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Draft Indian Standard

CRITERIA FOR HYDRAULIC DESIGN OF SEDIMENT EJECTORS FOR HYDRO POWER PROJECTS

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FOREWORD

(Formal clauses will be added later)

In most of the run-of-the river schemes, suspended load, especially sharp edged high silt contents, of coarser size and sediments transported by mountainous streams causes rapid wear of penstock and extensive abrasion of the turbine blades and other parts of the machine. This results in loss of turbine efficiency. Abrasion effects become more pronounced with increasing head. For the successful functioning of hydropower plant, it is necessary that the water be free from suspended sediment particles as far as possible. Sediment ejectors are required to be provided for removal of suspended sediments.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated expressing the result of a test or analysis, shall be rounded off in accordance with IS 2:1960 `Rules for rounding off numerical values (revised)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this special publication.

Draft Indian Standard

CRITERIA FOR HYDRAULIC DESIGN OF SEDIMENT EJECTORS FOR HYDRO POWER PROJECTS

1 SCOPE

This standard covers the criteria for hydraulic design of sediment ejectors for hydropower projects.

2 REFERENCES

The Indian Standard listed below contain provisions which, through reference in this text, constitute provisions of this standard. At the time of publication, the edition indicated was valid. All standards are subject to revision and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standard indicated below:

IS No.	***Title***
6004:1980	Criteria for Hydraulic Design of Sediment Ejector for Irrigation and Power Canals (first revision)

3 TYPES OF SEDIMENT EJECTORS

Various types of sediment ejecting devices generally used are

(i) Settling Basin cum Hopper type ejector
(ii) Scalper-ejector type of silt ejector
(iii) Vortex type ejectors
(iv) Diaphragm type ejector and
(v) Settling-cum-Flushing tank.

Among these ejectors, settling basins are being used extensively because of its higher efficiency and suitability for wide range of incoming sediment particles. Hence this standard deals at length with the hydraulic design of settling basin, other type of ejectors have been described briefly and supported by figures where ever possible.

4 SYMBOLS

The symbols used in the standard are given below**:**

a = co-efficient
= 36, for $d > 1$mm
= 44, for 1 mm$>d>$0.1 mm
= 51, for $d<$ 0.1 mm
d = diameter of particles in mm
b = width of settling basin in m
C = the value of sediment concentration of raw water in ppm
C_p = the permissible value of sediment concentration of clarified water in ppm
D = vortex chamber diameter in m
g = acceleration due to gravity in m/s^2
h = water depth/depth of settling basin in m
ℓ = settling length in m
n = rugosity co-efficient
Q = Discharge passing through the basin in m^3/s
$(q_s)e$ = quantity of sediment of given particle size in effluent
$(q_s)i$ = quantity of sediment of given particle size in influent

t = settling time in s
v = flow through velocity in m/s
w = Settling velocity in m/s
w' = reduction in settling velocity in m/s
W = ratio of settled sediment to total load entering the flow
β = sediment transport function
λ = Coefficient dependent on the removal ratio, defined as f(w)
α = Coefficient given by $0.132 / (h)^{1/2}$
Y = specific weight of water on t /cum

5 SETTLING BASIN

Settling basin is provided to reduce undesirable sediment particles in water from entering the head race tunnel or channel. The underlying principle is to provide a section wide and long enough so that the resulting reduced flow velocity will allow the sediment to settle out. The flow into the basin is regulated by gates at intake. The settled sediment is flushed out of the basin through the flushing conduit/tunnel back into the river. The gates should be provided in flushing tunnel considering the ease in approach, operation and maintenance.

5.1 Classification

Settling basins can be classified into various types as follows:

Basis of Classification		*Types*	
i)	Mode of construction	a)	Natural
		b)	Artificial
ii)	Mode of operation	a)	Intermittent
		b)	Continuous
iii)	Method of cleaning	a)	Manual
		b)	Mechanical
		c)	Hydraulic
iv)	Type of flow	a)	Open channel
		b)	Closed conduit
v)	Configuration/Layout	a)	Single unit
		b)	Multiple units

5.2 Exploration of Sediment Conditions

The quantitative and qualitative analysis of the sediment load carried by the river is to be explored. The suspended sediment is generally of mixed gradation i.e. of different particle sizes including colloidal grains (smaller than 0.002 mm) upto the grains of sand fraction.

5.3 Extent of sediment removal

5.3.1 The extent of sediment removal is governed by the operating requirements imposed in order to increase the useful life of hydro-mechanical equipment i.e. penstocks, valves, turbines etc. The operating requirements are approximately specified by the diameter of the particle size to be settled out and the allowable concentration of sediments.

5.3.2 The settling basin should normally be provided if the total suspended sediment concentration in water is greater than 0.2 kg/m^3 (200 ppm). However, the opinion of turbine manufacturer/designer should be obtained.

5.3.3 For projects with heads ranging from 15m to 50m, removal of particles larger than 0.2mm is usually specified. It is usual to remove sediment particle of size 0.15mm and above for high head (greater than 50m) power projects. For heads greater than 50m, the sediment particle size of larger than 0.1mm may be objectionable if the fine sediment fraction include sharp edge quartzite grains.

5.3.4 Instead of using limits of particle size, the removal ratio is also used. The ratio of concentration after settling expressed as percentage is termed removal ratio.

$$\text{Removal ratio (\%)} = 100\frac{C_p}{C}$$

Where Cp = the permissible value of sediment concentration of clarified water
C = the value of sediment concentration of raw water

By specifying or assuming the limit particle size, the removal ratio may easily be calculated or read off directly from the gradation curve, if the gradation of the suspended sediment is known. The lower sized particles may be removed by flocculation.

5.4 Location and Orientation

The settling basin may be suitably located in the head reach of the water conductor system, just downstream of the hydropower intake structure. The orientation of the basin has to be proper with respect to the alignment of the inlet tunnel/channel on the upstream to achieve satisfactory distribution of flow, as naturally as possible. The tunnel upstream of the basin should be straight for at least a length equal to ten times the average width of the channel, or diameter of the tunnel, to achieve uniform flow in the basin. In case the approach channel is curved due to unavoidable site conditions, the transition reach of suitable length and proper design should be provided. Turbulence can be minimized to a great extent by providing proper transitions. Upstream and downstream bed slope of the desilting chamber should be such so as to minimize silt deposition on the bed slopes.

5.5 Hydraulic design

5.5.1 The settling velocity of the sediment particle to be removed should be estimated. The experimental approach to this problem, with the given type of sediment is deemed most expedient. The computation method, may however, be resorted to in the preliminary design. Several charts are available for estimation of settling velocity. Settling velocities in stagnant water at a water temperature of about 5 ^{o}C to 10 ^{o}C is given in Fig.1. The chart provides information as to the settling of coarse quartzite particles but cannot be used for determining the settling characteristics of fine sand and smaller particles. Another chart is given in Fig.2 for estimation of fall velocity of quartz spheres in fresh water and in air under a pressure of one atmosphere, for temperatures ranging from 0 ^{o}C to 40^{0} C, which generally satisfies most of the practical requirements.

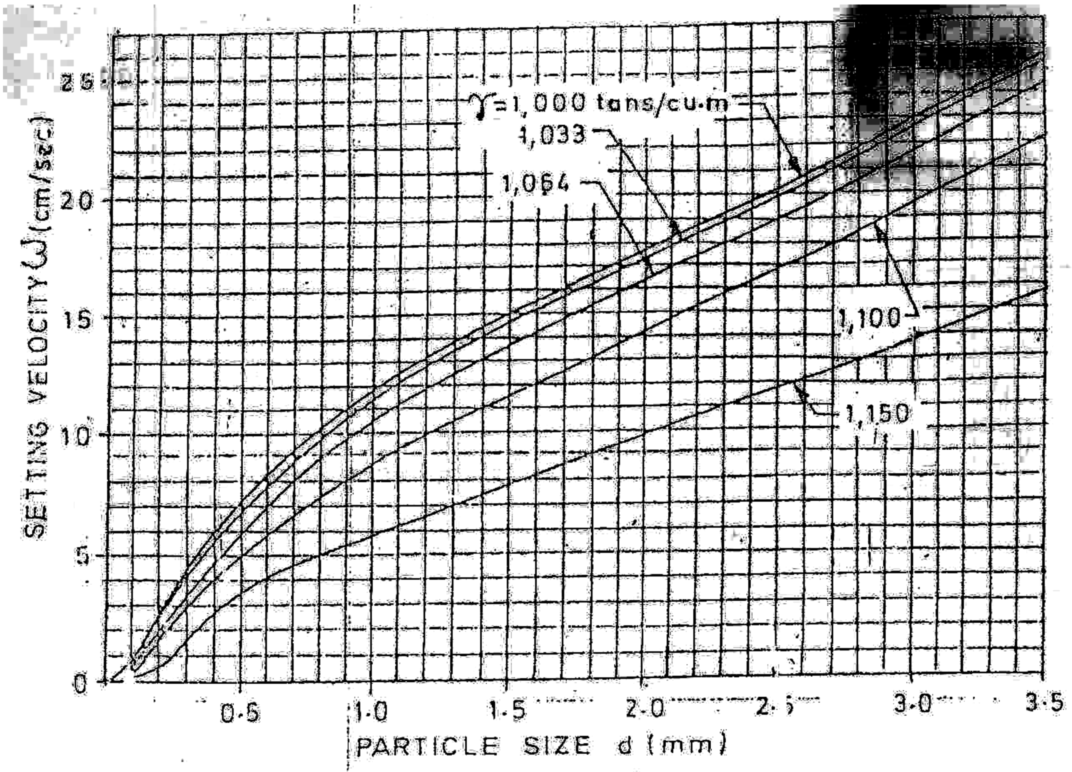


Fig. 1 SETTLING VELOCITY IN STAGNANT WATER PLOTTED AGAINST THE DENSITY OF SILTY AND THE PARTICLE DIAMETER (AFTER L. SUDRY)

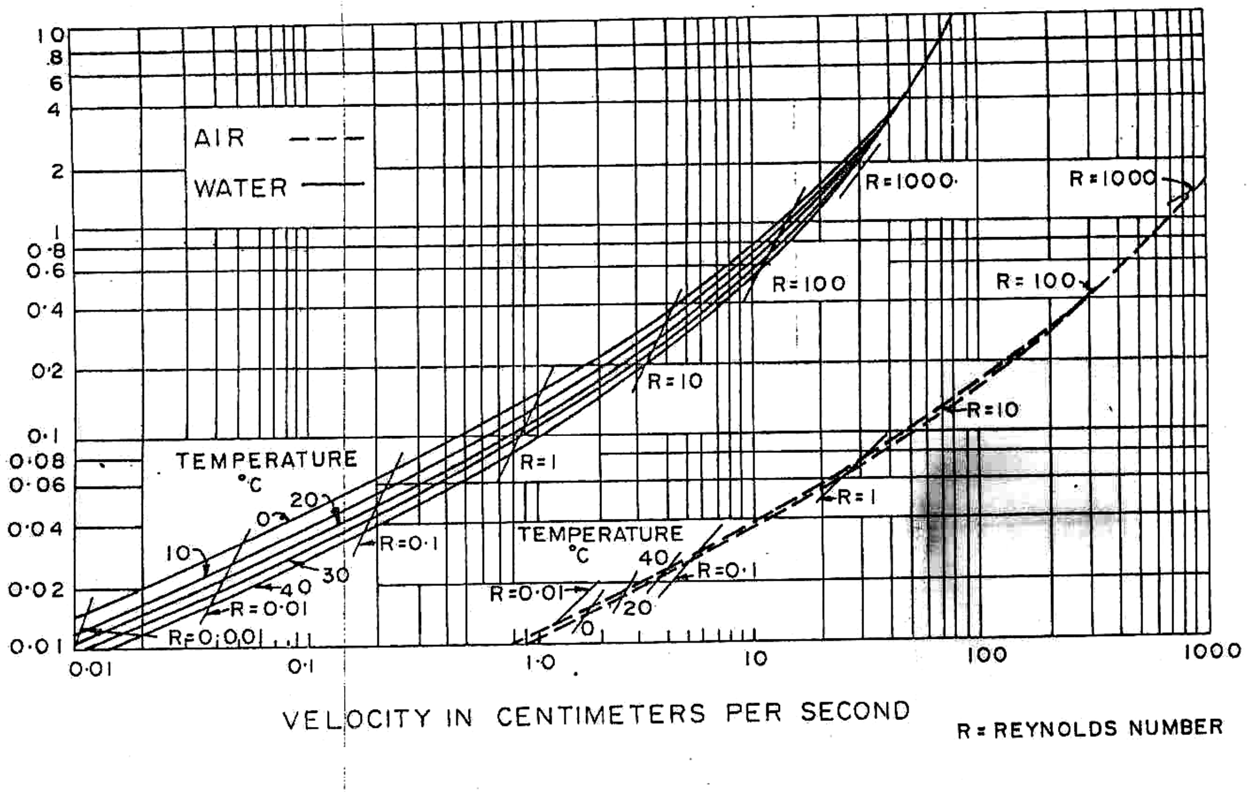


FIG. 2: FALL VELOCITY OF QUARTZ SPHERES IN AIR AND WATER

5.5.2 Owing to the retarding effect of the turbulent flow on settling particles, settling is slower in flowing water. Thus, use of a lower settling velocity (w-w'), will yield greater values for the length of the basin also called settling length.The reduction in settling velocity w' is related to the flow through velocity.

$$w' = \alpha v \text{ (m/sec)} \qquad \text{...........(i)}$$

$$\text{The coefficient } \alpha = \frac{0.132}{(h)^{1/2}} \qquad \text{..........(ii)}$$

Where 'h' is the water depth in m. The settling length is therefore

$$\ell = hv/(w-\alpha v)$$

$$\ell = \frac{h^{3/2}\, v}{h^{1/2}\, w-0.132v} \qquad \text{.........(iii)}$$

A negative denominator would indicate that no settling can be attained under assumed conditions. The computations should be repeated using modified dimensions.

5.5.3 The settling length for turbulent flow is computed from the settling velocity in stagnant water and the flow through velocity. The settling length.

$$\ell = \frac{\lambda^2\, v^2\, ((h)^{1/2}-0.2)^2}{7.51\, w^2} \qquad \text{..........(iv)}$$

Where λ depends on the removal ratio. Values of 'λ' defined by the function

$$\lambda = f(W) \qquad \text{...........(v)}$$

are given by Velikanov's relationship curves (Fig.3). 'W' denotes the ratio of settled sediment to the total load entering with the flow and can be computed as follows:

$$W = 100 – 100\ Cp/C \text{ (per cent)} \qquad \text{..........(vi)}$$

Satisfactory values can be obtained by using coefficients (λ) pertaining to a 95 percent to 98 per cent removal of the limit particle size.

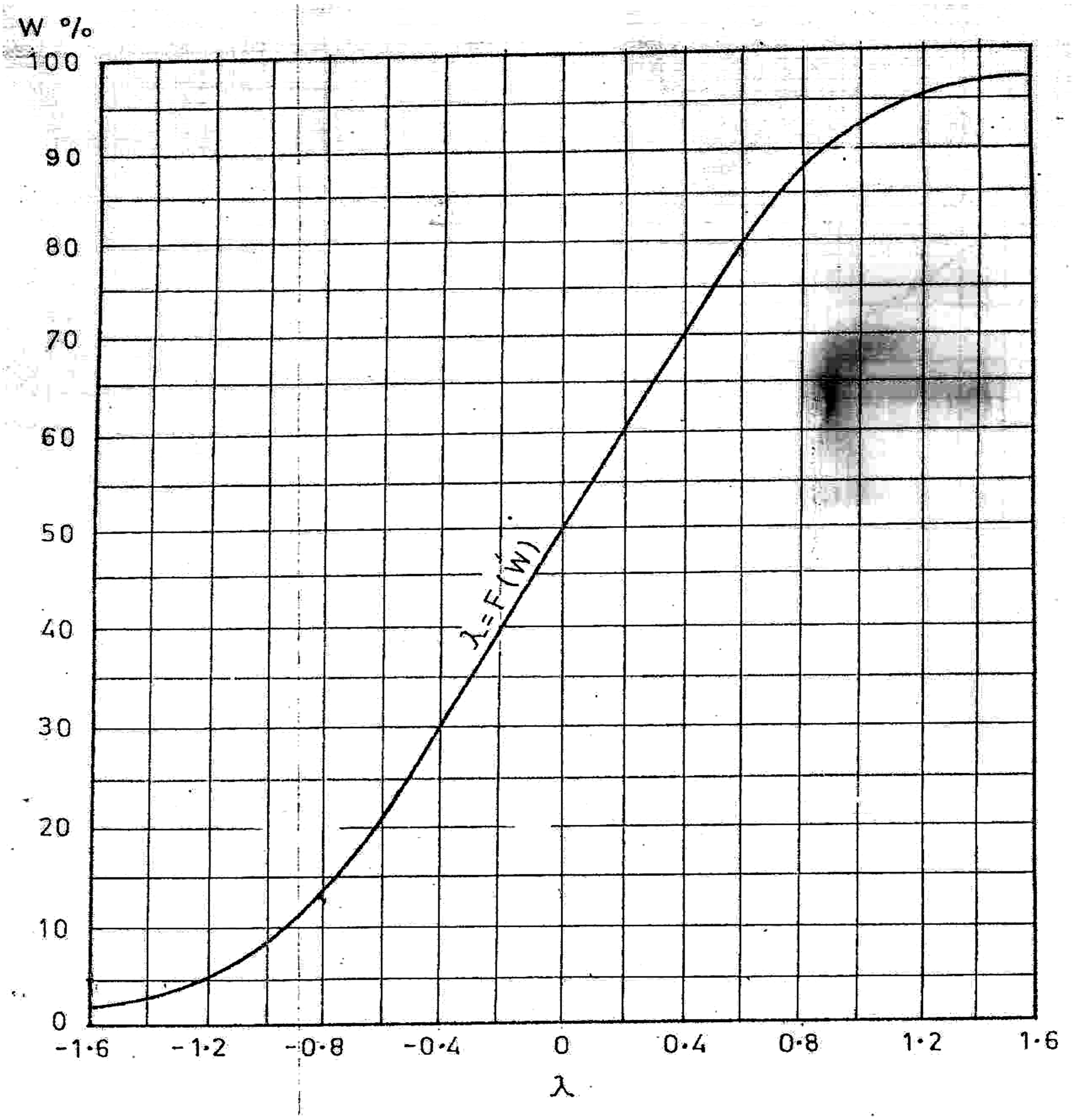


Fig 3. Velikanov's relationship curves

5.5.4 There are three basic relations for the determination of the required basin length 'ℓ'. Denoting the depth of the basin by 'h' and its width by 'b', the discharge passing through the basin is given below.

$$Q = b.h.v \ m^3/sec \qquad ....(vii)$$

5.5.5 The second equation expressing the relation between the settling velocity 'w' the depth of basin 'h' and settling time 't' is

$$t = \frac{h}{w} \qquad \left[\frac{m}{m/sec} = sec\right] \qquad ....(viii)$$

5.5.6 Camp investigated Settling conditions differing from turbulent equilibrium conditions of sediment transport. After evaluating the turbulent transport function for two dimensional flow he derived a functional relation for the ratio of sediment leaving the basin to that entering. This relation is shown in Fig. 4.

Efficiency of a sedimentation chamber is a function of following two factors:

(i) $\frac{w\lambda}{v\,h}$ and (ii) $\frac{w(h)^{1/6}}{v.n\sqrt{g}}$

where

$\frac{\ell}{V} =$ travel time of particle along length

$\frac{h}{w} =$ travel time of particle along depth

Depending on the sediment size to be removed, a velocity of 0.15 m/s to 0.3 m/s is generally kept in the basin to avoid hydraulic short circuiting.

Most of settling basins have been constructed in power channels/tunnels for projects located in mountainous region, where longer lengths of basin may be more economical than deeper basins to achieve same sedimentation area. Optimal depth and length of the basin should be worked out for economical design.

Sediment transport function β is worked out as

$$\beta = \frac{w(h)^{1/6}}{v.n\sqrt{g}} \qquad \text{..........(ix)}$$

For sediment transport function and desired efficiency β is read from Camp's curves

Thus length of sedimentation chamber is

$$\ell = \frac{\beta\, v\, h}{w} \qquad \text{..........(x)}$$

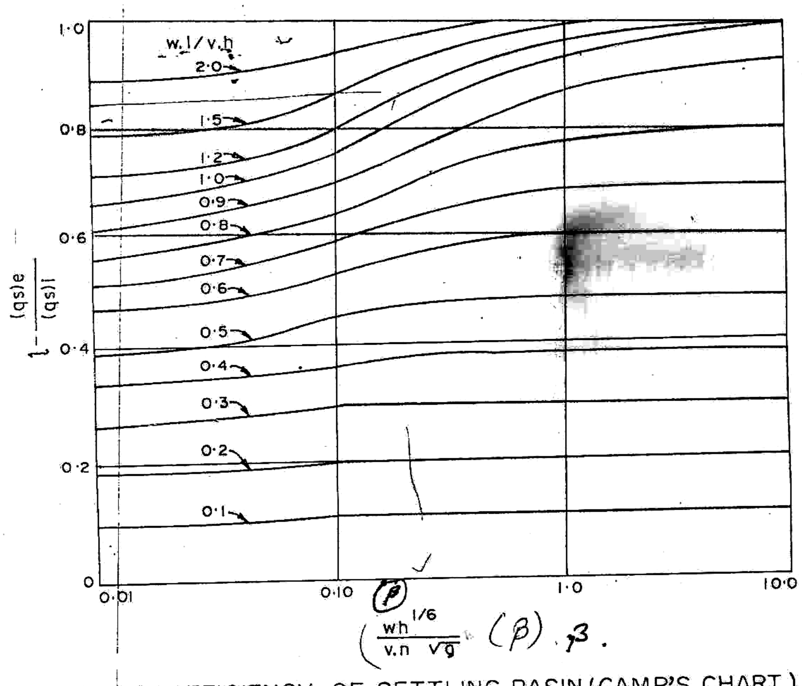


FIG.4 : EFFICIENCY OF SETTLING BASIN (CAMP'S CHART)

5.5.7 Finally, the length of the basin will be governed by the consideration that the water particles entering the basin and the sediment particles conveyed by them with equal horizontal velocity should only reach the end of the basin after a period longer than the settling time. In other words the retention period should not be shorter than the settling time. The required length of the basin is thus

$$\ell = v.t \ [\,m\,] \qquad \text{..........(xi)}$$

5.5.8 Eliminating 't' from the equations (viii) and (xi), two relations will be established between the six values governing the hydraulic design.

$Q = b.h.v$

$\ell w = hv$ ....(xii)

The solution of the problem is not possible unless four of the six quantities are known. The discharge 'Q' is known and settling velocity 'w', defined by the initially specified degree of removal, can be established by calculation or experimentally. The highest permissible flow-through velocity should also be defined, in order to prevent particles once settled from being picked up again. The actual flow-through velocity should not exceed this limit whereas excessive dimensions computed by substantially lower velocities would again result in uneconomical design. Velocities higher than the permissible tend to scour the material settling to the bottom which may even become suspended again. This limit velocity may be considered equal to the theoretical suspending velocity or to the critical velocity. The value of the critical velocity may be determined by using the following Camp's equation or any other equation.

$v = a (d)^{1/2}$ cm/sec ....(xiii)

Where 'd' is the diameter of particles in mm and the coefficient

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

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

$a = 51$ for $d < 0.1$ mm

(the velocity 'v' computed above should be converted into m/sec).

5.5.9 The fourth value that can be assumed in advance is one of the main dimensions of the basin. In view of the fact that long and/or wide basins can in general be constructed at lower costs than deep ones, the minimum practical depth should be assumed for the design. In underground construction, the width may become the governing factor on account of supporting problem and may have to be restricted thus necessitating and increase in depth.

5.5.10 The remaining two dimensions of the basin may be computed from equation (vii) and (xii). The width/depth should be calculated by the first equation and length by the second equation. Elimination of 'v' from Equations (vii) and (xii) yields.

$Qt = b.h.\ell$ = Volume of settling basin in m^3 .....(xiv)

expressing the condition that the water mass conveyed during settling time should equal the capacity of the settling basin.

For the economic design of settling basin, the length of the basin should be computed for a set of various depths and widths, in consideration of practical aspects and given site condition, and the dimensions which give least basin area/minimum cost should be adopted.

5.5.11 At least two rows of hoppers are advisable with the provision that each may be run in isolation so that if there is chocking in any row of hopper, it may be cleaned without 100% shutdown of the power house. The holes of hopper should be so decided that each hole may pass almost equal discharge. The first hole should be of big size as there will be coarser material in this portion. The minimum slope of hopper and sides of the chamber equal to 40^o from horizontal are advisable.

5.5.12 The required silt carrying capacity should be computed with the help of Camp's curve. The available silt carrying capacity of the flushing duct should be computed with the help of flow velocity, hydraulic gradient and size of flushing duct. The available silt carrying capacity of the flushing duct should be more than required silt carrying capacity of the duct. If reverse slope in the flushing duct is provided, the flushing velocity of the duct must be increased in respect of slope. The velocity of 3m/s to 5m/s in increasing order from entry to outfall is preferable in the flushing conduit. Normally, 10% to 20% of the inlet discharge is required for flushing of the sediment. Typical layout and section of the hopper type settling basin is given in Fig.5.

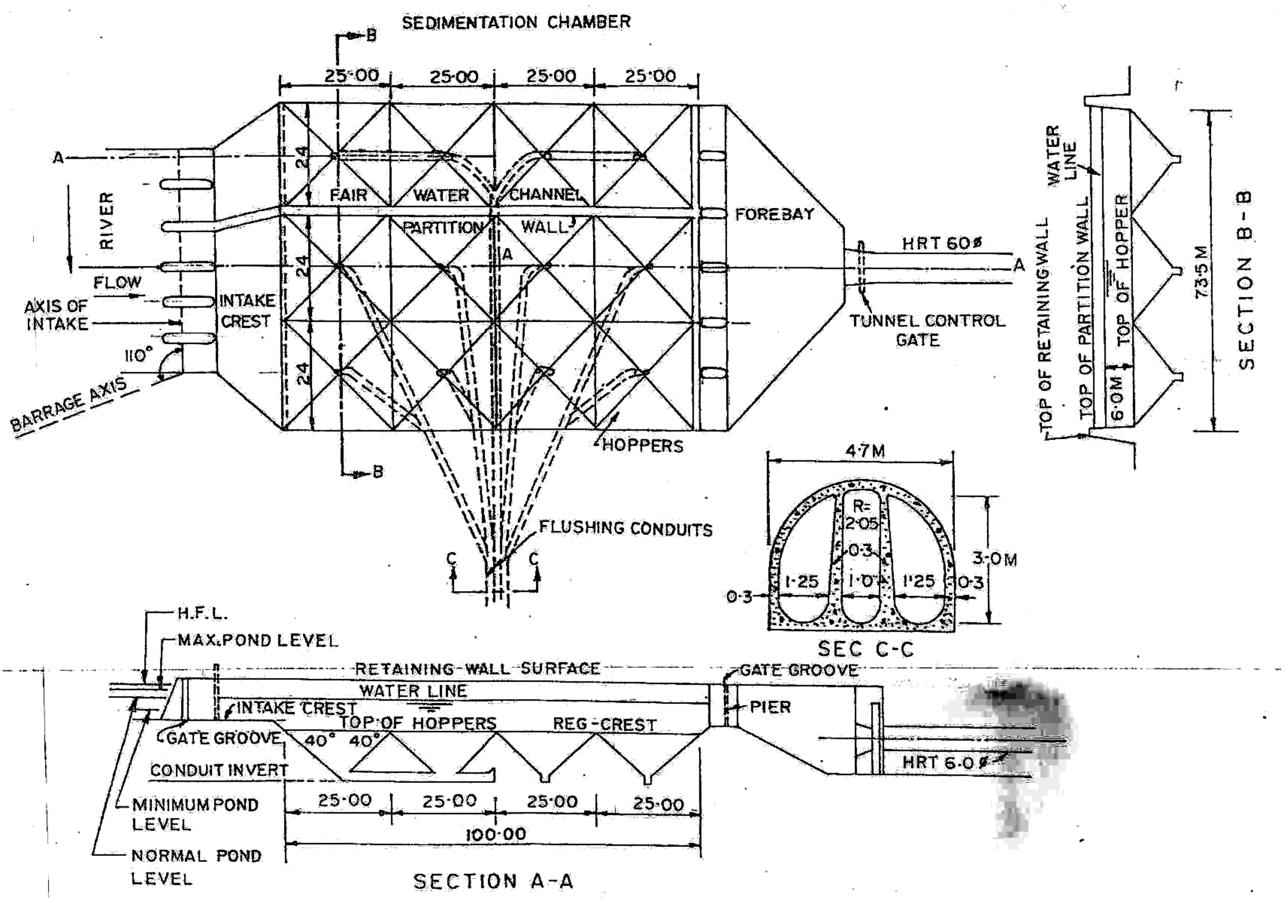


FIG.5 : PLAN OF SETTLING BASIN . AND HOPPER TYPE EJECTOR

6 SCALPER – EJECTOR TYPE OF SILT EJECTOR

A number of systems are available for sand benefication viz., Bowl classifier, Rake classifier, Hydrocones, Scalping tank. The scalping tank is the most efficient of all, with no moving parts and about 85 per cent removal efficiency is achieved. It works on the Stoke's theorem. The significant feature of the scalping tank is that the sediment is taken out of the tank from the very place of settlement in the settling chamber. This feature is used in the design of silt ejector, therefore is called a scalper-ejector type. This type of ejector can be adopted in a power channel for medium head (61m) development with Francis turbine in hilly region to obviate the requirement of long space for conventional type silt ejector/settling basins. The design of scalper ejector developed theoretically and subsequently rectified with aid of hydraulic model is shown in Fig. 6 and 7. Uniformity of flow in sedimentation chamber is of great importance, since the design makes use of the property of isovels to drop off from the mean value significantly at the side. This can be achieved with the aid of sloping bars suitably located in upstream of settling basin with the aid of hydraulic models. It is preferred that as far as practicable this type of ejector should be located in straight reach to avoid non-uniformity of flow. The settling basin is 91 m long and 30 m wide in contract to lengths of 1000 m and 200 m required for settling of particles of 0.1 mm and 0.2 mm respectively computed after Camp. Another important aspect of this new design is conservation of water viz. escapage discharge is about 7 percent to 10 percent of the parent channel flow as against 15 percent to 20 percent in the case of conventional silt ejector.

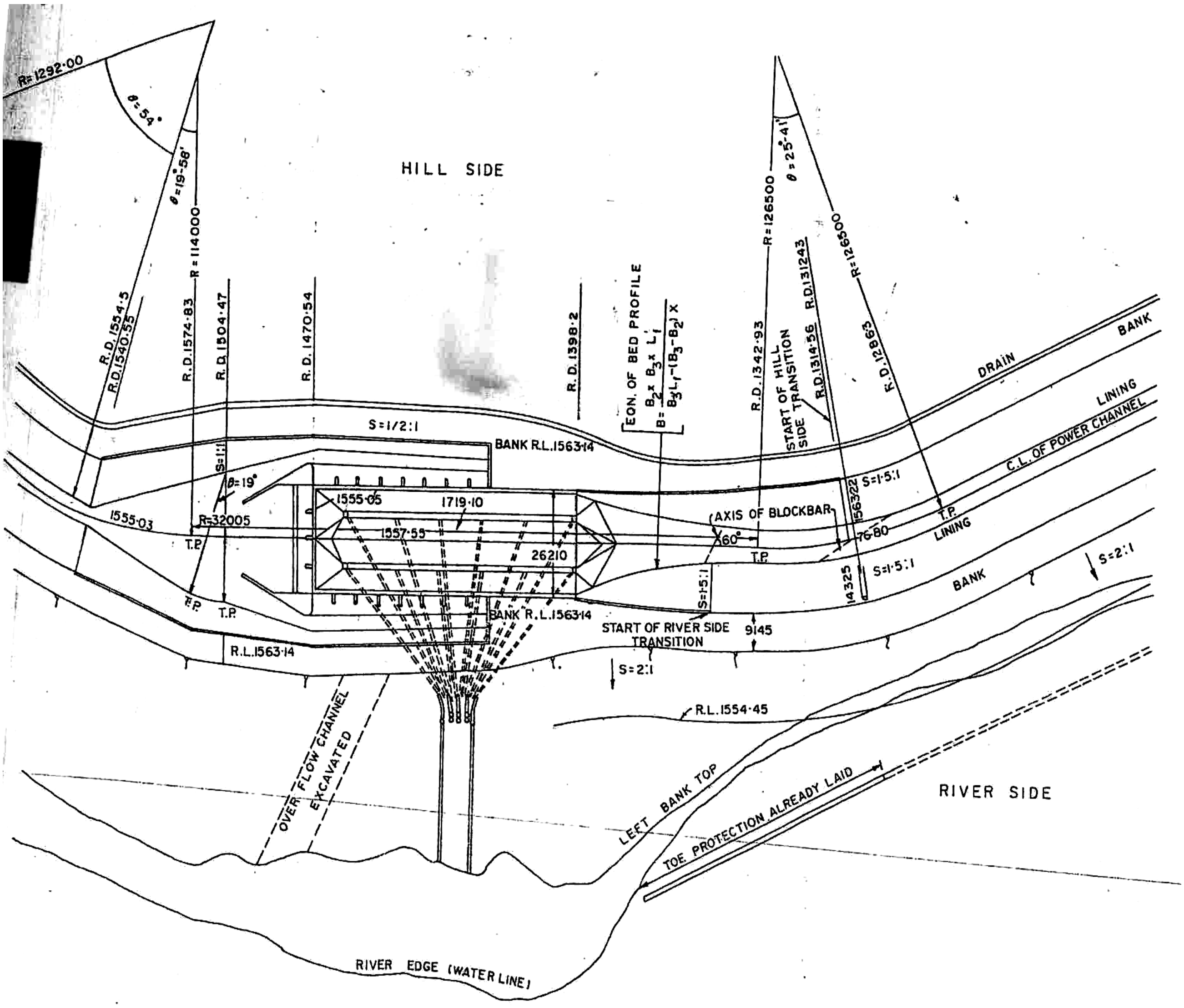
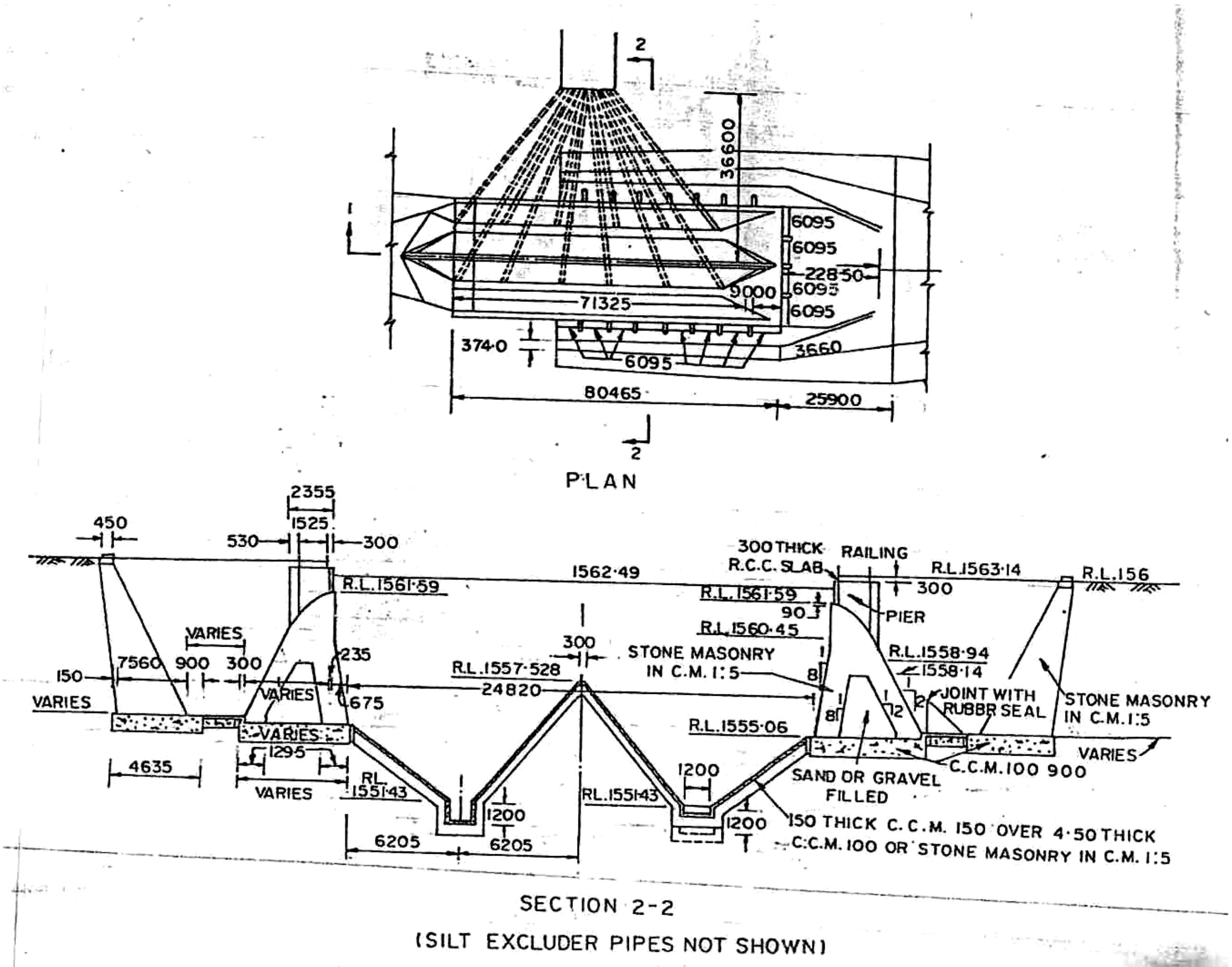


FIG. 6: LAYOUT OF SEDIMENTATION TANK FOR SCALPER-EJECTOR TYPE OF SILT EJECTOR



SECTION 2-2

(SILT EXCLUDER PIPES NOT SHOWN)

FIG.7 : PLAN AND SECTION OF SCALPER-EJECTOR TYPE OF SILT EJECTOR

7 VORTEX TYPE EJECTORS

The vortex type ejector can broadly be of two types

7.1 Vortex Chamber:

The vortex chamber uses a vortex motion with vertical axis to remove sediment from flow. If flow is introduced tangentially into a cylindrical tank with an orifice at its center, the flow pattern in the tank is a combination of those for free and forced vortices. The concept is shown in Fig.8. The water flows in tangentially, preferable from opposite sides to keep the vertical axis of the motion more or less in the center of the cylinder, and flows out over the rim, except for the small amount (5 percent to 8 percent) that leaves though the central opening. The funnel that forms in the center reduces substantially the effective area of the bottom outlet. Due to the secondary current that develops in the flow the sediment travels along a spiral path on the bottom towards the point of central discharge. The chamber operates effectively if its height is greater than or equal to one third of the radius, inlet tube(s) are placed at about mid-height, and the bed slope is greater than 0.02. Such vortex chambers are suitable for relatively coarse sediments. For these the chamber diameter (D) is related to flow rate (Q) and fall velocity (w) of the sediment to be removed by the equation.

$$D^2 = 2Q/w$$

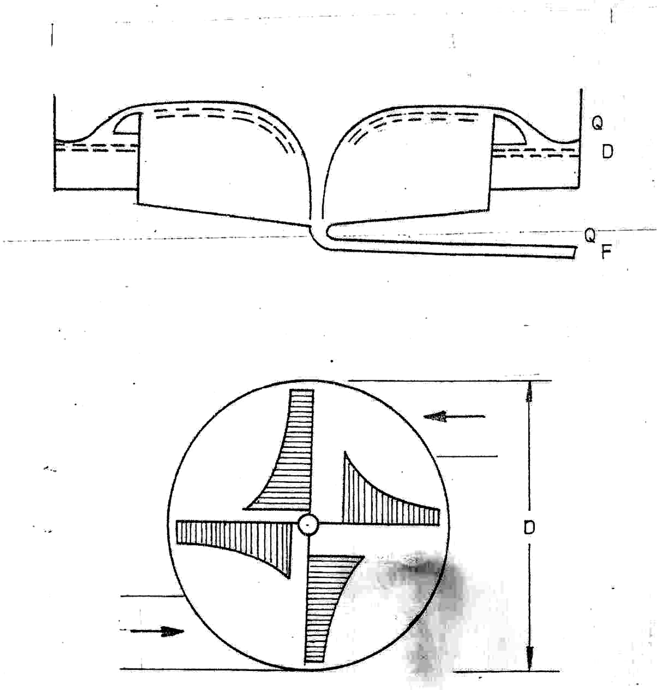


Fig 8. Vortex Chamber

7.2 Vortex tube sediment ejector

The vortex tube type ejector continuously extracts sediment from bottom layers of diverted flow by the utilization of vortex motion. It is a tube with longitudinal opening or slot at the top that is placed in the bed of the channel. The tube may be perpendicular to the flow or at a smaller angle down to 30^{0}. The flow rate is controlled by a valve or gate at the end of the tube. The spiral current generated in the tube is by suitable combination of flow and sediment characteristics and efficient conveyor of sediment. The width of the slot is function of the particle size. A wide slot is effective for coarse sediment moving over the bed. The slot should be narrower for fine sediment to minimize the quantity of water required. Longer vortex tubes should be divided into sections, each with its own outlet, because long vortex tubes tend to choke at the outlet, particularly with fine sediments.

The performance of the vortex tube depends on so many factors that it is not possible to give a general design formula. An efficient design is usually arrived at with the help of hydraulic model studies. The performance is sensitive to particle size, slot size, ratio of flow depth to tube diameter, concentration, approach flow velocity, ratio of channel to tube flow, lip height, etc. A layout of a vortex tube sediment ejector is shown in Fig.9 (a to f)

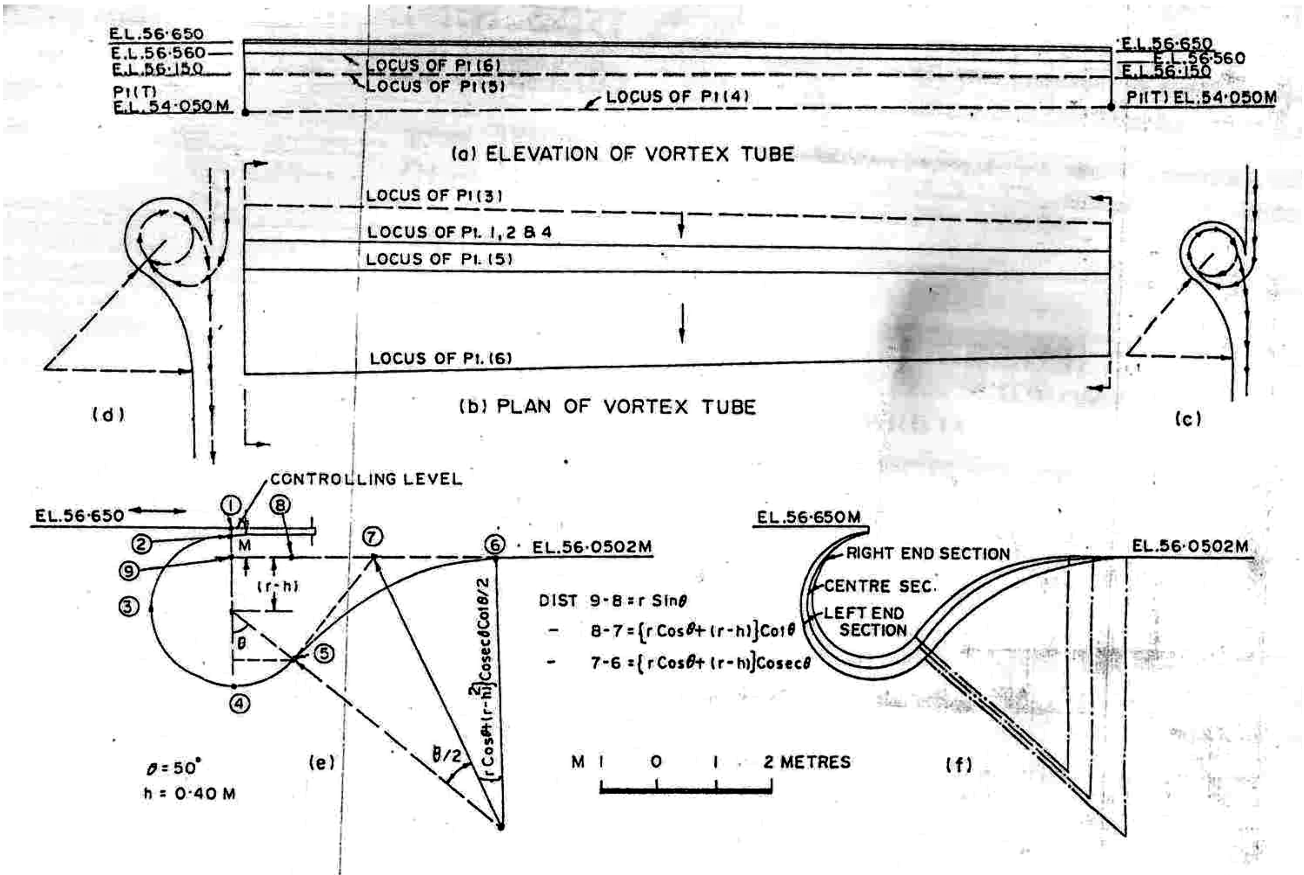


FIG.9, (a TO f): DETAILS OF VORTEX TUBE

8 DIAPHRAGM TYPE EJECTORS

The diaghragm type ejectors may be designed on the basis of IS 6004.

9 SETTLING-CUM-FLUSHING TANK

The conventional devices such as ejectors and vortex tubes have been utilised for removing the sediment from canals and power channels but only with partial success. These devices remove the sediment at and near the bed which is mostly coarse and have been observed to attain maximum efficiency of 60 percent to 70 percent for coarse sediment and only 25 percent 30 percent for medium sediment in field. The medium sediment, when present in considerable amount, poses serious problems to the functioning of water conductor system even after the provision of ejector or the vortex tube. For achieving higher efficiency settling-cum-flushing tank are designed and constructed. This system is effective in removing all sizes of sediment above 0.075mm, and works in conjunction with the sediment ejector. The arrangement consists of tank divided into two compartments, each provided with independent inlet and outlet gate. The compartment is further sub divided into flushing channels, and each flushing channel provided with separate flushing gate at the tail end. Normally, the entire tank function as settling tank, but during flushing one compartment acts as a settling tank while in the other compartment flushing operation is undertaken with the balance discharge. When flushing is over, this is used as a settling tank, and the flushing operation switched on to the other compartment. The efficiency of the model for the removal of all sizes of sediment held in suspension/excepting wash load from the entire cross-section of the flow from surface to bottom was found to be as high as 87.5 percent to 95 percent while the prototype efficiency was observed to be 77 percent. Normally the bed slope of the desilting basin should be adequate to generate flushing velocity of 3.0 m/s or higher with the designed flushing discharge in the compartment under flushing. For computing the energy and bed slopes, the sediment transport rate, etc. and bed material load for coarse and medium sediment, bed load functions after DuBoys and Laursen respectively may be used. A typical settling-cum-flushing tank constructed on power channel is given in Fig. 10.

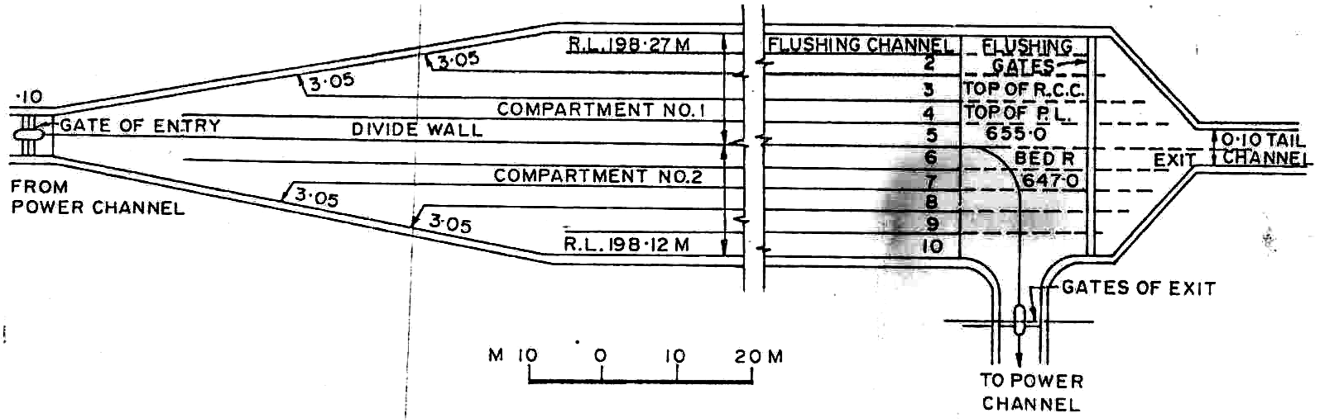


FIG.10: SETTLING-CUM-FLUSHING TANK

10 MODEL STUDIES

Physical and numerical modeling shall be resorted to wherever necessary to ascertain the hydraulic efficacy, and flushing efficiency of the sediment ejector.