ANALYSIS OF MODEL STUDIES FOR DESILTING BASINS

A DISSERTATION

submitted in partial fulfilment of the
requirements for the award of the degree
of
MASTER OF TECHNOLOGY
in
WATER RESOURCES DEVELOPMENT

By

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CANDIDATE'S DECLARATION

I hereby declare that the work presented in this dissertation entitled "Analysis of Model Studies for Desilting Basins" in a partial fulfillment of the requirement for the award of Degree of Master of Technology in Water Resources Development (Civil) submitted in the Department of WRDTC, Indian Institute of Technology, Roorkee is an authentic record of my own work carried out at CW& PRS, Pune, since 16th July 2001 to January, 2002 under the supervision of Dr. Nayan Sharma, Professor, Dr. B.N. Asthana, Emeritus Fellow at WRDTC, IIT, Roorkee and Shri M.S. Shitole, Joint Director, CW&PRS, Pune.

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

Date : 11.02.2002

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

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CERTIFICATE

Certified that the dissertation titled "Analysis of Model Studies for Desilting Basins", which is being submitted by Shri Manoj Kumar Verma in partial fulfillment of the requirements for the award of Degree of Master of Technology in Water Resources Development (Civil) of the Indian Institute of Technology, Roorkee, is a record of student's own work carried out by him at CW& PRS, Pune, under my supervision and guidance. The matter included in this dissertation has not been submitted for the award of any other Degree.

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LIST OF SYMBOLS

C_D = Drag coefficient

Ca = Sediment concentration at level a

Cv = Sediment concentration, fraction by volume

Cy = Sediment concentration at level y

D = Diameter of pipe

d = Depth of flow

d = Size of particle

f = Dary-Weisbach friction factor

g = Acceleration due to gravity

hf = Head loss

i = Energy gredient for pipe flow

im = Energy gradient for pipe with suspended particle

K' = Constant of proportionality

K = Coefficient

k = Von Karman universal constant

L = Length of basin

Ro = Bed roughness number

r = Hydraulic radius

S = Water surface slope

s = Specific gravity of sediment

u = Shear velocity in settling basin

V = Mean velocity

V_L = Limit deposit velocity

Vc = Critical velocity for entraining sediment

w = Fall velocity of particle

β = Constant of proportionality

γ = Specific weight of liquid

γ_S = Specific weight of sediment grain

η = Efficiency of basin

η_0 = Limiting settling efficiency

τ = Shear stress

τ_c = Critical tractive force

F_r	=	Froude number
R_1	=	Hydraulic radius corresponding to grain resistance
$\bar{c}$	=	Average Concentration
W	=	Settling Velocity
W_0	=	Initial Weight of particle
C_2	=	Concentration at depth 2 m.
V_*	=	Critical shear velocity
Z	=	Bed elevation above datum
Z_1	=	Theoretical exponent in suspended distribution equation

SYNOPSIS

River flows carry considerable sediment load which creates problems in operation of irrigation and hydroelectric projects. Canals get silted up, turbine's blade / buckets are subjected to abrasive action of sediment and require frequent repaire.

The problem of sediment management is complicated and it is tackled in each case in one or in combination of several of the following ways.

(i) Water Shed Management

(ii) Stabilization of river course by training and channel improvements

(iii) Sediment exclusion devices at the diversion and head works

(iv) Sediment ejection devices in the canals

The sediment exclusion and ejection devices remove coarse fractions of sediment which move as bed load. Desilting basins are commonly used for removal of the sediment from the water conductor system of the Hydro Electric Projects. These basins are designed to exclude particles larger than certain size depending upon the head on the turbine and experience of the designer. The performance of the desilting basin depends upon the reduction in the velocity and turbulence, provision of adequate length of basin, which in turn mainly depends upon diffuser, for achieving the desired settlement and the skimming arrangements at the outlet.

For dimensioning of the basin length various approaches and sediment removal functions are available. Since these approaches are semi-emperical, of the layout as well as other design aspects in each case are therefore, required to be assessed by conducting studies in physical hydraulic models.

Several alternative designs can be tried in a model before adopting a final one. Geometrical similar scale models are constructed for desilting basins and simulation of suspended sediments is done by using available low specific gravity material. Settling efficiency curve for prototype is obtained from removal ratio of various size particles in the model.

Generally, hydraulic model studies for desilting basins are conducted for various aspects such as; estimation of settling efficiency, assessment of the efficacy of the flushing system of the basin, optimizing the length of the desilting basin, optimizing the magnitude of flushing discharge, transition length of the desilting basin.

The objective of the present study is to identify the critical design parameters of a desilting basin responsible for its efficient funtioning, to review the available guidelines / empirical approaches for design, to analyze the role of model studies in finalizing the design and to elaborate it with a model study.

From the study, it is seen that while dimensioning the basin, estimation of sediment distribution on a vertical at the inlet of the basin is of vital importance. Once the requirement of critical velocity is satisfied, narrow, shallow and longer basins are economical from removal efficiency point of view. It is also concluded that separate model studies would be required to assess the adequcy of the manifold arrangement of different flushing tunnels from different units of desilting basin joining into common flushing tunnel beyond the desilting basin. Various investigators have given empirical relations for the design of desilting basin and they all give quite different results from each other. But, the results obtained in model studies are in close agreement with Camp's criteria. Hydraulic model is useful in evolving final design on various aspects of desilting basins.

INTRODUCTION

1.0 GENERAL

River flows carry considerable sediment load due to which a variety of complicated problems arise be it a multipurpose dam or a diversion weir for irrigation, navigation or hydel channel or storage tank. The water sediment equilibrium is very sensitive and intricate. Despite the quantum of work done in this field, the laws of sediment transport are not clearly understood. Sediment plays such a vital role in the design of hydraulic structures that a new branch of engineering known as "Sedimentation Engineering" has come into existence.

Success of an irrigation canal system depends to a large extent on the degree of control achieved on the sediment entry into the off-taking channel. The Upper Bari Doad Canal in its reach R.D. 18, 288 to 23,470 m (where it is 45.6m wide, 3.7 m deep and carried 283 cusecs of discharge) got silted up by 2.4m due to excessive sediment entry at the head in the year 1951 (18) and consequently its banks and bridges had to be raised by 3.0m.

In the case of hydel projects, heavy sediment load, particularly sharp edged silt / sand, may lead to damage of the turbine runner blades / vanes due to abrasion and sediment deposits (in pits downstream of the turbines) resulting in decrease in the efficiency of the power plant. The turbines of Florida Alta Plant in Chile (head 95 m) were found to have been entirely worn out after 2,000 hours of operation because of presence of sand in water (77). Also, in the case of Trishuli Power Project (Nepal) in the first 3 years of commissioning of the system 80,000 cum of silt deposition has been reported to have occurred. At this rate the entire storage would have been consumed in about 13 years (46). In some cases turbines are required to be repaired twice in a year. This results in shut down of units for considerable duration thereby causing enormous loss of power and revenue.

In the case of thermal / nuclear power projects, the presence of sediment in the water may affect the performance of the pumps and water conductor system. The deposition of sediment in the condenser tubes may also reduce the efficiency of heat transfer besides requiring replacement of tubes. Several ejectors have been constructed in the canal especially in the north India for ejection of the excessive and undesirable sediment entering the water conductor system. They are designed for tapping the heavily sediment laden layers near the bed and hence their efficiency mainly depends on the distribution of the sediment over the vertical in the approach channel. These are also found to be more suitable for exclusion of the coarse sediment. Some other methods such as vortex tubes are also provided across the bed of the canal for extracting the sediment moving along the bed. However, these tubes are found to be effective for Froude number higher than 0.8 and as such these are useful for removal of only very coarse sediment.

Studies have been conducted in IPRI, Amritsar (30) and by Curikriton et. al. (28), on vortex type sediment ejector which function as a solid-liquid separator on the principle of vorticity. This device is also useful mainly for the removal of the sediment moving as bed load. All these devices are obviously useful for elimination of the bed load but their efficiency in respect of the removal of the suspended sediment load is limited.

However, in case of power project above 90% exclusion of 0.2 mm particles is achieved through desilting basins and these are commonly used.

1.1 NEED FOR DESILTING BASINS

Run-of-river schemes are generally provided with desilting basins to exclude sediment of harmful size. Following are the recommendations / guidelines for the necessity of a desilting basin :

- Particles of + 0.5 mm size and hardness + 5 on Mohr's scale are harmful.
- If the concentration of particle is + 200 ppm, desilting measures are required.
- Concentration of harmful particles should be reduced by 85% to 95%.
- Du Tong (33) has concluded from experimental results that damages take place due to cavitation and the process is accelerated by sediment. He has recommended that if the turbine is likely to be eroded within 5-10 years then, the sediment exclusion measures are necessary and if the life of the turbine works out to be more than 20 years, the sediment exclusion measures can be eliminated.

Thus, it can 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 guidelines are available.

1.2 DESIGN APPROACHES

The length of the basin would depend upon the fall velocity of the particles, depth of flow and forward velocity of flow in the basin. Initially, the length of the basin used to be determined by working out the horizontal distance travelled by the particles for its settlement from the top layer of the flow to the bed of the desilting basin. Subsequently, based on the diffusion and probability theory, several functions such as those proposed by Camp (17), Technical Conditions and Standard of USSR (83), Hippola (48), USBR approach (87), Sumer (80), Garde et al. (44), Masonyi (61) etc. have been used. Lamble, while proposing a function based on the hypothesis of turbulent diffusion, showed that if a uniform distribution of sediment along the verticla is assumed, the length of the basin would be excessive by as much as 35% on the otherhand, Hippola proposed a design procedure on the basis of experimental research and the theory of probability and claimed that the length of the basin could be reduced by about 30 to 40%, in comparison with that obtained by assuming uniform distribution of sediment along the vertical.

In the absence of any definite criteria, the design is generally based on broad guidelines, assumptions and experience. Verification of these assumptions and adequancy of the layout as well as other design aspects is, therefore, assessed by conducting studies in hydraulic models.

1.3 NEED FOR MODEL STUDIES

"Experimenting with models seems to afford a ready means of investigating and determining before hand the effects of any proposed hydraulic structure; a means, after what I have seen, I should feel it madness to neglect before entering upon any costly undertaking", so says Osborne Reynolds (19). It is often worth to study the performance of small replica or "model" of the system or "prototype" that is to be built, before an expensive engineering project is undertaken. Model studies are made for two purposes viz., in order to avoid costly mistakes and to obtain information that will help in the design of the prototype. Since, it is comparatively inexpensive to modify the construction of a model, several alternative designs in the model may be tried before adopting a final one; such experiments would be excessively costly if they were undertaken with the full scale system.

As far as the mathematical model studies are concern for desilting basins, various assumptions, approximations and simplifications are required to be made to make it convenient for numerical computations. Therefore, mathematical models are unable to provide required information on account of simulation and injection rate of suspended particles, inlet divergence (diffusor), opening sizes from desilting basin to fushing tunnel for flushing sediments and dune formation in the hopper. Two and three - dimensional flow patterns and the associated changes can be studied, at present only by using physical models because geometrical approximations can be considered adequately.

It is only through model experiments and research that improvements in the existing works, safe and economical design and construction of new works and furtherance of knowledge on various aspects of hydraulic engineering can be effected. The view that hydraulic models provide a suitable means of specific solutions of the hydrodynamic equations of motion under a known set of boundary conditions, if it is possible to establish quantitative rules for transferring data, is often held. Further, hydraulic models provide the only means of testing and evolving the final design in case of desilting basins for optimizing the transition length and length of the desilting basin, optimizing the flushing discharge, estimation of settling efficiency and estimation of the efficacy of the flushing system.

1.4 OBJECTIVE OF STUDY

The objective of the present study is :

(i) To identify the critical design parameters of a desilting basin responsible for its efficient functioning.

(ii) To review the available guidelines / empirical approaches for design.

(iii) To analyze the role of model studies in finalizing the design and to elaborate it with a model study.

1.5 METHODOLOGY

Various design approaches / empirical equations are available for the design of desilting basins and they all give quite different results from each other. Parameters such as inlet arrangements, size of the basin, forward velocity, fall velocity of particles, outlet arrangement, side slope and size of hoppers, flushing conditions etc. are studied by model experiments, as no definite design criteria is available for these parameters. A few cases have been reviewed for which model studies have been conducted in past at various research stations. Length of a basin is checked by two empirical methods given by Mysonyi and Camp. Method for conducting model study has also been described in detail along with the results for Chamera HE Project (Stage-II) in Himachal Pradesh.

1.6 ORGANISATION OF STUDY

The study is presented in seven chapters. The contents of each chapter in brief are given below :

CHAPTER – 1

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

CHAPTER – 2

This chapter deals with concepts of sediment transport in which sediment load and its classification, various theories available, effect of suspended sediment on velocity distribution and fall velocity etc. have been described.

CHAPTER – 3

This chapter gives the details about the types of desilting basins, their function principle of design, layout and other design aspects etc. Brief description of some desilting basins are also given which were used for various projects.

CHAPTER – 4

This chapter describe the role of models in design of desilting basins wherein, model scales, method of simulation of sediment, limitations of models and field data required for model studies have been discussed.

CHAPTER – 5

This chapter deals with critical review of some past model studies conducted at various research stations. Also feed back available from completed project is given.

CHAPTER - 6

This chapter covers in detail of the hydraulic model studies conducted at CW&PRS, Pune for desilting basin for Chamera Hydro Electric Project (Stage-II) in Himachal Pradesh.

CHAPTER - 7

This chapter contains conclusions and suggestions for further studies.

CONCEPTS OF SEDIMENT TRANSPORT

2.1 INTRODUCTION

The principles of design and operation of desilting basins are based on the concepts of sediment transport. These are briefly discussed in this chapter.

2.2 SEDIMENT LOAD AND ITS CLASSIFICATION

Soil erosion in the catchment of a stream and bed and bank erosion has been identified as the chief sources of sediment. The entrainment and transport of sediment is attributed to the physical properties of the sediment and the hydraulic characteristics of flow.

Sediment in a stream is transported by a 'Coordinated simultaneous' combination (or occurrence) of three basic movements of individual particles: (i) movement by rolling or sliding along the bed (caused by the tractive force of the moving water) which constitutes bed load; (ii) movement in suspension for a considerable period of time without contact with the stream boundary, held (in suspension) by vertical components of velocity in turbulent flow and carried forward by the horizontal components of velocity, classified as suspended load; and (iii) movement in saltation caused by forces of flow (other than vertical components) or by the impact of other particles which are intermittently out of contact with stream boundary and are carried away by the horizontal components of flow- termed saltation load . Since these three modes of transportation are closely related and it is not possible to separate either the suspended load and saltation load or bed load (when particles are fine) from the suspended load (which is rather an advanced stage of bed load transport), the term bed material load and 'wash load' have been coined to define the two portions of total sediment load. A more practical breakdown of total sediment load in use is ' measured load' and 'unmeasured load'.

2. 3 CONCEPTS OF SEDIMENT TRANSPORT

2.3.1 Critical Force Concept

The stream exerts certain finite force 'critical force' to initiate motion of particles. Particles located above the mean bed level are considered to possess a lower critical force than those lying in the surface layers. Whenever the force exerted by the stream exceeds the 'critical force' particles are set into sliding or rolling motion and at some stage when their transfer to the main flow takes place, particles are said to have been 'suspended' or 'entrained'.

2.3.2 Lifting force concept

Presence of 'lifting force' normal to the direction of flow was demonstrated by Leliavasky (56), Jeffreys (51) for the first time in 1929, theoretically derived this lift force for two-dimensional flow (disregarding drag). For sand and water, he showed that for lift force to exceed the weight of the particle $\left(\frac{1}{3} + \frac{1}{9}\pi\right) U^2 > \left(\frac{\rho_s - \rho}{\rho}\right)$. g.a.,

where U = Free stream velocity; g = acceleration due to gravity; a = particle radius; ρ_s = the density of the solid particle ; ρ = the density of the liquid phase. The actual presence of lift force having a constant average value with random fluctuations superimposed according to Gaussian frequency law was confirmed by experimental studies reported by Chepil (23), and Einstein and El. Samni (36). Einstein and Ning-Chien(39) attributed the lift force to the difference between the velocities of flow above and below the particle. Sutherland (81) believes that impingement of turbulent eddies on the bed is responsible for ejection of particles.

2.3.3 Shearing Stress Concept

Shields(78) and White(91) opined that if shear force exceeds the critical shear stress at bed, movement of particles would be initiated. Relation developed by Shields is as under.

$$\frac{\tau_c}{(\gamma_s - \gamma)d_s} = f\,\frac{(U.\,d_s)}{\nu}$$

where τ_c = critical shear stress at the bed γ_s and γ are the specific weights of sediment and fluid respectively, d_s is particle size, ν is kinematic viscosity of the fluid and U_* critical shear velocity.

White (91) derived the relation from the interaction between the forces due to drag and weight on a particle for flows where motion around the particle was laminar as :

$$\frac{\tau_c}{(\gamma_s - \gamma)d_s} = 0.18 \tan \theta$$

where, θ = angle of repose of the sediment .

2.3.4 Critical Velocity Concept

The initiation of movement of sediment or its deposition depends on the critical velocity of flow in a stream was demonstrated by Kennedy (52) by the empirical formula:

$V_0 = CD^n$ where, V_0 = critical velocity (i.e., non silting – non scouring) and D = depth of flow; later modified by Lacey as

$V_0 = C' R^{n'}$ where, R = hydraulic mean depth. Different values of C, n, C' and n' are in use for different types of bed material.

Mavis and Laushey (57) using stability equation, viz, at critical stage of movement hydrodynamic force on a particle due to bed velocity must equal its weight, showed critical velocity to be related as :

$V_B = ½ D^{4/9} (S_s\text{-}1)$

where, V_B	=	Critical bed velocity in ft/sec
D	=	Particle diameter in mm
S_s	=	Specific gravity of the particles

The relation in metric units is $V_B = 1/6.56 \times D^{4/9}\ (S_s\text{-}1)$.

From consideration of equilibrium of a particle resting on stream bed under the action of effective body force (due to its submerged weight), dynamic lift force F_L due to the difference of velocity V_c over the height of particle, and total drag force F_D (for constant viscosity and fluid density) due to form drag and skin friction, Ippen (50) developed a unique functional relation linking critical velocity as :

$$\frac{\bar{V}_c}{W} = 0.12 \left\{ S^{1/2} \frac{D}{K_e} (S_s - 1) \right\}^{-0.3}$$

where,

K_e	=	The effective hydraulic roughness in feet
$\bar{V}_c$	=	Difference of velocity over the height of particles in ft/sec.
W	=	Fall velocity in ft/sec.
S_s	=	Specific gravity of the particles
S	=	Slope

2.3.5 Lift and Drag Forces Concept

Einstein (34) recognized the influence of turbulence on bed load movement and according to him the movement of a particle is as a series of jumps, the mean length and frequency of which depend only on its size.

From measurement of drag and lift forces at different heights above the surface of the particles Chepil (22) concluded that lift is caused by a steep velocity gradient and lift alone cannot make the saltating particles to rise vertically. Sutherland (81) recommended that the formulation of any realistic theory to explain satisfactorily the phenomenon of sediment transport must take a serious note of lift forces and shearing forces.

2. 4 SUSPENDED SEDIMENT CONCENTRATION

2. 4.1 Turbulent Diffusion Theory

O'Brien (62) in 1932, made the most significant contribution by formulating the theory of sediment suspension by fluid turbulence. He assumed that a state of equilibrium existed between the rate of fall of particles under their own weight, and the rate at which they are lifted by the fluid due to turbulent mixing viz.,

$$c.w = -\varepsilon_s \frac{dc}{dy} \quad (2.1)$$

where,

c	=	Concentration of sediment at a distance y from the bed.
w	=	Sediment terminal settling velocity
ε_s	=	The sediment diffusion coefficient.

For the solution of Equation (2.1) the relation between ε_s and y must be known and assuming

$$\varepsilon_s = \beta \varepsilon_m \tag{2.2}$$

where β is a numerical constant and ε_m is kinematic eddy viscosity coefficient. Rouse (68,69) using ε_m as derived from Prandtl-Von Karman velocity law for turbulent flow, solved Equation (2. 1) and from its integration obtained the expression :

$$\frac{C}{C_a} = \left\{\frac{d-y}{y} \frac{a}{d-a}\right\}^z \tag{2.3}$$

where, C_a = The concentration of sediment with settling velocity w at level y = a

d = Depth of flow

$$Z = w / \beta K U_* \tag{2.4}$$

where, K is Von Karman constant.

and $U_* = \sqrt{\tau_0 / \rho}$ and ρ = density of fluid. This is the classical suspended load distribution (Figure 2. 1). Einstein and Chien (37) also developed a general suspended sediment distribution function without assuming equality between the exchange coefficients for water and sediment. Their function for the same values of exchange coefficients for water and sediment and small local concentration reduced to the one formulated by O'Brien (Equation 2. 1).

Since Z is proportional to w [Equation (2.4)], suspended sediment distribution curves in Figure 2.1 revealed that :

(i) When Z is greater than 2 or 3, most of the sediment moves near the bed, and the suspension becomes negligible when Z exceeds 6 or 7, and

(ii) When Z is low say 0.1, there is even distribution and a uniform dispersion of finer particles over the entire depth. This theory was first verified by Christiansen (25) and later by Anderson (5) in irrigation channels and natural streams respectively. Vanoni (88) by laboratory studies found the suspended sediment distribution curve.

A comparison between measured and calculated values of exponent Z made by Vanoni (88) revealed good agreement for large Z values for large particle size. Anderson (5) contradicted the findings by Vanoni (88), and showed that for small values of Z, measured and calculated values agreed well but for large Z, measured values were smaller and tended to approach a finite value. Einstein and Chien (38) while agreeing with Anderson (5) finally proved that for fine sediment, measured value is less than the computed one, i.e., a more uniform sediment concentration (Figure 2.2) existed than predicted by theory. This was also confirmed by Colby and Hembree (26).

As 'y' approaches zero, i.e., the region close to the bed, Equation (2.3) indicates that the concentration of suspended sediment would be infinite which is impossible. Another limitation of the theory is that the choice of reference level is not clearly defined. Zagustin (94), in an attempt to improve upon the prediction of distribution of sediment concentration and to avoid the singularity of zero concentration at the surface, proposed the relation :

$$\frac{C}{Ca} = e^{-z\phi} \qquad (2.5)$$

where $$\phi = 1/2 \log \frac{\left[\left(\frac{d-y}{d}\right)^{3/2}+1\right]\left[\left(\frac{d-y}{d}\right)^{1/2}-1\right]}{\left[\left(\frac{d-y}{d}\right)^{3/2}-1\right]\left[\left(\frac{d-y}{d}\right)^{1/2}+1\right]^{3}} + \sqrt{3}\tan^{-1}\frac{\sqrt{3}\cdot\sqrt{\frac{d-y}{d}}}{\left(\frac{d-y}{d}\right)}\Bigg|_{y=a}^{y} \qquad (2.6)$$

and Z = w / βKU*

For given value of a/d, ϕ is evaluated as a function of parameter (y-a) / (d-a). A comparison between equations (2. 3) & (2.5) for the same value of parameter 2 is given in Figure 2.3 and shows that major difference arises in the flow region far away from the bottom and at the flow surface. A comparison between this theoretical sediment distribution and experimental data (1) revealed that magnitudes of Z parameter were smaller by 7 percent than given above.

2.4.2 Effect of Suspended Sediment on Von Karman Constant –K

Einstein and Chien (37) for the amount of energy required to keep the sediment in suspension proposed the parameter :

$$\sum \frac{C_w V_s}{U S_e} \frac{\rho_s - \rho_f}{\rho_f}$$

where C_W is the average sediment concentration by weight of a given particle size fraction with settling velocity V_s, U is the average velocity over the vertical, S_e is the energy gradient and ρ_f and ρ_s are the densities of fluid and sediment. They showed that K reduced with increasing value of energy parameter or the sediment concentration. Bendict (6) showed that reduction in K value was considerable and bed form also affected K. Grade (42) demonstrated that with increase in Richardson number 'K' decreased in plane bed regime (Figure 2.4), and was a function of $C_{2D}w / V_* S_f$; for dune bed regime, K decreased as $\tau_* = \tau_0 / (\rho_s - \rho_f) D$ increased (Figure 2.5) where, C_{2D} = concentration at depth 2D, w is fall velocity, V_* is the shear velocity and S_f, the energy gradient.

U.P.I.R.I. (84) from the data collected on suspended sediment concentration and velocity distribution at various points in a vertical from channels of Ganga, Yamuna and Sarda Canal Systems, confirmed the tendency for K to decrease with increase in Richardson number [Figure 2.6(a)]. With the aid of dimensional analysis, a new relationship between K and $\frac{\tau}{\overline{C} D_m}$ (where τ = shear stress, $\overline{C}$ = average concentration, D_m = mean depth of flow) was given. It was found (Figure 2.6(b)], that K increased with $\frac{\tau}{\overline{C} D_{mi}}$.

2.4.3 Effect of Suspended Sediment on Velocity Distribution

Vanoni (88) held that in flow with suspended sediment logarithmic velocity distribution law was applicable but K reduced in magnitude, thereby increasing the mean velocity of flow. Einstein and Chien (37) investigated the effect of heavy suspended sediment concentration on velocity and sediment distribution and showed that for the main part of flow (where sediment concentration is small or particle size is so small as to not interfere with the flow) and for the zone near the bed (for y/h < 0.10) the velocity distribution was governed by :

$$\frac{U}{U_*} = 17.4 + \frac{2.3}{K}\log_{10}\left(\frac{y}{35.45\,K_s}\right) \quad and$$

$$\frac{U}{U_*} = 5.75\frac{\sqrt{1+\frac{\rho_s-\rho_f}{\rho_f}\frac{1}{h}\int_0^h c\,dy}}{\sqrt{1+\frac{\rho_s-\rho_f}{\rho_f}-C_0}}\log_{10}\frac{A_y}{K_s}$$

respectively, where U is the average point velocity at distance y from the bed, K = Karman universal mixing length constant. K_s is sand roughness height, C_0 was sediment concentration at the surface of bed layer and A, a constant. For the average velocity of sediment-laden flow they proposed the following equation :

$$\frac{U}{U_*} = 17.66 + \frac{2.3}{K}\log_{10}\left(\frac{h}{96.5\,K_s}\right)$$

Figure 2.7 shows increase in average velocity of sediment-laden flow for the same depth, slope and bed material size. Garde (42) on the considerations that K is influenced by sediment concentration and by bed ripples and dunes, gave the following relation :

$$\frac{V}{V_*} = \frac{2.3}{K}\log\frac{y}{K_s'}$$

where, K = Dimensionless number

K_s' = A variable length parameter different from K_s.

$$\frac{K_s'}{D} = f\left[\frac{(V_*D)}{\nu}, F_r, \frac{\tau_0}{(\rho_s-\rho_f)D}\right]$$

Figure 2.8 gives a correlation between F_r and $\left[\frac{\tau_0}{(\rho_s - \rho_f)D}\right]$. Thus knowing K and K'_s, logarithmic velocity distribution law was completely defined.

U.P.I.R.I., Roorkee (84) has reported increase in velocity with increase in suspended sediment concentration for the same discharge. It has been observed that the velocity curves for higher sediment concentration have greater velocity gradient.

2.4.4 Effect of Suspended Sediment Concentration on Fall Velocity

Einstein and Chien (37) formulated the relation $\frac{V_{sc}}{V_s} = f\left(\frac{D}{C^{1/3}}\frac{dc}{dy}\right)$, where, V_{sc} & V_s are the settling velocities in clear and sediment water respectively, D sediment particle size and C sediment concentration by volume. They showed that actual fall velocity V_s in sediment-laden water decreased as the sediment concentration and size of sediment particles increased towards the bed (i.e., in a zone of heavy concentration).

2.5 DETERMINATION OF TOTAL SUSPENDED SEDIMENT LOAD

Total suspended load per unit width, q_s, is obtained by integrating the product of velocity and concentration over the entire depth. Lane and Kalinske (53) obtained the following transport function using mean value of :

$$q_s = \int_0^d ncdy = qC_a Pe^{15\left(\frac{a}{d}\frac{w}{\sqrt{\tau/\rho}}\right)} \tag{2.7}$$

where,

q_s	=	Volume rate of sediment transport per unit width
q	=	Rate of flow per unit width
n	=	Manning's roughness coefficient

in which P is an integral in terms of $\frac{w}{\sqrt{\tau/\rho}}$ *and* $\sqrt{\frac{\tau}{\rho/V_*}} = 6.8\sqrt{g}\,\frac{n}{d^{1/6}}$. Sediment load in suspension per unit width measured in weight per unit time q_s between water surface and reference level y=a after Einstein (35) is

$$q_s = 11.6 V_* \, C_a \, a \left\{ \left(2.3 \log_{10} \frac{30.2d}{\Delta} \right) I_1 \right\} + I_2 \quad (2.8)$$

where, Δ = the apparent roughness of the surface = K_s / x

x = a corrective parameter

Integral value of I_1 & I_2 are obtained from graphs. Einstein (35) further showed that total suspended load per unit width could also be determined in terms of bed load :

$$i_s q_s = i_b q_b \, (P \, I_1 + I_2) \quad (2.9)$$

where,

$P = \frac{1}{0.434} \cdot \log_{10} \frac{(30.2x)}{K_{s/d}}$ has the same value for all different grain sizes of a section. And i = fraction of material in a given particle size.

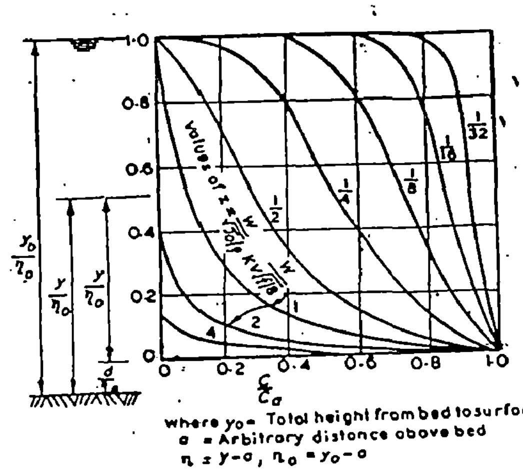
q = load rate in weight per unit of time and width b & s are suffixes for bed and suspended load.

Garde (42) proposed that concentration at a distance 2D from bed in percent volume is :

$$C_{2D} = f \left\{ \tau_* \, \frac{wD}{\tau} \, \frac{w^2 \rho_f}{(\rho_s - \rho_f) D} \right\} \quad (2.10)$$

and showed Figures 2.9 & 2.10 that for plane bed $V_* D / \gamma$ did not have much significance but in dune bed both the parameters V_* / w & $V_* D / \gamma$ were pertinent.

U.P.I.R.I. (84) adopted Schroeder (76) relation for suspended sediment load in a stream vertical for analyzing Sarda Main Canal data and showed that the measured suspended load was 88% of the total suspended load and recommended the trail of this method in the sand bed streams. A quick and easy method for the calculation of suspended load discharge from velocity and concentration parameters has also been presented by Books (7) .



where, y_o=Total height from bed to surface
a=Arbitrary distance above bed

$\eta = y - \alpha$

$\eta_o = y_o - \alpha$

Fig. 2.1 Dimensionless Plot of Suspended Load Distribution

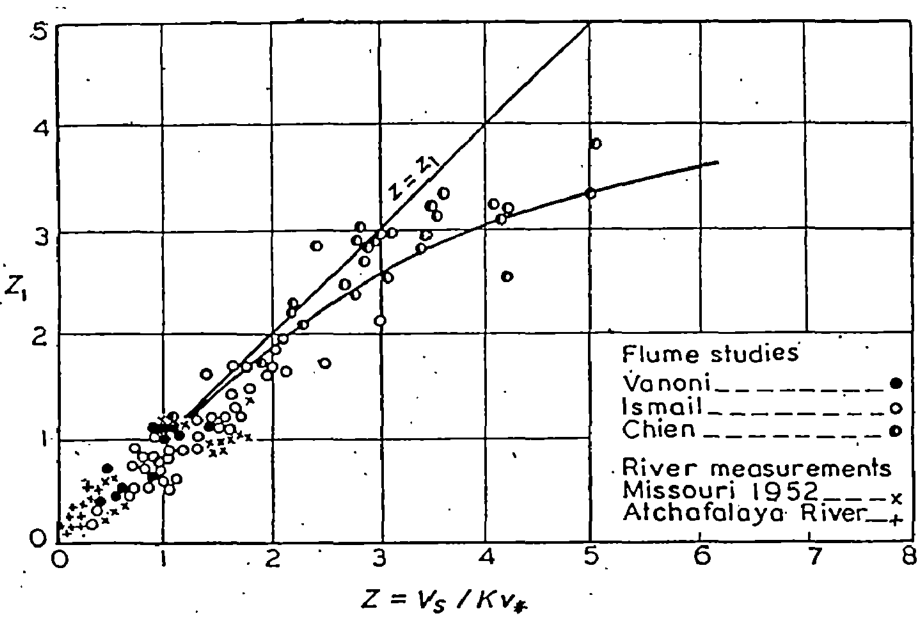


Fig. 2.2 Relation between Z & Z_1

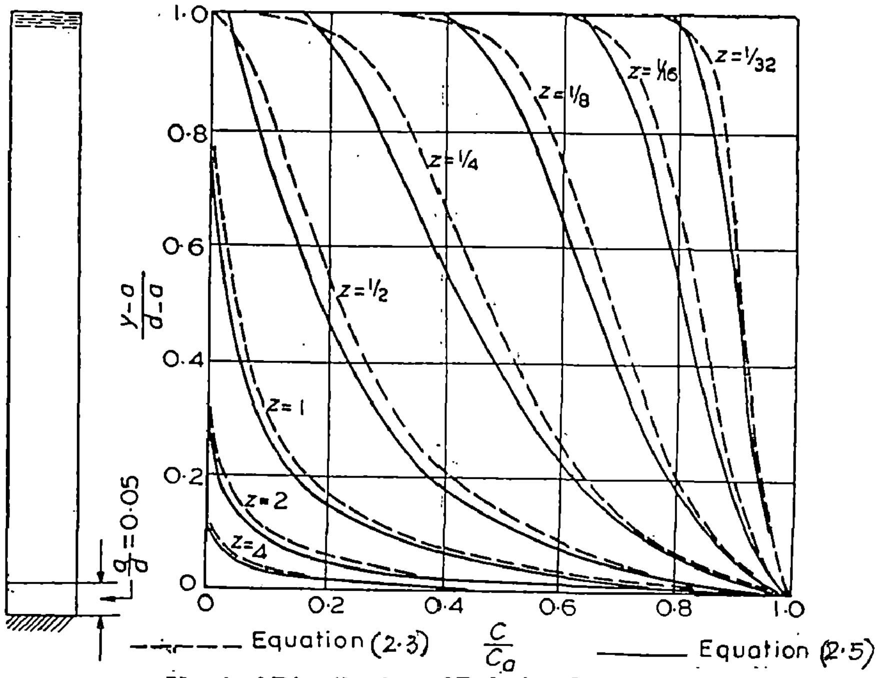


Fig. 2.3 **Vertical Distribution of Relative Concentration C/Ca given by Equation (2.3) and Equation (2.5) for different Z values.**

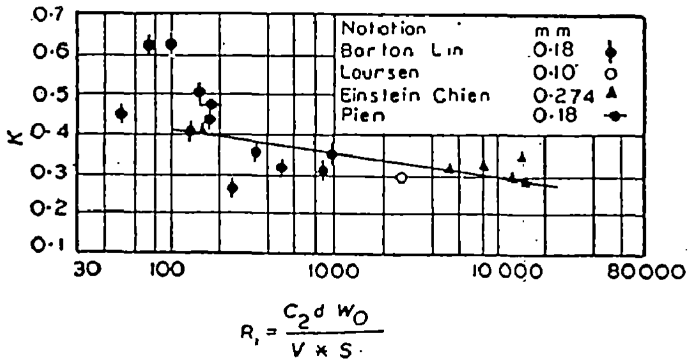


Fig. 2.4 **Variation of K with R_1 for Plane Bed Data after Garde**

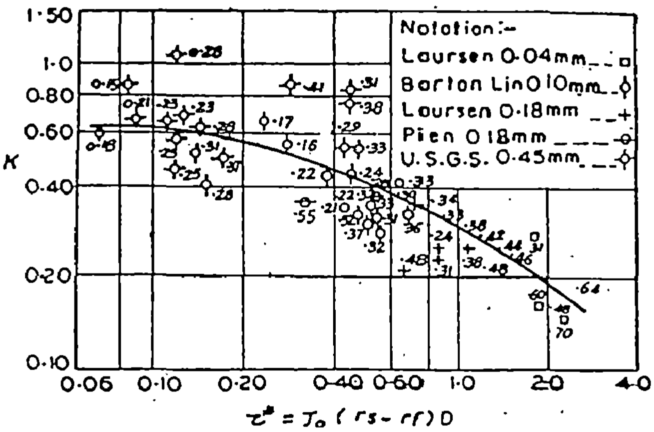


Fig. 2.5 **Variation of K with τ_* and F_r for Dune Bed Data after Garde**

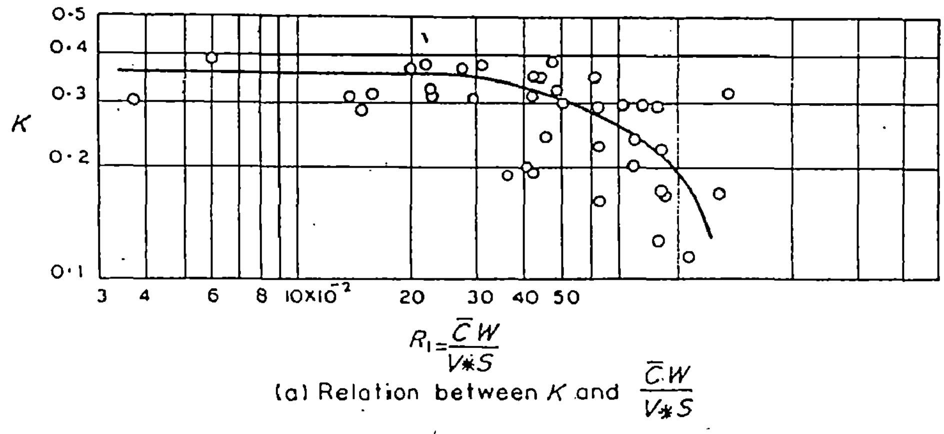


Fig. 2.6 (a) Relation with K & $\bar{C}$ W / V* S

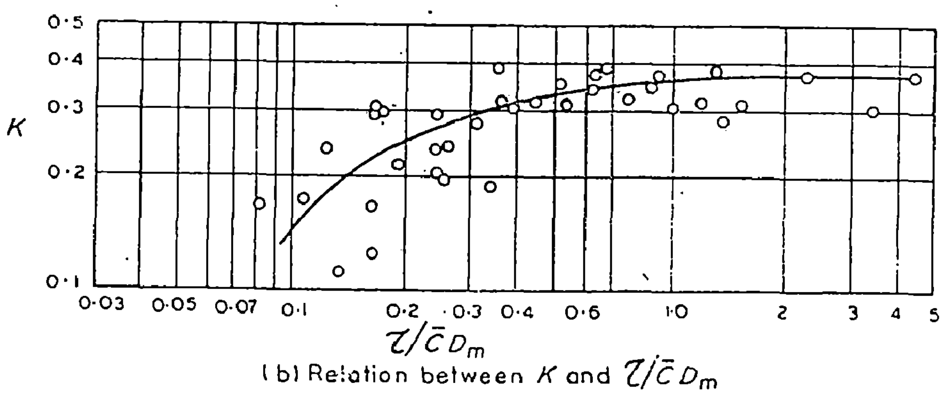


Fig. 2.6 (b) Relation between K & τ / $\bar{C}$ D_m

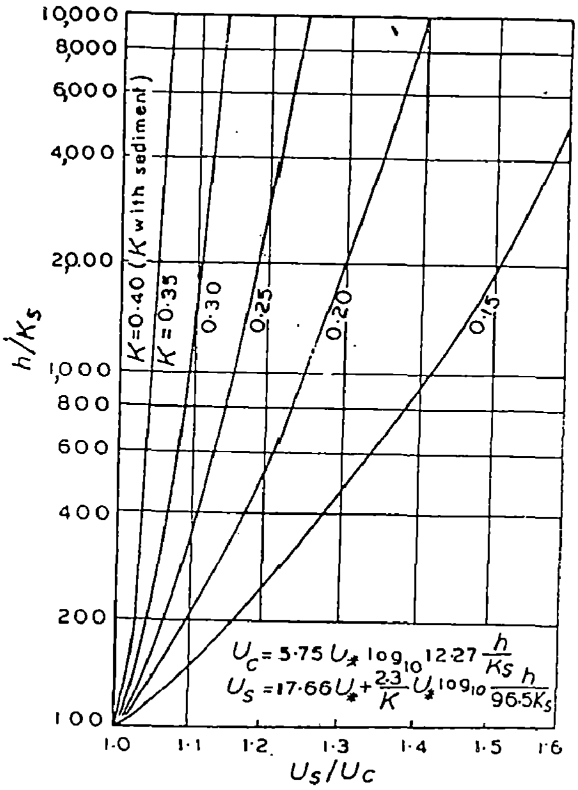


Fig. 2.7 Comparison of Average Velocity of a Sediment Laden Flow with that of a Corresponding clear Water Flow After Einstein – Chien

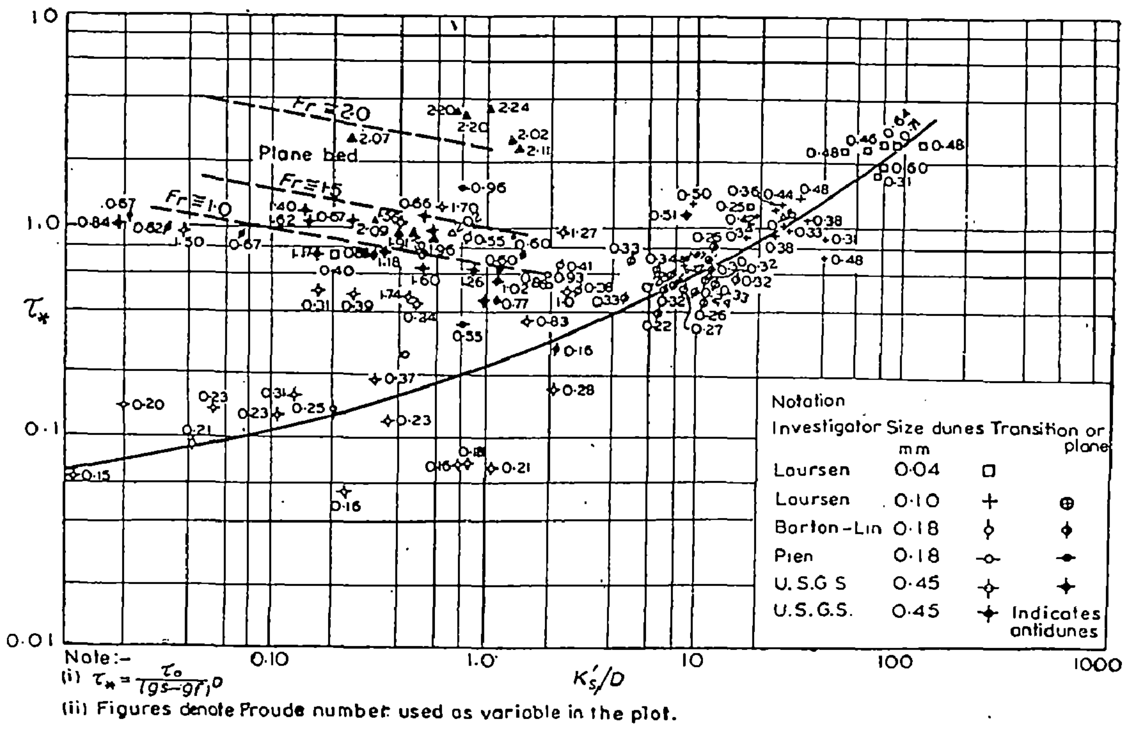


Fig. 2.8 Variation of K's / D with τ_* and F_r for Plane Bed and Dune Bed Data after Garde.

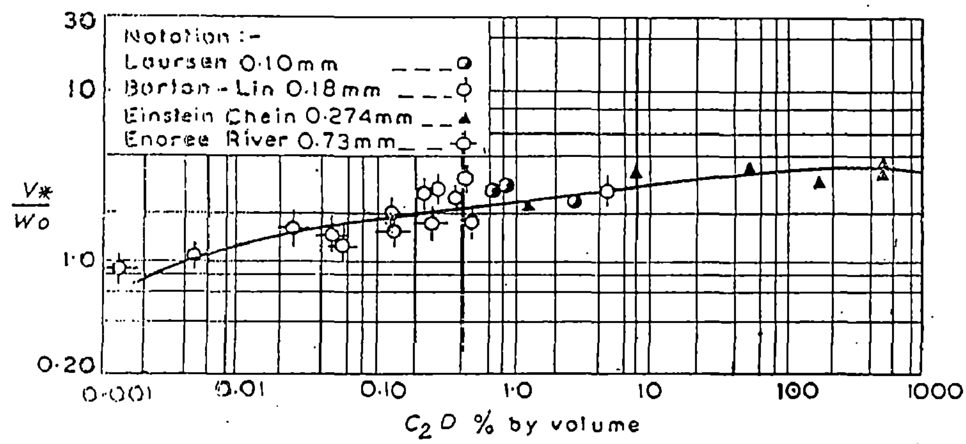


Fig. 2.9 Variation of C_2D with V_* / W_0 for Plane Bed Data after Garde.

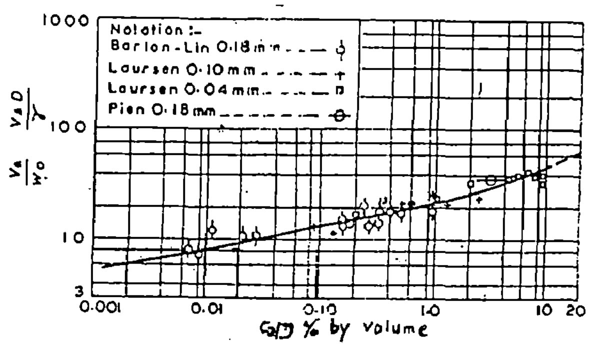


Fig. 2. 10 Variation of C_2D with V_* / W_0 $V_* D/\gamma$ for Dune Bed Data.

DESILTING BASINS

3.1 GENERAL

Various types of desilting basins are in use to remove harmful sediment. These are briefly described in this chapter. The components of desilting arrangement on which the efficient functioning of basin depends are also described. There are various approaches for design of basins. These are also briefly discussed in following paras.

3.2 TYPES OF DESILTING BASINS

3.2.1 Desilting basins are also known by other names such as settling tanks, settling basins, debris tanks, sediment traps, de-cantation chambers, desandars etc. Desilting basins can be classified into various types as indicated below :

Sl. No.	Type of basin	Basis of classification
1.	Natural or artificial	Mode of construction
2.	Manual or mechanical or hydraulic removal of deposition	Method of cleaning
3.	Continuous or intermittent	Mode of operation
4.	Open channel or closed conduit	Type of flow
5.	Single or multiple unit	Configuration/layout

3.2.2 Natural Desilting Basin

Natural depressions can be used as desilting basins which are also known as settling tanks. Water is let in at the upstream end and is taken out on the downstream end of the settling tank. The increased area of tank causes reduction in flow velocity resulting in the deposition of suspended sediment in the tanks. After sometime when the low lying area gets silted up and the resultant velocity through settling basin is no longer small to induce settling of the sediment load, the tank has to be abandoned. Such tanks were provided on the Western Yamuna Canal and on the Upper Bari Doab Canal before the development of silt excluders and ejectors. According to Uppal (86), these have functioned successfully.

3.2.3 Artificial Desilting Basins

These types of basins are constructed in the water conductor system by enlarging the area for reducing the velocity to the desired extent depending upon the size of material to be removed. Generally basins are designed for the settlement of sediment coarser than 0.2 mm in diameter in the case of medium head plants. In the case of small head project, higher velocity is permissible when the particles coarser than 0.2 mm are permissible to some extent. In the case of high head hydel plant or cooling water system for nuclear or thermal projects, sediment upto 0.1 mm or sometimes even upto 0.075 mm diameter is required to be removed.

In specially constructed basins, the inlet is properly oriented and designed to achieve satisfactory distribution of flow in the desilting basin. In addition, the grid or screens are also provided near the inlet for reducing the turbulence. The outlet is also oriented and designed for skimming off the flow without disturbance to the already settled sediment at the bottom near the outlet zone.

3.2.4 Basin With Manual Cleaning

The deposited sediment is required to be removed for maintaining its settling efficiency. Manual cleaning is one of the ways and is generally adopted in the case of irrigation /water supply projects. In this case the size of the basin is decided mainly from the point of view of storage of the sediment which is likely to be deposited during the entire monsoon period. When the monsoon period is over or when the canal is shut down during the period of no demand, cleaning is done manually. Such an arrangement has been proposed for a desilting basin on Periyar Main Canal which has been designed to accommodate the expected volume of 25,000 cum of annual sediment load in the monsoon.

3.2.5 Basin with Hydraulic Flushing

When sufficient head is available between the water level in the basin and the flow level in the outlet channel near the river, the provision of hydraulic flushing system becomes convenient and economical. In this case, the bed of the basin is given a steeper slope and the deposited sediment on the bed is periodically flushed by opening the low level large size outlets, or sediment is allowed to settle continuously on the steep hopper bottom through which it slips into the holes provided at the bottom and is then sucked through flushing conduit or trench which outfalls into the nearby drainage channel.

3.2.6 Basin with Mechanical Sediment Removal

When adequate head for hydraulic flushing is not available, the flushing conduits are allowed to discharge the sediment load into a sediment pit or well from where the sediment is pumped into the river. Sometimes pumps are directly connected to the flushing system through booster pumps to get the required head. This arrangement is suitable when the designed discharge of the basin is small and, therefore, the discharge in the flushing system is also less. In the case of the basin with large discharge, the quantity of the sediment laden water to be pumped becomes enormous. Under such circumstances mechanical removal by means of dredge pumps mounted on floating barges is preferable. Such an arrangement has been provided for Soccaro settling basin (85) at San Acacia Diversion Dam in New Mexico.

3.2.7 Basin with Combination of Mechanical and Hydraulic Flushing

Sometimes the accumulated sediment on the bed is scraped by mechanical scrapers towards the location of the sluice from where it is syphoned or sluiced. Such an arrangement has been provided on All American Canal (41) at Imperial Dam across Colorado river in Arizona and California in U.S.A.

3.2.8 Basin with Intermittent Flushing

In the case of the basin where hydraulic flushing is proposed from the low level outlets, the sediment is allowed to accumulate on the bed of the basin for some period. After sufficient accumulation of the sediment, the low level outlets at the downstream end are opened and the water level is lowered for generating high velocity for flushing. After flushing out the deposition, the outlets are closed, the basin is filled and the discharge on the downstream canal is resumed. This is a simple arrangement. However, it needs a provision of a balancing reservoir on the downstream for continuing the flow to the power house during the flushing operation. Such an arrangement has been provided for Trisuli Desilting Basin (46).

3.2.9 Basin with Continuous Flushing

In this case, the sediment settling on the steep slope of the hopper into deep and narrow flushing trench on the bed of desilting basin from where it is flushed continuously. The flushing conduit is located either below or by the side of flushing trench and it is connected with flushing trench with openings at closer interval. The size of the flushing conduit and the sizes and the spacing of the openings from the sediment trench to the flushing conduit varies from upstream to downstream. The velocity in the flushing conduit generally varies from 2.5 to 4 m/s. This system requires 10 to 20 % of the inlet discharge for the flushing of the sediment. This type of arrangement has been provided for basins in Siul (74), Kahalgaon (14) and other projects such as Tala, Chamera, Dhauli Ganga, Teesta projects.

3.2.10 Open Channel Desilting Basin

These types of desilting basins are provided on the irrigation canals or in the run of the river systems where atleast upstream reach of the power canal from the diversion weir runs in open channel. Such types of basins are common and some of the examples could be cited as desilting basin for the Trisuli (46), Shanan (8), Kahalgaon (14) and Kosi Projects (11).

3.2.11 Conduit Type Desilting Basin

These types of basins are provided for the diversion works located in the very narrow and steep valleys where the intake has to be located abutting the hills and the flow is required to be diverted to the head race tunnel through the hills. In such a case the excavation above the FSL of the basin is avoided by converting the basin into a conduit. The forward velocity is, however, restricted to achieve the desired settlement of specified diameter of the sediment. Such types of basins have been constructed for Chukha Hydel Project in Bhutan (12), Dul-Hasti (13) in J & K State, Nathpa Jhakri Projects (15) (16) in Himachal Pardesh, Tala (Bhutan), Teesta (Sikkim), Dhauliganga (Uttranchal) and Chamera (Himachal Pardesh).

3.2.12 Single or Multiple Unit Basin

Many a time the basin is required to be divided into multiple units for achieving flexibility in the operation or for limiting the size of the tunnels in the hills. In the case of the Shanan Hydel Project (8), the basin has been divided into six compartments for obtaining the continuous flow to the power house with intermittent flushing arrangement for each unit separately. In the case of Chukha, Dul-Hasti and Nathpa Jhakri Projects, the basins have been divided into 2, 2 and 4 units respectively depending upon the number of turbines and permissible size of tunnels.

3.2.13 Other Types of Desilting Basins

a) 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 3.1). This has been evolved at UPIRI, Roorkee and adopted at Ganvi Project in H.P.

b) Tunnel Extractor

It consists of horizontal slab a little above the canal bed which separates the sediment laden bottom layers from the top layers. Under the diaphragm are tunnels which carries these bottom layers of flow 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 canal 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. No.3.2). It has been provided on practically all the power channels.

c) Vortex Settling Basins:

A relatively recent method of sediment injection is the vortex settling basin (shown in Fig.3.3). In a vortex settling basin the flow enters tangentially as overflow over a weir on a part of the circumference. The settled sediment is removed through the pipe located at the center of the bottom of the circular basin. The bottom of the basin slopes towards the center thereby helping collection of sediment near the center due to the combined action of vortex and the radial flows. This is suitable for small hydro projects. It has been provided in Gaj Project in H.P.

3.3 FUNCTIONS OF THE BASIN

The functions of the basins are to induce the settlement of sediment by reducing the velocity and the turbulence and to skim the sediment free layer of the water from the surface at the outlet. Depending upon the flushing system, the basin also has to be provided with the required storage for the accommodation of the sediment as in the case of intermittent flushing and also to be provided with adequate hopper arrangement with openings at the flushing conduit for efficient transport of settled sediment.

3.4 PRINCIPLE OF DESIGN OF DESILTING BASINS

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 governed by the magnitude of u and w_0. The time required for the particle on the water surface to settle to bottom is D/w_0, where D is the depth of water in the basin. The horizontal distance traveled in this time interval is $L = (U_1 \Delta t + U_2 \Delta t + U_3 \Delta t + ----)$, 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% is recommended (43). 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 settling 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.

3.5 LAYOUT AND DESIGN ASPECTS

The performance of the desilting basin depends upon the reduction in the velocity and turbulence, provision of adequate length of the basin for achieving the desired settlement and the skimming arrangements at the outlet. The settled sediment is however, required to be removed periodically or continuously to maintain it's settling efficiency. The design of the desilting basin includes two main parts viz.

i) Size of basin
ii) Flushing system

The following aspects are also taken into consideration :

a) Location and orientation
b) Inlet arrangement
c) Grid or the flow distribution device
d) Size of the basin
e) Outlet arrangement
f) Bed slope (in the case of intermittent flushing)
g) Size of the flushing outlets (in the case of intermittent flushing system)
h) Size and slope of the hoppers (in the case of continuous flushing)
i) Size of flushing conduit (in the case of continuous flushing)
j) The size and spacing of the openings from the hopper bottom to flushing conduit (in the case of continuous flushing)
k) Escape channel/tunnel
l) Location of the flushing outlet.

Thes are briefly discussed in following paras:

3.5.1 Location and Orientation

The selection of the proper location and orientation of a basin is an important aspect from the point of view of its overall performance. Generally desilting basin should be located as near the head works/intake as possible to achieve the desired control and to minimise the sedimentation in the approach channel. However, the location of the basin too near the intake/ head works would create a problem due to the turbulence down-stream of the intake/head regulator. Moreover, the required head for flushing may not be available in the immediate vicinity of the head works in the case of hydraulic flushing.

The basin is also required to be properly oriented with respect to the alignment of the inlet channel/tunnel on the upstream to achieve satisfactory distribution of flow as naturally as possible. For this purpose, the basin may be located in the reach where atleast a straight length equal to ten times the average width of the channel or diameter of the inlet tunnel is available on the upstream. The center line of the desilting basin in such a case should coincide with the center line of the channel/tunnel on the upstream.

3.5.2 Inlet Arrangement

The flow area in the desilting basin is required to be increased for reducing the velocity to induce the settlement of the sediment. This increase in the area is to be achieved by suitable horizontal or vertical divergence. It has been observed that in the expansion the boundary zone of retarded liquid expands rapidly, velocity distributions becomes highly uneven with increase in the divergence and the flow may fail completely to follow the channel walls which would result in a separation zone. Under such circumstances the detention period is reduced which in turn affects the settling efficiency. This effect is also defined as short circuiting.

For obtaining the satisfactory distribution of flow, the flow with relatively large velocity at the inlet has to mix satisfactorily in a desilting basin and a proper diffusion/ dispersion is to be achieved. From the study of the mechanism of the dispersion of the jet in the water body, it has been seen that the region of the expansion of flow is the region of appreciable modification of mean flow pattern and the region of appreciable eddy motion (71) (3). Under normal circumstances, an angle of 12^0 to 14^0 on either side of the center line of the jet has been found to include the major portion of this region which gives the expansion ratio approximately to 1:4 to 1:5. In the case of wide desilting basins in the open area the inlet divergence is, therefore, required to be flatter than 1:4 to 1:5.

In the case of deep basins in the tunnels, such a flat vertical expansion results in the deposition along the bed. If the bed slope in the inlet transition is kept steeper than the angle of repose for the sediment settling on the bed to slip in the first opening to the flushing conduit, a zone of separation develops resulting in the burial of the upstream reach of the flushing trench. Such a phenomenon was observed at the inlet for desilting basins for Dul-Hasti and Nathpa Jhakri Projects. For these two basins a bed slope between 1:2.5 to 1:3 has been found satisfactory.

3.5.3 Grids and other Flow Distribution Devices

In addition to the proper design of the inlet divergence, provision of grids/screens or other flow equalising devices are required to be provided for further reducing the turbulence as well as the inequalities in the flow distribution. The design of the grid could be similar to the trash rack at the intakes. The purpose of these screens/ grids is to break the large eddies into small ones. Too large openings would defeat the purpose whereas too small openings would increase the head loss. Screens having openings upto 60 to 80 % of gross flow area at the location of screen may be considered as a general guide line for the initial design. The grids are required to be located at the end of inlet transition. When the intermittent flushing is to be adopted, the bottom level of the grid should be above the depth of flow during the flushing.

3.5.4 Size of the Basin

As mentioned earlier, the velocity of the flow in the basin is required to be reduced to induce the settlement of the sediment. For obtaining the desired removal, it is also necessary that the particles for which the basin is designed, once settled, should not be thrown again in suspension. From this point of view, the flow area i.e. the width and the depth of the basin is to be designed for limiting the velocity given by the critical velocity concept or to keep the shear stress below the critical tractive force for the size of the particle for which the basin is designed.

3.5.5 Permissible forward Velocity in the Basin

If the bottom is covered with a levelled sand bed, Shields (78) (66) reasoned that the turbulent flow theory as developed by Nikuradse, Prandtl, and Karman, should be applicable to the beginning of bed-load movement.

The results of experiments by Shields and others on the critical tractive force of uni-granular materials of varying specific gravity are plotted in Fig. 3.3(a). For the beginning of bed load movement, the experiments show that

$$\tau_c = \beta (\gamma_s - \gamma) d_s \qquad (3.1)$$

in which the value of β , is about 0.04. For non-uniform material or for sticky and flocculent material, the value of β may be greater than 0.04. Fine non-uniform sands tend to exhibit two values for the critical tractive force, a lower value (β equal to about 0.04) for impending motion from smooth beds and a higher value (β equaling from 0.10 to 0.25) for impending motion from sand ripples formed from the smooth bed; the values of β, in both cases corresponding to the mean grain size.

Using a large volume of data collected subsequently, Yalin and Karahan (93) developed a relation for the critical tractive force similar to that proposed by Shields. The data considered by Yalin & Karahan covers more range and indicates lower value of the critical tractive force than obtained using the relationship proposed by Shields. However, the relation in this form cannot yield a direct solution for critical tractive force and hence trial and error method is needed. For direct solution of critical tractive force, the relation given below is useful and enables direct determination of τ_c.

Variation of $\tau_c/(\gamma_s - \gamma)d$ with Ro^{*2} (where Ro* is Reynold's number)

Ro^{*2}	0.05	1.78	6.40	60.0	2065	3225	11764	40000	108900 and above
$\dfrac{\tau_c}{(\gamma_s - \gamma)d}$	0.2	0.14	0.1	0.066	0.031	0.031	0.034	0.04	0.045

Chitale (24) has given comprehensive compilation of data on critical velocity and critical tractive force. The Hjulstorm's diagram reproduced by Rubey (72) indicates the regimes of erosion and transportation of sediment vide Fig.3.4. which gives the range of velocity from 15 to 25 cm/sec, for medium sand having diameter of 0.25 to 0.50 mm.

For computation of permissible velocities no generally accepted formula or procedure has yet been developed. Generally velocity is lowered to 30 cm/s in the desilting basins designed for removal of sediment coarser than 0.20 mm. For removal of sediment upto 0.1 mm diameter, velocity in the basin is generally limited to 0.15 m/s.

3.5.6 Fall Velocity of Particles

Length of the desilting basin depends upon the horizontal distance traveled by the particle within the time needed for the particle to fall from the top layer of the flow to the bed of the desilting basin. Fall velocity depends upon the size, shape and specific weight of the sediment. The fall velocity of a spherical particle depends on the drag co-efficient which is a function of Reynold's number. Estimation of fall velocity from the relationship given by Rouse (67) between drag co-efficient and Reynold's number involves tedious trials and error procedure and is inconvenient. For practical purposes, Rouse (70) has given a chart vide Fig. 3.5. for estimation of fall velocity of quartz spheres in fresh water and in air under a pressure of one atmosphere for temperature ranging from 0 to 40^0 C, which generally satisfies most of the practical requirements.

The sediment grains are never exactly spherical and their shapes vary over a wide range from rod-like to sphere-like to disk-like. McNown and Malaika (59) and Albertson (2) have studied the effect of shapes of the particles on fall velocities. As a result of these investigations it is found that a shape factor defined as $c/\sqrt{ab}$ is most suitable for studying the effect of shape on the fall velocity. Where; a, b & c are major, intermediate and minor axis. Fall velocities determined from Fig. 3.5 are for a single spherical particle in an infinite fluid. Where there are a number of particles dispersed in the fluid, the fall velocity will differ from that of the fall velocity of a single particle, due to mutual interference of the particles. This interference is said to hinder the settling and the process is often referred to as a hindered settling.

This problem has been studied theoretically and experimentally by McNown and Lin (60). The graphs given by McNown and Lin are based on approximate theory using Oseen's modification of Stoke's theory for motion of spheres in a viscous liquid at a low velocity. The curves are not expected to apply for Reynold's number in excess of 2.

In view of the above mentioned factors it is preferable/ advisable to determine the fall velocity of sediment particle by laboratory analysis of suspended sediment samples collected at the site.

3. 6 VARIOUS PRACTICES OF DESIGN OF DESILTING BASIN

The sedimentation processes in settling basins under turbulent flow conditions are rather complicated phenomena and depends upon many factors, which cannot be mathematically formulated. Therefore, the existing methods of hydraulic design are approximations to solving the problem of sedimentations in coplanar uniform flow. The following approaches are available for the design of desilting basins :

3.6.1 Basic Design Approach

The length of the basin would depend upon the fall velocity of the particles, depth of flow and forward velocity of flow in the basin. The length of the basin can be determined by working out the horizontal distance traveled by the particles for its settlement from the top layer of the flow to the bed of the desilting basin. Since, the actual fall velocity of the particle in the desilting basin would be reduced due to turbulence in the flow, some adhoc factor of safety upto 2 used to be adopted(74). Undoubtedly the length of the basins designed for such conditions would be highly exaggerated and this simple settling theory could be used only for preliminary estimation of lengths.

3.6.2 Technical Conditions and Standards of the U.S.S.R. (TCaS-1949 (83))

In this method, solution to the problem of sedimentation in turbulent flow is based on the theory of probability. The probability of settling sand particles of definite fall velocity within a given length can be calculated instead of calculating the length of the basin directly. The following formula is suggested for the computation of probability of settling.

$$p = \frac{1}{H/L} \int_{0}^{H/L} d\left(\frac{h}{L}\right) \frac{1}{\sqrt{\pi}} \int_{-\alpha}^{\lambda} e^{-t^2}\, dt \qquad (3.5)$$

Where ; $\lambda = \dfrac{\dfrac{L\,\omega}{v} - H}{\sigma\, h\, \sqrt{2}}$

where,

ω = Fall velocity of sand particles

v = Average velocity of flow

H = Depth of flow

L = Length of settling basin

σ h = Standard deviation of vertical reflections from the mean horizontal trajectory of the particles.

Here, the probability 'p' is the ratio of the amount of sediment that settles within the given length to the amount of sediment that enters the basin.

The limitations of this method are :

(a) As Suspended sediment is never distributed along the vertical uniformly.

(b) The empirical formula $\sigma h\,\sqrt{2} = \dfrac{\sqrt{LH}}{2.73}$ for the standard deviation given in the TCaS is very approximate, as it has been derived from a limited number of experiments. The constant 2.73 needs thorough experimental verification.

(c) Theory is based on the experiments carried out by S.F. Savelev using particles of density $\gamma = 1$ g /cm^3 (coloured emulsion bubbles). The theory has to be proved by using particles of $\gamma > 1$ g /cm^3.

3. 6. 3 Recommendations of U.T.B. Hippola

Based on experimental research on the nature of the motion of hard particles in turbulent flow U.T.B. Hippola (48) suggested some recommendations on settling basin design techniques. The research work was carried out at the Moscow Institute of Civil Engineering (under the guidance of Professor F.F. Gubin, the Head of Department of Utilisation of Water Power).

The experimental model consisted of a narrow flume with glass walls and having the following dimensions; length 360 cm, height = 50 cm and width = 17 cm. In the experimental research study artificial silt in the form of hard spherical particles having $\gamma >$ 1 g /cm^3 were used. These particles were made out of a mixture of bitumen, calophony and Paraffin. The density of the mixture was 1.03 g/cm^3.

Experimental results shows that σ h, the standard deviation of the particles from their mean height of passage depends not only upon parameters H & L as assumed by A.P. Zegshda in TCaS, but also upon the ratio of velocities ω/v. From the experimental data the following formula was derived.

$$\sigma h \sqrt{2} = \frac{\sqrt{\frac{\omega}{v} LH}}{4.1} \quad (3.6)$$

Considering surface sediment concentration in natural streams is not more than 5-10% of the sediment concentration at the bottom, he suggested the following formula for settling basin design when adequate data about sediment concentration of streams are not available.

The probability or removal ratio of settling could be expressed as :

$$p = \frac{2}{H/L} \int_0^{H/L} d\left(\frac{h}{L}\right) \frac{1}{\sqrt{\pi}} \int_{-\infty}^{\lambda} e^{-t^2}\, dt - \frac{2}{(H/L)^2} \int_0^{H/L} \frac{h}{L} d\left(\frac{h}{L}\right) \frac{1}{\sqrt{\pi}} \int_{-\infty}^{\lambda} e^{-t^2}\, dt \quad (3.7)$$

For solution of equation (3.7) Hippola suggests use of Simpson's method of approximate integration. To make the computation easier a series of curves p = f (H/L) are suggested for different values of ω/v (Fig.3.6) using these curves the length of the basin for any desired probability of settling could be computed. The standard practice adopted is to design basins for 90% probability of settling of the 'harmful' fractions of sand.

Comparison of these curves with curves suggested by A.P. Zogshda in TCaS shows an apparent increase in the probability of settling for the same values of H/L and ω/v.

On the basis of theoretical and experimental investigation carried out by Hippola the following conclusions and recommendations could be made on settling basin design techniques :

(1) Probability methods of settling basin design have sound theoretical basis and could be used as standard methods for evolving economical dimensions of these structures.

(2) Experimental investigations revealed that hard particles whilst in motion in turbulent flow deflects from their mean trajectory in accordance with the Gauss Law of normal distribution, thus establishing the validity of Velikanov's theory.

(3) The assumption of constant vertical distribution of suspended sediment concentration seriously affects the computation of settling basin dimensions. Assuming trapezoidal or triangular vertical distribution or vertical distribution in accordance with the gravitational theory, a more general formula for settling basin design is obtained.

(4) When adequate data about silt is not available it is suggested to adopt triangular vertical distribution and to use the suggested curves for estimating basin dimensions.

(5) By adopting the suggested modifications to the existing methods it is possible to evolve economical lengths resulting in a reduction of 30 to 40% in the basin lengths.

(6) A formula for the standard deviation σ h has been evolved from the experimental data.

3. 6. 4 Camp T.R. & Ensign Dobbin's Approach

An analysis of flow in settling basin has been presented by T.R. Camp (17) & Ensign Dobbin's (31). Dobbin 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 gωL/u D graphical solution of Dobbin's equation, Camp used the parameters q_{sc} / q_{si}, ω/u_*, ωL/u D, where q_{sc} 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&L are the depth and length of the basin respectively. Using Manning's equation the parameter ω/u_* can be written as :

$$\frac{\omega}{u_*} = \frac{\omega \quad D^{1/6}}{n \; u \sqrt{g}} \tag{3.8}$$

where; n is Manning's roughosity coefficient and thus ω/u_* can be determined. Fig. 3.7 shows the graphical relationship of these parameters for removal efficiency of basin.

Camp's relationship has also been expressed in terms of $\frac{\omega D}{2 \in}$ *and* $\frac{\omega}{\omega_d}$. Here ω_d is the design fall velocity and 'ε' is the sediment transfer coefficient or mixing coefficient. Fig 3.8 shows this relationship for the removal efficiency of the settling basin. If ω_d is expressed as uD/L and 'ε' as 0.075 u_* D fig. 3.8 reduces to fig. 3.7 .These are the values proposed by Camp for ω_d & ε.

3. 6. 5 Cean et. al. Approach

Cean et. al (20) 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 mean flow. The assumed distribution is :

$$C(x,y) = C_a \exp\left[\frac{\omega}{\varepsilon_y}(y-a)\right]\left[\exp\left\{\frac{u}{2\varepsilon} - \frac{u}{2\varepsilon}\sqrt{1+\frac{4\omega^2}{u^2}\frac{\varepsilon_x}{\varepsilon_y}}\right\}\right] \tag{3.9}$$

where, x-axis is chosen in the direction of flow, y-axis vertically upwards, 'c' is the concentration at a point, 'ε_y' is the cross-sectional mean of vertical diffusion coefficient, ε is sediment transfer coefficient, C (O, a) = Ca. Here 'Ca' is the sediment concentration at a distance 'a' above the bed. The solution of above equation (3.9) is used to determine the similarity criteria for settling basins. The distribution of concentration is found to depend on three non-dimensional variables, $\omega D / \in_y, U x / \in_x$ *and* $\omega^2 \in_x / u^2 \in_y$. 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 is grains.

Sumer transformed Cean et. al., solution in to a series of graphs as shown in Fig. 3.8(a) which could be used in predicting the removal ratio of fine sediment in the settling basin.

3. 6. 6 Richardson et.al., Approach

Richardson et.al., (65) have given the methodology for deisng 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 $(\tau_c / \rho_f)^{1/2}$ the equation of continuity coupled with the resistance equation developed for a plane bed with little or no sediment transport as given below :

$$U / U_* = 5.9 \log D / d_{85} + 5.44 \qquad (3.10)$$

Equation (3.10) 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 ω of particle by making use of curves proposed by Camp and McNown and Lin as shown in Fig.3.9. Knowing, ωD and U, the length of settling basin L, is evaluated as $L = U D/\omega$.

3. 6. 7 U.S.B.R. Approach

The United States Bureau of Reclamation (87) has developed a basic relation to aid in the design of settling basins. The following is the removal efficiency equation proposed by them :

$$\eta = 1 - \frac{q_{se}}{q_{si}} = 1 - \exp\left(-\frac{\omega L}{u D}\right) \qquad (3.11)$$

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
ω	=	Fall velocity of sediment
L	=	Length of settling basin
D	=	Depth of water in settling basin

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

3. 6. 8 Sumer's Approach

Sumer (80) 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 :

$$\frac{\varepsilon_y}{U\,D} = \frac{6y}{D}\left(1 - \frac{y}{D}\right) \tag{3.12}$$

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 (82) 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.

$$f(\bar{t}) = \frac{\lambda}{\mu} \exp\left(-\frac{\lambda}{\mu}x\right) \tag{3.13}$$

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

Therefore, mean settling length

$$X = \int_0^\infty X\,f(X)\,dx = \frac{\mu}{\lambda} \tag{3.14}$$

Let η denotes the efficiency of basin. Taking into consideration that efficiency is actually equal to (1-cumulative distribution of the settling length of the particle) and using equation 3.13 the efficiency can be found as :

$$\eta = \int_0^x f\,(X)\,dx = \exp\left(-\frac{\lambda}{\mu}X\right) \qquad (3.15)$$

From equation 3.15 the design settling length corresponding to certain 'η' is obtained as:

$$L = \frac{-6\left(\frac{u}{u_*}\right)D}{K\lambda} - \ln\,(1-\eta) \qquad (3.16)$$

where, K is Karman's constant.

If the removal efficiency 'η' of sediment is desired, one can determined the length from the preceding equation. For λ one should refer Fig. 3.10 of λ vs. β as given by Syre's (82) numerical solution, where, β is non-dimensionalised settling velocity parameter whose value is equal to ω / KU_*. The value of K may be taken as 0.4.

3. 6. 9 Garde et. al. Approach (44)

They conducted laboratory experiments in 16m long, 0.75m wide and 0.5m deep flume for verification of existing methods of design of settling basins. Natural sand of specific gravity of 2.65 was used as sediment. Two uniform samples of diameter 0.082mm and 0.106 mm were used. The discharge varied from 15.6 to 40.50 lps. Depth of flow varied from 0.114 m to 0.405 m. The forward velocity ranged from 0.08 m/sec. to 0.2234 m/sec., the concentration ranged from 33 to 615.4 ppm. A total of 162 experiments were conducted. They found that the measured values of removal efficiency were considerably different from those given by Camp, USBR and Sumer. On the basis of the experimental results Garde has proposed following relationship for estimation of settling efficiency :

$$\eta = \eta_0\,\left(1 - e^{-K\,L/D}\right) \qquad (3.17)$$

For η_0 & K, relationships with ration of fall velocity to shear velocity (ω_0 / U_*). Here U_* is the shear velocity in the settling basin and ω_0 the fall velocity of sediment particle in clear water. The values of η_0 & K for different values of (ω_0 / U*) as obtained by them are given in table below:

ω_0 / U*	0.70	0.90	1.20	1.60	2.0	> 2.2
K	0.02	0.03	0.06	0.14	0.215	0.24
η_0	34	40	50	70	97	100

The results of the experiments with coarse sediment were in good agreement with those estimated by Camp's criteria. However, in the case of fine sediment of 0.086 mm or so the actual efficiency was much less.

3.6.10 Ranga Raju et. al. Approach

Ranga Raju et. al., (64) found that the following equation yields better results than equation 2.4.17 and recommended it for use, when ω_0 / U* < 2.5.

$$\eta = 11.7 \left(\frac{\omega_0}{U}\right)^{0.81} \left(\frac{LB}{B_c\, D_c}\right)^{0.23} \left(\frac{D^{1/6}}{n\sqrt{g}}\right)^{0.98} \qquad (3.18)$$

Here, ω_0 is the fall velocity of the 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 of basin. The applicability of the above equation for field situations is still to be checked.

From comparing the results obtained from the above methods 3.6.4 to 3.6.9 Ranga Raju, et. al. found that these methods given 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.

3.6.11 Mosonyi Method

Mosonyi (61) takes into consideration, the effect of turbulence on the fall velocity of sediment particles. He 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 :

	$Q = b.h.v.$		(3.19)
	$t = h / w$		(3.20)
and	$L = v.t$		(3.21)

where, Q = Discharge passing through the basin
b = Width of the basin
h = Depth of flow
v = Flow velocity
L = Length of basin
w = Fall velocity of a particle in stagnant water

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

$Q = b.h.v.$
and $Lw = h.v.$

Thus, for the solution of the above equations four variables must be known. Of these, Q,v, and w 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, Masonyi, suggested to assume the value of 'h' as the minimum practical depth for the solution of the problem. In deciding the parameter 'v', Masonyi 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.

$V = a\, d^{1/2}$ cm/sec.

where, d = diameter of the particle in mm and coefficient
a = 36 for d > 1mm
a = 44 for 1mm > d > 0.1 mm
a = 36 for d < 1mm

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 Masonyi 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. 3.11). The value of fall velocity 'w' in stagnant water should be corrected for turbulence effect as below :

$w_e = w - w'$

where, w_e = effective velocity

$w' = \alpha v$ (m/sec) & $\alpha = 0.132/\sqrt{h}$ in which 'h' is in m.

Therefore, making substitutions for the fall velocity

$$L = \frac{h v}{w_e} = \frac{h^{3/2}}{h^{1/2}\; w - 0.132 v}\ (m) \tag{3.22}$$

3.6.12 Velikanov's Design Function

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

$$L = \frac{\lambda^2\, v^2\, \left(\sqrt{h} - 0.2\right)^2}{7.51\, w^2}\ (m) \tag{3.23}$$

where,

	v	=	Velocity of flow in basin
	h	=	Depth of flow
	w	=	Fall velocity of silt particle

Here, λ depends upon the removal ratio values of W defined by Velikanov's function W = f (λ), can be determined from the curve given in Fig. 3.12 in which W denotes the ratio of the settled sediment to the total amount entering with the flow and is obtained as below :

$W = 100 - 100\, C_0 / C$ where, 'C_0' 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 obtained 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.

3.6.13 J. Lamble Equation

J. Lamble has also given following equation to find length of basin

$$\ln \frac{(C_m)}{(C_m)_0} \doteq -\lambda\infty\xi + (\lambda\infty - 1)^2 \ln\left[\frac{\xi + (\lambda\infty - 1)}{\lambda\infty - 1}\right] \qquad (3.24)$$

$$where,\ \xi = \frac{wX}{V_b D_b}$$

V_b & D_b are the mean velocity of flow in the basin and depth of basin. 'w' is the fall velocity, X is the horizontal distance from point of entrance, C_m is the mean concentration at any distance X from the entrance (C_m). C_m at X = 0, λ & ∝ is the ratio of concentration at bed to concentration at infinite distance from X = 0. Prototype measurements have indicated that while the sediment concentration of 0.25 mm grains show close conformity with the value computed after Lamble yet for the fine particles i.e. <0.1mm size the observed values are invariably higher, i.e. fine particles settle at rates slower than that given by Lamble's relation. Sediment removal function given by J. Lamble is shown in Fig. 3.13.

3.7 OUTLET ARRANGEMENT

The settling efficiency of the desilting basin also depends upon proper arrangement at the outlet for skimming off the relatively less sediment laden top layers of flow. From the results of the model studies and prototype data for desilting basins, it is evident that settling efficiency improves with provision of outlets having higher sill level.

The center line of the outlet should coincide with the axis of the desilting basin for uniform withdrawal of flow over the entire width of the basin. The outlet should be as high and as wide as possible. Narrow outlets or outlets located on the side would result in a reduction in the effective length of the basin.

3.8 BED SLOPE IN THE CASE OF INTERMITTENT FLUSHING

For efficient flushing of the sediment, higher velocity is required to be generated in the entire length and width of the basin. The velocities required during flushing are many a times more in comparison to the forward velocity of flow during settling. The basin is thus practically required to be emptied as the depth of flow would be much smaller during flushing. A steeper bed slope is, therefore, needed for conveyance of the flow with a small hydraulic depth and higher value of roughness to account for roughness due to bed forms with high rate of sediment transport.

If a large head is available, the bed slope may be made steeper to achieve supercritical flow during flushing. With supercritical conditions, the flow would fan over the entire width of the basin satisfactorily and works almost as a hydraulic broom as was seen in the model of Trisuli desilting basin.

3.9 SIZE OF THE FLUSHING OUTLET IN THE CASE OF INTERMITTENT FLUSHING

The sill of the flushing outlet should flush with the bed of the desilting basin at the downstream end for transporting the sediment in the escape channel. If small outlets are provided, the time required for emptying the basin would be longer which may not be permissible. Moreover, complete emptying of the tank for generating higher velocities throughout the length and the width of the basin may not be possible. The flushing outlet should have the overall width equal to the bed width of the basin at the outlet. If this width is smaller, the sediment deposited in the corner portions may not get flushed out. Similarly if the flushing outlets are located on one side, the flushing of the deposition from the entire width of the basin as observed in the case of desilting basin on Fort Laramie Canal (41) may not be possible. If flushing outlet is required to be located on the side, a better arrangement would be to provide a deep flushing trench on the downstream. During flushing the basin would be almost emptied and in that case the flow from the entire width of the basin would fall freely in the flushing trench. The flushing trench in that case would function as a side channel spillway. Such an arrangement was tried in the model for desilting basin for Rammam and Lodhama Project in the Darjeeling District of West Bengal and was found to be satisfactory.

3.10 SIZE AND SLOPE OF THE HOPPERS

In the case of continuous flushing system, the bed of the desilting basin will have to be divided into a number of hoppers. For long and narrow basins a single row of hoppers could be sufficient. However, in the case of wide basins, more rows of hoppers would be needed as seen in the case of desilting basin for Kosi Project (11). The slope of the hoppers is required to be steeper than the angle of repose of the suspended sediment to allow the sediment to slip into the openings at the bottom connecting to the flushing conduits/pipes underneath. The width of the hopper is thus related to the depth of the hopper, size of the opening at the bottom of hopper and bed width of the basin. In the case of narrow desilting basins, instead of individual rectangular hopper, a continuous hopper of sloping sides with sediment accumulation trench below is preferable. The spacing of the openings between the flushing trench and flushing conduit is decided in such a way that the top of the dunes formed between the successive openings would not protrude in the settling zone above.

3.11 SIZE OF FLUSHING CONDUIT

The size of the flushing conduit is required to be decided for the efficient transport of the sediment. From the experience of the performance of the ejectors and excluders, it is seen that the minimum velocity of 3 to 3 m/sec depending on sediment size is required for the efficient functioning of the tunnels. In the flushing system of the desilting basins, the concentration of sediment is likely to be more. The flow in the flushing system could be a pressure flow since the sediment enters in the flushing conduit through the opening from the basin. The flushing discharge is controlled by a gate at the downstream end or an open channel flow depending upon the site considerations.

Since the sediment in the flushing system would be mostly coarse having a wide range of particle size, the flow in the flushing system is likely to be in the two regions such as :

i) Flow with moving bed/saltation
ii) Heterogeneous flow with all solids in suspension

Heterogeneous flow is the most important regime of sediment transport in pipes since it gives the maximum sediment transport per unit of head loss. Due to its importance, great research has been concentrated in this regime, but unfortunately no generally accepted criteria to describe head loss under various conditions within this regime has yet been established. The analysis of data/results published by various research workers such as Wilson (92), Durand and Condolios (32), Zandi and Gawatos (95) etc. and by the CWPRS (9) (10) revealed the validity of Durand and Condolios expression for heterogeneous flow. Durand and his co-workers at Sogreach Laboratory, Grenable, France, contributed greatly to the understanding of sediment transport through pipes. They conducted 310 tests with sediment sizes ranging from 0.2 to 25 mm, sediment concentrations ranging from 2 to 23 % by volume, and pipes ranging in size from 1.5 to 28 inches in diameter. They concluded from their experiments that for heterogeneous flow

$$\phi_D = \frac{im - i}{i\ cr} = K' \left(\frac{\sqrt{gD}}{\gamma} \right)^3 \left(\frac{1}{\sqrt{c_D}} \right)^{1.5} \qquad (3.25)$$

where,

ϕ_D	= dimensionless parameter
im	= energy gradient for pipe with suspended particle
i	= energy gradient for clear water flow at same velocity
γ	= specific weight of liquid
C_D	= drag coefficinet
g	= acceleration due to gravity
cr	= sediment concentration by volume.
k'	= constant of proportionality
D	= diameter of pipe.

This functional relationship together with the data points are shown in Fig. 3.14.

The ASCE (89) also have concluded that the equation given by Durand and his co-workers seems to give the best agreement with the observations and the value of the constant `K' in the equation is 176.

The above equation is applicable for heterogeneous flow which occurs in the pipe for the velocity greater than the limit velocity V_L, which is given by Figs.3.15 & 3.16. The above recommendation of ASCE is based only on hydraulic conditions in the pipe line. The design velocity in the conduit should be greater than V_L. At mean velocity less than V_L for heterogeneous flow, some of the suspended particles begin to settle and move along the bottom of the pipe boundary as bed load. Generally the head losses in the transportation pipe line with bed load are greater than those associated with the limit deposit velocity. However, due to some practical and site considerations it may not be possible to satisfy the criteria of limit deposit velocity. After a review of the literature on this aspect, ASCE has concluded that a formula for use in pipe can not be suggested, although experienced specialist may be able to recommend some values for the friction coefficient that may be used in some specific cases. The figure presented by Graf and Acaroglu (47) may be used as a guide line which gives following relationship.

$$\frac{C_v\, V r}{\sqrt{(s-1)\, g\, d_s^3}} = 10.39 \left[\frac{(s-1)\, ds}{i_m\, r}\right]^{-3.52} \qquad (3.26)$$

where,

C_v = sediment concentration by volume.

i_m = energy gradient for pipe with suspended particle

S = ρ_s/ρ_f, , ρ_s is mass density of sediment, ρ_f is mass density of fluid.

g = acceleration due to gravity

γ = hydraulic radius in the free flow region (above the deposit) in the pipe).

V = velocity of flow

d = diameter of particle.

The above equations for heterogeneous flow or flow with bed are applicable for uniform size of sediment. Little is known about transportation of graded sediment having a wide range of particle size. Previous investigators have concentrated their efforts on the determination of characteristic size that will represent the entire range of sediment. It is difficult to choose a representative sediment size from a graded sediment. The size most likely depends upon the concentration of sediment in the flow. If very large concentration is involved, perhaps d_{90} may be selected as the representative size. For moderate concentrations, a less conservative choice of d_{75} may be called as representative size.

Generally, velocities larger than 3.0 m/s are provided in flushing systems. The velocity should increase towards the downstream with addition of flow from the basin to the flushing trench. However too high velocities may create problem to the linings and should not be adopted. Normally 10 to 20 % of the inflow discharge is used for flushing of the basin from which the size of the flushing conduit could be decided.

3.12 THE SIZE AND SPACING OF THE OPENINGS FROM THE HOPPER BOTTOM TO FLUSHING CONDUIT

The first opening from the desilting basin to flushing conduit is required to be larger to allow for the higher rate of deposition and larger size of particles. But no definite criteria exists. The size of the openings may decrease progressively towards the downstream as concentration and size of the sediment settling goes on decreasing towards downstream. This reduction could be done in steps on the basis of the practical considerations. Model studies have been found useful in deciding this parameter.

3.13 ESCAPE CHANNEL/TUNNEL

As mentioned earlier, the flushing discharge varies generally between 10 and 20 % of the inlet design discharge. Since the sediment transport is a function of the velocity for given characteristics and concentration of sediment and hydraulic parameters of transporting system, it is essential that the velocities in the escape channel should be more or atleast equal to the velocities in the flushing system at its outlet at the tail end of the desilting basin. Generally the escape channels are lined. However, for the estimation of flow depth and slope, the resistance of the sediment moving on the bed in different bed forms is required to be taken into consideration. Nearly every investigator of the problem has developed his own formula and no single formula has been generally accepted. As a broad guide line, the hydraulic parameters such as width, depth and slope may be calculated on the basis of Manning's formula with appropriate roughness corresponding to the bed forms and its adequacy verified for the desired rate of sediment transport for the coarse material using an appropriate sediment transport formula adopting the guide lines given by ASCE (89).

In the case of escape tunnels, the adequacy of the size may be ascertained using the criteria given for the design of flushing conduit.

3.14 LOCATION OF FLUSHING OUTLET

In the case of the escape channel, the sill level in the escape channel should be such that it discharges freely in the river during floods also. If the slope of the flushing channel is flatter than the slope of the river, which would generally be the case in the case of diversion works in hilly streams, the outfall may be shifted further down to satisfy the above requirement. In the case of the tunnel, it may get submerged during the floods. However, it may be ascertained that the residual energy in the tunnel after allowing for the head loss is adequate for letting out the desired discharge in the river. In both the cases the outfall should be located in the forward region of the flow along the bank or on the concave bank of the bend for further efficient transport of the sediment in the river.

3.15 BRIEF DISCRIPTION OF SOME DESILTING BASINS USED FOR VARIOUS PROJECTS

Different types of desilting basins have been or are being constructed for several projects in India as well as abroad. A brief description of some of the basins is given below.

3.15.1 Desilting Works On All American Canal (U.S.A.) [41]

The All-American Canal takes off from the Colorado river upstream of Imperial Dam. Colorado river carries considerable sediment load. The desilting works were, therefore, designed for removal of sediment upto 0.05 mm. The desilting works on All-American Canal (Fig. 3.17) consists of three settling basins, each 234.7 m long and 164.6 m wide, running parallel to each other. Other structures forming a part of the works are four inlet channels, influent channels, by-pass and effluent channels. When the desilting basins are in operation, their floors are continuously swept by a total of 72 revolving scrapers, each covering a circle of 38 m diameter. Each scraper collects gradually the deposited silt towards a circular pit near its center. The material thus collected in the trenches is sluiced out to the river through sluice pipes. It is estimated that with a deposited load of 71,120 tones of silt per day in the basins, the average quantity removed by each scraper in one revolution is approximately 5.7 cum.

3.15.2 Gilla Main Canal Desilting Works (U.S.A.)

(Ref. Vetter C.P.: "Technical Aspects of Silt Problem on Colorado River", Civil Engineering Vol. 10, NO. 11, Nov. 1940, pp 698-701).

The Gilla Main Canal also takes off from the opposite bank of the Colorado river upstream of the Imperial Dam. Flushing type of desilting work is constructed in the Gilla Canal (U.S.A.); water is conducted at low velocity through a basin of such length that by the time the water reaches the diversion gates at the exit, a large part of the suspended load has settled to the bottom and clear and skimmed water at the top is diverted back into the canal.

This is a rectangular basin (Fig.3.18) located downstream of the dam designed for 56.63 cumec and is about 353.6 m long with a cross-sectional area of 278.7 sq.m and an average depth of 7.6 m.

3.15.3 Desilting Basins On Nangal Hydel Channel

The Nangal Hydel Channel takes off from the Satluj river. At the head of the canal boulders were transported by the river. For the two power houses, the sediment size had to be restricted to 0.2 mm. For this purpose the desilting basins have been constructed on the Nangal Hydel Canal in India. The first basin (Fig. 3.19) has been built at Dabatwali at R.D. 46,390 upstream of Power House No.1 at Ganguwal, while the second basin is at Bassowal (Fig. 3.20), R.D. 57,250 upstream of the Kotla Power House. At both these sites, two natural drainage channels cross the power channel, which serve as the outfall for sluicing the material deposited in each of these basins.

At Dabatwali, the canal bed is depressed from 6.7 to 17.1 m. The basin is 243.8 m long. The velocity in the normal section of this canal is 1.6 m/s while, at the aqueduct it is 3.35 m/s. This reduction in the velocity results in the settlement of sediment at the bottom of the trough. For flushing this material deposited on the upstream slope of the basin, slits of size 3 m x 1.8 m have been provided on the upstream face of the first arch and 0.15 m diameter pipes at the end. The total outfall discharge is 8.92 cumec. The depth of the basin at Bassowal is 10 m and has a flat bottom unlike the basin at Dabatwali.

The designs of both these desilting basins were tested on the models and improvements were effected. It was seen that 15.2 cm diameter pipes proposed in the original design for sluicing the sediment did not work satisfactorily. These were replaced by 15.2 cm wide slits of 3 m length.

These desilting basins have been under operation since 1954. Their efficiency varies between 15 and 60 per cent. The discharge escaped is very small and varies from 1.42 to 5.66 cumec. The sediment intensity in the outfall is sometimes as high as 10 grams per litre.

3.15.4 Desilting Works at Ichari Dam [45]

UPIRI, Roorkee has evolved a unique arrangement of settling basin combined with flushing conduits for continuous flushing, for Yamuna Hydel Scheme Stage II to convey a discharge of 235 cumec through a 6.287 km long and 7 m diameter pressure conduit to feed high head (124 m) turbines situated in the underground Power House at Chibro, wherein a great degree of sediment control is required, (Fig. 3.21). The basin has been divided into compartments having trough like traps to avoid dune formation and also to guide or lead the deposited sediment to the flushing conduits. The size of the flushing conduits is 0.8 m x 2 m, velocity through these is 4 m/sec and side slope of the hoppers is steeper than 30^0. The flushing discharge (75 cumec) is 32% of the intake discharge, and the efficiency is 85 percent. Settling traps are provided at three places and the shares of 1st, 2nd and the 3rd from upstream are 48,25 and 12 percent of the total material collected respectively. Criteria after Craven (27) and Ambrose (4) have been found suitable for evaluation of conduit size/flushing velocities by Sharma (45).

3.15.5 Desilting Basin On Fort Laramie Canal - U.S.A.

Intermittent type desilting basin is provided on Fort Laramie Canal in Nebraska, U.S.A. The basin is 182.88 m long and 45.72 m wide and is provided with 93 m long skimming weir at the tail end vide Fig.3.22. The sluice gates are located on one side of the basin just downstream of lower end of skimming weir for flushing the deposition. The working of the basin is similar to the desilting tank provided for Trisuli Project, Nepal.

Since flushing gates are located on one side, it was felt that some pockets may remain un-flushed. The authorities in U.S.A. were, therefore, approached for obtaining further information on this aspect. From the report received subsequently it was learnt that some portion did remain un-flushed in the prototype and further tests were conducted to overcome this difficulty. On the basis of the model studies, a 38.10 m long guide wall as shown in Fig.3.22 was recommended.

In the meantime a Pershall flume was constructed downstream of desilting basin which caused a rise in water-level of about 0.61 m in the desilting basin. This resulted in the reduction of sand entry into the basin to such an extent that the necessity of flushing was felt only once during 1950 irrigation season.

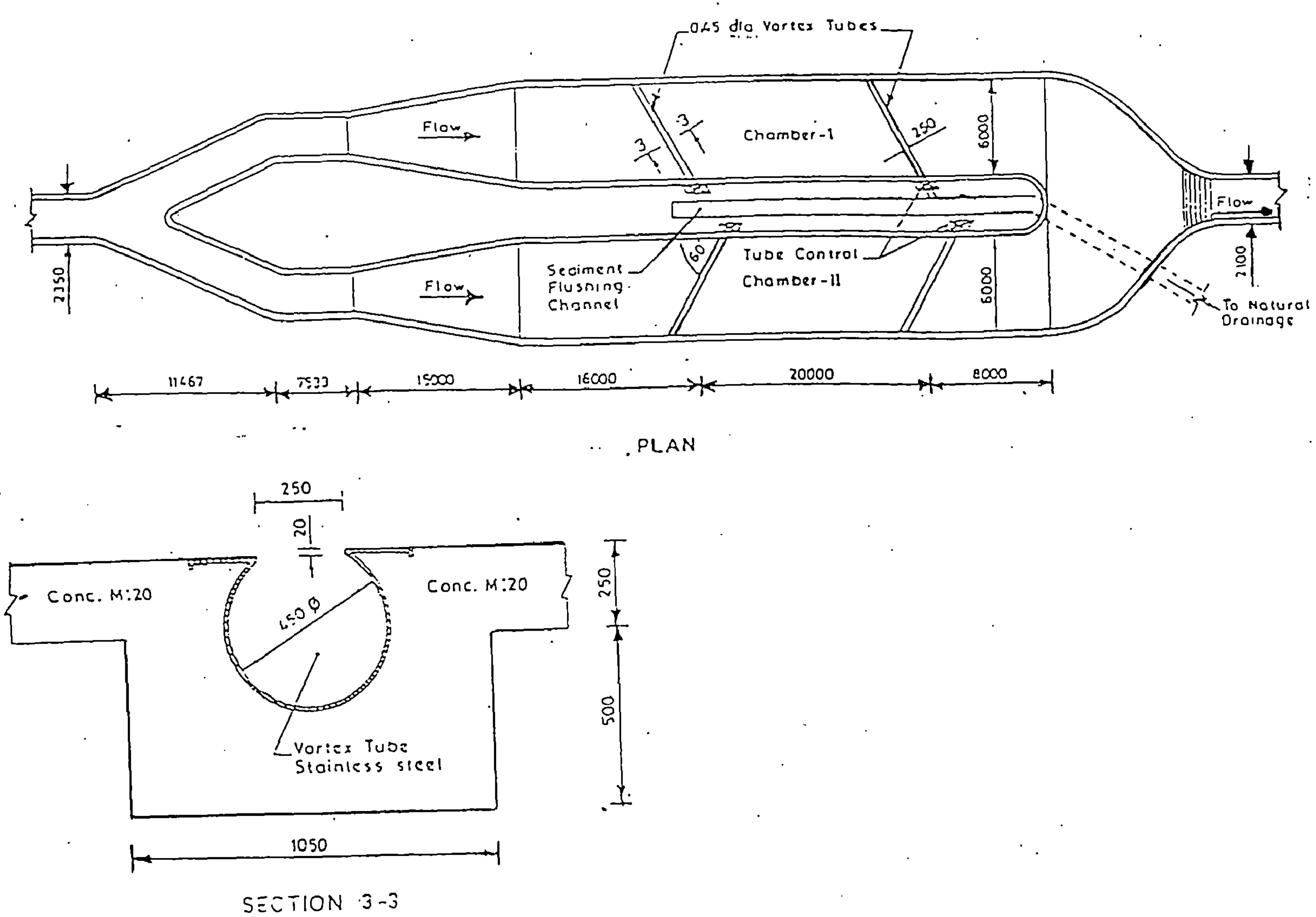


Fig. 3.1 **Vortex Tube Desilting Basin**

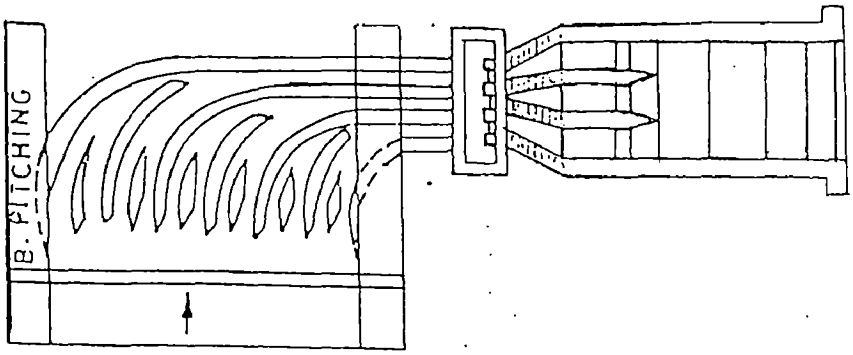


Fig. 3.2 **Typical Layout of Tunnel Extractor**

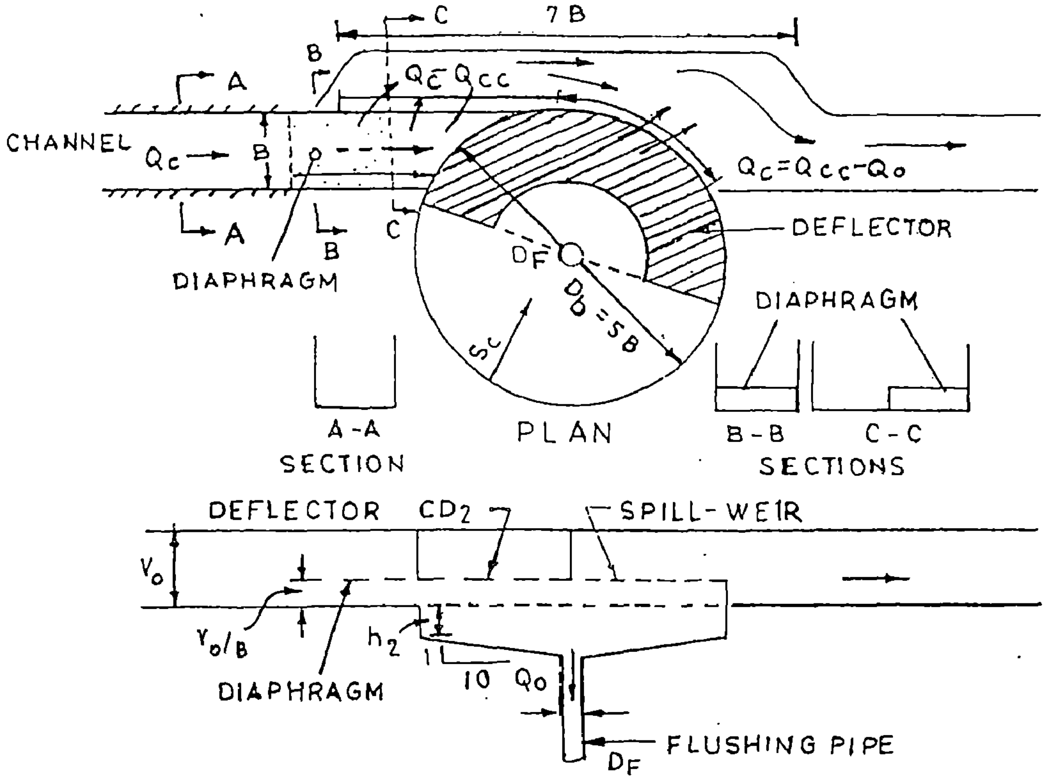


Fig. 3.3 **Vortex Settling Basin**

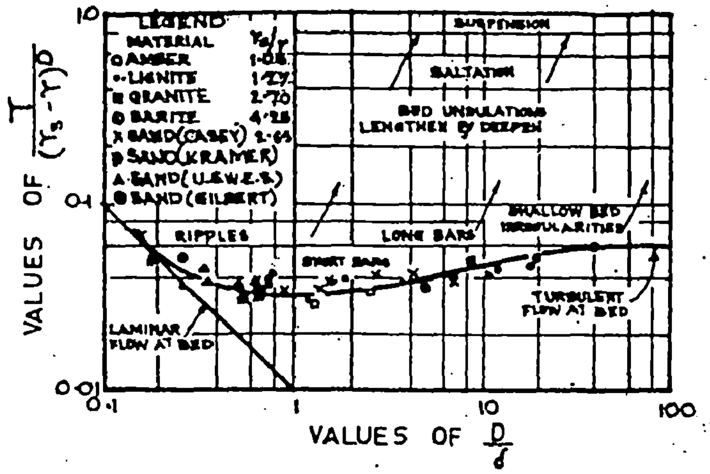


Fig. 3.3(a) **Beginning of Bed-load movement as a Function of Grain Diameter And Boundary Layer Thickness.**

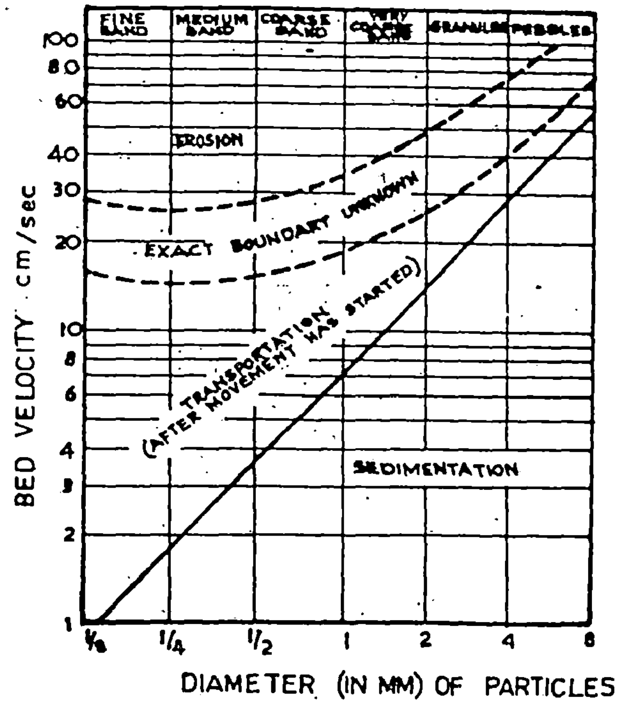
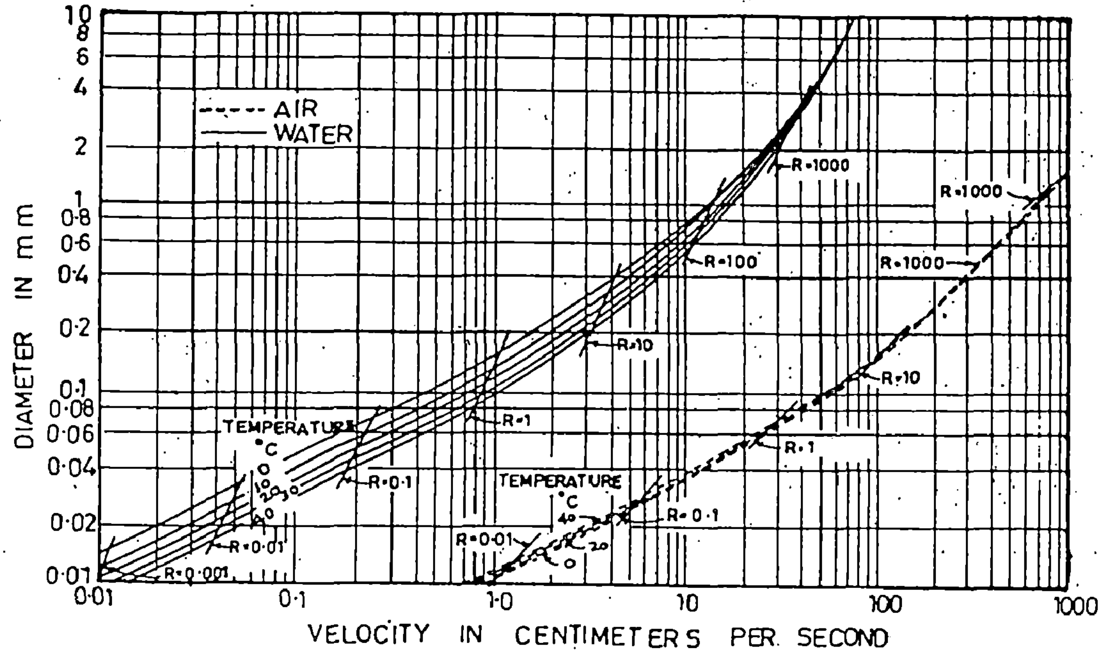


Fig. 3.4 **The Field of Erosion, Transportation and Sedimentation for well Sorted Sediment.**



R = REYNOLDS NUMBER

Fig. 3.5 Fall Velocity of Quartz Spheres in Air & Water.

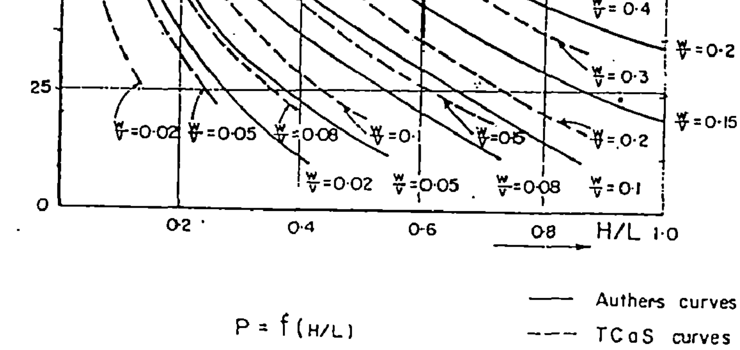


Fig. 3.6 Probability Curves

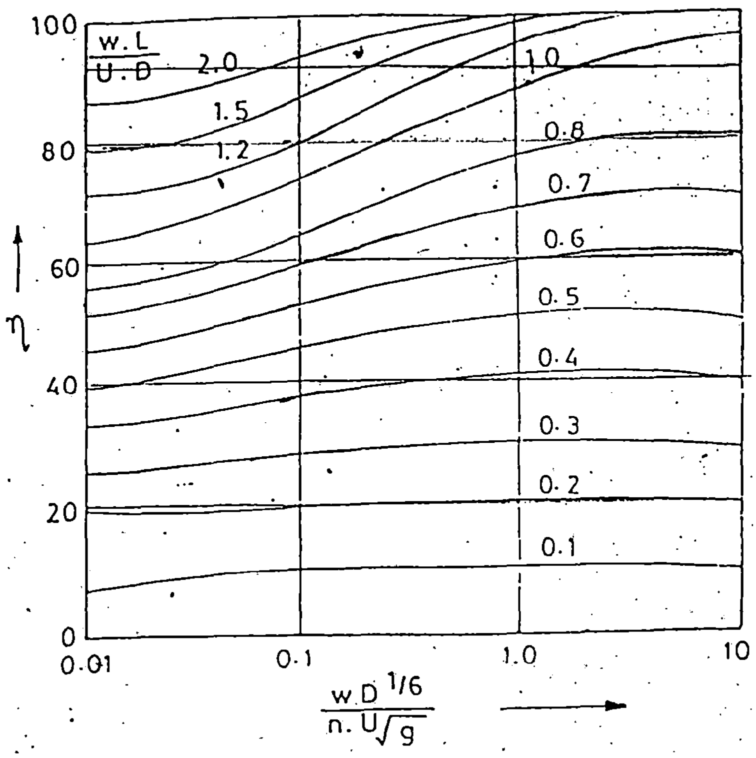


Fig. 3.7 Camp & Dobbins Relation of Efficiency of Desilting Basin

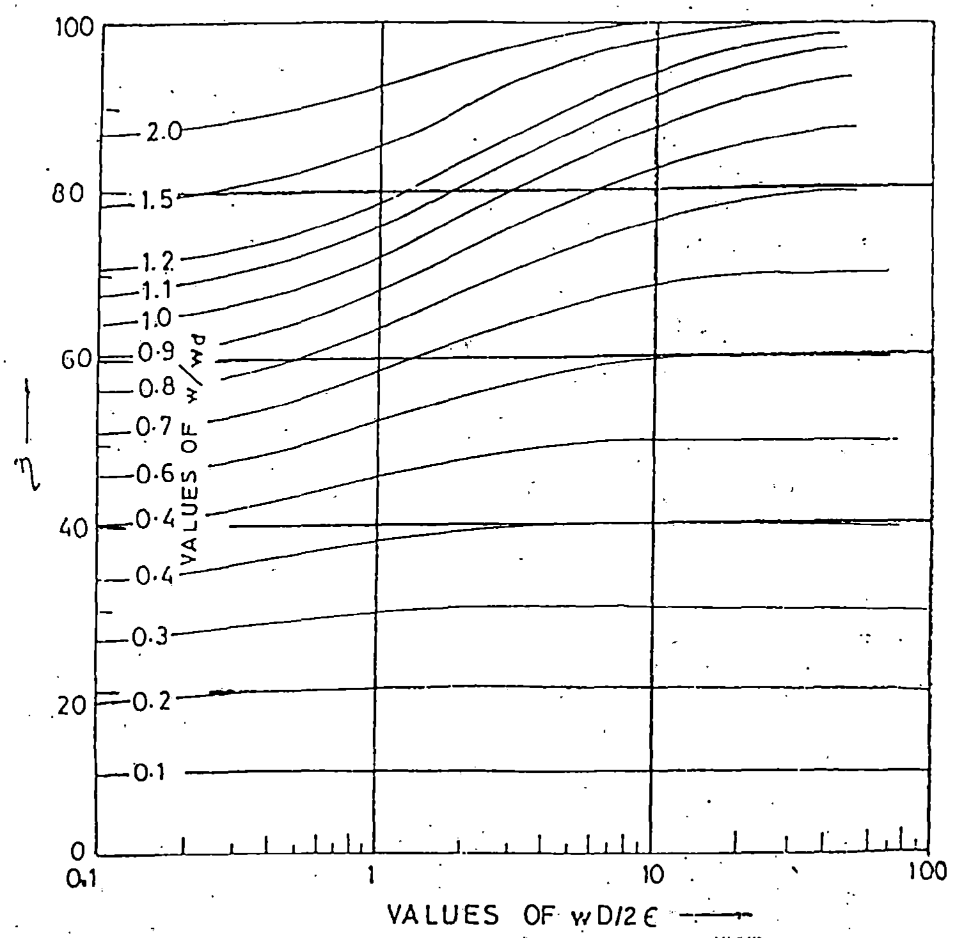


Fig. 3.8 Efficiency in Terms of Mixing Coefficient

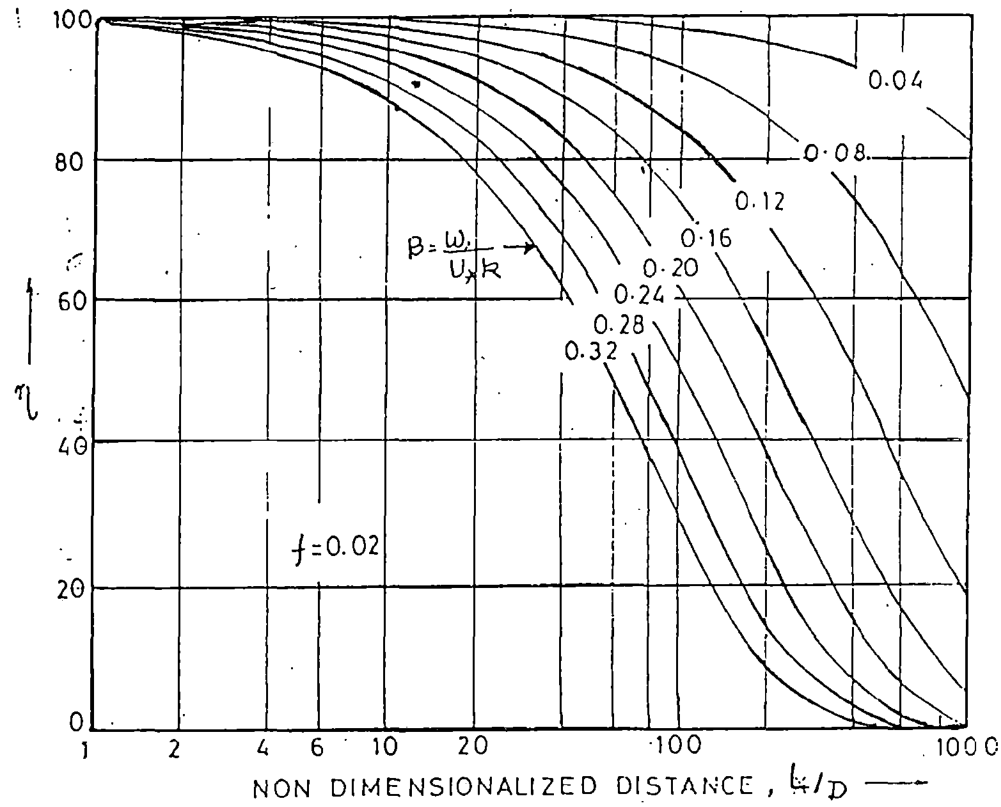


Fig. 3.8(a) **Sumer's Efficiency Curves for Design of Settling Basins.**

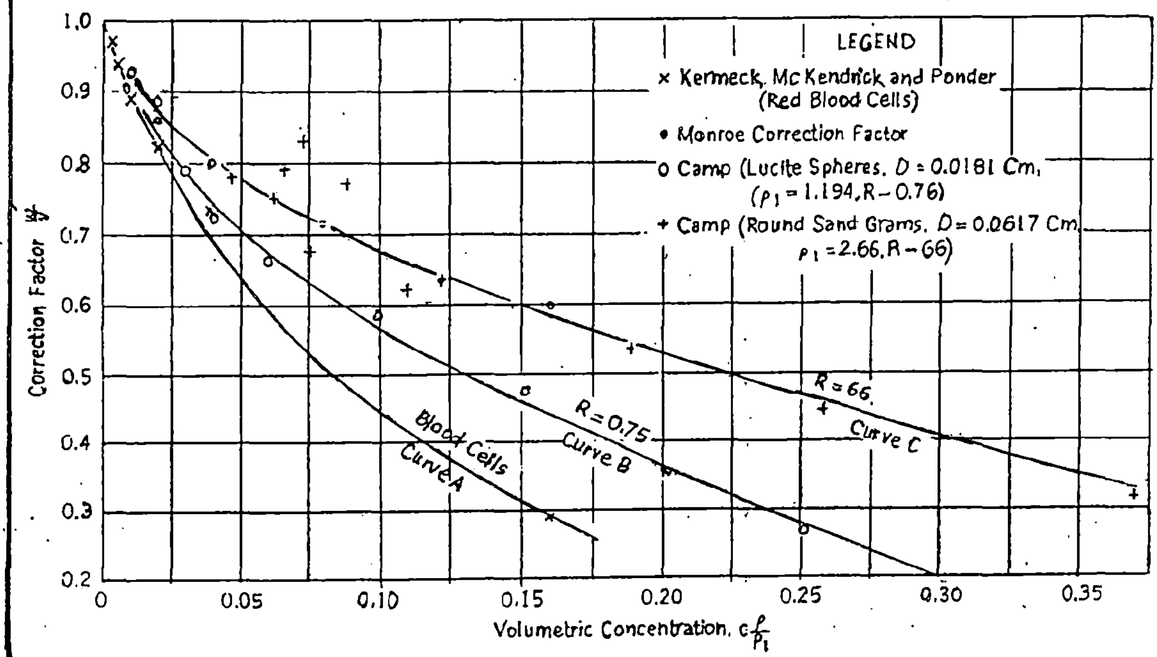


Fig. 3.9 Reduction in Velocity due to Hindered Settling.

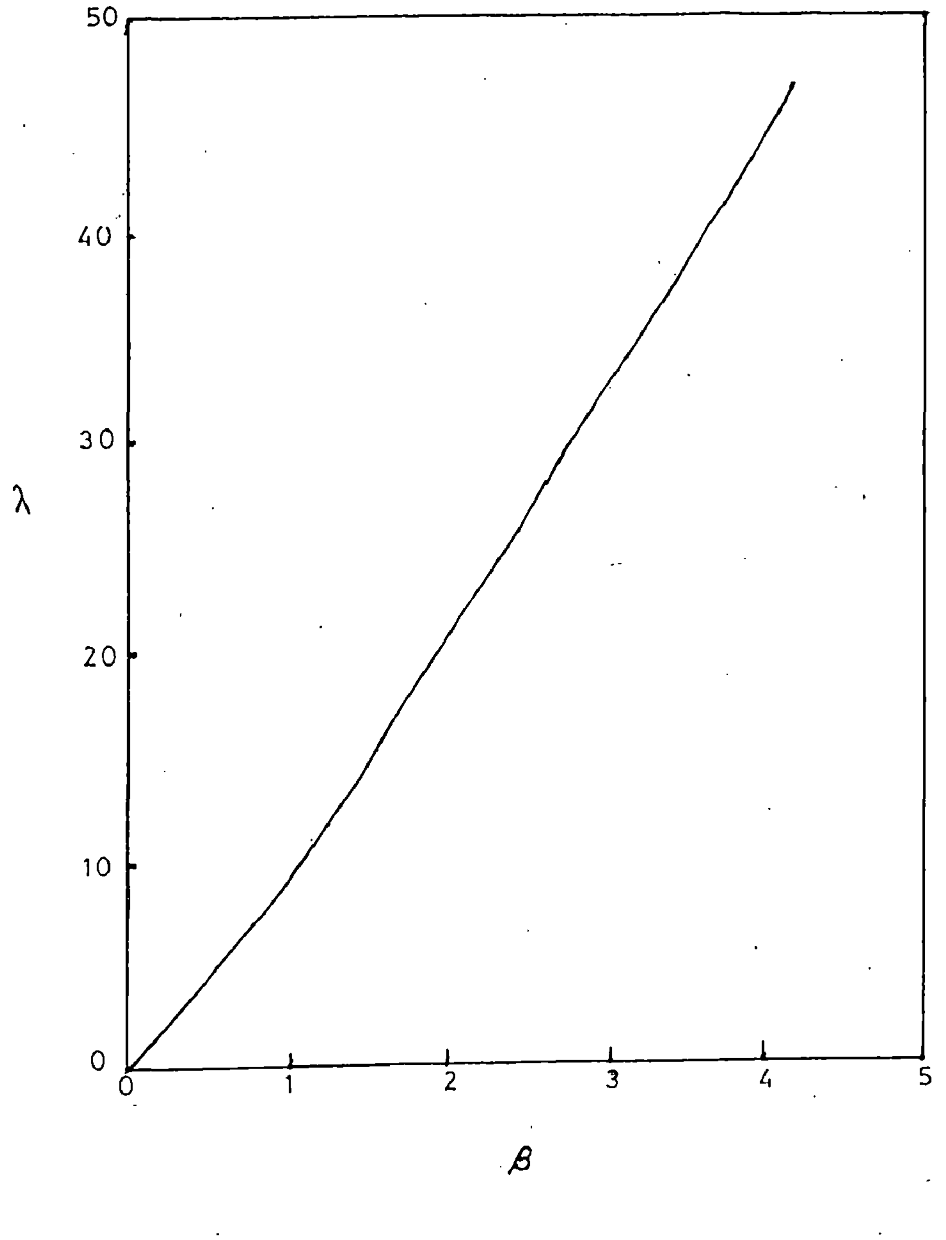


Fig. 3.10 Relation between λ and β for Particle Settling

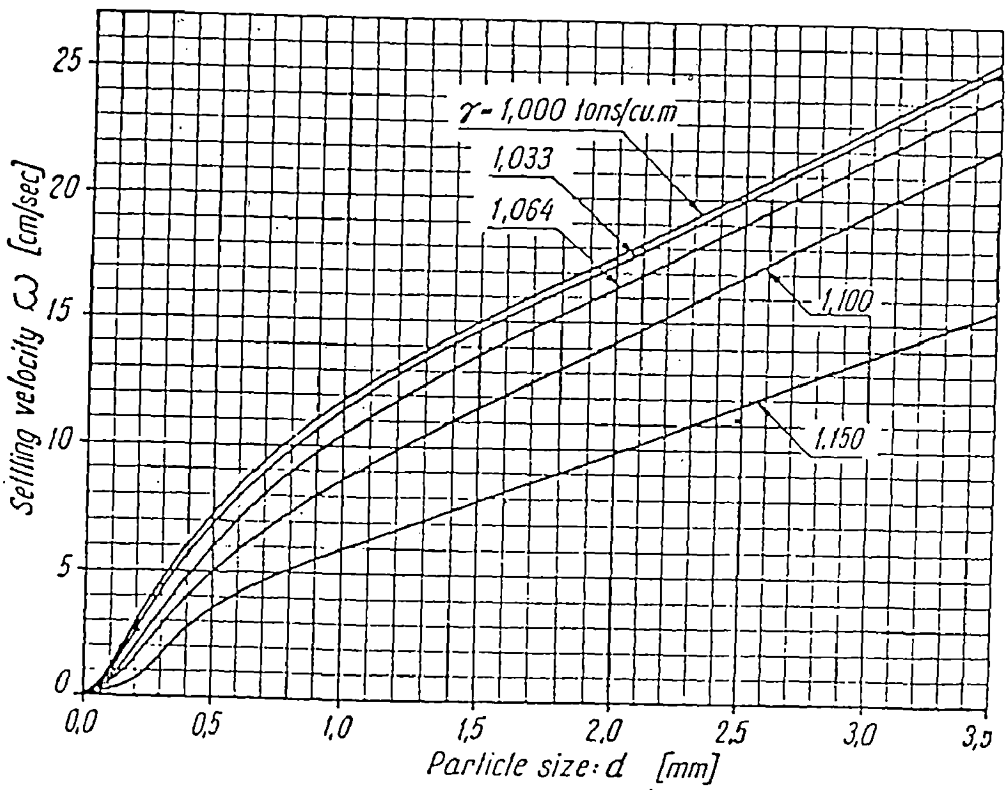


Fig. 3.11 Settling Velocity in Stagnant Water (Sudry's Curve)

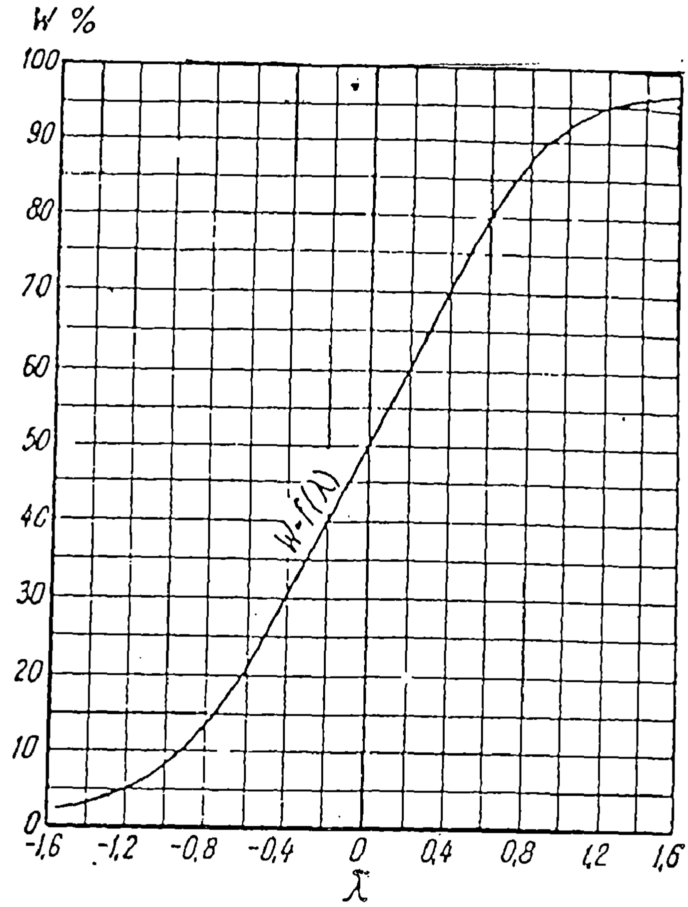


Fig. 3.12 Velikanov's Relationship w = f (λ) for Designing Settling basins

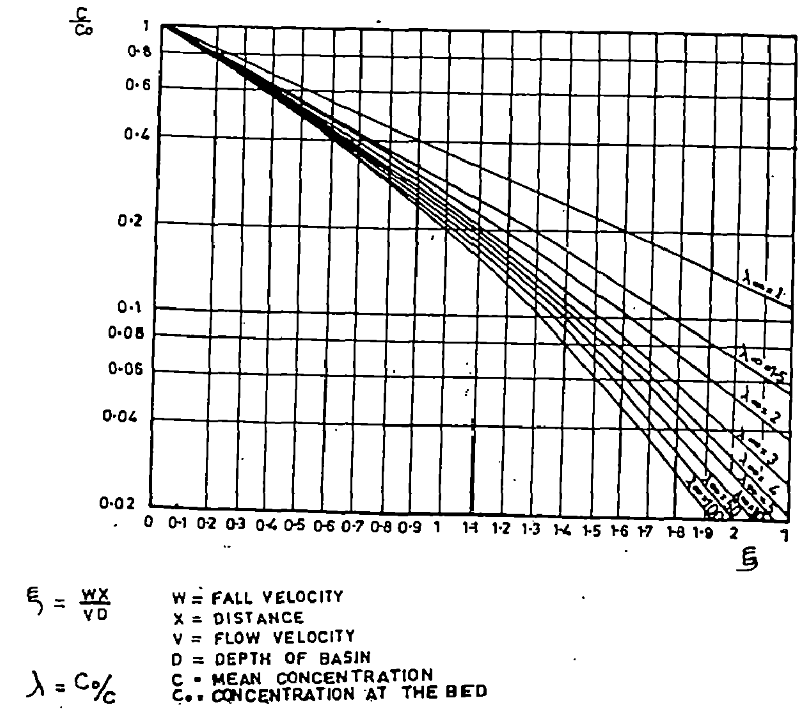


Fig. 3.13 Sediment Removal Functin given by J. Lamble.

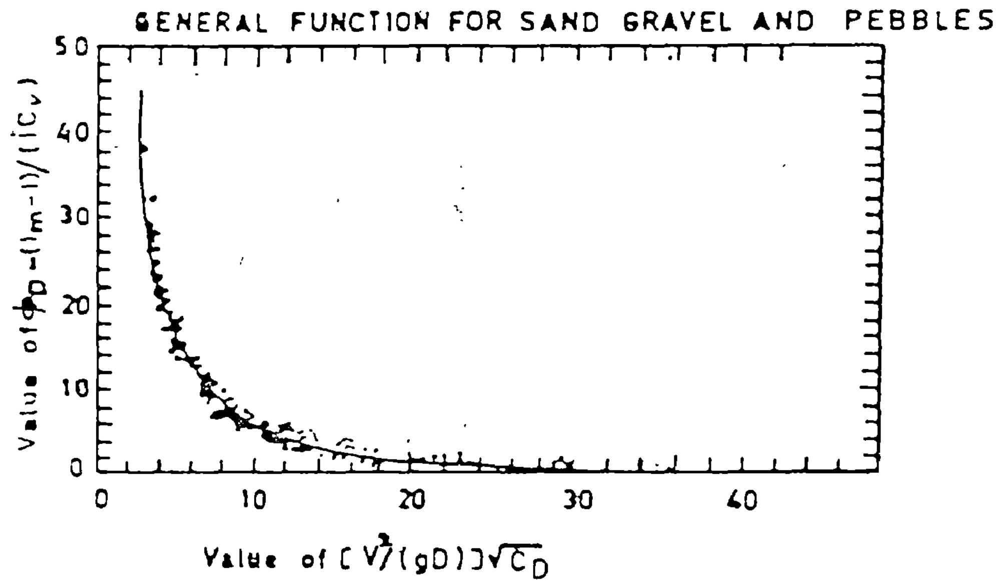


Fig. 3.14 Head losses in pipes with non-deposit Flow Regims.

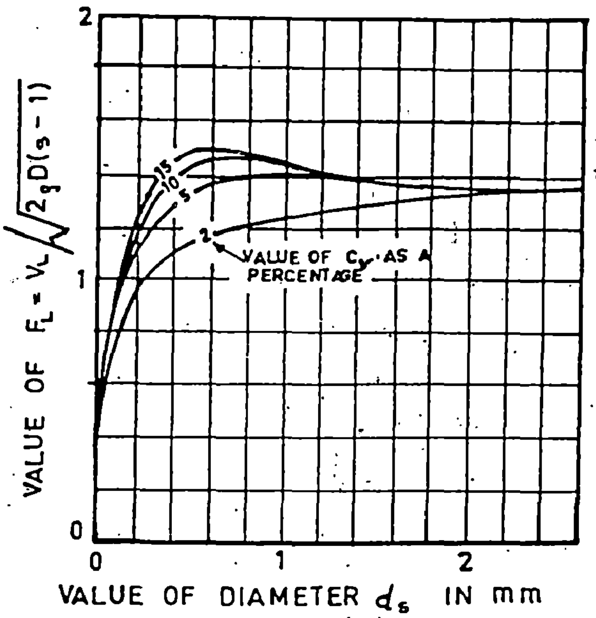


Fig. 3.15 **Limit Deposit Velocity for Uniform Material.**

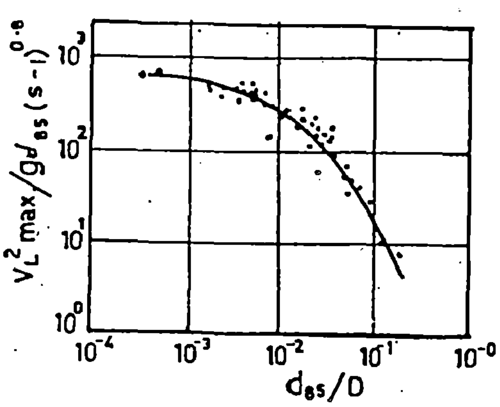


Fig. 3.16 **Proposed co-relation for Maximum Limit Deposit Velocity.**

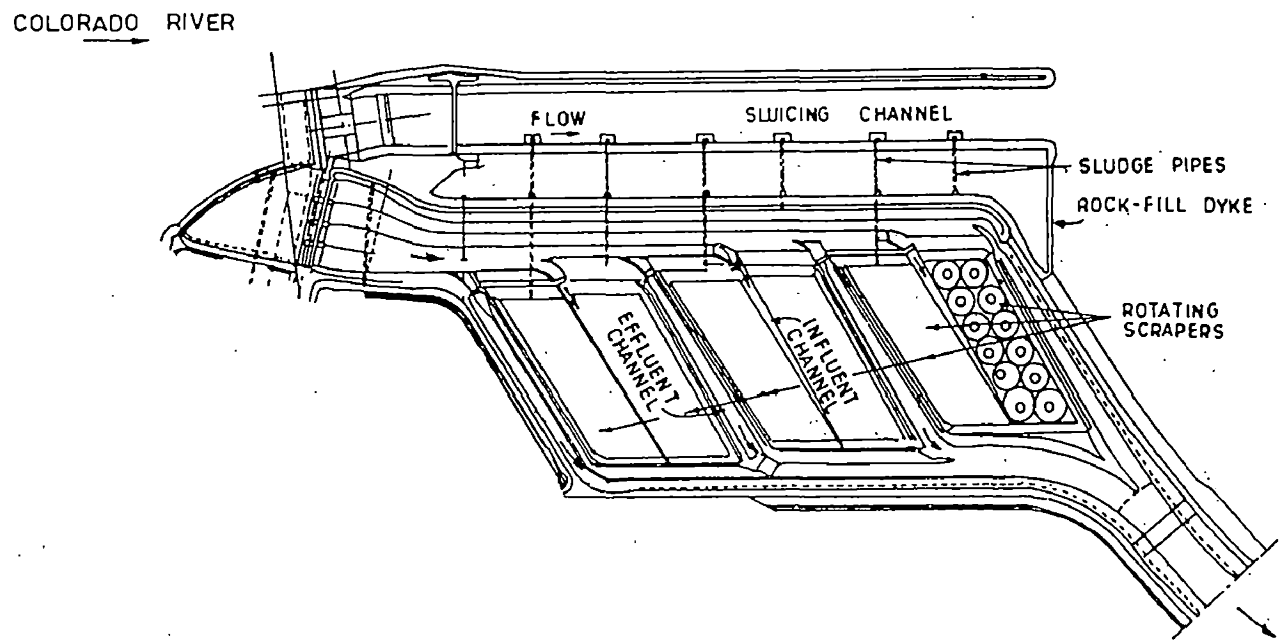


Fig. 3.17 Desilting Basin – All American Canal.

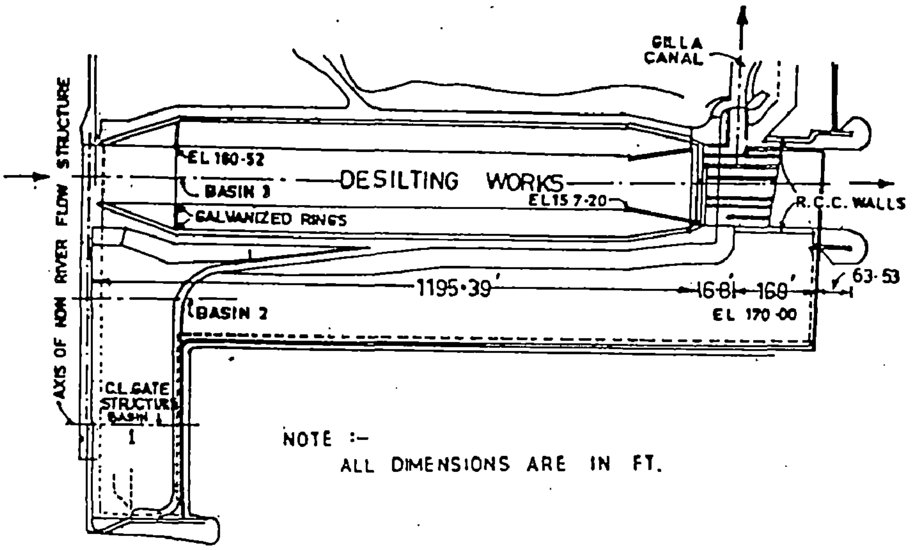


Fig. 3.18 Desilting works in Gilla Valley Canal.

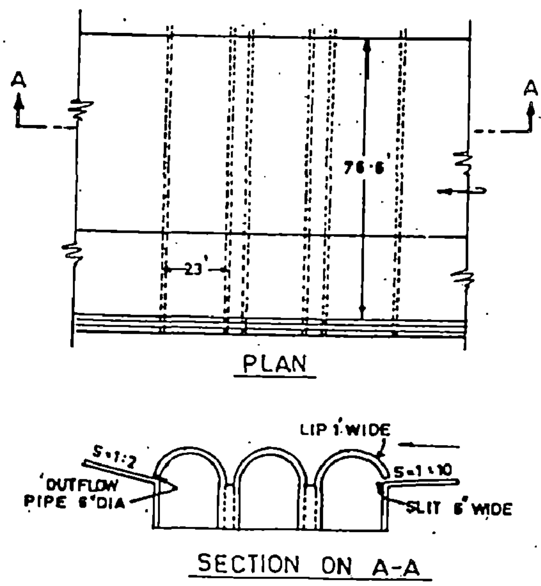


Fig. 3.19 Desilting Basin at Dabatwali Aqueduct Nangal Hydel Channel.

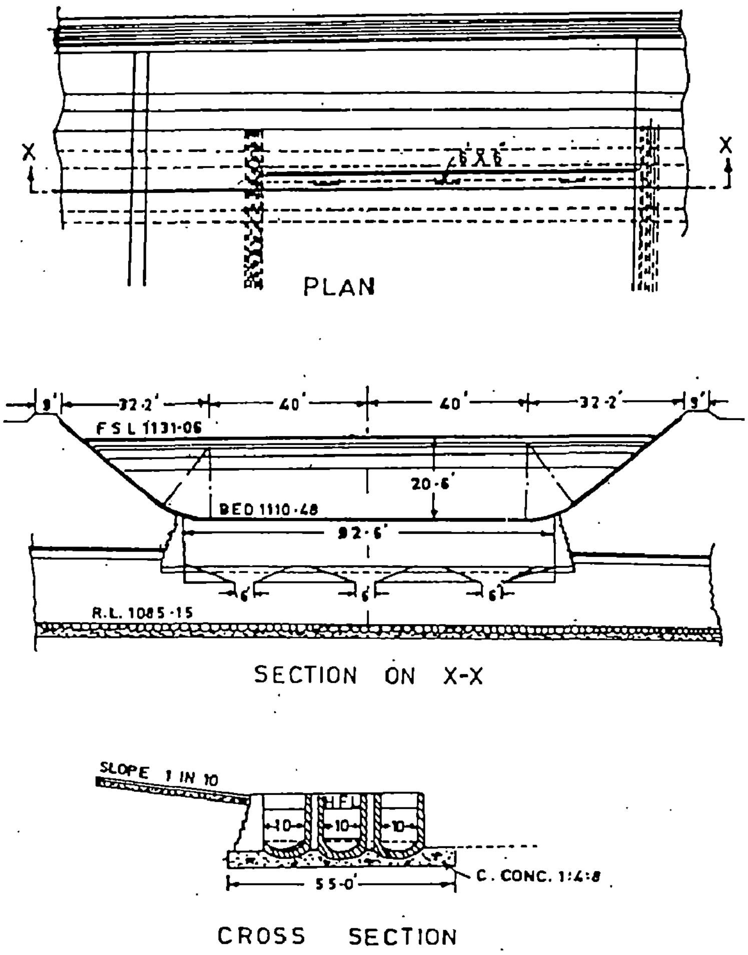


Fig. 3.20 **Bassowal Desilting Basin Nangal Hydel Channel.**

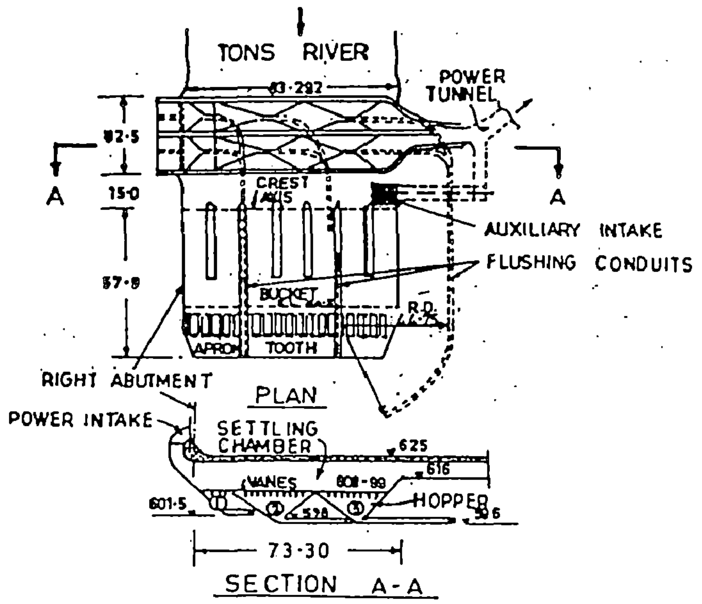


Fig.3.21 Layout of ICHARI Desilting Tank.

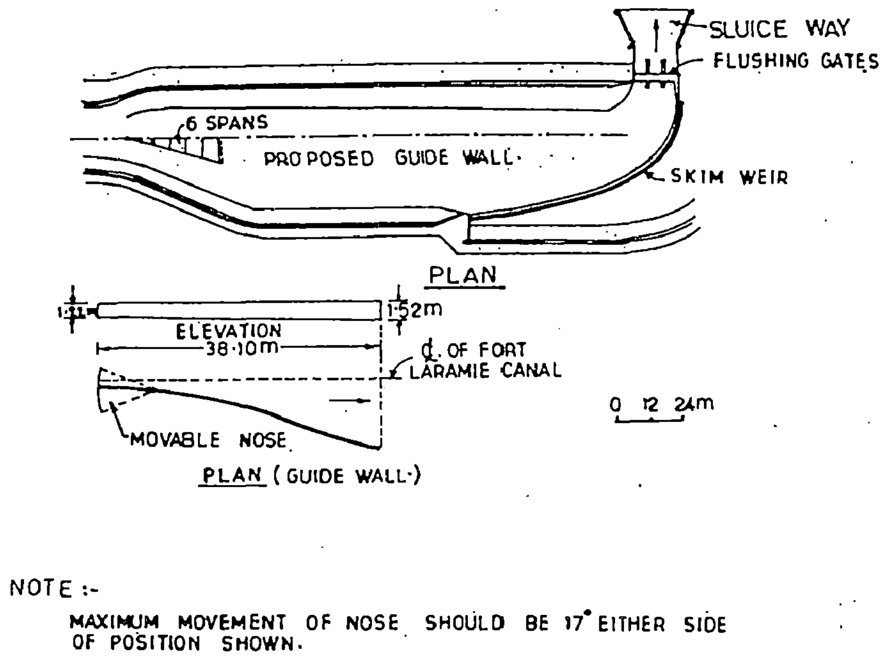


Fig. 3.22 Desilting Basin on Fort Laramie Canal U.S.A.

ROLE OF MODELS IN DESIGN OF DESILTING BASINS

4.1 INTRODUCTION

A number of approaches for determining the size of basin are given. These are based on experimental data and on certain assumptions about the the flow velocity, fall velocity, sediment concentration and its movement. The experience has been that each gives a size quite different from the other for same sediment settling efficiency. The settling efficiency in prototype is also dependent on the hydraulics of inlet and outlet structures as well as on flushing arrangements but no design criteria of general application for their design is available. Therefore, preliminary design in each case is tested on physical hydraulic models. The type of models and their scales, the method of simulation of sediment, the limitation of models etc. are briefly discussed in this chapter. Model studies of some desilting basins and their results are also described.

4.2 TYPE OF MODELS AND THEIR SCALES

Model studies are generally conducted in geometrically similar scale rigid bed models for open channel type desilting basins. In the case of closed conduit type basins, geometrical similar models, fully transparent acrylic (Perspex) material/polycarbonate sheets are used for convenience of visualization of the flow in the basin.

The scales of such models are determined on similarity of geometry and the Froude's law. These are worked out as below.
Various similitude ratios for a geometrically similar model with Froude's law are as follows;

Let length scale ratio be $L_m/L_p = L_r$ for geometrically similar model. Since Froude Number has to be same in model and prototype

$$\left(\frac{V^2}{Lg}\right)_m = \left(\frac{V^2}{Lg}\right)_p$$

Since force of gravity is nearly same in model and prototype.

$$\left(\frac{V^2}{L}\right)_m = \left(\frac{V^2}{L}\right)_p$$

This leads to

$$\frac{V_m}{V_p} = \sqrt{\frac{L_m}{L_p}} \quad i.e. \;\; V_r = \sqrt{L_r}$$

From this basic model law other model laws can be derived.

Length scale ratio	=	L_r
Area scale	=	$(L_r)^2$
Volume scale	=	$(L_r)^3$
Velocity scale V_r	=	$(L_r)^{1/2}$

Therefore, Time Scale T_r = Length Scale / Velocity Scale = $L_r / (L_r)^{1/2} = (L_r)^{1/2}$

Discharge Scale = Area Scale x Velocity Scale = $(L_r)^2 \; (L_r)^{1/2} = (L_r)^{5/2}$

The scales adopted for some model studies are given in the Table 4.1. the scales are based on the availability of space, head, discharge etc. at the testing station. The experience has been that bigger models yield better and more reliable results.

In the case of the multiple unit layout of the basin such as those adopted for two tunnel arrangement for Chukha and four tunnel arrangement for Nathpa Jhakri Project, only a single unit with adequate reach of the inlet tunnel on the upstream and the Head Race Tunnel on the downstream is reproduced.

4.3 SIMULATION OF SEDIMENT

Generally basins are designed for removal of the sediment coarser than 0.20 mm or 0.10 mm. For simulation of the sediment in the model, a low specific gravity material is required to be used. Following low specific gravity materials can be used:

i) ***Coal Dust :*** Average sp.gr 1.4 to 1.5. Difficult to get uniform size

ii) ***Saw Dust :*** It floats. Hence it can simulate suspended load. However, as it becomes wet, it sinks to form a lump (This is due to fungus). To avoid this, it can be treated with saturated lime water, washed and then treated with 1% solution of copper sulphate.

iii) ***Pumice stone :*** sp. gr. 1.4 to 1.7. Grain size 1 to 3 mm.

iv) ***Plexiglass or plastic sand :*** sp. Gr.1.8, costly.

v) ***Powdered bakelite :*** sp. gr. 1.37 Free from defects like absorption of moisture, lump formation etc. cheap since scrap bakelite articles can be used for preparing the powder.

vi) ***Lignite :*** sp. gr. 1.2 to 1.6 Defect : water repellent. Should be treated with a wetting agent.

vii) ***Lac :*** sp. gr. 1.47 and can be varied by varying proportion of berates.

viii) ***Walnut shell :*** sp. gr. 1.4 can be crushed.

ix) ***Shellac :*** sp. gr. 1.07

Many of these materials can be pulverized to suitable size so as to satisfy the requirement of the scales.

However, it would not be possible/advisable to go in for very small size of particles of low specific gravity material also from the practical considerations. Taking these aspects into consideration, the scales of the models generally vary from 1/10 to 1/30. Table 4.1 shows the scales adopted for the various models.

Apart from proper reproduction of design features and inlet and outlet conditions for achieving adequate distribution of flow in the basin, the accuracy of the results of the model studies would depend upon the realistic simulation of the distribution of the suspended sediment on a vertical which is given by following equation developed by Rouse (1936).

$$\frac{C_y}{C_a} = \left[\frac{d-y}{y} \; \frac{a}{d-a}\right]^z \qquad (4.1)$$

where,

C_y	=	Concentration at depth "y" above bed level
C_a	=	Concentration at 0.05d above bed level
d	=	Depth of flow
y	=	Depth at which concentration C_y is to be calculated
a	=	0.05d

and $Z = \dfrac{w}{K\sqrt{g\,d\,s}}$

wherein;

w	=	Fall velocity of particles
K	=	Von Karman constant ref. Fig 4.1
g	=	Acceleration due to gravity
s	=	Water surface slope

Thus, for the proper simulation of the distribution of sediment on a vertical, `Z' in model should be equal to `Z' in prototype for corresponding diameter of the sediment.

$$Z_m = \frac{w_m}{K_m \sqrt{g_m\, d_m\, s_m}} = Z_p = \frac{w_p}{K_p \sqrt{g_p\, d_p\, s_p}}$$

$$\therefore w_p = w_m \frac{K_p}{K_m} \sqrt{\frac{g_p\, d_p\, s_p}{g_m\, d_m\, s_m}}$$

$$\frac{K_p}{K_m} \text{ and } \frac{g_p}{g_m} \text{ are equal to } 1$$

Moreover in geometrically similar scale model

$$\frac{s_p}{s_m} = 1$$

Hence for geometrically similar scale models

$$w_p = w_m \sqrt{\frac{d_p}{d_m}}$$

Thus, a relationship between the diameter of low specific gravity material used in the model and that of the sediment in prototype can be worked out using above equation.

Value of K is 0.4 for clear water and reduces with sediment concentration. The relationship between concentration of suspended sediment and K is given by Vanoni (90) is shown in Fig. 4.1.

A relationship between the diameters of quartz particle in the prototype to the diameter of the low specific gravity material used in the model is established by using equations 4.1. & 4.2. The specific gravity of bakelite, walnut shell or the coal powder is about 1.4. Curves giving the fall velocities of low specific gravity materials are given in Fig. 4.2. In the earlier studies, a procedure of crushing the low specific gravity material and sieving the same through different sieves and remixing it in the required proportion for obtaining the desired size distribution curve or proportion of coarse, medium and fine fractions of the sediment in the prototype was adopted. This procedure was tedious and clumsy. To avoid these difficulties, the following alternative procedure was followed in the subsequent studies.

The available low specific gravity powder is analyzed for the determination of the size distribution curve. After injecting the material in the model, the settling efficiency of the basin is determined by measurement of the volumes trapped at the outlet of the desilting basin and flushing system, taking into due consideration of the volume of the sediment trapped inside the desilting basin or by simultaneous measurements of the concentration in the inlet and both the outlets, the settling efficiency in the model is estimated. The expected settling efficiency using Camp's and others criteria is also estimated, for the gradation curve using the mean diameter of the different fractions of the gradation curve and by integrating the results. Thus, once the satisfactory correlation between the model results and the estimated settling efficiency for the model parameters is established, the actual efficiency curve for the sediment in the prototype could be estimated. This results not only convenience for the model studies but also enables to estimate the actual efficiency for the different gradation curves at site.

After the development of numerical methods for simulation of two dimensional flow pattern, better mathematical models for the desilting basin, such as those proposed by Imam (40), Schamber (75), Larock (54), Abdel-Gawad (58), Devantier (29), Bhargava (63), Stamou (79) etc are coming up. These models are divided into the following two parts.

- Flow field model
- Suspended sediment transport model

In the flow field model, sophisticated numerical methods have been proposed, which manage to predict the flow field in the settling tanks with atleast partial success. These models employ various forms of mean flow equations. Finite difference or finite element techniques are used for the numerical solution of the flow. Some of the models employ simple constant eddy diffusivity assumptions while others uses more refined turbulent models.

In a suspended sediment transport model, the suspended sediment transport equations are numerically solved for the determinations of suspended sediment and concentration field. The suspended sediment particles are assumed to be discrete and their size distribution is described by settling velocity curve. The complete spectrum of particle size is divided in different groups of constant particle size associated with the corresponding settling velocity and representing a mass function of total sediment which is determined by the settling velocity curve. The boundary conditions used for solving the suspended sediment equations are the following.

- There is no flux of suspended sediment to the side wall.
- All the particles reaching the bottom are not thrown again in suspension.
- There is no net transfer of suspended sediment across the surface.

In the settling basin flow is three dimensional especially in the inlet divergence and outlet convergence. At the inlet, there are structural arrangements for proper distribution of flow. Similarly, at the outlet the arrangements are made for smooth skimming off the flow layers containing less sediment in the suspension. Geometrical approximations are required to be made in two dimensional mathematical modelling which is not considered adequately in the mathematical modelling. All these add to the three dimensionality of the flow.

4.4. ASSUMPTIONS IN THE DERIVATION OF SEDIMENT DISTRIBUTION

The equation is not able to give results at extreme points i.e. at the water surface level and near bed because of the following assumptions in its derivation (43):

- It has been assumed that flow is steady and uniform and two dimensional. However, even in straight channels this condition is not often satisfied because of the presence of secondary currents.
- It is assumed that the sediment has a known constant fall velocity ω. However, the fall velocity changes with the sediment concentration and the intensity of turbulence.
- It has been assumed that the sediment transfer coefficient ε_s is equal to the momentum transfer ε_m. Vanoni found that for fine material ε_s is greater than ε_m, while for coarser material ε_s tends to be smaller than ε_m. Ismail confirmed Vanoni's findings. On the other hand, Carstens after studying the simple harmonic motion of quartz spheres came to the conclusion that ε_s is less than ε_m.
- It has been assumed that logarithmic velocity distribution law holds good and that the Karman Universal constant (K) assumes a value of 0.40. But in alluvial channels, Karman constant can assume any value between 0.20 and 0.60 depending upon the flow conditions and sediment characteristics. This variation in K can change the value of the exponent in the sediment distribution equation.
- It is assumed in the derivation that the intensity and scale of turbulence for the upward and downward flows are the same and that for a given value of y and the mixing length 'l' have unique values.
- While evaluating the value of ε_m, it is assumed that ρ_f is constant and is thus independent of y. However when sediment is in suspension, the mass density of the fluid decreases with increase in y because of the concentration gradient. The foregoing assumption is justified for fine material, since the concentration gradient is small in this case. However, the assumption can lead to some error for coarse material and at small values of y. Nevertheless, such an assumption is necessary to simplify the theoretical analysis.

4.5 LIMITATIONS OF SEDIMENT DISTRIBUTION

Sediment distribution equation given by Rouse, though qualitatively correct, has certain limitations (43). One of the most important limitations is that the theoretical exponent does not agree with the actual exponent. Secondly, it gives only the relative concentration distribution and the concentration at any level can be found only if Ca is known. Further, equation is satisfactory, even qualitatively, only in the main flow and not close to the bed. According to this equation concentration at the water surface is zero and concentration at the bed is infinity. This is not true in practice; physical reasoning will show that the concentration at the bed should be finite. However, equation is valuable in as much as it provides a tool for studying the distribution of suspended load. The plotting of the relative concentration curves shows that the sediment concentration is nearly constant in the vertical for Z less than 0.031. On the other hand suspension is insignificant for Z greater than 5.0. This means that suspended load is negligible if U^*/ω is less than 0.50.

4.6 LIMITATIONS FOR MODEL STUDIES

It does not necessarily follow that model studies provide ready answers to all questions. For, one cannot devise a suitable model test or interpret the model test results, unless one understands the basic theory of the phenomenon under study. Time and money are wasted by a test of a model that does not adequately represent the prototype. Sometimes it is impracticable to build a model that will furnish all the desired information. And lastly, it is wasteful to resort to model study if the results can be predicted by theory. Inspite of these limitations, model tests have proved to be invaluable in many cases and the use of models in hydraulic engineering is steadily increasing. However, following are the limitations for desilting basin models.

- It is essential to develop effective flushing system studies to realise anticipated settling efficiency.
- Necessary to develop different type of flushing system to suit the site conditions.
- Quantitative estimation of the performance of flushing system could not be attempted since low specific gravity material is used.
- For low specific gravity material weight - volume relationship of the sediment in the model differed from the prototype.
- In the case of hydraulic model experimentation, it is the hydraulic similitude and not geometric similitude, which is the guiding and controlling factor in the design of models.

- Efficiency of desilting basin in prototype is expected to be more than that estimated using the model results, as the ratio of size of opening to the size of particle to be removed is very high in prototype than that in the model.
- In Nature, the forces that play, cannot be gauged accurately, neither the duration of forces for which the resultant action is responsible is known. It is therefore to be found out from actual experiments, the optimum hour that a particular model should be run so as to be able to faithfully represent the prototype conditions. It is only possible for a skilled observer with long practical experience in this line to diagnose from the behaviour of a model, how far the results can be relied on and to what extent they can be applied in practice.

It is difficult to simulate all the conditions and properties of nature in the hydraulic models and consequently difficulties do arise in the translation of results obtained from studies in the models. The hydraulic models have, therefore, been considered as means towards an end in predicting certain factors atleast qualitatively to be met within the prototype.

4.7 FIELD DATA REQUIRED FOR CONDUCTING MODEL STUDIES FOR DESILTING BASINS

Following field data are required for conducting Hydraulic Model studies for Desilting Basins :

(i) Preliminary drawing of the desilting basins viz. longitudinal section, plan, cross-sections at important locations.

(ii) Design calculations for desilting basin and the flushing arrangement

(iii) Concentration of the suspended sediment giving breakup of coarse, medium and fine sediment.

(iv) Gradation curves of bed material and suspended sediments.

(v) Maximum sediment concentration for which studies are to be made.

(vi) Details of inlet and outlet transitions of the basins.

(vii) Plan, longitudinal section and cross-section of flushing arrangement.

(viii) Discharge of each unit of desilting basin at inlet and outlet.

(ix) Size of openings in trash rack.

Table-4.1
Design parameters of desilting basins in protoype and model scales

Project	Size (m)			Discharge in cumec			Size of particle to be settled (mm)	Mean flow through velocity m/s	% effi-ciency	Model Scale (G.S.)
	L	B	D	Inlet	Outlet	Flus-hing				
Trishuli	170	33.5	7.4	31.2	*	*	0.2	0.15	90	1:20
Shanan	30.5	46.2	2.5	33.3	27.75	5.55	0.2	0.3	80	1:16
Ramam	75	22	4	9.35	*	*	0.1	0.1	90	1:10
Kosi	138	84	3.92	240	201	39	0.23	0.55	80	1:25
Baira-Siul	105	6.6	5.2	14.2	11.34	2.86	0.2	0.35	90	1:20
Chukha	348	8.5	11.7	59.4	47.4	12.0	0.2	0.63	90	1:25
Dul Hasti	300	15	14.5	122.5	106.5	16	0.3	0.64	90	1:30
Kahalgaon	50	13.5	2.75	2.83	2.27	0.56	0.1	0.13	90	1:10
Nathpa Jhakri	525	15	25.5	121.5	101.25	20.25	0.2	0.33	90	1:30
Dhauli Ganga	300	13.0	16.2	64.0	53.5	10.5	0.2	--	90	1:30
Tala	250	13.9	18.5	57.0	47.5	9.5	0.2	0.263	90	1:30
Chamera (II)	375	16	21.8	85.2	71.0	14.20	0.2	0.262	90	1:30
Teesta (V)	300	20.0	22.8	116.95	97.46	19.49	0.2	0.317	90	1:30
Parbati	200	15.0	16.0	38.67	29.01	9.66	0.2	0.251	90	1:25

* Intermittent flushing using all the inlet discharge.

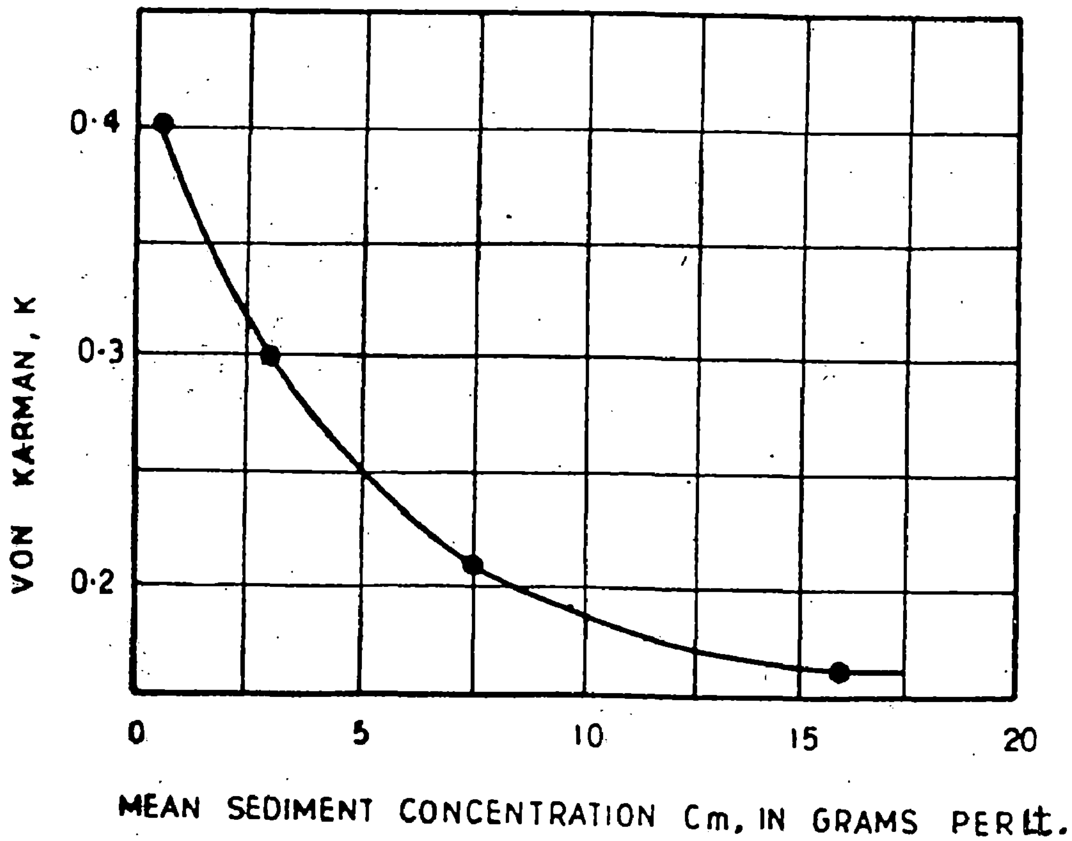
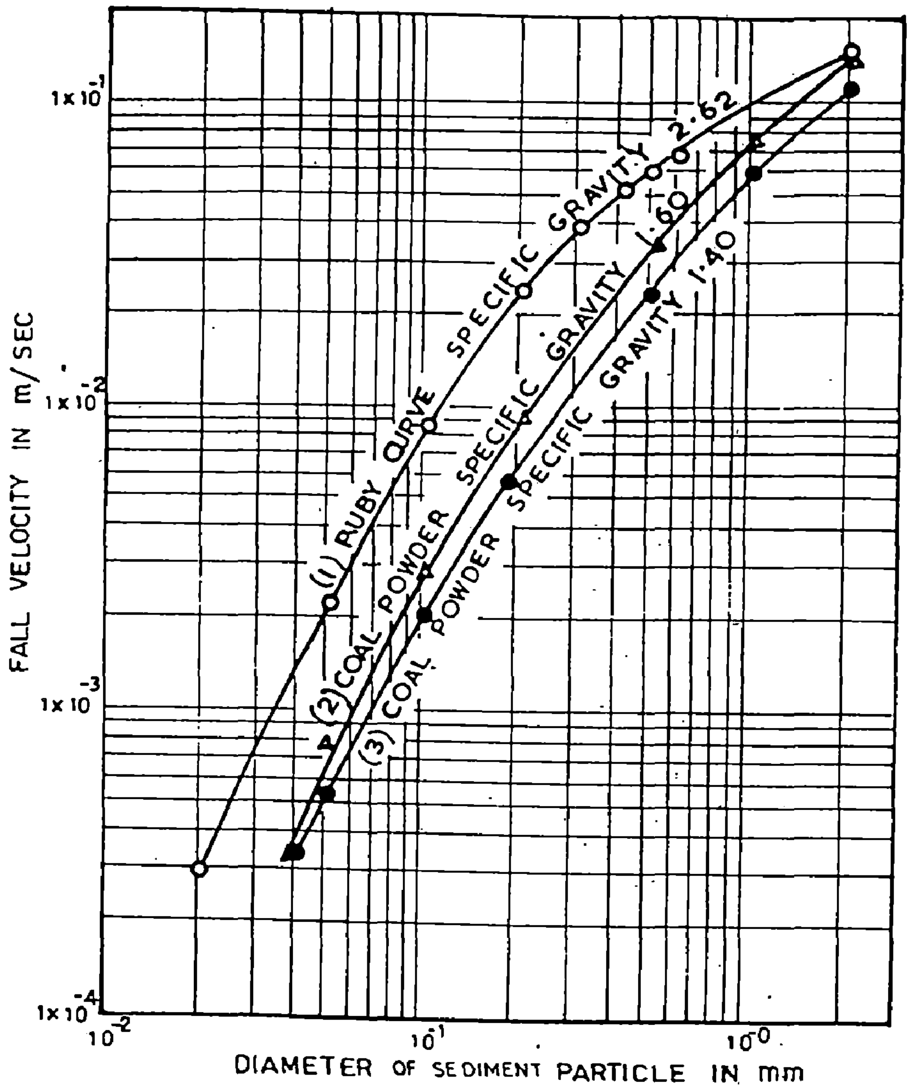


Fig. 4.1 : **Effect of Concentration of Suspended Load on Karman's Constant.**



NOTE:
CURVE NO. 2 AND 3 PREPARED USING FIG. 2 GIVEN IN THE PAPER BY THOMAS R. CAMP SEDIMENTATION AND THE DESIGN OF SETTLING TANK PP 445 TO 486 PROCEEDING A. S. C. E. VOLUME NO. 71 NO. 4 PART 1, APRIL 1945.

Fig. 4.2 Fall Velocities of Particles.

CRITICAL REVIEW OF PAST MODEL STUDIES

5.0 GENERAL

In this chapter model studies for design of desilting basin of some hydro power projects are reviewed with a need to examine the usefulness of model studies in finalizing the design and layout of desilting basins. The model effciency for desilting basin has also been compared with the theoretical efficiency.

5.1 MODEL STUDIES FOR DESILTING BASIN FOR DUL-HASTI HYDRO-ELECTRIC PROJECT [13]

This is the largest project in the State of Jammu & Kashmir. The project is located on the river Chenab, near the city of Kishtwar in the lower ranges of Himalyas. The development of 236 m of head on river loop around Kishtwar is obtained by 65 m high dam, a 10.6 km long HRT with intake, two desilting basins and an underground power house complex with installed capacity of 390 MW.

The in flow discharge for each desilting chamber is 122.5 cumec and 106.5 cumec is outflow for power generation. Thus, 16 cumecs is the flushing discharge.

The typical total, normal and maximum concentration of the coarse, medium and fine sediments considered for the design and model studies of the desilting basin system are given in Table 5.1.

The design requirement was to flush out more than 90% of the sediment having a diameter greater than 0.3mm. Initial dimensions for the basin were set as 300 m long x 12.5 m wide x 14.5 m high. The width was later increased to 15 m and the efficiency of settlement for different sizes of particles was worked out theoretically using Camp's approach. It worked out to be 98% and 87% for 0.30 mm and 0.25 mm size sediment particles respectively.

In addition, the following modifications were made to the initial design to improve sediment removal and flushing :

1. Steepening the slopes of the hoppers at the bottom of the basin.
2. Increasing the flushing discharge to 15 cumec to achieve a minimum velocity of 3 m/s in the flushing system.
3. Separating the flow of the flushing gutter from the one in the desilting basin by a slab provided with openings to flush out the sediment with the least disturbance to the sediment settlement process.

The objective of the model studies was to optimize the length of the basin in order to achieve the design criteria, to review the preliminary design, to conduct studies for continuous as well as discontinuous flushing and consequently to suggest operation recommendations, especially during low-flow periods.

To minimize the scale effects, the prototype sediment material was used in the model. This results in the need for the velocity scale factor to be unity. Because the very fine material will hardly be trapped, only the sieve curve for particles larger than 0.075 mm with D_{50} = 0.3 mm has been used on the model for a quantitative evaluation of the performance. Hence, it was checked that the use of coarser material did not significantly influence the bed form on the model.

The importance of achieving the near-uniform distribution of flow conditions over the entire cross section and length of the desilting basin in order to optimize the efficiency in the sediment settlement process was considered essential. The 20m transition length with a divergence of 1:4.2 which would lead to flow separation and the introduction of disturbed conditions over a much longer stretch into the desilting chamber, was modified to a 47.5 m long transition with a divergence of 1:10 which was considered better for the optimization of desilting basin dimensions.

It was shown that for a discharge of 123 cumec, a 240 m long desilting basin equipped with an upstream 48 m long diffusor and having a cross-sectional area of 170 sq.m was able to trap more than 90% of the particles larger than 0.3 mm in diameter, which are in suspension in the water if a continuous flushing system is functioning with a discharge not less than 13 cumec, and preferably 16 cumec, and provided that the sediment concentration is higher than 600 ppm.

It was also shown that the trapping efficiency increases with the sediment concentration, even with a very high value of 5000 ppm, and that the presence of fine particles (finer than 0.25mm) in the sediment load does not affect the results adversely.

In case of intermittent flushing, the trapping efficiency is progressively reduced during the filling process of the basin. Thus, with sediment concentration of 600 ppm, this efficiency reduced from 91.5%, just after closing the flushing tunnel down, to 75% at the end of 17.5 h (prototype) of operation without flushing. These results helped to assess the frequency of operation of the silt flushing system not only during the monsoon period but also during the low flow periods. This operation rule, which was based initially on the model studies was later modified on the basis of actual experience during the operation of the project and updated every year as additional data was made available.

TABLE – 5.1

Concentration and particle size of sediment load

Particles Size	CONCENTRATION OF SEDIMENT LOAD			
	Normal		Maximum	
	g/L	%	g/L	%
Coarse ($\phi > 0.2$ mm)	0.1239	18.2	0.2403	17.3
Medium ($0.2 > \phi > 0.075$ mm)	0.2363	34.6	0.4075	29.3
Fine ($\phi < 0.075$ mm)	0.3222	47.2	0.7428	53.4
Total	**0.6874**	**100**	**1.3906**	**100**

5.2 MODEL STUDIES FOR DESILTING BASIN FOR TALA HYDRO-ELECTRIC PROJECT, BHUTAN

(Ref. CW& PRS, Pune Specific Note for Tala Hydro-Electric Project, Bhutan for Disilting Basin, Sept. 2000)

Tala H.E. Project is situated in western Bhutan near Honka 3.0 km downstream of existing Chukha Tail Race. A 91 m high dam would be constructed across river Wangchu for diversion of a discharge of 171 cumec for generation of 1020 MW of power at 820 m head through a 2.2 km long head race tunnel. The Power House will be located near Tala.

The concentration of suspended sediment during floods, is expected to go upto 2000 ppm. It contains about 17.40% coarse, 19.00% of medium and 63.60% of fine sediment.

For removal of 90% sediment coarser than 0.2 mm there units of desilting basin, of size 250 m (L) x 13.92 m (w) x 18.5 m (H) have been provided based on Camp's criteria.

Hydraulic model studies were conducted for :

i) Estimation of settling efficiency of the desilting basin.

ii) Estimation of efficacy of flushing system of the basin.

iii) Optimising the flushing discharge

iv) Optimising the length of the desilting basin.

Each unit of desilting basin has been designed for inlet discharge of 57 cumec out of which 47.5 cumec is HRT discharge and 9.5 cumec is for flushing. On the basis of experience and earlier studies for similar projects, following modifications were done to improve the performance of the basin.

- Flushing trench provided with hopper bottom is modified to rectangular one.
- Flushing tunnel which is D-shaped is modified to a rectangular shape to facilitate provision of flat slab as a roof of flushing tunnel.
- The bed slope of the inlet transition is modified to IV:2H from 1V to 1.1891H.
- The size of flushing tunnel in the beginning is kept as 0.5 m (W) x 1.2 m (H) instead of 1.09 m (H).
- The size and spacing of the openings connecting settling trench to flushing tunnel is also modified.

The studies were conducted on a geometrically similar modal at 1:30 scale wherein one complete unit of desilting basin covering inlet tunnel, inlet transition, desilting basin, outlet transition, HRT was constructed partly in fibre glass and partly in transparent perspex sheets. Three number flushing tunnels having size of 0.5 m (W) x 1.2 m (H) at upstream end and 0.75 m (W) x 1.2 m (H) at the down stream end were also reproduced in the model.

For simulation of suspended sediments, crushed and sieved walnut shell powder having specific gravity 1.32 was used.

For efficiency of the desilting basin, 400 liters of sediment equivalent to 2000 ppm by volume was injected and continued for sufficient period for each run so that the quantities of sediment injected and collected are measured separately in the traps. Several model runs were done to ascertain the overall settling efficiency of the basin.

Static pressure observations were taken at four points in the desilting basin as well as in the flushing tunnel corresponding to three different water levels in the reservoir. The observations of static pressure are given in Table – 5.2 and the pressure gradients are shown plotted in Fig. 5.1.

The settling efficiency was estimated analytically using Camp's criteria as 85.96%.

The model runs indicated that the overall settling efficiency of the basin for the material used in the model was of the order of 83.25%.

The observation of static pressure indicated that the pressure in the flushing tunnel was always less than that in the desilting basin at any section. This pressure difference created the flow from the desilting basin to the flushing tunnel through the opening provided in the bottom slab. However, the velocities through the openings were not proportional to the difference in the head because the total discharge was ultimately controlled by the gate provided at the downstream in the flushing tunnel.

The slope and length of the inlet transition were adequate for the uniform distribution of the flow in the inlet transition as observed in the model. Since the higher sediment concentration above 2000 ppm was expected only for a few days in a year, the efficiency of 90% settlement of sediment coarser than 0.20 mm.at design discharge was considered acceptable and accordingly 250m length of the basin was adopted. Flushing tunnel below desilting basins were adequate for flushing of the settled sediment.

TABLE – 5.2

Observations for Static Pressure in Desilting Basin Model in Tala H.E. Project

Point No.	Distance from end of transition (m)	Reservoir Water Level (m)		
		EL 1355.81	EL 1358.18	EL 1359.00
1	36	Basin 1355.61	1358.00	1358.96
		FT 1349.33	1349.64	1350.29
2	36	Basin 1355.34	1357.70	1358.93
		FT 1345.52	1346.87	1347.50
3	168	Basin 1355.27	1357.70	1358.93
		FT 1343.06	1344.32	1344.95
4	217	Basin 1355.12	1357.60	1358.83
		FT 1340.90	1342.32	1343.00

Inlet discharge	-	57.00 cumec
HRT Discharge	-	47.5 cumec
Flushing Discharge	-	9.5 cumec
FT	-	Flushing Tunnel

Note : The pressure plots are shown in Fig. 5.1.

5.3 MODEL STUDIES FOR DESILTING BASIN FOR CHUKHA HYDRO ELECTRIC PROJECT (BHUTAN) [12]

The water conductor system for the Chukha Hydel Project, which is situated in Bhutan, includes a diversion dam across the Wangchu river, desilting chambers with a common flushing tunnel, 6.4 km long Head Race Tunnel, a surge shaft, 543 m long penstocks, underground power house of capacity 336 MW and 953 m long tail race tunnel outfalling into the Wangchu river at Chukha.

In the original design, the desilting chamber complex comprised of two parallel tunnels each 300 m long, 8.5 m wide and 11.75 m deep and were spaced at a distance of 40 m c/c.. For flushing of the deposition from the bottom of the tunnel, 1 m diameter horizontal pipes, spaced at 50 m c/c were provided at the bed. These pipes were then connected to a central flushing tunnel which ultimately joined to river on the downstream.

These chambers were designed for a total discharge of 104.28 cumecs, which included flushing discharge of 9.48 cumecs.

The objectives of the model studies were to determine the adequacy of the desilting chamber for achieving the desired settling efficiency of 90% for the suspended sediment coarser than 0.2 mm and to assess the efficacy of the flushing system.

Before construction of the model, based on previous similar studies, formation of dunes along the longitudinal trench were considered. The ratio of the height of the dune to its base-width along the flow was more or less constant nearly about 0.33. Under these circumstances, the height of the dune would have been about 17 m which on the other hand would have almost blocked the flow in the tunnels. Spacing of the flushing outlets is kept at 6 m instead of 50 m interval. This would have restricted the height of the dune to 2 m which is the depth of the flushing trench.

Similarly the size of the flushing tunnel was kept at 0.5 m x 2 m at the upstream end, gradually increasing it to the size 1.5 m x 2 m at its downstream end so as to ensure the flushing velocity of 3 m / sec and above, through the flushing tunnel. The requirement of flushing discharge was also increased from 9.48 cumec to 24 cumec for the twin tunnels.

In view of the above, the increase of the total discharge would result in modification in the basin legnth from 300 m to 350 m and removal ratio comes out to be 89%.

For easy removal of the air locked in the dome from the downstream side at the time of filling, the crown of dome was given an upward slope of 1 in 600. However, the bed of the flushing trench was given a nominal downward slope of 1 in 200 to facilitate dewatering for the maintenance of the system.

Studies were connected in a 1:25 G.S. scale model after incorporating above modificaitons. Since the twin tunnels were identical, only one tunnel was reproduced in the model.

Studies were conducted for estimation of the settling efficiency. For this purpose, available low specific gravity walnut shell powder was used for simulation of suspended sediment. On the basis of concentration, average settling efficiency comes out to be 94.26%. On volumetric basis, average settling efficiency comes out to be 92.83%. Settling efficiency was calculated theoretically also using the gradation curves on the basis of Camp's criteria. The average settling efficiency comes out to be 93.7%.

The settling efficiencies estimated in the model by two different methods i.e. by volumetric and concentration basis were comparable and were in close agreement with the value estimated using Camp's criteria. 90% settling efficiency was achieved in the model for 0.12 mm size diameter walnut shell powder. When fall velocity of this size particles was correlated with fall velocity of sand particle of specific gravity of 2.62, the diameter of snad particle comes out to be 0.20 mm. This would mean that in the prototype, 90% settlement of sediment coarser than 0.20 mm diameter could be expected.

In view of the above, the proposed size of the desilting chamber, section as well as the length is adequate.

5.4 MODEL STUDIES FOR DESILTING BASIN FOR NATHPA JHAKRI H.E. PROJECT [15,16]

Nathpa Jhakri Hydro-electric Project is situated in Himachal Pradesh at 150 km North East of Shimla. A 60.50 m high dam on Sutlej river at Nathpa is in progress for diversion of 485 cumec of discharge for generation of 1500 MW of electricity at 488 m gross head through a 27.70 km long head race tunnel. The Power House is at Jhakri.

The concentration of suspended sediment in Sutlej river during flood is high and goes beyond 5000 ppm. It contains about 17.48 % of coarse, 24.99 % medium and 57.43 % fine sediment.

For removal of 90 % of sediment coarser than 0.2 mm, a desilting basin comprising of 4 tunnels each of 525 m long, 27.50 m high and 15.00 m wide, is provided. Studies were conducted in 1/30 geometrically similar scale model. For simulation of suspended sediment, crushed and sieved walnut shell powder having specific gravity of 1.40 was used.

Each tunnel of desilting basin has been designed for inlet discharge of 121.50 cumec which includes 20.25 cumec for flushing. It was seen that almost 98.5 % of the injected sediment was trapped. Only fine particles which will not be settled in the desilting basin would escape through the HRT.

Heavy deposition was found to occur on the slope as well as in the first 30 m length of the hopper bottom of the desilting basin. In this length the openings from desilting basin to the flushing tunnel were buried under the deposition. The length of inlet transition was 25 m, which resulted in a bed slope of 1:1.07. So it was proposed to modify the inlet transition by increasing its length by 25 m and lowering the inlet 5.0 m which would give bed slope of 1 vertical to 2.732 horizontal.

Studies were conducted with modified inlet transition. The distribution of the flow was satisfactory and the dunes did not protrude above the top of the trench and did not interfere with the flow in settling zone.

The average settling efficiency of the basin in the model using walnut shell powder comes out to be 92.5%. The efficiencies for three gradation curves of the walnut shell powder were also estimated using Camp's criteria which comes out to be 94%. The results are in the close agreement with the actually measured efficiency.

With the 20% discharge for the flushing the velocity in the flushing tunnel varies from 3.0 m/s on the upstream to 3.75 m/s at the end. Since ample head is available, the flushing discharge is required to be restricted to 20% of the total discharge by operating the gates at the end. In the model it has been observed that after opening the gate at the end of the silt flushing tunnel (SFT) fully, about 35 cumec of discharge against 20.25 cumec can be passed. Under such circumstances the velocity in the SFT will increase to 5.2 m/s at inlet to 6.48 m/s at outlet. Such operation can be adopted during high floods. However, the lining of the flushing tunnel will have to be designed for such high velocities. It is evident that whatever material is being transported in the inlet tunnel should also be transported in the SFT. Taking all these points into consideration the flushing system is expected to function satisfactorily in the prototype also.

With the modified inlet transition, the size of the desilting basin was found to be adequate for 90% settlement of sediment coarser than 0.2 mm and performance of the flushing system is good. Reduction in the depth of the basin will also not affect the settling efficiency theoretically. However, increase in the velocity will result in re-suspension of the settled sediment and hence reduction in the depth is not advisable.

5.5 MODEL STUDIES FOR DESILTING BASIN FOR BAIRA-SIUL HYDRO ELECTRIC PROJECT [74]

The flows of Siul and Bhaled rivers are pooled in a reservoir constructed across Baira river in Himachal Pradesh for making up the deficit in the peaking demand in Bhakra Nangal grid. For this purpose a 51.50 m high dam is constructed across Baira river, upstream of which discharges from Bhaled and Siul river are let-in through the tunnels. However, during the monsoon the flow from the Siul river is sometimes directly utilised for power generation. In view of this, elaborate desilting arrangements were provided at the head works on Siul river.

Siul river carries very large concentration of sediment including big size boulders. In addition to divide wall with intermittent openings and sediment exclusion gallery having openings below the sill of intake, desilting basins for settlement of sand and silt for removal of 90 % of sediment coarser than 0.2 mm has been provided.

The basin comprises of two units each 105 m long and 6.2 m wide running parallel at a distance of 15 m c/c. The basin is designed for 90% removal of sediment of 0.2 mm in size at the full supply discharge of 28.32 cumec, with forward velocity of 0.45 m/sec and flow depth of 5.20 m using the sediment removal function proposed by Hunter Rouse.

Flushing system of the basin consists of 34 small tubes buried at right angle to the flushing trench with their openings flush with the vertical side of flushing trench. The size of the tubes was adjusted to obtain self cleansing velocity of 3 m/sec, with total flushing discharge of 2 .83 cumec, which is 20% of gross inflow of 16 cumec in each unit. These tubes, in turn, join to a pipe, running parallel to the flushing trench. Size of the pipe was increased towards the downstream end to maintain faster velocity of 3.0 m/sec with increased discharge. These pipes joined together and ultimately out-falled into the parent stream. The layout of basin and schematic details of flushing system are shown in Fig.5.2 and 5.3.

The studies were conducted in 1/20 geometrically similar scale model where one unit of basin with flushing arrangement was reproduced. In the model, however, the parallel pipe was eliminated for tapping the sediment laden flow from each tube separately. Since these tubes were flowing freely in model, their lengths were adjusted for obtaining the desired total flushing discharge. The extra frictional resistance of smaller tubes in model eventually helped in achieving the objective. The longer lengths required in the basin are also boons in disguise, as these helped in taking the exit ends of the tubes out of the basin for sampling the flow individually.

For reproduction of the sediment load in the model, a fine grained low specific gravity coal powder was used. The specific gravity varied from 1.40 to 1.60. The fall velocities were also determined for these samples and these were in close agreement with the values estimated using Stoke's law.

For determining the efficiency of the basin in the model, measured quantity of the coal powder was injected at the inlet. The 100% deposition was ensured in the traps provided at the tail end of the model. Studies were conducted for three different concentrations. Efficiency of the basin varied from 95.2% to 94%.

Efficiency of the basin was also determined on the basis of concentrations and rate of flow measured in the flushing tubes. The results shows that the overall efficiency of the basin was 93.25% by concentration which is in close conformity with efficiency of 95.20 to 94 % measured on the basis of volume.

Efficiencies of the basin were worked out for various lengths using different functions for the model flow parameters and settling properties of the coal powder. Results of the estimated efficiencies are shown in Fig. 5.4 and 5.5. It has seen that removal ratios worked out using different functions differ to a considerable extent and this disparity increases as the basin length reduces. The reason for this disparity is mostly due to different distribution of the suspended sediment along the vertical assumed in the various functions

In view of this, the correlation between removal ratio estimated on the basis of uniform distribution of sediment on vertical was worked out with the removal estimated on the basis of triangular distribution of sediment on vertical, for unit depth of flow.

From designer's point of considerations the utility of the above correlation was studied for reduction in the disparity between the removal ratios. In the model as well as in many prototypes designed for higher efficiencies, the distribution of sediment would be parabolic with the low turbulence and slack velocities. If this actual distribution is taken into consideration, the 10 percent disparity could also be reduced further.

It is seen that while dimensioning the basin, estimation of the distribution of the sediment on vertical at the inlet of the basin is of vital importance. This could be done by conducting actual measurement at the site. If the distribution is nearing triangular, the function proposed by Hippola would be appropriate, if it is parabolic or trapezoidal, method proposed by Lamble would be preferable. If the distribution of the sediment at the inlet is nearing rectangular shape, then any other functions such as by Camp, Hunter Rouse, Vetter and Einstein could be used. In these also, if the sediment is mostly of medium size and the basin is to be designed for the removal of medium sediment, then the function proposed by Rouse or Camp would be suitable. However, if the sediment is mostly fine or the basin is to be designed for the removal of fine fractions also, then the function proposed by Vetter or Einstein would be preferable as they have been derived for such conditions.

It is also concluded that desilting basin is capable for removal of more than 90% of sediment coarser than 0.2 mm.

5.6 CONCLUSIONS FOR REVIEW OF PAST MODEL STUDIES

Various parameters of model studies conducted for the Dul-Hasti, Tala, Chukha, Nathpa Jhakri and Baira Siul Project, the have been summarized in the Table 5.2. As these desilting basins are underground, their width has been decided on the basis of cavity that can be safely excavated in the rocks to be encountered at site. Flushing arrangements are different in each case to suit the site for efficient functioning of the flushing system. A removable flat hopper bottom slab in the basin is found convenient for maintenance of flushing tunnel below the basin. Inlet transition in each case has been modified after model studies because no definite criteria is available for the design of inlet transition. Wide variations (ranging from 0.25 to 0.65 m/sec) has been found in flow through velocities. This range is recommended by Mosonyi.

Settling efficiencies worked out by Camp's criteria are in closed agreement with settling efficiencies obtained by model studies. This indicates that Camp's criteria is the best suited for theoretical design. This was also verified by Garde et al. (43) after conducting laboratory experiments.

Table 5.3

Design Parameters for Desilting Basin used in Past Model Studies

Project	Size (m)			Discharge in cumec			Size of particle to be settled (mm)	Mean flow through velocity m/s	% efficiency. by model studies	% efficiency by Camp's criteria	Model scale (G.S.)	Material used for simulation
	L	B	D	Inlet	Outlet	Flushing						
Dul-Hasti	300	15	14.5	122.5	106.5	16	0.3	0.64	90.00	98.00	1:30	Natural sand
Tala	250	13.9	18.5	57.0	47.5	9.5	0.2	0.263	83.25	85.96	1:30	Crushed walnut shell
Chukha	348	8.5	11.7	59.4	47.4	12.0	0.2	0.63	93.70	94.26	1:25	-do-
Nathpa Jhakri	525	15	25.5	121.5	101.25	20.25	0.2	0.33	92.50	94.00	1:30	-do-
Baira-Siul	105	6.6	5.2	14.2	11.34	2.86	0.2	0.35	94.00	93.00	1:20	Coal powder

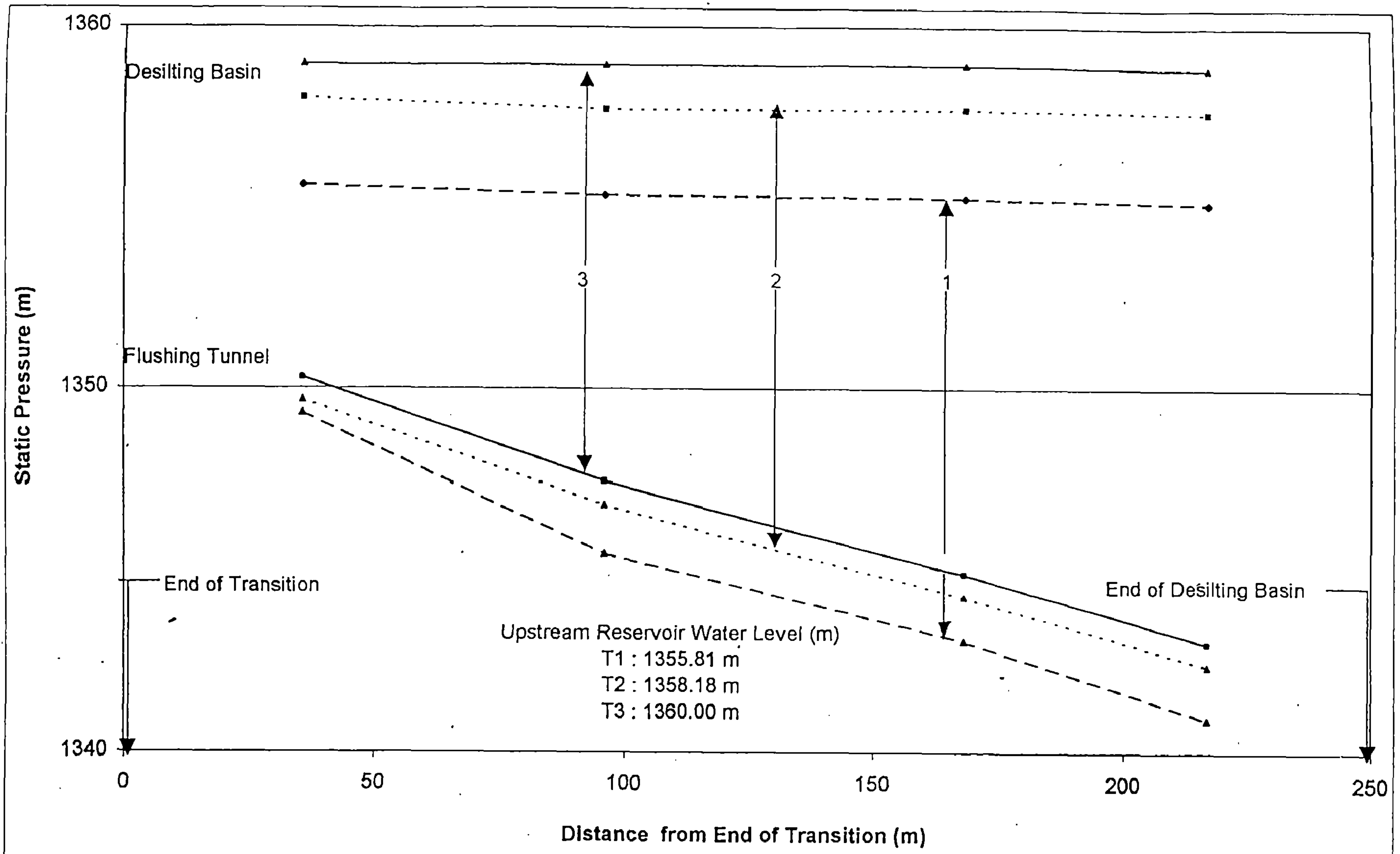


Fig. 5.1 Observation of Static Pressure in Desilting Basin ; Tala HE Project

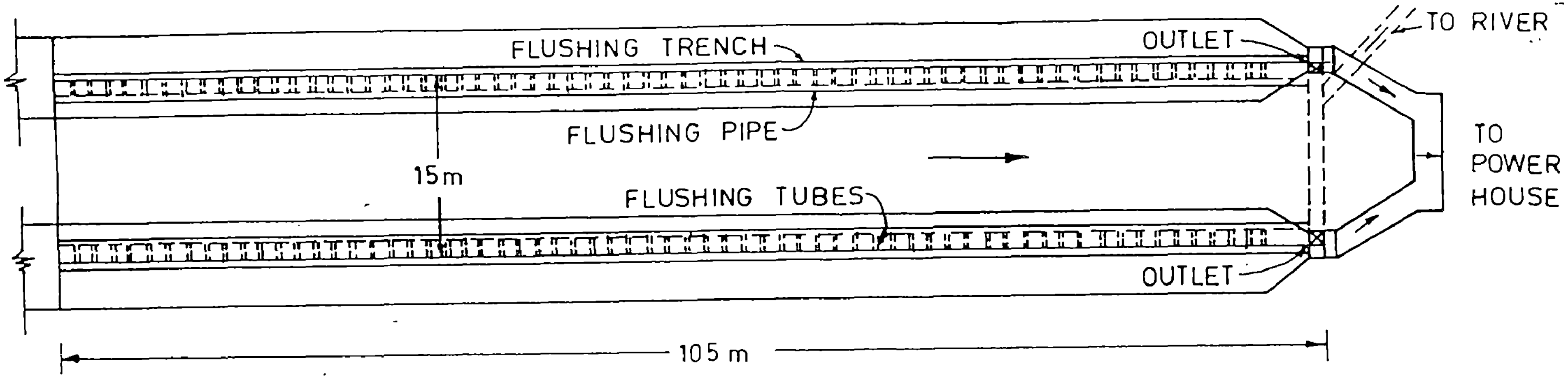


Fig. 5.2 Layout Plan of Desilting Basin ; Siul Desilting Basin

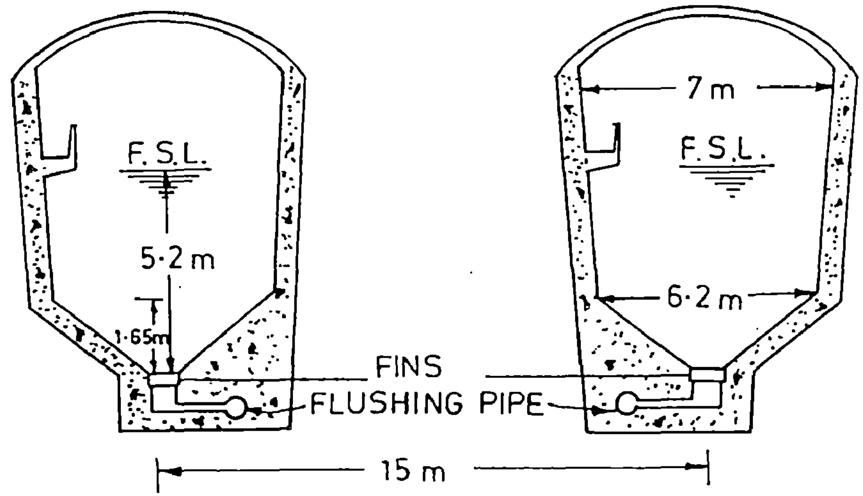


Fig. 5.3 Section of Desilting Basin ; Siul Desilting Basin

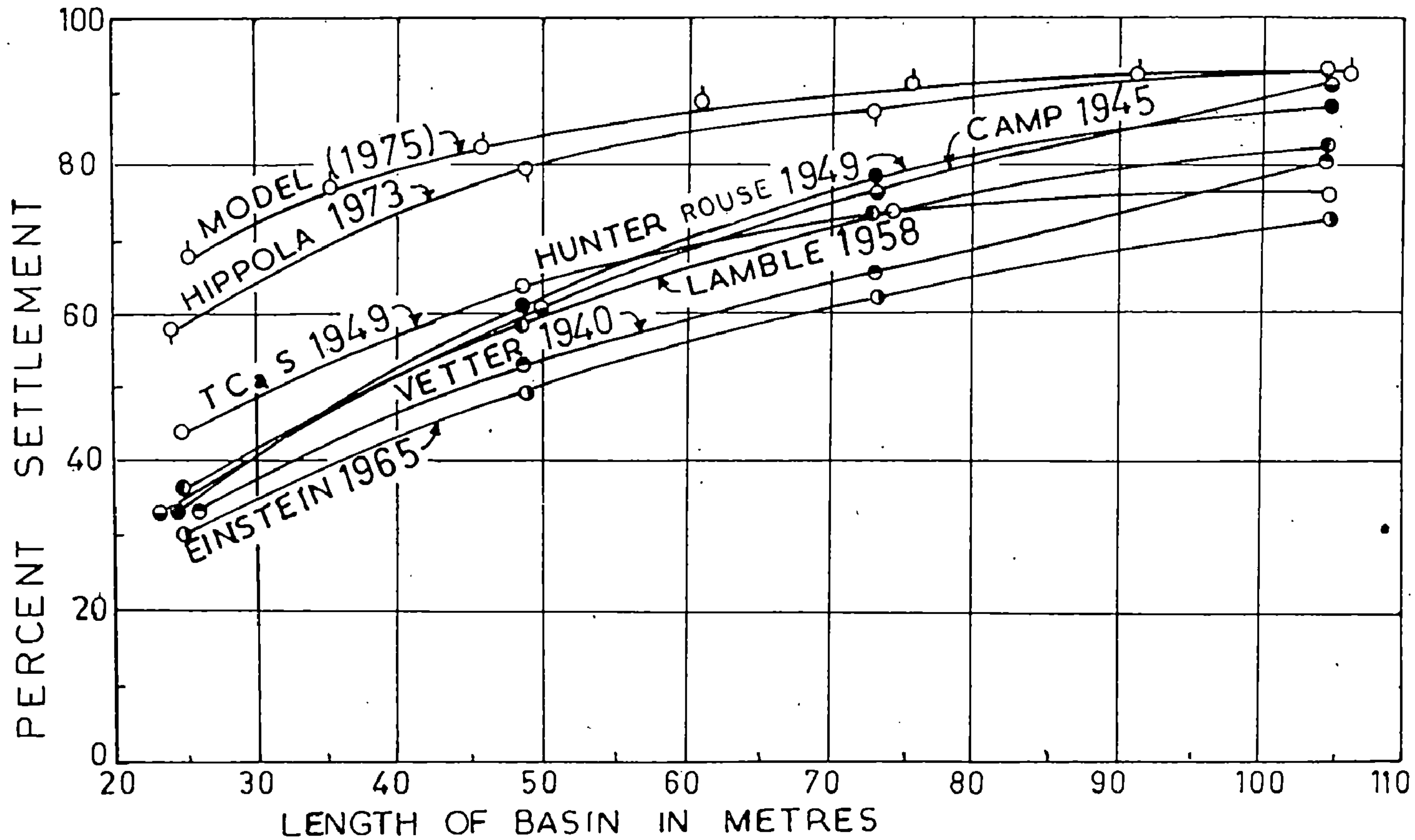


Fig. 5.4 **Settling Efficiency of Desilting Basin in a model ; Siul Desilting Basin.**

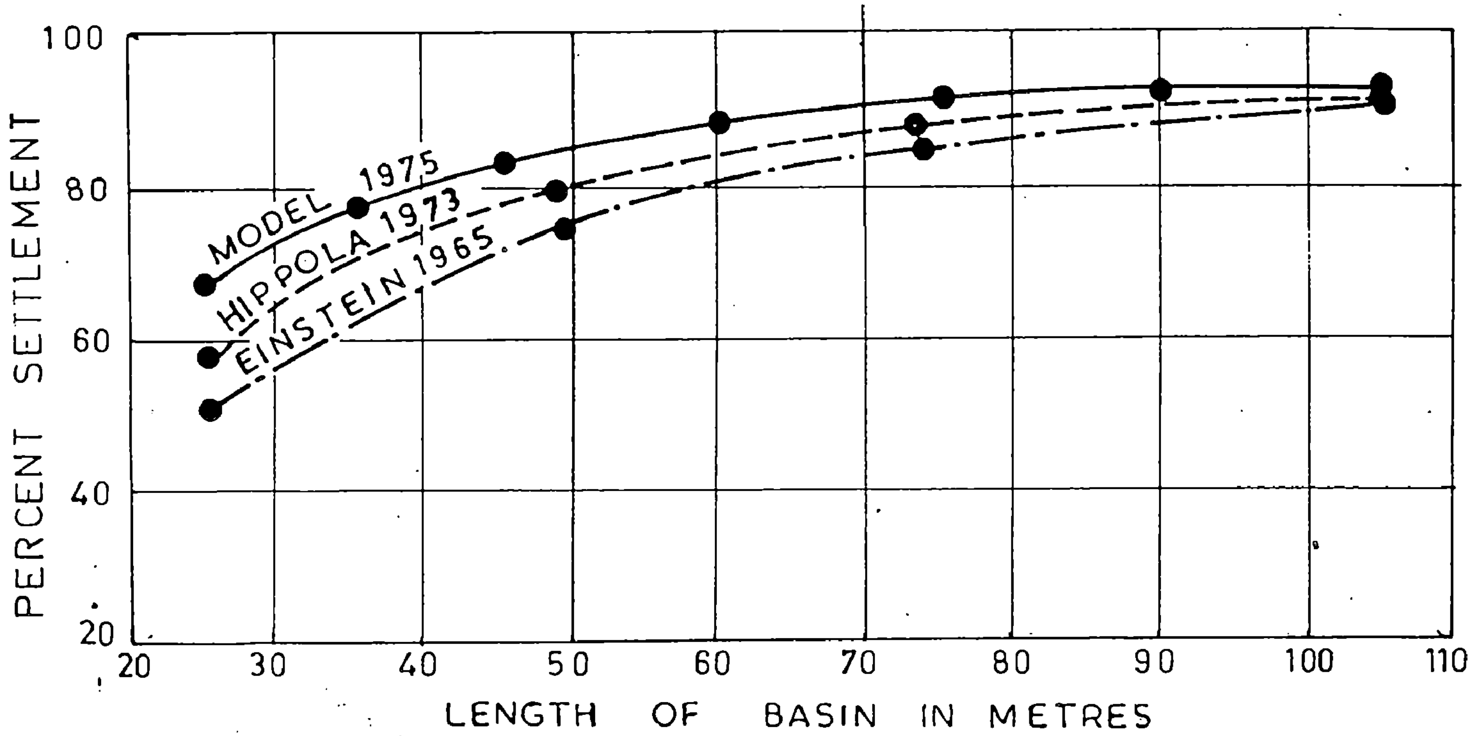


Fig. 5.5 Settling Efficiency of the Desilting Basin after Correction for Sediment Distribution on Vertical ; Siul Desilting Basin

HYDRAULIC MODEL STUDIES FOR DESILTING BASIN OF CHAMERA H.E. PROJECT, STAGE-II, HIMACHAL PRADESH

6.1 INTRODUCTION

It is seen in earlier chapter that model studies have been very helpful in finalizing the hydraulic design of desilting basins in a number of projects. The detailed model studies carried out at CW&PRS, Pune in case of Chamera project are described in this chapter.

6.2 THE PROJECT

Chamera H.E. Project Stage II is a run-of-the river scheme for hydropower generation on river Ravi utilizing a gross head of 267 m. The project is located about 6 km from Chamba town in Himachal Pradesh on Chamba-Kharamukh road and 30 km upstream of Chamera H.E. Project , Stage-I (540 MW), which is in operation since March 1994. The project layout is shown in Fig. 6.1.

The project envisages construction of a 39 m high gravity dam across river Ravi about 20 km upstream of Chamba town. The water stored by construction of dam would be diverted through a water conductor system comprising of an intake structure, two 375 m long underground desilting chambers, a 7860 m long and 7.0 m diameter horse shoe shape power tunnel, a 17.2 m dia and 102 m high surge shaft, an underground power house and about 3500 m long tail race tunnel on the right bank of river Ravi. The powerhouse has three units with an installed capacity of 300 MW (3 x 100 MW). The project when completed would provide peaking capacity benefits to the Northern Regional Grid of India.

The Ravi limb of the Chamera-I reservoir is getting around 22-24 million cubic metre sediment load every year as per the annual reservoir cross section survey conducted in the post monsoon season every year since 1995. Based on these data, the expected sediment inflow in Stage-II reservoir would be about 19.6 M.cum./year.

Chamera stage-II has a very small reservoir having a fetch of about 3.6 km, total capacity at FRL of 2.24 M.cum. and the live storage capacity of 1.56 M.cum.

6.3 SEDIMENT CHARACTERISTICS

The concentration of suspended sediment in the river Ravi is likely to be very high during floods and is expected to be more than 2000 ppm, which would find its way into the intakes. Available data received from Project Authorities revealed that it contains about 18% coarse, 28% medium and 54% fine sediment, (Table 6.1). The sediment coarser than 0.20 mm size is proposed to be extracted from the river water, before it enters the Head Race Tunnel. To arrest entry of larger size particles, a trash rack having 75 mm size openings is proposed to be provided at power intake.

Hydraulic model studies were conducted at the CWPRS to determine settling efficiency and the efficiency of flushing system of the proposed basin. The results of model studies are described in following paras:

6.4 ORIGINAL PROPOSAL

General layout of desilting basins has been shown in Fig. 6.2. The original proposal comprised two parallel desilting chambers each with common inlet tunnel and common flushing duct. With this arrangement it was necessary to shut down the powerhouse during the period of dewatering of desilting chambers and/or flushing duct for inspection and repairs. It was, therefore, proposed that separate inlet tunnels and separate flushing ducts be provided for each desilting chamber so that one chamber at a time can be inspected/repaired while the other could be used for conveyance of water for power generation. The other features of this proposal were:

1. Two nos. of 16 m (W) x 20.65 m (H) x 375 m (L) size desilting chambers having 43 hoppers of varying lengths.
2. 60 m long diffuser (inlet transition) on the upstream.
3. 30 m long outlet transition on the downstream.
4. 7.0 m dia horse-shoe shaped head race tunnel on the downstream.
5. Separate flushing duct varying from 1 m (W) x 0.5 m (H) at first hopper to 2.0 m (W) x 2.0 m (H) section at last hopper below each desilting basin unit.
6. Total flushing discharge of 35.5 cumec.

6.5 PRE-STUDY OF THE DESIGN

Based on the experience and earlier studies conducted at CW&PRS this proposal was further reviewed. Modified features are as under :

1. Two nos. of desilting chambers each having size of 375 m (L) x 16 m (W) x 21.75 m (H) have been provided, vide Figure-6.3. A 2 m wide cunnet having holes of varying sizes to connect chamber to flushing duct is provided.
2. Each desilting chamber is provided with a separate intake structure and 6 m dia circular inlet tunnel. The radius of curvature in the inlet tunnel is proposed to be 50 m to minimize turbulence on upstream of diffuser.
3. The side slope of the bottom of chambers above their invert is increased to 40^{O} to prevent deposition of sediment over the slope.
4. On the upstream of each desilting basin unit, 60 m long diffuser is provided, Figure 6.4.
5. On the downstream of each desilting chamber, 30 m long outlet transition is provided.
6. Underneath of each desilting basin unit, flushing duct having 0.8 m (W) x 2.00 (H) rectangular section at its upstream end varying uniformly to 2 m (W) x 2 m (H) at its downstream end has been provided, Figure 6.5.
7. After the regulatory control gates of the flushing duct, both the flushing ducts will combine together to form one common flushing tunnel having 4.50 m dia D shape with 4.0 m x 2.50 m rectangular trough in which free flow will prevail during the operation of the power house, Figure 6.6.
8. The flushing tunnel will have its outfall in river Ravi on downstream side of village Rakh, where water level in the river during normal monsoon months remains lower than invert of the tunnel at its outlet.

6.6 THE MODEL

One complete unit of desilting basin as shown in Photo No.1 (covering straight and curved lengths of the inlet tunnel), inlet transition (original proposal) as shown in Photo No.2, desilting chamber, HRT and outlet transition as shown in Photo No.3 was reproduced as a geometrically similar model in 1:30. scale The model was constructed partly in fiber glass and partly with clear transparent perspex sheets according to the drawings received from Project Authorities. Flushing tunnel having size of 0.80 m

(W) x 2.00 m (H) at upstream end increasing gradually to 2.00 m (W) x 2.00 m (H) at the downstream end was reproduced in the model in transparent perspex material as shown in Photo No.4. Openings of different sizes at different spacing were provided in the slab separating flushing tunnel and the desilting basin.

Sediment traps of adequate sizes were provided at the outlet of H R T and flushing tunnel. For measurement of the inlet discharge, a 0.61 m wide Standing Wave Flume (SWF) was constructed conforming to IS: 6063-1971 having an error in discharge measurement less than ± 2.5 %. On the downstream end of the traps, two triangular thin plate weirs were provided separately for measurement of discharge passing through H R T and flushing tunnel.

6.7 STUDIES FOR INLET TRANSITION

The required length of the desilting basin depends on the flow distribution at the upstream side of the basin and on the adjustment length of the sediment transport. The total length will be minimal if the diffuser is operating properly. If the divergence of a diffuser is too rapid, flow separation will occur and downstream of the separation a mixing zone will develop converting velocity head to static head. This is an inefficient process compared with diffusion, consequently, it requires a greater length.

A 60 m long inlet transition, Figure 6.4 was provided as per project design for desilting basin unit for uniform diffusion of flow. This being a very important component of the desilting basin, it was reproduced using clear transparent perspex sheets. Initially inlet discharge of 85.40 cum/s was simulated in the model at Minimum Draw Down Level (MDDL). Visual observations indicated that mild return flow existed along the bed in the reach of the downstream portion of the inlet transition. As the return flow was not very strong, further studies were conducted after injecting sediment with high concentration of coarse sediment. From these studies it was seen that most of the coarse sediment settled on the bed of the inlet transition (Photo No.5) and the deposited material travelled in the forward direction with the slope of about 2 H to 1 V. Though the forward flow was seen above the deposited material, the deposition of the sediment continued to remain along the slope of the inlet transition through out.

The bed slope of the inlet transition provided in the original design is 4.21 H to 1 V. From these studies it was concluded that there is scope for reduction in the length of inlet transition. From the experience of the past studies conducted at the CWPRS for other similar transitions provided for different projects, the bed slope of the transition could be in the range of 2 H to 1 V to 2.7 H to 1 V for its efficient functioning. With this slope it was observed that the flow diffusion is uniform in the transition reach and there is no major deposition of coarse sediment along the sloping portion of the inlet transition as is happening in the case of original design.

To obtain a uniform flow distribution in the transition reach, the length of the transition was reduced to 35 m from its original length of 60 m. The bed slope of the inlet transition was kept at 2.5 H to 1 V, vide Figure 6.7. It was expected that this reduced length of the transition could be adequate for the desired performance in respect of flow diffusion and transport of sediment in inlet transition of the desilting basin.

Accordingly, modified transition having length of 35 m vide figure 6.7 was fabricated using clear transparent perspex and incorporated in the model (Photo No.6).

Model studies conducted with the modified transition indicated that there was marginal improvement in the flow and substantial quantity of coarse sediment was remaining on the slope of the transition.

As an alternative to this modification, transition with two slopes was tested in the model. In this transition of 35 m length, slope at 1 in 5 was given to the bed in first five meter length and there after 2.3 H, to 1 V, as shown in Figure 6.7 and Photo No.6.

With this modification of double slope, it was seen that there was no appreciable improvement in the performance of the transition and material remained on the slope. In addition to this, large quantity of sediment was deposition in the settling trench just downstream of the inlet transition. Finally it was decided that transition with bed slope of 2H to 1V be tested in the model. Accordingly the transition was fabricated as per details given in Figure 6.8 and tested in the model. It was seen that no sediment remained on the slope except a very thin layer of very fine material. It was also seen that the material in thin layer also did not remain on the slope permanently and the material once deposited on the slope was thrown again in suspension. As such this transition with bed slope at 2H to 1V was considered to be suitable for the desired flow distribution and transport of sediment. With this changed slope of inlet transition, the length of the transition was reduced to 28.5 m.

6.8 ANALYTICAL STUDIES FOR ESTIMATION OF SETTLING EFFICIENCY

The length of the desilting basin was checked by two methods as shown in Annexure 6.1. A basin of length 375 m was adopted following Camp's criteria. The efficiency of this basin using prototype gradation curve was worked out by Camp's method. The results of the analysis are as below:

The sediment gradation curve (Fig. 6.9) gives D_{50} as 0.072 mm. The size of the opening in the trash rack was 75 mm and hence it was expected that the coarse sediment would also enter into the desilting basin. Considering this aspect a notional gradation curve of sediment likely to enter into the desilting basin was also prepared vide Figure 6.9, Curve 2. This curve was further analysed for analytical estimation of settlement of suspended sediment using Camp's criteria, results of which are given in Table 6.2. From table 6.2, it would be seen that for inlet gradation as per curve 2 of Figure 6.9, the overall settling efficiency of the desilting basin would be of the order of 47.4%. Using results in the Table 6.2, settling efficiency curve for various size particles has been prepared and shown in Figure 6.10. From Figure 6.10, it would be seen that the settling efficiency of 0.2 mm diameter particles would be of the order of 95%. It would also be seen that for sediment particles coarser than 0.20 mm, settling efficiency would be more. Thus average settling efficiency for coarse sediment would, therefore, be much more than 90% depending upon the percentage of particles coarser than 0.20 mm at inlet. Similarly for particles finer than 0.20 mm, the settling efficiency would reduce gradually to 48% for particles of 0.10 mm in diameter.

6.9 ESTIMATION OF SETTLING EFFICIENCY BY MODEL STUDIES

The sizes and spacing of the openings suggested by project authorities have been shown in Figure 6.3 and given in Table 6.3. From these sizes of openings, it was seen that openings from 3rd to 82nd openings were relatively small considering their location in the desilting basin. Hence bigger openings were proposed to be tested in the model. Their sizes are also given in Table 6.3, from which it would be seen that even though the sizes of the openings are bigger, their spacing have been kept the same as proposed by project authorities and these were finally adopted in the model. Other relevant details of prototype and model are given in Table 6.4.

For estimation of settling efficiency, model was run simulating inlet discharge of 85.20 cum/s, which comprises of H.R.T. discharge of 71.00 cum/s and flushing discharge of 14.20 cum/s. At the upstream of model water level was maintained at MDDL.

For simulation of suspended sediment in the model, low specific gravity crushed and sieved walnut shell was used (Sp. gr. 1.32). The sediment size were simulated as per fall velocity criteria given in para 4.3. The gradation of model material is shown in Fig. 6.12. Using this material, model was run with various concentrations of suspended sediment. Results of these studies are given in Table 6.5, from which it would be seen that the overall settling efficiency of the desilting basin was of the order of 88.83% for the inlet gradation of suspended sediment shown in Figure 6.12.

It was also seen that the flushing tunnel was working very efficiently and there was no deposition of sediment or formation of dunes in the flushing tunnel. However, some openings in a reach of about 80 to 150 m from end of inlet transition were getting choked.

To eliminate the possibility of choking of this openings the sizes of the openings were further reviewed. It was seen that there was a scope for reducing the size of first opening and utilize the reduction in the area to increase the size of the openings in the initial reach of the desilting basin. Accordingly the size of the first opening was reduced from 2000 x 800 mm to 1700 x 600 mm. The sizes of other openings are given in table 6.10. From table 6.10 it would be seen that 3rd to 17th openings have 300 mm dia in place of 250 mm dia. With these modifications, the model was run and it was seen that there was considerable improvement in the overall functioning of the entire system including settlement and flushing of the sediment.

The size of the flushing tunnel at the beginnings is 0.80 m (W) x 2.00 m (H). As such the size of the first opening in the initial proposal was 2000 x 800 mm, vide table-6.3. With the modification in the sizes of the openings mentioned above, the size of the first opening is 1700 x 600 mm. As such it was apprehended by project authorities, that there would be some reduction in the forward velocity between first and second opening. Hence slope of 1 in 50 was proposed for the flushing tunnel in the initial 30 m length. As such the size of the flushing tunnel would be 0.8 m (W) x 1.40 m (H) at the upstream end with slope 1 in 50 in initial 30 m length of the flushing tunnel vide figure 6.11. This modification in the slope of the flushing tunnel was incorporated in the model (Photo 8) and tested. It was seen that the overall system was functioning well without any deposition on the slope of transition, in the basin and the flushing tunnel.

The gradation curves of the suspended sediment used in the model, Figure 6.12 were further analysed for model parameters using Camp's criteria. Results of these analysis are given in Tables 6.6, 6.7 and 6.8. From these tables, it would be seen that the overall settling efficiency of the model was of the order of 85.91%, 85.29% and 85.69%.

On the basis of these results the various sizes of particles and their settling efficiency (Removal Ratio) and equivalent prototype size of the sediment are given in Table 6.9. This was in close agreement with the efficiency estimated using model results.

A curve has been prepared showing the sediment size and its percentage removal for model as well as prototype using the results mentioned above, vide Figure 6.13, from which it would be seen that the settling efficiency of particle size of 0.20 mm dia would be of the order of 97%.

As such the transition with bed slope of 2H to 1V, having a length of 28.5 m desilting basin having length of 375 m and the flushing tunnel with modification size and slope appears to the adequate for the 90% settlement and removal of the sediment coarser that 0.20 mm diameter.

6.10 CONCLUSIONS OF THE MODEL STUDIES

1. The overall size (375 m x 16 m x 21.75m) and shape of the desilting basin (Fig.6.8) is found adequate to achieve 90% settlement of sediment coarser than 0.2 mm dia.
2. The inlet transition having a length of 28.5 m with a bed slope of 2H:1V was found to be efficient in respect of flow diffusion and transport of sediment.
3. Flushing tunnel having size of 0.8 m (W) x 2.0 (H) at the end with a bed having slope of 1 in 50 in the initial reach of 30 m is suitable for efficient transport of sediment without any deposition. The first opening may be provided as 1700 x 600 mm and openings from 3 to 17 may be provided of size of 300 mm dia.

DESIGN OF DESILTING BASIN BASED ON MYSONYI'S APPROACH

Inlet discharge for each basin	Q_1	=	85.2 cumec
Outlet discharge for each basin	Q_2	=	71.0 cumec
Flushing discharge @ 20%		=	14.2 cumec
Average discharge $(Q_1 + Q_2) / 2$		=	78.1 cumec
Depth of flow		=	21.75 m
Flow area		=	297 m^2
Particle size to be settled		=	0.2 mm
Settling velocity,	w	=	0.02 m/sec for 0.2mm particle
Average flow through velocity,	v	=	78.1 / 297 = 0.26 m / sec.
Reduction in settling velocity,	w'	=	(0.132 x 0.26) / √ 21.75
		=	0.00742 m / sec.
Length of settling chamber,	L	=	h v / w - w'

$$= \frac{21.75 \; x \; 0.26}{(0.02 - 0.00742)} \quad = 450 m$$

Also settling length as given by Velikanov's function

$$L = \frac{\lambda^2 \;\; v^2 \; \left(\sqrt{h} - 0.2\right)^2}{7.51 \;\; w^2}$$

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

$$\lambda = \sqrt{\frac{7.51 \times L \times w^2}{v^2 \; \left(\sqrt{h} - 0.2\right)^2}}$$

$$= \sqrt{\frac{7.51 \times 450 \times (0.02)^2}{(0.26)^2 \; \left(\sqrt{21.75} - 0.2\right)^2}} \quad = 1.01$$

Settling efficiency for λ = 1.01, from Velikanov's curve (Fig. 3.12) = 94%

DESIGN OF DESILTING BASIN BASED ON T.R.CAMP'S APPROACH

a)	Design discharge for the power house (3x100 MW)	=	142 cumec
b)	Flushing discharge @ 25% of design discharge	=	28.4 cumec
c)	Total discharge at Power Intake	=	170.4 cumec
d)	Total discharge in power tunnel	=	142 cumec
e)	Manning's Rugosity coefficient	=	0.014
f)	Sediment size to be removed	=	0.2 mm
g)	No. of desilting chambers	=	2 Nos.
h)	Design flow through velocity	=	0.3 m/s

Design discharge through each chamber	(170.4/2)	=	85.2 cumec
Required sectional area of each chamber	(85.2/0.3)	=	284 m^2

Since the chambers will be constructed underground, their width has been decided on the basis of cavity that can be safely excavated in the rocks to be encountered at site. Accordingly, the width of each chamber has been fixed as 16 m. To provide the required sectional area, each chamber, has been provided with 190 m radius circular segmental roof with height of crown above springing being 4 m, 11.75 m high vertical side wall and 6.00 m high invert of 16 m width at its top to 2 m width at its bottom. Thus total height of each sedimentation chamber becomes 21.75 m. The sectional area of each chamber works out to be as follows :

i) Area of crown portion above springing i.e. A_I (Ref. Fig.6.8)

Radius of crown R		=	10 m
Height of crown h		=	4 m
Half width of crown	b	=	8 m
Area	A_I	=	$R^2 \sin^{-1}(b/R) - b \times (R-h)$
		=	$10 \times 10 \times \sin^{-1}(8/10) - 8 \times (10-4)$
		=	92.73-48 = 44.73 m^2

ii) Area of portion below springing i.e. A_2

Width of chamber	B	=	16 m
Height of vertical sides	h_1	=	11.75 m
Height of invert	h_2	=	6.0 m
Width of Invert	B_1	=	2 m
Area	A_2	=	$Bxh_1 + (B+B_1) \times h_2/2$
		=	16x11.75 + (16+2) x 6.00/2
		=	188 + 54.00 = 242.00 m^2
Thus total area of each chamber		=	$A_1 + A_2$
		=	44.73 +242.00
		=	286.73 m^2 > 284 m^2 (safe)

LENGTH OF CHAMBERS

Camp investigated settling conditions differing from turbulent equilibrium conditions of sediment transport. However, basin length has been related with fall velocity in still water. For different removal ratio, he has suggested the following relationship :

W	=	Fall velocity in still water		
	=	0.02 m/s for 0.2 mm particles		
Y	=	Depth of flow	=	21.75 m
V	=	Flow through velocity	=	0.3 m/s
η	=	Rugosity Coefficient	=	0.014
L	=	Length of Basin		

Sediment Removal Function $= \dfrac{W(Y)^{1/6}}{V\eta\sqrt{g}}$

$$= \frac{0.02\times(21.75)^{1/6}}{0.3\times0.014\sqrt{9.81}} = 2.54$$

For Camps curves, for 95% efficiency

$$\frac{WL}{VY} = 1.10$$

$$L = \frac{1.10\times V\times Y}{W} = \frac{1.10\times0.3\times21.75}{0.02} = 358.9m$$

$$say\ 360\,m$$

Length of basin comes out to be 360 m by Camp's criteria for 95% efficiency and length of basin is 450 m by Masonyi's for 94% efficiency. So, length of basin 375 m is adopted which is slightly on safer side for efficient silt removal based on Camp's criteria.

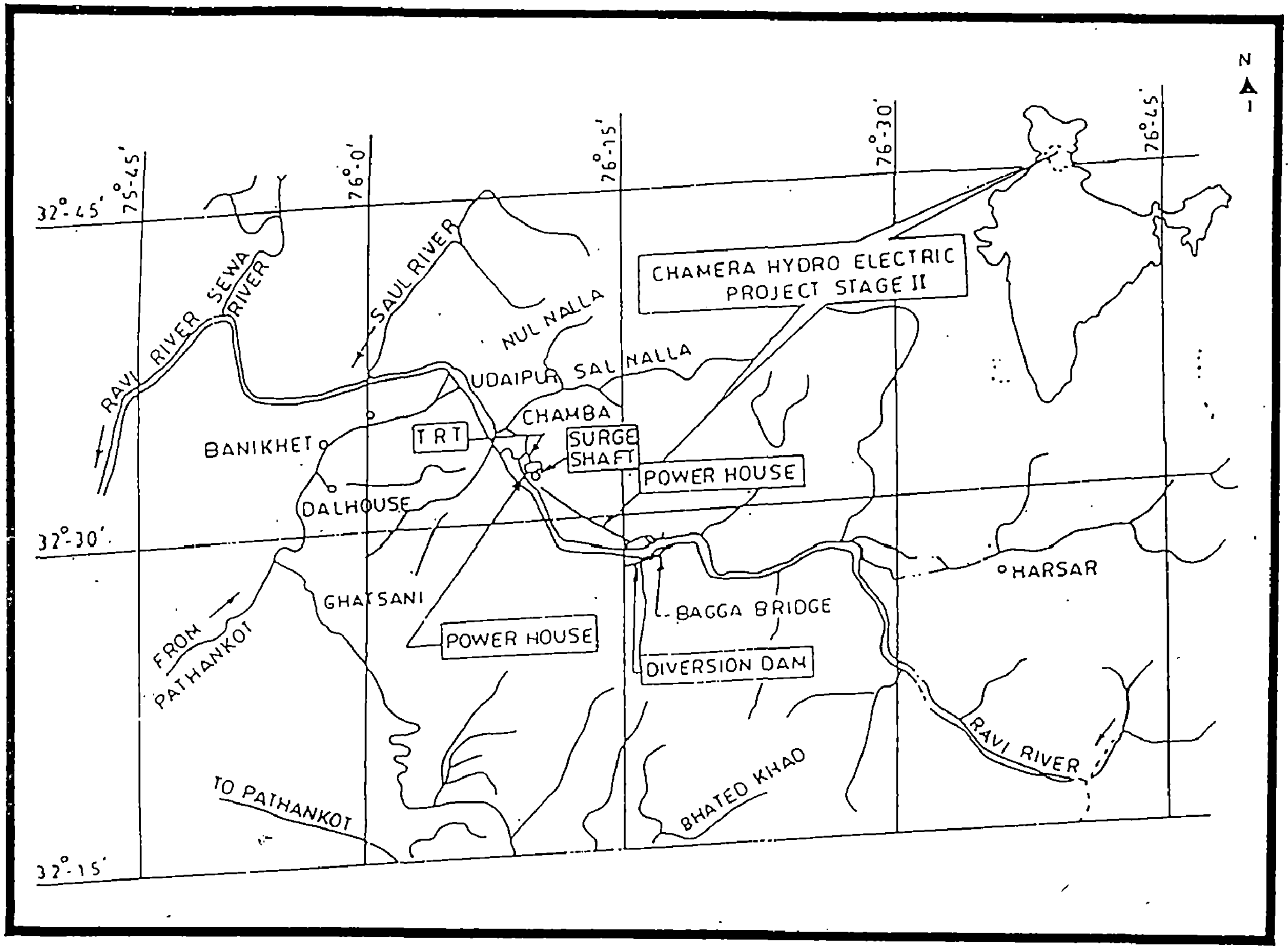


Fig. 6.1 Index Map; Chamera H.E. Project (Stage-II).

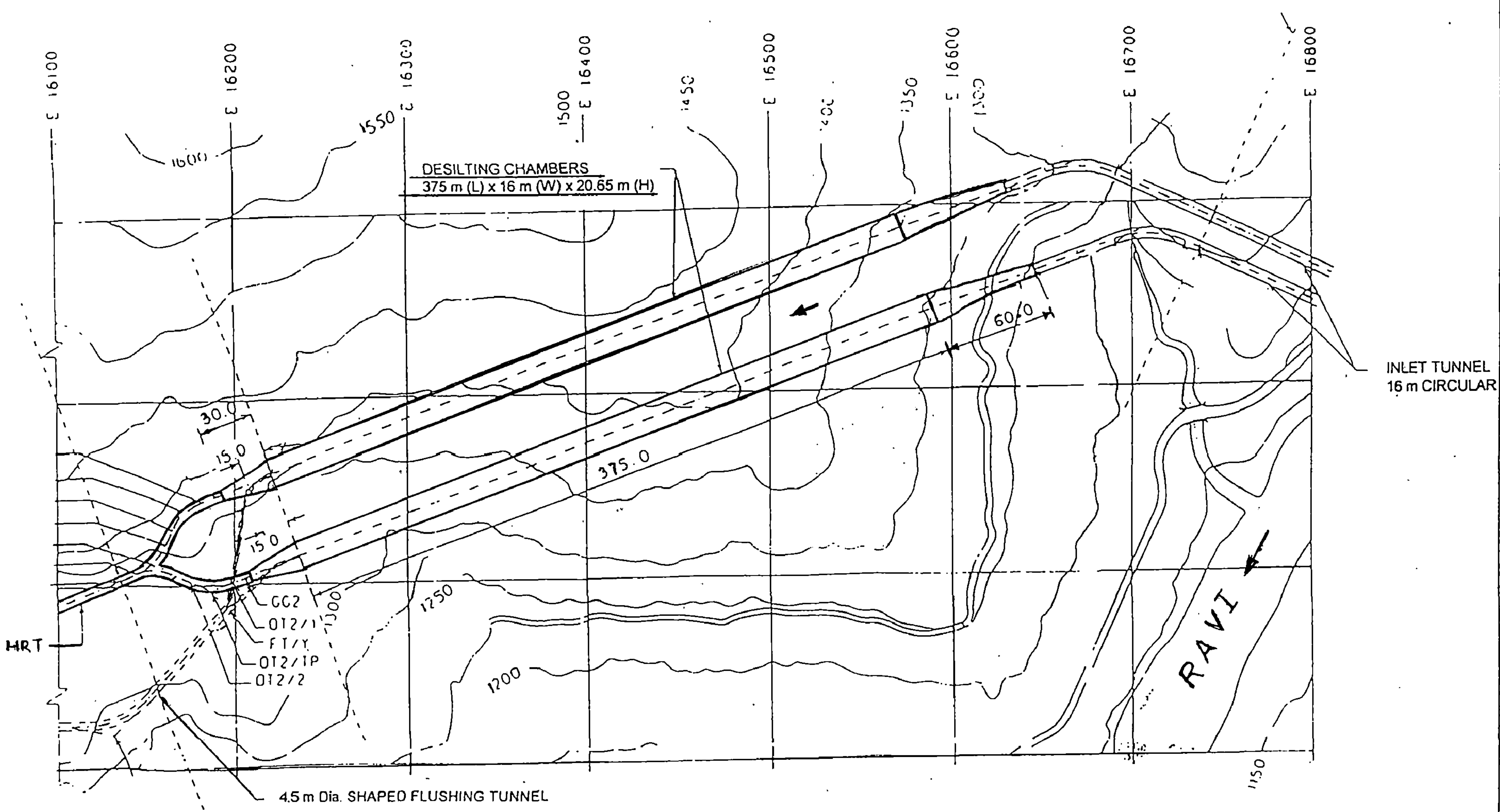


Fig. 6.2 General Layout of Desilting Basin; Chamera H.E. Project (Stage-II).

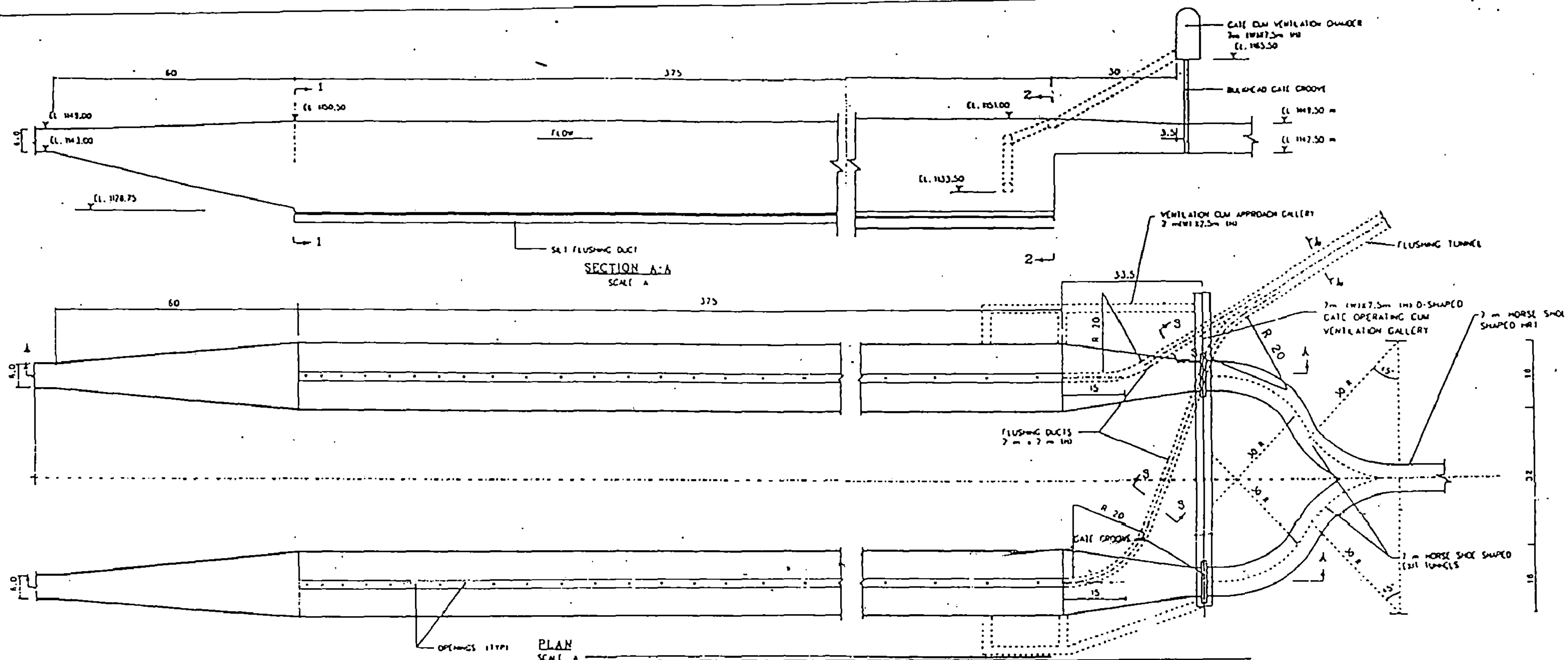


TABLE SHOWING SIZES AND LOCATION OF OPENINGS				
OPENING NO.	DISTANCE OF ℄ OF HOLE FROM TOE OF U/S SLOPE (m)	OPENING SIZE (m)	NO OF OPENING AND SPACING	DUCT SIZE (m)
1	1	2.0x1.2	1 NO	
2	3	0.20 DIA.	1 NO	
3 TO 17	6 TO 48	0.175 DIA	15 NOS @ 3.0 m C/C	UNIFORMLY VARYING FROM 0.8 (W)X2.0 (H) TO 2.0 (W)X2.0 (H)
18 TO 27	52 TO 88	0.175 DIA.	10 NOS @ 4.0 m C/C	
28 TO 37	92 TO 128	0.175 DIA	10 NOS @ 4.0 m C/C	
38 TO 57	133 TO 228	0.150 DIA	20 NOS @ 5.0 m C/C	
58 TO 67	233 TO 278	0.125 DIA	10 NOS @ 5.0 m C/C	
68 TO 82	284 TO 368	0.175 DIA	15 NOS @ 6.0 m C/C	
83	374	0.20 DIA	1 NO	

Fig. 6.3 **Paln & Section of Desilting Basin; Chamera H.E. Project (Stage-II)**

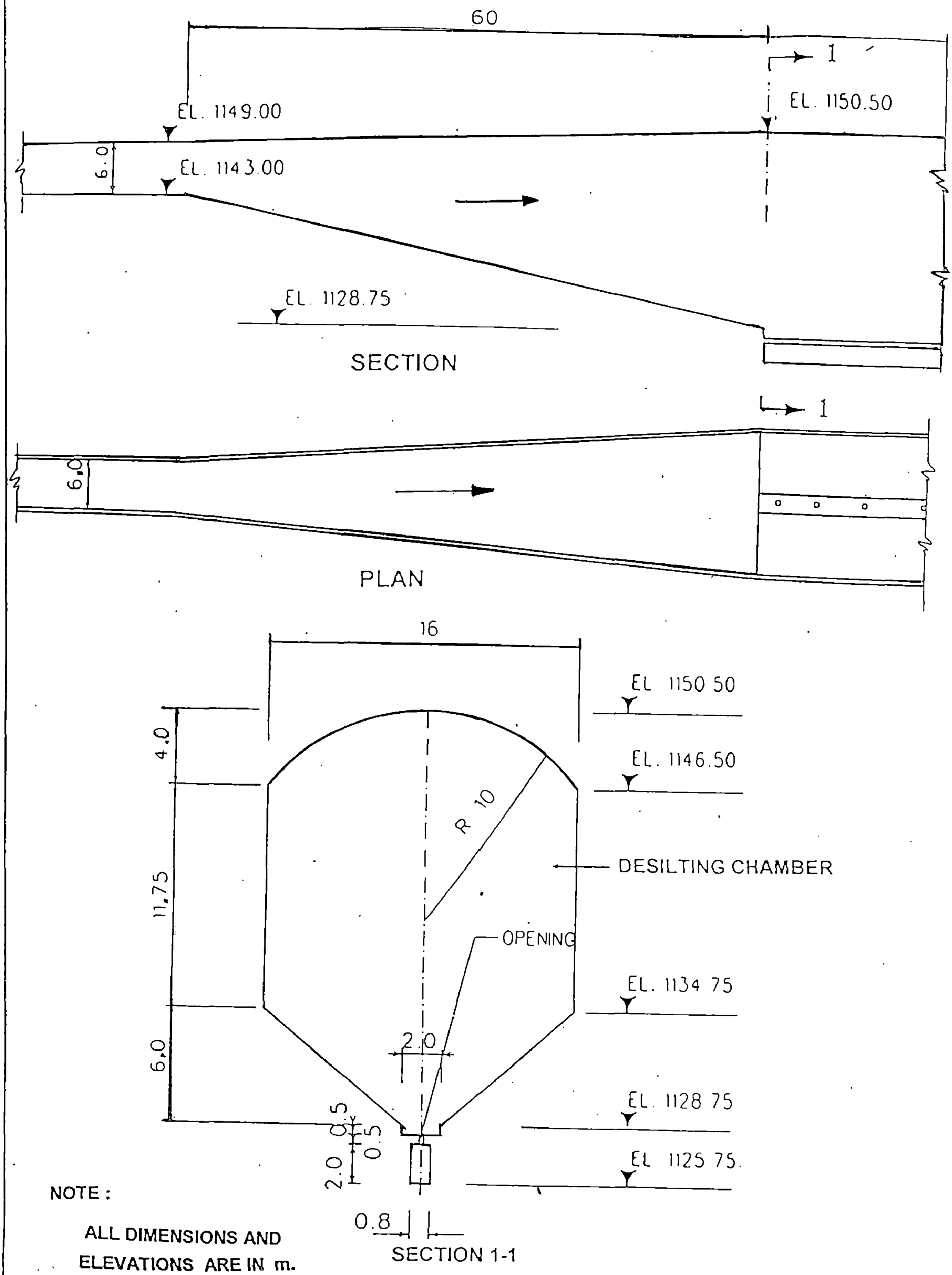


Fig. 6.4 Plan & Section of Inlet Transition ; Chamera H.E. Project (Stage-II)

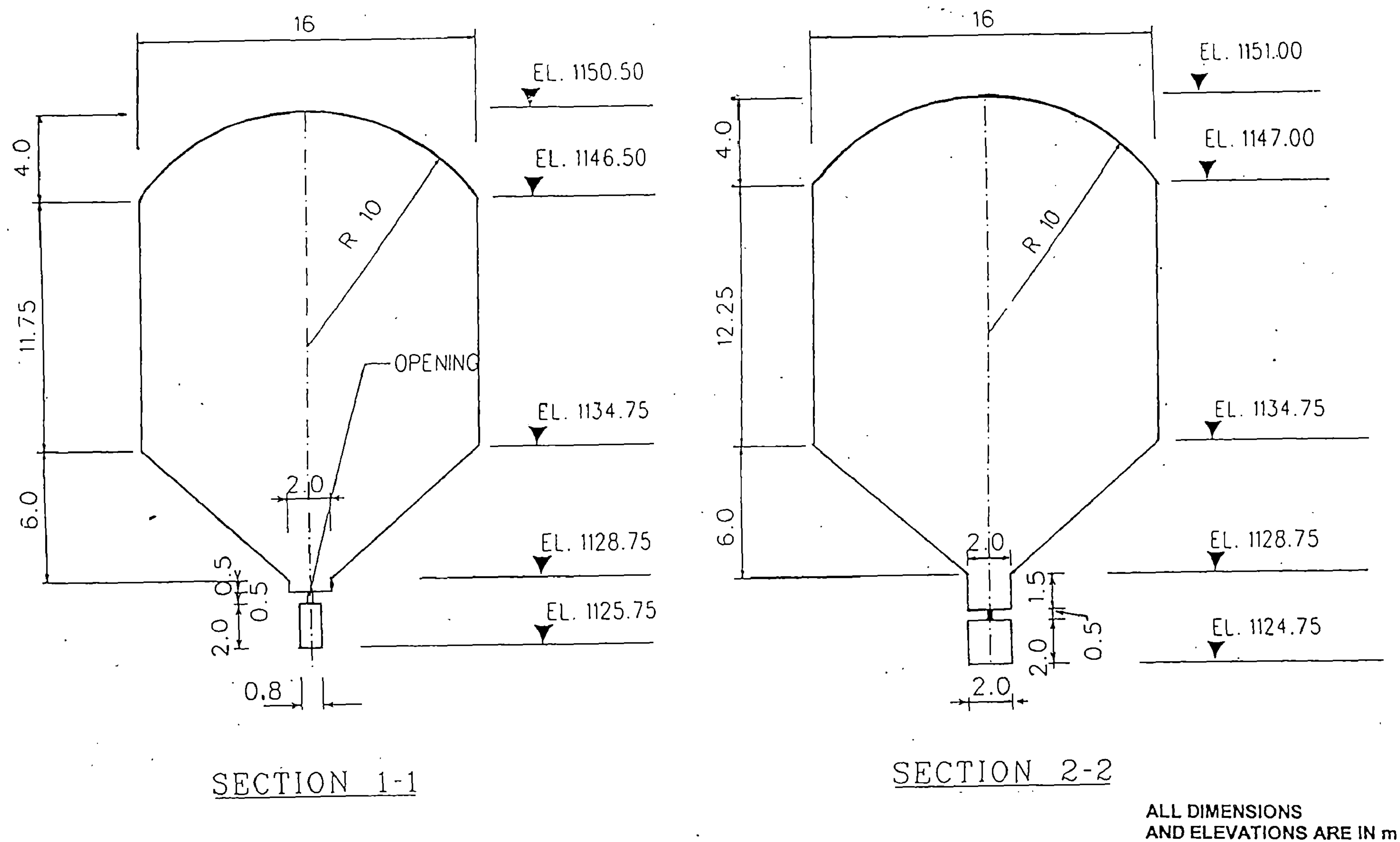
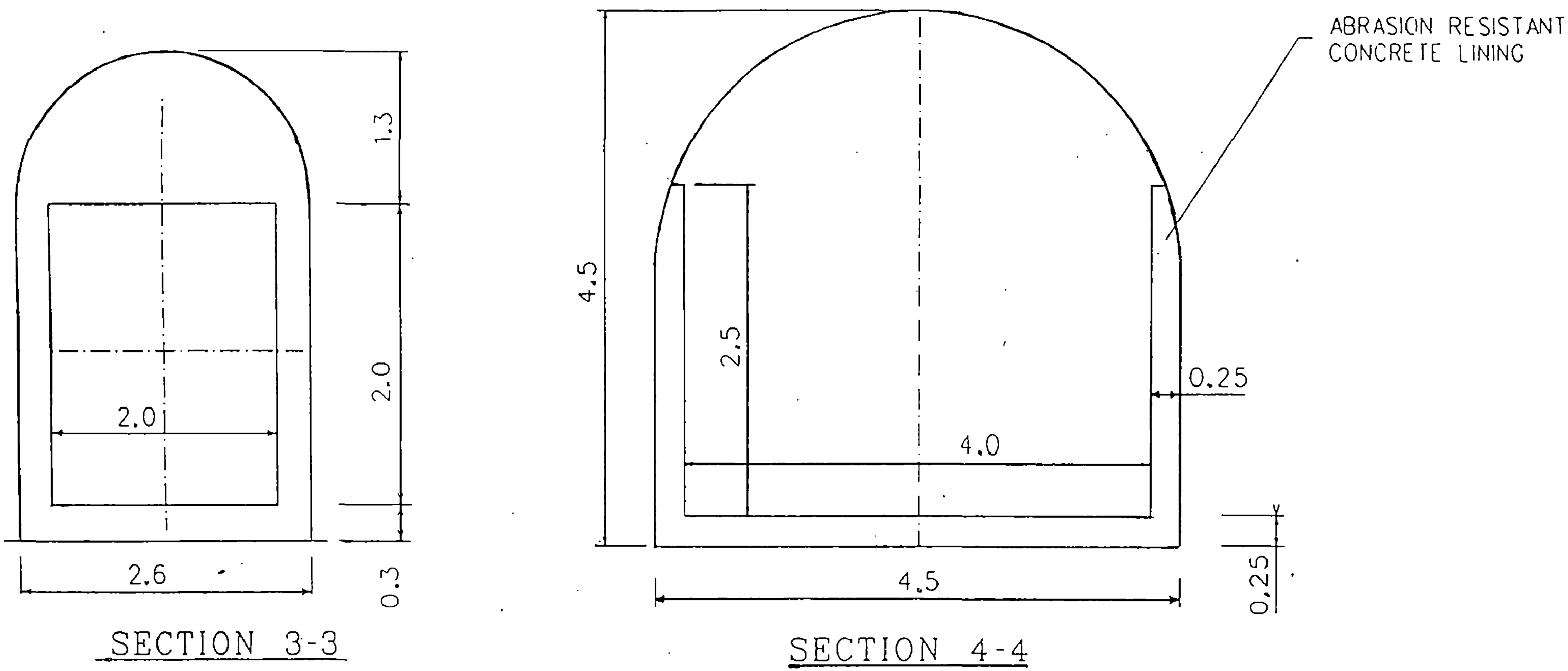


Fig. 6.5 **Sections of Desilting Basin; Chamera H.E. Project (Stage-II)**



NOTE :

ALL DIMENSIONS AND ELEVATIONS ARE IN m.

Fig. 6.6 **Sections of Desilting Basin; Chamera H.E. Project (Stage-II)**

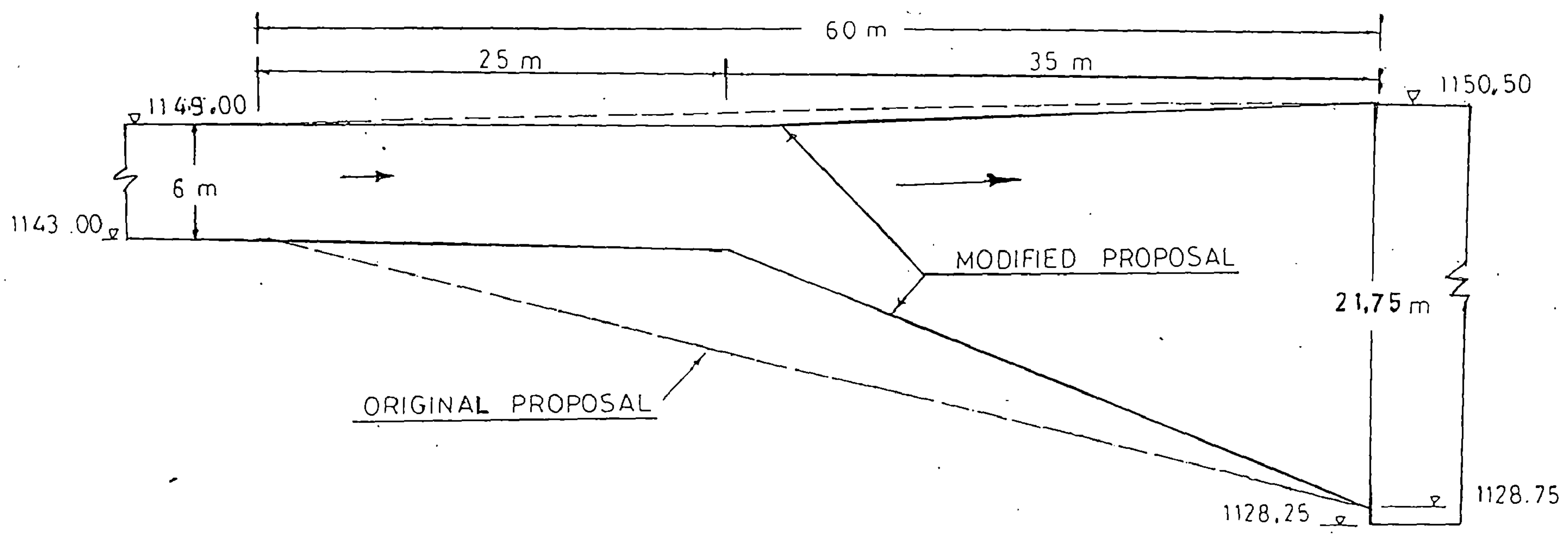
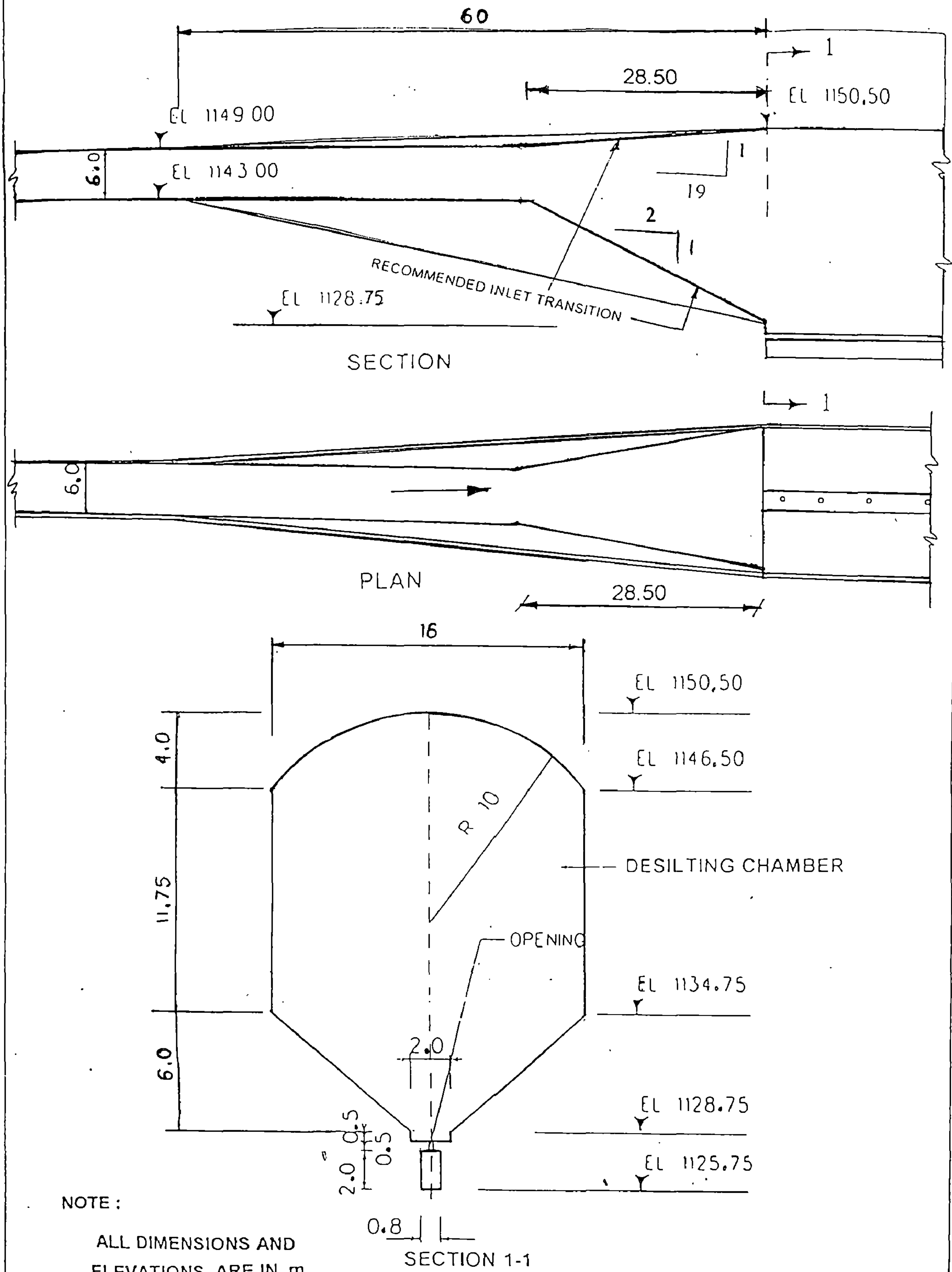


Fig. 6.7 **Original & Modified proposal of Inlet Transition ; Chamera H.E. Project (Stage-II)**



NOTE :

ALL DIMENSIONS AND ELEVATIONS ARE IN m.

Fig. 6.8 Plan & Section of Inlet Transition; Chamera H.E. Project (Stage-II)

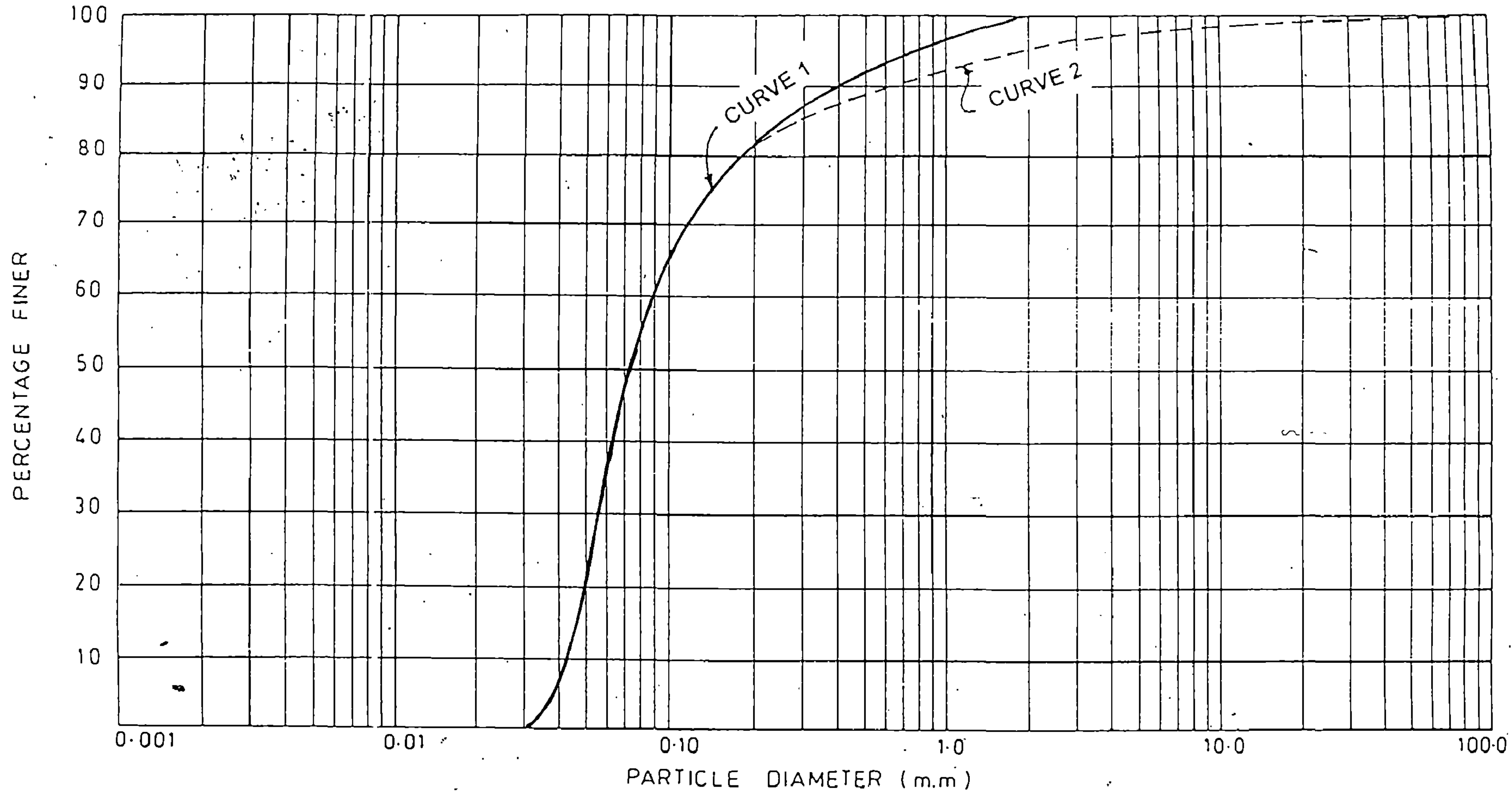
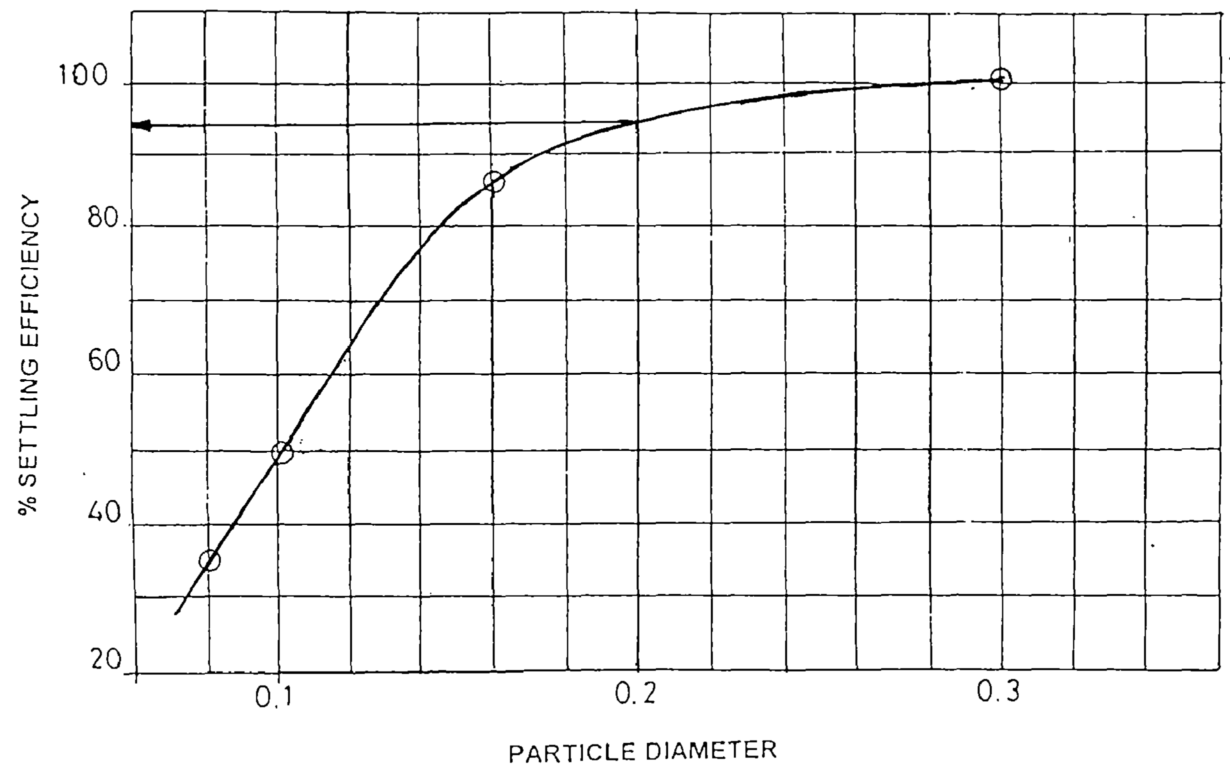


Fig. 6.9 Gradation of Suspended Sediment in Ravi river ; Chamera H.E. Project (Stage-II)

NOTE :

1) CURVE 1 – GRADATION OF SUSPENDED SEDIMENT IN THE RIVER (REFER TABLE 6.1)
2) CURVE 2 – NOTIONAL GRADATION OF SEDIMENT LINKELY TO ENTER INTO THE INTAKE



NOTE :

FOR GRADATION CURVE REFER FIGURE – 6.9
FOR ANALYSIS REFER TABLE – 6.2

Fig. 6.10 **Settling Efficiency of Particles in Desilting Basin ; Chamera H.E. Project (Stage-II)**

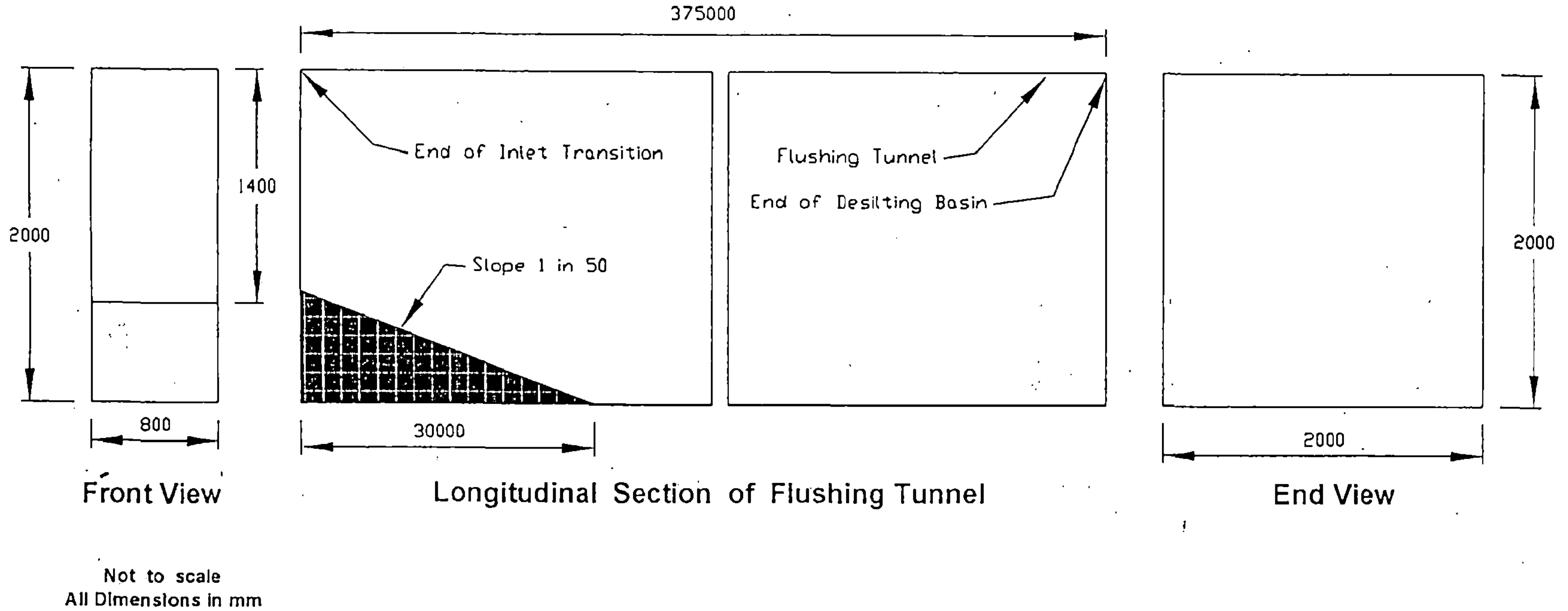


Fig. 6.11 **Modified Slope in the *Flushing Tunnel* below Desilting Basin; Chamera H.E. Project (Stage-II)**

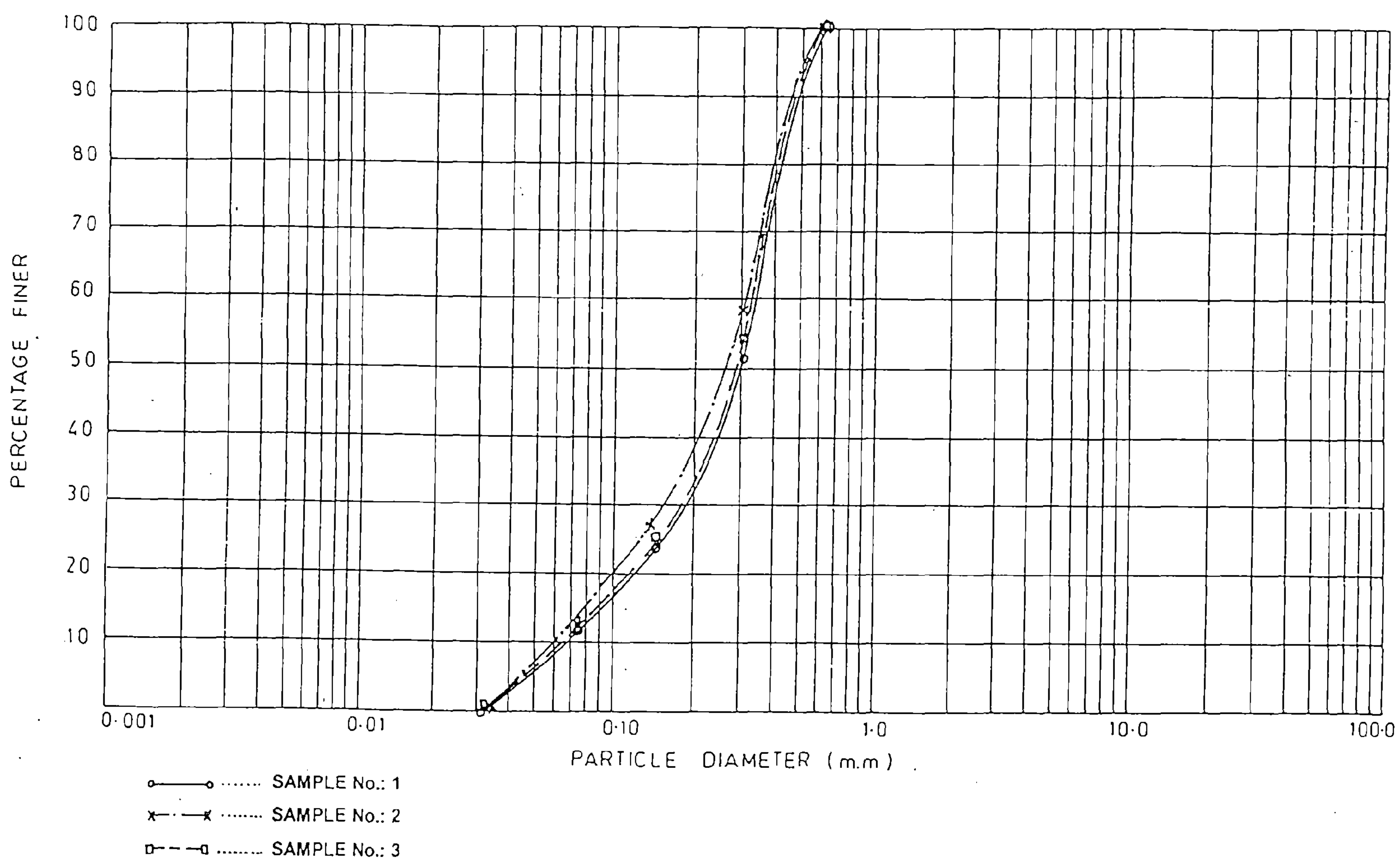
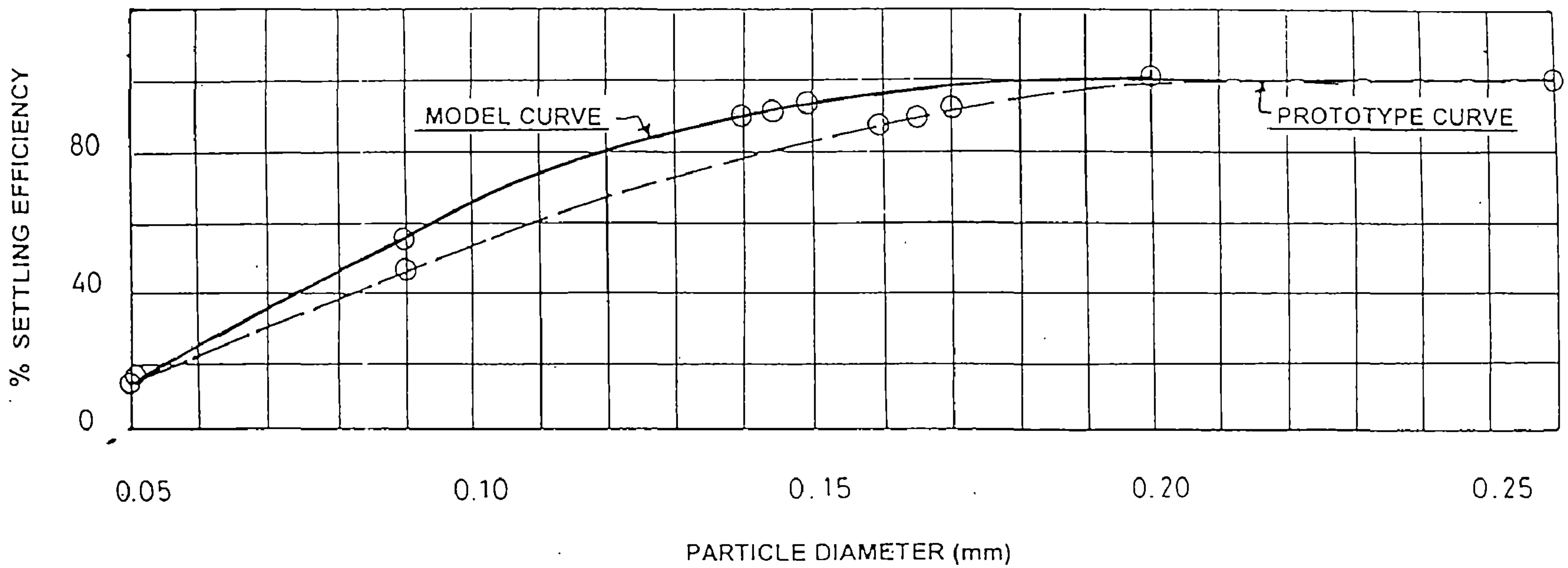


Fig. 6.12 **Gradation curve of Sediment used in the model, specific gravity 1.32; Chamera H.E. Project (Stage-II)**



NOTE :

FOR GRADATION CURVE REFER FIGURE -6.10
AND TABALE -6.9

Fig. 6.13 Settling Efficiency Curve for model & Prototype ; Chamera H.E. Project (Stage-II)

MODEL STUDIES FOR DESILTING BASIN OF CHAMERA H.E. PROJECT, STAGE –II, HIMACHAL PRADESH.

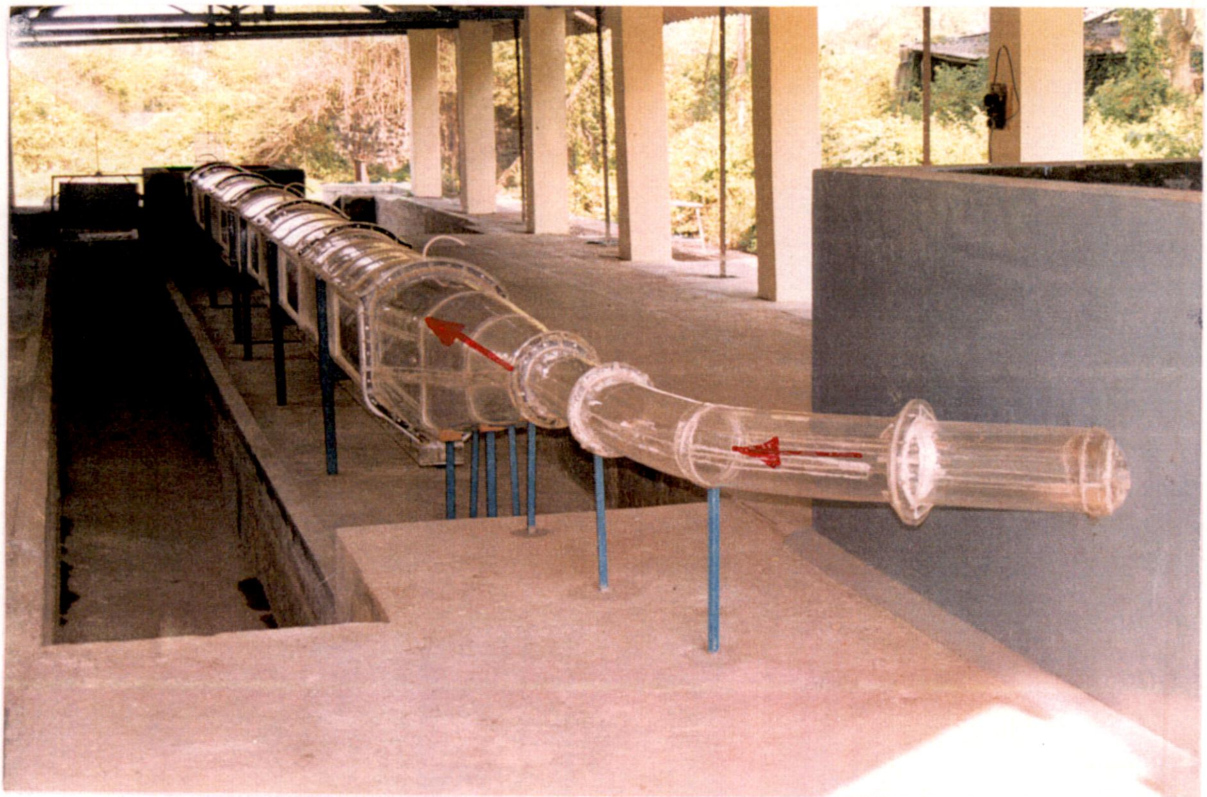


Photo No. 1 : Desilting Basin Model

Photo No. 2 : Inlet Transition (Original Proposal)

MODEL STUDIES FOR DESILTING BASIN OF CHAMERA H.E. PROJECT, STAGE –II, HIMACHAL PRADESH.

Photo No. 3 : Outlet Transition

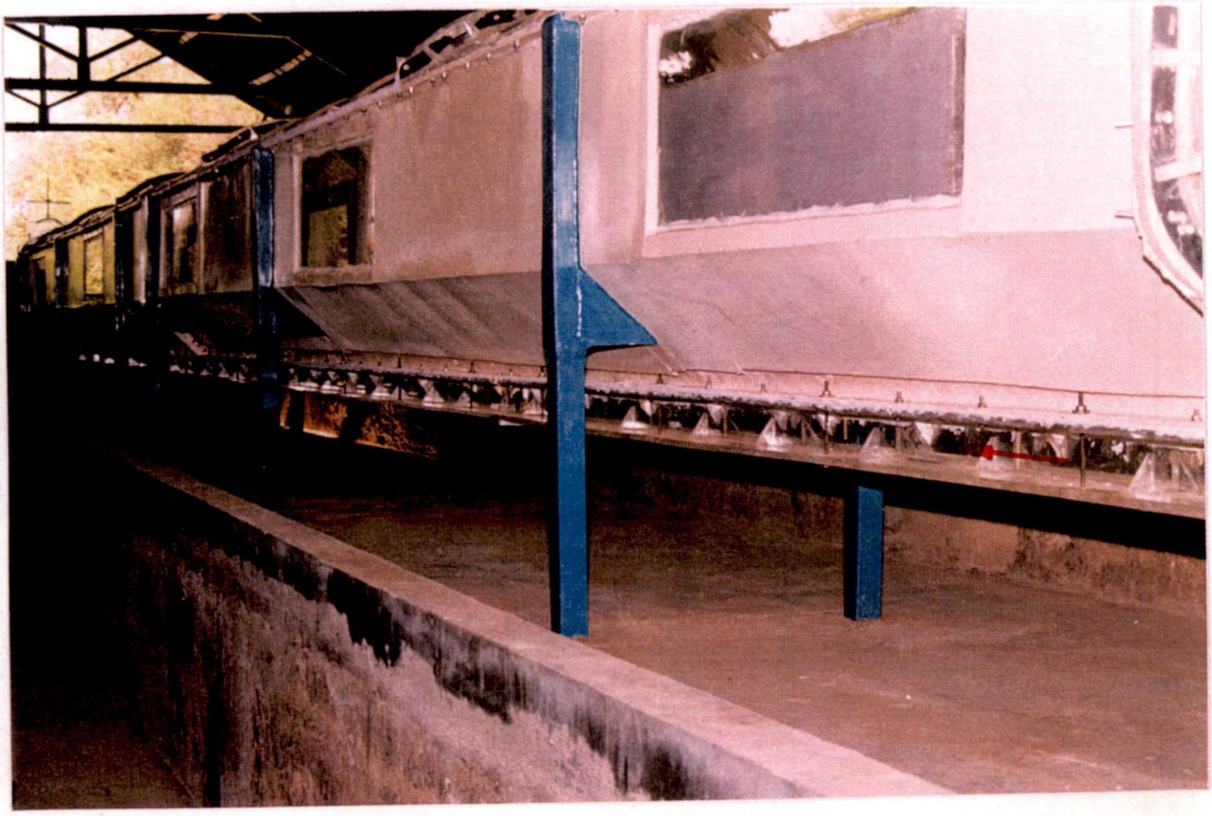


Photo No. 4 : Flushing Tunnel

MODEL STUDIES FOR DESILTING BASIN OF CHAMERA H.E. PROJECT, STAGE –II, HIMACHAL PRADESH.

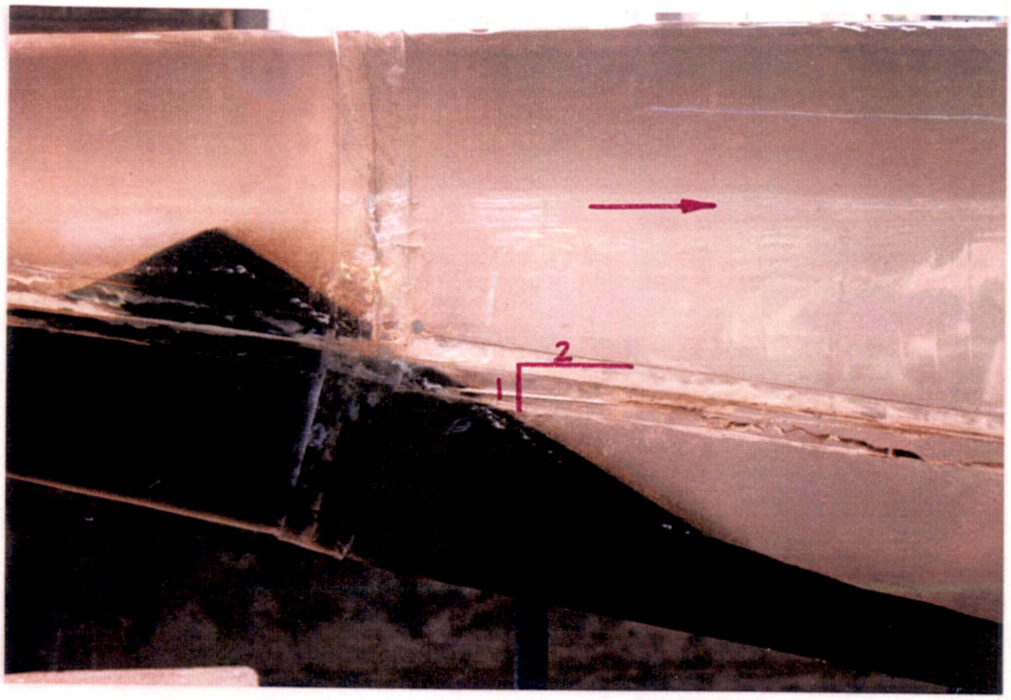


Photo No. 5 : Deposition in original Inlet Transition

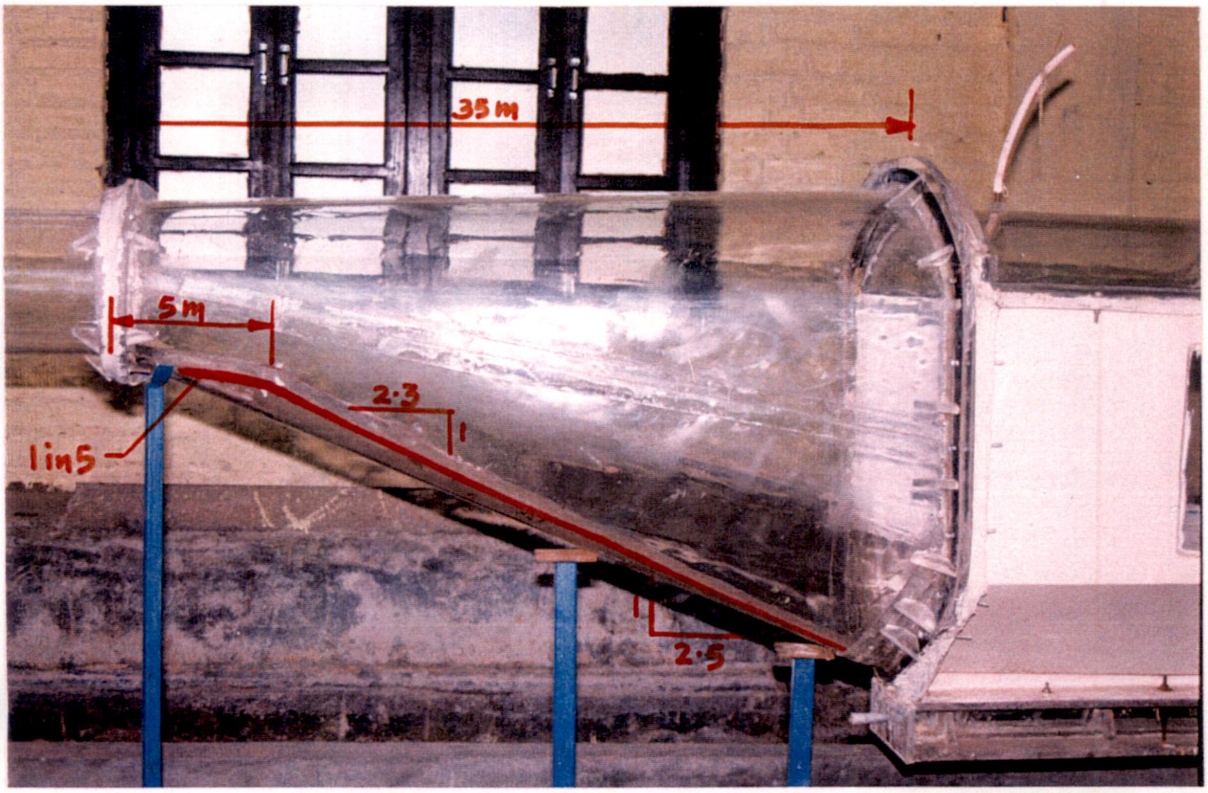


Photo No. 6 : Modified Inlet Transition (2.5 H : 1 V)

MODEL STUDIES FOR DESILTING BASIN OF CHAMERA H.E. PROJECT, STAGE –II, HIMACHAL PRADESH.

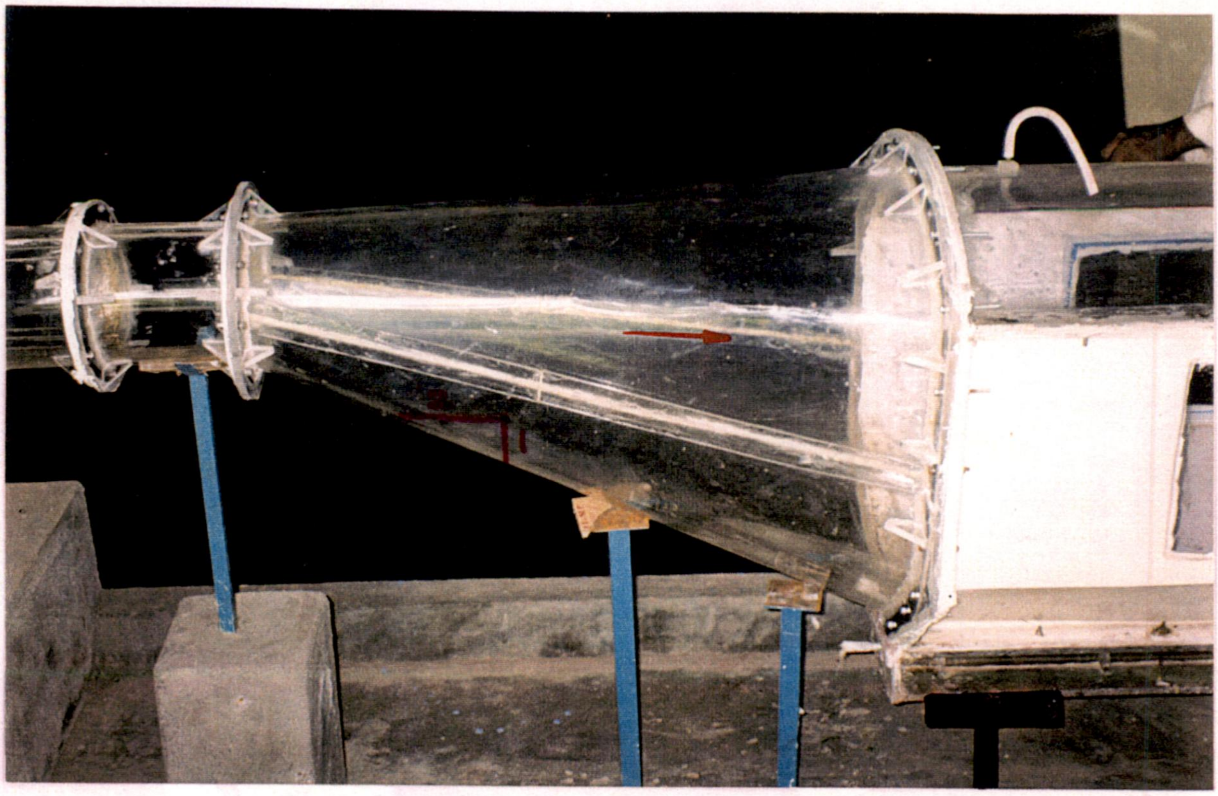


Photo No. 7 : Recommended Inlet Transition (2H : 1V)

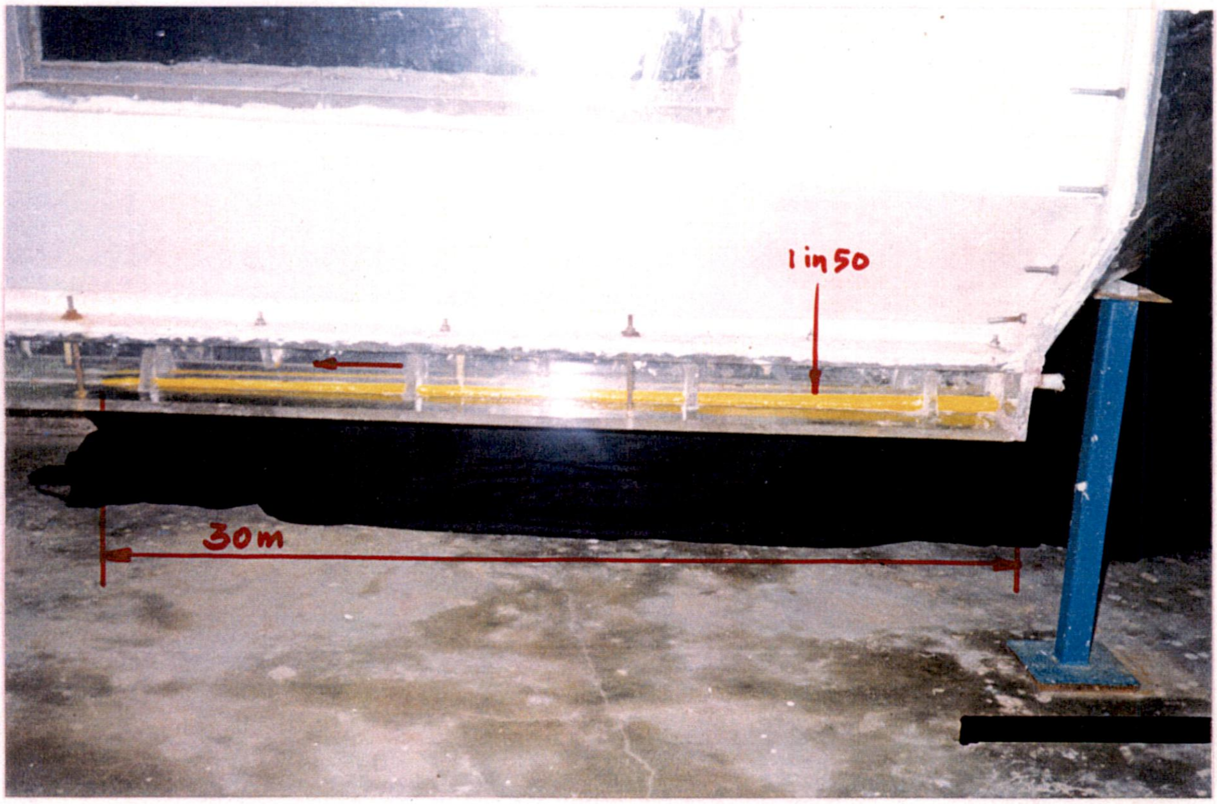


Photo No. 8 : Modifications in Flushing Tunnel

TABLE – 6.1

AVERAGE MONTHLY SUSPENDED SEDIMENT LOAD

Month & Year		**Coarse** ($\phi > 0.2$ mm) (g/lt)	**Medium** ($0.2 > \phi > 0.075$ mm) (g/lt)	**Fine** ($\phi < 0.075$ mm) (g/lt)
July	1995	0.12830	0.2678	1.1197
August	1995	0.11130	0.2350	0.7218
September	1995	0.03858	1.4240	2.9060
October	1995	0.02840	0.0833	0.1796
July	1996	0.40200	0.9560	1.6112
August	1996	1.90190	1.6076	2.0619
June	1997	0.74170	0.5490	1.2188
July	1997	0.73350	1.00469	2.2623
August	1997	1.05980	1.6028	3.0330
July	1998	0.26650	0.6095	0.9995
	Total	5.41198	8.33969	16.1138
	Average	.541198	.833969	1.61138
	Percentage	18 %	28 %	54 %

TABLE-6.2

ESTIMATION OF SETTLING EFFICIENCY

V = 0.262 m/s Vo = 0.0153 m/s

Sl. No.	% finer	Mean dia (mm) from gradation curve	Fall velocity (w) (m/sec)	$122\frac{w}{V}$	$\frac{w}{Vo}$	Removal ratio
1	2	3	4	5	6	7
1.	5	0.05	2.0×10^{-3}	0.92	0.13	0.13
2.	15	0.06	2.9×10^{-3}	1.34	0.19	0.19
3.	25	0.065	3.5×10^{-3}	1.61	0.23	0.23
4.	35	0.07	4.0×10^{-3}	1.84	0.26	0.26
5.	45	0.07	4.0×10^{-3}	1.84	0.26	0.26
6.	55	0.08	5.0×10^{-3}	2.31	0.33	0.33
7.	65	0.10	7.5×10^{-3}	3.46	0.49	0.48
8.	75	0.16	1.65×10^{-2}	7.63	1.08	0.86
9.	85	0.40	5.0×10^{-2}	22.10	3.77	1.00
10.	95	2.00	1.4×10^{-1}	64.69	9.15	1.00
					Total	4.74
					i.e.	47.4%

V = Average forward velocity
Vo = Required vertical velocity

Note:- (i) For gradation curve refer figure –6.9
(ii) 122 is a constant as given in column no. 5

TABLE-6.3

SIZES AND SPACINGS OF THE OPENINGS BETWEEN SETTLING TRENCH AND FLUSHING TUNNEL SUGGESTED AFTER MODEL STUDIES

Opening No.	Distance(m)	Size (mm)	No. of opening & spacing	Equivalent proto size (mm)	Size proposed by Project Authorities (mm)
1	0.033	66.66x26.66	1	2000 x 800	2000x1200
2	0.10	10 mm dia	1	300 dia	200
3 to 17	0.20 to 1.6	8.33 mm dia	15 Nos. 100 mm c/c	250 dia	117.5
18 to 27	1.73 to 2.933	8.33 mm dia	10 Nos. 133.33 mm c/c	250 dia	175
28 to 37	3.066 to 4.266	8.33 mm dia	10 Nos. 133/33 mm c/c	250 dia	175
38 to 57	4.433 to 7.60	6.66 mm dia	20 Nos. 166.66 mm c/c	200 dia	150
58 to 67	7.76 to 9.266	6.66 mm dia	10 Nos. 166.66 mm c/c	200 dia	125
68 to 82	9.466 to 12.266	5.00 mm dia	15 Nos. 200.00 mm c/c	150 dia	125
83	12.466	10.00 mm dia	1	300 dia	200

Note : Distance in column no.2 is from the end of inlet transition

TABLE-6.4

DIMENSION AND DETAILS OF DESILTING BASIN MODEL SCALE 1:30 GEOMETRICALLY SIMILAR

Data	Prototype	Model
Inlet discharge (cum/s)	85.20	0.0173
Outlet discharge (cum/s)	71.00	0.0144
Flushing discharge (cum/s)	14.20	0.00288
Depth of flow (m)	21.75	0.725
Length of basin (m)	375.00	12.50
Width of basin(m)	16.00	0.5333
Flow area (sq.m.)	297.85	0.331
Average flow thorugh velocity (m/s)	0.262	0.047
Specific gravity of sediment	2.62	1.32
Flushing tunnel at beginning (m) *	0.8 x 2.00	0.026 x 0.0667
Flushing tunnel at the end (m)	2.00 x 2.00	0.0667 x 0.0667
Velocity in flushing tunnel at beginning (m/s)	3.00	0.547
Velocity in flushing tunnel at end (m/s)	3.55	0.648

* The size of the flushing tunnel at the beginning would be 0.8 m (W) x 1.4 m(H) with a bed slope of 1 in 50 in the initial reach of 30 m.

TABLE-6.5

ESTIMATION OF SETTLING EFFICIENCY IN THE MODEL

Sr. No.	Total Injection time (Hrs.)	Material injected (litres)	Material found in		Material washed away (litres)	Efficiency Col.4 ------- x100 Col.3 (%)	Concentration (ppm)
			H.R.T. (litres)	Flushing Tunnel (litres)			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1.	4.00	350	32.50	305	12.5	87.14	4200
2.	4.30	400	35.50	350	14.5	87.50	4500
3.	4.85	500	38.00	440	17.0	88.00	5000
4.*	5.00	300	10.00	278	12.0	92.66	3000
							Average 88.83%

Average efficiency from model experiments : 88.83%

Average efficiency estimated analytically : 85.63%

* Experiment conducted with

(i) Modified transition of 28.5 m length having bed slope of 2H : 1V
(ii) Modified sizes of the openings as given in Table 6.10 and
(iii) Modified size and bed slope for flushing tunnel in the initial reach of 30 m.

TABLE-6.6

ANALYTICAL ESTIMATION OF SETTLING EFFICIENCY IN THE MODEL

Sample No.1

V = 0.047 m/s   Vo = 0.00273 m/s

Sl. No.	% finer	Mean dia (mm) from gradation curve	Fall velocity (w) (m/sec)	$122 \frac{w}{V}$	$\frac{w}{Vo}$	Removal ratio
1	2	3	4	5	6	7
1.	5	0.050	0.000435	1.129	0.159	0.159
2.	15	0.09	0.0014	3.634	0.512	0.49
3.	25	0.15	0.00375	9.73	1.37	0.96
4.	35	0.22	0.0079	20.50	2.89	1.00
5.	45	0.28	0.011	28.55	4.03	1.00
6.	55	0.32	0.013	33.74	4.76	1.00
7.	65	0.38	0.016	41.53	5.86	1.00
8.	75	0.40	0.0176	45.68	6.44	1.00
9.	85	0.45	0.020	51.91	7.32	1.00
10.	95	0.55	0.0247	64.11	9.04	1.00
					Total	8.591
					i.e.	85.91%

V = Average forward velocity
Vo = Required vertical velocity

Note:- (i) For gradation of the material refer figure –6.12.
(ii) 122 is a constant as given in column no. 5

TABLE-6.7

ANALYTICAL ESTIMATION OF SETTLING EFFICIENCY IN THE MODEL

Sample No.2

V = 0.047 m/s   Vo = 0.00273 m/s

Sl. No.	% finer	Mean dia (mm) from gradation curve	Fall velocity (w) (m/sec)	122 w/V	w/Vo	Removal ratio
1	2	3	4	5	6	7
1.	5	0.050	0.000435	1.129	0.159	0.159
2.	15	0.085	0.00125	3.24	0.46	0.45
3.	25	0.14	0.0033	7.78	1.21	0.93
4.	35	0.18	0.00524	13.60	1.92	0.99
5.	45	0.24	0.0085	22.06	3.11	1.00
6.	55	0.30	0.012	31.14	4.39	1.00
7.	65	0.34	0.0139	36.08	5.09	1.00
8.	75	0.38	0.016	41.53	5.86	1.00
9.	85	0.45	0.020	51.91	7.32	1.00
10.	95	0.55	0.0247	64.11	9.04	1.00
					Total	8.529
					i.e.	85.29%

V = Average forward velocity
Vo = Required vertical velocity

Note:- (i) For gradation of the material refer figure 6.12.
(ii) 122 is a constant as given in column no. 5

TABLE-6.8

ANALYTICAL ESTIMATION OF SETTLING EFFICIENCY IN THE MODEL

Sample No.3

V = 0.047 m/s　　Vo = 0.00273 m/s

Sl. No.	% finer	Mean dia (mm) from gradation curve	Fall velocity (w) (m/sec)	$122 \frac{w}{V}$	$\frac{w}{Vo}$	Removal ratio
1	2	3	4	5	6	7
1.	5	0.050	0.000435	1.129	0.087	0.159
2.	15	0.087	0.0013	3.37	0.097	0.46
3.	25	0.145	0.0035	9.08	0.103	0.95
4.	35	0.200	0.0063	16.35	0.123	1.00
5.	45	0.260	0.010	25.95	0.134	1.00
6.	55	0.310	0.013	33.74	0.164	1.00
7.	65	0.360	0.0157	40.75	0.260	1.00
8.	75	0.390	0.0170	44.12	0.670	1.00
9.	85	0.450	0.020	51.91	1.960	1.00
10.	95	0.550	0.0247	64.11	6.700	1.00
					Total	8.569
					i.e.	85.69%

V = Average forward velocity
Vo = Required vertical velocity

Note:- (i) For gradation of the material refer figure –6.12.
(ii) 122 is a constant as given in column no. 5

TABLE-6.9

REMOVAL RATIO OF VARIOUS SIZE PARTICLES

Sl. No.	Particle diameter in model	Fall velocity m/s	Removal Ratio (%)	Proto fall velocity m/s	Equivalent proto particle mm
1.	0.050	4.35×10^{-4}	15.9	2.30×10^{-3}	0.051
2.	0.085	1.25×10^{-3}	45	6.80×10^{-3}	0.090
3.	0.090	1.40×10^{-3}	49	7.66×10^{-3}	0.095
4.	0.150	3.75×10^{-3}	96	2.05×10^{-2}	0.170
5.	0.180	5.24×10^{-3}	99	2.87×10^{-2}	0.230
6.	0.200	6.30×10^{-3}	100	3.45×10^{-2}	0.260

TABLE – 6.10

SIZES AND SPACINGS OF THE OPENINGS BETWEEN SETTLING TRENCH AND FLUSHING TUNNEL RECOMMENDED

Opening No.	Distance(m)	Size (mm)	No. of opening & spacing	Equivalent proto size (mm)
1	2	3	4	5
1	0.0383	56.66x20.00	1	1700 x 600
2	0.10	10 ø	1	300 ø
3 to 17	0.20 to 1.6	10 ø	15 Nos. 100 mm c/c	300 ø
18 to 27	1.73 to 2.933	8.33 ø	10 Nos. 133.33 mm c/c	250 ø
28 to 37	3.066 to 4.266	8.33 ø	10 Nos. 133/33 mm c/c	250 ø
38 to 57	4.433 to 7.60	6.66 ø	20 Nos. 166.66 mm c/c	200 ø
58 to 67	7.76 to 9.266	6.66 ø	10 Nos. 166.66 mm c/c	200 ø
68 to 82	9.466 to 12.266	5.00 ø	15 Nos. 200.00 mm c/c	150 ø
83	12.466	10.00 ø	1	300 ø

Note : Distance in column no.2 is from the end of inlet transition

CHAPTER –7

CONCLUSIONS & SUGGESTIONS FOR FURTHER STUDIES

7.1 GENERAL

In the foregoing chapters a study has been made for desilting basins in respect of parameters on which its efficiency depends, the design approaches and the role of the model studies in finalising hydraulic design of basins. Hydraulic model studies connected with one desilting basin carried out at Central Water & Power Research Station, Pune to develop overall size, shape & slope of inlet transition, desilting basin and flushing tunnel for 90% removal of sediment coarser then 0.2 mm have been described in detail. Following conclusions and suggestions have been drawn from the study:

7.2.1 The review of literature and the results of the model studies have shown that the following are the important parameters on which the efficiency of a desilting basin depends:

(i) The sediment distribution at the inlet of the basin.

(ii) Flow through velocities in the basin.

(iii) The shape of hoppers.

(iv) The transitions at the inlet and the outlet.

(v) Flushing arrangements.

7.2.2 There are several approaches for determining the size of a desilting basin. These basically depend on the size of particle to be excluded and its fall velocity. The approaches differ in accounting for the effect of turbulence and concentration of sediment on fall velocity of particle, shear stress at the bottom required not to move the sediment already deposited. These approaches are found to give largely varying size of basin for a particular size of sediment to be excluded. This is the basis for the necessity of a model study.

7.2.3 A review of several model studies has shown that the basin size worked out on Camp's criteria shows satisfactory performance on the model.

7.2.4 Model study of Chamera, stage II which has been carried out at CW&PRS, Pune and described in detail in this study has revealed following important aspects.

(i) The geometrically similar large scale model shall be constructed.

(ii) It is advisable to construct the model of transparent material so that flow conditions and sediment transport may be properly visualised.

(iii) The prototype fine sediment shall be simulated through fall velocity consideration using low density material.

(iv) The inlet and outlet transitions and the efficient flushing system can be evolved only through the model study.

7.3 SUGGESTIONS FOR FURTHER STUDY

The model studies have shown that most of the design approaches are valid for excluding sediment size upto 0.15 mm. Ranga Raju et. al. (64) have suggested an approach for design of basin for fine particles. Studies are required to validate this approach.

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