# SILT REMOVAL THROUGH DREDGING WITH REFERENCE TO BALANCING RESERVOIR OF BSL PROJECT

**A DISSERTATION**

*submitted in partial fulfilment of*
*the requirements for the award of the degree*
*of*
MASTER OF ENGINEERING
*in*
WATER RESOURCES DEVELOPMENT
(MECHANICAL)

*By*

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MARCH, 2000

# CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the dissertation entitled **"SILT REMOVAL THROUGH DREDGING WITH REFERENCE TO BALANCING RESERVOIR OF BSL PROJECT "** in partial fulfillment of the requirement for the award of the Degree of **MASTER OF ENGINEERING IN WATER RESOURCES DEVELOPMENT** (MECHANICAL) submitted in the Department of Water Resources Development Training Centre (WRDTC), University of Roorkee, Roorkee is an authentic record of my own work carried out during the period from July 16, 1999 to March 10, 2000 under the supervision of **Prof. Gopal Chauhan**, *Professor*, **Dr. B.N.Asthana**, *Emeritus Fellow* and **Dr. H.S. Badarinath**, *Associate professor*, WRDTC, University of Roorkee, Roorkee.

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

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# ACKNOWLEDGEMENT

It is a privilege to express my sincere gratitude and deep respect to Professor GOPAL CHAUHAN, Former Director W.R.D.T.C., and Dr. H.S. BADARINATH, Associate Professor, W.R.D.T.C, University of Roorkee for their valuable guidance and encouragement throughout this dissertation work. They patiently heard and gave suggestion to sort out problem and made helpful reviews whenever required.

It is my proud privilege to express my most sincere gratitude to Dr. B.N. ASTHANA Emeritus Fellow & Formerly Visiting Professor, W.R.D.T.C., University of Roorkee for his valuable guidance, suggestions and constant encouragement during the preparation of this dissertation.

I am grateful to Professor D. D. DAS, Director, all the faculty members and staff of W.R.D.T.C., for their support, kind co-operation and facilities extended to me.

I am also very much grateful to my parent organization 'HIMACHAL PRADESH STATE ELECTRICITY BOARD', Govt. of Himachal Pradesh for having deputed me in this prestigious center for higher studies to enrich myself with the latest knowledge of Water Resources Development.

It is great pleasure for me to acknowledge my parents, wife and son master Aryan, who have been my pillars of strength and wisdom. It would not have been possible for me to complete this work without their constant encouragement and moral support.

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# SYNOPSIS

The planning and design of any Irrigation / Hydroelectric project involve consideration of various parameters so that the system runs at peak efficiency as long as possible. One of the factors, which affects adversely the functioning and life of any project is the silt.

Weathering of rocks and disintegration, soil erosion, transportation, depositions are the continuing processes to produce the sediment and to bring it to reservoirs. This problem is more serious with run-of-river hydropower projects.

Preventive and curative measures are taken in the form of excluders, ejectors and desilting chambers to reduce adverse impact of silt on electro-mechanical equipments of the power station and their efficiency. These are found effective in removing sediment upto a size of + 0.15 mm. Despite the provision of these measures serious damages to equipment have been experienced. These damages are caused due to fine angular quartz particles in the flow of many rivers. Settling tanks of larger size have been found effective in settling fine sediment in tanks. The removal of the settled sediment is a problem in such situations.

Dredging is one of the curative methods used for the removal of the sediment deposits to reclaim the lost storage capacity of the settling tanks/reservoirs. The selection of proper dredger is one of the most important aspects of mechanized dredging operation. The performance and capability of particular type and size of dredger must be studied carefully to accomplish the job economically with in proposed time schedule.

In this dissertation the use of dredging technique for removal and disposal of silt with reference to Balancing Reservoir of BSL Project has been studied and the design of

dredging system has been made. The methodology developed in this study provides guidelines to select a dredger type, size, production estimate, cost of dredging & disposal and planning for long–term dredged material disposal alternatives complying with environmental requirements and engineering constraints of dredging operation etc.

# CHAPTER - 1

# INTRODUCTION

## 1.1 GENERAL

"Silt" is a stream-born material derived from the disintegration of rocks and includes in its definition all material transported by flowing water whether carried in suspension or transported as bed load. The main factors causing disintegration are the diurnal and seasonal variations in temperature, wind and rainfall and the chemical agencies in air and water. Disintegration, erosion, transportation and sedimentation are various stages leading to silting. Geological history is marked by a succession of sedimentation and uplifts, in which varying climates, water supplies, vegetation, glaciations, and volcanism have played and are playing all-important role. The processes of disintegration, erosion, transportation, sedimentation, mountain building and plain leveling are still in progress and are as effectual as ever. One cannot hope to halt the processes of mountain erosion and plain building.

## 1.2 ORIGIN OF SILT [Ref. 37]

Exposed rocks disintegrate into soil by various complex mechanical, chemical and organic processes. Rainwater dissolves certain constituents; it enters crevices, freezes and spalls off blocks and particles. Chemical agents in the air re-act with those of the rocks, causing them to breakdown. Wind, rain, and streams transport the soils thus made to lakes and oceans, sorting and depositing them in layers or beds. Forest and other vegetable cover hold the soil in place effectively against ordinary rains but are relatively ineffective in preventing erosion by intense rainfall. Rainfall, if it comes in a series of erratic cloudbursts, will accelerate erosion and transportation of silt. The greater part of the sediment transportation by streams occurs at the time of a flood. Sediments originate from the erosion of the hydrological basin by surface waters, and their transportation downstream can be interrupted by a barrier across the flow. This causes a reduction of the water velocity, depositing the eroded material into the pond so created. In deep ponds/reservoirs density currents can from which may transport the fine material farther downstream near the barrier be, unless they pass through the outlets. These deposits in the pond reduce its useful capacity.

## 1.3 SILT CONTROLLING METHODS

The natural rate of sediment production from catchments can, to some extent, be regulated by afforestation, controlling deforestation and grazing and by suitably protecting the most silt producing regions of the catchments. But experience has shown that these control measures could only produce limited results in large catchments. There are two different categories of methods for controlling the silt [Ref. 33].

### a) Preventive Methods

These methods control the inflow of sediment into water conductor system through reservoir. These are:

- Watershed management, for example, afforestation, stabilization of banks, check dams, and so on;
- By passing the heavily sediment laden flows through the construction of bypass channels / tunnels.
- Construction of smaller dams upstream to stop the sediment inflow.

- Tunnel type excluders, curved approach for location of intake, and suitable operation at the intake.

**b) Curative Methods**

These are adopted to eject the sediment, which enter the water conductor system, before it reaches to the use point such as power plant, and include:

- Sediment extractors or ejectors, These can be tunnel type or vortex tube type (Fig.1.1& 1. 2)
- Desilting chambers. These are generally hopper type (Fig. 1.3).
- Settling basins or tanks. These are large basins or reservoirs / tanks. Flow enters in it from one end and goes out from other end. Fine sediment settles in this reservoir. The deposited sediment has to be removed or flushed. For removal of sediment manual operations or dredging techniques are often used.

The selection of preventive methods requires thorough studies. These studies have to take into account the geomorphological, hydrological and the environmental aspects of the upstream basin to evolve suitable means for watershed management and the flow characteristics and structural details of headwork's to select the sediment exclusion devices.

The curative methods essentially depend on fall velocity of the sediment size to be ejected. Sediment flushing arrangement is an essential part of these measures. The desilting chambers with hopper type flushing arrangement are found effective to eject sediment size of + 0.15 mm. For finer sediment settling tank provision are provided. They need larger areas so these are provided when natural depressions are available. The sediment deposition reduces capacity of these tanks and make them inefficient and inoperative in the long run, unless it is removed. Dredging is considered as one of the most effective and economical method of removing sediment for such tanks / reservoirs.

## 1.4 OBJECTIVE OF STUDY

The objective of this study is to examine the techno-economic feasibility of dredging-disposal system as a curative desilting measure in hydropower projects. The study has been carried out in respect of the problem of Beas Sutlej Link (BSL) Project.

## 1.5 ORGANISATION OF DISSERTATION

The study is presented in nine chapters. The contents of the chapters are briefly given below.

**Chapter-1:** Describes the problem and scope of study and gives the basics of silt controlling methods.

**Chapter-2 :** Describes dredging , types of dredgers, selection of dredging equipment, importance of hydraulic dredging and its plant components.

**Chapter-3 :** It deals with hydraulics of dredging and parameters affecting the output of dredging plant.

**Chapter-4 :** It describes the BSL Project in brief including its silt problem, desilting remedial planned during the planning stage and the measures being presently adopted.

**Chapter-5 :** It gives a review of existing dredging system and dredged material disposal arrangements deployed at BR of BSL Project.

**Chapter-6 :** It deals with the design of a dredging system for the removal of sediment deposits from balancing reservoir (BR) of BSL Project.

**Chapter-7 :** It describes long-term planning and management strategy for the disposal of dredged material particularly the deployment of pipeline arrangements.

**Chapter-8 :** It deals with the economics of dredging and the alternative proposals for disposal of dredged material.

**Chapter-9 :** Conclusions and recommendations are given in this chapter.

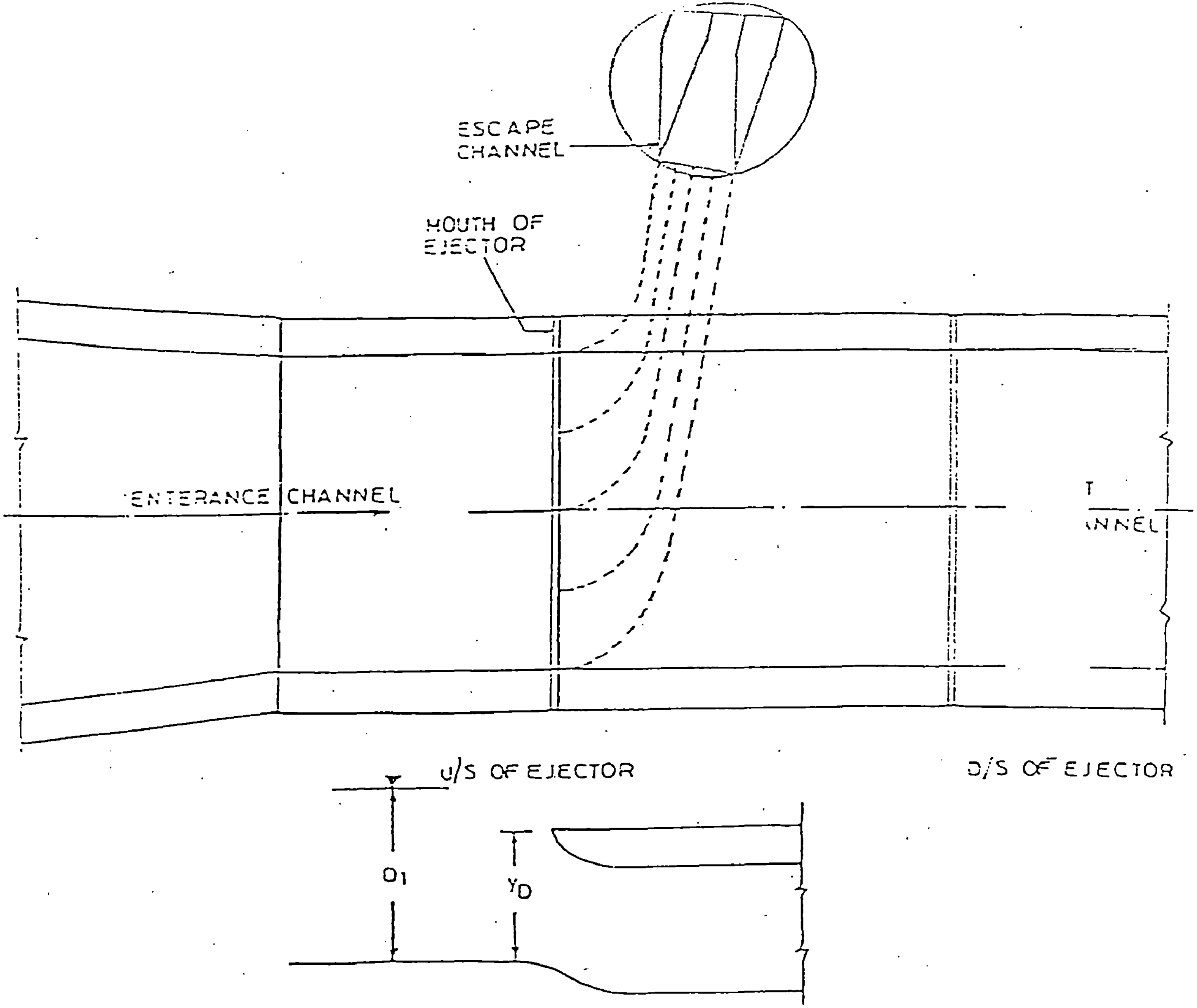


Fig.1.1 Definition sketch of Silt Ejector

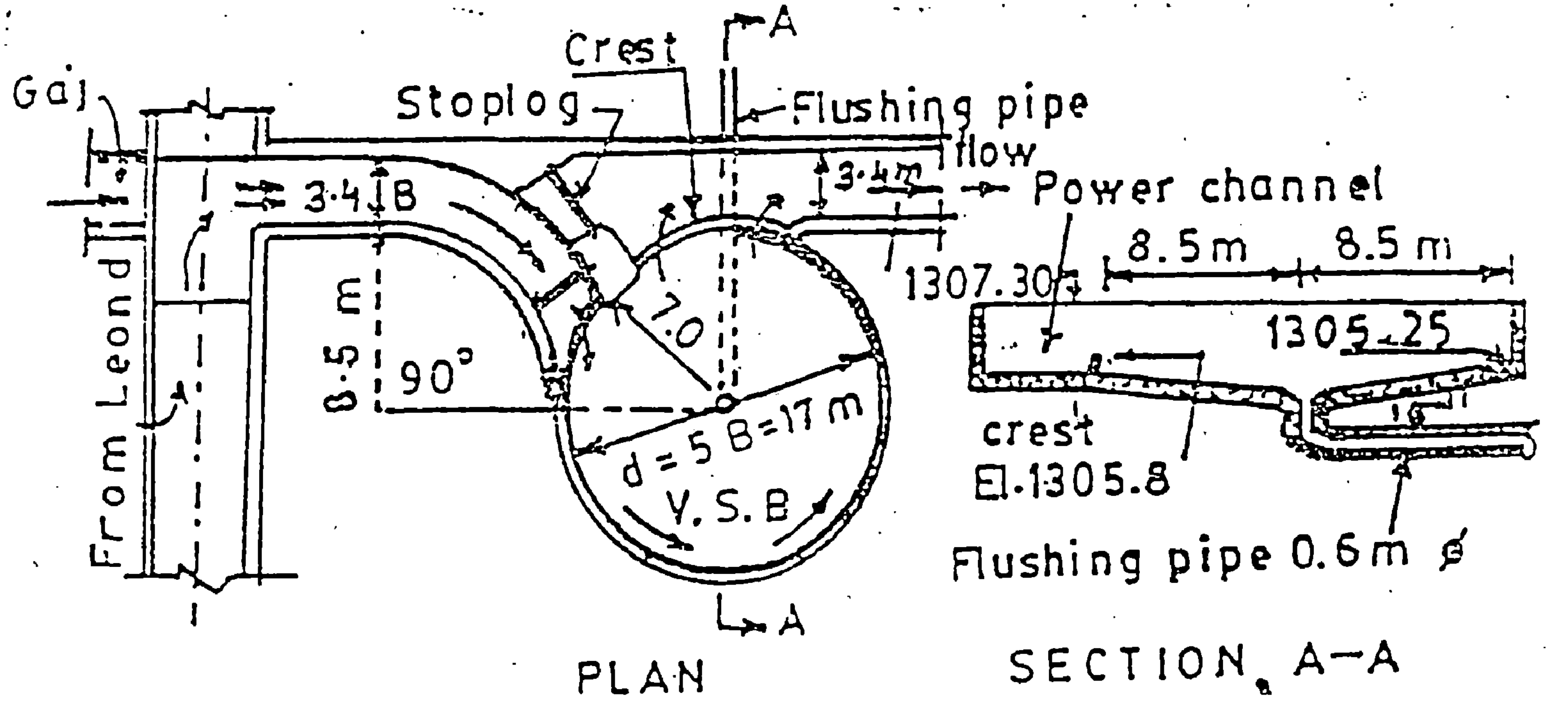
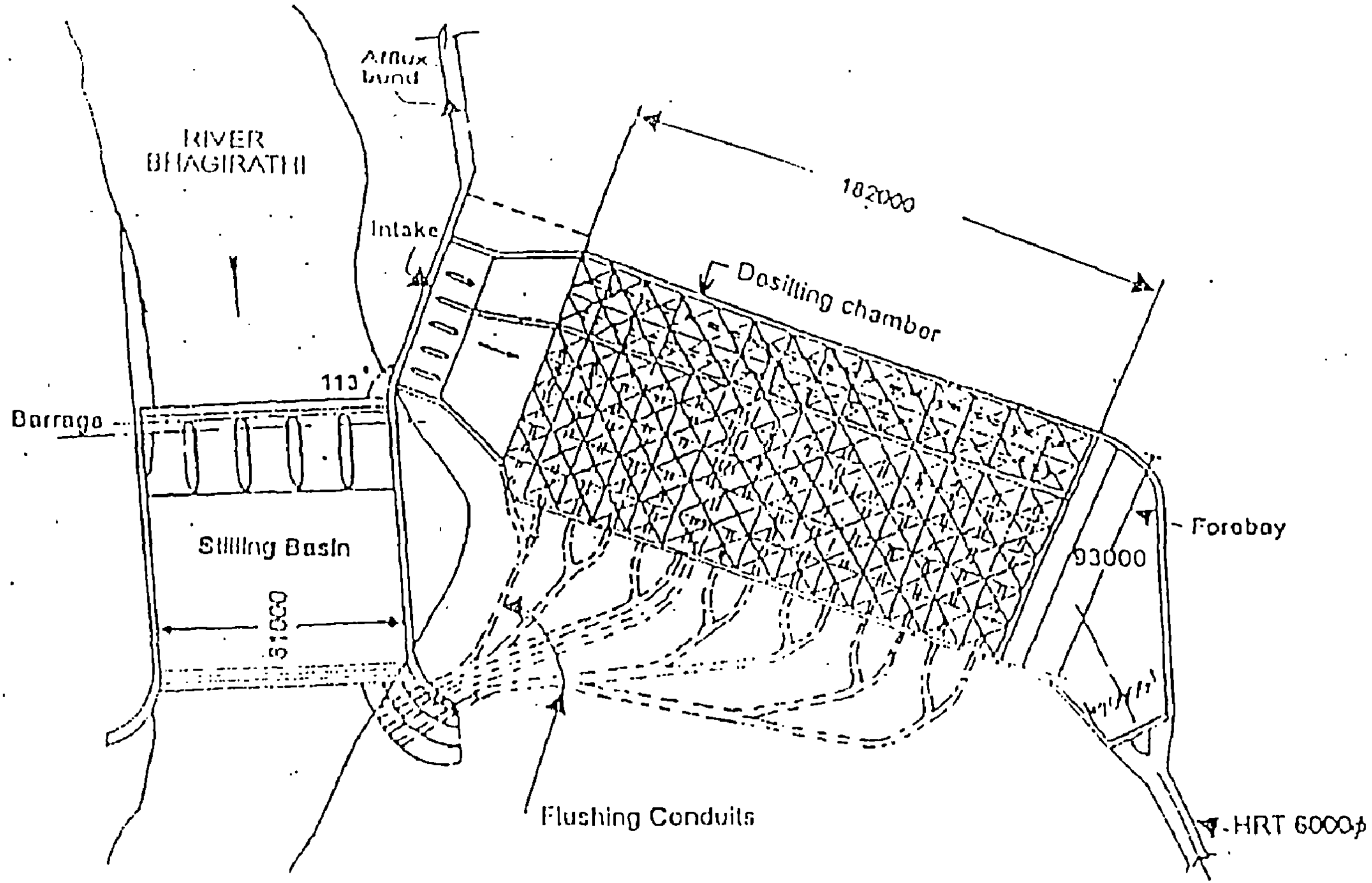
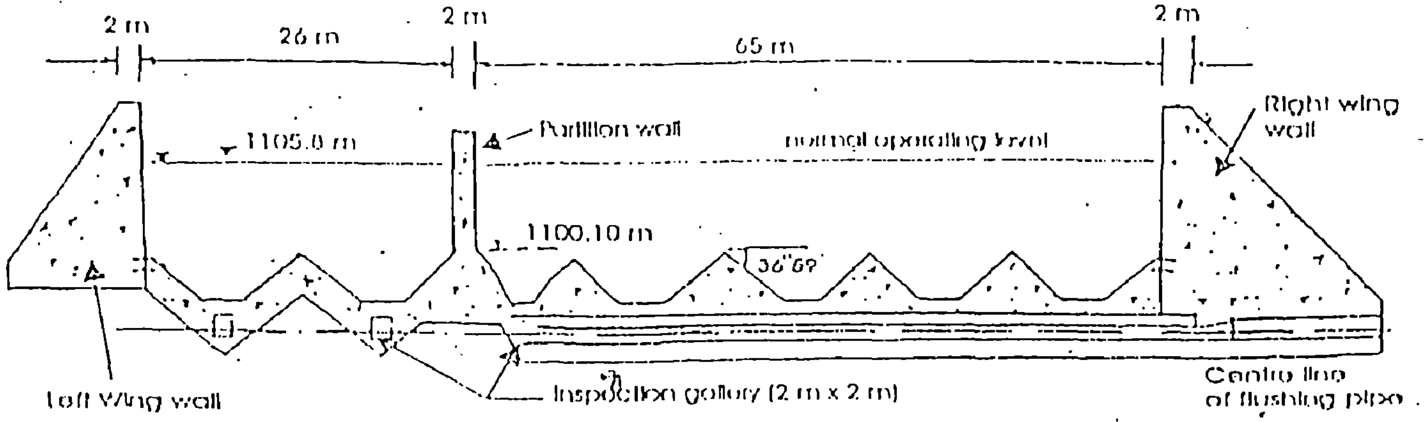


Fig. 1.2 Vortex Type Sediment Ejector (Gaj Hydroelectric Project, H.P.)



Dimensions are in mm

(a) General Arrangement of Diversion Works



(b) Cross-section of Desilting Chamber

Fig. 1.3 Diversion works and Hopper type Desilting chamber

(Maneri Bhali H.E.P. Stage-II, UP)

# CHAPTER – 2

# DREDGING APPLICATIONS IN WATER RESOURCES PROJECTS FOR SILT REMOVAL

## 2.1 GENERAL

Dredging can be defined as the science of excavating materials, which are submerged under water. Dredging is moving material submerged in water from one place to another in water or out of water with equipment called dredgers. A dredger is always kept a float on water and excavates soils from the bottom of the river/reservoir or lake. It may or may not be self-propelled. While the excavating machine is always self-moving type and is kept or installed on the bank and may excavate soils either from land or from the bottom of water. Therefore dredging is a process by which the sediment deposited on the beds of the rivers, lakes and coastal waters are removed from the bottom of streams, transported and placed on a desired area.

There are four principal objectives of dredging as follows:

i) To develop and maintain greater water depths than exist naturally, chiefly for canal, rivers and harbours,

ii) To raise the level of lowland and, thus, create new land areas and improve drainage and sanitation ,

iii) To construct dams, dikes and other works for stream and seashore, and

iv) To recover subaqueous deposits or marine life having commercial value, such as precious metal and minerals, shellfish for food and pearls, coral and sponges, sand and gravel, and fertilizer.

Dredging is an ancient art. The Chinese used spoon and bag devices to clear waterways thousands of years ago. In Italy Leonardo da Vinci devised ways to drain marshes and improve harbours; in Holland large areas have for centuries been wrested from the sea by dredging process. The word dredger refers in this study to only floating equipment utilized in under water excavation of deposited / settled sediment from the settling tanks /reservoirs and disposing these to the disposal areas. Other concepts, including land dredgers and special equipment utilized in oceanography, are not included in this study.

## 2.2 DEVELOPMENT OF DREDGING EQUIPMENT

The mechanical dredging started with the rapid development of navigation. One such equipment "dredger wheel" was invented by Leonardo da Vinci in about 1500A.D. The source of power for this dredger was manpower, which was required to crank over the multi-bucked wheel. Another dredger that was in use about that time was the "Spoon and bag dredger" which is the direct ancestor of the dipper dredger. In 1565, a manpowered scrapper-type dredger was used in Holland. The next dredging equipment that appeared was what the Dutch called a "mud mill" in about 1600. Various improvements continued to take place in subsequent years but the revolution in mechanical dredging equipment came with the invention of the centrifugal pump by Papin in 1705 and the steam engine by Watt in 1795. Several inventors of various countries rivaled for the invention and the first application of this new technology. The

Frenchman, M. Bazin employed a hydraulic pump to lift spoil in dredging the Suez canal in 1867. The discovery of the practicability of transporting spoil through a pipeline is attributed to Alexisvon Schmidt in 1874 who is believed to have been the first to develop practical pipeline suction dredger. The development of the dredger occurred because of a need to excavate submerged or waterlogged materials. Because of the different classes of materials and varied excavation requirement throughout the world, many different types of dredgers have been evolved. Most of them pertain to the cutting, shearing, or agitating of the material to be removed. It was a geological , geographical and climatical type of evolution [Ref. 18 & 26].

## 2.3 SOME PAST APPLICATIONS OF DREDGERS

The dredgers or floating excavators have been used for about 250 years. In Holland large areas have for centuries been wrested from the sea by dredging process. Hendry Emile Bazin of France invented a hydraulic pump in 1836, and in 1867 employed centrifugal pumps in excavating the Suez Canal. A suction dredger was built in England in 1861 and a self-propelled hydraulic sea going hopper dredger was employed in the United States for dredging at Charleston, S.C. in 1855[Ref. 35].

Dredger designs have improved alongwith advances in technology and have also been promoted by demands of shippers and other interested in improved waterways and water fronts. Early devices were for relatively shallow depths and of small capacity and were operated by the muscle power of men and horses. Devices in one country have often been improved in another, largely because of the characteristics of materials encountered.

## 2.4 THE ANTECEDENCY OF DREDGING

Today's dredger, in contrast to the earlier dredgers, is an unparalleled excavating plant. When sufficient water is available it has no economic competitor. Without the dredger, commercial navigation of waterways and rivers would have ended, waterborne industry would have collapsed, and ocean shipping, as it is known today would have been nonexistent. Dredging is most challenging field because we are dealing with a medium which we can not actually see in its in-situ condition and also a field in which there are so many variables whose determination is not susceptible to a simple analytical solution[Ref. 18].

The dredger's scope of operation is broad based. Small dredgers operate in water only a few meters deep. Large dredgers require more draft, but can dig to greater depths. Dredging has been increasingly recognized as one method for restoring some of the numerous lakes. Table (2.1) lists the names and locations of some of the projects in which dredging is being utilized as a lake restoration technique. The overall objective in all of these projects is to restore the capacity and improve recreational amenities, which have been lost over the years due to siltation [Ref. 25].

## 2.5 TYPES OF DREDGERS

Dredgers are classed as mechanical and hydraulic. Many special types in both classes, and ingenious combinations of the two, have been devised. A great variety of auxiliary devices (rotating cutter teeth, scrapers, water jets and disks) have been devised to increase dredger efficiency. Likewise numerous arrangements have been resorted to for holding dredgers in horizontal position and on an even heel. Both basic dredger categories have been developed into several distinct types. These types are outlined in the diagram as shown in Fig. 2.1 [Ref. 2]. Following are the principal types of dredgers in use throughout the world.

### 2.5.1 MECHANICAL DREDGERS

Mechanical dredgers lift the dredged material by means of buckets or scoops of various designs. They raise material above the waterline and deposit it into conveyance for transportation and disposal. Mechanical dredgers are sometimes referred to as bucket dredgers and are classified as grab, dipper, and ladder. All bucket dredgers have one limitation – the disposal must be alongside the place of excavation, or when the spoil cannot be placed along side, scows or barges must be used to carry it away. For large quantity, widely dispersed use of this type of dredger is not practical [Ref. 29].

#### (a) Dipper Dredger

Dipper dredger (Fig. 2.2) is merely a floating power shovel. This equipment has advantage when excavating hard material, and are especially useful for breaking up shales and broken-up rock or excavating blasted rock.

The dipper dredger is usually operated with 3 spuds, two forward and one at stern. Prior to starting the work, a large percentage of the dredger's weight is hoisted on to the two forward spuds. This makes solid foundation for the machine from which dipper operates. As the dipper dumping radius is extremely limited, the barge must constantly be moved while the loading operations are taking place.

#### (b) Grab Dredger

This type is also called a grapple, clamshell or orange peel bucket. Clamshell dredgers (Fig. 2.3) are used where the material to be excavated is rock or hard material that requires blasting or where the spud area is considerable distance from the excavation area and hauling is required. Depth of material can be a factor in selection of a clamshell. It has a long reach. A clamshell is a machine that is used as a clamshell on land and becomes a dredger when mounted on a barge. With this type of dredger, production is very low and unit cost of material excavated is high.

In operation the bucket is dropped to the bottom in opened position and bites into soil because of its own weight and the action of the closing mechanism. Some have one line while others operate with two lines (one each for closing and hoisting). Dredged material is discharged by releasing the bucket closing line. When constructed in two halves, the bucket is called a clamshell, when consisting of more than two parts, it is called, an orange peel, when tongs are used, it is called a grapple.

The greatest advantage of this dredger is that the depth to which it can work is practically unlimited. It can also operate in restricted areas. The chief disadvantages are that it leaves an irregular bottom, and the bucket may spin, thereby routing the lines.

### (c) Ladder Dredger

The ladder dredgers (Fig. 2.4) have endless chain of buckets, also called an elevator, which is a continuous chain of buckets rotating around a rigid adjustable frame called ladder. When the ladder is lowered into operating positions buckets descend empty along the under side of the ladder. At the bottom position the bucket lips dig into material as the chain lines, and the loaded buckets ascend along the upper side of the ladder. As each bucket turn the upper most position preparatory to descending, it spills its contents by gravity into a chute, which in turn, may be used to direct disposal of the spoil. The buckets discharge on a belt conveyor, which carries the material to a stacker conveyor at the rear of the dredger for disposal. Because the spoil stackers are limited in length (about 100 m) the ladder dredger cannot be used where the spoil is to be discharged at a considerable distance from the dredger. This equipment is used for excavating sand and gravel material.

Many European bucket ladder dredgers are of sea going type and are used for works in exposed location. In United States this type of dredger is used principally for mining and for recovery of sand and gravel for construction purpose. In the latter case, screening and cleaning equipment is located on the vessel. Mining dredgers initially worked in river bottoms but they may operate away from streams, carrying along as they advance. Rubber conveyor belts are used with mining dredgers for stacking rock tailings. The efficiency of ladder dredger depends on the capacity and number of buckets over the tumbler and dredging depth. In addition, factors inherent in the machinery design and type of prime mover and efficiency of disposal methods also affect production. A disadvantage is that loose material tends to be out of the moving buckets.

### (d) Scraper Dredger

The scraper dredger (Fig. 2.5) also called a dragline, handles material with a scoop suspended from a swinging boom. The scoop is drawn forward by a line attached to the front, while a second line attached at the rear holds the scoop at the proper angle to slice the earth away as the device is pulled along. When filled scoop is lifted to the peak with both lines tight. After being swung around to a desired position, the scoop dumps automatically when the drag or hauling line is released.

### 2.5.2 HYDRAULIC DREDGERS

Hydraulic dredgers lift the dredged material by means of pumps. Hydraulic dredgers dedger, transport, and deposit the material. All hydraulic dredgers have one thing in common – they have a centrifugal pump discharging either into the hold of the dredger itself, into barges along side, or ashore. They all have a suction line through which the pump is supplied with material. The means of loosening and picking up the material is where they differ [Ref. 2 & 26] . The common type of suction or hydraulic dredgers are dustpan dredger, cutter head dredger and sea going hopper dredger.

#### (a) Cutter Head Dredger

The Cutter head dredger (Fig. 2.6) has a rotating head installed at the outer end of movable frame called ladder. The cutter is actuated by a shaft that runs the length of the ladder. Also installed on the ladder is a suction pipe which leads from just behind packed material released by cutter action to form a mixture with surrounding water, and is then handled hydraulically through the pipeline leading through to the disposal area. Control of the dredger is by lever, push button or switch from a central ventage point. Some dredgers of this type are self propelled. Smaller ones are portable. Cutter head dredger finds popular application for the excavation, improvement and maintenance of ports, navigation channels, land reclamation, aggregate recovery, reservoir and industrial pond desilting and for maintaining irrigation system. The dredger can also excavate compacted deposits like clay. For hard material larger and more powerful machines have to be used .

### (b) Hopper Dredger

The plain suction dredger often uses a special suction head called a dustpan or drag head attached to the end of the suction (Fig. 2.7). Dredgers using these attachments are generally hopper dredgers, but occasionally they pump into barges tied alongside. The drag head dredger requires the drag to be in contact with the bottom and the dredger in motion while dredging. When the hopper is full the dredger stops dredging and transports the material to a disposal area. The main disadvantage of the hopper dredger is that it has to stop dredging while transporting the material. These dredgers of this type who dredge while in motion are called trailing suction dredgers.

### (c) Plain-Suction Dredgers

Plain-suction dredgers Fig.(2.8) are similar in hull construction to a regular ship, but they often differ from other dredgers in the location of the suction pipe. The plain – suction dredger often has its suction pipe in a well at the bow, whereas other types, such as the hopper – dredgers, have their suction pipes alongside. The suction pipe, regardless of its location, extends through the hull to the pump. The pump discharges either into hoppers within the dredger itself or into barges alongside. Occasionally there is a pump-ashore arrangement. The modern plain-suction dredger often has water jets installed at the lower end of the suction. High-pressure water is forced through the jets to break up the material. The end of the suction is also often flattened out in a rectangular shape much like mouth piece of a vacuum cleaner and the jets are attached around the perimeter. These dredgers operate best when they are able to remain stationary and can dredge a hole into which the surrounding sand can run. In hard materials they are not very effective.

## 2.6 SELECTION OF DREDGING EQUIPMENT

The selection of the most suitable type of dredger is dependent upon :

- the characteristics of the material to be dredged,
- the depth of dredging ,
- the quantity and disposition of the material and,
- the location of the disposal site

It is difficult to recommend an installation, which may be suitable for the removal of sediment from every reservoir. Therefore, a study of the individual case has to be carried out. However, in many cases the use of a hydraulic dredger particularly the cutterhead, pipeline, is preferred because it dredges, transports and deposits the material quickly while mechanical dredgers do not transport and dispose of the dredged material. Hydraulic dredging is the quickest method for removal of sediment. Mechanical dredgers raise material above the waterline and deposit it into conveyer for transportation and disposal. On the other hand pipeline - hydraulic dredgers excavate underwater solids and transport. them without re-handling to almost any location leading to disposal area. With the aid of booster pumps, solids are pumped to long distance. They, also known as pump excavators, use centrifugal pumps, which are connected with cutters to deal with the consolidated deposits. For discharge pressures under 45.5 kg /cm$^2$, maximum flow up to 50000 u.s. gpm and lower installed capital cost of centrifugal pumps, are some advantages of this type. The hydraulic dredgers have, therefore, become the most suitable dredger in the field of harbour engineering. [Ref. 17].

## 2.7 SYSTEM LAYOUT

Figures 2.9 & 2.11 show the components and their location of a dredger. The heart of the hydraulic dredger is the main centrifugal pump with its suction and discharge lines. Except for hog box work, the pump, power plant, and accessories are mounted in a floating hull. The suction line is carried in a live boom called the ladder. Its position and the working movements of the hull are controlled by winches and spuds on the hull, and by anchors on the bottom or on shore. The cutter-head, pipeline, hydraulic dredger, shown in Fig. 2.10 loosen material by means of revolving blades or chain. Position control is through two spuds on which the machine pivots, and a pair of swing anchors. While digging, the cutter is kept in almost continuous horizontal motion back and forth through an arc. The cutter- head, pipeline, hydraulic dredger, in conjunction with its supporting equipment, is essentially a floating power plant used to move material hydraulically to some other location without re-handling. Dredgers are usually rated to size by the diameter of the pump discharge line, which is usually smaller, than the suction pipe. Ranges are 150 mm to 1200 mm [Ref. 12, 21,30 & 35].

### 2.7.1 Dredger Plant Components

The dredger is comprised generally of a cutter, ladder, suction pipe, "A" and "H" frames, cutter motor, hull, house, lever room, hoisting machinery, main pump and prime mover, auxiliary pumps and engines, spud frame and spuds. During operation the floating line and the shore line are attached to the dredger. The supporting equipment is generally comprised of a derrick, one or more tugs called tenders, fuel and pipe barges, surveying craft, and other special equipment that may be required for a specific job. The dredger with its pipe and all supporting equipment is referred to as the plant. The main components of the cutter head dredger are as follows:

### (a) Cutter

The cutter is attached to the forward end of the ladder. It is connected by a shaft to a cutter motor, which rotates it. The cutter agitates soft or loose material or cuts hard material, so that it can be picked up by the suction. Horsepower applied to the cutter varies with the job and size of the dredger. Small dredgers (200 to 300 mm) may have motor of 400HP. Larger dredgers may have motors of more than 4000HP. Speeds at which cutters are turned usually are between 10 and 30 rpm, depending upon the materials being dredgerd and the size of the cutter. Cutters are made of wear – resistant steel. The leading edge of the cutter blade should have a hardness of at least 500 Brinell or 51 Rockwell C, and yield strength of around 14000 kg / cm$^2$. Cutters are usually classified as basket or straight-arm as shown in Fig. 2.12 [Ref. 26].

#### (i) Basket cutter

The basket cutter has a front hub, a back wearing ring and several spiral-shaped blades integral with the hub and ring. A closed- nose basket with spiral, integral blades is best suited for digging in soft materials or loose sands. An open- nose basket is suitable for clay or hard materials, because when dredging in stiff clay a cutter with blades close together may become clogged. A closed-nose basket cutter with chisel- pointed teeth closely spaced on the blades is used for hard materials.

### (ii) The Straight-arm Cutter

The straight - arm cutter with its blades extended beyond the hub and attached with bolts to a spider is used in hard clays. In exceptionally hard materials, serrated blades, or blades with shovel-type teeth may increase the output. Pick-shaped blades, or blades with shovel-type teeth may increase the output. Pick-shaped teeth can be used to good advantage in coral and other brittle materials.

### (b) Ladder

The ladder carries, in addition to the cutter, the suction pipe, lubrication lines, and most usually the cutter motor and its reduction gear. The upper end of the ladder is supported by heavy trunnions set in a well in the hull (on small dredgers the ladder is often mounted directly on the hull and no well is used.), and its front end is suspended from an “A” frame by a multiline block- and- tackle which is connected to the hoisting machinery within the dredger. The length of the ladder determines the maximum dredging depth, usually considered as 0.7 of the ladder's length when at 45° inclination. Ladders vary in length from 8 to 50 m and some weigh as much as 400 tons [Ref. 26].

### (c) Suction Pipe

The suction pipe transports material from the cutter to the pump. It is supported beneath the ladder and is connected to the hull suction-pipe by a ball - joint, trunnion elbow, or rubber sleeve located opposite the ladder trunnion. Its diameter depends upon the size of the pump. Technically, the diameter of the suction is dependent upon the pump output, the minimum velocity allowable in the pipe, etc. The suction pipe diameter could be the same as that of discharge pipe and have the same quantity of flow at the same velocity. However, the maximum suction available at the pump is about 8.54 m of water or 64 cms. of mercury. Losses in the suction are kept as low as practicable, so that as much energy as possible is left for lifting material. Usually diameter of the section is kept 1.25 to 1.50 times the pump discharge diameter. Practically, however, the suction is usually sized one standard pipe size above the discharge. For example, with a pump size of 400 mm , the suction pipe might be 450 mm in diameter. Thickness of pipe varies, but in general, it is usually not less than 12 mm and more than 25 mm [Ref. 26].

### (d) Cutter Shaft and Motor

The cutter -shaft is mounted on top of the ladder directly above the suction pipe. The cutter motor, usually located on the rear end of the ladder, is attached through a reduction gear or other mechanism to the shaft. In some instances, the cutter motor is located near the cutter on the outer end of the ladder. This arrangement is particularly suitable to the use of hydraulic motors, and in such instances long shafts are eliminated. Cutter speeds vary between 5 rpm and 40 rpm on most dredgers, and power applied to the cutter may be as high as 4,000 hp[Ref. 26].

### (e) Anchors

Attached to both sides of the outer part of the ladder are sheaves. Through these, from the drums of the winding gear within the deck house, run cables called swing wires, attached to anchors. The anchors, when placed outward from the dredger, allow the dredger to be pulled from side to side by the swing wires. The anchors are always placed sufficiently outside the cut so that the cutter will not become fouled by them or the wires, and sufficiently far ahead of the dredger so that they will not have to be moved ahead frequently. The distance they are placed ahead and outward is a compromise between getting a wide enough swing and not having to move them often.

### (f) Hull and House

The hull and house enclose all main operating machinery. Usually the house is a flat-topped, one-or two-deck structure with the upper story often serving as quarters for the crew. Hulls are rectangular with rounded corners and are strongly built to withstand the shocks and constant vibration of dredging. Usually two truss frames are installed along the length of the hull on either side of the ladder well, and one adjacent frame is placed at each sidewall. This four-frame construction gives good longitudinal stiffening. Four to six cross-frames provide for transverse stiffening. New hulls are generally welded and usually divided into watertight compartments. Hull size in determined first by weight of machinery to be floated and secondarily by the need for supporting and counter balancing the overhead ladder. Cross section is varied according to special requirements. In most dredgers, hull space on both sides is used for fuel and water storage. Width and length of hulls vary, being roughly on a one – fourth ratio of width to length, and a one -third ratio of depth to width.

### (g) Hoisting Equipment

Hoisting equipment, or winding gear, is normally forward in the hull house and is generally set cross-deck. It usually is made up of two drums for hoisting the spuds, two for swinging the dredger, and one for raising and lowering the ladder. Spud hoists are placed at the stern of the dredger in some of the newer dredgers. Line pull of the drums may be as much as 68 ton with average wire speeds of 10 to 15 mpm, but some dredgers have been known to have wire speeds as much as 55 mpm. Operation of the winding gear is almost exclusively by air or hydraulic means, in contrast to the mechanical lever systems of earlier days. The hoist must also be capable of raising the spuds and ladder. It must develop a pull and speed in accordance with the equipments it controls [Ref 26].

### (h) Lever Room

The lever room is on top of the engine house where a full view of operations can be obtained. It houses the controls for operating the dredger's machinery. These controls include those for operating the clutches and sometimes the speed of the pump. Vacuum and pressure gauges and recorders are usually located in the lever room, such as meters for reading the voltage and current of the cutter and winding gear motors.

### (i) Main Pump

Generally a centrifugal pump is used for lifting clear water or even muddy water of ordinary degree, but for disposing of muddy water containing remarkably sandy mud or for conveying similar sort of water, special consideration should be given to materials and structure of the pump against damage caused by friction of sandy mud.

In case of using a centrifugal pump for lifting up muddy water of ordinary degree it does show not much difference in its capability as compared with using it for clear water. However, if employed for muddy water containing high concentration of sand, it will have remarkably harmful effects depending on the amount of sand contained.

The main pump is located forward in the hull, its center near the loaded water line. It is generally operated by a diesel engine on small and medium-sized dredgers, but by steam turbine or diesel-electric drive on large dredgers. In some instances dredgers are powered through high-voltage cable from shore when commercial power is available and economical. . As much as 15,000 hp is applied to the pumps of large dredgers, while smaller ones may have as little as 250 or 300 hp. Speed of the pump is relatively slow, being 800 to 900 rpm on small dredgers and as low as 300 rpm on larger ones [Ref. 26].

### (j) Power Plant

The power may be diesel, electric or steam, the dredger has generally two diesel engines. One drives the pump; the other drives the main generator that supplies current to run the cutter, winches and accessories. Two engines are used so that the pump can work steadily at full capacity, without being affected by variable requirements of the other equipment.

In small dredgers , only one diesel engine is used to drive the main pump and the hydraulic triple pump (to drive cutter motor, winches and other equipment). All electric drive is frequently used in the dredgers that reach of power lines. The advantages of using electric power are a cleaner and quieter dredger, and eliminate the fueling problem. The disadvantages by electric power are that current is brought from shore by special sub-marine cable or supported on the discharge pipe floats. Carrying of the power lines may be difficult because of danger from high voltage, movements of the dredger, and change in length of the discharge line. Steam power is used, but to a decreasing extent. Each unit may be driven by a separate steam engine, or only the pump may have stream drive, while a steam powered generator supplies current to individual electric motors [Ref. 1].

**(k) Spuds**

The dredger is held in position or moved ahead with the spuds. They are usually round and generally made of cast steel or built-up plate, from 0.6 to 1.2 m in diameter. Wall thickness varies, but on large dredgers it is some times 6-7 cms. Spuds weigh as much as 30 ton. They are located at the stern of the dredger, one on either side. Spud rigging includes a gantry for supporting the spuds, hoisting sheave, wires from the hoisting drums, and the spud wells or keepers. The wells carry horizontal thrust created during dredging or bad weather, and keep the spuds aligned as well. When weather conditions are bad, or the cut too deep, three-wire mooring is often used instead of spuds. Dredgers have, however, worked on spuds in depths of over 30 m. The size and strength of a spud is determined by the displacement of the dredger, its digging depth, and the cutter power [Ref. 26].

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### (I) Discharge Lines

The discharge line is more easily described and located by considering it in three- separate sections:

(i) the pipe on the dredger

(ii) the floating line , and

(iii) the shore line.

(i) The pipe on the dredger runs from the discharge of the pump to the stern, preferably along the deck on the outside of the house. The principal reason being to prevent flooding and possible sinking of the dredger in case the pipe breaks. It has a thicker wall than other discharge pipes, the wall sometimes being as much as 25 mm thick. Some where along the way to the stern, but as close to the pump discharge as practical, a discharge flap valve is installed. This valve is normally closed by gravity and its function is to prevent a reversal of the pump and possible serious water hammer. The pipe continues on from the flap valve to the stern where it is connected to the floating line through the stern connection. This is a rubber hose, a swivel elbow, or one or more ball joints.

(ii) The floating line extends from the rear of the dredger to shore. It is made up of sections of individual pipe 10 to 15 m long and 12 to 16 mm thick. Each section is supported by one or more floating pontoons (Fig. 2.13). These pontoons are of various shapes, but usually on the larger dredgers they are circular cylindrical type, sometimes with tapered ends [Ref. 26].

(iii) The shoreline consists of shorter and generally lighter sections of pipe than the floating line. Usually these sections are between 3 to 5 m long with wall thickness of from 6 to 8 mm. The shoreline in contrast to the suction line can be run in any direction, vertical or horizontally without serious impediment of the operation. Normally the pipes are laid on the ground, but in some instances, they are placed on cribbing. Wye is also placed in the shoreline to provide two outlet possibilities. When pipes are to be added, one leg of the wye can be closed, stopping the flow of that leg but allowing the flow to continue through the other leg. This arrangement saves time by not having to stop the dredger to add pipe and it provides for two separate discharges that often give a better spoil distribution over a wider area.

Table 2.1 Some Project Locations with Dredging Activities

| Lake Name | Location | Total Project Volume in Cubic yard | Predominate Materials being Dredged | Start of Dredg-ing (Year) | Dredging Cost/cubic yard | Objective |
|---|---|---|---|---|---|---|
| 1. Nutting Lake | Billerica Mass.(UK) | 360,000 | Silt | 1978 | $1.90 | To increase depth lost due to sedimentation , improve water quality and reduce Macrophytes. |
| 2. Bantam Lake | Morsis & Litchield, Conn. (U.K) | 232,000 | Silt, clay & sand | 1982 | $2.00 | |
| 3. Dunn's Pond | Gardner, Mass.(U.K) | 163,000 | Silt,fibrous peet | 1983 | $2.25 | |
| 4. Allentown Lake | Allentown, New Jersey. | 154,000 | Silt, sand, fibers | 1983 | $1.80 | |
| 5. 1860 Reservoir | Wethersfield, Conn.(U.K) | 140,000 | Silt | 1984 | - | |
| 6. Van Corttandt Lake | Bronx, New York. | 150,000 | Silt, muck | 1986 | - | |
| 7. Porter Lake | Springfield, Mass(U.K) | 120,000 | Silt and sand | 1986 | - | |

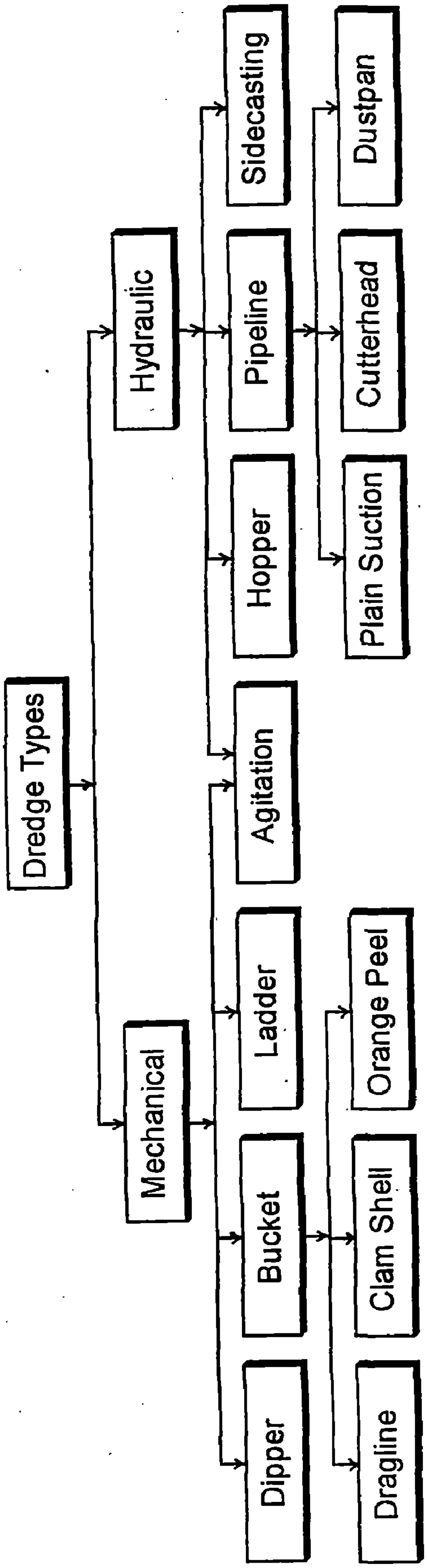


Fig 2.1 Basic Types of Dredgers

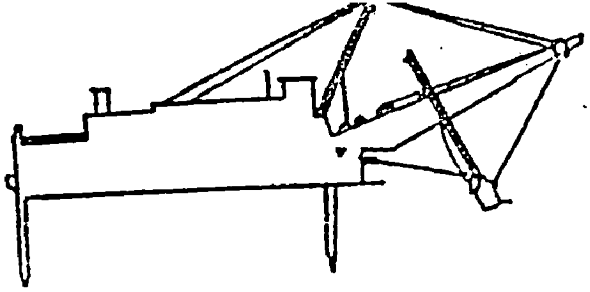


Fig. 2.2 Sketch of Dipper Dredger

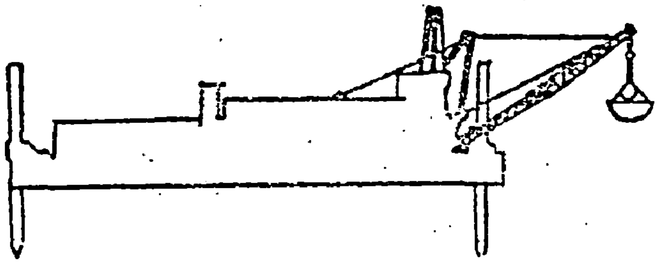


Fig. 2.3 Sketch of Grab Dredger

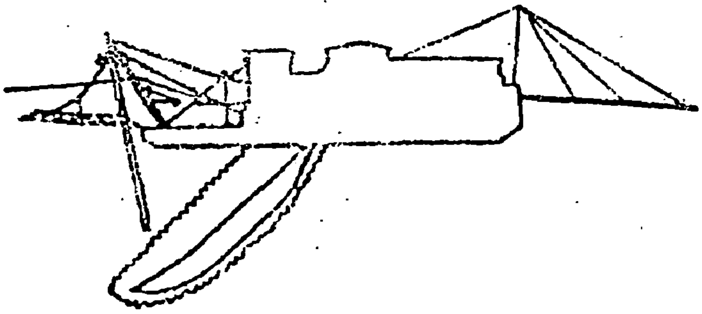


Fig. 2.4 Sketch of Ladder Dredger

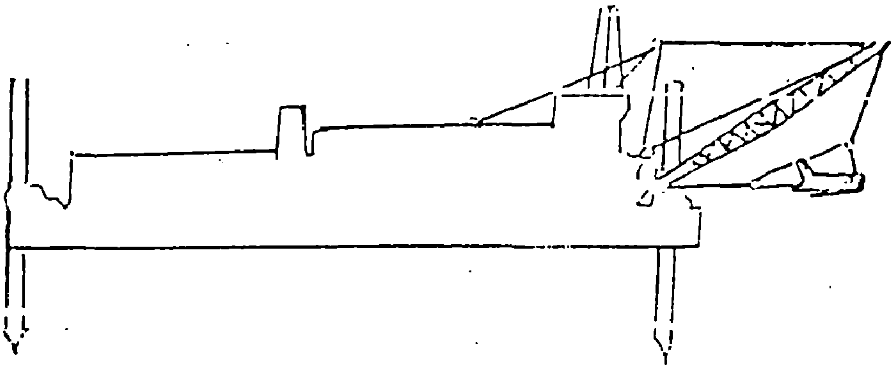


Fig. 2.5 Sketch of Scraper Dredger

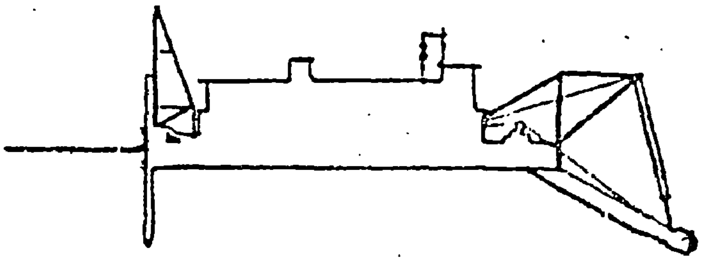


Fig. 2.6 Sketch of Cutter Head Dredger

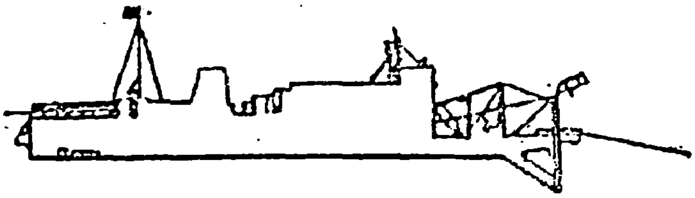


Fig. 2.7 Sketch of Drag head Dredger

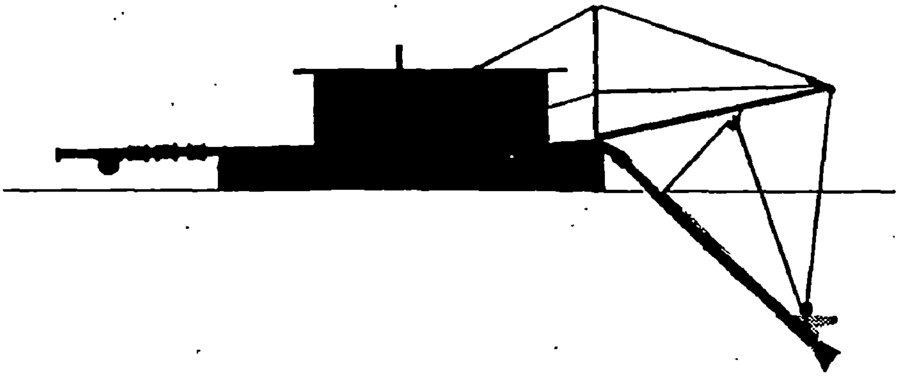
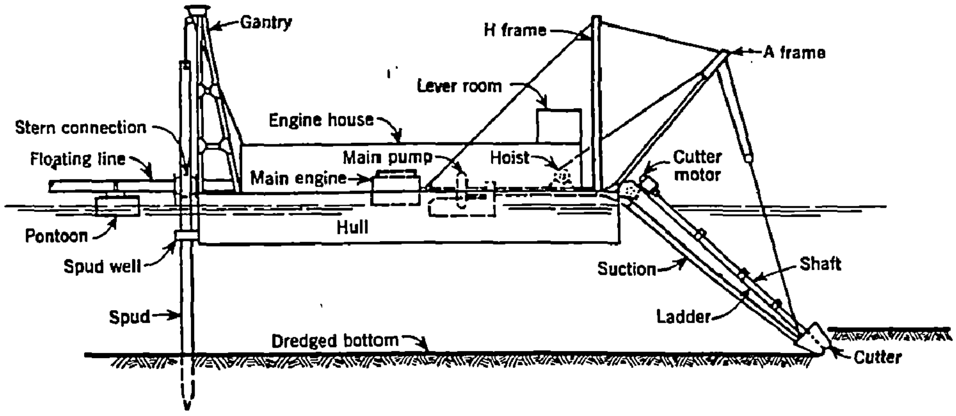


Fig. 2.8 Sketch of Plain-Section Dredger



Dredge Components.

Fig. 2.9 Dredger Components and their Location on the dredger (System Layout)

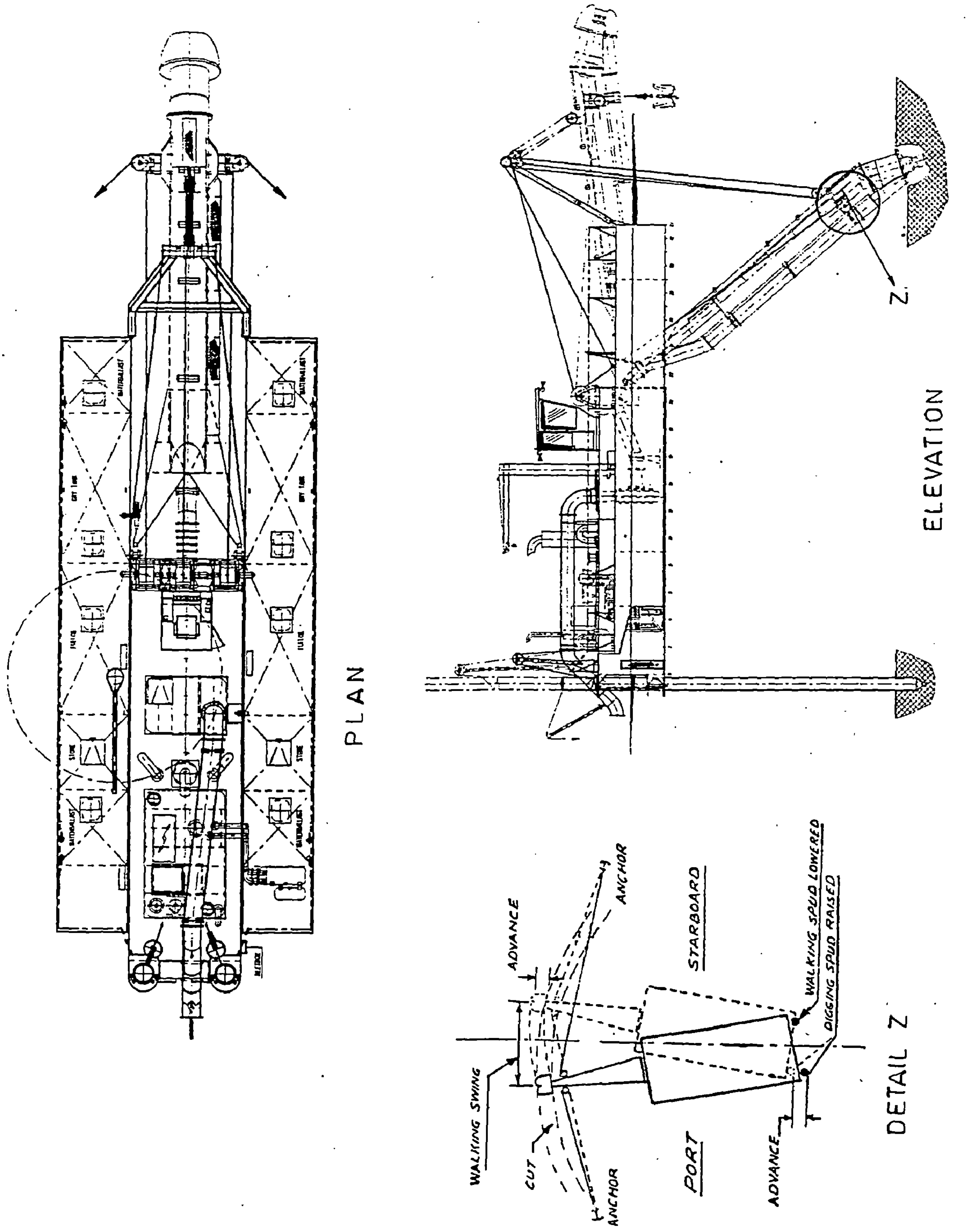


Fig 2.10 Cutter-Head Pipe Line Hydraulic Dredger

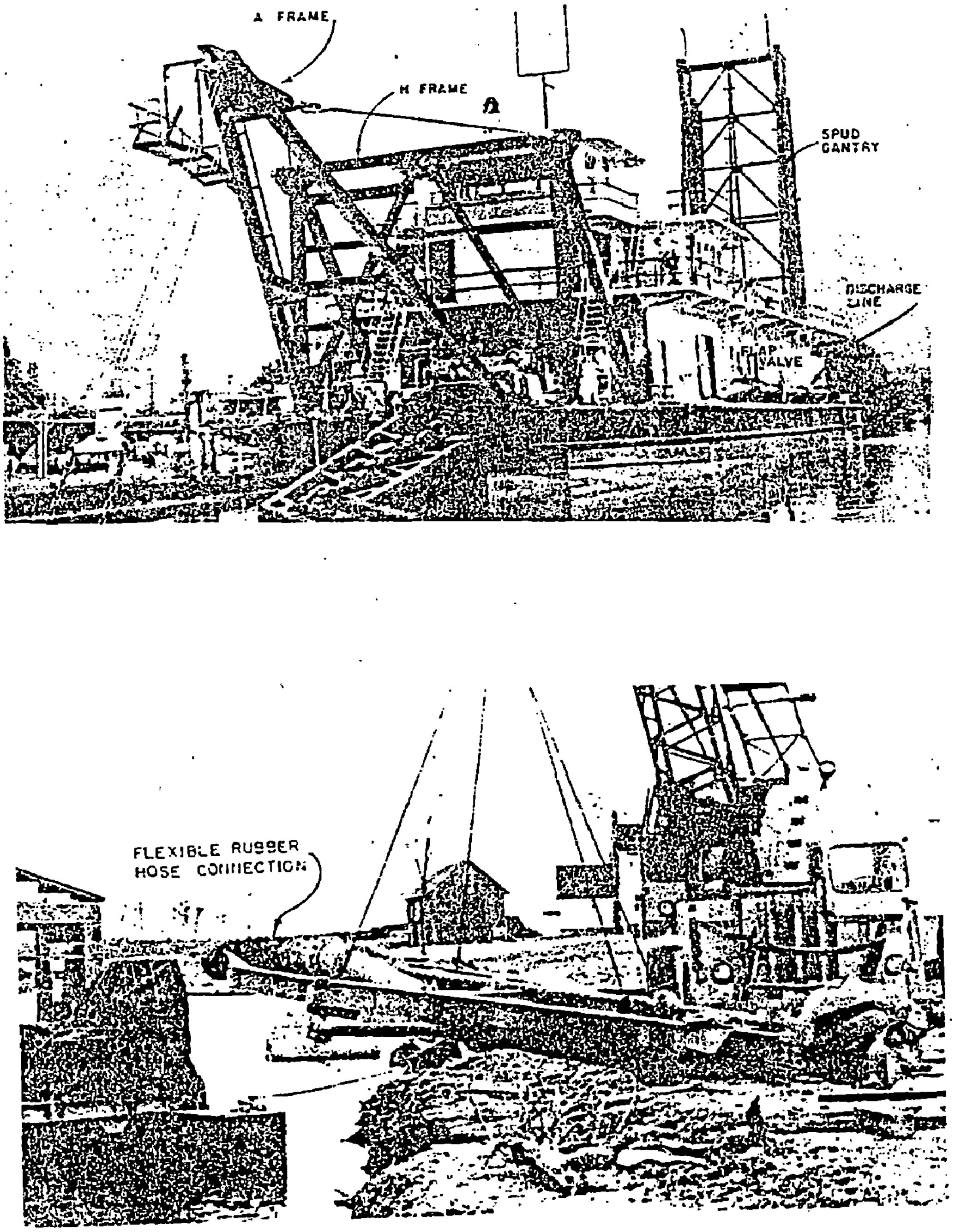
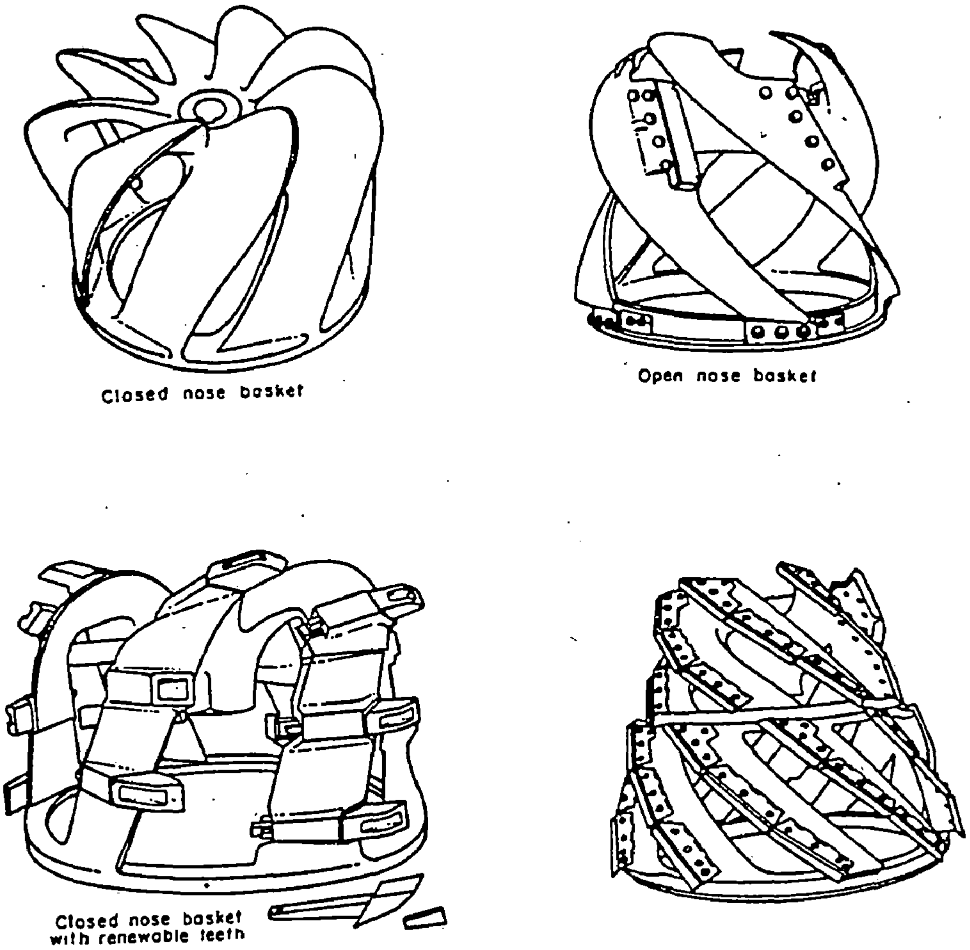


Fig. 2.11 View of 'A' & 'H' Frames and flexible Connection on Dredger

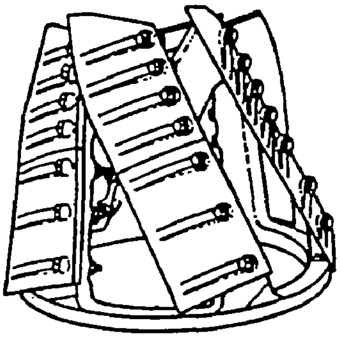


Closed nose basket

Open nose basket

Closed nose basket with renewable teeth

(a) Basket Type cutters



Straight Arm

(b) Straight-arm cutter

Fig. 2.12 Types of Cutter

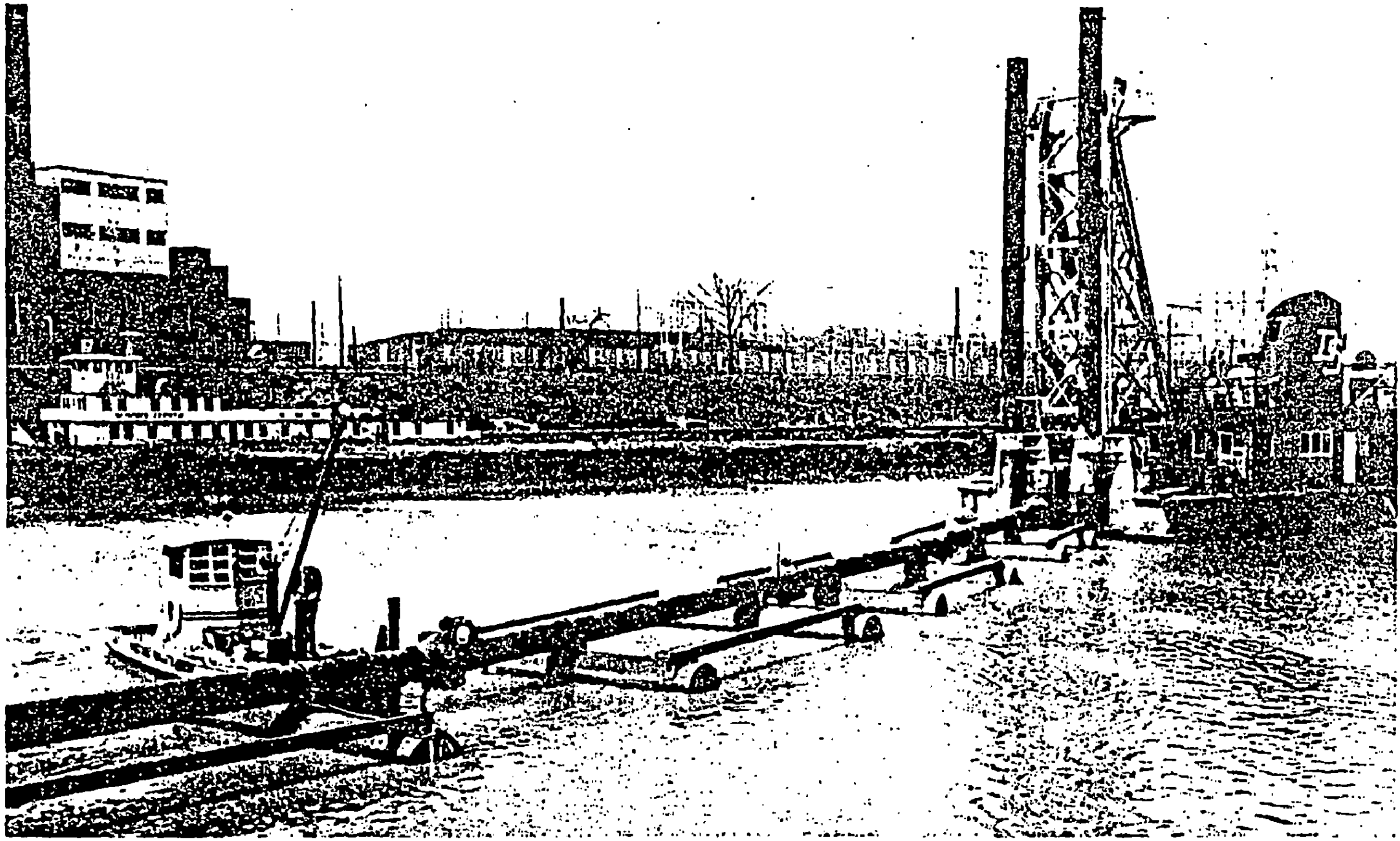


Fig. 2.13 View of Floating Pontoons on Dredger

# CHAPTER – 3

# HYDRAULICS OF DREDGING

## 3.1 GENERAL

Pressure in dredging is always referred to in pounds per square inch (kg/cm$^2$) or in feet or meter of fresh water above atmospheric pressure. Vacuum, which is the amount of pressure below atmospheric, is measured by the number of cms of mercury. At sea level the atmospheric pressure is considered as 10 m of water or 76 cm of mercury, or 1 kg/cm$^2$ (14.7 pounds per square inch). As one goes above sea level this pressure is reduced. A cubic metre of fresh water at sea level weighs 1 tonne or 1000 kg. The dredger is designed on the principle of floatation i.e. a body floating in a liquid will displace its own weigh of that liquid. Pressure in dredging is referred to as head. When dredgermen uses pressure they imply kg/cm$^2$ above atmospheric pressure, but when they say head they are usually referring to the weight of water column [Ref. 26].

## 3.2 FLOW IN PIPELINES

In the dredger pump-pipe system, the fluid flow, whether it be fresh water or a mixture of water and material, will be a turbulent flow. Laminar flow does not occur in dredger systems because of the high velocities. Turbulent flow is an irregular motion and has three velocities - one parallel to the main stream and two other which vary in their direction. In this flow, pressure increases at a rate of 1.7 to 2.0 times the rate of increase in velocity [Ref. 26].

## 3.3 PUMP HYDRAULICS

The pump is the heart of the dredger. Other components are important individually, but all must work in close conjunction with the operation of the pump. Basically it has two functions to perform:

- it must develop sufficient vacuum to allow enough water to be forced in the suction at a velocity high enough to carry the excavated material to the pump.
- it must discharge with enough pressure and velocity to keep the dredged material in suspension.

In a centrifugal pumping system, the pump does not lift anything. It acts as a device to assist the atmospheric pressure in pushing the water or the mixture of material and water. The pump assists the outside atmospheric pressure by removing some of the pressure within the suction. This then creates a lower pressure in the suction than on the outside. The outside pressure being greater therefore tends to force the water or mixture into the suction to equalize the pressure. In a normal dredging hydraulic system the only force acting to move the material in the suction is the effective force of the atmosphere. To create a complete vacuum in the suction the pump would have to lower the pressure of 1 kg/cm$^2$. As 0.23 kg of pressure corresponds to approximately one 25 mm of vacuum, this would be the equivalent of 76 cm of vacuum. It is practically impossible to obtain this vacuum anywhere. In dredging systems, 60 to 64 cm of vacuum are about the maximum that can be obtained. This allows only about 5/6 of the force of the atmosphere, or at sea levels, 0.9 kg/cm$^2$ of usable force. So, 0.9 kg/cm$^2$ would be equivalent to approximately 8.63 m of fresh water or head. However, not all this head will be available for lifting the mixture. The pump has to perform as below

- Lift the material in the mixture
- Overcome friction in the system (friction head)
- Give velocity to the mixture (velocity head)
- Get the mixture started into the suction, (entrance head) and where Necessary
- lift the mixture from the elevation of the surface of the water to the center of the pump (Static head).

Where the center of the pump is at or below the water surface, this fifth job is eliminated. The sum of these above said four heads subtracted from the usable head is the head left available to lift the material.

## 3.4 HEAD LOSS AND FRICTION

Head is the source of energy used in pumping. It is usually referred to in metres of water. A head of 100 m corresponds to a pressure of approximately 10 kg/cm $^{2}$. The total head on a dredge pumping system is the energy available to move mixture of solids and water to the disposal area. It is often desirable to know what head will be required prior to the planning of dredging systems.

### (a) Total Discharge Head

#### (i) Discharge friction head ($H_{df}$)

It has been found by various experiments that in turbulent flow, friction is little affected by the viscosity, but the loss in head caused by friction will decrease as the percentage of material increases [Ref.26]. A familiar equation for head loss in pipelines carrying fresh water is the Darcy-Weisbach Equation

$$H = (f)\frac{(L)(V^2)}{(d)(2g)} \tag{3.1}$$

where H = head loss, in m of fresh water

L = length of pipe in m

d = inside diameter of the pipe in m

V= average velocity of the water in m/sec.

g = acceleration of gravity in m/sec$^2$

f = friction factor

If the velocity is low enough to allow the materials to drop out and roll along the bottom of the pipe, the Equation will not apply. Here friction factor (f) will be independent of the mixture in dredging systems. It will remain the same with a water - material flow as with a clear-water flow. When the exponent of the velocity in Equation (3.1) taken as 1.75 instead of 2 [ Ref. 26 ] , it has been found that friction factor becomes constant at a value of 0.0280 when applied to dredge mixtures. Equation (3.1) becomes

$$H = 0.0280\frac{(L)(V^{1.75})}{(d)(2g)} \tag{3.2}$$

It is believed that the increase in head in a dredge pipeline is dependent upon the friction loss plus the relative percentage of material in the mixture. By modifying the Darcy-Weisbach Equation (3.2) to take this into account, a closer approximation of the losses can be obtained.

As the percentage material in the line directly affects the specific gravity of the mixture, multiplying the modified Darcy-Weisbach Equation by the specific gravity of the mixture gives [Ref.26].

$$H = (SG)(f)\frac{(L)(V^{1.75})}{(d)(2g)} \tag{3.3}$$

where SG = Specific gravity of the mixture

f = 0.0280

This equation gave the closed approximation to the friction effects of water-solid mixtures in dredge pipelines. Therefore the discharge friction head ($H_{df}$) can be computed from equation 3.3. These are given in Table 3.4 & Fig.3.1. In determining the equivalent length of discharge pipe the length of floating line is multiplied by a constant of 1.3 to 1.5 to correct the additional friction caused by the ball joints and elbows in the floating line, when these are not determined individually. Shoreline pipe length multiplied by a constant 1.1 to correct for the friction created by the ram-joint connections. Fittings and bends are in terms of equivalent lengths of pipe with the familiar velocity-head relation.

$$H = K\left(\frac{V^2}{2g}\right) \tag{3.4}$$

Where $K = \left[0.131 + (1.847)\left(\frac{r}{R}\right)^{3.5}\right]\frac{\phi}{180^0}$

R = radius of the bend in meter

r = radius of the pipe in meter

$\phi$= degree of bend in decimal degrees (see Fig.3.2)

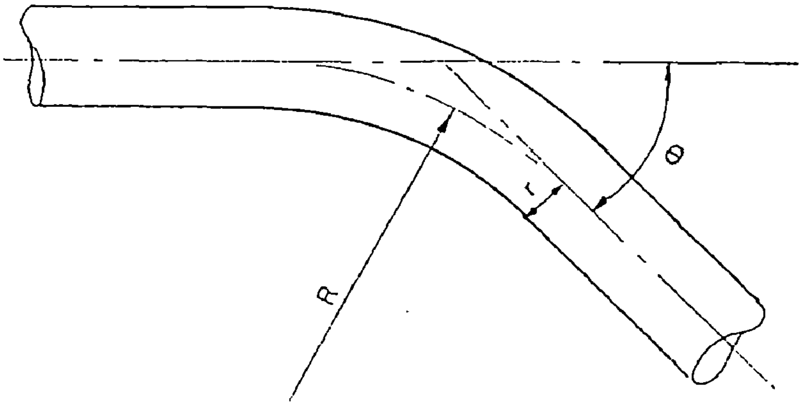


Fig. 3.2 Parameters of a Pipe Bend

**(ii) Discharge static head ($H_{ds}$) :**

The discharge static head is the vertical distance in metre of fresh water between the center of the pump and the point of discharge. It must be multiplied by the density of the pumped mixture to obtain a representative value in metre of fresh water.

**(iii) Discharge velocity head ($H_{dv}$) :**

The discharge velocity head is represented as the change in velocity occurring between the suction and the discharge system, brought about by the different diameters of the suction and discharge pipes. It is obtained from the relation

$$H_{dv} = S\frac{V_d^2 - V_s^2}{2g} \qquad (3.5)$$

where $H_{dv}$ = the discharge velocity head, in metre of fresh water;

$V_s$ and $V_d$ = the velocity of the mixture being pumped through the suction and discharge pipes respectively, in m/sec.

S = the density of the mixture being pumped, and

g = the acceleration of gravity in m./sec$^2$.

$\therefore$ Total discharge head $(H_d) = (H_{df}) + (H_{ds}) + (H_{dv})$ (3.6)

### (b) Total Suction Head ($H_s$)

Total suction head is the head needed to overcome the suction entrance head, the suction static head, the suction velocity head, and the suction friction head. It is the algebraic sum of these four heads. Only the suction static head may be negative, the other three are always positive.

#### (i) Suction static head ($H_{ss}$)

The static suction head when pumping clear, fresh water is the vertical distance in metre between the surface of the water and the center of the pump. It may be either positive or negative - pressure or vacuum - depending on the location of the pump center with respect to the water surface. When pumping salt water or dredging a mixture of solids and water, density corrections must be made. The following formula is used.

$$H_s = (S_1 C) - (S_2 B) \qquad (3.7)$$

where,

$(H_{ss})$ = the static suction head, in metre of fresh water,

C = the distance between the bottom of the cut and the water surface in metre,

B = the distance, the pump center is above the bottom of cut in metre,

$S_1$ = the specific gravity of the water in which the dredger is operating,

$S_2$ = the specific gravity of the mixture being pumped.

If $H_{ss}$ results in a positive value, as it will if the center of the pump is below the water surface, it must be subtracted from the sum of all the other heads in the suction system to obtain the total suction head.

### (ii) Suction velocity head ($H_{sv}$)

The suction velocity head is that required to imparting flow to the mixture in the suction pipe. It can be calculated from

$$H_{sv} = (s)\frac{(v^2)}{(2g)} \tag{3.8}$$

where

$H_{sv}$ = the velocity head, in metre of fresh water;

S = the specific gravity of the mixture being pumped,

V = the velocity of the mixture in m/sec. and

g = the acceleration of gravity in m / sec$^2$.

### (iii) Suction friction head ($H_{sf}$)

The suction friction head is the head required to overcoming all friction losses in the suction system, and is obtained from [Ref. 27]:

$$H_{sf} = 0.015\left(1+\frac{P-K}{100}\right)\frac{LV^{2}}{2gD} \tag{3.9}$$

where $H_{sf}$ = the friction head, in metre of fresh water per metre of pipe;

L = the equivalent length of the suction pipe, in metre;

D = the inside diameter of the suction pipe, in metre;

V = the velocity of the mixture being pumped, in m/sec and

K = a constant, usually 10.0 for concentrations lower or higher than 10%

P = the percentage by volume of material in suspension.

Fittings, bends and elbows create additional friction and their equivalent length of straight pipe can be determined from standard tables and added to the length of suction pipe to obtain the equivalent length.

Other losses, such as entering loss etc. are small and can be disregarded for a properly designed suction mouthpiece.

$\therefore$ The Total Suction Head ($H_s$) = ($H_{ss}$) +($H_{sv}$)+ ($H_{sf}$) (3.10)

### c) Total Dynamic Head ($H_t$)

The total dynamic head is the algebraic sum of all the suction and discharge heads.

$$(H_t) = (H_s) + (H_d) \tag{3.11}$$

## 3.5 DREDGER OUTPUT

Dredge output is a function of many variables viz. (i) Velocity of flow (ii) Size of discharge pipe (iii) Length of pipe line (iv) Lift (v) Concentration of the material in the mixtures (vi) Water horse power (vii) Efficiency (viii) Type and quantity of material (ix) Depth of dredging

Dredge out put is usually measured in cubic yard or cubic metre of in-situ material per hour. The number of cubic metre per hour is a function of the discharge - pipe diameter, the velocity of flow, and the concentration of the material in the mixture. The total flow of the pump in gallons per minute of lpm as it is usually expressed does not involve the concentration of the mixture. The total flow output in the product of area and velocity. It is given as:

$$Q = \frac{\pi}{4} \times 448.83(d^2)(V)$$

$$\text{or} \quad Q = 352.51\,(d^2)\,(V) \qquad (3.12)$$

where Q = flow in gallons per minute

d = Inside diameter of the discharge pipe in feet

V = Velocity of flow in feet/sec

The quantity (Q) above can be expressed in cubic metre per hour by multiplying it by 0.227 and the concentration percentage of the material as

Cubic meter/Hour = Q x Ave% solids x 0.227

or Cubic meter/Hour = GPM x Ave % of solids x 0.227 (3.13)

## 3.6 WATER HORSE POWER

The power actually expended in forcing the material and water out the discharge line is called water horsepower.

Water horsepower can be determined by

$$WHP = \frac{SG(q)(H_t)}{4500} \tag{3.14}$$

where WHP = Water horse power

q = the discharge of the pump in cumec.

$H_t$ = the total dynamic head on the pump in m of fresh water

SG = Specific gravity of the mixture being pumped

The power expended in forcing the material out the discharge, plus the power required to turn the pump and over coming all losses, is called brake horsepower. Brake horsepower involves the efficiency of the pump. Dredge pumps have low efficiencies, mainly because of the large clearances required to pass solids through the pump, and usually operate in the range of 60% to 65% [Ref. 27]. The brake horsepower (BHP) can be calculated from

$$BHP = \frac{WHP}{E} \quad \text{where E is efficiency} \tag{3.15}$$

## 3.7 EFFICIENCY

Dredge efficiency and pump efficiency are not synonymous. Dredge efficiency is the moving of a unit of material at the lowest over-all cost. Pump efficiency is the moving of a unit of material at the lowest power cost. A unit of material dredged with least power expended is not necessarily dredge efficiency. Since pipeline losses vary nearly as the square of the velocity, a high velocity pipeline would to be detrimental to economic dredge operation. High velocity, because of its greater material carrying capacity, can within certain limits, increase the efficiency of dredger.

## 3.8 SPECIFIC SPEED

Dredge pumps turn at relatively slow speeds generally between 100 and 800 rpm because as the speed goes up the available vacuum in the suction decreases. This creates lifting problems. In addition, the materials the pump must handle are usually large and bulky. Consequently large openings are required for them to pass through the pump. It means large runners and with large runners high speeds are not necessary to develop the heads required. The specific speed of a pump is a factor, which can be used to compare all pumps. It establishes a pump's operating capabilities. Specific speed of a pump is the speed at which an exact model of the pump runs if it were designed to give one gallon per minute against a head of one foot. It is a function of the runner speed , the output , and the total head and given by [Ref.26]:

$$N_S = N\frac{(Q)^{0.5}}{(H)^{0.75}} \qquad (3.16)$$

where $N_s$ = specific speed in rpm

$Q$ = output in cumec.

$N$ = speed of runner in rpm

$H$ = head on pump in m.

For a given head and capacity a pump with a low specific speed will operate at a greater suction lift than the one with a higher specific speed. Dredge pumps, because of their need for higher dynamic suction lifts, are all low specific speed pumps. The term low is usually considered as being below 1000 rpm. The maximum speed of small dredge pumps is usually not more than 800 rpm, and speeds of large one usually not more than 400 rpm.

## 3.9 SYSTEM CURVES

A system curve indicates graphically the head against which a pump has to work for any particular pipeline. When this curve is plotted on the same graph as the Q-H curve, its inter-section with the Q-H curve indicates the point of operation. The system curve is determined by the discharge static head and the discharge friction head. A pump operating against a static head only (no friction) would have a horizontal system curve displaced vertically from zero by the amount of the static head, as shown in Fig. 3.3(a) pump operating with a pipeline at constant elevation no lift would expend all its head in overcoming friction. As the friction in a pipeline increases approximately as the square of the output, the system curve would be a parabola with its origin at zero head Fig. 3.3(b). Where there was a combination of these two conditions, friction plus lift, the system curve would be a parabola originating at a point on the ordinate, or head axis, a distance above zero equal to the total static lift, as shown in Fig. 3.3(c).

A decrease in pump speed will lower the Q-H curve, Fig.3.4 as will a decrease in runner diameter, capacity varying directly with speed, and head as the runner diameter squared. For the same pipeline, a decrease in speed or runner diameter decreases output and requires less horsepower. Increasing the speed or runner diameter will do the opposite. Any change in pipeline length will change the slope of the discharge system curve. An addition of pipe will steepen it, causing the pump to operate at a point higher on the Q-H curve, with higher head and less output.

### 3.9.1 System Curve with Boosters

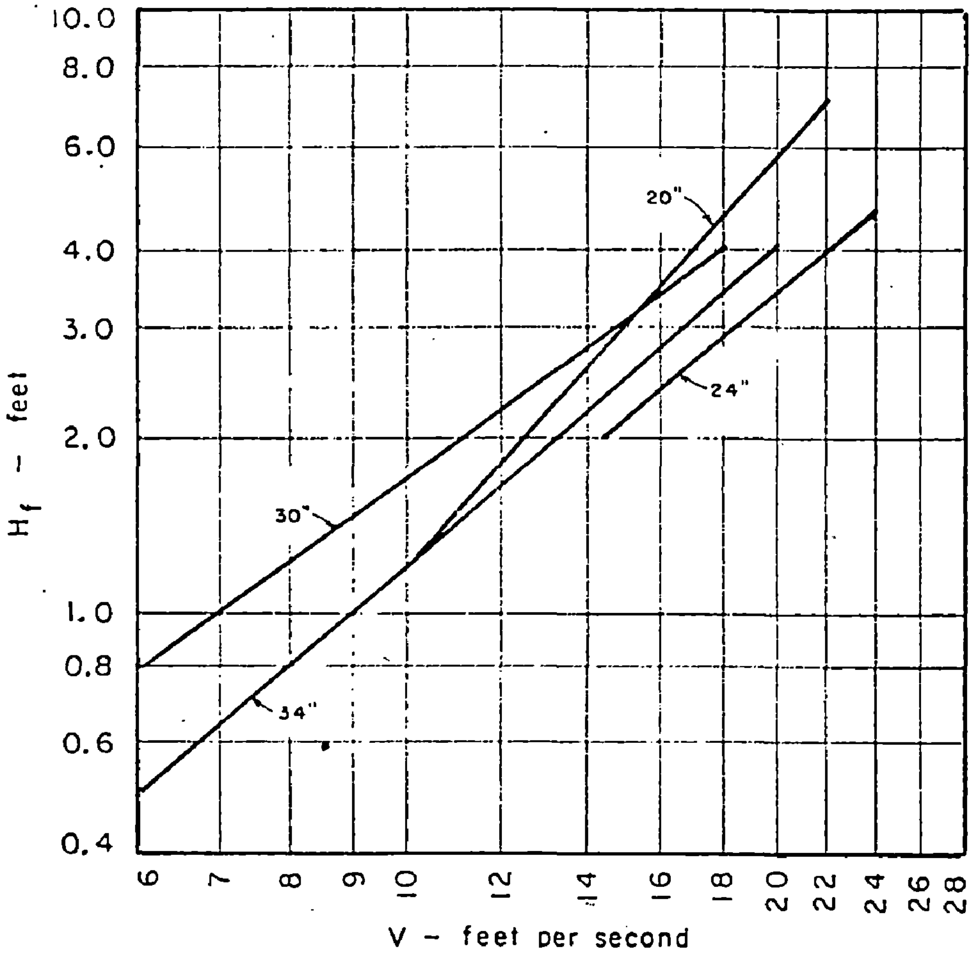
In instance where long lines and high lifts are required, and where speed or runner diameters cannot be increased sufficiently, booster pumps are often used. A booster can be placed anywhere in a discharge line, the only criteria being that it has sufficient suction pressure. Fig. 3.4 shows a characteristic Q-H curves for a single dredger pump and the resulting Q-H curve obtained when a booster is added. The discharge system curves are also shown. The new characteristic for both pumps in series will be the arithmetical sum of the head of each pump at identical outputs.

It can be seen that if the dredger pump alone was used, it would be able to produce low discharge corresponding to point, A on the Q-H curve, an amount too low for economy, and velocity too low to move the material. By adding a booster pump, however, the combination Q-H curve will be more than double that of the dredger pump alone, and sufficient capacity will be developed to almost double the discharge(point B on the Q-H curve). It is usually preferable to distribute the load as evenly as possible between each pump, one reason being the reduction of the total pressure in the line. When pumps of different characteristics are used, it is best practice to distribute the load proportionally with their characteristics.

Table 3.1 Head Loss as a Function of Velocity in Various Sizes of Dredge Pipe.

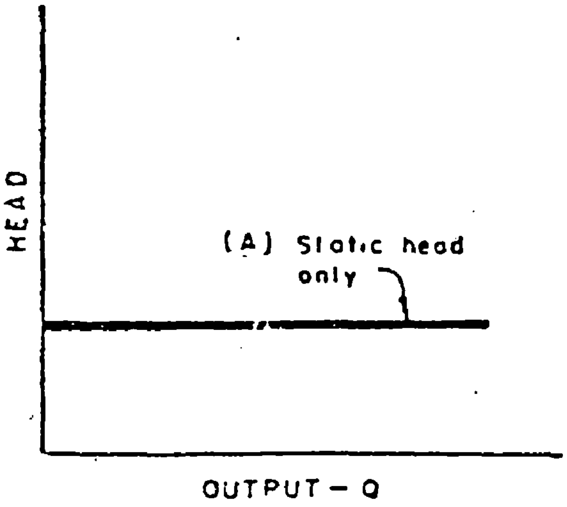
| V | 6" | 8" | 10" | 12" | 14" | 16" | 18" | 20" | 24" | 27" | 30" |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ft/sec | Nom | Nom | Nom | Nom | OD | OD | OD | OD | OD | OD | OD |
| 10 | 4.89 | 3.67 | 2.93 | 2.44 | 2.17 | 1.89 | 1.68 | 1.50 | 1.25 | 1.08 | 1.00 |
| 11 | 5.78 | 4.33 | 3.47 | 2.89 | 2.57 | 2.24 | 1.98 | 1.78 | 1.48 | 1.28 | 1.18 |
| 12 | 6.73 | 5.05 | 4.04 | 3.36 | 2.99 | 2.60 | 2.31 | 2.07 | 1.72 | 1.49 | 1.37 |
| 13 | 7.74 | 5.80 | 4.64 | 3.87 | 3.44 | 3.00 | 2.65 | 2.38 | 1.98 | 1.72 | 1.58 |
| 14 | 8.81 | 6.61 | 5.29 | 4.41 | 3.92 | 3.41 | 3.02 | 2.71 | 2.25 | 1.98 | 1.80 |
| 15 | 9.94 | 7.45 | 5.97 | 4.97 | 4.42 | 3.85 | 3.41 | 3.06 | 2.54 | 2.21 | 2.03 |
| 16 | 11.13 | 8.34 | 6.68 | 5.57 | 4.95 | 4.31 | 3.82 | 3.42 | 2.84 | 2.47 | 2.27 |
| 17 | 12.38 | 9.28 | 7.43 | 6.19 | 5.50 | 4.79 | 4.24 | 3.81 | 3.16 | 2.75 | 2.52 |
| 18 | 13.68 | 10.25 | 8.21 | 6.84 | 6.08 | 5.29 | 4.69 | 4.21 | 3.49 | 3.04 | 2.79 |
| 19 | 15.04 | 11.27 | 9.02 | 7.52 | 6.68 | 5.82 | 5.16 | 4.62 | 3.84 | 3.34 | 3.07 |
| 20 | 16.45 | 12.33 | 9.87 | 8.22 | 7.31 | 6.37 | 5.64 | 5.06 | 4.20 | 3.65 | 3.36 |
| 21 | 17.91 | 13.43 | 10.75 | 8.96 | 7.96 | 6.93 | 6.14 | 5.51 | 4.58 | 3.98 | 3.65 |
| 22 | 19.43 | 14.57 | 11.66 | 9.72 | 8.64 | 7.52 | 6.67 | 5.98 | 4.97 | 4.31 | 3.96 |
| 23 | 21.01 | 15.74 | 12.60 | 10.50 | 9.34 | 8.13 | 7.21 | 6.46 | 5.37 | 4.66 | 4.29 |
| 24 | 22.63 | 16.96 | 13.58 | 11.32 | 10.06 | 8.76 | 7.76 | 6.96 | 5.78 | 5.02 | 4.62 |
| 25 | 24.31 | 18.22 | 14.58 | 12.15 | 10.80 | 9.41 | 8.34 | 7.47 | 6.21 | 5.40 | 4.96 |

All head losses are for 100 feet of pipe, obtained by using equation 3.3 with a specific gravity of 1.00 and a friction factor of 0.0280

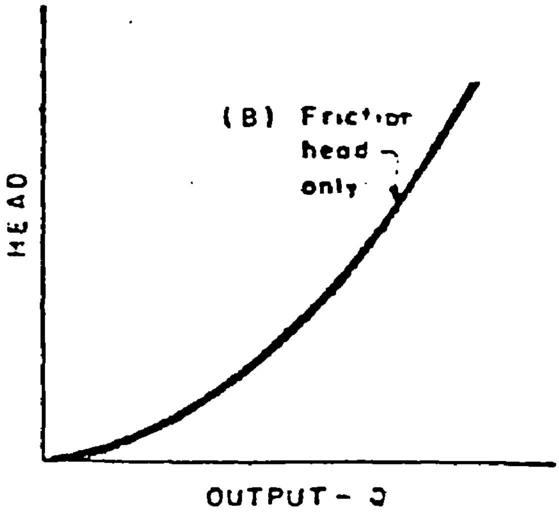


Actual Head Losses in Dredge Pipes. (University of California Press)

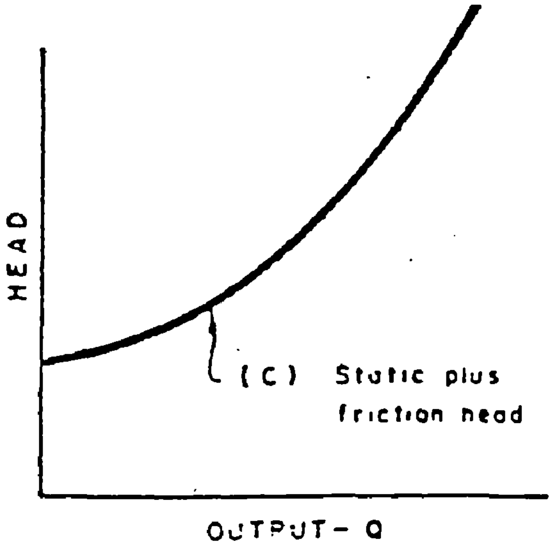
Fig. 3.1 Head Losses in Dredger Pipes



(a) For Static Head only



(b) For Friction Head only



(c) For Static Plus Friction Head

Fig. 3.3 System Curves

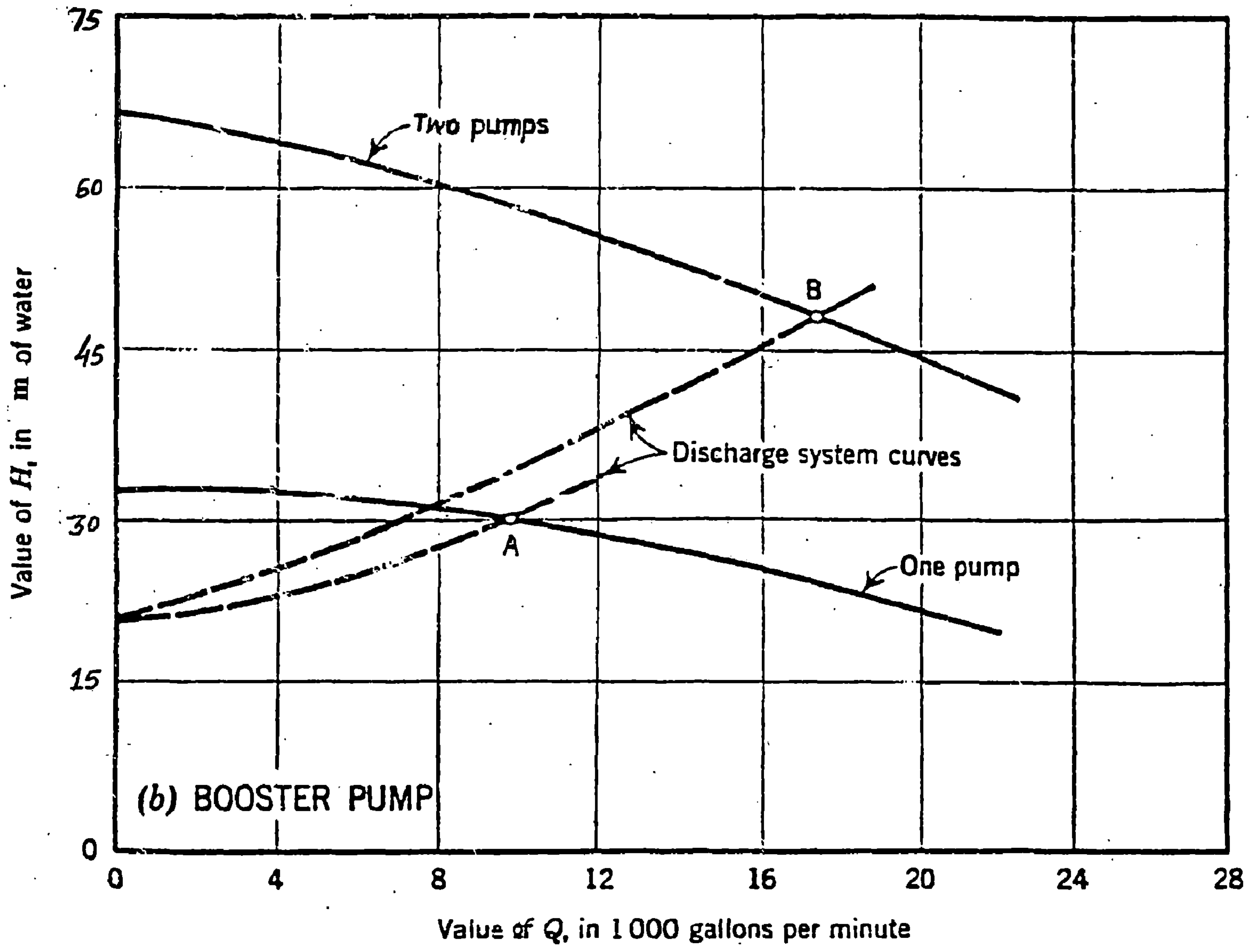


Fig. 3.4 Characteristic and System Curves of Booster and Dredge Pump

# CHAPTER – 4

# SILT PROBLEM AND REMEDIAL MEASURES AT BSL PROJECT

## 4.1 GENERAL

The Beas Sutlej link Project (BSL) is one of the largest hydroelectric projects in the country. It comprises of an earth-cum-rock fill diversion dam at Pandoh in Mandi district of Himachal Pradesh across river Beas, a 40 km. long water conductor system to link river Beas with the Sutlej consisting of two tunnels and an intervening high contoured open channel, and Dehar power plant at the downstream end of the second tunnel. The BSL water conductor systems diverts about 4716 million cubic metre of Beas water annually to River Sutlej. A head of 320 metres is available to generate 990 MW of power at Dehar. The diverted water after generation of power at Dehar further augments the water supplies to Sutlej and subsequently increases power generation at Bhakra, Kotla and Ganguwal powerhouses. The Beas waters thus diverted are also utilized for irrigation of a large chunk of Haryana state which otherwise was not possible, from river Beas itself. The 451.60 crores rupees BSL project commenced power generation in late 1977 for the three beneficiary states of Punjab, Haryana and Rajasthan as well as other contiguous areas. This project has been designed and constructed with complete indigenous know-how. The general layout and longitudinal section of the project are shown in Figs. 4.1 & 4.2. The basic data and salient features of BSL are given in Appendix-(4.1) [Ref. 6 to 11]:

## 4.2 SILTATION OF BSL PROJECT

Beas River carries sizable quantity of silt during monsoon season generally extending from June end to late September and sometimes even extending up to the month of October. The Beas catchment receives the moisture bearing winds both from Arabian Sea and Bay of Bengal. Most of the catchment area lies under denuded forest and cultivated land and therefore, the proportion of silt is relatively high. The catchment area of Beas River upstream of Pandoh Dam is 5278 sq. km out of which 780 sq. km is under permanent snow. The catchment area comprises mostly precipitous slopes and the metamorphic rocks are mainly granite, gneiss & schist's. These contribute mostly to the coarse and medium sized sediment, thereby providing source of large quantity of silt in the catchment area. The average annual rainfall in the catchment is about 1800 mm. The length of river up to Pandoh Dam is about 116 km and the gradient of the river decreases from 77m/km between Rohtang pass to Manali to 6 m/km between Larji and Pandoh. With these characteristics the catchment yields a lot of sediment during monsoon. Lot of silt-fine, medium, coarse and boulders come with floodwater. There is no in-built silt excluder at Pandoh Dam, which is a rock fill diversion dam. The dead storage of dam has been found silted up in 9 years time, since it's commissioning in 1977 as against anticipated period of 27 years. This speaks of the magnitude of silt problem. The sketch showing the catchment area is at Fig. 4.3.

## 4.3 QUANTITATIVE ASSESSMENT OF SILTLOAD AT THE PANNING STAGE

Based on a few years silt observations, it was estimated that suspended silt load of 395 ha.m would enter Pandoh reservoir. In addition 15% would be bed load. The gradation and gradewise distribution was assumed as below [Ref. 7]:

| | | |
|---|---|---|
| Coarse Silt | > 0.2 mm | 18% |
| Medium Silt | 0.2 to .075 mm | 13% |
| Fine silt & clay | < 0.075 mm | 69% |

The computations for the life of reservoir were made assuming following mode of sediment deposition in the reservoir.

Fine silt would pass through the spillway and 33% of coarse and medium would pass through Pandoh Baggi tunnel (PBT) and the rest would get deposited in the reservoir. Table (4.1) shows the distribution of the sediment load.

Table (4.1) : Distribution of the sediment load at BSL Project

| | Coarse silt | Medium silt (ha.m) | Fine silt (ha.m) | Fine silt & clay (ha.m) | Total (ha.m) |
|---|---|---|---|---|---|
| 1. | Suspended silt entering reservoir | 71 | 51 | 273 | 395 |
| 2. | Bed load (15%) | 11 | 8 | 41 | 60 |
| 3. | Total silt | 82 | 59 | 314 | 455 |
| 4. | Passing through spillway | 8 | 6 | 314 | 328 |
| 5. | Balance | 74 | 53 | - | 127 |
| 6. | Diverted through PBT (33% of balance) | 25 | 17 | - | 43 |
| 7. | Deposition in reservoir | 49 | 35 | - | 84 |

It was, thus, estimated that the reservoir capacity up to spillway crest (El. 883.920) would get silted up in (2250/84=27) 27 years.

It was also assumed that the entire bed load would be entrapped in the reservoir and 50% of the suspended load, on an average 215.778 ha.m would enter the water conductor system. The silt ejector would exclude 52.77 ha.m and rest 163 ha.m would reach the balancing reservoir. Fifty percent of it i.e. 81.50 Ha.m would settle in the balancing reservoir and the rest would pass through Sundernagar Sutlej tunnel (SST) to the power house. It is summarized in Table (4.2) as follows [Ref. 34].

Table (4.2): Summary of sediment load at BSL Project

| Sl. No. | Silt Grade | Total entering Hydel channel (ha.m) | Silt excluded through ejector (ha.m) | Silt entering balancing reservoir (ha.m) |
|---|---|---|---|---|
| 1. | Coarse | 29.96 | 29.96 | - |
| 2. | Medium | 30.21 | 6.66 | 23.55 |
| 3. | Fine | 155.60 | 16.15 | 139.45 |
| Total | | 215.77 | 52.77 | 163.00 |

## 4.4 DESILTING MEASURES AS PLANNED

BSL Project has a long water conductor system comprising Pandoh Baggi Tunnel (PBT), Sundernagar Hydel channel (SHC), Sundernagar Balancing Reservoir (BR) and Sundernagar Sutlej Tunnel (SST), besides Pandoh dam and power plant. The silt if allowed to enter the water conductor system in large quantities will result in frequent break down of powerhouse machinery, interruption in power generation, increase in maintenance & operation cost and decreased revenue. So, silt has to be 'excluded' or 'ejected' or 'dredged out' to maximum possible extent. All the three desilting arrangement have been provided not only to exclude the silt at its entry but also to extract the sediments through various other works constructed on water conductor system for the purpose after detailed studies. Even then difficulties are being experienced in disposal of silt-laden water from the silt ejector and also from the dredger installed in the balancing reservoir due to strong resistance of the local inhabitants.

As per provisions of the project, following desilting arrangements have been provided.

### 4.4.1 Exclusion of Sediment at Pandoh

Since no desilting arrangement has been provided at the intake of PBT to prevent the sediment entry into the tunnel, reservoir operation based on model studies has been relied upon to check sediment entry during floods. Therefore, Reservoir Operation Manual contains detailed guidelines for reservoir operation, which is divided into two stages pre-delta and post-delta and for flood and non- flood seasons. When the reservoir gets silted up upto the spillway crest and bed load passes through spillway, it is called post-delta stage. This stage has, as per records reached in 9 years after the commissioning of the project. After this stage lot more sediment would enter PBT. To check the entry of sediment into PBT after the post delta stage, the following important guidelines are given in the operation manual.

a) Still pond regulation shall be followed up to a river flow of 3000 cumecs (1.0 lacs cusec) during monsoon period. Regulate flow through Spillway Bays 3, 4, 5, while Bays 1 & 2 shall remain closed. In order to induce still pond regulation a stepped divide wall at the end of Bay 2 (Fig. 4.4) has been provided with top, at El. 886.97 m and 887.58 m along with a long curved approach in the upstream.

b) Reservoir shall be maintained at lowest possible elevations varying between EL.883.92 m and 883.27m. higher water levels shall be maintained with raised crest at tunnel intake. It shall be subject to prevention of vortices at tunnel mouth.

c) For discharge more than 3000 cumecs (1.0 lac cusecs) all spillway bays shall be opened and discharge in PBT shall be reduced to minimum. The intake crest shall also be raised with blank panels.

d) Since river bed material is likely to be deposited in the still pocket in front of the intake and may find entry into PBT, the provision of occasional flushing of the pocket by opening gates of Bays 1 and 2 has been made in the Operation Manual. Bay 3 shall also be kept open. Suitable means (through a dragline) shall be adopted for dredging the pocket if flushing alone is not adequate. Bays 1 & 2 shall be kept closed during dredging. During flushing and dredging operation the crest level of intake shall be raised with blank panels.

### 4.4.2 Silt Ejector at Hydel Channel

To eject coarse material from the sediment, which may find entry into PBT, a sediment ejector as shown in (Fig. 4. 5) has been provided on the Hydel channel. The flushing discharge is fixed as 30 cumecs (1000 cusecs.) Thus, the Hydel Channel downstream of ejector would carry a discharge of 250 cumecs (8000 cusecs). The ejector escape channel discharges into a natural khad on the right side of the Hydel Channel.

### 4.4.3 Dredging From Balancing Reservoir

The Hydel Channel discharges into a balancing reservoir which has a live storage of 3.7 x $10^6 m^3$ to be used for peaking and a dead storage of 1.1x $10^6 m^3$ below EL. 833.32 m. The full reservoir level is EL 842.47 m. As mentioned (under Para 4.3) an estimated 81.50 ha.m of sediment would settle in the balancing reservoir annually and if allowed to remain in reservoir it would encroach upon the live storage. Therefore, a cutter-suction dredger has been provided for the removal of the deposited sediment from the beginning of the project.

The balancing reservoir (Fig. 4.6) at the downstream end feeds Sundernagar-Sutlej tunnel (SST), which is 8.535 m in dia. It feeds the machines of the Dehar powerhouse.

## 4.5 PRESENT STATUS OF SILT MANAGEMENT AT BSL

The BSL power complex has been in operation since 1977 and more than twenty years have passed. On the basis of data and the information collected during site visits and the record with reference to sediment management, the actual operation of BSL complex has been visualized. The data of sediment entering the reservoir and its disposition at different components, based on the adopted operation, has been compiled in Table (4.3). The following observations are derived from the data:

**(a)** In the initial years of project operation all the sediment entering the reservoir got deposited in the reservoir and a small fraction entered PBT and deposited in balancing reservoir while fine sediment passed through reservoir.

**(b)** By the year 1985 the sediment deposit in reservoir reached the stage, which was anticipated during planning after 27 years. Since 1984, about 50% of the sediment entering reservoir started entering PBT. Therefore, the post delta stage started after seven years of operation.

**(c)** Flushing of the pocket in front of intake was started during floods of 1986. It was found effective when free flow conditions were created and PBT was closed. With five flushing in 1986 about 104.80 ha.m of sediment was flushed. In 1987 only two flushing were done and so these were not found very effective in flushing sediment deposits. The data in table 3 reveals that flushing thereafter has been irregular.

**(d)** The dredging of the pocket in front of PBT intake has never been carried out.

**(e)** The reservoir is seen to be operated with water levels varying between EL.890m and EL.891.54 m during monsoon period. Since the top of divide wall, provided for inducing still pond regulation, is at El 886.97m, it remains submerged and so effective still pond regulation is not achieved.

**(f)** The table shows that the sediment ejector came into operation in 1982, but its effectiveness is very insignificant. It is occasionally run with low discharge varying from 1 to 12 cumecs to prevent the choking of ejector tunnels while it has been designed for 30 cumecs (1000 cusecs) of discharge. Objections of the cultivators settled in the escape channel area are stated to be the reason for non-functioning of ejector.

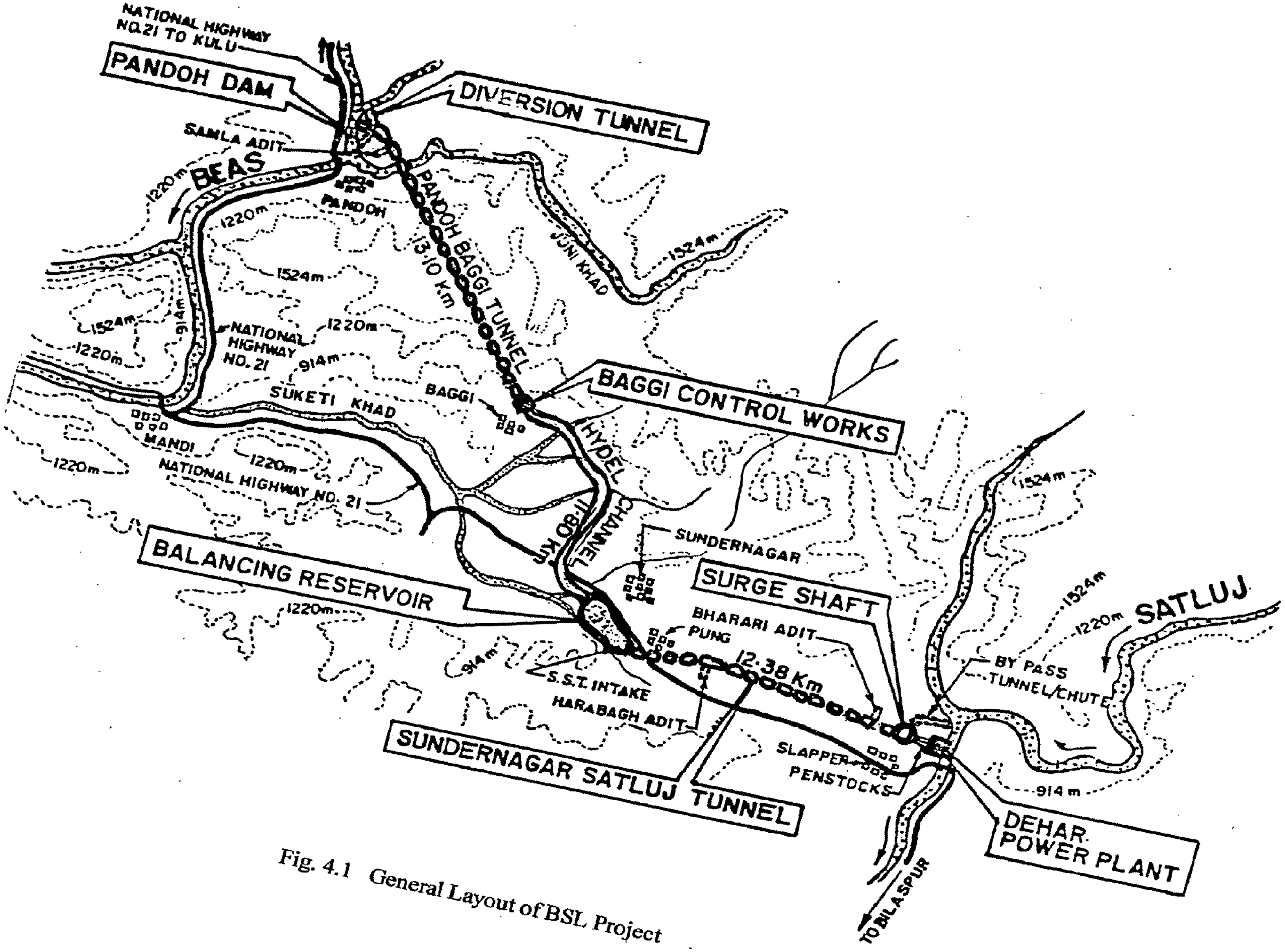


Fig. 4.1 General Layout of BSL Project

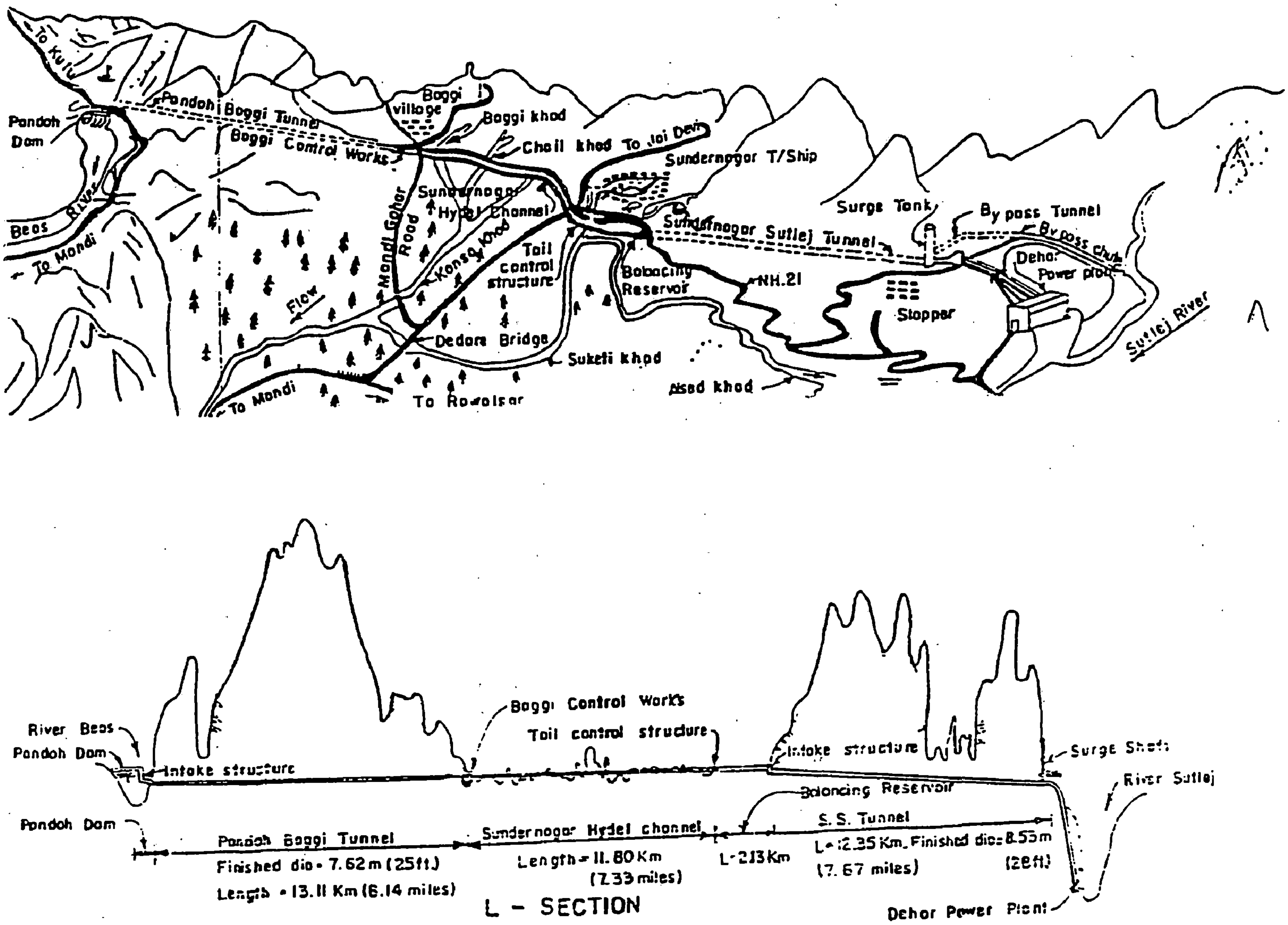


Fig. 4.2 Illustrative View and Longitudinal Section of BSL Project

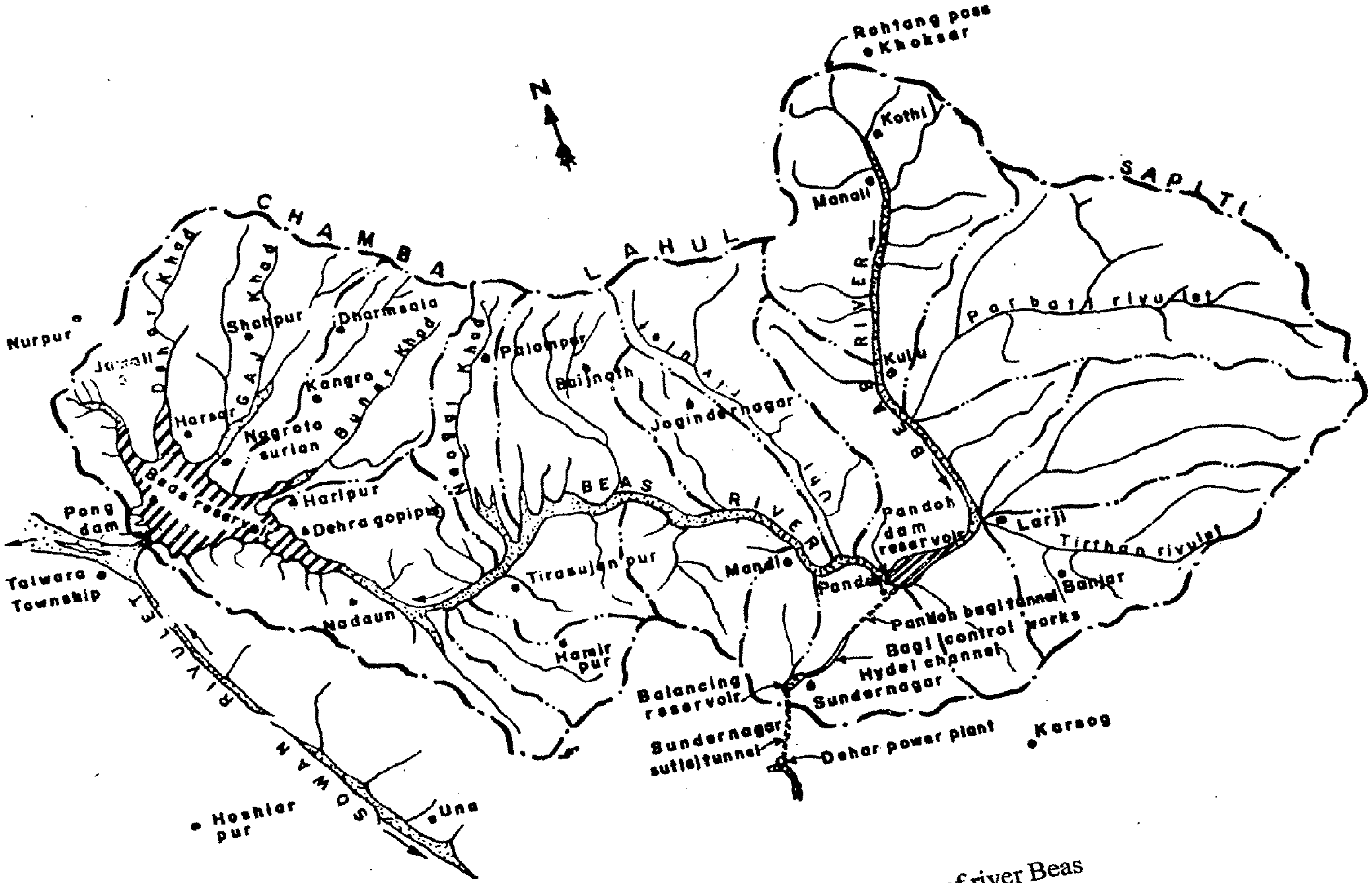


Fig. 4.3 Sketch showing the Catchment Area of river Beas

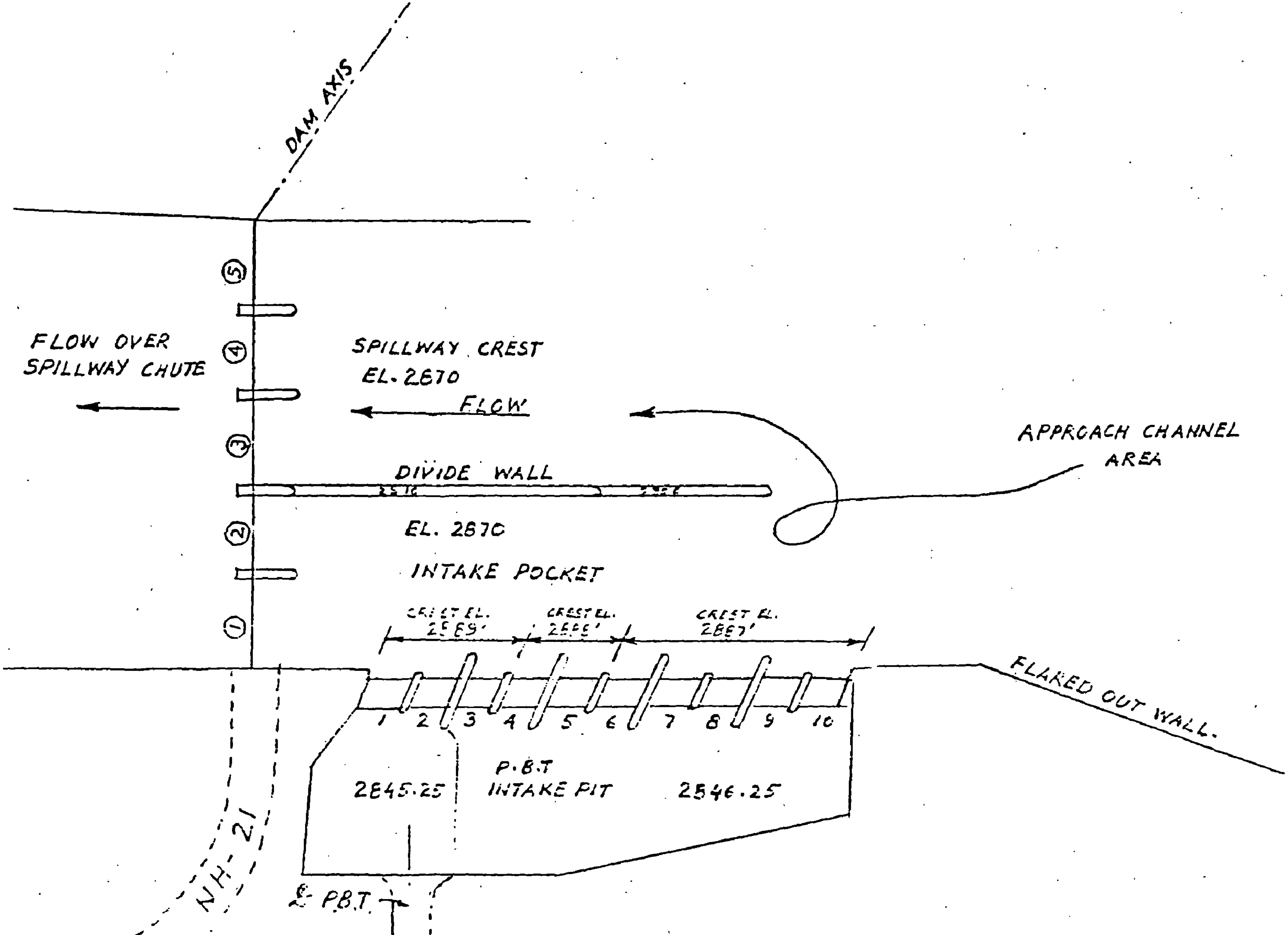


Fig. 4.4 Layout Plan of Spillway and PBT Intake Structure

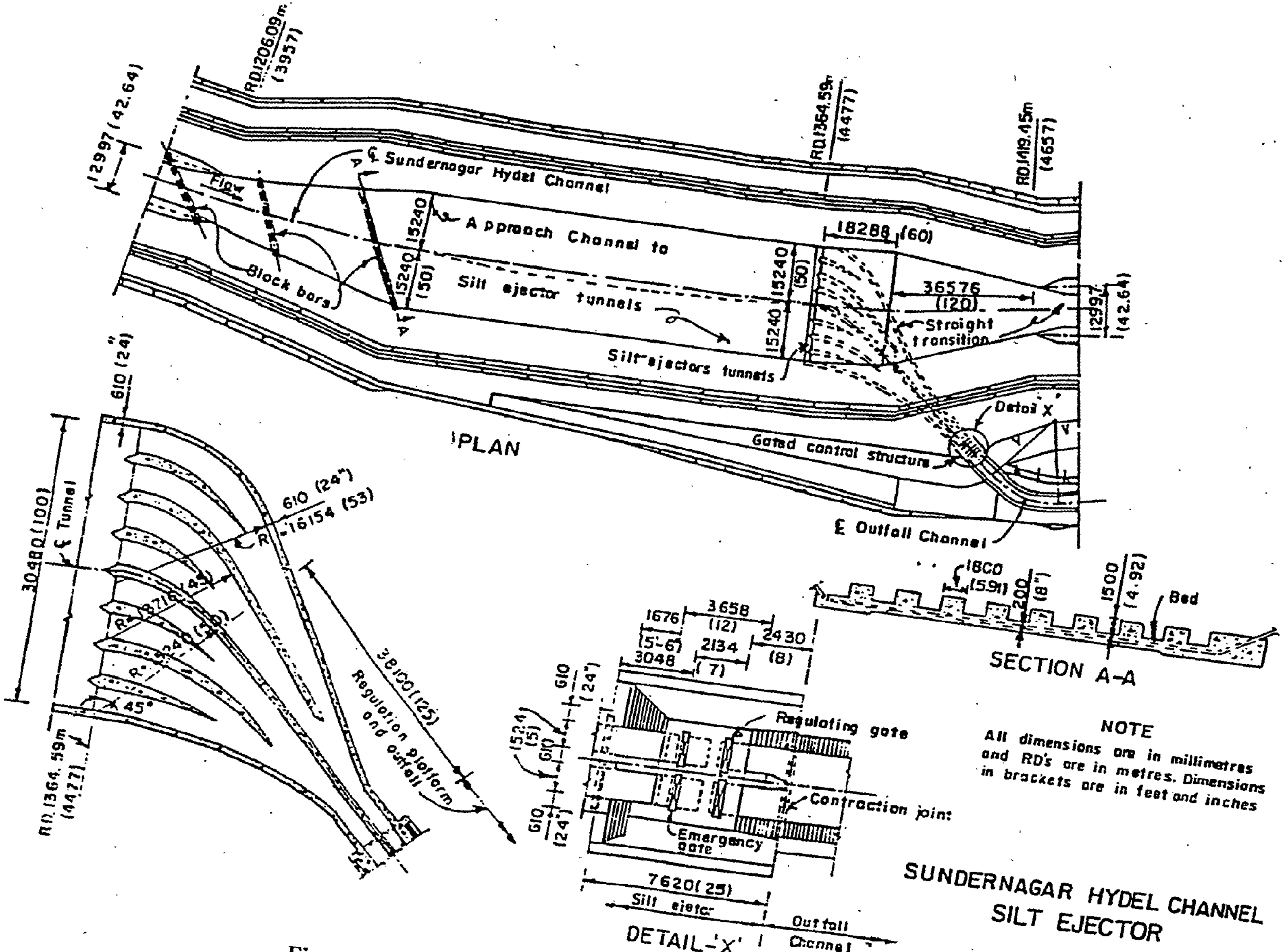


Fig. 4.5 Sundernagar Hydel channel Silt Ejector

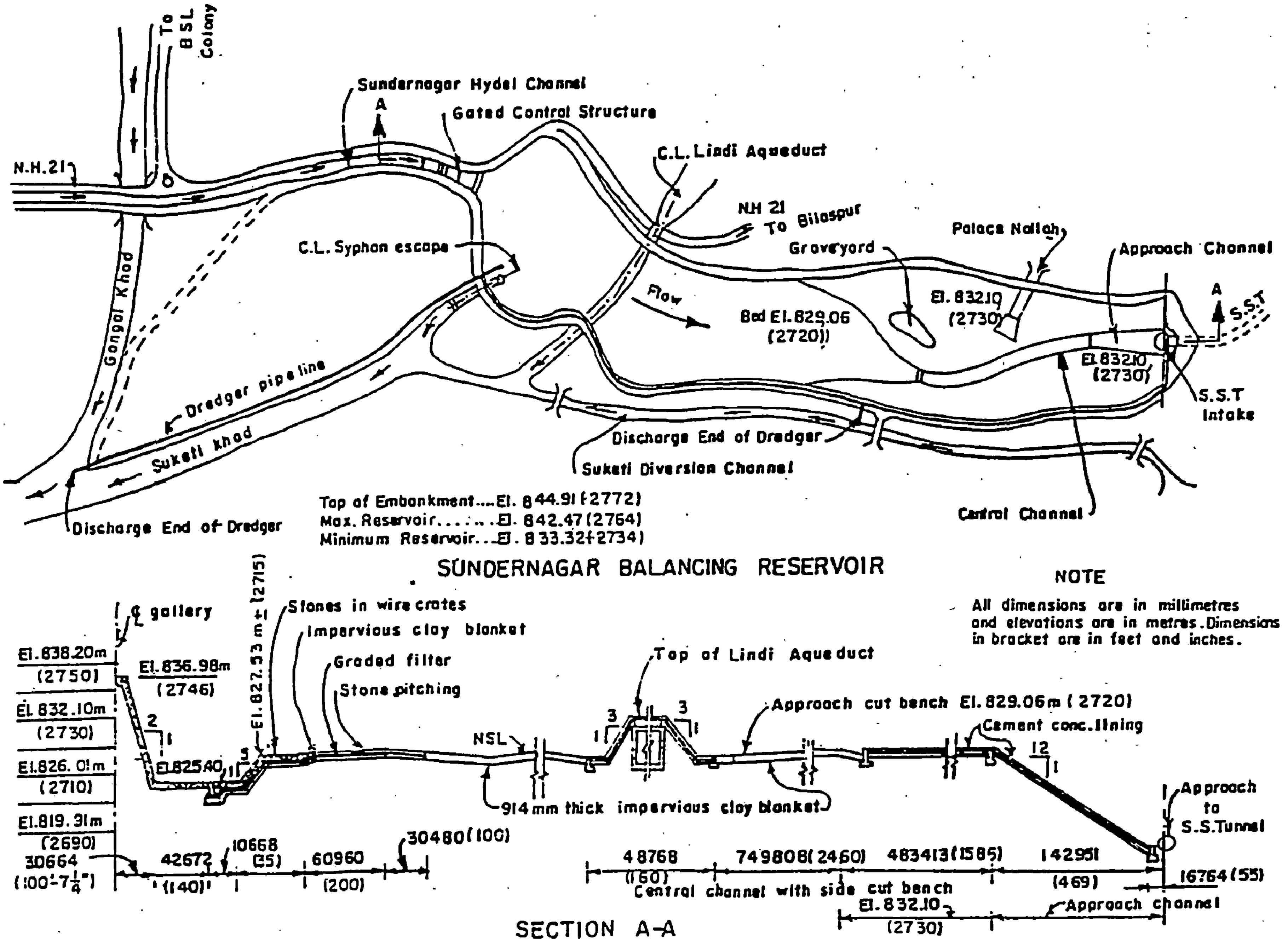


Fig. 4.6 Sundernagar Balancing Reservoir

## Table (4.3): SEDIMENT DATA OF BSL POWER COMPLEX

| Year | Total sediment entered in reservoir (Ha.m) | Sediment deposited in reservoir (Ha.m) | Sediment entered in PBT (Ha.m) | Sediment passed through ejector (Ha.m) | Sediment deposited in BR (Ha.m) | Sediment passed through PH (Ha.m) | Sediment dredged from BR (Ha.m) |
|---|---|---|---|---|---|---|---|
| 1977 | - | 590.97 | - | - | - | - | - |
| 1978 | - | 510.58 | 37.60 | - | 11.46 | 26.14 | - |
| 1979 | - | 232.79 | 28.85 | - | 8.75 | 20.10 | - |
| 1980 | 221.57 | 198.02 | 46.98 | - | 14.30 | 32.67 | - |
| 1981 | 286.67 | 234.64 | 29.22 | - | 8.88 | 20.34 | - |
| 1982 | 147.84 | 84.71 | 58.81 | 2.96 | 12.57 | 43.28 | 2.09 |
| 1983 | 176.07 | 133.90 | 36.99 | 0.86 | 12.33 | 23.80 | 2.96 |
| 1984 | 130.57 | 88.28 | 74.84 | 1.48 | 29.96 | 43.40 | 7.89 |
| 1985 | 209.49 | 161.52 | 106.16 | 3.45 | 50.55 | 52.15 | 44.26 |
| 1986 | 318.11 | (-)111.34 | 189.88 | 8.38 | 123.17 | 55.85 | 117.63 |
| 1987 | 142.04 | 131.07 | 87.29 | 2.09 | 51.29 | 33.91 | 89.76 |
| 1988 | 141.84 | (-)433.03 | 152.40 | 4.81 | 85.20 | 62.39 | 94.08 |
| 1989 | 241.17 | 258.56 | 96.05 | 1.85 | 46.98 | 46.24 | 77.80 |
| 1990 | 302.33 | 104.56 | 103.69 | 0.98 | 64.24 | 38.47 | 7.27 |
| 1991 | 186.92 | 193.58 | 91.86 | 0.37 | 58.20 | 33.29 | 45.62 |
| 1992 | 311.46 | (-)207.88 | 128.48 | 0.98 | 91.61 | 35.88 | 19.36 |
| 1993 | 1001.20 | 480.87 | 123.79 | 4.81 | 67.81 | 51.04 | 81.87 |
| 1994 | 403.19 | (-)201.10 | 179.77 | 5.92 | 100.61 | 73.24 | 83.35 |
| 1995 | 333.77 | 3.32 | 210.47 | 9.12 | 134.39 | 67.44 | 90.38 |
| 1996 | 338.21 | 34.15 | 164.60 | 3.94 | 100.36 | 60.29 | 137.23 |
| 1997 | 303.32 | 296.78 | 158.56 | 6.16 | 83.47 | 65.59 | 96.17 |
| 1998 |  | (-) 96.05 |  |  | 131.19 |  | 101.84 |

(-) ve sign indicates flushing from reservoir.

# CHAPTER –5

# DREDGING AT BSL BALANCING RESERVOIR

## 5.1 GENERAL

The quantity of silt actually entering/settling in the BR increased considerably due to non-adoption of still pond regulation, inefficient operation of silt ejector provided upstream of the balancing reservoir. Further the inability to drain the balancing reservoir coupled with the need to protect the uninterrupted operation of balancing reservoir during the dredging activity has led to the selection of hydraulic dredging as the preferred method while planning the dredging at BSL project. Accordingly a cutter-cum suction dredger (IHC Beaver 1500) was procured and installed in the year 1982.

## 5.2 REVIEW OF DREDGING AT BR OF BSL PROJECT

Dredging operations in the balancing reservoir were thus started in full swing from 1985-86 when more than 50% of sediment entering Pandoh reservoir started entering PBT and the dead storage of the balancing reservoir was filled up by sediment. To determine the actual pattern of the sediment deposits in the Balancing Reservoir, silt surveys are being carried out every year since December 1981. However, since 1987 it is being carried out during March, June and October every year. From the analysis of field data as shown in Fig. 5.1. It has been observed that the balance silt deposits at the end of September 1998 were of the order of 214.01 ha.m. and more than 50% of live storage capacity has been lost due to deposit of sediment in Balancing Reservoir of BSL Project. The quantity of silt deposited and dredged out during different years is given in Table 5.1.

Fig. 5.1 shows the quantity of silt deposited and dredged out during different years. It can be seen from the chart that sediment left every year in BR after dredging is progressively increasing since 1991 and is much more than the dead storage capacity of 110.97 ha.m. Thus, sediment level in BR has reached around El 835.15 m, and so the water level to feed the powerhouse in now ranging around El 838.20 m as against initially planned levels of 835.15 m to 833.32m.

The performance of dredging plant presently deployed at BR of BSL Project has been analyzed and shown in Table (5.2). Figures (5.2 & 5.3) show that at present the dredger output is less than 300m$^3$ of solids per hour and effective utilization of dredging equipment is less than 40%. It is very clear that the measures planned for sediment removal of BSL complex which included still pond regulation, flushing of intake pocket & dredging at Pandoh dam, functioning of ejector on Hydel Channel, dredging of BR and maintaining low level in BR to feed SST tunnel have not been followed during actual operation. At present the project authorities totally depend on dredging the BR for the sediment removal from BSL complex. The actual capacity of the installed dredger was 740 cum. of solids per hour. This was considered adequate to remove the anticipated annual silt deposition of about 80 ha.m during monsoon months. But due to the reasons explained above and the progressive decline in the efficiency of dredger have resulted in the loss of live storage capacity of balancing reservoir despite 3-shift working of the dredger round the year. Keeping in view the above facts and considering the constraints in following other measures, there is a need to design a new dredging system in order to meet the present requirement of dredging for the removal of silt from the BR of BSL

## 5.3 REVIEW OF EXISTING DREDGED MATERIAL DISPOSAL SYSTEM

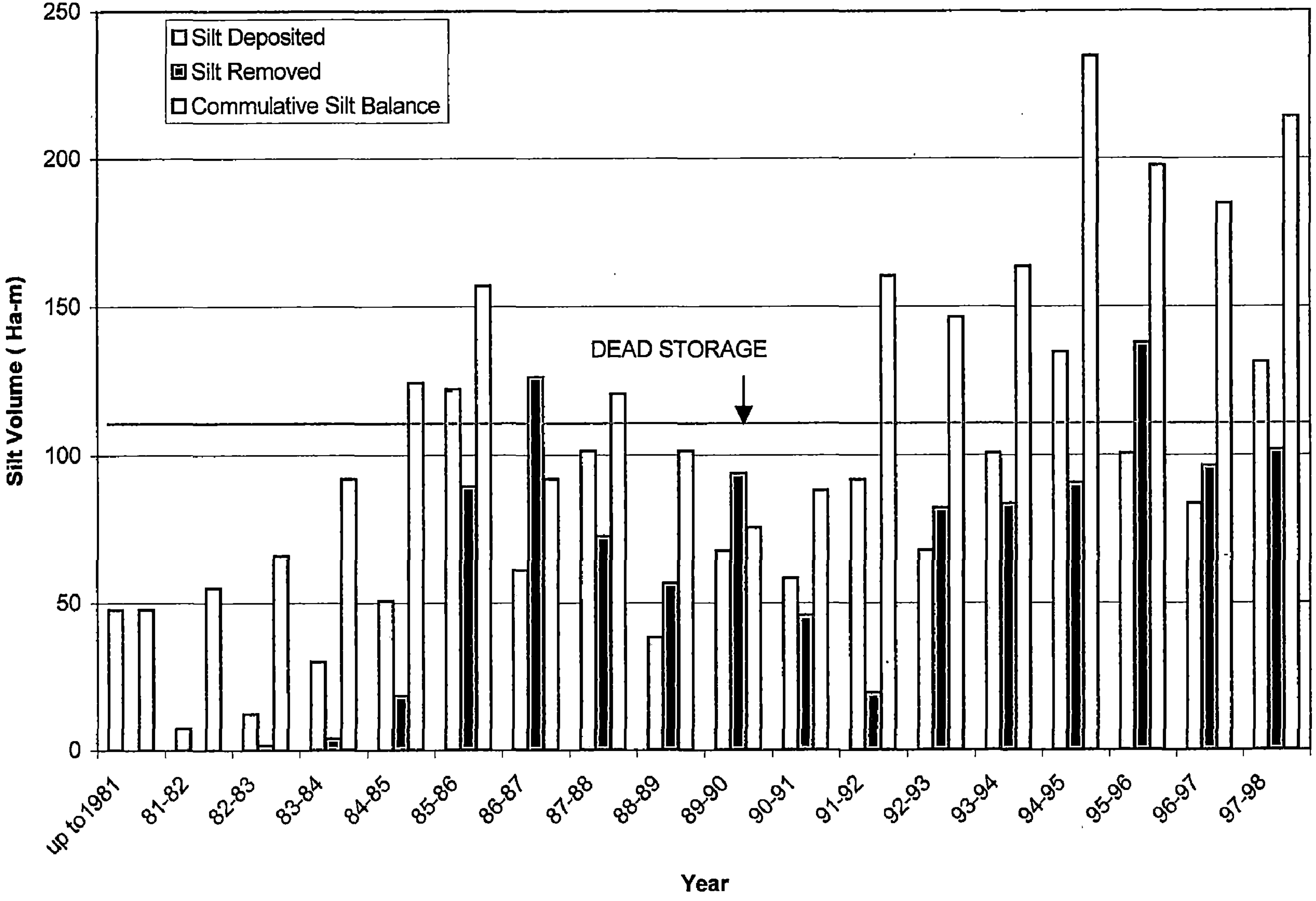
Initially dredging of BR was planned to remove 81.50 ha.m of expected deposits during monsoon. The dredger and the other accessories were planned accordingly. In the initial years (in 1980s') the dredger could dredge out the required quantity of sediment during the monsoon season.

The dredged material was disposed off as planned, in Suketi khad during monsoon when the khad has its own discharge, which was considered adequate to flush the dredged sediment. Slowly the sediment entry into the BR increased, as other measures of sediment removal became inoperative, and the efficiency of dredger reduced and so the working period for dredging increased. Since 1994-95 the dredger has been put to work in three shifts round the year, disposing highly silted water (25 cusecs with 20 to 30% sediment) into the khad round the year. Suketi khad has flat a slope after 9 km (L-section is shown in Fig. 5.4) and has insignificant flow of its own in non-monsoon month. Therefore the sediment disposed off from the dredger into the khad in non-monsoon period does not flushed down to river Beas (to which the khad joins at Mandi).

This sediment deposition in the khad has created various environmental problems for the people living along the khad such as entry of sediment into the fields through irrigation kuhls, blocking of irrigation kuhls, adversely affecting drinking water quality, water for cattle, river crossing problems, etc. As a result of these problems local people are agitating since long and occasionally obstructing the functioning of the dredger. Project authorities tried to solve the problem considering various alternatives. They carried prototype experiment with a separate cunette with a slope of 1.5 m/km to carry the dredger discharge of silted water to river Beas so that it may not mix with Suketi khad flow and create problems for the villagers. It was found that it was inadequate to carry coarse sediment dredged from the first pocket of BR. The proposal was dropped. They considered the proposal of passing fine sediment through SST tunnel to power house but was not pursued due to the apprehension that damage to turbine blades may be accelerated, though the present damage is considered to be due to cavitations and not due to abrasion by silt.

The project authorities, at present, are attempting to flush the dredged material in the flat slope reach by making kuchcha cunette in the bed of khad through dozers but such cunette get silted up in no time. The effort of making cunette continues through out the non-monsoon period with little success. Hence there is a need to evolve a new arrangement and develop an eco-friendly management strategy for disposal of dredged material.

Fig. 5.1: Status of Silt at BR of BSL Project (Dec. 1981 to Sept. 19~~8~~98)



**TABLE(5.1): Status of silt at BR of BSL Project**
**(Dec. 1981 to Sep. 1998)**

| Period | Year | Silt deposited during the period (ha-m) | Silt removed during the period (ha-m) | Balance silt deposit in BR (ha-m) |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |
| Up to 12/81 | up to1981 | 47.61 | 0 | 47.61 |
| 1/82 to12/82 | 81-82 | 7.4 | 0 | 55.01 |
| 1/83 to10/83 | 82-83 | 12.3 | 1.48 | 65.84 |
| 11/83 to 9/84 | 83-84 | 29.97 | 3.92 | 91.89 |
| 10/84 to 9/85 | 84-85 | 50.54 | 18.37 | 124.06 |
| 10/85 to 9/86 | 85-86 | 122.02 | 89.37 | 156.95 |
| 10/86 to10/87 | 86-87 | 61.06 | 126.08 | 91.93 |
| 11/87 to 9/88 | 87-88 | 101.34 | 72.52 | 120.75 |
| 10/88 to 9/89 | 88-89 | 37.98 | 56.62 | 101.48 |
| 10/89 to 9/90 | 89-90 | 67.55 | 93.75 | 75.28 |
| 10/90 to9/91 | 90-91 | 58.22 | 45.58 | 87.92 |
| 10/91 to 9/92 | 91-92 | 91.66 | 19.39 | 160.2 |
| 10/92 to 9/93 | 92-93 | 67.77 | 81.94 | 146.2 |
| 10/93 to 9/94 | 93-94 | 100.69 | 83.44 | 163.28 |
| 10/94 to 9/95 | 94-95 | 134.48 | 90.48 | 234.57 |
| 10/95 to 9/96 | 95-96 | 100.45 | 137.49 | 197.53 |
| 10/96 to 9/97 | 96-97 | 83.5 | 96.3 | 184.81 |
| 10/97 to 9/98 | 97-98 | 131.19 | 101.83 | 214.01 |

## TABLE (5.2): Performance of Dredging Plant at Balancing Reservoir of BSL Project (From November 1986 to December 1999)

| Year/Month | Effective Running Hrs (Hrs) | Volume of silt removed | | | Effective Utilisation of Dredging Plant (%) | Remarks |
|---|---|---|---|---|---|---|
| | | Original Data (Acre-feet) | Derived data in in $m^3$ | Derived data in ($m^3$/hr) | | |
| 1 | 2 | 3 | 4 | 5 | 6 | |
| Nov-86 | 148.25 | 52.43 | 64643.72 | 436.05 | 58.93 | |
| Dec-86 | 231 | 85.18 | 105020.78 | 454.64 | 61.44 | |
| Jan-87 | 288.25 | 101.37 | 124987.98 | 433.61 | 58.60 | |
| Feb-87 | 188.25 | 67.21 | 82866.23 | 440.19 | 59.49 | |
| Mar-87 | 278 | 101.39 | 125010.17 | 449.68 | 60.77 | |
| **Total** | 1133.75 | 407.57 | 502528.88 | 443.24 | 59.90 | |
| Apr-87 | 261.25 | 95.95 | 118302.65 | 452.83 | 61.19 | |
| May-87 | 263 | 94.39 | 116381.64 | 442.52 | 59.80 | |
| Jun-87 | 253 | 90.95 | 112138.88 | 443.24 | 59.90 | |
| Jul-87 | 164.75 | 61.42 | 75734.56 | 459.69 | 62.12 | |
| Aug-87 | 192 | 66.47 | 81952.58 | 426.84 | 57.68 | |
| Sep-87 | 193 | 65.76 | 81078.38 | 420.10 | 56.77 | |
| Oct-87 | 180.75 | 60.52 | 74616.23 | 412.81 | 55.79 | |
| Nov-87 | | | | | | |
| Dec-87 | | | | | | |
| Jan-88 | 129.75 | 38.81 | 47847.80 | 368.77 | 49.83 | |
| Feb-88 | 224.75 | 74.77 | 92192.64 | 410.20 | 55.43 | |
| Mar-88 | 229.5 | 79.54 | 98075.29 | 427.34 | 57.75 | |
| **Total** | 2091.75 | 728.57 | 898320.65 | 429.46 | 58.03 | |
| Apr-88 | 17.5 | 5.57 | 6869.04 | 392.52 | 53.04 | |
| May-88 | 273.25 | 91.48 | 112788.68 | 412.77 | 55.78 | |
| Jun-88 | 214 | 73.11 | 90142.16 | 421.23 | 56.92 | |
| Jul-88 | 148.25 | 50.49 | 62255.40 | 419.94 | 56.75 | |
| Aug-88 | 207.75 | 67.36 | 83052.41 | 399.77 | 54.02 | |
| Sep-88 | 141.5 | 46.11 | 56857.33 | 401.82 | 54.30 | |
| Oct-88 | 157.5 | 48.46 | 59748.71 | 379.36 | 51.26 | |
| Nov-88 | 162 | 51.60 | 63621.57 | 392.73 | 53.07 | |
| Dec-88 | 335.25 | 94.58 | 116617.14 | 347.85 | 47.01 | |
| Jan-89 | 315.75 | 83.80 | 103327.87 | 327.25 | 44.22 | |
| Feb-89 | 297.75 | 76.02 | 93727.73 | 314.79 | 42.54 | |
| Mar-89 | 317.25 | 74.34 | 91662.45 | 288.93 | 39.04 | |
| **Total** | 2587.75 | 762.91 | 940670.50 | 363.51 | 49.12 | |

*Note: Data not shown in particular months indicates the period of drydocking / mainteances of dredger plant.*

| Year/Month | Effective Running Hrs (Hrs) | Volume of silt removed | | | Effective Utilisation of Dredging Plant (%) | Remarks |
|---|---|---|---|---|---|---|
| | | Original Data (Acre-feet) | Derived data in in $m^3$ | Derived data in ($m^3$/hr) | | |
| 1 | 2 | 3 | 4 | 5 | 6 | |
| Apr-89 | 254.75 | 55.41 | 68314.37 | 268.16 | 36.24 | |
| May-89 | 296.25 | 65.60 | 80884.80 | 273.03 | 36.90 | |
| Jun-89 | 327.5 | 70.07 | 86393.84 | 263.80 | 35.65 | |
| Jul-89 | 338.25 | 72.20 | 89023.83 | 263.19 | 35.57 | |
| Aug-89 | 212.25 | 47.00 | 57951.00 | 273.03 | 36.90 | |
| Sep-89 | 191 | 42.01 | 51800.80 | 271.21 | 36.65 | |
| Oct-89 | | | | | | |
| Nov-89 | | | | | | |
| Dec-89 | 216.25 | 59.01 | 72760.56 | 336.47 | 45.47 | |
| Jan-90 | 273.75 | 79.76 | 98340.38 | 359.23 | 48.55 | |
| Feb-90 | 247 | 67.12 | 82757.73 | 335.05 | 45.28 | |
| Mar-90 | 308.5 | 76.96 | 94896.61 | 307.61 | 41.57 | |
| **Total** | 2665.5 | 635.14 | 783123.92 | 293.80 | 39.70 | |
| Apr-90 | 306.25 | 70.67 | 87141.04 | 284.54 | 38.45 | |
| May-90 | 352 | 79.30 | 97776.90 | 277.78 | 37.54 | |
| Jun-90 | 308.25 | 65.26 | 80469.28 | 261.05 | 35.28 | |
| Jul-90 | 360.75 | 74.26 | 91567.51 | 253.83 | 34.30 | |
| Aug-90 | 305.5 | 62.73 | 77339.93 | 253.16 | 34.21 | |
| Sep-90 | 154.5 | 33.74 | 41605.12 | 269.29 | 36.39 | |
| Oct-90 | 260.25 | 56.07 | 69130.61 | 265.63 | 35.90 | |
| Nov-90 | 219 | 46.06 | 56788.28 | 259.31 | 35.04 | |
| Dec-90 | 48.5 | 12.09 | 14902.04 | 307.26 | 41.52 | |
| Jan-91 | 158.75 | 37.64 | 46411.35 | 292.35 | 39.51 | |
| Feb-91 | 95.25 | 19.91 | 24552.73 | 257.77 | 34.83 | |
| Mar-91 | 151.5 | 34.28 | 42267.24 | 278.99 | 37.70 | |
| **Total** | 2720.5 | 592.01 | 729952.03 | 268.32 | 36.26 | |

| Year/Month | Effective Running Hrs (Hrs) | Volume of silt removed | | | Effective Utilisation of Dredging Plant (%) | Remarks |
|---|---|---|---|---|---|---|
| | | Original Data (Acre-feet) | Derived data in in $m^3$ | Derived data in ($m^3$/hr) | | |
| 1 | 2 | 3 | 4 | 5 | 6 | |
| Apr-91 | 126 | 25.53 | 31472.33 | 249.78 | 33.75 | |
| May-91 | 122.75 | 25.87 | 31891.55 | 259.81 | 35.11 | |
| Jun-91 | 131.5 | 27.93 | 34440.16 | 261.90 | 35.39 | |
| Jul-91 | 164.5 | 33.98 | 41898.57 | 254.70 | 34.42 | |
| Aug-91 | 126.5 | 26.51 | 32690.53 | 258.42 | 34.92 | |
| Sep-91 | 111 | 23.06 | 28432.98 | 256.15 | 34.62 | |
| Oct-91 | | | | | | |
| Nov-91 | | | | | | |
| Dec-91 | | | | | | |
| Jan-91 | | | | | | |
| Feb-91 | | | | | | |
| Mar-92 | 139.25 | 27.83 | 34311.92 | 246.41 | 33.30 | |
| **Total** | 921.5 | 190.70 | 235138.03 | 255.17 | 34.48 | |
| Apr-92 | 153 | 29.85 | 36805.05 | 240.56 | 32.51 | |
| May-92 | | | | | | |
| Jun-92 | | | | | | |
| Jul-92 | | | | | | |
| Aug-92 | 147.5 | 27.95 | 34462.35 | 233.64 | 31.57 | |
| Sep-92 | 237.75 | 46.25 | 57026.25 | 239.86 | 32.41 | |
| Oct-92 | 231.75 | 45.95 | 56650.19 | 244.45 | 33.03 | |
| Nov-92 | 259.25 | 51.81 | 63875.57 | 246.39 | 33.30 | |
| Dec-92 | 260.75 | 51.59 | 63615.40 | 243.97 | 32.97 | |
| Jan-93 | 223.75 | 46.80 | 57704.40 | 257.90 | 34.85 | |
| Feb-93 | 206 | 43.13 | 53182.99 | 258.17 | 34.89 | |
| Mar-93 | 303.5 | 67.15 | 82791.02 | 272.79 | 36.86 | |
| **Total** | 2023.25 | 410.47 | 506113.21 | 250.15 | 33.80 | |

| Year/Month | Effective Running Hrs (Hrs) | Volume of silt removed | | | Effective Utilisation of Dredging Plant (%) | Remarks |
|---|---|---|---|---|---|---|
| | | Original Data (Acre-feet) | Derived data in in $m^3$ | Derived data in ($m^3$/hr) | | |
| 1 | 2 | 3 | 4 | 5 | 6 | |
| Apr-93 | 227.25 | 46.54 | 57382.59 | 252.51 | 34.12 | |
| May-93 | 282.5 | 58.54 | 72182.29 | 255.51 | 34.53 | |
| Jun-93 | 285.75 | 59.39 | 73232.80 | 256.28 | 34.63 | |
| Jul-93 | 321 | 66.12 | 81521.03 | 253.96 | 34.32 | |
| Aug-93 | 247.5 | 52.68 | 64959.37 | 262.46 | 35.47 | |
| Sep-93 | 274.75 | 59.43 | 73273.49 | 266.69 | 36.04 | |
| Oct-93 | 279.25 | 50.65 | 62453.92 | 223.65 | 30.22 | |
| Nov-93 | 261.75 | 59.56 | 73437.48 | 280.56 | 37.91 | |
| Dec-93 | 299.5 | 70.73 | 87206.39 | 291.17 | 39.35 | |
| Jan-94 | 285 | 66.04 | 81427.32 | 285.71 | 38.61 | |
| Feb-94 | 273 | 66.63 | 82159.72 | 300.95 | 40.67 | |
| Mar-94 | 298 | 75.17 | 92685.84 | 311.03 | 42.03 | |
| **Total** | 3335.25 | 731.49 | 901922.24 | 270.42 | 36.54 | |
| Apr-94 | 298.5 | 73.64 | 90801.82 | 304.19 | 41.11 | |
| May-94 | | | | | | |
| Jun-94 | 47.5 | 11.06 | 13630.82 | 286.96 | 38.78 | |
| Jul-94 | 299.75 | 72.89 | 89867.21 | 299.81 | 40.51 | |
| Aug-94 | 252.25 | 64.09 | 79021.74 | 313.27 | 42.33 | |
| Sep-94 | 244 | 65.97 | 81344.71 | 333.38 | 45.05 | |
| Oct-94 | 244.25 | 70.95 | 87485.05 | 358.18 | 48.40 | |
| Nov-94 | 322 | 80.83 | 99659.69 | 309.50 | 41.82 | |
| Dec-94 | 344.25 | 90.63 | 111751.72 | 324.62 | 43.87 | |
| Jan-95 | 415.5 | 85.90 | 105909.77 | 254.90 | 34.45 | |
| Feb-95 | 370.25 | 80.51 | 99263.90 | 268.10 | 36.23 | |
| Mar-95 | 209.25 | 50.62 | 62408.30 | 298.25 | 40.30 | |
| Total | 2091.75 | 728.57 | 816712.07 | 390.44 | 52.76 | |
| Jul-95 | 209.75 | 60.02 | 74005.89 | 352.83 | 47.68 | |
| Aug-95 | 329.25 | 96.59 | 119094.24 | 361.71 | 48.88 | |
| Sep-95 | 396 | 117.45 | 144810.92 | 365.68 | 49.42 | |
| Oct-95 | 384.5 | 117.88 | 145343.57 | 378.01 | 51.08 | |
| Nov-95 | 397 | 121.63 | 149971.02 | 377.76 | 51.05 | |
| Dec-95 | 342.5 | 107.37 | 132385.98 | 386.53 | 52.23 | |
| Jan-96 | 418.75 | 131.93 | 162668.46 | 388.46 | 52.49 | |
| Feb-96 | 405.75 | 112.16 | 138296.98 | 340.84 | 46.06 | |
| Mar-96 | 404 | 117.80 | 145243.70 | 359.51 | 48.58 | |
| **Total** | 3287.5 | 982.82 | 1211820.76 | 368.61 | 49.81 | |

| Year/Month | Effective Running Hrs (Hrs) | Volume of silt removed | | | Effective Utilisation of Dredging Plant (%) | Remarks |
|---|---|---|---|---|---|---|
| | | Original Data (Acre-feet) | Derived data in in $m^3$ | Derived data in ($m^3$/hr) | | |
| 1 | 2 | 3 | 4 | 5 | 6 | |
| Apr-96 | 387 | 98.55 | 121507.22 | 313.97 | 42.43 | |
| May-96 | 293.5 | 76.22 | 93984.19 | 320.22 | 43.27 | |
| Jun-96 | 382.5 | 98.10 | 120952.37 | 316.22 | 42.73 | |
| Jul-96 | 440.75 | 100.09 | 123415.90 | 280.01 | 37.84 | |
| Aug-96 | 411.5 | 94.39 | 116387.80 | 282.84 | 38.22 | |
| Sep-96 | 466.5 | 114.80 | 141548.40 | 303.43 | 41.00 | |
| Oct-96 | 442 | 110.76 | 136560.92 | 308.96 | 41.75 | |
| Nov-96 | 456 | 113.04 | 139382.02 | 305.66 | 41.31 | |
| Dec-96 | 388 | 102.60 | 126500.87 | 326.03 | 44.06 | |
| Jan-97 | 343 | 93.12 | 114810.80 | 334.73 | 45.23 | |
| Feb-97 | 376 | 95.19 | 117363.11 | 312.14 | 42.18 | |
| Mar-97 | 460 | 110.49 | 136232.94 | 296.16 | 40.02 | |
| **Total** | 4846.75 | 1207.34 | 1488646.52 | 307.14 | 41.51 | |
| Apr-97 | 398 | 95.11 | 117264.47 | 294.63 | 39.82 | |
| May-97 | 424 | 91.36 | 112648.11 | 265.68 | 35.90 | |
| Jun-97 | 417.5 | 93.04 | 114718.32 | 274.77 | 37.13 | |
| Jul-97 | 387 | 80.71 | 99515.43 | 257.15 | 34.75 | |
| Aug-97 | 339.5 | 67.49 | 83215.17 | 245.11 | 33.12 | |
| Sep-97 | 411 | 91.21 | 112461.93 | 273.63 | 36.98 | |
| Oct-97 | 313 | 65.91 | 81267.03 | 259.64 | 35.09 | |
| Nov-97 | 253 | 42.45 | 52340.85 | 206.88 | 27.96 | |
| Dec-97 | 461 | 96.03 | 118404.99 | 256.84 | 34.71 | |
| Jan-98 | 443 | 95.19 | 117369.27 | 264.94 | 35.80 | |
| Feb-98 | 412 | 83.92 | 103473.36 | 251.15 | 33.94 | |
| Mar-98 | 476 | 95.96 | 118318.68 | 248.57 | 33.59 | |
| **Total** | 4735 | 998.38 | 1230997.61 | 259.98 | 35.13 | |

| Year/Month | Effective Running Hrs (Hrs) | Volume of silt removed | | | Effective Utilisation of Dredging Plant (%) | Remarks |
|---|---|---|---|---|---|---|
| | | Original Data (Acre-feet) | Derived data in in $m^3$ | Derived data in ($m^3$/hr) | | |
| 1 | 2 | 3 | 4 | 5 | 6 | |
| Apr-98 | | | | | | |
| May-98 | | | | | | |
| Jun-98 | 409 | 80.87 | 99712.71 | 243.80 | 32.95 | |
| Jul-98 | 336 | 77.57 | 95643.81 | 284.65 | 38.47 | |
| Aug-98 | 411 | 88.99 | 109724.67 | 266.97 | 36.08 | |
| Sep-98 | 467 | 99.07 | 122153.31 | 261.57 | 35.35 | |
| Oct-98 | 352 | 74.66 | 92055.78 | 261.52 | 35.34 | |
| Nov-98 | 414 | 91.06 | 112276.98 | 271.20 | 36.65 | |
| Dec-98 | 379 | 77.05 | 95002.65 | 250.67 | 33.87 | |
| Jan-99 | 480 | 90.56 | 111660.48 | 232.63 | 31.44 | |
| Feb-99 | 445 | 90.08 | 111068.64 | 249.59 | 33.73 | |
| Mar-99 | 398 | 83.54 | 103004.82 | 258.81 | 34.97 | |
| **Total** | 4091 | 853.45 | 1052303.85 | 257.22 | 34.76 | |
| Apr-99 | 404 | 88.46 | 109071.18 | 269.98 | 36.48 | |
| May-99 | 371 | 80.36 | 99083.88 | 267.07 | 36.09 | |
| Jun-99 | 289.5 | 63.70 | 78542.10 | 271.30 | 36.66 | |
| Jul-99 | 448.5 | 100.93 | 124446.69 | 277.47 | 37.50 | |
| Aug-99 | 366.5 | 86.07 | 106124.31 | 289.56 | 39.13 | |
| Sep-99 | 318.75 | 69.67 | 85903.11 | 269.50 | 36.42 | |
| Oct-99 | 312.75 | 68.36 | 84287.88 | 269.51 | 36.42 | |
| Nov-99 | 356.25 | 83.68 | 103177.44 | 289.62 | 39.14 | |
| Dec-99 | 242.25 | 56.37 | 69504.21 | 286.91 | 38.77 | |
| **Total** | 3109.5 | 697.6 | 860140.8 | 276.62 | 37.38 | |

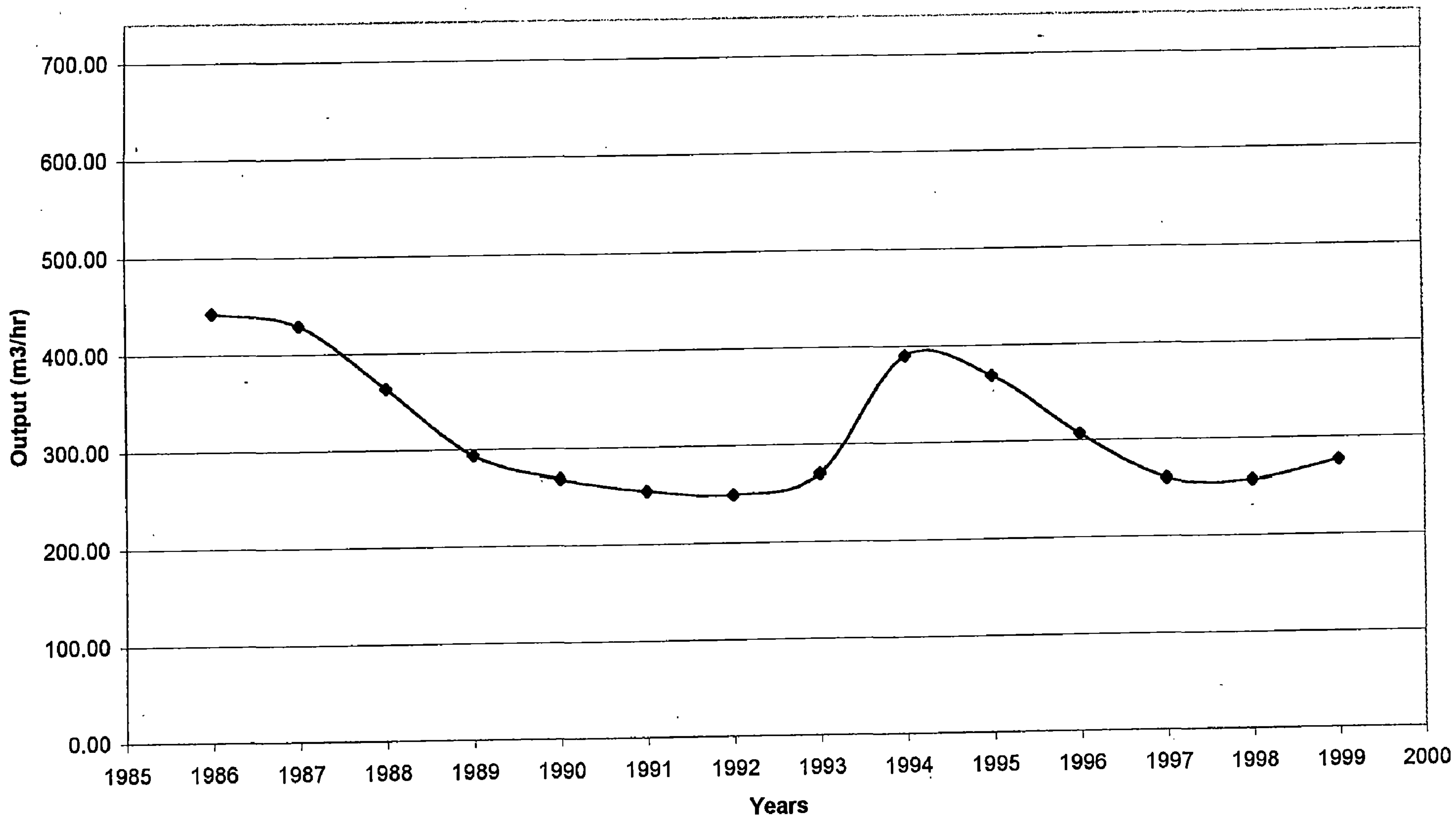


Fig.5.2: Output vs Year

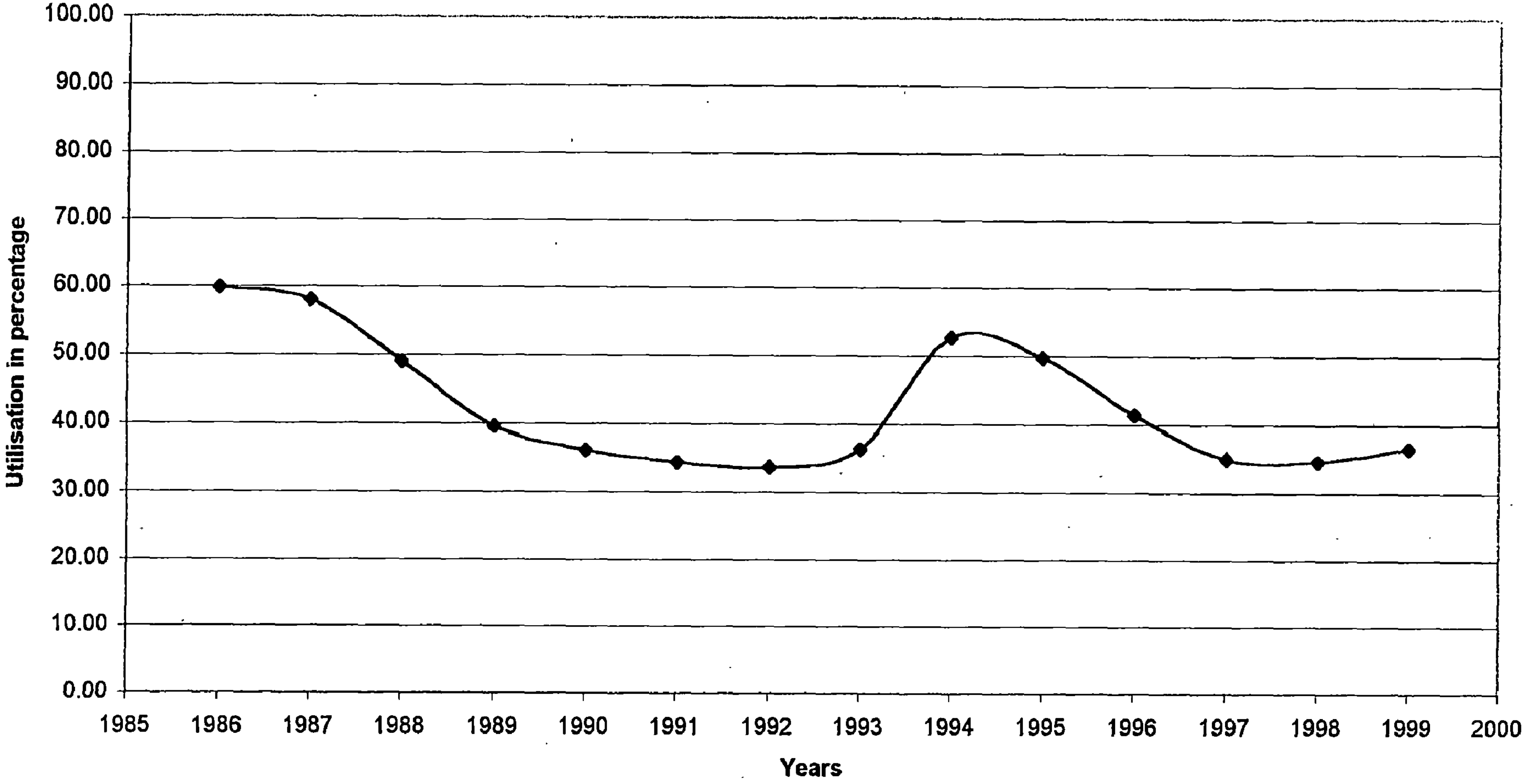


Fig.5.3: Effective Utilisation of Dredging Plant (%)

# CHAPTER – 6

# DESIGN OF NEW DREDGING SYSTEM

## 6.1 GENERAL

The design of dredging system is usually quite complex. Because we are dealing with a medium, which we cannot actually see in its in-situ condition, and also a field in which there are so many variables whose determination is not susceptible to a simple solution. There are special problems regarding

- Quantity and characteristics of the silt material
- The depth of dredging
- The location of the disposal sites and transportation of dredged material
- Environmental consideration

## 6.2 DESIGN STEPS

A step-by step design process is described below.

### 6.2.1 First Step- Data Collection

The sediments should be analyzed for chemical and physical characteristics. The presence of high concentration of a toxic organic or heavy metal may restrict the options for disposal. The grain size distribution, organic content, specific gravity, and possible consolidation characteristics can be evaluated to determine if the reservoir sediment has any market value. If the sediment has any market value, it may be possible to improve the cost-effectiveness of the system. The grain size of sediment can vary significantly in a reservoir. The production of hydraulic dredger varies being dependent upon grain size distribution. The disposal basin for hydraulic dredging should be designed so that the over flow rate does not exceed the settling velocity for sediment particles that are smaller than 95% of the sediment particles present in the dredged slurry.

### 6.2.2 Second Step – Evaluation of sediment Removal Techniques

This step usually begins after the designer has analyzed information on chemical and physical characteristics of sediment, topography, size and type of the reservoir. For example, in BSL – BR presence of a graveyard and Lindi aqueduct under the BR restrict the dredging operation.

### 6.2.3 Third Step – Disposal Sites

Solution of disposal sites, their distance and the required area is quite important for designing efficient system. It is normally done concurrently with evaluation of dredging methods. Limitations of available area, the proximity of urban or rural settlements etc. need careful consideration.

### 6.2.4 Fourth Step- Environmental Consideration

After the data collection, sediment removal techniques and sediment disposal sites have been evaluated, it is usually useful to solicit public opinion about the scheme. They shall be informed about environmental impacts and the measures envisaged in the scheme to reduce the impact.

### 6.2.5 Fifth Step – Design

The next step is the design of the dredging system. It needs an estimate of daily production of a hydraulic dredger.

## 6.3 DESIGN OF DREDGING SYSTEM FOR BSL

### 6.3.1 Size and number of Dredgers

The dredger size depends mainly on availability, job duration, type of material, exposure to the elements and capability of meeting minimum production requirements. Dredgers are usually rated as to size by the diameter of the pump discharge line, which is usually smaller than the suction pipe.

**a) Dredger capacity**

Dredger capacity for BSL has been worked out for two alternatives based on job duration and assuming that sediment entering the balancing reservoir would remain the same as is at present i.e. 1200 Ac.ft.

**Proposal – I**

Considering that dredger will work for 8 months in a year and $6\frac{1}{4}$ hours in each shift of 8 hours [ Ref. 4 & 39]

Working hours available per year for two shifts $= 8 \times 25 \times 12.5 = 2500$ hours

Scheduled production Hours available $= 2500 \times 0.8 = 2000$ hours

(With average utilization factors @ 0.80)

Quantity of silt load estimated to settle in BR. annually

$$= 1200 \times 0.1233 \times 10^4 = 1.479 \times 10^6\ m^3$$

Say 1.5 million cum/year

Silt to be handled/dredged per hour $= \dfrac{1.5 \times 10^6}{2000}$

= 750 cum. Say 800 cum.

$\therefore$ Provide one no. dredger of capacity @800 cum. of solids per hour.

**Proposal –II**

Considering seasonal operation only (i.e. during the monsoon period form mid June to mid October for 4 months)

Scheduled production Hours available = 4 x 25 x 12.5 x 0.8

=1000 hours

$\therefore$ Silt to be dredged/handled per hour $= \frac{1.5 \times 10^6}{1000}$

= 1500 cum.

Provide two number dredgers each of capacity @ 800 cum of solids per hour

**b) Depth of Dredging**

Maximum water level of BR = EL 842.47 m

Bed level of BR = El 829.0 m

$\therefore$ Maximum dredging depth = 842.47 – 829.0 = 13.47 m

Say 14 meters

**c) Dredger size**

The dredger capacity assumed is 800 cum/hr. of solids. Assuming 30% sediment concentration the dredger production can be worked out from equation as below

$$\text{Cum/Hours} = \text{GPM x Ave\% solids x } 0.227 \qquad (6.1)$$

$$\therefore \text{GPM} = \frac{Cum\,/\,HR}{\%solid \times 0.227} = \frac{800}{0.30 \times 0.227} = 11747.43$$

Say 11750 GPM

### d) Discharge line size and velocity

The velocity corresponding to the minimum pressure loss is the optimum velocity for the operation of a pipeline at constant solids concentration. It is therefore important from the point of view of operational economy to be able to calculate the critical velocity corresponding to the proposed design and conditions of operation of the pipeline. Operation at the critical velocity has the additional advantage of providing a margin above the critical deposit value thereby reducing the likelihood of deposition occurring as a result of changes in the hydraulic characteristics of the system brought about by such causes as fluctuations in the velocity of flow or in the solids feed rate. According to Durand and Condolios [Ref. 20],the critical velocity corresponding to minimum pressure drop for a two-phase mixture of constant solids concentration is given by empirical formula as [Ref. 5 & 20].

$$Vc = 3.48c^{1/3}\left[\frac{gD(s-1)}{\sqrt{(cd)}}\right]^{1/2} \text{ or } V_c = K\sqrt{D}$$

where $V_c$ = Critical velocity in ft/sec.

c = Concentration of solids delivered (by volume) =0.30

$c_d$ = drag coefficient of the solid particles for average size($d_{50}$ of 0.25mm)=0.4

g = gravitational constant =32.2 feet/sec$^2$.

D = pipe diameter in feet =20/12=1.67 feet (Assuming 20" diameter)

s = specific gravity of mixtures = (1.9-1.0)(0.30)+1= 1.27

$$\therefore \; Vc = 3.48(0.30)^{1/3}\left[\frac{32.2(1.67)(1.27-1)}{\sqrt{(0.4)}}\right]^{1/2} = 11.15 \text{ feet/sec.}$$

$$= 3.4 \text{ m/sec.}$$

"The fundamental of Hydraulic Dredging" [Ref.38] states that the percent of agiven solids transported in a slurry line, is a function of line velocity and size. The larger the line, the higher the velocity needed to carry the 30% solids used in the production calculation. Since we will be pumping medium sand and silt mixture, we can determine velocities required for optimum transport by referring to the medium sand velocity limiting curves (Fig. 6.4).

**Table: (6.1) Flow rates in GPM required to transport $d_{50}$ in various sized lines**

| Size (inches) | Velocity for optimum transport (ft/sec.) | GPM = 2.448 x V x $(d)^2$ (GPM) | Remarks |
|---|---|---|---|
| 18 | 12.00 | 9520 | Required velocity taken at assuming normal dredge efficiency of 50% |
| 20 | 12.65 | 12320 | |
| 22 | 13.25 | 15700 | |
| 24 | 13.88 | 19570 | |

Since we have calculated the required GPM = 11750 in step (i) for our production

∴ Smallest standard size line as per table (6.1) = 20 inches(500cm) at 12320 GPM

And velocity for optimum transport = 12.65 feet/sec. i.e. 3.86 m/sec.

From the typical specifications and average characteristics given in Table (6.2), size of dredger discharge line for a maximum dredging depth of 14 m is also 20" (500 mm) [Ref. 26].

**d) Ladder**

Maximum dredging depth is generally considered as about 0.7 of the ladder's length when the ladder is inclined at $45^0$ to the horizontal [Ref. 26].

$$\therefore \text{Length of ladder} = \frac{\text{maximum dredging depth}}{0.7} = \frac{14}{0.7} = 20m$$

**e) Suction Pipe**

Suction diameter depends upon the size of the pump. Usually this is accomplished by making the diameter of the suction 1.25 to 1.50 times the pump discharge diameter. Practically the suction line diameter is usually one above the discharge line to reduce the velocity to a low value, but high enough to carry the material in suspension [Ref. 26].

∴ Size of suction assumed =22" (550mm) (as size of discharge is 500mm)

**f) Cutter Ratings**

Horsepower applied to the cutter varies with the job and size of the dredger. Speed of the cutter usually varies between 10 and 30 rpm, depending upon the material being dredged and size of the cutter. Fig. (6. 2) shows following equation plotted as cutter horsepower verses cutter speed[Ref. 26]. The equation of horsepower is given as:

$$\text{HP} = \frac{(D^3)(rpm)S_s)}{321{,}000(K_t)}$$

where, D = diameter of the shaft, in inches

$K_t$ = fatigue factor (1.0 to 1.5)

$S_s$ = allowable torsional shearing stress, in psi.

### g) Hull

Flotation requirements determine both length and breadth. A dredger's length and breadth must be such that the minimum depth will meet flotation required. The American Bureau of Shipping allows a length – to depth ratio of 14 to 1 for a dredger, which is to be used outside. Using a dredging rule-of-thumb [Ref. 26].

Width of hull (W) = 3 D or $\leq$ 15 m

Length of hull (L) = 4W

Where D = Depth of hull

W = Width of the hull

### h) Anchor booms

Anchor booms are used for shifting anchors directly from the dredger. Booms may be as long as 30 m or more, and have lifting ability of 40 to 50 tons. They are most effective when dredging in soft material where ahead is important.

### 6.3.2 Dredger Pump

Pumps for dredgers must handle large solids without clogging, withstand wear, and have a low power consumption and minimum maintenance cost. Centrifugal pumps are the standard choice for modern dredgers. They are generally end-suction single- stage and flexible. Volute pumps with large clearances handle a variety of materials from silt and marl to coarser gravel and boulders. For discharge pressure under 45.5kg/cm$^2$

(650psi) their lower installed capital cost and high flow rate gives economic advantages over positive displacement pumps. The heart of the hydraulic dredging is the main centrifugal pump with its suction and discharge lines. To ensure the success of the hydraulic transport system it is necessary to select a dredge pump, which can meet the minimum production requirement. Following pump performance characteristics are required to be checked for the selection of the dredger pump [Ref. 38].

- pump duty
- minimum flow rate
- discharge line size
- discharge optimum velocity
- impeller vane width
- impeller diameter
- pump RPM
- Pump HP

### (a) Impeller Vane Width

The inside width between the shrouds of the closed impeller is an important determinant of solids handling capability. It should be 0.6 of the discharge line size.

∴ Impeller vane width = 0.6 x 20 = 12" or 300 mm

If large particles are non-existent, this dimension can be compromised to 50% or 9″, but even small particles are encumbered in their passage at higher concentration if the vane width is too narrow. On the other hand, a vane too wide reduces pump efficiency.

### b) Impeller diameter

The impeller diameter should have a minimum ratio of 2:1 and a maximum of 2.75:1 to the eye of the impeller. Since the eye is normally the size of the suction line, which is never smaller than the discharge line, we can use the discharge line size in our calculations of impeller diameter

$\therefore$ Impeller diameter = 2.75 x 20 = 55"

If size of suction line is kept 22"

Impeller diameter = 2. 75 x 22 = 60.5 say 60" or 1500 mm

### c) Pump RPM

Dredging practice is to provide for an eye speed not exceeding 12.2 m/sec. (to avoid cavitations) and a tip speed of 33.5 m /sec. (to create adequate head without excessive wear)

Using maximum eye speed of 40 ft/sec (12m/ sec).

$$\text{RPM of pump} = \frac{40 \times 229.2}{20} = 458.4 \text{ say } 458$$

Since the impeller diameter is 2.75 times the eye diameter of 500mm, the tip speed is 2.75 times the eye speed i.e. 12.2 x 2.75 = 33.5 m/ sec. (110 feet/sec) 33.5m/sec at 458 rpm.

### d) Pump HP

The book "The fundamental of hydraulic dredging" [Ref. 38]" develops a horsepower coefficient defined as:

$$C_{HP} = \frac{HP}{(d)^{2.5}}$$

where d = inside diameter of discharge line

$C_{HP}$ = Varies between 0.7 and 1.0 with an average of 0.85

$\therefore HP = 0.7 \times (20)^{2.5} = 1252$

$= 085 \times (20)^{2.5} = 1520$

$= 1.0 \times (20)^{2.5} = 1789$

∴ Pump hp shall be between 1252 to 1789hp.

Now, if we assume the total losses in the suction and discharge line as 4m/100 m [Ref.16] (a reasonable estimate for medium sand) we get

$$\frac{1500 \times 3.284 \times 4}{100} = 196.86\,feet \text{ of head say 200 ft or 60m}$$

Adding 38' (2772-2734) for terminal elevation and velocity head we can check against the HP equation

$$HP = \frac{GPM \times 8.34 \times SG \times h}{33000 \times efficiency}$$

$$HP = \frac{11750 \times 8.34 \times 1.0 \times (200+38)}{33000 \times 0.65} = 1087.31$$

Say 1088 hp, which is quite close to the above calculated value of 1252 corresponding to $C_{HP} = 0.7$.

### 6.3.3 Head Calculations [Ref. 26]

#### (a) Suction static head

Mixture specific gravity (SG) = $(SG_m - SG_w)\ \frac{P}{100} + SG_w$

where,

SG = specific gravity of mixture in terms of fresh water

$SG_m$ = specific gravity of the in-situ material in terms of fresh water = 1.9

$SG_w$ = Specific gravity of the water in the mixture, in terms of fresh water = 1

P = Percentage of the solids, by volume.

$$SG = (1.9 - 1.0)\,\frac{30}{100} + 1 = 1.27$$

Suction static head ($HS_s$) $= SG_1\,(B) - SG_2$

$SG_1$ = Sp. gravity of mixture

$SG_2$ = Sp. gravity of water in which dredge is operating.

$(H_{ss}) = 1.27\,(43) - 1.0\,(45) = 9.61$ feet

This is positive head and must be added to the following two heads to obtain the true total suction head. When '$H_{SS}$' is negative it is not a head, but a vacuum and this will contribute to the reduction of total head. However, the density and quantity of material being pumped may cause it to be positive, particularly when the pump center line is only slightly below the water line.

**(b) Suction velocity head ($H_{sv}$)**

$$\left(H_{sv}\right) = SG\,\frac{V^2}{2g} = \frac{1.27\ (12.65)^2}{2 \times 32.2} = 3.16 \text{ feet}$$

**(c) Suction friction head ($H_{sf}$)**

$$H_{sf} = \frac{SG(f)\,(L)\,(V^{1.75})}{(d)\,(2g)}$$

where, L = equivalent length of suction line in feet = 120 feet

$$H_{sf} = \frac{1.27\,(0.028)\,(120)\,(12.65)^{1.75}}{(1.83)\,(64.4)} = 3.07 \text{ feet}$$

**(d) Suction entrance head ($H_e$)**

$$H_e = (SG)\,(0.25)\,\frac{V^2}{2g}$$

$$= \frac{1.27\,(0.25)\,(12.65)^2}{64.4}$$

$= 0.79$ feet

**(e) Suction total head ($H_{st}$)**

$$(H_{st}) = (H_{ss}) + (H_{sv}) + (H_{sf}) + (H_e)$$
$$= 9.61 + 3.16 + 3.07 + 0.79$$
$$= 16.63 \text{ feet of fresh water}$$
$$= \frac{16.63}{1.133} = 14.68 \text{ inches of vacuum.}$$

**(f) Discharge static head ($H_{ds}$)**

The discharge end is 38 feet (2772 – 2734 = 38 feet) above the centerline of the pump. The discharge static head

$$(H_{ds}) = (38)\,(1.27) = 48.26 \text{ feet.}$$

**(g) Discharge velocity head ($H_{dv}$)**

The amount of mixture entering the suction must equal the amount leaving the discharge. Therefore, the velocity in the 20" discharge pipe is increased inversely as the square of the diameters of the suction and discharge pipes.

$$V_d = 12.65\,\frac{(D_2)^2}{(D_d)^2} = 12.65\,\frac{(22)^2}{(20)^2} = 15.30 \text{ feet/sec}$$

And then

$$(H_{dv}) = 1.27\left(\frac{V_d^2 - V_s^2}{2g}\right)$$

$$= 1.27\left(\frac{(15.30)^2 - (12.65)^2}{2\times 32.2}\right)$$

$= 1.46$ feet.

**(h) Discharge friction head ($H_{df}$)**

Taking in to consideration the dimensions of balancing reservoir (2130 x 450m) at BSL project, the length of pipe line assumed as 1500 meter (including 400 m floating line)

The equivalent line length

| | |
|---|---|
| Pipe on dredge | = 60 feet |
| Floating line | = (400 x 3.28 x 1.5) = 1969 feet |
| Shore line | = (1100 x 3.28 x 1.1) = 3970 feet |
| Two 90° elbows | = 120 feet |
| Flap valve | = 10 feet |

Total equivalent length = 6069 feet.

$$(H_{df}) = SG\ (f) = \frac{(L)V^{1.75}}{(d)(2g)}$$

$$= \frac{(1.27)\,(0.028)\,(6069)\,(15.30)^{1.75}}{(1.67)\,(64.4)}$$

$$= 237.51 \text{ feet}$$

**(i) Discharge total head ($H_{dt}$)**

$$(H_{dt}) = (H_{ds}) + (H_{dv}) + (H_{df})$$

$$= 48.26 + 1.46 + 237.51$$

$$= 287.23 \qquad \text{Say 288 feet or 88 m}$$

Reading on the pressure gauge at the discharge of the pump = 288 x 0.434 =125 psi or 8.8kg/cm$^2$.

### (j) Total dynamic head ($H_t$)

$H_t = (H_{st}) + (H_{dt})$

$= 16.63 + 288$

$= 304.63$, Say 305 feet of fresh water head.

That is it would take a head of 88 m of fresh water to push the material through 1500m of 550mm(22") diameter suction and 500mm(20") diameter of discharge pipe with a discharge elevation of 11.60m (38') and at a velocity of 4.66 m/sec. (15.30 feet per second).

### 6.3.4 Dredger Output

$Q = 352.51\ (d)^2(V)$

where, Q = flow in gallons per minute

d = inside diameter of discharge pipe in feet

V = velocity of flow in feet/sec. or

Cubic meter/hour = Q x Ave. % of solids x 0.227

**Table: (6.3) Dredger Output**

| Pipe size of dredge (Inch) | Output in cubic meter per hour | | | | |
|---|---|---|---|---|---|
| | At 10% solids | At 15% solids | At 20% solids | At 25% solids | At 30% solids |
| 16 | 217.65 | 326.48 | 425.30 | 544.13 | 652.96 |
| 18 | 275.47 | 413.21 | 550.94 | 686.68 | 826,40 |
| ***20*** | ***340.08*** | ***510.12*** | ***680.17*** | ***850.20*** | ***1020.25*** |
| 22 | 411.50 | 617.25 | 823.0 | 1028.75 | 1234.50 |
| 24 | 489.72 | 734.58 | 979.44 | 1224.30 | 1469.16 |
| 28 | 666.56 | 999.84 | 1333.84 | 1666.40 | 1999. 69 |

So pipe size of dredger 20" was adopted, which will meet the required production rate @ 800 m3/hr. at 25 to 30% of solid concentration.

### 6.3.5 Water Horsepower (WHP)

$$\text{WHP} = \frac{SG(Q)(Ht)}{3960}$$

$$Q = 352.51(d)^2V$$

$$= 352.5 \text{ x} \left(\frac{20}{12}\right)^2 x15.30$$

$$= 14981.675 \text{ Say } 15000 \text{ GPM}$$

$$\text{WHP} = \frac{1.27 \text{ x } 15000 \text{ x } 305}{3960} = 1467 \text{ , Say } 1500 \text{ hp.}$$

### 6.3.6 Brake Horse Power (BHP)

$$\text{BHP} = \frac{WHP}{E}$$

$$E = 0.60 \text{ (assumed)}$$

$$\text{BHP} = \frac{1467}{0.6} = 2445 \text{ hp}$$

### 6.3.7 Summary of Principal Particulars of Dredging System

The detail of dredger hydraulic system are shown in Fig. (6.3) and summary of principal particulars are:

| | |
|---|---|
| (i) Maximum dredging depth | = 14m |
| (ii) Size of dredger | = 500 mm |
| (iii) Diameter of Suction Pipe | = 550 mm |
| (iv) Diameter of Discharge Pipe | = 500 mm |

**(v)** Size of Dredger Pump = 500 mm

**(vi)** Impeller vane width = 305 mm

**(vii)** Impeller Diameter = 1524 mm

**(viii)** R.P.M. of Pump = 458 r.p.m.

**(ix)** H.P. of Dredger Pump = 1500 hp.

**(x)** Optimum velocity in Suction Pipe = 3.86 m/sec. (12.65ft/sec.)

**(xi)** Optimum velocity in Discharge Pipe = 4.66 m/sec. (15.30ft/sec.)

**(xii)** Total Dynamic Head = 88m (305 feet of fresh water)

**(xiii)** Length of Discharge Pipeline =1500m* (1100m on shore and 400m floating)

* Length of discharge pipeline taken at output of @ $800m^3$/hour.

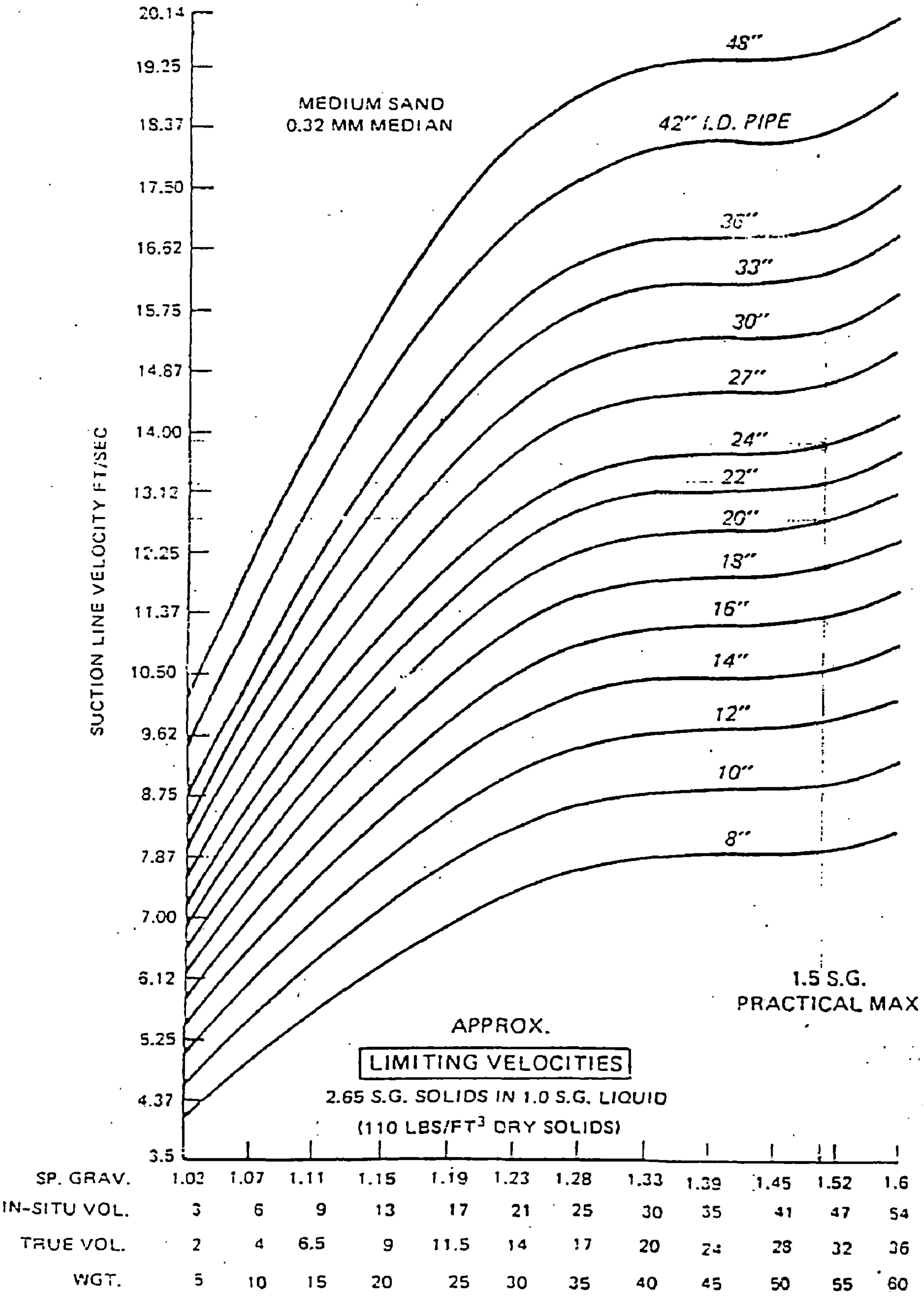


Fig. 6.1 Limiting Velocity Curves [Ref. 38]

Table 6.2 Typical Specifications for Five Sizes of Dredges

| Item | Size of Dredge, in inches | | | | |
|---|---|---|---|---|---|
| | 12 | 16 | 20 | 24 | 28 |
| Length, in feet | 100 | 120 | 140 | 160 | 175 |
| Beam, in feet | 35 | 40 | 45 | 50 | 50 |
| Depth, in feet | 8 | 9 | 10 | 12 | 15 |
| Displacement, in tons | 560 | 840 | 1200 | 1850 | 3000 |
| Pump Power, in brake horsepower | 570 | 1000 | 1500 | 2700 | 5000 |
| Pump Speed, in revolutions per minute | 500 | 400 | 350 | 325 | 300 |
| Cutter Power, in brake horsepower | 150 | 200 | 400 | 750 | 1000 |
| Cutter Speed, in revolutions per minute | 5-30 | 5-30 | 5-30 | 5-30 | 5-30 |
| Spud Length, in feet | 55 | 60 | 70 | 90 | 100 |
| Ladder Length, in feet | 50 | 55 | 60 | 70 | 80 |
| Maximum Pipe Line, in feet | 2,500 | 4,000 | 5,000 | 7,000 | 9,000 |
| Maximum Width of Cut, in feet | 160 | 200 | 220 | 270 | 325 |
| Minimum Width of Cut, in feet | 50 | 60 | 70 | 90 | 90 |
| Maximum Digging Depth, in feet | 35 | 40 | 45 | 50 | 60 |
| Minimum Digging Depth, in feet | 4 | 5 | 6 | 8 | 12 |

Typical Specifications for Dredgers

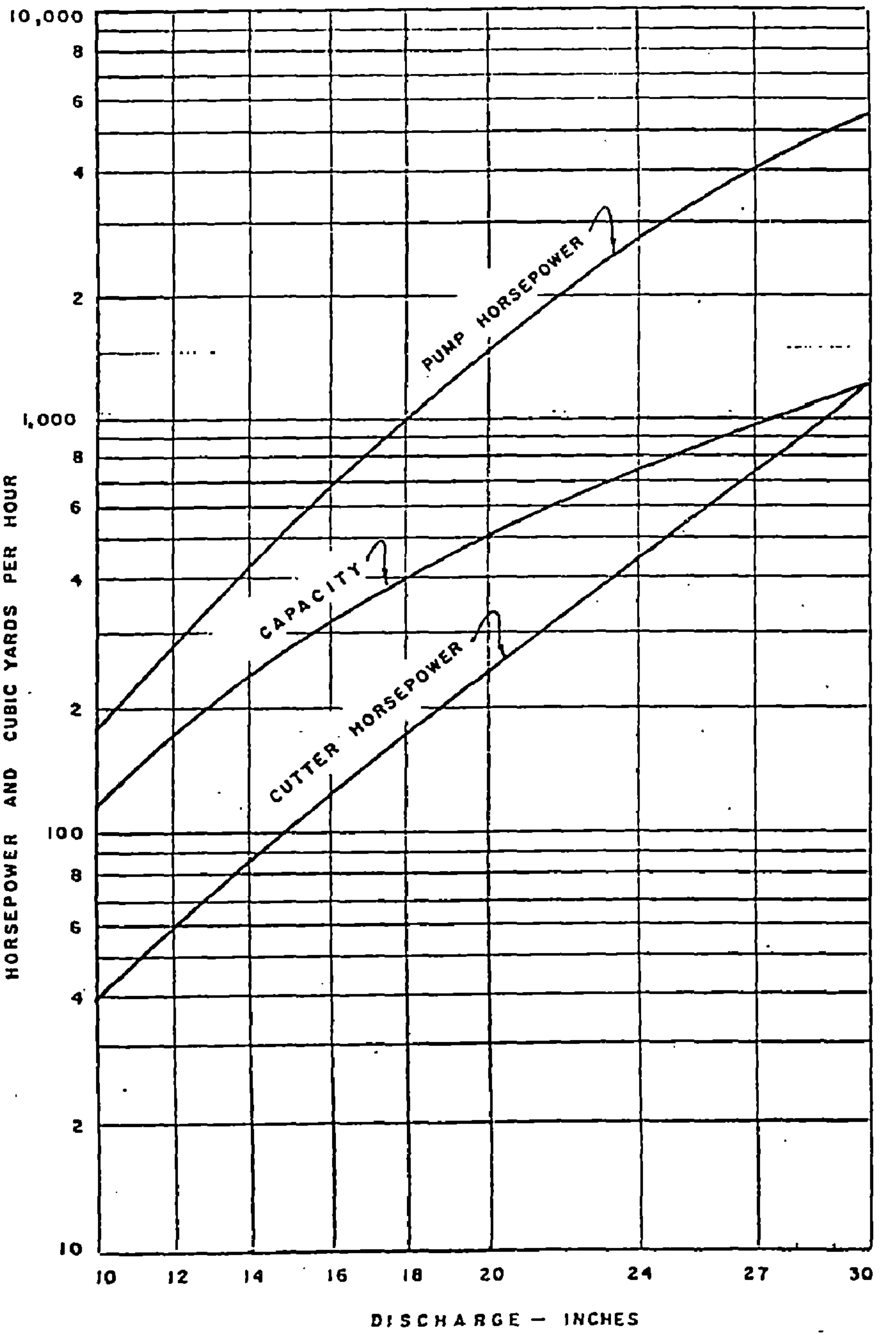


Fig. 6.2 Specification and Average characteristics of Pipeline Dredger [Ref. 26]

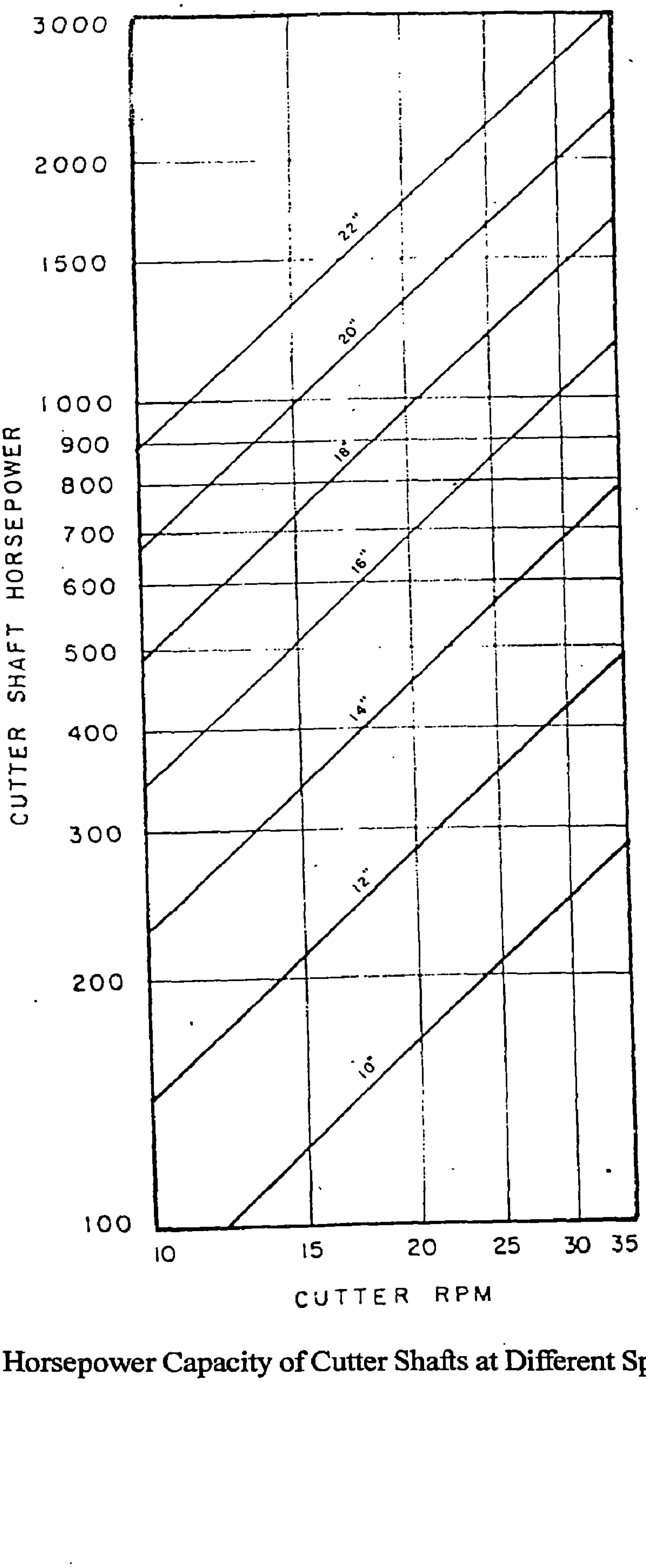


Fig. 6.3 Horsepower Capacity of Cutter Shafts at Different Speeds.[Ref. 26]

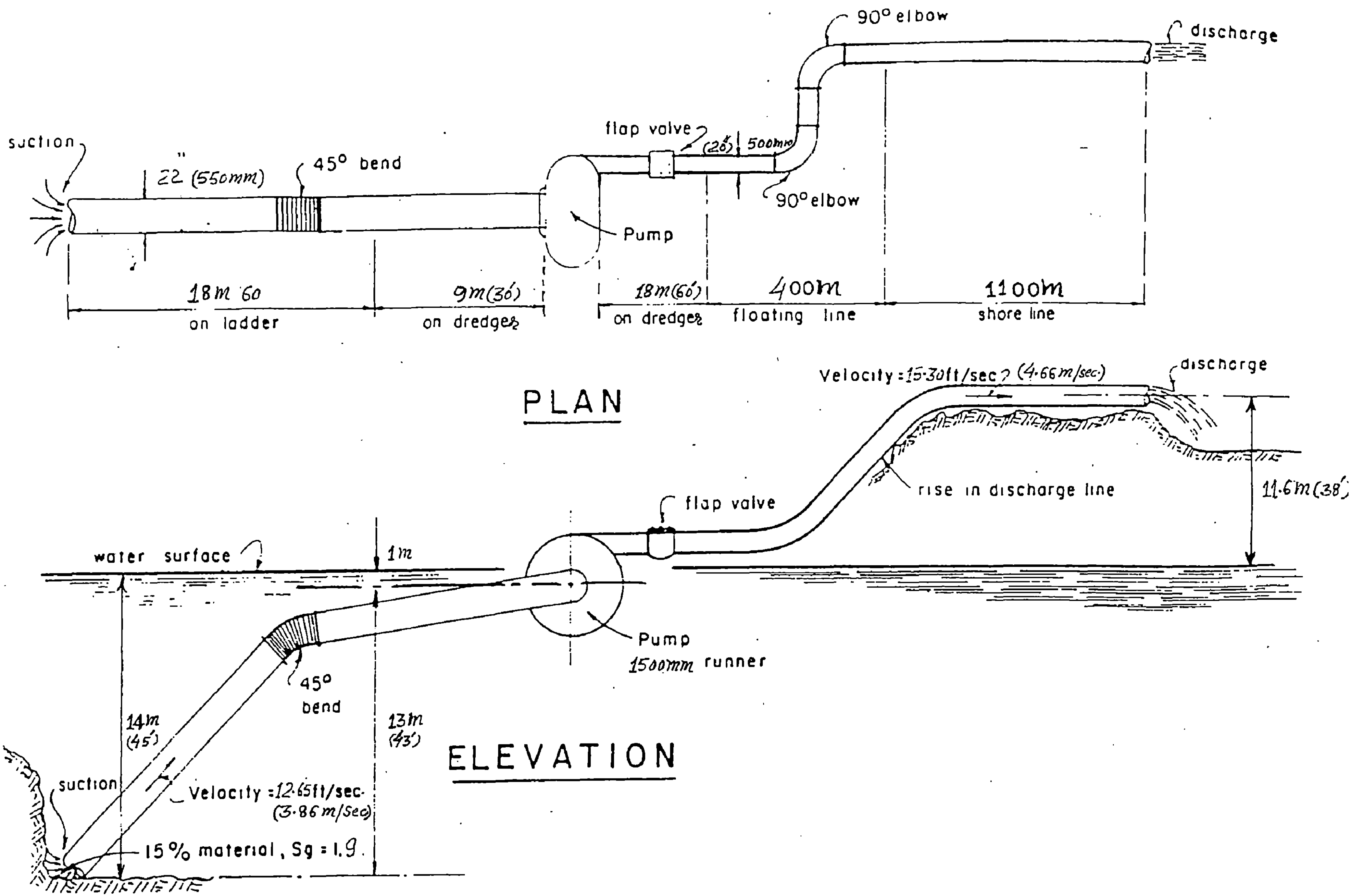


Fig. 6.4 Dredger Hydraulic System

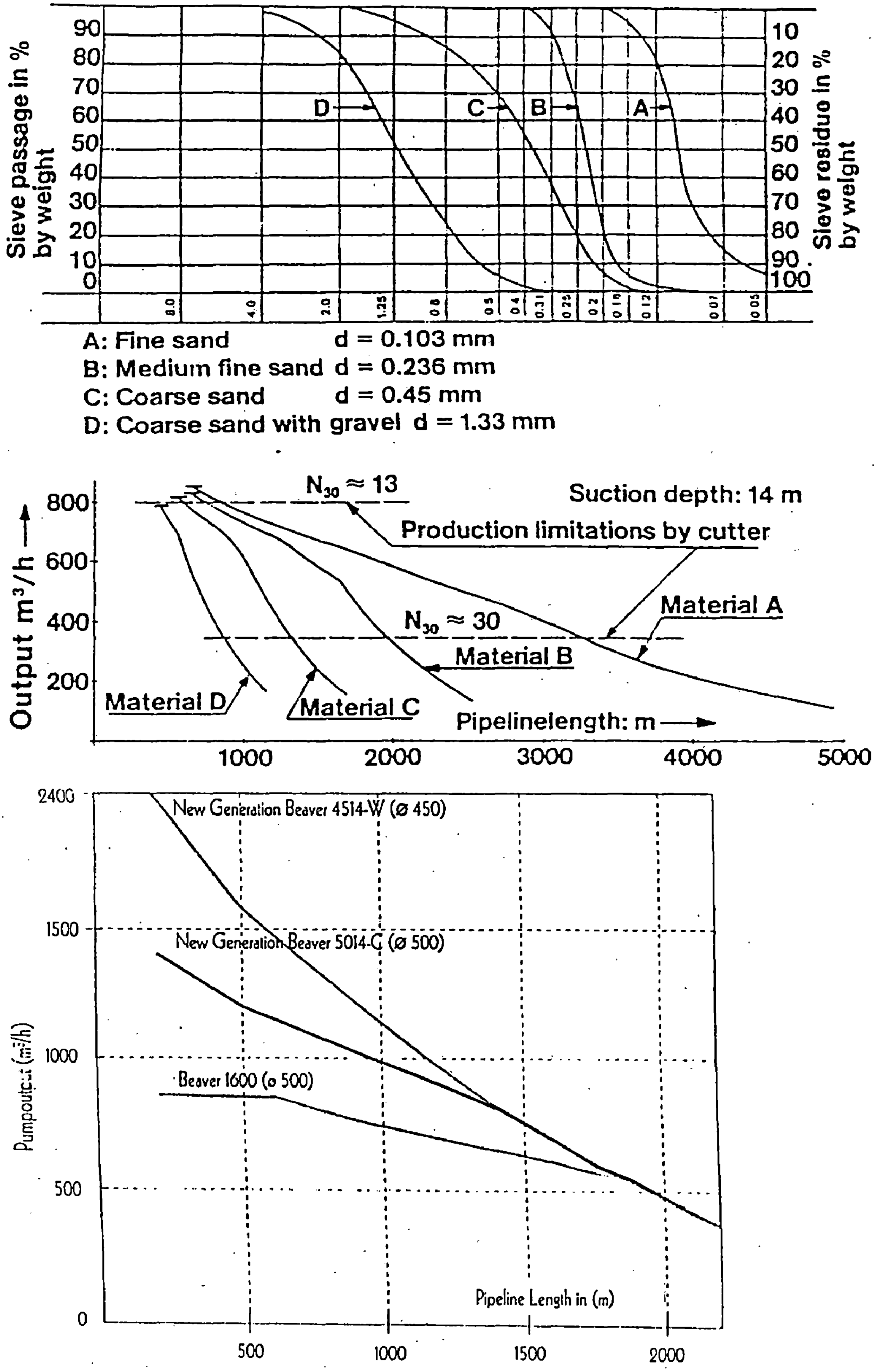


Fig. 6.5' Production Curves of Dredgers

(Output in different materials as function of Discharge Length)

# CHAPTER-7

# DISPOSAL SYSTEM FOR DREDGED MATERIAL

## 7.1 GENERAL

Planning for long-term dredged material disposal is a challenging task because of adverse environmental impact. To secure large disposal areas is becoming increasingly more difficult. Therefore, a detailed study is needed for the dredging material disposal problem and to develop the methodologies required for long-term planning and management. Regarding the long-term solution, the general criteria, which should be followed, is as below.

i) It must be technically feasible to construct,

ii) It must be operationally efficient and practical,

iii) It must be reasonably cost-effective and,

iv) It must be environmentally sound.

## 7.2 MANAGEMENT STRATEGY

The selection of a disposal management strategy must consider the nature of the sediment to be dredged, potential environmental impacts of the disposal of the dredged material considering nature and degree of contamination (if any), dredging equipment, project size, site-sediment conditions, technical feasibility, economics, and other socioeconomic factors. Flow diagram for comprehensive dredged material disposal plan and the major disposal alternatives and management strategy flow chart are shown in Fig. (7.1) [Ref. 31].

The usual disposal systems are:

a). Open-water disposal

b). Confined disposal

c). Open-water disposal with restrictions

d). Confined disposal with restrictions.

Disposal alternatives with restrictions are used whenever results of testing samples indicate possibility of contamination. If available information indicates that contaminants are not present above background levels, restrictions are not required. In that case any disposal alternative may be selected though the possibility of other environmental effects such as turbidity, salinity, suspended solids, temperature changes, and low dissolved oxygen concentrations must be considered in the final selection. Three disposal alternatives are possible for uncontaminated or so-called clean sediments

- Open water
- Confined
- Productive uses which include marsh or wetland developmental and other beneficial uses.

Open-water disposal alternative involves conventional open-water disposal techniques. This alternative would be selected for the initial evaluation and tested for restrictions indicated that water column and benthic effects are acceptable.

## 7.3 PROPOSAL FOR DISPOSAL SYSTEM AT BSL

We consider two situations. In first case no change in present mode of operation of Pandoh reservoir for reducing sediment entry into PBT is feasible. In such a situation an average of 1.5 million cubic meter (1200 Ac ft) of sediment will be depositing every year during monsoon in the BR. This quantity shall be flushed down the Suketi khad during monsoon. It shall therefore be dredged out in 120 monsoon-days so that dredged material may be disposed of into Suketi khad when it has enough flow. To accomplish this task, two dredgers each of capacity 800 m3/hr of solids will be required. These two together will work two shifts a day. The existing dredger may serve as a standby. Each dredger pipe will be discharging about 27 cusecs of slurry (sediment + water) with 30% sediment concentration. This will, however, need a flow of around 5000 to 6000 cusecs[Ref40] in the Suketi khad to carry this sediment to river Beas. Another situation may be that Suketi khad flow is not adequate and so it is not used as the carrier for the silt-laden discharge from the dredgers. It means that independent carrier system shall be developed to carry the dredged material to river Beas or alternatively to river Sutlej either by mechanical transport or by hydraulic transport. From the economics point of view (detailed analysis attached as Appendix-8.1), mechanical transport is neither economical nor environmentally acceptable.

In view of the above an alternative of pipeline hydraulic transport is examined in this study for the disposal of dredged material from the BR of BSL Project. Pipelines have been widely used for the hydraulic transport of solid-liquid mixture since the invention of the centrifugal pump. Wasp, Thompson, and Aude (1970) have given a summary (Table 7.1) of the main features of selected commercial slurry pipelines. The so-called Black Mesa line in Arizona is the largest slurry pipeline ever constructed and is designed for the transport of some 6.0 million tons of coal per year from the Black Mesa coalfield of Arizona to Mohave in Nevada[Ref. 5 & 20].

Advantages of pipelines hydraulic transport.

(i) A pipeline can be installed more cheaply than a road or railway *track* and is cheaper to maintain.

(ii) Way leaves for a buried pipeline are more easily obtained than those for roads or railways.

(iii) The operation of a pipeline – particularly a buried pipeline- is not affected by weather conditions.

(iv) As the capital element constitutes a large proportion of the cost of Hydraulic transport, inflationary influences have a relatively small effect on transport costs.

In the dredger pump-pipe system, the fluid flow, whether it be fresh water or a mixture of water and material, will be a turbulent flow because of the high velocities. When the Reynolds number is greater than 3000 the flow is said to be turbulent. Turbulent flow is an irregular motion and has three-velocity components -one parallel to the main stream and two others, which vary in their direction.

### 7.3.1 Pipe Line Disposal To River Beas

The length of the pipeline will, approximately, be 25 Kms. A total drop of about 90 m (300 ft) is available from the BR to the outfall in river Beas near Mandi. To lay a pipe at a uniform slope of about 1/250 (300 ft/25km) is not practicable, as it will need supports of 10 to 15 m height as shown in Fig.7.2 1(L-section of the khad). Another alternative is shown on the L-section in which a pipeline can be laid along the khad slope in the first nine kms. at a slope of 1/150 and beyond that it may be laid in a cut and cover portion at a slope of 1/400 (8 ft/km).

The pipeline may be made to run free or full (under pressure). If the pipeline (made of steel) is made to run free then a velocity of 1.8 m/sec (in 0.75 m diameter pipe with depth of flow equal to 3/4th of diameter and carrying 25 cusecs of flow) will be generated (assuming Manning's f = .01). Taking the results of the prototype experiments carried out with a cunette laid at a slope of 1/600 by Beas and Bhakra Design Organization, Nangal and IPRI, Amritsar as the base, we can assume that a free flow pipe line will not be adequate for carrying high sediment concentration (25 to 30%) flow of the dredger containing coarse sand.

The pipeline shall thus be made to run under pressure. Such a pipeline may be laid along the banks of the khad. Computations show that a pipeline of 50 cms (20 inches) diameter carrying 27 cusecs of discharge will generate 3.77 m/sec velocity. A limiting velocity of 4.67 m/sec for this diameter of the pipe and 30% concentration of sediment of mean size 0.25 mm is required. The pipe diameter may have to be slightly increased. There will be considerable head loss in the pipe of length 25-km due to friction. There are a large number of empirical relations to work out the friction losses[Ref 27]. The thumb rule [ Ref. 38] is to assume a total pressure drops of 4 ft/100 ft length of dredger pipe. According to the formula given by Huston in his book Hydraulic Dredging[Ref. 27] the head loss works out as high as 39 m/km. In this case we assume that there will be a minimum head loss of 975 m over 25 km length. The total drop available is about 100 m only. Therefore internal type booster pumps will be required for a head of 875 m i.e. 88 kg/cm$^2$ These booster pumps (of similar specification as dredger pump) shall be provided in stages at regular intervals along the length depending on the horsepower of the pumps. Nine pumps each capable of boosting pressures equivalent to

80 -90 m of water head would be suitable for this purpose. These shall be electrically driven. Boosting in stages will keep a uniform pressure in the pipeline in the entire length. As the sediment concentration in dredger discharge of 27 cusecs (0.74 cumecs) is taken as 30% (to keep rate of abrasion of pipe low) then one dredger of 800m3/hr capacity of solid will have to work for 200 days with 12 hours a day to dredger 1200 Ac ft (150 ha.m.) of sediment from BR. This will result in deposition of sediment on the bank of river Beas near Mandi town in the non-monsoon period. It may be objectionable from environmental consideration. Therefore, it is proposed that the system shall consist of two dredgers in the BR and two pipe lines as the carriers so that major portion of sediment may be dredged and disposed off in the river Beas during monsoon period and the system may be properly maintained and repaired during the non monsoon months.

In this proposal a strip of land about 6m wide in the entire length of 25 km will be required to be acquired which may be difficult, besides being costly. If we take the average cost of land as Rs. 50, 000 per bigha (1 bigha = 800 sq. m.) the land cost will be around Rs. 1.0 crores. The cost of two pipe lines of 0.5m dia. and 10 mm thickness and 25 km length at a rate of steel plates & fabrication of Rs. 50000/- per tonne plus 15% of the cost for carriage and erection works out as Rs. 16 crores. Assuming supports 4-m high, 0.5 m wide and 3 m long spaced at 10 m, the cost of support work out as Rs. 10.0 crores including anchors, bends and joints. The cost of booster pumps motors and other accessories will be roughly Rs. 3.5 crores. Total cost excluding cost of Dredgers will be about Rs. 30 crores. The yearly O & M cost including replacement of pipes may be taken as 10% of cost of pipe, which will be Rs. 1.6 crores.

### 7.3.2 Pipe Line Disposal To River Sutlej

The sediment from BR may be carried to river Sutlej. From BR the dredger outflow may be carried through a pipe line laid along the road or tunnel of about 2 to 3 km length crossing the river can be dropped into Alsad Khad which meets river Sutlej downstream of Dehar power house tail race channel outfall. Alsad khad (Refer Fig. 7.3) has much steeper slopes (360 m in 12 Km i.e. 1/30) than Suketi khad and carry the dredged outflow. It will need boosting at the start to cross the ridge. But the apprehension, that after some time, like Suketi khad, the villagers who have settled and have their fields along the banks of Alsad khad may also agitate for the environmental degradation due to sand deposits in certain river reaches along the khad banks, needs careful assessment and environmental consideration. In order to avoid such a situation the alternative may be to put the flow in a pipeline running along the left bank of the Alsad khad between the NH21 and the bank but above the high flood level of the khad. It will have a bed slope of 1/35 (same as of natural khad). Since the available drop in this Nala is more than 300 m the pipeline system along the khad may function with nominal boosting arrangement (one at the start and two in between). The pipes may be laid at a uniform slope along the Alsad khad on the bank above high flood level. For laying the pipeline pedestals and anchors will also be required. The cost may be approximated on the basis of Suketi khad proposal (Rs. 1.0 crores/km) as Rs. 12 crores plus Rs. 1.0 crores for boosters and land etc. The proposal of carrying the sediment from BR to river Sutlej through a pipeline along the khad on the left bank above HFL is tech-economically feasible. In this proposal however, the sediment, which will be about 1.5 million cum/yr., will be dropped in river Sutlej. It will reduce the capacity of Bhakra reservoir by this amount. This can, however, be compensated by extra power generation due to additional discharge coming along with sediment. This proposal is therefore economically feasible and need careful consideration.

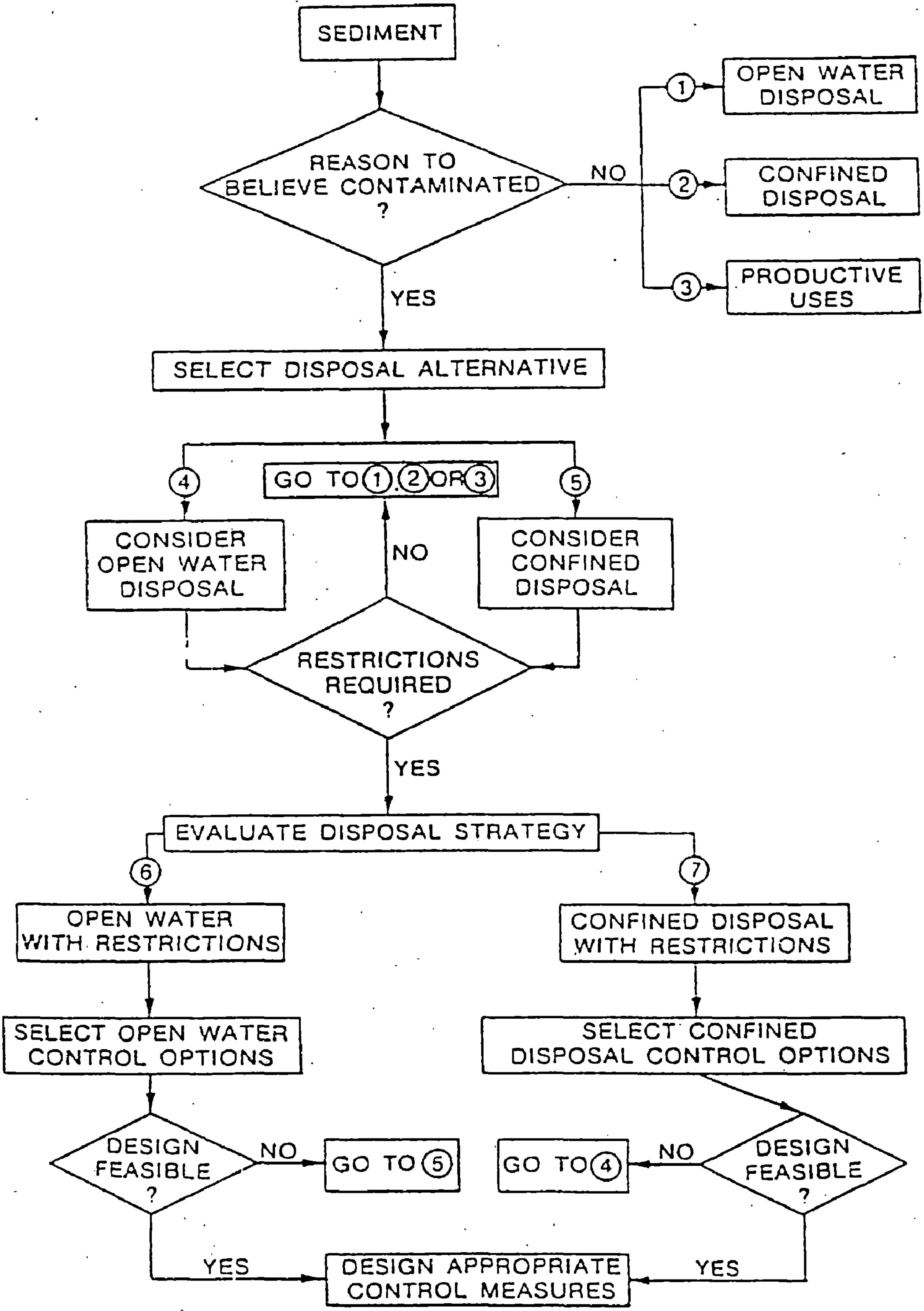


Fig. 7.1 Management Strategy flow chart for Disposal Alternatives

Table 7.1 Summary of Selected Commercial Slurry Pipelines [Ref. 23]

| Location | Material | Length, (miles) | Diameter ( inches) | Million Tons/Year |
|---|---|---|---|---|
| Ohio | Coal | 108 | 10 | 1.25 |
| Utah | Gilsonite | 72 | 6 | 0.38 |
| England | Limestone | 57 | 10 | 1.70 |
| Colombia | Limestone | 9 | 5 | 0.35 |
| Trinidad | Limestone | 6 | 8 | 0.57 |
| California | Limestone | 17 | 7 | 2.0 |
| South Africa | Gold tailings | 22 | 6&9 | 1.05 |
| Tasmania | Iron concentrates | 53 | 9 | 2.25 |
| Arizona | Coal | 273 | 18 | 6.0 |
| Japan | Copper tailings | 40 | 8 | 1.0 |
| Canada | Sulfur/hydrocarbon | 800 | 12-16 | - |
| New Guinea | Copper concentrates | 17 | 6 | 1.0 |
| Africa | Phosphate | 3 | 12 | 5.0 |

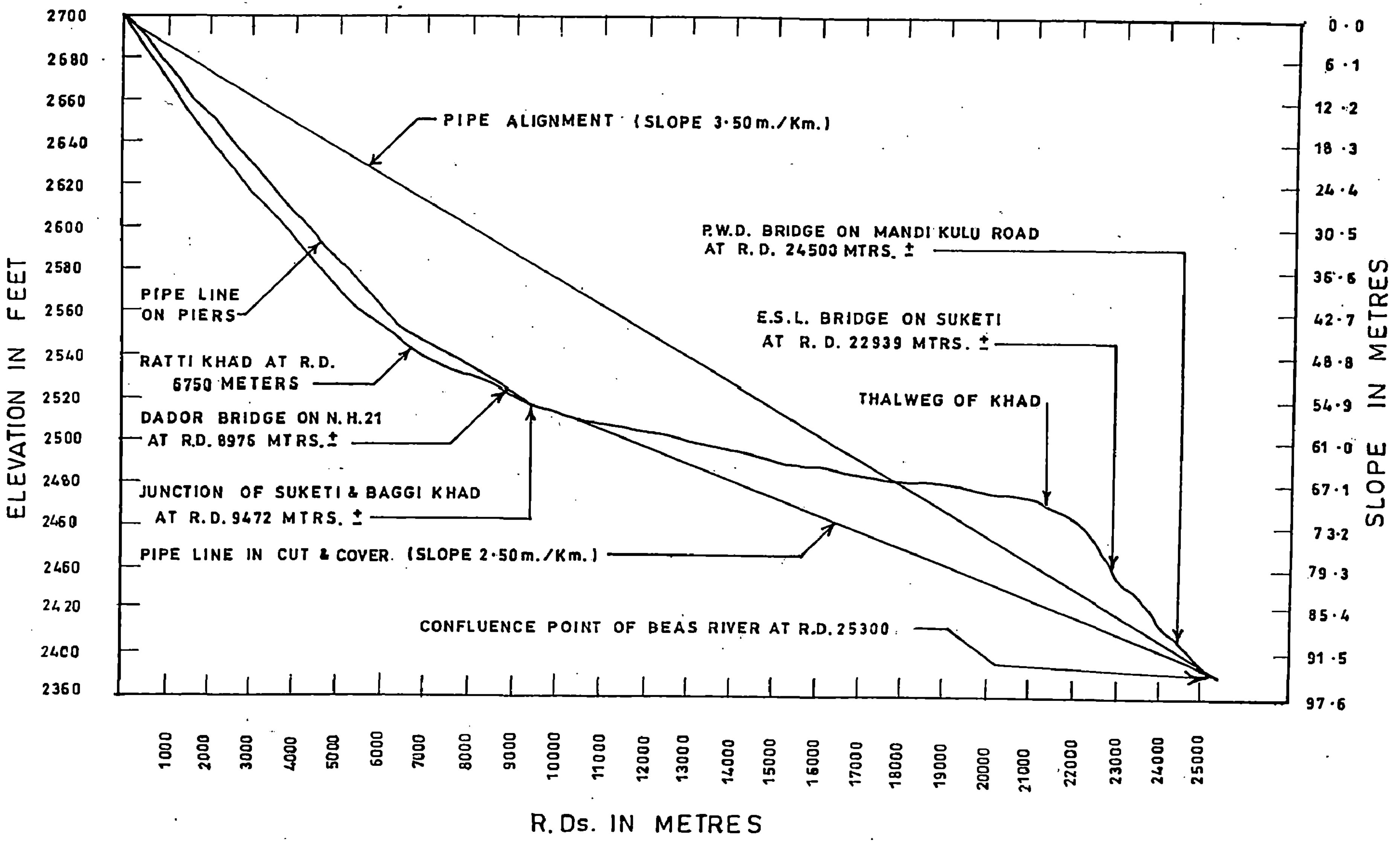


FIG. 7·2: L-SECTION OF SUKETI KHAD

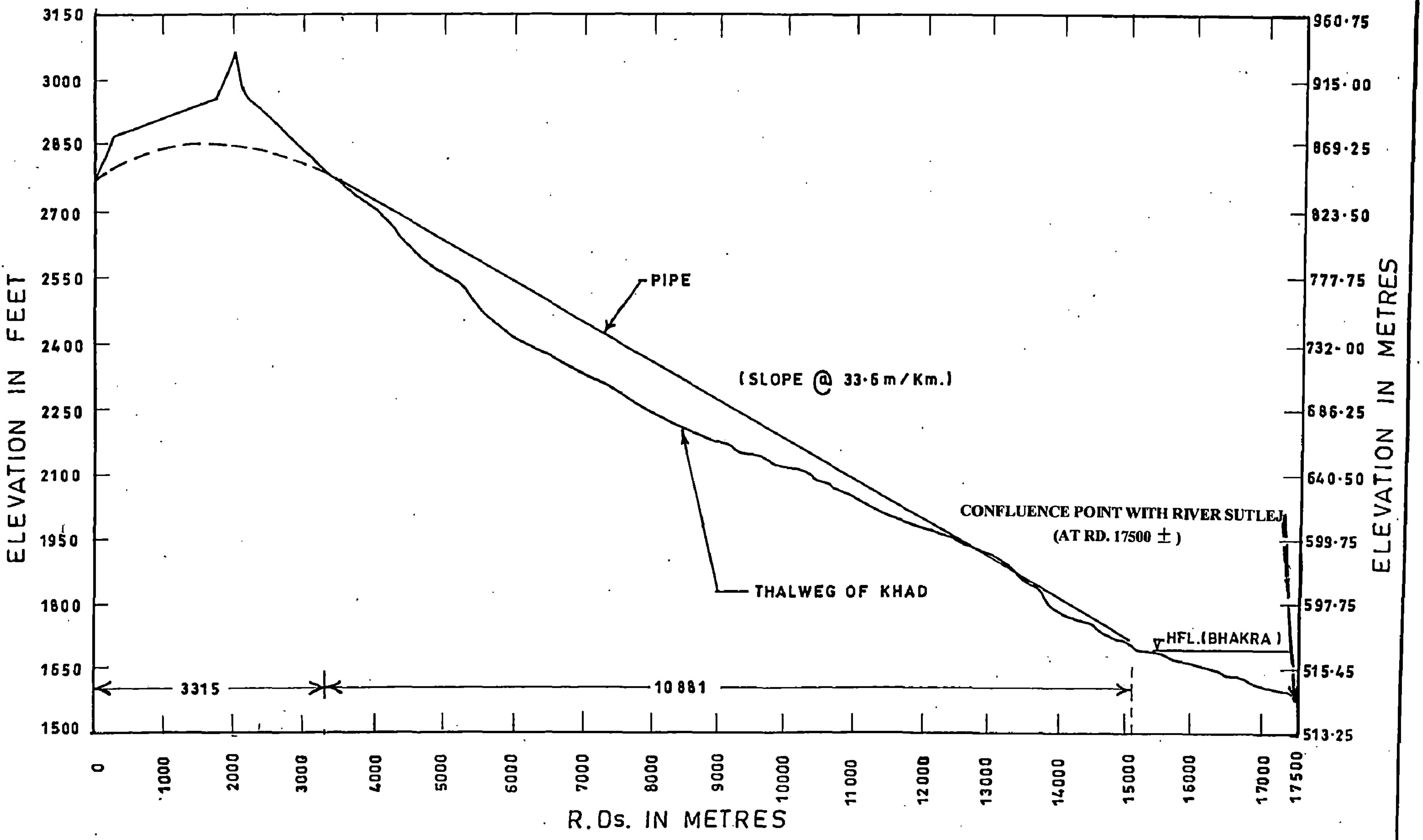


FIG. 7·3: L-SECTION OF ALSED KHAD

# CHAPTER - 8

# ECONOMICS OF DREDGING AND DISPOSAL ALTERNATIVES

## 8.1 GENERAL

All engineering or industrial operations depend on cost effectiveness, dredging is no exception to this fact. Efficient dredging is also a process of moving a unit of material at the lowest over- all cost. When considering dredging estimates the valuation of the plant to be employed forms one of the first items in the costing. Dredging machinery requires frequent replacement. So depreciation and replacement is a consideration. This replacement may be of a progressive nature and the new dredger may be functionally improved but more expensive type. The approximate estimates of dredging process including mechanical and hydraulic disposal systems to both river Beas and Sutlej have been made in this chapter in order to assess the cost-effectiveness of a dredging and disposal system.

## 8.2 COSTING OF DREDGING SYSTEMS

Although it is not practicable to develop a costing system that will be applicable to all dredging operation, the procedures presented here are from acceptable norms. The cost of plant is basically the cost of ownership plus the cost of operation [Ref .13 & 26].

### 8.2.1 Ownership Costs

The ownership cost includes fixed costs-such as delivery price, interest, insurance, depreciation

(a) Delivery Cost

The delivery price is the price that paid for equipment plus freight charges. Freight charges are usually based upon weight and transportation distance and consequently may vary considerably, depending upon the destination of the equipment.

$$\text{Freight charge} = \text{The rate of transport} \times \frac{\text{Weight of equipment}}{100}$$

(b) Average Investment Cost

The average investment price 52.5% of the delivery price, when a depreciation period of 20 years is used. Generally, 20 years is the most applicable period for dredger depreciation.

(c) Interest, Taxes And Insurance

These costs are generally considered equal to 15% (7% as interest, 4% for taxes and 4% for insurances) of the average investment.

(d) Depreciation

This cost is obtained by dividing the delivered price by the number of years used.

### 8.2.2 Repairs And Labour Cost

Empirical methods for average working conditions, the cost of repairs and labour per year is often considered as equal to the total delivered price multiplied by 15%. The two can be evenly divided into 7.5% for repairs and 7.5% for labour.

### 8.2.3 Operating Costs

Operating costs include expenses for services, supplies, fuels, lubricants and other similar items related directly from operations and which are used up in every day production. They do not include capital expenditures. Operating costs are difficult to determine precisely as they vary so much from job to job. Nevertheless, records of past operating costs can be indicative. When no previous data are available upon which to rely, the following are given as representative averages of a wide cross – section of dredging operation. These costs are for one year and are the percentage of delivered cost [Ref. 26].

Maintenance = 7.5 %

Fuel = 7.5 %

Lubricants = 0.8%

Supplies = 0.7%

TOTAL =16.5%

## 8.3 COST ANALYSIS FOR BSL PROJECT

The unit cost of various alternatives as discussed in the earlier chapter has been worked out using the approximate delivery price of dredging equipments from the manufacturer's and prevailing rate at BBMB workshop situated at Nangal. Repair & labour charges taken are based as per the existing norms followed by the BSL Project authority. The detailed computations of both the alternatives are appended as Appendix-8.1. Table (8.1) shows the abstract of unit cost of dredging for both the alternatives with hydraulic as well as mechanical transport systems.

The above results indicate that hydraulic transport system is economical and out of two alternatives it is economical to carry the dredged material to river Sutlej. Besides various constraints of this proposal mentioned in Chapter-7, it will eliminate present environmental problems of Suketi Khad,

## Table (8.1): ABSTRACT OF UNIT COST ANALYSIS

| Sr. No. | Proposal | Cost of Dredging in Rupees per cubic meter | | No. Of Booster Stations Required. (Nos.) | Remarks |
|---|---|---|---|---|---|
| | | Disposal by Mechanical transport. (Rs) | Disposal by Hydraulic Transport (Rs) | | |
| 1. | Alternative-I (Disposal towards River Beas) | 147- 00 | 115-00 | 9 | Approximate distance (25.3 kms.) |
| 2. | Alternative-II (Disposal towards River Sutlej) | 117-00 | 82-00 | 3 | Approximate distance (14.20 kms.) |

# CHAPTER-9

# CONCLUSIONS AND RECOMMENDATIONS

## 9.1 GENERAL

The foregoing chapters describe the criteria for selection of type of dredging equipment, various parameters governing the production rate and, techno-economic feasibility of dredging operation of silt disposition. These are illustrated in the case of Balancing Reservoir of BSL Project. The possible alternatives for the disposal of silt from BR have been studied and their techno-economic limitations are indicated. Assumptions made in the course of analysis in absence of detailed data have been explained. The economics of various possible alternatives has been worked out using the approximate delivery price of dredging equipment from the manufacturer's and prevailing rate of BBMB workshop situated at Nangal. The cost analysis has been done for comparison of the various alternatives. Following general conclusions may be drawn from the study and analysis.

## 9.2 CONCLUSIONS

(i) The selection of type of dredging equipment depends upon the quantity of material to be removed, the physical characteristics of materials, the distance of disposal sites and the availability of quantity of water as a transporting medium. Hydraulic dredging is the best alternative to remove silt from a reservoir.

(ii) The evaluation of head is the main criteria for selection of dredging pump. Because the total head on a dredge pumping system is the energy available to move spoil and water to the disposal area. It depends upon the suction head available, static head and friction losses in the carrier system.

(iii) In depth study is required to be carried out for selecting the size of dredger and characteristics of the dredge pump. Because in pump-line system dredge production rate depends upon the output of dredge pump, internal diameter of the pipe, the velocity of flow, and the percentage of solids in the mixture.

(iv) The maximum efficiency of dredging system can be attained by properly scheduling effective utilization of equipment taking into account the constraints of disposal system and the environments.

(v) Hydraulic disposal through pipelines is a techno-economically feasible and eco-friendly alternative for long distance disposal of dredged material, though such system needs intermediate boosters.

## RECOMMENDATIONS

(i) Each case needs in-depth study for selection and design of a dredging and disposal system and size of equipments.

(ii) Performance data of existing systems shall be collected and studied, as it is the best guide for improving the system in future.

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APPENDIX – (4.1)

# BASIC DATA AND SALIENT FEATURES OF BSL PROJECT

## I. Basic Information

| | |
|---|---|
| Name of project | : Beas project-unit I, Beas Sutlej Link |
| Type of Project | : Multipurpose Scheme for Irrigation and Power |
| Purposes | : Hydro-power & Irrigation |
| Year of first commissioning | : 1977 |

## II Location

| | |
|---|---|
| State | : Himachal Pradesh |
| District | : Mandi |
| i) Dam site | : Pandoh |
| ii) Enroute water conductor system | : Baggi & Sundernagar |
| iii) Power Plant site | : Dehar |
| Nearest rail head | : Kiratpur Sahib |
| Longitude | : Between $76^0$-50'E and $77^0$-05'E |
| Latitude | : Between $31^0$ –25' & $31^0$ – 40'N |

## III Hydrology and Climatology

| | |
|---|---|
| River on which located | : Beas |
| Sub basin | : Beas |
| Main river basin | : Indus |
| Catchment areas upto dam site | : 5278 Km$^2$ |
| Catchment area under permanent snow | : 780 Km$^2$ |
| Average of daily maximum temperature at dam site | : $28^0$c |
| Average annual rainfall in catchment area | : 1320 mm |

| | |
|---|---|
| Average annual run off | : 8200 x $10^6 m^3$ |
| Maximum flood discharge at Pandoh | : $4927 m^3/s$ |
| Design flood discharge | : $10194 m^3/s$ |

### IV Pandoh Dam & Reservoir

| | |
|---|---|
| Type of Dam | : Earth-cum-rock-fill |
| Height above deepest foundation | : 76.2 m |
| Elevation of the top of dam | : EL.899.16 m |
| Maximum reservoir level | : EL.896.42 m |
| Minimum reservoir level | : 883.92 m |
| Gross storage capacity | : $41x10^6 m^3$ |
| Live storage capacity above | |
| Normal reservoir level | : $18.55x10^6 m^3$ |

### V Spillway

| | |
|---|---|
| Radial gates | : 5 nos. 12m x 13 m each |

### VI Pandoh Baggi Tunnels (PBT)

| | |
|---|---|
| Diameter | : 7.62m |
| Length | : 13.11 km |
| Capacity | : $254.85 m^3/sec$(9000cusecs) |

### VII Sundernagar Hydel Channel (SHC)

| | |
|---|---|
| Full supply discharge at head upstream of silt ejector | : $254.85 m^3/sec$(9000 cusecs |
| Design discharge D/S silt ejector | |
| Length | : $233.62 m^3/sec$ |
| Average velocity | : 11.8 Kms |
| Capacity of silt ejector | : 1.84 m/sec |
| | : $28.3 m^3/sec$ (9000 cusecs) |

### VIII Sundernagar Balancing Reservoir (BR)

Live storage capacity : 3.7x10$^{6}$ m$^{3}$

*Dead* storage capacity : 1.1 x 10$^{6}$m$^{3}$.

Length of reservoir : 2130 m

Maximum width reservoir : 449.88 m

Maximum reservoir level : EL 842.47 m

Minimum reservoir level : EL 832.32 m

Top of embankment : EL 844.91 m

### IX Sundernagar Sutlej Tunnel (SST)

Diameter : 8.535 m

Length : 12.35 km

Capacity : 403.52 m$^{3}$/sec

### X Surge Shaft

Diameter of main shaft : 22.86 m

Height : 125m

### XI Penstock

No. of penstock : 3

Diameter : 4.877 m

No. of penstock branches : 6

Diameter : 3.353 m

### XII Dehar Power Plant

Installed capacity : 990 MW
(6 units of 165 MW each)

Designed head : 320m

Type of turbine : Vertical shaft Francis type

Bread dimensions : 118 .250 m long x 40.3 m wide x48.673 m high

# APPENDIX – (8.1)

# COST ANALYSIS FOR BSL PROJECT

## 1 COST OF DREDGING OPERATION

The cost analysis is based on data of a NG Beaver 5014 C cutter I.H.C Beaver, type Dredger (1500 hp) manufactured by IHC system in Holland.

### a) Data for 1500 H.P. Dredger

i) Initial cost (including transportation and erection) =Rs 15,00,00,000

ii) Life of dredger (i.e. 10 years or 27000 hours) = 27000 hours

iii) Consumption of fuel = 160 gms/h.p./ hr.

iv) Consumption of lubricating and hydraulic oils = 2.0 litres/ hour

v) Consumption of grease = 0.18 Kg/hour

vi) Repairs, including salaries etc. = 75% of fixed annual cost.

vii) Maintenance Labour crew charges 960 man days @ Rs. 54.70* (960 × 54.70) =Rs. 52512 /- per year *

viii) Consumable articles except pipelines (including duty etc.) =Rs 50/- per working hour.

ix) Cost of consumable pipeline =Rs. 10/- per hour.

x) Quantity of Silt dredged out per working hour =800m$^3$

xi) Actual pumping hours =75% of working hours (In other words, efficiency for hourly operation = 0.75)

**b) Unit Cost Analysis**

i) Total silt required to be dredged = 1.5 million cum/ year

ii) Number of working hours required @ 800m 3/hr $= \frac{1.5\times10^{6}}{800} = 1875\,hours$

iii) Annual fixed cost ($c_1$) $= \frac{c\cdot r(1+r)^{n}}{(1+r)^{n}-1}$

Where c = Total initial cost ($15\times10^{7}$)

r = Annual rate of interest =15% (assumed)

n = Life in years $= \frac{27000}{1875} = 14.4\,years$

$$\therefore c_1 = \frac{15\times10^{7}\times0.15(1+0.15)^{14.4}}{(1+0.15)^{14.4}-1} = 25970863.08$$

Say 259.71 lacs per year.

**c) O & M Costs per year**

i) Fuel @ 160 gm/ H.P/ hr. $= \frac{160\times1500\times1875}{680**} = 670590$ litres

∴ Fuel cost @ Rs 9. 42 */ litre =670590×9.42 =Rs. 63.17 lacs.

ii) Lubricating and hydraulic oils

@ 2.0 litres/ hr = 2×1875 =3750 litres

Cost @ Rs. 47. 46 */ litres =3750×47.46 = Rs.1.80 lacs

iii) Grease @ 0.18 Kg / hr = 0.18 ×1875 =337.50 kgs

@ Rs. 49. 05*/ 1Kg =337.50×49.05 = Rs. 0. 17 lacs

iv) Repairs @ 0. 75 of $c_1$ = 0.75×259.71 =Rs. 194.78 lacs

v) Maintenance crew = Rs. 0. 52 lacs

vi) Consumable articles except pipelines

@ Rs. 50 /hr =50×1875 =Rs: 0.94 lacs.

vii) Consumable pipe line

Rs.10 / hr =10×1875 =Rs. 0.19 lacs.

viii) Add because of efficiency =0.75

25% of [ (i)+(ii)+(iii)+(vi)+(viii)] =Rs 16.57 lacs.

∴ Total O & M Cost per year =(i)+(ii)+(iii)+(iv)+(v)+(vi)+(vii)

= Rs. 278.14 lacs.

d) **Total Annual Cost** =Fixed annual cost + O & M cost

=Rs. 537.85 lacs.

∴ Cost per cubic meter of Silt dredged

$$= \frac{\text{Total annual cost}}{\text{Volume of Silt/year}}$$

$$= \frac{537.85 \times 10^{5}}{1.5 \times 10^{6}}$$

=Rs. 35.85

Say Rs. 36/-

* Rate taken as per Beas Project annual maintenance Cost estimate for the year 1999-2000.

** Fuel weighs 680 gms. / litre.

## 2 COST OF DREDGED MATERIAL TRANSPORTATION

### 2.1 By Heavy Earth Moving Machinery

Quantity of silt estimated to settle

in balancing reservoir = 1.5 million cum/ year

Considering that the degree will work for 8 months in a year, 25 days in a month and $6\frac{1}{4}$ Hours in every shift of 8 hours.

Then working hours available in a year for two shifts working

with utilization factor 0.8 $=8\times25\times12.5\times0.8=2000$ hours

.Silt to be handled /hour $=\dfrac{1.5\times10^6}{2000}=750\text{m}^3$

Say $800\text{m}^3$

Dredger can handle silt at about 30% concentration. However, volume of silt and water to be handled by the dredger for $800\text{m}^3$ of solids /hour

$$=\frac{800\times100}{30\times60\times60}=3200 \text{ cum/hour}$$

=0.74 cumecs or 27cusecs of water

### a) Requirement of Machinery

Draglines / shovels

Material to be handled quantity =Slush /Saturated sediment

Quantity $=800\text{m}^3$/hour

Dipper yard Capacity required @ $100\text{m}^3$/hour/dipper yard so provide $=\dfrac{800}{100}=8\text{m}^3$

| | | |
|---|---|---|
| i) | 4 no. diesel Dragline of $2.5\text{m}^3$ bucket capacity | =10.0 |
| | Stand by @ 50% (availability) 2 no. $2\text{m}^3$ bucket capacity | =4.0 |
| | | 14.0 |

Or

ii) 4 no. Electrical Dragline of 2.5m$^3$ capacity (including standby) = 10.0

Or

iii) 2 no. electric Dragline of 5m$^3$ capacity and 2 No. Dragline of =10.0

2.5 m$^3$ capacity (including standby) = $\underline{5.0}$

15.0

**b) Carriers**

Deploy Rear dumpers 28m$^3$ (35 T) capacity

Norms for Slush

Capacity = 28m$^3$

Speed =20 km/hour loaded

=40 km/hour unloaded

Average Speed ($\frac{20+40}{2}$) =30 km/hour

Average lead =25 km (TO river Beas)

=17 kms (To river Sutlej)

**c) Cycle time of Dumper** ( Towards river Beas)

i) Hauling time for 25 Kms. $=\frac{2\times25\times60}{30}$ = 100 minutes

ii) Turn and dump (assumed ) = 1.5 minutes

iii) Spotting time (- do- ) =0.5 minutes

iv) Loading time with 2.5 m3 Dragline $=\frac{28\times0.4}{2.5}$ =4.48 minutes

Total Cycle time =106.48 minutes

Capacity hour $= \frac{60 \times 28}{106.48}$ $=15.78m^3$

No of dumpers required $= \frac{800}{15.78}$ =51 (working)

Add Standby @ 30% =15

Total no. of dumpers required =66 nos.

**d) Cost of Transport ( toward river Beas)**

i) 4 Nos. Dragline ( working rate @ Rs. 1300/-* per hour)

$= 4 \times 2000 \times 1300$ $=RS\ 10.4 \times 10^6$

ii) 51 No. Dumpers (working rate @Rs. 1250/-* Per hour)

$=51 \times 2000 \times 1250$ $=Rs.\ 127.5 \times 10^6$

Total $=Rs.\ 137.9 \times 10^6$

iii) Add 20% lumsum for misc. Items as below $=Rs.\ 27.58 \times 10^6$

-Working of Dozers/Dragline for re-handling of silt in the tanks.

- Working of Dozers at loading & unloading points.
- Maintenance of haul roads.
- Lease money is paid to be farmers for haul roads and/or for dumping the slush temporarily.
- Compensation to be paid to the farmers on a account of damage to their field due to silting as a result of meandering.
- Maintenance of drainage system behind area
- Unforeseen.

Total annual cost of transport system $=Rs.\ 165.48 \times 10^6$

Annual volume of silt to be transport $=1.5 \times 10^6 m^3$

Cost of silt transport per cubic meter $=\dfrac{165.48\times10^{6}}{1.5\times10^{6}}$ =Rs. 110.3

Say Rs. 111/-

**e) Cost of Transport (toward river Satlej)**

i) Cycle time of dumpers

Hauling time for 17 kms $=\dfrac{2\times17\times60}{30}$ =68 minutes

Turn & dump time (assumed) =1.5 minutes

Spotting time (-do-) =0.5 minutes

Loading time =4.48 minutes

Total time =74.48 minutes

Capacity /hour $=\dfrac{60\times28}{74.48}=22.56m3$

No of dumpers required $=\dfrac{800}{22.56}$ $=36nos.(working)$

Add standby @ 30% =11 nos.

Total number of dumpers required =47 nos.

(i) 4 nos. Dragline (working rate (@ Rs 1300/ -* per hour)

$=4\times2000\times1300$ =Rs. $10.4\times10^{6}$

(ii) 36 nos. dumpers working rate ( @ Rs. 1250/- per hour)

$=36\times2000\times1250$ =Rs .$90.0\times10^{6}$

Add 20% of (i) & (ii) for misc. items =Rs. $20.08\times10^{6}$

Total Cost =Rs. $120.48\times10^{6}$

Cost of silt transport per cubic meter $= \frac{120.48 \times 10^6}{!.5 \times 10^6}$

$=$Rs .80.32

Say Rs. 81/-

* (Use rate of carriers and Dragline are based on Theri Hydro-electric Project for the year 1998-1999)

## 2.2 BY HYDRAULIC TRANSPORT ( through pipelines)

Quantity of silt estimated to be settle in balancing reservoir =1.5 million cum/year

Considering that the degree will work for 8 months in a year, 25 days in a month and $6\frac{1}{4}$ hours in every shift of 8 hours.

Then working hours available in a year for two shift working with utilization factor 0.8

$= 8 \times 25 \times 12.5 \times 0.8 = 2000$ hours

Silt to handled /Hour $= \frac{1.5 \times 10^6}{2000} = 750m^3$

Say $800m^3$

### a) Useful Life of Pipeline

In general, the dredgers are supplied completed with the suction and discharge pipeline as on board pipes. For spoil discharge are required floating and shore pipes.

The estimated useful life of pipes can be calculated by formula [ Ref. 1]

$$T = \frac{f2d(133t - d)}{133p}$$

Where T = Estimated life of pipe in year

D= Inside diameter of pipe in inches =20 inches

T= Thickness of pipe in inches =0.394 inches

P= Estimated annual production in million cubic yard

F= Factor of material; for mud in soft water f =0.8

$$T = \frac{0.8 \times 2 \times 20(133 \times 0.394 - 20)}{133 \times 1.5 \times 1.308} = 3.969 \quad say\ 4\,year$$

Initial cost of pipe line (Including fabrication & erection) =Rs. 50,000/- per meters

Initial cost of booster pumps (including installation & price of equipment)

=Rs. $10^7$ /-per pump (assumed)

**a) Cost of Hydraulic Transport Towards River Beas**

No. of booster station needed =10 nos.

Length of pipeline required =25.3 kms.

Diameter of pipe =0.500m

Thickness of pipe =0.010m

Weight of pipeline having length 25.3kms. = $\pi\, pt \times 25.3 \times 1000 \times 7.85$

=3119.68 Say 3120 Mt

Total initial cost of system =$(10\times10^7)+(3120\times50000)=(10+15.6)\times10^7$= Rs. $25.6\times10^7$

i) Annual fixed cost ($C_1$) $= \frac{c.r(1+r)^{n}}{(1+r)^{n-1}}$

Where C =Total initial cost (Rs. $25.6\times10^7$)

R =Annual rate of interest =15%(assumed)

N =Life in years =4 Years

$$C_1=\frac{25.6\times10^{7}\times0.15(1+0.15)^{4}}{(1+0.15)^{4-1}}=Rs.896.68\,lacs\ per\ year$$

ii) O&M cost per Year =Rs. 278.14 lacs.

Total annual cost =896.68+278.14 = Rs. 1174.82 lacs

Cost of transport per cubic meter $=\frac{1174.82\times10^{5}}{1.5\times10^{6}}=78.32$ = Rs. 79 /-

**b) Cost Of Hydraulic Transport Towards River Sutlej**

No. of booster station needed =3 nos.

Length of pipeline required =14.20 kms.

Diameter of pipe =0.500m

Thickness of pipe =0.010m

Weight of pipeline having length 14.20 kms.

$$=\pi Dt\times14.20\times1000\times7.85$$
$$=1750.966\quad Say\ 1751MT$$

Total initial cost of system $=(3\times10^{7})+(1751\times50{,}000)$

$$=(3+8.76)\times10^{7}=Rs.11.76\times10^{7}$$

i) Annual fixed cost ($C_1$) $=\frac{c.r(1=r)^{n}}{(1+r)^{n-1}}$

$$=\frac{11.76\times10^{7}\times0.15(1+0.15)^{4}}{(1+0.15)^{4-1}}$$

=Rs. 411.912 lacs.

ii) O&M Cost per year =Rs 278.14 lacs

Total annual cost =Rs. 411. 912+278.14 =Rs 690. 052 lacs

$$\text{Cost of transport per cubic meter} = \frac{690.052 \times 10^{5}}{1.5 \times 10^{6}} = 46.00\, Say\ Rs.46/-$$

* Unit rate per metric ton of dispersal pipe is as per B.B.M.B. Workshop Nangal for 1999-2000.

Table (8.1) shows the abstract of Cost Analysis of dredging of different alternatives as below.

**Table (8.1): ABSTRACT OF UNIT COST ANALYSIS**

| Sr. No. | Proposal | Cost of Dredging in Rupees per cubic meter | | No. Of Booster Stations Required. (Nos.) | Remarks |
|---|---|---|---|---|---|
| | | Disposal by Mechanical transport. (Rs) | Disposal by Hydraulic Transport (Rs) | | |
| 1. | Alternative-I (Disposal towards River Beas) | 147- 00<br>(36+111) | 115-00<br>(36+79) | 9 | Approximate Distance (25.3 kms.) |
| 2. | Alternative-II (Disposal towards River Sutlej) | 117-00<br>(36+81) | 82-00<br>(36+46) | 3 | Approximate distance (14.20 kms.) |