TRAINING AND CONTROL OF HIMALAYAN RIVERS FOR FEEDING IRRIGATION CANALS WITHOUT PERMANENT DIVERSION WORKS - A CASE STUDY OF UPPER GANGA CANAL

A DISSERTATION

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By

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CANDIDATE'S DECLARATION

I hereby certify that the **dissertation "TRAINING AND CONTROL OF HIMALAYAN RIVERS FOR FEEDING IRRIGATION CANALS WITHOUT PERMANENT DIVERSION WORKS - A CASE STUDY OF UPPER GANGA CANAL"** is being submitted by me in partial fulfillment of requirement for the award of degree of **MASTER OF ENGINEERING IN WATER RESOURCES DEVELOPMENT** at the Water Resources Development Training Centre, University of Roorkee, is an authentic record of my own work carried out during the period from July 16, 1998 to December 21st, 1998 under the supervision of Professor Raj Pal Singh, Visiting Professor, WRDTC, University of Roorkee.

The matter embodied in this dissertation has not been submitted by me for the award of any other degree or diploma.

Dated : December 21st, 1998 **(PRAMOD BIHARI GIRI)**

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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(PRAMOD BIHARI GIRI)

SYNOPSIS

The Himalaya exercises a dominant influence on meteorological conditions over the Indian subcontinent as well as on its physical geography and they virtually affect the entire area and its water circulation system. Vast reservoir of water in the form of ice, snow fields and glaciers, give rise to many large rivers and innumerable streams which constitute three major rivers viz. the Brahamputra, the Ganga and the Indus.

The peculiar characters of these rivers such as outflanking bank erosion, aggradation, degradation, meandering and shifting of the river courses in its mountainous, sub-mountainous, alluvial and deltaic regions are caused by complex fluvial phenomenon and not understood fully till today.

On account of training and control of the major Himalayan rivers various practices such as Spurs, Levees, Guide Banks etc. have been very peculiar measures adopted in the recent years. However, in spite of several measures adopted to train and control these mighty rivers; no such full proof methodology and technique could be developed even today. There is always a necessity of suitable, sustainable and cost effective remedial measures to be chosen while dealing with these mighty rivers to maximise the benefits out of its vast waste resources and minimum the negative aspects like floods, bank erosion, shifting of river course etc. and research activity in the field of river engineering.

Western and Eastern Yamuna canals were the first irrigation canals in northern India which were taken up for rehabilitation and use for irrigation by the British Engineers in early part of the Nineteenth Century. These canals were taken off at suitable points in the sub - mountainous region and were continued to run without permanent head works for many decades by simple training and control on the river.

Incidentally from the mid of the 19 th century to the early part of the 20th century the railway, highway and the canal professionals had to face with the problems of training and control over these rivers while crossing them through road link or taking off canal system for irrigation purpose. This provided the real field for the professionals to train and control these rivers and it gave a real experience and professional knowledge on this subject.

The Upper Ganga Canal (U.G.C.) was the first major canal system projected for irrigation and navigation to command large fertile Doab land between the Ganga and the yamuna in the mid of the Nineteenth Century (1842-54). The canal was taken off from the river the Ganga near Hardwar close to the Shivalik range of the Himalayas and was continued to run for a period of more than seven decades without any Permanent Diversion Work. The efforts to feed the canal by temporary works and maintaining the thorough control on the morphology and the flow of the mighty river were really bold and adventurous resulting into utmost economy in project expenditure.

Immediately after the Upper Ganga Canal, Upper Bari Doab Canal was taken in the Indus valley, Punjab (1851-59) and that, too, was continued to run without any Permanent Diversion Work for more than two decades by suitable measures on the control of the river.

The above practices and attempts of the canal engineers resulted into very large savings in capital investment at the beginning of the project .This sort of planning also provided the conditions where the capital investment could be deferred to long period when revenue returns and benefits of the investments started coming in.

Now-a-days, experience on many major and medium irrigation projects have established that in spite of very heavy capital investments in the diversion works and the construction of main canal, the proposed irrigation could not be developed in the command resulting into quite unsatisfactory conditions as per the planning and construction of water resources project, because of extremely low financial returns and very limited benefits.

The study in this dissertation has been undertaken for critical review of the practices used for deciding the most suitable location of the off-take points and the simple and appropriate measures as well as effective control and training on the river for feeding the canals with temporary works for quite some time resulting into limited capital investments and substantial and satisfactory benefits.

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CHAPTER - I

INTRODUCTION

1.1 GENERAL

One scientist said, " Human being spends half of his life doing his best to control the environment for the utilization and exploitation of natural resources on the earth and he will spend the other half of his life doing his best to restore what he spoils and ruins in the nature."

In our present century, the human being's desire to exploit all the natural resources has forced him to review the way by which he deals with the environment to put the corrected plans to exploit it.

One of the Russian authors **"S.B.Zaligan"** said, " Our problem is that we put economic missions and try to realize them at all costs. The result is a debt for nature that is always increasing and the day of payment is inevitable. Human being is parcel of nature and when we strive against nature, we are fighting ourselves."

Promotion without destruction is an old philosophy which has been revived in order to overcome the new economic problems.

This is also true with water on the earth.

1.2 CHARACTERISTICS OF RIVERS

The characteristics of the river under study should be well understood so that engineering works can be designed that will help the river to do what it would do naturally rather than designed to force it into an unnatural situation which will fail ultimately.

As **Lorenz Straub** often said, "River engineering is more an art than a science. **Straub's** discussion (1942) of the difficulty of defining characteristics of a river is still valid:

> "Rivers differ greatly from one another in their physical characteristics and general behaviour ; hardly any two rivers can be found alike. The characterizing elements are so interwoven that it is extremely difficult, if not impossible, to describe them independently. The variation in mobility of the streambed together with variation in discharge, both over wide ranges, results in exceedingly complex phenomenon or a progressively changing nature. In their natural condition rivers seldom reach a state of equilibrium, even over short reaches. A state of change is the rule rather than the exception."

Rivers, particularly those which undergo wide variations in discharge, are observed to change their regimen continuously. For each condition of flow there is a new regimen which the river approaches but never reaches because the influence of time lag does not permit establishment of equilibrium before a new and changing condition of flow is encountered.

Each river is different and each reach of a stream is different from almost all other reaches of the same stream. The majority of the rivers subject to modification and improvement are meandering sand-bed, alluvial streams and river engineering works - for the most part - serve to control or modify discharge, stage, sediment discharge, stream alignment, channel depth, flood plain area or water quality.

In general, these objectives can be achieved by the use of a variety of structures or a combination of types of structures such as dams and reservoirs, levees and floodwalls, locks, bank revetment, channel contraction and other control works and dredging.

The most appropriate engineering solution for problems on some streams is clearly apparent. For others, the ultimate plan can be selected only after careful hydraulic, economic, social and environmental analysis. Also, the most appropriate design is sometimes determined by the kind of construction materials readily and economically available in the local area of the project.

Successful engineering works on one river can be expected to be equally successful on another river having similar characteristics, but could be completely unsuccessful on a river having different characteristics.

Some rivers are domestic, that is, within one country and others are international flowing through or between two or more countries. The problems of shared use of international rivers can be very complex. Almost all uses that upstream riparian people make of river water affect uses that downstream riparian people can make of a river.

1.3 OBJECTIVE AND SCOPE OF STUDY

The term "River Training and Control" in its broad aspects implies any suitable engineering construction provided on a river to direct and guide the river flow including floods to train and regulate the river bed or to increase the low water depth.

In the sub -mountain Himalayan reaches, the river Ganga, too, is having steep slopes, velocity of flow is high and carrying boulders and shingles etc. To utilise its water for irrigation, the past experience on many major and medium irrigation projects have established that in spite of very heavy capital investments in the diversion works and the construction of main canal, the proposed canal could not be developed in the command resulting into quite unsatisfactory conditions as per the planning and construction of water resources project.

The study in this dissertation has been undertaken for critical review of the practices used for deciding the most suitable location of the off-take points and the simple and appropriate measures as well as effective control and training on the river for feeding the canals with temporary works for quite some time resulting into limited capital investment, but substantial and satisfactory benefits from the diverted water through canals.

The understanding of the problem based on the above studies and the relevant technical comments on the functional dependability and expected performance over a long period have also been recorded so that economy in capital investment be exercised in projecting perennial as well as inundated canals for feeding depleting ground water (G.W.) table and providing irrigation in the proposed canals.

CHAPTER - II

CHARACTERISTICS OF MAJOR HIMALAYAN RIVERS

2.1 GENERAL

India is rich in rivers. The north Indian rivers originate from the Himalayas. The drainage system of the Himalayas, composed of rivers and glaciers is very complex indeed. Actually, Principal Himalayan rivers are even older than the mountains which they cut through. The great Himalayan range is a vast gathering of glaciers. Some of these glaciers are among the largest in the world outside the polar circles. In fact, these glaciers are important and ever - renewing sources of fresh water. In the sector of the Himalayas, where the monsoon is intense, these glaciers often melt and that is why likely to worsen the water inundation situations **(Fig. 2.1).**

It has been computed that in streams with glacierization the variation in run-off may be as much as 30% of the annual figure. This variation is due to the frequent change in the glacier mass balance.

2.2 NON- HIMALAYAN AND HIMALAYAN RIVERS

All the Indian rivers can be classified as non- Himalayan and Himalayan rivers **(Fig.2.2).**

2.2.1 NON- HIMALAYAN RIVERS

The Non- Himalayan rivers in the central and the south are actually not snow-fed at all. They get their supplies chiefly during the monsoon only and they dry up practically in the summer season. Hence, they are non-perennial rivers. These rivers arise from the Aravali, Vindhya, Satpura and Sahyadri ranges. Originating from these mountains, these rivers run in all directions. The river

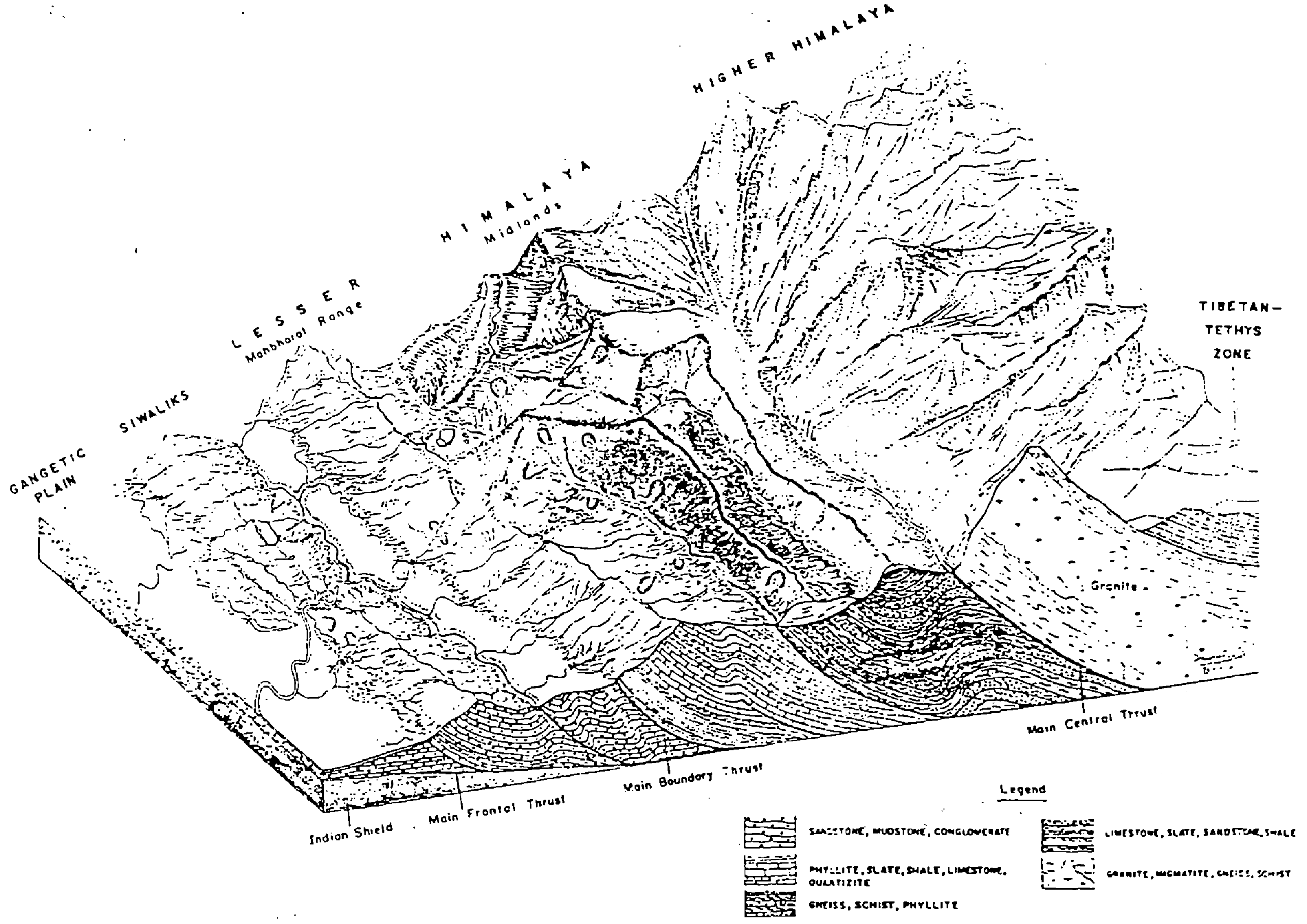
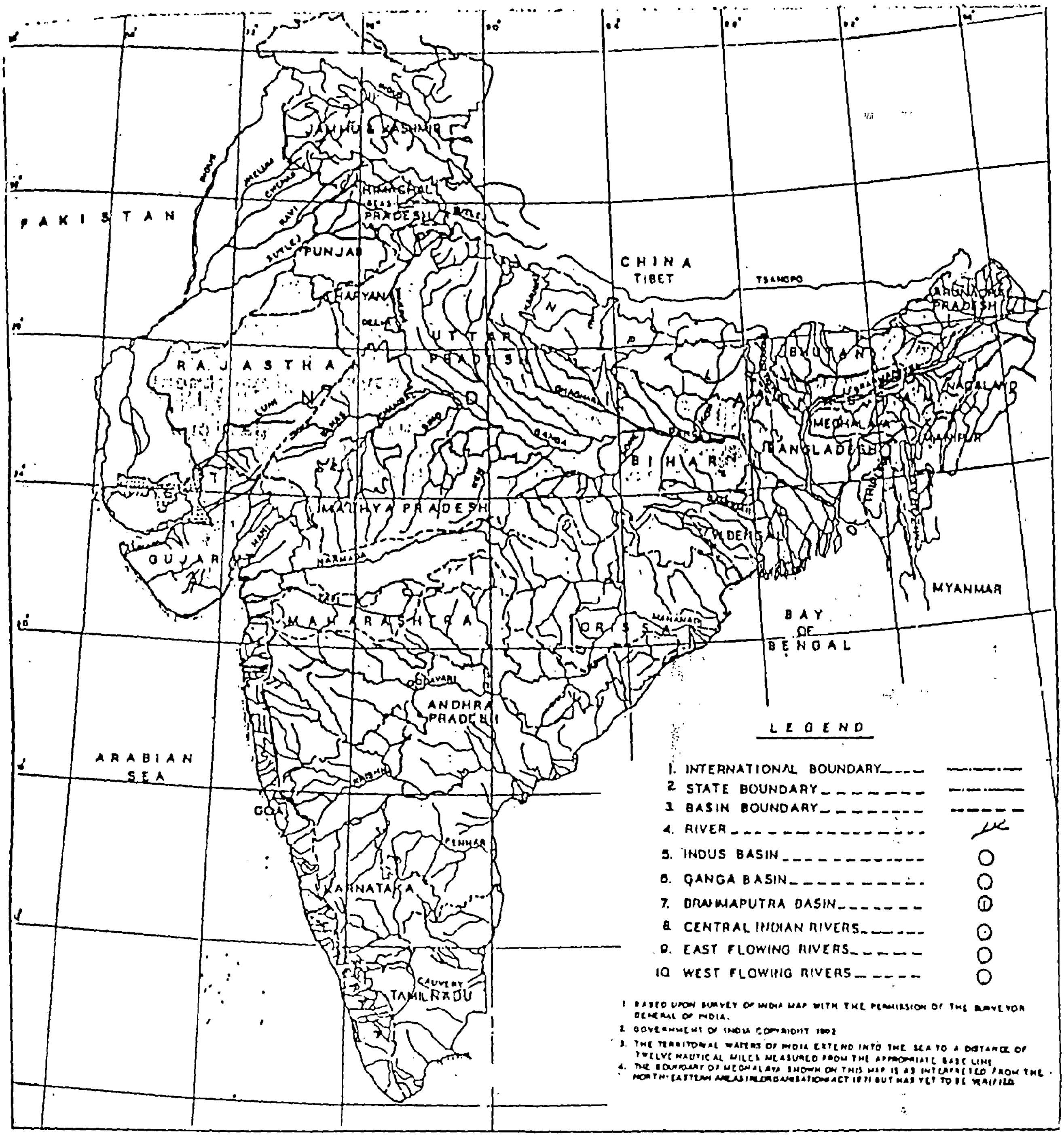


Fig. 2.1 Block diagram of the Himalayas



1. BASED UPON SURVEY OF INDIA MAP WITH THE PERMISSION OF THE SURVEYOR GENERAL OF INDIA.
2. GOVERNMENT OF INDIA COPYRIGHT 1992
3. THE TERRITORIAL WATERS OF INDIA EXTEND INTO THE SEA TO A DISTANCE OF TWELVE NAUTICAL MILES MEASURED FROM THE APPROPRIATE BASE LINE
4. THE BOUNDARY OF MEGHALAYA SHOWN ON THIS MAP IS AS INTERPRETED FROM THE NORTH-EASTERN AREAS (REORGANISATION) ACT 1971 BUT HAS YET TO BE VERIFIED

Fig. 2.2 River Basins of India

Chambal runs to the north, Mahanadi to the east , Cauvery and Godavari to the south-east, Tapti and Narmada to the west.

Rivers in the south run similarly to the east and the west. Peninsular rivers are mostly of incised type. These rivers are much more stable than the Himalayan rivers and pose lesser problems as they flow through non- alluvial soils.

2.2.2 HIMALAYAN RIVERS

The Himalayas explain the peculiarity that the great rivers drain not only the southern slopes of these mountains, but also to a large extent, the north Tibetan slopes as well. The watershed of the chain being not only along its highest peaks, but to a great distance to north of it. The Himalayan region is liable to experience earthquakes with all their potential for damage continuously (**Fig. 2.3).**

The Himalayas exercise a dominant influence on meteorological condition over the Indian sub- continent, as well as on its physical geography and they virtually affect the entire area and its water circulation system .

By virtue of their altitude and location in the path of the monsoons, the Himalayas cause precipitation of the most of the cloud moisture either as snow or rain. Hence, there is a vast reservoir of water in the form of ice, snow fields and glaciers thereby they give rise to innumerable streams which constitute the following Himalayan rivers - Indus, Jhelum, Chenab, Rabi, Beas, Sutlej, Ganga, Gandak, Ghagra, Gomti, Kosi, Brahamputra etc.

These Himalayan rivers derive their water from melting snow during the spring and summer and also from rains during the monsoons. Consequently,

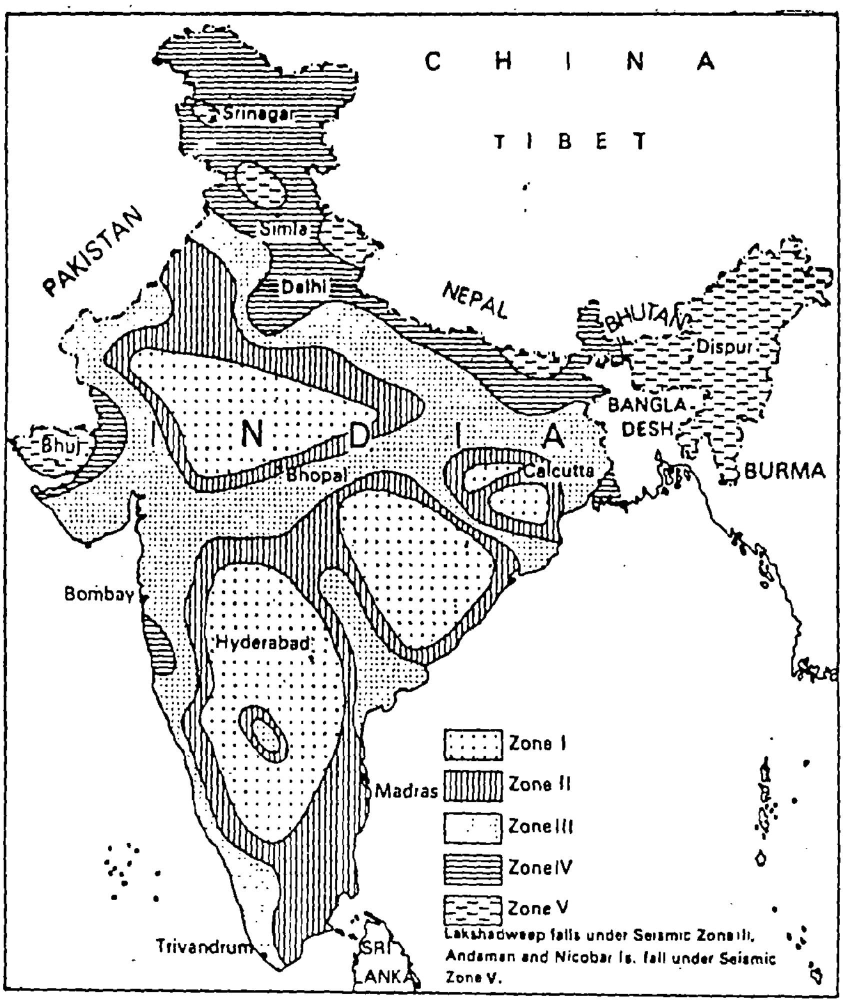


Fig. 2.3 Earthquake Zones of India

these rivers are more or less perennial and they can give dependable yields in the summer as well as in the monsoon.

The total annual water resources of India have been estimated at least 1.68 billion cubic meter (1360 million acre-feet), out of which the amount of water from the Himalayan river is almost 57%.

The pre-historic and historic civilization have prospered and flourished on the banks of these rivers. About 35% of India sits on deep alluvial strata through which major alluvial rivers such as Ganga, Brahamputra and their tributaries flow and, therefore, in this large area a variety of problems are encountered due to their complex fluvial phenomenon.

Hilly streams near foothills of the Himalayas have very steep slopes and carry large quantity of sediment during monsoon period mainly because of two reasons viz.

(i) The Himalayan rock is soft and friable,

(ii) The Himalayan zone, particularly the north - eastern part is susceptible to earthquake disturbances causing landslides, accelerated erosion of rock sediment. These are boulders, shingles etc.

The basic problems related to these ferocious rivers are erosion and deposition of sediment, migratory tendencies with large shifts in their courses, diversion of water, flood and flood control. The high flood discharge and then flow discharges are having a very big gap.

It is extremely difficult to stabilize their courses. Due to the heavy rainfall in the month of July and August about 3/4 th of the average annual rainfall, these north Indian rivers rise in high floods which are many times more than the normal supplies in them throughout the year. The flood discharge is about 50 to 100 times the normal winter supplies. The sections required for passing flood discharges are vastly out of proportion to the sections required for normal winter supplies. These large variations in discharge and sediment load make the hydraulics of these rivers very complex and cause them to meander.

The three major Himalayan rivers are the Brahamputra, the Indus, the Ganga. The Brahamputra and the Indus are to be north of chain near mansarovar lake and the Ganga in the middle of the chain in the Garhwal region (**Fig. 2.4**).

2.3 THE BRAHAMPUTRA SYSTEM

The Brahamputra ranks among the most mighty rivers of the world. This river rises in the great glacier of the Kailash range which is in the northern - most chain of the Himalayas. It is just south of lake Konggyu Tsho in the Tibet range.

In Tibet, this river is known as the Tsangpo where it flows eastwards for about 1700 kms through the southern part of that country. In this reach, it also joins Lhotse Dzony and it opens out into a wide navigable channel for about 640 kms.

After that, the river breaks through a succession of rapids and it turns first northwards and finally in a great loop southwest through Arunachal Pradesh in India where it is known as the Siang, then as the Dihang and the Lohit.

From here onwards , the river is known as Brahamputra. After flowing through a stretch of 720 kms in Assam valley, it enters Bangladesh and finally

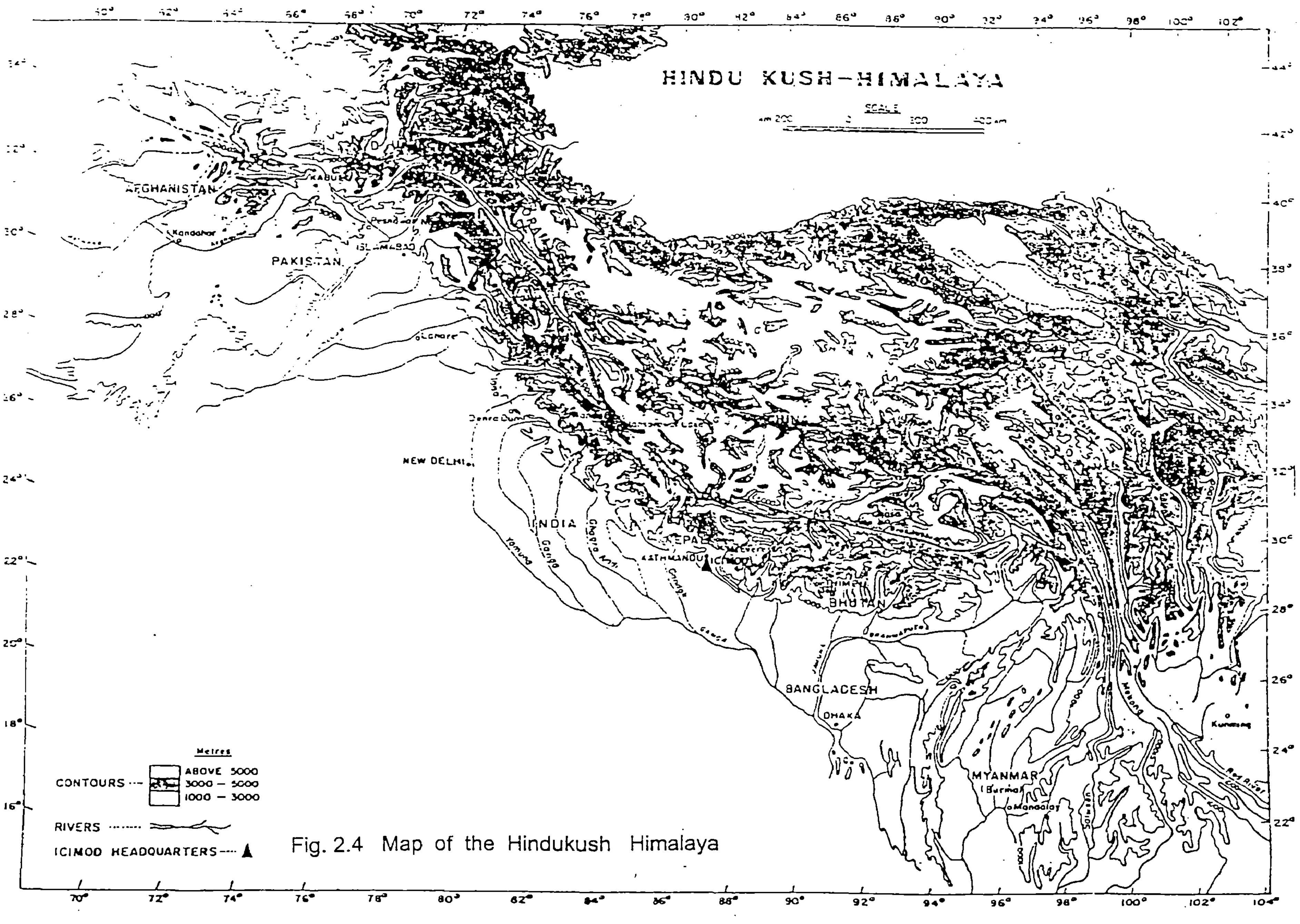


Fig. 2.4 Map of the Hindukush Himalaya

joins the Ganga at Goa lundu. This combined flow meets the Meghna - a broad estuary before flowing into the Bay of Bengal.

The principal tributaries of the river from the north are - Subansiri, Kameng, Dhansiri, Manas, Champamati, Saral - Bhange, Sankosi and the Tista. The important tributaries from the south are Burhi, Dihing and Kopili **(Fig.2.5).**

The total length of the Brahamputra is 2900 kms and it drains on an area of 5.8 lakh sq. kms before joining the Ganga in Bangladesh. Of the total drainage area - 1.87 lakh sq. kms is in India.

Most of the run -off in the river is contributed by heavy rainfall of about 5100 mm to 6400 mm in Abor and Mishmi hills in Arunachal Pradesh as well as 2500 mm 5100 mm in the Brahamputra plains.

2.4 THE INDUS SYSTEM

Like Brahamputra, the Indus river also rises in Tibet. Then it enters the south -eastern corner of Kashmir and after that it takes a southward turn where it enters Pakistan. In Pakistan, it flows at the foot of the great mountain Nanga Parbat and also it is joined by the Kabul river from the west. Near Mithankot, it receives the accumulated water of five eastern tributaries known as the Panchnad. The river finally empties itself into the Arabian Sea near Karanchi. The total length of the Indus from the source to the sea is 2880 kms out of which 1114 kms lies in India.

The Indus river system drains a large part of north- west India and most of the territory of Pakistan . The total catchment area of the Indus river system is 11.65 lakh sq. kms . Like the mighty Indus, its easternmost tributary called the Satluj also rises in the Tibetan plateau near Mansarovar lake whereas its next tributary - the Kabul rises in Afghanistan **(Fig. 2.6).**

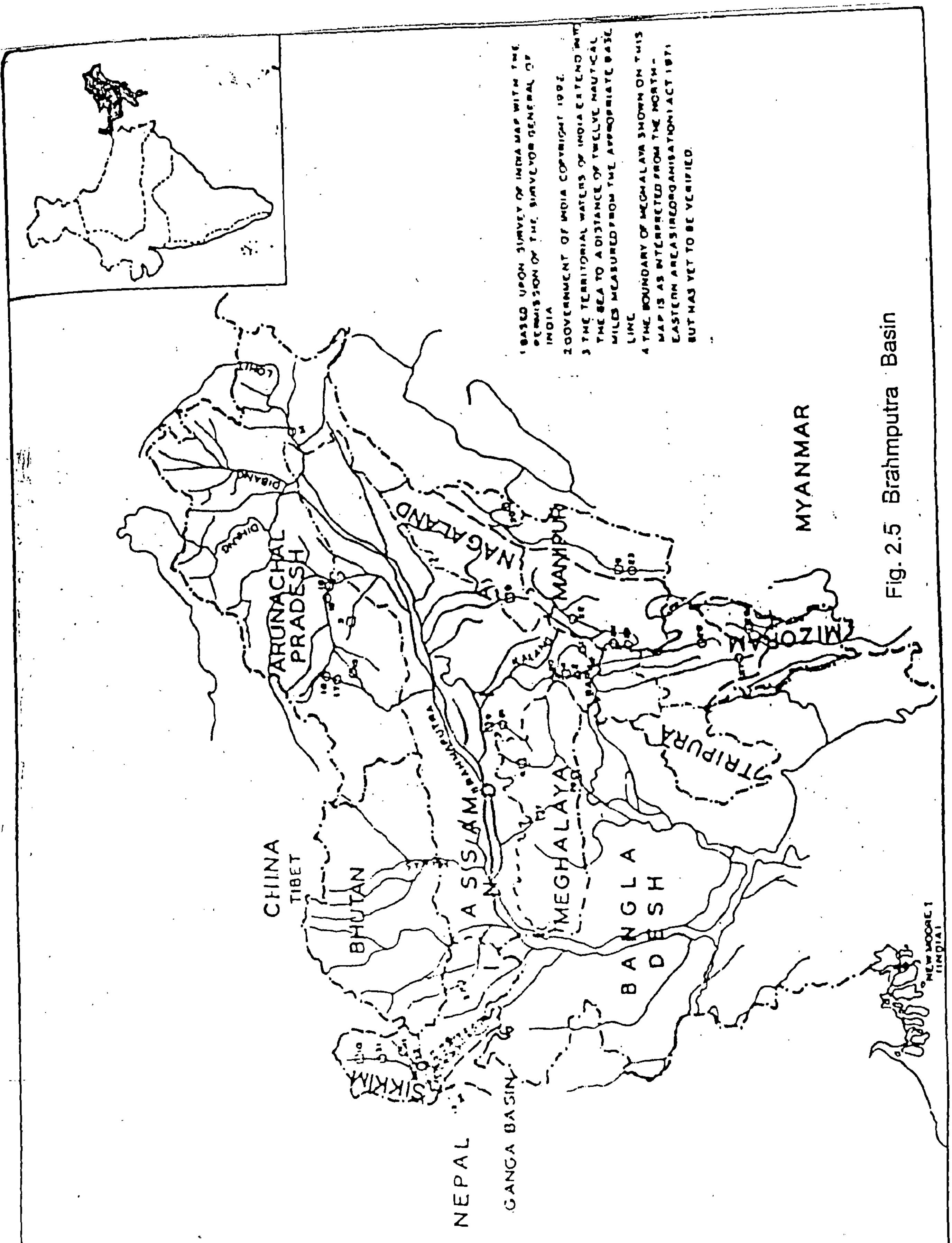
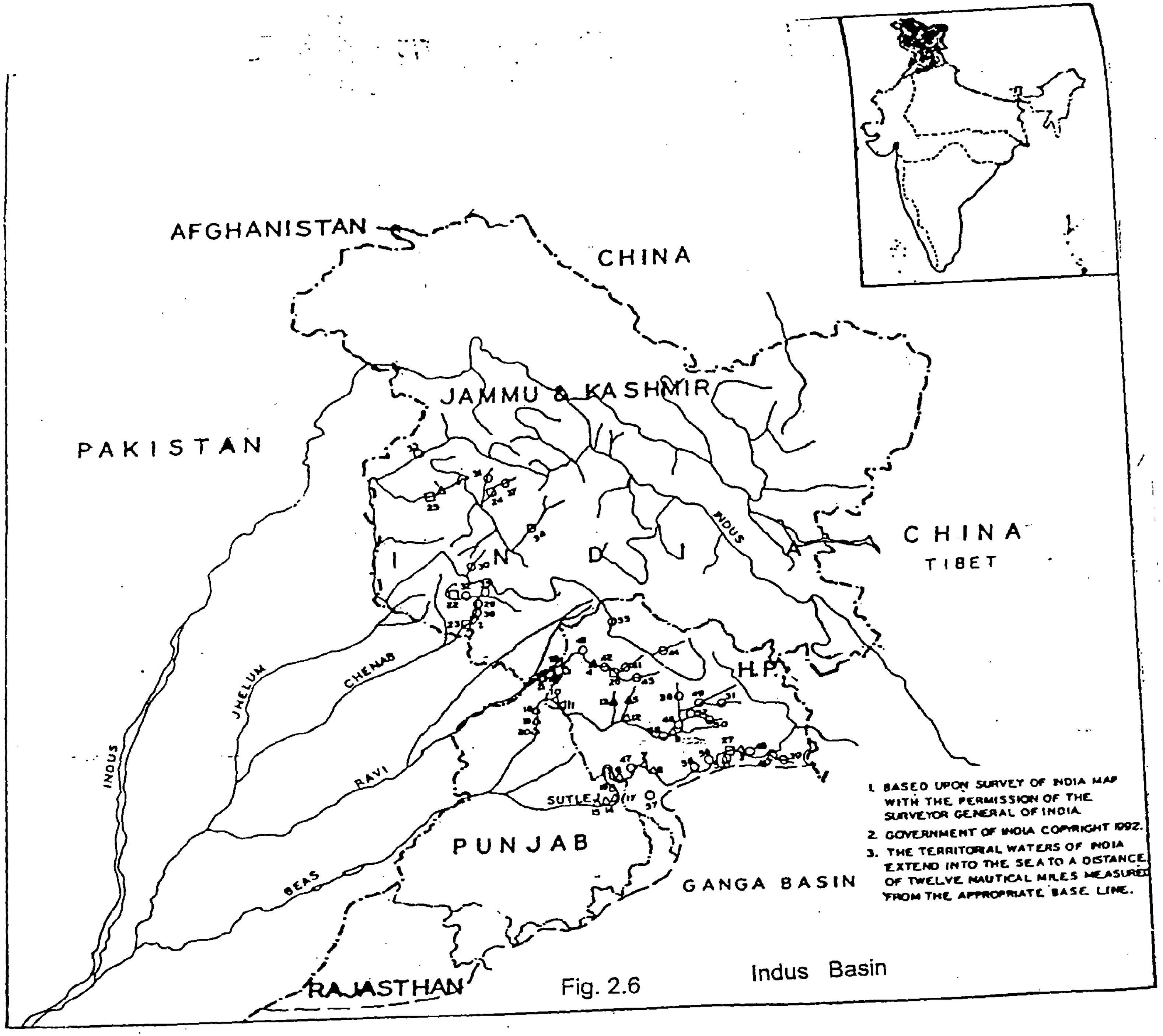


Fig. 2.5 Brahmputra Basin



1. BASED UPON SURVEY OF INDIA MAP WITH THE PERMISSION OF THE SURVEYOR GENERAL OF INDIA.
2. GOVERNMENT OF INDIA COPYRIGHT 1992.
3. THE TERRITORIAL WATERS OF INDIA EXTEND INTO THE SEA TO A DISTANCE OF TWELVE NAUTICAL MILES MEASURED FROM THE APPROPRIATE BASE LINE.

Fig. 2.6 Indus Basin

Most of the Indus basin lies in India and Pakiskan. The catchment area in Tibet and Afganistan is only 13% of the total area of the basin. Of the total catchment area of 11.65 lakh sq. kms., about 4.5 lakh sq. kms. lies in the Himalayan mountain and in the foothills which are really the source of water. The rest catchment area lies in the arid plain of India and Pakistan.

2.5 THE GANGA SYSTEM

The Ganga, the most sacred river of India, originates from the Gangotri glacier (now-a-days from the Gomukh glacier) which lies in the Uttarkashi district of northern Uttar Pradesh. It has twin sources. The one being the Gangotri and the other being the Satopanth glacier lying in the north- west of the famous pilgrim center of Badrinath , where it is called Alaknanda. These two sources join at Devprayag from where the river is called the Ganga. It emerges from the Himalayan hills at Haridwar after passing through Rishikesh.

At first, the river takes a southern direction and then turns eastwards flowing through the plains of Uttar Pradesh, Bihar and West Bengal in sequence. In the West Bengal the Ganga bifurcates into two rivers viz. the Padma entering into Bangladesh and the Hooghly in the lower reaches. The Hooghly flows through Calcutta and outflows in the Bay of Bengal after the Sunderban deltaic region.

The important tributaries of the Ganga are Yamuna (meeting at Allahabad), Ramganga, Ghagra, Gandak (meeting at Hazipur, Bihar), Bagmati, Kosi (meeting at Kursela, Bihar), and Sone. The total length of the river Ganga (measured along Hooghly) from the origin source to its outfall in the sea (i.e. the Bay of Bengal) is 2525 kms **(Fig 2. 7)**.

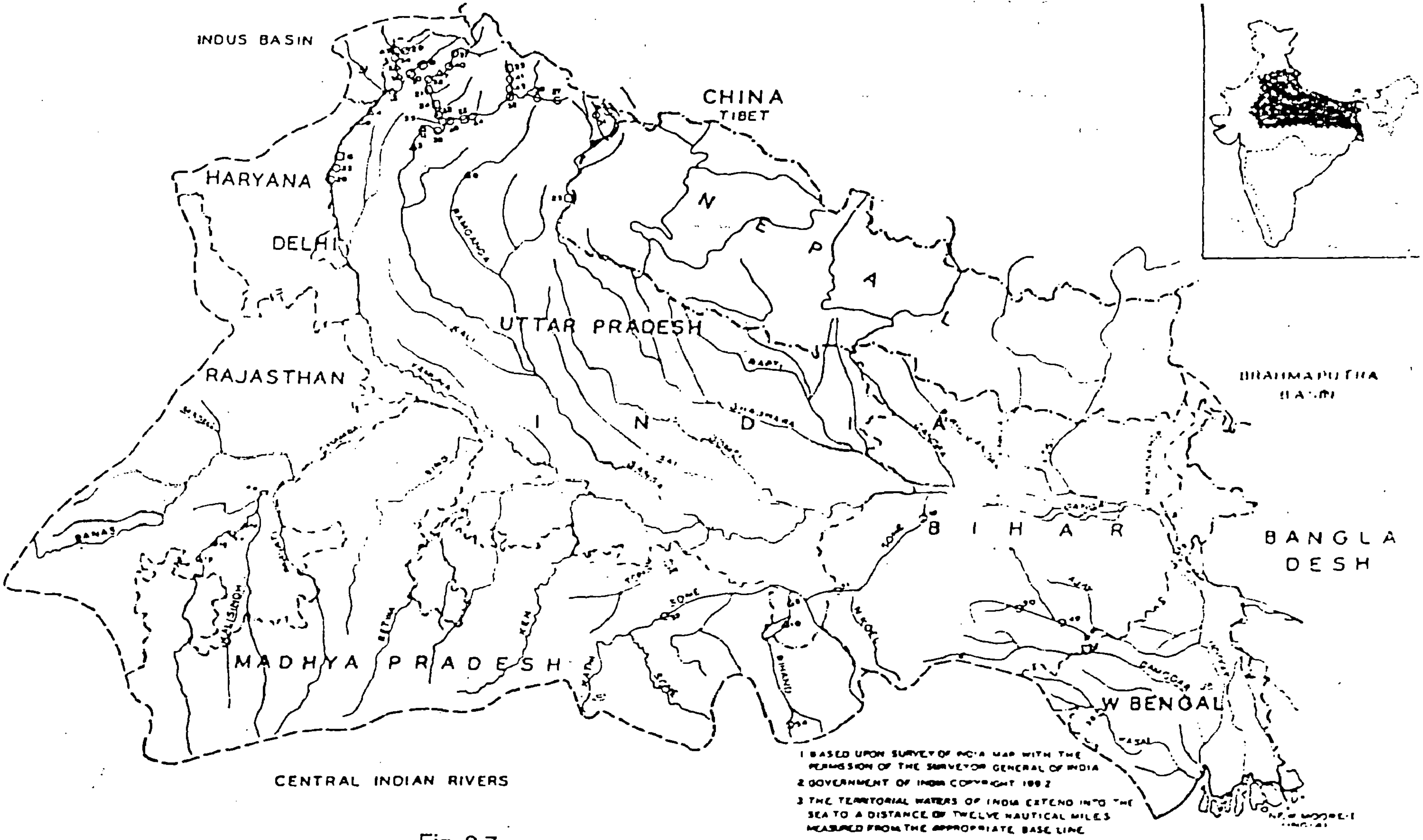


Fig. 2.7 Ganga Basin

The catchment area of the Ganga basin including its southern tributaries which originate in the Vindhya Plateau, is 10.86 lakh sq. km out of which 8.61 lakh sq. km is in India. The rest 2.25 lakh sq. km is in Nepal and Bangladesh.

The total drainage of the Ganga and its tributaries originating in the Himalayas, is 6.5 lakh sq. km. The Ganga basin covers slightly more one-fourth of the total geographical area of India. Hence , it is the biggest river basin in the country.

2.6 MORPHOLOGY OF MAJOR HIMALAYAN RIVERS

2.6.1 General

There are mainly two sources from which water flowing in the river is derived -

(i) From the upper end, fresh water entering the rivers are derived from the sea by a different process known as water cycle. The heat of the sun causes water from the sea to evaporate and collect in the form of clouds, which condensing in the form of rain, falls to the ground and is then collected by brooks and rivulets which feed rivers. The supply of fresh water is, however, variable and intermittent.

(ii) From the lower end, tidal water enters at the lower end of a river and is derived from the tidal wave of the ocean.

These rivers are formed along more or less defined channels. To drain from land, all water is obtained by way of precipitation as well as by melting of snow from high altitudes of the Himalayas. Their gradual development is the work of ages. These rivers carry and convey the sediment along with water (viz. shingles, boulders also) which is washed down from the catchment area and is eroded from beds and banks.

2.6.2 Types of River Reaches

The major Himalayan river reaches can be divided according to topography of the river basins into three parts as upper, middle and end reaches.

2.6.2.1 Upper Reaches of Rivers

The upper reaches comprise of the hilly and the sub -mountain regions.

(i) HILLY REACH - INCISED RIVERS

In this type, the channel is generally formed by the process of degradation. The sediment which it transports, is often dissimilar in character to that of the river bed, since the most of it comes from the catchment due to denundation and soil erosion . The bed and the banks of the reach itself are usually highly resistant to erosion. As bed conditions do not determine the sediment load , the rate of transportation cannot be determined as is usually done, as a function of bed characteristics.

In the hilly reaches, the rivers are further characterized by the steepness of their slopes, the swiftness of their flows and the formation of the rapids along their courses. These rivers do not present any regular pattern of meanders because of the varying resistance of beds and banks of erosion which vary along their lengths.

(ii) FOOTHILL SUB -MOUTAIN REACH - BOULDER RIVERS

In the sub -mountain reaches, these rivers are characterised by the steepness of their slopes and their beds consists of a mixture of boulders, gravels, shingles and sand. These rivers, moreover, differ considerably from those which are carrying sand and silt. In place of regular meandering courses, deep well defined beds and wide flood plains - the boulder rivers tend to have straighter courses with wide shallow beds as well as shifting, braided and interlaced channels.

During a flood, the high velocity flow transports boulders, shingle and gravel downstream, but as soon as the flood subsides, the flow of the material is checked and the bed materials pile in heaps. The flow with reduced velocity then finds it more difficult to shift the heaps then to go round them and the channel thus wanders in new directions, often attacking its banks and widening the bed thereby.

When the river descends from the steep hilly region into the foothill area, the slope suddenly flattens resulting in considerable reduction in sediment transporting capacity. The sediment accordingly deposits forming an alluvial fan.

2.6.2.2 Rivers in Flood Plains (Alluvial Reach Rivers)

Rivers in flood plains have the characteristics of meandering freely from one bank to the other and of carrying material which is similar to that of the bed .

Rivers in flood plains are further classified as---

(i) AGGRADING TYPE ,
(ii) DEGRADING TYPE , and
(iii) STABLE TYPE

(i) AGGRADING TYPE OR ACCRETING TYPE

If a river is building up its bed, it is called an aggrading or accreting river. An aggrading river is a silting river and thus builds up its slope. A river builds up its bed because of a variety of reasons : heavy load , obstruction like a barrage or a dam across it raising the level of water and flattening the slope, extension of the delta at the river mouth, sudden intrusion of sediment from a tributary. Such a river is called an aggrading type. It has usually straight and wide reaches with shoals in the middle which shift with floods, the flow being divided into a number of braided channels .

(ii) DEGRADING TYPE

If the river bed is constantly getting scoured, then it is known as degrading type. This type of river is found either above a cut- off or below a dam (or a barrage). These result, respectively, in the sudden lowering of the water surface upstream of the cut- off which increases its slope of flow and in the sudden diminution of its sediment load .

For example, the Colorado (U.S.A.) has become a degrading type on the downstream after the construction of the boulder dam .

(iii) STABLE TYPE

A river which does not change its alignment, slope and its regime significantly is called a stable river. Changes such as silting or scouring or advancement of delta into the sea may take place, but they are negligible and may fail to produce any change in the regime of the channel, except, perhaps, that the river may migrate (or shift) within the Khadirs (i.e. the extreme limits within which a river is known to have ever wandered). Such rivers mould their characteristics in such a manner that most of the sediment load brought by them is carried to the sea.

A river remains seldom of a single type. The same river may have either aggrading, degrading and other river characteristics from its source to its mouth . The behaviour of a particular reach (whether to aggrading, degrading or stable) depends mainly upon the variations of silt (size as well as quantity) and flow discharge with time.

2.6.2.3 Lower Reaches of Rivers - Tidal and Delta Rivers

In the lower reaches, the rivers are called the alluvial rivers when they descend from the sub-mountain regions to alluvial plains. The rivers have also got the characteristics of meandering freely from one bank to the other. Here the rivers carry the material which is similar to that of the bed.

(i) TIDAL RIVERS

A river reach in which periodic changes in water level occur due to tides, is called a tidal river. Actually, the tail reaches of the rivers adjoining the oceans are affected by the tides in the ocean.

The ocean water enters the river during the flood tide and goes out into the ocean during the ebb tide. The river, therefore, undergoes periodical rise and fall in its water level depending upon the nature of the tide. The distance up to which the tidal effect is experienced depends upon the various factors such as shape and configuration of the river, the tidal range, freshet discharge etc.

(ii) DELTAIC RIVERS

A river before it joins the sea, gets divided into branches, thus forming a delta shape. As the river approaches the sea, its velocity is reduced and consequently the channel gets silted and water level rises resulting in spills and eventual formations of new channels. These branches multiply in their number as the river approaches the sea **(Fig.2.8).**

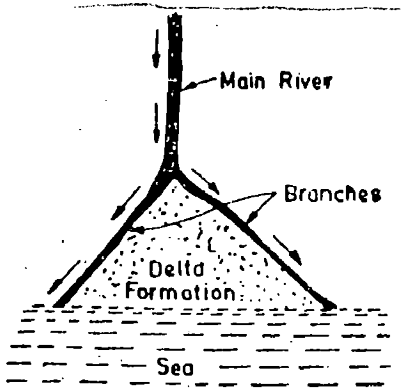


Fig. 2.8 Delta Formation

2.6.2.4 Other Types of Rivers

(i) FLASHY RIVERS

Rivers can also be classified according to the stage and nature of flood hydrographs. Thus, a river is called flashy, if the rise and fall of its floods are sudden .

In the case of flashy rivers, the flood hydrographs are steep, indicating thereby, that the flood flow occurs all of a sudden. The flood rises and falls in a very short period of a day or two. A sizeable small flow is however, maintained for some time till the end of the rainy season. Bed and banks of such rivers are in no way different from those of rivers in alluvial plains . There are several rivers of flashy type in India in the states of Rajasthan, Andhra Pradesh, Tamil Nadu and Karnataka.

(ii) VIRGIN RIVERS

In arid zones, a river may completely dry up before joining another river or the sea. Such a river is called a virgin river. Water in the rivers of this type disappear due to high percolation and evaporation losses after flowing a certain distance from their source. There are several virgin rivers in the states of Gujarat and Rajasthan.

2.7 EROSION ACTION

Erosion in rivers is a general phenomenon prevailing throughout their length off and on. This is caused by the rapid cutting away of steep banks or bottoms whether extending above water or below it just as soil is attacked and washed down by a jet in hydraulic mining, erosion is also caused by the impringement of a current. The common cause of erosion may be short cut or the rapid currents alongside and parallel to an erodible bank. Erosion of the flood plain areas takes place to the rapids which forms parallel or oblique to the shore. There are evidences that 30 m to 1525 m (100 ft to 5000ft) breadth of ground is eroded in one flood season. All along the length of about 1600 km (1000 mile) of one river may vary in breadth of 1.6 km to 19.2 km (1 mile to 12 miles). Most often, the inhabitants of these very frtile Khadir tracts are liable to find themselves either at the other side of the main stream as the result of a cut-off or dug out of house or home as the result of erosion. The newly deposited soil on the fields are a boon to the farmers.

The depth of scour is usually considered to be dependent mainly upon the two factors viz.

(i) the velocity of the stream and
(ii) the quality of the bed material.Scour is the worst in falling flood. The major Himalayan rivers spread themselves during the flood time about 6.4 km (4 miles) of width over a flat bottom valley or Khadir.

Between uptopped banks, the soil of the valley being sand of any depth up to 16 m to 60 m (50 to 200 ft) and is capable of being lifted up or dropped again with small alteration of velocity. The fall of the bed being such that the velocity of a stream is running straight along the river axis. The river lengthens itself out into great bends between the permanent banks and owing to short cuts in some places as well as silting up in others, these bends are changing continuously.

The above description is applicable to the greater part of the Ganga, the Indus and the Brahamputra and 4800 km (3000 miles) of tributaries viz. Jhelum, Chenab, Rabi, Beas, Sutlej, Yamuna, Gogra, Dharla, Sankas, Gangdhar etc. between their exits from the mountains and the debouchment into each other or into the sea .

2.8 SEDIMENT CHARACTERISTICS OF MAJOR HIMALAYAN RIVERS

There is a vast difference between the sediments of the major Himalayan Rivers in various reaches of the same river. The underscour of an attack on a river bank not depends merely on the steepness of the slope and the velocity of the current, but also depends on the coarseness or the fineness of the average sand of the river at the place. Also, the depth of the scour, the rapidity with which the bed area enlargement will take place, the face of a rising flood, the incipient afflux etc.- all are dependent on the quality of the local sand available. The shape of the grains of sand has a good deal more to do with their transportability than their specific gravity.

2.8.1 Classification of Sediments

Most of the sands of the Ganges and its tributaries may be classified as of the fine micaceous variety, the, coarseness or the fineness are varying with the location. The sand specimens of the Indus and its tributaries consist of mica mixed with quartz of extreme fineness, the fineness of the mica and the quartz is varying with location up to Kotri (on the Indus) 225 km (150 miles) from the sea. The inclination of the high flood surface is 8.25 cm per km (5.25 inches per mile). 99 percent of the sediment is passing through a 75 mm wire sieve of an inch.

Truly speaking, to design a logical classification schedule for these sands is not very easy. Much depends on the relative value attached to an element in sand's ability to resist the current of water. Sorting by size does not convey a true idea of the relative ability of these two extreme classes of sand to resist erosion.

However, the following classification gives a fair idea about the characteristics of the sediment : **(Table 2.1).**

C--- Coarse : 80% stopped by 40 wire of an inch and coarser sieve.
VC--- Very Coarse : 25% stopped by 16 wire and coarser sieve .
F --- Fine : 80% passes through 75 wire sieve.
M--- Medium : Between coarse and fine.

TABLE - 2.1: GRAIN SIZE CLASSIFICATION

Class Name	**Size range in mm**
Boulders	> 256
Cobbles	64- 256
Gravel	2- 64
Sand	0.064 - 2
Silt	0.004- 0.064
Clay	> 0.004

The combination of certain falls of river-bed per km with certain classes of sand may conceivably lead to a fair judgment arrived at the depth of the possible scour holes, it may prove practicable to formulate the role of co-ordination between bed fall, sand quality and design of training works. Some co-ordination between observed depth of scour and the quality of sand, velocity of river and duration of flow - on which maximum depth of scour and consequently the design of river engineering works - are undoubtedly dependent.

The angle of repose of the river sand might prove a useful factor in the diagnosis: The slope of the embankments are kept 2:1 or flatter (i.e. about 26 34 or flatter) usually.

The Ganges - Indus group in the relative coarseness and fineness of their sands, stands at natural slopes which do not differ greatly. The classification of sand of the bed of these rivers becomes an index of the permissible depth of scour which may occur when narrowed.

CHAPTER - III

BACKGROUND OF DEVELOPMENT OF RIVER TRAINING AND CONTROL IN INDIA

3.1 GENERAL

Rivers take off from mountains, flow from the mountainous plain terrains and finally join the oceans. They are formed along more or less defined channels, drain away the land water obtained by precipitation and snow melting in high altitudes and discharge the unutilised water back into the sea and thus completing the hydrologic cycle. The rivers not only carry this huge amount of water but also carry a tremendous of silt and sediment which is washed down from the catchment area and is eroded from their beds and banks and hence needs river training and control.

River training covers all those engineering works which are constructed on a river so as to guide and confine the flow to the river channel and to control and regulate the river bed configuration and ensuring safe and effective disposal of floods and sediment loads. Stabilising and training the river along a certain alignment with a suitable waterway is the first and foremost aim of river training.

In the primitive times, though there was not absolute control on the rivers, however, river training by embankments for flood protection has a long history and must be one of the earliest engineering achievements of man. History records the early attempts at dyking of Ganga in India.

In the last century, the rivers necessitated construction of the wider river channel at the site by guide banks to control and direct the flow through the weir openings. The system was initiated by **Bell** in 1890 and protected later by

Spring.

3.2 THE ARTIFICIAL NARROWING OF A RIVER BY "GUIDE-BANKS"

3.2.1 Earlier Concept Of Guide -Banks

Most often, it becomes necessary to construct an engineering structure such as a weir or a barrage etc. across a river. It is being used since ancient period, but in different ways.

The river course width varies at places continuously. This happens mostly in alluvial reaches. At some places, the width may be from one to sixteen kms and at some other places one fourth of this width ; when it passes through a gorge, with not abnormal velocity, too **(Fig. 3.1).** When we feel to bridge an unduly wide river bottom and fail to find a rocky gorge within a reasonable distance from proposed alignment, then such a gorge is made artificially. In fact, to control the river, it is a real engineering work. A pair of banks is made at the distance apart so that the entire flood discharge of the river may pass through it. Also, its natural fall of bed is maintained, however, with a greatly improved cross-section. This way, the river width is reduced and trained in such a fashion so as to ensure not only the safe and expeditious disposal of flood water, but also to ensure a permanent seasonal width of the waterway for the river flow.

As rivers shift their courses, if today a structure such as a bridge is constructed across the existing river width, the other day, the river may shift and there may not be any river water below the existing bridge at all and this river will be found to be flowing away from it, necessitating the construction of another structure. This may lead to the extension of the structure for the entire river length between its khadirs **(Fig. 3.2)**, which is unwise and uneconomical.

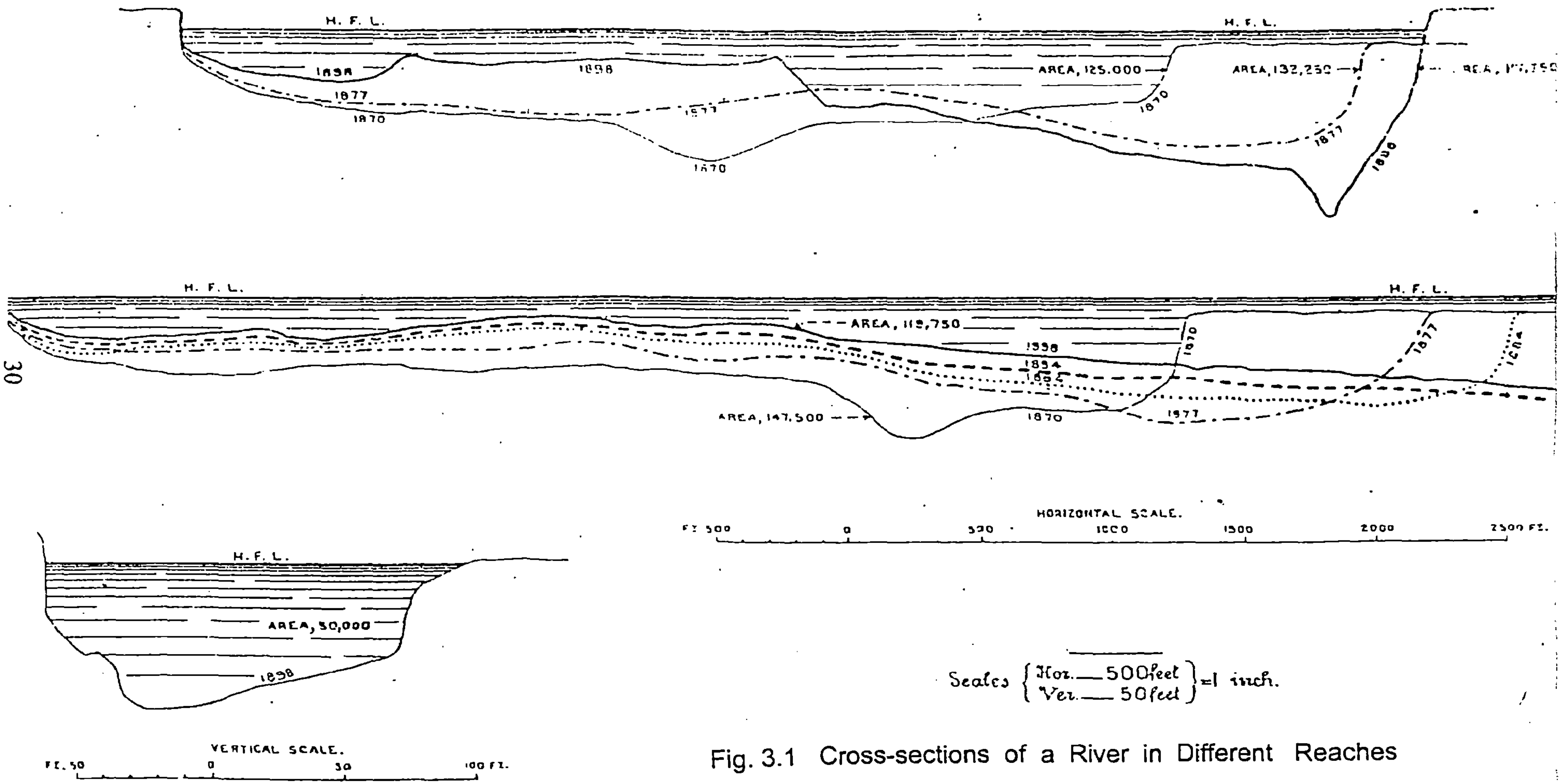


Fig. 3.1 Cross-sections of a River in Different Reaches

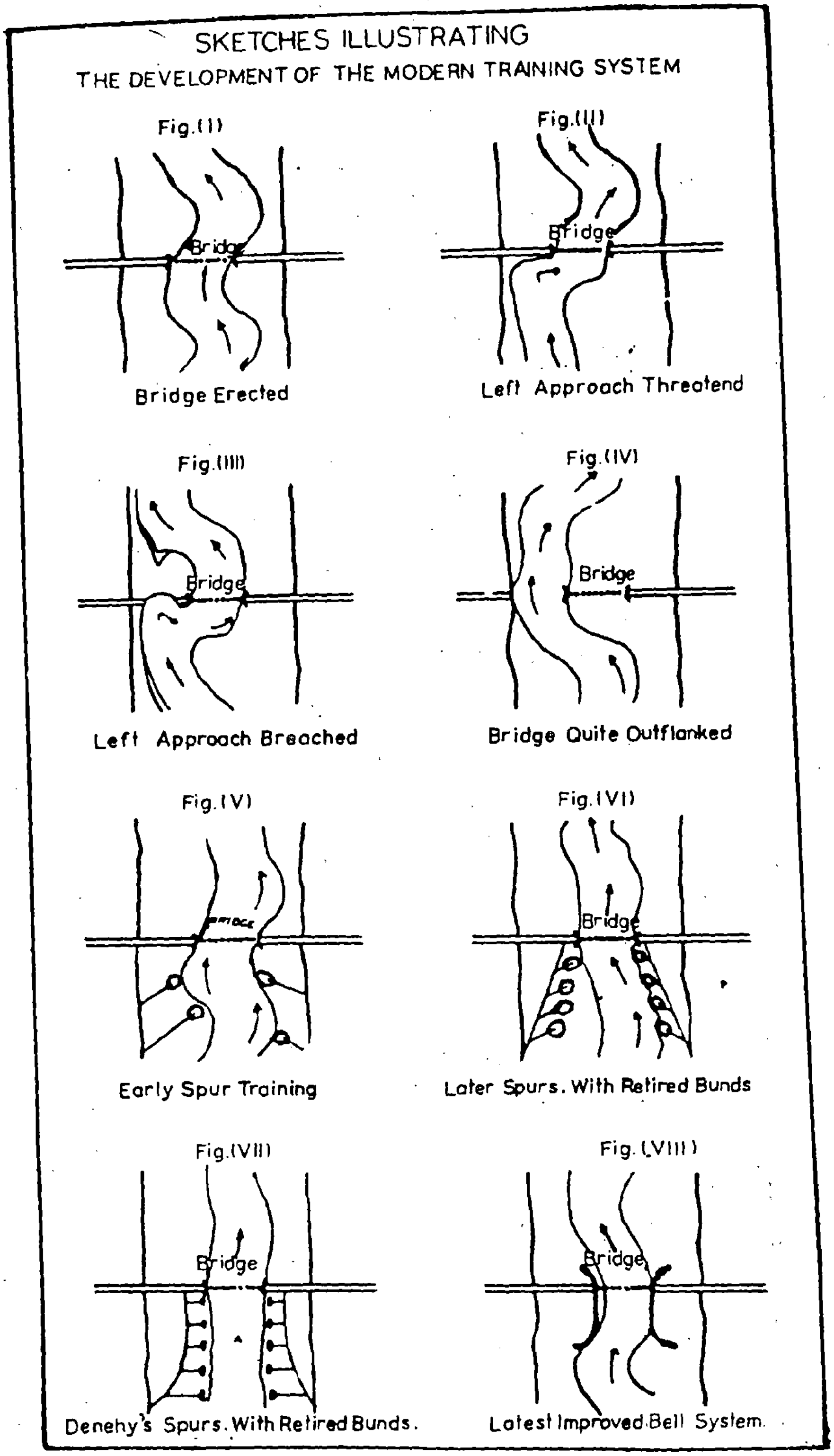

SKETCHES ILLUSTRATING
THE DEVELOPMENT OF THE MODERN TRAINING SYSTEM
Fig.(I)
Bridge
Bridge Erected
Fig.(II)
Bridge
Left Approach Threatend
Fig.(III)
Bridge
Left Approach Breached
Fig.(IV)
Bridge
Bridge Quite Outflanked
Fig.(V)
Early Spur Training
Fig.(VI)
Bridge
Later Spurs. With Retired Bunds
Fig.(VII)
Bridge
Denehy's Spurs. With Retired Bunds.
Fig.(VIII)
Bridge
Latest Improved Bell System.

Fig. 3.2

Hence, a structure such as a weir or a barrage or a bridge etc. is extended in a smaller width of the river and the river water is trained to flow almost axially through this trough without outflanking its structure. The river is normally trained for this purpose with the help of a guide banks.

The guide banks are generally provided in pairs, symmetrical in plan and may either be kept parallel or may diverge slightly upstream of works. Usually symmetrical and parallel guide banks are used. The guide banks consist of heavily built embankments in the river in the shape of a bell mouth (named after the name of the inventor **Bell**). The portion of the river between the normal river banks and the guide banks is closed by ordinary embankments.

Sometimes, one of the guide banks may become unnecessary and may be dispensed with for economical reasons. This may happen either when the khadir bank is very near the work-site, thus serving the purpose of guide bank itself or when the marginal bund is highly resistant to scouring - then only one guide bank is used economically **(Fig. 3.3).**

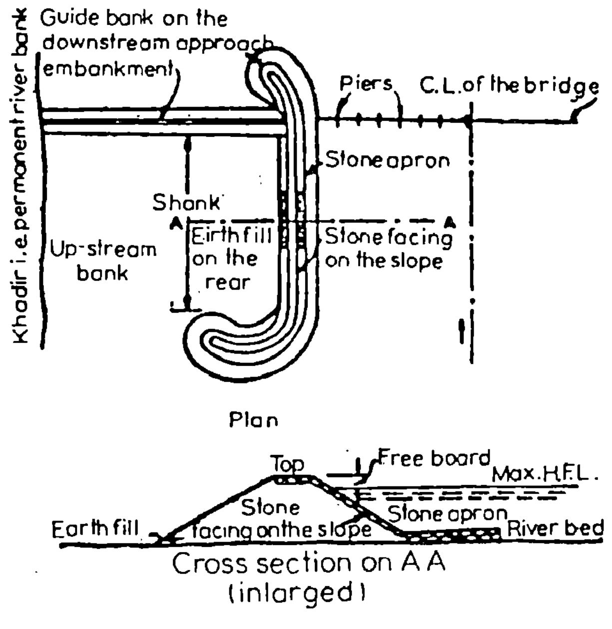


Fig.3.3 : Showing Guide Bank Details

Bank (or Banks) is (are) covered from low water upwards with such a thickness of loose rip-rap that there is not residual velocity enough to wash out the grains of sand. This covering above low water level is called the **SLOPE**. In case, when it is certain that the new channel will scour out deeper than the loose stone which can be laid, proper care is taken to put such extra stone at the foot of the stone such that if inevitable undermining comes, there should be enough stone ready to tumble in and so automatically to revert the exposed sand underlying the rip-rap slope.

The stone of the slope should not be undermined or fall in for any account. The design of this extra stone or **APRON** at the foot of the slope should be made such that it may fall in to a desired section, is a matter for consideration. **Fig. 3.4 & Fig. 3.5** give a clear picture of the above phenomenon. The design of APRON requires an exercise of great care and judgement.

While designing the two artificial gorge walls, utmost care should be taken. On plan, they should be such that they may not give rise to swirls, which have the effect of causing deep and dangerous scour. It is necessary to recognise and to provide fully for the attack which is certain to occur on the head and rear of the pair of gorge walls **(Fig. 3.6 & Fig. 3.7).**

Guide walls are placed in the direction of flow both upstream and downstream of the abutment, on one or both the flanks as required. With straight shanks of suitable lengths, they end in adequate curvature. Generally, the core is built in sand with stones on the sloping faces and an apron is provided for protection. Sufficient free- board and top width are provided in a good design .

Fig. 3.4 Sketches Illustrating an Attack of a stone-protected Bank

Fig. 1.

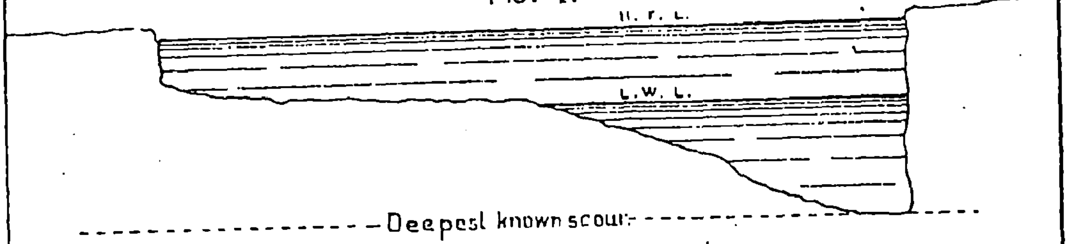


Fig. 2.

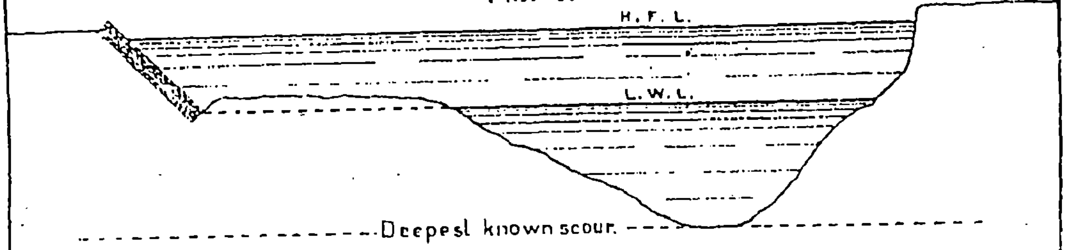


Fig. 3.

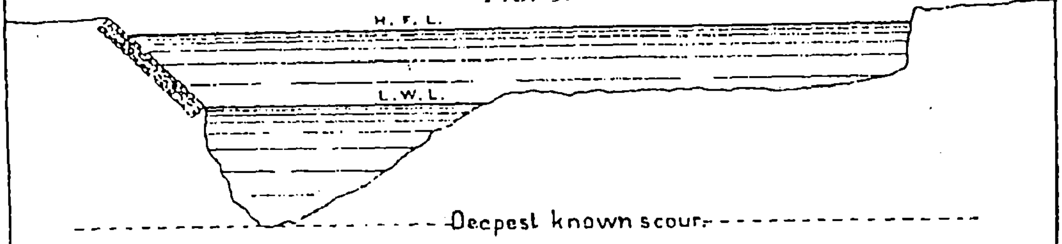


Fig. 4.

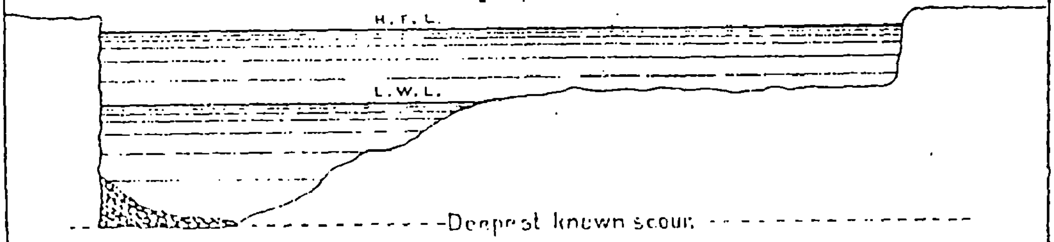


Fig. 5.

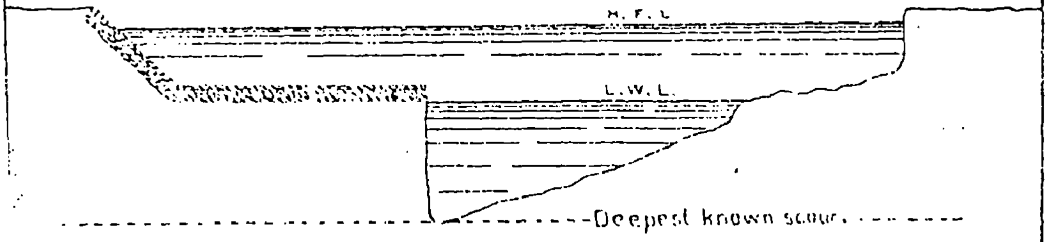


Fig. 6.

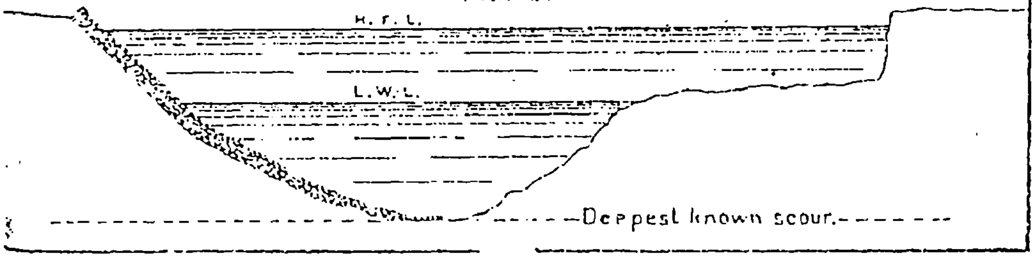


Fig. 3.5 The Dimensions of Guide Bank Aprons

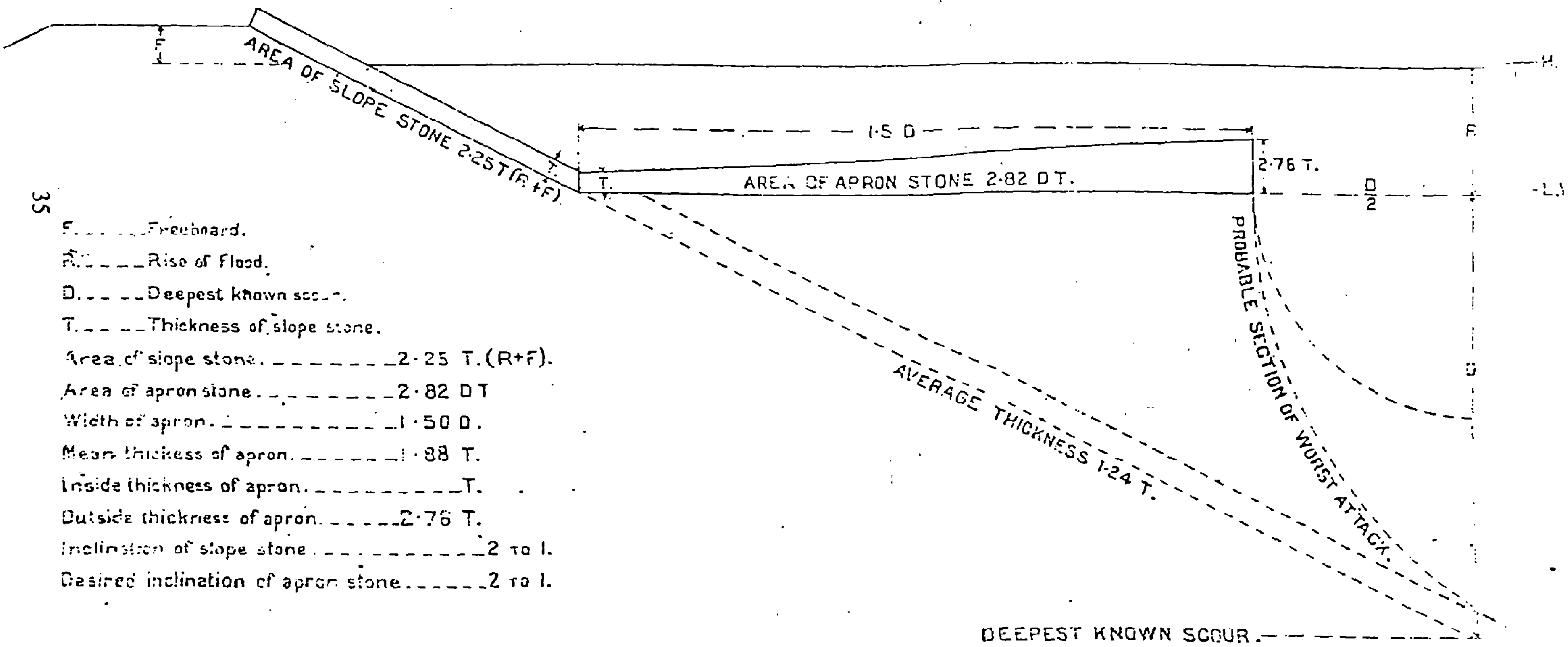


Fig. 1.

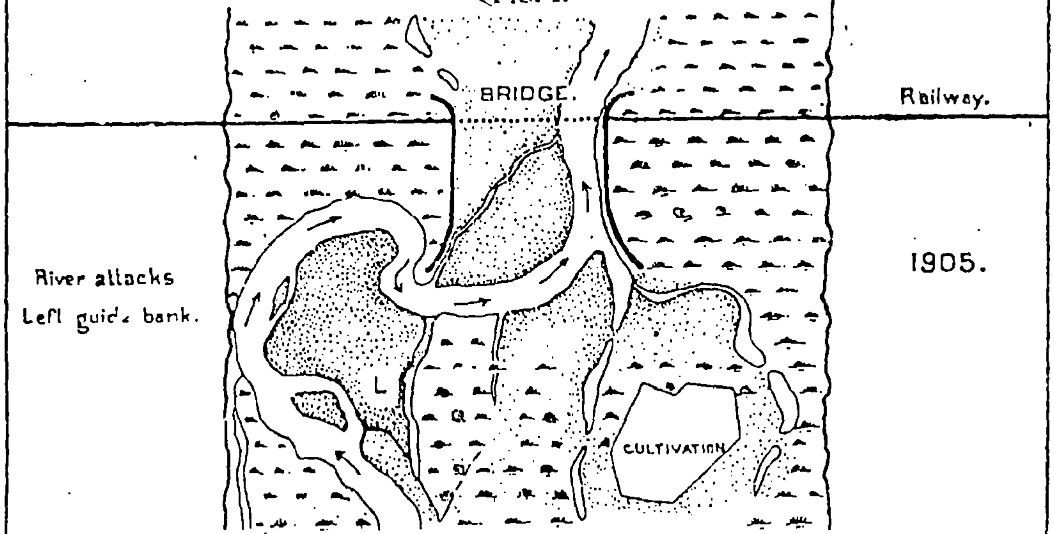


Fig. 2.

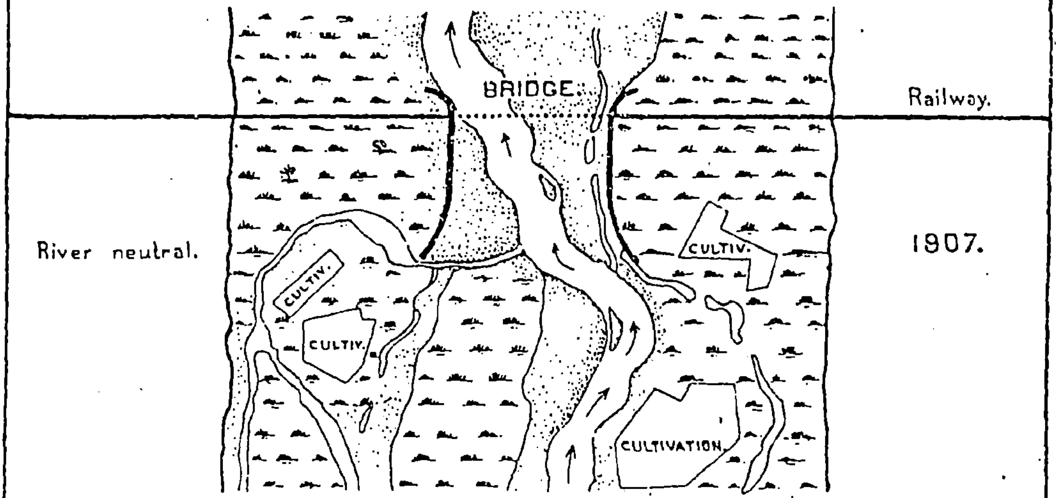


Fig. 3.

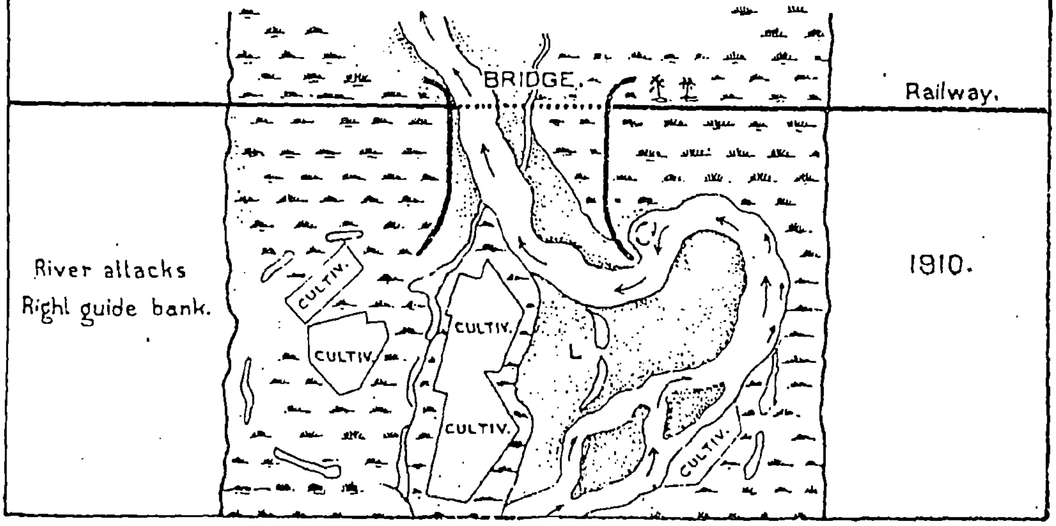
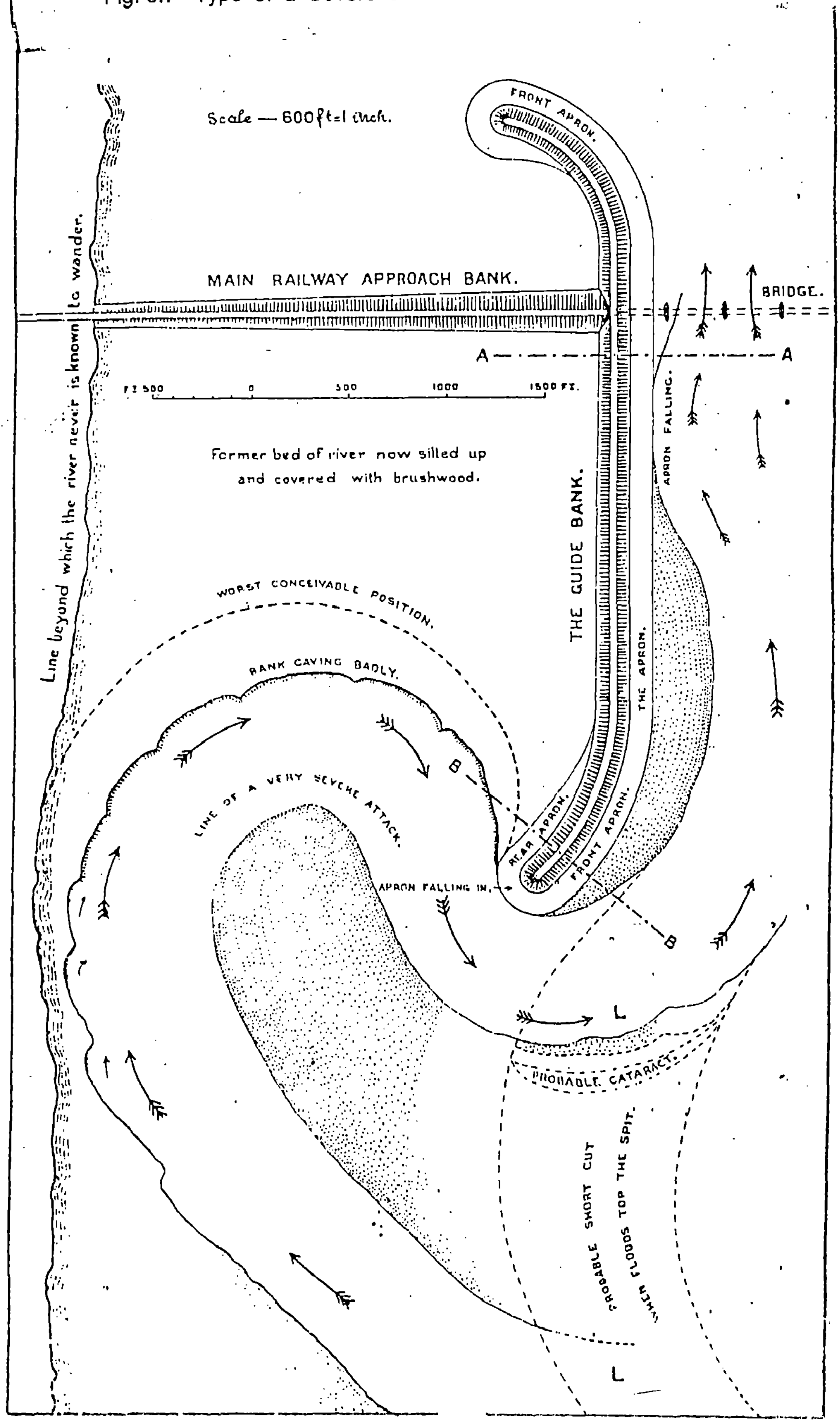


Fig. 3.7 Type of a Severe attack on a Guide Bank



Guide banks at a bridge serve a two-fold purpose. Firstly, they protect the approach embankments of the bridge from attack and secondly, they control the river and induce it to flow more or less axially through the bridge. When a river is bridged from bank to bank, guide banks are obviously unnecessary, but with constriction , they become indispensable. Thus, it is clear that in the design of the pair of gorge walls or guide banks, one has to consider first their shape in plan, length of shanks upstream and downstream of the bridge, their heads and second their cross-sections, aprons and materials of construction- have all to be carefully considered so that they may be proof against erosion whether the effect of impringment of upper current or of deep scour.

We can narrow a river which is having large cross-section to carry its full discharge without undue scour or afflux, if the beds of the river are composed of erodible, incoherent sand which is deepened by momentarily increase in velocity caused by the smallest momentary afflux.

By afflux, we mean the rise in the high flood level of the river, upstream of the weir (or the bridge in case of non-erodible soils) or barrage as a result of its constriction. This rise in water level is maximum just near the site of constriction and reduces as we go away from it in upstream. The afflux extends for a long distance on the upstream side **(Fig. 3.8).**

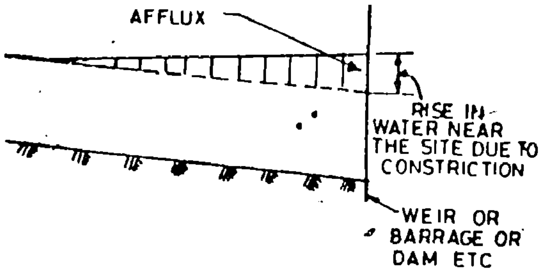


Fig. 3.8 Afflux Formation

The afflux which causes the increase in velocity and the concurrent increase in depth is not permanent and cannot be permanent. It cannot even last an appreciable time so long as the bed is erodible. The first flood which occurs after the artificial narrowing, digs out the sandy bottom as fast as its level rises and there is never a chance of more than a momentary afflux at the narrowed cross-section. As might reasonably be expected, however, the digging out of the bottom is by no means uniform all over.

The amount of afflux, in case of weirs or barrages founded on alluvial soils is generally limited to 1.0 to 1.2 m or more commonly as 1.0 m. In steep reaches of the river with boulder or rocky bed and in flashy rivers, a higher value of afflux occurs. The bed erosion and afflux are interlinked. In case, a bridge is founded on a river in which full bed scour develops before high floods, a negligible value of afflux may be taken. While in boulder beds and flashy rivers, the time for bed scour may not be adequate causing very high afflux . The amount of afflux governs the top levels of the guide banks as well as that of marginal bunds. The distance to which the afflux appreciably extends on the upstream side, governs the length and sections of the marginal bunds.

Sir J.E. Spring suggests the practice to assume the worst and to contemplate the very unlikely, but still possible, contingency of the whole enlargement from the successive points of view of :

(a) their widths apart,
(b) their lengths,
(c) their forms on plan,
(d) their forms in section,
(e) the arrangements for making them,
(f) the arrangements for maintaining them,

(g) their effects on the depths of the bridge pier foundations,
(h) the effects of narrowing of the river on marginal bund upstream.

Their are evidences of enlargement of bed sections offered by the Ganga at Garhmuktesar, where it shows substantial average deepening of river bed in one flood season. There is another example of enlargement of bed section by the river Ganga at Allahabad. There is a secondary effect of balancing up of high water in the Yamuna which joins the Ganga just below the bridge. Hence, the river easily adapts itself to rise and fall of flood in enlargement of its cross-section.

3.2.2 Selection Of Work Site

So, it follows that a river may be narrowed quite safely in a sandy-bedded river, furnishing it with a short straight rocky-sided gorge, through which the entire discharge of the river may be trusted to flow with no greater velocity than before. The narrowed river may cut out for itself a channel with a more favourable mean radius than it finds in its sprawling unregulated parts.

The object of narrowing is that it may be possible to build a short bridge instead of a long bridge. In fact, the limits of narrowing may be judged economically by a comparison of the cost of bridging the entire breadth of untrained river with the sum of the costs of

(a) the shorter bridge,
(b) embanking the unbridged part of the river,
(c) providing the pair of guide banks,
(d) deepening the bridge foundations, if necessary.

The experienced engineer will doubtlessly recognise the wisdom of selecting the place on the rivers cross-section where the bridge shall be located so that the area of scouring out of bed section must be minimum. It is evident that an engineering structure like a bridge or a weir should be spanned in that portion of the river where the distance between the khadir banks is minimum. This reduces the extent of possible embankment at the back of the guide banks and permits shorter guide banks. The river section at the bend is always wide and non-uniform; deep on concave bank and shallow on the convex. While the transition reaches connecting two adjacent bends are narrower and uniform in depth. Bridges should, therefore, be preferably built in these transition reaches, rather than on the bends.

Further, in case of bridges, the river bed at the proposed site should consist of deep strata of erodible land so that after constriction, the river may be able to deepen the bed to gain an adequate waterway. If the bed consists of stiff clay etc. the construction can be done only after the due allowance is made for afflux, which may make it costlier.

In case of weirs and barrages, the usual practice is to construct the weir or the barrage outside the main river channel in a minor creek which is dry in winter and then to divert the main river channel through it. At the weir site, the river width is constricted. The river upstream has, therefore, to be trained to flow between the two abutments of the weir without causing any damage.

The limits of narrowing of the river is achieved after continuous observation of the narrowing effects. The greater the narrowing, the deeper may be the scour and therefore, more expensive will be the stone protection of the guide banks. Thus, a practical limit of narrowing is soon reached. The general opinion is that in ordinary sandy-bedded rivers of the major alluvial with falls of 0.28 m/km (18 inches per mile) and less, narrowing may in practice be limited to what will cause an all over mean scour of from 2.44 to 4.88 metre (8 to 16 feet) between abutments.

It is important not to overlook the practical details of construction which may present the artificial narrowing of the river. It is not economical to construct a guide bank in deep water. The best place to construct it is a low, not too low, sandy flat where the horizontal low - water apron can be laid scientifically instead of being dumped into water.

3.2.3 The Length And Shape Of Guide - Banks

There is no hard and fast rule regarding the length of the guide banks to be adopted normally. Each case must be judged on its merit.

The length is dependent on two considerations viz.

(i) the distance necessary to secure a straight run for the river through the bridge, and

(ii) the length necessary to prevent the formation of a bend of the river above and behind the guide banks, circuitous enough to breach the main approach bank.

Rule of thumb compromises. No better rule may be arrived at than the rough one of the length of the guide bank upstream from the bridge to be equal to the length of the bridge **(Fig. 3.9).**

Fig. 3.9 illustrates the case, if unduly long guide bank is adopted - How the river behaves and other cases also. Thus, the length of the guide bank depends to a certain extent on the length of the bridge for a given river provided that the bridge is designed so that all its spans will be acting fairly equally, instead of some doing too much and some standing half useless.

Fig. 3.9 Sketches Illustrating the Design of Length of Guide Banks

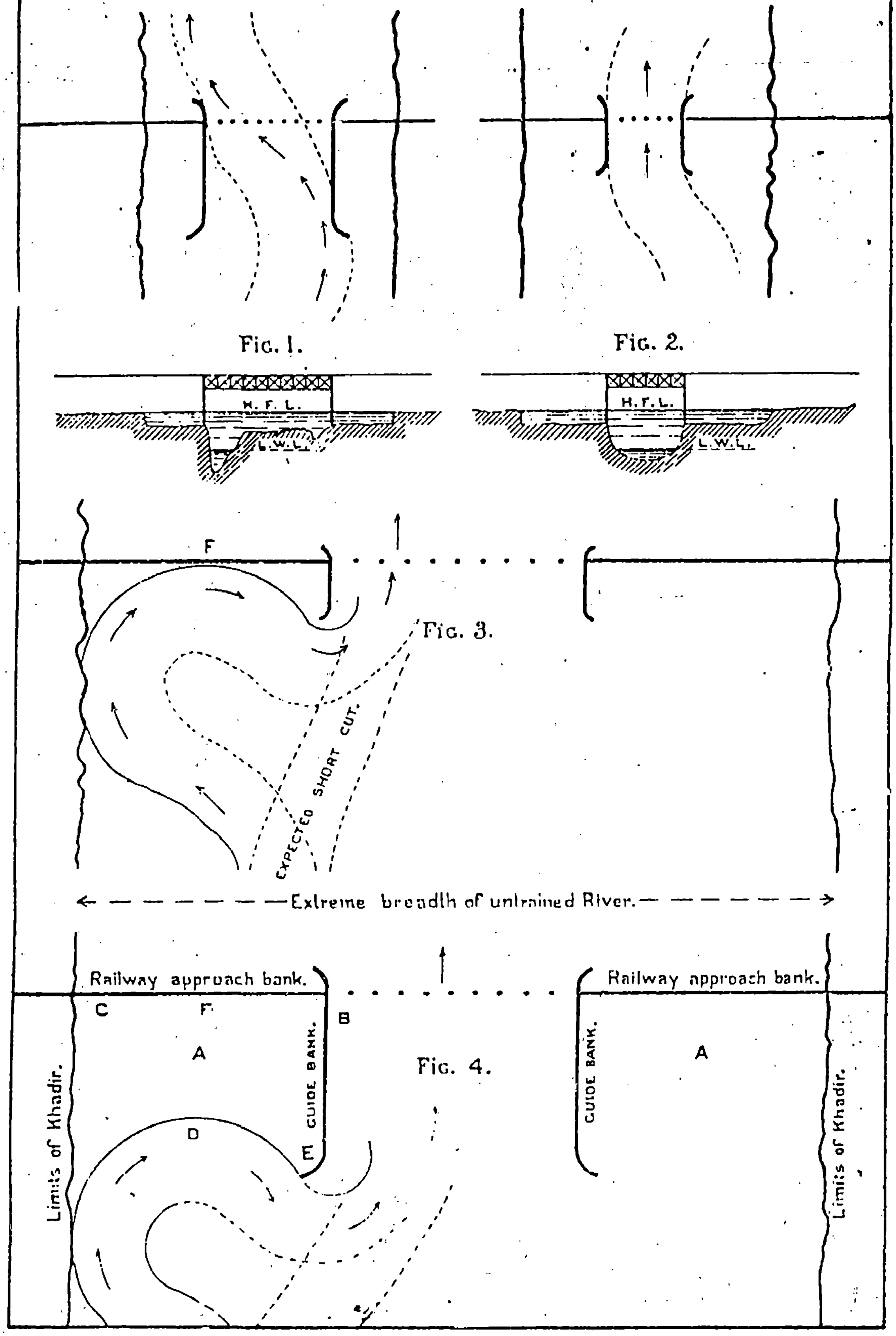


Fig. 1.

Fig. 2.

Fig. 3.

Fig. 4.

The upstream length of the guide bank is dependent also to some extent on the breadth of the unnarrowed river. If unduly short guide banks are made, then the bend may outflank the bridge leaving it high and dry **(Fig. 3.2).**

In this regard, the river maps should be studied to find that the radius of the worst curve, which a river is likely to form, before it short circuits itself by the establishment of a "cut-off "- is more or less ascertainable and stretch of 80 km (50 miles) - of a particular river.

The radius of the worst curve depends on many factors viz.

(i) relationship of velocity to coarseness or fineness of bed sand,
(ii) rise and duration of the flood over the low flat "point"- etc. all are incalculable.

There are more or less the same factors on which the breadth of such river is dependent. So, it follows that each stretch of river has more or less discoverable worst, that is, the smallest radius of bend to which its main channel may twist itself before it fits to short cut so as to straightens itself. As a general rule, the length of the upstream part of guide banks is made more or less from three quarters to the length of the bridge on the downstream side.

An important feature of the guide bank system , which is the most desirable to maintain at any reasonable cost owing to its great value, is the existence during high floods of still areas behind the guide bank. An important effect of the maintenance of still water area behind the guide bank is that it silts up very rapidly. The growth of vegetation reduces the risk of main approach being cut into by wave lap during the prevalence by windy weather in flood time.

To consider for the guide banks, the most suitable form on plan,

Mr.J.R.Bell recommended that the guide banks should be brought closer together at their upstream ends than at bridge so that the area at the bridge site must be clear of the obstruction in the form of piers which usually have a log of loose stone around them.

The summary of the advice given by **Spring** with regard to the form of guide banks on plan is as follows:

(i) The choice between parallelism, convergence and divergence must be dictated by the condition of the bed of the river for construction purposes during the working season. It is better not to be obliged to lay the apron in deep water, if possible **(Fig. 3.10).**

(ii) If practicable, it is better that the guide banks should approach each other near their upper ends before their upper curves begin. The amount of the contraction may be, say, anything up to double the combined thickness of the bridge piers below low water.

(iii) The length of the upstream part of the guide banks may be made equal to, or say, up to a tenth longer than the bridge (i.e. 1.10 L). But due attention should be paid to the possibility of the river bending round one guide bank into the still water area to the bank of it and eroding the main approach bank. Specially in wide khadirs, these may involve the use of very long guide banks.

(iv) The length of the downstream part of the guide bank may be one-tenth to one-fifth of the length of the bridge (i.e. 0.10L to 0.20L), according to the judgement that may be formed as to the activity of the swirls or disturbances likely to be caused by the splaying out the water on leaving the bridge. The guide bank must be kept far enough away from the swirls, if any, which endanger the approach banks.

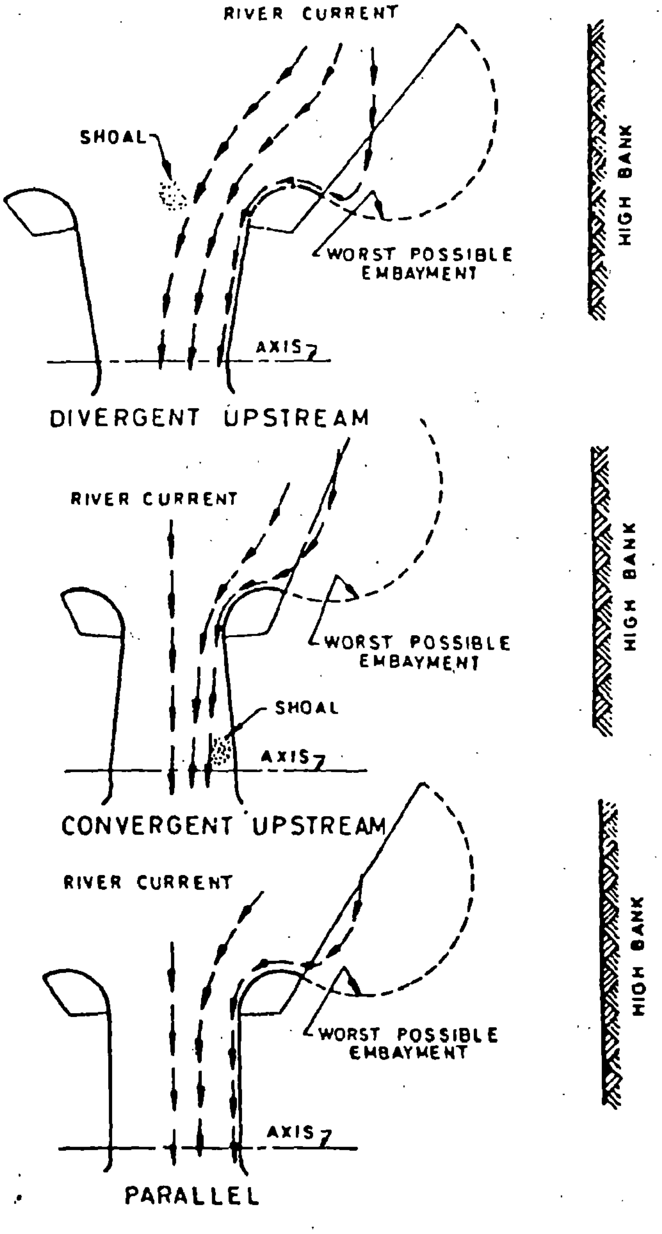


Fig. 3.10 Different Forms of Guide Banks

(v) The radius of the curve of the downstream end of the guide bank may be such as a convenient service to take the stone which can be arranged.

(vi) The radius of the upstream curved part of the guide bank may be anything from 150 m to 300 m (500ft to 1000 ft), according to the estimate that may be formed of the probable velocity of the current past it. The curve should be carried well round to the back fully 120° to 140°.

3.3 LOCAL PROBLEMS OF RIVER TRAINING

Before formulating some needs and problems related to river training, however, it is in order to offer a word of caution as to rivers themselves. We follow again **White's** view as formulated in, **" A perspective of River Basin Development" (Kates and Burton,1986) :**

" If there is any conclusion that springs from a comparative study of river systems, it is that no two are the same. Each river is distinctive in characteristics of basin and flow. Rare are the streams that, regardless of size, are homogeneous within their own drainage areas. The essential elements in a stream system are the river channels, the soils and aquifers by which the water reaches the channels and the flowing itself. At any one time, the channel section, the contributing slopes and aquifers and the stream flow bear definite, but not fully measured, relationships to each other, and these relationships change as the volume and quality of water in the stream change. For a true picture of a river, it is thus necessary to describe not only its condition at a given time, but its changes from day to day, from season to season and from year to year. It is possible to measure, for example, for any stream.

- Channel cross-sections at representative points,
- Channel gradient for the entire stream and by reaches,
- Length of channel,
- Angle of junction of tributaries,

- Area of the entire drainage basin and tributary basins ,
- Shape of the entire drainage basin and tributary basins,
- Flow of water,
- Mineral and biological contents of water,
- Slope and soil condition of tributary land surface, and
- Slope, permeability and thickness of contributing aquifers.

When any one of these characteristics is examined, an amazing range is found among the streams, and two are found to be precisely the same. Adequate explanation of differences in flow behaviour under different conditions of land use, for example is complicated and is not entirely practicable in our present state of knowledge. Knowledge of origin and flow of sediment in suspension is even less complete. The point here is that streams are unique combinations of natural features whose processes follow principles for the most part known. They cannot be regarded as interchangeable, and whole they may be grouped into broad classes according to their combinations of characteristics, the planning of their development always involves a new , adventurous exploration for each stream, revealing differences in flow, channel and sediment.

One must keep **White's** this view in mind when trying for river training.

3.4 OBJECTIVES OF RIVER TRAINING

The river training works may serve the following objectives or advantages:

(i) To prevent the river from changing its course and to avoid outflanking of structures like weirs etc.

(ii) To prevent flooding of the surrounding countries by providing a safe passage for the flood water without overtopping the banks.

(iii) To protect the river banks by deflecting the river water away from the attacked banks.

(iv) To ensure effective disposal of sediment load.

3.5 METHODS OF RIVER TRAINING

Most rivers show, in their natural state, a condition of equilibrium characterised by the stability of their alignments and slopes, as well as of regime, the regime may change within a year, but shows little variation from year to year. This does not mean that no changes like scouring and silting of bed, advancement of the delta into sea, changes in bed and water surface slope etc. take place in the river. These changes do take place, but are very small and imperceptible. Such rivers mould their beds so as to carry into the sea all the silt brought by them and can, therefore, be called nearly stable rivers. In river training, the chief aim is to attain this ultimate stability with the aid of training measures.

On the contrary, aggrading and degrading types of rivers are not equally amenable to river training on account of their inherent instability. On these, no training measures can impose stability unless complementary measures are undertaken.

On an aggrading river, bank protection works may either be destroyed by severe erosion or get burried under deposition. Soil conservation in the upper reaches is supplemented with check dams and dams on the tributaries are probably the most effective answer to problems of training and control of aggrading rivers.

Training measures should be planned with due regard to the limitations imposed by the type of river. Alignment of the river channel with reference to the training works has to be determined initially. Alignment of training works is usually based on the layout and number of the training structures involved. Training measures are so diverse and serve equally diverse purposes - that laying down rigid rules is impracticable.

The next step is the determination of the " normal cross-section" built by the river itself. It is to found where the channel is uniform and shows no signs of accretion or retrogression. The new section aimed at, either by river contraction or by river diversion, is then compared with the normal cross-section in respect of gauge and discharge relation , velocity of flow and total sediment run-off. The new cross-section is then modified by successive analysis, to make it coincide with the normal cross-section as far as possible.

Usually, river training is contemplated where the alignment of the river section is abnormal e.g. splitting of the river into several branches, development of sharp bends and formation of wide and shallow shoals. It may also be necessary for a specific purpose ; guiding a flow through a bridge or a weir by constructing guide banks, diversion of flow by groynes to avoid bank erosion etc; closing of river branches may be effected by constructing embankments across them at their upper ends. Sills may be constructed for filling abnormal depths and bank revetment may be used for preventing erosion. All these training works can be used alone or in conjuntion with other measures.

3.6 CLASSIFICATION OF RIVER TRAINING PROBLEMS

Keeping in view of the objects of river training, it aims at controlling and stabilising a river along a desired course with a suitable waterway for one or more of the following purposes:

(i) High water training or training for discharge,
(ii) Low water training or training for depth,
(iii) Mean water training or training for sediments.

Of the various kinds of training, mean water training is the most important training. Any attempt to change the configuration of river bed in alignment or in cross-section must obviously be designed in accordance with that stage of the river at which maximum movement of sediment takes place. The river is the most active during high stage which persists for a very short duration and is practically inert at low stage which persists for a very long duration. Somewhere between these two there is a stage at which the combined effect of forces causing sediment and the time for which such forces are maintained is maximum. The maximum bed building stage is somewhere in the neighbourhood of mean water. Mean water training , therefore, forms the basins on which both high and low water trainings are planned.

3.7 STABILISING THE RIVER CHANNEL FOR PREVENTION OF BANK EROSION

Bank caving is one of the main courses of river instability and, therefore, bank protection, especially of the pitching type, forms an important part of training works. The process of bank erosion is constantly active and river training for the protection of banks continues to be a recurring problem.

There is only a small difference between the bank protection and the river training. For instances, transverse groynes, designed for training a river by deflecting the flow away from the bank, protect a stretch of the bank; while a pitched bank, aimed at making the bank invulnerable, trains the river by drawing the flow towards the bank. Thus, the two objects cannot be isolated.

3.8 PROBLEMS IN HILLY STREAMS

Hilly streams near foothills of the Himalayas have very steep slopes and carry enormous quantities of boulders, shingles etc. In such cases, it is extremely difficult to stabilise their courses. Hence, one has to be much cautious in evolving training measures with proper evaluation of the long range effects.

The problem of directing the flow in a defined stretch of the river occurs usually in protecting hydraulic structures like canal headworks in danger of oblique attack or outflanking. It involves training over a considerable reach of the river. An outstanding example of this method is Bell's guide bank system evolved in India and is used extensively for protection of canal headworks.

3.9 TYPES OF TRAINING WORKS

The following are the generally adopted methods for training rivers except the Guide bank system which has been described earlier :

(a) Groynes or Spurs ,
(b) Levees or Embankments,
(c) Deflectors,
(d) Bed bars,
(e) Pitched islands,
(f) Miscellaneous methods such as sills, bandalling etc.

The above river training measures are described below .

3.10 GROYNES OR SPURS

3.10.1 General

Groynes are the embankments type structures constructed transverse to the river flow, extending from the bank into the river. That is why, they are known by several names, i.e. spurs, spur dikes and transverse dikes. These are the most widely used training works. They are constructed in order to protect the bank from which they are extended by deflecting the current away from the bank. As the water is unable to take a sharp embayment, the bank gets protected for certain distance upstream and downstream of the groyne. However, the nose of the groyne is subjected to tremendous action of water and has to be heavily protected by pitching etc. The action of eddies reduces from the head towards the bank and, therefore, the thickness of slope pitching and apron can be reduced accordingly.

3.10.2 Functions Of Groynes

Groynes serve one or more of the following functions :

(i) Training the river along a desired course by attracting, deflecting or repelling the flow in a channel ;

(ii) Creating a slack flow with the object of silting up the area in the vicinity ;

(iii) Protecting the river bank by keeping the flow away from it ; and

(iv) Contracting a wide river channel , usually for the improvement of depth for navigation .

3.10.3 Types Of Groynes

Groynes can be classified as follows:

(i) Classification according to method and materials of construction :

(a) Permeable groyne,

(b) Impermeable (solid) groyne.

ii) Classification according to the(height of spur below high water :

(a) Submerged groyne,

(b) Non-submerged groyne.

(iii) Classification according to the function it serves :

(a) Attracting groyne,

(b) Deflecting groyne ,

(c) Repelling groyne ,

(d) Sedimenting groyne.

(iv) Special types of groynes :

(a) Denehy's T- headed groyne,

(b) Hockey type groyne,

(c) Burma type groyne etc.

3.10.4 . Methods Of Use Or Choice Of a Groyne

Factors which influence the choice and design of groynes are :

(i) Fall and velocity of river ;
(ii) Character of bed material carried such as shingle , boulders, sand or silt ;
(iii) Width of waterway at high water, mean water and low water ;
(iv) Depth of waterway, height of flood rise and natuire of flood hydrograph;
(v) Availability of materials and funds ;
(vi) Amount of silt carried in stream .

Groynes for confining a river to a defined channel, especially during high water and low water are usually made impermeable. Permeable groynes are suitable for silt-laden rivers.

3.10.5 Types Of Alignment

The groynes may be built either perpendicular to the bank line or they may be inclined upstream or downstream.

(i) REPELLING GROYNE

The repelling groyne is constructed in such a way that it is pointing towards upstream at an angle of 10° to 30° to the line normal to the bank. The head of groyne causes the current to be deflected in a direction nearly perpendicular to itself. The current coming into contact with still water area adjacent to the spur causes vertical eddies and deep scour. The head of the groyne should be strong to resist the swirling action of the current. In case of repelling groyne a still water pocket is formed upstream of it and suspended load brought down by the river gets deposited in the pocket. Rapid success of the groynes depends upon how quickly still water pockets between grynes are filled with sediment, which can be accomplished only when they are sufficiently long **(Fig. 3.11).**

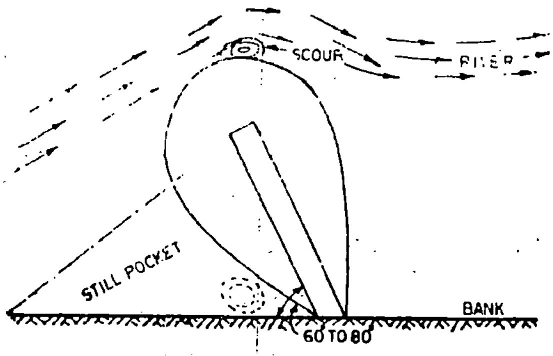
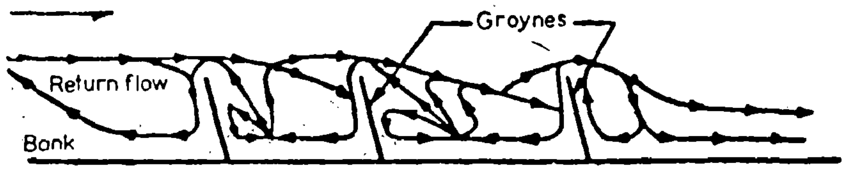
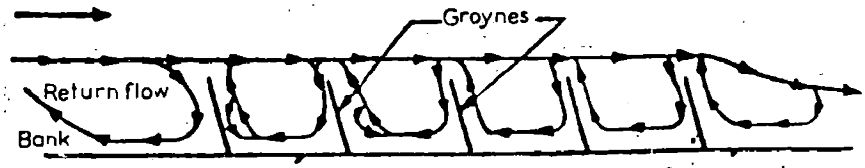


Fig. 3.11 Repelling Groyne

Flow spreads to the side below the nose of the groyne, and after flowing through the pocket formed by two successive groynes, it impinges on the lower groyne and is tuned towards the shore. This roller action is responsible for sedimentation in the pocket **(Fig. 3.12).**



Showing flow lines between groynes in series with uneven spacing



Showing flow lines between groynes in series with uniform spacing

Fig. 3.12 Showing Flow Lines between Groynes in Series with Uniform Spacing

Repelling groynes are usually successful in achieving desired results, if they are properly located with regard to their position in relation to their meander length.

(ii) Deflecting Groyne Or Normal Groyne

A deflecting groyne has a much shorter length than a repelling groyne and it is generally taken in a river perpendicular to the bank. It only deflects the flow **(Fig. 3.13).**

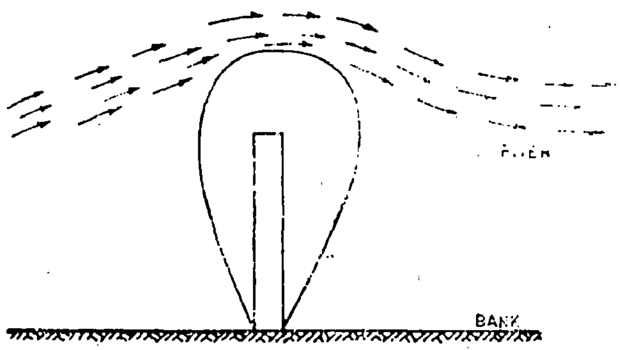


Fig. 3.13 Deflecting Groyne

(iii) Attracting Groyne

The attracting groyne is constructed in such a way that it points downstream to the direction of normal flow. When a groyne points downstream, it causes scour holes to form closer to the bank then the groyne inclined at right angles; therefore, they tend to maintain the deep current close to the bank. The attracting groyne bears the full fury of the frontal attack of the river on its upstream face and has, therefore, to be adequately strong; an equally heavy protection is not necessary on the downstream slope **(Fig. 3.14).**

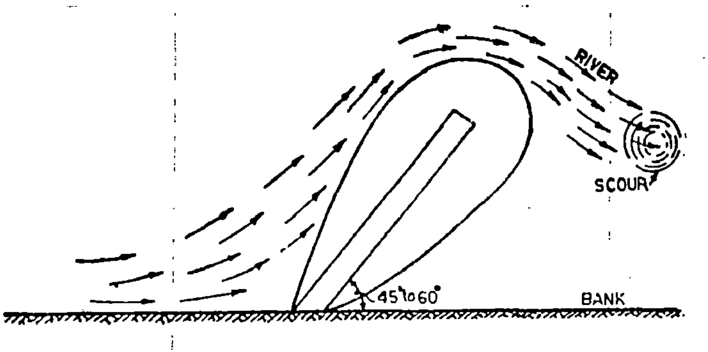


Fig. 3.14 Attracting Groyne

The groynes are, therefore, generally aligned either perpendicular to the bank or pointing upstream. The former is generally used on convex banks. When the length of an upstream - pointing groyne is small such that it changes only the direction of flow without repelling it, it is called a deflecting groyne, instead of calling it a repelling groyne. The repelling groynes are generally found to serve the desired results, provided they are properly located with regard to their position **(Fig. 3.15).**

Depending upon the purpose, groynes can be used singly or in series. They can also be used in combination with other training measures. The choice of using them in a series arises if the reach to be protected is long, or else if a single groyne is not strong enough to deflect the current nor quite effective for silt deposition upstream and downstream of itself. Generally, attracting groynes are avoided.

It is desirable to test their performance in hydraulic models before constructing them in actual field which are undertaken by Central Water and Power Research Station, Poona.

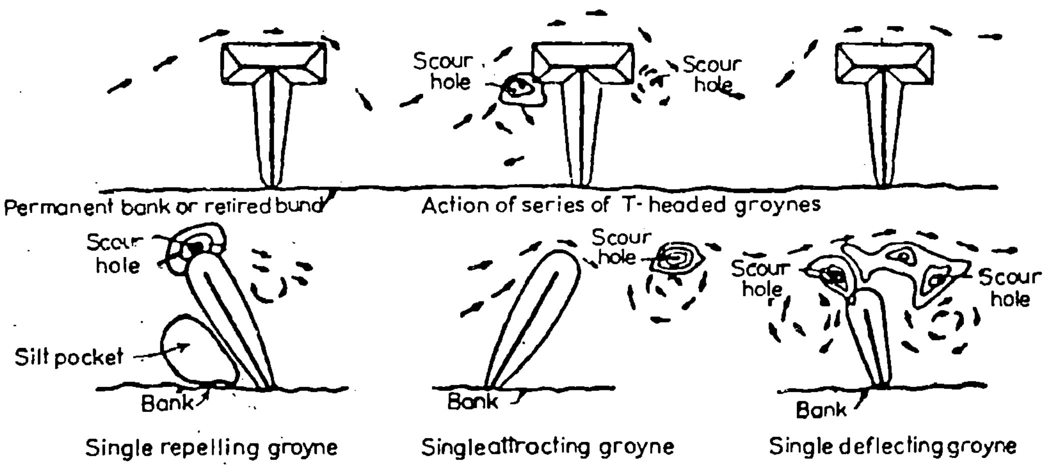


Fig. 3.15 Showing Illustrations of Spur Action

3.10.6 Length of Groynes

No general rules can evidently be formulated for fixing the length of groynes. It depends entirely on the exigencies arising in a specific case. For instance, if an entire river course is to be changed by repelling it towards the opposite bank by means of a single groyne, the groyne must necessarily be sufficiently long; erosion on the opposite bank should be anticipated and allowed for wherever necessary. In fixing lengths, the criteria are the objectives aimed at; the design, length, shape, angle etc. can best be finalised by model tests.

Length should not be shorter than that required to keep the score hole formed at the nose away from the bank. Thus, assuming angle of repose of sand to be 2.5:1 and depth of scour below bed be 'd_s', the length should be longer than '$2.5d_s$' . Short length may also cause bank erosion upstream and downstream of the spur due to eddies formed at the nose. On the other hand , too long a spur may dam up the river and would not withstand the flood attack on account of heavy discharge concentration at the nose and too high a differential head across the spur. Normally spurs longer than 1/5 th river width are not provided.

3.10.7 Type of Head

Various designs for groyne heads have been evolved with the aid of model experiments and after observations of the conformity of behaviour between prototypes and their models. A groyne with a curved head is termed **'a hockey head groyne'**. A groyne with a short straight head normal to the groyne direction is known as **'T- headed groyne'.**

3.10.8 Spacing of Multiple Groynes

Each groyne can protect a certain length. Hence, the primary factor governing the spacing between two adjacent groynes is their length. The spacing is, therefore, taken as a certain proportion of their lengths. Apart from the length, the spacing may be governed by the following factors :

(a) Type of bank where the groyne is to be located : A larger spacing can be adopted for convex banks and a smaller one for concave banks with intermediate spacing at the crossings. A spacing of 2 to 2.5 times the length of the groynes is generally adopted at convex banks, while a spacing equal to the length of the groyne is mostly adopted for concave banks.

(b) The width of the river : For rivers of equal flood discharges, a larger spacing is preferred for wider rivers than for narrower rivers.

(c) Type of groyne : A higher value of spacing may be used for permeable groynes as compared to that required for an impermeable groyne.

Sometimes, groynes are spaced far apart to lessen the cost of construction, or with a view to put more groynes in between at a later date; the result may be that either the flow is distributed and the groynes outflanked, or their heavy maintenance cost exceeds the saving attempted.

When the river bank has a curvature, groynes in series may have continuously varying lengths and , therefore, varying spacing. The angle of deflection may also change continuously according to the curvature of the bank line **(Fig. 3.16).**

3.10.9 Height

For maximum efficiency, the height should be above HFL with adequate freeboard. Spurs with top level lower than HFL have been used for economy but the action then becomes lesser. Precaution is also required to be taken to provide bank protection on upstream and downstream in order to prevent bank erosion due to submerged spur acting like a weir. Submerged spurs with height equal to or less than 1/3 rd the flow depth act as deflectors or bed bars.

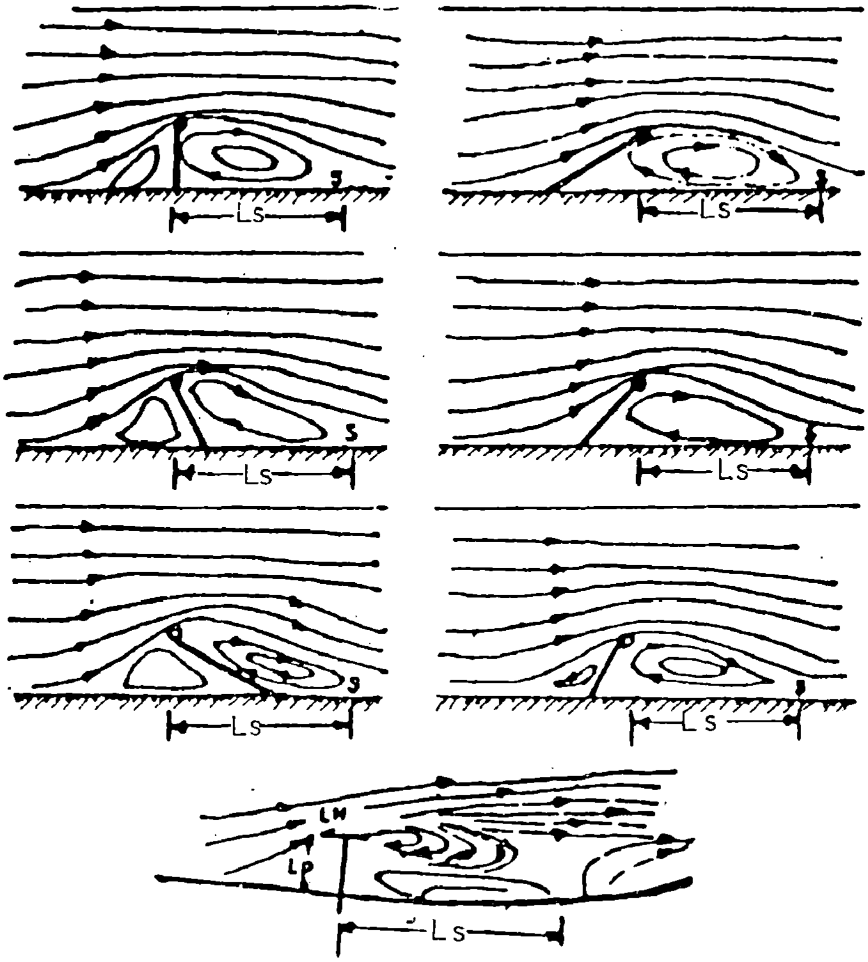
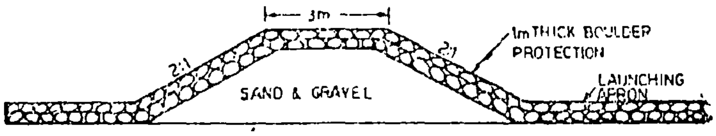


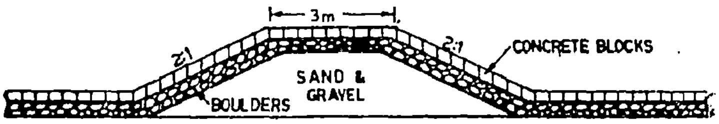
Fig. 3.16 : Length of Bank 'Ls' from Spur Head D/S which can be Protected by a Single Spur is about Three Times the Spur Projection (After Mustak Ahemad)

3.10.10 Top And Sides

Top width should be a minimum of 3 m for transport facility. Steepest side slope of the sand core should be 2 to 1 since angle of repose of sand is about 31° giving side slope of about 1.7 to 1. There should be side slope protection. Nose should be heavily pitched and apron should be provided for toe protection **(Fig. 3.17).**



(a) NORMAL SECTION



(b) SECTION AT NOSE

Fig. 3.17 Section of Groyne

3.10.11 Apron

Apron design depends on depth and shape of scour in plan. Scour depth predictors have been provided by various investigators which are in Table 3.1. Multiplying scour depth factor 'C' is defined as,

C = scour depth 'ds' below HFL/Scour depth below HFL by Lacey Formula 'D_L'

TABLE - 3.1

PREDICTORS FOR SCOUR DEPTH AT SPUR NOSES

S.N	Name of the Investigator	C=scour factor	Remarks
1	Inglis	1.7 to 3.8	Scour depth varies from 1.7 to 3.8 depending on severity of attack, length of projection, orientation and sharpness of of curvature.
2	Inglis	3.8	For steeply sloping nose of 1.5: 1
3	Mustaq Ahmed	1.5 2.0 2.5 3.0	Spur facing d/s at 30° to bank line Spur facing d/s at 60° to bank line Spur facing d/s at 90° to bank line Spur facing u/s at 30° to bank line

3.10.12 Additional Considerations

A few hints may be useful in groynes. Evidently, where the attacking current is maximum, the groyne section should be the strongest; in fact, the various designs of head, viz. , T.L. hockey etc. are intended to make the head impregnable to attack. The head and the toe may have to be armoured heavily with materials like stone, concrete blocks, soil current blocks etc.

In a series of repelling groynes, the first or the uppermost groyne should be constructed very strongly, as the attack on this groyne is usually the most severe. In the case of an attracting groyne, additional protection has to be afforded to the upstream side slope and the toe to bear the full direct attack and to prevent a breakthrough. Side slopes can be steeper for materials like stone than for sand and earth , for which the angle of repose cannot be a submerged one, since it may be washed away due to overtopping . It has to be armoured with stone or other resistant material.

Aggrading types of rivers carry heavy loads of sand generally split into a number of braided channels. When the flood subsides, the flow of sand is checked and large shoals and islands are formed. During the flood stage, the positions of shoals and island change constantly. During the half flood or at an ordinary stage, when the transporting power is substantially reduced, these islands cannot be washed away. Currents go round the islands and the channel wanders in new directions often attacking the banks squarely, causing bank erosion. In such cases, it is often difficult to align the groynes since there is no certainty that the zone between two groynes is not subject to a direct attack by the currents. Under these circumstances, the impermeable groynes should be supplemented by intermediate permeable ones. Precaution ,however, should be taken to see that the groynes do not get outflanked.

3.10.13 Groynes in Bouldery Bed Rivers

In the case of boulder rivers, braided channels are formed. When the flood subsides, transport of shingle downstream is checked and it piles in heaps; as in the aggrading type of rivers, the channel wanders during flood stage and attacks the banks.

Consideration in designing measures in shingle and boulder rivers is that if a channel is closed off by a groyne or by other means at its upper end, the lower end will be starved of shingle ; it will not fill up , thus remaining as a lagoon or a depression, which may become a potential danger in case of a breach.

If the grade permits, it is better to work from the downstream end upwards and from the toe towards the bank so as to get regular filling along the whole of the channel. In New Zealand , where there are many shingle rivers, embankments are first constructed along the rivers to stop flooding. Groynes of the impermeable type with their ends curved upstream are then built at right angles to the embankment to define the course and keep the shingle in movement.

In the case of boulder rivers or rivers where there is rock a few metres below the bed level, even an apron of one-man stone at the noses of and along groynes may get washed away. In such cases, stone is used on boulder crates for making the apron. If velocities are too high, bolder crates may be necessary even for the body of the groynes.

3.10.14 Limitations

Following are some of the important practical points in use of spurs :

(i) The success of the repelling groyne depends upon the extent and the quickness with which scour occurs at the nose, and also on how quickly the pockets between the groynes get filled with sediment.

(ii) This condition makes impermeable groynes useless in boulder rivers, in which the rate of deposition may be slow. It is useless in deltaic rivers and in flashy rivers where the desired silting does not take place. Hence, groynes cannot relied upon to afford immediate protection.

(iii) Silting between successive groynes can be accomplished only when their lengths are sufficient. Short groynes do not offer sufficient protection because the limited tendency that exists for silting, is counteracted by the turbulent flow between the groynes.

(iv) In the case of narrow and deep rivers , the cost of solid groynes above high water is substantial. Moreover, because of the narrow width of rivers, solid groynes cannot be extended much as otherwise they may cause harmful conditions on the opposite banks or further downstream. In such cases, submerged groynes are recommended.

(v) As the tractive force on the slope is maximum at 1/3 rd depth from the bottom, the top of the submerged groyne should be kept at least at half the depth of water. A single submerged groyne may not be as effective as a series of submerged groynes. Since flow over the groynes produces turbulence and scour below them, silting may not take place as rapidly as required. If there are important structures and valuable property along the bank, permeable submerged groynes should be preferred since their action is not as violent as that of submerged solid groynes.

It is ,however, noteworthy that permeable spurs are effective only in rivers which carry heavy suspended load.

3.10.15 Impermeable Groynes Or Solid Groynes

3.10.15.1 With Level Top

Impermeable or solid groynes consist of rock fill or earth core armoured with resistant material like stone, fascine mattress or sauges filled with stone. They are designed to attract, repel or deflect the flow away from the bank along a desired course.

The groyne section has side slopes varying from 2:1 to 3:1 depending on the materials used for its construction, and front slope varying from 3:1 to 5:1. Head slopes flatter than 5:1 are avoided to prevent gulletting i.e. washing away of stones from flat slopes.

An apron must be provided to prevent slipping of stone of the spur nose and shank into the scour hole in the vicinity. For this reason, the apron stone should be sufficient after launching , to shield the sloping faces of the sand bank from below the bottom of the slope faces down to the deepest bed level after scour. The stone weight should not be less than one-man -stone, weighing 45 to 54 kg (100 to 120 lb) each. Analysis of available data of scour depth at the noses of full height spur indicates that scour below high water at straight spurs is of the order of **3.8 D_{lacey}** with flat slope heads (1 in 20).

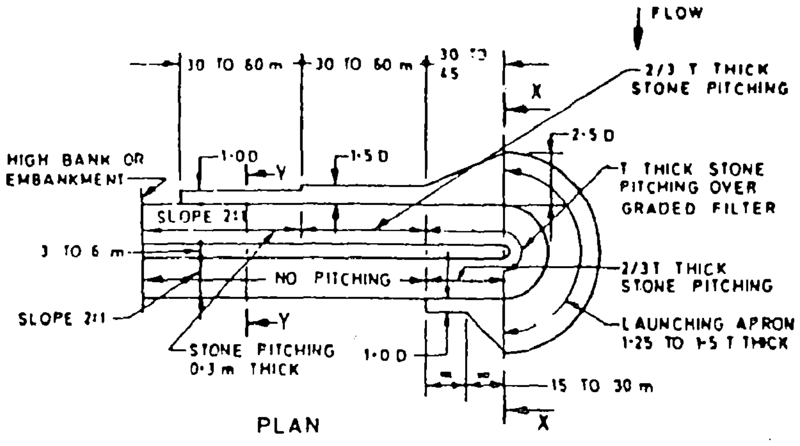
Generally, it is expensive to make a very flat slope for the nose of the groyne. Groynes are, therefore, given normally a slope of 1:3. Scour gradually diminishes from the head to the bank and the apron protection can be reduced accordingly **(Fig. 3.18).**

3.10.15.2 Sloping Spurs

Normally spurs are provided with shank having horizontal top and nose at its river side end having flat slope. In case of sloping spurs, the entire length including shank and nose is given one continuous flat slope so that obstruction to flow near the bank is maximum and at the river side end minimum. As a result, the scour at the river side end of the spur is much less and the return flow upstream and downstream of the spur is also much reduced.

3.10.15.3 Slotted Spurs

A slotted spur is a gabion construction with gaps in its length projecting from the river bank **(Fig. 3.19).** Stone masonry on piles has also been used. Whereas an ordinary spur protects a river bank of about 3 times the spur length, a slotted spur protects 10 to 12 times its length. This type of spur was used with success on Ingury river in Georgia . The dimensions adopted for



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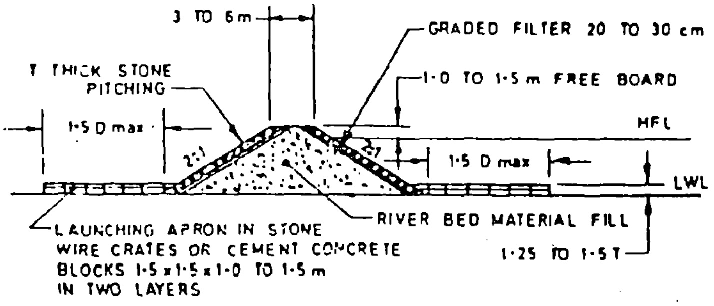

ENLARGED SECTION XX

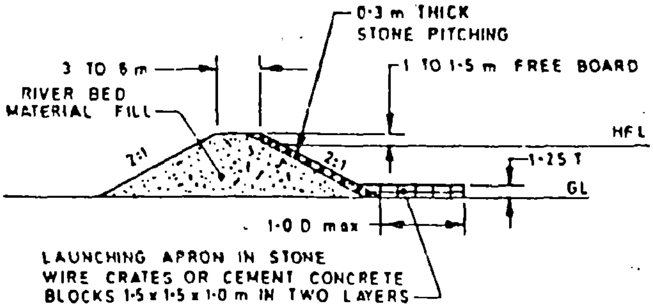

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Fig. 3.18 Typical Design of Spur

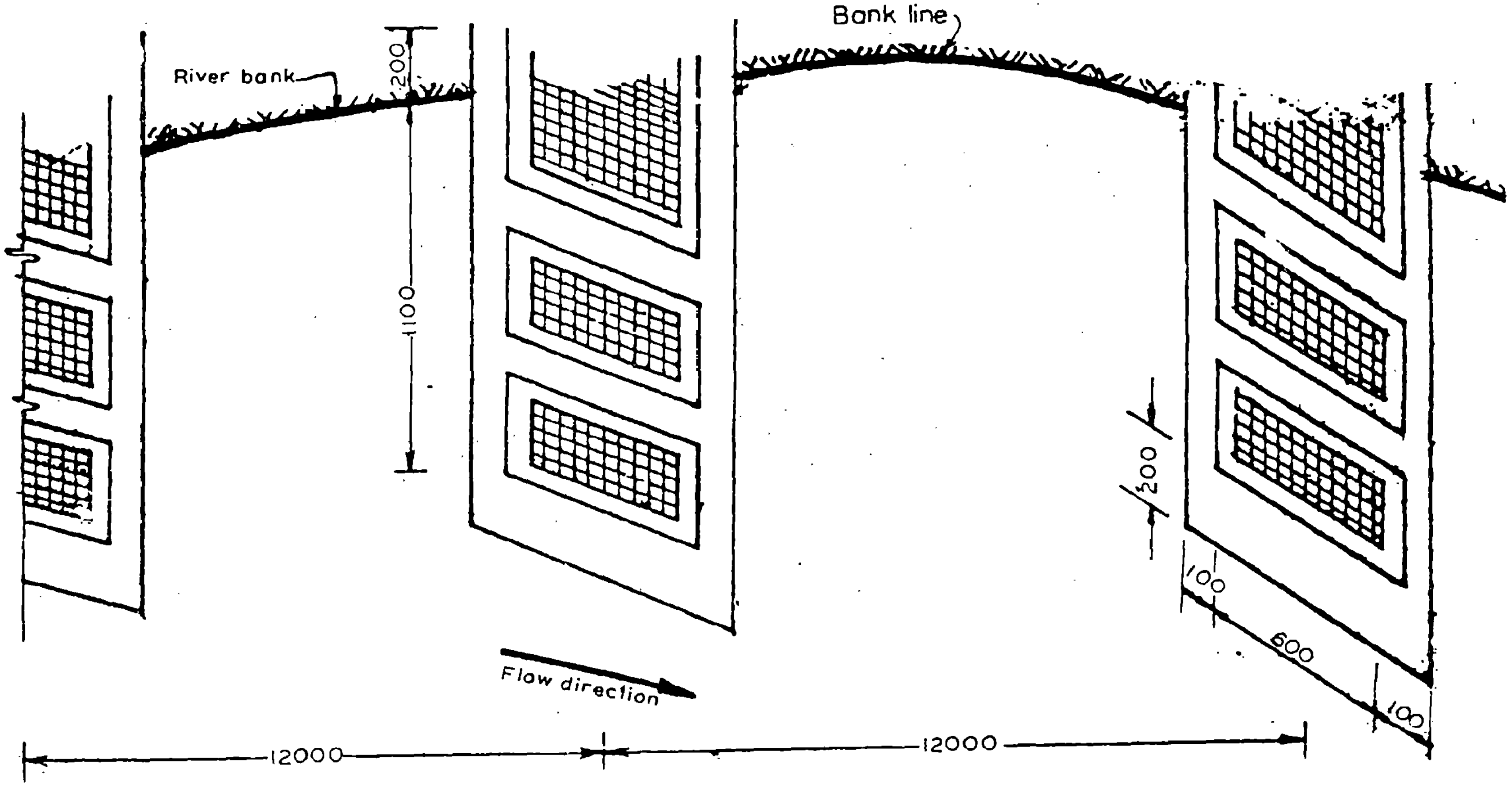


Fig. 3.19 :Sketch Plan of Slotted Spur General Layout

spur length were 18m, angle of spur to bank line 90°, angle of slots 30° to 45°, ratio of length of slot to its width in direction of flow 3 to 5. The flow velocity was 2 to 6 m/s.

3.10.16 Permeable Groynes

Permeability of a structure indicates a damping action on the velocity of flow as distinguished from the deflecting or repelling action of impermeable structure. Permeable groynes, therefore, fall into the class of the sedimenting groynes . They obstruct the flow and slacken it to cause deposition of sediment carried by the river. They are, therefore, best suited for sediment carrying streams. In comparatively clear rivers, their action results in damping the erosive strength of the current and thus prevent local bank erosion. As sediment accumulates between the groynes, the foreshore becomes more or less permanent, so that need to use durable materials does not arise. Permeable groynes require only temporary or semi-permanent construction.

Permeable groynes have the important advantage of being cheap. They are,therefore, specially adaptable for river works where stone is difficult to obtain. Practically, it has been experienced that permeable spurs are more effective than solid ones in the regulation of river courses or in the protection of banks and levees, especially in a silt-laden river. Flow through the spur does not change abruptly like that passing an impermeable spur, thus resulting in no serious eddies and scour holes. This is perhaps the reason why silt deposition is evenly and quickly affected.

In the case of deep and narrow rivers, where depths are considerable, solid groynes become expensive, and may cause undesirable flow conditions. In such cases, permeable grroynes can be effective in affording the necessary protection by damping velocities along the bank. They are also effective where protection to a bank, consisting of sand layers covered by clay, is required.

These groynes can be either submerged or non- submerged. Submerged permeable groynes are preferable to submerged solid groynes since the former do not create turbulent and eddy conditions as strong as with the latter.

However, permeable spurs are not strong enough to resist shock and pressures from debris, floating ice and logs. They are, therefore, unsuitable for upper reaches of rivers. During floods, submerged groynes are a danger to navigation.

Initially, tree groynes should be laid pointing upstream at an angle 60° to 70°, so that when the groyne launches and becomes sand-bound, it assumes a position facing slightly upstream. Unlike an impermeable groyne, which is generally made to face 60° upstream a permeable groyne should make a larger angle with the bank upstream , since it would collect floating debris against the face, converting it to an almost impermeable one with attendant disadvantages. Proper care should be taken that, after launching, it is not bodily shifted to assume a position of an attracting spur, which would induce accretion only downstream of it.

3.10.17 Other Types : T- Headed Spur : Training of River Ganga at Narora by Series of Denehy's Groynes

T-headed spur or groyne which is known as **"Denehy's Groyne"** was first used in 1880 by **Mr. P. Denehy** at the **OKHLA HEADWORKS** on river Yamuna . In 1887, similar construction was carried out to make the river Ganga flow steady and prevent spill at Narora Headwork (U.P.).

About 208 km (130 miles) from the point of its exit from the Himalayas on Ganga river, there use to be weir at Narora where now- a - days a barrage stands. There is an interesting example of river training works which was designed by Mr. P. Denehy , an Assistant Engineer , incharge of works. After 0.50

kms upstream of Narora headworks, there is a railway bridge having 33 spans (25.40 m each) at Rajghat. The river Ganga has permanent high bluffs on its right bank. But its left bank is low. The main aim of these training works were to make the river flow steady between weir and railway bridge and to protect the Lower Ganges Canal downstream on the right bank **(Fig. 3.20).**

The **Fig 3.20** gives a layout plan of the scheme of training works at Narora. There is a marginal levee or retired embankment from the railway bridge to headworks which extends further downstream of weir up to 3.2 km. These false bluffs are about at an average distance of a 2.40 km (1.50 miles) from the true or natural bluffs of the right bank. About 0.80 km apart and at both sides of the river, earthen embankments have been run out more or less at right angles to the lines of bluffs, until their noses are within about 915 m of each other. The end of each is protected by an earthen T- head , whose upstream part is 3-4 times as long as the downstream parts of it. T- head is provided with a heavy apron, slope and reserve of one man with a heavy apron slope and reserve of one man rock. There are 14 nos. of T- headed spur in the upstream of headworks.

Similarly, there is a similar line of 32 nos. of Denehy's spurs, extending for a distance of 25.6 kms (16 miles) downstream from the weir but on the right bank only of the Ganges. The objective of this is to prevent the Lower Ganges Canal from the cutting of the river which after taking off from the right end of the headworks, runs practically for the whole 25.6 km (16 miles) in the Ganges khadir before cutting out through the bluffs, in the high doab land. Along there, 25.6 km (16 miles) the embankment running back of the T- heads joins up the canal bank, which in this case performs as the artificial bluff. In all

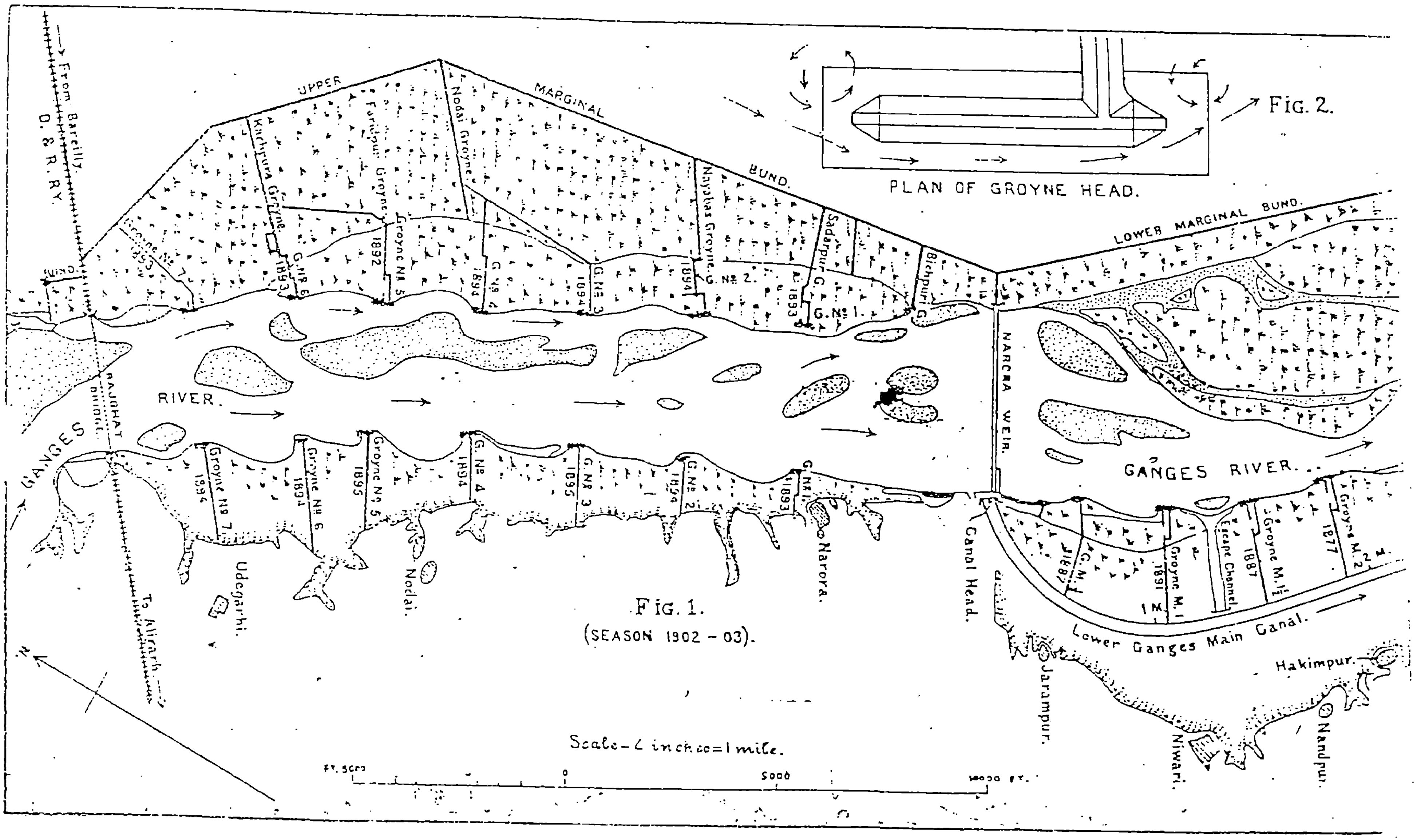


Fig. 3.20 Narora Canal Headworks with Denehy's Groynes

the 38.40 km (24 miles) of protected river bank , there are about 72 km (45 miles) of earthen embankments and 46 stone T- headed groynes.

The original objective of design of Denehy's spurs was to produce a permanent effect by adopting a suitable measure, even if it is costlier in its initial experience. The whole objective of the training works above the weir was to protect the levee or afflux bund on the left of the river, which is known as left marginal bund. The afflux from the Narora weir is very considerable at the Rajghat bridge and naturally increases as the weir approaches the weir. The slope of the country to the east of the weir and bunds is very rapid towards the eastern high bank of the Ganges, which is some 16 to 19.2 km (10 to 12 miles) to the left. The whole of this reach of the country was intersected with spills from the Ganges which takes out from it some 32 km (20 miles) higher up. Some of them are very formidable streams in high flood. They all have been bridged by the Oudh and Rohilkhand Railway, the aggregate waterway is 396.24 metres to 426.72 metres or nearly half of that of the bridge over the main stream of the Rajghat. So, the left marginal bund is very important because a breach in it would be the most serious matter. The original weir was designed during 1874. The above reach was to be trained in 1894 and the first object was to project the marginal bund between Rajghat and Narora - a distance of about 8 km. **Mr. P. Denehy** had no other way of doing this within a reasonable cost. Then it was done by the same means as he had taken to protect the Lower Ganges Canal downstream of the weir by groynes at about 0.80 km intervals. It was considered necessary to have corresponding groynes on the right bank so that the river might be brought straight on to the weir otherwise the effect of seven groynes on the left would have been to drive the whole of the river into the narrow deep stream leading into the weir sluices and to leave the weir high and dry. Now, a pair of Bell's guide bund couldnot have protected the marginal bund for a greater length above the weir than by extended or say 0.80 km ; so something what was to be done with the remaining of 7.2 km (4.5 miles).

The idea was that between the two bluffs, the river wanders and would attack both bluffs in time doubtlessly. However, the river will play about between the earthen embankments at both sides of the river. T- headed groynes will prevent the cutting and sweeping away of embankments . In fact, each T-head with the embankment connecting it to the bluffs behind it, is a small model of a Bell's guide bank with the approach bank and still water area which are essential to it. The idea is that the river will never loop in very far in the interval between two successive spur heads . Also, before a loop becomes curved enough to cut into the approach embankment of any T- head , it will short-cut and straighten itself.

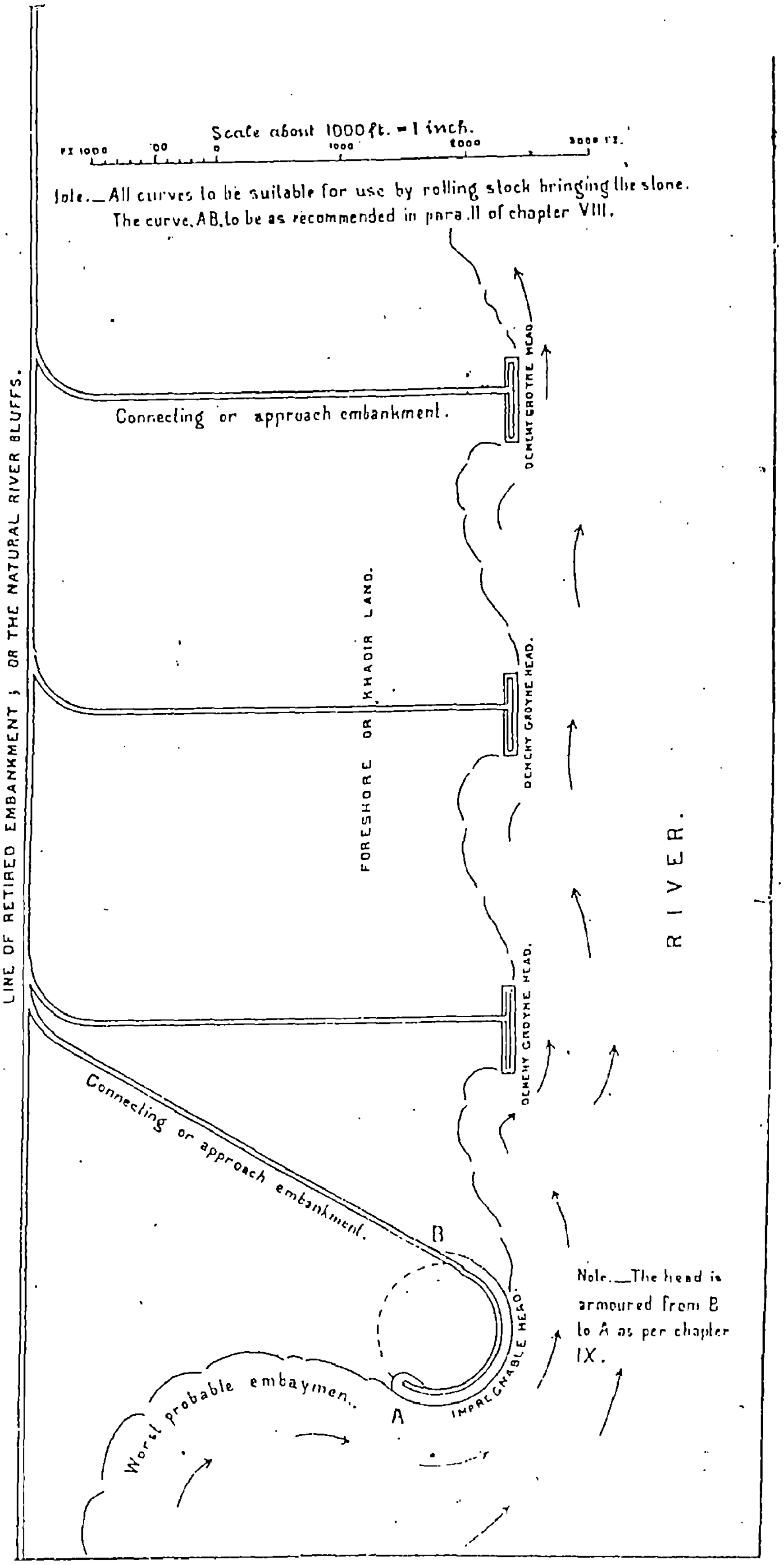
The fall of the river in the neighbourhood apart from the influence of the weir , is believed to be about 0.30 m to 0.35 m per km (12 to 14 per miles) and that is why the velocity is high. The mechanical analysis of the sand of the river Ganga at Narora classifies it as a very fine (93 percent of it passing the 75 wire-to-the inch sieve). It was expected that the attacks on the groynes will be severe.

The practice has a very special advantage of comparative cheapness for protection of a long reach of river bank. Mr. Francis & Mr. J.E. Spring tried to design a good enough head for Denehy's system where there is no readymade head **(Fig. 3.21).** The following advantages are obvious :

(i) It curves round to meet the inevitable embayment current,

(ii) Its approach bank recedes far enough downstream to be cut by the embayment and

Fig. 3.21 Design for an Impregnable Head



Note.—All curves to be suitable for use by rolling stock bringing the stone. The curve, AB, to be as recommended in para. II of chapter VIII.

Note.—The head is armoured from B to A as per chapter IX.

(iii) Its cross-section is designed on the principle laid down for guide bunds.

There are two important conditions to be remembered here viz.

(i) The groups of three or four miles of groynes should be in a straight line so that each groyne should be able to protect the one below it effectively,

(ii) It should be decided once for all that how far apart they have to be kept.

The study of the behaviour of the river flow indicated that the banks under such conditions could be afforded protection by constructing short repelling studs suitably sited in the embayment portion so as to keep the attack of the river current away from the T-head. In this regard, in 1958 and in 1959 - a 15 m long repelling stud was built which has served the purpose successfully .

3.11 DEFLECTORS

3.11.1 Types

Common problems met with in river engineering are the following :

(i) Erosion along the concave bank in a bend,

(ii) Formation of a sand shoal along convex side in bend flow,

(iii) Siltation of a navigation channel,

(iv) Siltation at the junction of the tributary with the main river and at the off-take point of an artificial canal.

Solutions of these problems can be devised by provision of deflectors, action of which is based on the principle of transverse circulation induced in the stream by a system of deflector shields or pontoons.

The method of transverse circulation was developed in the **RUSSIA** and the numerous protection works of the deflector type were installed in rivers of European and Asian Russia. A series of deflector systems were also designed for installation on the Ganges Kobadak Project in Bangla Desh. Their capital and maintenance cost is low and compare favourably with conventional alternative works.

Figure 3.22 shows action of surface deflectors. Deflectors placed on the bottom induce circulation currents of the same direction as that of the surface deflectors when bed deflectors are inclined in reverse position as shown in **Fig. 3.23**.

A combination of surface and bed deflectors suitably positioned in reverse direction to each other produce transverse currents of greater intensity and stability **(Fig. 3.24).** Deflectors placed at an intermediate depth induce two transverse currents. Two purposes can be simultaneously achieved by such deflectors. Both bed load and floating debris are deflected away from the bank **(Fig. 3.25).**

For streams of moderate depth, the deflector shields are constructed of timber planks. When velocities are high, it is desirable to give them curved or

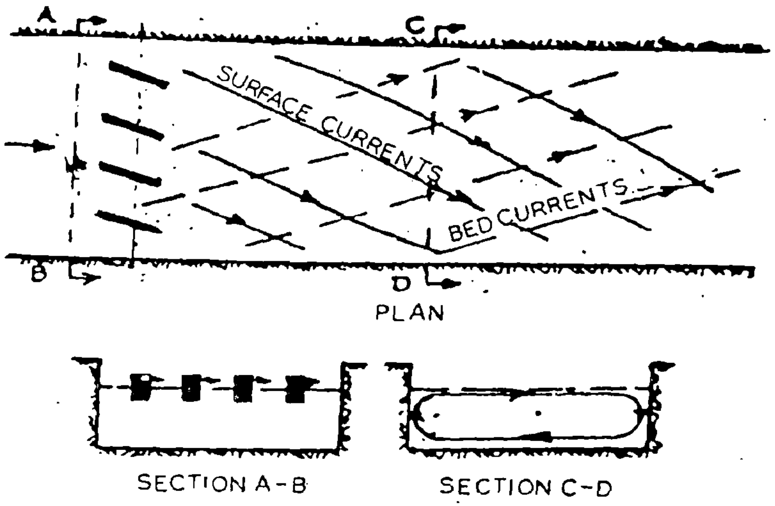


Fig. 3.22 : Transverse Circulation under Action of Surface Deflectors

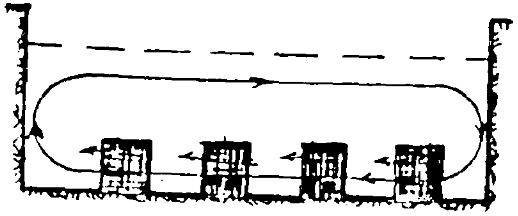


Fig. 3.23 :

Bed Deflectors Arranged at Opposite Inclination to that of Surface Deflectors, they Induce Transverse Circulation of the same Direction

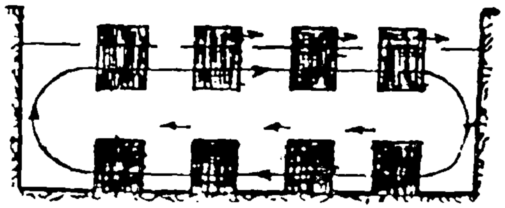


Fig.3.24 :

Surface and Bed Deflectors Induce Transverse Circulation of Greater Intensity and Stability

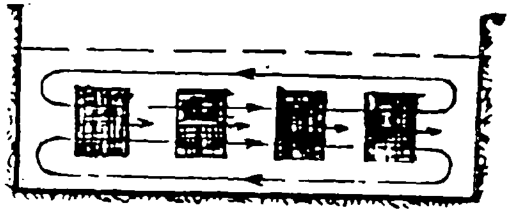


Fig. 3.25 .

Intermediate Deflectors as Shown would Reject Bed Load and Floating Object away from Right Side treamline shape. For heavy duty, they are made of segment shape. Deflectors are slid over the vertical posts and fixed at the designed height by bolting. When the channel is deep and velocities are high a row of floating deflectors are arranged. For still more severe conditions, a system of double row of pontoons is provided. The pontoon shields and the superstructure are fabricated in mild steel.

3.11.2 Deflectors For Bank Protection

For bank protection, two types of floating deflectors are used. These floating deflectors differ from each other in respect of angle of shields to the axis as shown in **Fig. 3.26.**

In deflectors, when shields are at right angles to the axis, the construction becomes simpler. At the exit end of the bend, deflector grids with obliquely fixed shields are more effective in action. The grids are usually arranged at a sharp angle to the direction of flow. The working depth of the shields is provided as 0.5 of the flow depth , when depth is small and 0.2 times the flow depth when it is big. Component of the force resulting from flow acts along the axis of the grid towards the post driven on the bank. The grid is fitted with rollers at this end, so that it can easily follow rise or fall in the water level.

With this arrangement, the deflectors induce a transverse circulation causing bed movement towards the bank. Heavier sediment after being brought to the bank deposits and forms a shoal. In shallow water, the shields can be of smaller dimensions and ,therefore, of fixed type. Such grids are suitable for protection of beaches or valuable land against erosion and undermining .

3.11.3 Deflectors For Sediment Exclusion

Fig. 3.27 shows the type of deflectors installed at sites which need to be protected from formation of shoals, or extension of shoals on convex side of channel bends.

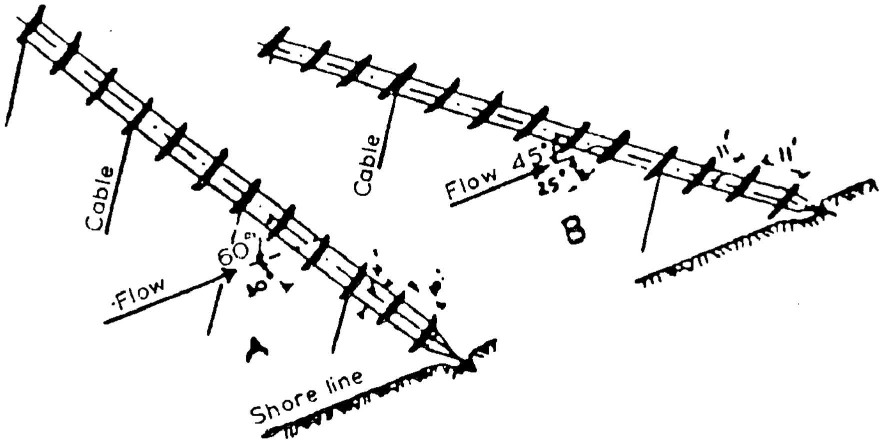


Fig. 3.26 : Floating Deflector Grids of Anti-Erosion Action
(a) Deflector Shields Fixed at Right Angles to Axis
(b) Deflector Shields Fixed at Oblique Angle to Axis

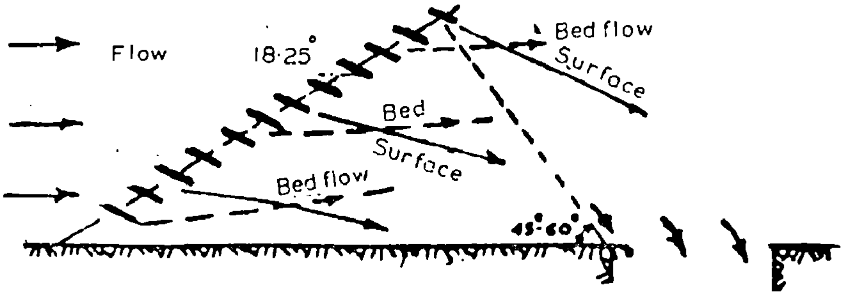


Fig. 3.27 : Surface Deflectors of Anti-Siltation Action

This type of deflector grid induces transverse currents which move the bed load away from the site. In case of intake channels, such a deflector system prevents entry of heavy bed material into the channel while the surface currents are directed towards and into the channel without creating eddies. The increase in discharge of the intake on account of the deflector system can be as high as 30 to 50 percent. Shoals previously formed can be washed away by means of such deflector grids.

Deflectors can have varied uses, too.

3.12 BED BARS

A bed bar is a submerged structure dividing the flow horizontally. Flow above the top level of the bed bar is comparable with weir flow while flow below top level is obstructed by the bar and is diverted towards the nose as in case of a full height spur.

In case of flow over a weir, if its alignment is skewed with respect to approach flow, the magnitude and direction of the flow downstream of the weir is governed by the head due to afflux and due to approach velocity. When the alignment of a bed bar is skewed, a pressure gradient is formed. When bed bar is facing upstream this pressure gradient helps sediment deposition on the upstream side of the bar while the surface flow gets deflected away from the bank **(Fig. 3.28 a)**. On the other hand, bed bar facing downstream directs the bottom current away from the bank while surface flow is deflected towards the bank **(Fig. 3.28 b)**. Bed bar facing upstream is accordingly used for bank protection and bed bar facing downstream is provided upstream of an off-take point for sediment exclusion.

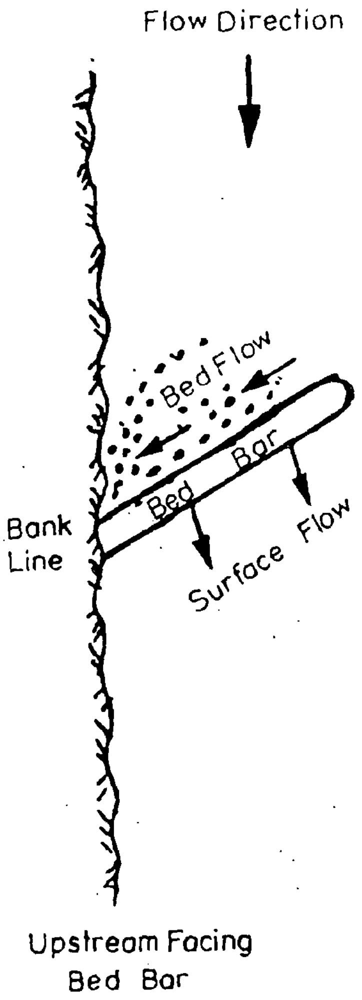


Fig. 3.28 (a) :
Upstream Facing Bed Bar

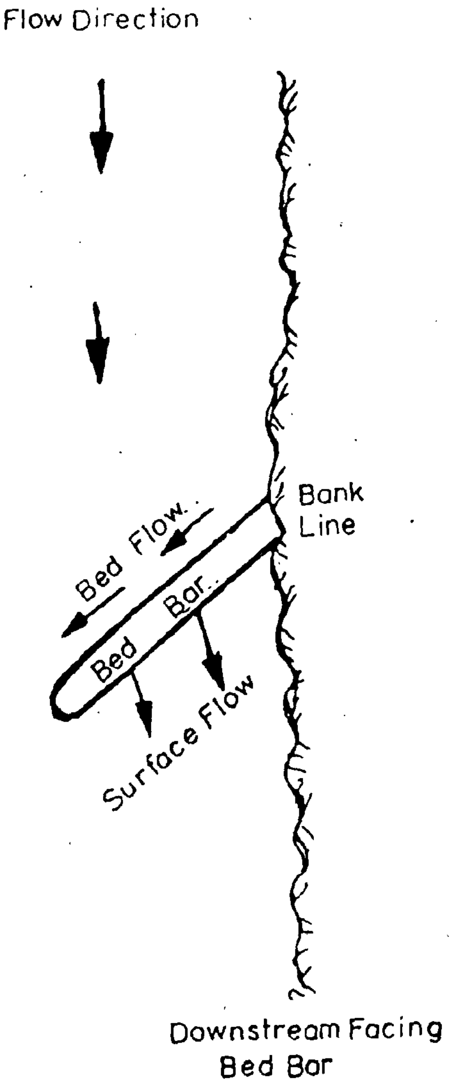


Fig. 3.28 (b) :
Downstream Facing Bed Bar

3.13 EMBANKMENTS OR LEVEES

3.13.1 Introduction

A levee or a dyke may be defined as an earthen embankment extending generally parallel to the river channel and designed to protect the area behind it (levee) from overflow by flood waters. The levee or embankment system for the control of flood is probably as old as recorded history.

Levees were built along the Nile about four thousand years ago. The Tigris and the Euphrates were also confined by levee lines. At the beginning of the Reconnaissance , embankments extended over miles along the River Po in Italy. In fact, embankments have been constructed on nearly every important river, subject to floods, in Europe and Asia. The Rhone, the Danube, the Rhine, the Po, the volga and the Yellow rivers. The principal rivers in India which are embanked are the Ganga, the Gandak, the Damodar in the deltaic regions, the Mahanadi, the Godavari, the Krishna and the Cauvery. In recent times, a huge programme of embankment construction has been carried out on the Mississippi River, U.S.A., and on the Kosi River (North Bihar), India.

The levee system is one of the methods used for a major flood control problem. The use of other methods of flood control, except as aids to an embankment system has been unusual. Model studies and intelligent planning are necessary in the location and construction of embankments.

3.13.2 Alignment Of Embankments

In general, they should be aligned on the high ridge of the natural banks of a river, where land is high and soil suitable for the construction of embankments. Their alignment has to be determined in such a way that the high velocity flow is sufficiently away from them. For this, hydraulic models are a useful guide.

The distance between the embankments is very important for floods of short duration , say, 4 to 6 days, especially for providing adequate absorption capacity for the floods. Bonneau has derived a theory of routing flood waters of an embanked river, with special reference to the distance between embankments.

Embankments are aligned so that important towns and properties along the river bank are left outside the embankment. When it is not possible to set back the embankments to avoid the high velocity flow, protection in the form of spurs and revetments is necessary. Sometimes, a ring bund has to be provided to protect a town or urban property, if it happens to be within the levees. In such cases, river side of the ring bund may have to be protected by short permeable or impermeable spurs or stone revetment and pumps to be provided to pump out drainage and rain water into the river when the river is in spate with high water-level. Such ring bunds have been provided for Mahadeo Math and the town of Nirmali on the Kosi River.

Even when the alignment of embankments is determined from model tests, it should be emphasized that this will not necessarily be the one which will give satisfactory results for a long time. River conditions change continually and an embankment, which have behaved satisfactorily over a certain period, may be susceptible to be attacked during subsequent years. The success of an embankment depends upon vigilant and continuous supervision during the floods. Where the embankments are likely to be attacked, immediate protection has to be provided. If, however, it is found that protection measures such as spurs, revetments etc. , would not give desired security to the embankments, a loop bund behind the existing embankment should be constructed. This will act as a second line of defence should the original embankment fail.

3.13.3 Effect of Embankments On River Regime

When the flood flow spills over the natural banks of a river, velocity of the spilling discharge is reduced as it spreads over a wider area. Suspended load carried by the spilling discharge is then deposited in an unbanked alluvial river. The spill waters spread over a vast area and practically all the suspended load deposits on the flood plains, as the flood recedes, clear water flows back to the main river . The rate of silt deposition varies inversely as the velocity of the overflow. The effect of embankments on the flow of a river is to increase the velocity of the flood flow as compared with an unembanked river. The main question in the case of embanked rivers is : what would be the rate of rise of the river bed after the construction of the embankments and whether the velocity of flow is sufficient to carry all the silt load to the sea ?

If the sea is deep enough to permit deposit of the sediment, or the sea current is capable of carrying silt away from the mouth, then the outlet channel would not be so lengthened as to affect the slope and consequently , the bed level of the river. In such a case, the rate of deposition of an embanked river should not be more than that of an unembanked river.

If on the other hand, the sea is shallow, the extension of the delta would initially cause a flattening of the river slope and , subsequently the rise of then bed level, as soon as the river regains its original gradient. Since the total silt carried to the sea by an embanked river would be more than by an unembanked river, other conditions being the same, the rate of extension of the delta will be naturally greater in the former (i.e. embanked river) case. It is this relatively greater extension of delta which may cause the embanked river bed to rise at a more rapid rate to resume its original gradient. The rate of building up of the river bed depends also upon the slope of the river itself, as well as on the concentration of silt. For a given rate of delta extension, the steeper the slope of the river, the larger will be the rate of aggradation. A higher silt rate will also give a higher rate of aggradation.

Apropos the effect of embankments on the rise of bed level, one should distinguish between embankments on aggrading and stable types of river. For the stable rivers, generally the most of the silt is carried to the sea. Where the quantity of sediment to increase because of artificial or natural causes, the river would change some of its characteristics so that it is able to carry the additional sediment load to the sea; it attains a new condition of stability by increasing its slope, either by raising its bed or by shortening its course. In the case of stable rivers, embankments have a considerable effect on raising the flood level, but induce no change in the river bed configuration. On the contrary, there is a definite tendency towards large cross-sections including deepening of the bed. In the case of aggrading river, embanked or otherwise, the inherent instability on account of the heavy sand load continues, and often no other solution is possible for stabilising such rivers.

In the tidal reach of a river, embankments should be constructed with due regard to their effect on the navigation requirements in the channel. Embankments may reduce substantially the tidal influx, which may result in the reduction of the available navigation depths. Flood protection by embankments in the tidal reach conflicts, generally, with the navigation requirements , since the tidal rivers are sensitive to obstructions caused in them.

Most rivers in the world do not carry as high a concentration of silt charge as the Yellow River in China, nor as steep slope in their last reaches. It is, therefore, reasonable to assume that these rivers, if embanked would not build up their beds as fast as the Yellow River. Continuous observation and indirect measurements will throw more light on changes in low water levels from year to year.

In conclusion, it can be said that in an embanked river, a greater quantity of silt is carried to the sea. This results in the extension of the delta which , in turn, causes rise in water levels of the river in the embanked portion. As regards changes in the bed levels, it may be concluded that the rate of rise of bed is very small in the case of small rivers. This rate is, however, higher in the case of aggrading type of rivers. Embankments are often supplemented by other flood control measures such as storage reservoirs, diversion of the river, soil conservation etc.

3.13.4 Cross-section Of Embankment

The cross-sections of embankments along some important rivers are shown **Figures 3.29 & 3.30.** They have to be designed mainly to keep the seepage gradient inside the body of the embankment with a minimum cover of 0.9 m (3 ft). The seepage gradient varies from 1:4 to 1:6 , according to the character of the soil. The essential conditions governing embankment construction are:

(i) An adequate height to prevent overtopping;

(ii) A cross-section sufficiently massive for security against dangerous seepage through the structure itself.

In fact, the development of various types of embankments has been largely the result of experience. In the embankments, trench dykes and sand cores are provided. The trench dyke is useful for storing water to soak the dykes before the floods arrive, thus enabling the deflection of cracks and leaks. The sand core is provided to check leakage, as well as eventual formation of rat holes. In the absence of trench dykes, soaking is also done by digging small ditches on the landslide slope and filling them with water. The latter method is cheaper than the trench dyke method. Similarly, leaks are liable to occur in embankments, when they are not in contact with high water for several years. In such cases, soaking can be done advantageously.

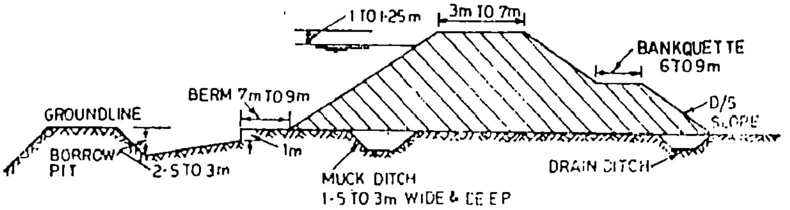


Fig. 3.29 Section of a Levee

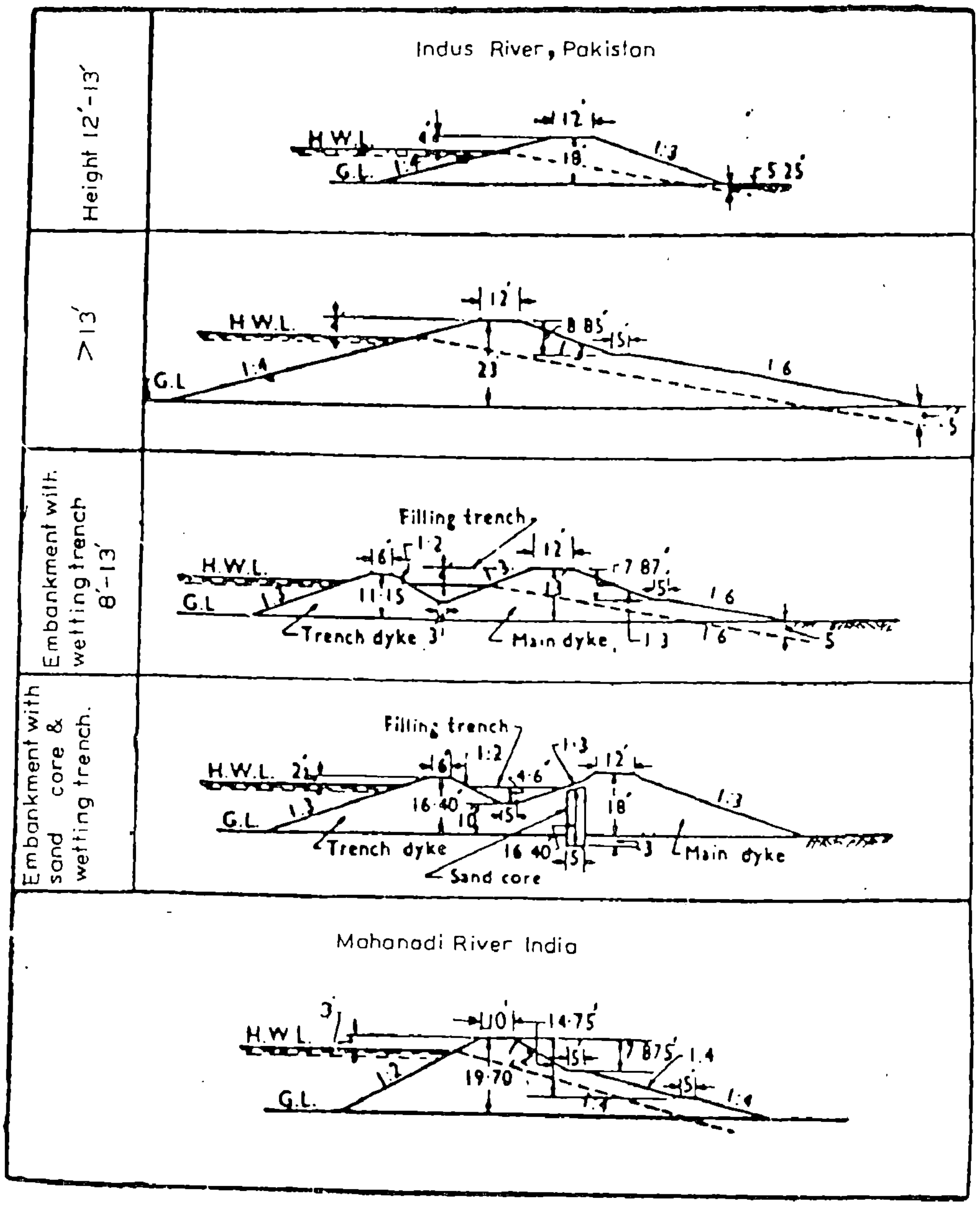


Fig. 3.30 Showing Type Designs of Embankments

The width at the top of embankments should be sufficient to provide a road for supervision and transportation of materials for emergency works during floods. The road, should preferably be supplemented by a berm on the landslide slope, to avoid reconstruction of the road in case it is desired to raise the height of dyke subsequently.

3.13.5 Protection Of Embankments

Embankments are generally constructed away from the main channel of the river and, hence, are not usually subject to strong currents. Otherwise, protective measures become necessary. Problems encountered in these measures are orotection of surface against currents and instability as a result of infiltration into the embankments. When not subject to strong currents, embankments can be protected from erosion by a vegetal cover or turfing. Low shrubs and willows are in effective cover, but require a longer period to grow. In such cases, a temporary cover with mattresses of woven willow brushes is useful for an initial period of 1 or 2 years.

If the current is strong, paving of slopes with materials which can resist erosion is necessary. Temporary covering by brushwood or lumber mattresses weighted by stones is used in emergencies. Indirect protection can be provided by means of groynes and other training measures.

3.13.6 Failure Of Embankments

In the absence of proper maintenance and supervision , embankments are susceptible to breaches due to various courses during floods. These causes are:

(i) Erosion of riverside slope due to river current and wave-wash;
(ii) Caving-in of the banks;
(iii) Overtopping during high floods;
(iv) Failure of fondations due to infiltration;

(v) Piping as a result of insufficient cross-section leaks and cracks due to shrikage of soil and rat-holes;

(vi) Increase in the moisture content of the soil material.

Embankments are fragile works, indicating an inherent weakness of this method of river training and control. However, it is possible to prevent them and remedy them if continuous supervision is exercised during floods and ample labour and materials are in reserve.

3.13.7 Merits And Demerits Of River Training By Embankments

Merits of embankments as a method of river training for flood protection are :

(i) Embankments are the only means of preventing inundation on tidal plains, where the low lying country is below the maximum tide level.

(ii) The initial cost of embankments is low, although when raised subsequently, they become expensive.

(iii) Construction is easy and presents no difficulty, as it can be done by utilising local resources in unskilled labour and materials. Maintenance is equally simple and cheap.

(iv) They can be executed in parts, provided that the ends are properly protected.

Demerits of this system are:

(i) Embankments cause raising of high flood levels.

(ii) Embankments are fragile works in that boring by small animals like crabs and worms may result in failure by piping. They must be supervised closely during floods and protected, as soon as they are in danger by measures which are generally temporary.

(iii) They require heavy maintenance.

(iv) They fall suddenly and inundate the low lying areas. They are susceptible to direct attack of river flow which can erode or undermine them.

(v) The interior drainage of the area is enclosed by embankment which may give rise to material climate.

(vi) They check the deposition of silt on flood-plain, thus hastens delta formation resulting in increase of flood stages and rate of aggradation of river bed.

The advantages are numerous and it is scarcely likely that the embankment method will ever be dispensed with. The disadvantages are also big enough to raise grave doubts in projecting new embankment works.

3.14 CUT-OFFS

3.14.1 Introduction

A cut-off is essentially a characteristics of alluvial rivers and signifies development of river meandering to acute conditions in the form of hair-pin bends Under favourable conditions, these bends become large loops with narrow necks. Unless the banks of the neck are protected, continuous caving takes place. The narrowing of the neck reaches a limit, when a break-through occurs and a chute channel known as a " cut-off " forms across the neck. This may also occur by the natural overflow during floods, when side channel becomes a major channel (**Fig. 3.31**).

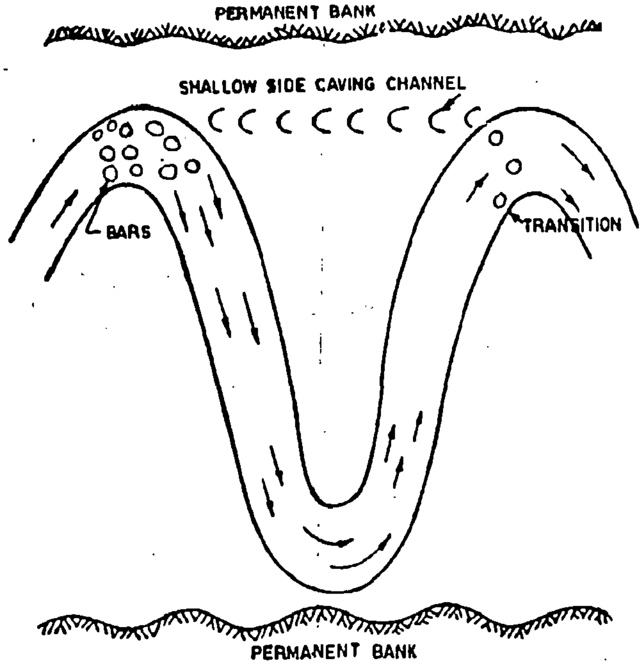


Fig. 3.31 Development of Cut - off

3.14.2 Cut-Off As A River Training Measure

Cut-offs result in violent changes in river regime. As the river tortuosity is decreased , the river slope upstream of the cut-off steepens and flood levels are lowered. This increases flow velocity resulting in appreciable bank erosion and bed scour in the upstream reaches of the river. At the same time, due to reduction of channel storage upstream, the inrushing of floods threatens the lower reaches also. Due to the excessive erosion upstream, the channel carries excessive sediment and causes deterioration of the lower channel. However, the erosive tendency due to the steep slope gives rise, sometimes, to beneficial effects by creating uniformity of cross-section of the river channel.

Because of the violence with which a cut-off affects the river regime, it is seldom that a full scale diversion of the river is brought about through an artificial cut-off. The beneficial effects of a cut-off, namely reduction of flood heights, flood periods and shortening of the navigation course, indicates its usefulness as a river training measure. The practice is to make pilot cuts which carry 8 to 10 percent of the discharge in the beginning and are permitted, subsequently, to develop the carrying capacity to about b 40 to 50 percent of the total river discharge.

A full scale natural cut-off alters, the river regime violently, however, only for a short duration. Subsequently, there is a marked tendency for the river to rebuild the slopes while characterised its prior profile, whenever it has a chance to scour its bottom. The process of rebuilding original slopes may be retarded by tough bottom materials, but can be accelerated by corrective dredging.

Thus, cut-offs are not enough by themselves. While they correct the instability and insufficiency at sharp bends and loops, where much head is lost by excessive river length, they do little to correct conditions in the reaches between these bends. It becomes necessary, therefore, to do extensive work between cut-offs to improve the alignment, width and depth of the channel by supplementary training works. Such work involves two procedures, viz. directing the flow and closing of pockets found at unduly wide points of the channel by training groynes of dredged sandfill. Revetment at places, where erosion is likely to take place, should also be provided. The objective is the creation of a uniform river width, and establishment where feasible, of a central river channel, deep enough to maintain itself by normal scour section.

3.15 PITCHING OF BANKS AND PROVISION OF LAUNCHING APRONS

Protection of banks is a part and parcel of river training works. Sometimes 'Bank Protection' is separated from the 'river Training' under the argument that the former has a limited function of protecting the bank while the latter aims at training the river to a desired course. However, since bank protection itself helps in training the river, the two terms are generally treated as one and the same thing.

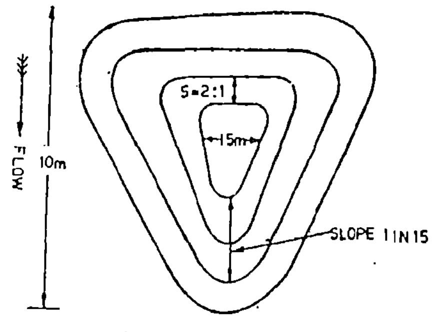
Banks of a river are directly protected by stone pitching or by concrete blocks or by brick lining or by growing vegetable cover etc. Concrete blocks are very costly and stone pitching is mostly adopted, if available without much difficulty. The banks of the river are made stable by giving them a stable slope varying from 1:1 to 2:1 depending upon the material of the bank. They are then pitched, so as to make them strong enough to resist erosion.

Sometimes, a launching apron is projected from the toe of the bank into the river so as to prevent scour at the toe and the consequent apron is based on the principle that stone in the apron has to launch into the deepest scour (D) possible at the location, to a slope of 2:1, at an average thickness of 1:25 times the thickness of pitching provided at the bank. The deepest scour may be taken equal to x times the Lacey's Regime-scoured depth; x generally varying from 1 to 2.5 or 3 for different places.

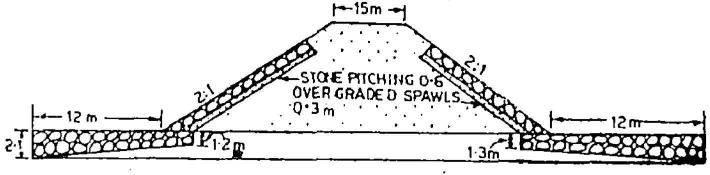
3.16 PITCHED ISLAND

A 'pitched island' is an artificially constructed island in the river bed and is protected by stone pitching on all sides. Because of the turbulence generated by the islands in their vicinity, the river channel around the island gets deepened and thus, attracting the river towards itself and holding it permanently. Pitched islands may, therefore, help in attracting the current towards themselves and thus, reduce undue contraction on the opposite banks **(Fig. 3.32).**

The device of pitched island as a river training measure is a recent origin and is still in the experimental stages. Nevertheless, experience has



(a) PLAN OF A PITCHED ISLAND



(b) SECTION OF A PITCHED ISLAND

Fig. 3.32 Pitched Island

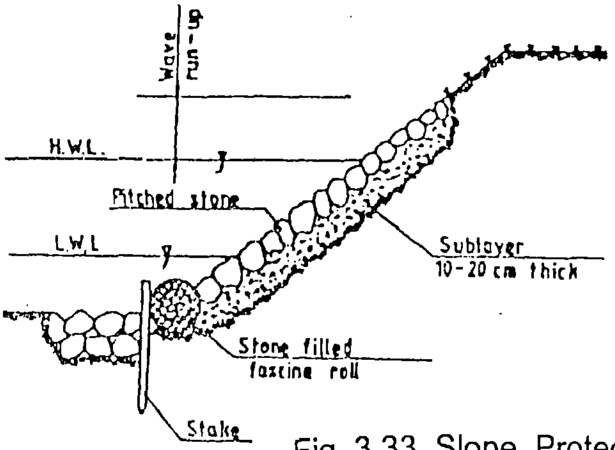


Fig. 3.33 Slope Protection with Pitched Stone

proved that pitched island is a very effective means of controlling and training rivers, especially in the vicinity of control points, such as a bridge or a weir or a barrage etc. However, model studies must be conducted before adopting pitched island, as a river training measure.

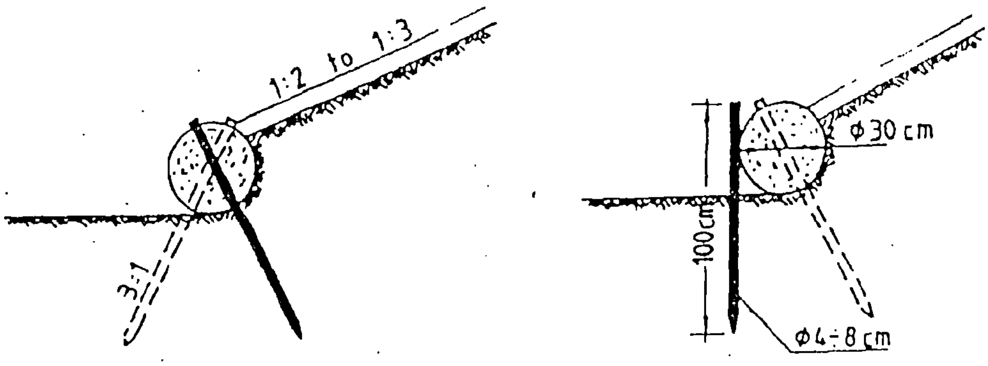
3.17 MISCELLANEOUS METHODS

(i) Submerged Dikes (called sills) are used as a river training measure in particular situations. Sometimes, a river may create deep channels in the vicinity of certain pucca structures and are required to be corrected. In such situations, sills are placed across the scoured portion of the bed, with their top levels at or slightly below the designed bed level aspired to be achieved after correcting the deep scours. They are spaced closely so as to ensure proper functioning.

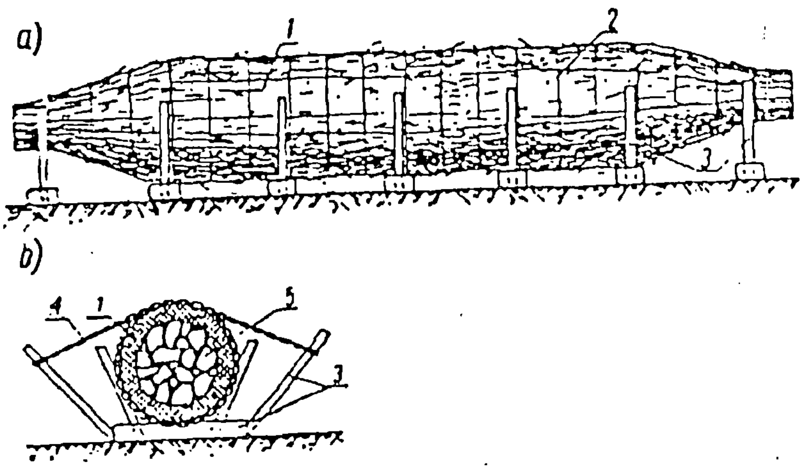
(ii) Closing Dikes are sometimes used to close a particular flow so that the river flow may be directed in some other desired direction.

3.18 CONSTRUCTION MATERIALS

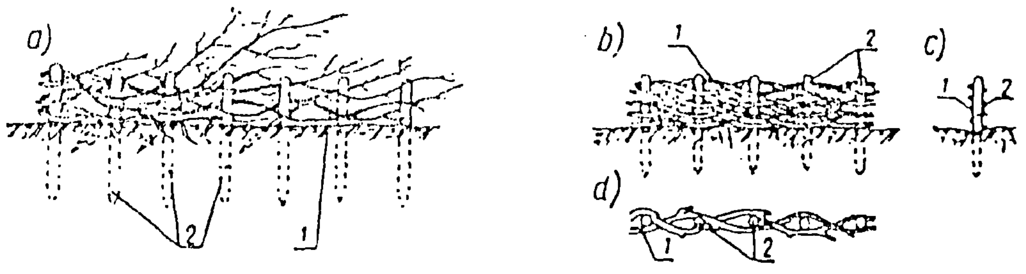
The construction materials for bank protection are Sand, Clay, Peat, Wood, Grass-mat, Stone, Steel, Bitumen, Geotextiles etc. The elements of brush are Brush sauges, Stone-filled fascine rolls, Brush woven fences, Brush works, Fascine mattresses etc. The elements of stone are Riprap, Pitched stone, Grouted stone



Toe Protection using brush sausages



Stone-filled fascine roll (after Mamak,1964); a) side view, b) Cross-section,
1-Fascine roll, 2- Wire, 3- Jacks, 4- Chain, 5- Stone (rubble)



Willow fence (after Mamak, 1964); a), b) Side views, c) Cross-section, d) Plan;
1-Fresh twigs, 2- Stakes

Fig. 3.34 Different Bank Protection Measures and Masonry etc. The elements of concrete are Loose non-interlocking precast blocks, Placed blocks and slabs, Interlocking blocks, Cable connected blocks, Geotextile - bonded blocks etc. There are container systems and other systems, too. These elements are used depending upon the river characteristics etc.

3.19 CONCLUSIONS AND REMARKS

River training works depend mainly upon the type of the river, its regime and upon the characteristics of its flow. There are no two countries with the same hydrology, in the same country with there are no two rivers with the same regime and even in the same characteristics. River training works, therefore, vary from place to place and from time to time and also depend upon the finances available at that time. A particular method of river training, which has been successful in a particular reach on a particular river, may not be the best solution for the other rivers or for other reaches of the same river.

Hence, no particular method of river control can be stated to be the best. It all depends upon the exigencies arising out of a particular problem. However, in general , it can be stated that no river training method is of immense use as a single unless, it is supplemented by other measures. A comprehensive planning and model testing is necessary before any measure is undertaken to control and train the river. If planned roughly , costly structures may either be washed away in a few days or may create worse or irreversible consequences causing tremendous losses and devastations.

CHAPTER - IV

CASE STUDY : TRAINING AND CONTROL OF RIVER GANGES IN CONNECTION WITH FEEDING OF UPPER GANGA CANAL (U.G.C.) AT HARDWAR

4.1 INTRODUCTION

The history of the Upper Ganga Canal starts from 1835. Prior to 1845, the western and central parts of Uttar Pradesh were entirely dependent on annual rainfall for Rabi and Kharif crops in the region which varied from 76 cm to 127 cm (30 to 50 inches).

The province was very inadequately protected by canals before the advent of the Ganges Canal and the Irrigation Engineers were always thinking of utilising the water of the Ganges River. Owing to the erratic pattern of the rainfall during the monsoon season, and its abrupt ending at the close of the monsoon season, the yield of the crops, in general, was poor.

With the same object in view, piecemeal surveys were carried out in the basin of the river off and on to find a suitable alignment for the canal. In 1837-38, the famine gave further impetus to tackle the project seriously.

Sir Col. Cautley, the Inspector General of Irrigation , conceived a gigantic scheme of constructing the Ganga canal for providing assured supplies to Rabi crops by harnessing the waters of the mighty Ganga. The science of hydraulic engineering was in its infancy and little was known about model experimentation and, therefore, it was nature in its entity that Cautley made use of in projecting this scheme which is really now responsible for the prosperity of the Indo-Gangetic Plains.

Col. Cautley intimated his views to the provincial Government and through them to the Governor General and succeeded in getting His Lordship's approval in December 1839, to start prelimenary investigations into the possibilities of a canal from Ganges River and two years later approval of the Provincial Government was confirmed.

A committee was then formed with Major Abbott as President and Col. Cautley and Capt. Baker as members. An order dated 24th November, 1841 was passed to the members to proceed to the site and to report on the efficiency of the proposed works. The committee submitted their report by the start of February 1842.By the end of the February 1842, orders were issued by the Agra Government for the commencement of the work on the terms of the committee's recommendations. In July 1843, the Supreme Government placed Col. Cautley in independent charge of the construction and with this the steps of the construction of the Upper Ganga Canal started under Col. Cautley's full charge.

After orders of the Agra Government were received for the construction of the Ganges canal, the next step was immediately adopted of selecting a site for the Headworks and the Feeder Channel. The clue for this was found from the religious views of that place. Actually, the inhabitants of Hardwar and Kankhal used to dig a water course and bring water from the branch for their religious and domestic purposes. A branch took off the Main Ganges River at about 3.6 kms above the town of Hardwar (or to be more precise above Har-ki- pauri). A spill from this branch overflowed towards Hardwar along old supply channel, which during winter months drew low supplies. Har-ki-pauri occpies a unique position for the Hindus who consider the water of Ganga river at this site the most sacred. The priests all felt interested in a scheme that would, for all the time, may bring the sacred water of the Ganges so close to the Hardwar ghats, besides the source from which the small water-course of the priests was fed was ample for the purposes of a canal,too.

The above fact gave Col. Cautley instantly a clue to the alignment of the canal from the Branch of the Ganga.

4.2 LAYOUT OF THE DIVERSION WORKS AND FEEDER CHANNEL TO THE GANGA CANAL

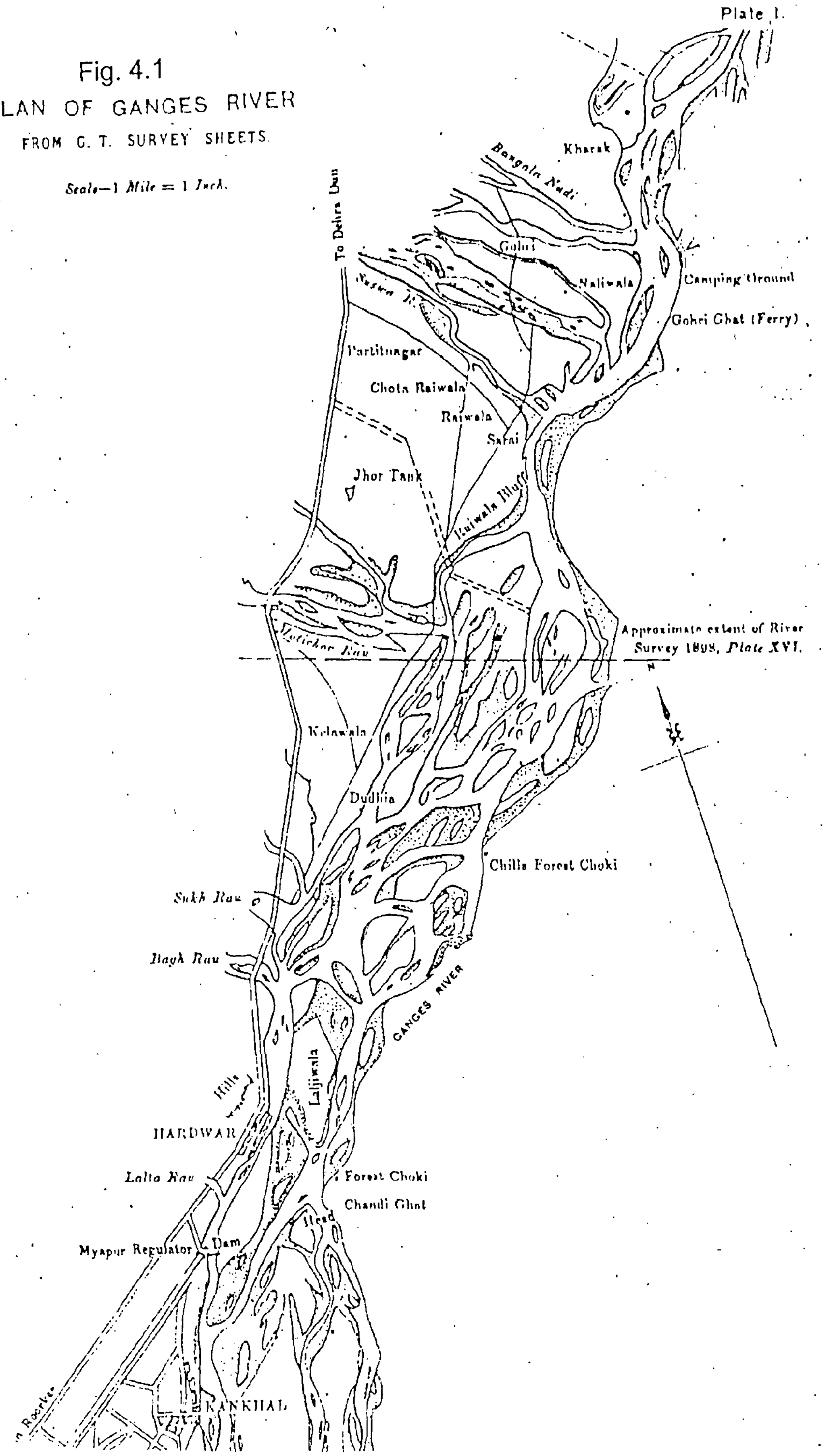
The whole length of the river Ganges in connection with the supply of the Ganges Canal extend from Raiwala to 3.20 kms below the town of Kankhal **(Fig. 4.1).**

The river channels were practically permanent at Raiwala. The river swang round its course at Raiwala and in doing so, it struck the clay bluff about 24 m (80 feet) in height, on which the Raiwala temple was placed. At this point, except in high flows in the channel immediately under the bluff and the site offered exceptional conditions for gauging the river. It was the bluff that the Raiwala gauge was located. For many years past, there had been little or no change at Raiwala. There had been cutting back of the clay bluff , but this was very gradual. It had cut back about 76 m (250 feet) in the last 20 years in 1843.

It was below Raiwala that the changes in the many channels of the river affected the conditions of supply to the Ganges Canal. It was the variations in these channels that had led to the system of Training Works taken up and their subsequent developments.

Fig. 4.1
PLAN OF GANGES RIVER
FROM G. T. SURVEY SHEETS.

Scale—1 Mile = 1 Inch.



The main stream of the Ganges, the discharges of which was estimated in the dried months of the year at 227 cum/sec (8000 cusecs), after passing through the valley Dehra, opens upon the plains by a well-defined gorge in the Siwalik hills **(Fig. 4.2).**

Immediately on the right and close at the foot of these mountains are situated the town and temples of Hardwar. On the left is the Chandi Pahar, a hill of a remarkably picturesque outline, on the top of which is a temple and place of pilgrimage connected with Hardwar itself. The river may be said to occupy the whole of this gorge, the width of which at its narrowest point is about 1.6 kms (1 mile).

Like all the great Himalayan rivers, where they are in immediate connection with the mountains, the bed consists of shingle. The wide expanse is intercepted by numerous channels separated by wide braided lands. Among these many channels, one branch was also formed by an island or islands of the sort, which passed directly under the town of Hardwar. This branch proceeding onwards in a tolerable, even and unbroken section-rejoined the main Ganga river at a point below Kankhal, a large town situated about 2.4 kms (1.5 miles) below Hardwar.

The main river, which runs under precipitous banks on its left, throws out on its right and within a distance of 3.62 kms (2.25 miles) above Hardwar, a minor stream of considerable importance, which under all the fluctuations, which characterise these constantly varying beds, appears to carry, and to have carried for years, a very uniform supply of about one-third of the whole volume.

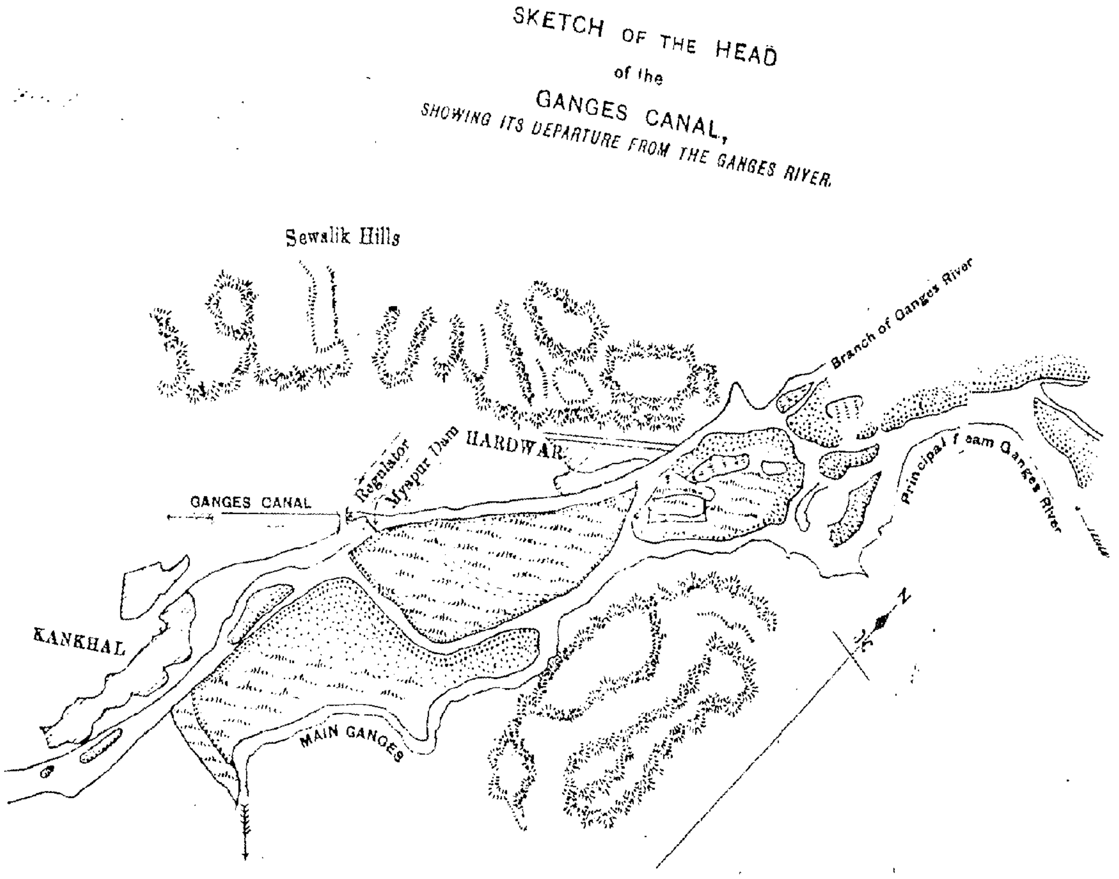

SKETCH OF THE HEAD
of the
GANGES CANAL,
SHOWING ITS DEPARTURE FROM THE GANGES RIVER.
Sewalik Hills
Branch of Ganges River
HARDWAR
Regulator
Myapur Dam
GANGES CANAL
Principal Stream Ganges River
KANKHAL
MAIN GANGES
N

Fig. 4.2

There are three hill streams viz. Bagh Rao Stream, Lalta Rao Stream and Bochna Nala Stream - related to this supply channel. These hill streams augment the discharge in the Supply or Feeder Channel during the rains, too.

4.3 LAYOUT OF DIVERSION WORKS AND FEEDER CHANNEL TO CANAL

The scheme of diversion of water from the river Ganges to canal was found from the religious views of that place. Actually, the inhabitants of Hardwar and Kankhal had been in the habit of bringing a water-course for the purpose of supplying the towns by digging a water-course for their religious and domestic purposes. Har-ki-pauri occupies a unique position for the Hindus who consider the water of the Ganges river at this site sacred. The priests all felt interests in a scheme that would, for all time, bring the sacred water of the Ganges so close to the Hardwar ghats and bathing places, besides the source from which the small water-course of the priests was fed, was ample for the purposes of a canal,too.

The above fact gave Col. Cautley instantly a clue to the alignment of the canal from this branch. The headworks of the Ganges canal, therefore, were determined by the priests and the people; so far as supply was concerned, it was only a matter of degree. The source from whence their small channels were fed, was ample for the purposes of a canal.

Following points were for consideration :

(i) The capabilities, which depended entirely on the results of a very simple series of longitudinal and cross-sections.

(ii) The former (i.e. longitudinal sections) extending from the departure of the branch from Hardwar to point south of Kankhal.

(iii) The latter (i.e. cross-sections) giving an accurate profile of the gorge through which the river flows.

(iv) Other than the above points, the following points were also necessary:

(a) The water marks of the floods,

(b) The effects that these floods had upon the islands, and

(c) The capacity of the different channels, especially of that one which passed under the towns of Hardwar and Kankhal had also to be ascertained.

A series of levels on the above plan, in connection with a survey, disentangled the whole question from any difficulties. At the same time, the point from whence the head of the canal was to leave the branch was determined unmistakably. The spot selected was on the lands of the Myapur estate. The total declivity of surface on this line was 10.63 m in a distance of 6054.55 m(19,864 feet). The Hardwar branch itself was well adapted to the purposes for which it was required. Its average width was 91.44 m (300 ft) and its section at these points where it was free from breaches was deep and well defined.

In 1839, the whole of water passing down the course of the branch from the main stream was equal to 71 cumecs (2,500 cusecs) i.e. one-third of the discharge of the main Ganges river. Also, there were strong rapids at its mouth offering in themselves facilities for the admission of a further supply. Immediately north of Hardwar, a great portion of this water escaped through a wide extended channel that passed off into the into the main stream; and opposite the great ghat, at the town itself, a further down the branch, which was only effective as a line of escape during heavy floods,

It was proposed to construct temporary bunds or embankments across the heads of these different channels and by advancing a spur into the river at the head of the supply- branch in order to obtain from the main stream whatever quantity was necessary. When designing the original work, and they have been carried out very closely as the changes have taken place in the bed of the river would admit of.

The above views were taken in 1839-40; in the year 1853, they were confined to diminution of water in the branch and an enlargement of the escape opposite the main ghat at Hardwar. In other respects, the state of the river and its numerous islands, was much the same as in 1839. Certain preparatory measures were adopted for excavating the canal channel down the branch during the year 1852. These measures consisted in throwing shingle bunds or embankments over the courses of numerous channels, that brought down during floods unnecessary supplies of water and did their duty very efficiently insuring the steady progress of the excavations without any material interruption. The channel, which was excavated entirely through shingle, was 4496 m (14,750 ft) long with a slope of bed of 7.3 m (24 ft). The initial depth of digging was 1.17 m (3 ft 10 inches).

Abbreviating the above description and referring to **Fig. 4.3,** we find that at the commencement about 1852 to 1854, the conditions were as follows:

(i) The channel ABC was the branch referred to carrying one-third the volume of the main river.
(ii) The channel CE , which was the Hardwar Dam Channel, returned the greater part of this supply to the main river.
(iii) The channel ABCD was the supply and main supply channel. This was excavated to levels and a width of 91.44 m (300 ft).
(iv) The islands of Laljiwala and Belwala formed an effective protection to the supply channel.
(v) The supply was taken in by a spur pushed into the river from the point A and partially obstructing it.
(vi) The escape channels, from the supply channel ABCD, were closed by simple boulder and shingle bunds.

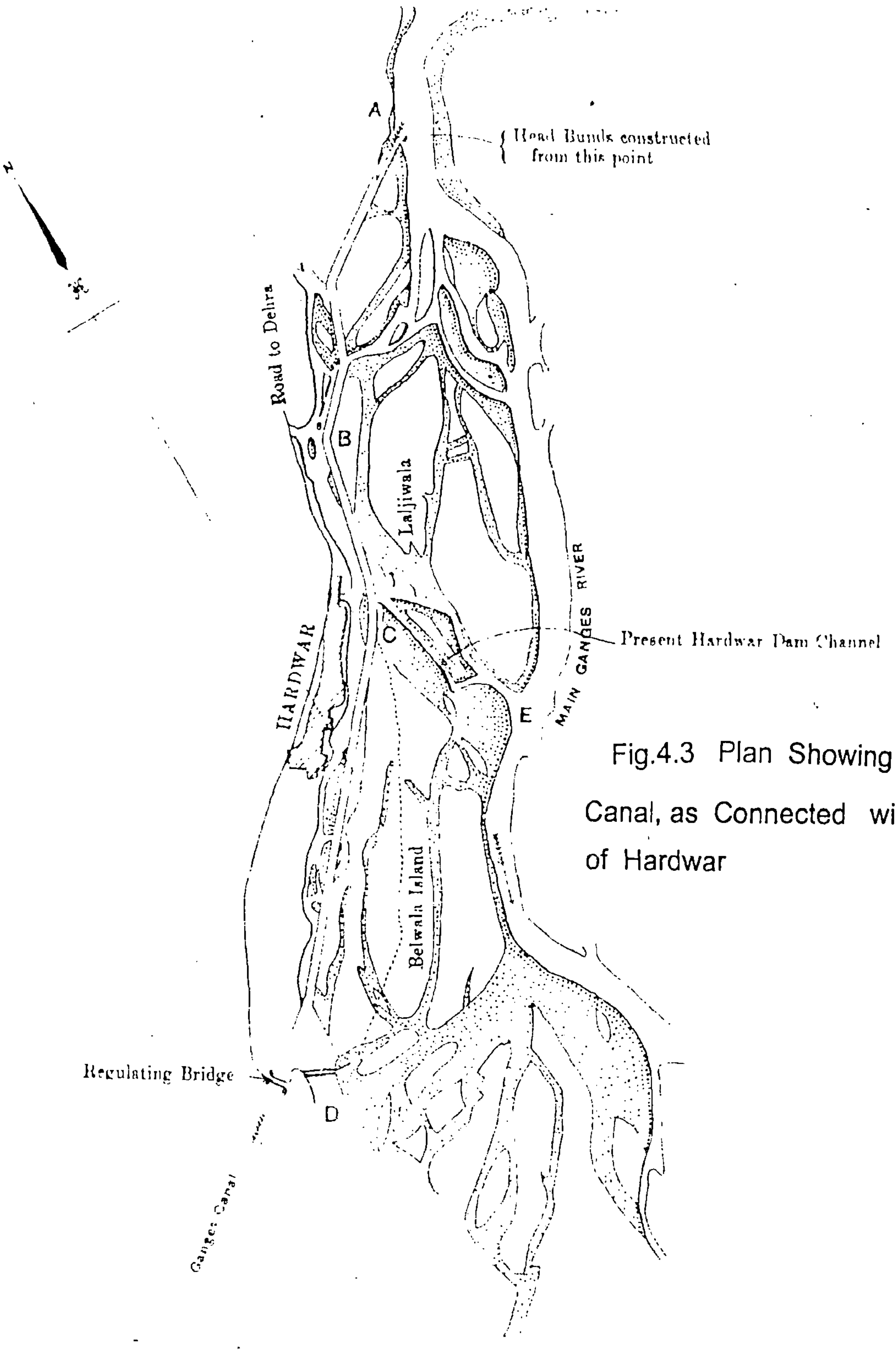


Fig.4.3 Plan Showing the Ganges Canal, as Connected with the Town of Hardwar

(vii) The supply channel was kept well away from the town of Hardwar to allow of a foreshore for the use of pilgrims during religious gatherings.

(viii) Apart from mere bunds to pond up the water, there were no training or protective works of any kind.

(ix) The minimum supply of the river was taken as 227 cumecs (8,000 cusecs) instead of the 125 cumecs(4,427 cusecs).

(x) During a period of 1839 to 1853 i.e. 14 years, there was very little change in the courses of the river channels.

The only masonry work on the whole system of supply was the Myapur Escape Dam. There were 15 openings of 3 m (10 ft) by 1.83 m (6 ft) in height, placed in the centre of the Dam, and a spill weir at each end 49 m in length. On the construction of the head-works of the Ganges Canal at Bhimgoda since 1854, the year of the opening of the canal, consisted of a spur of cribs runout into the river from the point A (Fig. 4.3), and this spur was constructed with the aid of boats worked on a rope across the channel.

4.4 TRAINING AND CONTROL ON THE RIVER FOR DIVERSION TO CANAL (1854-1917)

4.4.1 General

The training and control on the river Ganges for diversion to canal extended from the Chillawala weir, about 6.4 kms (4 miles) above Myapur on the left bank of the river, to the canal head at Myapur on the right bank of the river **(Fig. 4.4)**.

Colonel Cautley's original purpose was still there, and the whole system of the training works had developed gradually in maintaining and establishing his method in the face of all the changes and difficulties of the past 45 years. The order in which the works were taken was from the Bhimgoda head bunds

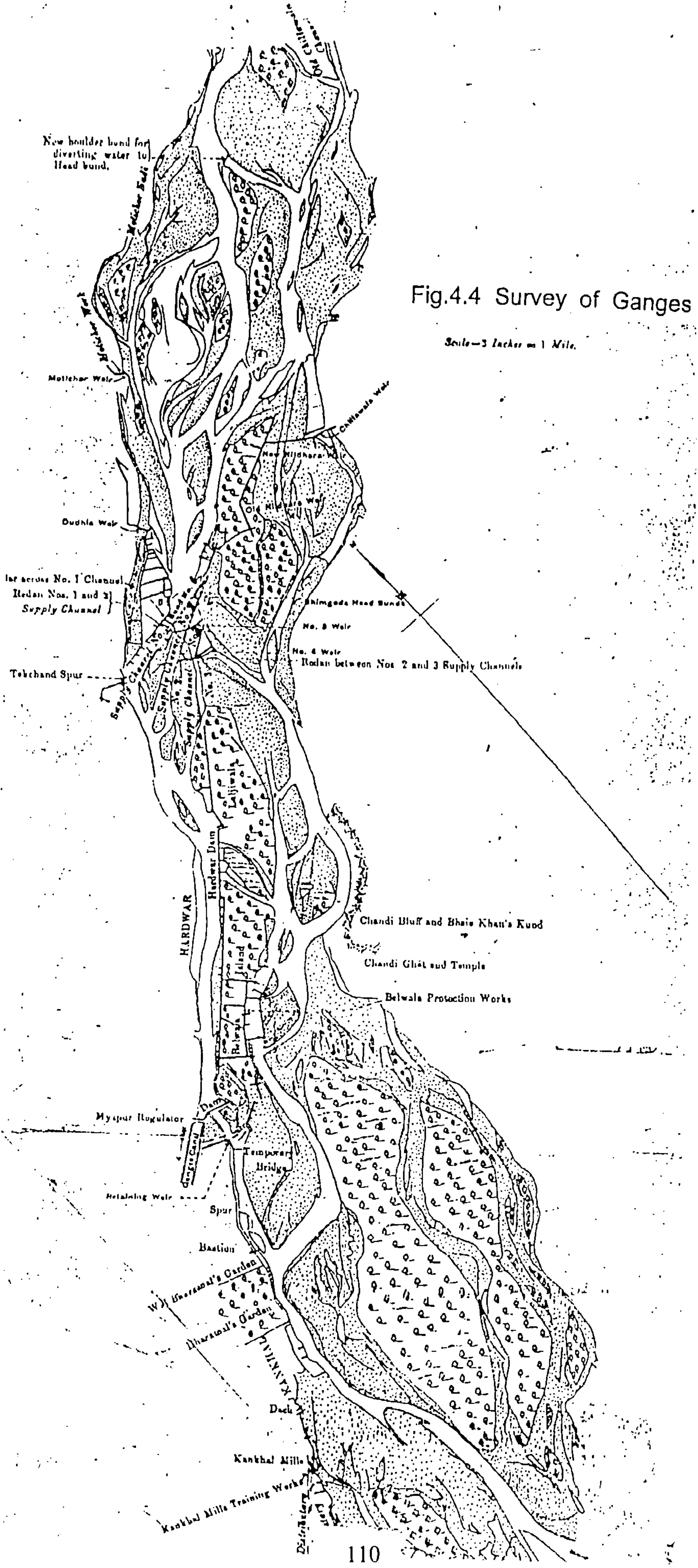


Fig.4.4 Survey of Ganges River, 1898

Scale—3 Inches = 1 Mile.

as the centre of the system, first up the river and then down the supply channel to Myapur.

4.4.2 Canal Opened In 1854

The Ganges Canal was opened in 1854, but there were no difficulties as regards the supply required. However, there was much evidence of trouble with the Falls, Superpassages and Escapes on the main canal and hence the volume of water must had been small.

The first evidence of the extent to which the Head bunds at Bhimgoda were constructed was given in a survey of the river made in 1859-60 **(Fig. 4.5).** This showed that four bunds in all were required to give the supply, viz.

(i) The first boulder bund was across the Nildhara channel of the Ganges.

(ii) No.1 Bhimgoda bund formed of triangular or prism-shaped cribs made of sal trees, from 5.5 m to 6.0 m (18 ft to 20 ft) in length which were floated to the required site, located with boulders and sunk down to the bed of the river. Bouldrs, small stones and gravels were then thrown in.

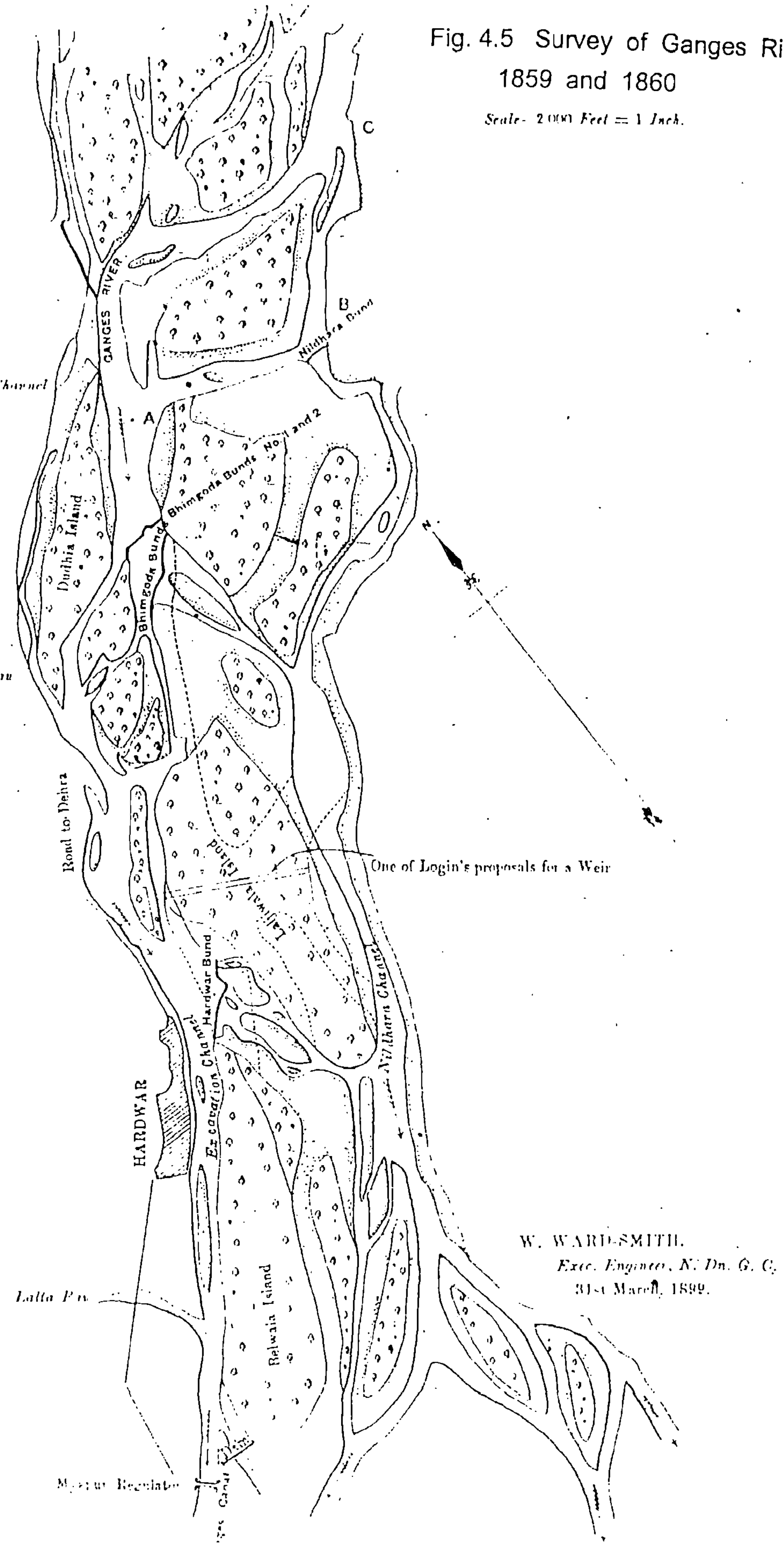
(iii) No.2 Bhimgoda bund was formed of boulders.

(iv) A bund across the Hardwar channel.

In 1862-63, Mr. Login gave a description of the work done showing the bunds of the present day resembled those constructed at the earlier period of the canal.

Fig. 4.5 Survey of Ganges River, 1859 and 1860

Scale- 2000 Feet = 1 Inch.



4.4.3 Cost of Head Bunds

The construction of the Bhimgoda bunds had been much the same year by year. It is markable to note the rise in the cost of these bunds as larger volumes had to be impounded and the work done at an earlier period of the year with increasing demands for payments for timber used. Thus:

In 1863-64, the Head bunds cost Rs. 5,424
In 1864-65, ---------- do------------ Rs. 11,462
In 1865-66,-----------do------------ Rs.17,664
In 1866-67,-----------do------------- Rs. 29,481
In 1867-68,-----------do ------------ Rs.50,360
In 1868-69, -----------do------------ Rs.32,509
In 1869-70,-----------do------------ Rs.28,131
In 1897-98, ---------- do------------- Rs.34,981

4.4.4 Description of The Construction of The Head Bunds At Bhimgoda

Mr. Buckley visited bunds at Bhimgoda. He gave an excellent description of the work involved as a means of showing the manner in which these bunds were constructed are as follows:

- There were three nos. of Bhimgoda head bunds(Dam nos. 1,2,3).
- The construction of these temporary dams (or bunds) at Bhimgoda was a work of some magnitude in a stream having a surface slope of 2 m per km in water.
- In the case of dam No.1, it was 3 m to 6 m deep.
- Dam no. 2 was always less difficult to make than Dam no.1, sometimes, it had to be made of cribs, but genarally it was an embankment of boulders and shingle.
- Dam no.3 was always a shingle dam.

The general construction method for dams made out of cribs were as given below:

(i) A nos. of cribs were first made on the foreshore of the river. These cribs were about 3 m (10 ft) in length **(Fig. 4.6).** Generally, these cribs varied in bottom width according to their vertical heights and hence had to be adjusted to the depth of the stream in which they were to be placed.

(ii) The first operation in the actual construction of the dam was to get a 36 cm coir rope across the river. This was done by the help of ropes of different sizes which were pulled across one after the other until one of sufficient strength was available to deal with the heavy rope. When the 36 cm rope was across the stream, it was propped up 6 m .

(iii) to 7.5 m above the water at various points on groups of piles standing on the river bed and between these supports, it hanged down to within 2.5 to 3 m above water, the ends of it being firmly lashed on shore.

(iv) Snatch blocks were run on each height of the 36 cm ropes which could be manipulated backwards and forwards on the rope by small windlasses on either bank. To these snatch-blocks, ropes were fastened, to which boats could be pulled backwards or forwards and placed at any point of the river.

(v) A barge, fitted with a derrick in the stern, first picked up one of the cribs which hanged over the stern of the boat in the water, the weight of it was counterbalanced by a quantity of boulders, which was placed in the bow, the boat was then attached to a snatch-block and was pulled into the required position in the river.

(vi) When the crib hanged in its right position in the line of the dam, it was gradually lowered by the derrick into the water, and the boulders

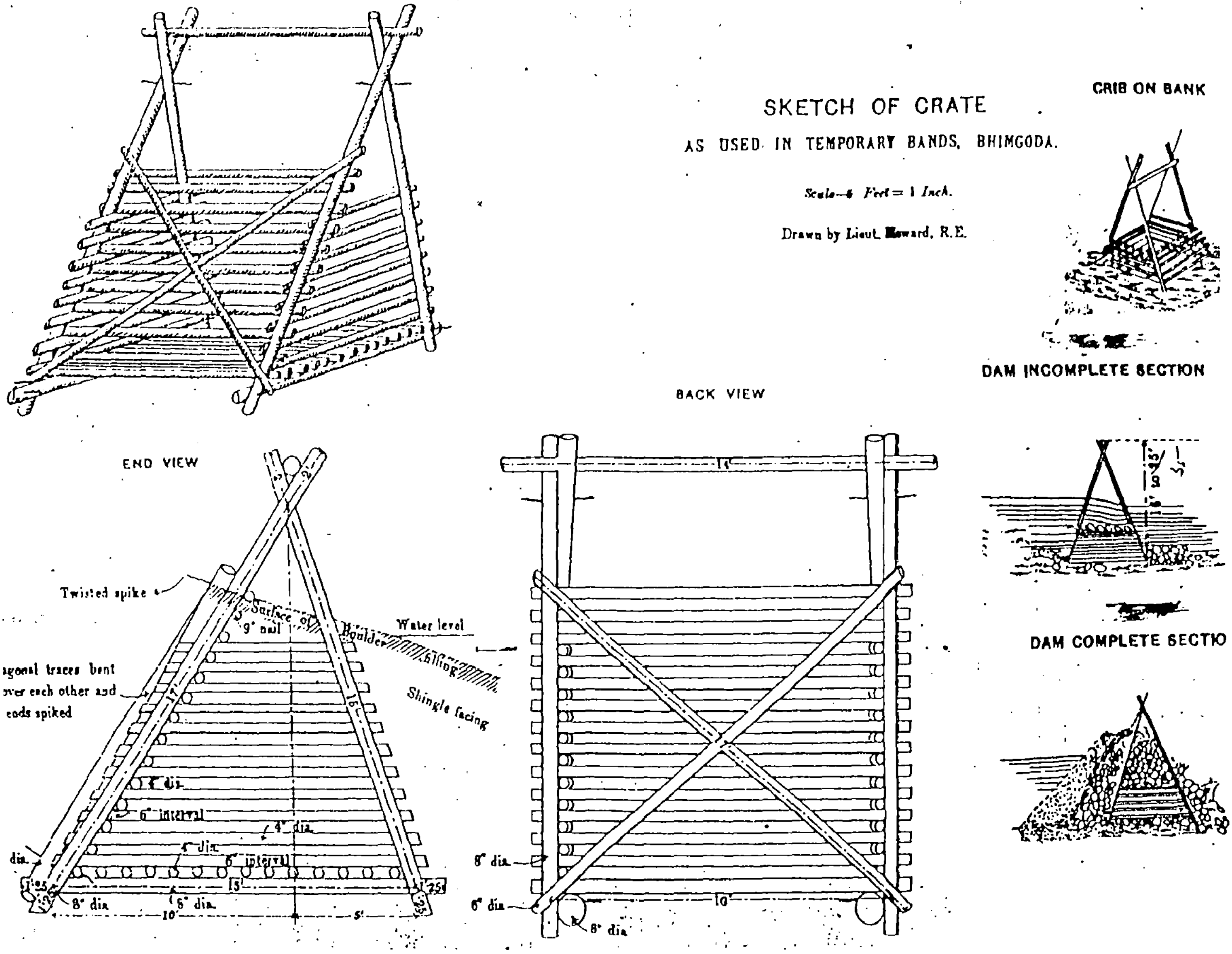


Fig. 4.6 Sketch of Crate

were taken from the bow of the derrick barge and dropped into the crib as it descended, other smaller boats were also dropped alongside, from which other boulders were placed in the crib, sufficient to sink it to the bottom.

(vii) When it was settled into its proper position, it was firmly lashed to the neighbouring crib, which had been sunk before it, and a few more boulders, making a total depth of 0.90 m to 1.20 m perhaps, were filled into it so as to make it secure.

(viii) The derrick boat was then pulled back to the shore by means of the snatch-block running on the 36 cm rope, where it picked up another crib , which was sunk in the same way next to the last one and secured to it.

In this way, a line of cribs were placed right across the river, or across the deeper part of it, where the velocity was too great to enable a dam of boulders to be made. The water ran over the top of the boulders in the cribs (Fig. 4.6) and the dam was a submerged weir. The dam was then raised, in a step of 0.30 m height with boulders, which were dropped into the cribs from boats, which were first pulled out one after another, by means of the snatch-blocks, and the dam gradually rose up to the surface of the water; the crest of the dam was kept , as near as may be,at a uniform level, so that the water flowed evenly over the top of it. When the crest was above water, there was, of course, copious leakage through the boulder dam. At this stage grass tatties or mattresses made of long bundles of grass or thin twigs 15 or 20 cm (6 or 8 inches) in diameter lashed together by ropes were placed in front of the dam. A pole or ballah was lashed to the lower edge of this mattress, and, behind this, boulders were placed on the mattress until it was shunk into position.

It was important to allow the mattress, to rest for a width of about 3 m (10 ft) on the river bed, as this was the point where the greatest amount of leakage appeared to occur. On the top of this mattress, a berm of small boulders and shingle was thrown, by labourers walking along the crest of the dam, until it had been made as strong and as staunch as was considered necessary.

There was always a stream flowing along the face of No.1 Dam, and the consistency of the shingle berm depended on the velocity of this stream.No.2 Dam was also constructed in the same manner, or a portion of it, but No.3 was a boulder and shigle Dam - no cribs being necessary . As the current in front of these lower dams was much less than that above No.1, they can be made of finer material, and therefore, are more water-tight.

After more than 50 years of the construction, it was concluded that the methods of the early days of the canal were still applied except that the bunds were more quickly and better constructed and the appliances in the way of derrick boats, snatch blocks etc. were better, but the methods were still the same.

4.4.5 Importance of Head Bunds

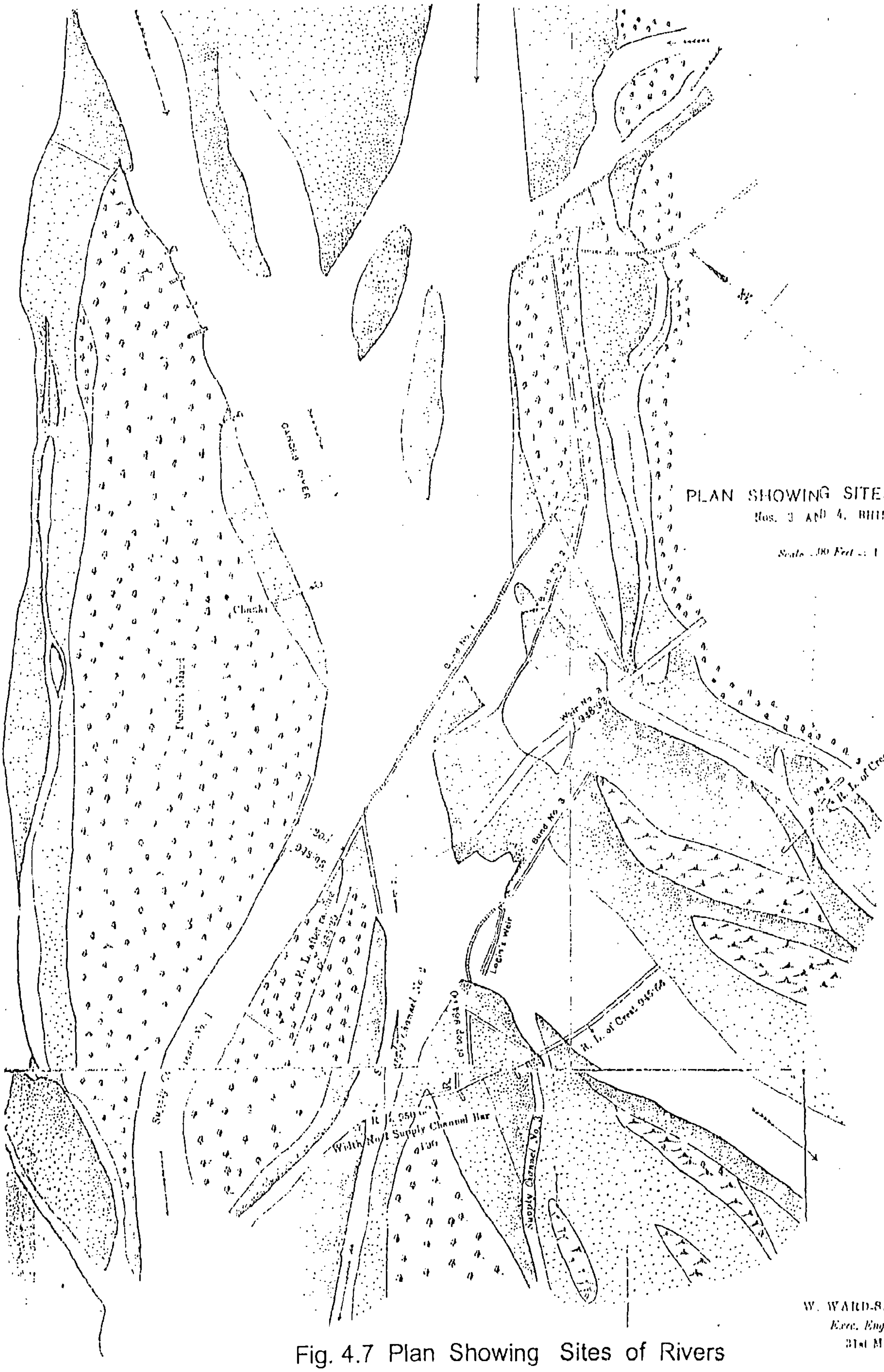
The Bhimgoda bunds were the the source of supply to the Ganges canal and , in fact, these bunds were the centre of nearly all the training works above and below them. The object of those above being to bring all water down to them and yet to be able to relieve them, when necessary. The object of those below being to regulate the volume passed down by them.

Even after 10 years of the opening of the canal, though several proposals for a permanent weir in place of the head bunds were made, yet consequently the same system of the training works were committed and all thoughts of a permanent weir were abandoned.

4.4.6 Training Works at Bhimgoda

- Experience showed that the bed levels of the main river and the supply channels at the site of the Head bunds must be maitained.

- In 1861-62, Mr. Login found that a rapid below the Bhimgoda bunds was cutting back.
- To prevent this, increase in the depth of water far back was necessary. Cribs had to be laid in such depth. Hence, crib bars were constructed at the head of the rapids **(Fig. 4.7).**
- In 1862-63, the cribs placed in the bed of the river last year had been a work of the greatest difficulty to have maintained a good supply in the canal, too. Hence, a second line of crib work had been thrown across the channel as a further security against the rapid cutting-back.
- In 1864-65, Liut. Forbs remarked that it was found after the rains of 1864 that the river had deserted its usual course and had gone to the left, leaving a shoal of shingle in front of the supply channel **(Fig. 4.8 & 4.9).**
- Moreover, the rapid below the Bhimgoda bund No.2 had cut back about 30 m (100 ft). A crib bar was made 90 m (300 ft) wide and 18 m (60 ft) in length to form a rapid on cribs and to prevent further cutting - back.
- In 1868-69, a crib dam across the deep channel of the river below the Bhimgoda bunds was made to protect " Login's Bund" **(Fig. 4.10).**
- The necessity for maintaining the bed levels in the main stream was established.
- In 1871-72, the construction of a masonry for bar took form. From 1871-72, there was steady record of expenditure in putting a masonry bar(called No.3 Bhimgoda Weir) across the main stream.
- In 1872-73, the work stood the rains in a satisfactory manner.



PLAN SHOWING SITES OF WEIRS
Nos. 3 AND 4, BHIMGODA.

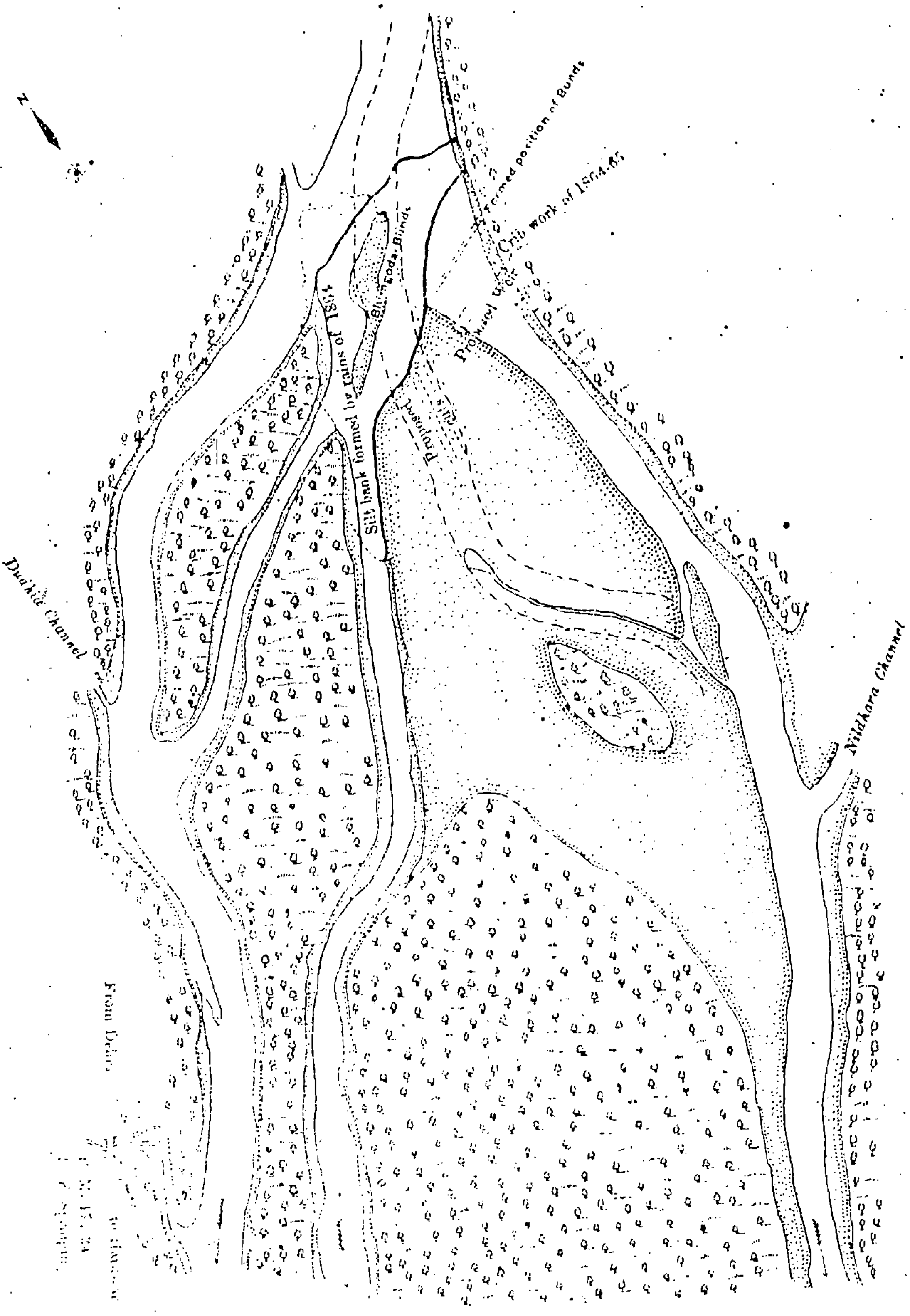
Scale 200 Feet = 1 Inch

W. WARD-SMITH,
Exec. Engineer, N. Dn. G. C.
31st March, 1899.

Fig. 4.7 Plan Showing Sites of Rivers

Fig. 4.8 Survey of Ganges River after Flood of 1865

Scale—750 Feet = 1 Inch.



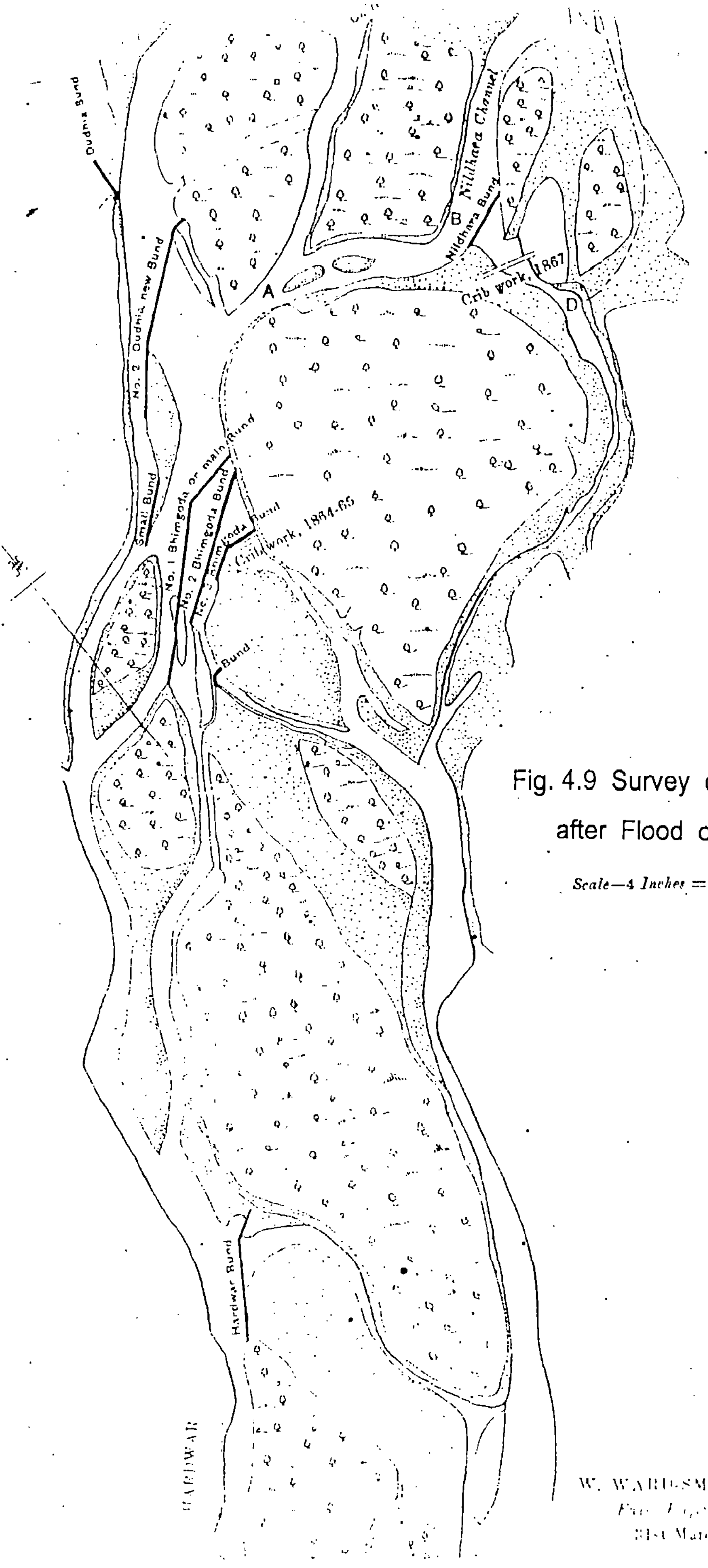


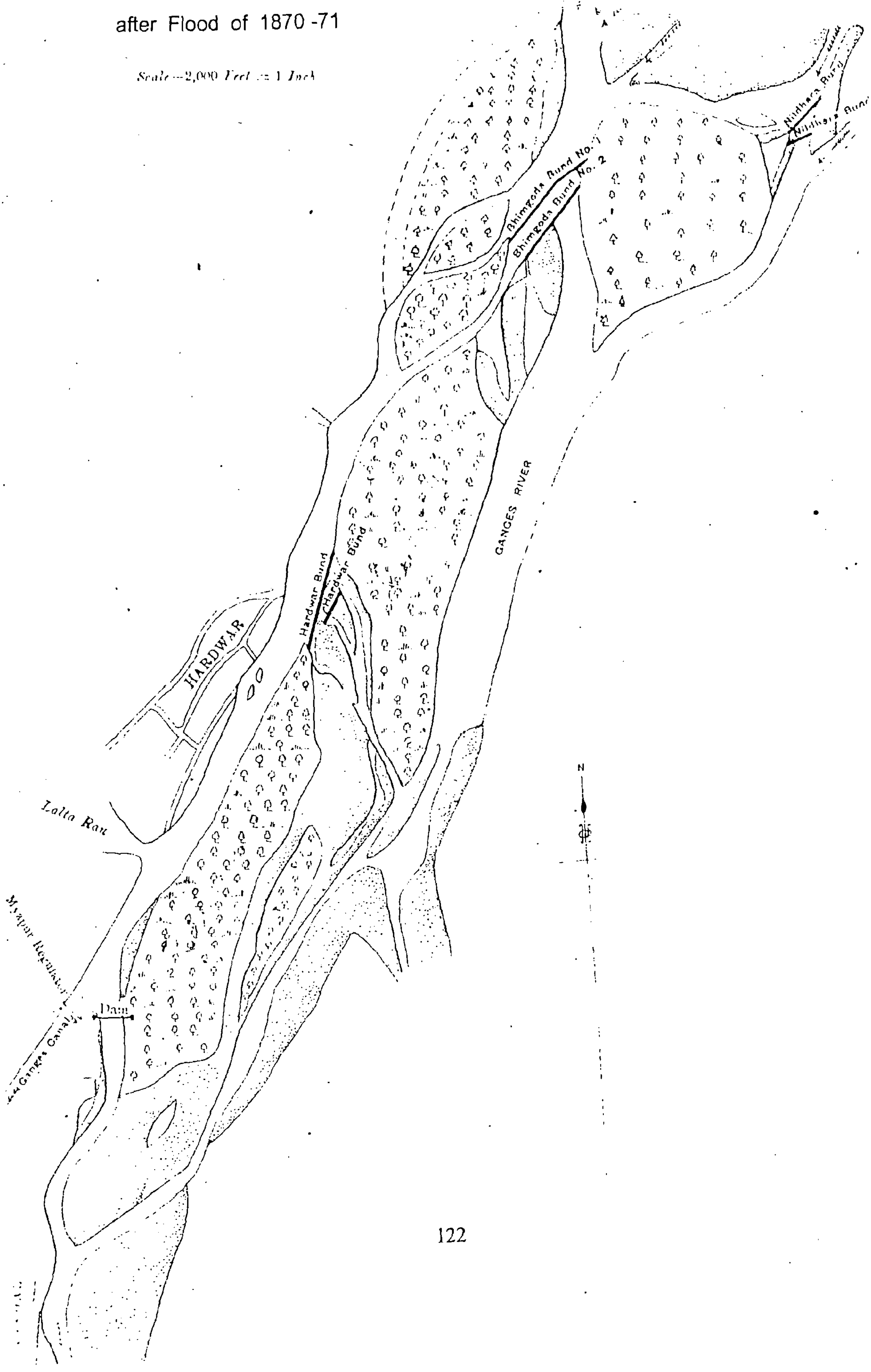
Fig. 4.9 Survey of Ganges River after Flood of 1867

Scale—4 Inches = 1 Mile.

W. WARDSMITH.
Exec. Engineer, N. Dn. G. C.
31st March, 1868.

Fig. 4.10 Survey of Ganges River after Flood of 1870 -71

Scale—2,000 Feet = 1 Inch



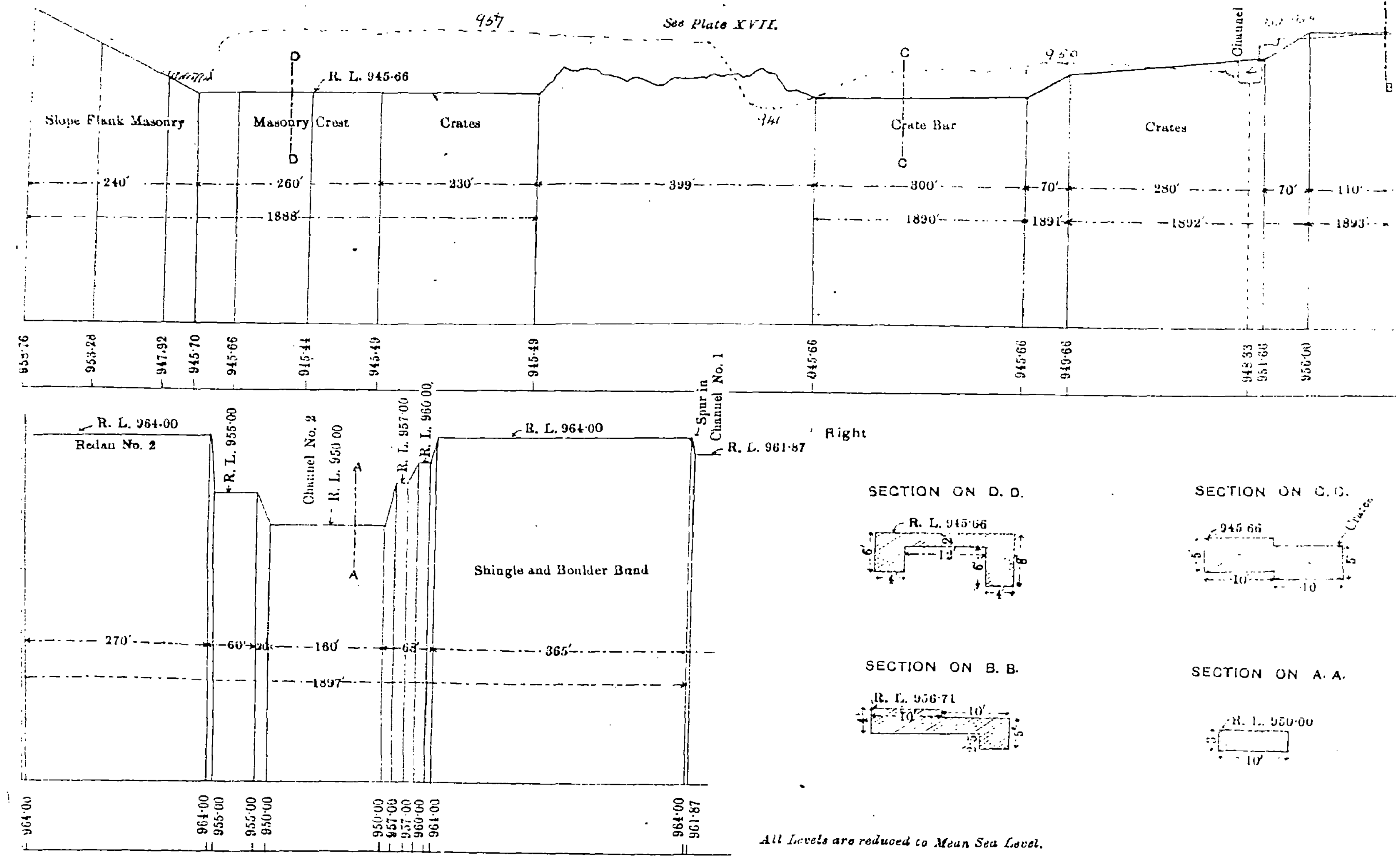
- In 1873-74, the work of No.3 Bhimgoda weir with masonry bar had been continued.
- At the end of 1875-76, a masonry bar 268 m (880 ft) in length was laid across the main stream of the Ganges from its left bank to the edge of the supply channel of the canal. The estimate for this work amounted to Rs. 30,003.
- In 1876-77, Captain Tickell wrote," Facing the Bhimgoda weir with masonry and completing the Bhimgoda Weir with masonry and
- completing the Bhimgoda Weir across the ganges are practically the same work , and it is, one of very great importance to the canal (Fig. 4.7).
- Bhimgoda No. 4 Weir was to protect "Login's Weir," on which the action of the river was becoming too severe. It was for maintaining the bed levels of the main stream. Its length had been added to year by year since 1885-86, but chiefly during the year 1891-1893 **(Fig. 4.11).**

4.4.7 Requirements at Bhimgoda

The other requirements at the site of the Bhimgoda bunds found necessary from experience were :

(i) That the main stream and channel should be adjacent to the head of No.1 supply channel.
(ii) That the width of the main stream channel should not increase.
(iii) That the entrance to No.1 supply channel ,at least, should be maintained of a depth and width to admit the supply required for the canal readily without giving the main stream of the Ganges any opportunity of taking a course down the supply channel.

Fig. 4.11 Longitudinal Section along crest of No. 4 Weir



All Levels are reduced to Mean Sea Level.

Following were also the important events related with the requirements at Bhimgoda:

- The results of annual surveys showed that the main stream of the Ganges had invariably been on the left bank of the valley between Raiwala and Chillawala till 1894.
- From Chillawala, it had been deflected to the right and this course had brought the channel conveniently into position at Bhimgoda for obtaining the canal supply.
- This condition was endangered in 1864 (Fig. 4.8) and again after Gohna flood of 1894 **(Fig. 4.12),** when the main stream deserted the left bank for a course along the right bank of the valley.
- In 1898, (Fig. 4.4) , the channels between Raiwala and Bhimgoda once more were working back to a favourable position.
- Hence, the width of the river channels at Bhimgoda had been maintained by the growth of a series of spurs and bunds which had followed the course of the damage done by floods year by year.
- On the right bank, the survey of 1859-60 showed the Dudhia Channel (Fig. 4.5) and the set of the river on it. A crib bar was put across this channel at a very early period to prevent its enlargement. This became a crib weir in 1872; then masonry followed in 1879 **(Fig. 4.13)** . It was a masonry weir with crest level at 294 m and the channel below the weir had been greatly shoaled up.
- To prevent erosion along the face of the Dudhia island, lying between the Dudhia Weir and the head of No.1 supply channel, a series of crib spurs were put out in about 1872.
- Somewhere about 1877 or 1878 , on the left bank of the main stream at Bhimgoda, the development of spurs and bunds began with the formation of new channel **(Fig. 4.14).**

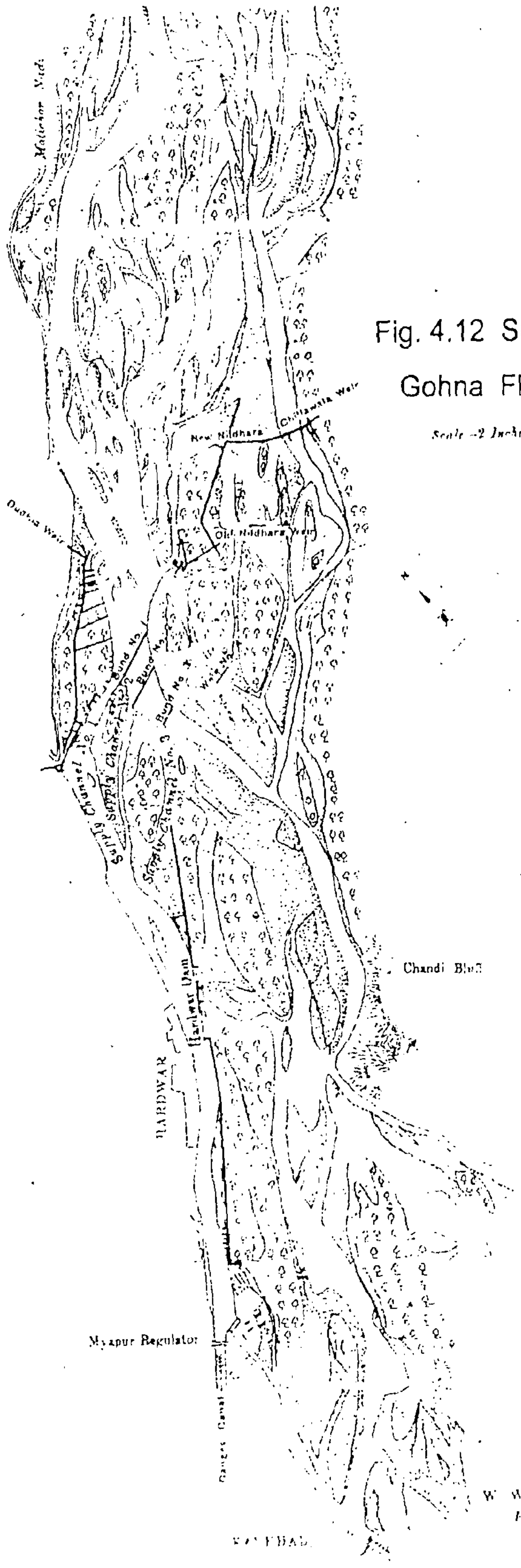
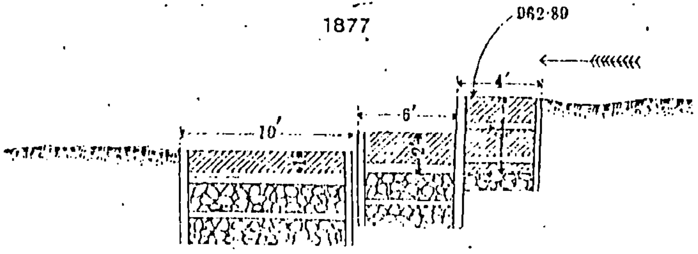


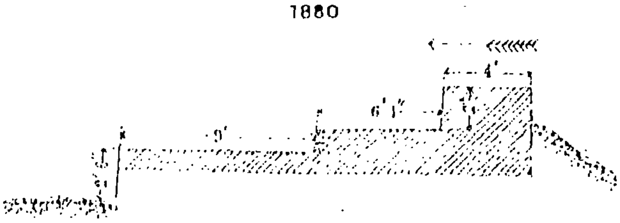
Fig. 4.12 Survey of Ganges River after Gohna Flood, 1894

Scale -2 Inches = 1 Mile.

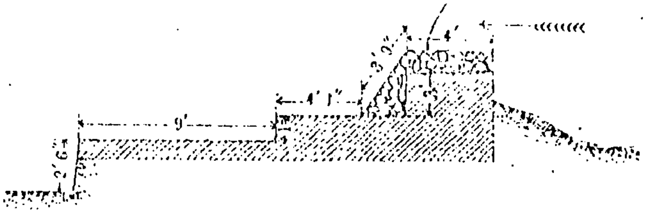
CROSS SECTIONS OF DUDHIA WEIR.



Scale—10 Feet = 1 Inch.



Scale—8 Feet = 1 Inch.



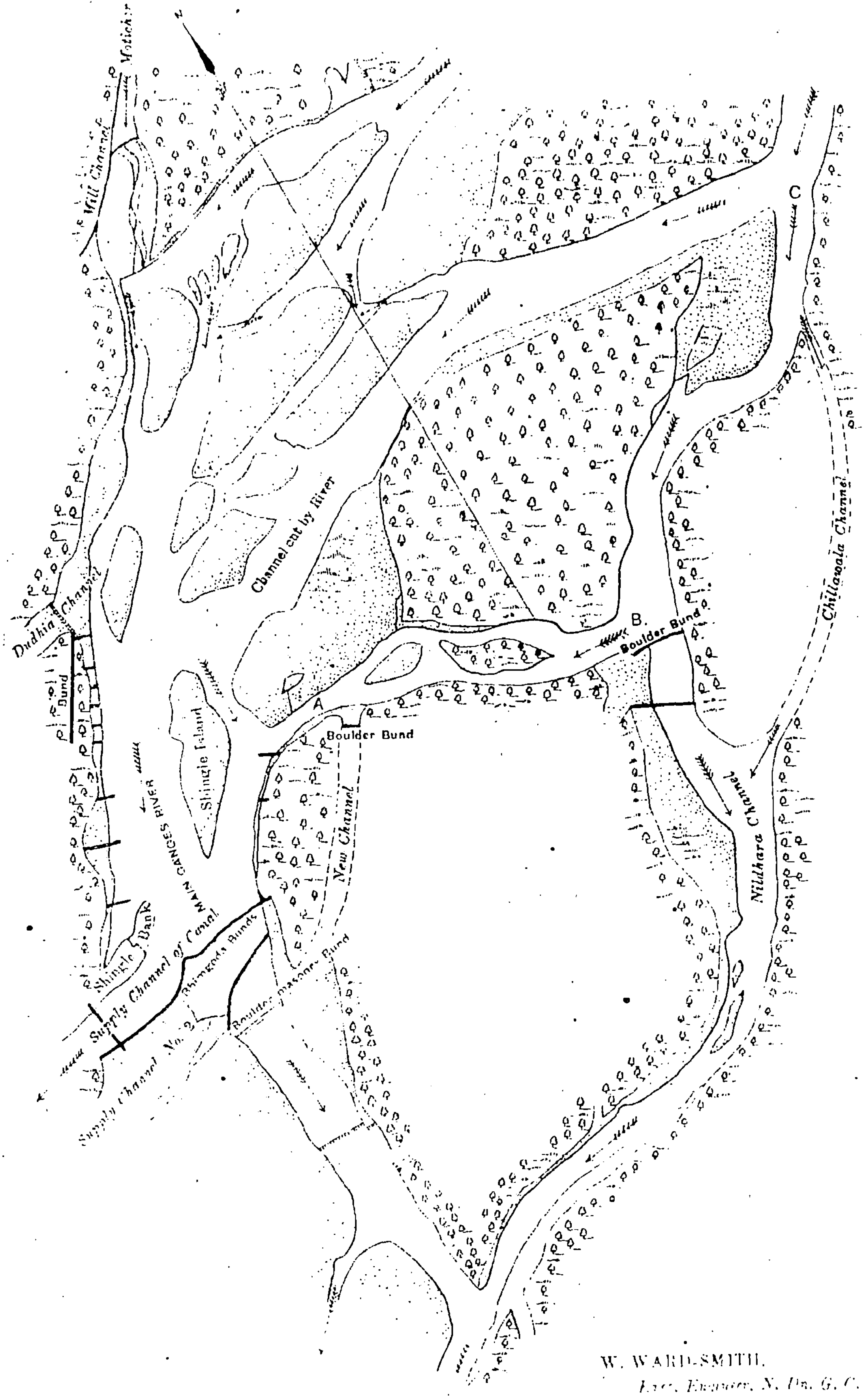
Scale—16 Feet = 1 Inch.

And in 1898 the R. L. of Crest is 964·84.

Fig.4.13 Cross-sections of Dudhia Weir

Fig. 4.14 Survey of Ganges river after Floods of 1873

Scale – 500 Feet = 1 Inch.



W. WARD-SMITH,
Exec. Engineer, N. Dn. G. C.
31st March 1893.

- The original spurs and bunds were much injured n by the Gohna flood of 1894 (Fig. 4.12).
- Thereafter, the spurs of great strength , chiefly of massive concrete blocks , were added (Fig. 4.4).

4.4.8 Old Nildharal Channel And Weir

The purpose of the training works up the river from the Bhimgoda head bunds as a centre was to maintain not only too excessive main stream at Bhimgoda, but also to facilitate the construction of temporary works to bring the cold weather supplies to the Head bunds.

The ruins of the Nildhara Weir are shown in Fig. 4.4. In 1859-60 (Fig.4.5), the channel ABC was of importance and the Nildhara bund of those days was constructed to divert the water from the several streams down the channel BA to the Head bunds. In 1866-67, a crib bar was constructed at the head of a rapid between the points B and D (Fig. 4.9) and in 1876-77, this crib bar was enclosed in masonry. The object of the work was to maintain the bed level of the Nildhara channel at the point where the branch AB left it. The channel gradually diminished in importance till the flood of 1880 practically obliterated it. The survey of 1898 (Fig. 4.7) shows that the site of the branch AB was overgrown with trees and the ruins of the old Nildhara weir frequently raised a question as to tthe purpose for which it was built.

4.4.9 Chillawala Channel And Weir

The Chillawala channel was advancing in importance, whilst the Nildhara channel was working. In 1867 (Fig. 4.9) , CBD was the Nildhara channel and CD the Chillawala channel, practically a dry bed of boulders. In 1873 (Fig. 4.14) ,it was not surveyed, but shown approximately in dotted lines, as of little importance. In 1876, a sum of Rs. 6,610 was spent in a masonry bar across the channel.

The section of the masonry bar constructed in 1876 is shown in **Fig.**

4.15. In 1877, it was found that this bar was not sufficiently high to restrain the river. In 1878, it was raised , strengthened and prolonged to the third section continuously. With all developments, the Chillawala Weir was as shown in **Fig. 4.16.**

4.4.10 New Nildhara Weir

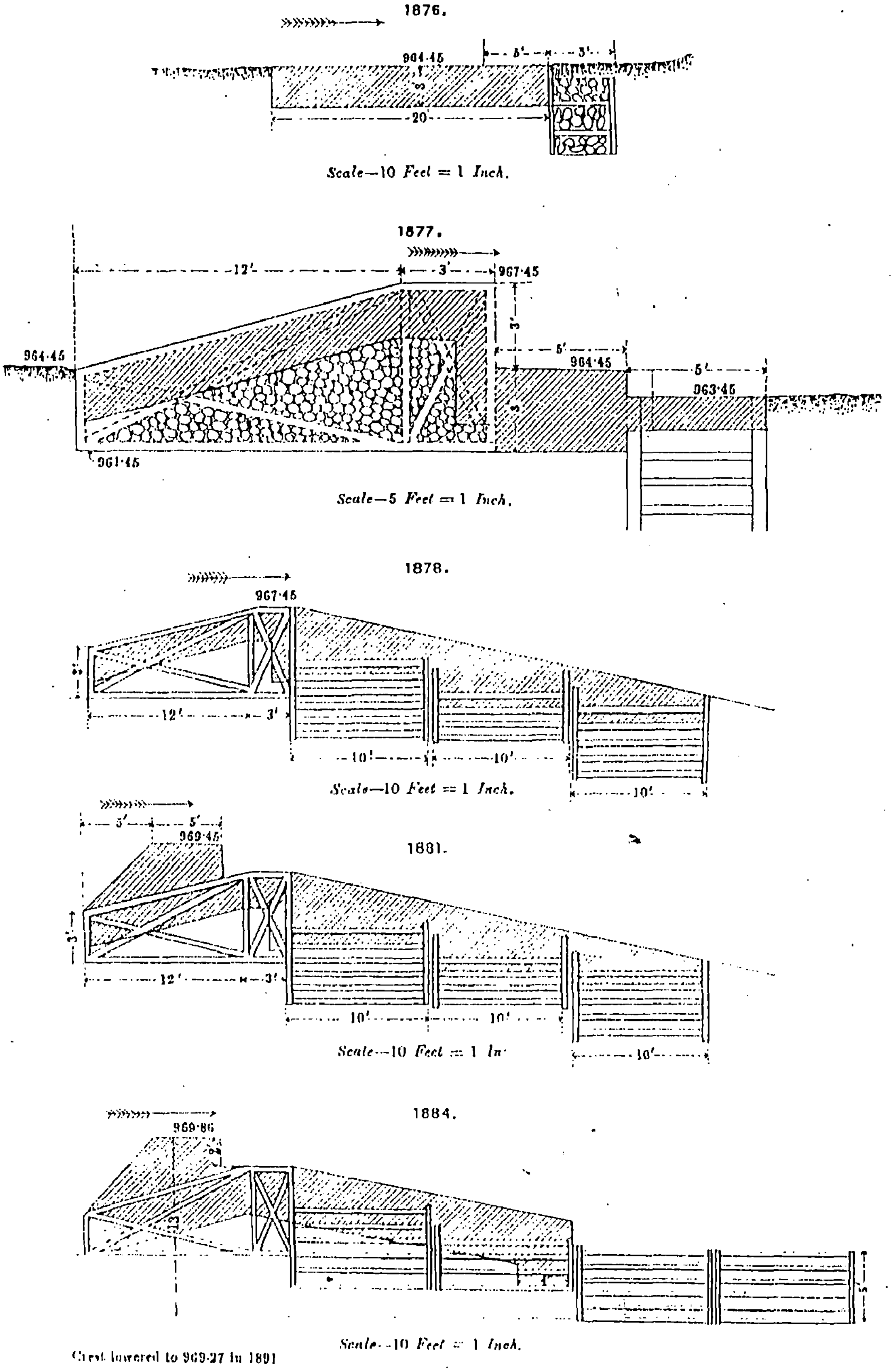
The branch AB between the Nildhara channel and the main stream at Bhimgoda had been obliterated in 1880. A comparison of surveys **Figs. 4.17 & 4.18** showed that the bed was shown as dry. The bed level of the Nildhara channel at its head was raised. But, in 1887, the Nildhara channel again showed signs of cutting out in 1888, the construction of a masonry weir across the Nildhara was begun on the line shown on Fig. 4.16.

In 1892, the weir was completed, and the length built in 1888 was lowered to 295 m (969.27 ft). It was attached to the marginal bund. This marginal bund had been advanced up the island and provided with a masonry spur head at the point of bifurcation **(Fig. 4.19).**The cross-section of the weir is given in Fig. 4.19.

4.4.11 Advantages of Combined Chilla-Nildhara Weirs

By combining the Chillawala and Nildhara Weirs, the total length of the level crest was 420 m (1,378 ft). This was capable of giving great relief in floods to the main stream at Bhimgoda and the works below that point. The main stream of the Ganga was directed on these weirs and was there deflected to the weir in a manner favourable to the bunds at Bhimgoda **(Fig. 4.20).** The position of the river was of great use in constructing and maintaining the Head bunds at Bhimgoda.

Fig. 4.15 Cross-sections of Chillawala Weir



Crest lowered to 969·27 in 1891
and to 968·77 in 1895.

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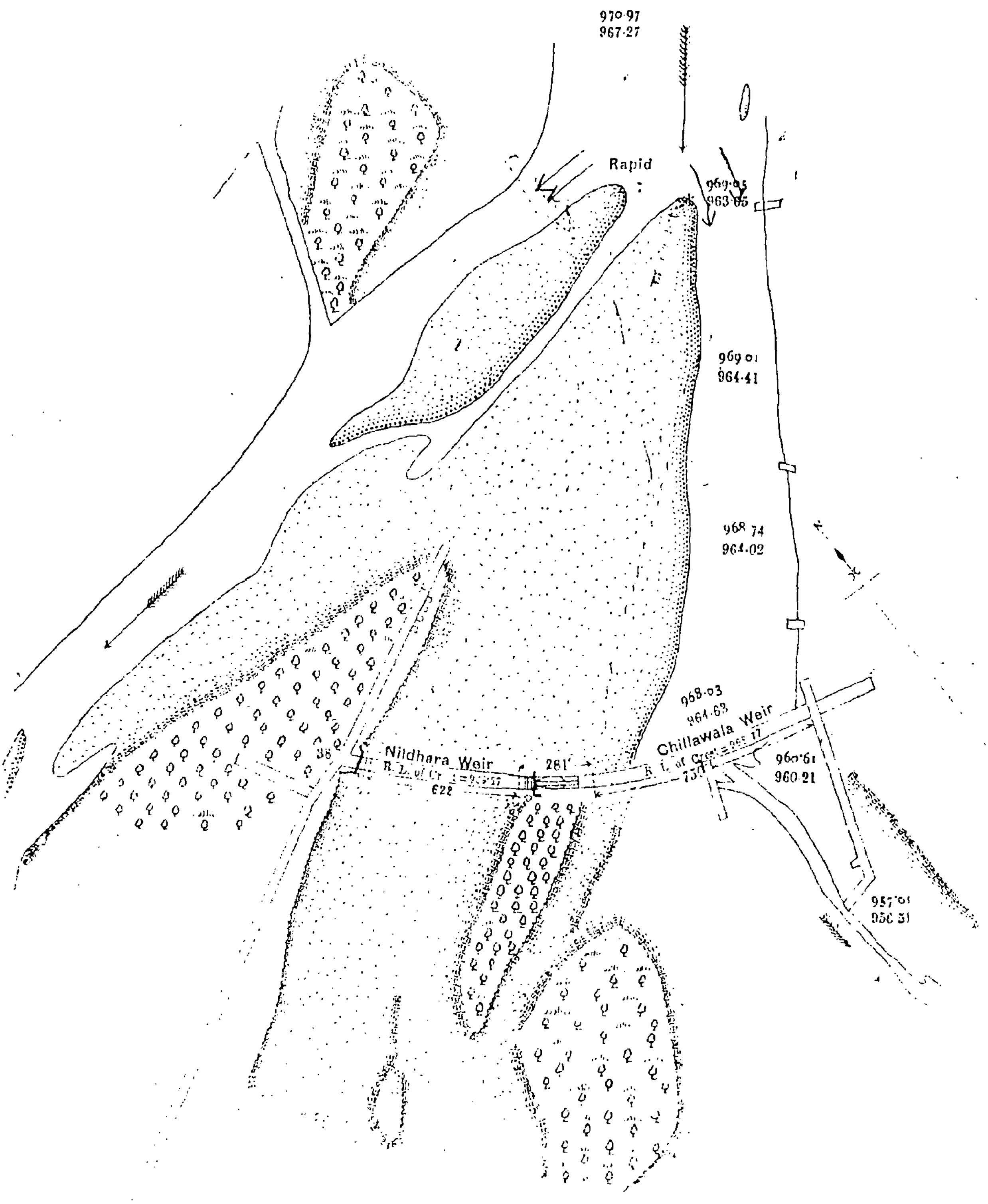
Fig. 4.16 Plan of New Nildhara and Chillawala weirs

Scale—525 Feet = 1 Inch.



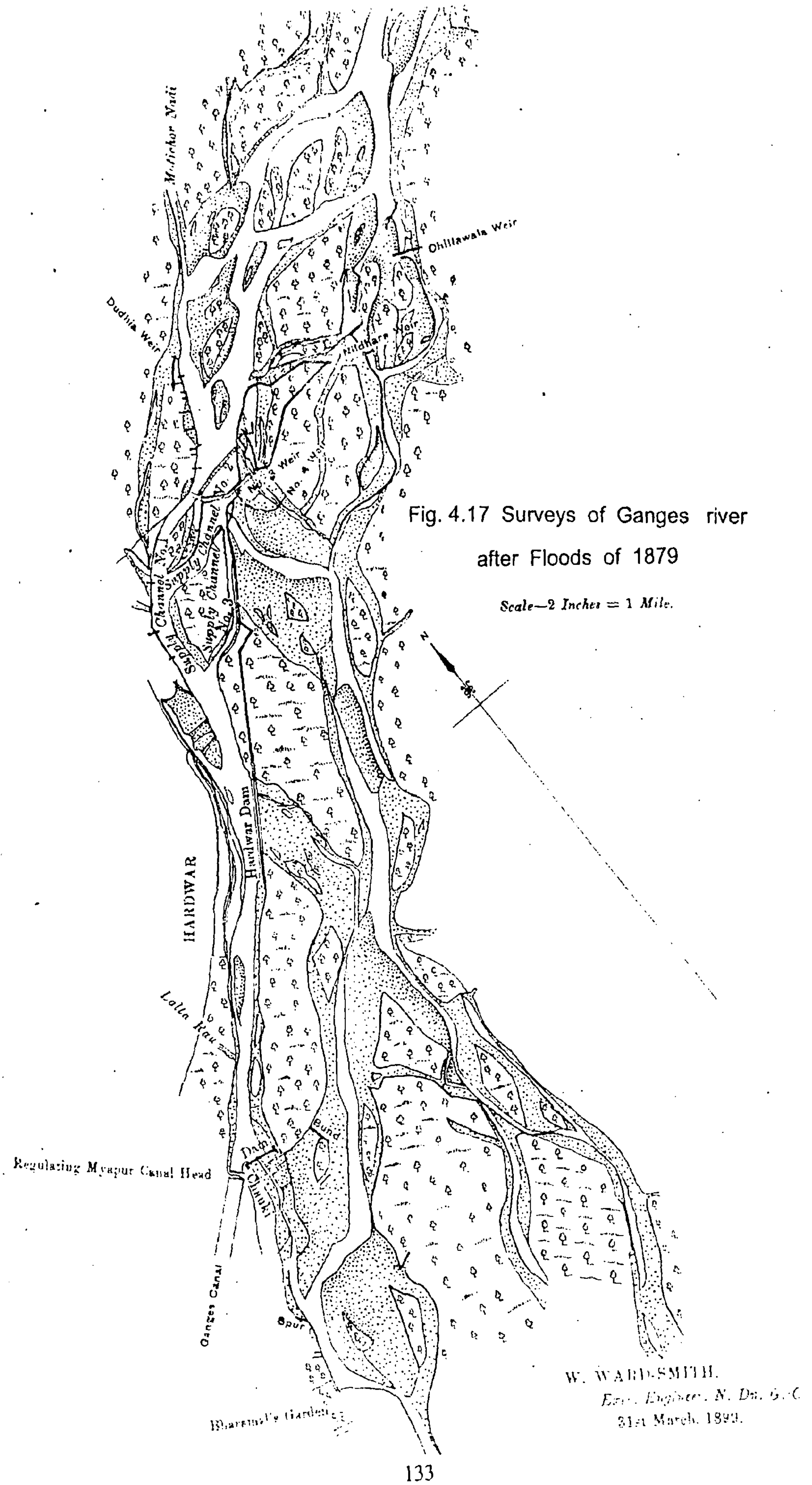


Fig. 4.17 Surveys of Ganges river after Floods of 1879

Scale—2 Inches = 1 Mile.

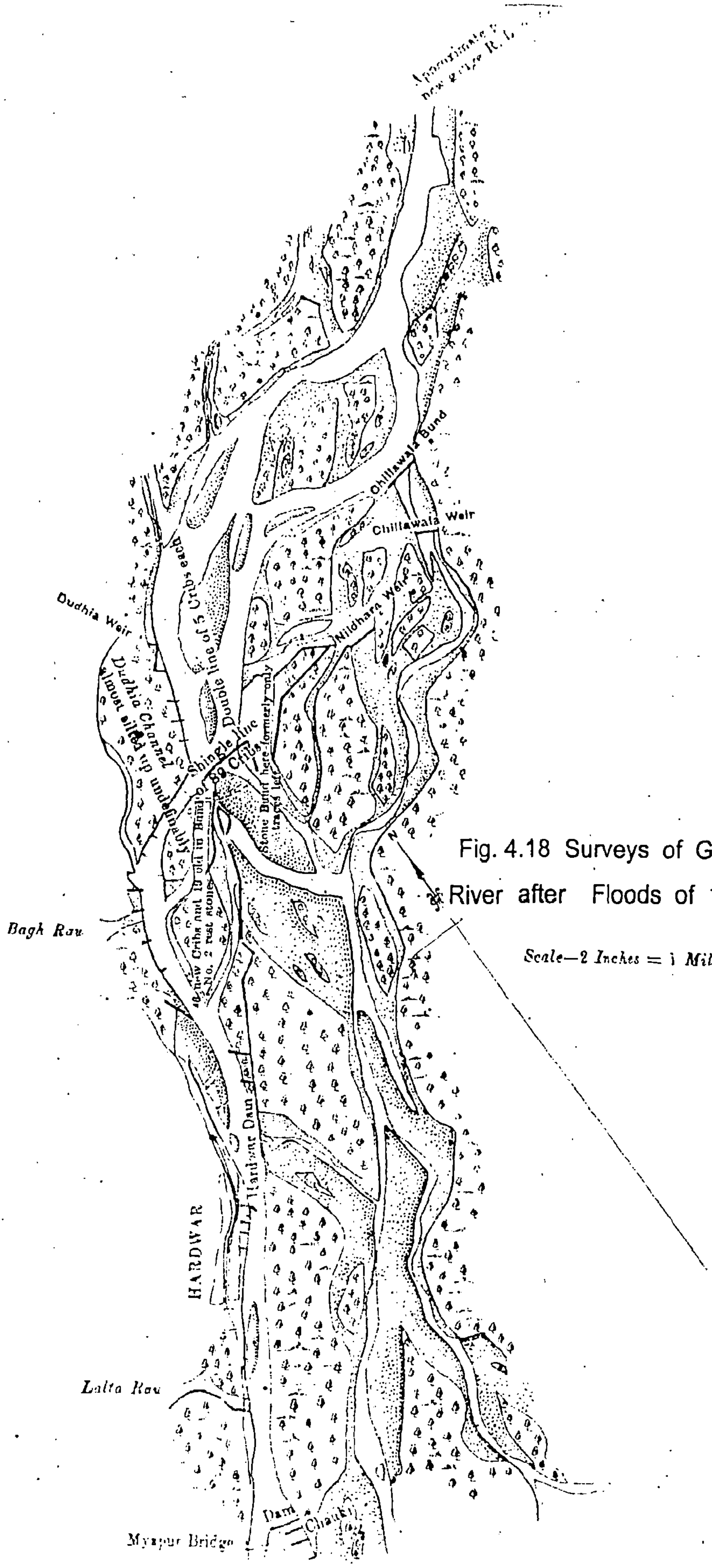


Fig. 4.18 Surveys of Ganges River after Floods of 1880

Scale—2 Inches = 1 Mile.

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Exe. Engineer, N. Dn. G. C.

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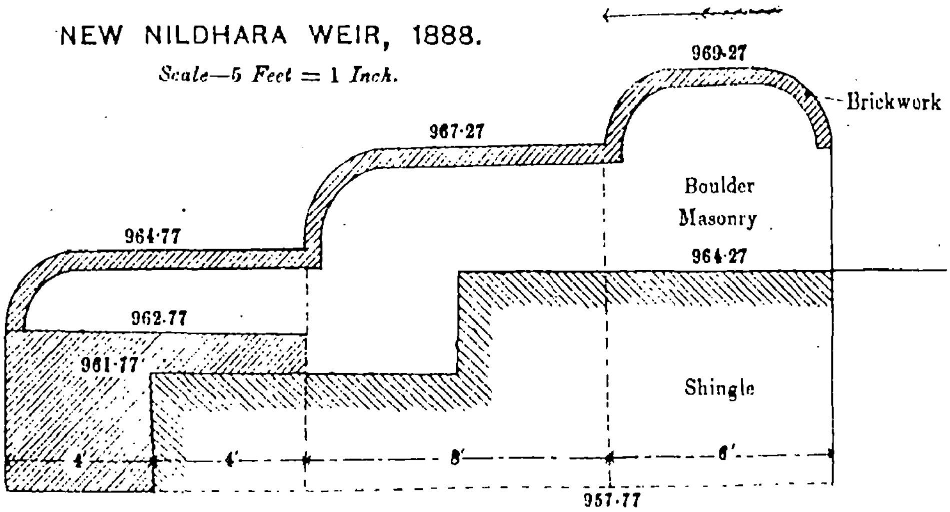


Fig. 4.19 New Nildhara Weir, 1888

It offered the following advantages:

(a) The Bhimgoda bunds could be begun at an earlier period after the floods, as the Chilla-Nildhara channels took off a larger position of the river supply.

(b) In freshets during the cold weather and when snow water came down in April or May, these channels were ready to give relieve to the Bhimgoda bunds and enabled to preserve them and the canal supply as long as practicable.

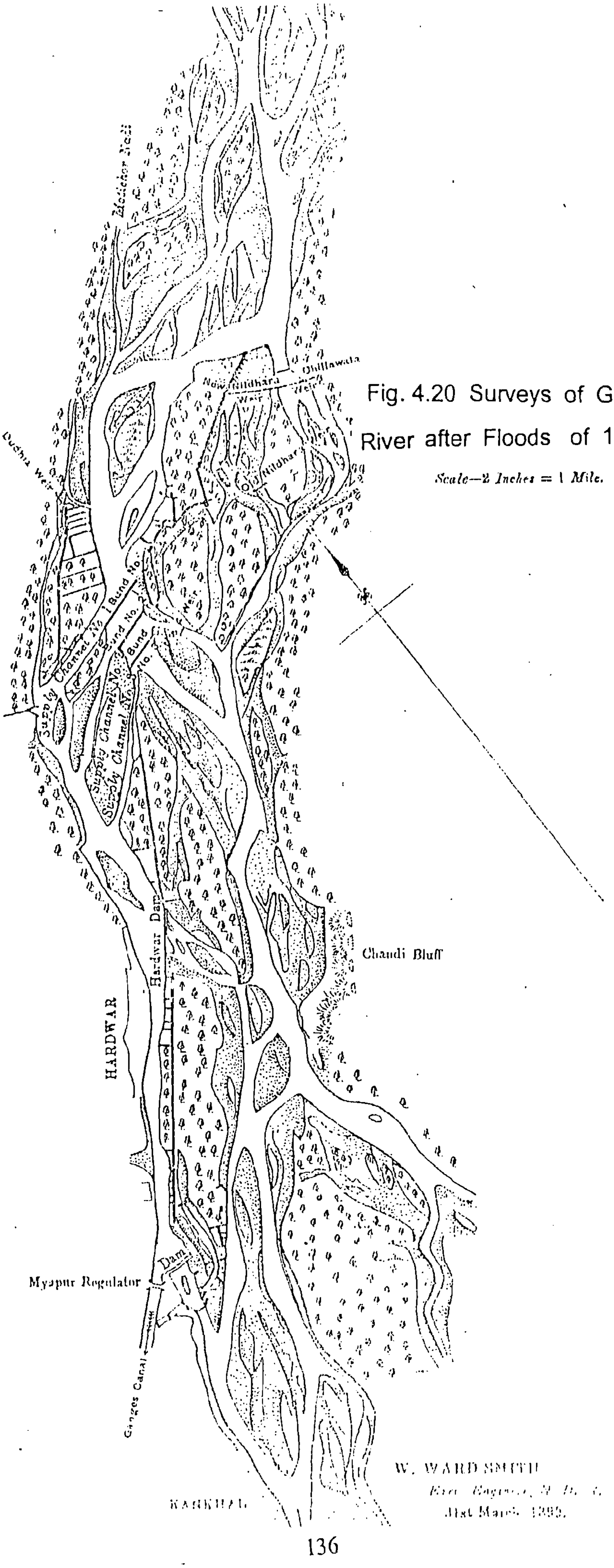


Fig. 4.20 Surveys of Ganges River after Floods of 1893

Scale—2 Inches = 1 Mile.

(c) In high floods, these channels took off a large fraction of the flood, and helped as a protection against bed erosion and other evils likely to be caused by an excessive volume in the main stream at Bhimgoda.

4.4.12 Gohna Flood : Its effect on the channel above Bhimgoda

There were two record floods - that of 1880 and of 1894 - the latter being the higher of the two , but not very much. The last record did not seem likely to be beaten. It was useless to work to average flood levels because these periodical excessive floods wrecked such works . Bunds, spurs and other works had been added to on the data of the Gohana flood observations.

The changes in the channels caused by the Gohna flood was obvious by comparing the surveys of 1893 and 1894 (Fig. 4.21 & Fig. 1.12). In 1893, the main stream headed on to Nildhara-Chillawala weirs. In 1894, the main stream above these weirs had deserted its old course and had taken to a channel on to the right of the valley, pointing directly on to the Bhimgoda bunds, by which change the utility of the Nildhara-Chillawala weirs was practically lost . But the survey of 1898 (Fig. 4.4) showed a slight working back to the old channels with the help of leading cuts and the Chillawala portion of the weirs was again in full work during floods, but the Nildhara portion still remained burried in shingle.

4.4.13 Gohna flood : Cause of Motichur Spur and Bunds

The Gohna flood had been the cause of the latest addition to the training works above Bhimgoda, namely the Motichur spur and bund on the right bank of the river (Fig. 4.4). A considerable amount of erosion on the right bank of the river took place, near the junction of the Motichur Nadi (Fig. 4.12). In 1895, it was pointed out that from the set of the river in that year, there was a possibility of further erosion as the banks were low, and during high floods over spill took place, following a direction west of the Dudhia weir, into an existing depression . If the main stream took to this course, the system of bunds and training works at Bhimgoda would be out of action, and there would be great difficulty in maintaining the supply. To avoid this trouble, the Motichur works were constructed **(Fig. 4.21).** The work involved a strong masonry spur 91.44 m (3oo ft) in length projecting from the right bank. On the bank was a boulder-pitched bund to prevent the spur being turned , and thereto was added a marginal bund. This work acted successfully . There had been difficulty in its maintenance.

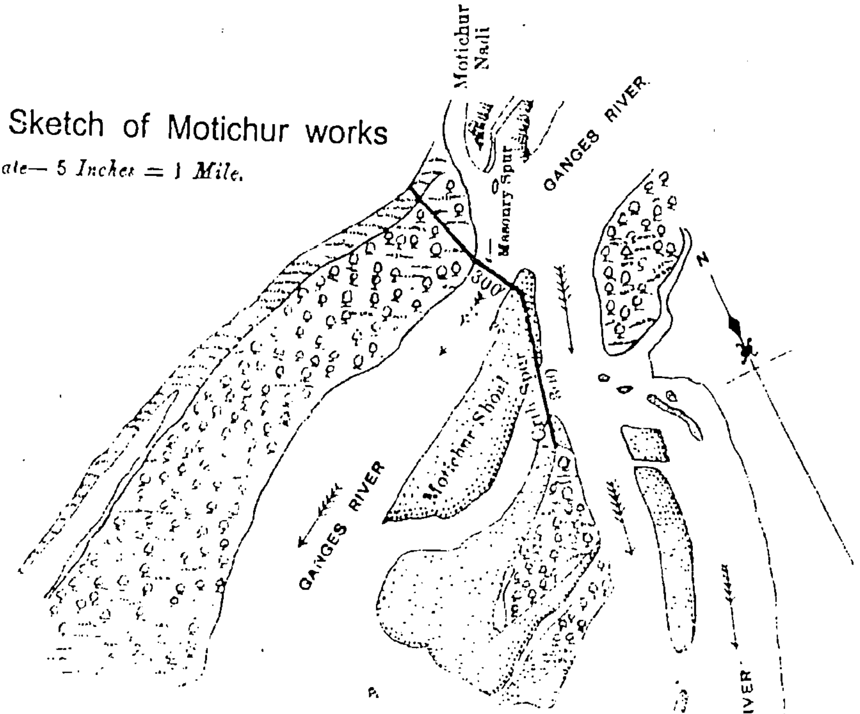


Fig. 4.21 Sketch of Motichur works

Scale— 5 Inches = 1 Mile.

4.4.14 Training Works Below Bhimgoda

There had been no training works on the river Ganga between Bhimgoda and Myapur. The supply channel from Bhimgoda to Myapur was generally considered in two lengths :

(i) From Bhimgoda to the Hardwar Dam.
(ii) From Hardwar to the Myapur Dam.

In Colonel Cautley's Report, the first was described as an important branch of the river. It was still that during floods, the river carried a large volume obtained from the following sources :

(i) The Motichur spill,

(ii) The Dudhia spill,
(iii) No.1 supply channel,
(iv) No. 2 supply channel,
(v) The broad shallow spill over No.3 supply channel,
(vi) The Sukh Rao from the Siwaliks,
(vii) The Bagh Rao from the Siwaliks.

The greater part of this water was returned to the main stream by means of the Hardwar Dam and channel, and a part of it passed down the second reach. The second reach received the flood water of the Lalta Rao and other small drainages from the Siwalik hills, too. In the rains, the volume passing over the Hardwar Dam was up to 1700 cumecs (60,000 cusecs), and that passing over the Myapur Dam was up to 850 cumecs (30,000 cusecs). No accurate estimate could be made as the floods brought down trees and debris which obstructed the works.

A marginal bund had been constructed from the upstream wing of the Hardwar Dam, in the direction of supply No. 3. along the Laljiwala island. The origin of this marginal bund dated back to 1876, and its purpose was to prevent the formation of fresh spill channels from the supply channel to the main stream across the island, which would entail further protective works to prevent the Hardwar dam from being out-flanked. The floods of 1880 and 1894 proved the necessity for this bund. On each occasion, it was breached and on each occasion, it was raised and strengthened.

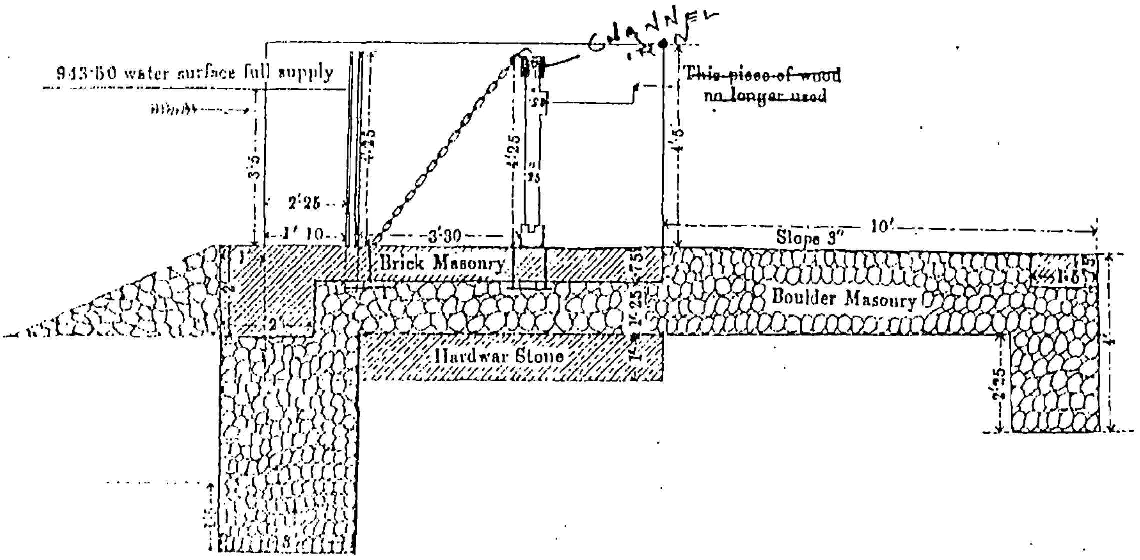
4.4.15 The Hardwar Dam

Initially in 1859-60, the Hardwar channel was closed with an ordinary boulder and shingle bund, which was fair evidence of a broad shallow channel. But there was soon a deepening of the channel, and in 1861-62, a crib bar was commenced at the head of a rapid which was cutting back below it. In 1862-63, the records showed that " the protective work placed last year in the bed of the Hardwar channel stood well, a good supply was not only maintained in the canal, but the work required to be done to the bund was much less than usual." From 1862-63 onwards, there were additions of crib work to maintain the level of the exit of the Hardwar channel.

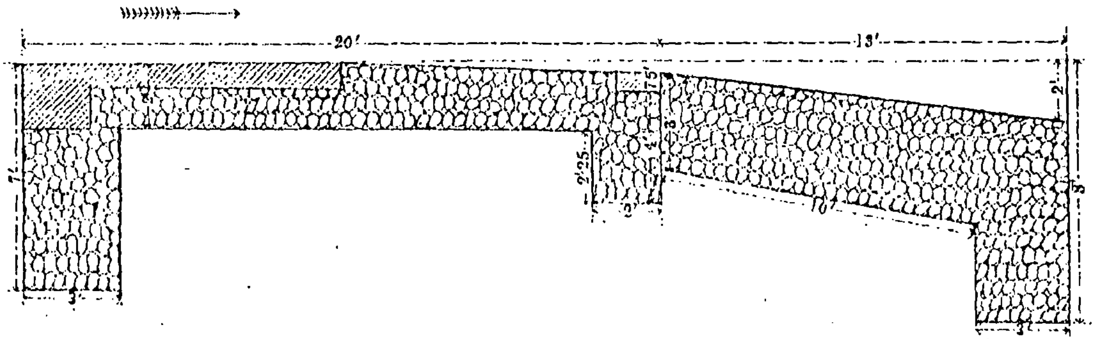
In 1870-71, a design for a masonry dam across the Hardwar channel was prepared by **Captain Colin Scott-Moncrieff, R.E.**. In 1872-73, the Hardwar masonry Dam was constructed, and in 1873-74 Captain Western wrote - " The Hardwar weir has practically remained in the same state as 1872-73 left it, owing to no decision having been arrived at regarding the form of gates or shutters to be erected." The records showed the proposals for gates for the Hardwar dam which was finally settled in favour of a drop-gate, hinged at the floor. The section of weir as constructed in 1872-73 is shown in **(Fig. 4.22 , diagram 1)** .

Fig. 4.22 CROSS SECTION OF HARDWAR DAM, 1876.

Scale—4 Feet = 1 Inch.



SECTION SHOWING ADDITIONS TO HARDWAR DAM, 1879.

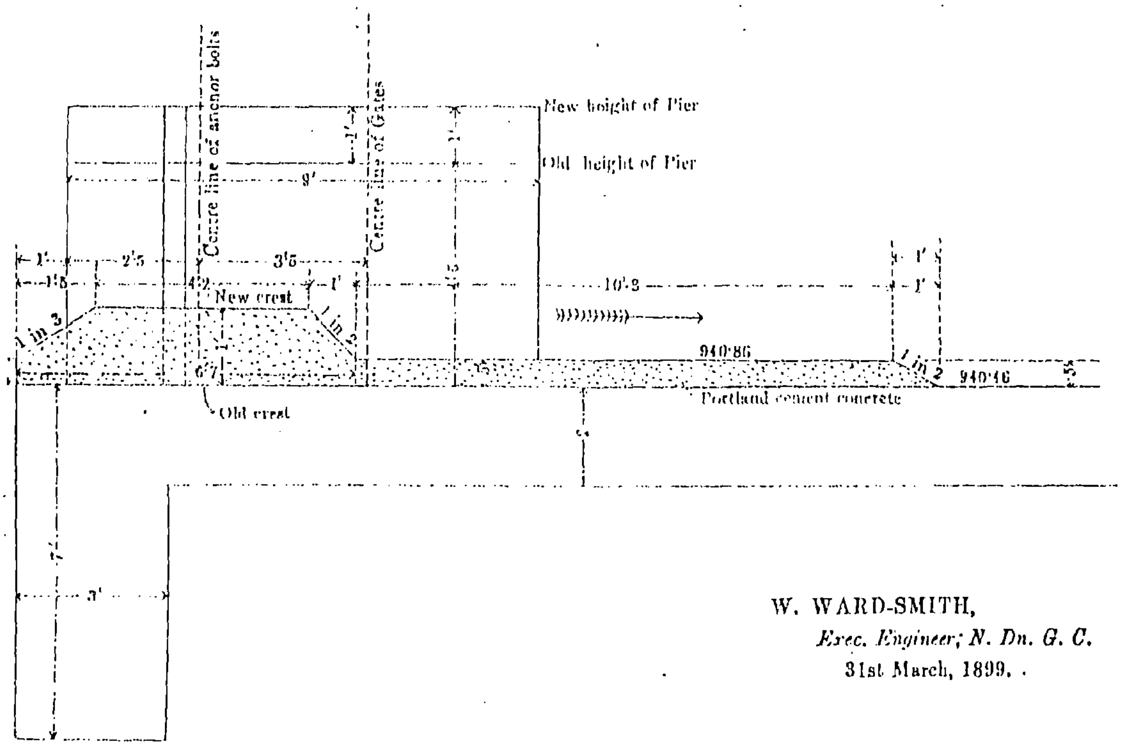


Between 1876 and 1879, the action below this dam gave trouble and in 1879, **Captain R.P.Tickel, R.E.** added the sloping masonry extension **(Fig. 4.22, diagram 2).** At this stage, the dam consisted of five bays of 53.64 m (176 ft). Each bay was fitted with 22 drop-gates, 2.44 m in length and 1.30 m high - making in all 110 gates on an open crest 268 m in length.

As mentioned earlier, the volume passing over the Hardwar Dam was 1700 cumecs and over the Myapur Dam was 850 cumecs; thus, the channel between Bhimgoda and the hardwar Dam was estimated to carry 2550 cumecs in very high flood. The hardwar Dam was practically midway between Bhimgoda and Myapur.

In flood, with the sudden reduction of volume occurring in the supply channel by the lateral escape over the Hardwar Dam, heavy shingle deposit took place at the head of the second reach of the supply channel immediately below the Hardwar Dam. This gave frequent trouble and

CROSS SECTION SHOWING DAM AS RAISED IN 1888 TO 1890.



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Exec. Engineer; N. Dn. G. C.
31st March, 1899.

clearance was necessary. The difficulty was that the Hardwar Dam gat were liable to be topped by less than the full supply level of the can Continued shingle deposits had modified the condition of the supply chann and as a complete clearance of the channel was not practicable withou closing it, a re-adjustment of the crest levels was made in 1880 to 1890. This was done with Portland Cement Concrete **(Fig. 4.22, diagram 3).** After this raising, the levels of crest above the gates were as shown in **Fig. 4.23.**

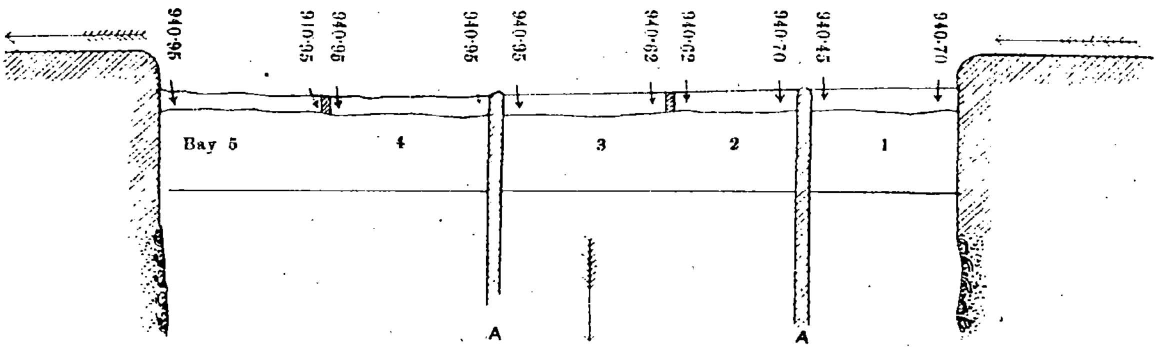


Fig. 4.23 Levels of Crest above the Gates

4.4.16 Effect of the Gohna flood on the Hardwar Dam

Between 1881 and 1894, the method of filling up scoured places with crates was abandoned and concrete blocks were used instead. This added greatly to the permanent character of the protection , and the work was in a strong condition when the Gohna flood once more brought the Hardwar Dam into severe action . The upstream flank was once more undermined, turned and wrecked, whilst the downstream one was very much damaged. The upstream wing was again re-built on the debris and raised a further 0.61 m and the Hardwar Dam was once more in full work. With all modifications, the dam had six bays of 53.65 each and a total length of open crest . It had 132 gates 2.44 m by 1.30 m **(Fig. 4.24 & Fig. 4.25).**

Fig. 4.24 Hardwar Dam Cross-sections

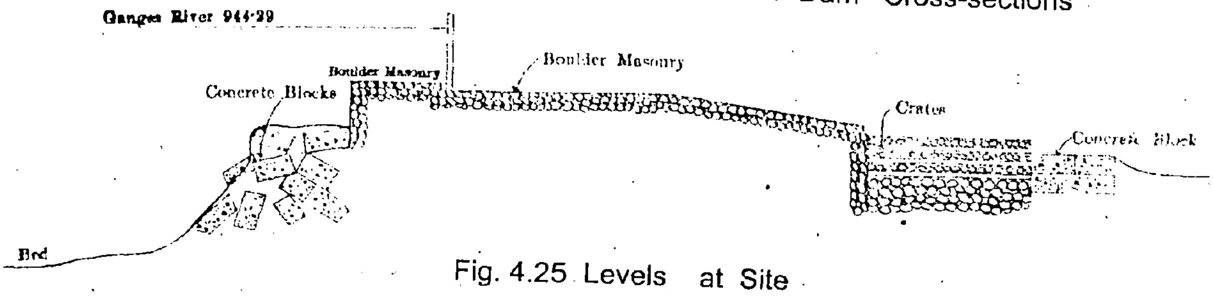
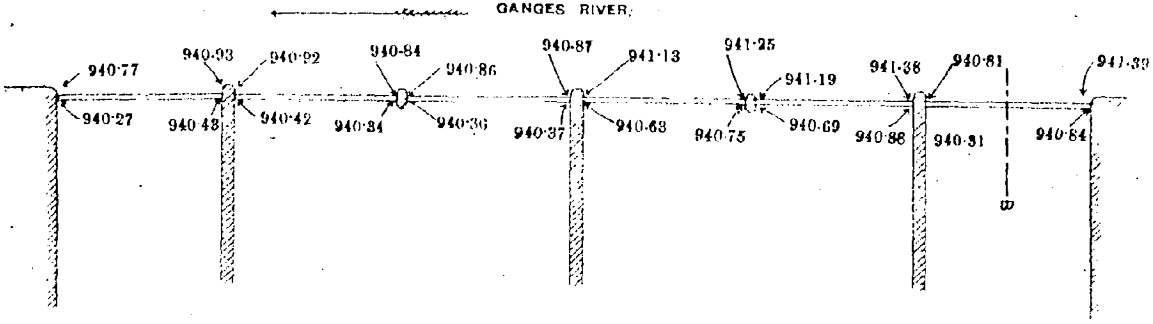


Fig. 4.25 Levels at Site



Working the gates of the Hardwar Dam had always been a dangerous undertaking to the men employed. Once the gates were topped, it was most difficult to drop them and when raising them, they had to work in a strong stream of water and in period of floods their lives were sometimes endangered.

4.4.17 Second Reach of the Supply Channel

The second reach of the supply channel is from the Hardwar Dam to the Myapur Dam. On its right, it has the town of Hardwar, the Lalta Rao, the high cliff leading to Ganesh Ghat and the right revetment of the canal head. On the right, the Hardwar front has been much improved by a masonry terrace and steps. The Lalta Rao had given little trouble; it had brought a quantity of light shingle into the supply channel each year, but this had been passed down the river by the larger volume of the supply channel.

The Belwala island on the left of the supply channel was of great importance to the Ganges canal because it separated the supply channel from the main stream of the Ganges. The left bank of the Myapur Dam rests on this island, and the destruction or extensive breaching of the island would necessitate changes in the method of obtaining the supply of the Ganges canal.

The Belwala island did not seem to have been seriously affected by flood till 1880. Along the supply channel from the Hardwar Dam to Myapur Dam, there was a marginal bund which was strengthened and thereafter followed the cross-bunds. The record of measures to check erosion was continuous up to the end of 1897-98 **(Fig. 4.26).**

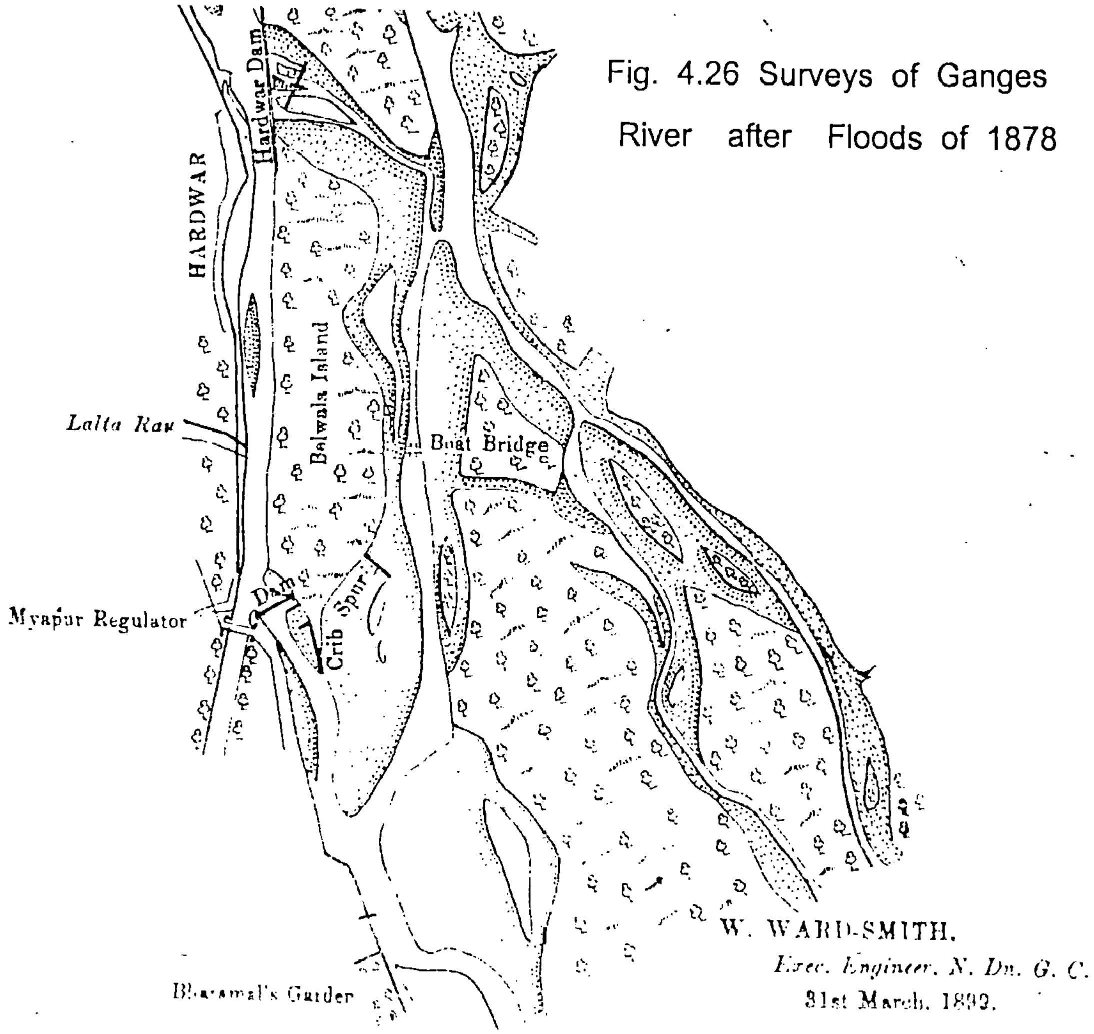


Fig. 4.26 Surveys of Ganges River after Floods of 1878

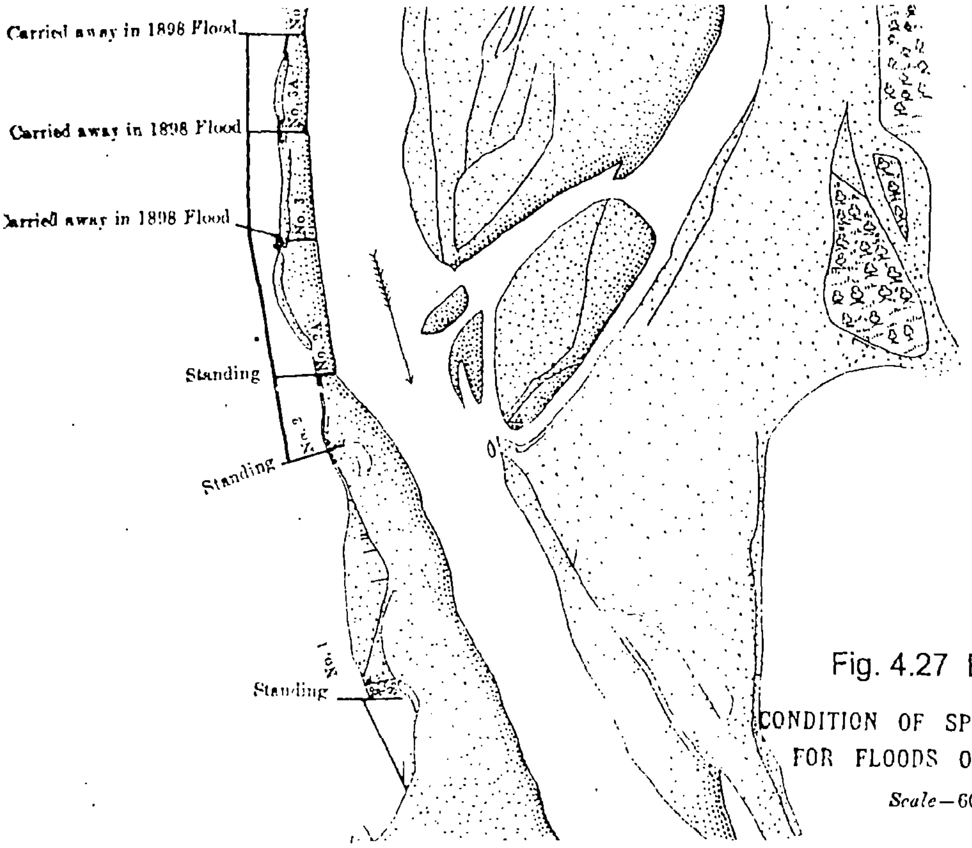


Fig. 4.27 Belwala Spurs

CONDITION OF SPURS IN PREPAREDNESS FOR FLOODS OF 1898 AND RESULT.

Scale—600 Feet = 1 Inch.

The River Survey Plans from 1880 to 1893 showed the action of the river on Belwala island gradually intensifying; but in 1894 the Gohna flood forced the main stream under the Chandi bluff (Fig, 4.13). From this natural spur, the river was deflected, with an excessively strong set, directly on the Belwala island and the system of spurs had been constructed to resist the action of a natural spur on the opposite side of the stream. It was, in fact, an effort to limit erosion on the island till natural causes lead to a change in the run of the river. **Fig. 4.27** & **Fig. 4.28** show the protection of Belwala island.

4.4.18 The Myapur Dam

The Myapur Dam was the only masonry work in connection with the Ganges river at the time the canal was opened. **Fig. 4.29** shows the original position of the branch of the Ganges and the manner in which

The Myapur works were located relatively to the original streams at that site.

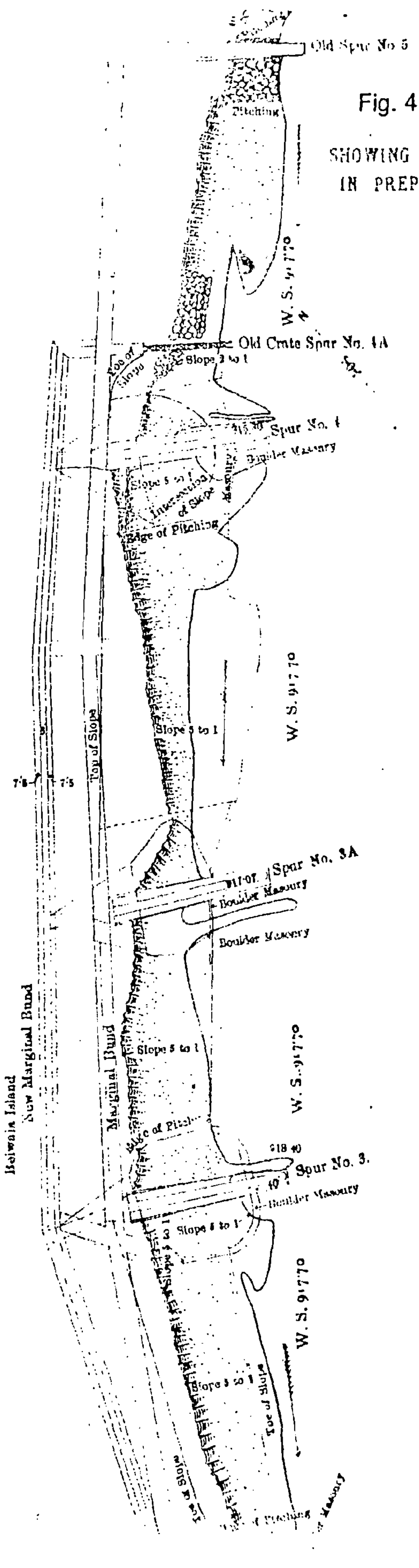


Fig. 4.28 Plan of Belwala Spur

SHOWING SPURS CONSTRUCTED IN 1898-99
IN PREPARATION FOR FLOODS OF 1899.
Scale—150 Feet = 1 Inch.

The supply channel, approaching the dam was excavated to a width of 91.44 m (300 ft) and a slope of 1.63 m/km (8.59 ft per mile). On this slope also the escape channel towards the main river at Kankhal was excavated. The left flank of the dam abuts on Belwala island which was composed of compact earth and shigle and afforded a sound and sufficient resting place for the flank walls. The high spoil on the left flank of the dam was from the original excavation.

The dam itself was 157.58 m (517 ft) between the flanks and was pierced in its centre by 15 openings of 3 m (10 ft) wide each, the sills or floorings of each opening being raised 0.762 m (2.5 ft) from the zero line.

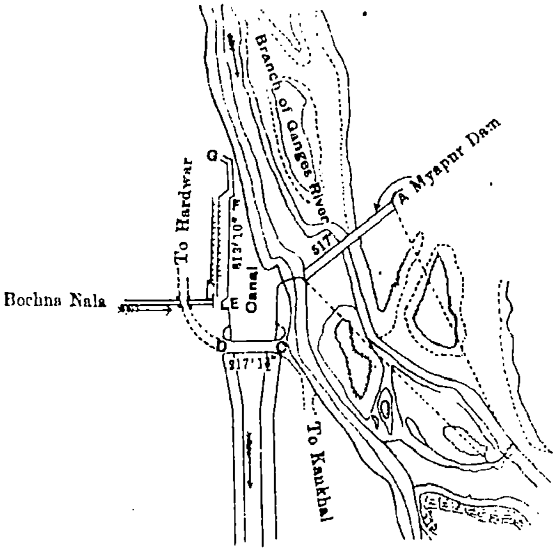


Fig. 4.29 Location of Myapur Works

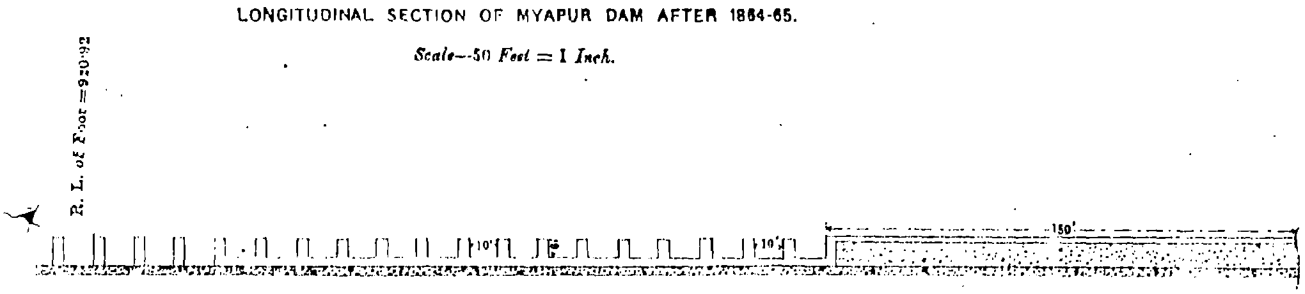


Fig. 4.30 Longitudinal Section of Myapur Dam after 1854 - 54

The Myapur Regulator floor was the zero datum of all the original Ganges canal levels.

The shingle deposit above the Myapur dam led to the many alterations to the original work. In floods, the Ganges brought down, by ersion of its woooded banks, large quantities of grass, shrubs, and trees of alll sizes, carried along by the force of the stream. To these were added logs, sleepers and other forest produce.

There was no difficulties met with at the Myapur dam till 1862-63. In 1864-65, the first modification to the Myapur Dam was made because it was recorded that the deposits of silt above Myapur Dam and Regulator was getting troublesome and necessitated improvements to the dam by substituting piers and openings, fitted with falling gates for the original solid portion of the right flank **(Fig. 4.30)**.

LONGITUDINAL SECTION OF MYAPUR DAM AFTER 1870-71.

Fig. 4·30(a)

Shingle still accumulated in spite of clearance. This led to next alteration to the Myapur Dam **(Fig. 4.31).** It was decided in 1869-70 to raise the dam and piers 0.61 m (2 ft) and so lift the supply over the lower deposits. It was found very difficult to lift the gates from stones and pieces of wood jamming under the hinge of the gate . To fend these off, the upstream sill abutting on the gate was raised 0.15 m (6 inches) (Fig. 4.31). In 1872, a new regulator construction across the canal head was proposed on line AB **(FIG. 4.32)** with an object to cut-off the pocket between that line and the Myapur Regulator, from shingle deposits brought down by floods.

The great flood of 1880 once more showed that the Myapur Dam was unsuited to the locality. The whole dam was blocked by trees, logs, sleepers or even roofs of the houses. The shingle deposits upstream were high and extensive, necessitating very heavy clearances before the canal could be re-opened. At the same time, the heading up endangered the canal itself, in that the water washed over canal roadway. As a result, the Myapur Dam was again altered between 1883 and 1884.

The Myapur Dam consisted of seven bays of 6.0 m width with floor at 281.00 m , and 272 lineal feet of spill weir with a crest at R.L. 283.00 m . this spill weir was fitted with 34 drop gates 2.44 m (8 ft) in length and 1.52 m (5 ft) high; they are the most difficult to work and all regulation was done with the 6.0 m (20 ft) gates. It was only in floods that the drop gates were lowered.

Fig. 4.31 Myapur Alterations , 1872 -73

Scale—2½ Feet = 1 Inch.

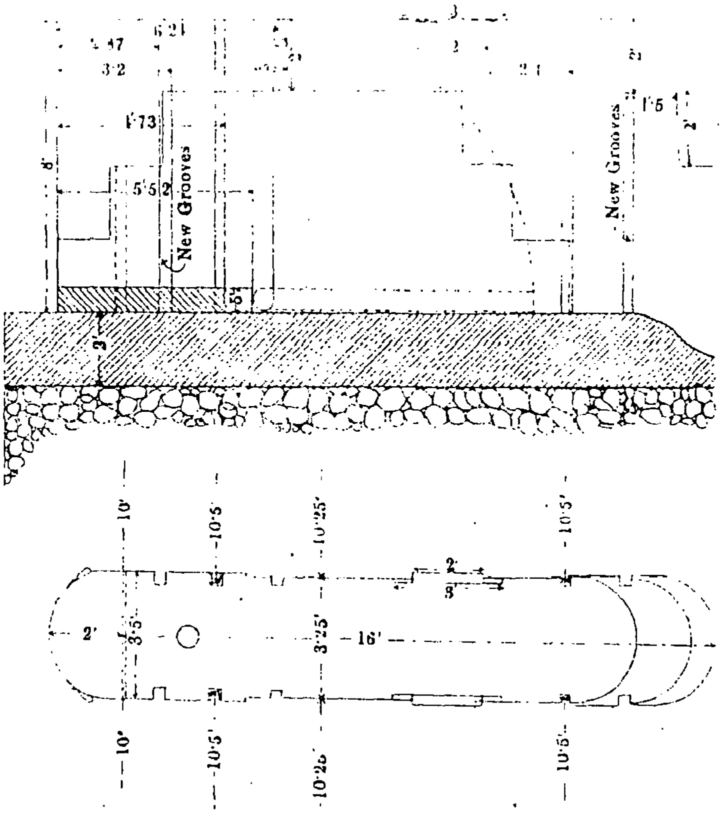
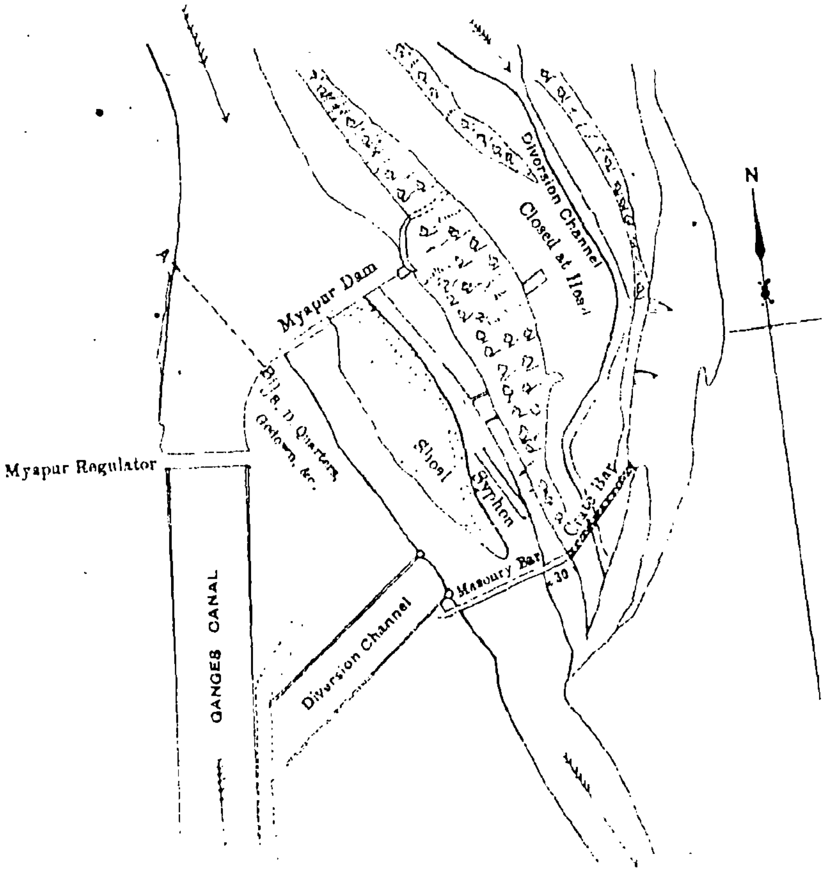


Fig. 4.32 Myapur Dam Plan



4.4.19 Situations till 1917

- In 1894 Gohna floods, part of the marginal bund built in 1992-93 was swept off clean and spur no.1 completely destroyed. Necessary repairs were done.
- There occurred a land slip in September 1893, near Gohna village in Garhwal district some 241.4 km (150 miles) above Hardwar, which formed an immense dam across the Biraha Ganga river, a branch of the Ganges, behind which a great lake was rising , this dam was likely to yield or to be over-topped any time and thus formed an impending danger to Ganges canal Headworks. A crate bund was erected commencing from the right flank of the dam.
- In 1905 monsoon, it was noticed that the Nildhara and Chilla channels were not taking their shares of floods and most of the water was thus flowing down the Bhimgoda channel and thereby making it hard to maintain crates in head bunds at supply channels.
- The headworks consisted of a weir 548.64 m(1800 ft) long divided into six bays of 91.44 m (300 ft) width each, in a line with the weir and on the right flank there were six undersluices of 15.24 m (50 ft) span each fitted with stony gates of 3.66 m (12 ft) height.
- The weir was designed to pass a maximum discharge 15434.4 cumecs (5,45,000 cusecs) made up of approximately 2854.66 cumecs through the undersluices.
- To facilitate the construction, a power plant was erected at Bahadrabad about 11.27 km (7 miles) below Hardwar, where two falls were combined to give a total fall of 5.80 m (19 ft) and there 150 kw alternators were installed.
- The total electric energy consumed n during the construction of the work was 24,94,470 units amounting to Rs. 3,11,808.

- The new Regulator was never used as a regulator, as the Hindus community objected to the Ganga water to be fettered and controlled above Har-ki-pauri. Therefore, it was ultimately decided to leave the work as a Regulating bridge only and to arrange to feed Har-ki-pauri with 28.32 cumecs (1,000 cusecs) in the old supply channel, for which purpose a temporary fund of crates was put in every tear.
- During the construction of the work two unforeseen accidents happened, which hampered its progress considerably - the first was the great war that broke out in 1914; and the second was the severe influenza epidemic that followed the war; labour became extremely difficult to obtain.
- In 1917, the Bhimgoda bund breached on 7th June. Bunds nos. 1 and 2 were built higher.

4.5 DIVERSION FROM BHIMGODA WEIR AND IMPROVEMENT IN TRAINING OF RIVER (1917 - 1980)

- In 1922- since the new weir at Bhimgoda had started functioning, only one bund used to be built to feed the old supply channel soon after the closing of the monsoon. 17 crates of this temporary bund had been washed away on 16 th July and on 18th July, the whole bund was finally wiped out on 19 th July with the Bhimgoda gauge at 2.44 m (8 ft). Some of the gates of the weir had worn out very much and needed being replaced. The wear and tear of the gates was rather high due to heavy boulders and shingle that was brought down by the floods.
- 1924 stands out in the history of the headworks as the year of the highest gauge was recorded at Raiwala as high as 9.75m (32.0 ft) on 29 th September.
- It was due to the construction of the weir at Bhimgoda that the gauge in Myapur exceeded as in 1894. On 28 th September, the flood

level had reached the top of Kankhal bund near the centre of its length and the bund was overtopped and 1219 m (4000 ft) of its length was washed away. At about the same time, stone masonry wall of Bhimgoda spur no.1 was topped, resulting in the scouring action at the toe of the afflux bund and in its eventual breaching below spur no.1.

- In 1929, weir bays were taking most of the discharge in the river above the weir due to the crest in bays nos. 3 and 4 having been raised. Bay no.2 was taking 50 percent more than no.1 being nearer to bays nos. 3 and 4 and a cross current was noticeable in front of bays nos. 1 and 2. There was no damage to this work worth mentioning.
- In 1935, the right bank of the river in Kankhal from Bharamal's garden and below it up to Patiala House was seriously eroded by the action of the river. The erosion was a menace to the town. To safeguard against this 69 crates were made in the form of crescent along the bank.
- In 1949 - 50, the monsoon on the whole was not very heavy and the total rainfall recorded at Bhimgoda was 147.32 cm (58 inches). It was again a year of low floods and the maximum Raiwala gauge recorded on August 9, 1949 was 6.27 m (20.6 ft) corresponding to a discharge of 5834 cumecs. As the river discharge remained in the boulder - moving stage only for about 3 weeks; the damage to the headworks as a whole was light.

The three channels past the left flank spurs opposite Dudhia Bund and so the Motichur channel continued to show signs of further development and need to be kept under watch. There was, however, no serious damage on the Dudhia and the Motichur Bunds.

This way, the damages caused to bunds etc. happed off and on thereby disturbing the canal supply as well as river safety which were repaired as much as possible and the canal supply continued.

4.6 CONCLUSION

It had been always questionable as to the above method of obtaining the Ganges canal supply was the best and economical . There had been doubt as to whether it was the best method in the early period after the opening of the canal. Later on, the thoughts of the officers of those days turned in the direction of permanent weir across the river. In the present day, its advantages and defects are known and it is concluded, in my opinion, the former method is still the more weighty.

There is, therefore, no new purpose to give as part of the intentions of the present day. As in the past, so now, the object is mainly to present the method of obtaining the canal supply in the direction of security and economy.

The objects are mainly :

(i) To bring the main stream of the river between Raiwala and Chillawala back to a course to the left of the valley, so as to obtain full benefit from the escaping power.

(ii) To further limit the volume passed into supply channels at Bhimgoda.

(iii) To improve the outfall from the Hardwar dam to the main stream of the river.

(iv) To defend and secure Belwala island from further erosion; and for this purpose to withdraw the main stream of the Ganges from the Chandi bluff.

(v) To improve the outfall at the Myapur Dam and thereby to reduce shingle deposits above it.

CHAPTER - V

SURVEY OF TECHNICAL LITERATURES CONNECTED TO TRAINING AND CONTROL OF RIVER FOR DIVERSION OF IRRIGATION SUPPLIES WITHOUT PERMANENT DIVERSION WORKS

5.1 INTRODUCTION

In the primitive times, though there was not absolute control on the rivers, however, river training by embankments for flood protection has a long history and must be one of the earliest engineering achievements of man. The earlier history records the embanking of the lands of the River Nile by the Egyptians. The city of Babylon was protected by levees. In China, unsuccessful attempts were made to dyke the overflowing banks of the Yellow River as early as the beginning of the Twenty-third century B.C. . Other rivers like the River Po in Italy, the Euphrates and the Tigris in Iraq and the Indus and the Ganga in India present early attempts at dyking .

In the East, the first attempt at river training consisted of retired embankments constructed across spill channels. The river was confined to flow in a single deep channel by groynes projecting from the river banks, designed to prevent erosion. In the last century, the rivers necessitated construction of the wider river channel at the site by guide banks to control and direct the flow through the weir openings.

In U.S.A., rivers were trained for increasing their flood carrying capacity, for example, the lower Mississippi, where the lower course was shortened to reduce the high flood levels and duration of floods.

5.2 PRACTICES OF CONTROL AND DIVERSION OF RIVERS USED IN CHINA

5.2.1 General

China is located in the southeastern of the Eurasian continent. There are about 5,000 rivers each with basin area larger than 100 square km. Among them more than 1,500 rivers are with basin area larger than 1,000 square km. The majority of the rivers in China are fed by rainfall. Some are fed by snow melt in spring and rainfall in summer and autumn. In addition, there are some rivers partly fed by glacier melting water (Fig. 3.1).

The longest length river in China is Yangtzem i.e. 6,300 kms. Amongst the world's largest river, the Yangtze river is next in length i.e. only to the Neil river in Africa (6,500 kms). The Heilong river is the second and the Yellow river is the third largest of the basin areas in China.

In China, the rivers in the mountainous area often flow through gorges and stretch of flat land alternatively with many sharp and narrow passages. The rivers in plain areas are smooth and straight, but the main current is always of winding, meandering and branched patterns.

The history of China reveals that achievement in harnessing and regulating water was an important condition for becoming a political leader or head of state at that time. There is an instance during 2200 B. C. to 2100 B. C. that in the Xia. Dynasty an ordinary citizen "YU " was made the King of that Dynasty . The reason behind this was that he could successfully control the flood caused by the river Yellow at that time. That great "YU" used **the method of dredging and diversion instead of blocking the river.**

The western modern science and technology including the hydraulic engineering and technique were introduced to China since the late 19 th century. After its founding in 1949, the peoples republic of China faced with sharp increase of population and lingering impacts of drought and flood calamities - the situations which carried through from the mid Qing Dynasty. According to the historical records, in the time span of 2155 years, starting from 206 B.C. to A.D. 1949, there occurred 1,029 big floods and 1,056 several droughts - totalling 2,085 disasterous events, almost once a year.

Construction of Dykes for flood defence started very early in China. The dykes of the Yellow River came into existence in Waring states period. The flood defence dykes of the Yellow River were built as early as 600 B.C.. This river has experience of breaches and rehabilitation many times in history. The dyke is snaky along the Yellow River banks having a total length of 1583 kms along both banks **(Fig.5.1)**. The dyke has a normal height of 10 m and maximum height of 14 m which narrows the Yellow River forming a famous " suspension river on the earth ", the river bed of which is higher than the grounds more than 10 m.

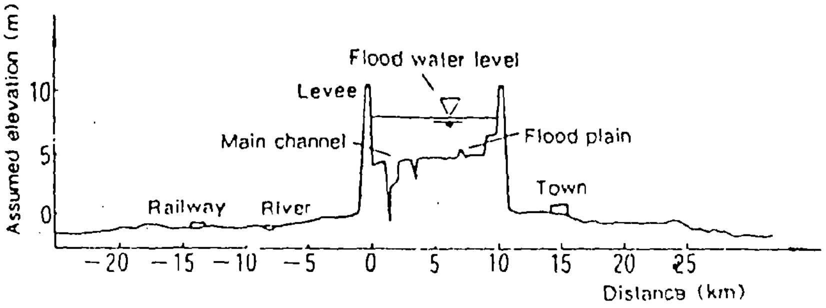


Fig. 5.1 Schematic Diagram of the "Suspension River" of the Lower Yellow River

The main dyke of the Jinjiang river, one of the major flood defence on the Yangtze River is located downstream of the Gzehouba hydro project with a length of 182 km. It was built in A.D. 345 acting as mainstay flood defence dyke project to protect the famous food grain barn in China covering the Jiang-Ham plain and important city of Wuhan in central China .

5.2.2 Training of the Dujiangya Weir (China)

In 1972, Chinese chairman Mao Tse -tung stood on the "Happiness Platform", on a natural bluff high above the Minjiang River, and marvelled at the feat of engineering, ingenuity and historical significance below. Overlooking the city of Dujiangyan, he praised the work of the ancient Chinese who designed and built the waterworks that still operate after 2,300 years.

The Dujiangyan weir is located in the vicinity for Guanxian country i.e. in the trasitional zone from the northwest Sichuan Plateau to the southeast Sichuan Basin at the juncture between the mountains of Longmen and Quionglai and the Chengdu Plain of compound alluvia. Sichuan province, where the Minjing River, flowing into the Chengdu plain, was built in the period of 256 B.C. to 251 B.C.. It is the world - famous diversion project built in ancient time having the longest history and being still in smooth function today.

River valleys are primarily controlled by tectonic forces, but are banked by alluvia, which constitute the river flats and first terraces of sandy soil and sand - gravel beds. A major fault penetrates the valley.

This region has a temperate, humid, monsoon climate and receives 1,258 mm of mean annual rainfall. The middle latitude location of the region still makes it susceptible to periodic flood and drought episodes.

This nearly 2,300 years old large scale Dujiangyan Water

Conservancy Works is located on the dividing line between the upper and middle reaches of the Minjiang River. The project provides a solution to a series of complex plains in Water Conservation engineering and technology, such as diversion, division, spill water and sediment discharge.

Libing took advantage of the high southwest and low southwest relief as well as an existing sandbar in the river to begin the initial layout. Designed without a dam for water diversion and under the general plan of water diversion for irrigation and flood diversion for disaster reduction, the conservancy works were built at the throat of the Western Sichuan Plain . The designed irrigation diversion (or inner river) feeds 30,000 canals that irrigate farmland in 30 municipalities and counties, directly benefiting an area of more than 730,000 ha with a mean agricultural yield of 9 kg / ha .

5.2.2.1 Design and construction

The Dujiangyan Project is mainly composed of three parts viz. The fish mouth (division dike), the sediment discharge weir (spillway) and the Treasure Bottleneck (division intake) i. e. the three major components are diversion structures (Yuzui), overflow structure (Feishyan) and intake structure (Baopingkau). There are auxiliary structures such as Dyke (Jingangi) and V-shaped dyke (Renzid) **(Fig.5.2).**

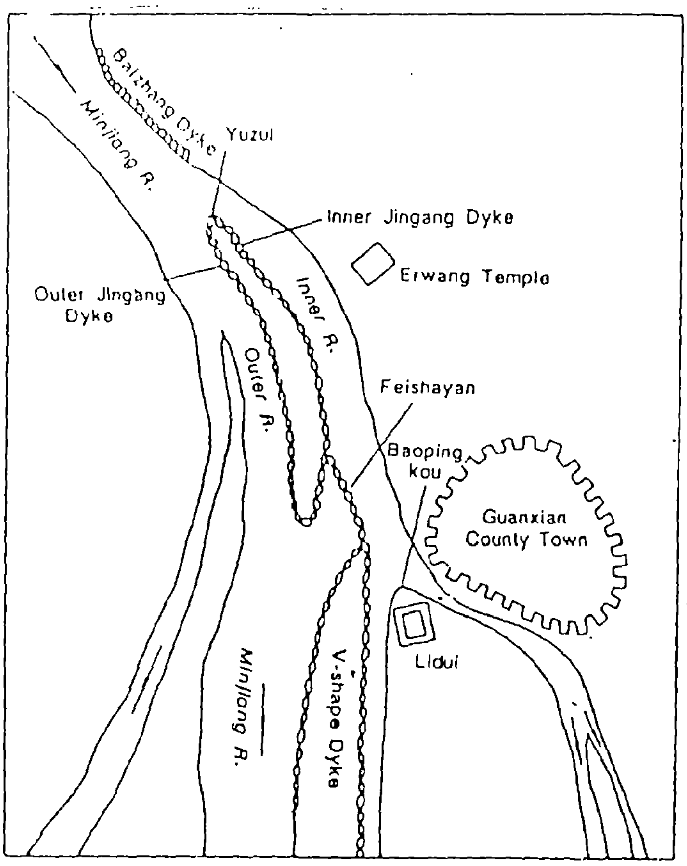


Fig. 5.2 Sketch Map Showing the General Layout of Dujiang Weir before 1949

The outer river is the main Minjiang and the inner river is the trunk diversion canal, which is located on the concave bank and therefore benefits the diversion because of the less quantity of sand carried in the water diverted. Overflow structure and intake structure are located in the innner river to re-regulate the diverted water. Below intake structure, the inner river is further divided into three trunk canals and those canals finally empty into the Tuojiang and Minjiang rivers respectively. Located on the convex bank, overflow structure is used for releasing floods and discharging sand by use of circulation current in the bend. When the inflow to the inner river exceeds the diversion water expected at intake structure the surplus water overflows the diversion structure and empties into the Minjiang River.

According to the observation data of year, when the Minjiang is 7000 m/sec, the discharge of the inflow to the inner river is 2800 m/sec with 700 m/sec of water flow diverted at intake structure and the rest 2100 m/sec of water flow spilling over diversion structure.

The fish mouth is connected to the inner and outer embankments of a 1 km long diversion dike in the middle of the river. This dike was a natural sandbar. Builders stabilised it for use as the divider. This dike separates the Minjiang River into an inner and outer rivers. At the other end of the dike, a 240 m wide sediment discharge weir dams the water into the Treasure bottleneck for irrigation in normal times and transfers surplus water discharge from the inner to the outer river during floods. In addition, a third but minor channel feeds the city of Dujiang yan, now a major urban area.

In order to guarantee the smooth functioning of the flood spilling and the water diversion at intake structure during dry seasons, the weir crest elevation and the length of the weir determines the inflow to the inner river.

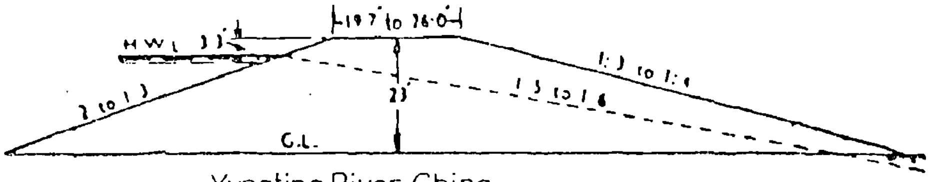
On its left lies the Yulei Hill and on its right lies the 'LIDUI' (a stone stack), which resembles a bottle-neck in shape and hence the name " Baopingkou ", or precious vase mouth. Dug by hand, the 80 m long, 20 m wide Treasure Bottleneck is the throat of the river. The water is normally 8.7 m deep but rises to 13 m deep during floods. It connects the inner river upstream to the four divided main canals downstream, performing the function of a natural regulative sluice. Along with irrigation and flood control, the main canal is used for log floating for logging operations in the region. The Dujiangyan Water Conservancy Works functions as well today as it did when built 2,300 years ago.

Today, Dujiangyan is a tourist centre with its magnificient waterworks, beautiful natural landscape and a colourful history that attract increasing numbers of visitors from China and abroad. The Erwang Temple honors Libing his son and all those who worked on the project.

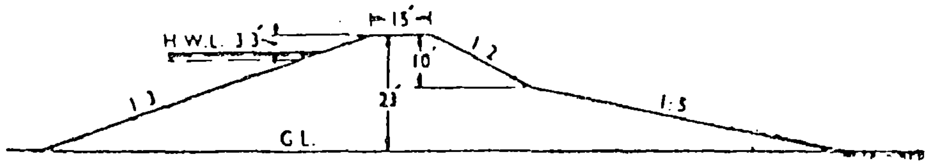
At the head of the canal, there are three stone figures installed separately in the water, which are the oldest gauge in the history securing as indexes of diversion for the irrigation district. It indicates that if the water level as low as the feet of the stone figures, the irrigation water is far from being sufficient and if the water level is as high as the shoulders of the stone figures, flood disasters might occur. As one leaves the temple, a stone tablet is visible with its curved message : **" When you drink water- remember!"**

5.2.3 River Regulation in China

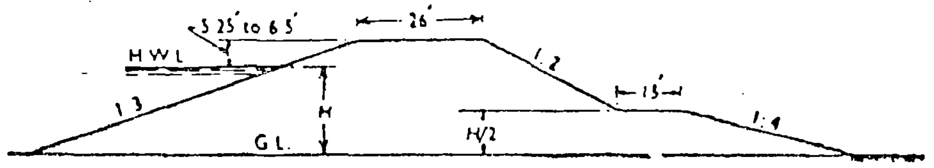
Based on the study of fluvial processes of the Yellow, Yangtze and other - four river patterns have been classified namely straight, meandering, braided and wandering pattern. The famous jinjiang reach of the Yangtze, river is a typical meandering reach. The wandering river occurs mainly in aggrading river with wide and shallow channel. Innumerable bars move rapidly in the channel making the channel appearance disorderly and varying all the time. The main channel shifts frequently and fast with large amplitude. The reach of the Yellow River in Henan province belongs to wandering one **(Fig. 5.3).**



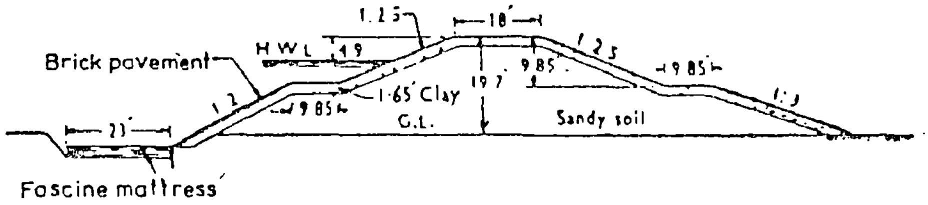
Yungting River, China



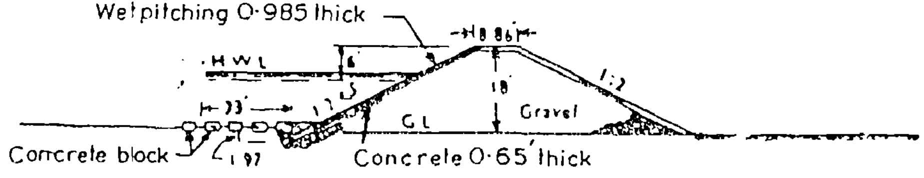
Yangtze River, China



Yellow River, China



Peikang River, (Taiwan) China



U. River, (Taiwan) China

Fig. 5.3 Type Design of Embankments in China

The common objective of river regulation is to guide the main current. Whether the main current is effectively guided is an indication of success or failure of river regulation. A scientifically based scheme of river regulation was worked out through long term observation and study. Much experience through long range practice has been summarized in China. The general principles are to make the best use of the situations to suit measures to local conditions and to local conditions and to build training works in time.

On mountainous rivers dredging, spurs and parallel dykes are used in river regulations for navigation. Bank protection works have a history of 500 years. Three types of bank protection works have been used viz.

(i) Revetment,

(ii) A group of spur dykes and

(iii) Groynes.

5.3 TRAINING OF MISSISSIPPI IN U.S.A.

5.3.1 General

The water and works on the Mississippi River as well as on its tributaries must rank at the top in history considered on the basis of its utilization and control. It is, in fact, one of the most extensive flood protection system, 2560 kms long levees, below Cairo-III. There is also unique system in inland water ways for navigation purpose for a single river. River training as well as bank protection, therefore, form an indispensable part of its works and owing to its long history of attempts to improve the methods of construction, practices on this river system is well worth a study by workers on the large rivers.

The Mississippi River **(Fig. 5.4)** is a silt bearing stream flowing through a bed of its own creation. It is never clear. Even at its lowest discharge as well as its floods - it is charged with sediments to an enormous extent. This involves the following consequences:

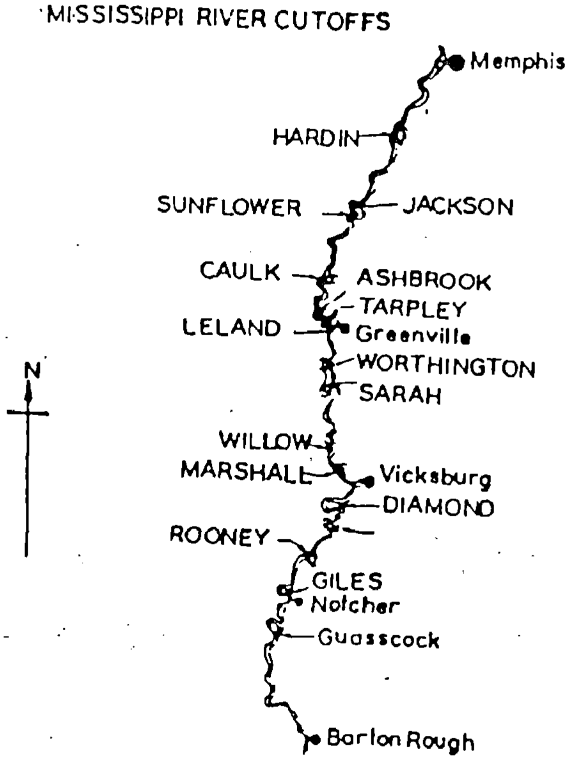


Fig. 5.4(a): **Mississippi River from Cairo to Sea**

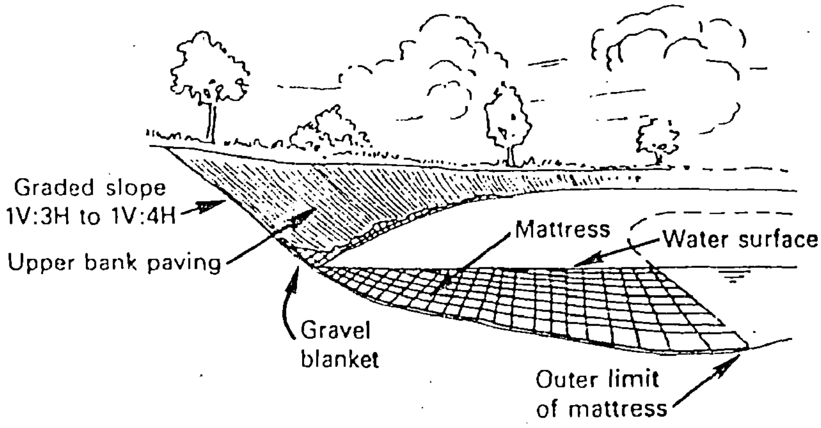


Figure 5·4(b) Channel cross section showing extent of articulated concrete mattress. (After Henley, 1966.)

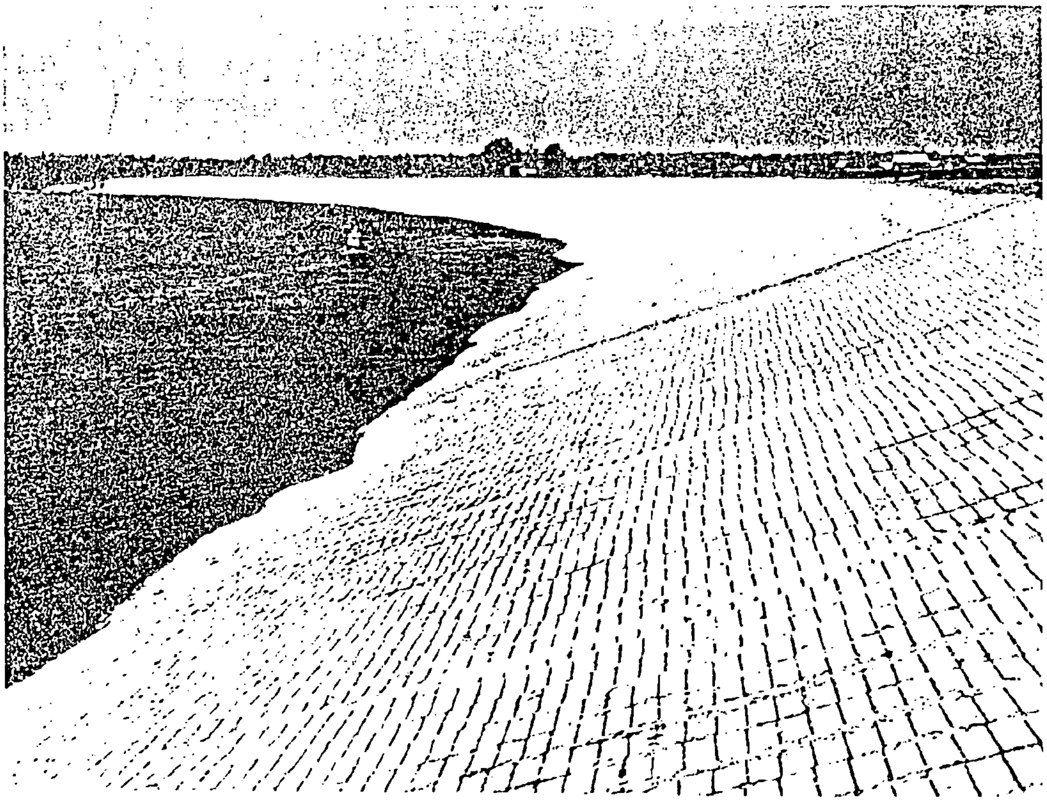


Figure 5.4(c) Bank protected with articulated concrete mattress, Lower Mississippi River. (Source: U.S. Army, Corps of Engineers, Vicksburg District.)

The banks are low and are subjected to overflow by the floods. The banks and bottom are friable to degradation and erosion. The channel is shifting and unstable and subject to obstruction by shoals.

5.3.2 Mississippi Delta

About 20,000 years ago, sea level was some 122 m (400 ft) below current levels and the northern shoreline of the Gulf of Mexico was located far south of its present location. As sea level lowered due to the formation of glacial ice in the polar regions in the last (Late Wisconsin) ice age, the Mississippi River became entrenched in a wide valley 16 km to 40 km (10 to 25 miles) across. About 17,000 to 15,000 years ago, sea level began to rise as the climate changed and glacial ice melted; in addition, there was regional subsidence along the northern Gulf Coast **(U. S. Army, Corps of engineers).**

In adjusting to rising sea level, the Mississippi River deposited sediment in its entrenched valley and the site of deposition moved upstream as the Gulf level rose. About 5000 to 70 years ago, the sea level reached its present stage and delta formations began extending out into the Gulf at the Mississippi River.

Since that time, the Mississippi River has changed the course of its exit to the Gulf several times, successively abandoning older, longer outlets and deltas to follow a shorter course to the Gulf and building up new outlets and deltas **(Fig. 5.5).**

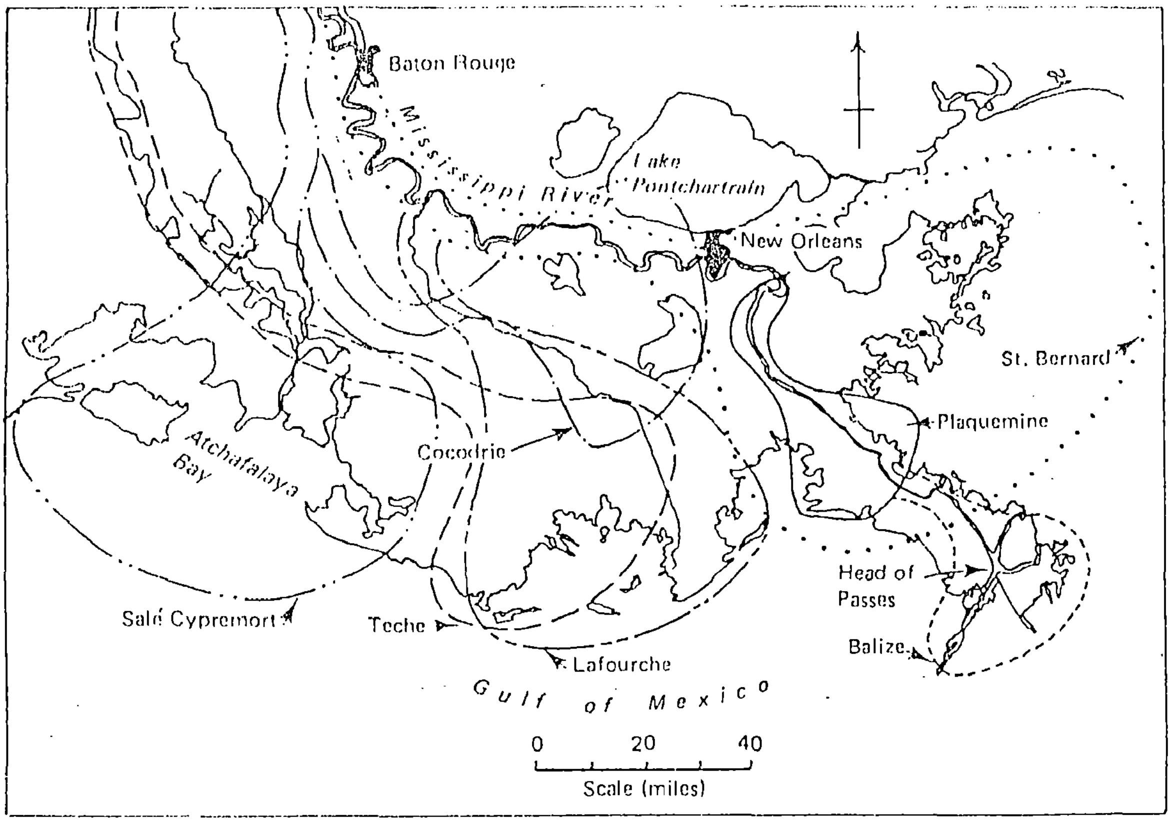


Fig. 5.5 Mississippi River Deltas

Below New Orleans, the Mississippi River transports an average sediment load of about 1 million tons per day with most of the material carried in high flows in January to July. During flood periods, natural levees built up along the distributary channels as flows exceeded channel capacity and spread over bank. Much of the sediment is deposited in the lower reach of South West Pass on the bar across the outlet of Pass.

In 1973, Mississippi river spring flood (one of the largest of record and the first major flood since 1950) formed large areas of marsh land and in Atchfalaya bay and major floods in 1974 and 1975 also contributed to formation of marsh areas. In 1975, it was estimated that there were about 8822 ha (21,800 acres) of marsh in the Bay and it is expected that by the year 2020 this will have increased to about 77702 ha (192, 000 acres).

5.3.3 The Problem Of The Mississippi River Basin

The lower Mississippi River valley i.e. below Cairo, up to the Gulf of Mexico about 1872 km (1170 miles) in length is extremely rich and developed. Every bit of its land has been occupied by the people. The river, therefore, cannot be allowed to meander. It forces its bends downstream every year taking away the land with it and destroying industries, farms and communities close to the levees. The main problem is caving of banks. The vertical height of the erodible bank varies from 21m to 66.6 m . The river banks are inherently unstable, being composed of finely divided clays and silts overlying easily erodible sands.

5.3.4 Bank Protection Used In U.S.A.

There are four ways of bank protection used in U.S.A. viz.

1. Bank protection by one or other type of revetment,
2. Intermittent protection such as dikes, retards or groynes,

3. Standard trench - fill revetment,
4. Other types.

The above ways are described below in brief:

1. BANK REVETMENT

Bank revetment is the principal structure employed on the Mississippi River as the problem is mainly of arresting bank recession in concave bends in which depths are too great for any other device to be constructed economically.

Revetments are structures aligned parallel to the current and are used to protect eroding banks and to form a smooth bank line, as for example, along the riverward ends of a dike field of spur dikes or across an old bendway that has been cut off.

In designing revetments, proper consideration should be given to the following:

(i) The stream bank should be graded to a slope in the order of 1V:2H to 1V:4H depending on the bank material to ensure stability of the protected bank and the protective material.

(ii) Protective blankets on the bank should be porous so that the bank drains through the blanket without the build up of excessive pore pressures which would lift and damage the blanket.

(iii) A filter should be placed under the blanket using either graded gravel or synthetic filter cloth, where bank material is likely to be leached out through the protective blanket.

(iv) Where erosion at the toe of the bank is a contributing factor to bank erosion, protective measures should either extend sufficiently riverward into the channel to protect the toe of the bank or excess material (usually stone) should be placed along the toe of the bank in such a manner as to slide into the developing scour holes.

(v) Some types of bank protection are unsuitable where access from the top bank to the water's edge by people or cattle is important.

Major types of revetments used in the United States of America are as follows:

STANDARD REVETMENT WITH MATTRESS:

This is the earliest type of stream bank protection used extensively in the United States and was originally developed for use on the **Mississippi River.**

It consists of two distinct parts viz.

(i) **Mattress (section below normal water level)** : This mattress is placed on the underwater bank and extends from the water's edge at low water out onto the stream bed beyond the toe of the bank . Mattresses have been constructed of a number of different materials and in a number of different ways over the years, but all were fabricated in large sections in the dry, usually on a work barge and [illegible] sunk in place against the underwater bank and bed **(Fig. 5.6).**

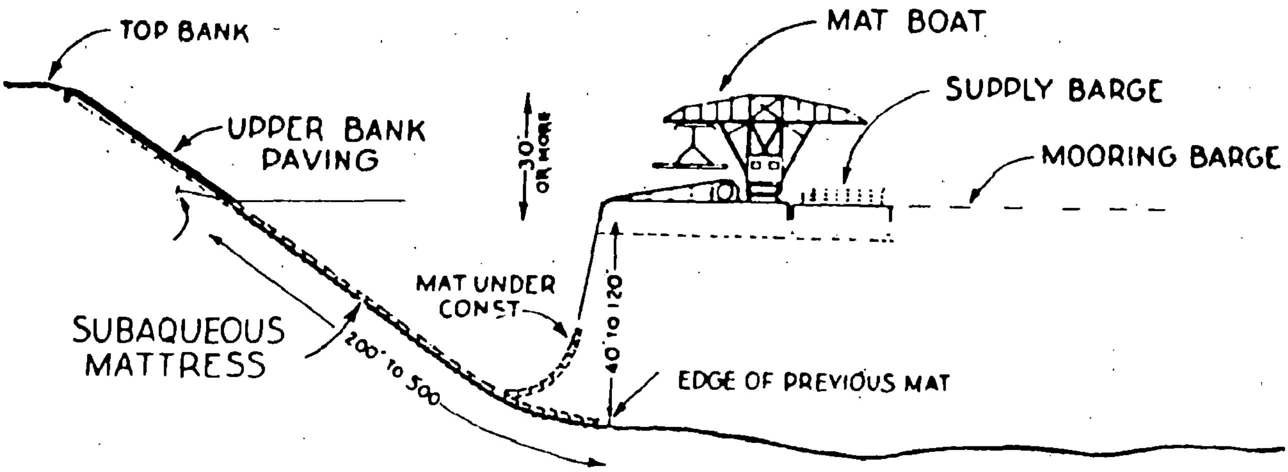


Fig. 5.6 Cross-section of Revetment Operation

(ii) **Bank paving i.e. above mattress.**

The mattress work comprises roughly three-fourths to four-fifths of the entire structure. It should have the following **qualities :**

(i) **Continuity,**

(ii) **Flexibility,**

(iii) **Strength,**

(iv) **Durability,**

(v) **Impregnability.**

Principal fabricated types of revetments used in the past were:

(i) **Willow framed mattress,**

(ii) **Articulated concrete mattress,**

(iii) **Asphalt mattress.**

The willow mattresses were effective, but became expensive to construct when suitable materials became scarce after about 1910 (**Miller,1978**) and labour costs increased.

The articulated concrete mattress is widely used on the Lower Mississippi River and the asphalt mattress is widely used on the Middle Mississippi River between the mouth of the Missouri as well as on the mouth of the Ohio.

These types of mattresses are described below in brief:

(i) WILLOW FRAMED MATTRESS:

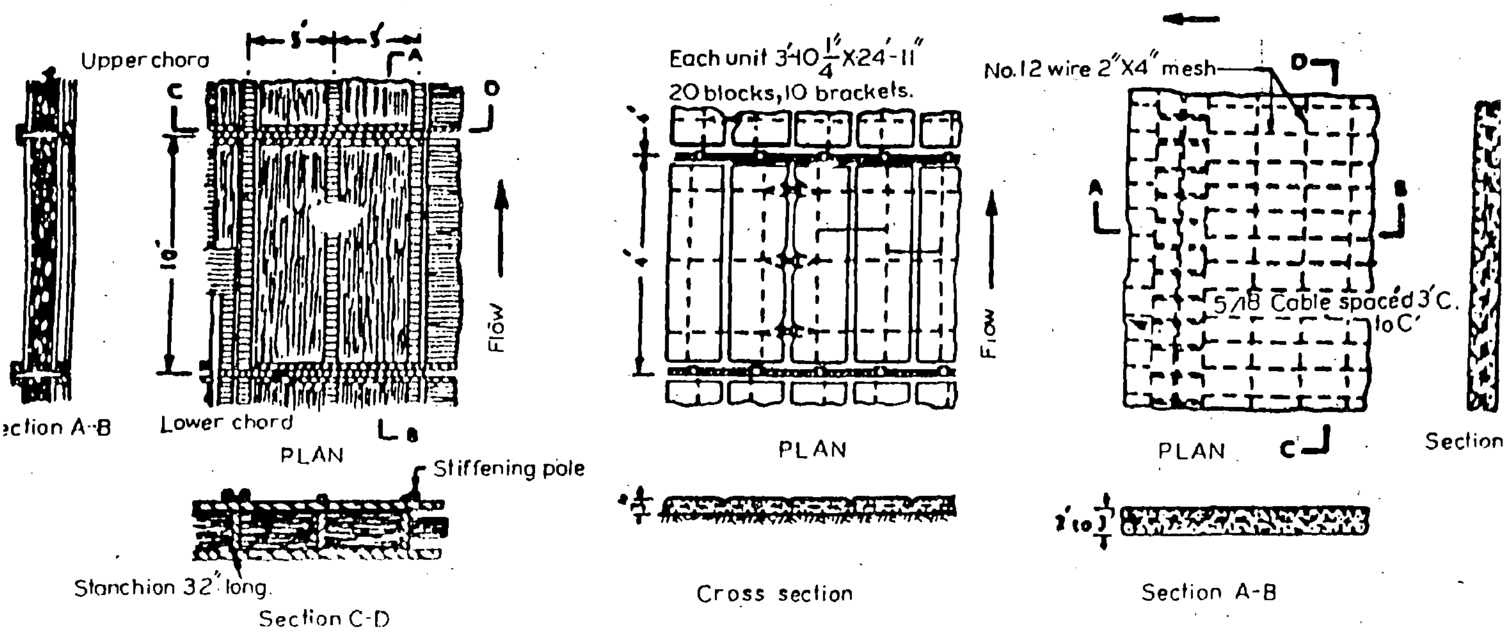
The willow framed mattress is a heavy type of construction used on the Lower Mississippi, usually in rectangular units of 45.7 m x 30.5 m (155 ft x 100 ft) and 0.9 m (36 in.) thick. A mattress is made by weaving either strips of 2.5 cm x 10.2 cm (1 in. x 4 in.) lumber or small willow poles until the desired size is built and is stiffened with longitudinal poles. The mattress is anchored to the top of the bank by " deadmen" and its buoyancy is overcome as in the case of other wooden mattresses by loading stone on it from bargers. About 726 kg (1,600 lb) of stone and 4.6 cum (6 cuyds) of willow brush are required for a 3m (10 ft) square mattress **(Fig.5.7a)**

The cost per 100 sq. ft was approximately $ 15.50 during the period 1928-29.

MODERN TECHNIQUES :

(ii) ARTICULATED CONCRETE MATTRESS :

This is a flexible reinforced concrete mattress capable of adjusting itself to the irregularities of the underwater slope in all directions. As the stream deepens and undermines the outer edge, the mattress is able to follow the slope and protect it .This flexibility is obtained by casting 1.2 m x 7.6 m (4 ft x 25 ft)



(a) Willow framed

(b) Articulated concrete mattress

(c) Asphalt mattress

Fig. 5.7 : Showing Bank Protection Works, Lower Mississippi River System

units, consisting of 20 slabs 118.1cm x 29.2 cm x 7.6 cm (3 ft-10 in.x11.5in.x 3 in) spaced 2.5 cm (1 in.) apart on heavy non-corrosive reinforcing fabric.

These units are laid side by side on the inclined way of a launching barge and 8 mm or 11 mm (5/16 in. or 7/16 in.) launching cables occupy the 3.2 cm (1.25 in.) spaces left between each pair of adjacent units and pass over drums of the launching barge. Loops of the reinforcing wire mesh projecting from the ends of the slabs of adjacent units are fastened in the launching cables by clips and twisted wires to form a mattress 7.6 m (25 ft) long measured normal to the shore line and 42.7 m (140 ft) long measured parallel to the shore line. The mattress is held in position by anchors spaced 1.2 m to 2.4 m (4 ft to 8 ft) apart.

A second series of units is placed over them, made fast to the launching cables and attached to the riverward ends of the preceding series by means of projecting loops of the reinforcing mesh at the shore end. The procedure of launching and adding units is repeated until the mattress has been carried, as a continuous sheet a certain distance riverward of the toe of the underwater slope. The launching cables are then cut at the barge, the outer end of the mattress released and the barge is moved upstream, ready to assemble the next mattress placed. The normal requirement of material for this type of mattress is 7 cum/100 sq m (0.84 cuyd/100 sq ft).

The rough idea can be taken that three plants can approximately revet 64 km (40 miles) of bank with a mattress averaging 350 ft wide.

The reinforcing fabric and fastenings are used in the articulated mattress of corrosion resisting metal. Copper coasted high -tension steel or stainless steel wires each having a breaking strength of 4000 lbs. **(Fig. 5.7b).**

ASPHALT MATTRESS :

This is either a reinforced or a mass asphalt mattress . The latter consists of sand and asphalt. The mix is placed in hopper barges, in which it is towed to the site and dumped in the water at a temperature of 375° F . The mix settles to the underwater slope, where it spreads to form a covering which is plastic enough to adjust to the bed. The former consists of reinforced strips of asphalt concrete with widths up to 66.1 m (217 ft). The thickness varies from 5 to 7.6 m (2 to 3 in.) and the length is determined by that of the " stringout" barges which guide the laying plant. The reinforcement consists of 7 mm (9/32 in.) launching cables, spaced at 0.9 m (3 ft) intervals and fastened to 1.8 m (6 ft) widths of welded fabric of No. 12 gauge wire. The mattress is cast on laying plant and then launched in the position. A thorough bond between successive launchings is obtained by hand tamping (**Fig 5.7c**).

The reinforced mattress weighs about 63.4 kg/sqm (13 lb/sqft) and its load strength varies from 10,415 to 20,833 kg /m (7000 to 14,000 lb/ft0 at 40 ^{0} F. Material required is 0.6 to 0.9 cuyds/100 sqft.

Principal advantages of this type of mattress are its flexibility, cheapness, ease of laying and maintenance. This type of construction is also used for upper bank caving with a little variation in the proportion of its aggregates.

2. INTERMITTENT PROTECTION - DIKES , GROYNES AND RETARDS

An effective bank protection is afforded by dikes, groynes and retards which are intermittent structures that may be permeable or impermeable according to the function performed and the material of which they are constructed. Pile dikes and triangular framed retards are permeable whereas groynes are impermeable. In the past, these structures have been used on the Mississippi River below Cairo mainly as contraction works and as a method of closing secondary channels.

STANDARD TRENCH-FILL REVETMENT

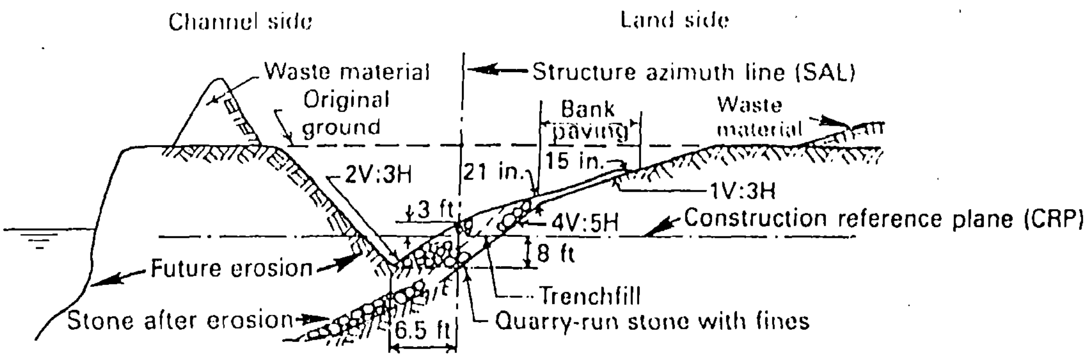
Trench-fill revetment includes paving the graded riverbank with a stone blanket or riprap (generally about 46 cm thick), and providing a large mass of stone in a trench at the riverward edge of the revetment **(Fig.5.8).** As the bank erodes and scour at the toe of the bank, the excess stone in the trench is launched down the slope and paves the eroding bank **(Fig. 5.8a).**

Three typical sections for trench -fill revetment are shown in Fig. 5.8. The section used at a particular location depends on the location of the Structure Azimuth Line (SAL) with respect to the bank.

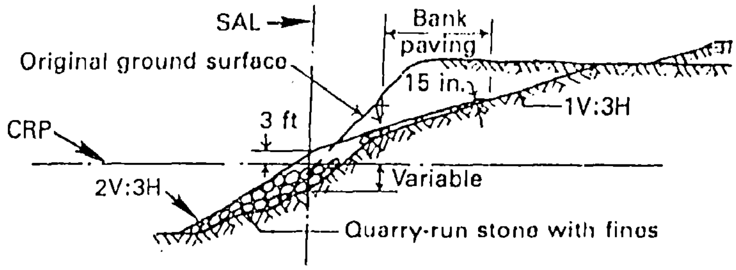
The section shown in Fig. 5.8(a) is used at locations where the rectified channel line is some distance landward from the existing river bank. The stone toe-trench fill and bank paving are placed in an excavated trench (e.g. a depth of 2 or 2.5 m i.e.7 or 8 ft below the construction reference plane on the Arkansas river).The quantity of stone placed in the toe-trench for paving the underwater toe depends on the estimated future maximum scour depth adjacent to the revetment and the quantity can be increased or decreased by modifying the size of the trench fill section. As the stream erodes the natural bank and any excavated spoil material riverward of the toe trench, the revetment provides protection through launching of a portion of the toe-trench fill.

Specifications normally require that dewatering equipment be used when necessary to obtain the design depth of trench because it is important that the stone in the toe trench be placed as low an elevation as practical.

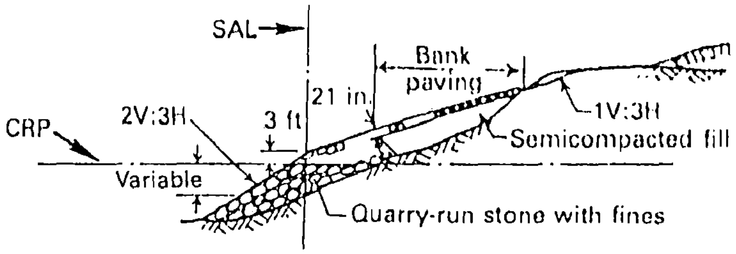
The best construction material for trench-fill revetment is quarry-run stone with fines, well graded from large to small so that larger voids are filled with the size of stone governed by requirements for stability against local velocities.



(a) SAL landward of bank



(b) SAL approximately along existing bank



(c) SAL slightly riverward of existing bank

Fig. 5.8 Standard trench-fill revetment, typical sections. (After Madden, 1963.)

The angularity of quarry stone results in a well-packed stone layer that is stable on a slope of 1V:2H; however, a slope of 1V:3H is used whenever practical because of increased stability.

4. OTHER TYPES : PERCUPINES MADE OF STEEL OR TIMBER

Steel jettis placed on a scouring bank in a line normal to the flow have been successful in inducing siltation along the banks. One variety, called Kellner Jack is composed of three steel angles about 5 m long bolted together at the centre with wire string between the legs **(Fig. 5.9)**. These spurs increase roughness of the channel thereby deflecting the eroding current away from the bank. In course of time, vegetation grows within the jacks and action of spur is further enhanced. This type of spur has been used with success in the United States of America (USA).

Bamboo percupines have also been used for a similar purpose. These are made of 3m long bamboo tied together at the centre in the form of a space angle and are weighted by tying stones to the centre. Fig. 5.9 shows a typical form of this type of spur.

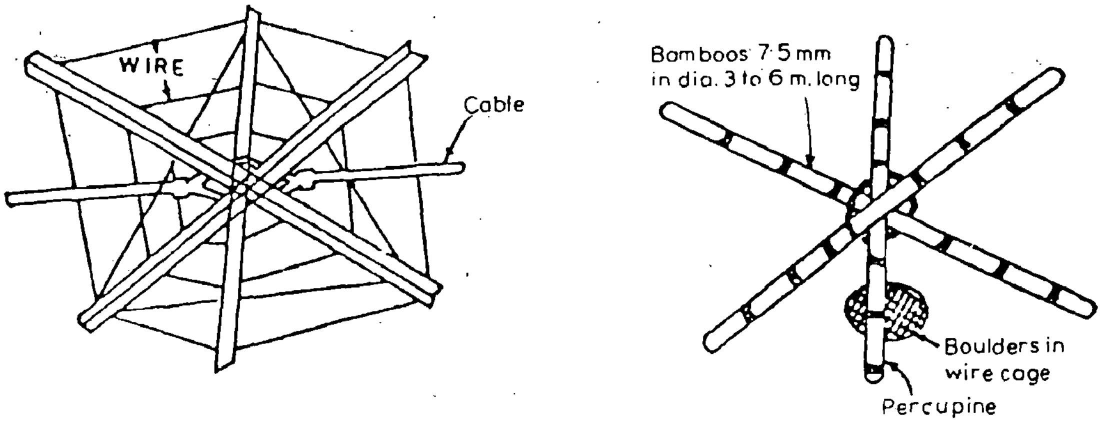


Fig. 5.9 (a): Steel Jetty-Kellner Jack (b) Percupine Spur

When installed on the concave bank of a meandering river, the system functions best. Diversion lines and back up retard lines are two principles on which it is employed. Diversion lines run almost parallel to the bank and are placed on a curve. The back up retard lines extend from the diversion lines to the bank and are anchored at the bank line.

5.4 PRACTICES USED IN EGYPT

5.4.1 General

Of all the rivers in the world, the Nile River is probably of the most interest to the greatest number of people. The Nile traversing the entire length of the country on its north ward course to the Mediterranean sea, annually brings down into Egypt from the Ethiopian Highlands, large volumes of water, heavily laden with silt and it was a common saying, even among the ancients that Egypt was the creation of the Nile mud. The Nile is 6700 km long. From its source Lake Tanganika to its mouth in the Mediterranean sea, only the terminal 1,550 km or so lies within the borders of Arab Republic of Egypt and in all this part of its course, it receives not a single tributary. Its basin covers approximately 3 million km^2 and includes parts of Kenya, Tanzania, the Congo(Zaire), Ruanda, Buruni, parts of Ethiopia, most of the Sudan and the cultivated parts of the Arab Republic of Egypt **(Fig.5.10).**

There are three main streams which form the Nile viz. (i) The Blue Nile, (ii) The Atbara and (iii) The White Nile.

The Blue Nile contributes the largest volume of 4/7 of the main Nile. It rises in the Ethiopian plateau at heights 2,000 to 3,000 metres above sea level. The Atbara joins Blue Nile 320 km north of Khartoum and it contributes 1/7 of the total supply of the main Nile and rises in the Ethiopian plateau. The White Nile is the longest tributary which supplies the remaining 2/7 of the total supply to the main Nile.

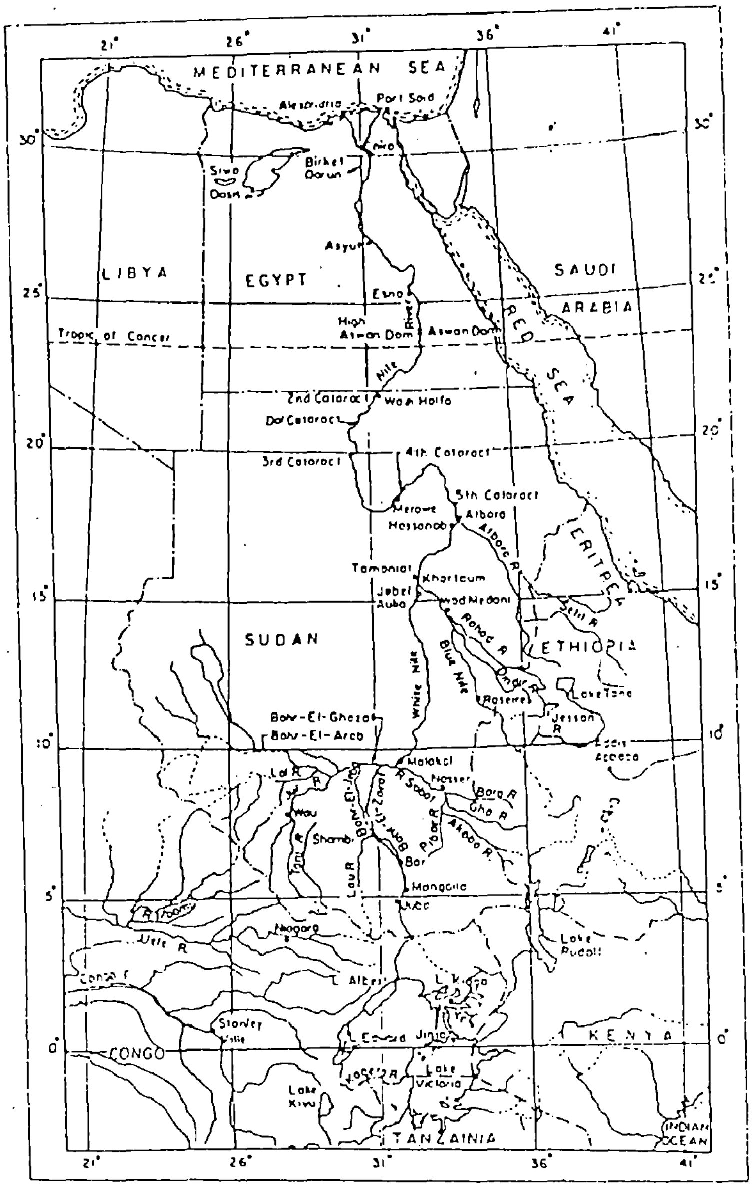


Fig. 5.10 Map of the Nile Basin

The discharge of the Nile of Aswan varies from 350 m^3/sec in the low stage to 13,500 m^3/ sec in floods. The concentration of suspended matter at Halfa or Kajnarty may reach over6,000 ppm in flood and drops to about 60 ppm in low stage. At Cairo, it may reach 2,000 ppm in flood and drops to less than 30 ppm in the low stage.

The principal feature of the Nile regime is the annual flood. It is caused by the Blue Nile and the Atbara. An interesting point is that when the Blue Nile is rising rapidly, it holds up the White Nile discharge and it is only when the Blue Nile rise slows down, then the White Nile discharge begins to increase. When the Blue Nile falls, the White Nile discharge increases.

It is due to the drastic changes in Nile discharges along with the floods that the great disasters involving the loss of thousands of lives and extensive damages to crops and property is caused.

The protective embankments to check the burst at some points or other constituted the sole means to train and control the river. A series of dams were constructed on its course to improve its management since the nineteenth century. The first of these dams, 25 km north of Cairo, was operated in 1886 as a diversion dam to feed high level canals to change the basin irrigation system to a perennial system. Willocks proposed a storage dam at Aswan which was constructed in 1902 with a storage capacity of 5 km . These two dams were followed by a series of dams and barrages, prompting the construction of considerable network of irrigation and drainage canals. Adrain Daninos (1951) suggested a high dam at Aswan for long terms storage of capacity 164 km3. This Aswan High Dam closed the Nile channel in 1964 and since then no flood occurred on the Egyptian territories.

Between Aswan and Cairo, the bed of the Nile consists of a sedimentary deposit composed of clay and sands laid down by river in more or less narrow valley along its course. In the north of Cairo, the river flows through the " Delta" created by itself. This plain is formed of finer particles of silt except a few isolated exceptions. The river cannot carry these silt particles owing to the reduced velocity resulting from a reduction of slope which occurs as it approaches the sea.

The continuous additions of fresh sediments brought down from the higher regions of the river catchments, cause aggradation of bed. This results in a frequent over spilling of the natural banks and consequently a rise in the surface level of the adjacent land.

The velocity of the Nile in Egypt was about 1.75 m/sec and 0.85 m/sec during low supply. From Aswan to Delta Barrage, the length of the river is 973 km and the average slope is 1 in 12,300. The Rosetta and Damietta branches are each about 240 km long and their average slope in flood is 1 in 13,000. Bed of the Nile is composed of sand almost entirely and the berms are mostly composed of well known Nile silt.

The Nile River course is tortuous. Its tortuosity is caused due to changes which it undergoes continuosly because of action of water and the effect of wind is having small significance. The action of the current is of purely dynamic nature similar to the blow of a hydraulic jet. The serpentine course of the river forms shoals, bars and bends due to water following the path of the least resistance and the destructive energy of the currents of river.

The Nile River changes the direction of its bed not only laterally, but also vertically. It attacks high points and bars continuosly. It fills up depressions owing to variations in discharges, undulations of the river bed and friability of the materials composing the bed. During low water, the Nile River tends to level its bed and when the water rises again in flood, new deposits occur at places where the bars were left by the last flood.

5.4.2 Training of The Nile River

Basis of training of the Nile River may be as given below:

(i) The channel follows the concave shore.

(ii) The shallows occur along the convex shore.

(iii) The sharper curvature deepens the channel and thereby projecting the shoals on the opposite side.

(iv) The maximum and minimum degree of curvatures correspond respectively to the maximum and minimum depths. Consequently, the least depth is at the point where the concavity changes into convexity or in other words, where the current shifts from one side to the other.

(v) The channel is regular in its longitudinal section, when the curvature of the stream varies gradually and continuously.

(vi) Abrupt changes of curvatures are accompanied by greater turbulence of water and abrupt changes of depths.

(vii) Careful observation of regular and well established curves shows that the greatest projection of the convex shore is not exactly opposite to the sharpest curvature of concave shore, but downstream of the later.

(viii) The width of the water surface is minimum at the points of the greatest curvature.

(ix) The formation of the serpentine repeats itself continuously until comparative equilibrium is established between the velocity of the current and resistance of the soil.

(x) The velocity of the river water is dependent on the river cross-section also rather than only on slope of water surface.

The continuous process of formation of bends associated with the modified slopes and velocity indicates that the total length of the river course tends to remain practically constant.

In Egypt, the object of river training had always been to keep the natural condition maintained as far as possible. The used idea is that the current cannot be suppressed, but can be only restrained and reduced in those places where it is violent or can be increased where it is too weak.

The following rules were used to obtain a permanent alignment, a regular channel and stable berms:

(i) The general direction of the current must form a succession of concave and convex curves connected by reaches approximately to straight lines. Angles must be avoided either in the berms or in the banks. The curve must be neither too large nor too small.

(ii) The curve should be parabolic.

(iii) The points of the maximum curvatures of the convex and concave banks should not be opposite to each other.

(iv) The cross-sections of the channel must possess the dimensions which are the most suitable to the natural conditions of the river. The more uniform the channel becomes, the less violent will be the action due to the changes in the river-bed alignment of the flood channel. It is then aimed at gradual persuation of the river to adopt a uniform section by allowing erosion here, preventing erosion there, reduction of the flood channel over shoals and judiciously placed spurs and revetments. Normal width is selected after a comparison of a great number of cross-sections selected in well-established reaches.

(v) On curves, the maximum width used to be calculated by the formula is.

$$Wc=Wn+Wf \text{...........(I)}$$

Where, Wc=maximum width in curve (m),

Wn=normal width (m),

Wf=a width factor for curves for different rivers (m).

For Nile River, in Upper Egypt Wf =350-50R...........(ii)

Where, R= Radius of the smaller curve in km.

5.4.3 Nile Dikes

The Nile Dikes are the earthen embankments originally thrown up alongside the river channel at a very early period to prevent the river from inundating unduly in the adjacent country. The basic idea behind this is to confine the river flow to raise the water level. The general theory adopted was to keep the banks aligned parallel to the streams. The heights of the banks used to be 3.50 m to 4.0 m.

The above **Fig. 5.11** shows the nine typical cross-sections for every half meter increment up to 4.50 m height above the natural ground level. All are based on a common slope of 1:5 of the line of seepage and a common top width of 5.0 meters. These were subsequently changed finally in 1914. They took a shape as shown in **Fig. 5.12**.

These are based on the following considerations:

(i) The bank is made of the ordinary Nile silt.

(ii) The slope of the line of seepage or percolation is 1:7.

(iii) The top width is 6 metres to meet the future traffic requirements. The upstream slope of the profile is 2V:3H throughout from top to bottom.

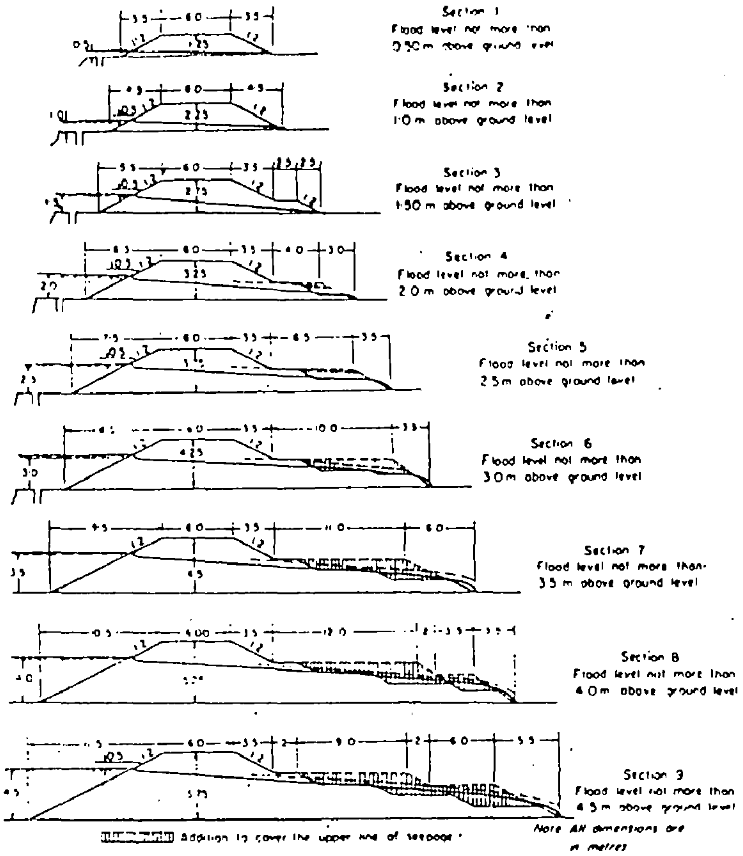


Fig. 5.11 Sections of the Nile River

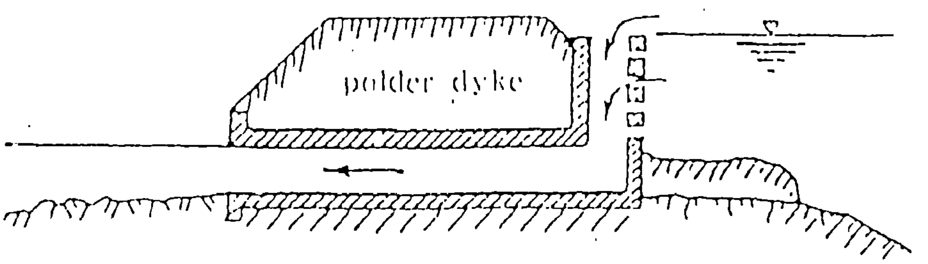


Fig. 5.12 Intake of Nile Water into Polder

(iv) The downstream slope is 1V:2H and is divided by berms of different horizontal widths to conform to a sloping line parallel to the line percolation and standing at half a metre above it.

(v) The lowest berm should run 1 meter at least above ground surface.

This was subsequently improved and filters were provided to solve the problem of seepage lines and reduction of cross-sections.

5.4.4 Inundation Canals of Nile

Colonel Justine Ross, who was the Inspector - General of Irrigation in Egypt, found that the old inundation canals of Nile were usually aligned by the Arab engineers on the following principles :

1. The offtake should be placed in the bank along which the deep water of the Nile flowed and the canal axis should be as nearly as possible, a tangent to the general curved sweep of the central current of the reach of the river in which the canal lay. The natives altered the heads of some canals, at great expense, in order to fulfill this condition.
2. When a canal had to be taken from a straight reach of the Nile, it should be taken at a very acute angle to the axis of the river.
3. That a canal head should not be placed at a point where a sand bank was forming.

The coarse sand, which rolls along the bottom of the Nile bed, does not enter the canal unless the bed of the river has become silted up to nearly the level of the canal bed. This coarse sand is the most fatl to permanence of supply, as it falls in the head of the canal and chocks the discharge.

5.4.5 Protection Works In Nile

Bank revetments of permanent nature and spurs, to divert the current and breaking the force of its action, are used to prevent the bank erosion. They are used to do revetment with dry rubble stone pitching having side slope not steeper than 1:1.

Spurs were devised to deflect the river currents away from the bank where revetments do not offer a sufficient guarantee of safety **(Fig.5.13).** Continuous study of the river and experience used to be the only guide for deciding the best angle which the spur angle should make with the streamlines at the erosion site. As a rule, the angle varies between 30° to 60° .

The idea adopted was that if the spur approaches perpendicular to the current, the action produced will be the severe because its partial damming effect causes a heading up and the current rushes in to fill the back water below the spur cased by the suction of eddies. The greater is the heading up by the spur, the stronger will become the backwash action **(Fig. 5.14 & Fig. 5.15).**

The distance between two consecutive spurs depends upon the degree of curvature and strength of the current. In general, it is found that the action of the river dies out if the proportion of the chord to the spur is slightly more than three **(Fig. 5 .16)**.

The protection of a bend called " Shimiya " calls for careful examination. As a rule, the middle part of the curve is eroded more actively than the lower part. However, during high floods, the downstream of a curve is attacked more severely. Spurs were built mainly of earth having a nose of solid stone. The footing of the spur is used to be the most essential part for preventing slips.

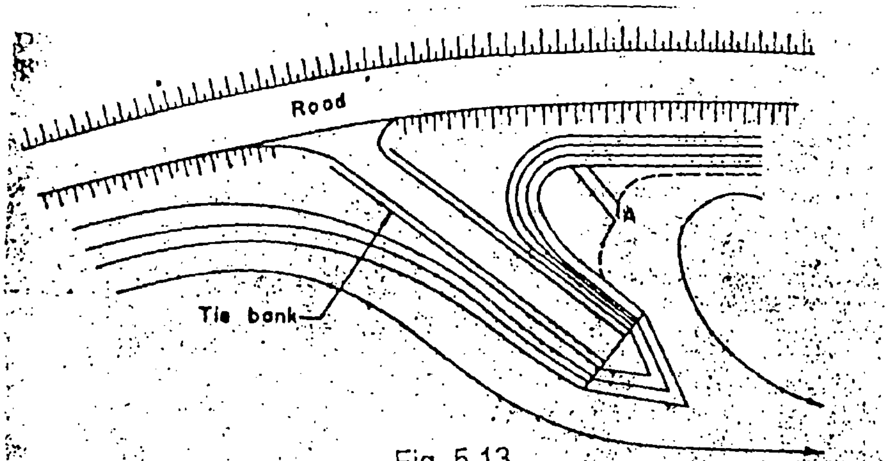


Fig. 5.13

Fig. 5.14

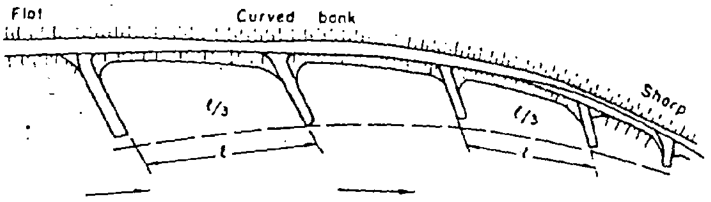


Fig. 5.15

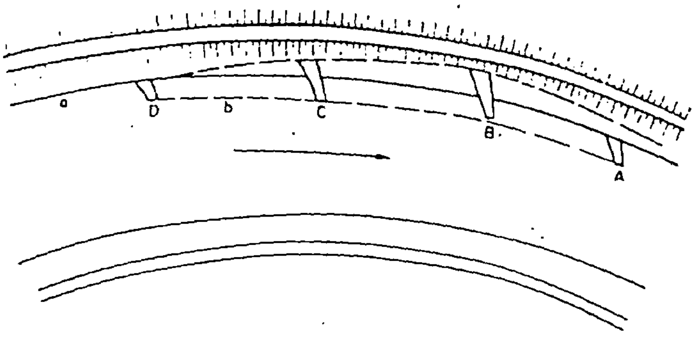


Fig. 5.16

Spur Protection in Egypt

The high flood from Egypt causes short term and long term environmental problems, besides the expected numerous economical benefits. There is a thought that the only solution is to divert silt or flood back to Egypt.

5.5 THE EASTERN YAMUNA (JUMNA) CANAL IN INDIA

5.5.1 The Headworks of The Eastern Yamuna Canal

No great engineering difficulties appear to have been experienced in the excavation of the channel in the construction of the numerous masonry work or in obtaining the required supply. The conditions of the Yamuna river, where it debouches from the Siwaliks, are very favourable for the supply of a canal taking off from the left or eastern bank.

No permanent weir is required across the main river. All that is necessary is to run a cheap gabion or boulder spur at Khara, immediately below the off-take of the channel of an old branch of the river called the Budhi Yamuna (Jumna). The required supply is thus turned into this channel, the bed of which runs at a higher level and with less slope than that of the main river. By this means, water is delivered at Naiashahr 10 km (miles) below Khara at a level suitable for the supply of the canal. The supply obtained from Khara can be supplemented by an additional supply obtained in the same way at Faizabad, 5 km (3 miles) below where there is a second spill channel leading off from the main river. Thus, the only works of a permanent character, which were required to regulate the supply of the canal, were the Naiashahr dam and regulating bridge, built at the point where the excavated portrion of the main canal takes off from the Budhi Yamuna (Jumna) into the high land. These were required to regulate the supply to the canal and to pass all surplus water back into the main river, Water, escaped in this way, reaches the river many km below the headworks of the Western Yamuna (Jumna) canal. To admit of any surplus water being utilised in that canal, a second dam was built in 1843 at Faizabad, midway between Khara and Naiashahr.

This simple system of headworks has continued to work satisfactorily and no provision was made for any additional works.

5.5.2 The Main Channel

The channel of the main canal constructed with some slight modifications, the tortuous alignment of the old Muhammadan work; between Balpur and Bhainswal, it maintained its old course down the Shamli Nala. The bed was excavated to gradients varying with the general slope of the country. This slope was too steep in many reaches and on the opening of the canal rapids in the bed at various points, many of the masonry works were endangered. To reduce the surface slope of the stream, plans of constructing masonry falls at suitable intervals were adopted. Between each set of falls, the slope was reduced to a minimum of 40 cm per km(2 feet per mile). The construction of these works enabled the canal to carry its supply with safety.

In other reaches, the tortuous course of the channel gave rise to heavy deposits of silt. To remedy this, the channel was re-aligned between Balpur and Bhainswal .The new channel, however, had not been opened long before it was discovered that the design was still faulty. The velocity was now too great and caused erosion of the banks and bed. This condition existed in 1864. During the interval (1860-1861), irrigation had developed rapidly and to meet the demand a volume of water,-one-third more than the canal, had been designed to carry, was being forced down the channel.

In addition to a re-adjustment of the bed levels, an increase in the sectional area of the channel was necessary. The required works were partially carried out under estimates sanctioned before 1871: the crests of five falls between Reri and Kheri were raised and the floors of three falls lowered ; a new fall was built at Kalarpur and another at Bahinswal, and two bridges were dismantled and rebuilt. The remaining works were included in the completion Estimate.

5.5.3 Torrent Works Or Level Crossings

The eastern Yamuna Canal (EYC) takes off from the left of the river Yamuna at Tajewala. In upper reach between Naiashahr and kalsia, that is, in the first 16 km (10 miles) of its course, the main canal crosses numerous torrents carrying the drainage from the southern slope of the Siwaliks. Naturally, these several drains have their bed levels the same as that of the bed level of the EYC at crossing points. Therefore, level crossing have been provided for facilitating the crossings of the canal.

Of these, the chief are the Naushera level crossing, the Maskara level crossing, the Gangoo torrent, the Raipur escape, the Naogaon dam etc. The works which were originally provided for the passage of the Naushera level crossing and the Maskara level crossings across the canal are as described below in brief:

(i) NAUSHERA LEVEL CROSSING

The Naushera Level Crossing is meant to cross the Badshahi Bag Rao River. It is the first level crossing (from the beginning of the EYC) located at a distance of 10 km (6 miles) from the canal take-off point. This torrent meets Yamuna river in downstream. The EYC after flowing for 10 km meets the river (torrent) called Badshahi Bagh Rao. The canal flows for 300 m in the river course. Thereafter, level crossing is located which diverts the canal water into EYC taking off from the left bank. An escape has also been provided there besides the main regulator.

Now-a-days, a new barrage called Hathnikund Barrage is under construction in upstream of the Tajewala headworks to replace this old structure. A feeder channel of 2.8 km length is under construction taking off from the left bank (in upstream of the Hathnikund Barrage). It will meet the Badshahi Bag Rao at a distance of 6 km in upstream of the present point of confluence (**Fig. 5.17**).

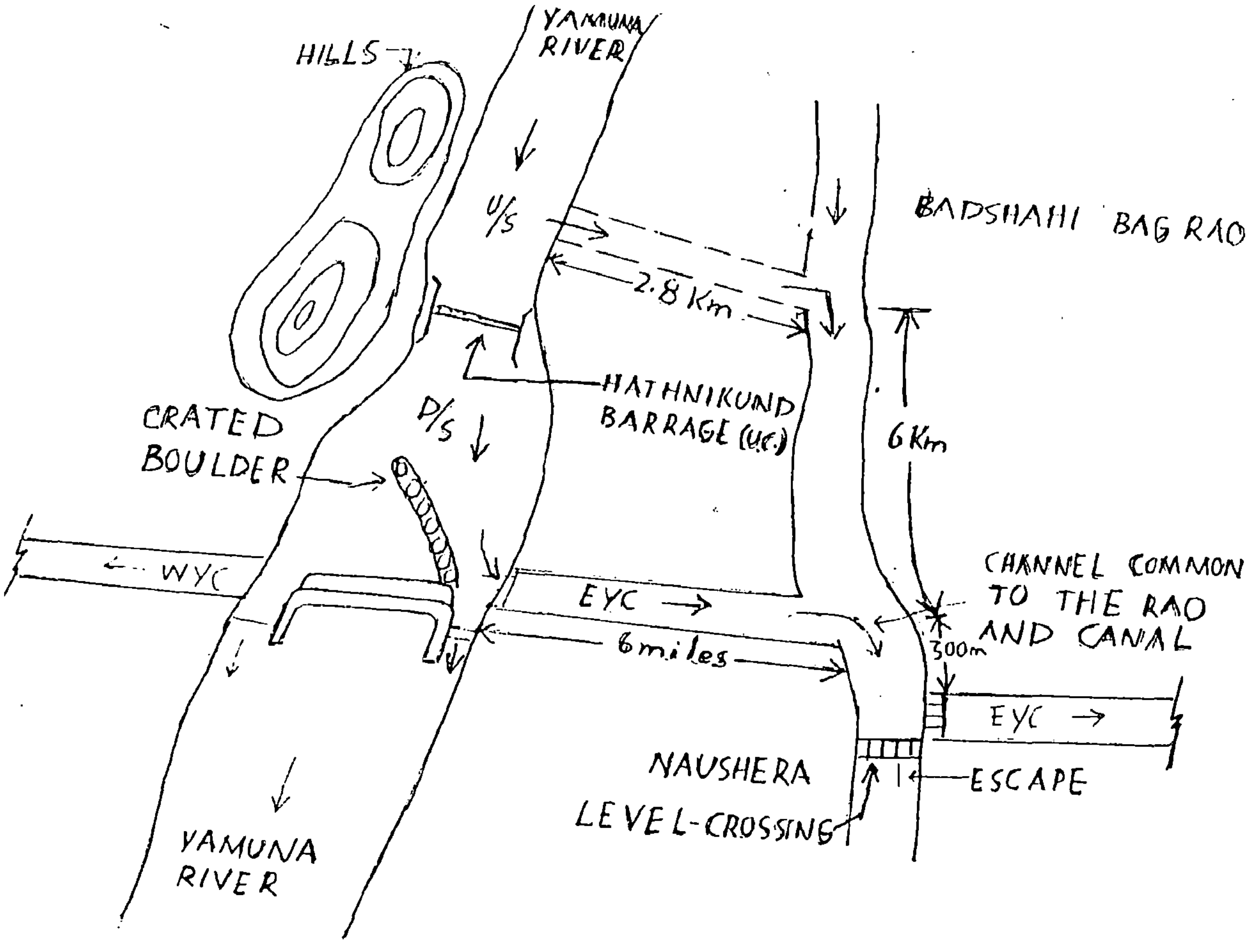


Fig. 5.17 Naushera Level Crossing

(PLAN)

(ii) MASKARA LEVEL CROSSING, KALSIA

The Maskara Level Crossing is meant to cross the river Maskara. It is one of the oldest structure constructed during the British Rule. It is on the boarder place of Uttar Pradesh and Haryana. It has been fulfilling the irrigation purposes since ancient times about 122 years back **(Fig. 5.18).**

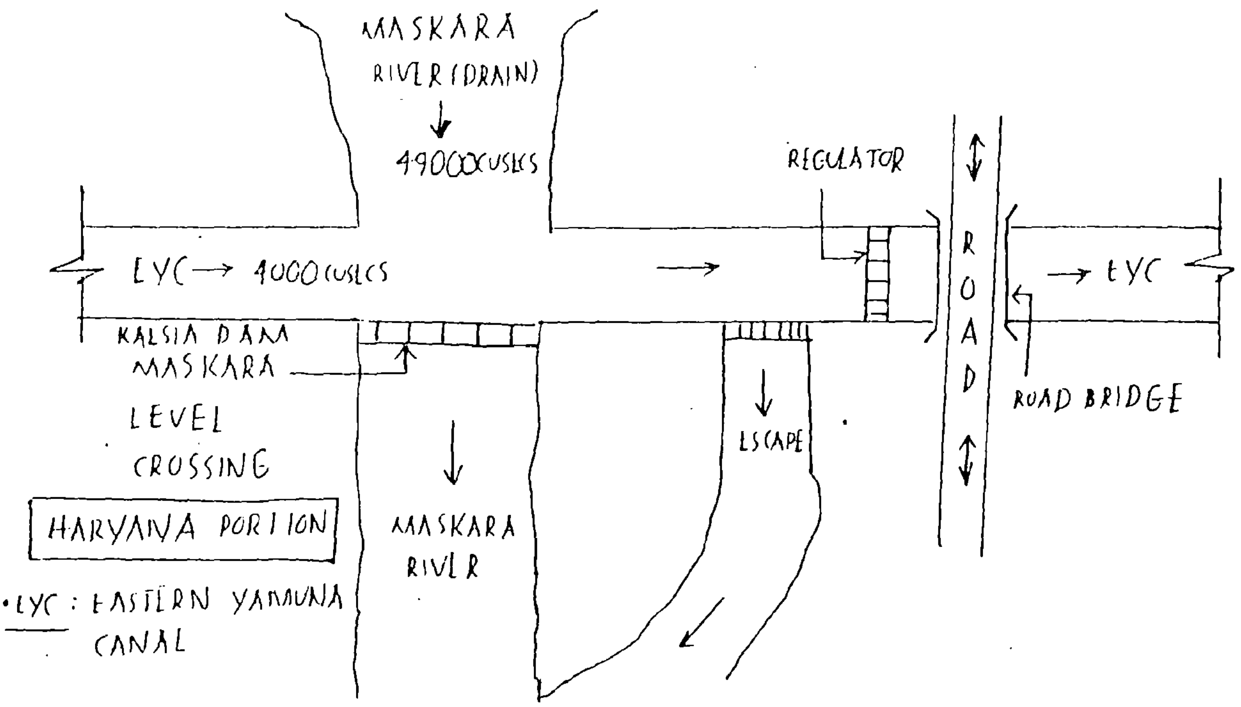


Fig. 5.18 Maskara Level Crossing

The EYC was constructed in 1874 and was remodelled in 1970. It was constructed on Maskara drain (hilly river). Maskara drain originates from the foothills of the Himalayas Shivalik hills near Dehradun. Its maximum torrent capacity is 1338 cumecs (49000 cusecs). It runs occassionally. The level crossing is operated during high rain i.e. from 16 th July to the end of the monsoon, it is operated. If the head discharge at Tajewala is above 850 cumecs (30000 cusecs), its discharge is closed. The EYC capacity is 113 cumecs (4000 cusecs). Now-a-days, its remodelling is going on to increase the canal capacity to 125 cumecs (4400 cusecs). About 20 km from Kalsia, the Maskara drain meets the Yamuna river.

5.5.4 The Original System Of Irrigation

On the opening of the canal in 1830, irrigation was carried on directly from the main canal; supply to the village water-courses being given through openings in the bank. Under this system, there was great waste of water and irrigation was also confined to the villages situated close to the main canal. An attempt was made to supply other villages by turning the water into the natural drainage lines of the country, across which dams of masonry or earthwork were constructed: but the channels and the reservoirs thus formed silted up quickly.

Moreover, it soon became evident that to ensure a fair distribution of water to the more distant villages, it would be necessary to make separate channels which would command and irrigate the country lying between the minor drainage lines. The rajbaha or distributary system was then introduced with the joint stock companies with the Zamindars of the villages who contributed ten times more sum in the construction than the Government. By the end of 1872, there were in all 978 km (608 miles) of distributary channels for the supply of which there were 90 separate heads in the main canal.

The above joint stock system led to inconveniences and after 1865, all expenditure on distributaries was incurred at the expense of the Government.

5.5.5 Alterations In The Headworks Since 1871

Initially, no provision was under Head-works, nor was any expenditure incurred under that head of account; but the modification in the system of Head-works was due to the construction by the Punjab Government of the Tajewala weir in connection with the Western Yamuna (Jumna) Canal and of the inexpensive means originally adopted for diverting water into the canal.

Subsequently (1875-1879) the Punjab Government, when constructing the Tajewala weir across the river Yamuna, built in connection with that work, a new head and regulator for the eastern Yamuna Canal and excavated a supply channel from the new head to the Budhi Yamuna (Jumna) near Naiashahr. The Government of these provinces objected to bearing any share of the cost of these works. In the opinion of the Engineers, the works were not required. As a matter of fact, they were not used for some years, but subsequently it became necessary for the Punjab Government to protect the weir by an embankment, the construction of which involved the closing of the alternative supply at Faizabad. The Tajewala channel then became the alternative means of supply. Eventually, it was agreed that the Eastern Yamuna Canal should not bear any share of the capital cost of the works constructed by the Punjab Government, but that it should contribute a sum of Rs. 8,000 per annum towards the maintenance of the work.

5.5.6 The Tajewala Head-Works For Eyc & Wyc

The Tajewala Head-works is a weir to divert the water of the river Yamuna into Eastern and Western Yamuna Canals. It is an old structure constructed constructed during the British period **(Fig. 5.19).**

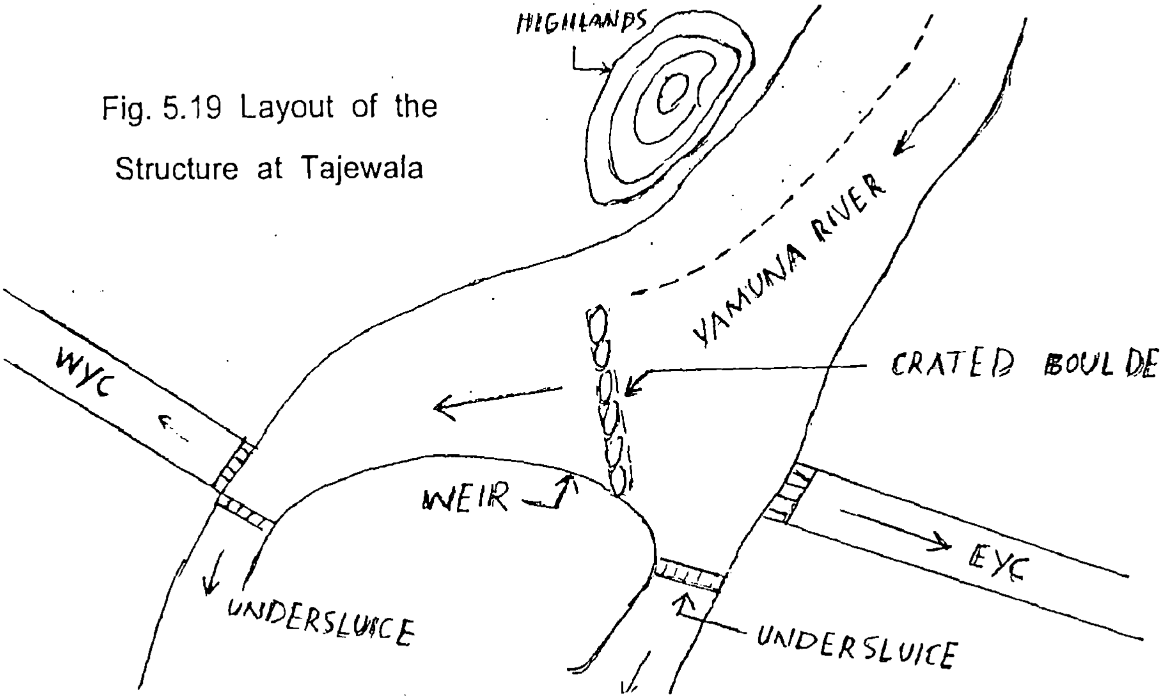


Fig. 5.19 Layout of the Structure at Tajewala

The central long portion is ungated (previously gated) and the undersluice portions on the two sides are gated foe discharge of Western Yamuna Canal (WYC) on the right side of the river and of Eastern Yamuna Canal (EYC) on the left side of the river. The design discharge of EYC is 113 cumecs (4000 cusecs) and of the WYC is 198 cumecs (7000 cusecs) **(Fig. 5.20).**

The river alignment is such that the major portion of water flows towards the western bank. Therefore, temporary obstruction of crated boulder is constructed every year to ensure the adequate supply towards the EYC. Also, the river carries big boulders during the flood. In 1978, the highest flood level (HFL) was observed of 332.84 m on 3.9.1978, when the whole structure was submerged.

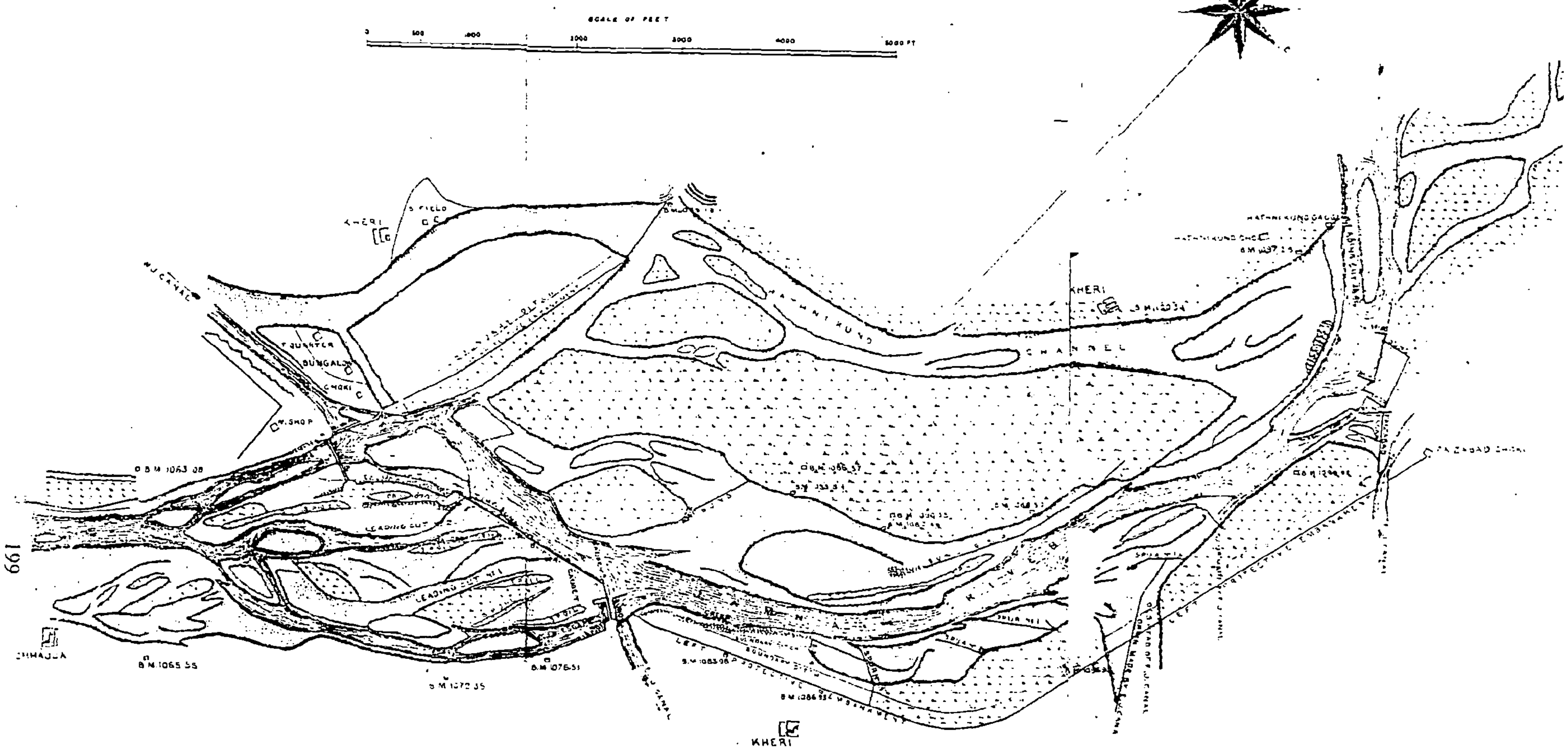
5.6 CANAL HEADWORKS ON ROCK AND BOULDERS IN INDIA

There are many other practical examples of canal headworks on rock and boulders other than described above. Two of them viz. the Betwa Canal and the Bari Doab Canal are described in brief as below:

5.6.1 The Betwa Canal

The headworks of the Betwa Canal are situated on the river Betwa, about 24 km (15 miles) from Jhansi, in Bundelkhand, in the North-west Provinces. The river has a course of about 580 km (360 miles) from its source in Bhopal to the Jumna river, which it joins near Humeerpore. The catchment area of the river above the Betwa canal is about 23289.28 square km , and the maximum flood discharge has been calculated to be 21240 cumecs.

Fig. 5.20 WESTERN JAMNA CANAL HEAD WORKS



The weir across the Betwa river in the North-West Provinces is a great contrast in design. It is founded on gneiss rock and is built of rubble masonry. The weir was designed to support the entire pressure from above in time of flood, on the supposition that the channel below was dry. The greatest height of the weir is 15.54 m for a short length and there is a considerable portion of it over 9 m in height. It is well functioning till then.

5.6.2 The Bari Doab Canal

The weir across the Ravi river at the head of the Bari Doab Canal in the Punjab is an important example of a weir of the second class in the boulder formation.

The weir itself is simple, and is only 0.91 m (3 ft) above the original river bed; in parts where the river bed was deep the weir wall was carried down to it. High floods rise to about 3 m (10 ft) over the weir crest. The wall itself is in boulder masonry, and it shows what good results can be obtained with small stones, provided they are thoroughly well set in good mortar. This wall is built with comparatively small boulders, hammer-dressed on the surface, thoroughly well bedded in mortar and although there have been several accidents to the weir, this wall has stood well.

The velocity over the weir in flood is said to be 4.5 m or 6 m (15 or 20 ft) a second, and the mortar joints are much scoured out by the water and sand, but the stones are rarely displaced. The slope of the river bed above the weir is over 6 m (20 ft) in a mile, and boulders the size of a man's head are carried down it.

Originally, the head was the only regulator and there was a weir wall across the channel. It was found that the channel was frequently blocked with the shingle which was brought down into it by the great velocity of the water. A regulator was then constructed at the site of the weir wall, so that the velocity of the indrought at the head could be controlled , but the difficulty in keeping this channel open still continued, and it was found necessary to construct the weir across the river.

The regulator had 21 openings of 4.5 m (15 ft), but 15 of the openings have been permanently closed up since the head-sluice was built and only six openings are used now as escapes to the supply channel. There has been considerable difficulty in this case in keeping open a channel in front of the head -sluice : heavy training works have been required in the river bed above the weir to direct the cold weather channel towards the left bank.

The movement of shigle in the river is considerable and the weir itself is now completely burried in parts by shingle and boulders. The training works consist of a series of embankments and spurs, which were at first constructed as bunds faced with boulder pitching , but this did not stand and considerable portions of some of these spurs are now in masonry. The result has been successful as there is now a good channel leading to the under-sluices, and, in the dry season, the entire discharge of the river is passed into the canal.

The selection of the site for the headworks of a canal from the ravi river was not a happy one. The site was higher up the river than was necessary in order to utilize the available water supply. The great velocity in the river and the flow of shingle and boulders has caused great trouble and expense and the cost of the construction of the canal itself has been high owing to the very rapid fall in the country. The canal takes out from the river in 53 feet of cutting and it is a very pretty piece of work. The soil is full of boulders and the deep slopes at the canal head are neatly revetted, in steps with them.

The slope of the bed of the canal in the first 19.31 km (12 miles) is 1 in 1250 (feet) .The bed width is 34.14 m (112 ft). the maximum discharge was designed to be 104.78 cumecs, but larger quanties are now passed. The velocity rises to as much as 1.74 m/sec.

Although the canal has this steep slope, the bed of it comes to the surface within three miles and a little irrigation is effected in the forth mile. But the slope of the country is so rapid that in the first !9.31 km(12 miles) of the canal, the bed level drops more than 61 m (200 ft), of which 45.72 m is obtained by 19 rapids or weirs constructed in the canal and the rest by the slope of the canal bed.

The cost of the construction and maintenance of these works has been great, and little or nothing has been gained by tapping the river at so high a level, and then dropping the water by fall after fall and rapid after rapid down to the point where the slope of the country is more suitable, nothing at least except beauty, **the first 12 miles of the Bari Doab Canal is perhaps the prettiest piece of canal scenery in the world.**

5.7 INUNDATION CANALS IN INDIA

Since ancient period , inundation canals were being most used in India, too. The heads of the inundation canals are generally situated on the true bank of the main river from which they draw their supply. In nearly all Indian rivers, especially in those parts of them, where inundation canals exist, there are depressions or hollows taking off from the main stream, which are dry, or nearly so, during the dry season , but are filled by the annual flood in the river : these are generally old courses of the parent stream which have been abandoned by the river; they are called "dunds" in Sind and "Sotas" in Bengal.

These depressions are frequently used in Sind as the sites for the heads of the inundation canals. One of the arguments used in their favour is that, as they are much larger than the canals they feed, the velocity of the water is less in the dund than in the canal channel, and consequently the silt which would otherwise be deposited in the canal is deposited in the dund, and the labour of the annual silt clearances of the canal is reduced.

This is undoubtedly the case with reference to the coarser sand - which is carried along the bed of the river by the force of the current. The fact that the bed of the dund is above that of the river prevents the inflow of this material into the dund to a considerable extent, and the reduced velocity in the dund itself checks the onward flow of that which may enter, so that a still smaller quantity reaches the canal.

The inundation canal is drawn off the dund at a level slightly above the bed of the dund, which is considerably above the bed of the main river. The dund is open at its lower end. Sometimes an embankment may be made at some point such that the entire discharge of the dund is forced into the canal. In such case, the silting of the channel would be greatly increased and the length above that embankment would silt up more rapidly.

When the lower end of the dund is open , the amount of silt deposit would be much less. However, it is doubtful whether the amount of silt in the canal would be greatly less than in the case of the canal, which is drawn directly from the main channel of the river, provided that the level of the bed was the same and that the bank of the river above the canal head was a stable one.

A canal taken off on a cutting bank or immediately below a cutting bank is soon chocked with silt. These remarks apply mainly to rivers such as the Indus and the Nile, which carry a preponderance of earthy matters in suspension in the water.

Following are some of the important points necessary for selecting spots for the heads of the canals which were screened from the full force of the current during the inundation (from the experiments made by **Colonel Tremenheere, R.E.)** on the Indus :

1. That inundation canals of Sind, which draw their supply from branches separated from the main river by islands covered with brushwood and long grass, contain a comparatively small amount of material in suspension. The brushwood and grass impede the velocity of the water and clarify it.
2. That canals having their heads in the main stream where the velocity is normally may be expected to contain silt to nthe extent of 1/300 by weight, and that about one-third of this quantity is ordinarily deposited in the canals.
3. That canals having their heads on the main stream in a part where the channel is restricted and the velocity increased may contain silt to the extent of 1/200 by weight, of which half may be deposited in the canal.

The above points have always to be considered in selecting a site for the head of an inundation canal and they explain why a favourite site is a little way above the point where the lower end of a dund joins the main stream, for if, as is often the case, the dund ultimately silts up at the head, a backwater is formed at the lower end, from which water can be drawn which is comparatively free from the heavier silt. But, such a head would only be a temporary one, as a rule, for the backwater would sooner or later become filled up by deposit.

CHAPTER - VI

IN - DEPTH STUDIES ON TRAINING AND CONTROL OF RIVERS IN BRAIDED FORMS

6.1 INTRODUCTION

Rivers are characterized by the fact that the types of materials on which the rivers flow, are built up by the rivers themselves. The rivers are classified depending upon the materials carried by them.

The rivers generally take off from the mountains and flow through the hilly regions before traversing the plains. The upper reaches of the rivers may be termed as the Rivers in Hills which are further sub-divided into Rocky River Stage and Boulder River Stage.

The river bed in the Boulder River Stage (Upper Reaches) consists of a mixture of boulders, gravels, shingles and alluvial sand-deposits created by itself. In order to assess the flood damage problem and thereby to suggest the appropriate river control measures in gravel bed streams, it is very important to understand its hydrological, morphological and fluvial characteristics. In addition to those sediment transport phenomenon within the gravel bed, stream is also another crucial parameter which must be dealt within a greater depth.

Gravel bed rivers are mountain streams, which are generally found near the head of the most of the river system in upland areas. These rivers supply the most of the sediments to the river system in the primary sediment sources. They are steeper, possess greater energy to transport sediment, generally have higher and much more turbulent velocities and have the energy to maintain the channel basically in its original form unless flows are very dramatically reduced. Sediment supply events tend to be incidental and non-uniform in their spatial distribution with the result that in a channel sediment transport is both unsteady and non-uniform. This complicates the understanding of gravel bed river considerably and hence it is very difficult to tackle the problem associated with such rivers.

A river of aggrading type or section of it has usually a straight and wide reach with shoals in the middle and divided flow which may even result in braided flow and an intricately woven system of channels.

There is a definite regime for each river to flow with its distance and elevation from the source to the sea, the magnitude and variation of its discharge and sediment load and the composition of its bed and banks. Although these elements of river flow are in no sense permanent and some vary considerably from year to year, yet there is a limit which controls the general dimensions of a river. The training of the river is meant to confine it within its limit for efficient flow and, therefore, the type to be followed for river training should be the fully developed final stage of the river i.e. the meandering type.

The purpose of river training is to stabilize the channel along a certain alignment with certain cross-section for one or more of the following objects:

(i) Safe and expeditious passage of flood flow,
(ii) Efficient transportation of bed load,
(iii) Stable river course with minimum bank erosion,
(iv) Direction of flow through a certain defined stretch of the river.

6.2 RIVER MORPHOLOGY

6.2.1 General

Rivers show complex combinations of various morphological elements. Morphology of rivers results from the entrainment, transportation and deposition of sediment particles of the valley fill and floodplain deposits across which they flow. Channel forms of these rivers are dependent on hydrological, geological and sedimentological features and while these features remain constant in a given drainage basin the river morphology remains stable even though the stream or river may not be static. A lot of field and laboratory measurements demonstrate both adjustment of river form to process and interrelationships between various aspects of channel form. Equilibrium river forms can be referred to a continuum of force-resistance relationships.

Areal slope erosion and bank erosion yield sediment which the rivers transport from the various source areas to its mouth. Spatial variability of sediment yield results from the influences of climate, vegetation, relief, geology and man on the erosional processes. This report is concerned with the physical processes responsible for the observed regularity of channel behaviour.

Major variables which effect any river channel during designated time spans. However, in general, the average lifetime of engineering structures in rivers are related to intermediate (modern) or short-time scales. The integrated effect of a set of upstream controls and mutual interrelationships of these variables are shown in **Fig. 6.1.**

Soils are the end results of Geologic conditions and the soil variables are much the same as the Geologic variables. The Hydrologic variables are to a slight degree dependent on the Geologic variables and to a lesser degree on Man's activities, but for the purposes of river engineering, they are considered

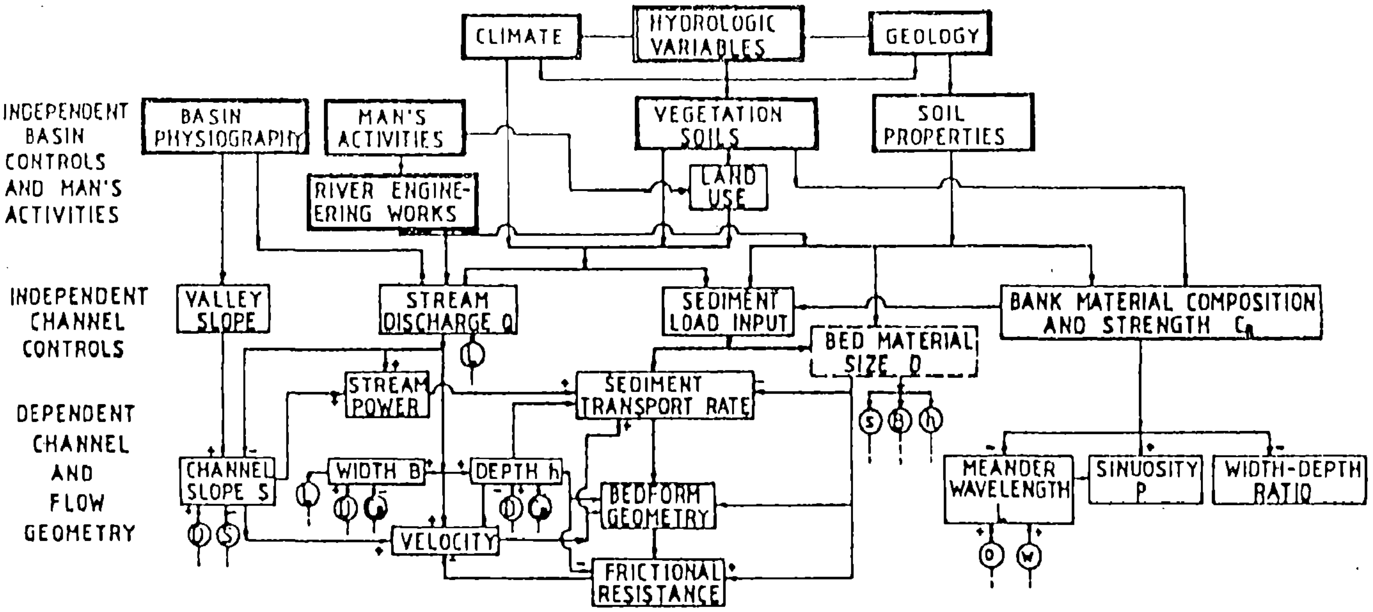


Fig. 6.1 Mutual interrelationships of river channel variables. Direct relationships are indicated by +, inverse ones by −. Arrows indicate the direction of influence.

Independent. The degree of dependence on man's Activities varies, because they may consist of past or future projects and may be permanent or constantly changing. The Geometric variables are the result of the Hydrologic and Geologic conditions of the river i.e. they are the result of the interaction between water discharge and the composition of the bed and bank material.

Man may force a river into an unnatural condition, but because the most independent variables do not change in engineering time. The river will always attempt to return to its natural condition. The natural river is adjusted to all the factors imposed on it. The more man works with the river, not trying to force it, the easier the job of controlling it will be.

6.2.2 Morphological Studies

The river morphology is concerned with river planform, channel geometry, bed form and longitudinal profiles. Channel morphology changes with time and is affected by water and sediment discharge including sediment characteristics, composition of bed and bank materials and vegetation. Because of the complex interrelations between river channel variables, it is still not possible to give a complete physical and mathematical description of various morphological processes. For this reason, two approaches have been commonly used **(Ackers,1982):**

1. EMPIRICAL STUDIES

- Field studies of plane geometry of natural rivers,
- Laboratory studies for the classification of plan form,
- Correlations of geometry with discharge,
- The formative (or dominant) discharge when flow is not steady,
- Statistical analysis of geometric data,
- Measurements of flow patterns including secondary current,
- Observations of sediment motion including bank erosion and sedimentary features.

2. THEORETICAL STUDIES

* The solution with various degrees of simplification, of the Navier-Stokes equations for flow in curvilinear channels, including secondary current generation,
* Variation of shear stress and other flow properties in rigid boundary curved channels, supported by laboratory research,
* Instability in water movement,
* Instability in sediment movement,
* Numerical modelling of the interaction between flow and sediment in curved flow,
* The theory of minimum rate of energy dissipation (**Yang and Song,1989**),
* Theoretical analogues e.g. random work, free chain most probable path.

6.2.3 Planform

The planform of rivers can be classified into broad types of straight, meandered or braided. A meandering river has a single channel while a braided river has a number of channels. This division is in part arbitrary and it is difficult to distinguish between a straight channel and a meandering channel of low sinuosity and not everybody agrees on what constitutes a meandering or braided channel. A classification of river channels in terms of relative stability and sediment load characteristics and flow properties has been suggested by **Schumm** and **Meyer(1979)** and **Schumm (1981)**. The most unstable channels are characterized by braiding, rapid shift in the thalweg and steep slope.

Sand bed rivers may change dramatically from one planform to another as significant changes in discharge are having greater tendency to be transitional, braided or somewhere between these limits and due to which it is very difficult to define the thalweg of the stream.

Brotherton (1979) developed a theory of origin of channel patterns. He concluded that meanders from where the discharge erodes and transports bank particles where as braids characterize river with highly erodible banks. In both cases, the bank erosion can be induced either by deposition of input sediment (deposition meander or braid) or directly by a discharge with excess energy (erosion meander or braid). Deposition braids from where the bank material is coarse-grained or where banks are incoherent and fine-grained. Erosion braids carry a flow which moves bank materials to bed without downstream transport.

White (1987) indicates that braiding occurred when the valley slope exceeded the equilibrium slope indicated by a diversion of the main channel into three channels.

According to **White,**

When $I_v < I_1$: Straight channels
$I_1 < I_v < I_3$: Meandering channels
$I_3 > I_v$: Braided channels

Where, I_v = the valley slope,
I_1 = the equilibrium slope of single channel,
I_2 = the equilibrium slope of double channel,
I_3 = the equilibrium slope of triple channel.

Bed topography and planform geometry are the result of the complex interaction of the fluid flow with the channel boundaries and sediment to follow a sinusoidal path. The result of the varying curvature of this path is a secondary flow and net fluid mass flux in the transversal directions. The lateral velocity components to its downstream propagation and thus the amplification is intensified as the function forces become more important. The secondary flow component also contributes to the growth of the bed deformations. The relation between these three mechanics for a given flow will determine whether the channel will remain stable or not. For an unstable channel, the bed deformation dictates whether the channel will meander or braid.

Fredsoe (1978) concluded that prevailing mode of channel depends only on the Shield's parameter and width-depth (B-ho) ratio. He also indicates that in the absence of suspended sediments and Shield's parameter >1, all streams should remain straight . This is why, gravel-bed stream (D > 2 mm) in the absence of suspendible sediments will be stable regardless of the depth-width ratio.

Further, **Fredsoe** recommended the following stability criteria for channel pattern (**Fig. 6.2**).

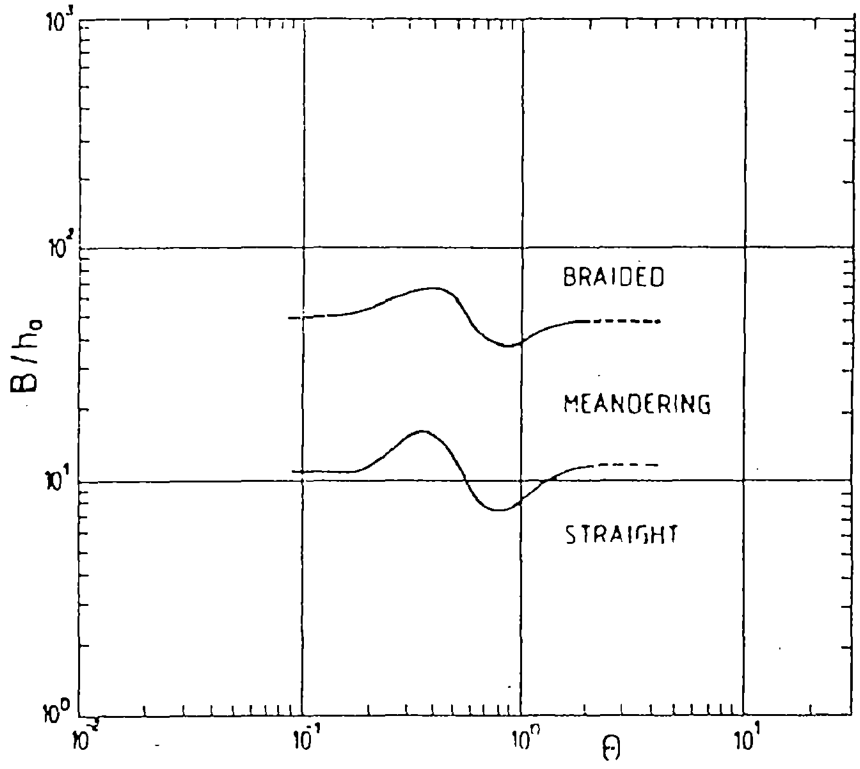


Fig. 6.2 Planform classification diagram (after Fredsøe, 1978).

If B/ho < 8 : straight channel

B/ho > 60 : braiding channel

5 < L/B < 15 ; meandering channel and is supported by field data.

The longitudinal profile of the river is a characteristics feature. From the source of the river to the mouth, the discharge gradually increases due to the inflow of tributaries.

A braiding river observed in the upstream part of a middle course gradually becomes a meandering river. Near the mouth (lower course) a delta formation can take place **(Fig. 6.3).**

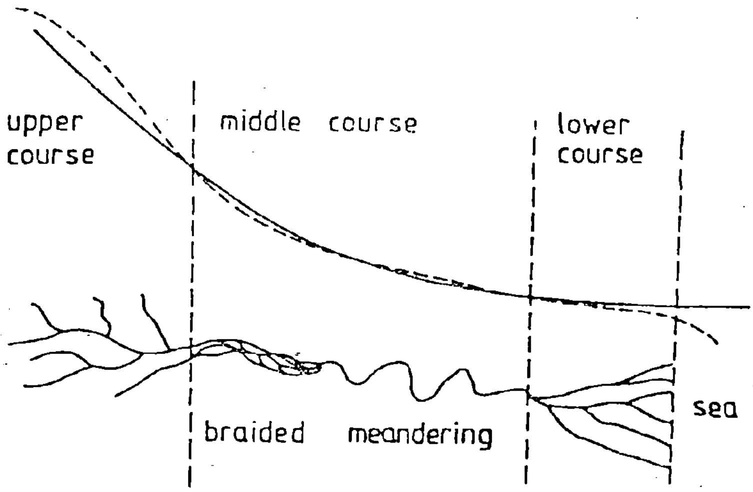


Fig. 6.3 Longitudinal Profile of the Ri

Along the river, the grain size is gradually decreasing due to sorting and abrasion.The change in mass (dM) of a grain is proportional to its mass (M) and the travelling distance (dx). Thus:

$$dM = -\alpha M \, dx$$

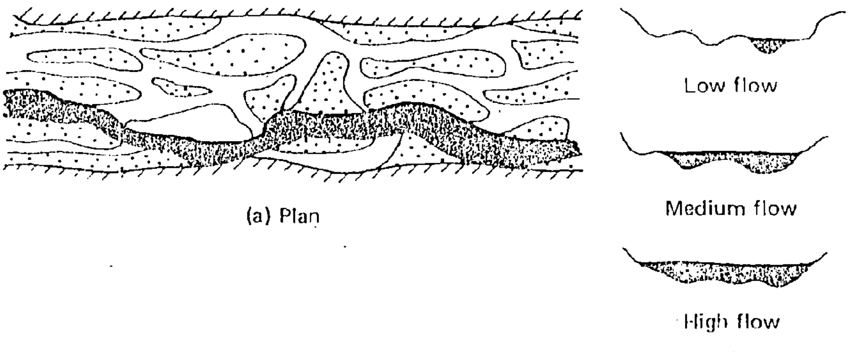
which leads to $M = M_o \exp(-\alpha x)$

where, α = co-efficient describing the properties of the particle of the river, and Mo is the mass at $x = 0$.

In many river systems a variety of sediment are usually supplied to the given river by the tributaries.

6.3 BRAIDING

If the bank material is easily eroded, if the sediment load is composed in large parts of sands and gravels moving as bed load, and if the dunes that are formed are large, the stream will almost certainly be braided **(Fig. 6.4).**



(a) Plan

(b) Typical sections

Fig. 6.4 Braided Stream

At low flow, there could be just one filament of flow wandering between the dunes left behind from the previous flood flow. At a higher flow, several filaments will combine and branch to make a network. The filaments at low flows will transport sediment, will enlarge and will make their paths continuous so that at moderate flows the network will tend to be preserved and even enlarged. At higher flood flows, however, all the passages between dunes will take flow and all or most of the dunes will be submerged. The complex, low flow network of flow filaments becomes even more complex. The bed configuration may be more a function of this complex flow network with deposition forming bars and erosion forming channels rather than " whatever - the - process is" that forms true dunes. The flow and sediment load will not be distributed evenly (or proportionally) in this internal network of flow; bars will form in what were channels, channels will be scoured out where there were bars; the stream will look quite different in detail, but overall it will be very much the same as it was.

6.3.1 Braided Rivers : Braiding Pattern

A distinctive characteristics of braiding pattern is multiple channels. There are, however, two types of multichannel streams; one is the interlaced multichannel stream separated by islands at low stages giving an appearance of a hair braid. At high flow stages, the islands may get submerged and the stream may flow from high bank to high bank. This is called a braided pattern.

The other kind of multichannel stream is of distributary type in which several separate channels branch out of the parent stream as in case of river building an alluvial fan or a debris cone. All these multichannels again combine at the foot of the cone. Distributary type multichannel stream is also formed in building up of delta where all these channels finally disappear into sheet flow at sea end .

Figs. 6.5 show the braided pattern as distinct from distributary channels of the Ganga.

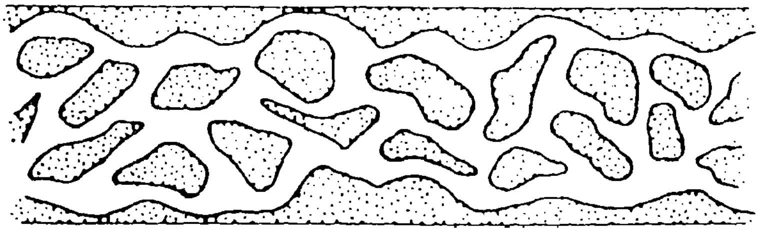


Fig. 6.5 Braided and Distributary Chamnnels

Real case illustrations of these two types of channels are shown in **Figs. 6.6 & 6.7.**Out of these, the Brahamputra river in Assam carries about 34,000 cumecs (12,00,000 cusecs) discharge at bankful stage and is intensely braided about 29 Km (18 miles) upstream of Gauhati within a width of about 9.6 Km (6 miles).

The Kosi river in North Bihar has an annual maximum discharge of 5550 cumecs (2,00,000 cusecs) to 8500 cumecs (3,00,000 cusecs), an average width of 6.4 Km (4 miles) and has got several distributary channels formed in the process of building of an alluvial fan.

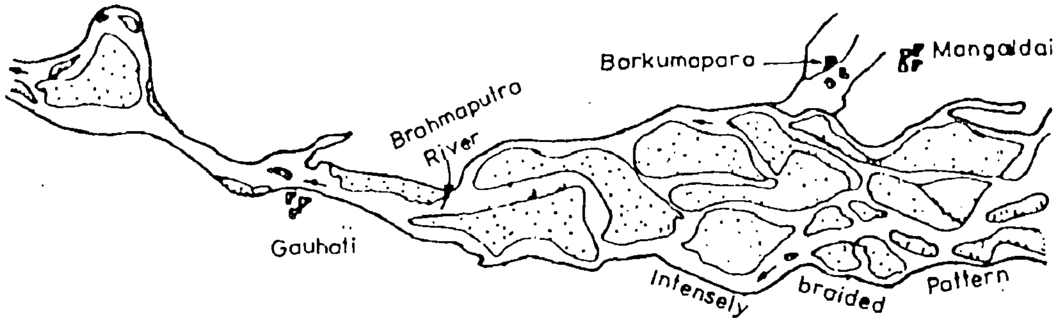


Fig. 6.6 Braided Pattern in Brahmputra

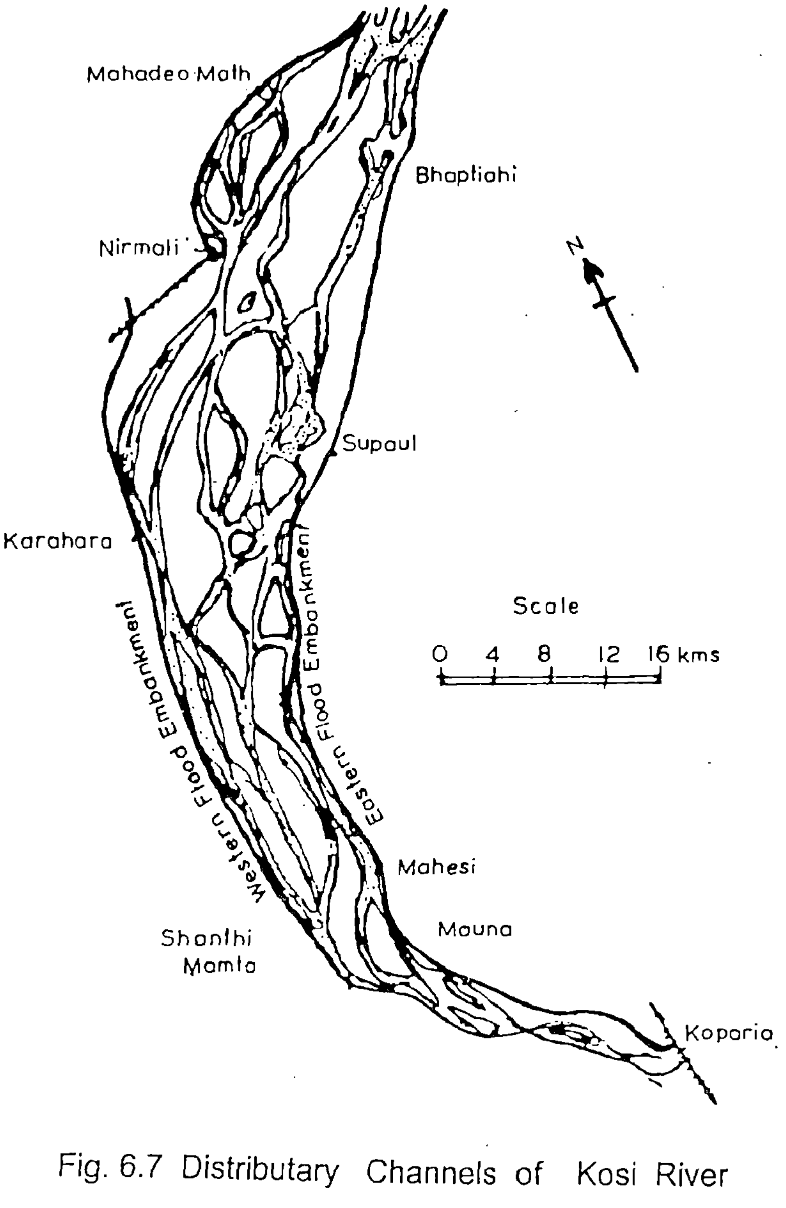


Fig. 6.7 Distributary Channels of Kosi River

6.3.2 Causative Factors

Braiding results when a stream is supplied with more material than it can transport. **Lane (1957)** suggested that steep slopes could also cause a braided channel in the process of carving a wide and shallow section in which bars and islands form readily.

Ackers and Charlton (1970) opined that when the valley slope is insufficient for the development of the hydraulic gradient necessary to transport the discharge and sediment as a straight or meandering channel, depending on the sediment charge, then a braided channel pattern develops in which deposition occurs and slope gradually increases.

Leopold and Walman (1957) have expressed the opinion that braiding is one of the many patterns that can maintain quasi-equilibrium between discharge, sediment load and sediment transport capacity. They also maintained that a braided channel does not necessarily indicate an excess of total sediment load.

Yang (1971) observed that division of the channel into smaller and steeper channels is caused in a braided river to keep the balance between sediment inflow and outflow, It was further maintained by him that channel braiding is likely to occur where channel width exceeds that which is necessary to carry the given discharge.

Chitale (1973) reviewed the above theories. His hypothesis is that all braided channels carry heavy charge of bed load. In order to generate sufficient transporting capacity for this heavy bed load, a wide and shallow cross-section is formed and in such a cross-section, conditions for building of braided pattern are favourable.

In a given channel, velocity is governed by slope, depth and boundary rugosity coefficient. Slope is normally dependent on general ground or valley slope. With a given discharge, the velocity obtained with this slope may or may not be sufficient for transport of bed load. If bed load is heavy, the velocity may become inadequate for its transport and there would be deposition of bed load material. In the process, the slope would steepen which in turn would increase the velocity and hence the bed load transport capacity. Higher velocity simultaneously causes bank erosion and the channel widens. Wider the channel, bed load per unit width reduces. This helps to diminish the deposition of bed load in the channel. By this self correcting process, the channel adjusts its cross-section and slope so as to generate adequate capacity for bed load transport and tries to be free from tendency for either deposition or scour and reach stability. In this attempt, a wide and shallow cross-section with steep slope is formed. When the cross-section is wide and shallow, it is difficult to obtain uniform discharge distribution all across the channel. The resulting non- uniformity of discharge distribution leads to development of interlacing channels. This reasoning appears to provide a rational explanation of formation of a braided pattern.

6.3.3 Characteristics Of Braided Pattern

(a) AGGRADATION : Since braided pattern emerges when bed load transport is heavy, braiding of channels is often associated with tendency for aggradation. Braiding channel, however, need not always experience aggradation .

(b) CHANNEL ALIGNMENT : Heavy bed load, generating a wide and shallow cross-section, was seen to be the basic reason for formation of a braiding pattern. Associated characteristics were fond to steeper slope, coarser bed material and higher velocities. All these factors being unfavourable for meander formation, the alignment of braided channels is more or less straight, subject to constraint of valley boundaries.

(c) **MOVEMENT OF ISLANDS** : Islands in braided rivers get eroded on their upstream faces and build up on the downstream faces. The islands, therefore, appear to be unstable and moving downstream. The rate of this apparent movement is slow and depends on several factors like frequency and duration of high floods, size and gradation of material forming the island, its susceptibility to erosion, vegetable cover which retards velocity, clay content which retards erosion etc. Tendency for movement of islands, therefore, can be significant in some rivers and not noticeable in others. Movement of a typical island in lower Brahmputra river is shown in **Fig. 6.8.**

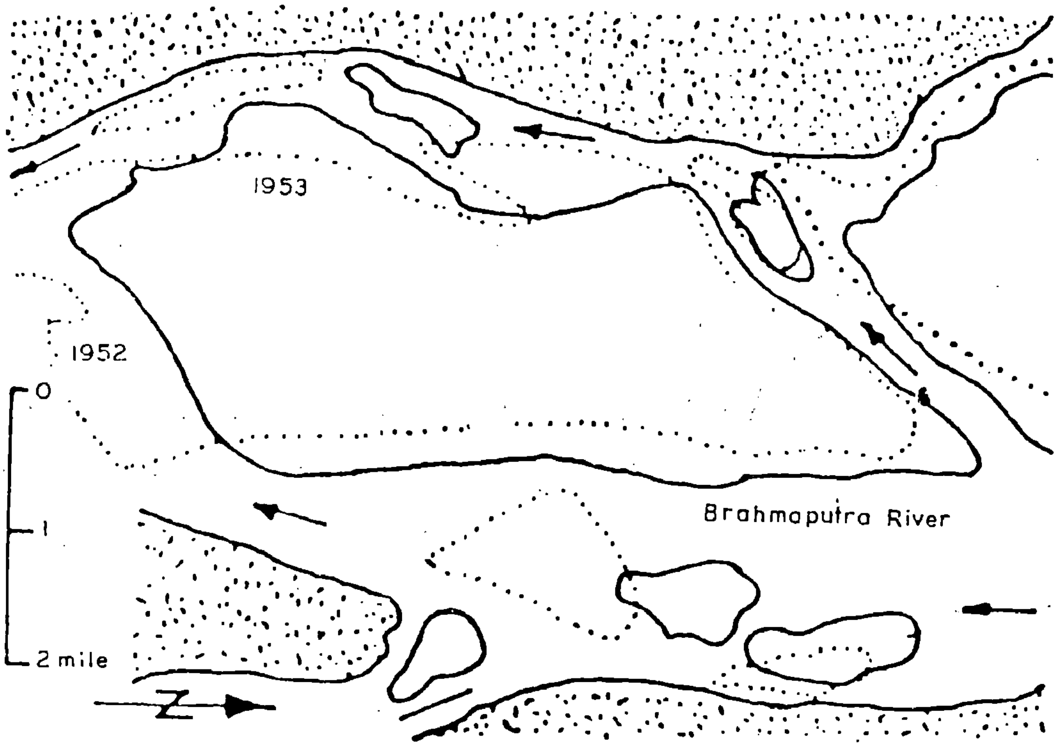


Fig. 6.8 Shifting of an Island in Kosi River

(d) BANK EROSION : Islands in some of the braided rivers have a tendency to move downstream, With movement of islands, the channel along the bank gets squeezed causing increase in discharge concentration, thus leading to local bank erosion .

6.3.4 Relationships For Braided Channels

It has been noticed that there is a significant difference in slopes of braided and meandering rivers. Slope of a braided river is found to be much steeper than that of meandering river.

Lane(1957) found a general relationship of the form $S=K/Q^{0.25}$ and believed that with the value of K= 0.0017, this relationship was applicable to all meandering streams in equilibrium conditions with sediment of the size found in the lower Mississippi river and having a similar tortuosity ratio. For braided streams of high slope and sandy beds, the slope discharge relation suggested by him was $S= 0.01/Q^{0.25}$ Thus, the slope for a specific discharge in case of braided streams would be almost six times that of a meandering stream.

Leopold and Wolman (1957) sought similar relationship and found that braided channels were separated from meandering channels by a line defined by the equation $s= 0.06 / Q^{0.44}$ indicating that for a given discharge , meandering would occur with smaller slopes and braiding with steeper slopes.

Henderson (1966) attempted to refine the criterion given by **Leopold and Wolman** by taking the size of bed material into account. He found that in 67 percent of cases , meandering channels follow the line given by

$S = 0.64dm^{1.14}/Q^{0.44}$, where dm is the medium size of the bed material in feet. Braided channels had slope substantially steeper than indicated by the equation . Since bed material in braided rivers is coarser than in meandering ones , the implication of **Henderson** criterion is that the estimated slope would be steeper on account of coarser materials as well.

Chitale (1973) verified that out of the three, **Leopold - Wolman** criterion was superior and was borne out by 80 percent of field data. He also observed that width to depth (W/D) ratio was a physical factor governing formation of braiding pattern and for all braided rivers, value of this ratio was found to be more than 400 in the field data examined by him .

The example of this type river can be given to the Ganga which extends from Raiwala to 3.20 Km (2 miles) below the town of Kankhal (**Fig.6.9**). In this reach, the river swings round on its course near Raiwala and in doing so, it strikes the clay bluff at the important place where the Raiwala temple is located about 24 meter (80 ft) in height . At this point, except in high floods, the whole supply of the river flows in the channel immediately under the bluff and hence the site offers exceptional conditions for the gauging the river.

For many years past, there has been little or no change at Raiwala and it is unlikely that any change will take place in the near future. There has been cutting - back of the clay bluff, but this is very gradual . It is below Raiwala that the changes in the many channels of the river affect the conditions of supply to the Ganges Canal and it is the variations in these canals that led to various problems while training the Ganges at Hardwar .

6.4 GRAVEL BED STREAMS CATEGORIZED

Braided rivers are gravel (boulder) bed streams or rivers. Hey and Thorne (1986) defined that the gravel bed streams are those in which hydraulic processes are controlled by material coarse than 2 mm in diameter and have a significantly different hydraulic geometry from those developed is fine grained sandy material. However it is common to find a gap in the range of river bed material sizes as D_{50} increases from the sand range to the gravel range. Very few rivers have a bed made of coarse sand (0.5mm –2.0mm) or fine gravel (2mm-16mm).

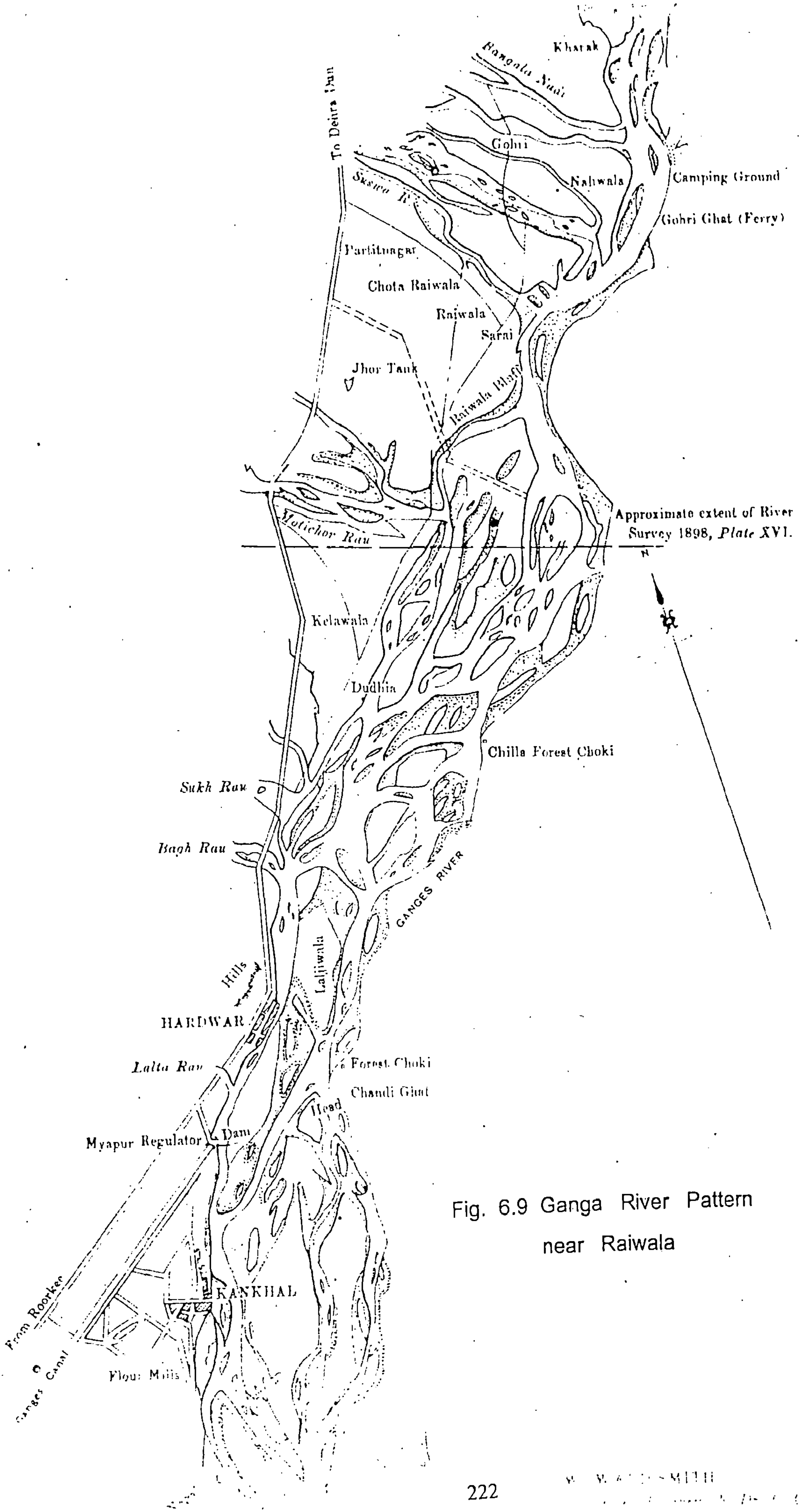


Fig. 6.9 Ganga River Pattern near Raiwala

In addition to sand bed gravel-bed streams, boulder-bed and cobble-bed streams are also frequently used in describing the morphological characteristics of the rivers. But such categorical distinction have not been made as far as the process of sediment transport, armouring, resistance to flow and river training analysis are concerned. Hence, all rivers with coarse bed material including cobbles and boulders will be considered as gravel-bed rivers.

6.5 DIFFERENCE BETWEEN GRAVEL-BED RIVERS AND SAND-BED RIVERS

The gravel-bed reaches of a river system will exhibit totally different morphological characteristics and in general they show less responsiveness to modest changes in discharge and discharge duration than in sand bed rivers. Under more normal natural discharge or even regulated flows, the mountain rivers are relatively stable.

According to **Bathurst**, sand bed rivers are different from the gravel bed rivers in the following four significant aspects :

(i) Wide bed material size distribution

In sand sediments, size ranges up to little more than 2mm. In gravel sediments, on the other hand, sizes range from 1 mm to 100 mm or so, while boulder sediments range up to 1000 mm or more in size. With such wide distributions, it is not always possible to assume that all the sediment size move in the same manner or under the same conditions. For example, the mobility of a given size may be affected by the position of that size within the overall size distribution. Consequently, transport calculations cannot always be based on just one characteristic sediment size, for example the median diameter, and sediment routing may have to be carried out for each size fraction in turn.

(ii) Sediment supply

Gravel bed rivers are generally found near the head of a river system, while sand bed rivers occur at the lower, flatter reaches. Thus gravel bed rivers are generally in upland regions and are therefore nearer the primary sources of sediment. Sediment supply events tend to be episodic and non-uniform in their spatial distribution, with the result that the in-channel sediment transport is both unsteady and non-uniform, even for steady water discharges. Depending on the supply of sediment to the channel, there may be two orders of magnitude of variation in the sediment transport for a given water discharge. This considerably complicates the calculation of sediment discharge relative to the case of sand bed rivers.

(iii) Episodic transport

Whereas sediment transport occurs at almost all flows in sand bed rivers, significant transport in gravel bed rivers takes place only at relatively high flows (approaching bank full). One result of this is that there are long periods of low flow with no transport, during which the sediment is able to settle, interlock and generally become consolidated. Consequently, it is more difficult to move at a subsequent high flow than would be expected on the basis of a simple Shield's shear stress calculation.

(iv) Ratio of bed load to suspended load

Bed load can account for a larger proportion of the total load in coarse sediment channels than in sand bed channels. In the latter the bed load may form 5-20% of the total load. Similar proportions can be observed in gravel bed rivers. However, the proportion may also rise to 10-50% especially for mountain river.

According to **Simon's** some basic difference between the sand bed and gravel bed rivers are described as follows:

(i) Variations in planform

Sand bed rivers can be meandering, transitional and braided and they may change easily from one plan form to another as significant changes in discharge are experienced. On the other hand, gravel bed rivers have a much greater tendency to be transitional, braided or somewhere between these limits, while for cobbles and boulder bed rives, it is rare to find reaches that meander significantly. Moreover, it is very easy to define the thalweg of sand bed stream but for cobble and boulder bed stream, it is virtually impossible to define its location.

(ii) Variations in bed material size and their distribution

The most obvious difference is that sediment of gravel bed river is coarser than that of sand bed rivers. In sand sediments, sand sizes range from 0.625 mm to 2.0 mm whereas in gravel sediments, size ranges from 2 mm to 100 mm or more in size. With respect to grain size variability, sand is normally well-sorted but since sand and fine particles are also present in gravel bed rivers, gravel sediments are poorly-sorted i.e. their size distribution are wider and the bed material are exceedingly non-uniform. These characteristics of the gravel bed rivers make them behave differently compared to sand bed rivers in respect of flow resistance, sediment transport, armour layer formation bed packing. Due to the bigger particle size in the gravel bed rivers, the ratios of depth to sediment size is always on the lower side than the sand bed rivers.

(iii) Variations in channel slope

Sand bed channels are generally flat but gravel bed channels usually possess higher gradients and they flow along the steep terrain. Generally, the gradient of the stream is directly correlated with the median diameter of the bed material forming the stream, the steeper the river the coarser the material on the bed of the channel. That is why the sediment size in the gravel bed rivers is on the higher side.

(iv) Variations in bed armouring

With regard to the armouring of the bed of the river, it is literally impossible to form an effective armour in sand bed rivers whereas in gravel bed channels, due to sorting of material in the transport process, fairly significant armouring may occur. However, the armouring observed may not be continuous across the full width of the river bed.

(v) Variations in regimes of flow

Sand bed rivers are often classified as flowing in lower regime (i.e. bed forms are usually a combination of ripples and dunes) or upper regime (i.e. bed forms usually a combination of plain bed with standing wave and antidunes) connected by a transition. The magnitude of the Froude number at which the land bed channel changes from lower regime to upper regime may be in the order of 0.2, 0.3 or 0.4 depending upon the size of the bed material. On the other hand, in mountain streams where the beds are formed of coarse material, it may be necessary for flow condition to produce a Froude number greater than 1.0 before the stream has sufficient energy to cause any general movement of the bed material.

(vi) Variations in bed forms

With sand bed channels, it is common to experience ripples and dunes followed by a transition zone connecting upper regime conditions of standing wave and antidunes to occur. Whereas in the gravel bed streams, ripples do not form because they are not found when the median diameter of the bed material is larger than approximately 0.6mm.

(vii) Variations in bar forms

Bar forms are another common feature in alluvial rivers and result from the localized deposition of bed material. The most common types are the point bar which forms on the inside of bends, alternate bars which are a precursor of meandering systems, middle bars that subsequently may become islands where the river is exceptionally wide and tributary bars where steep tributaries carrying heavy sediment loads deposit material in the mainstream at the confluence. The bar material is of sufficient size and of sufficient quantity that it cannot be immediately transported. All these bar forms mainly develop in sand bed rivers and sometimes in gravel bed rivers. However, it is unusual to find middle bars in the cobble and boulder bed streams.

(viii) Variations in resistance to flow

The resistance to flow in alluvial channel is dependent on the physical features namely ripples, dunes, standing waves, antidunes, all types of bars and river alignment. For the sand bed channels the resistance to flow is a function of the form of the river, the discharge and its duration, the type of bed forms, the size and gradation of bed material, the bars, their geometry and location etc. Whereas for the gravel bed rivers the resistance to flow is largely a function of the grain size, the grain size distribution and the degree to which the space between the larger particles may be filled with finer sediments.

(ix) Variations in sediment transport and supply

Sediment transport occur at almost all flows in sand bed rivers. But in gravel bed rivers, transport of coarse material occur only during the period of high flow. In boulder bed mountain rivers, the large sizes may only move in extremely high floods. In gravel bed rivers, there are long periods of low flow with no sediment transport, during which the sediment is able to settle, interlock and generally become consolidated. As a result, it is more difficult to move at a subsequently high flow than would be expected on the basis of a simple Shield's shear stress calculation. In gravel bed rivers, bed load may form a higher proportion of the total load than it does for sand bed rivers, in which the suspended load typically provides most of the total load. Large concentrations of wash load in a sand bed river significantly alter the viscosity, reduce the fall velocity and diameter of the particles being transported and in many instances greatly increase the ability of the river to transport sand. Conversely, in gravel bed rivers, even though the wash load significantly affects the viscosity of the water, it has small effect on the movement of the bed material.

(x) Variations in bed scour and fill

All alluvial channels are prone to bed scour and fill through time. In sand bed rivers the rate of change of bed elevation can be both large and rapid. This may be due to downstream movement of large bar or local aggradation or degradation resulting from natural or man-induced changes. In the case of gravel bed rivers, bed elevation changes can be significant but they are not usually as dramatic or as large as in sand bed rivers. These changes are usually associated with larger events, ice jams that have failed, dam breaches and storms.

6.6 BANK MATERIAL

The bank material of natural channels is frequently more variable than the bed material. In many cases channel banks posses some degree of cohesion because of finer material, such as silt or clay, so that the analysis of bank erosion is not a complication, is caused by vegetation whose root system can reinforce bank materials and thereby increase resistance to erosion.

Studies on some gravel bed rivers in Britain have shown that the composition of banks of gravel bed rivers may vary as follows:

- Banks can be composed of materials varying from gravel to clayey silt.
- Banks are often composed of layers of material of different sizes (sometimes slit overlying gravel etc.).
- Banks vary in composition vertically at any section.
- Banks vary in composition between the upper left and right banks.

This great variation in the composition of the bank significantly affect channel geometry, and particularly the channel width, The stability of bank with respect to mass failure depends on bank material properties and bank geometry. Different types of materials possess different values of cohesion 'c' and angle of friction 'ϕ' and these are the bank material characteristics upon which its shear strength highly depends on.

Hence, the stability of banks increases with the increase in the value of ‘c’ and ‘ϕ’ . So, it can be concluded that resistance of river bank to erosion is closely related to the characteristics of the bank material.

It is important to note bank are generally not composed of uniform materials throughout their height, but rather are stratified with layers of gravels, slit, sand and clays.

Stream bank may generally be classified as cohesive, non-cohesive and stratified. Soil mixture containing clays are usually cohesive while soil mixtures of gravels, sands and slits are non-cohesive.

6.7 BANK EROSION / BANK FAILURE MECHANISM

Bank erosion is a significant source of the sediment load in many streams. Bank erosion may be an essentially a natural phenomenon, or it can be initiated by man made changes in the river basin or channel surroundings. Bank erosion is probably the most common problem faced in the river engineering practice.

The mechanics of bank erosion and the stability of protective structures subjected to hydraulic loading are really the complex problems. It was found that bank erosion along braided rivers is far more difficult to predict due to the much more complex processes. In this case, bank erosions occur both along curved channels and along straight reaches. The bank erosion along curved channels is similar to this process for meandering rivers, notably an increase of the celerity of bank erosion with decreasing relative radius of curvature. A further complication is caused by vegetation whose root system can reinforce bank material and thereby increase resistance to erosion.

Bank failures occur as a result of one or a combination of the following :

- Removal of soil particles from the bank surface either continuously or intermittently over a period of time.
- Sequential failures of small segments of bank material.
- Failure of a single layer segment of bank material.

The main processes and causes that contribute to the bank failure are listed below (**Knighton , 1984 ; US Army Corps of Engineers , 1981 ; Van der Knaap, 1990 ; Comer , 1990) :**

(A) Surface soil abrasion :

1. Rainwater impact,
2. Aeolian transport,
3. Ice and debris attack,
4. Over-bank drainage (rilling and gullying),
5. Waves (wind and vessel induced),
6. Bank material composition.

(B) Subsurface soil alteration :

1. Frost heaves,
2. Permafrost,
3. Piping,
4. Freeze/thaw,
5. Stage fluctuation,
6. Vegetation / animals,
7. Soil moisture levels.

(C) Fluvial entrainment :

1. Vessel propeller forces,
2. Water currents,
3. Point bar building,
4. Head- cutting.

Additional causes of bank erosion in natural environments and effects of human activities include the following **(Neill and Yaremko , 1989 ; US army Corps of Engineers, 1981) :**

1. Long term geological processes of valley widening .
2. Geotechnical instability, as a primary cause of bed erosion, is important mainly in entrenched streams with high steep banks in weak soils and formations.
3. Basin development : Where the drainage basin has been altered by developments, such as conversion from forest to farmland or from farmland to urban use, flood peak and sediment loads often increase.
4. Removal of bank vegetation.
5. Local bank protection and river training works often provoke accelerated bank erosion elsewhere.
6. Mining from the stream bed can contribute to bank erosion by causing bed degradation and undercutting of banks.
7. Reduced dam release may produce aggradation in an outlet channel whenever the resulting flows are insufficient for removing sediment inflow from tributary streams.

The US Army Corps of Engineers (1981) summarized changing conditions that affect bank stability as follows :

1. At the surface :

(a) Severe surface deterioration that may result in an unstable bank configuration, such as erosion by streamflow at the toe of the bank; erosion at the water surface due to waves; and erosion along the bank surface due to over-bank flows.

(a) Deep tension cracks due to excessive drying of a cohesive soil or similar structural change that may cause the bank to weaken and become unstable.

(b) Overburden placed along the top of bank that may cause an otherwise stable bank to become unstable.

2. Moisture Content within the bank :

(a) The slope of a cohesionless bank may be temporarily steeper than the angle of repose of the bank material due to capillarity or other temporary stabilising effect. When the stabilising effect is removed, the bank becomes unstable.

(a) With piping, cohesionless material is eroded from a location on the bank surface by seepage flow; a cavity develops and extends rapidly into the bank along a dominant seepage path.

(b) With a high water table and low stream level, an added hydraulic load is placed on the bank and may result in failures unless relieved by seepage or piping.

3. Miscellaneous conditions :

(a) Artesian or gravity flow in a cohesionless or porous layer can remove sediment by piping, resulting in shear failure of layers higher in the bank.

(b) A thin clay layer that weakens and compresses when saturated can cause shear failure in the upper bank.

(c)Lubrication by water and high hydrostatic pressure along interfaces between bank materials can cause low resistance to sliding , resulting in massive bank failure.

(d) Other site-specific combinations of failure mechanisms.

Different types of banks have different failure mechanisms as follows **(US Army Corps of Engineers, 1981; Peterson, 1986) :**

1. Cohesive banks have low permeability and tend to drain slowly. They become unstable under conditions of rapidly falling stage. They are sudden to failure by bank caving, sloughing or sliding when the banks are undercut or saturated. Large amount of material can erode into the channel almost instantaneously. Bank height is important in assessing stability of cohesive banks because such banks tend to be more unstable than non-cohesive banks or banks of low cohesivity of equal height.
2. Non-cohesive banks are subject to surface erosion, resulting in a slow, piecemeal loss of bank material over a period of time. The rate of surface erosion is affected by such factors as:

- Direction and magnitude of flow velocity adjacent to the bank.
- Turbulent fluctuation of the flow.
- Magnitude and fluctuation of shear on the bank.
- Seepage, piping and wave forces.

The angle of repose is small (as low as about 20 degrees) for soils made up of fine well-rounded particles and large (to values greater than 45 degrees) for coarse angular particles. Finer grained cohesionless soils drain more slowly than coarse grained cohesionless soils and are, therefore, more susceptible to failure. Loose sandy material containing some fines is subject to liquifaction failure (flow slides). When such banks are saturated and the water level drpos, presures in the bank build up to where the sand particles slip and the soil mass acts as a liquid, with large quantities of bank material suddenly flowing into the channel.

3. Stratified banks exhibit a complex erosion process. The layers of non-cohesive material are subject to surface erosion, but are partially protected by layers of cohesive material. Stratified banks are subject to erosion and sliding as a result of subsurface flow and piping.

However, with so many causes of bank erosion their individual effects cannot be separated or an erosional threshold defined. Thus, the detail research of bank erosion mechanisms requires attention to long-term field studies **(Knighton , 1984 ; Neil and Yaremko, 1989).**

The bank erosion along rivers depend on both the morphological process in rivers that determine the erosive forces, and the soil-mechanical properties of the river banks that characterize their ability to resist erosion.

The main factors are:

1. Flow e.g. discharge flow, groundwater flow, shear stresses exerted by discharge flow.
2. Sediment transport e.g. removal of slump debris after mass failure.
3. Bank properties e.g. bank material weight and texture, shear strength including cohesive properties, bank height and cross-sectional slope, groundwater level permeability, vegetation and constructions.

Process of bank erosion on river bank primarily fall into two major categories:

1. Fluvial entrainment, and
2. Sub -areal / sub aqueous weakening and weathering.

Fluvial processes are associated with hydraulics of flow in the channels whilst weakening and weathering of the bank materials are controlled by climatic conditions in general and the movement and physical state of soil moisture in particular.

Fluvial entrainment causes bank retreat in two ways. First, material may be entrained directly from the bank and transported downstream as a result of the shear stress generated by the flow. Secondly, the flow may the bed at the base of the bank (increasing bank angle and height) to bring about gravitational failure of the intact bank.

On the other hand, process of weakening act on intact bank material to reduce its strength and decrease bank stability. The mechanics of failure again depends on the size, geometry and structure of the bank and the engineering properties of the weakened bank material.

Bank erosion is a significant source of the sediment load in many streams. Hence, bank erosion is probably the most common problem faced in river engineering practice. Basically instability of river banks is due to bed degradation and lateral erosion. The process of lateral erosion increases the bed width of the channel and result in steepening of bank and the bed lowering increases the bank height combinedly esulting to decrease the stability of bank. Moreover, the relative amount of vertical and ateral erosion are a function of bank material properties, bank geometry, type of bed material and the flow characteristics. Bank failures occur as a result over or more of the combination of the following :

Removal of the soil properties from the bank surfaces either continuously or intermediates over a period of time.

- Sequential failures of small segments of bank material.
- Failure of a single large segments of bank material.

The ASCE Task committee on channels Stabilization Works (1965) identification the most common cause of bank failure as attack by stream flow at the toe of the bank. As the toe erodes and the eroded material is carried away by the flow, the bank progressively steepens to where it becomes unstable and fails, either as a series of successive small failure or as mass failure of single large segments of the bank.

It has been investigated by many river engineers that fluvial factors are the main factor, which is basically responsible for the stream bank erosion. The fluvial factors leading to bank erosion may be classified as follows:

(i) Increase discharge, causing increased velocities and securing;
(ii) increase or decrease discharge, causing change in meander wave length and hence is geometry of embayment;
(iii) Migration of meander pattern in dynamic equilibrium;
(iv) Increased sediment discharge, causing bed aggradation and higher velocities;
(v) Decreased sediment discharge, causing bed degradation and loss of bed bank stability;
(vi)Relative and rapid change in river water level causing seepage pressure in the bank;

(vi) Natural or artificial obstructions deflecting currents towards the bank-these may be boulders, channel bar formation, crossing over tree trunks, tree roots, spurs, jetties, bridge abutment and pier;
(vii) River traffic or winds generating waves.

The mechanics of bank erosion and stability of procedure structures subject to hydraulic loading are a complex problem. The understanding of erosion process and failure mechanics of structure is still in a rudimentary stage.

CHAPTER - VII

DISCUSSIONS AND CONCLUSIONS

7.1 DISCUSSIONS

The present dissertation includes the study of the practices used to train and control of the major Himalayan rivers, mainly in gravel beds. Many research works have been conducted on fluvial processes and on morphological changes in gravel bed rivers as a result of which some established theories and procedures are available. The major Himalayan rivers are different from the Non-Himalayan rivers. A sizeable proportion of India's vast water resources are contributed by three major Himalayan rivers viz. the Brahmputra, the Indus and the Ganges. The Himalaya exercises a dominant influence on the behaviour of these mighty rivers. The sediment (boulders or gravels) concentration during monsoon discharges of these rivers are very high. The high flood discharges and the lean flood discharges are having a very big gap.

Sediment (Gravel) load and discharge vary with respect to time and the complex fluvial phenomenon is not understood clearly so far. Training and control of these mighty rivers need a careful consideration and a scientific as well as practised approach. Execution of each scheme should also be accompanied by a continuous study of gradually growing effect on a river and basic characteristics of river in that particular reach.

The historical development of training and control of rivers is needed to be studied carefully. River improvement techniques based on observations and practical experiences need to be linked with the modern tools to prepare some full proof methods for river regulations. In fact, the river regulation for the major Himalayan rivers needs a separate attention in order to utilise our vast water resources the most effectively.

The first and foremost important task before deciding a methodology to train and control these rivers is to study the behaviours and changes in their plan in detail. The plan from major Himalayan rivers are typical and irregular. The effects of the Himalayan glaciers on these mighty rivers are also remarkable.

The river Ganga in its sub-mountainous reach at Hardwar has strong rapid currents due to steep slope of the river and swinging river course due to steep slope of the river and swinging river course due to which many problems at the head of the Upper Ganga Canal has arisen. The techniques of damming the main river and the bifurcated streams to divert the currents towards main supply channel had been an interesting affair. The wooden crib dam filled with boulders were used during those days over a long period, and recently during demolition of the old Bhimgoda weir, the same technique was adopted to dam the river and to divert the current away from the old weir successfully because the methodology was based on the local materials and manpower.

The Kankhal spur is another example of training of the river Ganga in its sub-mountainous reach at Hardwar. A single massive bold spur 300 m long, slightly inclined upstream (95° to 110°) has successfully deflected the entire flow and still functioning well with least maintenance problems. This spur was also constructed with local materials and simple designs.

The concept of Guide Banks is derived from the natural behaviour of a river which passes from its wide shallow zone to narrow gorge with no abnormal velocity. The artificial narrowing of a river in a wide shallow zone for constructing a bridge or other suitable control structure can be done in incoherent bed of alluvium. The plan layout should be as such that there is swirls generated.

The Denehy's Groynes at Narora is a magnificient work planned to train the river Ganga in its long reach alluvial. The T-headed spur spaced suitably can be adopted cheaply according to the embayment characteristics of a particular river. The bad point is that this system requires a lot of materials (stones) which may not be available within the reach of a control measure at all the sites and was found more useful in training and control of river in a long reach with availability of stone, rock etc.

The approach of bringing about permanent effect on the regime of a river by means of appliances of a temporary character has proved quite useful. However, ~~[illegible]~~. In India, the material used in temporary application like rope, tree, net mattress and brush wood are bound to rot sooner or later. For example, on Indus, the temporary structures which were tried were swept away by the violent attack of the river. The failure was mainly due to incorrect diagnosis of the erosion.

The river Mississippi (and its tributaries) in U.S.A. present it in the top position to utilisation and control of its water. The main training practices are bank protection and intermittent protection measures are dikes, retards and groynes. The toe-trench revetment and Kellner Jettis are also effective measures and are still in use. The basic concepts and requirements of training were for navigation and flood control to lower the high flood levels by a series of cut-offs.

The harnessing and control on rivers was an important requirement for becoming a political leader or head of the state in China. A world famous diversion project named as 'DUJIANG WEIR' was built in ancient times, having the longest history and is still in smooth function today. The structure is an interesting example about the deep sense of river engineering and the river behaviour to the Chinese people. The outer curve or concave bank has been used for the location of a trunk diversion canal and the overflow structure on convex bank to release floods and discharge sands by use of circulation current in bend.

In Egypt, the Nile river has always been of interest to river engineers. Experience used to be a guide besides scientific methods to deduce the suitable training measures. The High Aswan dam has made the flood absent from Egypt has caused short term and long term environmental problems besides the expected numerous economical benefits. There is a thought that the only solution is to divert silt or flood back to Egypt because the silt was the primary source of fertility of Nile valley agriculture. In Egypt, specially the Nile water has been diverted for irrigation use through inundation canals without any permanent diversion work and the practice continued for a very long period and it presented a good overlook for the river diversion.

However, there is a definite regime for each river to follow with its distance and elevation from the source to the sea, the magnitude and variation of its discharge with sediment load and composition of its bed and banks.

7.2 CASE STUDY

The training and control of the river Ganga near Hardwar for the **Upper Ganga Canal (U.G.C.)** has been taken as a case study.

The well recorded severe famine in 1837 in Ganga-Yamuna doab had drawn the attention of British Canal Engineers to protect this agricultural land against recurring droughts. **Captain Proby Thomson Cautley,** a Royal Artillery Officer, first prepared the project of Upper Ganga Canal (U.G.C.) in 1838 with a proposal to take out a canal from Ganga near Hardwar and brought it in final form by 1845.

At the time of commencement of U.G.C. project, there was no science of soil mechanics and the knowledge of hydraulic engineering was also in primitive stage. There was no large extensive canal system existing in the country and in the world ,too, by that time. sir cautley used his engineering skill in producing simple and bold designs with locally available material (e.g. brick, lime and surkhi etc.). Foreseeing the constraints and limitations, the project works were ultimately taken up with full swing in 1848 and the canal was commissioned on 8th of April, 1854 with a head discharge of 189 cumecs at Myapur.

The location of the diversion points and alignments in the upper initial reaches was based on thorough understanding of diversion requirements without permanent works and extensive foresights in planning of such works. The training and control of the river Ganga from Chillawala weir to Myapur Dam was being done as per requirements only by temporary structures and it worked in a well manner for a long period. The whole system of training works developed gradually in maintaining and establishing the face of all the changes and difficulties of the past many years.

The Bhimgoda head bunds worked as the centre of the system, first up the river and then down the supply channel to Myapur. The beginning of the training works was from 1861-62 by Login's crib bar. Additions to Login's bar were no. 1,2,3 & 4. Dudhia channel, Nildhara channel and Chillawala channel were trained, when required. The basic approach behind the training was to control the discharge carrying capacity and bed levels during floods.

The Gohna floods caused the latest additions to the training works above Bhimgoda namely the Motichur bund . The Hardwar Dam started in

1859-60, in 1861-62, a crib bar was commenced.

The masonry Hardwar dam was constructed in 1870-71 which was added continuously for bays etc. The Belwala island was also protected by spurs. The Hardwar Dam was the first and foremost important controlling dam to escape the surplus flood discharge approaching that point (just opposite to Har-ki-Pauri).

Timber crates of the shape and size required for each locality formed almost the only method of constructing the various training works till about 1872-73 , when masonry began to be used. The sal wood for crates was obtained from young forest trees divided into ballas, ballies and tors varying from 4.5 m to 6 m (15 to 20 ft) in length and mean diameter of about 10 cm.

There were many advantages in working with crates. There was no delay as in masonry work in waiting for the mortar to set. The crate could be constructed when required, floated out to site and gradually filled with boulders as it was lowered down into the requisite position; and when completed, it was of for greater bulk and weight than any block of concrete or masonry which could be handled and conveyed to site. Unfortunately, crates were of temporary character and needed to be retained quite for some time proper maintenance was required. Nevertheless, crates still were used where protection was required.

The first advance in the direction of masonry work was about 1872-73, but a mortar was used of white lime and surkhi which took time in setting . From motives of economy, the masonry was combined with crates. In 1879, crates were omitted and a spur was constructed. In 1876, the first concrete blocks were made with the purpose of dropping them into the deep erosions at the points of the masonry spurs and so permanently protecting the spur. Concrete blocks were used chiefly in front of the Hardwar Dam and at the points of the Dudhia island spurs. The only appliance available at that time for carrying concrete blocks and laying them in water was the derrick boat used for laying the crates at the head bunds.

The Upper Ganga Canal, being the oldest and major irrigation system in Ganga_Yamuna inter - basin in Uttar Pradesh , is run-off the river scheme and was designed primarily as a famine relief measures/protective irrigation during Rabi. A temporary diversion bund was constructed every year immediately after the monsoons to feed the UGC. The bund happened to be washed away on the commencement of monsoons. As irrigated agriculture developed and there was a demand for water for Kharif crops, a permanent weir, known as Bhimgoda weir, was constructed across the Ganga at Hardwar in 1920 to direct the water flow in UGC. The capacity of UGC was increased from time to time and the designed capacity of the canal had been raised to 297.00 cumecs after carrying out minor modifications in some of masonry works like lowering the bed level to pass extra discharge without excessive afflux. The Bhimgoda weir was replaced by the modern barrage in 1985-86.

The Upper Ganga Canal (UGC) was confidently aligned to carry the canal water from Hardwar to Roorkee, a stretch of nearly 32 km with khadir zone of Ganges intersected by mighty and wild four major torrents descending from Siwalik hills and crossing the canal. This reach of the canal was very difficult in construction and also in subsequent operation and maintenance.

7.3 CONCLUSIONS

1. After considering the operational efforts in feeding UGC over a long period, it is concluded that the method of obtaining the Ganges Canal was the best and the most economical. At that time, the control on the capital cost of the project was a primary consideration for getting suitable and timely returns on investment benefits. Also, with the available technical knowledge and resources , the construction approach of major structures across the Himalayan Rivers was a real challenging and extremely difficult task, no doubt.
2. Western and Eastern Yamuna Canals were the first irrigation canals in the northern India taken up for irrigation after rehabilitation in the early part of the Nineteenth century. The UGC was the first major canal system projected for irrigation. Immediately after the UGC, the Upper Bari Doab Canal was taken in the Indus Valley, Punjab (1851-59) and that , too, was continuous to run without any permanent diversion work for more than the two decades by suitable measures on the control of the river.
3. The above practices and attempts of the canal engineers resulted into very large savings in capital investment at the beginning of the project especially when such projects do take reasonable long period over a decade or so to give good results.
4. This sort of planning also provided the conditions where the capital investment could be deferred to long period when revenue returns and benefits of the investments started coming in.
5. Now-a-days, many major and medium irrigation projects have established that in spite of very heavy capital investments in the diversion works and the construction of main canal, the proposed irrigation could not be developed in the command over a long period resulting into quite unsatisfactory conditions as per the

planning and construction of water resources project because of extremely low financial returns and very limited benefits. The diversion structures being the most cost consuming and of larger magnitude involved the main attention of water resources engineers and distribution of water management . experience and concepts of inundation canals used for a long time in Egypt and the Indus valley do reveal that water can be fed economically with diversion of rivers during floods without permanent costly structures.

6. Therefore, it is concluded that after considering the situations, it should be decided for the most suitable location of the off-take points and the simple and appropriate measures as well as simple and effective control and training on the river for feeding the canal with temporary works for some time resulting into limited capital investments and substantial and satisfactory benefits. These diversion schemes and practices can be suitably strengthened and utilised as per requirements.

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