HYDROPOWER DEVELOPMENT IN SATLUJ RIVER BASIN WITH REFERENCE TO SEDIMENT PROBLEM

A DISSERTATION

Submitted in partial fulfilment of the requirements for the award of the degree

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WATER RESOURCES DEVELOPMENT

By

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CANDIDATE'S DECLARATION

I hereby certify that the work, which is being presented in this dissertation entitled **"HYDROPOWER DEVELOPMENT IN SATLUJ RIVER BASIN WITH REFERENCE TO SEDIMENT PROBLEM"** in partial fulfilment of the requirement for the award of Degree of **MASTER OF ENGINEERING IN WATER RESOURCES DEVELOPMENT (CIVIL)** submitted in the Department of Water Resources Development Training Centre of the University of Roorkee, Roorkee, is an authentic record of my own work carried out during the period from 16th July to February 2001 under the supervision of Dr B.N. Asthana, Emeritus Fellow, Formerly Visiting Professor, Water Resources Development Training Centre, University of Roorkee, Roorkee, Uttaranchal (India).

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

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Satluj river, a major tributary to river Indus, has its source in the Himalayan range in Tibet. The hydropower potential of Satluj river basin is to the tune of 9500 MW, out of this only 1200 MW has been harnessed, and projects for 2800 MW are under construction. The river is snow fed. It carries considerable amount of flow and sediment, during summer and monsoon months. The sediment load is only a fraction of a g/l during low flows, but increases to an average of 10-12 g/l in high flow period. The peak values are far above this figure.

Due to distinct V-shape valley characteristics of Satluj river, only run-of-the river schemes with a small dam/barrage for diversion of water are possible, except a few storage schemes at the foothills. In such diversion schemes silted water passes through turbines and damage underwater parts and other equipments. It is therefore imperative to provide suitable desilting arrangements. At present desilting basins are designed to exclude particles larger than certain size depending upon the head on the turbine and experience of the designer. But now with high head developments, the fraction size of the silt to be removed becomes small resulting in large size basins. Some times these basins cost more than the diversion works itself. Hence, there is a need for the optimisation of the size of silt to be removed taking in to account the repair and maintenance cost of the turbine. From the field experience and experimentation in the laboratory, it has been established that the effect of silt erosion to underwater parts depends upon the grain size, shape, hardness, gradation and total content of suspended sediment. It also depends on runner design as well as metallurgy of underwater parts.

Based on the studies carried out by NOZAKI, T., of Japan on 18 power plants in Peruvian rivers, a relation has been established for the turbine abrasion potential of silt particles and curves for the repair and maintenance cycle of the turbines have been developed. A procedure has also been developed to optimise the size of desilting basin i.e., to arrive at the size of silt particle which gives a cost effective size of desalting basin and the repair and maintenance cost of runner and other equipments.

The objective of this study is to validate the curves developed by Nozaki from the data of power schemes in Himalayan region where silt problem is severe and to illustrate the approach of the proposed optimisation approach to evolve cost effective desilting basins for a few proposed schemes in Satluj basin. The study has shown that the cost effective optimum sediment size to be excluded is in the range of 0.3 to 0.4 mm against the size of 0.2 mm adopted in all the proposed schemes in the basin.

CHAPTER 1

INTRODUCTION

1.0 GENERAL

Economic development is dependent on energy. Per capita energy consumption is a parameter to measure the level of economic development of a nation. India is at a very low rank as far as per capita energy consumption is concerned. Electrical energy is the main constituent of total energy. Amongst other sources of electrical energy hydropower is an economic, renewable, non-polluting source of energy. It has inherent advantage of meeting the peak demand. Presently it is about 25 % of the total installed capacity of about 1.0 lac MW, whereas the estimated potential at 60 % load factor is 84,000 MW, out of it the share of Himalayan river basins is 64000 MW, but so far only 19,000 MW has been harnessed. Thus, there is large scope for harnessing hydropower potential of Himalayan rivers. This study is limited to Satluj river basin and its problems.

Satluj river, a major tributary to river Indus, has its source in the Himalayan range in Tibet, beyond the borders of Indian sub-continent. It rises near Rakas-Tal lake which is mainly fed by lake Mansarover at an altitude of about 4572 m above mean sea level. Before entering India near Shipkila, Satluj river travels about 322 kms in Nari Khorsam province of Tibet. After entering India the river takes south westerly direction and travels about 322 kms up to Bhakra gorge, where it emerges in the plains of Punjab. Satluj river being snow fed is a perennial river.

The estimated hydropower potential of Satluj river basin is to the tune of 9500 MW, out of this only 1200 MW has been harnessed till now, and 2800 MW is under various stages of construction. Schemes for 5585 MW are in different stages of planning.

1.1 HYDROPOWER DEVELOPMENT IN SATLUJ BASIN

Like other river basins, this basin is also planned in a cascade manner to utilize entire drop and the flow for the development of hydropower and other water uses. The projects are both run -of- the river type with a small dam/barrage for diversion of water and the storage dams.

Due to distinct V-shape valley characteristics of this basin the storage schemes could be possible only at the foothills. Some of the schemes of both the types have been constructed. The run-of-the river projects under operation in Satluj basin are:

i) Sanjay Vidyut Pariyojna (120MW).

ii) Ganvi Hydel Project (22.5MW)

iv) Rong Tong Hydel Project(2 MW)

v) Chaba Hydel Project (1.75 MW)

vi) Nogli Hydel Project (2.5 MW)

It can be seen that the major run-of-the river scheme in operation is Sanjay Vidyut Pariyojna. Four run-of-the schemes, totalling an installed capacity of 2800 MW are under construction and about 20 such schemes are being planned for 5585 MW. These are under different stages of planning.

The only storage scheme in operation is Bhakra dam, which is multipurpose project for irrigation and power generation with a gross storage of about 10,000 MCM created by the highest concrete gravity dam in the country. Another storage scheme upstream of Bhakra which is being constructed is Kol dam. Baspa-I is one storage scheme which is in planning stage.

It is therefore indicated that in future a large number of run-of the river schemes may be taken up for construction to harness the hydro power potential of the basin, as storage sites are a few.

1.2 SEDIMENT PROBLEM

The river Satluj and its tributaries are snow fed and these bring considerable amount of sediment with the flow during summer and monsoon months. The sediment load is only a fraction of a gm/litre during low flows, but increases to an average of 10-12 gm/litre in high flow period .The peak values are far above this figure.

The sediment gets settled in storage reservoir reducing its live and dead storage and so the under water components of the power houses fed from the reservoir are not severely affected as has been the case with Bhakra in Satluj basin. But in case of Sanjay vidyut pariyojna which is a run-of- the river project, the sediment has severely affected the turbine and other underwater parts despite the provision of sediment exclusion measures such as desilting chamber designed to exclude particles +0.2 mm. Such has been the experience in many run-of-river schemes in other Himalayan river basins.

Since a large number of run-of river schemes are in planning stage in Satluj basin a critical study of sediment problem and cost effective removal measures is necessary.

1.3 NEED FOR OPTIMISATION OF DESILTING BASINS

Run- of- river schemes are generally provided with desilting basins to exclude sediment of specific size. The size and cost of the desilting basin depend upon the size of silt particle to be removed. The permissible particle size limit recommended by Emil Mosonyi(17) for medium head plants is 0.5 mm to 0.2 mm and for high head plants, particle size of 0.1 mm or less may sometimes be damaging. BHEL has the guidelines as below:

i) Particles of +0.5 mm size and of hardness + 5 on Mohr's scale are harmful.

ii) If concentration of particle is +200 ppm, desilting measures are required.

iii) Concentration of harmful particles should be reduced by 85 % to 95 %.

Du Tong[16] has concluded from experimental results that damages take place due to cavitation and this process is accelerated by sediment. He has given the following guidelines based on experimental relations.

i) If the life of turbine work out to be more than twenty years, the sediment exclusion measures may be eliminated.

ii) If the turbine is likely to be eroded within 5-10 years then, the sediment exclusion measures are necessary.

It may, thus be concluded that in each case certain limit of sediment concentration and particle size has to be fixed for provision of sediment exclusion device but no definite guide lines are available. For planning projects in Satluj basin the sediment above 0.2 mm size has been proposed to be excluded. The same has been adopted for Nathpa Jhakari HE project, which is under construction. In this case the cost of desilting basin is Rs 284 crores which is two times the cost of diversion dam and intake works put together (Rs 145 crores) and is about 15 percent of the total cost of the civil works of the project which is Rs 2049 crores at 1993 price level. It has been the experience that the cost of desilting basin increases abnormally as the sediment size to be excluded is reduced and it is not possible to exclude sizes below 0.15 mm, because of very small fall velocities. It has also been the experience in several cases that machinery gets damaged even with the provision of desilting basins. The damage to machinery has been found dependent on many other factors besides the size of sediment.

From the foregoing it may be concluded that an approach in which the cost of desilting measures and the repair /replacement cost of equipment put together is minimum should be adopted. Such an approach has been suggested by Nozaki,T.[29], it is based on observed repair cycle of some power stations of Peru.

1.4 OBJECTIVE OF STUDY

The objective of the present study is to validate the approach of Nozaki, T.[26], of Japan with the performance data of Indian power stations and to illustrate the applicability of the approach in case of some projects on river Satluj ,which carries lot of silt.

1.6 ORGANISATION OF STUDY

The study is presented in seven chapters. The following briefly indicates the contents of each chapter.

Chapter-1

This chapter gives an introduction to the problem, scope of study and the organisation of dissertation report.

Chapter-2

This chapter deals with the topographical and hydrological characteristics of Satluj basin and the status of hydropower development.

Chapter-3

This chapter gives the outline of the hydro-abrasion problem in power stations and various ways to mitigate this problem.

Chapter-4

This chapter deals with the performance appraisal of some run-of-the river hydropower plants in Satluj basin as well as plants located in other river basins of western Himalayas.

Chapter-5

This chapter gives in detail the approach developed by NOZAKI and as applied to optimize the size of desilting basins vis-à-vis repair and maintenance cycles of turbines.

Chapter-6

In this chapter an attempt has been made to validate the optimization approach with Indian data and to illustrate its application in some projects in Satluj basin.

Chapter -7

This chapter contains conclusions and suggestions for future studies.

CHAPTER 2

SATLUJ BASIN

2.0 GENERAL

This chapter deals with the topographical and hydrological characteristics of Satluj basin and the status of hydropower development.

2.1 CATCHMENT CHARACTERISTICS [48]

The geographical limits of Satluj basin up to Bhakra dam lie between latitude 30°N and 33°N and longitude 76°E and 83°E. It covers it's area in Nari Khorsam province of Tibet (China) and in the state of Himachal Pradesh (India). The catchment area at Bhakra dam is about 56,875 sq. km. out of which about 36,900 sq. km., falls in Tibet and 19975 sq. km., in India.

The basin represents some of the remarkable physical features. Below it streches the loftiest mountain ranges of the world radiating from the Pamir Knof. The most southerly of these is the Himalayan range which is the loftiest and longest range in the world. The Himalayas which run first south-eastwards from the Pamir Knof and later in an easterly direction, constitute a massive mountain wall extending over 2500 kms with a varying width 250 to 300 km. The catchment area has been shown in figure 2.1.

Topographically and climatically the catchment has been divided into four categories as follows:-

I) Tibetan Plateau

River Satluj rises in Tibetan plateau in the region of the Mansarover lake situated at an elevation of about 4570 m, above mean sea level .The river passes through the Tibetan province of Nari

Khorsam. The best known portion of Nari Khorsam is the plateau situated between Zaskar and Ladakh ranges. This plateau has been formed by successive deposits of boulders, gravel, clay and mud in the trough between two ranges. The deposits lie in parallel and nearly horizontal beds. River Satluj has been able to cut a channel about 915 m deep through the plateau with the water receiving from glaciers. The vertical banks stand uneroded as there is no local rainfall. River Satluj in the Nari Khorsam region is joined by several tributaries, the beds of which lie about 305 m or more below surfaces of the plain and their over hanging cliffs, similar to those of Satluj have been spared from destruction by rain. The flat portion of the plateau now remain standing between profound gorges. There is absolutely no vegetation in this region. When the snow melts deep channels are formed on the surface. The river Satluj enters India near Shipkila after traversing a length of about 322 kms in the Tibetan Province of Nari Khorsam.

ii) Spiti Valley

Spiti river is the biggest tributary of river Satluj and joins river Satluj at Khab, 14 kms upstream of Pooh. The characteristics of this catchment area are identical to that of the Tibetan plateau. Rainfall in this area is scarce. Height of the catchment area drained by river Spiti is between 3048 m and 4570 m. In this area, there is absolutely no vegetation .The melting snow forms deep flow channels.

iii) Khab to Karcham

This catchment is bounded by moderately high hills, 1525 m to 3048 m and has little rainfall but heavy snow. The snow line in this region is at about 3048 m. The flows in the river are mainly due to snow melting which follows more or less a regular pattern. Due to the absence of rain, arid conditions prevail and the good forests seen below Karcham are not existing in this area. The well formed pine forests near Karcham give way to 'CHILGOZA' plantations at the higher elevation. The area has steep slopes with little earth cover and very little rain.

When snow falls, water enters into the crevices where its freezing during winter cracks and crushes the rocks. The subsequent loads of snow accelerates this phenomenon. When the snow melts, the disintegrated debris slides with the water into the river. This cycle repeats year after year.

ii) Karcham to Bhakra

The catchment has high surrounding hills like Narkanda, Shimla (3050 m) etc., but is flanked by foot hills of Shiwaliks near Bhakra Dam (915m). Rainfall in this area is moderate to heavy. The rocks are well formed and have a good earth cover.

iii) Below Bhakra

The river in downstream of Bhakra emerges out of the hills. About 15 kms downstream of Bhakra is Nangal dam which acts as a balancing reservoir for the Bhakra canal. Down stream of Bhakra the river traverses about 100 km in plains before it meets river Beas.

2.2 THE RIVER PROFILE

River Satluj rises near Rakas-Tal lake which is fed by lake Mansarover at about 4570 m above mean sea level. Between Rakas-tal and Shipkila, (near the Indian border), the Satluj river takes a north-westerly course for a length of about 322 kms in the Tibetan Province of Nari Khorsam. The Satluj is joined by several tributaries in Nari Khorsam such as Zangchu, Drame Yangti, Chonak Suma Trape etc. Immediately after entering the Indian territory near Shipkila the river takes a south westerly direction on its way to Bhakra gorge about 322 kms away after which it emerges into the plains of Punjab.

The principal tributaries of Satluj below Shipkila are the Spiti, Kashang, Kiran, Baspa, Bhaba, Nogli, Sholding, Sir, Bharari, Ali and Gamber khad.

Numerous glaciers large and small, drain into the Satluj river at various points on its course, East of Mansarover and feeding it principal source are the glaciers of the Ganglung, Gaungni, the southern glaciers of Kailash, flow into the river through the lake of Rakas-tal, the northern glaciers of peak Pamir Knof also contribute to the stream. The glaciers of peak Riwa Phargul which stands in the Satluj catchment also flow in to it. There are many Himalayan glaciers draining into its tributary, the Baspa, and many more from the direction of the Bara -Lacha pass from the water sheds of the Chenab and Beas.

The fall of Satluj river from its source to the plains of India is very uniform. The height of the bed is about 4570 m near Rakas Tal, 2530 m near Shipkila, 915 m at Rampur, 460 m at Bilaspur and 350 m at Bhakra. Thus, a gross fall of 2180 m is available in the river bed from Shipkila to Bhakra in a length of about 322 kms.

The bed slope of the river is flat from Shipkila to Jangi dam site for a distance of about 42 kms which is of the order of 1 in 175. It becomes steep between Jangi dam site and Rampur, the slope being 1 in 87 and is again flatter from Rampur to Kol dam site with a slope of 1 in 300. It is flattest in the Bhakra reservoir area, the portion down stream of Kol dam, where it is 1 in 500.

2.3 METEOROLOGICAL ASPECTS

From meteorological considerations the catchment of Satluj may be divided in two parts, one falling in Tibet and Spiti valley and the other below Wangtu in India. The two parts have different climatic characteristics which are briefly described below:

Zone in Tibet and Spiti Valley:-

It comprise plateaus of Chamdo, Chingai and Tibet. The topography plays a vital role in the weather and climate of this zone. The influence of physical features on climate is afforded by the Tibetan plateau and the Himalayas which shield the plains of north India from the cold continental air moving outward from Siberian anticyclone in the winter months. The climate of this zone can be defined as "mountain climate".

Zone Below Wangtu:-

It comprise north India and generally enjoys an annual rainfall in excess of 1000 mm and most of the rainfall occurs in summer months from June to October. Tropical storms and depressions affect the weather over the zones in these months. The north western parts receive winter precipitation from western disturbances. Day temperature in the summer months exceed 40°C over the western half of the Zone. The climate of this zone may be called as "tropical monsoon climate".

2.4 HYDROLOGY

2.4.1 Precipitation

Satluj basin receives precipitation due to the south -west monsoon as well as due to western disturbances that pass over the north-west part of the country during winter. The south west monsoon generally lasts from June to October, precipitation during this season which falls as rain is generally not heavy but at times may contribute significantly towards flood run off. The winter precipitation falls either as rain or snow depending upon the altitude and other meteorological conditions. Following table, shows the mean monthly and mean annual precipitation in mm at seven stations within the Satluj basin [44] (Shown in figure 2.1).

Month	Rainfall station					
	Rampur	Nichar	Kilba	Sangla	Kalpa	Purbani
January	63	122	93	90	94	67
February	65	142	164	103	109	84
March	95	123	123	88	127	96
April	45	68	82	73	77	59
May	55	84	60	60	61	48
June	57	45	23	24	31	27
July	158	125	63	56	48	26
August	153	155	63	62	44	32
September	84	97	58	58	53	40
October	28	37	38	35	32	25
November	14	20	20	15	16	17
December	26	64	60	57	45	42
Annual	843	1082	845	720	737	563

2.4.2 Stream Flow Gauging

There are river gauging stations on the Satluj river at Bhakra, Kasol, Suni, Rampur Wangtu and Khab and on several of its tributaries namely the Spiti, Baspa, Bhaba, Sholding. Ganvi, Sir, Sukar and Sarihyali khads etc.

The total annual water yield from the Satluj basin at Bhakra dam[45] site is about 10,16,25 billion m^3 in a dry, average and wet year respectively. Its comparison with the other gauging sites upstream of Bhakra is as below.

Khab[44]	Rampur[44]	Bhakra
9.600	15.120	25.011
7.250	12.290	16.775
5.240	9.710	11.295

2.5 SEDIMENTOLOGY

The whole of Satluj basin lies in Himalayas which are geologically young. Most of the runoff is contributed by heavy rains in monsoon season but snow melt also contributes significantly to the total runoff. The river carries a lot of silt during monsoon season.

The silt observations are being regularly made at various stations in the basin at Khab, Wangtu, Rampur, Suni and Kasol. Based on the observations taken at these stations the estimated average annual sediment yield at Khab, the point of confluence of Spiti (one of the largest tributary of Satluj), and the point where the river enters India is as follows (44).

Satluj	7.30 Million Tonnes
Spiti	7.66 Million Tonnes

The catchment area of Satluj at Khab is 36,900 sq kms ,and that of Spiti is about 8000 sq km. The annual discharge of Spiti river is on an average twice the annual discharge of Satluj river upstream of Khab. The annual sediment yield estimated at Bhakra reservoir(45) is 35 million tonnes.

The grain size distribution of silt carried by the river at various stations, estimated by Sharma et al. (44), is as given below:-

River	Percentage of sediment		
	Fine	Medium	Coarse
	<0.075 mm	0.075-0.20 mm	>0.20 mm
Satluj at khab	64.1	22.3	13.6
Spiti at Khab	66.4	21.2	12.4
Satluj at Wangtoo	59.9	23.2	16.9

The petrographic analysis of the sediment of river Satluj at Wangtu (Table 2.1) shows that about 50 % sediment consist of particles of hardness more than 7 on Mohr's scale, 40 % of sediment is of quartz and most of the sediment is angular or sub rounded.

2.6 STATUS OF HYDROPOWER DEVELOPMENT

Exploitation of hydropower in Satluj basin started, in the beginning of last century when in 1912, Chaba power house(1.75 MW) was constructed on Nauti khad, a tributary of Satluj river near Shimla, the summer capital of British India. Following paragraphs give a brief description of existing, under construction and planned hydropower schemes in Satluj basin. Figure 2.2 shows the existing/under construction and planned hydropower projects in Satluj river.

2.6.1 Existing Hydropower Schemes

The following hydropower projects are in operation in the basin.

1. Sanjay Vidyut HEP(120 MW)
2. Ganvi HEP(22.5MW)
3. Rongtong Hydel Project(2MW)
4. Nogli Hydroelectric Project(2.5 MW)
5. Chaba Hydroelectric Project(1.75MW)
6. Rukti Hydel Project (1.59 MW)
7. Bhakra Dam Project (1020 MW)

Out of the seven schemes Bhakra is the major reservoir project at the downstream end of the basin. The other major project is Sanjay (Bhaba) vidyut pariyojna project which is run-of-river scheme. The others fall in the category of small hydro projects.

2.6.2 Hydropower Schemes Under Construction

1. Nathpa Jhakari Hydroelectric Project (1500MW)
2. Baspa -II Hydroelectric Project (300 MW)
3. Bhaba Augmentation Power House(3 MW)
4. Karcham Wangtu HEP (1000 MW)

These are the run-of river projects.

2.6.3 Planned Hydropower Projects

Table 2.2 gives the list of planned hydro power projects in the Satluj basin. These are planned to harness the rest of the potential of the basin. Except Kol dam and Baspa-I all are run -of-river projects.

2.7 PROJECTS AND THEIR DESILTING ARRANGEMENTS

Following paragraphs describe in brief the projects and the silt removal measures adopted in these projects which are in operation and under construction on Satluj river basin.

2.7.1 Projets Under Operation

1. SANJAY VIDYUT PARIYOJNA (120 MW):-

Sanjay vidyut pariyojna is a run-of-the river project on river Bhaba a tributary of Satluj river. The project consists of a diversion weir, desilting basin, balancing reservoir, 5.55 km long head race tunnel, surge shaft, a pressure shaft and an underground power house on the right bank of Satluj river. Three, twin jet vertical axis Pelton turbines integrally cast 13Cr: 4Ni runners of 21 buckets, each of 40 MW capacity have been installed. The project utilizes a design discharge of 17.5 cumecs and a net head of 825 m, to produce 120 MW(3x40MW) of power.

As already stated the river is snow fed, and carries a lot of silt during melting of snow and monsoon season, adequate desilting arrangement in the form of two desilting basins each 50 m long, 12.5 m wide and 6 m deep, with five hoppers each of 10m x 10m size has been provided to exclude particle size larger than 0.2 mm. The desilting arrangement has been shown in figure 2.3.

The project commissioned in the year 1989 is experiencing a lot of damage to its under water parts despite the provision of desilting basin. Petrographic analysis[6] of silt has indicated that it has 76% Quartz, 11 % Magnetite, 13 % Biotite and the balance is Muscovite.

2. GANVI HYDEL PROJECT (22.5 MW)

Ganvi hydel project is a run-of- the river scheme on Ganvi khad a tributary of river Satluj. The scheme consists of a trench weir across Ganvi khad, head race channel/tunnel, desilting arrangement, fore bay, penstock, and an under ground power house. Three,four jet vertical axis Pelton turbines, each of 7.5 MW capacity have been installed. The project utilizes a gross head of 385 m. The project has been commissioned in the year 2000.

Ganvi khad carries significant quantity of sediment in suspension during summer season when snow melts and the monsoon season, which is predominantly abrasive in nature. Keeping in view the silt carried by Ganvi khad adequate silt removal arrangement in the form of vortex tube shown in Fig 2.4 has been provided to exclude the particles greater than 0.2 mm in size.

3. RONG TONG HYDEL PROJECT(2.5MW)

Rong tong hydel scheme is a run-of the river scheme, on Rong tong nallah a tributary of Spiti river in Satluj basin. The project consists of a 35 m long crated type diversion weir, 2.435 kms long head race channel/tunnel, desilting tank, fore bay and a surface power house. The project utilizes a gross head of 60 m for a design discharge of 4.25 m^3/sec. A 60 m long, 4.75 m wide desilting basin has been provided to exclude particles larger than 0.2 mm size.

4. NOGLI HEP(2.5 MW)

Nogli HEP is a run-of -the river project on Nogli khad a tributary of river Satluj. Nogli khad carries a lot of silt and is experiencing a lot of damage in under water parts of power station.

5. CHABA POWER HOUSE (1.75MW)

Chaba hydel project is a run-of-the river type development on Nauti khad a tributary of river Satluj. The Nauti khad carries a lot of silt in monsoon season. The under water parts of the Chaba power house are experiencing a damage due to presence of silt in the waters. Sediment exclusion devices have been provided upstream of the head regulator of the power channel.

6. BHAKRA DAM (1020 MW)[45]

This is a multi purpose project .The project consists of 225.55 m high concrete gravity dam, built across Satluj river to create artificial reservoir, named as Gobind Sagar. It has a water spread area of 17,000 ha at its maximum water level. Its designed live storage capacity at maximum water level is 7436 MCM and dead storage capacity is 2432 MCM.

Satluj river being a snow fed river, carries a lot of silt during melting of snow and monsoon season. As per the silt load data observed in its catchment, it is estimated that the river carries about 35 MT of silt every year in to the Govind Sagar reservoir. Silt deposition is affecting its capacity.

The turbines and other under water parts of the project are not experiencing any significant silt damage as the trapping efficiency of the reservoir is about 98.5 %.

2.7.2 Projects Under Construction

1. NATHPA JHAKRI PROJECT(1500 MW) [30]

Nathpa Jhakri Hydel Project is a run-of-the river scheme on Satluj river. The project consists of a concrete gravity diversion dam, desilting arrangement, 27.35 kms long head race tunnel, surge shaft, three pressure shafts and an under ground power house, where six number vertical axis. Francis turbines, each of 250 MW capacity will be installed. The project utilizes a net head of 425 m and a designed discharge of 425 m^3/sec to produce 1500 MW of power.

Satluj river carries a lot of silt. Severe sediment damage to under water parts of powerhouse is anticipated. To combat this problem four desilting chambers each 525 m long, 16.1 m wide and 27.5 m deep have been provided to exclude particles larger than 0.2 mm. The desilting arrangement has been shown in figures 2.5 and 2.6.

2. BASPA HYDEL PROJECT STAGE-II (300 MW)

Baspa-II hydel project is a run-of-the river type development on Baspa river a tributary of Satluj river. The project consists of a diversion barrage, desilting arrangement, 7.77km long head race tunnel, surge shaft, underground pressure shaft, an underground power house on the right bank of river Satluj near Karcham. Three vertical axis Pelton turbines each of 100 MW capacity have been installed in the powerhouse. The project utilizes a gross head of 683 m and a design discharge of 52 m^3/sec to produce 300 MW of power.

The river carries a lot of silt. To save the underwater parts of power station from silt damage desilting basin comprising two chambers each 105 m long and 34 m wide has been provided to exclude particles greater than 0.2 mm size.

3. KARCHAM WANGTU HYDEL PROJECT (1000 MW):-

Karchham Wangtu Hydel Porject is a run- of- the river scheme on river Satluj. The Project consists of a concrete gravity diversion dam, desilting arrangements, head race tunnel, surge shaft, underground pressure shaft and an underground power house on the right bank of Satluj river near Wangtu.

Satluj river carries a lot of silt. Desilting chambers of size comparable to that of Nathpa Jhakari Project have been proposed. Model studies are in progress.

4.BHABA AUGMENTATION PROJECT (3MW)

Bhaba Augmentation Project is a run-of-the river scheme on Shango khad a tributary of Bhaba. The project consists of a diversion weir, desilting basin, power tunnel, fore bay, a surface penstock, and surface power house just upstream of intake weir of Bhaba project. It will utilize a net head of 148.4 m. This project discharge will also be utilized for augmentation of power at Bhaba project.

The Shango khad carries a lot of silt. To combat the problem of sediment damage, an under ground desilting basin 30 m long, 13 m wide and 3 m deep has been provided to exclude particles size greater than 0.2 mm.

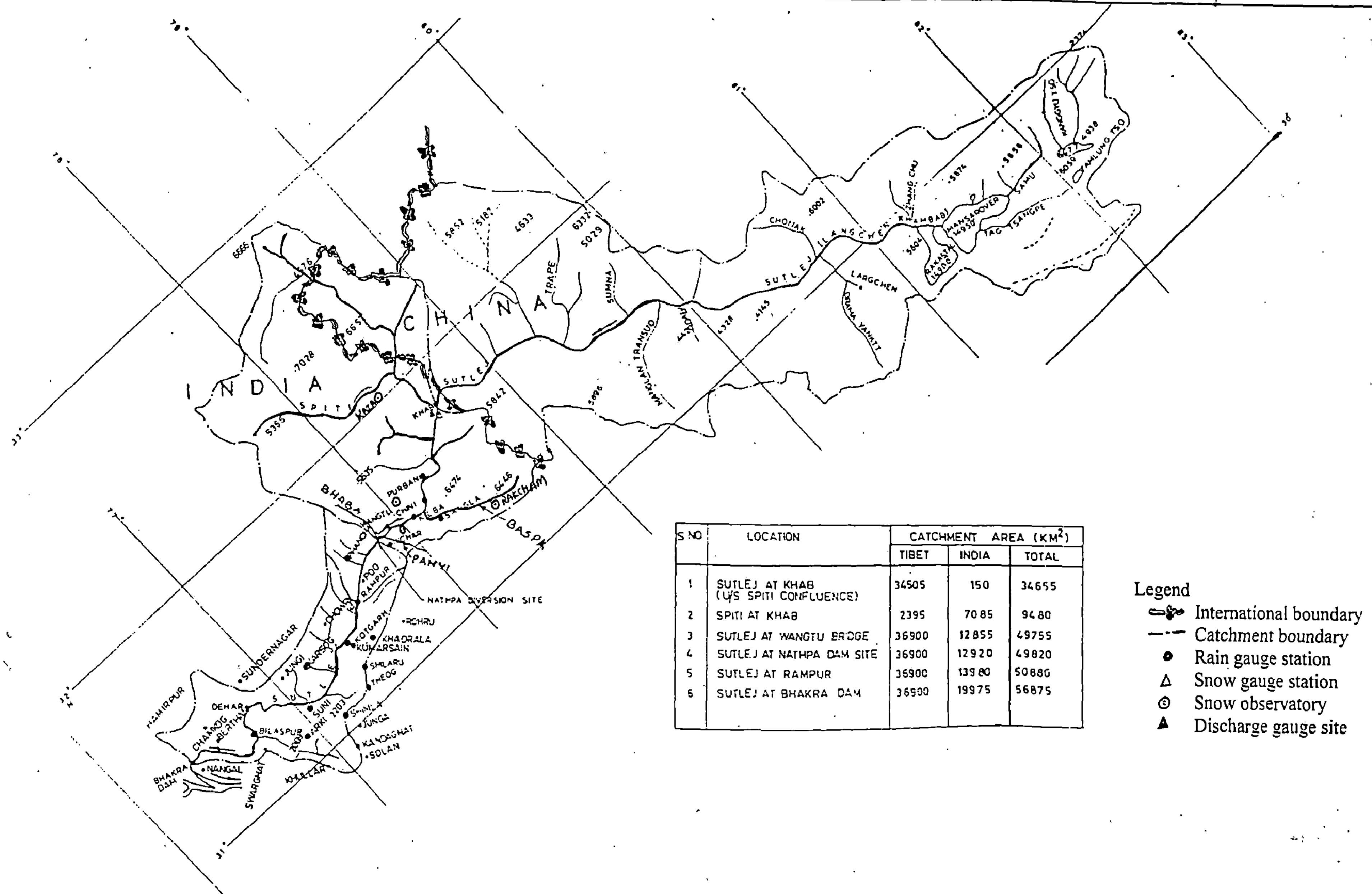
TABLE 2.1:- PETROGRAPHIC ANALYSIS OF THE SEDIMENT OF SATLUJ RIVER AT WANGTU

Constituent	Hardness on Mohr's scale	Percentage of the whole sample(%)	Shape of grains
Quartz	7	38.2	Smaller grains are angular and larger grains are sub-rounded
Biotite	2.5-3	13.8	Flakes
Muscovite	2-2.5	9.1	Flakes-specks
Tourmaline	7-7.5	0.6	Sub-rounded
Zircon	7.5	2.7	Sub-rounded
Epidate	6-7	0.7	Sub-rounded to rounded
Hornbllende	5-6	1.8	Prismatic
Augite Garnet	6.5-7.5	4.4	Sub-rounded
Felspar	6	5.4	Sub-rounded
Chlorite	1.5-2.5	3.6	
Apatite	5	0.7	Sub-rounded
Sphene	5-5.5	0.9	Sub-rounded
Magnatite and other dark material	5.5-6.5	14.9	Sub-rounded
Clay mineral		3.2	

TABLE 2.2 :- PLANNED HYDROPOWER SCHEMES IN SATLUJ BASIN

Sr No	Name of Project	Estimated potential (MW)	River /Khad
1	Kealing -Lara	40 MW	Spiti
2	Lara Hydel Project	60 MW	Spiti
3	Mane-Nadang	76 MW	Spiti
4	Nadang Lara	60 MW	Spiti
5	Sumte Kathang	130 MW	Spiti
6	Lari Sumte	104 MW	Spiti
7	Chango Yangthang	140 MW	Spiti
8	Yangthang-Khab	400 MW	Spiti
9	Khab-Pooh	360 MW	Satluj
10	Pooh-Spillo	200 MW	Satluj
11	Spillo-Thopan	440 MW	Satluj
12	Thopan-Shongtong	520 MW	Satluj
13	Shongtong Karcham	280 MW	Satluj
14	Rampur Hydel Project	439 MW	Satluj
15	Suni Dam Project	400 MW	Satluj
16	Kol Dam Project	600 MW	Satluj
17	Kirang Taiti	120 MW	Kirang
18	Tidong	100 MW	Tidong
19	Kashang	66 MW	Kashang
20	Baspa-I	210 MW	Baspa
21	Ropa	80 MW	Ropa
22	Sorang	80 MW	Sorang
	Total	**5585 MW**	

Note:- 1. All the projects except, Kol Dam and Baspa-I are run-of-the river projects.



S NO	LOCATION	CATCHMENT AREA (KM²)		
		TIBET	INDIA	TOTAL
1	SUTLEJ AT KHAB (U/S SPITI CONFLUENCE)	34505	150	34655
2	SPITI AT KHAB	2395	7085	9480
3	SUTLEJ AT WANGTU BRIDGE	36900	12855	49755
4	SUTLEJ AT NATHPA DAM SITE	36900	12920	49820
5	SUTLEJ AT RAMPUR	36900	13980	50880
6	SUTLEJ AT BHAKRA DAM	36900	19975	56875

Fig. 2.1 CATCHMENT OF RIVER SATLUJ

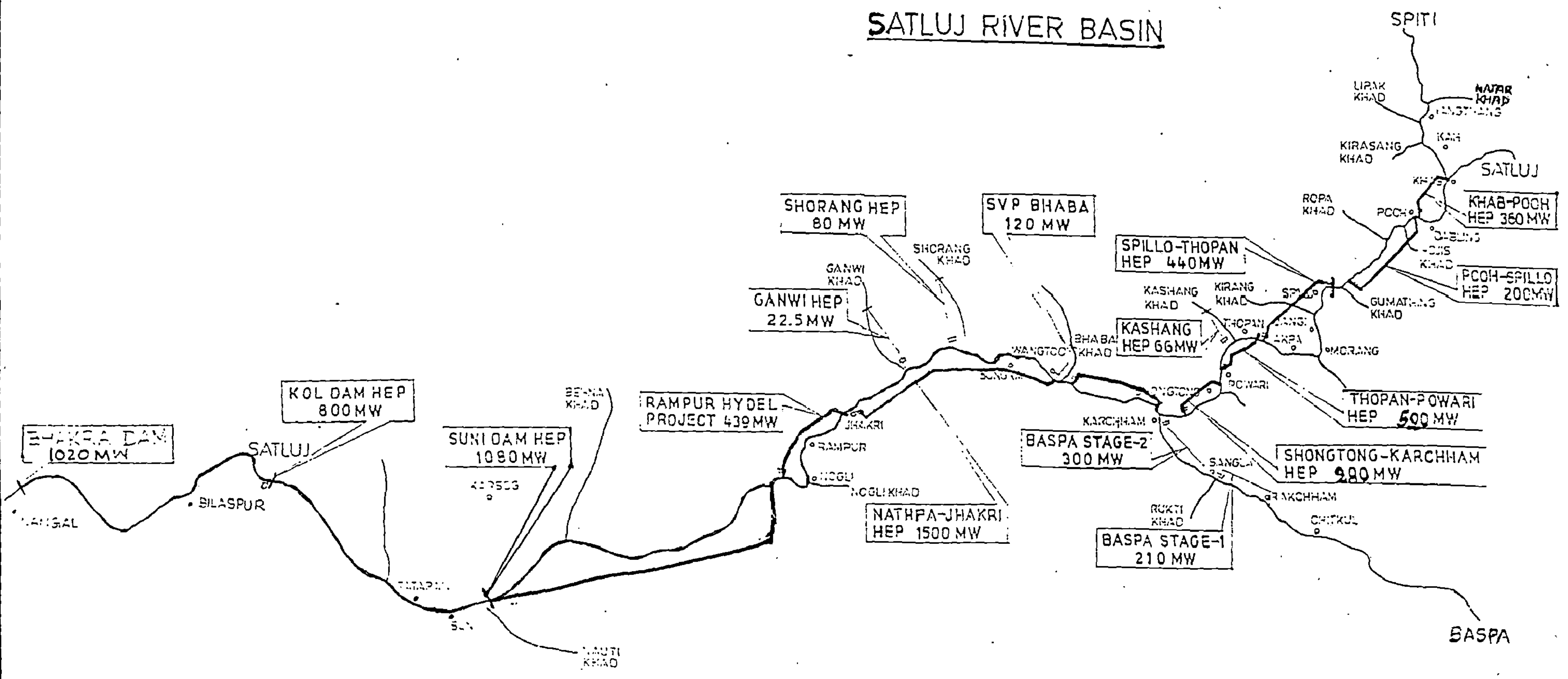


Fig. 2.2 HYDROPOWER PROJECTS IN SATLUJ RIVER BASIN

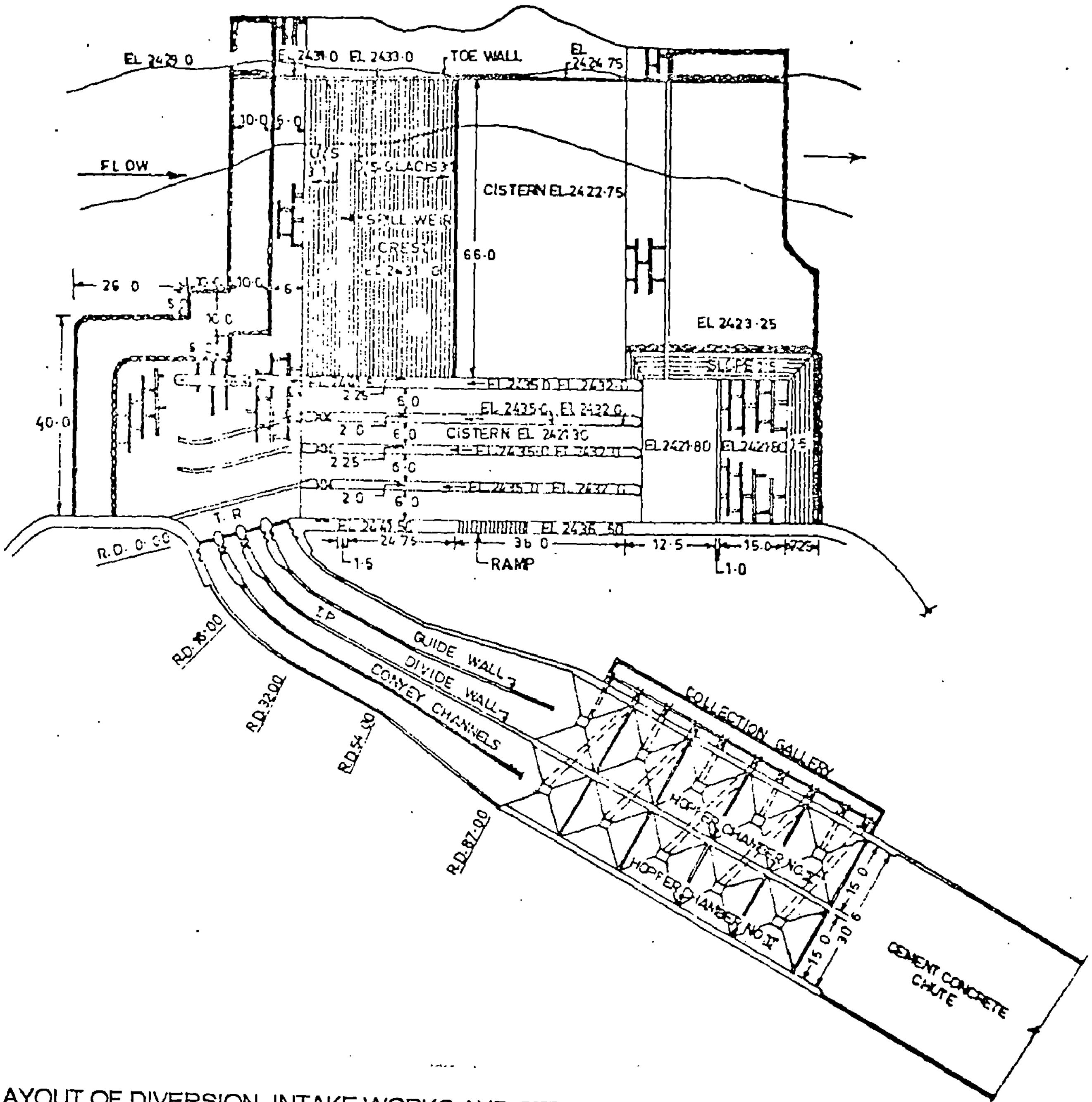
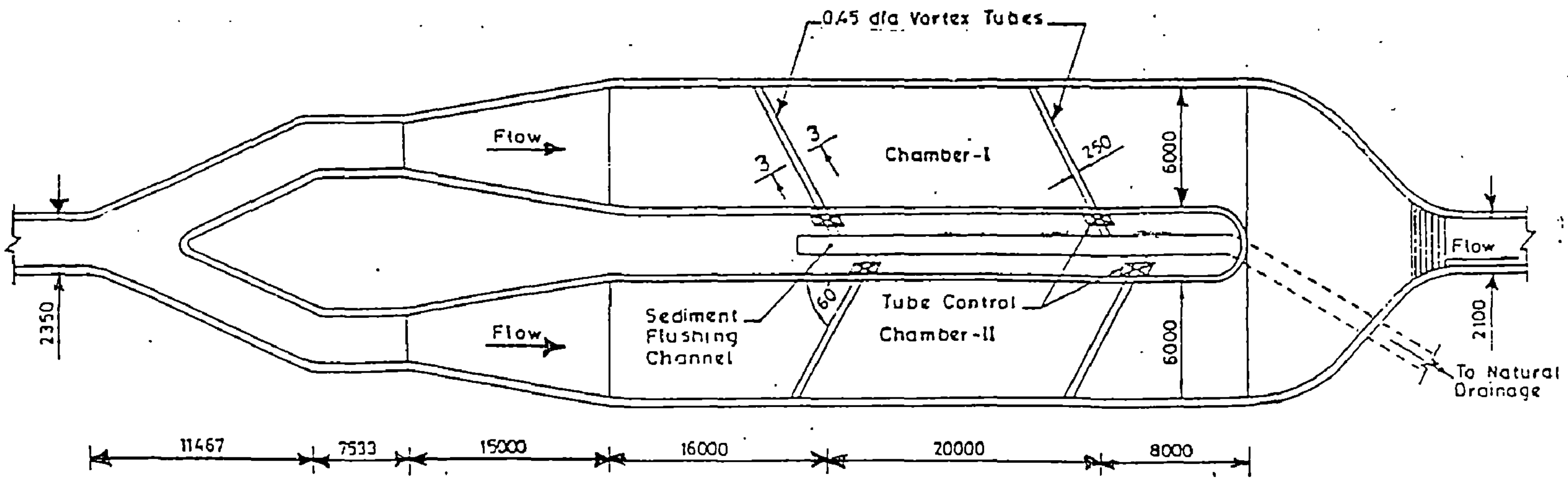
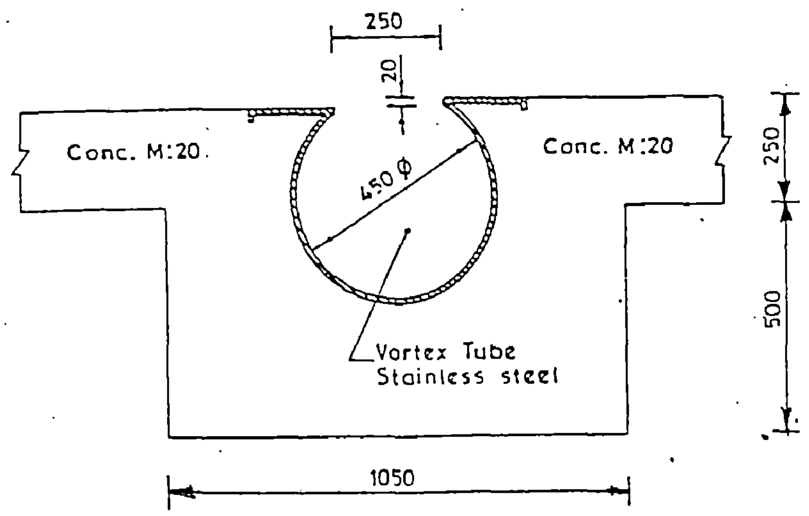


Fig. 2.3 LAYOUT OF DIVERSION ,INTAKE WORKS AND SETTLING BASIN OF SANJAY VIDYUT PARIYOJNA



PLAN



SECTION 3-3

Fig. 2.4 VORTEX TUBE DESILTING BASIN FOR GANVI HYDEL PROJECT.

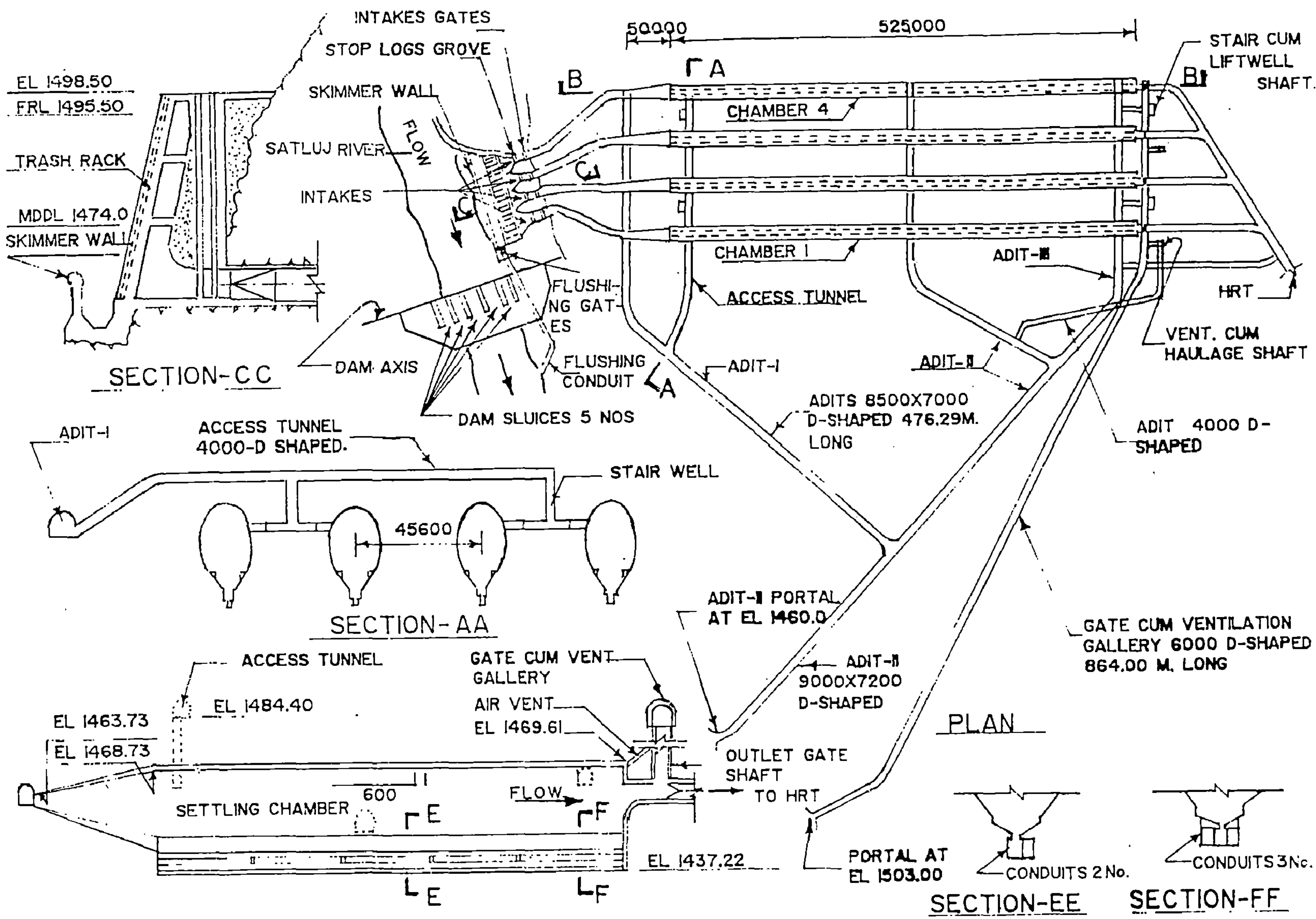


Fig. 2.5 LAYOUT OF DESILTING COMPLEX OF NATHPA JHAKARI HEP

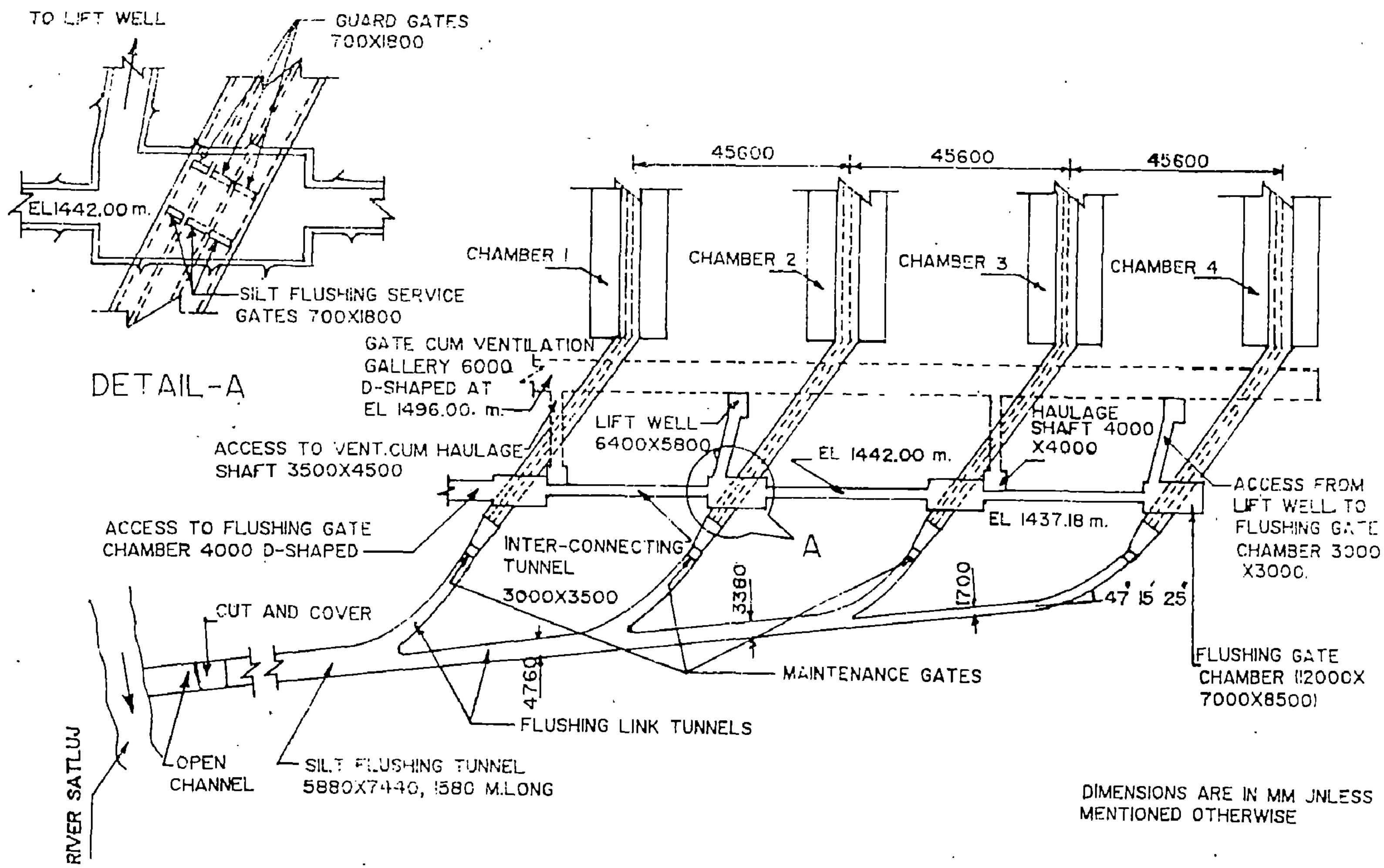


Fig. 2.6 DETAILS OF FLUSHING ARRANGEMENTS FOR DESILTING BASIN OF NATHPA JHAKARI PROJECT.

CHAPTER 3

REVIEW OF LITERATURE

3.0 GENERAL

This chapter deals with the literature review about the damages to the under water parts of powerhouse equipments due to sediment in river water. It also includes a review of methods developed for design of desilting basins provided in all the power projects to minimise the damages in the turbine.

3.1 HYDRO ABRASION

Suspended silt in water, while passing through the under water parts of power station is subjected to the forces of gravity, viscosity, inertia, turbulence and cavitation. Combination of these forces make silt movement highly complex under varying velocity profiles and pressure gradients.

Hydro abrasion is mainly caused by abrassive particles being transported into the vicinity of wetted surfaces. Some of the particles flowing with the water through hydraulic machines are transported by centrifugal force towards these surfaces and each time a particle impinges on a surface the energy released during decelaration removes a small amount of material. Silt erosion or abrasion is understood to be the removal of material due to microscopic surface tearing by solid particles, transported in water. The extent of material removal depends upon the velocity and force with which the particle acts over the surface.

3.1.1 Causes of Abrasion Damage [40]

Silt particles of different sizes, shapes and hardness pass through the under water parts of hydro-turbine, and cause damage in varying degree. There are two basic causes for this damage to surfaces of material. These are briefly summed up below:

(a) Hard sediment particles of quartz, which are carried along with the water, impinge at a very small angle on the surface of various turbine components against which these are pressed perpendicularly. As they move over the surface, they scratch, furrows causing removal of microchip of metal. This is known as sliding abrasion/scouring caused by the tangential flow over the surface of material. Angular quartz particles which have greater hardness are likely to cause more severe damage, while hard polished surfaces and hard coatings over metal withstand these forces, soft material are easily abraded.

When silt particles impinge on the surface at wide angle, it causes material fatigue failure due to repeated impacts. Brittle and hard coatings are prone to such impact abrasion while tough elastic materials are more resistant to wear.

b) Where cavitation problem also exists, besides abrasion, such areas experience accelerated material damage. Solid particle forms nuclei of vapour bubble and when it bursts, the impact energy on metal surface is much more and causes accelerated damage.

3.2 PARAMETERS AFFECTING ABRASION

The parameters which are found responsible for hydro abrasion are categorised into three groups, the characteristics of sediment particles the flow characteristics and the characteristics of base material. These are briefly described below:

3.2.1 Characteristics of Sediment Particles

The physical characteristics of sediment may be defined in many ways, such as grain size (equivalent diameter), shape (round or sharp edges), geological structure (mainly hardness) and grading (distribution of varying sizes). The simplest and most widely used in practice is the particle size, expressed as d_{50}.

The abrasion of turbine parts is related to the following characteristics of silt particles.

a) Size and shape

b) Hardness

c) Gradation

The effect of these characteristics on abrasion is briefly described below:

a) Size and shape

Results[28] obtained from rotating disc specimens of different materials in forced recirculating test devices indicate a definite relationship between the abrasion intensity and particle size d_{50}. It has been found that abrasion remains moderate for all particles smaller than 0.05 mm, and rises sharply for larger sizes. Generally d_{50} of 0.05 mm is taken as a threshold value, although some investigators argue that it should be a much smaller value, of 0.02 or 0.03 mm.

Erosion due to angular and sharp edged particles is significant rather than round shape. Sharp quartz doubles the erosion as compared to round edged particles.

b) Hardness

The intensity of erosion has been found directly proportional to the hardness of particles (irrespective of sizes).Particles with Mohr's hardness above 5 are considered damaging. Incidently sediment in Himalayan rivers comprises 70 % or more of quartz, whose hardness is 7 on Mohr's scale.

c) Concentration

Erosion damage is found to increase with increasing concentration of silt. Field observations and laboratory experiments indicate that intensity of erosion is directly proportional to concentration of silt .It is observed that particles with Mohr's hardness above five and size even less than 0.1 mm but with high concentration cause extensive erosion damage.

3.2.2 Pattern of Flow Velocities[40]

Flow velocities, turbulence, vortices, etc. are the flow characteristics which effect rate of abrasion. This effect can be summarised as under.

Damage is proportional to at least relative flow velocity squared to flow velocity raised to the power three.

Excessive local velocities due to sharp flow and deflection of water flow causes increased local damage because flow deflection causes lateral acceleration and hence increased particle pressure on material surface. Therefore, smaller the radius of curvature of parts in water flow path, more the damage.

Stream lined water flow conditions in the runner and distributor resulting to homogeneous velocity and pressure distribution causes less abrasion damage.

More turbulence causes more particles to come in contact with wetted surface and hence more damage.

First stage of abrasion damage is indicated by surface polishing of effected components, followed by pronounced waviness. Cavitation damage can also set in a secondary effect.

3.2.3. Characteristics of Base Material [27]

The material used for turbine components is equally important factor influencing the erosion damage. Hardness of the material, its chemical composition, micro-structure and its work hardening property, influence the intensity of erosion. The choice of material for a particular component is to be made considering its ability to meet the functional requirements like impact strength and ability to withstand cyclic loading in addition to its wear resistance.

3.3. RATE OF EROSION [27]

Silt erosion rate (w) can be generally governed by the farmula

$$W \propto S_1\ S_2\ S_3\ S_4\ M_r\ V^x$$

Where,

S_1 - Coefficient of silt concentration

S_2 - Coefficient of silt hardness

S_3 - Coefficient of silt particle size

S_4 - Coefficient of silt particle shape

M_r -Coefficient of wear resistance of base material

V^x - Relative velocity of water with exponent x

Based on experience of some hydropower stations in Latin America, following values of exponent x have been suggested;

X =3.0 for Francis runners

X = 2.5 for Guide vanes and pivot ring liners

X = 2.5 for Pelton nozzle

X = 1.5 for Pelton runner bucket

3.4 COMPONENTS PRONE TO DAMAGE DUE TO HYDRO -ABRASION

Following components of the hydropower station are prone to hydro abrasion due to sediments.

3.4.1 Turbines

Abrasion of various turbine components causes considerable loss of efficiency.

Among the three types of turbines namely Francis, Kalpan and Pelton, the last is the most sensitive to erosion effects followed by Francis and Kalpan is the least sensitive (26). Erosion effects on various turbines are described below:

1. FRANCIS TURBINES

In case of Francis turbine, since the relative velocity of the water compared to Pelton turbine is low, the effect of any roughness is not so detrimental. The silt passing through the clearances, however, would wear the runner band and the stationary ring thus increasing the clearances which in turn would reduce the efficiency. Increased guide vane clearances, top and bottom guide vane clearances with respect to top cover and pivot ring guard plates results in loss of efficiency. Increased leakage through labyrinth, following increased clearances not only lowers efficiency but also causes increase in down thrust of turbine. Abrasion guard plates disturbs streamlined flow of water causing loss of efficiency. On runner, abrasion causes blades to thin out, followed by cracking and severe damage besides efficiency loss. As a whole, depending upon severity of erosion there is considerable efficiency loss.

Following components are more prone to damage in case of Francis turbine:-

a) Runner blades especially intersection of runner blades with band
b) Guide vanes ,guide vane bushes and seals
c) Shafts seals
d) Labyrinths
c) Guard plates for pivot ring and top cover

Decrease in peak efficiency (η) has been found directly proportional to increase in ppm. The experiments conducted in Japan on Francis turbine model give the peak efficiency reduction as, $\eta_m = [1\text{-}0.85\ C_w]\ \eta_w$

where,

$\eta_m = \eta$ with sediment laden flow

C_w = Fraction of solid by weight

$\eta_w = \eta$ with sediment laden flow

2. PELTON TURBINES

The effect on Pelton turbines is severe because the roughened surfaces of the nozzle and needle, due to coarse silt, tend to distort the impinging jet and cause it to loose its compactness. The jet therefore, breaks into a spray and looses part of its kinetic energy. In addition, the splitter in the bucket, being a sharp and delicate edge, will also get damaged and create further loss in efficiency. It has been estimated that even 0.5 mm to 1 mm wear of the needle can produce as much as 9 % loss of efficiency (26)

Pelton turbines normally suffer from following damages due to hydro-abrasion:-

a) Damage to needles and nozzle tip liners due to scouring.
b) Damage to inside of bucket of runner due to impingement of silt particles.

3. KALPAN TURBINES

The effect of erosion due to silt is not very important in the case of Kalpan turbines (being low head) except when large amount of heavy silt particles pass through the runner and cause erosion on the periphery of the blades ,especially at the inflow edge(as noticed at Chila Power House in UP)[1].

3.4.2 Other Hydro Mechanical Equipments

Other hydro –mechanical equipment which are effected by hydro – abrasion are as under:-

a) Spherical valve seals where damage is more if start/stop operations are more.

b) Bypass valves, brake jet valve, drain valve s specially where flow velocities are high.

c) Cooling water system is also affected in following ways:-

   (i) Loss of efficiency of pumps due to increase in clearances between impeller and throat ring .This requires frequent overhauling of pumps.

   (ii) Damage to pump bushes and seals.

   (iii) Frequent choking of strainers.

   (iv) Deposit in heat exchangers, thinning of cooling tubes followed by leakage.

3.5 PERMISSIBLE LIMITS OF PARTICLE SIZE AND CONCENTRATION IN WATER

The maximum size of particles that can be safely permitted to enter form the main criteria in design of silt exclusion works. By experience gained on the working of existing plants and evaluating the damage caused by erosion, it has been found that the maximum permissible size which can safely be permitted will vary between 0.1 mm and 0.7 mm depending upon the type of turbine (17) as given below:

Pelton turbine	0.1 mm
Francis turbine	0.3 mm to 0.5 mm
Kalpan turbine	0.5 mm to 0.7 mm

Other factors which determine the choice of the limit of the particle size are:

(a) Composition of silt: If silt is composed of hard material like quartz, the particle size should be limited to a lower value. In absence of hard material a larger particle size may be allowed.

(b) Clearance between moving and stationary rings: The clearance between the runner and the stationary discharge ring is an important consideration in case of Francis and Kalpan runners. The size of silt that can be permitted to pass will depend on the clearance. If the turbine has to be specially designed for the heavily silt laden water then it has to be fitted with replaceable discharge rings which in some plants are made of rubber. In some cases devices for the injection of clean water into the clearance are provided. When this is so, a less exacting design of desilting works is permitted but these in turn involve additional cost in terms of plant closure for ring replacement etc.

The permissible particle size limit recommended by E.Mosonyi [17] for medium head plants is 0.5 mm to 0.2 mm and for high head plants particle size of 0.1 mm and even smaller may sometimes be objectionable. The abrasion effects in case of high head plants may sometime be prevented by removal of as small size as 0.01 mm and above.

Bharat Heavy Electrical Limited (B.H.E.L) [2] which is the only agency manufacturing medium and large size Hydro units in the country, has fixed some guide lines in regard to the size of particles, hardness of the particles and their concentration in flow and head acting on turbines for selecting the type of material for manufacture of such units.

i) Ensure desilting of harmful particles to the extent of 85 % to 95 %.

ii) If concentration of harmful particles is less than 200 ppm then desilting may not be necessary

iii) Particles greater than 0.25 mm size and having hardness beyond 5 on Mohr's scale are considered harmful

iv) Material of runner and guide vanes with respect to head on turbine for the limit concentration is recommended as given in table 3.1.

v) If silt concentration is more than 200 ppm, of harmful particles, having 0.25 mm size and above, then desilting is necessary for all heads.

Based on pioneering research over a period of 20 years, Du Tong of Chang-to –Agricultural Machinery college, China [16] concludes that in many cases the damage attributed to wear, is caused by cavitation and presence of sand only intensifies the effect of cavitation but its own effect are less serious. He has given the following guidelines to the machines operating in sandy water.

As a first step the probable service life of the machine, based on measurements of wear obtained from the simulative experiments, may be calculated using available relations for such calculations.

i) If the possible operating life of the hydraulic turbine work out to be more than twenty years, such sandy water can be treated normal and only measures to prevent /eliminate cavitation are required.

ii) If the turbine is likely to be eroded to an extent that it becomes unserviceable within 5-10 years then sandy water may be considered as a destructive force and measures to precipitate the sand from water are necessary. The requirement for elimination/prevention of cavitation, however, may still be considered more important.

From the fore going it can be concluded that there is no standard design criteria for the extent of elimination of particle size and concentration in water for the purpose of design.

3.6 MEASURES TO PREVENT EROSION DAMAGE

These can be classified into two group viz.,

a) layout and design of civil works with the aim of reducing size and concentration of harmful particles in the flow passing through turbine and

a) Plant design including the characteristics of base material

These measures are discussed below:

3.6.1 Layout and Design of Civil Works

In run-of -river schemes, following design features are helpful in reducing sediment entry into turbines.

i) Intake gate sill level:

Intake gate sill level should be 3 to 4 meters higher then sill level of spillway gates. Heavy boulders and silt tend to settle near intake gate and periodic flushing of these through undershot operation of gates, helps in preventing higher sized silt particles getting into the power channel/tunnel.

Provision of silt excluder at the intake in under sluice pocket is also helpful in checking entry of coarse sediment in water conductor system. Orientation of intake with respect to Dam/barrage axis should also be such that silt entry is minimum. An angle of 100° to 105° with dam/barrage axis is found best suited for the purpose.

ii) Sediment ejectors

The sediment, which has entered the water conductor system may be ejected out by the provision of tunnel type ejectors or desilting basins. These are located in the down stream of the intake in the water conductor system. Desilting basins are commonly provided. These are discussed in details separately.

3.6.2 Plant Design Aspects

In view of the factors affecting the erosion damage and the components of the plant which are damaged, the following aspects shall be taken into consideration in plant design with a view to reducing erosion damage and repair and maintenance time.

a) The speed of the machine shall be less

b) The shape and spacing of blades should be such that flow is smooth and there is less of turbulence and vortex formation.

c) The following features in plant design may reduce the cost of outages due to erosion damage:

1. Provision for easy replacement of wearing parts i.e. runner, wear plates, labyrinth in Francis turbine and needle tips, nozzle liners and deflector cutting edge in Pelton turbines. Runner removal, and

other turbine components could be designed for easy replacement preferably from bottom.

2. Interchangeability of wear parts from spares and among the units.
3. Main inlet valves should have provision for maintenance seal in addition to service seal.
4. Provision of suitable guard valves to facilitate bypass, drainage and other valves maintenance without dewatering of unit. This provision is helpful especially for high head machines.
5. Replacement of trunion bush of inlet valves without dewatering.
6. Adequate redundancy in cooling water pumps, strainer, heat exchangers.
7. Pressurised shaft seal with provision for maintenance seal.
8. Good quality tools and devices designed for easy dismantling and assembly.

d) In case of overlapping head range for Francis and Pelton wheel it has been argued that Pelton is better from erosion damage consideration.

3.6.3 Material Technology

The most commonly used stainless steel for hydraulic machinery is 13/4 Cr/Ni, it represents a good compromise to withstand the damage mechanism due to cavitation, corrosion and erosion, although it is not specially effective against any one of them. Cavitation and silt erosion tests conducted at BHEL in Hyderabad(17)revealed that while 13/4 Cr/Ni stainless steel performs better for cavitation erosion, there is only a marginal difference in silt erosion rate of different steels, the maximum variation being 13.8 %.

For turbine runners, labyrinth, guide vanes, top covers and bottom rings, the best compromise is to use 13/4 Cr/Ni or equivalent martensites with a cromium content of 13 to 17 percent and Nickel content 4 to 6 percent. These are tough and hard enough, with a high elastic limit with good welding and machining properties.

The use of stainless steel 13/4 Cr/Ni has shown lot of damages in high head power plants. To increase the interval between the repairs some erosion resistant coatings have been developed. These are briefly described below:

Characteristics of Wear Resistance Coatings

The characteristics of abrasion resistance coatings have to be assessed in a quite different way. In contrast to base materials, no generally valid theory exists to estimate their abrasion behaviour. The specific properties of each type of coating and the way in which it is applied have to be considered. To investigate the behaviour of plasma sprayed hardmetal and ceramic coatings, a wide variety of surfacing material and application techniques have been tested.
Various types of protective coatings are as under:-

1. Metallic Coatings

Metal based coatings are tungsten carbide, chromium boride, chromium carbide and alumna titania. Plasma coating is one of the most widely used coating which is described below;

Plasma coating is done by a technique known as plasma nitriding. In the plasma nitriding process, the nitrogen gas is activated by an electric field. The process takes place in a furnace which is partly evacuated and with an internal pressure in the range of 0.1 to 10 mbar.

The components to be treated are connected to the cathode. By switching on an electrical voltage, which is normally in the range of 300-800 V, the treatment gas (nitrogen plus some additional gases) will be ionised. The nitrogen ions will then be accelerated in the electrical field and hit the component (cathode) at high velocity. Ions then will be implanted in to the surface, and some of them will form metal nitrides. This will result in a significant increase in the surface hardness. Typically, for martensite stainless steels, a nitriding depth of 0.15 mm is obtained after 30 hours at a treatment temperature of 550°C. Another important factor is that plasma nitriding will give no, or minimal, distortion to the parts being coated. Therefore the components can be treated in their final machining condition.

Such techniques have also been developed by BHEL in India and were applied on experimental basis on the guide vanes of Baira Siul power station. Guide vanes of Baira Siul Power Station were found to be heavily eroded with deep pits of 15-20 mm, due to silt erosion, after a service period of two years. After a series of experiments done by BHEL on protective coatings, a 500 micron thick plasma coating was applied on one of the guide vanes (13Cr, 5Ni steel). Guide vanes did not exhibited any sign of erosion even after five monsoon seasons.

As a result of the tests, it has been decided that first two turbines to be installed at Nathpa Jhakri Project will be hard coated by plasma nitriding. All other critical parts of the turbines which will be in contact with water, namely the turbine runner, guide vanes and upper part of the draft tube cone, plus check plates and labyrinth rings, will also be coated by plasma nitriding.

2. Non-metallic Coatings

Dura Tough, Ceramic, Epoxy and Polyurethane based plastics come under the category of this type of coatings.

Durah Tough an elastomeric copolymer, developed and patented by Palmer International Inc., USA can offer a viable solution to the quick and reliable repair of critical underwater parts like runner, guide vanes and guard ring liners. Elastomeric means epoxy with flexible properties. It is cold applied without adding metal or heat.

Thin ceramic coating has been used successfully on runner, labyrinth and guide vanes of Francis turbines even under high heads offering good protection from abrasion for more than 10,000 operating hours[27].

Various epoxy and polyurethane based plastics have proved very suitable for the components which are not very much susceptible to abrasion. These coatings are recommended for the following new components and as well as for repair of the same:

i) Spiral casing
ii) Draft tube
iii) Nozzle pipes.

3.7 DESILTING BASINS

One of the major problem faced by hydraulic engineers concerned with the design of hydroelectric and irrigation schemes is the control of sediment entering the power/irrigation canals .

3.7.1 Various Types of Sediment Control Devices

Following are some of the sediment control measures which are commonly used to reduce the sediment entered into the power/irrigation canals:

a) Settling Basins

Settling basin is a popular method for removal of both bed load and suspended load from canal/power channel. The underlying principle is simply to provide a section wide enough so that the resulting reduced flow velocity will allow the sediment to settle out.

b) Vortex Tube Sand Trap

Vortex tube sand trap is open tube placed across the canal bottom either normal to the flow or at some angle such as 30° or 45° to the flow. As the water flows over the tube, vortex flow with a speed of rotation of the order of 200 to 500 rpm is set up, which is sufficient to eject coarse sediment (Ref. figure 2.4 p 25).

c) Tunnel Extractor

It consists of a horizontal slab a little above the canal bed which separates the sediment laden bottom layer from the top layers. Under the diaphragm are tunnels which carries these bottom layers into escape channel. In each tunnel there are sub-tunnels which are formed by constructing curved vanes. The downstream end of the tunnels is located in the bank from which the escape channel takes off, the tunnels usually converge at the downstream end. Typical layout of tunnel extractor is given in fig 3.8.

d) Vortex Settling Basins:

A relatively recent method of sediment ejection is the vortex settling basin(shown in fig.3.9). In a vortex settling basin the flow enters tangentially along the periphery of a circular basin and leaves nearly tangentially as overflow over a weir on a part of the circumference. The settled sediment is removed through the pipe located at the centre of the bottom of the circular basin .The bottom of the basin slopes towards the centre thereby helping collection of sediment near the centre due to the combined action of vortex and the radial flows.

In this study only the principles of operation and design of desilting basin are discussed in details, as these are used with major power projects. Other types are used with small head power plants.

3.7.2. Principle of Operation of Settling Basins

The settling basin is one of the most effective devices for removing sediment particles from flowing water. The reduction in the velocity of flow in the settling basin is caused by expansion of the channel cross section over the length of the basin. Such reduction in velocity also reduces the bed shear stress and the turbulence. Reduction in the velocity, shear stress and turbulence, if adequate, stops the bed material from moving and also causes part of the suspended material to deposit. Once the minimum size of sediment to be excluded has been decided the design of settling basin involves determination of length of the basin and choice of the method of removal of the deposited sediment.

A simple analysis can be made if it is assumed that turbulence does not effect the fall velocity of sediment. For known velocity of flow in the basin, one can determine the length of the basin required to remove sediment of a given size. Let u be the horizontal velocity of flow at any section in a vertical and w_0 be the fall velocity of the sediment to be removed. Hence a sediment particle on the water surface follows a trajectory which is governed by the magnitude of u and w_0. The time required for the particle on the water surface to settle to the bottom is D/w_0, where D is the depth of water in the basin. The horizontal distance traveled in this time interval is $L = (u_1\Delta t + u_2\Delta t + u_3 3\Delta t + ...)$,where $u_1, u_2 ...$ are the velocities at different points in the vertical and Δt is the time. If U is the mean velocity of flow, then L is given by UD/w_0. Because of turbulence, the fall velocity of the particles reduce and the length of the basin required is correspondingly increased. Since quantitative information concerning the effect of turbulence on fall velocity is inadequate, an arbitrary increase of 20 percent is recommended [19]. It may be noticed that any particle which is at lower depth will be deposited on the bottom in a shorter distance. Also the coarser material will be deposited in a shorter distance.

Since the length of basin is directly proportional to the velocity, it is usually economical to decrease the velocity; for this purpose the cross-sectional area of the basin is increased by increasing the width as well as by lowering the bottom. The mean horizontal velocity in the selttling basin that is considered desirable depends on the smallest size of sediment to be removed and the economic length of basin. The velocity in the existing settling basin ranges from 0.08 m/s to 0.45 m/s. The smaller velocity should be used if finer material is to be removed.

3.8 REVIEW OF VARIOUS APPROACHES OF DESILTING BASIN DESIGN

1. Camp Dobbin's Approach

An analysis of flow in settling basin has been presented by Camp [8] and Dobbin's [13]. Dobbins obtained an analytical solution for the design of settling basin assuming no diffusion of suspended matter in the longitudinal direction, the velocity to be constant throughout the depth and the diffusion coefficient to be constant over the cross section. Camp expressed the above solution in graphical form .In giving the graphical solution of Dobbin's equation, Camp used the parameters q_{se}/q_{si}, w/U_*, w.L/U.D., where q_{se} and q_{si} are the amount of suspended sediment of a given size leaving and entering the basin, U is the mean velocity of flow, U_*, is the shear velocity, D and L are the length and depth of the basin respectively. Using Manning's equation the parameter w/U_*, can be written as :

$$w/U_* = \frac{w.D^{\frac{1}{6}}}{n.U.\sqrt{g}}$$

Where, n is Mannings rugosity coefficient, and thus w/U*can be determined. Fig. 3.1 shows the graphical relationship of these parameters for the removal efficiency of basin.

Camp's relationship has also been expressed in terms of $\frac{wD}{2\varepsilon}$ and $\frac{w}{wd}$. Here 'w_d' is the design fall velocity and 'ε' is the sediment transfer coefficient. Fig 3.2 shows this relationship for the removal efficiency of settling basins. If w_d is expressed as $\frac{U.D}{L}$ and ε as 0.075 U* D fig 3.2 reduces to Fig 3.1. These are values proposed by Camp for 'w_d'and ' ε'.

2. Cean et.al., Appraoch

Cean et. al.[14] established a mathematical model for the settling of suspended grains in turbulent flows. They obtained a differential equation for suspension concentration in a settling basin from the law of conservation of matter and assuming concentration distributions to be similar along the direction of the mean flow .The assumed distribution is

$$c(x,y) = C_{a}.\exp[\frac{w}{\varepsilon_y}(y-a)][\exp\{\frac{U}{2\varepsilon} - -\frac{U}{2\varepsilon}\sqrt{1+\frac{4w^2}{U^2}.\frac{\varepsilon_x}{\varepsilon_y}}\}] - - - - - (3..1)$$

where, x-axis is chosen in the direction of flow, y-axis vertically upwards, 'c' is concentration at a point, 'ϵ_y'is the cross-sectional mean of vertical diffusion coefficient ,ϵ is sediment transfer coefficient, c(0,a)=Ca. Here 'Ca' is the sediment concentration at a distance 'a' above the bed. The solution of equation (3.1) is used to determine the similarity criteria for settling basins. The distribution of concentration is found to depend on three non-dimensional variables, $w.D/\epsilon_y$, $U.x/\epsilon_x$ and $w^2 \epsilon_x/U^2\epsilon_y$. The significance of these variables was investigated. It was found that the models of settling basins must have similarity for both the flow velocity and settling velocity of grains.

Sumer transformed Cean.et.al., solution into a series of graphs as shown in fig 3.5, which could be used in predicting the removal ratio of fine sediment in the settling basin.

3. Richardson et.al., Approach

Richardson et.al., [32] have given the methodology for design of settling basin. In this method, critical shear stress, τ_c, for removal of particle is determined. First critical shear stress velocity U_* is thus computed as equal to $(\tau_c/\rho_f)^{\frac{1}{2}}$. The equation of continuity coupled with the resistance equation developed) for a plane bed with little or no sediment transport as given below:

$$\frac{U}{U_*} = 5.9\log_{10}\frac{D}{d_{85}} + 5.44 \text{-------------}(3.2)$$

Equation 3.2 is solved for U, assuming D. The velocity U, obtained this way is non –scouring velocity. Correction for effect of concentration is applied to the fall velocity 'w', of particle by making use of curves proposed by Camp, McNown and Lin [22] as shown in Fig 3.4.

Knowing w, D and U, the length of settling basin L, is evaluated as L=U.D/w.

4. U.S.B.R Approach.

The United State Bureau of Reclamation [42] has developed a basic relation to aid in the design of settling basins. The following is the removal efficiency equation proposed by them:

$$\eta = 1 - \frac{q_{se}}{q_{si}} = 1 - \exp\left(-\frac{w.L}{U.D}\right) \text{---------}(3.3)$$

where

η = Basin efficiency

q_{se} = Amount of sediment leaving the basin per unit time.

q_{si} = Amount of sediment entering the basin per unit time.

w = Fall velocity of sediment

L = Length of settling basin.

D = Depth of water in settling basin

This equation is a particular form of a function relationship as given by Camp and Dobbin's.

5. Sumer's Approach

Sumer [38] analysed the settling of a sediment particle in an open channel assuming logarithmic velocity distribution and the diffusion coefficient 'ϵ_y' to be given by :

$$\frac{\varepsilon_y}{U_* D} = \frac{6y}{D}\left(1 - \frac{y}{D}\right) \text{---------}(3.4)$$

where, 'y' is the elevation above the bed. Since the particle is under the influence of turbulence, it will trace random path after its release. Hence, particles in suspension would be statistical quantities. The statistical properties of the settling length of particle are predicted by the following approach.

Syre [35] pointed out that since the heaviest deposition should occur close to the source and the amount of particles deposited should decrease with distance, the distribution of deposited particles should follow an exponential function with increasing $\bar{t}$ i.e.

$$f(\bar{t}) = \frac{\lambda}{\mu} . \exp\left(-\frac{\lambda}{\mu} . x\right) \text{--------}(3.5)$$

Where, $\bar{t}$ is the mean retention time, x is the non-dimensionalised settling length of a particle x/D. (here x is distance in flow direction), λ is mean rate at which particles settle out in suspension and μ is the non-dimensionalised mean flow velocity (μ= U.D/ϵ_y). Here, the average number of particles that settles out of the suspension in unit length interval is considered to be equal to $\frac{\lambda}{(\mu-\lambda)}$.

Therefore mean settling length

$$X=\int_0^{\infty} X.f(X).dX=\frac{\mu}{\lambda}\text{----------}(3.6)$$

Let η denotes the efficiency of basin. Taking into consideration that efficiency is actually equal to (1- cumulative distribution function of the settling length of the particle) and using equation (3.5), the efficiency can be found as :

$$\eta=\int_0^{X} f(X).dX=\exp(-\frac{\lambda}{\mu}.X)\text{----------}(3.7)$$

From equation 3.7, the design settling length corresponding to certain 'η' is obtained as:

$$L=\frac{-6(\frac{U}{U_*}).D}{K.\lambda}\ln(1-\eta)\text{--------}(3.8)$$

Where, k is Karman's constant.

If the removal efficiency 'η' of sediment is desired, one can determine the length from the preceding equation. For λ one should refer figure (3.3) of λ V_s β as given by Syre's (3.5) numerical solution, where, β is non-dimensionalised settling velocity parameter whose value is equal to w/KU_*. The value of K may be taken as 0.40.

6. Garde et al., Approach [18]

They have conducted laboratory experiments and found that the measured values of removal efficiency were considerably different from those given by Camp, USBR and Sumer. They analysed the data to express the efficiency of the settling basin, η (expressed in %).

$$\eta=\eta_o(1-e^{-CL/D})\text{--------------}(3..9)$$

Where, η_o and C are function of w_o/U_*. Here, U_* is the shear velocity in the settling basin and w_o the fall velocity of sediment particle in clear water. The values of η_o and C for different values and of w_o/U_* as obtained by them are given in table below:

w_o/U^*	0.70	0.90	1.20	1.60	2.0	>2.2
C	0.02	0.03	0.060	0.14	0.215	0.24
η_o	34	40	50	70	97	100

7. Ranga Raju et.al., Approach[31]

Ranga Raju et.al.,, found that the following equation yields better results than equation 3.9 and recommended it for use, when $w_0/U_* <$ 2.5.

$$\eta = 11.7\left(\frac{w_o}{u}\right)^{0.81}\left(\frac{L.B}{B_c D}\right)^{0.23}\left(\frac{D^{\frac{1}{6}}}{n\sqrt{g}}\right)^{0.98} \text{------------} (3.10)$$

Here, w_0 is the fall velocity of particle, U_* is the shear velocity of flow, u is mean velocity of flow, D_c is the depth of flow in the approach channel of width B_c, B is the width and D is the depth the basin. The applicability of the above equation for field situation is still to be checked.

From comparing the results obtained from above methods one to six Ranga Raju ,et.al.[31], found that these methods give uniform results for coarse sand. For finer sediments where $U/U_* <0.4$, these methods does not give satisfactory results and proposed method as described above.

Nandana Vittal and M.S.Raghav, applied Garde et.al., method for design of desilting basin for Maneri Bhali stage-II (particle size removed +0.15 mm) and found that it gives identical results as obtained by

Irrigation Design Organisation U P, which designed the basin by Camp's method.

It has also been stated[17] that settling lengths computed for settling out small fractions by the methods of Dobbin's and Camp are excessive and that deviation from the actually required dimension increases rapidly as the design particle size is reduced to below 0.1 mm.

As per the present practice, desilting basin are designed as per Mosonyi's method, which takes into consideration, the effect of turbulence on the fall velocity of sediment particles and give good results in model studies. The theoretical settling efficiency is determined from the Velinakov's method. These two methods are described below.

a) Mosonyi Method

Mosonyi has adopted the fundamental approach for determining the length of the basin by finding the settling time of the particle through the depth after accounting for the effect of turbulence. The three basic equations used are.

$$Q = b.h.v \quad \text{---------------------} (3.11)$$

$$t = \frac{h}{w} \quad \text{---------------------} (3.12)$$

$$\text{and } L = v.\ t \quad \text{---------------------} (3.13)$$

where , Q = discharge passing through the basin (cumec)

b = width of basin (m)

h = depth of flow (m)

v = flow velocity (m/sec)

L = Length of basin (m)

ω = fall velocity of a particle in stagnant water (m/sec)

Estimating 't' from the two latter equations, two relations are established between six variables i.e.

$$Q = b.h.v \quad \text{---------------------} (3.14)$$

and $L\omega = h.v$ ----------------------(3.15)

Thus, for the solution of the above equations four variables must be known. Of these, Q, v and ω are generally known and /or calculated. In view of the fact that long and/or wide basins can in general be constructed at lower costs than deep ones, Mysonyi, suggested to assume the value of 'h' as the minimum practical depth for the solution of the problem. In deciding the parameter v, Mosonyi recommends adoption of the critical flow through velocity which will not entrain the particles once settled at the bottom. He recommended use of critical velocity relation given by T.R.Camp.

$V = a\sqrt{d}$ cm/sec

where, d is diameter of particle in mm and coefficient

$a = 36$ for $d > 1$ mm

$a = 44$ for $1\text{ mm} > d > 0.1$ mm

$a = 36$ for $d < 1$ mm

However, if the velocity of flow in the desilting chamber, as computed from above is very low, hydraulic short circuiting may occur. This phenomena has been observed by Davis and Mosonyi and has recommended that flow velocity may be kept as 0.4 to 0.6 m/sec.

The value of fall velocity can be determined from Sudry's curve (fig.3.6). The value of fall velocity 'ω' in stagnant water should be corrected for turbulence effect as below.

$\omega_e = \omega - \omega'$

where ω_e = effective velocity

$\omega' = \alpha .v$ (m/sec)

and $\alpha = \dfrac{0.132}{\sqrt{h}}$ in which h is in m

Therefore, making substitutions for the fall velocity

$$L = \frac{h.v}{\omega_e} = \frac{h^{\frac{3}{2}}}{h^{\frac{1}{2}}\omega - 0.132v}(m) \text{ --------------------(3.16)}$$

a) Velikanov's Design Function

Investigation of M.A.Velikanov[17] of were based on the calculation of probabilities. He concluded that settling length 'L' for the turbulent flow can be computed from the settling velocity 'ω' in stagnant water and from the flow through velocity 'v' i.e.

$$L = \frac{\lambda^2 v^2 (\sqrt{h} - o.2)^2}{7.51\omega^2}(m) \quad \text{------------------------------}(3.17)$$

where, v= velocity of flow in basin

h = depth of water

ω = fall velocity of silt particle

Where λ depends upon the removal ratio values of WW defined by Velikanov's function W= f(λ), can be determined from the curve given in figure 3.7 in which W denotes the ratio of the settled sediment to the total amount entering with the flow and is obtained as below:

$W = 100\text{-}100\frac{C_o}{C}$ where, 'C_o'is the permissible concentration of sediment in water at exit of basin and 'C' is concentration of sediment in incoming water in the basin.

The following considerations should be remembered in applying Velikanov's formulae to obtain satisfactory results.

i) In the positive range of 'λ' coefficient pertaining to 'W' values of 90 to 98 % removal of the limit particle size should preferably be applied.

ii) It should be noted that W is related only to the fraction to be settled out and, therefore, cannot be used for the total sediment load unless the limit particle size is the smallest particle in the load or also the sediment is composed of uniform size.

TABLE 3.1 RECOMMENDATIONS OF BHEL(2)

No	Head (m)	Parameters of harmful particles		Erosion prevention, measures on turbine components
		Diameter (mm)	Concentration (ppm)	
I	All heads	i)Less than 0.25 ii) More than 0.25	No bar up to 100 ppm	I.1 No special measures need to be taken on water path surfaces including guide vanes. I.2 Runner to be cast steel/Mild steel with stainless steel over lay on the areas prone to cavitation.
II	Less than 60 m	More than 0.25	More than 100 and less than 200	II-1 Stainless steel (13Cr.with properties of work hardening). Liner plates to be provided on top cover and pivot ring surfaces in water path. II-2.Stainless steel lining(13Cr% (with properties of work hardening) to be considered for the discharge ring . Depending upon the model test results. II.3 Guide vanes to be ordinary steel II.4 Same as I.1
III	More than 60 but less than 100	More than 0.25	----- do ----	IIII.1 Same as II.1 III.2 Stainless steel lining (13 Cr.) to be considered for the discharge ring /inlet portion of draft tube for 200-500 mm. III.3 Stainless steel 13 % Cr over-lay (with work hardening properties) to be provided on guide vane bedding surfaces. III.4 Runner to be of erosion resistant stainless steel (13 % Cr, 1% Ni, or13 % Cr,4 % Ni, or 13 % Cr,6% Nii odr 17 % Cr,4% Ni or 10 % Cr,3% Ni).
IV	More than 100 less 200	----- do ----	----- do ----	IV.1 Same as II.1. IV.2 Stainless steel lining (13 Cr) to be considered for the discharge ring /inlet portion of draft tube for 200-500 mm height, depending upon the Model Test Results. IV.3 Work hardening 13 % Cr Stainless Steel to be considered for guide vanes with reinforced rings on the stem bearing faces of the same material. IV.4 Same as III.3.
V	More than 200 meters	----- do ----	----- do ----	V.1 Same as II.1. V.2 Same as IV.2. V.3 Complete guide vane to be work hardening steel (13 % Cr) 13/1 or 13/4 or 13/6 or 17/4.
VI	All heads		More than 200 ppm	Desiltation necessary.

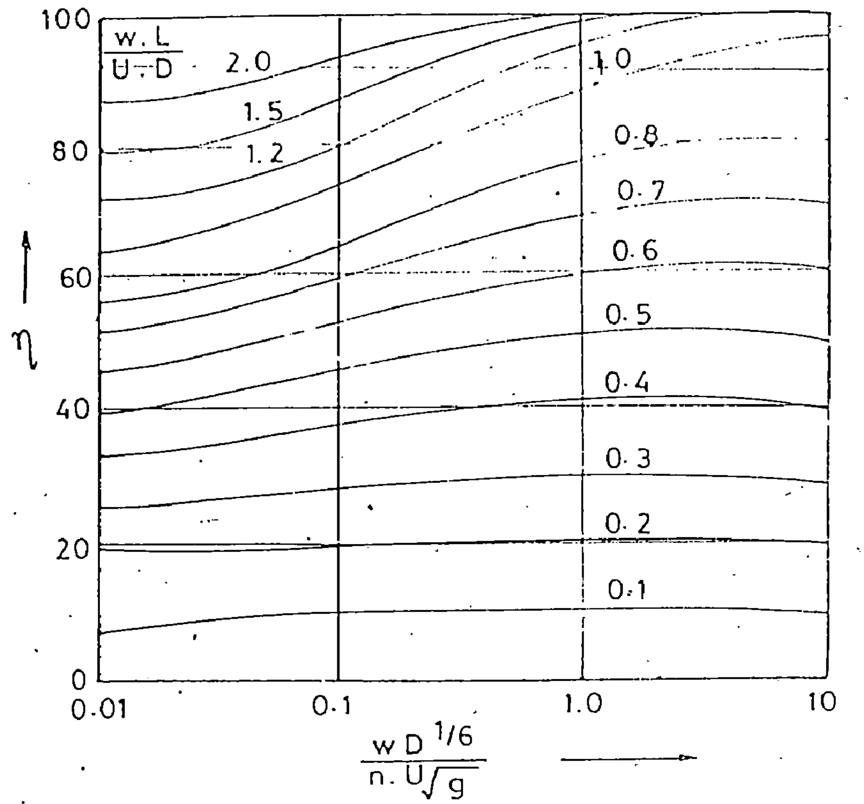


Fig. 3.1 CAMP AND DOBBINS RELATION FOR EFFICIENCY OF DESILTING BASIN.

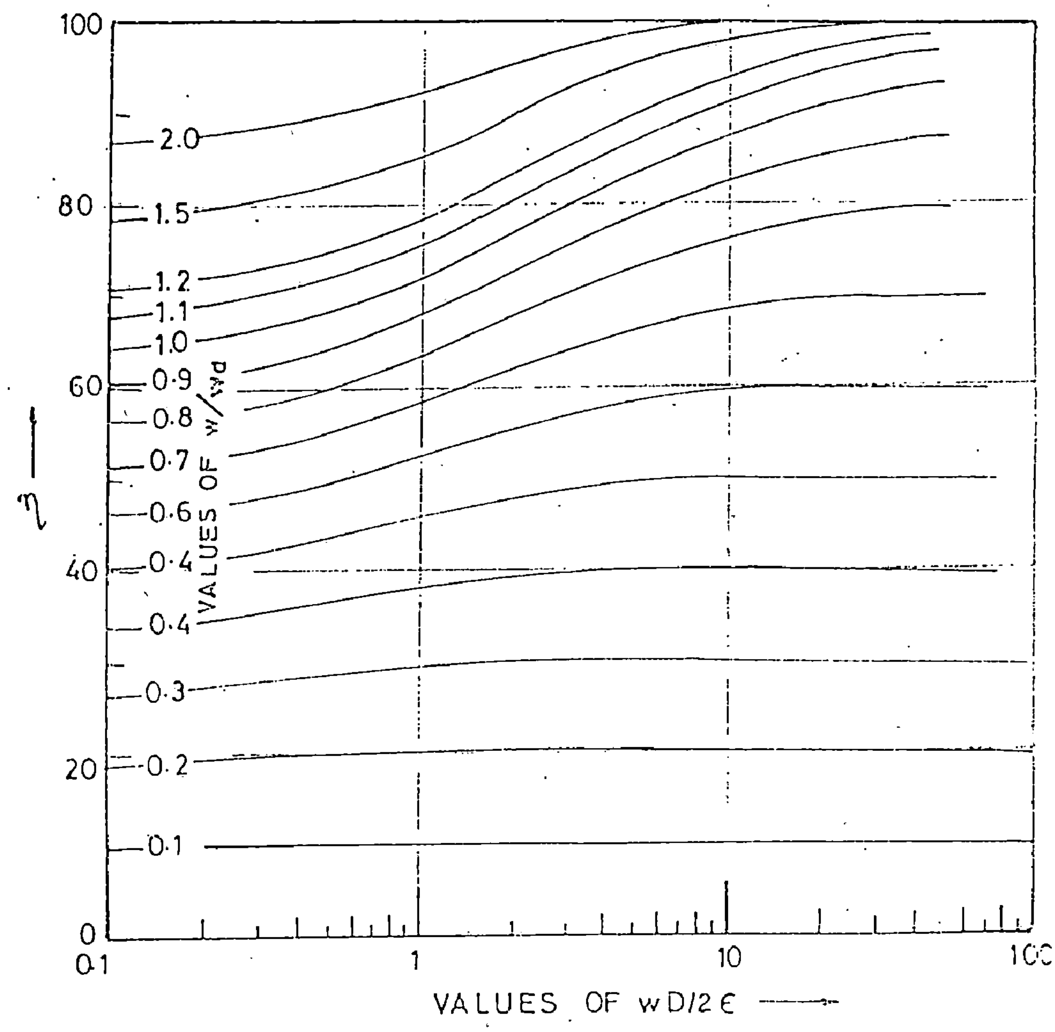


Fig. 3.2 EFFICIENCY IN TERMS OF MIXING COEFFICIENT

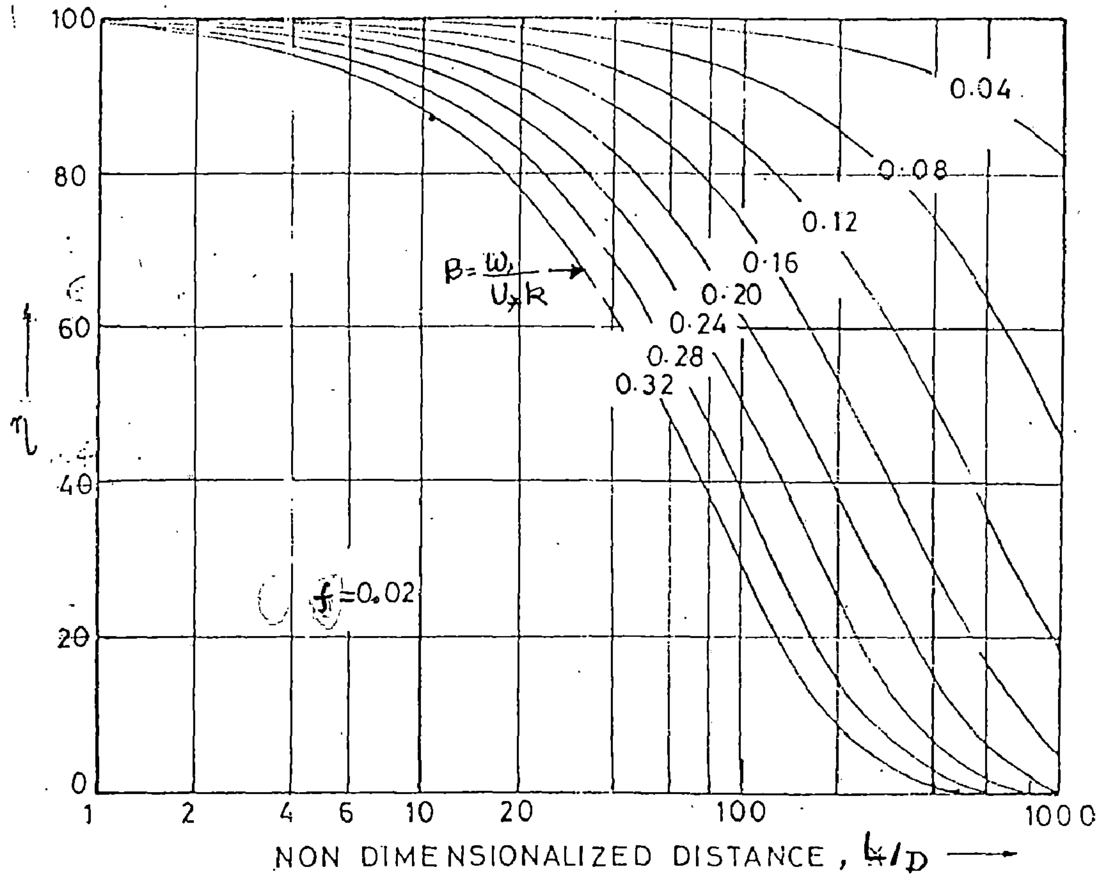


Fig. 3.3 SUMER'S EFFICIENCY CURVES FOR DESIGN OF SETTLING BASINS.

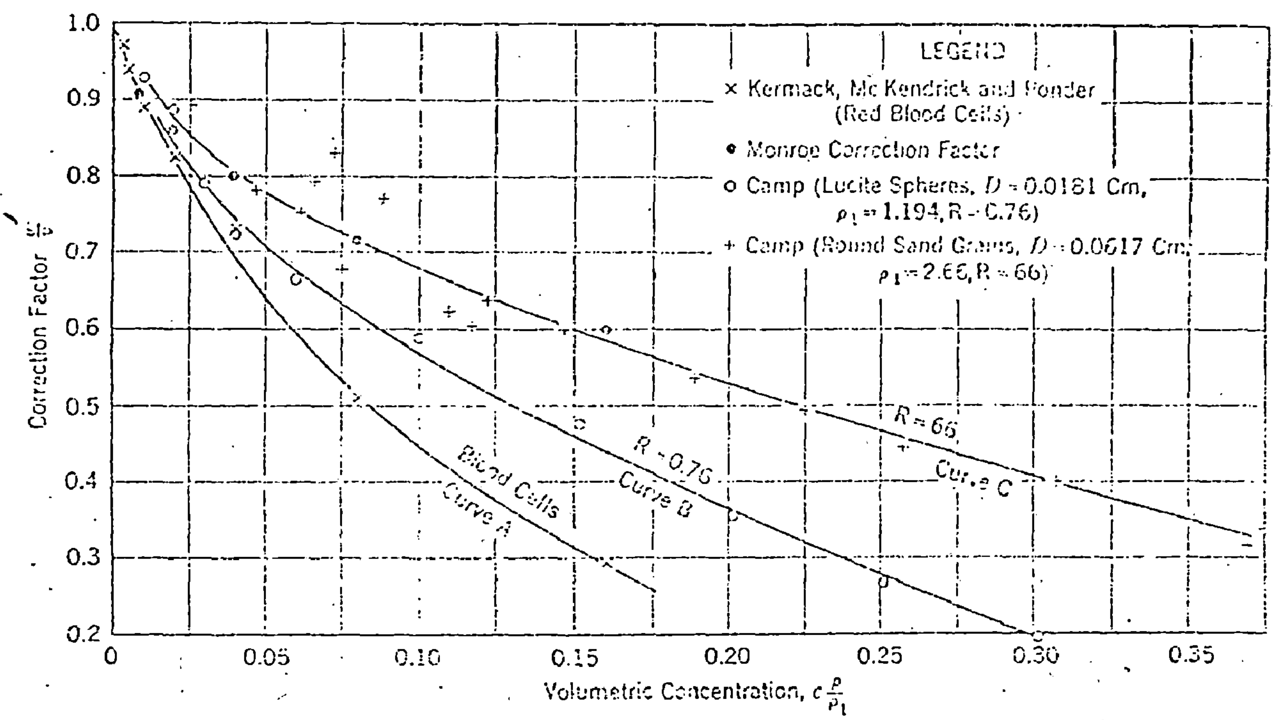


Fig. 3.4 REDUCTION IN VELOCITY DUE TO HINDERED SETTLING

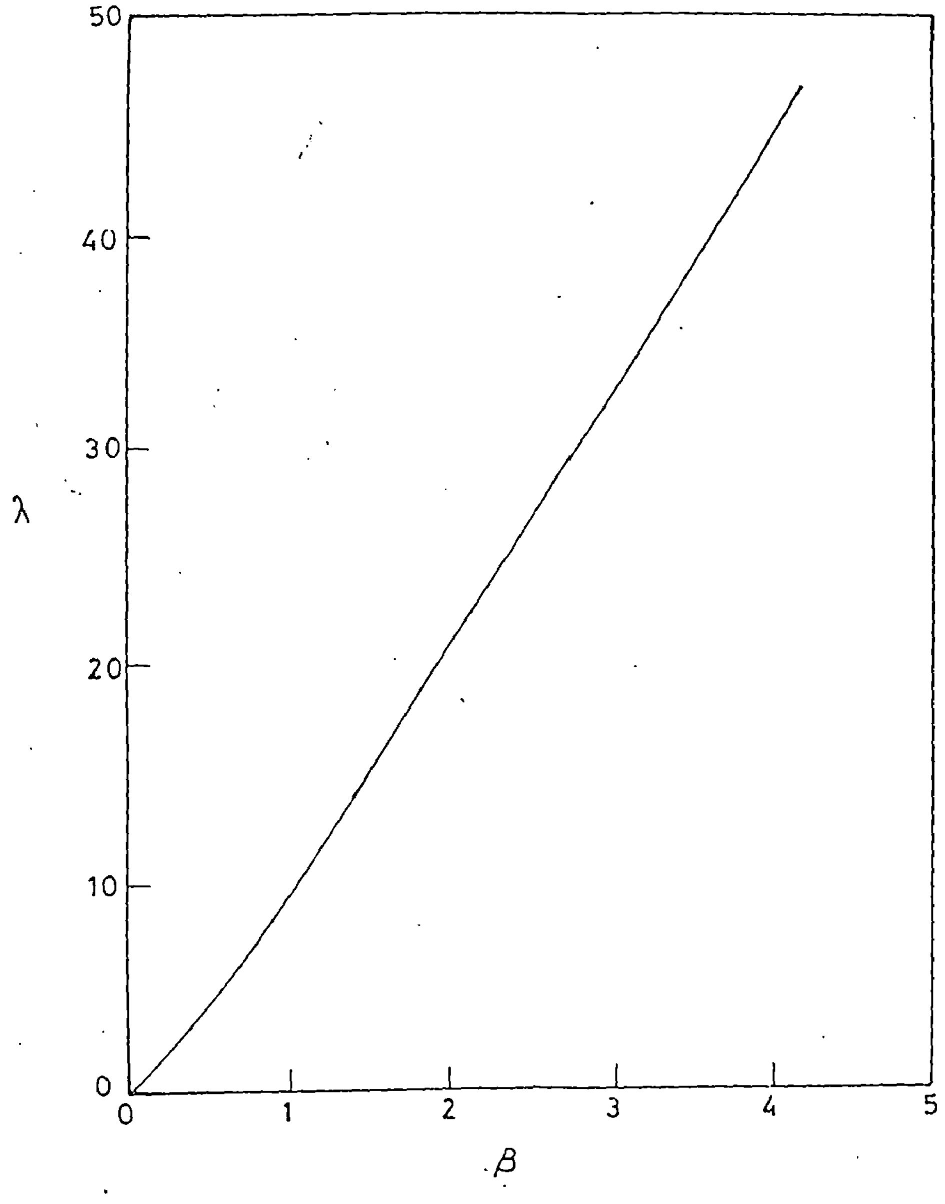


Fig. 3.5 RELATION BETWEEN λ AND β FOR PARTICLE SETTLING

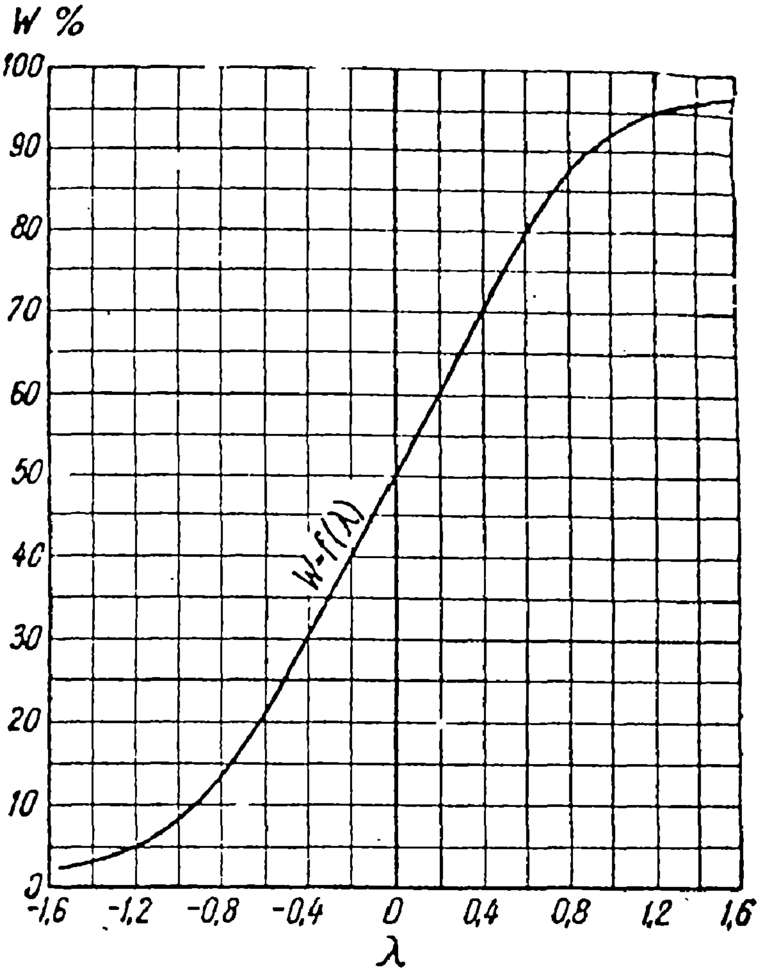


Fig 3.7 VELIKANOV'S RELATIONSHIP w=f(λ) FOR DESIGNING SETTLING BASINS

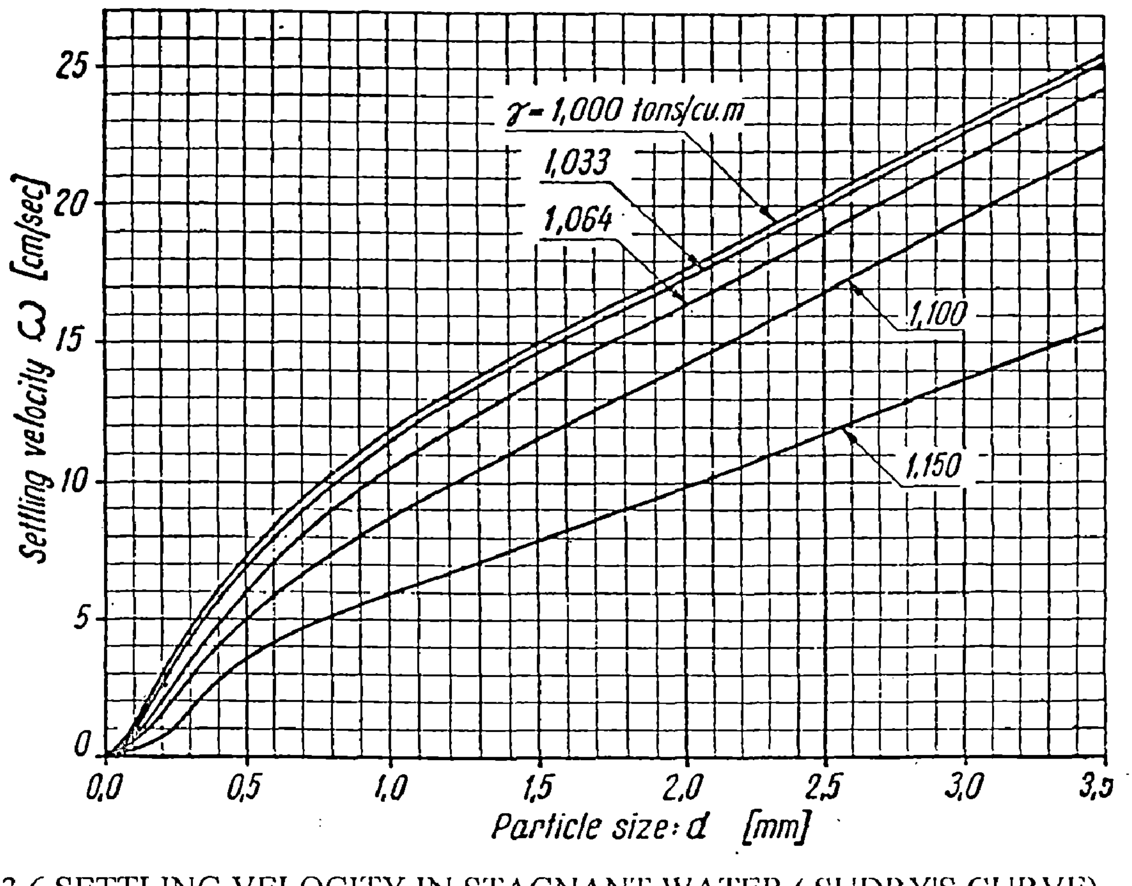


Fig 3.6 SETTLING VELOCITY IN STAGNANT WATER (SUDRY'S CURVE)

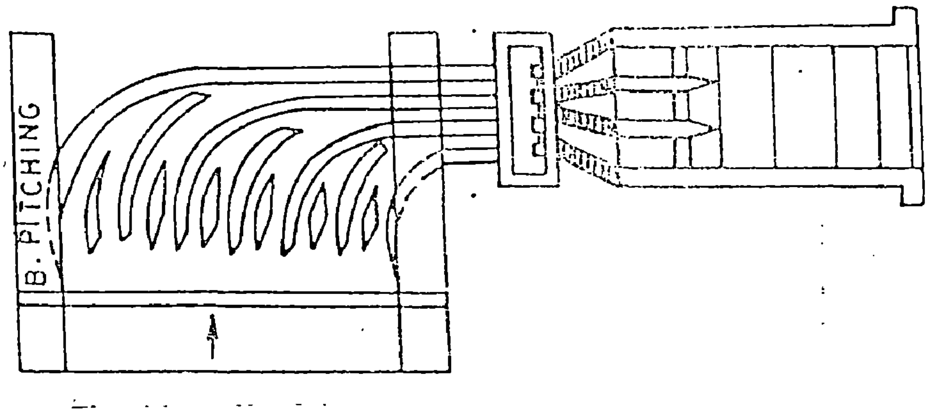


Fig 3.8 TYPICAL LAYOUT OF TUNNEL EXTRACTOR

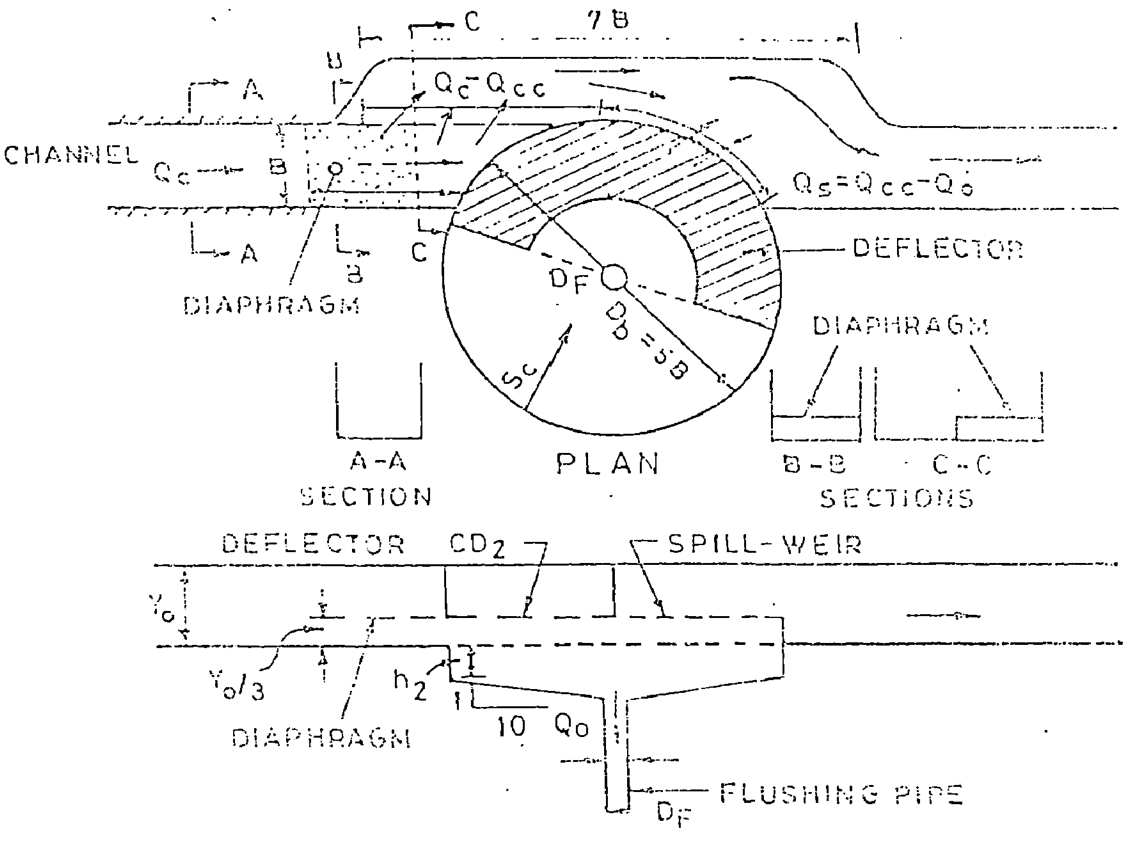


Fig 3.9 VORTEX SETTLING BASIN

CHAPTER 4

PERFORMANCE APPRAISAL OF VARIOUS HYDRPOWER STATIONS IN HIMALAYAN REGION

4.0 GENERAL

In this chapter the performance of some run-of-the river hydro power plants has been reviewed. These are located in western Himalayas and are provided with sediment exclusion devices. The information collected regarding sediment damages and the repair and maintenance operation carried out in each case has been documented. The power plants included in the study are the following:

1.	Sanjay Vidyut Pariyojna	(3x40 MW)
2.	Nogli Hydel Porject	(2x 250KW+ 4x500 KW)
3.	Dehar Power plant	(6x165MW)
4.	Baira Siul Project	(3x66 MW)
5	Giri Power Plant	(2x30MW)
6.	Chibro Power plant	(4x60 MW)
7.	Maneri Bhali-I	(3x30 MW)

4.1 SANJAY (BHABA)VIDYUT PARIYOJNA (120 MW)

4.1.1 Performance Appraisal [6]

It is a run-of-the river project on river Bhaba, a tributary of river Satluj. Desilting basin to exclude +0.2 mm size particles has been provided, details are given in chapter-2, Fig. 2.3.

Three units of Bhaba Hydel project were commissioned on 15th May, 14th July and 23 rd July 1989, respectively. Initially there were four runners and one additional runner was purchased in February 1999, at a cost of Rs 4.63 crores .The project worked satisfactorily for six years i.e., up to November 1995. One day while unit one was running at 30 MW, increased vibrations were noticed. Inspection revealed that from bucket no 12, a large piece from curved portion adjoining to the bucket root has chipped off. This piece weighing 12 kg and measuring 300 mm X 240 mm was lying on the grating below. Subsequent inspection during January 1996, revealed the following.

Unit no -I: - A piece had chipped away from upper half of the bucket no 12 from near the bucket root. In addition, 18 buckets had cracks measuring up to 75 mm on the bucket lips.

Unit no -II:- Twenty buckets had long cracks on the bucket lips. In one case the crack was found to be almost reaching the centre of bucket.

Unit no -III:- Sixteen buckets had long cracks on the bucket lips.

Table no 4.1 gives the complete history of repair of unit -I runner.

4.1.2 Repair Details

With the spare runner, the runner of unit-I was immediately replaced in 2/96 .The runners of the other two units whose buckets had fine cracks continued to function. The runner of unit -III was replaced by the repaired runner of unit-I in 1/97. The runner of unit -II was replaced by the repaired runner of unit-III in 3/99. In 2/99 a new runner replaced the runner of unit-III. Thus at present the repaired runners of unit-I & II have been kept in spare.

The parts which got affected by silt erosion are:-

i) Bucket
ii) Spear
iii) Spear mouth
iv) Spear mother screw
v) Needle stamp
vi) Nozzle desanding valve.

Main inlet valve:- Service seal, maintenance seal, SS rings have been more frequently replaced in case of unit-II as compared to other units.

It can be concluded that despite the provision of desilting basin the runners have been replaced after 6-7 years and the buckets of the runner need constant repairs.

4.2 NOGLI HYDEL PROJECT (2.5 MW)

Nogli HEP is a run-of-the river scheme, on Nogli khad a tributary of Satluj river. The project consists of diversion weir, power tunnel/channel, forebay, three penstocks and a surface power house on the right bank of Nogli khad. The surface power house has two 250 kw units and four 500 kw units with horizontal axis Francis turbine. The project utilizes a head of 72 m and a design discharge of 4.67 m^3/sec to generate 2.5 MW of power.

4.2.1. Performance Appraisal

Due to presence of silt in khad flow the following are experiencing damage :

i) Runner
ii) Guide vanes
iii) Bearing
iv) Slip rotating ring
v) Bush link/guide vane bush
vi) Stiffening box
vii) Split brush
viii) Thrust collar
ix) Sluice valve disc, seating ring and spindle .

The commissioning schedule of the project was as follows;

Unit I & II(2x 250KW) from Dreeze & Company ,Germany January 1963.
Unit III & IV(2x500 KW) -------------- do ------------ 1969.
Unit IV & V(2x500 KW) from Jyoti India Ltd. 1974.

Since its installation unit -III & IV, only have been replaced once. The repair cycle of runners has been about two years.

4.3 DEHAR POWER PLANT (6 x 165 MW)

Beas Satluj link project is a run-of- the river type development, with provision of balancing reservoir for peaking. The scheme consists of a 74.39m high earth and rockfill dam at Pandoh on Beas river in Mandi district of Himachal Pradesh. The waters of the river are diverted through 13.1 km long Pandoh- Buggi tunnel, 11.8 km long Buggi- Sundernagar hydel channel, 3.7 MCM capacity balancing reservoir at Sundernagar, 12.38 km long Sundernagar- Satluj tunnel,surge shaft and three penstocks each feeding two units each of 165 MW capacity installed in a surface power house on the right bank of Satluj river at Dehar. The project, with storage for peaking, utilizes a gross head of 341.4 m to produce 990 MW of power. Six number, vertical axis Francis turbines have been installed. The net head is 320 m and design discharge is 403.8 cumecs.

4.3.1 Desilting Arrangements

It was estimated that Pandoh dam will arrest coarse sediment and its dead storage would be filled up in twentyseven years. The medium and fine sediment will pass through under sluices. Medium size sediment entering the tunnel will be extracted through the silt ejector provided in the power channel and only fine sediment will reach the balancing reservoir. A part of it will settle in the balancing reservoir and rest will pass through turbines. A dredger was provided to dredge the sediment depositing in balancing reservoir. The storage of Pandoh reservoir got silted up in nine years only and the silt ejector could not be operated. Thus, all the river sediment entered the balancing reservoir. The deposition in the balancing reservoir has reduced its capacity because of inadequate dredging capacity and the sediment entering the tunnel leading to powerhouse is causing damage. The desilting arrangements i.e., silt ejector and balancing reservoir provided in the project have been shown in Fig.4.1 and Fig.4.2.

4.3.2 Repair and Maintenance Schedule

Generally two types of repairs are being carried out.

a) Yearly repairs

b) Capital maintenance

a) Yearly repairs:- Yearly repairs or annual maintenance of each unit is done every year for which the unit is shut down in low flow season. Unit is not dismantled, it takes 20-22 days for such repairs.

b) Capital maintenance:- Capital maintenance of two units is done every year i.e., the whole unit is dismantled (as no arrangement of runner removal from bottom is provided), and all the parts affected by silt are checked and repaired through welding. It takes about four to five months for capital maintenance of each unit. The capital maintenance cost of a unit is approximately Rs 80 lac. Table 4.3 shows the operation schedule of units. It reveals that on an average the capital maintenance is required after every three years.

c) Major overhauling:- After six to seven capital maintenance at site, the turbine runner and guide vanes are sent to BHEL for major overhauling.Unit no-II, was sent to BHEL on 12.11.1999, after working for twenty years (about eighty thousand hours).

4.4 BAIRA SIUL HE POWER STATION (3 x 66 MW)

Baira Siul project, situated in Chamba district of Himachal Pradesh, utilizes a combined flow of river Baira, Siul and Baldeh. The flow of Baira is diverted to the head race tunnel by constructing a rockfill dam across the river. The discharge of Baldeh is fed to Baira just upstream of dam through, Baldeh feeder tunnel. Power tunnel taking off from Baira reservoir passes under river Siul. The flow of river Siul is picked up with diversion weir and fed into the power tunnel through drop shaft. A surface power station housing three vertical axis Francis turbines (66 MW each) is located on the right bank of Siul river. The project thus utilizes a net head of 282 m, with a design discharge of 88 cumecs to generate 198 MW of power. The project layout has been shown in Fig 4.3.

4.4.1 Desilting Arrangement

Desilting arrangements have been provided at three locations.
A desilting basin of size (4mx2.445mx45 m long)has been provided in the Baldeh feeder tunnel to restrict entry of silt of 0.2 mm size and above. Another desilting chamber (15 m x12 mx30 m long) divided in two parts has been provided in the power tunnel. Each chamber has six hoppers for collecting sediments. The velocity of flow is kept approximately 0.46 m per second to exclude particles above 0.2 mm size.

At Siul weir, six silt excluder ducts of size (0.50m x 1.255m) are provided below intake opening, which flushes bed load and large size particles back into the river. Further two identical desilting chambers of size (7.2mx12.5mx102.45m) have been provided with an aim to exclude 90 % of silt particles of 0.2 mm and above.

In addition to the above desilting arrangements Baira reservoir acts as a siltation tank and the diversion tunnel is now used for flushing the silt accumulated in Baira reservoir. Fig. 4.4, 4.5 and 4.6 show the layout of desilting arrangements.

4.4.2 Performance Appraisal

Two units of the project were commissioned in May 1980 and third unit in September 1981.

Guide vanes at Baira Siul power station were found to be heavily damaged /eroded with deep pits of 15-20 mm, due to silt erosion, after a service period of two years.

To reduce the damage due to silt, runners were replaced by modified and uprated ones each of to 66 MW. The modified first unit was installed in March 1989 and II & III unit were commissioned in March 1991 .In the modified runner and guide vanes, material composition of steel was changed to 13Cr: 4 Ni. Still the damages to guide vane and runner etc. are severe.

4.4.3 Repair and Maintenance Schedule:-

Due to high concentration and highly abrasive nature of silt, the plant is experiencing heavy damage to its under water parts. Every year all the units are dismantled and heavy repair under taken. As a precautionary measure the plant is closed down when the silt concentration in the water exceeds 3000 ppm. The average repair cycles of the turbines is 4000 hours.

Different types of wear resistant coatings are being tried to reduce the silt erosion. These are still in experimental stage and their cost effectiveness is being examined.

4.5 GIRI HYDEL PROJECT (2x30 mw)

Giri Hydel Project is a run-of- river type scheme on river Giri, a tributary of Yamuna river in Sirmour district of Himachal Pradesh. The project consists of a barrage, head race tunnel, surge shaft and two penstocks each feeding one unit. Two, vertical axis Francis turbines each of 30 MW capacity, have been installed in a surface powerhouse. The scheme utilizes a net head of 147.5 m. The power house was commissioned in 1978.

4.5.1 Desilting Arrangement:-

A silt excluder at the intake of head race tunnel has been provided, which is operated during floods and high flow period. No desilting basin is provided in the head race tunnel.

2.5.2 Repair and Maintenance

Various parts which require frequent repairs are:-

i) Turbine shaft sleeve.
ii) Sealing ring
iii) Labyrinth
iv) Guide vanes
v) Runner

Two types of repairs are being under taken

a) Annual repairs
b) Major repairs

a) Annual repairs are being carried out every year, and the expenditure is minimal.

b) Major repairs

Unit-I

Major repair to unit no-I was taken up in 11/87, after 43,713 hours of running at a cost of Rs 7.80 lac. The second major repair is undertaken in 8/2000.

Unit –II

First major repair of unit –II, was undertaken after 43,617 hours of running at a cost of 9.5 lac in 1987. It was fitted with the spare runner, procured in 1985 which worked for 35,000 hours without any major repairs. After the repairs this runner has also worked for 25,090 hours and is due for repairs.

Spherical Valve:- Maintenance seal of spherical valve of unit -II only has been replaced by stainless steel.

4. 6 CHIBRO POWER STATION (4x60 MW)(3)

This project is a run-of-river scheme on Tons river, a tributary of river Yamuna. The scheme comprises of 60 m high concrete diversion dam at Ichari, a 12 km long, 7 m diameter power tunnel, to carry water to under ground power house at Chibro, which has four vertical axis Francis turbines each of 40 MW capacity. The scheme utilizes a net head of 110 m to generate 240 MW of power.

4.6.1 Desilting Arrangement

The project has been provided with a desilting chamber 83 m long, having two bays each of 12.75 m width separated by 2 m wide pier. The desilting basin has been designed to exclude particle larger than 0.3 mm.

The velocity of flow with maximum discharge of 235 cumecs decreases from 1.39 m/sec to 0.63 m/sec from one end of duct to other. Figure 4.7 shows the layout details of desilting arrangement.

4.6.2 Performance Appraisal

The effect of silt on under water parts of power station is observed to be moderate. Table 4.4 gives the operation schedule of Chibro power plant units. The repair cycle is observed to be 6.0 years.

4.7 MANERI BHALI STAGE -I (2X30 MW)

Maneri Bhali hydroelectric project is a run-of-river scheme on river Bhagirathi, a tributary of the Ganges.The project consists of a 39 m high, 127 m long concrete diversion dam with four bays each of 13.0 m wide, with a slotted bucket type energy dissipator and fitted with 13 m x14.55 m high radial gates to create a diur nal pondage. The scheme utilizes a gross head of 175 m and design discharge of 70 m^3/sec to produce 90 MW of power. Francis type turbines have been installed for power generation.

4.7.1 Desilting Arrangement

The desilting basin of size 62.8 m x30 m with eight hoppers of size 15.7m x15 m each has been provided to exclude particles larger than 0.3 mm with a removal efficiency of 90 %. Figure 4.8 shows desilting chambers of Maneri Bhali stage-I.

Petrographic analysis of silt has shown that the sediment contain 80 % quartz of sub-angular shape and size ranging from 0.06 to +0.5 mm.

4.7.2 Performance Appraisal

The commissioning schedule of Maneri Bhali-I is:-

Ist unit	31st October 1984
2nd unit	19th November 1984
3rd unit	14th December 1984

The generating units performed satisfactorily until June 1985. Soon after the start of monsoon rains heavy leakage occurred in all the units and whole power station had to be closed down. The turbines were found seriously damaged after about 2600 hours of operation. They were repaired, but again, within 3000 to 5000 hours of operation, extensive damage occurred.

The inspection revealed heavy damage to the under water parts such as turbine runners, guide vanes, trunions, guide vane brushes, seals, labyrinths, etc. These components were repaired and the machines were restarted.

However, all the three units were again damaged within a further operation of 3000 to 5000 hours. This time the damage was much more severe. Sever operation restrictions have been placed on the machine, when the silt content in the water exceeds 2000 ppm. The plant is shut down due to these restrictions. There is more than 40 % generation loss. Sedimentation chamber is designed to exclude particle particles larger than 0.3 mm. But presence of high percentage of sharp edged, quartz particles of smaller size cause severe damage to under water parts. The station is testimony to the menance of silt abrasion to the power plants. Plant could not achieve, design energy generation level, despite plenty of water available.

Some experiments for preventive coating were attempted to contain the problem. Alumna ceramic tiles were epoxy bonded on runner surface. The experiment was not successful due to debondage of the same.

A new profile runner for the station was developed with a view to minimise wetted area and increased blade thickness. The performance of the runner has been much better but problem of severe silt damage still persists.

4.8 SUMMARY

The summary of performance and repairs and maintenance of seven stations described above is as follows.

Sr No	Station Name	Head (m)	Sediment exclusion arrangement	Particle size extracted	Repair cycle	Remarks (Replace- -ment of runner)
1	SVP (Bhaba)	825	Desilting basin	+0.2 mm	One year	After six repair cycles
2	Nogli HEP	72	-	-	Two years	-
3	Dehar	320	Silt ejector and balancing reservoir	Not specified	Three years	After six repair cycles
4	Baira Siul	282	Desilting basin	+0.2 mm	One year	Nine to ten repair cycles
5	Giri	147.5	Silt excluder	-	Eight years	Six repair cycles
6	Chibro	110	Desilting basin	+0.3 mm	Six years	-
7	Maneri Bhali	175	Desilting basin	+0.3 mm	One year	-

TABLE NO 4.1 REPAIR HISTORY OF RUNNER-I BHABA POWER PLANT

Bucket No 1

Sr No	Date	Type of repairs
1	18.04.1996	CA
2	15.09.1997	CA
3	08.01.1998	NCA
4	20.06.1998	NCA
5	10.11.1998	Polishing
6	27.07.1999	CA+NCA

Bucket No 2

Sr No	Date	Type of repairs
1	24.04.1996	CA
2	26.06.1996	CA
3	02.12.1996	CA
4	08.07.1997	NCA
5	04.08.1997	NCA
6	20.06.1998	NCA
7	14.07.1998	NCA
8	10.08.1998	NCA
9	09.09.1998	NCA
10	10.11.1998	Polishing
11	30.07.1999	CA+NCA

Bucket No 3

Sr No	Date	Type of repairs
1	30.03.1996	CA
2	08.07.1996	CA
3	16.01.1998	NCA
4	20.06.1998	NCA
5	14.07.1998	NCA
6	09.09.1998	NCA
7	10.11.1998	Polishing
	31.07.1999	CA+NCA

Bucket No 4

Sr No	Date	Type of repairs
1	24.04.1996	CA
2	08.01.1998	CA
3	10.11.1998	NCA
4	21.07.1999	Polishing

Bucket No 5

Sr No	Date	Type of repairs
1	20.04.1996	CA
2	08.01.1998	CA
3	10.11.1998	Polishing
4	06.08.1999	CA+NCA

Bucket No 6

Sr No	Date	Type of repairs
1	15.04.1996	CA
2	08.01.1998	CA
3	20.06.1998	NCA
4	10.08.1998	NCA
5	10.11.1998	Polishing
6	27.07.1999	CA+NCA

Bucket No 7

Sr No	Date	Type of repairs
1	15.04.1996	CA
2	08.01.1998	CA
3	10.11.1998	Polishing
4	05.08.1999	CA+NCA

Bucket No 8

Sr No	Date	Type of repairs
1	23.04.1996	CA
2	07.02.1997	CA
3	15.09.1997	NCA
4	08.01.1998	NCA
5	20.06.1998	NCA
6	10.11.1998	Polishing
7	21.07.1999	CA+NCA

Bucket No 9

Sr No	Date	Type of repairs
1	02.04.1996	CA
2	08.07.1997	CA
3	15.09.1997	NCA
4	08.01.1998	NCA
5	20.06.1998	NCA
6	10.08.1998	NCA
7	10.11.1998	Polishing
8	04.08.1999	CA+NCA

Bucket No 10

Sr No	Date	Type of repairs
1	23.04.1996	CA
2	15.09.1997	CA
3	10.08.1997	NCA
4	10.11.1998	Polishing
5	27.07.1999	CA+NCA

Bucket No 11

Sr No	Date	Type of repairs
1	19.04.1996	CA
2	08.01.1998	NCA
3	10.11.1998	Polishing
4	02.08.1999	CA+NCA

Bucket No 12

Sr No	Date	Type of repairs
1	01.04.1996*	CA
2	27.06.1996	CA
3	02.07.1997	NCA
4	15.09.1997	NCA
5	18.01.1998	NCA
6	20.06.1998	NCA
7	10.08.1998	NCA
8	09.09.1998	NCA
9	10.11.1998	Polishing
10	06.02.1999	CA+NCA

Note:-
CA :- Splitter root,thin section of lip of bucket or splitter is termed as critical area
NCA:- Deeper inside portion and outer portion of bucket is termed as non critical area.

TABLE NO 4.1(contd) REPAIR HISTORY OF RUNNER-I BHABA POWER PLANT

Bucket No 13

Sr No	Date	Type of repairs
1	06.04.1996	CA
2	18.08.1998	CA
3	10.11.1998	Polishing
4	07.08.1999	CA+NCA

Bucket No 14

Sr No	Date	Type of repairs
1	22.04.1996	CA
2	07.02.1997	NCA
3	08.07.1997	NCA
4	04.08.1997	NCA
5	09.09.1998	NCA
6	10.11.1998	Polishing
7	12.08.1999	CA+NCA

Bucket No 15

Sr No	Date	Type of repairs
1	04.06.1996	CA
2	21.06.1996	CA
3	08.07.1997	NCA
4	04.08.1997	NCA
5	08.01.1998	NCA
6	20.06.1998	NCA
7	10.08.1998	NCA
8	09.09.1998	NCA
9	10.11.1998	Polishing
10	28.07.1999	CA+NCA

Bucket No 16

Sr No	Date	Type of repairs
1	14.04.1996	CA
2	26.06.1996	CA
3	20.06.1996	NCA
4	11.11.1998	Polishing
5	02.08.1999	CA+NCA

Bucket No 17

Sr No	Date	Type of repairs
1	29.03.1996	CA
2	26.06.1996	NCA
3	10.01.1997	NCA
4	07.02.1997	NCA
5	08.07.1997	NCA
6	04.08.1997	NCA
7	15.09.1997	NCA
8	15.01.1998	NCA
9	10.11.1998	Polishing
10	10.08.1999	CA+NCA

Bucket No 18

Sr No	Date	Type of repairs
1	12.04.1996	CA
2	17.01.1998	CA
3	10.11.1998	Polishing
4	29.07.1999	CA+NCA

Bucket No 19

Sr No	Date	Type of repairs
1	08.04.1996	CA
2	09.01.1998	CA
3	10.08.1998	NCA
4	10.11.1999	Polishing
5	10.08.1999	CA+NCA

Bucket No 20

Sr No	Date	Type of repairs
1	15.04.1996	CA
2	09.01.1998	NCA
3	10.08.1998	NCA
4	10.11.1998	Polishing
5	07.08.1999	CA+NCA

Bucket No 21

Sr No	Date	Type of repairs
1	12.04.1996	CA
2	26.06.1996	CA
3	08.07.1997	NCA
4	15.09.1997	NCA
5	09.01.1998	NCA
6	20.06.1998	NCA
7	09.09.1998	NCA
8	10.11.1998	Polishing
9	24.07.1999	CA+NCA

TABLE 4.3 OPERATION SCHEDULE OF DEHAR POWER PLANT UNITS

Sr No	Unit	From	To	Working duration Months	Years	Unit	From	To	Working duration Months	Years
1	I	Nov-77	Jul-79	20		IV	Jun-97	Sep-85	75	
		Jul-80	May-83	34			Mar-86	Jan-90	46	
		Jul-85	Oct-87	27			Jul-90	Feb-92	20	
		May-88	Feb-91	31			Dec-92	Feb-96	39	
		Sep-91	Jan-94	31			Jun-96	Sep-98	27	
		Apr-94	Oct-95	18			Feb-99	Aug-00		
		Mar-96	Feb-99	35						
		May-99	Aug-00							
			Average	28	2.33			Average	41.4	3.45
2	II	Mar-78	Dec-80	33		V	Jul-83	Sep-86	38	
		Jul-81	Jan-82	6			May-87	Oct-91	53	
		Apr-82	Oct-83	18			Mar-92	Sep-96	54	
		Mar-84	Sep-86	30			Feb-97	Feb-00	36	
		Feb-87	Oct-89	32			May-00	Aug-00		
		Aug-90	Jan-93	29						
		Sep-93	Jan-99	64						
		Jan-00	Aug-00							
			Average	30.29	2.52			Average	45.25	3.77
3	II	Jun-79	Nov-81	29		IV	Nov-83	Jan-89	62	
		Jun-82	Nov-85	41			Jun-89	Sep-91	27	
		Apr-86	Sep-88	29			Dec-91	Oct-94	34	
		Mar-89	Dec-91	33			Feb-95	Mar-98	37	
		Mar-92	Mar-95	36			Jun-98	Aug-00		
		Jun-95	Jul-97	25						
		Aug-98	Aug-00							
			Average	32.17	2.68			Average	40	3.33

TABLE 4.2 OPERATION SCHEDULE OF CHIBRO POWER PLANT

Unit no	From	To	Period (months)	Years	
I	20.4.75	21.10.80	66	5.5	
	9.07.81	27.10.83	25	2.1	
	7.7.84	22.11.88	52	4.3	
	12.7.89	13.11.96	76	6.3	
	6.6.97	08.08.00	Average	4.6	Years
II	24.4.75	8.10.89	54	4.5	
	9.10.80	1.1.86	63	5.3	
	9.7.86	7.11.95	112	9.3	
	18.6.96	08.08.00	Average	6.4	Years
III	30.4.75	21.9.82	89	7.4	
	25.5.83	10.11.90	90	7.5	
	24.7.91	27.10.97	75	6.3	
	5.8.98	08.08.00	Average	7.1	Years
IV	20.2.76	1.10.81	68	5.7	
	9.7.82	1.12.86	53	4.4	
	23.7.86	2.12.92	77	6.4	
	12.8.93	08.08.00	Average	5.5	
Average repair cycle of turbine =				5.87	Years

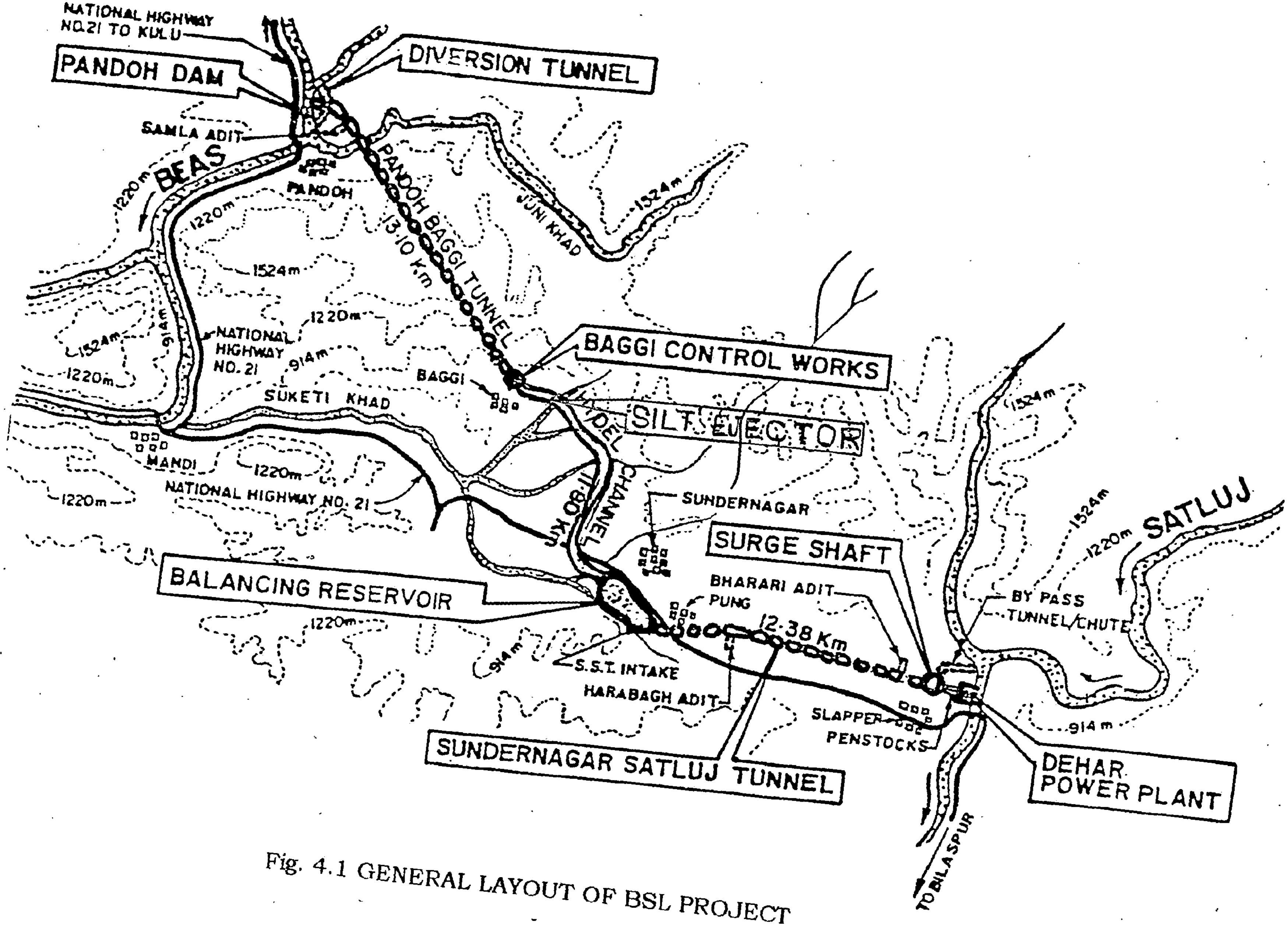


Fig. 4.1 GENERAL LAYOUT OF BSL PROJECT

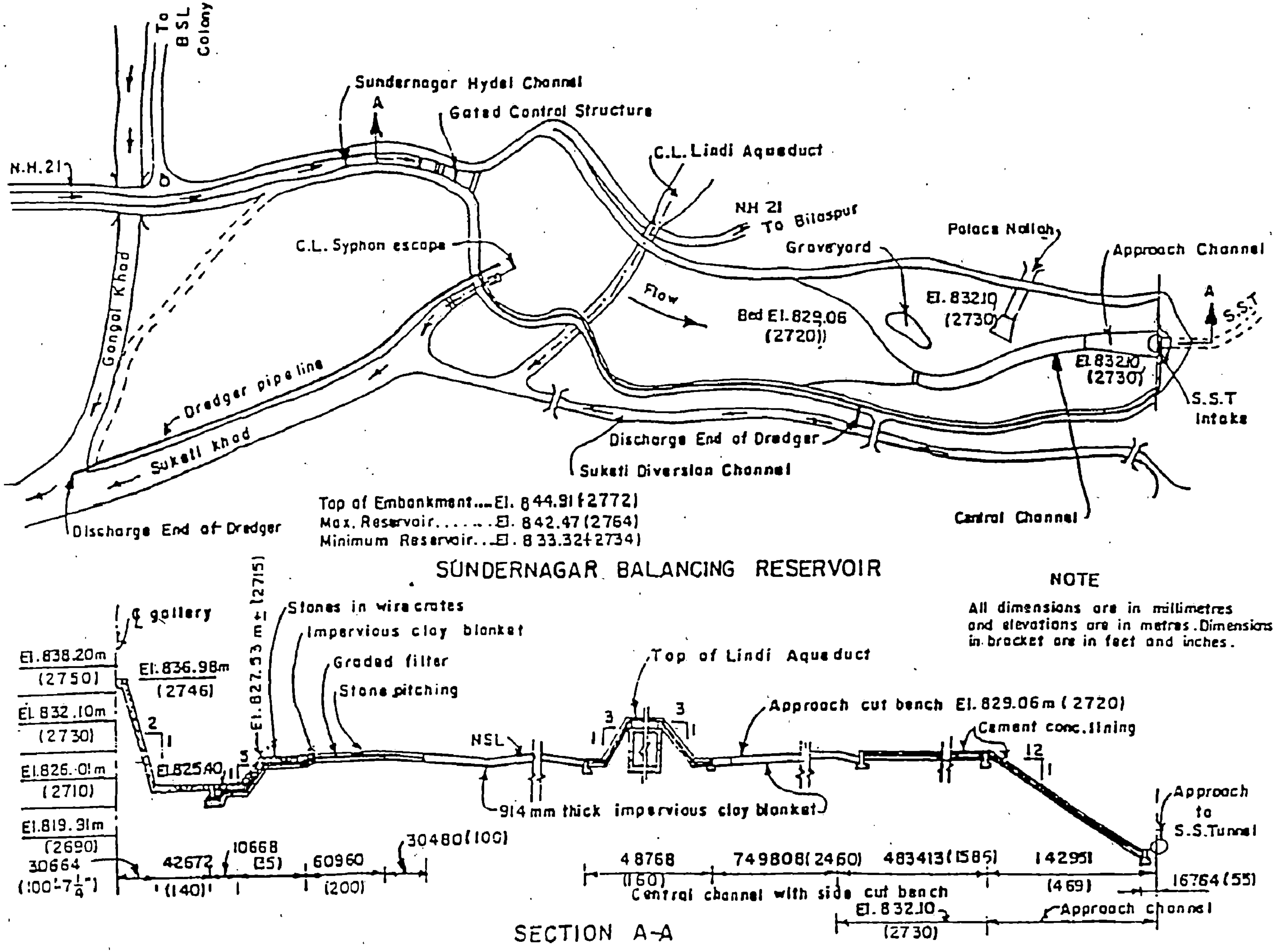


Fig. 4.2 SUNDERNAGAR BALANCING RESERVOIR

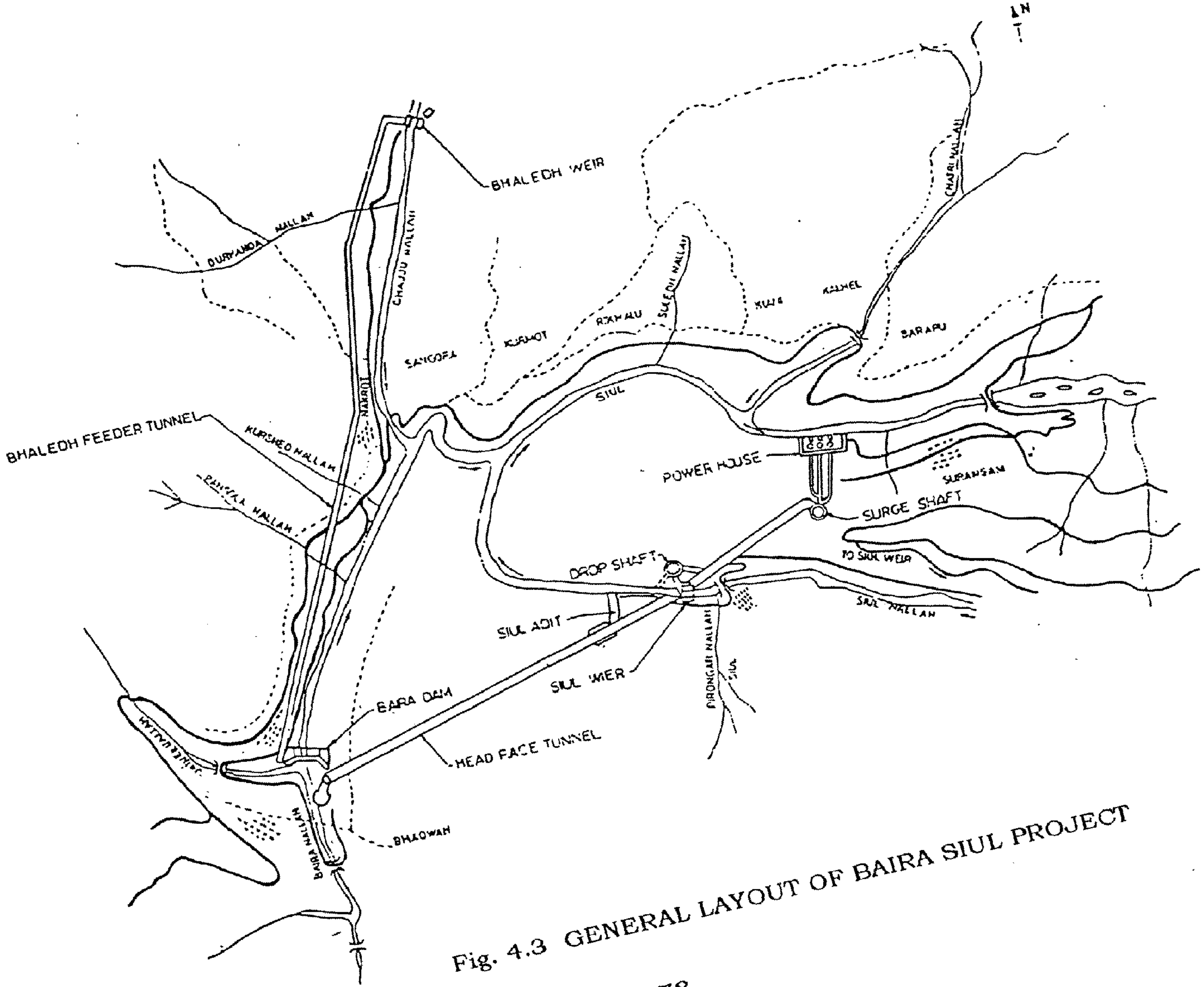


Fig. 4.3 GENERAL LAYOUT OF BAIRA SIUL PROJECT

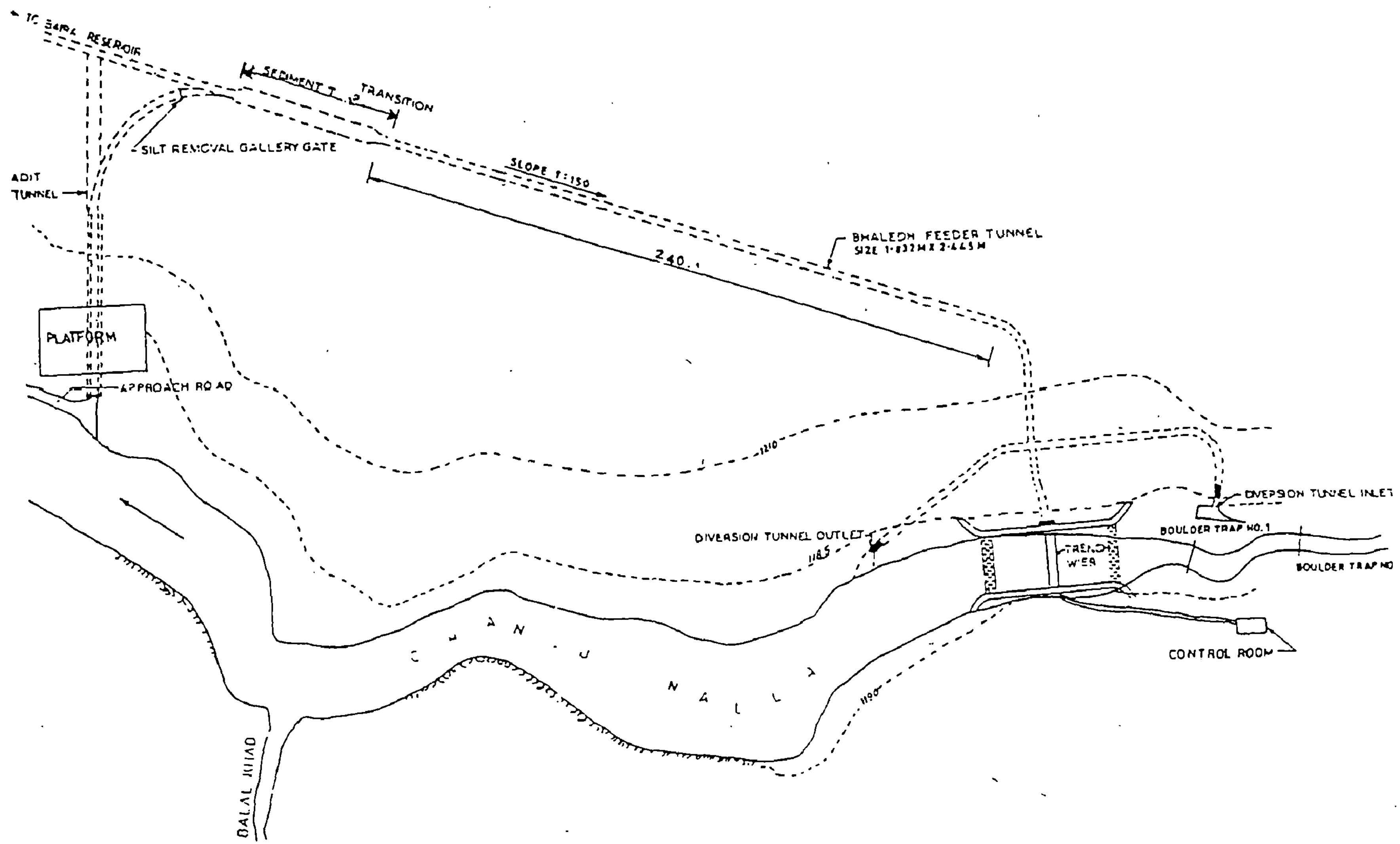


Fig. 4.4 BHALDEH COMPLEX LAYOUT SHOWING DESILTING ARRANGEMENT

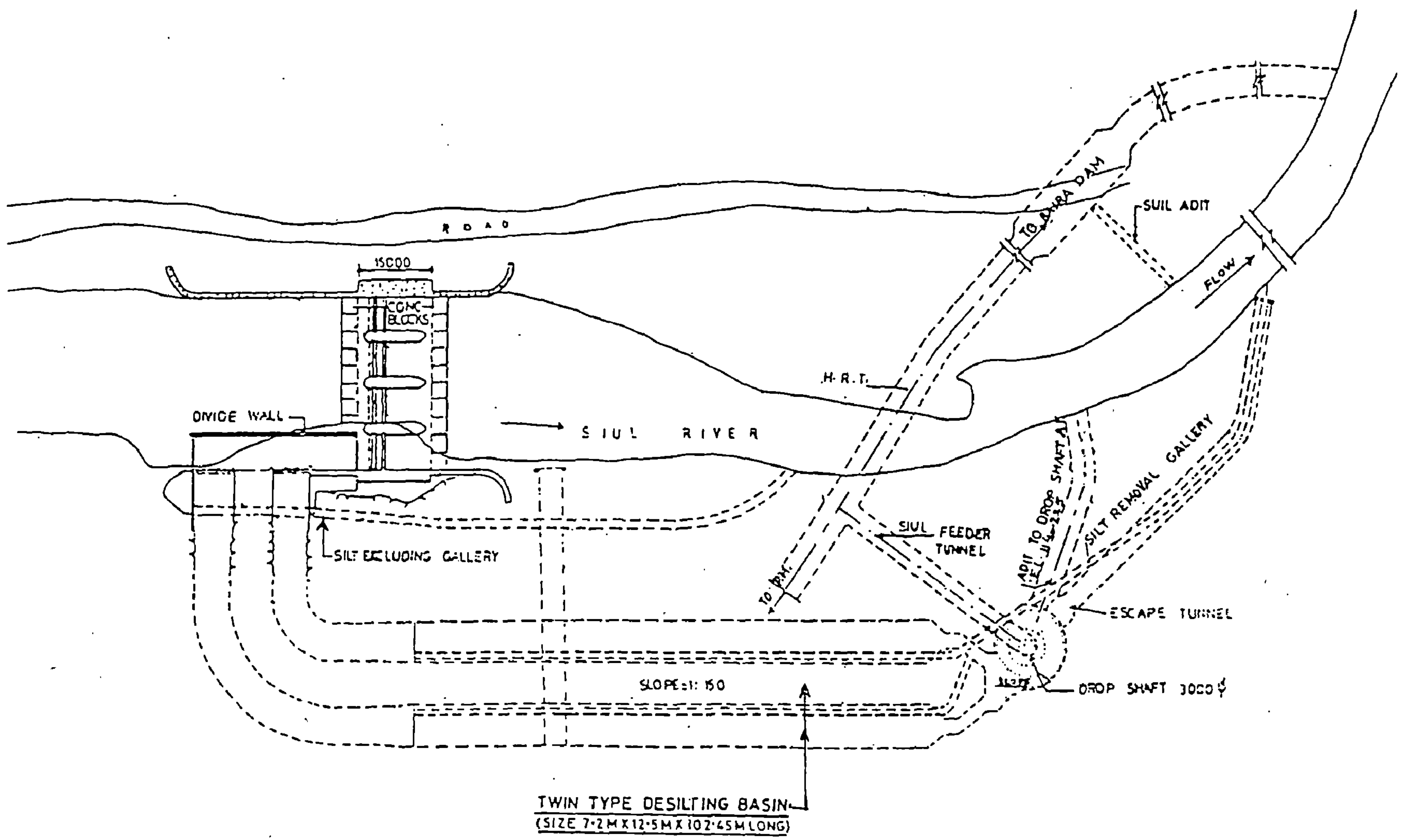
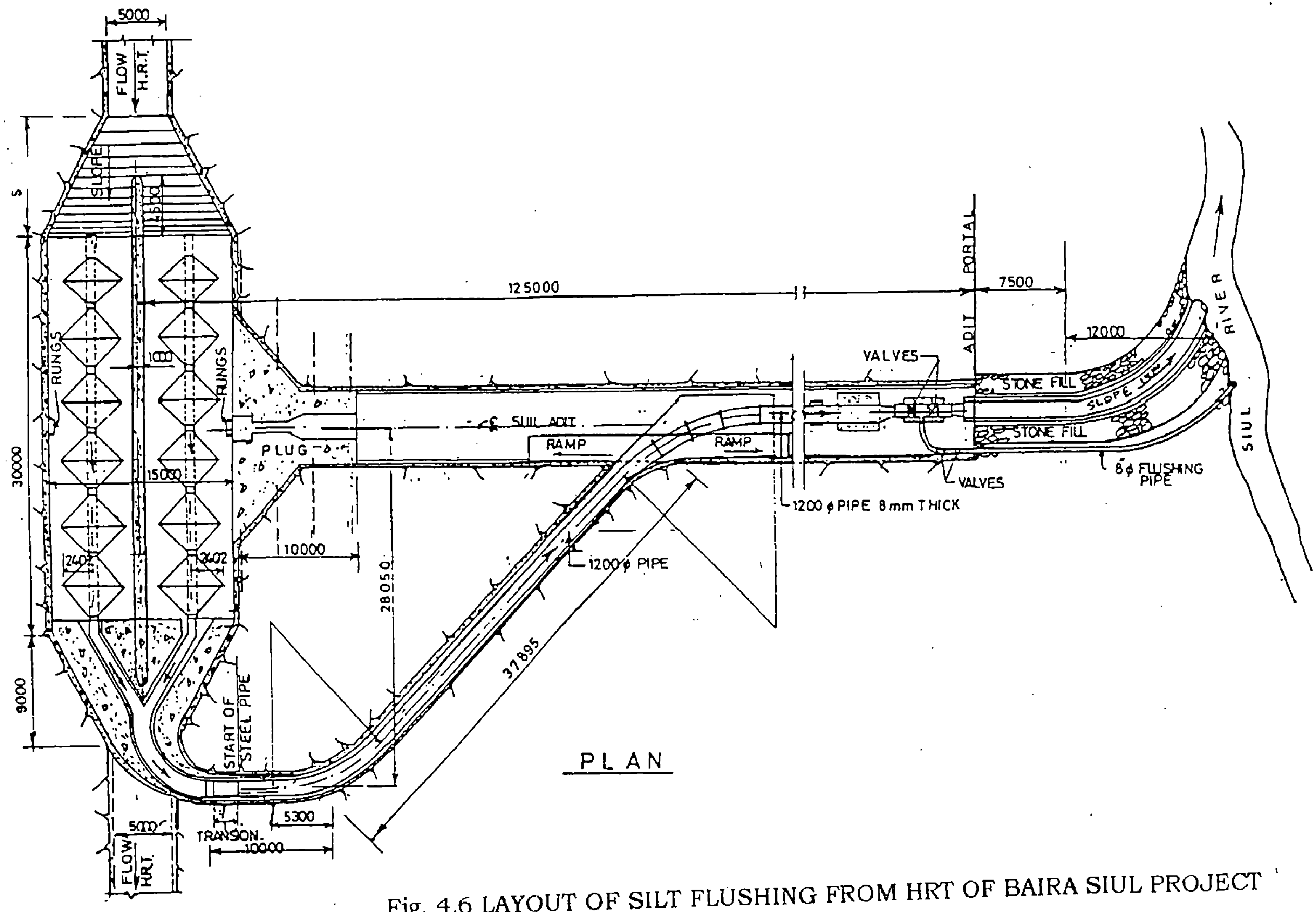


Fig. 4.5 SIUL COMPLEX LAYOUT SHOWING DESILTING ARRANGEMENT



PLAN

Fig. 4.6 LAYOUT OF SILT FLUSHING FROM HRT OF BAIRA SIUL PROJECT

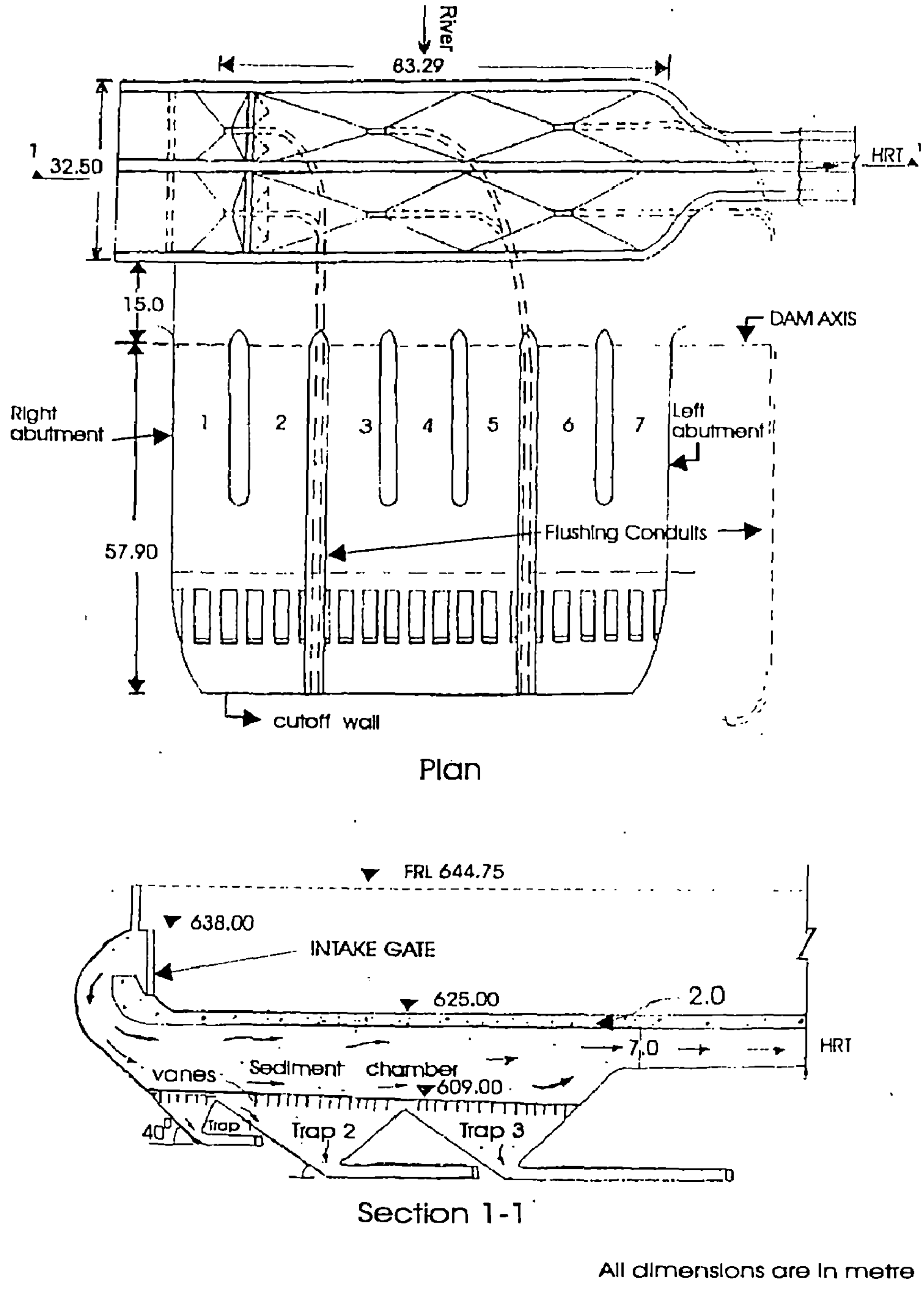


Fig.4.7 DESILTING CHAMBER AND FLUSHING ARRANGEMENT OF ICHARI PROJECT

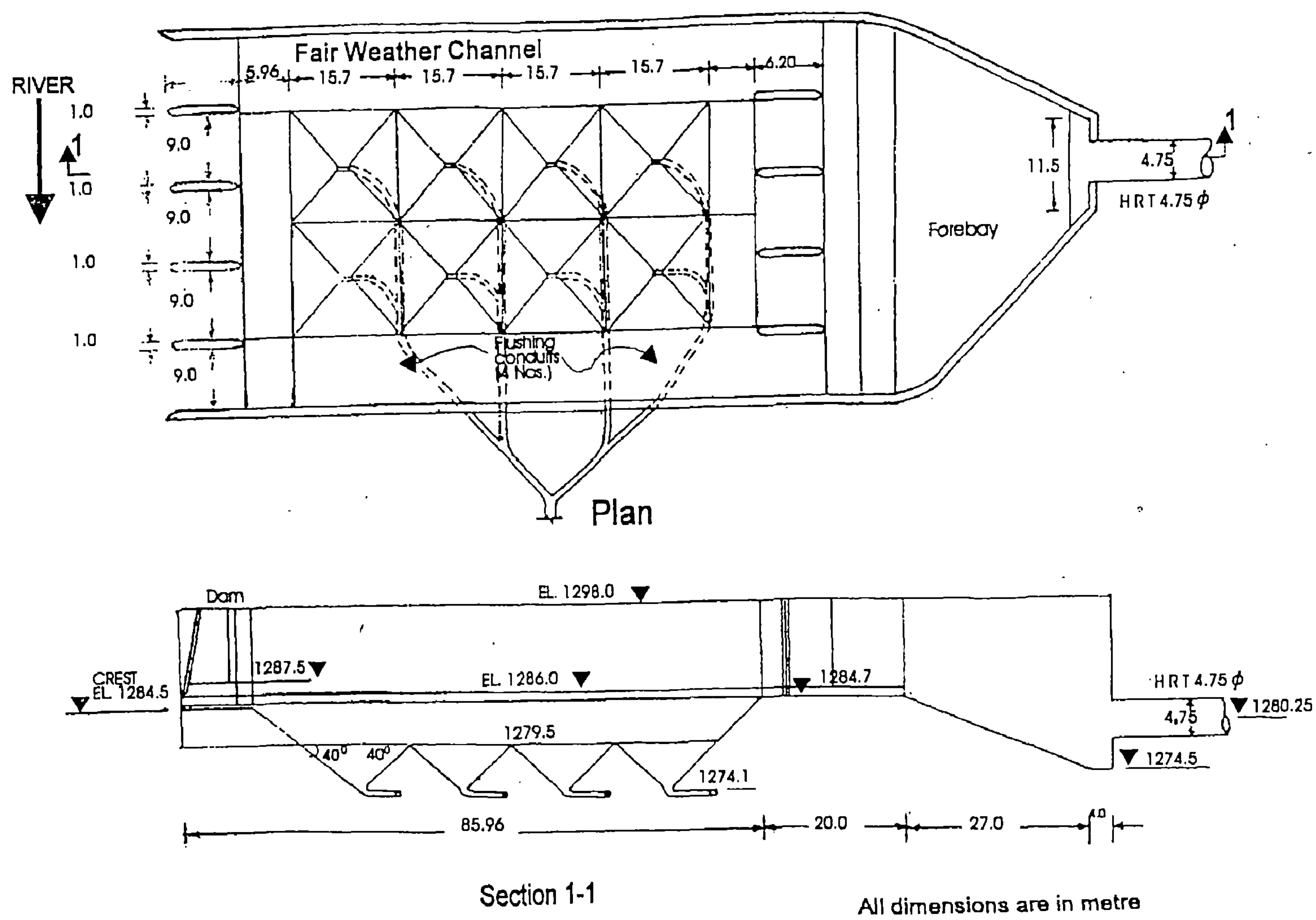


Fig. 4.8 DESILTING CHAMBER OF MANERI BHALI HEP STAGE -I.

CHAPTER 5

OPTIMISATION APPROACH

5.0 GENERAL

This chapter describes in detail the optimisation approach, which can be applied to the design of desilting basins.

5.1 NEED FOR OPTIMISATION

Desilting basins are invariably provided to exclude particles of specific size in run-of-river projects. The dimensions of the desilting basin depends on the size of particle to be extracted from water. As per present practice the size of the silt particle to be removed is related with the head on the turbine. Experimental and field observations have shown that there are many other factors which affect the hydro abrasion of turbine parts. No specific findings for selection of size of particles to be excluded are available.

Turbine manufacturers based on their experience, data from laboratory experiments on abrasion resistance of metal by sand particles of various sizes and hardness use different type of metal in the turbine and other under water parts.

The cost of these basins increases as the particle size to be excluded is reduced. In case of Nathpa Jhakari Project the cost of desilting basins designed to exclude +0.2 mm particles has exceeded twice the cost of dam and intake.

It has also been observed from the performance of existing power stations in Himalayas that the damage to under water parts is moderate to severe in all cases despite the expensive provision of desilting arrangements, repair or replacement of runners have to be undertaken.

Therefore there is a need to correlate the particle size to be extracted and the design of desilting basin with the repair and replacement of the turbine and other parts so that the problem of sediment abrasion may be resolved in cost effective manner. To address this problem of manufacturers and planning engineers of hydroelectric power stations, T.NOZAKI[29] of Japan, under the auspices of Japan International Cooperation Agency(JICA),undertook the study of eighteen power plants in Peru between 1972 and 1980 and suggested an approach for optimisation of size of particle to be excluded through desilting basin. It is based on the principle that the cost of desilting basin and cost of repair and maintenance of turbines taken together shall be minimum. This approach and procedure has been briefly described in this chapter.

5.2 BASIC PRINCIPLE

Factors affecting the abrasion of turbine have been identified as:

i) Sediment concentration

ii) Grain size distribution

iii) Mineral composition of sand

iv) Material used for turbine manufacture

v) Relative velocity of water inside the turbine

vi) Form of water flow.

For the factors other than relative velocity and form of water flow, it is possible to obtain data from field investigations. Relative velocity is decided more or less by effective head (regardless of output). Therefore, if the characteristics of the sand carried in the water, the head and material of turbine are known, and it is possible to determine the repair cycle of the turbine and the corresponding capacity of the desilting basin considering the grain size, shape, density of flow, turbulence and diffusion of flow, and resuspension of settled sand, the optimisation of desilting basin is also possible. It needs study of field data of turbine abrasion and their repairs carried out vis a vis sand characteristics of flow. Nozaki carried out the following two studies and developed tables and graphs for the use of designers.

i) Based on data of abrasion of turbines and sediment characteristics of 18 power stations of Peru he prepared repair cycle curves of turbines depending on sediment concentration and head varying from 25 m to 1200 m. These are shown for Francis turbines and Pelton wheel in fig 5.1 and fig 5.2 .To develop these curves Nozaki expressed the turbine abrasion by the following relation

$$TA = f(PE, V^Z) \qquad \text{-----------------} \qquad (1)$$

where,

TA = turbine abrasion

PE = modified suspended sediment content

V = relative velocity between the flowing water and turbine parts where abrasion is severe.

Z = exponent for relative velocity.

ii) For designing desilting basin, factors affecting desilting efficiency such as shape of particles, density of flow, turbulence and diffusion of flow and resuspension of settled particles have been accounted for and graphs are developed.

5.3 DETERMINATION OF ABRASION PARAMETERS

The modified sediment content (PE), is expressed by the following equation:

$$PE = p^X \times a^Y \times k_1 \times k_2 \times k_3 \qquad \text{---------------------} \qquad (2)$$

where,

P = The average annual suspended sediment content in g/l. .It is based on long term measurement in the river.

X is correction factor for suspended sand concentration. The experiments[41] have shown that for the concentration of sand in the range of 0 to 5 g/l, which is usually the concentration in a desilting basin, the value of x may be taken as 1.0 in the abrasion farmula.

a is average grain size coefficient of suspended sediment. The suspended sediment contains various grain sizes. As per the experiments [43], it has been found that sediment of larger grain size causes greater abrasion of metal than sediment of smaller grain size even though the concentrations may be the same. It may be said that the relationship is proportional to grain size from zero to about 0.6 mm. In this analysis, the basis of grain size has been taken as 0.05 mm, and sediment of various sizes are represented by a single average size. On examination of existing experimental data, it has been found that there is a linear relationship in a certain range, but there are also ranges in which no proportionality is seen, therefore, a correction factor was considered for 'a' in the form of exponent y.

Y is correction factor for average particle shape. The experiments[43] regarding the influence of grain size and particle shape of sand on abrasion, it has been found that for the sand of grain size 0 to 0.6 mm, the correction factor 'y' can be taken as 1, for curved flow and jetting from the nozzle.

V is the relative velocity between flowing water and turbine proper where abrasion of the turbine is severe. Since abrasion of the turbine will vary greatly depending upon the eccentric flow, eddying flow, jet flow etc., and on the location inside the turbine and the type of the turbine, the relative velocities at the various parts of the turbines were calculated. The relationship between relative velocity and abrasion from data on abrasion at 18 hydroelectric power stations of Peru was found in the form of V^Z, where Z was estimated as below:

Francis turbine

Turbine runner	$Z = 3.0$
Guide vane and protective ring	$Z = 2.5$

Pelton Wheel

Bucket	Z = 1.5
Nozzle	Z = 2.5

k_1 is particle shape coefficient. The experiments and field observations have shown significant effect of shape of sand particles on abrasion. Nozaki has adopted following values for k_1.

Few irregularities	k_1= 0.75
Ordinary irregularities	k_1= 1.00
Severe irregularities	k_1=1.25

k_2 is hardness coefficient. On the basis of experimental results on hardness of sand and abrasion of metal the following values are adopted by Nozaki

k_2 = 1	for hardness greater than 3
k_2 = 0.5	for hardness between 0 to 3.

k_3 is the abrasion resistance coefficient. Based on the experimental results and data obtained in Peru, the following values are adopted.

13 Cr:4Ni	:	k_3 = 1.0
Cast steel	:	k_3 = 2.3
Bronze	:	k_3 = 4.0
Satellite	:	k_3 = 0.3

5.3.2 Estimation of Repair Cycle of Turbine due to Abrasion

It is evident from above that abrasion of turbine and its parts depends on PE, the modified sediment content which represents sediment characteristics and the metal resistance to abrasion, and on relative velocity, which is a function of head. Using the data of sediment and repairs at 18 power plants of Peru, Nozaki has developed curves between PE and head for repair cycles of Francis and Pelton wheel. The determination of PE depending on the efficiency of the desilting basin is explained in the next para.

The repair cycle curves for runners of Francis turbines are shown in fig. 5.1(a) and the repair cycle curves for guide vanes in fig. 5.1 (b). The repair cycle curves for nozzles and needles of Pelton turbines are shown in fig. 5.2(a) and those of buckets in fig. 5.2(b).

5.4 DETERMINATION OF THE SEDIMENTAION EFFICIENCY OF DIFFERENT PARTICLE SIZES

The determination of sedimentation efficiency of different grain sizes in a desilting basin is required to work out the modified sediment content(PE). It depends on the following factors.

i) Sediment concentration in flow.
ii) Grain size distribution of sand.
iii) Flow velocity increase of density flow.
iv) Settling rate considering particle shape of sand.
iv) Turbulence and diffusion of flow
v) Resuspension of sedimented sand

To evaluate these factors, the sediment characteristics including grain size distribution, texture, shape etc., are required. The evaluation can be made as explained below leading to evaluation of PE.

i) The increase in flow velocity due to density of flow can be worked out by;.

$$V = \frac{1}{2}\sqrt{2\alpha\frac{\Delta\rho}{\rho}g\frac{\Delta H}{k}}$$

where,

α = coefficient indicating proportion of potential energy possesed by in- flowing water, transferred to flow velocity energy of density flow.

The value suggested by Nozaki is 0.5.

$\Delta\rho$ = quantity of sediment (g/l).

ρ = density of water in basin (gm/cm^3)

g = acceleration due to gravity.

ΔH = average settled height of inflow water (cm)

k = dilution ratio

taking α= 0.5 , ΔH= H/2, k = 1.75, g=980 cm/sec^2

$$V = (28 \times w \times H)^{\frac{1}{2}}$$

where, w is sediment concentration

ii) Settling velocity depending upon particle shape and size can be determined from fig 5.3.

iii) Critical velocity for a particle to go in suspension is given by

$$V_c = (20070 x\ d)^{\frac{1}{2}}$$

Where, d is depth of desilting basin in m.

iv) Mean flow velocity is taken as discharge divided by area of basin plus the increase due to density as worked in (i) above.

v) On comparison of mean flow velocity with critical velocity the particle which will be in suspension can be identified.

vi) The sedimentation rate (Eo) is defined as the ratio of settling velocity and the surface flow velocity.

vii) The sedimentation rate decreases due to turbulence and diffusion of flow inside the desilting basin. The sedimentation ratio (Eo) is modified taking into consideration turbulence and difussion of flow velocity and grain size of sand in a desilting basin by using the relation developed by Dobbin's(15) and latter simplified by Camp(1946), and as shown in figure 5.4

Following the above steps it becomes possible to know the sedimentation efficiency of desilting basin i.e., quantity of sediment passing through the turbines in case of a hydropower project. The summation of this quantity for all particle sizes gives PE. It is explained step by step in a tabular form as below.

Step by step procedure (Refer table 5.1)

S.No Notation Details

1. d- grain size (0.6 to 0.001 mm)of sediment contained in water.
2. a - average grain size coefficient with particle size 0.05 mm as basis
3. k_1 - shape factor, decided as per the shape of the size fractions.
4. k_2 - hardness factor, calculated as per the mineral composition and their hardness.
5. k_3 - abrasion resistance factor of turbine material.
6. Ap- abrasion potential of size fraction, $Ap = a \times k_1 \times k_2 \times k_3$
7. Gr -gradation in percentage by weight of each suspended sediment size fraction.
8. Pi - sediment distribution according to size fraction at intake.
9. Ve - settling velocity as per particle shape, determined from figure 5.3
10. Vd - velocity due to density flow. It is equal to (28 x w x H)^0.5. Where w is annual average sediment content of the river at diversion site and H is depth of desilting basin.

11 Vc- criticlal resuspension flow velocity (cm/sec) Vc =(200704 x d)^0.5

12 L,B,H-length, breadth and depth of desilting baisn in m.

13 V - mean flow velocity in desilting basin (cm/sec) V=Q/(LxB)x100+ Vd

14 G_c - grain size at which critical resuspensory flow velocity Vc is equal to V. It is worked out assuming the linear variation between two values of Ve and corresponding grain size.

15 Rw/2- coefficient for estimation of sedimentation rate considering turbulence and diffusion of flow. It is taken equal to 137x Ve /V

16. Eo - sedimentation rate. It is taken as $Eo = (\frac{V_e}{(Q/A)} x100)$, where A is surface area of the basin (L x B).

17. EI- sedimentation rate considering turbulence and diffusion from graph (fig 5.4).

18 S- sediment quantity in effluent considering resuspension.

S= Pi (1-EI)

19 PE- modified suspended sediment content of each size fraction.

PE= Ap x S

5.5 OPTIMISATION APPROACH

The repair cycle curves developed by Nozaki are found helpful in developing an approach for economic optimisation of desilting basin. The economic size of basin can be worked out by comparing the cost of basins designed for various particle sizes to be excluded with the cost of repair, replacement and down times of the turbine. The particle size which gives the minimum cost for desilting basin and repair and maintenance of turbines shall be adopted for the cost effective design of desilting basin.

TABLE 5.1 SAMPLE CALCULATION FOR PE

Sr No	ITEM	UNIT	CALCULATION FOR EACH PARTICLE SIZE																	Total
1	d	mm	0.005		0.01		0.05		0.075		0.1		0.2		0.3		0.4		0.5	
2	a	-	0.1		0.2		1		1.5		2		4		6		8		8	
3	k1	-	1		1		1		1		1		1		1		1		1	
4	k2	-	1		1		1		1		1		1		1		1		1	
5	k3	-	1		1		1		1		1		1		1		1		1	
6	Ap	-	0.1		0.2		1		1.5		2		4		6		8		8	
7	Gr	%	15	10		24		5		4		12		8		7		15		100
8	pi	g/1	0.077		0.065		0.056		0.017		0.031		0.038		0.029		0.042		0.029	0.384
9	Ve	cm/sec	0.002		0.008		0.180		0.200		0.580		1.500		2.300		3.500		4.800	
10	Vd	cm/sec	11.36		11.36		11.36		11.36		11.36		11.36		11.36		11.36		11.36	
11	Vc	cm/sec	31.68		44.80		100.18		122.69		141.67		200.35		245.38		283.34		316.78	
12	Dimensions of desilting basi			L(m)=	30		B(m)=		7.00		H(m)=		12.00		Q/A=		0.115			
13	V	cm/sec	40.17		40.17		40.17		40.17		40.17		40.17		40.17		40.17		40.17	
14	Gc			0.008																
15	Rw/2		0.0		0.03		0.6		0.7		2.0		5.1		7.8		11.9		16.4	
16	Eo		0.000		0.001		0.016		0.017		0.050		0.130		0.200		0.304		0.417	
17	Ei				0.001		0.014		0.016		0.046		0.012		0.182		0.278		0.382	
18	S	g/1	0.077		0.065		0.055		0.017		0.029		0.038		0.024		0.030		0.018	
19	PE	g/1	0.008		0.013		0.055		0.026		0.059		0.152		0.141		0.244		0.142	0.839

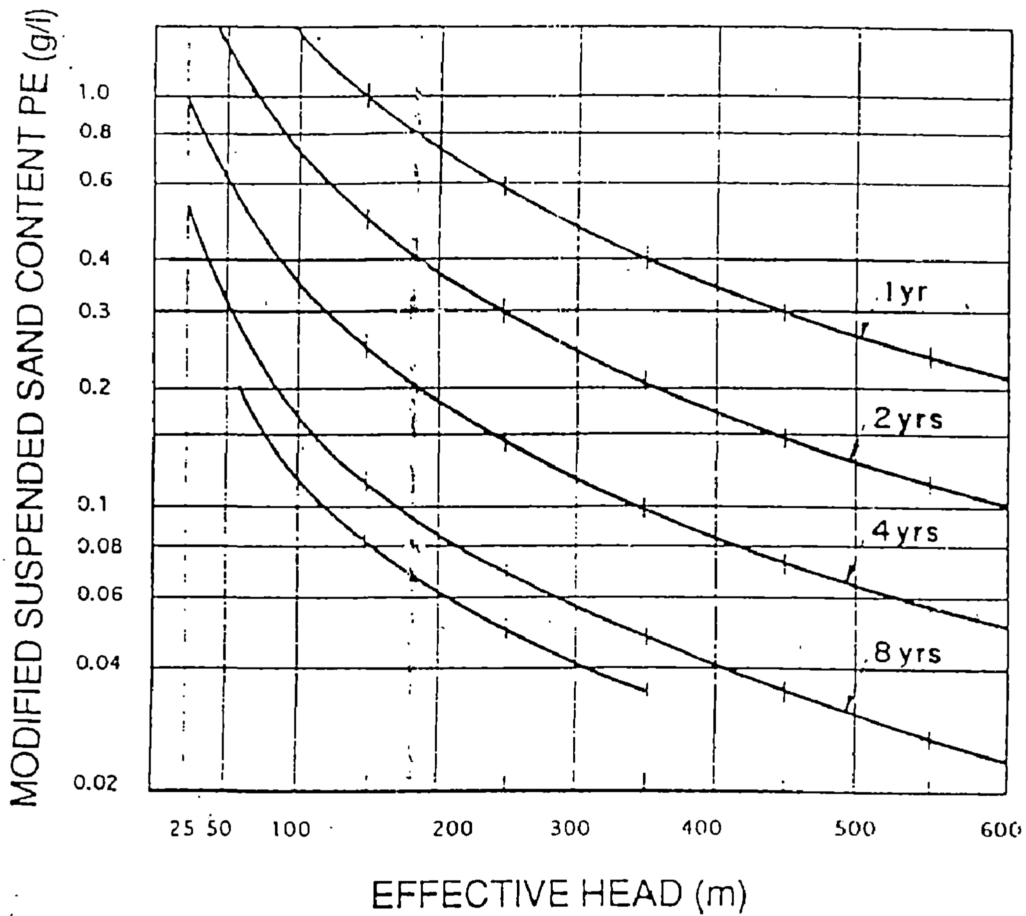


Fig 5.1(b) REPAIR CYCLÉ CURVES FOR FRANCIS TURBINE GUIDE VANES (NOZAKI[29])

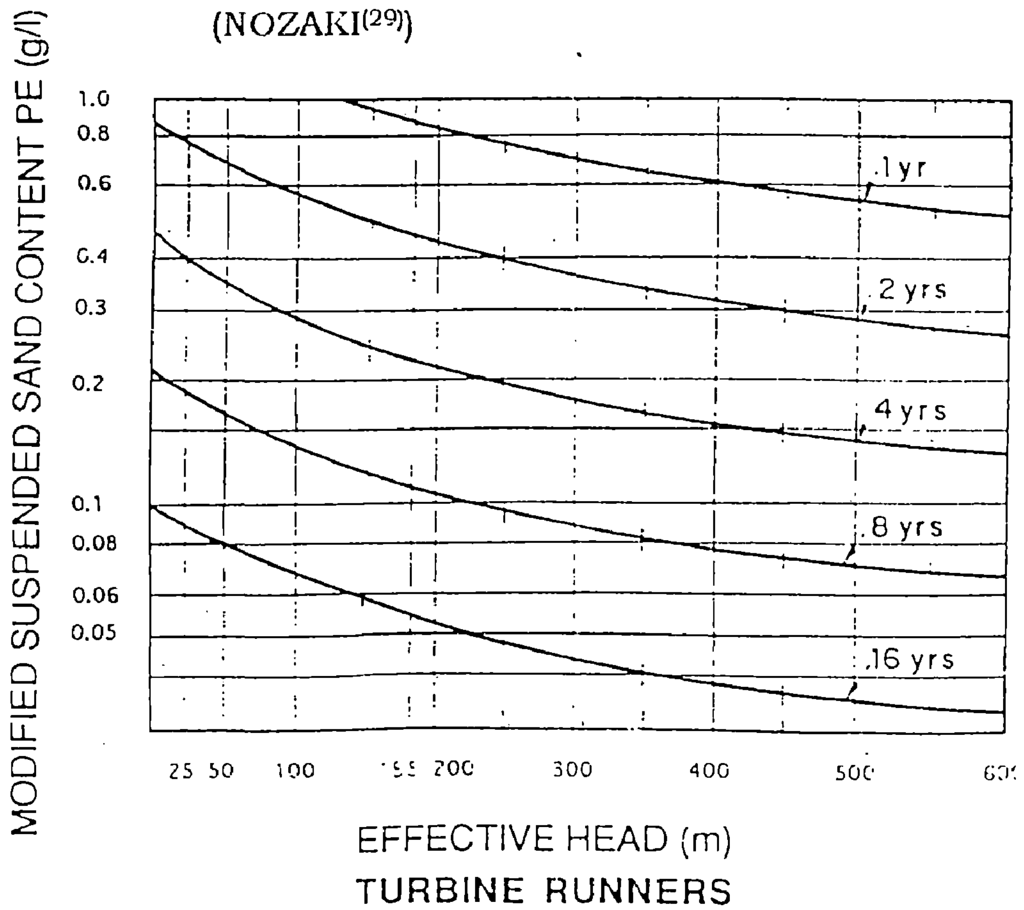


Fig 5.1(a) REPAIR CYCLE CURVES FOR FRANCIS TURBINE(NOZAKI[29])

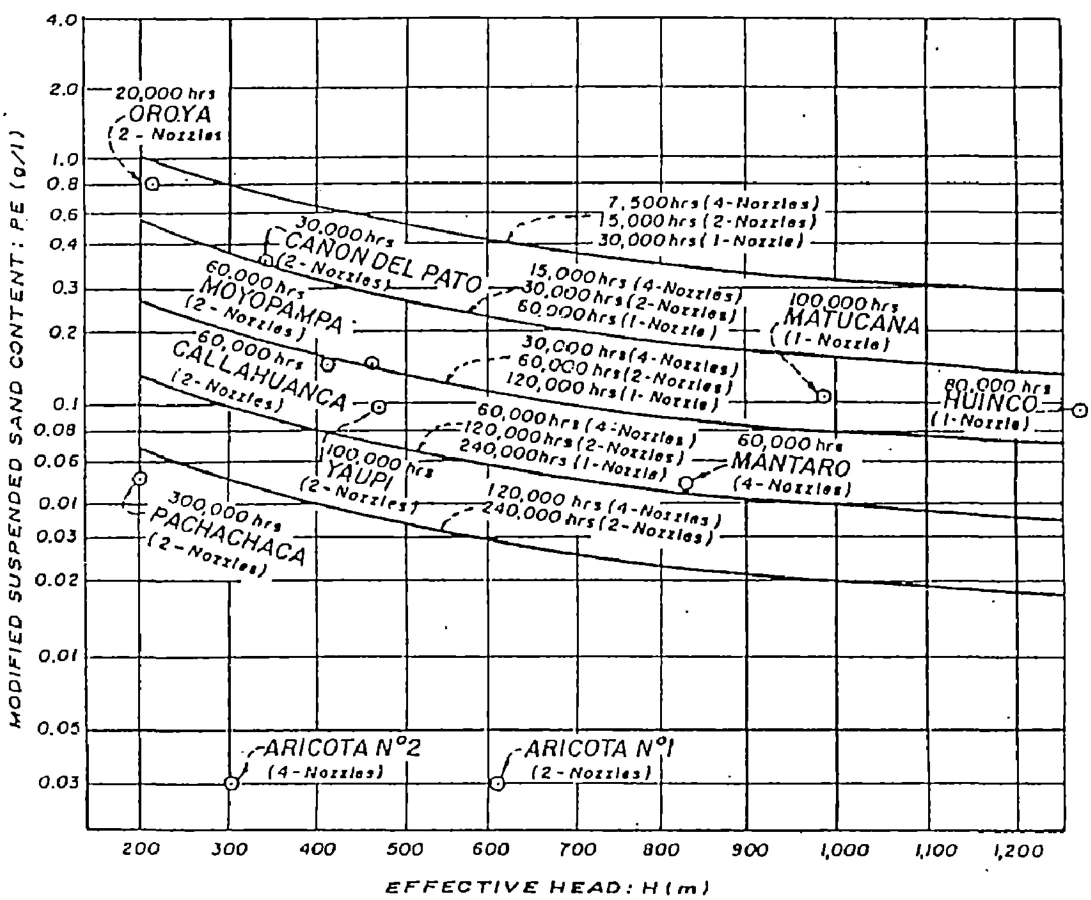


Fig 5.2(b) REPAIR CYCLE CURVES FOR BUCKETS OF PELTON TURBINE (NOZAKI[29])

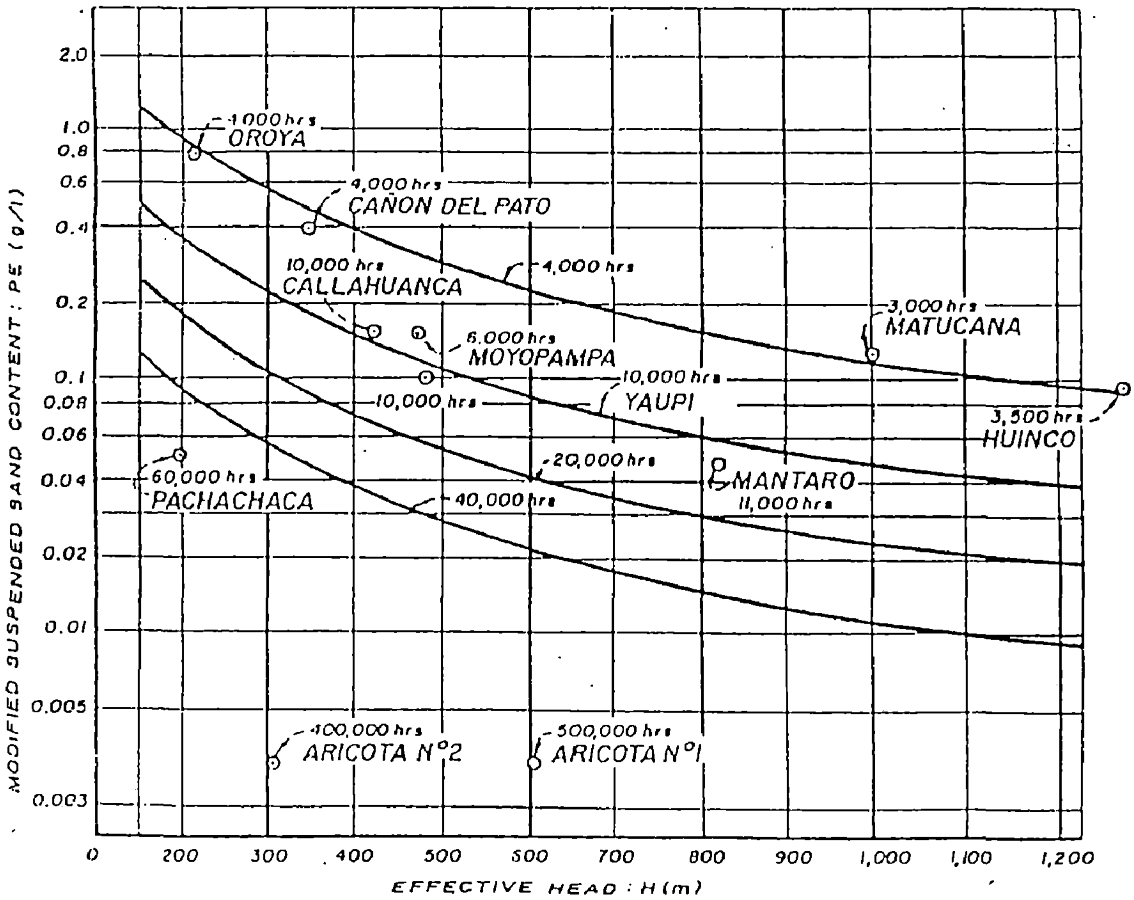


Fig 5.2(a) REPAIR CYCLE CURVES FOR NOZZLES AND NEEDLES OF PELTON TURBINE (NOZAKI[29])

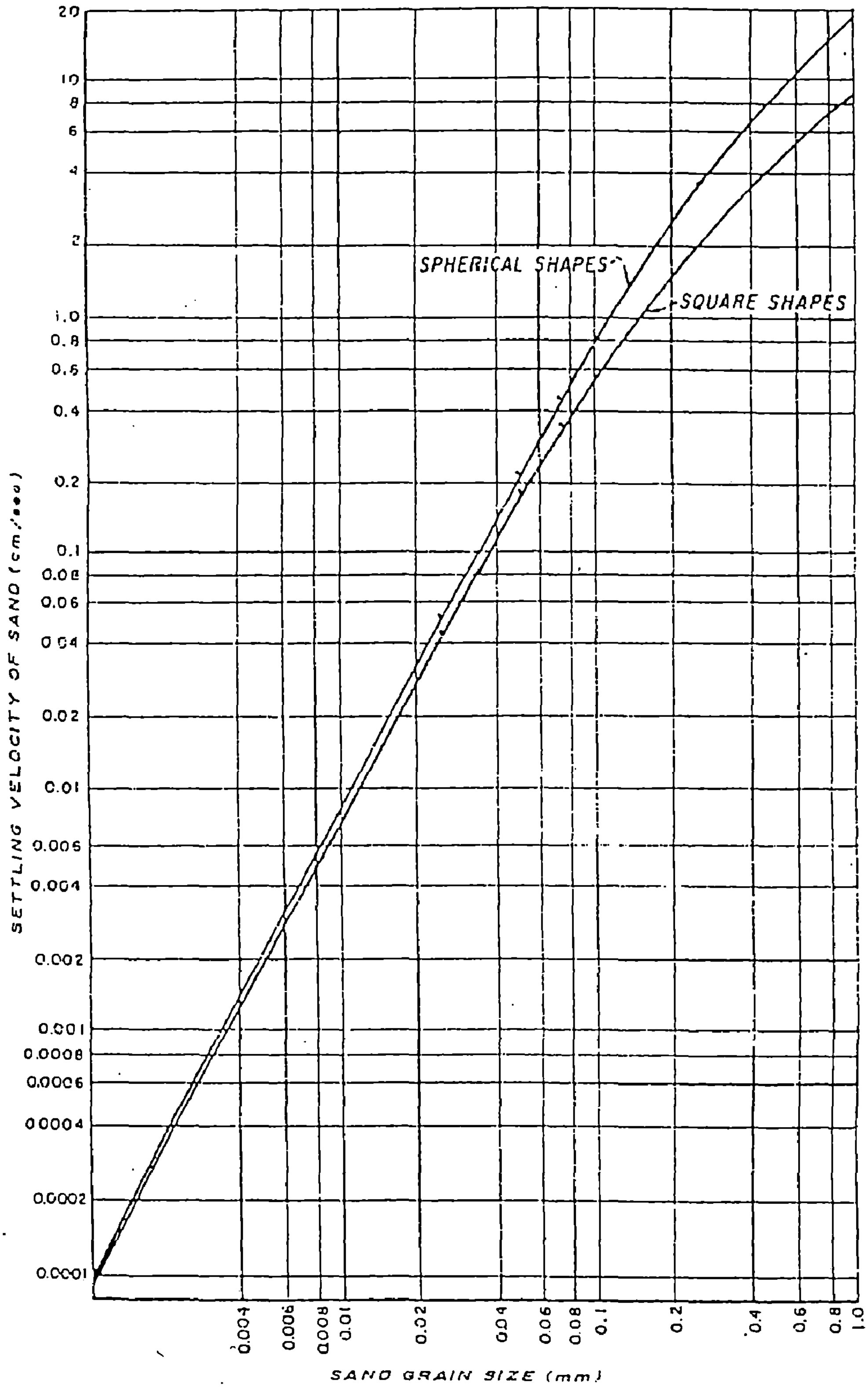
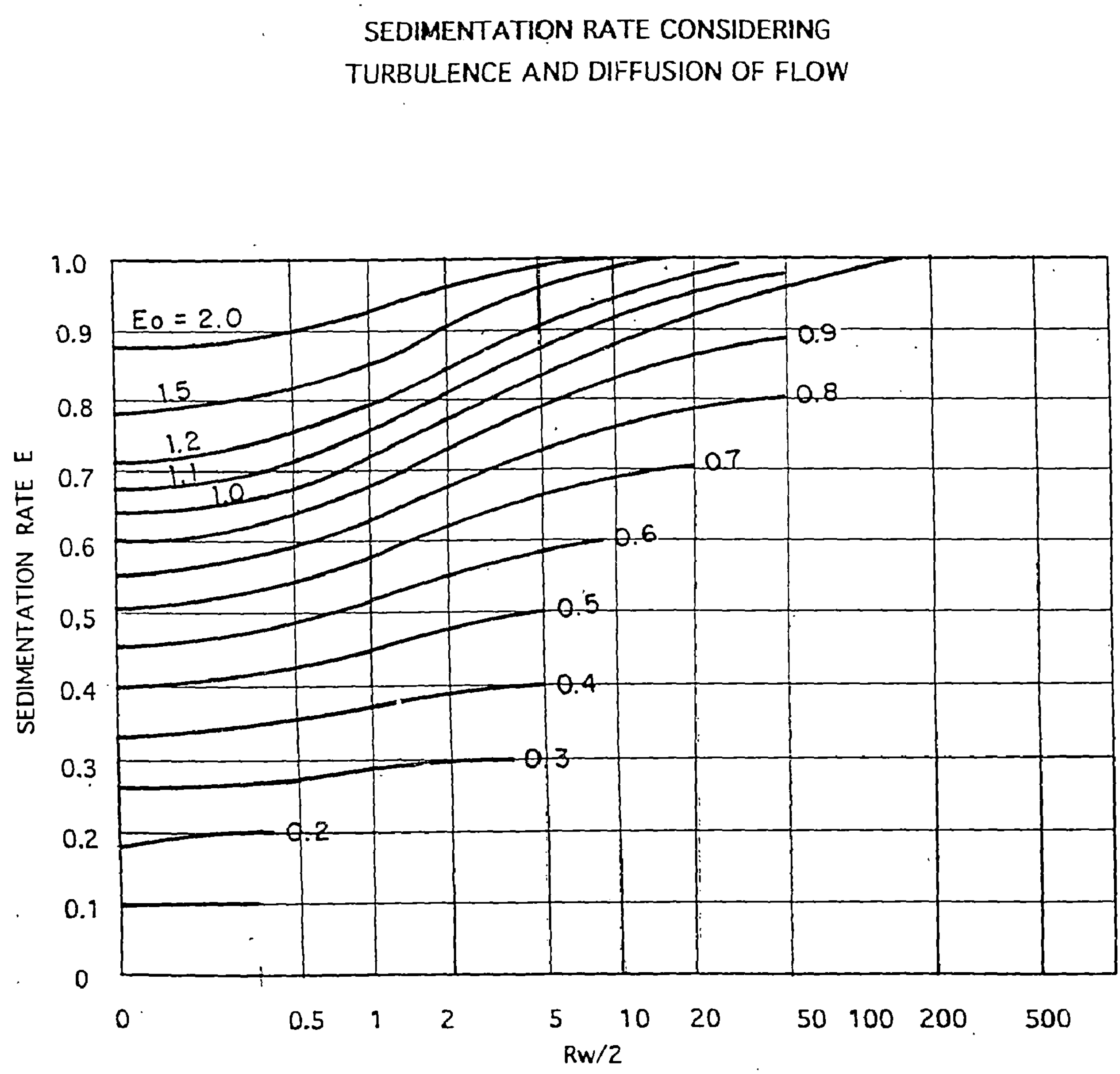


Fig 5.3 SETTLING RATE CONSIDERING PARTICLE SHAPE.



$$\frac{Rw}{2} = \frac{7.5 \cdot \omega}{v \cdot \sqrt{\frac{f}{8}}}$$

Rw = Value defined for consideration of turbulence and diffusion of flow

ω = Settling velocity in flowing water

v = Flow-through velocity in settling basin

f = Weisbach-Darcy friction factor

Fig. 5.4 SEDIMENTATION RATE CONSIDERING TURBULENCE AND DIFFUSION OF FLOW

CHAPTER 6

VALIDATION AND APPLICATION OF OPTIMISATION APPROACH

6.0 GENERAL

The turbine repair cycle curves developed by Nozaki on the basis of 18 power stations of Peru and their use in developing an approach for determining economic size of desilting basin have been described in chapter 5. The Nozaki curves are based on limited data of a particular region. These have, however, been used for planning power stations in Sri Lanka[20], Nepal[36], etc. In this chapter an attempt has been made to collect data of power stations of Himalayan rivers and to validate the repair cycle curves of Nozaki for Indian conditions. The approach of economic sizing of desilting basins has also been illustrated in a few cases in Satluj basin.

6.1 VALIDATION OF OPTIMISATION APPROACH

For validation of the curves developed by NOZAKI, T., for repair cycles of the Francis turbines, field data from the following projects have been collected. The performance of these projects has been discussed in chapter 4.

-DEHAR POWER PLANT
- GIRI POWER PLANT
- BAIR SIUL POWER PLANT
- CHIBRO POWER PLANT

6.1.1.DEHAR POWER PLANT (6x165 MW)

6.1.1.1 Sediment Data

Sediment data at Baggi tunnel outlet, intake to balancing reservoir, intake to Sundernagar-Satluj tunnel inlet and tail race channel is being regularly observed to keep check on the silting/dredging of balancing reservoir. Following table shows the silt passing through the turbines of Dehar power plant and observed in tail race channel for the last five years.

Table:-Monthly average silt load passing through turbines of Dehar power plant(g/l)

Month	**Year**						
	1995	1996	1997	1998	1999	2000	Average
January	-	0.020	0.021	0.028	0.023	-	0.023
February	-	0.040	0.026	0.047	0.031	0.029	0.035
March	-	0.084	0.041	0.103	0.031	0.035	0.040
April	-	0.102	0.055	0.125	0.051	0.054	0.077
May	0.100	0.106	0.072	0.133	0.088	0.095	0.099
June	0.169	0.329	0.103	0.234	0.116	0.181	0.189
July	0.448	0.318	0.364	0.406	0.387	0.271	0.366
August	0.291	0.340	0.273	0.328	0.401	0.304	0.318
September	-	0.107	0.219	0.265	0.117	0.102	0.162
October	0.046	0.042	-	0.138	0.031	0.027	0.065
November	0.025	-	0.049	0.057	0.020	0.019	0.034
December	0.022	0.021	0.050	0.041	0.016	-	0.030
- Not available				**Annual average**			= **0.120**

i) Size, Shape and classification of silt

The size, shape and silt classification of sediment particles is given below.

No	Particle size in (mm)	Classification	Shape
1	0.125-0.062	Very fine sand	Angular to sub angular
2	0.062-0.031	Coarse silt	-------- do----------
3	0.031-0.016	Medium silt	-------- do----------
4	0.016-0.008	Fine silt	-------- do----------

ii) Mineral composition and hardness

The table below gives, mineral composition and hardness of silt particles.

No	Name	Amount of particle(%)				Hardness
		Sample-1	Sample-2	Sample-3	Average	
1	Quartz	85	90	91	89	7
2	Biotite	10	7	7	8	2.5-3
3	Muscovite	5	3	2	3	2-2.5

iii) Gradation analysis of silt

The average gradation of the sediment is as follows:-

Size in fraction	>0.4 mm	0.2 mm to 0.4 mm	<0.2 mm
Amount (%)	1.16	3.17	95.67

6.1.1.2 Modified sediment content

Modified suspended sediment content of silt at Dehar power plant is calculated from the above data as follows.

i) Grain size coefficient (a)

From the percentages of various grain sizes passing through the turbines as given above, grain size coefficient is calculated as follows

$$a = [(\frac{(0+0.2)}{2} x0.9567 + \frac{(0.2+0.4)}{2} x0.0317 + 0.4x0.00116]/0.05$$
$$= 2.1968$$

ii) Shape coefficient (k_1) The shape coefficient for angular to sub angular particles is taken as 1.0.

iii) Hardness coefficient (k_2)

From the mineral composition and hardness of various silt constituents as given above the hardness coefficient is calculated as follows:-

Hardness	Average (%)
3 and above	89
0 to 3	11

The hardness coefficient using above data will be.

k_1 = 0.89 x 1.0 +0.11 x 0.5 =0.945

iv) Abrasion resistance coefficient (k_3)

The abrasion resistance co-efficient of turbine, since it is made of 13Cr: 4 Ni steel, will be 1.0.

Average annual sediment quantity (P) contained in the water passing through turbine is 0.120 g/l.

Therefore, the modified suspended sediment content (PE) will be calculated as follows:-

$$PE = P \times a \times k_1 \times k_2 \times k_3$$
$$= 0.120x\ 2.1968 \times 1.0x\ 0.945x1.0$$
$$= 0.249\ g/l.$$

6.1.1.3 REPAIR CYCLE

From the details given in chapter 4, the net head on the turbine is 320 m. The plot of head and PE is shown on Nozaki curves in fig. 6.1 for Francis runner. It lies between the curves of 2 years and 4 years repair cycles. The actual cycle based on performance is 3.33 years (Ref.table - 4.2).

6.1.2 BAIRA SIUL HE POWER STATION (3x60 MW)

6.1.2.1 Sediment Data

A typical distribution of silt load at intake of Baira Siul project for an yearly cycle is as follows(27)

0 to 300 ppm	68 % of operating time
300 to 1000 ppm	25 % of operating time
1000 to 2000 ppm	4 % of operating time
>2000 ppm	3 % of operating time

The average yearly silt concentration thus comes out to be as

$$\text{Silt conc. (ppm)} = \left(\frac{(0+300)}{2} x0.68 + \frac{(300+1000)}{2} x0.25 + \frac{(1000+2000)}{2} x0.04\right.$$

$$+2000 \text{ x } 0.03$$

$$= 384 \text{ ppm}$$

i) Mineral composition and hardness of silt

Table below gives the mineral composition and hardness of silt particles

Table :-Mineral composition and hardness of silt particles

No	Name	Amount of particle (%)	Hardness
1	Quartz	85	7
2	Phyllite	13	3
3	Calcite	2	3

ii) Grain size distribution

No grain size distribution data is available however on the basis of similar catchments in the Himalayas it is assumed to be as follow;

Table :- Gradation analysis of silt

Size fraction	>0.4 mm	0.2 mm to 0.4 mm	<0.2 mm
Amount (%)	15	15	70

6.1.2.2 Modified suspended sediment content - (PE)

i) Shape coefficient (k_1)

The shape coefficient for angular to sub angular particles is taken as 1.0.

ii) Hardness coefficient (k_2)

From the mineral composition and hardness of various silt constituents as given above the hardness coefficient is taken as 1.0 because hardness of all the particles is above 3.

The modified suspended sediment content of silt has been calculated in table no 6.1, as per procedure described in chapter 5. It worked out to be 0.839 g/l.

6.1.1.3 REPAIR CYCLE

From the details given in chapter 4, the net head on the turbine is 280 m. The plot of head and PE is shown on Nozaki curves in fig. 6.1 for Francis runner. The point lies very near to the curve for one year repair cycle. The actual cycle based on performance is one year.

6.1.3.GIRI HYDEL PROJECT (2x30 mw)

6.1.3.1 Sediment Data

Sediment data of Giri river at barrage site has been shown in table 6.2 .The annual average sediment concentration is 80.88 ppm.

i) Grain size distribution

Table 6.3 givesthe grain size distribution of sediment at the intake.

ii) Mineral composition

Table 6.4 and 6.6 give, mineral composition of sediment.

iii) Hardness of silt particles

Table 6.5 gives the hardness of silt particles.

6.1.3.2 Modified sediment content

Modified sediment content of sediment at Giri power plant is calculated from the above data as below.

i) Grain size coefficient (a)

From the following percentages of various grain sizes at intake (table 6.3), since no desilting arrangement has been provided, the grain size coefficient has been worked out as follows:-

Grain size of sediment (mm)	Percentage(%)
<0.053 mm	50.99
0.074-0.053 mm	12.81
0.149-0.074 mm	19.51
0.25- 0.149 mm	16.69
> 0.25 mm	0.00

Grain size coefficient a

$$a=[\frac{(0+0.053)}{2}x\,0.5099+\frac{(0.074+0.053)}{2}x0.1281+$$

$$\frac{(0.149+0.074)}{2}x0.1951+\frac{(0.25+0.149)}{2}x0.1669]/0.05$$

= 1.5339

iii) Shape coefficient (k_1)

The shape coefficient for angular to sub angular particles is taken as 1.0.

iv) Hardness coefficient (k_2)

In the sediment sand and clay is in the ratio of 49:51 %.(table 6.3).The petrographic analysis results show that there are 2.72 percent micaseous minerals having hardness less than 3 in the sand part of sediment. In clay constiuent of sediment quartz is 34 %. The hardness of sand particles is therefore as follows:-

Hardness	Average (%)
3 and above	97.28 x 0.49+ 0.34 x 51=51 %
0 to 3	2.72x0.49+ 0.66x51 =35 %

The hardness coefficient using above data will be.

k_2= 0.51x1.0+ 0.35x0.5 = 0.825

v) Abrasion resistance coefficient (k_3)

The abrasion resistance co-efficient of turbine, since it is made of 13 Cr: 4 Ni sttel, will be 1.0.

Therefore, the modified suspended sand content (PE) is calculated as

$$PE = P\ x\ a\ x\ k_1\ x\ k_2\ x\ k_3$$

$$= 0.08088x\ 1.5339\ x\ 1.0x\ 0.825x1.0$$

$$= 0.102\ g\ /l.$$

6.1.3.3 REPAIR CYCLE

From the details given in chapter 4 the net head on the turbine is 147.5. The plot of head and PE is shown on Nozaki curves in fig. 6.1 for

Francis runner. It lies just above the curve of 8 year repair cycle. The actual cycle based on performance is also about 8 years.

6.1.4 CHIBRO POWER STATION (4x 60MW)

6.1.4.1 Sediment Data

Sediment data of Tons river at Ichari dam site for various years are given in table no 6.7.

i) Mineral composition and hardness of silt particles

The mineral composition and hardness of river water at Ichari dam site is as follows:-

Table :- Mineral composition and hardness of silt particles at Ichari

No	Name	Amount of silt particles(%)	Hardness
1	Quartz	20	6-7
2	Mica	28	2
3	Clay	37	2
4	Rock fragments	15	2.5

ii) Grain size distribution

No grain size distribution data is available, however on the basis of similar catchments in the Himalayas it is assumed to be as follow;

Table :- Gradation analysis of silt

Amount (%)	> 0.4 mm	0.2 mm to 0.4 mm	<0.2 mm
Amount(%)	15	15	70

6.1.4.2. Modified sediment content

Modified sediment content of silt at Chibro power plant is calculated from the available data as below:-

i) Shape coefficient(k_1)

The shape coefficient for angular to sub angular particles is taken as 1.0.

ii) **Hardness coefficient (k_2)**

Using the mineral composition and hardness of various silt constituents as given in above. The hardness coefficient is worked out as below.

Hardness	Average content
3 and above	27.5 %
0 to 3	72.5 %

The hardness coefficient

$k_2 = 0.275x1.0 + 0.725x0.5 = 0.638$

a) **Abrasion resistance coefficient (k_3)**

The abrasion resistance co-efficient of turbine, since it is made of 13 Cr: 4Ni steel, will be 1.0.

Average annual sediment quantity (P) contained in the water passing through turbine as per table 6.7 is 0.06857 g/l.

The modified suspended sediment content (PE) of the silt has been calculated in table no 6.8 as per procedure described in chapter 5. It worked out to be 0.093 g/l.

6.1.1.4 REPAIR CYCLE

From the details given in chapter 4, the net head on the turbine is 110 m. The plot of head and PE is shown on Nozaki curves in fig. 6.1 for Francis runner. This gives a repair cycle of more than eight years. The actual cycle based on performance is about 6 years. The difference may be attributed to the assumption made for grain size distribution.

6.1.5 RESULTS OF ANALYSIS

The results of above studies of four projects are tabulated below

S.No	Name of Power Station	Head (m)	PE(g/l)	Repair cycle as per Nozaki's curves (years)	Repair cycle as per actual (years)
1	Dehar Power Station	320	0.249	3.0	3.0
2	Baira Siul Power Station	280	0.839	About one year	1.0
3	Giri Power Station	147.5	0.102	9.6	8.0
4	Chibro Power Station	110	0.093	12	5.87

Except Chibro Power Plant all the result validate the correctness of Nozaki's curves for Franci's runner. The variation in case of Chibro may be because of assumed grain size distribution. Thus, it may be concluded that the Nozaki's curves are also applicable in Himalayan rivers.

TABLE 6.1 CALCULATION OF MODIFIED SEDIMENT CONTENT (PE) FOR BAIRA SIUL PROJECT

Design discharge	=	24.2 cumecs per basin
Sediment concentration	=	0.384 g/l
Length of basin	=	30 m

Sr No	ITEM	UNIT	CALCULATION FOR EACH PARTICLE SIZE																	Total
1	d	mm	0.005		0.01		0.05		0.075		0.1		0.2		0.3		0.4		0.5	
2	a	-	0.1		0.2		1		1.5		2		4		6		8		8	
3	k1	-	1		1		1		1		1		1		1		1		1	
4	k2	-	1		1		1		1		1		1		1		1		1	
5	k3	-	1		1		1		1		1		1		1		1		1	
6	Ap	-	0.1		0.2		1		1.5		2		4		6		8		8	
7	Gr	%	15	10		24		5		4		12		8		7		15		100
8	pi	g/l	0.077		0.065		0.056		0.017		0.031		0.038		0.029		0.042		0.029	0.384
9	Ve	cm/sec	0.002		0.008		0.180		0.200		0.580		1.500		2.300		3.500		4.800	
10	Vd	cm/sec	11.36		11.36		11.36		11.36		11.36		11.36		11.36		11.36		11.36	
11	Vc	cm/sec	31.68		44.80		100.18		122.69		141.67		200.35		245.38		283.34		316.78	
12	Dimensions of desilting basi			L(m)=	30		B(m)=		7.00		H(m)=		12.00		Q/A=		0.115			
13	V	cm/sec	40.17		40.17		40.17		40.17		40.17		40.17		40.17		40.17		40.17	
14	Gc			0.008																
15	Rw/2		0.0		0.03		0.6		0.7		2.0		5.1		7.8		11.9		16.4	
16	Eo		0.000		0.001		0.016		0.017		0.050		0.130		0.200		0.304		0.417	
17	Ei				0.001		0.014		0.016		0.046		0.012		0.182		0.278		0.382	
18	S	g/l	0.077		0.065		0.055		0.017		0.029		0.038		0.024		0.030		0.018	
19	PE	g/l	0.008		0.013		0.055		0.026		0.059		0.152		0.141		0.244		0.142	0.839

TABLE 6.2 SEDIMENT DATA OF GIRI RIVER AT BARRAGE SITE

Year	Month	Days	Avearge silt(ppm) Daily	Average silt(ppm)	Average silt(ppm) Monthly	Average silt(ppm) Yearly
1998	Aug	17.8.98	206			
		21.8.98	2484			
		22.8.98	1954			
		26.8.98	1052			
		28.8.98	834	1306	378.39*	
	Sept	24.9.98	971			
		26.9.98	946			
		25.9.98	850	922.33	272.2*	
	Oct.	16.10.98	970			
		17.10.98	2306			
		18.10.98	480			
		19.10.98	1027	1195.75	328.52*	81.59
1999	July	20.7.98	2878			
		21.7.98	987			
		22.7.98	630			
		23.7.98	798			
		24.7.98	617			
		25.7.98	372			
		26.7.98	174			
		27.7.98	95			
		28.7.98	48	733.22		
	Aug	3.8.99	605			
		4.8.99	436			
		6.8.99	878	639.67	686.44*	
2000	June	8.6.2000	1957			49.78
		9.6.2000	1831			
		10.6.2000	1263	1683.67	348.37*	
	July	1.7.2000	1653			
		8.7.2000	1010			
		9.7.2000	633			
		15.7.2000	3286			
		16.7.2000	2708			
		17.7.2000	2564			
		18.7.2000	2526			
		19.7.2000	1680			
		20.7.2000	1300			
		21.7.2000	1102			
		22.7.2000	1245			
		23.7.2000	993			
		24.7.2000	1221			
		25.7.2000	867	1627.71	708.89*	111.26
	August	13.8.2000	2613		277.84*	
Annual average silt concentration of Giri river at diversion site					=	80.88

Note:- Minimum silt in flood season has been considered as 200 ppm. Measurements are generally made when the concentration exceeds 200 ppm. Hence for working out monthly average the silt concentration in rest of the days is taken as 200 ppm

TABLE 6.3 GRAIN SIZE DISTRIBUTION OF SEDIMENT(GIRI PROJECT AT INTAKE)(47)

Sample no	Medium and coa sand >0.25 mm (G1)	Fine sand 0.25-0.149 mm (G2)	Very fine sand' 0.149-0.074 mm (G3)	Coarse silt 0.074-0.053 mm (G4)	Silty clays <0.053 mm (G5)
1	Nil	10.07	15.8	14.02	60.11
2	Nil	31.78	19.12	5.75	43.34
3	Nil	12.11	17.25	15.52	55.12
4	Nil	12.7	25.88	15.96	45.38
Average		16.67	19.51	12.81	50.99

TABLE 6.4 MODAL CONSTITUENTS (PERCENTAGE) OF SILTY CLAY FRACTION (G5) OF SEDIMENT SAMPLE

Sample no	Clay Mineral (%)			Quartz : Clay Minerals
	Ilmanite	Chlorite	Kaolinite	
1	59	16	25	32:68
2	56	22	22	38:62
3	58	19	23	30:70
4	63	16	21	37:63
				Average 34 :66

Note :- These investigations are based on X-ray diffractograms of 16 slides For each sample , The following slides were sca nned using Cu K target. 1. Oriented clay minerals 2. Glaycol treated 3. Oriented and heated to 180 C 4. Oriented and heated to 550 .

TABLE 6.5 HARDNESS OF PETROGRAPHIC CONSTITUENTS AS PER MOHR'S SCALE

Sr No	Petrograhic constituent	Hardness
1	Quartz	7
2	K-Feldspar	6
3	Plagioclase	6
4	Biotite	2.5-3
5	Muscovite	2.5-3
6	Iron oxide	5-6.5
7	Illmanite	5-6
8	Rutile	6-6.5
9	Tourmaline	7-7.5
10	Calcite	3
11	Garnot	7
12	Sphene	5.5
13	Monazite	5
14	Sillimanite	6-7.5
15	Quartzite	7
16	Gneiss	6-7

Tabele 6.6 PETROGRAPHIC ANALYSIS OF SEDIMENT AT GIRI BARRAGE SITE.

Sample of grain	Petrographic constituents										Others	Angularity of hard grains	Remarks
	Feldspars		Mica				Titanium	Rock fragments					
	Quartz	K-feldspar	Plagioclase	Biotite	Muscovite	Iron Oxide	Minerals	Concretio	Gneiss/ Schist	Quartzite			
G4	29.7	25.3	17.7	3	0.3	14.3	6	Tr	Tr	Tr	4.7	2-3	Feldspars mainly alted.
G3	30.5	6	8	3.5	0.5	23.5	5	12	9	Tr	1	2-3	of two generations. iron
G2	7	3	1	1		22	1	57	4	Tr	4	2-3	coated grains.
G4	27	Tr	41.5	Tr		17	1.5	12	0.5	-	0.9	2-3	Feldspars highly altered
G1	33	Tr	21	Tr	0.5	17	2.5	21.5	0.5	-	2	2-3	and coat distinguish.
G2	58	Tr	41	Tr		1	Tr	-	-	-	-	2-3	generations.iron. G2 all coated grains.
G4	35	3.5	34	2	0.5	8	2	9.5	4	Tr	1.5	2-3	Two generations of
G3	33.5	7.5	26.5	2.5	Tr	19.5	0.5	4.5	5	Tr	0.5	2-3	quartz and Feldspars
G2	28	3	10.5	6	Tr	24	1	5	12.5	10	Tr	2-3	iron coated grains
G4	30.7	4.7	27	11.7	Tr	16.7	3.9	1.3	6.3	6.7	1	2-3	Two generations of
G3	27.5	2.5	19	5.5	Tr	20.5	3.5	1.5	10	8.5	1.5	2-3	Feldspars,Most grains
G2	21	1	12.7	2	Tr	24.3	3	Tr	28.7	7.3	Tr	2-3	iron coated.
Avragerage	30.08	6.28	21.66	4.13	0.45	17.32	2.72	13.81	8.05	8.13	1.90		

1 Mainly ilmanite,rutile,occasionally anatase.

2 Consists of grain of quartz ,feldspar.rock fragments,calcitic and ferugenious cement.

3 Mainly calcite,tourmaline,occassionally monazite,sillimenite.garnet,sphene and opaques.

TABLE 6.7 MONTHLY AVERAGE SUSPENDED SEDIMENT OF TONS RIVER AT ICHARI DAM SITE(PPM)

Month	Year								Avrerage
	1984-85	1987-88	1988-89	1989-90	1993-94	1994-95	1995-96	1996-97	
June	36	72	43	38	118	382	38.5	135	103.3
July	63	58	427	100	574	650	303.9	71	273
August	96	60	310	123	565	181	215.6	232	210.8
September	60	20	100	119	368	185	523.1	17	166.5
October	15	21	24	6	8	11	4.2	12	10.8
November	12	12	17	4	3.3	1.8	2.2	1.2	5.2
December	10	10	45	5	1.4	0.5	1.2	0.8	8
January	9	10	34	3	2.7	3	23.5	7.5	10.5
February	9	14	15	6	1.9	7	15	1.5	7.6
March	10	44	14	27	1.3	1.4	6.4	0.4	11.8
April	13	20	13	8	7.2	1	1	1.2	6.4
May	23	14	22	13	7.5	2.8	3.7	9.3	9
	Annual average silt concentration =								68.57

TABLE 6.8 CALCULATION OF MODIFIED SEDIMENT CONTENT (PE) FOR CHIBRO POWER STATION

Design discharge = 129.25 cumecs per basin

Sediment concentration = 0.0808 g/l

Length of basin = 83 m

Sr No	ITEM	UNIT	CALCULATION FOR EACH PARTICLE SIZE																	Total
1	d	mm	0.005		0.01		0.05		0.075		0.1		0.2		0.3		0.4		0.5	
2	a	-	0.1		0.2		1		1.5		2		4		6		8		8	
3	k1	-	1		1		1		1		1		1		1		1		1	
4	k2	-	0.638		0.638		0.638		0.638		0.638		0.638		0.638		0.638		0.638	
5	k3	-	1		1		1		1		1		1		1		1		1	
6	Ap	-	0.0638		0.1276		0.638		0.957		1.276		2.552		3.828		5.104		5.104	
7	Gr	%	15	10		24		5		4		12		8		7		15		100
8	pi	g/l	0.016		0.014		0.012		0.004		0.006		0.008		0.006		0.009		0.006	0.081
9	Ve	cm/sec	0.002		0.008		0.180		0.200		0.580		1.500		2.300		3.500		4.800	
10	Vd	cm/sec	11.36		11.36		11.36		11.36		11.36		11.36		11.36		11.36		11.36	
11	Vc	cm/sec	31.68		44.80		100.18		122.69		141.67		200.35		245.38		283.34		316.78	
12	Dimensions of desilting basi			L(m)=	83		B(m)=		12.75		H(m)=		14.00		Q/A=		0.122			
13	V	cm/sec	83.77		83.77		83.77		83.77		83.77		83.77		83.77		83.77		83.77	
14	Gc					0.038														
15	Rw/2		0.0		0.01		0.3		0.3		0.9		2.5		3.8		5.7		7.9	
16	Eo		0.000		0.001		0.015		0.016		0.047		0.123		0.188		0.287		0.393	
17	Ei						0.015		0.016		0.047		0.123		0.188		0.287		0.393	
18	S	g/l	0.016		0.014		0.012		0.004		0.006		0.007		0.005		0.006		0.004	
19	PE	g/l	0.001		0.002		0.007		0.003		0.008		0.018		0.019		0.032		0.019	0.109

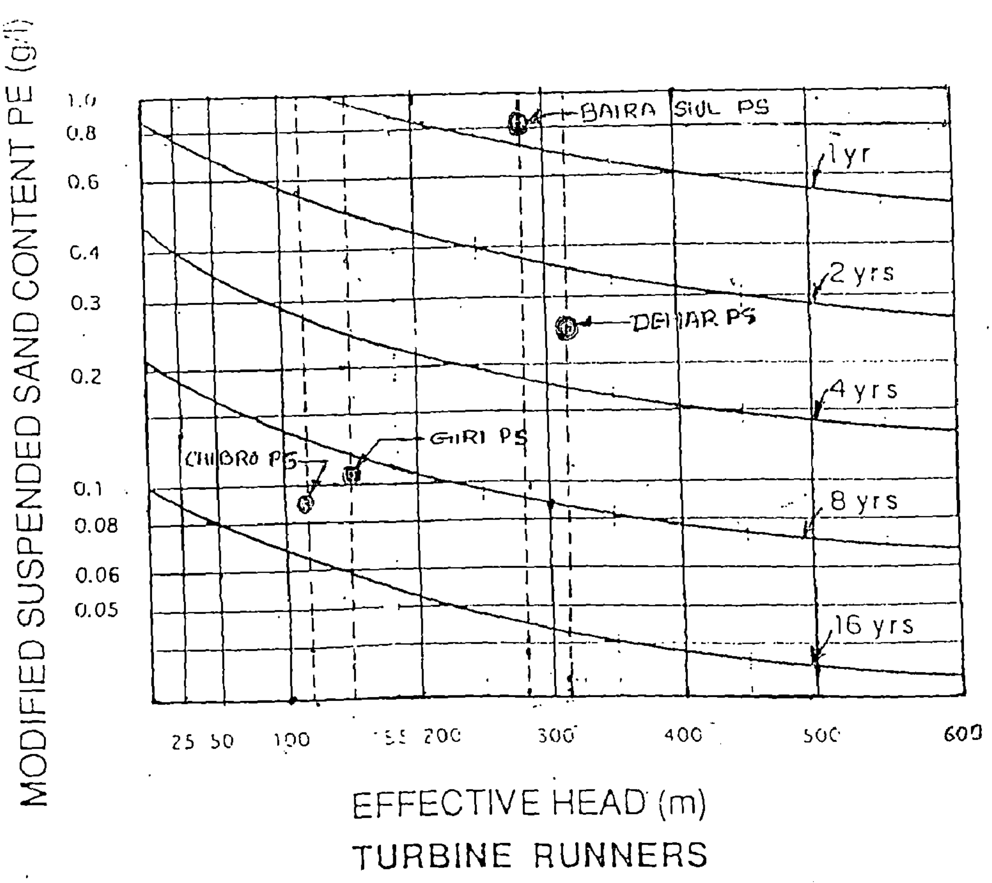


Fig. 6.1 PLOT OF SUSPENDED SEDIMENT CONTENT 'PE' AND HEAD 'H' FOR PROJECTS IN OPERATION IN HIMALAYAN REGION ON NOZAKI'S CURVES

6.2 APPLICATION OF OPTIMISATION APPROACH

The application of optimisation approach discussed in earlier chapters, has been illustrated in following two run-of-the river projects which are being planned in Satluj basin.

Thopan- Shongtong HEP(4x130MW)

Shongtong - Karchham HEP(4X70MW)

6.2.1 THOPAN SHONGTONG HEP

Thopan Shongtong hydroelectric project is a run-of-the river project on Satluj river. The project envisages construction of a concrete diversion dam, under ground desilting arrangement, 5.5 km long head race tunnel, surge shaft and a underground powerhouse on the left bank of Satluj river. Four vertical axis Francis turbines, each of 130 MW shall be installed in the powerhouse. The project shall utilize a head of 188.78 m and a design discharge of 319 m^3/sec to generate 520 MW of power.

Satluj river is a snow fed river and carries a lot of sediment during summer and monsoon months (i.e. from April to September). Hence adequate desilting arrangement has to be provided.

6.2.1.1 Design of Desilting Basin

Design of desilting basin (as per DPR) based on Mysonyi's approach is described below:-

Design discharge at outlet of each basin	(Q2)	= 319/4
		= 79.75 m^3/sec.
Flushing discharge @20 %		= 15.95 m^3/sec.
Inlet discharge for each basin	(Q1)	= 95.7 m^3/sec.
Flow area (15m x 23m)		= 345 m^2
Depth of flow		= 23 m
Particle size to be settled		= 0.2 mm
Settling velocity, w		= 0.024 m/sec

(for density γ=1.033 t/m^3) from Sudry's curve, (fig 3.6).

Average discharge, Q =(Q1+Q2)/2

=(95.7+79.75)/2

=87.73 m^3/sec

Average flow through velocity v =87.73/345

= 0.25m/sec.

Reduction in settling velocity w' = 0.132/√23x 0.25

=0.0070 m/sec

Length of settling chamber L = h v/(w-w')

=344 meters

Also settling length as given by Velikanov's function

$$L = \frac{\lambda^2 x V^2 (\sqrt{h} - 0.2)^2}{7.51 x w^2}$$

Where,λ=f(w),w is ratio of settled sediments to sediment load entering with flow.

$$\lambda = \sqrt{\frac{7.51 x L x w^2}{V^2 (\sqrt{h} - 0.2)^2}}$$

$$= \sqrt{\frac{7.51 x 344 x (0.024)^2}{0.26^2 (\sqrt{23} - 0.2)^2}}$$

= 1.0385

Settling efficiency for λ=1.04, from Velikanov's curve (fig.3.7) = 95 %. Similarly for removal of particle sizes of 0.3 mm, 0.4 mm and 0.5 mm and keeping the cross sectional area the same, for simplification, the length of sediment chambers is calculated as follows.

For removal of 0.3 mm particle size length $L = \frac{23 x 0.25}{(0.038 - 0.0070)}$

= 185 meters

For removal of 0.4 mm particle size length $L = \frac{23 x 0.25}{(0.052 - 0.007)}$

= 128 meters

For removal of 0.5 mm particle size length $L = \frac{23x0.25}{(0.065 - 0.007)}$

$= 99$ meters

6.2.1.2. Sediment Data

Suspended sediment data of Satluj river at Wangtu is given in table no 6.9. Thopan shongtong project is a upstream development of Nathpa Jhakari project and the sediment load shall be somewhat less, however, the data of Wangtu site has been used.

i) Petrographic analysis and hardness of sediment in Satluj river has been given in table 2.1 page 20.

ii) Grain size distribution for sediment in Satluj at Wangtu is as follows:-

Constituent	Clay <0.002 mm	Fine 0.002 to 0.075 mm	Medium 0.075 to 0.2 mm	Coarse >0.2 mm
Amount(%)	3.2	56.7	23.2	16.9

6.2.1.3 Modified Sediment Content (PE)

i) Shape coefficient (k_1)

The shape coefficient for angular to sub angular particles is taken as 1.0.

ii) Hardness coefficient (k_2)

From the mineral composition and hardness of various silt constituents as given in fig. 2.19 page 19, the hardness coefficient is calculated as follows:-

Hardness	Average sediment content (%)
3 and above	70.3
0 to 3	29.7

The hardness coefficient using above data will be.

$k_1 = 0.703x1.0 + 0.297x0.5 = 0.945$

iii) Abrasion resistance coefficient (k_3)

The abrasion resistance co-efficient of turbine, since it is made of 13 Cr: 4 Ni steel, will be 1.0.

Modified suspended sediment content (PE) for removal of different particle sizes (0.2, 0.3, 0.4 and 0.5 mm) have been calculated separately for each size in tables 6.10 to 6.13. Repair cycles for each case has been determined from Nozaki's chart fig 5.1. Modified sediment content and repair cycles as calculated above are shown in table below.-

Repair cycle for the turbine with different particle size

Particle size 'd' removed (mm)	PE(g/l)	Repair cycles for Francis turbine(years)			No of cycles in 50 years. (Economic life)
		Runner	Guide vanes	Minimum	
0.2	0.361	2.8	2.2	2.2	23
0.3	0.534	1.8	1.7	1.7	29
0.4	0.707	1.7	1.3	1.3	38
0.5	0.791	1.15	1.1	1.1	45

6.2.1.4 Cost Estimation

Cost of Desilting Basin

For optimisation study, four cases of desilting basin based on the removal of particle sizes 0.2, 0.3, 0.4 and 0.5 mm have been considered. Cost of civil works of desilting basin for removal of 0.2 mm particle size is based on the estimated cost of the project as per master plan(44) (based on 1995 price level). For simplification, a linear variation with respect to length has been considered to work out cost of other basins assuming that the cost of inflow, outflow portion, adits etc., is same in all cases. The cost for various basins on the above assumption is shown in table below;-

Particle size removed 'd' (mm)	Length (m)	Width (m)	Depth (m)	Cost(Rs x crore)
0.2	344	15	23	200.84
0.3	185	15	23	127.70
0.4	128	15	23	101.48
0.5	99	15	23	88.14

6.2.1.5 Repair and Replacement Cost of Turbine.

Cost of turbine has been taken as Rs 10 crores. It is based on the master plan studies. The repair and replacement costs have been worked out on the following assumptions:-

i) Repair cycle is assumed smaller of the two required for turbine and guide vanes.

ii) Replacement will be required when turbine has been operated for a duration of six repair cycles.

iii) The life of project for economic analysis is taken as 50 years.

iv) Discount factor of 10 % has been taken to calculate the present worth.

v) Generation loss during down time has not been considered as the repair and replacement shall be done during lean period when all the units will not be in operation.

vi) Yearly escalation in the cost of turbine is taken as 5%.

vii) Repair cost of turbine after each cycle has been taken as 12.5 % of the initial cost.

6.2.1.6 Escalated Costs for Turbine

Escalated cost of turbine during period of economic analysis for four cases, considering 5% annual escalation, is as follows:

Cost for spare runner and guide vane =Rs 11 crores
for one unit (taking guide vane cost as 10 % of turbine cost).

1.1 Cost of replacement for four units (Rs x crores)

Case-I	1st replacement cost	= 97.94
(0.2 mm)	2nd replacement cost	= 207.62
	3rd replacement cost	= 462.14
Case-II	1st replacement cost	= 78.63
(0.3 mm)	2nd replacement cost	= 147.55
	3rd replacement cost	= 276.88
Case-III	1st replacement cost	= 68.59
(0.4 mm)	2nd replacement cost	=112.28
	3rd replacement cost	=183.78
	4th replacement cost	=300.82
	5th replacement cost	=492.14
Case-III	1st replacement cost	= 64.06
(0.5 mm)	2nd replacement cost	= 97.94
	3rd replacement cost	=149.73
	4th replacement cost	=228.90
	5th replacement cost	=349.94

Based on the above assumptions, present worth cost of construction of desilting basin and repair and replacement cost of turbine have been worked out in tables 6.14 to 6.17 and is presented below.

Summary of Present Worth Cost

S No	Length of basin (m)	Particle size removed (mm)	Present worth cost (Rs x crores)		Total cost
			Basin	Turbine	
1	344	0.2	272.5	74.5	346.9
2	185	0.3	173.2	96	269.3
3	128	0.4	137.7	131.8	269.5
4	99	0.5	130.8	152.5	283.3

6.2.1.7 Optimisation Results

Present worth of cost of desilting basin and corresponding repair and replacement cost has been calculated separately for each particle size to be excluded and is shown in table 6.14 to 6.17. A graph between particle size removed v/s cost of desilting basin, repair and replacement cost, has been drawn and is shown in figure 6.2, below. The optimum particle size giving the minimum construction cost of desilting basin and repair and replacement cost of turbine considered together comes out to be 0.3 mm.

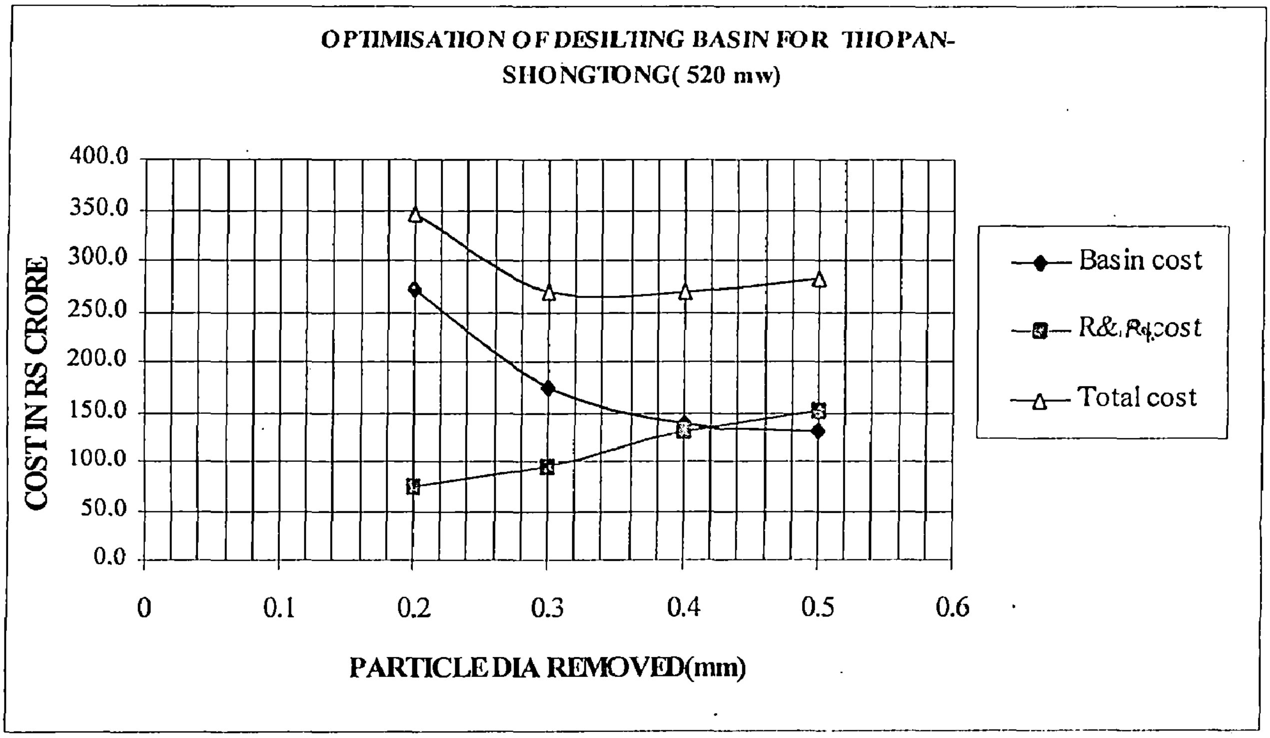


Fig. 6.2 Optimisation of desilting basin for Thopan Shongtong HEP

Table 6.9 SUSPENDED SEDIMENT DATA OF SATLUJ AT WANGTU (g/l)

Month	Year										Avrerage
	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	
January	0.005	0.005	0.040	0.008	0.044	0.064	0.020	0.013	0.048	0.010	0.026
February	0.012	0.008	0.040	0.012	0.011	0.078	0.010	0.010	0.084	0.028	0.029
March	0.047	0.025	0.043	0.092	0.560	0.300	0.024	0.054	0.155	0.180	0.148
April	0.126	0.117	2.573	0.179	2.266	0.455	0.032	0.130	0.489	0.233	0.660
May	0.290	0.885	2.519	1.234	3.820	1.633	0.082	0.884	0.600	0.412	1.236
June	2.514	1.832	6.729	1.270	4.788	1.334	0.687	2.157	3.027	1.585	2.592
July	2.625	1.762	4.543	1.981	1.916	3.144	2.865	1.655	3.658	5.750	2.990
August	3.303	1.357	2.861	1.444	1.946	1.088	2.093	1.668	1.288	2.128	1.917
September	0.436	0.540	1.131	0.418	0.580	0.092	0.586	0.674	0.204	0.303	0.497
October	0.029	0.081	0.074	0.087	0.175	0.039	0.060	0.144	0.037	0.144	0.087
November	0.017	0.044	0.025	0.052	0.108	0.020	0.017	0.094	0.024	0.042	0.044
December	0.007	0.030	0.015	0.030	0.049	0.012	0.017	0.021	0.016	0.017	0.021
Annual average silt convcentration from year 1970 to 1980 =											0.7369

Month	Year										Avrerage
	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	
January		0.014	0.048	0.010		0.021	0.042	0.014	0.049	0.054	0.031
February		0.021	0.042	0.041	0.027	0.023	0.062	0.021	0.043	0.054	0.037
March			0.075	0.130	0.038	0.078	0.100	0.042	0.102	0.090	0.082
April			0.237	0.269	0.060	0.263	0.392	0.751	0.344	0.456	0.347
May		0.447	2.704	0.668	0.105	0.700	0.403	0.676	0.841	2.297	0.982
June	0.654	3.963	4.138	1.616	0.169	4.397	1.809	0.766	2.351	2.064	2.193
July	2.233	7.143	2.829	1.305	1.714	3.035	1.364	1.321	3.304		2.694
August	2.991	4.527	2.081	1.927	2.099	2.206	0.611	1.321	0.832		2.066
September	0.466	0.291	0.561	0.722	0.413	2.929	0.254	0.745	0.353		0.748
October	0.349	0.068	0.090	0.086	0.198	0.203	0.040	0.208	0.090		0.148
November	0.263	0.056	0.042	0.051	0.137	0.074	0.019	0.101	0.046		0.088
December	0.012	0.052	0.029	0.012	0.043	0.049	0.021	0.065	0.041		0.036
Annual average silt concentration from year 1981 to 1990 =											0.788
Annual average silt concentration from year 1970 to 1990 =											**0.7620**

THOPAN-SHONGTONG PROJECT

TABLE 6.10 MODIFIED SUSPENDED SEDIMENT CONTENT (PE) CALCULATIONS FOR REMOVAL OF PARTICLES +0.2 mm

Design discharge = 87.73 m^3/sec per basin

Sediment cconcentration = 0.762 g/l

Length of basin = 344 m

Sr No	ITEM	UNIT	CALCULATION FOR EACH PARTICLE SIZE																			Total
1	d	mm	0.001		0.005		0.01		0.05		0.075		0.1		0.2		0.3		0.4		0.5	
2	a	-	0.02		0.1		0.2		1		1.5		2		4		6		8		8	
3	k1	-	1		1		1		1		1		1		1		1		1		1	
4	k2	-	0.852		0.852		0.852		0.852		0.852		0.852		0.852		0.852		0.852		0.852	
5	k3	-	1		1		1		1		1		1		1		1		1		1	
6	Ap	-	0.017		0.0852		0.1704		0.852		1.278		1.704		3.408		5.112		6.816		6.816	
7	Gr	%		18		12		25		5		8		15.1		4.9		7		5		100
8	pi	g/l	0.0686		0.1143		0.141		0.1143		0.04953		0.088		0.0762		0.0453		0.0457		0.0191	0.762
9	Ve	cm/sec	9E-05		0.0019		0.0083		0.18		0.2		0.58		1.5		2.3		3.5		4.8	
10	Vd	cm/sec	22.152		22.152		22.152		22.152		22.15238		22.152		22.1524		22.152		22.152		22.152	
11	Vc	cm/sec	14.167		31.678		44.8		100.18		122.6899		141.67		200.352		245.38		283.34			
12	Desilting basin dimensions				L(m)=		344		B(m)=		15.00		H(m)=		23.00		Q/A=		0.017			
13	V	cm/sec	47.58		47.58		47.58		47.58		47.58		47.58		47.58		47.58		47.58		47.58	
14	Gc							0.012														
15	Rw/2		0.00		0.01		0.02		0.52		0.58		1.67		4.32		6.62		10.08		13.82	
16	Eo		0.00		0.00		0.00		0.11		0.12		0.34		0.88		1.35		2.06		2.82	
17	El								0.105		0.117		0.290		0.750		0.950		1		1	
18	S	g/l	0.069		0.114		0.141		0.102		0.044		0.062		0.019		0.002		0.000		0.000	
19	PE	g/l	0.001		0.010		0.024		0.087		0.056		0.106		0.065		0.012		0.000		0	0.361

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TABLE 6.11 MODIFIED SUSPENDED SEDIMENT CONTENT (PE) CALCULATIONS FOR REMOVAL OF PARTICLES +0.3 mm

Design discharge	=	87.73 m3/sec per basin
Sediment cconcentration	=	0.762 g/l
Length of basin	=	185 m

Sr NO	ITEM	UNIT	CALCULATION FOR EACH PARTICLE SIZE																			Total
1	d	mm	0.001		0.005		0.01		0.05		0.075		0.1		0.2		0.3		0.4		0.5	
2	a	-	0.02		0.1		0.2		1		1.5		2		4		6		8		8	
3	k1	-	1		1		1		1		1		1		1		1		1		1	
4	k2	-	0.852		0.852		0.852		0.852		0.852		0.852		0.852		0.852		0.852		0.852	
5	k3	-	1		1		1		1		1		1		1		1		1		1	
6	Ap	-	0.017		0.0852		0.1704		0.852		1.278		1.704		3.408		5.112		6.816		6.816	
7	Gr	%		18		12		25		5		8		15.1		4.9		7		5		100
8	pi	g/l	0.0686		0.1143		0.141		0.1143		0.04953		0.088		0.0762		0.0453		0.0457		0.0191	0.762
9	Ve	cm/sec	9E-05		0.0019		0.0083		0.18		0.2		0.58		1.5		2.3		3.5		4.8	
10	Vd	cm/sec	22.152		22.152		22.152		22.152		22.15238		22.152		22.1524		22.152		22.152		22.152	
11	Vc	cm/sec	14.167		31.678		44.8		100.18		122.6899		141.67		200.352		245.38		283.34			
12	Desilting basin dimensions				L(m)=		185		B(m)=		15.00		H(m)=		23.00		Q/A=		0.032			
13	V	cm/sec	47.581		47.581		47.581		47.581		47.58137		47.581		47.5814		47.581		47.581		47.581	
14	Gc							0.012														
15	Rw/2.		0.00		0.01		0.02		0.52		0.58		1.67		4.32		6.62		10.08		13.82	
16	Eo		0.000		0.001		0.003		0.057		0.063		0.183		0.474		0.728		1.107		1.518	
17	El								0.057		0.063		0.183		0.470		0.690		0.95		1	
18	S	g/l	0.069		0.114		0.141		0.108		0.046		0.072		0.040		0.014		0.002		0.000	
19	PE	g/l	0.001		0.010		0.024		0.092		0.059		0.123		0.138		0.072		0.016		0.000	0.534

TABLE 6.12 MODIFIED SUSPENDED SEDIMENT CONTENT (PE) CALCULATIONS FOR REMOVAL OF PARTICLES +0.4 mm

Design discharge = 87.73 m3/sec per basin

Sediment concentration = 0.762 g/l

Length of basin = 128 m

Sr No	ITEM	UNIT	CALCULATION FOR EACH PARTICLE SIZE																			Total
1	d	mm	0.001		0.005		0.01		0.05		0.075		0.1		0.2		0.3		0.4		0.5	
2	a	-	0.02		0.1		0.2		1		1.5		2		4		6		8		8	
3	k1	-	1		1		1		1		1		1		1		1		1		1	
4	k2	-	0.852		0.852		0.852		0.852		0.852		0.852		0.852		0.852		0.852		0.852	
5	k3	-	1		1		1		1		1		1		1		1		1		1	
6	Ap	-	0.017		0.0852		0.1704		0.852		1.278		1.704		3.408		5.112		6.816		6.816	
7	Gr	%		18		12		25		5		8		15.1		4.9		7		5		100
8	pi	g/l	0.0686		0.1143		0.141		0.1143		0.04953		0.088		0.0762		0.0453		0.0457		0.0191	0.762
9	Ve	cm/sec	9E-05		0.0019		0.0083		0.18		0.2		0.58		1.5		2.3		3.5		4.8	
10	Vd	cm/sec	22.152		22.152		22.152		22.152		22.15238		22.152		22.1524		22.152		22.152		22.152	
11	Vc	cm/sec	14.167		31.678		44.8		100.18		122.6899		141.67		200.352		245.38		283.34			
12	Desilting basin dimensions				L(m)=		128		B(m)=		15.00		H(m)=		23.00		Q/A=		0.046			
13	V	cm/sec	47.581		47.581		47.581		47.581		47.58137		47.581		47.5814		47.581		47.581		47.581	
14	Gc							0.012														
15	Rw/2		0.00		0.01		0.02		0.52		0.58		1.67		4.32		6.62		10.08		13.82	
16	Eo		2E-05		0.0004		0.0018		0.039		0.043771		0.1269		0.32828		0.5034		0.766		1.0505	
17	El								0.039		0.044		0.127		0.328		0.503		0.725		0.91	
18	S	g/l	0.069		0.114		0.141		0.110		0.047		0.077		0.051		0.023		0.013		0.002	
19	PE	g/l	0.001		0.010		0.024		0.094		0.061		0.131		0.175		0.115		0.086		0.012	0.707

TABLE 6.13 MODIFIED SUSPENDED SEDIMENT CONTENT (PE) CALCULATIONS FOR REMOVAL OF PARTICLES +0.5 mm

Design discharge	=	87.73 m3/sec per basin
Sediment cconcentration	=	0.762 g/l
Length of basin	=	99 m

Sr No	ITEM	UNIT	CALCULATION FOR EACH PARTICLE SIZE																				Total
1	d	mm	0.001		0.005		0.01		0.05		0.075		0.1		0.2		0.3		0.4		0.5	
2	a	-	0.02		0.1		0.2		1		1.5		2		4		6		8		8	
3	k1	-	1		1		1		1		1		1		1		1		1		1	
4	k2	-	0.852		0.852		0.852		0.852		0.852		0.852		0.852		0.852		0.852		0.852	
5	k3	-	1		1		1		1		1		1		1		1		1		1	
6	Ap	-	0.017		0.0852		0.1704		0.852		1.278		1.704		3.408		5.112		6.816		6.816	
7	Gr	%		18		12		25		5		8		15.1		4.9		7		5		100
8	pi	g/l	0.0686		0.1143		0.141		0.1143		0.04953		0.088		0.0762		0.0453		0.0457		0.0191	0.762
9	Ve	cm/sec	9E-05		0.0019		0.0083		0.18		0.2		0.58		1.5		2.3		3.5		4.8	
10	Vd	cm/sec	22.152		22.152		22.152		22.152		22.15238		22.152		22.1524		22.152		22.152		22.152	
11	Vc	cm/sec	14.167		31.678		44.8		100.18		122.6899		141.67		200.352		245.38		283.34			
12	Desilting basin dimensions				L(m)=		99		B(m)=		15.00		H(m)=		23.00		Q/A=		0.059			
13	V	cm/sec	47.581		47.581		47.581		47.581		47.58137		47.581		47.5814		47.581		47.581		47.581	
14	Gc							0.012														
15	Rw/2		0.00		0.01		0.02		0.52		0.58		1.67		4.32		6.62		10.08		13.82	
16	Eo		0.000		0.000		0.001		0.030		0.034		0.098		0.254		0.389		0.592		0.812	
17	El								0.300		0.034		0.098		0.254		0.389		0.592		0.78	
18	S	g/l	0.069		0.114		0.141		0.080		0.048		0.079		0.057		0.028		0.019		0.004	
19	PE	g/l	0.001		0.010		0.024		0.068		0.061		0.135		0.194		0.142		0.127		0.029	0.791

TABLE 6.14 PRESENT WORTH COST CALCULATIONS FOR CONST. OF DESILTING BASIN AND REPAIR AND REPLACEMENT COST FOR TURBINE FOR +0.2 mm PARTICLES SIZE

a) PRESENT WORTH COST CALCULATIONS FOR DESILTING BASIN CONST.COST

Cost of desilting basin Rs= 200.84 Crores

Particle size removed = + 0.2 mm

Time	Unit	Desilting basin cost				Present worth factro	Present worth cost
		Distribution ratio	Construction cost	O&M	Total		
-5	Year	10	20.08		20.08	1.536	30.85
-4	Year	20	40.17		40.17	1.386	55.67
-3	Year	30	60.25		60.25	1.269	76.46
-2	Year	25	50.21		50.21	1.154	57.94
-1	Year	15	30.13		30.13	1.049	31.60
	O & M cost @ 1 %	for 50 years		2.01		9.915	19.93
			200.84				
					Sub total desilting basin cost =		272.45

b) PRESENT WORTH COST CALCULATIONS FOR REPAIR AND REPLACEMENT OF TURBINE

Repair cycle year = 2.2 Years

Time	Unit	Turbine cost			Present worth cost	Present worth cost
		Repair cost	Replace. cost	Total		
0	Spare runner					11
1	Repair Cycle	5.50	0.00	5.50	0.811	4.46
2	Repair Cycle	5.50	0.00	5.50	0.657	3.62
3	Repair Cycle	5.50	0.00	5.50	0.533	2.93
4	Repair Cycle	5.50	0.00	5.50	0.432	2.38
5	Repair Cycle	5.50	0.00	5.50	0.350	1.93
6	Repair Cycle	5.50	0.00	5.50	0.284	1.56
	1st replacement	0.00	97.94	97.94	0.209	20.52
1	Repair Cycle	12.24	0.00	12.24	0.170	2.08
2	Repair Cycle	12.24	0.00	12.24	0.138	1.69
3	Repair Cycle	12.24	0.00	12.24	0.112	1.37
4	Repair Cycle	12.24	0.00	12.24	0.091	1.11
5	Repair Cycle	12.24	0.00	12.24	0.073	0.90
6	Repair Cycle	12.24	0.00	12.24	0.060	0.73
	2nd replacement	0.00	207.62	207.62	0.048	10.02
1	Repair Cycle	25.95	0.00	25.95	0.036	0.92
2	Repair Cycle	25.95	0.00	25.95	0.029	0.75
3	Repair Cycle	25.95	0.00	25.95	0.023	0.61
4	Repair Cycle	25.95	0.00	25.95	0.019	0.49
5	Repair Cycle	25.95	0.00	25.95	0.015	0.40
6	Repair Cycle	25.95	0.00	25.95	0.012	0.32
	3rd replacement		462.14	462.14	0.010	4.67
					Sub total turbine cost =	74.45
					Total present worth cost of turbine and desilting basin =	346.91

TABLE 6.15 PRESENT WORTH COST CALCULATIONS FOR CONST. OF DESILTING BASIN AND REPAIR AND REPLACEMENT COST FOR TURBINE FOR +0.3 mm PARTICLE SIZE

a) PRESENT WORTH COST CALCULATION FOR DESALTING BASINCONST.COST

Cost of desilting basin Rs = 127.70 Crores

Particle size removed - + 0.3 mm

Time	Unit	Desilting basin cost				Present worth cost	Present worth cost
		Distribution ratio	Construction cost	O&M	Total		
-5	Year	10	12.77		12.77	1.536	19.6
-4	Year	20	25.54		25.54	1.386	35.4
-3	Year	30	38.31		38.31	1.269	48.6
-2	Year	25	31.93		31.93	1.154	36.8
-1	Year	15	19.16		19.16	1.049	20.1
	O & M cost @ 1 %	for 50 years		1.28		9.915	12.66
			127.70				
				Sub total desilting basin cost =			173.22

b) PRESENT WORTH COST CALCULATIONS FOR REPAIR AND REPLACEMENT OF TURBINE

Repair cycle year - 1.7 Years

Time	Unit	Turbine cost			Present worth cost	Present worth
		Repair cost	Replace. cost	Total		
0	Spare runner					11.00
1	Repair Cycle	5.50	0.00	5.50	0.850	4.68
2	Repair Cycle	5.50	0.00	5.50	0.723	3.98
3	Repair Cycle	5.50	0.00	5.50	0.615	3.38
4	Repair Cycle	5.50	0.00	5.50	0.523	2.88
5	Repair Cycle	5.50	0.00	5.50	0.445	2.45
6	Repair Cycle	5.50	0.00	5.50	0.378	2.08
	1st replacement		78.63	78.63	0.322	25.29
1	Repair Cycle	9.83	0.00	9.83	0.249	2.44
2	Repair Cycle	9.83	0.00	9.83	0.211	2.08
3	Repair Cycle	9.83	0.00	9.83	0.180	1.77
4	Repair Cycle	9.83	0.00	9.83	0.153	1.50
5	Repair Cycle	9.83	0.00	9.83	0.130	1.28
6	Repair Cycle	9.83	0.00	9.83	0.111	1.09
	2nd replacement		147.55	147.55	0.094	13.88
1	Repair Cycle	18.44	0.00	18.44	0.073	1.34
2	Repair Cycle	18.44	0.00	18.44	0.062	1.14
3	Repair Cycle	18.44	0.00	18.44	0.053	0.97
4	Repair Cycle	18.44	0.00	18.44	0.045	0.83
5	Repair Cycle	18.44	0.00	18.44	0.038	0.70
6	Repair Cycle	18.44	0.00	18.44	0.032	0.60
	3rd replacement		276.88	276.88	0.028	7.62
1	Repair Cycle	34.61	0.00	34.61	0.021	0.74
2	Repair Cycle	34.61	0.00	34.61	0.018	0.63
3	Repair Cycle	34.61	0.00	34.61	0.015	0.53
4	Repair Cycle	34.61	0.00	34.61	0.013	0.45
5	Repair Cycle	34.61	0.00	34.61	0.011	0.39
6	Repair Cycle	34.61	0.00	34.61	0.009	0.33
				Sub total turbine cost =		96.03
		Total present worth cost of turbine and desilting basin =				108.69

TABLE 6.16 PRESENT WORTH COST CALCULATIONS FOR CONST. OF DESILTING BASIN AND REPAIR AND REPLACEMENT COST FOR TURBINE FOR +0.4 mm PARTICLE SIZE

a) **PRESENT WORTH COST CALCULATION FOR DESALTING BASINCONST.COST**

Cost of desilting basin Rs= 101.48 Crores

Particle size removed = + 0.4 mm

Time	Unit	Desilting basin cost				Present worth cost	Present worth cost
		Distribution ratio	Construction cost	O&M	Total		
-5	Year	10	10.15		10.15	1.536	15.6
-4	Year	20	20.30		20.30	1.386	28.1
-3	Year	30	30.44		30.44	1.269	38.6
-2	Year	25	25.37		25.37	1.154	29.3
-1	Year	15	15.22		15.22	1.049	16.0
	O & M cost @ 1 %	for 50 years		1.01		9.915	10.06
			101.48				
				Sub total desilting basin cost =			137.66

b) **PRESENT WORTH COST CALCULATIONS FOR REPAIR AND REPLACEMENT OF TURBINE**

Repair cycle year = 1.3 Years

Time	Unit	Turbine cost			Present worth cost	Present worth
		Repair cost	Replace. cost	Total		
0	Spare runner					11.00
1	Repair Cycle	5.50	0.00	5.50	0.883	4.86
2	Repair Cycle	5.50	0.00	5.50	0.781	4.29
3	Repair Cycle	5.50	0.00	5.50	0.690	3.79
4	Repair Cycle	5.50	0.00	5.50	0.609	3.35
5	Repair Cycle	5.50	0.00	5.50	0.538	2.96
6	Repair Cycle	5.50	0.00	5.50	0.475	2.62
	1st replacement	0.00	68.59	68.59	0.420	28.81
1	Repair Cycle	8.57	0.00	8.57	0.337	2.89
2	Repair Cycle	8.57	0.00	8.57	0.298	2.56
3	Repair Cycle	8.57	0.00	8.57	0.263	2.26
4	Repair Cycle	8.57	0.00	8.57	0.233	1.99
5	Repair Cycle	8.57	0.00	8.57	0.206	1.76
6	Repair Cycle	8.57	0.00	8.57	0.182	1.56
	2nd replacement	0.00	112.28	112.28	0.160	18.01
1	Repair Cycle	14.03	0.00	14.03	0.129	1.81
2	Repair Cycle	14.03	0.00	14.03	0.114	1.60
3	Repair Cycle	14.03	0.00	14.03	0.101	1.41
4	Repair Cycle	14.03	0.00	14.03	0.089	1.25
5	Repair Cycle	14.03	0.00	14.03	0.078	1.10
6	Repair Cycle	14.03	0.00	14.03	0.069	0.97
	3rd replacement		183.78	183.78	0.061	11.26
1	Repair Cycle	22.97	0.00	22.97	0.049	1.13
2	Repair Cycle	22.97	0.00	22.97	0.043	1.00
3	Repair Cycle	22.97	0.00	22.97	0.038	0.88
4	Repair Cycle.	22.97	0.00	22.97	0.034	0.78
5	Repair Cycle	22.97	0.00	22.97	0.030	0.69
6	Repair Cycle	22.97	0.00	22.97	0.026	0.61
	4th replacecment		300.82	300.82	0.023	7.04
1	Repair Cycle	37.60	0.00	37.60	0.019	0.71
2	Repair Cycle	37.60	0.00	37.60	0.017	0.62
3	Repair Cycle	37.60	0.00	37.60	0.015	0.55
4	Repair Cycle	37.60	0.00	37.60	0.013	0.49
5	Repair Cycle	37.60	0.00	37.60	0.011	0.43
6	Repair Cycle	37.60	0.00	37.60	0.010	0.38
	5th replacement		492.41	492.41	0.009	4.40
				Sub total turbine cost =		131.82
		Total present worth cost of turbine and desilting basin =				269.48

TABLE.6.17 PRESENT WORTH COST CALCULATIONS FOR CONST. OF DESILTING BASIN AND REPAIR AND REPLACEMENT COST FOR TURBINE FOR+0.5 mm PARTICLE SIZE

a) PRESENT WORTH COST CALCULATION FOR DESALTING BASIN CONST.COST

Cost of desilting basin Rs= 88.14 Crores

Particle size removed - + 0.5 mm

Time	Unit	Desilting basin cost				Present worth cost	Present worth cost
		Distribution ratio	Construction cost	O&M	Total		
-5	Year	10	8.81		8.81	1.536	13.5
-4	Year	20	17.63		17.63	1.386	24.4
-3	Year	30	26.44		26.44	1.269	33.6
-2	Year	25	22.04		22.04	1.154	25.4
-1	Year	15	13.22		13.22	1.049	13.9
	O & M cost @ 1 %	for 50 years		2.01		9.915	19.93
			88.14				
						Sub total desilting basin cost =	130.75

b) PRESENT WORTH COST CALCULATIONS FOR REPAIR AND REPLACEMENT OF TURBINE

Repair cycle year - 1.1 Years

Time	Unit	Turbine cost			Present worth cost	Present worth
		Repair cost	Replace. cost	Total		
0	Spare runner					11.00
1	Repair Cycle	5.50	0.00	5.50	0.900	4.95
2	Repair Cycle	5.50	0.00	5.50	0.811	4.46
3	Repair Cycle	5.50	0.00	5.50	0.730	4.02
4	Repair Cycle	5.50	0.00	5.50	0.657	3.62
5	Repair Cycle	5.50	0.00	5.50	0.592	3.26
6	Repair Cycle	5.50	0.00	5.50	0.533	2.93
	Ist replacement	0.00	64.06	64.06	0.480	30.75
1	Repair Cycle	8.01	0.00	8.01	0.393	3.15
2	Repair Cycle	8.01	0.00	8.01	0.354	2.83
3	Repair Cycle	8.01	0.00	8.01	0.319	2.55
4	Repair Cycle	8.01	0.00	8.01	0.287	2.30
5	Repair Cycle	8.01	0.00	8.01	0.258	2.07
6	Repair Cycle	8.01	0.00	8.01	0.233	1.86
	2nd replacement	0.00	97.94	97.94	0.209	20.52
1	Repair Cycle	12.24	0.00	12.24	0.171	2.10
2	Repair Cycle	12.24	0.00	12.24	0.154	1.89
3	Repair Cycle	12.24	0.00	12.24	0.139	1.70
4	Repair Cycle	12.24	0.00	12.24	0.125	1.53
5	Repair Cycle	12.24	0.00	12.24	0.113	1.38
6	Repair Cycle	12.24	0.00	12.24	0.102	1.24
	3rd replacement		149.73	149.73	0.091	13.69
1	Repair Cycle	18.72	0.00	18.72	0.075	1.40
2	Repair Cycle	18.72	0.00	18.72	0.067	1.26
3	Repair Cycle	18.72	0.00	18.72	0.061	1.14
4	Repair Cycle	18.72	0.00	18.72	0.055	1.02
5	Repair Cycle	18.72	0.00	18.72	0.049	0.92
6	Repair Cycle	18.72	0.00	18.72	0.044	0.83
	4th replacement		228.90	228.90	0.040	9.13
1	Repair Cycle	28.61	0.00	28.61	0.033	0.93
2	Repair Cycle	28.61	0.00	28.61	0.029	0.84
3	Repair Cycle	28.61	0.00	28.61	0.026	0.76
4	Repair Cycle	28.61	0.00	28.61	0.024	0.68
5	Repair Cycle	28.61	0.00	28.61	0.021	0.61
6	Repair Cycle	28.61	0.00	28.61	0.019	0.55
	5th replacement		349.94	349.94	0.017	6.09
1	Repair Cycle	43.74	0.00	43.74	0.014	0.62
2	Repair Cycle	43.74	0.00	43.74	0.013	0.56
3	Repair Cycle	43.74	0.00	43.74	0.012	0.51
4	Repair Cycle	43.74	0.00	43.74	0.010	0.46
5	Repair Cycle	43.74	0.00	43.74	0.009	0.41
					Sub total turbine cost =	152.53
					Total present worth cost of turbine and desilting basin =	283.29

6.2.2 SHONGTONG KARCHAM HEP

Shongtong Karcham hydroelectric project is a run-of-the river project on Satluj river. The project envisages construction of a diversion dam/barrage, under ground desilting arrangement, 5.5km long head race tunnel, surge shaft and a underground power house on the right bank of Satluj river. Four vertical axis Francis turbines, each of 70 MW capacity shall be installed in the powerhouse. The project shall utilize a net head of 88.49 m and a design discharge of 336 m^3/sec to generate 280 MW of power.

Satluj river is a snow fed river and carries a lot of sediment during summer and monsoon months (i.e. from April to September). Hence, adequate arrangement of desilting arrangement has to be provided.

6.2.2.1 Design of a Desilting Basin

Design of a desalting basin (as per DPR) based on Mysoni's approach is described below:-

Design discharge at outlet of each basin	(Q2)	= 336/4
		= 84 m^3/sec.
Flushing discharge @20 %		= 16.8 m^3/sec
Inlet discharge for each basin	(Q1)	= 100.8 m^3/sec
Flow area (15m x 24m)		= 360 m^2
Depth of flow		= 24 meters
Particle size to be settled		=0.2 mm
Settling velocity, w		=0.024 m/sec

(for density γ=1.033 t/m^3) from Sudry's curve fig.3.6)

Average discharge, Q	=(Q1+Q20/2
	=(84+100.8)/2
	=92.4 m^3/sec
Average flow through velocity v	=92.40/360

= 0.2567m/sec.

Reduction in settling velocity w' = $0.132/\sqrt{24} x\ 0.26$

=0.0069 m/sec

Length of settling chamber L = h v/(w-w')

=360 m

Also settling length as given by Velikanov's function

$$L = \frac{\lambda^2 x V^2 (\sqrt{h} - 0.2)^2}{7.51 x w^2}$$

Where,λ=f(w),w is ratio of settled sediments to sediment load entering with flow.

$$\lambda = \sqrt{\frac{7.51 x L x w^2}{V^2 (\sqrt{h} - 0.2)^2}}$$

$$= \sqrt{\frac{7.51x360x(0.024)^2}{0.26^2 (\sqrt{23} - 0.2)^2}}$$

= 1.0385

Settling efficiency for λ=1.04, from Velikanov's curve (fig. 3.7) = 95 %.

Similarly for removal of particle sizes of 0.3 mm, 0.4 mm and 0.5 mm and keeping the cross sectional area the same, for simplification, the length of sediment basins is given by:-

For removal of 0.3 mm particle size length $L = \frac{24x0.2567}{(0.038 - 0.0069)}$

= 198 meters

For removal of 0.4 mm particle size length $L = \frac{24x0.2567}{(0.052 - 0.0069)}$

= 137 meters

For removal of 0.5 mm particle size length $L = \frac{24x0.2567}{(0.065 - 0.0069)}$

= 106 meters

6.2.2.2. Sediment Data

Suspended sediment data of Satluj river at Wangtu is given in table no 6.9. Shongtong Thopan project is upstream development of Nathp Jhakari project and the sediment load shall be somewhat less, however, the data of Wangtu site has been used. Sediment characteristics and various coefficients are the same as calculated in the case for Thopan Shongtong project above.

6.2.2.3 Modified Sediment Content (PE)

Modified suspended sediment content for removal of different particle sizes have been calculated in table 6.18 to table 6.21. Repair cycles for each case has been determined from Nozaki's chart fig 5.1. Modified sediment content and repair cycles as calculated above are shown in table below.-

Repair cycle for the turbine with different particle size

Particle size 'd' removed (mm)	PE(g/l)	Repair cycles for Francis turbine(years)			No of cycles in 50 years (Economic life)
		Runner	Guide vanes	Minimum	
0.2	0.361	2.9	4.0	2.9	17
0.3	0.533	2.4	2.8	2.4	21
0.4	0.762	1.7	2.2	1.7	29
0.5	0.811	1.4	2.0	1.4	36

6.2.2.4 Cost Estimation

Cost of Desilting Basin

For optimisation study, four cases of desilting basin based on the removal of particle sizes 0.2, 0.3,0.4 and 0.5 mm have been considered. Cost of civil works of desilting basin for removal of 0.2 mm particle size is based on the estimated cost of the project as per master plan[44]. Based on 1995 price level). For simplification, a linear variation with respect to length has been considered to work out cost of other basins assuming that the cost of inflow, outflow portion, adits etc., is same in all cases. The cost for various basins on the above assumption is shown in table below;-

Particle size removed 'd' (mm)	Length (m)	Width (m)	Depth (m)	Cost (Rs x crore)
0.2	360	15	24	208.20
0.3	198	15	24	133.68
0.4	137	15	24	105.62
0.5	108	15	24	91.36

6.2.2.5 Repair and Replacement Cost of Turbine

Cost of turbine has been taken as Rs 8 crores. It is based on the master plan studies. The repair and replacement costs have been worked out on the assumptions as detailed at 6.2.1.5.

6.2.2.6 Escalated Costs for Turbine

Escalated cost of turbine during period of economic analysis for four cases, considering 5% annual escalation, is as follows:

1.0 Cost for spare runner and guide vanes = Rs 8 crores for one unit (taking guide vane cost as 10 % of turbine cost).

1.1 Cost of replacement for four units (Rs x crores)

Case-I 1st replacement cost = 94.77

(0.2 mm) 2nd replacement cost = 281.32

Case-II 1st replacement cost = 79.90

(0.3 mm)2nd replacement cost = 190.41

Case-III 1st replacement cost = 62.91

(0.4 mm) 2nd replacement cost = 118.04

3rd replacement cost = 221.50

Case-III 1st replacement cost = 56.78

(0.5 mm) 2nd replacement cost = 96.17

3rd replacement cost =162.89

4th replacement cost =275.89

Based on the above assumptions, present worth cost of construction of desilting basin and repair and replacement cost of turbine have been worked out in tables 6.24 to 6.27 and is presented below.

Summary of Present Worth cost

S No	Length of basin (m)	Particle size removed(mm)	Present worth cost (Rs x crores)		Total cost
			Basin	Turbine	
1	360	0.2	263.84	42.76	306.6
2	198	0.3	169.41	52.37	221.78
3	137	0.4	133.85	76.82	210.67
4	106	0.5	115.78	95.62	211.4

6.2.2.7 Optimisation Results

Present worth of cost of desilting basin and corresponding repair and replacement cost has been calculated separately for each particle size to be excluded and is shown in table 6.22 to 6.25. A graph between particle size removed v/s cost of desilting basin, repair and replacement cost, has been drawn and is shown in figure 6.3. The optimum particle size giving the minimum construction cost of desilting basin and repair and replacement cost of turbine considered together comes out to be 0.40 mm.

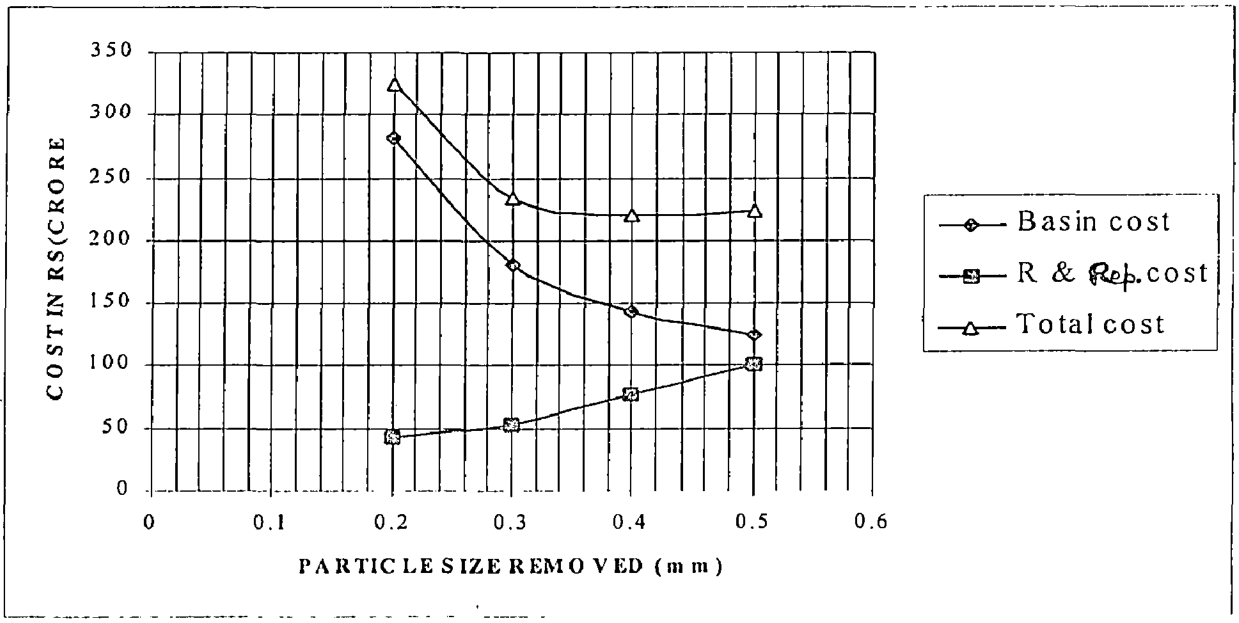

Fig. 6.3 Optimisation of a desilting basin for Shongtong Karcham HEP

TABLE 6.18 MODIFIED SUSPENDED SEDIMENT CONTENT (PE) CALCULATIONS FOR REMOVAL OF +0.2 mm PARTICLES SIZE

Design discharge = 92.4 m3/sec

Sediment cconcentration = 0.762 g/l

Length of basin = 360 m

Sr No	ITEM	UNIT	CALCULATION FOR EACH PARTICLES SIZE																			Total
1	d	mm	0.001		0.005		0.01		0.05		0.075		0.1		0.2		0.3		0.4		0.5	
2	a	-	0.02		0.1		0.2		1		1.5		2		4		6		8		8	
3	k1	-	1		1		1		1		1		1		1		1		1		1	
4	k2	-	0.852		0.852		0.852		0.852		0.852		0.852		0.852		0.852		0.852		0.852	
5	k3	-	1		1		1		1		1		1		1		1		1		1	
6	Ap	-	0.017		0.0852		0.1704		0.852		1.278		1.704		3.408		5.112		6.816		6.816	
7	Gr	%		18		12		25		5		8		15.1		4.9		7		5		100
8	pi	g/l	0.0686		0.1143		0.141		0.1143		0.0495		0.088		0.0762		0.0453		0.0457		0.0191	0.762
9	Ve	cm/sec	9E-05		0.0019		0.0083		0.18		0.2		0.58		1.5		2.3		3.5		4.8	
10	Vd	cm/sec	22.629		22.629		22.629		22.629		22.629		22.629		22.629		22.629		22.629		22.629	
11	Vc	cm/sec	14.167		31.678		44.8		100.18		122.69		141.67		200.35		245.38		283.34			
12	basin dimensions				L(m)=		360		B(m)=		15.00		H(m)=		24.00		Q/A=		0.017			
13	V	cm/sec	48.30		48.30		48.30		48.30		48.30		48.30		48.30		48.30		48.30		48.30	
14	Gc	mm						0.013														
15	Rw/2		0.00		0.01		0.02		0.51		0.57		1.65		4.26		6.52		9.93		13.62	
16	Eo		5E-05		0.0011		0.0049		0.1052		0.1169		0.339		0.8766		1.3442		2.0455		2.8052	
17	EI								0.105		0.117		0.290		0.750		0.950		1		1	
18	S	g/l	0.069		0.114		0.141		0.102		0.044		0.062		0.019		0.002		0.000		0.000	
19	PE	g/l	0.001		0.010		0.024		0.087		0.056		0.106		0.065		0.012		0.000		0	0.361

TABLE 6.19 MODIFIED SUSPENDED SEDIMENT CONTENT (PE) CALCULATIONS FOR REMOVAL OF +0.3 mm PARTICLES SIZE

Design discharge = 92.4 m3/sec

Sediment cconcentration = 0.762 g/l

Length of basin = 198 m

Sr NO	ITEM	UNIT	CALCULATION FOR EACH PARTICLES SIZE																			Total
1	d	mm	0.001		0.005		0.01		0.05		0.075		0.1		0.2		0.3		0.4		0.5	
2	a	-	0.02		0.1		0.2		1		1.5		2		4		6		8		8	
3	k1	-	1		1		1		1		1		1		1		1		1		1	
4	k2	-	0.852		0.852		0.852		0.852		0.852		0.852		0.852		0.852		0.852		0.852	
5	k3	-	1		1		1		1		1		1		1		1		1		1	
6	Ap	-	0.017		0.0852		0.1704		0.852		1.278		1.704		3.408		5.112		6.816		6.816	
7	Gr	%		18		12		25		5		8		15.1		4.9		7		5		100
8	pi	g/l	0.0686		0.1143		0.141		0.1143		0.0495		0.088		0.0762		0.0453		0.0457		0.0191	0.762
9	Ve	cm/sec	9E-05		0.0019		0.0083		0.18		0.2		0.58		1.5		2.3		3.5		4.8	
10	Vd	cm/sec	22.629		22.629		22.629		22.629		22.629		22.629		22.629		22.629		22.629		22.629	
11	Vc	cm/sec	14.167		31.678		44.8		100.18		122.69		141.67		200.35		245.38		283.34			
12	Desilting basin dimensions				L(m)=		198		B(m)=		15.00		H(m)=		24.00		Q/A=		0.031			
13	V	cm/sec	48.295		48.295		48.295		48.295		48.295		48.295		48.295		48.295		48.295		48.295	
14	Gc	mm						0.013														
15	Rw/2		0.00		0.01		0.02		0.51		0.57		1.65		4.26		6.52		9.93		13.62	
16	Eo		3E-05		0.0006		0.0027		0.0579		0.0643		0.1864		0.4821		0.7393		1.125		1.5429	
17	Ei								0.058		0.064		0.186		0.470		0.690		0.95		1	
18	S	g/l	0.069		0.114		0.141		0.108		0.046		0.072		0.040		0.014		0.002		0.000	
19	PE	g/l	0.001		0.010		0.024		0.092		0.059		0.122		0.138		0.072		0.016		0.000	0.533

SHONGTONG-KARCHAM HEP(280MW)

TABLE 6.20 MODIFIED SUSPENDED SEDIMENT CONTENT (PE) CALCULATIONS FOR REMOVAL OF +0.4 mm PARTICLES SIZE

Design discharge	=	92.4 m3/sec
Sediment concentration	=	0.762 g/l
Length of basin	=	137 m

Sr No	ITEM	UNIT	CALCULATION FOR EACH PARTICLE SIZE																			Total
1	d	mm	0.001		0.005		0.01		0.05		0.075		0.1		0.2		0.3		0.4		0.5	
2	a	-	0.02		0.1		0.2		1		1.5		2		4		6		8		8	
3	k1	-	1		1		1		1		1		1		1		1		1		1	
4	k2	-	0.852		0.852		0.852		0.852		0.852		0.852		0.852		0.852		0.852		0.852	
5	k3	-	1		1		1		1		1		1		1		1		1		1	
6	Ap	-	0.017		0.0852		0.1704		0.852		1.278		1.704		3.408		5.112		6.816		6.816	
7	Gr	%		18		12		25		5		8		15.1		4.9		7		5		100
8	pi	g/l	0.0686		0.1143		0.141		0.1143		0.0495		0.088		0.0762		0.0453		0.0457		0.0191	0.762
9	Ve	cm/sec	9E-05		0.0019		0.0083		0.18		0.2		0.58		1.5		2.3		3.5		4.8	
10	Vd	cm/sec	22.629		22.629		22.629		22.629		22.629		22.629		22.629		22.629		22.629		22.629	
11	Vc	cm/sec	14.167		31.678		44.8		100.18		122.69		141.67		200.35		245.38		283.34			
12	Desilting basin dimensions				L(m)=		137		B(m)=		15.00		H(m)=		24.00		Q/A=		0.045			
13	V	cm/sec	48.295		48.295		48.295		48.295		48.295		48.295		48.295		48.295		48.295		48.295	
14	Gc	mm						0.013														
15	Rw/2		0.00		0.01		0.02		0.51		0.57		1.65		4.26		6.52		9.93		13.62	
16	Eo		2E-05		0.0004		0.0018		0.040		0.0445		0.129		0.3336		0.5115		0.7784		1.0675	
17	EI								0.040		0.044		0.129		0.334		0.512		0.74		0.9	
18	S	g/l	0.069		0.114		0.141		0.110		0.047		0.077		0.051		0.022		0.012		0.002	
19	PE	g/l	0.001		0.010		0.024		0.093		0.061		0.131		0.173		0.113		0.081		0.013	0.700

SHONGTONG-KARCHAM HEP(280MW)

TABLE 6.21 MODIFIED SEDIMENT CONTENT (PE) CALCULATIONS FOR REMOVAL OF +0.5 MM PARTICLE SIZES

Design discharge = 92.4 m3/sec

Sediment cconcentration = 0.762 g/l

Length of basin = 106 m

Sr No	ITEM	UNIT	CALCULATION FOR EACH PARTICLES SIZE																			Total
1	d	mm	0.001		0.005		0.01		0.05		0.075		0.1		0.2		0.3		0.4		0.5	
2	a	-	0.02		0.1		0.2		1		1.5		2		4		6		8		8	
3	k1	-	1		1		1		1		1		1		1		1		1		1	
4	k2	-	0.852		0.852		0.852		0.852		0.852		0.852		0.852		0.852		0.852		0.852	
5	k3	-	1		1		1		1		1		1		1		1		1		1	
6	Ap	-	0.017		0.0852		0.1704		0.852		1.278		1.704		3.408		5.112		6.816		6.816	
7	Gr	%		18		12		25		5		8		15.1		4.9		7		5		100
8	pi	g/l	0.0686		0.1143		0.141		0.1143		0.0495		0.088		0.0762		0.0453		0.0457		0.0191	0.762
9	Ve	cm/sec	9E-05		0.0019		0.0083		0.18		0.2		0.58		1.5		2.3		3.5		4.8	
10	Vd	cm/sec	22.629		22.629		22.629		22.629		22.629		22.629		22.629		22.629		22.629		22.629	
11	Vc	cm/sec	14.167		31.678		44.8		100.18		122.69		141.67		200.35		245.38		283.34			
12	Desilting basin dimensions				L(m)=		106		B(m)=		15.00		H(m)=		24.00		Q/A=		0.058			
13	V	cm/sec	48.295		48.295		48.295		48.295		48.295		48.295		48.295		48.295		48.295		48.295	
14	Gc	mm						0.013														
15	Rw/2		0.00		0.01		0.02		0.51		0.57		1.65		4.26		6.52		9.93		13.62	
16	Eo		0.000		0.000		0.001		0.031		0.034		0.100		0.258		0.396		0.602		0.826	
17	El								0.031		0.034		0.100		0.258		0.396		0.6		0.78	
18	S	g/l	0.069		0.114		0.141		0.111		0.048		0.079		0.057		0.027		0.018		0.004	
19	PE	g/l	0.001		0.010		0.024		0.094		0.061		0.135		0.193		0.140		0.125		0.029	0.811

TABLE 6.22 PRESENT WORTH COST CALCULATION FOR CONST. OF DESILTING BASIN AND REAPIR AND REPLACEMENT COST OF TURBINE FOR +0.2 mm PARTICLE SIZE

a) **PRESENT WORTH COST CALCULATION FOR BASIN CONST. COST**

Cost of desilting basin Rs= 208.20 Crores

Particle size removed = + 0.2 mm

Time	Unit	Desilting basin cost				PWF	Present worth
		Distribution ratio	Construction cost	O&M	Total		
-5	Year	10	20.82		20.82	1.536	32.0
-4	Year	20	41.64		41.64	1.386	57.7
-3	Year	30	62.46		62.46	1.269	79.3
-2	Year	25	52.05		52.05	1.154	60.1
-1	Year	15	31.23		31.23	1.049	32.8
	O & M cost @ 1 % for 50 years			2.082		9.915	20.6
		Total	208.20				
			Sub total for desilting basin cost =				282.4

b) **PRESENT WORTH COST CALCULATION FOR REPAIR AND REPLACEMENT COST OF TURBINE**

Repair cycle year = 2.9 Years

Time	Unit	Turbine cost			PWF	Present worth cost
		Repair cost	Replace. cost	Total		
0	Spare runner					8.8
1	Repair Cycle	4.40	0.00	4.40	0.759	3.34
2	Repair Cycle	4.40	0.00	4.40	0.575	2.53
3	Repair Cycle	4.40	0.00	4.40	0.436	1.92
4	Repair Cycle	4.40	0.00	4.40	0.331	1.46
5	Repair Cycle	4.40	0.00	4.40	0.251	1.10
6	Repair Cycle	4.40	0.00	4.40	0.190	0.84
	1st replacement	0.00	94.77	94.77	0.144	13.69
1	Repair Cycle	11.85	0.00	11.85	0.100	1.18
2	Repair Cycle	11.85	0.00	11.85	0.076	0.90
3	Repair Cycle	11.85	0.00	11.85	0.057	0.68
4	Repair Cycle	11.85	0.00	11.85	0.043	0.51
5	Repair Cycle	11.85	0.00	11.85	0.033	0.39
6	Repair Cycle	11.85	0.00	11.85	0.025	0.30
	2nd replacement	0.00	281.32	281.32	0.017	4.85
1	Repair Cycle	11.85	0.00	11.85	0.013	0.15
2	Repair Cycle	11.85	0.00	11.85	0.010	0.12
			Sub total turbine cost		=	42.76
	Total present worth cost of turbine and desilting basin				=	325.18

TABLE 6.23 PRESENT WORTH COST CALCULATION FOR CONST. OF DESILTING BASIN AND REAPIR AND REPLACEMENT COST OF TURBINE
FOR +0.3 mm PARTICLE SIZE

a) **PRESENT WORTH COST CALCULATION FOR BASIN CONST. COST**

Cost of desilting basin Rs- 133.68 Crores
Particle size removed - + 0.3 mm

Time	Unit	Desilting basin cost				PWF	Present worth
		Distribution ratio	Construction cost	O&M	Total		
-5	Year	10	13.37		13.37	1.536	20.5
-4	Year	20	26.74		26.74	1.386	37.1
-3	Year	30	40.10		40.10	1.269	50.9
-2	Year	25	33.42		33.42	1.154	38.6
-1	Year	15	20.05		20.05	1.049	21.0
O & M cOst @ 1 % for 50 years				1.34		9.915	13.3
		Total	133.68				
			Sub total for desilting basin cost =				181.3

b) **PRESENT WORTH COST CALCULATION FOR REPAIR AND REPLACEMENT COST OF TURBINE**

Repair cycle year - 2.4 Years

Time	Unit	Turbine cost			PWF	Present worth cost
		Repair cost	Replace. cost	Total		
0	Spare runner					8.80
1	Repair Cycle	4.40	0.000	4.40	0.796	3.50
2	Repair Cycle	4.40	0.000	4.40	0.633	2.78
3	Repair Cycle	4.40	0.000	4.40	0.503	2.22
4	Repair Cycle	4.40	0.000	4.40	0.401	1.76
5	Repair Cycle	4.40	0.000	4.40	0.319	1.40
6	Repair Cycle	4.40	0.000	4.40	0.253	1.12
	1st replacement		79.9	79.90	0.202	16.11
1	Repair Cycle	9.99	0.000	9.99	0.146	1.46
2	Repair Cycle	9.99	0.000	9.99	0.116	1.16
3	Repair Cycle	9.99	0.000	9.99	0.092	0.92
4	Repair Cycle	9.99	0.000	9.99	0.073	0.73
5	Repair Cycle	9.99	0.000	9.99	0.058	0.58
6	Repair Cycle	9.99	0.000	9.99	0.046	0.46
	2nd replacement		190.4	190.41	0.037	7.04
1	Repair Cycle	23.80	0.000	23.80	0.027	0.64
2	Repair Cycle	23.80	0.000	23.80	0.021	0.51
3	Repair Cycle	23.80	0.000	23.8014	0.017	0.40
4	Repair Cycle	23.80	0.000	23.8014	0.013	0.32
5	Repair Cycle	23.80	0.000	23.8014	0.011	0.25
6	Repair Cycle	23.80	0.000	23.8014	0.009	0.20
			Sub total turbine cost		=	52.37
	Total present worth cost of turbine and desilting basin				=	233.71

TABLE 6.24 PRESENT WORTH COST CALCULATION FOR CONST. OF DESILTING BASIN AND REAPIR AND REPLACEMENT COST OF TURBINE FOR +0.4 mm PARTICLE SIZE

a) **PRESENT WORTH COST CALCULATION FOR BASIN CONST. COST**

Cost of desilting basin Rs= 105.62 Crores

Particle size removed = + 0.4 mm

Time	Unit	Desilting basin cost				PWF	Present worth
		Distribution ratio	Construction cost	O&M	Total		
-5	Year	10	10.56		10.56	1.536	16.2
-4	Year	20	21.12		21.12	1.386	29.3
-3	Year	30	31.69		31.69	1.269	40.2
-2	Year	25	26.41		26.41	1.154	30.5
-1	Year	15	15.84		15.84	1.049	16.6
O & M cOst @ 1 % for 50 years				1.06		9.915	10.5
		Total	105.62				
			Sub total for desilting basin cost =				143.3

b) **PRESENT WORTH COST CALCULATION FOR REPAIR AND REPLACEMENT COST OF TURBINE**

Repair cycle year = 1.7 Years

Time	Unit	Turbine cost			PWF	Present worth cost
		Repair cost	Replace. cost	Total		
0	Spare runner					8.80
1	Repair Cycle	4.40	0.000	4.40	0.850	3.74
2	Repair Cycle	4.40	0.000	4.40	0.723	3.18
3	Repair Cycle	4.40	0.000	4.40	0.615	2.71
4	Repair Cycle	4.40	0.000	4.40	0.523	2.30
5	Repair Cycle	4.40	0.000	4.40	0.445	1.96
6	Repair Cycle	4.40	0.000	4.40	0.378	1.66
	1st replacement	0.00	62.9	62.91	0.322	20.24
1	Repair Cycle	7.86	0.000	7.86	0.249	1.96
2	Repair Cycle	7.86	0.000	7.86	0.211	1.66
3	Repair Cycle	7.86	0.000	7.86	0.180	1.41
4	Repair Cycle	7.86	0.000	7.86	0.153	1.20
5	Repair Cycle	7.86	0.000	7.86	0.130	1.02
6	Repair Cycle	7.86	0.000	7.86	0.111	0.87
	2nd replacement	0.00	118.0	118.04	0.094	11.10
1	Repair Cycle	14.76	0.000	14.76	0.073	1.07
2	Repair Cycle	14.76	0.000	14.76	0.062	0.91
3	Repair Cycle	14.76	0.000	14.76	0.053	0.78
4	Repair Cycle	14.76	0.000	14.76	0.045	0.66
5	Repair Cycle	14.76	0.000	14.76	0.038	0.56
6	Repair Cycle	14.76	0.000	14.76	0.032	0.48
	3rd replacement		221.5	221.50	0.028	6.09
1	Repair Cycle	27.69	0.000	27.69	0.021	0.59
2	Repair Cycle	27.69	0.000	27.69	0.018	0.50
3	Repair Cycle	27.69	0.000	27.69	0.015	0.43
4	Repair Cycle	27.69	0.000	27.69	0.013	0.36
5	Repair Cycle	27.69	0.000	27.69	0.011	0.31
6	Repair Cycle	27.69	0.000	27.69	0.009	0.26
			Sub total turbine cost		=	76.82
	Total present worth cost of turbine and desilting basin				=	220.10

TABLE 6.25 PRESENT WORTH COST CALCULATION FOR CONST. OF DESILTING BASIN AND REAPIR AND REPLACEMENT COST OF TURBINE FOR +0.5 MM PARTICLE SIZE

a) **PRESENT WORTH COST CALCULATION FOR BASIN CONST. COST**

Cost of desilting basin - 91.36 Crores

Particle size removed = + 0.5 mm

Time	Unit	Desilting basin cost				PWF	Present worth
		Distribution ratio	Construction cost	O&M	Total		
-5	Year	10	9.14		9.14	1.536	14.0
-4	Year	20	18.27		18.27	1.386	25.3
-3	Year	30	27.41		27.41	1.269	34.8
-2	Year	25	22.84		22.84	1.154	26.4
-1	Year	15	13.70		13.70	1.049	14.4
O & M c0st @ 1 % for 50 years				0.9136		9.915	9.1
		Total	91.36				
Sub total for desilting basin cost =							123.9

b) **PRESENT WORTH COST CALCULATION FOR REPAIR AND REPLACEMENT COST OF TURBINE**

COST OF TURBINE - 1.4 Years

Time	Unit	Turbine cost			PWF	Present worth cost
		Repair cost	Replace. cost	Total		
0	Spare runner					8.80
1	Repair Cycle	4.4	0.0	4.4	0.875	3.85
2	Repair Cycle	4.4	0.0	4.4	0.766	3.37
3	Repair Cycle	4.4	0.0	4.4	0.670	2.95
4	Repair Cycle	4.4	0.0	4.4	0.586	2.58
5	Repair Cycle	4.4	0.0	4.4	0.513	2.26
6	Repair Cycle	4.4	0.0	4.4	0.449	1.98
	1st replacement	0.0	49.5	49.5	0.513	25.42
1	Repair Cycle	6.2	0.0	6.2	0.313	1.94
2	Repair Cycle	6.2	0.0	6.2	0.274	1.69
3	Repair Cycle	6.2	0.0	6.2	0.239	1.48
4	Repair Cycle	6.2	0.0	6.2	0.209	1.30
5	Repair Cycle	6.2	0.0	6.2	0.183	1.13
6	Repair Cycle	6.2	0.0	6.2	0.160	0.99
	2nd replacement	0.0	73.2	73.2	0.239	17.52
1	Repair Cycle	9.1	0.0	9.1	0.112	1.02
2	Repair Cycle	9.1	0.0	9.1	0.098	0.89
3	Repair Cycle	9.1	0.0	9.1	0.086	0.78
4	Repair Cycle	9.1	0.0	9.1	0.075	0.68
5	Repair Cycle	9.1	0.0	9.1	0.065	0.60
6	Repair Cycle	9.1	0.0	9.1	0.057	0.52
	3rd replacement		162.9	162.9	0.050	8.17
1	Repair Cycle	20.4	0.0	20.4	0.040	0.81
2	Repair Cycle	20.4	0.0	20.4	0.035	0.71
3	Repair Cycle	20.4	0.0	20.4	0.031	0.62
4	Repair Cycle	20.4	0.0	20.4	0.027	0.54
5	Repair Cycle	20.4	0.0	20.4	0.023	0.48
6	Repair Cycle	20.4	0.0	20.4	0.020	0.42
	4th replacement		275.9	275.9	0.018	4.94
1	Repair Cycle	34.5	0.0	34.5	0.014	0.49
2	Repair Cycle	34.5	0.0	34.5	0.012	0.43
3	Repair Cycle	34.5	0.0	34.5	0.011	0.38
4	Repair Cycle	34.5	0.0	34.5	0.010	0.33
Sub total turbine cost					=	100.08
Total present worth cost of turbine and desilting basin					=	224.01

CHAPTER 7

CONCLUSIONS AND SUGGESTIONS

7.0 GENERAL

In foregoing chapters a study has been made for hydropower potential and the status of its development in Satluj river basin. A number of run-of- river schemes are in different stages of planning. The study of the performance of existing run-of-river schemes has highlighted the problem of sediment erosion in the turbines and other underwater parts. A review of various desilting arrangements provided to mitigate the impact of sediment damage on the underwater parts of hydropower stations has been made. Various factors responsible for hydro abrasion and their remedial measures have been studied. The sediment exclusion and ejection devices provided at different schemes, their design procedures and their performance in some projects has been studied and the performance data including repair cycles, cost involved etc., have also been collected.

The damage to the underwater parts can be assessed by knowing the factors responsible for it viz., characteristics of sediment such as, size,. shape, mineral composition, their hardness, metallurgy of base material and velocity of flow. The optimum dimensions of desilting basin can be worked out by optimising the size of sediment particles to be removed on which the size of desilting basin depends, in such a way that the overall cost of desalting basin vis-à-vis repair and replacement cost are minimum. This approach has been applied in two cases which are in planning stage. Following conclusions can be drawn from the study.

7.1 CONCLUSIONS

1. Satluj basin has a hydropower potential of 9500 MW out of which only 1200 MW has been harnessed, 2800 MW is under construction and rest is planned through a number of run-of-river schemes.
2. Satluj river brings down lot of sediment during snowmelt and monsoon season. Sediment consists of large size bed load and fine sand and silt as suspended load. The sediment in river contains large quantities of quartz which has a hardness of 7 and more on Mohr's scale. Concentration of sediment in river may be little in lean flow season, and may be very high (10-12 g/l) during high flow season.
3. The study of the performance of run-of-river schemes has revealed severe damage to the turbine and other under water parts despite the provision of desalting basins. The Master Plan envisages extraction of +0.2 mm particle size for all the projects in the basin.
4. The construction cost of the desilting basins provided to remove +0.2 mm size sediment is found about twice the cost of dam and intake taken together. Still the damages to the turbines etc., are anticipated. Hence, there is a need to optimise the design of desilting basin on the basis of minimum total cost of basin and repair and replacement cost of turbine.
5. For optimisation of desilting basin, the approach formulated by Nozaki, T., of Japan, and repair cycle curves developed by him have been used in this study.
6. The curves developed by Nozaki from the field data of power stations in Peru have been validated from the data of power stations under operation in Himalayas. The application of this

approach based on these curves has been illustrated in two run-of -river schemes of Satluj basin.

7. The optimum size of the particles to be removed in the two cases has been worked out in the range of 0.3 to 0.4 mm instead of 0.2 mm as adopted in the master plan and the existing and under construction project of Nathpa Jhakari.

7.1 SUGGESTIONS FOR FURTHER STUDIES

1. A Regular programme of sediment sampling to know the sediment characteristics such as concentration size, shape, mineral composition and hardness and recording repair and maintenance cost shall be made on existing run-of-river projects. This data will help in developing more refined repair cycle curves for use in optimisation approach.
2. The optimisation approach has been illustrated in this study for two projects in Satluj basin. It is based on a set of assumed costs. Studies on better cost estimates can give the exact particle size to be extracted. The cost studies may further include the following aspects;
   i) The loss of power generation between two repair cycles due to loss in efficiency.
   ii) Cost of repair and replacement of other components affected by sediment.
   iii) The economic life of equipments may be taken as 35 years.
3. Optimisation approach results in reduced cost of the project. It shall be adopted in all the run-of-river projects in planning stage.

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