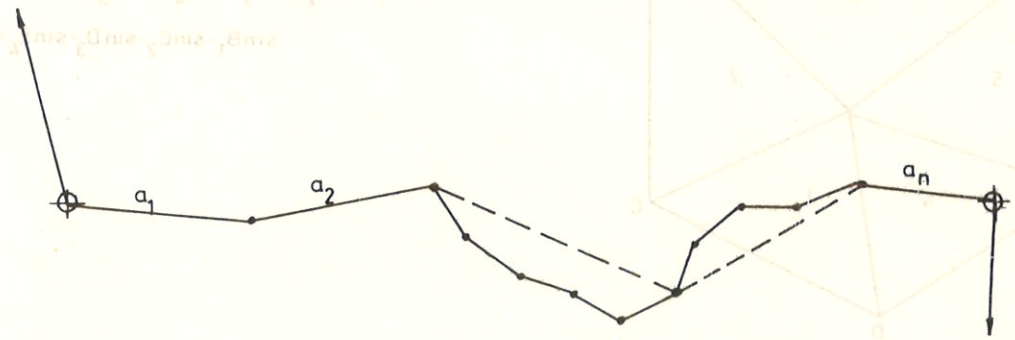


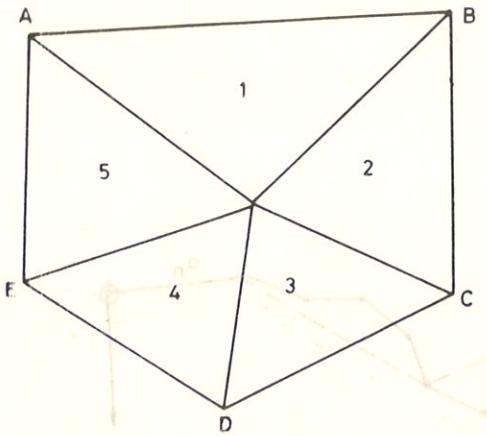

Figure II - 1.10 Broken traverse.

A connecting bearing has to be measured, to tie up the broken line with a known bearing. Closing errors in the measured angles should be spread evenly and therefore all distances $a_1$, ... $a_n$ should be roughly the same. If for the purpose of measuring the alignment of embankments, it is not possible to maintain these distances roughly the same, then a secondary traverse can be inserted and separately calculated. Special attention has then to be paid to the correction of angles and lengths.

### 1.3.3 Execution of triangulation surveys

In order to minimize the propagation of faults and differences in the measuring of bearings and their influence on the lengths to be calculated, a network of triangles should be as uniform as possible with angles of approximately 60°. Closing differences should be spread over all angles. Correcting the measured values to make the network fit is a rather complex procedure based on three conditions:

- In all triangles the summations of the three angles should be 180°.
- In every central point the summation of angles should be 360°.
- The products of the sinus of the right angles of all triangles around one central point should be equal to the products of the sinus of all left angles of these triangles (see Figure II - 1.11).




$$\sin A_1 \cdot \sin B_2 \cdot \sin C_3 \cdot \sin D_4 \cdot \sin E_5 = \sin B_1 \cdot \sin C_2 \cdot \sin D_3 \cdot \sin E_4 \cdot \sin A_5$$

Figure II - 1.11. Corrections of angles.

Closing corrections also have to be made when a chain of triangles is measured from one T.S. to another. These triangle chains (see Figure II - 1.12) are often used for the measuring of rivers and other elongated survey areas.

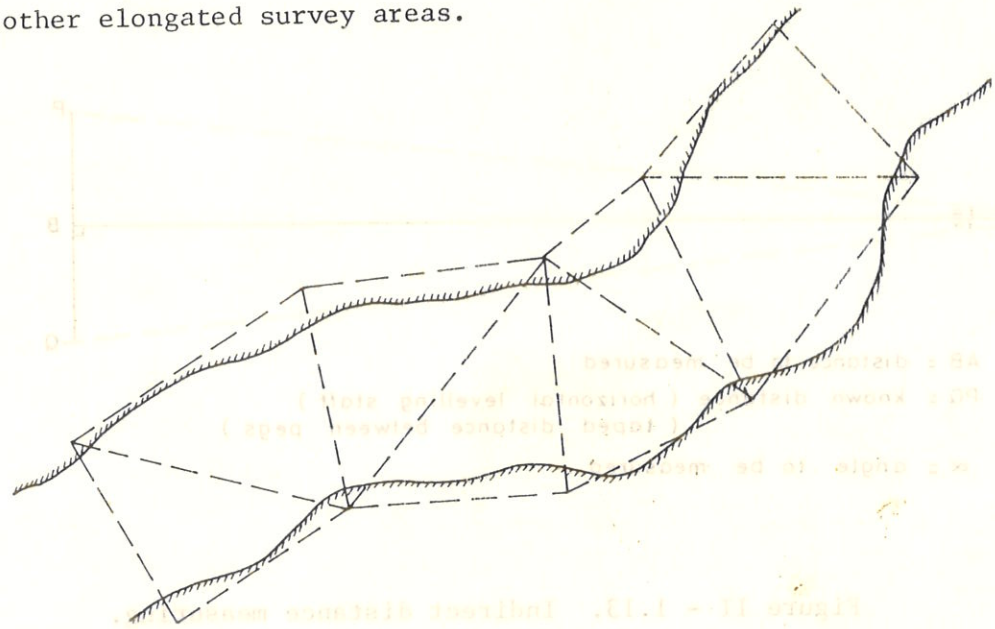


Figure II - 1.12. Triangle chain.

If no G.T.S. or T.S. are available to tie-up the triangle chain or any triangle network, then a measurement is necessary of the length of one of the triangle's sides. If two major stations are available then the distance between them should be used as a base for the calculations.

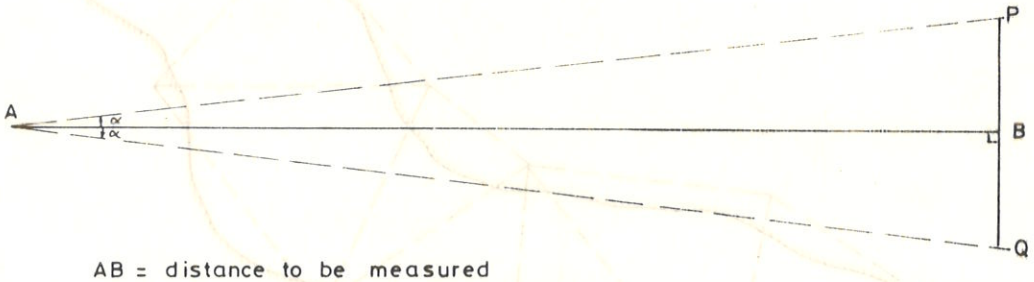
How to connect a loose network, which in it self is complete and fully corrected, but only is based on assumed coordinates, with the G.T.S. - network is discussed in paragraph 1.3.5

Basic standard requirements for triangulation surveys are summarized in ANNEX II - 2.

### 1.3.4 Distance measurements

Distances can be measured with a tape, but for bigger lengths or if the area to be crossed or the distance to be measured does not guarantee sufficient accuracy, other methods are applied.

In case no optical or electronic distance measuring instrument is available, a distance can be measured indirectly with angle measurement to a measured or known base-line (see Figure II - 1.13).




AB = distance to be measured
PQ = known distance ( horizontal levelling staff )
( taped distance between pegs )
α = angle to be measured

Figure II - 1.13. Indirect distance measuring.

When the starting and ending point of a distance are not in line of sight, a complete triangulation-network has to be made, from which coordinates are to be calculated, yielding the distance between the two points.

A modern method of distance measuring is with electromagnetic or electro-optical distance meters. Accuracies are very high and ranges upto 50 km. (depending on type and make of instrument) can be measured. Most of these intruments are to be used in combination with a theodolite.

### 1.3.5 Local grid system, true north bearing, transformations

In case the stations necessary for a detailed survey of an area, can not be connected to the G.T.S. network immediately, a local grid system can be established.

The major station in the local grid system is given coordinates in such a way that all points in the whole area to be surveyed can be expressed in the same coordinate system. An approximate north-direction of a local grid system can be obtained with the help of a compass. A more

exact true north bearing can be calculated from observations of the sun's azimuth with the theodolite. The true north bearing can then be calculated using tables in the Nautical Almanac.

If at a later stage the local grid is connected to the G.T.S. network, coordinates have to be re-calculated for all established stations. If the relation between national and local bearing an national coordinates and local coordinates is known, then the coordinate transformation can be calculated using the following formula's:

$$X' = X.\cos\varphi - Y.\sin\varphi + A$$

$$Y' = X.\sin\varphi + Y.\cos\varphi + B$$

in which: $X', Y'$ = G.T.S. grid - coordinates

$X, Y$ = local grid - coordinates

$\varphi$ = difference in bearing

$A, B$ = transversal difference in resp. X and Y coordinates.

## 1.4 Mapping

### 1.4.1 Aerial photography

For the preparation of maps the aerial photography is widely used. Terrestial surveys and measurements can therefore be limited to certain control points. The average scale of the photos equals f/h in which f is the focus distance of the camera and h is the flighing height during photography. Aerial photos resemble a map, but there are geometrical differences. The aerial photo represents a central projection ($P \rightarrow p$) and a map shows a orthogonal projection ($P \rightarrow p_o$) of the area. Vertical photos show a radial displacement of all features of $\Delta r = (P_o - P_c)$ except in the centre of the photo (see Figure II - 1.14).

Photos are usually taken with 50-75% overlap in flighing direction and 10-20% overlap for two parallel runs, so that the edges of each photo are also covered by the centre part of the next photo.

The fastest way to produce a map from aerial photos is to prepare an photo-mosaic, by fitting all photos together or better: fit together the centre-parts (the most accurate, with the least radial

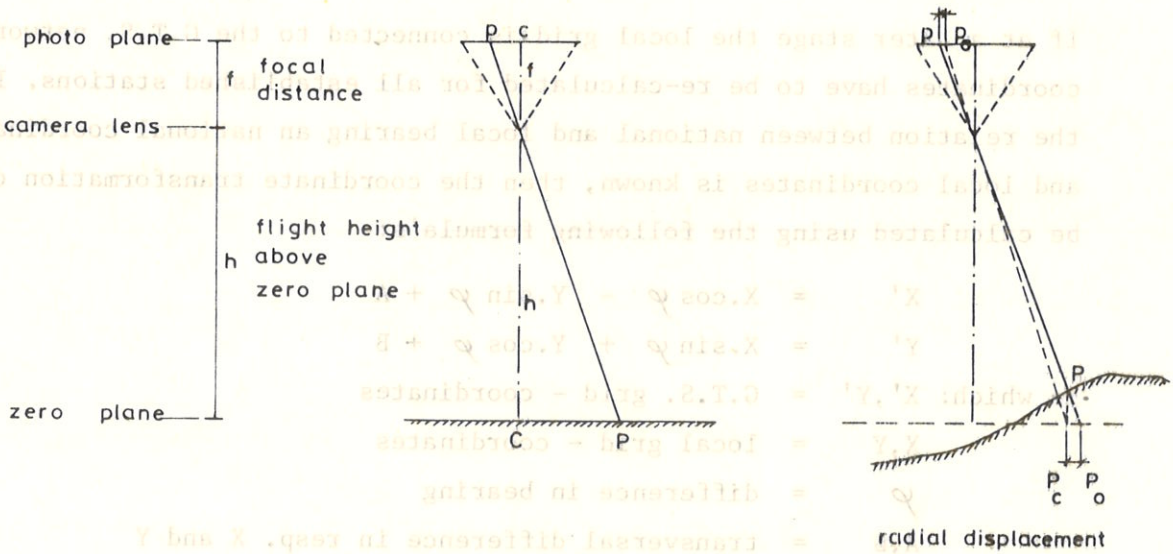



Figure II - 1.14. Projections from aerial photos.

displacements) of all photos . However the accuracy of a mosaic map is not very high. In case of differences upto 2% in the distance between aero plane and ground surface, either due to instable flying course or terrain height changes, the errors on the mosaic-fittings will be upto 3 mm per photo.

When the terrain is rather flat the photos can be corrected for camera tilt and flighing height differences with the help of optical mechanical rectifying instruments. Three or four control points with known coordinates have to be identified on each photo. Fitting these controlled photos together will result in controlled mosaic maps or better: photomaps. These maps have a graphical accuracy of 0.2 - 0.5 mm (see paragraph 1.4.2).

Several aerial photography surveys have been made over the delta area. The first photography was done in 1942. All information on available photos ,maps and mosaics of the aerial surveys upto 1961 can be found in the Photo and Map Catalog, prepared by Survey of Pakistan. The catalog can be consulted at the Cartography Section - BWDB - Dhaka.

Photos may be collected from this office upon submission of special request forms.

For the aerial surveys since 1961, the available photographs of the area of interest are summarised in ANNEX II - 3.

### 1.4.2 Cartography

Topographical maps are prepared from the survey results, either aerial or landbased, but mostly both.

The appropriate scale of a map is depending on requirements of accuracies and amount of details to be shown. Maps are usually made upto graphical accuracy standard, i.e. measures taken from the map have errors with a standard deviation of 0.2 - 0.5 mm. Practically this means that, if the mapuser wants to know a certain distance upto 5 m accurate, then he should use a map of 1:25000 scale. For higher accuracies he should take bigger scale maps. When plotting survey results or preparing additional maps, this graphical accuracy standard should be considered.

ANNEX II - 4 gives a summary of available maps in Bangladesh; they can be obtained at BWDB's Cartography Section or at Survey of Bangladesh.

Under preparation, by Survey of Bangladesh, are the Yearly General Reports, covering the period 1971 - 1981, in which all information on available maps, aerial photography and other surveys and all new map issues are presented for the respective years. The first reports are available as from early 1983.

## 1.5 Topographic surveys for polder development works

### 1.5.1 Organization of the survey work

If prior to the design of polder construction works like embankments, regulators, drains, canals, bridges, roads, etc., no detailed topographic maps are available, surveys have to be carried out to fill in the missing data. The surveys are necessary to determine the alignment of embankments and canals, to estimate the work and to determine the area to be acquired. After completion of the works, surveys have to be repeated regularly.

For proper maintenance of the embankments surveys have to be repeated at five year intervals. In case of calamities, damages due to floods, subsidence or erosion, a re-survey has to be made immediately.

All survey work has to be connected to the national survey grid system (G.T.S.). The reason is that all new stations, benchmarks and structures will thus form part of the same framework and that extension and comparison with former and neighboring surveywork is possible.

For this purpose, two or three stations have to be established in the area to be developed. These stations have to be connected to the G.T.S. grid ultimately, although initially a local grid system can be applied. For big areas more stations will be required, depending on what is practical.

The thus established main polder survey stations will serve as the basis for all further measurements. These further measurements can be:

- extensive levelling of the polder area for the preparation of a detailed contour-map,
- triangulation and levelling for an existing or planned embankment, in order to locate and plot the exact alignment and/or to assess maintenance works,
- measuring of alignment and cross-sections of internal canals,
- measuring cross-sections of the rivers surrounding the polder,
- measuring location and elevation of existing structures,
- preparation of detailed maps for locations where structures are planned.

For the setting out of drainage and irrigation canals, at first the centre-line of the work is set out with pegs and then the slope lines are pegged. The top of the pegs in one cross-section should be on the same level. For easy reference for the labourers an inspectors, slope frames as shown in Figure II - 1.15, indicating the slope of the cut, are to be placed every 50 m.

For re-excavation works and rehabilitation of embankments, only the shoulder or toe-lines can be pegged out. In case of excavations, post work depths can be checked with a pole, measuring the distance from the excavation bottom upto a line which is spanned between the shoulder

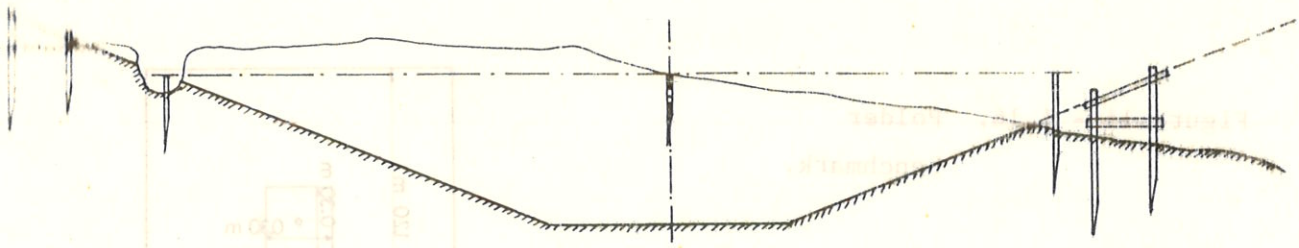


Figure II - 1.15 Excavations of canals.

pegs. For embankment rehabilitation, the post work crest height can be measured from reference posts or poles, erected and measured before the start of the work.

For the required density of the surveys, reference is made to paragraphs 1.2.3 and 1.2.4 of this Volume.

### 1.5.2 Stations, benchmarks and pillars

As a reference for a survey to be carried out in a certain area, benchmarks have to be established. For major benchmarks, it is proposed to use a solid construction of reinforced concrete, consisting of a massive pillar with a foot plate (see Figure II - 1.16).

The foot plate should be burried 1.00 m under ground. On top of the pillar a bolt is to be fixed of which coordinates xyz are to be established. Construction details are presented in Volume VIII of this design manual. The benchmarks should be erected at a well chosen spot, preferably on higher grounds, not at settlement or erosion-prone locations, and not at a place where it is likely to be damaged or demolished.

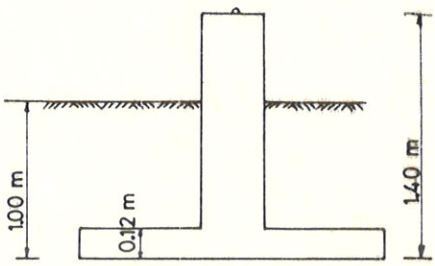
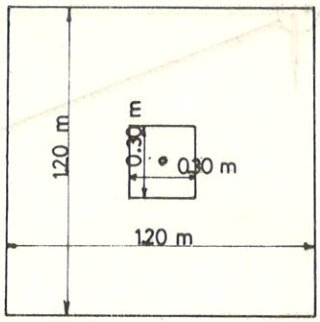



Figure 11 - 1.16. Polder benchmark.




The inscription on the benchmark should be :

| | |
|---|---|
| BWDB<br>P-22/B.M.1 | P-22 to indicate polder No.<br>B.M.1 to indicate sequence |

The inscription is to be made on a steel plate to be cast into the concrete at the side of the pillar.

To establish the alignment of embankments and roads, a simpler type of benchmark is proposed, consisting of a reinforced concrete pillar to be erected every 250 m along the alignment. The inscription on the these pillars should be :

| | | | |
|---|---|---|---|
| BWDB<br>P-22/R 1.25 | for roads | BWDB<br>P-22/E 1.50 | for embankments. |

The number is an indication for the kilometre chainage. The pillars preferably should be erected in a line parallel to the country side toe-line of an embankment at 25 m distance from this toe line. Dimensions of this pillar : 0,1 x 0,1 x 1,20 m.

## CHAPTER 2, River Morphology Surveys

### 2.1 Introduction

River morphology surveys have the objective to monitor the processes and changes which take place in the river bed, and the river banks.

By means of hydrographic surveys, the topography of the river bottom is measured and mapped. River bank alignment surveys are executed to measure any scour or accretion which may have taken place since a previous survey. Sediment transport is measured in case extensive studies are to be carried out in which sediment transport formulas will be used. River bottom sampling may also be an instrument to assess erodibility and dredgeability, in a cheaper way then borings.

### 2.2 Methods

#### 2.2.1 Bathymetric Surveys

The measuring of waterdepths is generally indicated with the term "taking soundings" or bathymetric surveying and can be executed with a sounding pole, a sounding line or an echosounder. For small scale surveys in not too deep water the first two methods are used. For extensive surveys over larger areas an echosounder is used which has the advantage to give a continuous picture of a bottom profile.

An official sounding line has a length of 15 or 30 m. and is made of steel wire with numbered leads for depth indication. At the bottom end a sink-weight is fixed. An alternative sounding line can be made of any available material provided that the length of the line will not change due to the forces exerted (Nylon) or due to getting wet (jute or manilla rope). Depth marks can be fixed with little pieces of leather or plastic, to be inserted in the strings of the wire.

For extensive bathymetric survey works the echosounder is used. The instrument consists of a transducer (oscillator), which is fixed to the side or in the hull of a boat, and a recorder.

Via the transducer, sound waves with a velocity or ± 1500 m/s are transmitted to and reflected by the bottom and received again by the transducer. The interval between transmission and reception of the sound wave is measured and transformed into a length, which is shown

on the recording paper. Most echosounders are working on a 24 Volt D.C. power source. As the speed of sound through water depends on waterdensity (salinity) and temperature the echosounder has to be calibrated before every sounding work. This calibration is done with a barcheck: an iron plate or bar is lowered in the water under the transducer. The reflected depth on the recorder should now correspond with the depth shown on the marked line of the test bar, and the instrument is adjusted accordingly. A bar check has to be executed before and after every sounding work and has to be shown on the echo registration paper.

Accuracies in bathymetric surveying can be split in vertical and horizontal direction.

Vertical inaccuracies (measuring the depth) of echosounding increase with the depth. If the recorded depth is 5 m the total inaccuracy can be upto 0.15 cm. The accuracy is influenced by the sensitivity of the instrument and physical aspects like bottom configuration and composition. Inaccuracies in soundings with a line or a pole are relatively bigger due to unknown penetration into the bottom and never exact vertical position of the sounding device. Inaccuracies in horizontal direction will be discussed in paragraph 2.3.3.

### 2.2.2 River bank alignment surveys.

These surveys are normally executed with the help of a sextant. The observer measures his position while walking or moving by boat as close to the riverbank as possible. Positioning is done by re-section method (see paragraph 1.1.3 and 1.3.2) using stations established on the opposite bank. The intermediate distance between the consecutive position fixes depends on the character of the bank. Straight or smoothly curved banks require less position fixes than irregular shore lines.

### 2.2.3 Sediment transport measurements

The purpose of measuring the amount of sediment transported by a river, is to select and check a suitable formula with which the sediment transport of that particular river can be approximated. Although sediment

transport formulas still are rather inaccurate due to the high complexity of the phenomena, these formulas facilitate the design of engineering works in rivers and estuaries and are an instrument to predict morphological changes resulting from these works.

Sediment transport consists of washload, transported in suspension, and suspended load, considered to be fine sand grains kept in suspension by turbulencies and bed load, which is that part of the transport which moves close along the river bottom. Different instruments are used to sample the three components of sediment transport.

In order to compute the total sediment transport of a river, whether inclusive or exclusive the wash load, the following data are also required.

- Cross-sectional profile of measuring site
- Velocity profile, in vertical and over the width
- Sampling depth of velocities and sediments
- Measuring time of velocities and sediments
- Slope of the water surface
- Catches of sediment in volume and weight
- Grain size distributions of bottom samples and transport catches.

The exact calculation procedure depends on the requirements of the specific sediment transport formula to be tested with the results of the measurements.

In case it is considered necessary to carry out sediment transport measurements, it is advised to contact the expertise available within the River Research Institute.

### 2.2.4 Bottom sampling

Bottom sampling results are important to assess the erodibility and dredgeability of a riverbed and to determine origin and characteristics of the riverbed material. For the sampling of the bottom of rivers and canals a grab or scoop type of instrument can be used. Samples can be taken upto a penetration depth of 10-20 cm. Special free-fall samplers have been developped to sample at larger depths (upto 1.5 m penetration) depending on the type of material. The most common bottom samplers are:

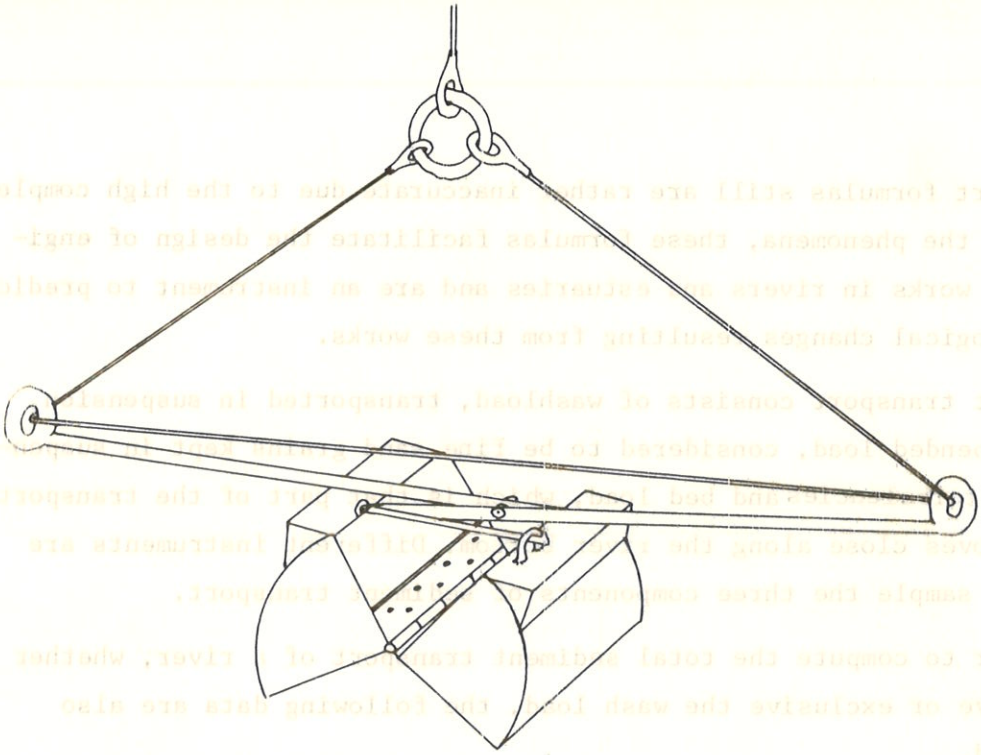


Figure II - 2.1. Van Veen bottom grab.

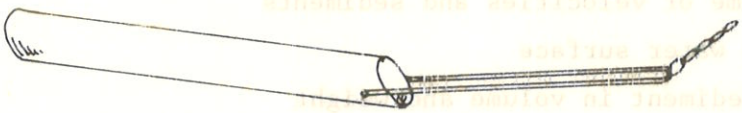


Figure II - 2.2. Drag bucket sampler.

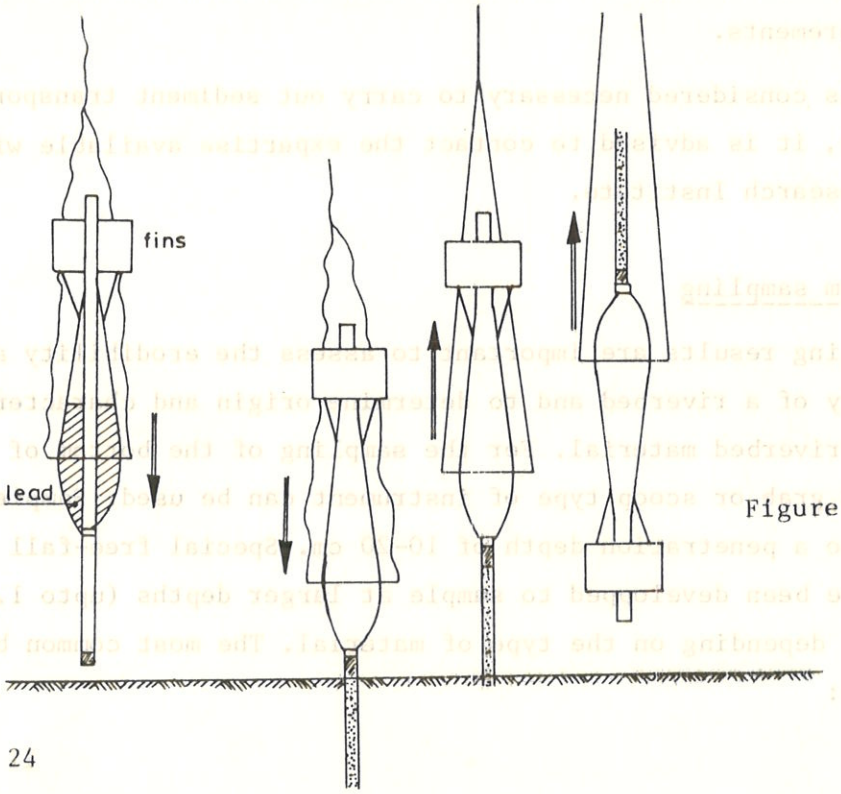



Figure II - 2.3. Free fall sampler.

| | |
|---|---|
| Van Veen grab | Figure II - 2.1 |
| drag bucket sampler | Figure II - 2.2 |
| free fail sampler | Figure II - 2.3 |

Samples taken are dried and weighed and grain size distribution is determined.

## 2.3 Position fixing during surveys

### 2.3.1 Methods

For hydrographic surveys, positioning can be obtained via mechanical, optical or electronic means.

In the mechanical methods the instrument (sounding pole, sounding line, echosounder, sediment sampler, all operated from a boat) is moved along a wire which is fixed across the creek or river to be sounded. The beginning and ending point of the line are measured via land survey methods and in the line itself tags are fixed to indicate distance from the ends of the line. It is obvious that this method only can be used in not too wide creeks and small rivers. For wider waters either use is made of a lane set out with visual beacons and positioning in the lane is determined by angle measurement, or by simultaneous angle measurements to known points.

### 2.3.2 Positioning by angle measurement

In case a limited number of cross-sections have to be sounded regularly (i.e. cross-section for discharge and/or sediment measurements, site for closuredam), the lanes to be sounded are marked on the shore or on both shores, with three markers. The sounding vessel is kept exactly in this lane and its position in the lane is determined by measuring the angle to a fourth beacon, established at a known distance perpendicular to the lane (see Figure II - 2.4).

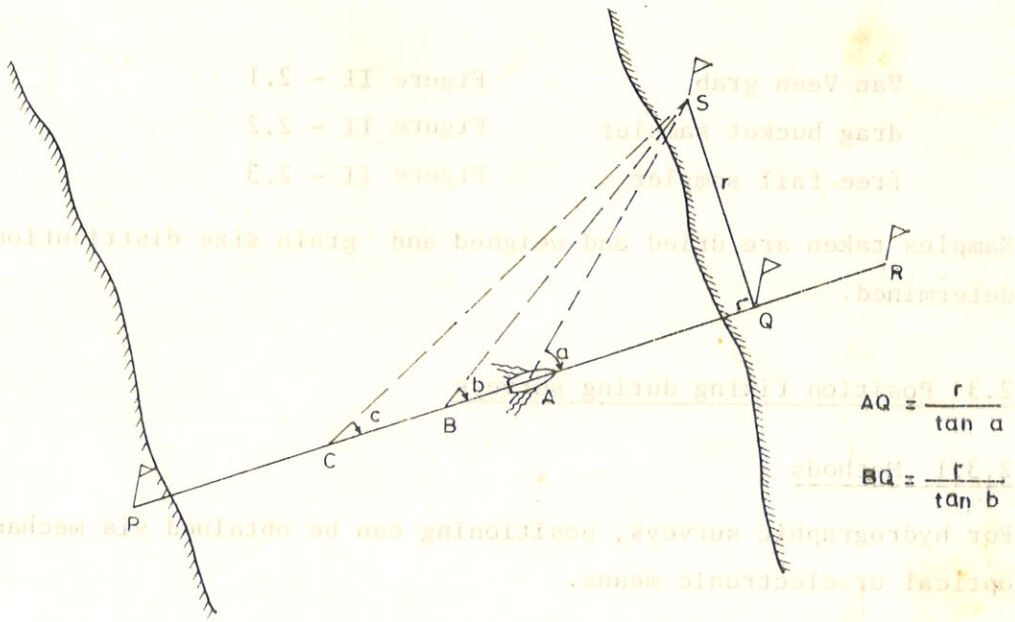



Figure II - 2.4. Positioning bu one sextant angle measurement.

For accurate positioning, not necessarily in the measuring lane, the position of the sounding vessel can be measured simultaneously with two theodolites from two known points (see Figure II - 2.5) (section-method).

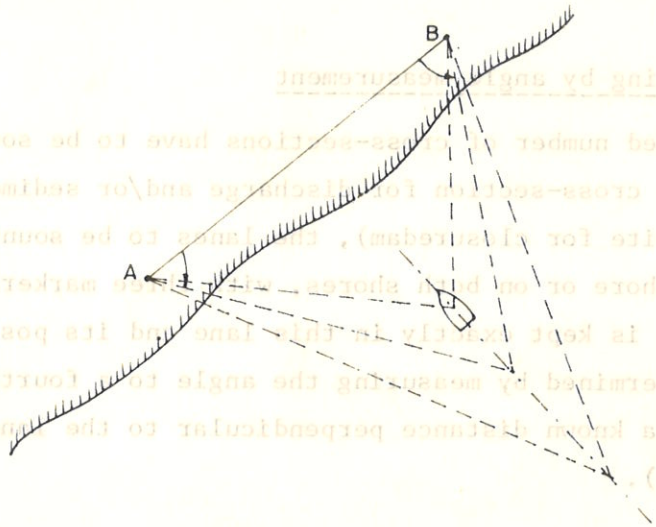
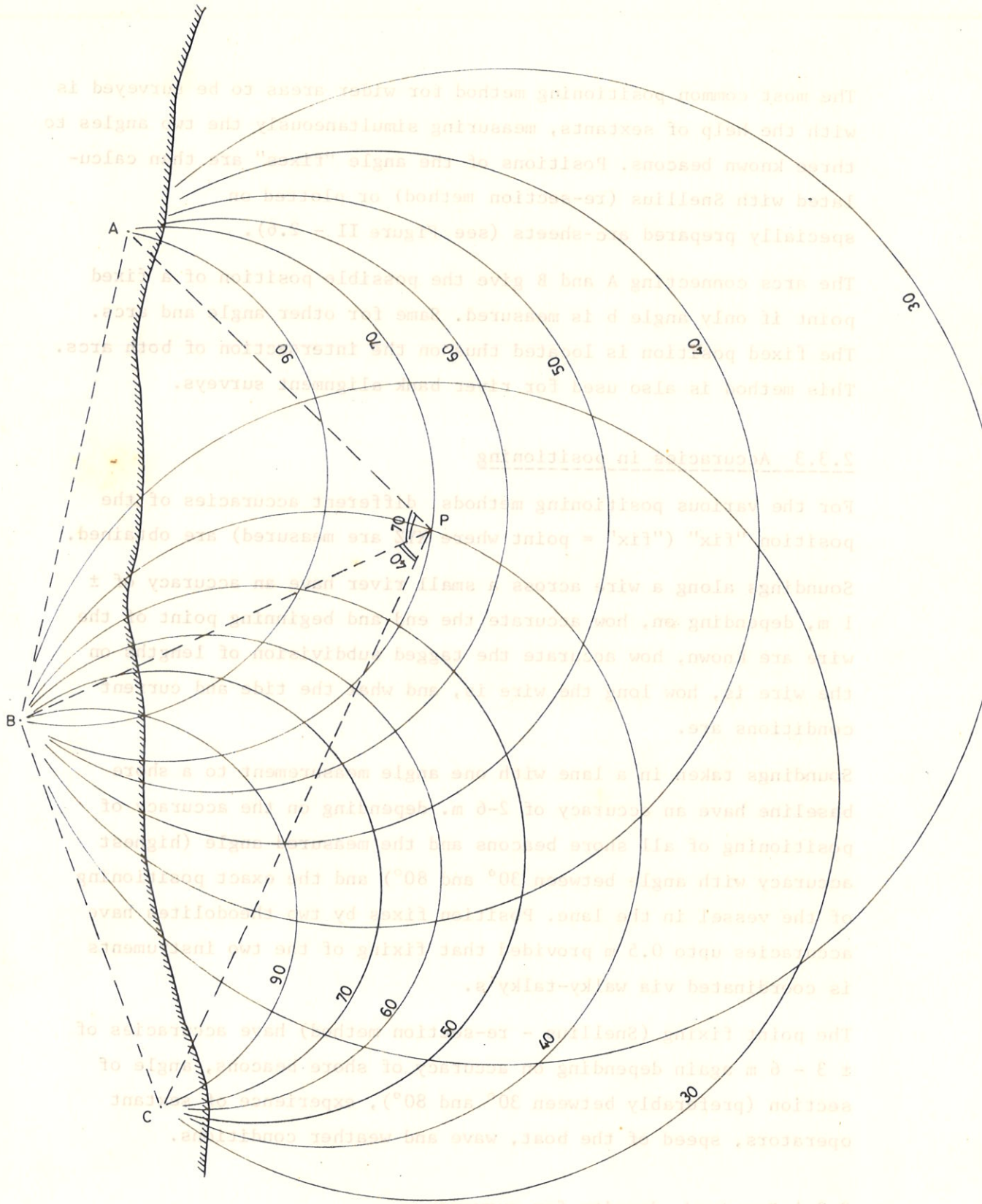



Figure II - 2.5. Positioning by two simultaneous angle measurements from the shore.




P is plotted from angle measurements: $\angle APB = 70°$
$\angle BPC = 40°$

Figure II - 2.6. Positioning by re-section angle and arc-sheets.

The most common positioning method for wider areas to be surveyed is with the help of sextants, measuring simultaneously the two angles to three known beacons. Positions of the angle "fixes" are than calculated with Snellius (re-section method) or plotted on specially prepared arc-sheets (see Figure II - 2.6).

The arcs connecting A and B give the possible position of a fixed point if only angle b is measured. Same for other angle and arcs. The fixed position is located thus on the intersection of both arcs. This method is also used for river bank alignment surveys.

### 2.3.3 Accuracies in positioning

For the various positioning methods, different accuracies of the position "fix" ("fix" = point where XYZ are measured) are obtained.

Soundings along a wire across a small river have an accuracy of ± 1 m, depending on, how accurate the end and beginning point of the wire are known, how accurate the tagged subdivision of lengths on the wire is, how long the wire is, and what the tide and current conditions are.

Soundings taken in a lane with one angle measurement to a shore baseline have an accuracy of 2-6 m. depending on the accuracy of positioning of all shore beacons and the measured angle (highest accuracy with angle between 30° and 80°) and the exact positioning of the vessel in the lane. Position fixes by two theodolites have accuracies upto 0.5 m provided that fixing of the two instruments is coordinated via walky-talky's.

The point fixing (Snellius - re-section method) have accuracies of ± 3 - 6 m again depending on accuracy of shore beacons, angle of section (preferably between 30° and 80°), experience of sextant operators, speed of the boat, wave and weather conditions.

### 2.3.4 Required density for surveys

The distances between the cross-sections along which the depth of a river is to be measured, depends on the purpose of the survey.

For long term monitoring of river bottom behaviour, with surveys executed once or twice a year, the distance between two cross-sections can be big. Normally in such cases the intermediate distance is in the range of the river-width.

For detailed surveys, with the purpose to monitor smaller scale features like moving shoals, exact location of future boat landings, jetties, water level recorders and closure dams the distance is to be much smaller. In ANNEX II - 5 density requirements of various bathymetric survey work are summarized.

## 2.4 Water levels and Tides

### 2.4.1 Datum for soundings

Waterdepths are always measured relative to the water level at the time of the sounding. This water level will never be the same at different places and different times due to changing tides, discharges, etc, etc. Therefore all measured depths have to be corrected in such a way that bottomdepths are relative to a fixed reference plane. P.W.D. (Public Works Datum) is used as a reference plane.

To apply the water level correction it is imperative that the water level is recorded during the time of the sounding. In case of very slow changing levels a reading before and one after the soundings is sufficient, as long as this water level difference is within the accuracy range of the echosounder. For tidal areas the tide has to be registered continuously and the soundings should be reduced accordingly, using the time-fixes made during the sounding.

If the survey area is within 5 km of a permanent gauge station then the tidal information from this station can be used to reduce the survey measurements to P.W.D.

If no permanent gauge is available then a temporary gauge should be established, which has to be levelled to the nearest point with known elevation.

In case elongated river stretches have to be measured, more gauges should be placed and the reduction to be applied should be interpolated between the gauges. Special care has to be taken if both such

gauges have a tidal character. Then a reduction curve should be plotted of each gauge and the reduction for the survey area should be derived from both results. In ANNEX II - 6 an example is elaborated for plotting such a reduction curve.

Generally a gauge (temporary or permanent) should not be further away than 5 km from the centre of the survey area. If a river stretch to be surveyed is longer than 5 km then the readings of two gauges have to be used for determining the reduction in relation with the time. The maximum distance between these two gauges should not exceed 10 km but is highly dependant on tide characteristics (if any), and river regime.

Above standards are only indicative and especially near complicated bifurcations and confluences a practical solution has to be chosen.

2.4.2 Tides

Tides are generated by the attracting forces of sun and moon on the surface waters of the earth. The attraction force is proportional to the mass and to the inverse of the distance to the power three of the two bodies. Therefore the influence of the moon in the earth's sea-tide is much stronger than the sun's influence. Nevertheless both celestial bodies are taken into account in determining the tide generating constituents. Tidal constituents can be determined mathematically, with the help of astronomical information on the sun's and moon's movement. The calculation process will not be further elaborated. The main tidal constituents are the $M_2$, $S_2$, $N_2$, $K_2$, $K_2$, $K_1$, $O_1$ and $P_1$ - tides.

Each constituent has its own amplitude, and phase and forms part of the complex formula describing the tidal curve.

The general form of this complex formula is :

$$H_{(t)} = H_{(o)} + h \times \text{cosine (of the phase)}.$$

in which : $H_{(t)}$ = water level at time t
$H_{(o)}$ = average water level (M.S.L.)
h = amplitude of the tidal constituent
phase = time required for a constituent force to re-occur

The phase of the most important tidal constituents is presented in Table II - 2.1.

The amplitudes of the constituents are determined by analysing long term continuous tidal information on a certain gauge station. These analyses are only possible with the help of sofisticated computer equipment

Table II - 2.1 Tidal Constituents

| Name | Tidal constituent | Period | Speed = 360°/period |
|---|---|---|---|
| $M_2$ tide | Mean lunar tide | 12 h 25 m | 29° |
| $S_2$ " | Mean solar tide | $12^h$ | 30° |
| $N_2$ " | Moon elliptical tide | $12^h$ $40^m$ | 28°, 44 |
| $K_2$ " | Sun/Moon declination tide | $11^h$ $58^m$ | 30°, 08 |
| $K_1$ " | Sun/Moon declination tide | $23^h$ $56^m$ | 15°, 04 |
| $O_1$ " | Moon declination tide | $25^h$ $49^m$ | 13°, 94 |
| $P_1$ " | Sun declination tide | $24^h$ $04^m$ | 14°, 96 |

Apart from above primary tides, secondary or shallow water tides are distinguished. The amplitudes of these tides are much smaller but have to be considered because the harmonic smoothness of the tide is distorted in shallow seas and gulfs.

| Tidal constituents | Speed | |
|---|---|---|
| $S_4$ tide | $2 \times S_2$ | The tidal constituents indicated with a 4, give 4 times high water and 4 times low water every day. 2 MS is a semi diurnal tide. |
| $M_4$ " | $2 \times M_2$ | |
| $MS_4$ " | $M_2 + S_2$ | |
| 2 MS" | $M_4 - S_2$ | |

The character of a tide depends on whether the semidiurnal constituents, indicated with a 2, or the diurnal constituents ($K_1$, $O_1$, $P_1$) are predominent. A semidiurnal tide, with main constituents

$M_2 + S_2$ has two high and two low waters every day and a spring tide every $14^3/4$ days. Both high waters (HW) are equal in height as are the low waters (LW) and the LW lies halfway in between two high-waters.

A diurnal tide depends mainly on $K_1$ and $O_1$ constituents and has one HW and one LW a day and the spring tide occurs every $13^2/3$ days, equalling the time laps between two maximum moon declinations.

Mixed tides occur at places where there is a change in predominancy of semi-diurnal and diurnal constituents. Its main characteristic is the difference between two consecutive HW - elevations and LW elevations. The tides in Bangladesh have a predominantly semi-diurnal character, with at night-time slightly higher amplitudes than at the day-time.

The Mean Sea Level is the average level of the sea surface measured over a long period. It is the water level that would occur in the absence of tides.

M.S.L. is used for design purposes when floor slab levels and discharge capacities through regulators in tidal areas have to be calculated.

M.S.L. is determined from the analyses of the tidal constituents which is quite an extensive computation . However the admiralty method can be used to calculate M.S.L. from shorter periods of record and gives sufficient accuracy for the above purposes. The method is based on 39 consecutive hourly tidal readings. Each reading is multiplied by a factor, and the total sum of these products is divided by the number of multiplyers, i.e. 30. The result gives the M.S.L. The series of 39 tidereadings can start at any moment. The observations should be executed during spring tide.

The multiplyers are presented in the following Table II - 2.2.

Table II-2.2 Multipliers for M.S.L. - determination according to Doodson

| hr | Hi | Xi | hr | Hi | Xi | hr | Hi | Xi | hr | Hi | Xi |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | " | 1 | 10 | " | 2 | 20 | " | 2 | 30 | " | 1 |
| 1 | " | 0 | 11 | " | 0 | 21 | " | 1 | 31 | " | 1 |
| 2 | " | 1 | 12 | " | 1 | 22 | " | 1 | 32 | " | 0 |
| 3 | " | 0 | 13 | " | 1 | 23 | " | 2 | 33 | " | 1 |
| 4 | " | 0 | 14 | " | 0 | 24 | " | 0 | 34 | " | 0 |
| 5 | " | 1 | 15 | " | 2 | 25 | " | 1 | 35 | " | 0 |
| 6 | " | 0 | 16 | " | 1 | 26 | " | 1 | 36 | " | 1 |
| 7 | " | 1 | 17 | " | 1 | 27 | " | 0 | 37 | " | 0 |
| 8 | " | 1 | 18 | " | 2 | 28 | " | 2 | 38 | " | 1 |
| 9 | " | 0 | 19 | " | 0 | 29 | " | 0 | | | |

$$M.S.L. = \frac{(Hi \times Xi)}{30}$$

Hi = gauge reading
Xi = multiplier.

The Mean Sea Level determined in this way does however include any seasonal variation, and is only valid for the specific time of year when it was determined. For more accuracy and the determination of seasonal variations, the measurements have to be repeated.

### 2.4.3 Definitions of tidal levels presented in Tide Tables

H.A.T. Highest Astronomical Tide

L.A.T. Lowest " "

The highest/lowest level which can be predicted to occur under average meteorological conditions and any combination of astronomical conditions.

H.A.T. and L.A.T. are not extreme levels since adverse meteo conditions (storms - surges) are not included.

M.H.W.S. Mean High Water Spring

M.L.W.S. " Low " "

The average level throughout the year of High/Low water spring tides, occurring approximately every fortnight. Springtide is occurring when the tidal amplitude is the greatest in a period of $13^3/4$ days.

M.H.W.N. Mean High Water Neap

M.L.W.N. " Low " "

The average level, throughout the year of High/Low water neap - tides, occurring approximately every fortnight. Neap - tide is occurring when the tidal amplitude is the smallest in a period of $13^3/4$ days.

M.H.H.W. Mean Higher High Water

M.L.H.W. " Lower " "

M.H.L.W. " Higher Low "

M.L.L.W. " Lower " "

In case of semi-diurnal tidal conditions generally one of the two high waters occurring per day is higher then the other. The same applies for the low waters.

The above levels are the average over a long period of time of the higher high water, the lower high water, the higher low water and the lower low water.

## Chapter 3. Hydrological Measurements

### 3.1 Waterlevels

The collection of waterlevel data is necessary for the plotting of a stations hydrograph (water level against time), duration curve (indicating probability of occurrence of waterlevels), rating curve, (waterlevel against discharge). Comparing hydrographs of different stations along a river gives insight in propagation and deformation of floods. Stage relation curves can be drawn for steady flow conditions, comparing water levels at various stations.

Gauge stations should be located at places where changes in discharge of river regime are abrupt, i.e. downstream bifurcations and confluences, at places where a change in waterslope is expected. Effects of backwater, degradating or aggradating banks, accelerated or retarded flow, transversal slopes of water level in bends, wind effects (waves) should be avoided. For reference, the 'O' of the gauge should be connected to preferably 2 or 3 benchmarks and should be checked regularly. Water levels can be measured via a common staff gauge or with a water level recorder. The accuracy of water level readings is in between 1 and 3 cm depending on the location of the gauge, maintenance of gauge, type of gauge and operator. For flood crest gauges a maximum accuracy of 5-10 cm can be attained, due to the rare occurrence of floods, the infrequent maintenance and local disturbences of the flood wave.

The visual observations on a staff gauge in tidal areas should comprise the recording of water level and time at each high water and low water during day - time hours. For special purposes, like the determination of the tide curve, readings should be taken at every quarter hour, during a 24 hours period. For the purpose of soundings, or discharge measurements, readings should be taken every half hour during the time of the measurement.

In ANNEX II - 7 the locations of all permanent water level recording stations in Bangladesh are shown. It is also indicated which organization or authority is maintaining the station.

## 3.2 Discharges

The basis for the determination of discharges of rivers and waterways are the velocity measurements. For the discharge measurements a cross-section of the river has to be selected where in several positions along the cross-section the velocity is determined. This cross-section should preferably have a uniform profile and a smooth evenly spread current pattern without cross-currents. For the determination of the discharge also the river bed profile has to be measured. The depth of the river can be determined the best with an echosounder, although most propellor current meters are equipped with a special device measuring the length of the suspension cable when the instrument is touching the bottom. In this case depths are only known at the verticals where the velocity has been sampled.

From the above measurements the discharge can be calculated graphically, by plotting width against depth and against the mean velocity per vertical and multiplying both areas measured with a planimeter (see Figure II- 3.1).

The accuracy of discharge measurements depends mainly on the number of velocity profiles that are measured, because the general geometry of a river or tidal inlet is such that the width is far greater than the depth. The number of velocity measurements over the depth at one location is of less important; usually the two point method (see paragraph 3.3) is satisfactory.

It is the general practice within the WDB - Hydrology Department that discharge measurement results are presented in a tabulated format on which the tidal discharge is calculated arithmitically.

In non tidal rivers the changes in discharge during the execution of the discharge measurement is negligible.Usually the measurement is executed with one instrument which is moved along the cross-section, measuring all the velocity profiles required.

In tidal rivers not only the water level will change but currents and discharge will fluctuate between maximum flood stage and maximum ebb stage. In the ideal case both water level and velocities in all the required profiles should be measured continuously. However

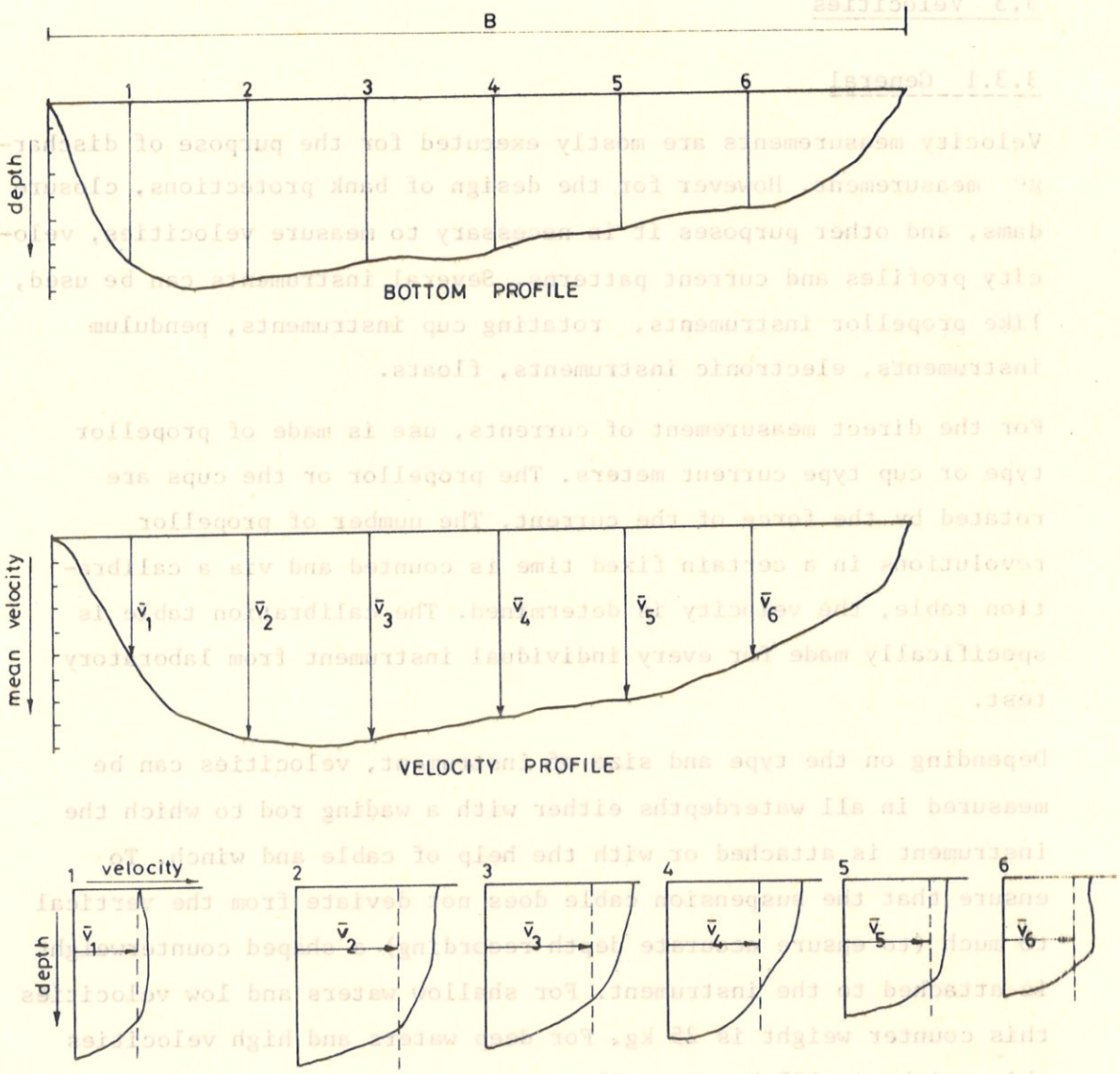



Figure II - 3.1. Discharge calculation.

normally one or two instruments are only available and the change of discharge is measured in relation to one or two reference verticals, where the instruments are located during the whole measurement, (lasting 13 hrs.) measuring the velocity in the vertical every half or full hour.

Special attention should be given to the presence of ebb - or flood channels, i.e. different paths of out-flowing and entering tide.

## 3.3 Velocities

### 3.3.1 General

Velocity measurements are mostly executed for the purpose of discharge measurement. However for the design of bank protections, closure dams, and other purposes it is necessary to measure velocities, velocity profiles and current patterns. Several instruments can be used, like propellor instruments, rotating cup instruments, pendulum instruments, electronic instruments, floats.

For the direct measurement of currents, use is made of propellor type or cup type current meters. The propellor or the cups are rotated by the force of the current. The number of propellor revolutions in a certain fixed time is counted and via a calibration table, the velocity is determined. The calibration table is specifically made for every individual instrument from laboratory test.

Depending on the type and size of instrument, velocities can be measured in all waterdepths either with a wading rod to which the instrument is attached or with the help of cable and winch. To ensure that the suspension cable does not deviate from the vertical to much (to ensure accurate depth recording) a shaped counterweight is attached to the instrument. For shallow waters and low velocities this counter weight is 25 kg. For deep waters and high velocities this weight is 100 kg. Propellor type instruments are less sensative to external disturbances, influencing the measurements. If also the flow pattern has to be determined use is to be made of floats (see paragraph 3.3.3).

### 3.3.2 The velocity profile

The water velocity at a certain location in a river is not evenly distributed from surface to bottom, and even at a certain depth the velocity will never be constant but will have a stochastic character caused by turbulence. In order to eliminate the stochastic component in the velocity, measurements at one spot should last for at least 30 - 60 seconds. To measure the velocity profile from surface to

bottom, observations are carried out at several different depths. The mean velocity for each profile can however be approximated by the two-point method.

$$\bar{v} = \tfrac{1}{2}(v_{o.2} + v_{o.8})$$

$\bar{v}$ = average velocity

$v_{o.2}$ = velocity at 0.2 of the depth

$v_{o.8}$ = velocity at 0.8 of the depth

In case velocity measurements are carried out at stages in which the tide has not fully developed (i.e. around slack water periods) one should be carefull in applying the 0.2/0.8 method. In such cases it is advised to sample velocities at a number of depths from bottom to surface in order to detect any deviations from the assumed velocity profile.

### 3.3.3 Float observations

Both velocity and the direction of streamlines can be determined with float observations and measurements. The most simple way is to release the float from an anchored boat. The time is recorded that it takes for the line attached to the float to stretch. Velocity and also direction can thus be determined. Another method is the free float method. The floats are released and are followed by boat or from the shore, while at fixed intervals the position of the floats is determined by measuring angles with sextants.(see Figure II - 3.2).

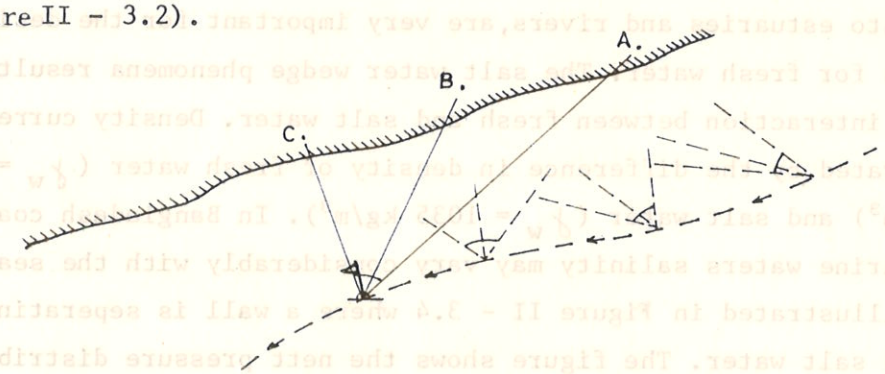



Figure II - 3.2. Float position measurement.

To reduce the influence of the wind on a float, a resistance body is to be fixed. If the determination of the mean velocity is the objective of the measurement then this body should be at depth 0.6 x d (assuming parabolic velocity distribution (see Figure II - 3.3). The resistance body can also be made of a banana tree, to which some bricks are attached.

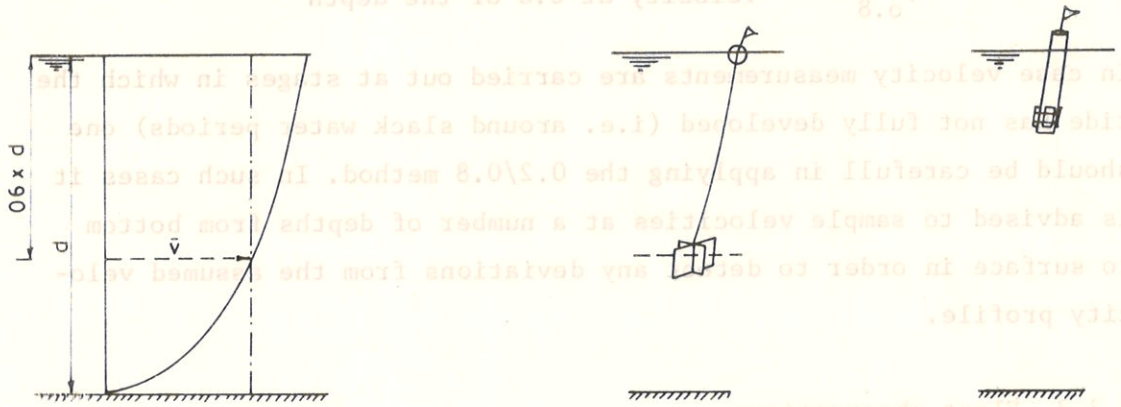



Figure II - 3.3. Floats and velocity distribution.

## 3.4 Salinity measurements

The movements and interactions between sea water (salt) and fresh-water river discharge, specially the penetration of salt water wedges into estuaries and rivers, are very important for the design of inlets for fresh water. The salt water wedge phenomena results from the interaction between fresh and salt water. Density currents are generated by the difference in density of fresh water ($\gamma_w$ = 1000 kg/m$^3$) and salt water ($\gamma_w$ = 1035 kg/m$^3$). In Bangladesh coastal and estuarine waters salinity may vary considerably with the season. This is illustrated in Figure II - 3.4 where a wall is seperating fresh and salt water. The figure shows the nett pressure distribution and the resulting movement of the water when the separation is removed.

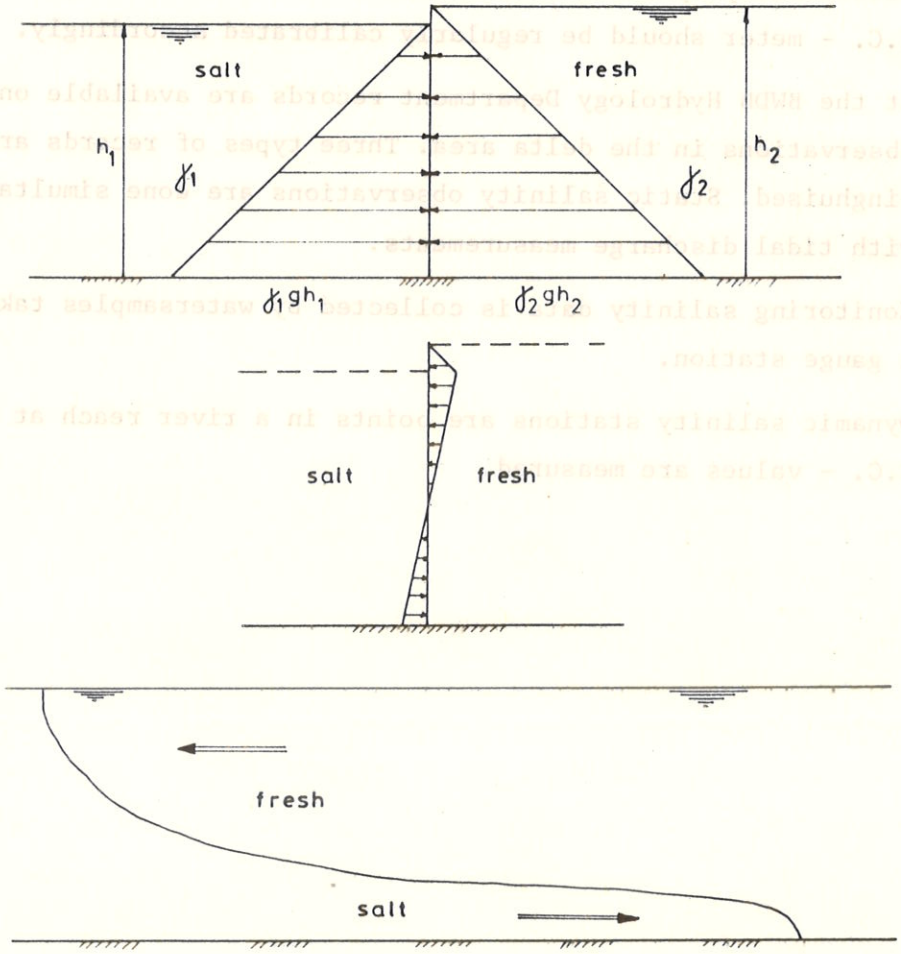



Figure II - 3.4. Effects of density differences.

Another phenomenon which results from the density currents is the siltation that takes places. Due to chemical processes in salt and fresh water boundaries, silt particles carried seaward in suspension by the freshwater river discharge are coagulating to bigger units with heavier weight and are consequently sinking to the bottom.

In Bangladesh the salinity of the water is measured as the EC-value (electric conductivity) in micromho/cm, from which the salinity can be calculated.

Salinities measured with the E.C. - method need to be checked periodically by laboratory analyses of the water samples. The E.C. - meter should be regularly calibrated accordingly.

At the BWDB Hydrology Department records are available on salinity observations in the delta area. Three types of records are distinghuised. Static salinity observations are done simultaneously with tidal discharge measurements.

Monitoring salinity data is collected by watersamples taken near a gauge station.

Dynamic salinity stations are points in a river reach at which E.C. - values are measured.

## Chapter 4. Meteorological Observations

The main purpose of the meteorological data collection in relation to the development of the delta area is the supply of data for the estimate of the drainage and irrigation requirements. In addition, the data may serve to determine agro climatological potentials and constraints regarding the cultivation of certain crops.

On ANNEX II - 8 the location of all presently maintained meteo-stations and the maintaining organization are indicated. Which data is to be gathered depends on the design requirements and formula's to be used. Most information is available in tabulated form and can be collected from the agencies mentioned in ANNEX II - 8.

For further applications reference is made to Volume IV - Design Criteria - Irrigation and Drainage Requirements. If data is originating from meteo stations too far away, additional measurements have to be executed. The purpose of these additional measurements can either be the creation of new set of data or to provide a means of checking the data generated from interpolation of data from surrounding stations.

## Chapter 5. Groundwater Surveys

### 5.1 Introduction

In the delta area the salinity in the shallow aquifers, to depths of 60 m, is extremely variable and changes rapidly over short distances. The salinity appears to be closely related to the relative amounts of saline and fresh water flooding from estuarine tidal effects. In this respect the coastal embankment project will result in an overall improvement in shallow groundwater salinities.

It is common experience that whenever there is fresh groundwater in deltaic areas, it usually floats on top of highly saline water, due to density differences. If this fresh water is skimmed off for irrigation use, this will result in a drawdown, which will raise the interface of the saline water and fresh water.

In many places the shallow groundwaters are too saline for domestic or irrigation use.

In general it can be stated that the groundwater cannot be used for irrigation purposes. In the dry season the soil will dry out. Under neutral drainage conditions, which means no natural drainage nor any subsoil supply, the groundwater table will drop rapidly as a result of evapotranspiration. This drop will occur to that depth at which the vertical moisture and salt transport becomes practically zero. This depth is called the critical depth. In this case the evaporation of the groundwater through capillary rise is usually restricted to 20 - 50 mm of soil moisture per year.

In low lying polders, however, the groundwater may be replenished by seepage from the surrounding estuaries, which, in the dry period, are often highly saline. The groundwater may stay above the critical depth and evaporation through capillary rise of soil moisture may continue throughout the dry season, resulting in very high salt contents of the top soil. These salts have to be superficially flushed out via the drainage system or leached down to the subsurface layers in the next rainy season before cultivation of a crop can start. This limits the possibilities of an Aus crop or

delays the start of an early Aman crop. Especially in the western part of the Khulna district, with a relatively short rainy season, the opportunities for double cropping are greatly reduced. To reduce the salinization it may be necessary to combine the shallow surface drainage system, which evacuates the excess rainfall, with additional drainage channels to provide groundwater control.

To investigate the necessity and the scope of the groundwater control, surveys and investigations have to be carried out to obtain data on desiccation of the soil, capillary rise, groundwater quality and groundwater flow (replenishment).

It should be realised that a full scale groundwater survey programme is an expensive and time consuming affair. Therefore full scale groundwater surveys should only be undertaken in case there is reason to assume that there is clear scope for the irrigation use of groundwater.

## 5.2 Preparatory study

Prior to the groundwater survey, all available data should be collected on topography, geology, hydrology, groundwater quality, existing tubewells with possible strata descriptions, borelogs of sluices and aquifer zones indications.

## 5.3 Observation network

The lay-out should be based on any information on topography, geology, hydrology, soils, etc., collected and studied during the preparatory phase.

The observation points should be located

- along lines of expected groundwater flow. In general this will be perpendicular to the polder embankments.
- in areas where shallow water tables occur.

With regard to the density of the observation network, no strict rule can be given as it depends entirely on the topographical, geological and hydrological conditions of the area under study. Table II - 5.1 may serve as a rough guide :

Table II - 5.1 Relations of area size viz. observation points

| Size of area under study (ha) | Number of observation points | Number of observation points per 100 ha. |
|---|---|---|
| 100 | 20 | 20 |
| 1000 | 40 | 4 |
| 10000 | 100 | 1 |

The spacing of observation points may be increased as they are further removed from lines of recharge (surrounding estuaries) in approximately the following sequence : 10, 40, 100, 250 and 500 m, etc., with a maximum of 2000 to 3000 m.

Normally the groundwater observation points will consist of an open-ended thick walled plastic pipe placed into a bore hole to the depth below the groundwater table (expected groundwater table in the dry season). The diameter of the pipe may vary from 2½ to 5 cm and should be perforated over the lower 0.3 to 0.5 m. To prevent fine soil particles from entering the pipe or clogging the perforation holes, some cotton or jute is wrapped around the perforation part and the lower open end is sealed with a plug. The pipe is then placed at the centre of the bore hole and the space between the pipe and the wall of the hole backfilled with coarse sand. The top few decimeters are backfilled with well compacted clayey material whose permeability is low to prevent leakage of surface water along the pipe. The top of the pipe is fitted with a cap provided with a tiny hole to allow air to escape.

## 5.4 Additional observations

During the installation of the observation wells, the texture of the various layers should be noted down. In case of a shallow water table in material of low permeability some bore holes should be extended to a depth of at least 5 m to investigate the existence of any aquifers at greater depth.

In a homogeneous soil the hydraulic head corresponds with the water table height phreatic level). The hydraulic head of the water in a

semi-confined aquifer (see Figure II - 5.1) may be higher or lower than the phreatic water in the overlying semi-pervious layer, corresponding with an upward or downward flow through this layer from or towards the aquifer.

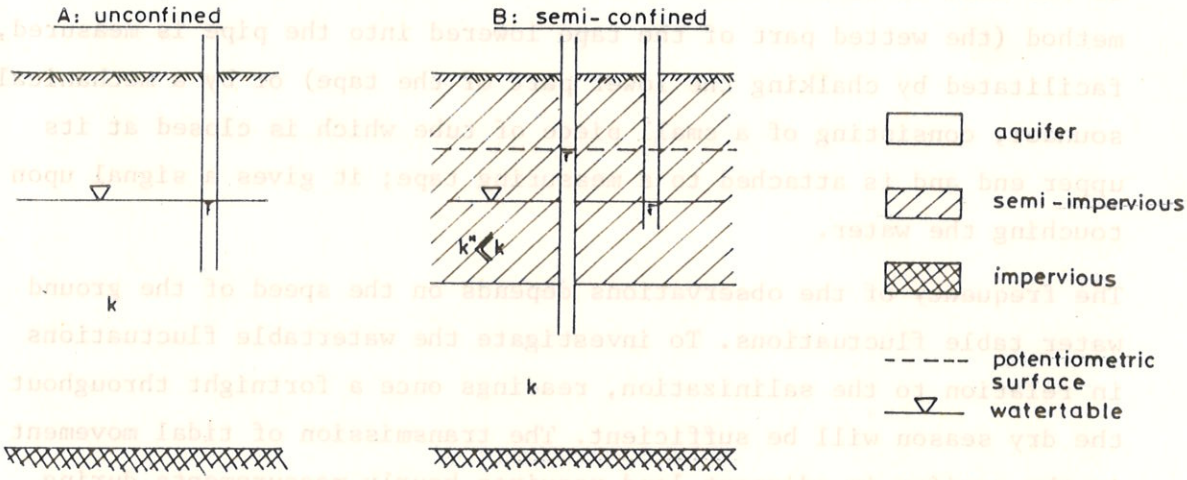



Figure II - 5.1. Schematic sections through an unconfined aquifer (A) and a semi-confined aquifer (B).

In this case two piezometers should be installed at the same location. A piezometer is the same as a groundwater observation well, except that the backfill of coarse sand is only around the perforated part of the pipe. With a piezometer the hydraulic head at the depth of the perforation is measured whilst with a groundwater observation well the maximum hydraulic head along the full depth of the tube is measured.

The water level of the first piezometer with the perforations in the semipervious covering layer is a function of its depth because the flow direction in this layer is mainly vertical. To measure the water table, the piezometer should therefore penetrate not more than a few centimeters into the saturated zone; but since water tables are usually changing during the course of the year the piezometer will fall dry when the water table is dropping. For practical purposes piezometers are therefore placed somewhat deeper, i.e. just below the lowest expected water table depth. The perforation of the second piezometer should reach well within the pervious aquifer.

## 5.5 Groundwater level readings

Groundwater level measurements are always taken from a reference point, for example the rim of the pipe. The height of the reference point in relation to the ground surface and its absolute elevation in relation to PWD must be taken. Water levels can be measured by the wetted tape method (the wetted part of the tape lowered into the pipe is measured, facilitated by chalking the lower part of the tape) or by a mechanical sounder, consisting of a small piece of tube which is closed at its upper end and is attached to a measuring tape; it gives a signal upon touching the water.

The frequency of the observations depends on the speed of the ground water table fluctuations. To investigate the watertable fluctuations in relation to the salinization, readings once a fortnight throughout the dry season will be sufficient. The transmission of tidal movement in the aquifer in adjacent land requires hourly measurements during one day.

## 5.6 Groundwater quality determination

A survey of groundwater conditions forming part of a drainage survey involves also the groundwater chemistry. This mainly comprises:

- The total concentration of soluble salts. This can be determined in the field with a portable conductivity meter. To ensure that the water sample is representative of the groundwater near the observation point, water should be withdrawn by means of a small bailer. When a sufficient quantity of water has been removed from the well, a sample is taken for the investigation in relation to salinization. The samples can be taken with the same frequency as the water level readings.
- For some wells the major constituents should be determined in the laboratory viz. $C_a^{++}$, $Mg^{++}$, $Na^{+}$, $K^{+}$, $CO_3^{=}$, $HCO^{-}$, $SO_4^{=}$ and $CL^{-}$.

## 5.7 Remarks

Groundwater observations in Polder 22, Khulna BWDB - Circle, showed at some places high watertables with higher salinity along the embank-

ment. A subsoil flow into the polder through the peatlayer at shallow depth (around 1 m) was suspected. Careful observations, however, revealed that this water originated from leakage through the embankment. This leakage occured in two ways viz.

- leakage at places were cuts were made in the irrigation season and that were not properly backfilled.
- leakage through holes made by crabs that burrow into the embankment during winter season.

The leakage was not a result of a subsoil flow through the peat layer.

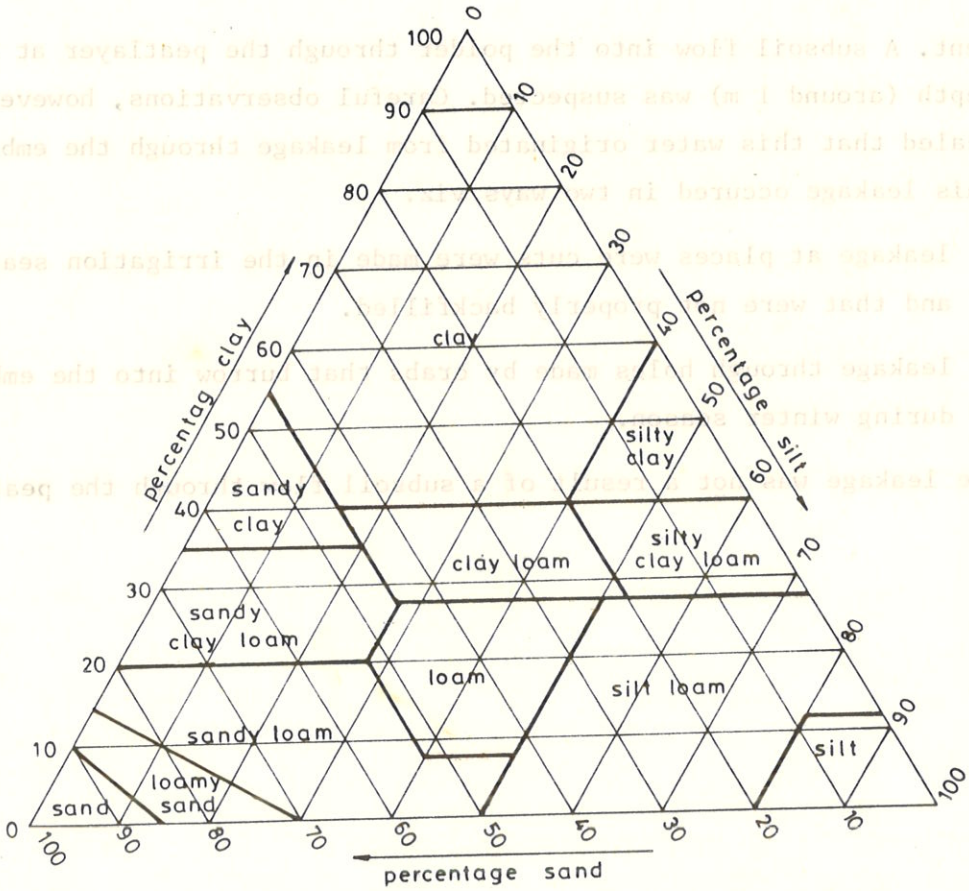



Figure II - 6.1. Piper diagram for grain size classification.

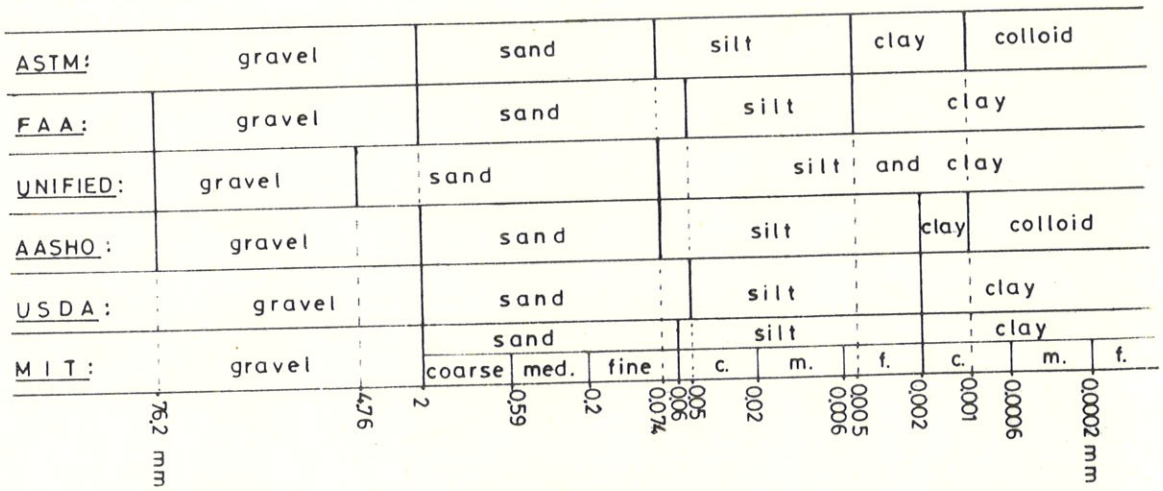



Figure II - 6.2. Grain size classifications.

## Chapter 6. Soil Investigation for Foundation Purposes

### 6.1 General

For the design of foundations for structures information has to be available or gathered on the properties, character and the strength of the soil. Therefore samples have to be taken and subsequently tested and evaluated. Apart from the physical properties like texture, colour, moisture content, consistency, plasticity, the designer of foundations is basically interested in the strength of the soil. Two fundamental features are distinguished.

a) the bearing capacity of the soil, being the average contact pressure on the soil at a stage that compression and settlement of the soil is still permissable for the structure, and

b) the shear resistance or shear strength of the soil, being the load at which a complete failure (subsiding) of the subsoil will result.

One of the two features can be the determining factor in the design of foundations.

In principle no pre - information on the type of soil prevailing at the construction site is available and a soil investigation programme has to be decided on in order to gather the necessary information.

Preferably the conclusion of such a soil investigation programme should be preceeded by a field trip to the proposed construction site, during which some simple field tests are to be carried out which may help to identify the general characteristics of the available soil.

### 6.2 Field tests, soil identification, soil sampling

There are various ways to characterize the soil. One is by it's origin. Peaty soils are of an organic origine, while gravel, sand, silt,clay, are the result of an erosion process of rock. Characterizing soil by the grainsizes can be done according the diagram of Figure II - 6.1, and the classification of grainsizes presented in Figure II - 6.2.

The consistency and general properties of the soil can be tested in the field from disturbed samples taken from the bore holes with a number of simple field test.

- The texture of a soil can be determined by mixing a small sample with water and add more water to make a dilute suspension. Pour the suspension in a bottle and shake vigorously and allow the soil to settle. Sand will sink within a minute, silt will settle within an hour, clay may take hours or even days to settle completely. By measuring the thickness of the layers, a rough impression is obtained of the particle size distribution.
- Dark colour and odor indicate organic matter in the soil. Pure sands and silts have no odor. Clay has a peculiar odor associated with kaolin. Sulphur (rotten egg) and ammonia (barn yard) smells indicate presence of organic material.
- Dry strength can be tested by crushing a dryed fragment of soil 0.5 cm in size between thumb and forefinger. Silt will crush easily, clay only with effort.

Several simple field test are available for testing the plasticity of the soil which is indicative for the compressibility. High plasticity indicates high compressibility.

- With the shaking test, a 2 cm dia soil sample is remolded with water to make it soft but not sticky. The pat of soil is placed in the palm of one hand and with the other hand the back of the first hand is patted rapidly. If the sample is silty then the surface will appear to turn glossy due to the expelled water. When remolded again, the water will be drawn into the sample and the surface will became dull. Clay does not react to this test.
- In a thoughness test a soil sample is manipulated in the hand to reduce the moisture content. After some time the non-plastic state will be approached and the sample becomes crumbly. Just before this stage a highly plastic clay can be rolled into a 3 mm dia thread which can support its own weight when suspended by one end. Silt can seldom be rolled out in this way without

breaking and has no tensible strength unless clay is present in the sample. The thoughness of a sample refers to a high strength coupled with large deformations before rupture.

From the general impression obtained from the field tests a further investigation programme with laboratory testing of soil samples can be decided on.

Normally for every construction site, independant of the type of soil encountered, a boring scheme is required in order to obtain samples of the different layers for laboratory testing.

Soil borings, should be located in such a way as to determine the extent, thickness and depth of the different layers. The pattern of the bore holes should cover the whole area of the future structure. If the bottom configuration can be assumed uniform or nearly uniform, which is normally the case in flat alluvial floodplains, a distance of 15 m between the bore holes is adequate.

The depth of a boring should be 2 to 3 times the smallest (hor.) dimension of the foundation.

Borings upto 4 m depth can be executed by hand with an auger drill. For deeper borings a rig is required.

However, soil dug from a bore hole is always disturbed and does not represent the real in-situ properties. Therefore at regular depths, and if a significant change in soil characteristics is found, undisturbed samples are taken with a spoon sampler. This sampler can consists of an open ended steel cylinder, split in two halves, held together with a cutting shoe at the lower end and a coupling ring at the top end for the connection with the drill rod. The device is called a split spoon sampler. The sampler is driven 18" into the ground at the required depths of the bottom of the bore hole.

For undisturbed samples in cohesive soils the spoon consists of a thin walled tube which is pushed into the ground. The term Shelby tube is widely used for this sampling device.

The sampler is used in combination with the standard penetration test (S.P.T.). For this test the sampler is driven into the soil

at the bottom of a bore hole through a drive pipe with a 140 lb. (63,5 kg) hammer falling 30". The sampler cylinder, ext. dia. 2", int. dia. 1-3/8" is at first pushed or hammered a few inches into the ground and then the number of blows is counted that are necessary for a 12" penetration. The number of blows N is a means to characterise the soil but should only be used for comparison purposes. The test should be calibrated for the particular site by direct measurement from undisturbed samples taken. For cohesionless material an accepted relationship between N and the relative density of soil is presented in Table II - 6.1.

Table II - 6.1 S.P.T. - values and soil characteristics

| N | relative density | stability |
|---|---|---|
| 0 - 4 | very loose | subject to liquifaction if fine grained and saturated |
| 4 - 10 | loose | subject to volume decrease from vibration |
| 10 | medium | questionable |
| 30 - 50 | dense | little decrease in volume from virbation |
| 50 | very dense | no volume decrease |

For more details, reference is made to Volume VI, paragraph 3.9.

The S.P.T. originally was developed to be used in cohesion-less soils from which it was difficult to take undisturbed samples.

For application in cohesive soils Cone Penetrometer Tests (C.P.T.) have been developed. With these test a cone is pushed into the ground while the resistance is measured continuously. The resistance may be of the cone alone, or, more commonly, cone resistance and side or skin resistance of a short piece of the pushing shaft are measured.

The cone resistance is related to the undrained shear strength of the soil.

The data from a C.P.T. can be used to estimate bearing capacity and settlements or static pile capacity of foundations to be designed. Figure II - 6.3 shows a typical output of a C.P.T.. Since C.P.T. equipment is usually mounted on a van or truck, its applicability in remote areas of the delta is limited.

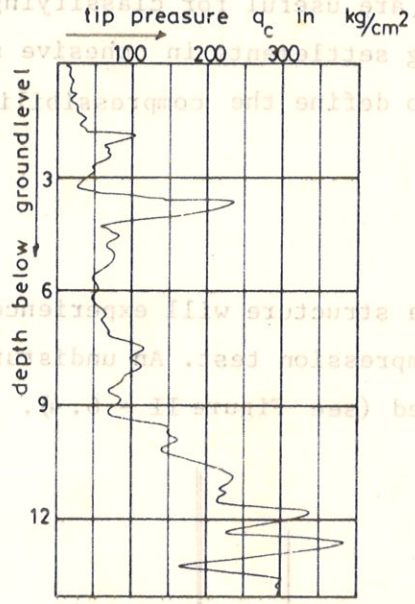



Figure II - 6.3. C.P.T. output.

## 6.3 Laboratory tests

### 6.3.1 Index properties

The previously mentioned field identification of soils is primarily meant to identify the major soil constituents and general properties. For numerical results, laboratory tests have to be executed, yielding the index properties, that are related to the physical properties of the soil on which the engineer will base his design. However the index properties have only quantitative value unless another soil with same index properties and known physical properties is available for comparison. The soil properties of interest to the engineer and the appropriate tests to determine these properties including information on which tests to be carried out on which soils are presented in ANNEX II - 9.

### 6.3.2 Atterberg limits test

These tests are carried out on remolded cohesive soils to determine the plastic and liquid limit of the soil. The plastic limit, $P_w$, is the water content in percent of the dry weight, corresponding to the boundary between a plastic and a solid state of the soil. The test is quite similar to the thoughness test mentioned in paragraph 6.2. Liquid and plastic limits are useful for classifying the soil and for empirically estimating settlements in cohesive soils. The liquid limit sometimes is used to define the compressibility index $C_c$ of a soil.

### 6.3.3 Compression test

The amount of settlement a structure will experience can be investigated with a confined compression test. An undisturbed sample is placed in a ring and loaded (see Figure II - 6.4).

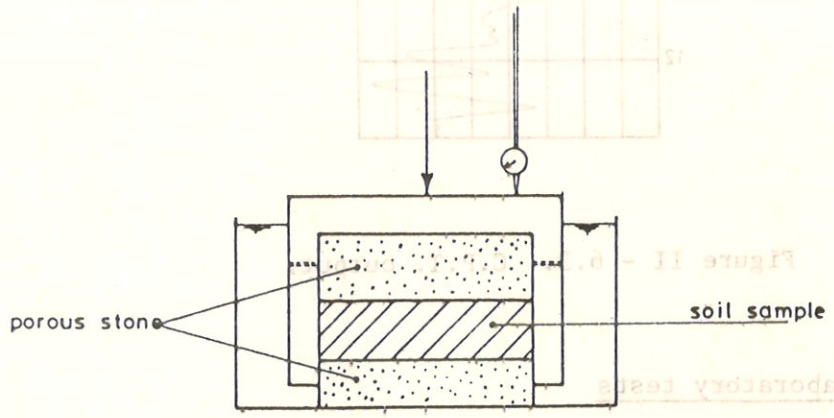



Figure II - 6.4. Confined compression test.

As the soil is often saturated, the sample is placed between two porous discs to permit the water to escape during the test. During the test the load is gradually increased and compression is measured. The load increments are permitted to remain on the sample for 24 hours before the next load increment is applied. The load increments usually consist of a doubling of the previous load. The results of the test are plotted as an e-ln p - curve as shown in Figure II - 6.5.

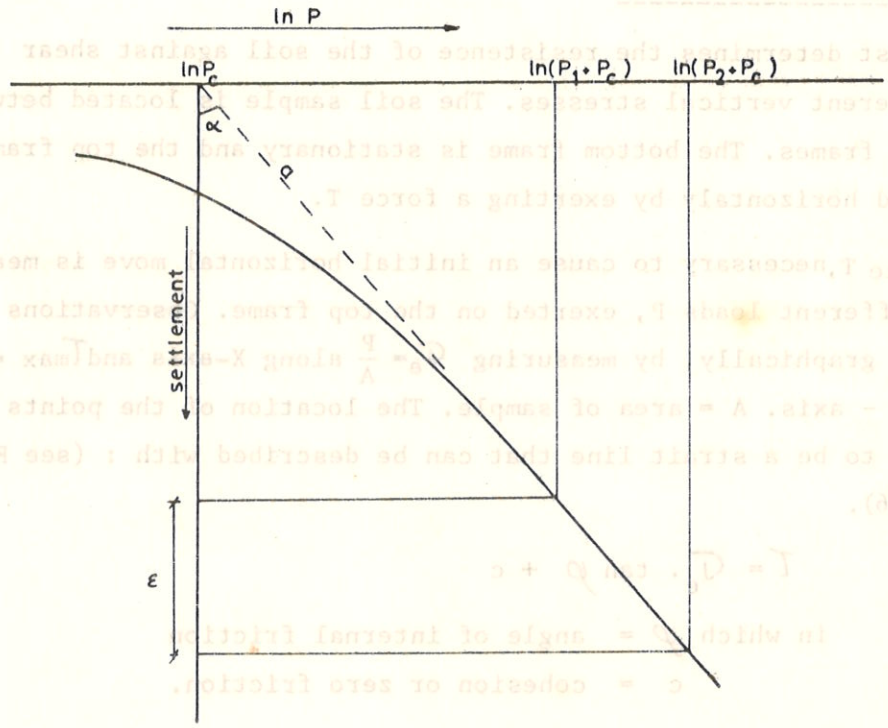



Figure II - 6.5. Load-settlement diagram.

The right part of the curve can be regarded as a straight line; actually it approaches the straight line "a" which intersects the X-axis in a point Pc. The pressure P = 0 is represented at the negative end and the X-axis in the infinite. The e - ln p - curve approaches the X - axis asympthotically. A settlement e can now be expressed as :

e = settlement per unit height of sample

$$e = 1/C \ln \frac{P_2 + P_c}{P_1 + P_c}$$

If $P_c$ is very small in comparison with $P_1$ and $P_2$, it may be deleted. C is a coefficient depending on the soil properties.

Some values are:

| | | | | | |
|---|---|---|---|---|---|
| for sand | 50 | < | C | < | 400 |
| clay | 10 | < | C | < | 20 |
| peat | 3 | < | C | < | 10 |

### 6.3.4 Direct shear test

This test determines the resistence of the soil against shear stress, at different vertical stresses. The soil sample is located between two grooved frames. The bottom frame is stationary and the top frame can be moved horizontaly by exerting a force T.

The force T, necessary to cause an initial horizontal move is measured with different loads P, exerted on the top frame. Observations may be plotted graphically, by measuring $\sigma_e = \frac{P}{A}$ along X-axis and $\tau_{max} = T/A$ along Y - axis. A = area of sample. The location of the points appears to be a strait line that can be described with : (see Figure II - 6.6).

$$\tau = \sigma_e \cdot \tan \varphi + c$$

in which $\varphi$ = angle of internal friction

c = cohesion or zero friction.

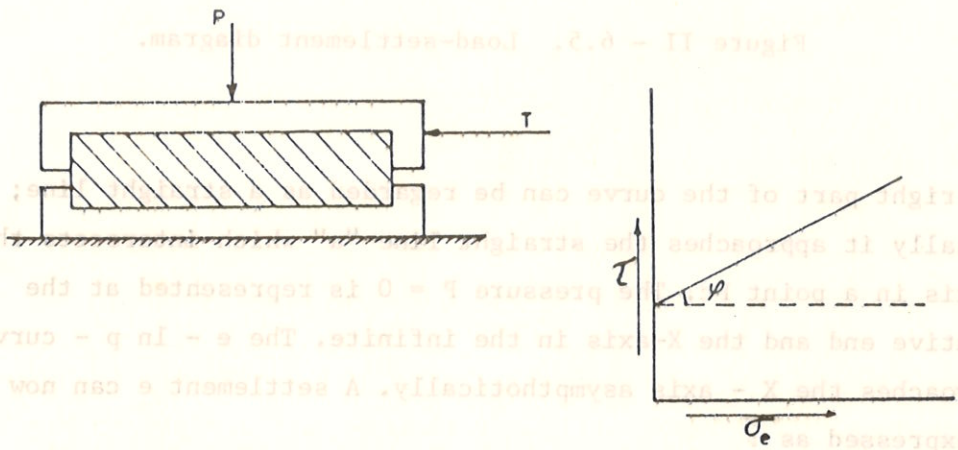



Figure II - 6.6. Direct shear test.

Under the influence of compression, the void ratio of the sample will change. If the sample is saturated the flow of water through the sample will form a resistance and influence the test-result.

If the load and the shear force are applied so slowly that the water is squeezed out gradually with the volume change of the sample, then

it is called a slow test. If the water is allowed to adjust itself to the vertical load applied, but the shear force is exerted quickly, then it is called a consolidated quick test. If both vertical load and shear load are applied quickly then it is called a quick test.

### 6.3.5 Triaxial Test

A more modern and sophisticated way of soil testing in which a greater control of the mechanical aspects of testing is possible is by means of the triaxial apparatus (see Figure II - 6.7), in which also a lateral stress can be applied on the soil sample. The lateral pressure is executed via a fluid which surrounds the sample that is protected by a rubber membrane.

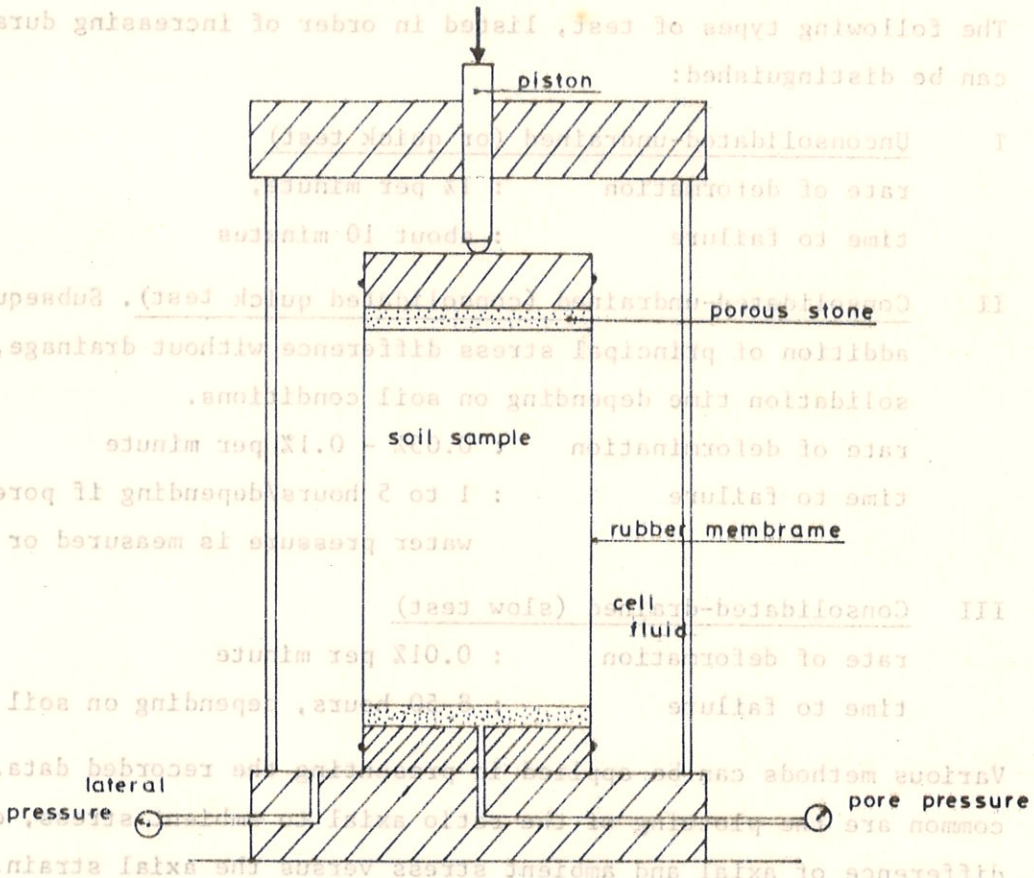



Figure II - 6.7. Triaxial apparatus.

There are several ways of performing triaxial tests on soil, all of which differ in the extend of control of pore water pressure which is effected by the changing loading condition of the sample during testing. Because of the low permeability of cohesive soils, special measures must be taken to run a test either with full development of pore pressures (P.P.), the test is then called undrained, or with P.P. effectively absent (drained test). In the latter case considerable time will elapse before consolidation (= the process of trancient flow of water through a soil structure which compresses or expands in time) is complete after changing loading conditions. On the other hand, if the sample is saturated and drainage is completely prevented, then the effective stresses will be affected by the external hydrostatic stress and if the pore pressure is not known, the effective stresses cannot be calculated. The following types of test, listed in order of increasing duration, can be distinguished:

I <u>Unconsolidated-undrained (or quick test)</u>

rate of deformation : 1% per minute,

time to failure : about 10 minutes

II <u>Consolidated-undrained (consolidated quick test)</u>. Subsequent addition of principal stress difference without drainage, consolidation time depending on soil conditions.

rate of deformination : 0.05% - 0.1% per minute

time to failure : 1 to 5 hours/depending if pore water pressure is measured or not.

III <u>Consolidated-drained (slow test)</u>

rate of deformation : 0.01% per minute

time to failure : 8-50 hours, depending on soil types.

Various methods can be applied in presenting the recorded data. Most common are the plotting of the ratio axial to ambient stress, or the difference of axial and ambient stress versus the axial strain. On the same diagram the volume change or, if measured, the P.P. may also be plotted against the strain.

If shearing or failure planes occur , the angle to the horizontal is recorded. For foundation purposes, usually consolidated undrained triaxial tests are performed on undisturbed soil samples. A choise has to be made to test representative samples from the borings made at the construction site.

### 6.3.6 Permeability test

A soil sample is placed in a container in such a way that no water can pass between sample and container wall. Then an arrangement of tubings is fitted to the container as to de-air the sample and saturate it with water. Subsequently a vertical tube is placed above the sample container, filled with water to a desired level. At the other end of the sample another tube is connected with a constant tailwater - head device (see Figure II - 6.8).

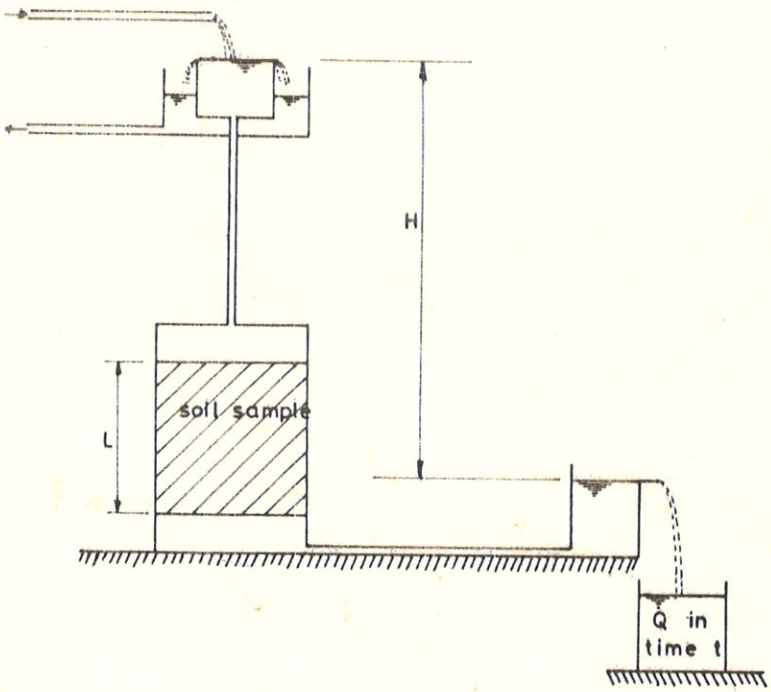



Figure II - 6.8. Permeability test.

In case of a constant head permeability test, the head difference between the two basins is kept constant and the time is recorded

to allow a certain volume to pass the sample. The permeability k is then expressed as :

$$k = \frac{Q.L}{H.A.t}$$ in which k = permeability coefficient (m/s)

Q = volume of passed water

L = length of sample

H = head difference

A = sample area

t = time.

## Chapter 7. Agricultural Surveys

### 7.1 General

In this chapter the additional surveys are dealt with which are required to assess the present and potential parameters for agricultural development. These involve soils, present land use, land suitability.

Above named surveys are time consuming and costly operations. If enough time, money and manpower are available the above surveys are necessary to :

a. Determine the priority of design and implementation between the various projects.

b. Furnish the necessary information for the detailed design.

c. Evaluate the performance of the project after implementation.

ad a. To this end pre-feasibility studies of all projects should be made, resulting in cost benefit ratio's. The projects are detailed designed and implemented in the sequence of increasing cost benefit ratio's. Costs involve all civil works, but also infrastructural works judged necessary, such as a jetty, a store or a new school building.

Benefits are the estimated increase in production compared to the present production in the area.

At this stage the costs are estimated rather roughly, the present situation is surveyed in detail :

- present land use: cropping pattern, cropped area's and yields per acre as well as farm inputs
- infrastructure: stores,dispensaries, schools, rice mills, transport to nearest market etc.
- social factors: population, income level, size of holdings etc.

From this information and the other technical surveys on irrigation water etc. the future land use can be reasonably estimated.

ad b. Once that the priority of the projects is determined the technical surveys described elsewhere in this mannual, can start. The soil survey, see chapter 7.2, is necessary to further define the agricultural potential of the area. Furthermore the soil survey is the starting point in case that a ground water survey is necessary.

ad c. The performance of the new project is evaluated about three years after completion of the works. This is done by surveying the change in cropping pattern, cropped areas and yields as well as of income levels and distributions. This survey may result in additional civil works, on a reinforcement of the extension service, or the removal of any other bottleneck identified by the survey.

The above sequence of surveys represents the ideal case when enough time, money and manpower are available. If this is not the case the pre-feasibility phase is skipped and the project is defined on non-technical grounds.

To determine the outline of the design the following questions are to be asked:

- Outside water quality good for irrigation ? All year, during monsoon, never.
- Shallow groundwater quality acceptable during the dry season ? yes, no.

If the outside water quality is acceptable during the monsoon only, and the shallow groundwater is brackish the present Design Manual is followed.

If the groundwater quality is acceptable pumping tests are necessary to evaluate the technical and economical feasibility of pumped irrigation during the dry season.

If the outside water quality is acceptable all year then a groundwater survey is necessary to evaluate the risk of salinization and to determine the economic feasibility of groundwater control measures.

This will normally require lowering the groundwater table for at least part of the year; consequently the risk of land subsidence should be carefully evaluated.

If the outside water quality is unacceptable during the whole year the prospects are rather bleak. Flood control and drainage, as

described in this Design Manual may permit to extend the area of aman paddy. The farmers should construct bunds around all their fields to put the rainfall to best advantage.

## 7.2 Soils

Reconnaissance soil surveys can be carried out for the whole project area by the Department of Soil Survey. The survey reports include land capability classification for agricultural use.

For implementation, planning and design, detailed surveys are pre-requisite. The scale of the maps should be 1 : 5000.

The standard profile characteristics which should be included are the followings:

- Textural class
- Organic - matter content
- Free-carbonate content
- Soil structure
- Soil porosity
- Soil consistency (Atterberg limits)
- Soil colour
- Soil reaction (pH)
- Electrical conductivity of the saturation extract (ECe)
- Soluble ions
- Cation Exchange Capacity (C.E.C.)
- Exchangeable cations and Exchangeable Sodium Percentage (E.S.P.)
- Total acidity
- Content of water soluble sulphate
- Pyrite contents
- Plant nutrients
- Mineral plant - nutrient reserve
- Permeability (auger hole method in the field)
- Soil moisture characteristics (pF at saturation point, field capacity and wilting point)
- Bulk density
- Infiltration rate.

Due attention should be given to the location and depth of peat layers and the occurrence of potential acid-sulphate soils. In addition to the standard survey some more measurements are required regarding the salinization of the topsoil (see chapter 5.1). At the beginning and the end of the dry season soil samples should be taken of the top 15 cm of the soil for determination of the EC. Preferably these samples should be taken at the locations of the groundwater observation wells. Since the $EC_e$ (electrical conductivity of the saturation extract) is quite difficult to determine, the electrical conductivity of the 1:5 extract can be determined instead. The relation between $EC_e$ and EC 1:5 extract has then to be established first. In case of highly soluble salts this relation is more or less inversely proportional to the dilution; with less saluble salts like Mg $SO_4$ this relation is not directly inversely proportionate to the dilution and the relation should be established by determining the EC value of both the saturation extract and the 1:5 extract of the same samples.

## 7.3 Land use and land evaluation

Land evaluation is the term to describe the process of collating and interpreting basic inventories of soil topography, hydrological conditions, etc., in order to identify and compare land use alternatives. Land evaluation and socio-economic analysis provide the foundation for landuse planning. They refer to the present conditions as well as to land potentials that will materialise as a result of the implementation of the land improvement measures and involves also a comparison of both situations.

The following attributes are relevant for the selection of land use alternatives.

- cropping patterns and cropping intensities,
- produce and other benefits,
- market orientation e.g. subsistence or commercial production,
- the inputs per unit area, both recurrent and non recurrent,
- labour per unit area and its distribution,

- size and configuration of holdings. These data are also required for the design of the lay-out of the tertiairy irrigation and drainage systems,
- land tenure,
- infrastructural requirements (mills, institutional provisions),
- income levels (per capita, per production unit or per unit area).

## Chapter 8. Socio-economic surveys

### 8.1 Introduction

The aims of this chapter may be summarized as follows :

a) to discuss the usefulness and relevance of socio-economic surveys for the kind of projects which the Bangladesh Water Development Board usually designs and implements; this will be done by referring to the ultimate, development-related goals of these projects (section 8.2.1 below), discussing the consequence of such goals in terms of the concrete applications of socio-economic surveys (section 8.2.2) and analysing the kinds of information they may be expected to yield (section 8.2.3);

b) to give a general idea of how socio-economic surveys are designed and carried out (section 8.3) and

c) to discuss some of the problems and difficulties that may arise in the course of a socio-economic survey and their effect upon the reliability and usefulness of the information it generates (section 8.4).

The chapter has been written with the purpose of increasing the engineer's capacity to communicate effectively with the social scientist who will normally be in charge of the socio-economic survey, so that he can specify clearly what he wants to learn and make better use of the information generated. Its presence in this manual - in spite of the fact that it is not directly design - oriented - reflects the increasing importance of the role played by explicit socio-economic objectives in development projects, including those of a predominantly technical nature.

### 8.2 The role and contents of socio-economic surveys

#### 8.2.1 The fundamental goals of development projects

In addition to their specifically technical objectives, a major part of the projects designed and implemented by the BWDB have ultimate goals of a socio-economic nature, related to their character as

development projects. Rural development and the subordinate objectives of increased employment and production, technological development and improvement in the situation of the poor (to mention but a few) are among the major priorities of government policy, in Bangladesh as in other developing countries; they are also the ultimate goals of a large number of BWDB projects, which are directly and immediately geared towards flood control, drainage, irrigation, land reclamation or other specific technical objectives.

Given the scarcity of available resources, it is important, when considering the undertaking of a new project, to ensure in advance that it will actually play a role in furthering those basic goals. In fact, the development of infrastructure (or, for that matter, the reclamation of new land), by itself, does not bring about rural development, or growth in agricultural production; whether or not this will happen depends entirely on the use that people will make of the newly created resources and this, in turn, depends on the socio-economic conditions which prevail in the area.

The importance of the basic socio-economic objectives mentioned above justifies that we consider them in somewhat greater detail. It is important, first of all, to note that rural development usually implies, but cannot be reduced to, the growth of agricultural production. In addition to agricultural growth, rural development also entails social and technical change, increased employment and the improvement of the situation of the poorest groups of the rural population. It is clear, therefore, that rural development is both more general and more important, as an objective, than agricultural growth.

In terms of development projects, this means that it is necessary to pay attention not only to the question of whether, but also by whom and in what way, the potential benefits of projects are likely to be realized. In certain cases, the primacy of the rural development objective may entail that, in spite of lower returns in purely economic terms, a project may be considered preferable to another one because it brings more substantial benefits to the small farmers and landless, rather than only to the richer farmers.

It must also be pointed out that often the two questions are related i.e., 'who benefits' has a strong bearing on 'whether the benefits will be realized'. This is because economic motivations and constraints - and therefore, economic behaviour - are different for different groups in the rural areas. In this way, an increase in production will normally tend to be used in different ways by a share cropper, a small-holder, a middle farmer or a large landonwer and these uses will affect, directly and significantly, the impact of the project upon the area where it is carried out. It is also well known, for instance, that in situations where the environmental conditions and the agricultural technology used are the same, the productivity per acre is in general negatively correlated with the size of the landholding and, perhaps even more important, those differences in productivity are more pronounced in bad agricultural years. In such cases, both the economic growth and the distribution oriented objectives should obviously lead the decision makers to favour projects where the benefits are directed mainly at the poor. For all the reasons presented above, a clear picture of the socio-economic situation in the project area is of great importance, both to assess the project's viability and to design and plan its implementation.

### 8.2.2 The uses of socio-economic surveys

Socio-economic surveys are exercises designed to throw light on the socio-economic situation in particular areas, in connection with specific sets of objectives; they improve the ability to understand, analyse and forecast the effects of projects upon the situation in their areas. As such, they may be used for at least three different types of purposes:

i) Socio-economic surveys generate information which is directly relevant for the evaluation of project proposals. In this case, the fundamental question that a survey may help to answer is how likely it is that a particular project will in fact stimulate rural development in the project area, in terms both of increased agricultural production and in terms of

social change - especially relating to the improvement of the situation of the poorest groups.

ii) Socio-economic surveys may be used to guide the implementation of a project, i.e. to help indicate, in the particular setting of the project area, how the project should be implemented and what kinds of complementary action should be taken to increase the effectiveness of the project as a vehicle of rural development.

iii) Once a project has been implemented, fully or in part, socio-economic surveys may be used to indicate what the actual impact of the project has been (ex-post evaluation) and, if the project is still going on, to provide the basis for recommendations concerning the way in which it should continue - which in fact is a variant of (ii), above.

The distinction that is established between the three different types of uses is somewhat artificial, especially in relation to the first two. In fact, a survey that is carried out with the purpose of assessing what are the likely effects of a particular project will also yield useful information concerning what should be done to minimize adverse effects and to stimulate favourable ones. The distinction is, however, useful because it underlines the important fact that, in each of the three types of uses mentioned, there are different decisions at stake. In the first two cases this is obvious, since the first concerns a direct act of choice (viz. should the project be taken up for implementation or not), and the second relates to a set of design decisions concerning implementation. The same is true, albeit in a less direct fashion, also for the third type of application; ex-post evaluations are important ways of learning from past experience, and this learning is incorporated into decisions concerning ongoing and future projects.

It must be stressed at this point that, regardless of the quality of the survey work - or, for that matter, of its cost - the information generated by a survey has no intrinsic value; it is only when it is used as a basis for making decisions that this information becomes valuable. This important fact is often forgotten, with the consequence that surveys are then carried out routinely, without due

attention to the decisions that they are supposed to support. In such cases there is a heightened risk that time and money will be wasted collecting useless or irrelevant data (from the decision-making point of view), while at the same time, more seriously, some necessary information remains uncollected. This is one of the main reasons why it is so important to ensure that effective communication exists between the people in charge of implementing the projects (normally engineers) and the social scientists responsible for the socio-economic surveys.

The fact that the three types of uses of socio-economic surveys mentioned above are inter-related implies that there will be many points in common between surveys of the three types. There will, however, normally be differences, which reflect the differences in the uses of the survey. We shall next mention briefly some of the main areas normally covered by socio-economic surveys. Even though the summary list of topics contained in a socio-economic survey is based on direct and indirect acquaintance with a number of projects (particularly BWDB projects) in Bangladesh, what will be said has a very general, and purely illustrative, character. A detailed and substantial specification of the contents of a survey is only meaningful in the specific context of a particular case, when both the objectives of the survey and the special characteristics of the area where it will take place are known.

### 8.2.3 The contents of socio-economic surveys: a general over view

Besides information for specific purposes, socio-economic surveys are normally designed to yield a certain amount of general information, necessary to characterize the socio-economic and institutional context in which the survey (and the project) takes place. This usually includes data on population, employment, wealth and income distribution, institutions and relations with governmental or non-governmental organizations.

In relation to population, the variables which are usually studied comprise age-sex structure, density, household size and composition,

growth rates, educational level, occupation, etc. Usually, these variables are tabulated, not only for each of a number of geographical or administrative units, but also, within these units, for a number of classes in which the population is divided, on the basis of socio-economic criteria (e.g. land ownership, per capita income, employment situation or others). The same applies also to several of the other variables mentioned below.

In relation to employment, wealth and income distribution, the information sought includes land ownership, control and tenureship, percentage of landlessness, occupational structure, employment and income in agricultural and non-agricultural activities, agricultural production and productivity, etc.

Information on institutions concerns not only religious and political institutions in the rural areas, but also economic institutions (related, particularly, to control over, and access to, land, capital and labour), and social institutions (e.g. inheritance laws, kinship rules, mutual aid and cooperation).

Finally, information is also sought and collected about the role of, and relations with, governmental and non-governmental organizations: what organizations are active in the area, what functions they perform, with what groups of the rural population they interact and how frequently, etc.

In addition to this information of a relatively general nature, which is necessary to provide a framework for all other activities in the project, socio-economic surveys in projects directly or indirectly concerned with rural development must also focus upon the particular aspects of social organization which are most likely to influence social change and the growth of production. To fulfill this objective the surveys must throw light on some major aspects of rural social organization which are intimately connected with rural development and which significantly condition the extent to which the potential benefits of the project are likely to be effectively realized. This include :

a) The organization of production: which groups control land, capital and labour, and how each of these factors is controlled

by each group; how (i.e. by what mechanisms) this control is exercised and how it affects the relations between the different groups and classes, in the production process.

b) The investment behaviour and attitudes towards investment of the various groups, and the way in which these interact with the control over investable surplus to determine investment patterns.

c) The integration of the project area into the regional and national economic spaces (e.g. through the organization of marketing of the products of the area, systems of distribution of agricultural inputs and consumption goods in the area, periodical or permanent movements of population and labour into and out of the area, relations of the area with the regional and national urban centres, financial flows into and out of the area, etc.), and the ways in which this integration affects the organization of production in the area. And, finally,

d) The effect of all these factors upon the potential of the area for incorporating the benefits of the project, in the form of social change, improvement of the situation of the poor, modernization of agriculture and increases in agricultural and non-agricultural production.

In the specific context of delta development, certain issues acquire special importance, which must be reflected in the treatment that they receive in socio-economic surveys. These issues include:

- The availability of and access to infrastructure.
- Water resources, from the point of view of their present utilization and control, potential for development and expected distribution of benefits from this development.
- Water management practices, potential for their improvement and likely benefits to be derived from it.
- Land resources: since most of the land is privately owned, khas land and land under the direct control of the BWDB acquire a special significance in relation to what can be done to improve the situation of the landless.

As was already mentioned, we cannot do more, here, than illustrate the kinds of information that are sought in socio-economic surveys and, even that, only to a limited extent, since the design of each survey must be done paying close and careful attention to the objectives of the project, to the direct purpose of the survey in the general context of those objectives and, last but not least, to the specific characteristics of the area itself. It is obvious, for instance, that some of what was said above does not apply in the case of a survey for ex-post evaluation of a project; in such a case, the purpose will be to assess the extent to which the objectives of the project were realized and the role played by various factors in the success or failure to reach the various objectives, and the content of the survey will obviously differ from the one specified above. The set of variables mentioned in this section should be seen as an example, not as a prescription.

## 8.3 Survey design and implementation

### 8.3.1 General observations

The first step in designing a socio-economic survey must be to set out, very clearly, its objectives. Vague objectives will inevitably lead to inadequacy and waste, to the collection of useless information and, at the same time, the ommission of information that subsequently turns out to be needed. For basically the same reasons, the area and population to be surveyed must also be identified as soon as possible. Only when both the subject matter and the area to be covered by the survey are identified can the logical process of survey design begin.

A practical way of minimizing the danger of inadequacy and waste is for the decision makers or the people concerned with the implementation of the project to draw up a list of questions for which they need the survey to provide answers; these questions should be directly related to the objectives of the project and formulated in terms of the decisions that are necessary. They can then be used both as a set of guidelines for the design of the survey and as a means for checking the relevance of the information that is to be collected in the course of the survey.

Early in the process of survey design it is necessary to choose the type of unit that will be surveyed. Depending on the specific objectives of the survey, these units may be, for instance, villages, households or individuals; in the first two cases, an unambiguous operational definition of what constitutes a unit (in this case, a village or a household) is needed to avoid imprecision. The interviewers must be provided with a clear set of operational criteria, to ensure that only units of the same nature are surveyed.

The surveys we are concerned with are predominantly based on interviews; these may be divided into three main types:

- structured interviews, in which precisely the same questions are put, in the same way, to each of the respondents by the interviewer, who records the answers on an interview schedule, where the questions are written and space for the answers is provided;
- unstructured interviews, in which the interviewer discusses informally with the respondents (individually or in groups) the questions that he is interested in, without following any predetermined plan; and
- semi-structured interviews, in which the interviewer discusses informally with the respondents but uses an interview guide in which, to ensure completeness, the topics to be covered (but not the precise questions) are set out.

These three types of interview are often used complementarily; unstructured interviews are extremely useful in the initial stages of the design of a survey, to help identify the questions which will be dealt with, in the formal survey, by means of structured interviews. Often, also, after the survey has been carried out and analysed, contradictions and problems can be solved by resorting to longer, unstructured or semi-structured, interviews.

It is important, when reporting the results of a survey, that the researchers describe exactly the methods adopted and the questions asked, so as to enable the reader to form his own opinion about the reliability and limitations of the survey.

A key decision, when designing a survey, concerns the choice of the set of units which will actually be surveyed. If the survey covers all the units of a particular area, it is called a census survey; if, however, the number of units is very large, a census survey may be unacceptably expensive and time consuming; it will, then, be necessary to resort to sampling methods for the selection of the subset of units, or sample, which will actually be surveyed. A survey of this type is called a sample survey. There are various kinds of sampling techniques, which will not be discussed here; they all have the same basic purpose, which is to select a sample in such a way as (i) to decrease the cost of the survey; and (ii) to allow the drawing of conclusions, valid for the whole set of units (or population), from the information yielded by the sample. Sampling theory is normally dealt with in textbooks of applied statistics.

### 8.3.2 Stages in survey design and implementation

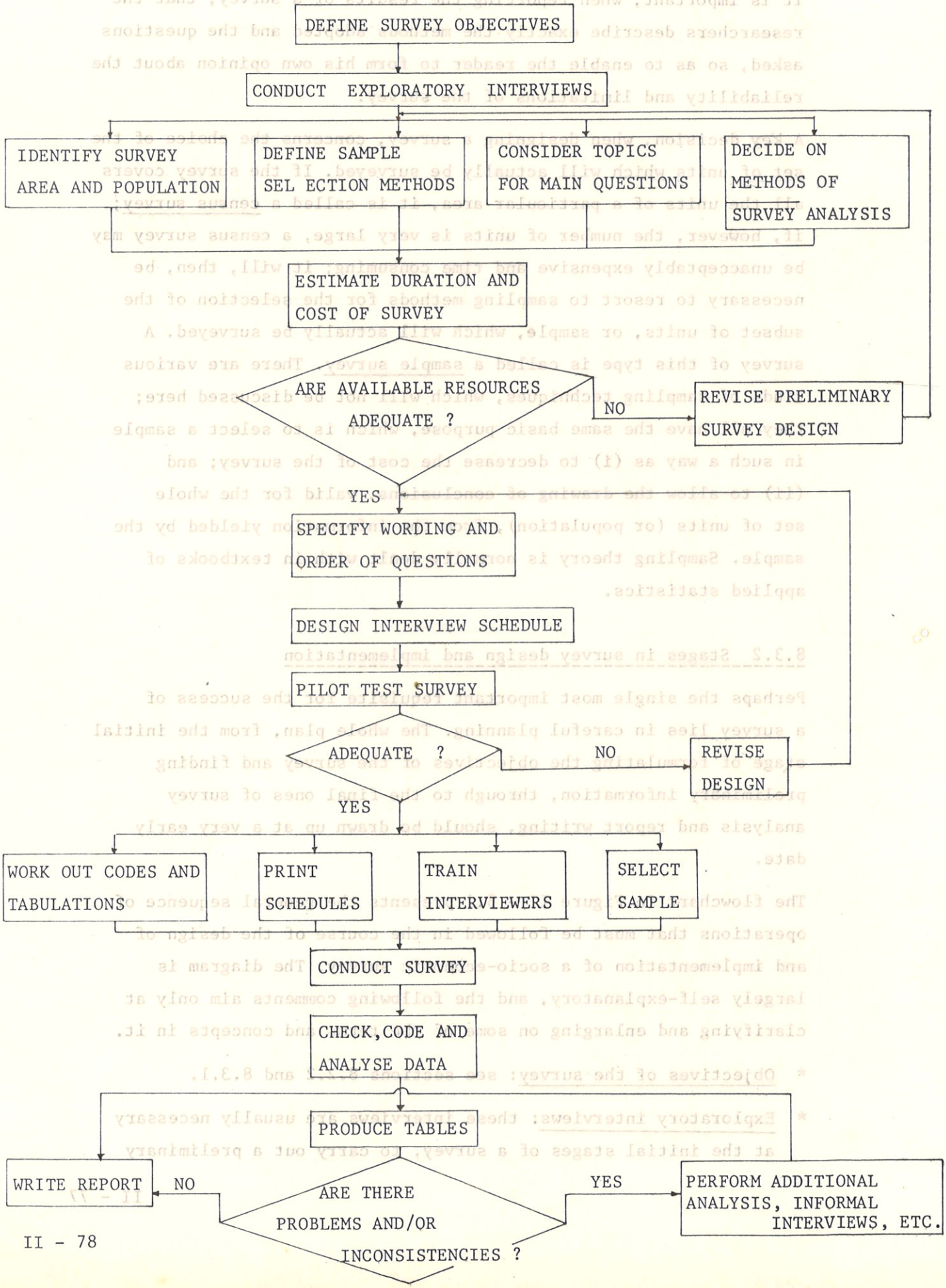
Perhaps the single most important requisite for the success of a survey lies in careful planning. The whole plan, from the initial stage of formulating the objectives of the survey and finding preliminary information, through to the final ones of survey analysis and report writing, should be drawn up at a very early date.

The flowchart in Figure II - 8.1 presents the general sequence of operations that must be followed in the course of the design of and implementation of a socio-economic survey. The diagram is largely self-explanatory, and the following comments aim only at clarifying and enlarging on some of the terms and concepts in it.

* Objectives of the survey: see sections 8.2.2 and 8.3.1.

* Exploratory interviews: these interviews are usually necessary at the initial stages of a survey, to carry out a preliminary

Figure II- 8.1. Sequence of operations in a socio-economic survey.



reconnaissance of the area and of the problems and topics upon which the survey will focus; given their exploratory nature, these interviews are normally of the unstructured (or, if the area is relatively well-known, semi-structured) type.

* Methods of survey analysis: even at a very early stage, attention must be paid to the question of how coding and analysis of the survey data are to be done. Small sample surveys may be analysed by hand, but larger sample sizes (say, more than a hundred cases) are likely to require computer analysis. Early consideration of the problems likely to be faced at the stage of data analysis will help to avoid problems and save time.

* Duration and cost of survey: as soon as the main characteristics of the survey have been specified it is possible to form a reasonably good idea of the duration and cost of the survey. This is important because an over-ambitious survey specification may turn out to be incompatible with the wider project objectives by leading to a cost or a duration of the survey that is unacceptable for the project as a whole. In such cases, it will be necessary to revise the design (e.g. by decreasing the amount of information sought or the size of the sample), or even the survey objectives themselves.

* Wording of questions and questions order: the careful wording of each question plays an important role in ensuring that the respondents a) will understand the question; and b) will not be influenced in their answers by the way in which the question is formulated. One of the most common problems in surveys occurs when respondents are influenced by question biases which are the result of defective wording. The proper ordering of questions is needed to ensure that the interview 'flows', i.e. that there is a gradual and natural transition from topic to topic, and from question to question within the same topic.

* Design of the interview schedule: this is concerned with the text of the instructions to the interviewer, text of the questions, space left for the recording of answers and for notes, etc. The

layout of the interview schedule must also be designed so as to render the task of interviewing as easy as possible.

* Pilot test of survey: once the schedule design is finalised, the whole design of the survey should undergo a pilot test, to detect and correct any deficiencies which may remain, from the point of view of wording, question order or content, layout, correctness of the assumptions made, etc. Since the purpose here is to test the design of the survey, the pilot survey should preferably be carried out by experienced interviewers. It will also help if some of the these people have not been involved in the previous stages of design, so that they can bring a fresh mind to the test. The results of the pilot survey should indicate ways in which the original design should be changed for greater clarity and effectiveness.

* Training of the interviewers: the interviewers should be trained in such a way that they will interact with the respondents in basically the same way, so as to minimize the effects upon the survey results of differences between interviewers. This means that not only should all interviewers thoroughly understand the instructions and the questions set down in the interview schedule, but they must also share the same perceptions concerning the objectives of the survey, the meanings of certain basic terms and the hypotheses underlying the specific ways in which the questions are formulated.

* Sample selection: see section 8.3.1 above.

* Conduction of the survey: this is the most crucial stage of the whole exercise and itself requires adequate planning. Especially when there are several interviewers, it is vital to ensure their efficiency and reliability, by monitoring their performance, both in quantitative and qualitative terms. The reliability of the interviewers is normally checked, on a regular basis, by having senior interviewers repeat some of the interviews, selected at random. A systematic checking of the first few interviews may give useful indications as to whether the interviewers have fully

assimilated their training or whether, on the contrary, a further round of training is needed.

* Remaining problems and inconsistencies: the stage of analysis of the survey may indicate that there are inconsistencies in the data; these may result from deficiencies that, in spite of everything, still have affected the interviews, from biased reporting of certain variables by the respondents, or even from the fact that certain of the assumptions made during the survey design stage were wrong. Longer, unstructured interviews with some key respondents may help throw light on the problems and even solve the difficulties. It may also happen that the problems remain; in such a case there is no alternative but to include them in the final report, with as careful and conscientious an analysis of what their causes may be as possible.

* Reporting: the report of a survey should contain not only the results arrived at, preferably formulated in terms of the original objectives of the survey and of the questions derived from them, but also enough information about methods, processes and problems to allow an independent reader to come to his own conclusions as to the quality of the data and the validity of the conclusions. In addition to this, the report must be written in a style as simple and as free from professional jargon as possible, so that the people to whom it is addressed do not have any difficulty is understanding and using it.

## 8.4 Some difficulties and limitations of socio-economic surveys

No matter how carefully designed and tested a survey has been, or how experienced and well trained and group of interviewers who carry it out, there will still, inevitably, be problems and difficulties. We cannot do more, here, than briefly discuss some of these difficulties and how they are usually dealt with; this will be done with the purpose of giving an idea of the kinds of problems that face socio-economic surveys and, by implication, of the limitations of the information produced.

Even in collecting apparently straightforward factual materials, problems may arise in connection with definitions. To give a simple example, the question 'How many fruit trees do you have?' may produce different responses according to whether the respondent includes old trees which no longer bear much fruit and young trees which are still unproductive, or counts only the adult trees in full production.

Whenever possible, the definitions adopted should be identical or equivalent to those of official statistics or of other studies, so that the data collected are comparable. It is not possible to foresee all the problems of definition which are likely to come up during the survey in the initial design stages, which is a reason why a pilot survey is so useful. Daily discussion sessions among the interviewers, during the pilot stage, are or great help in this respect.

A difficulty of a related nature occurs when the respondent does not understand a question, or a term used in a question. Whenever possible, this should be avoided by presenting to the respondent the definitions of the terms immediately before, or in the text of, the question. If, in spite of this, the problem still occurs, the interviewer will have to explain what is meant; in such cases, he should note down both the difficulty and his explanation. The explanation should be as neutral as possible, starting with the simple repetition of the question and avoiding the introduction of new ideas or terms. There is also a number of neutral ways of elliciting more information when the response is considered inadequate or not sufficiently detailed: asking the respondent to repeat or to elaborate, to 'explain a little more fully', etc.

In questions concerning opinions or attitudes, no explanantion should be given, since it cannot fail to influence the reply. In cases like this, the interviewer should either turn the request for clarification back to the respondent (e.g. by asking "what do <u>you</u> think it means?") or, if the respondent still clearly fails to understand the question, record him as giving no reply and make a note about the difficulty.

It is common for a survey to include questions about events that have happened in the past, rather than about the present situation. This can lead to some very inaccurate responses, both because the memory of past events tends to decay rapidly and unevenly and because it is often difficult for respondents, especially in the rural areas, to date past events with precision. In this respect, momentous occurrences like wars, natural disasters or major political upheavals often help to reduce the imprecision of dating. Careful wording and ordering of questions involving recall is necessary to reduce the tiring effect of remembering and to avoid giving the respondents the feeling that they are being tested. A certain amount of redundancy is also frequently introduced, to allow the checking of the precision of the recall when the interview schedule is being processed.

The most important source of difficulties, however, relates to the collection of certain types of sensitive information. For instance, when asked about his income or wealth, and even assuming that there are no problems of definition (e.g. income over what period, in cash or also in kind, gross or net, etc) and no error of estimation, the respondent may give willfully misleading replies, for a variety of possible reasons.

Underreporting of own income or wealth is one of the most frequent biases that respondents introduce in their responses; among other factors, this may be due to:

- suspicion concerning the intentions underlying the question (e.g. fear that the information might be passed on to the tax-collecting authorities);
- an attempt to manipulate the entity or organization by or for whom the survey is being performed into allocating resources which will benefit the respondent, directly or indirectly ('the poorer I appear to be, the more likely they are to do something for me");
- reluctance to admit one's income in front of the neighbours - whose presence during the interview is often difficult to prevent; and
- non-reporting of income or wealth from certain sources which are

the object of social disapproval, or are even illegal (e.g. usury, ownership of more than the legal maximum area of land, etc.).

On the other hand, in some cases respondents over-report their own income or wealth, either because they think that this may bring them advantage (for instance, increase their credit-worthiness), or simply to impress the interviewer or the neighbours.

There is a number of ways in which biases of this type can, to a certain extent, be reduced. They comprise, among others, the following:

i) the inclusion of a careful explanation, at the beginning of the interview, of the purposes of the survey and the use that will be made of the data collected, to dispel doubts about the possible utilization of the data for purposes which the respondent sees as prejudicial to his interests;

ii) the introduction, at different points of the interview, of a number of 'check' questions, i.e. questions concerning the same or related information, formulated in different ways;

iii) instructing the interviewers to do a certain amount of careful probing; this is, however, a difficult technique, which can easily lead to other types of error;

iv) the ordering of questions so that the most sensitive topics are left towards the end of the interview; this may permit the building up of a certain amount of trust between the respondent and the interviewer and, in case the questions lead to suspicion and to willful distortion of the responses, avoids 'contaminating' the whole of the interview with bad feelings and false responses;

v) finally, in certain cases the interviewers may be asked to supplement the data collected in the course of the interview with additional observation (e.g. the size and condition of the house, the size of the grain store and of the piles of straw, etc), or by means of informal questions addressed at the respondents neighbours, in his absence; again, great care should be taken not to generate suspicion and mistrust by this additional probing.

We have mentioned only a few of the main types of difficulties with which socio-economic surveys are normally faced. Taken as a whole, they imply that the information collected is always, inevitably, less than perfect. As a consequence, no matter how much care has been taken in preparing and carrying out a socio-economic survey, a critical attitude towards its results and an awareness of its limitations are imperative. At the same time, to allow the people for whom the survey has been carried out to come to an independent assessment of the results contained in it - so that decisions can be based on them - the interview schedule, the instructions to the interviewers and a detailed description of the approach and methods adopted should be attached, as appendices, to the report of the survey. It is essential that the people who will be responsible for decisions based on the results of the survey have full information on how these results were reached.

ANNEX II - 1. BASIC STANDARDS FOR LEVELLING SURVEYS

| Type of survey | Long-section (spotlevels) | Cross-Section interim distances | Cross-Section Spot levels |
|---|---|---|---|
| Embankment survey | | | |
| 1. Preliminary surveys for rough cost estimate, feasibility study. | 25 m | 100 m | 2 m |
| 2. Detailed surveys for detailed cost estimate, pre, post work surveys. | 5 m | 20 m | 1 m |
| Area surveys | | | |
| 1. Preliminary area surveys. | - | 500-200*)m | 50 m |
| 2. Semi detailed surveys (contour maps). | - | 100 m | 10 m |
| 3. Detailed surveys. | - | 50-25*)m | 5 m |

*) depending on size of the area.

ANNEX II - 2. BASIC STANDARDS FOR TRIANGULATION SURVEYS

| Type of survey | required density |
|---|---|
| 1. Triangulation network | |
| establishing a triangle network for the purpose of detailed mapping and to tie-up level-survey information. | coverage of the area with maximum distance of ± 3 km between the stations. |
| 2. Traverse measurements | |
| for alignments of embankments, channels, etc. | distances between the points as required by the bends in the alignment ; sub-traverses to be inserted as necessary. |
| 3. Triangle chain measurements | |
| along rivers or channels, to tie-up hydrographic surveys and river bank surveys. | coverage of the path of the river or channel with maximum distances between the stations depending on the width of the river. |

ANNEX II - 3. AVAILABLE AERIAL SURVEYS OF THE DELTA AREA SINCE 1961

| Year | area covered | photoscale |
|---|---|---|
| 1963 | whole of Bangladesh | 1:50.000 |
| 1965 | Ganges - Jamuna Rivers | 1:50.000 |
| 1967 | Main Rivers, including | 1:30.000 |
| | Teesta, Meghna, Jamuna | 1:40.000 |
| | | 1:50.000 |
| 1968 | Several area's including | 1:10.000 |
| | coastal region | 1:50.000 |
| 1969-1970 | Main Rivers | 1:50.000 |
| 1970-1971 | Cyclone affected areas | 1:10.000/1:50.000 |
| 1975 | Whole of Bangladesh | 1:30.000 |
| 1981-1982 | Coastal region | 1:30.000 |

ANNEX II - 4. AVAILABLE TOPOGRAPHICAL MAPS

| Scale | Year of first issue | Remarks |
|---|---|---|
| 1:250.000 | 1961 | Based on surveys of 1900-1908, 1914 - 1925, corrected from airphotos 1952, verified on the ground 1953 - 1954. |
| 1:50.000 | 1959 | based on cadastral surveys of 1921 - 1923, corrected from airphotos 1952, verified on the ground 1953 - 1954. |
| 1:50.000 | 1964 | based on enlargements of 1929 issue, corrected from airphotos 1958, 1963. |
| 1" : 1 mile(1:63.360) | | Various editions, corrected upto various years. Mainly based on 1907-1908 surveys and compiled from various sources a.o. airphotos 1942. |
| 4" : 1 mile(1:15.840) | | enlarged from preliminary edition 1927 (1" - mile) and corrected from airphotos 1951. |
| 8" : 1 mile(1:7920) | | Specially prepared maps of project areas, like Ganges Kobadak, Coastal embankment project, etc. etc. showing contour lines. |
| 16" : 1 mile(1:3960) | | Mouza - cadastral maps*), showing land tenancy and plots. Surveyed 1921 - 24 and corrected in 1953. |

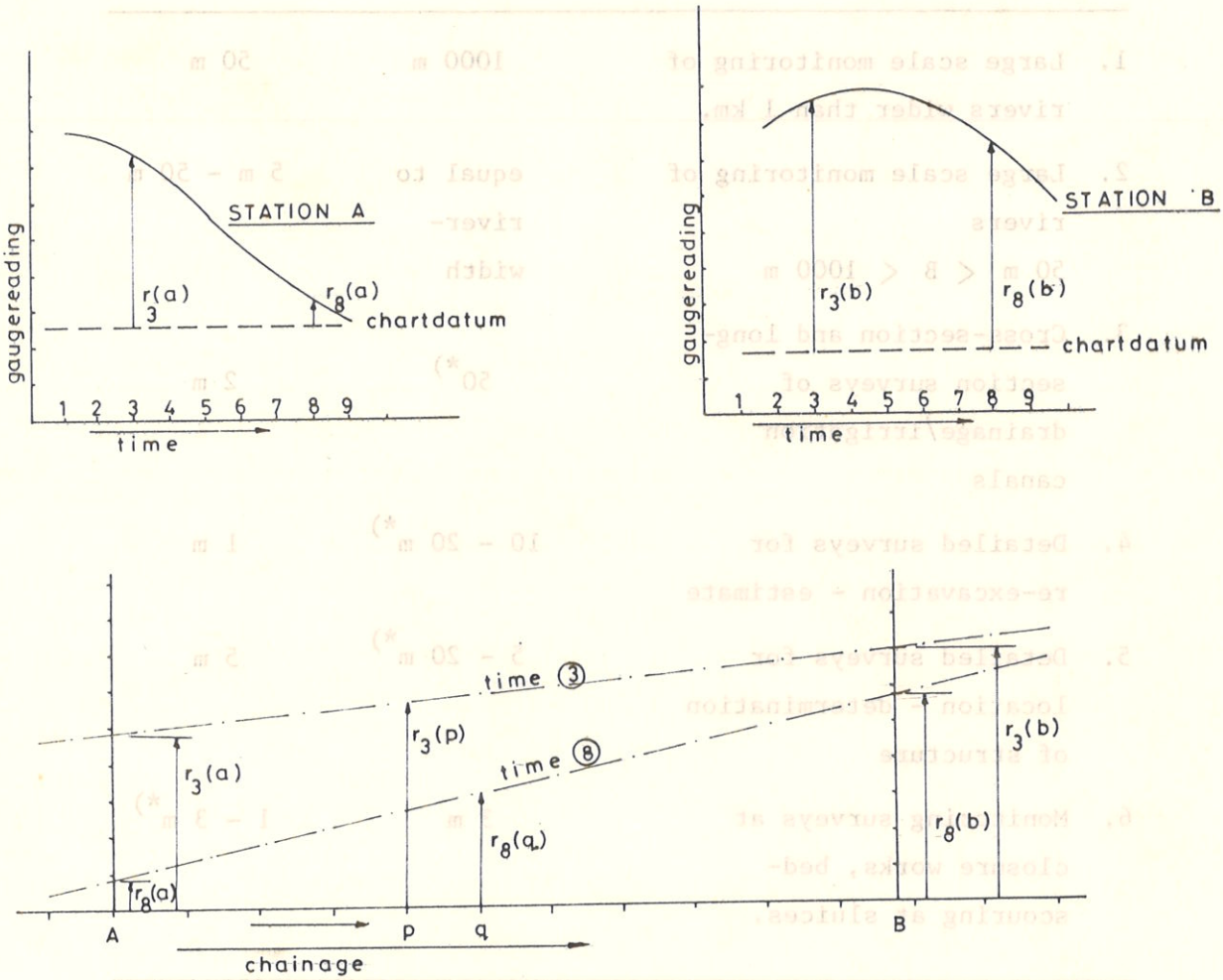
*) available at District Land Revenue Offices.

ANNEX II - 5. DENSITY REQUIREMENTS OF BATHYMETRIC SURVEYS

| Type of survey | intermediate distance between X-sections | Sounding fix at ... m intervals |
|---|---|---|
| 1. Large scale monitoring of rivers wider than 1 km. | 1000 m | 50 m |
| 2. Large scale monitoring of rivers 50 m < B < 1000 m | equal to river-width | 5 m - 50 m |
| 3. Cross-section and long-section surveys of drainage/irrigation canals | 50*) | 2 m |
| 4. Detailed surveys for re-excavation - estimate | 10 - 20 m*) | 1 m |
| 5. Detailed surveys for location - determination of structure | 5 - 20 m*) | 5 m |
| 6. Monitoring surveys at closure works, bed-scouring at sluices. | 3 m | 1 - 3 m*) |

*) depending on the width of the river or canal.

ANNEX II - 6. PLOTTING OF REDUCTION CURVE FOR HYDROGRAPHIC SURVEYS FROM TIDAL INFORMATION OF TWO GAUGE STATIONS




At time ③ the water level at station A is $r_3$ (a) and at station B the water level is then $r_3$ (b). These two readings are plotted in the lower graph and connected by a line marked with "time ③". This line represents the linear interpolation of all water levels at time ③ along the riverstretch between station A and station B.

For instance : at place ⓟ the water level at time ③ is $r_3$(p).

The same procedure is applied for any required time and place. (see time ⑧ and place ⓠ .

ANNEX II - 9. SOIL PROPERTIES, SYMBOLS, TESTS AND APPLICATIONS

| Property | symbol | test | suggested for type of soil |
|---|---|---|---|
| 1. Specific gravity : | $G_s = \frac{\gamma_s}{\gamma_w}$ | measuring volume drying, | all |
| 2. Natural unit weight : | $\gamma_s = \frac{W_s}{V_s}$ | | |
| 3. Dry unit weight : | $\gamma_d = \frac{W_s}{V_t}$ | weighing | " |
| 4. Wet density : | $\gamma_{wet} = \frac{W_t}{V_t}$ | " | " |
| | $\gamma_{wet} = \gamma_d + n.\gamma_w$ | " | |
| 5. Porosity : | $n = \frac{V_v}{V_t}$ | " | |
| 6. Void ratio : | $\varepsilon = \frac{V_v}{V_s}$ | " | sand and sandy soils |
| 7. Relative density : | $Dr. = \frac{\varepsilon_{max} - \varepsilon}{\varepsilon_{max} - \varepsilon_{min}}$ | " | all |
| 8. Moisture content (%) : | $W = \frac{W_w}{W_s} \times 100$ | " | " |
| 9. Saturation (%) : | $S_r = \frac{V_w}{V_v} \times 100$ | " | clays silty clays |
| 10. Atterberg limits: Liquid limit : | $I_w$ | Atterber - limit tests | cohesive soils |
| Plastic limit: | $P_w$ | | " |
| 11. Compressibility : | $C_c$ | compression - test | clay, plastic soils, peaty soils |
| 12. Shear resistence: | $\tau$ | direct shear test | all |
| 13. Cohesion : | c | triaxial test | cohesive soils |
| 14. Permeability : | k | permeability test | sand |
| 15. Grain size distribution : | - | sieves. | sand |

Symbols used :

$V_v$ = total volume of voids

$V_t$ = total volume of sample

$V_s$ = total volume of solid substance = $V_t - V_v$

$e_{max}$ = void ratio of the soil in its loosest state

$e_{min}$ = void ratio of the soil in its densest state

$W_w$ = weight of water in the soil

$W_t$ = total weight of soil sample = $W_w + W_s$

$W_s$ = oven dry weight of sample

$V_w$ = volume of water in a sample

$\gamma_s$ = unit weight of soil

$\gamma_w$ = unit weight of water

$\gamma_d$ = unit weight of dry soil