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SEDIMENT EXCLUSION FROM POWER PLANT INTAKES

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SEDIMENT EXCLUSION FROM POWER PLANT INTAKES

by

Lok Bahadur Pun

A Thesis Submitted to the Faculty of the

DEPARTMENT OF CIVIL ENGINEERING AND ENGINEERING MECHANICS

In Partial Fulfillment of the Requirements
For the Degree of

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WITH A MAJOR IN CIVIL ENGINEERING

In the Graduate College

THE UNIVERSITY OF ARIZONA

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ABSTRACT

In a hydro-power plant, turbines are susceptible to damage by sediment abrasion. To avoid the problem, suspended sediment particles of a size and concentration such as would be damaging should be eliminated from the water entering the turbine. In this investigation, the efficiency of trapping natural sand as a function of the velocity and depth of approach flow and length of settling basin was observed. A relationship for design of a settling basin is provided.

CHAPTER 1

INTRODUCTION

Practically all natural streams transport varying amounts of silt, sand, and gravel. In mountainous areas particularly, rivers flowing with high velocities can carry large amounts of suspended materials and transport sand and gravel as bed load. When a part of the flow from these rivers is diverted into power stations, the suspended sediment particles at least are carried along with the diverted water and may cause significant damage in passing through the hydraulic turbines.

Statement of the Problem

In general practice, hydraulic turbines are designed for clear water. However, most natural water courses contain a considerable amount of suspended particles. If the silt-laden water is allowed to pass through a turbine, all surfaces in contact with water are susceptible to damage to some extent. Serious abrasion of turbine blades and runner chambers has been experienced in numerous hydro-plants situated on silt-laden rivers.

In some instances turbines have become inoperable after only one flood season due to excessive abrasive action, and the plants were shut down for six months, thereby seriously upsetting the energy supply. Heavy maintenance cost and loss of turbine efficiency due to silt-laden water is of grave concern in many power stations where special care was not taken to avoid suspended material in the water.

Today some special methods are employed to reduce sediment abrasion, such as using special materials and different design criteria for silt-laden water. Low specific speed turbines and reduced water velocities are the main design differences, but they result in relatively larger turbine and generator sizes and, ultimately, in an over-all increase in the cost of the plants. Experience shows that propeller type turbines are less subject to erosion by sediment than other types, and this seriously limits the options for selecting the turbine type considering other features of the plant.

There are two options for reducing turbine maintenance costs due to sediment abrasion; either a special design of, or a special material for the turbine, or the removal of the abrasive particles before the water enters the turbine. The choice is a purely economic matter. Obviously, the initial cost of sediment removal will be higher, but removal will substantially reduce the maintenance cost and ensure continued efficiency of the power plant.

The subject of turbine problems due to suspended sediment has been of concern for well over fifty years. Several methods have been suggested for the design of turbines in silt-laden water, but there are conflicting views about the phenomenon of sediment abrasion of turbines. As long as there are no definite turbine design procedures to solve the problem, settling out the suspended particles is probably the best way of reducing turbine abrasion.

The maximum size particle that can be safely permitted to pass through the turbine is the main criterion in design of sediment exclusion works. Although a definitive quantitative relationship between extent of abrasion and size of particles has not been established, experience gained in existing plants and evaluation of abrasion damage indicates that the maximum size particle that can be safely passed varies between 0.1mm and 0.7mm (Murthy and Madhaven, 1959) depending upon type of turbine, as follows:

Type of turbine	Particle size
Pelton	0.1mm
Francis	0.3mm to 0.5mm
Kaplan	0.5mm to 0.7mm

Purpose of the Research

If turbines are designed with erosion potential in mind, the resulting turbines will be different from those designed for clear water. Lower specific speed, restricted operating range, and lower level setting of the equipment are the main features differing from a design for clear water conditions. The cost of the equipment and the plant will be higher due to:

i. Extensive use of special materials.

ii. Larger conveyance facilities to reduce water velocity.

iii. Lower rotational speed.

iv. Extensive civil work associated with lower setting and larger equipment.

v. Design features of the power house to facilitate replacements of the parts exposed to erosion.

vi. Higher maintenance cost.

Therefore, elimination of abrasives from water saves the higher costs of a special turbine and power house.

The main concern of this study was to examine trapping efficiency of a simple sediment trap for particles less than 0.125 diameter. A trap designed for this size should also trap all larger particles even better, and, although 0.1mm particles are generally considered acceptable, they must do some damage. At high concentrations, there are more numerous particles in contact per unit area of turbine surfaces and, obviously, erosion will be higher than for lower concentrations. Therefore, the concentration should be negligibly low. The results of this study give a tentative solution for designing a trap which will be efficient even for fine particles.

Scope of the Study

Several attempts have been made to establish analytical solutions for designing settling basins for irrigation canals and municipal and industrial water supply. They are mainly based on hydraulic parameters in the trap proper. In this work an attempt was made to relate velocity and depth of the approach flow with the efficiency of a trap. Since there are several unknown flow parameters associated with the trap proper, it is easier to depend on definite quantities like depth and velocity of the approach flow.

Various combinations of velocity and depth were tried to check the efficiency of a trap, and a condition for high efficiency was found, which should be practical and sufficient.

CHAPTER 2

LITERATURE REVIEW

Turbines are subject to cavitation, abrasion, and corrosion. Cavitation can be limited to a great extent by using proper design, and corrosion by using noncorrosive material. However, erosion of turbine surfaces in contact with silt-laden water is still not completely understood. It is related to numerous factors like hydrodynamics, sand parameters, and flow conditions; the interrelation of these factors is highly complex.

Turbine Damage Due to Sediment

Opinions of different researchers are contradictory as to whether the combined effect of cavitation and sediment abrasion is greater or less than the effect of either one of the two alone. Du-Tong (1981) concluded that silt erosion alone is a very slow process, but that it increases the rate of cavitation in the turbine. His observation of the abrasion effect on a metal piece with silt-laden water inside a compressed air chamber led him to conclude that no matter how high or low the sediment concentration, erosion is insignificant. When the same test was repeated at atmospheric pressure, erosion was noticeable. He argues that when cavitation occurs in clear water, a film is formed which slows down the cavitation. In the case of sandy water, this protective film cannot form; the rate of cavitation is, therefore, accelerated in the silty water.

Surprisingly, there is no universally accepted relationship between rate of erosion and sediment size or concentration. Many researchers believe that erosion is proportional to sediment size and concentration, but some state that wear rate is proportional to size only in the case of sliding abrasion. Truscott (1972) suggests that wear is proportional to the number of grains per unit surface area (e.g. concentration).

Wear rate also depends on shape, mass, and hardness of sediment particles as well as on sediment size and concentration. Sharp, heavy particles harder than the turbine material will cause far more abrasion than rounded, light, and soft particles. Truscott (1972) determined that angular grains cause twice as much wear as rounded ones.

Wear rate is also a complex function of water velocity, head, and the turbine design. With other factors remaining the same, wear is proportional to the cube of the velocity and the half power of the head (Truscott, 1972). Wear also depends on impact angle and design of the turbine blade (such as angle of inclination and curvature). Truscott (1972) summarized pertinent factors in the following equation.

$$\text{wear} = u^3(p-\rho)d^3pk/D$$

in which
u = velocity of liquid,
p = density of particle,
d = diameter of particle,
k = experimental coefficient depending on abrasiveness of particle,
D = dimension of machine,
ρ = density of liquid.

The abrasive action of the sediment particles (sand or silt) on the turbine parts must involve contact between the particle and turbine blade (and other parts) and relative motion between the two. Although the particles can impact against the blades, the more important action is probably a sliding motion which scratches the blade surface. The sharper (more angular) and harder the particle, the more wear that would be expected. The higher the concentration, the more particles that would scratch the surface and the more the wear that would be expected. Even with a 10 percent concentration by volume (very high), the particles would act independently, and the effect should be linear with concentration until the concentration is so great as to affect the velocity distribution in the boundary layer. The amount of wear, therefore, should be linear with the concentration. The particles will be at a velocity close to the velocity of fluid surrounding them, differing because of the resistance force of the contact between particle and blade and, in some situations, because of a gravity effect. The larger the particles, the higher the velocity surrounding them because the particle diameter is a larger fraction of the thickness of the boundary layer. The larger the relative velocity between the particles and the turbine blade, the more wear that would be expected.

The geometry of the turbine would affect the relative velocity of the fluid (and sediment particles) and turbine parts and the boundary layer; therefore, different types of turbine and differently designed turbines should be expected to wear at different rates.

Sand Traps and Settling Basins

To avoid heavily sediment-laden water entering the turbine and to minimize the wear on the turbine, measures can be adopted in two steps.

1. Proper location and design of the intake works.
2. Construction of a desilting basin or sediment excluders in the water supply system.

The point of diversion should be selected in such a manner that a minimum amount of bed load will be carried into the power canal. The outside, concave side of a bend is considered the best location for diversion because the outer curved bank tends to be scoured and deposition takes place along the inner convex bank. Therefore, there is less sediment concentration along the outer curve than the inner bank. This can be explained by spiral flow, first discussed by Thompson (1876). In a bend the deeper part of the flow is directed toward the inner convex bank, and the upper part of the flow is directed toward the outer concave side of the curve. Hence bed load is swept towards the inner convex side of the curve. Thus the sediment in the diverted flow is finer and of less concentration than the average sediment load of the stream if the point of diversion is on the outer bank.

Various kinds of devices are used to prevent rolling bed load from entering a diversion canal. In general, the invert level of the canal should be higher than the bed level of the river at the intake. Guide vanes, guide walls, sand screens, and training walls are some of the structures commonly used to divert sand from canal intakes, but it is difficult to establish exact criteria for design of such diverters. Thus, a model study is the best approach for determining the most effective solution for particular site conditions.

Sediment Excluders

Regardless of the type of diverter employed upstream of canals, some heavy particles are held in suspension due to heavy turbulence near the gates and are bound to enter the canals. Sediment excluders commonly known as sediment ejectors, are structures designed to remove sediment which has entered the canals. In India and Pakistan tunnel type ejectors are widely used. The cross section of the excluder is transitioned into a number of tunnels having a height of about 25% of the water depth. These tunnels are laid out in a right angle and are made to converge into an outlet canal. Velocity of 8 fps to 10 fps is enough to remove sand through the tunnels. A minimum head difference of 2.5 feet is needed to operate the ejector.

In the United States, the vortex tube sand trap, first introduced by Parshall (1950), has been developed as an ejector. The vortex tube sand trap is a tube with a narrow opening along the top which is placed on the bed of a canal at an angle of about 45° to the direction of flow. In some cases deflectors are added for better performance. When flow passes over the opening, a spiral motion is developed in the tube. Particles drop into the tube and are washed to an outlet by a spiral vortex. Vortex tubes are found to be most efficient at a Froude number of 0.8, and require 15 to 20 percent of the flow (depending on the size and shape of the tube) to be wasted for washing out the sediment (Robinson, 1962).

Desilting Basins

Heavy particles moving near the stream bed can be diverted from the canal intake by proper location and design of the intake structures, but bed load is usually less than 10 percent of total sediment load. The larger portion of the total sediment load moving in suspension is bound to enter the canal. If the canal velocity is low enough, particles will settle in the canal and cause heavy maintenance cost; otherwise, particles will be carried through to the turbine.

Many attempts have been made to develop a rational and theoretical approach for design of desilting basins and sand traps in order to prevent suspended sediment from entering the canal. Major examples of such facilities in the U.S. are at the All-American Canal and the Gila Main Canal of the U.S. Bureau of Reclamation.

The earliest rational approach for designing a desilting basin is that of Hazen (1904). In his article "On Sedimentation" assuming that water is constantly mixed so that sediment concentration is the same in all parts of it, he gave the following expression:

$$x = 1/(1+a/t)$$

where, x = proportion of sediment remaining in suspension in the effluent, taking the amount at the beginning as unity,

a = ratio of capacity of the sedimentation tank to quantity of inflow and outflow,

t = time required for a particle to fall from the water surface to the bottom of the tank.

The design of the All-American canal desilting basin was based on this proposition. Vetter (1940) notes that in a natural channel water particles and suspended particles are constantly mixed due to turbulence. In these conditions some particles will settle to the bottom and some will be thrown back into the flow. If the number of particles thrown into suspension is equal to the number of particles settling, the stream is said to be in equilibrium. If turbulence is reduced, the number of particles settling will exceed the number of particles going into suspension. Turbulence can be reduced by reducing the velocity, and in the All-American canal velocity is kept at 0.25 ft. per second.

Another assumption made in the design of the All-American canal was that the concentration is constant through any vertical line in the tank. The number of particles settling on a unit area in unit time depends solely on the percentage of sediment in the water immediately above the bottom. Hence, the weight of silt deposited on the bottom per unit time and per unit area is proportional to the weight of sediment per unit volume of water vertically above the bottom unit area. From this assumption the following expression was obtained

$$dw/dt = -kw/d$$

where, w = weight of sediment in water per unit area,

d = depth of water,

k = constant, having a value equal to the fall velocity of the particle.

By integration,

$$W = W_o e^{(-kx/q)}$$

where, W = weight of sediment going cut,

W_o = weight of sediment coming in,

q = discharge per unit width,

x = distance from entrance to the water exit.

Based on Dobbin's work (1944) on sediment transport in turbulent flow, Camp (1966) gave the following formula for the sediment removal ratio:

$$r = 1-8\left(\frac{wH}{2\varepsilon}\right)^2 e^{\frac{wH}{2\varepsilon}} \sum_{n=1}^{n=\infty} \frac{a_n^{\,2}\, H_n e^{-\left[\left(\frac{wH}{2\varepsilon}\right)^2 + a_n^{\,2}\right] \frac{w}{w_0}\ \frac{1}{2wH}/2\varepsilon}}{\left[\left(\frac{wH}{2\varepsilon}\right)^2 + a_n^{\,2} + 2\frac{wH}{2\varepsilon}\right]\left[\left(\frac{wH}{2\varepsilon}\right) + a_n\right]^2}$$

Where, w = settling velocity of particle,

w_0 = overflow rate or discharge per unit area,

ε = mixing coefficient,

a_1, a_2 and a_n are the successive real roots of the equation

$$2 \cot \alpha = \frac{\alpha}{wH/2\varepsilon} - \frac{2H/2\alpha}{\alpha}$$

Camp (1966) presented graphs for the solution of this equation using Dobbin's (1944) solution for the differential equation of turbulent sediment transport, with the following assumptions:

1. The fluid velocity is the same at every point in the channel,
2. The mixing coefficient is the same at every point in the channel.

These two assumptions are apparently incompatible, because for a constant mixing coefficient a parabolic velocity distribution should result. Furthermore, Camp assumed uniform concentration throughout the depth, which is not true because turbulence decreases as distance from the bottom increases, and the concentration decreases as the turbulence decreases.

While working on the design of artificial spawning grounds for salmon, Einstein (1968) studied the settlement of suspended particles on a gravel bed. As the turbid water passed over the gravel bed, he noticed that water near the bed always remained clear. This lead him to derive the following equation

$$\ln C - \ln C_o = (v_s/d)$$

where, C_o = concentration at the beginning,

C = concentration after time t,

v_s = fall velocity of a particle,

d = depth of basin.

The quantity of sediment deposited on the bed can be calculated as the cumulative volume of a set of the particles. After knowing the volume of the sediment to be deposited, the size of the basin can be selected.

There is no evidence of practical use of this equation which indicates that water velocity does not play any role in the settlement process of the particle. Since there is no obvious way to determine the length of the basin, this equation could not be used in practice.

CHAPTER 3

LABORATORY STUDIES AND THEORETICAL CONSIDERATIONS

Experimental Equipment

A schematic diagram of the laboratory equipment used, basically a flume having a uniform approach section and a sediment trap of variable dimension, is shown in Figure 1. The approach section was 5 ft. long, 1 ft. wide, and 1 ft. deep. The basin for trapping sediment was 6 ft. long, 1 ft. wide, and 2 ft. deep. One side of the trap and part of one wall of the approach flume were made of plexiglass so that trapping could be observed. It was possible to vary the length of the trap by using false-work. Water was supplied from a tank through a pipe controlled by means of a gate valve. Water passed through the trap reach and out of the flume into a tank with a sharp-crested weir at the downstream end to measure the rate of flow. The weir tank also acted as a secondary trap for particles which were not caught in the trap. The sediment was supplied from an overhead hopper with the supply end about 6 inches above the bed of the approach flume. A buzzer vibrated the hopper to ensure constant supply of the sand.

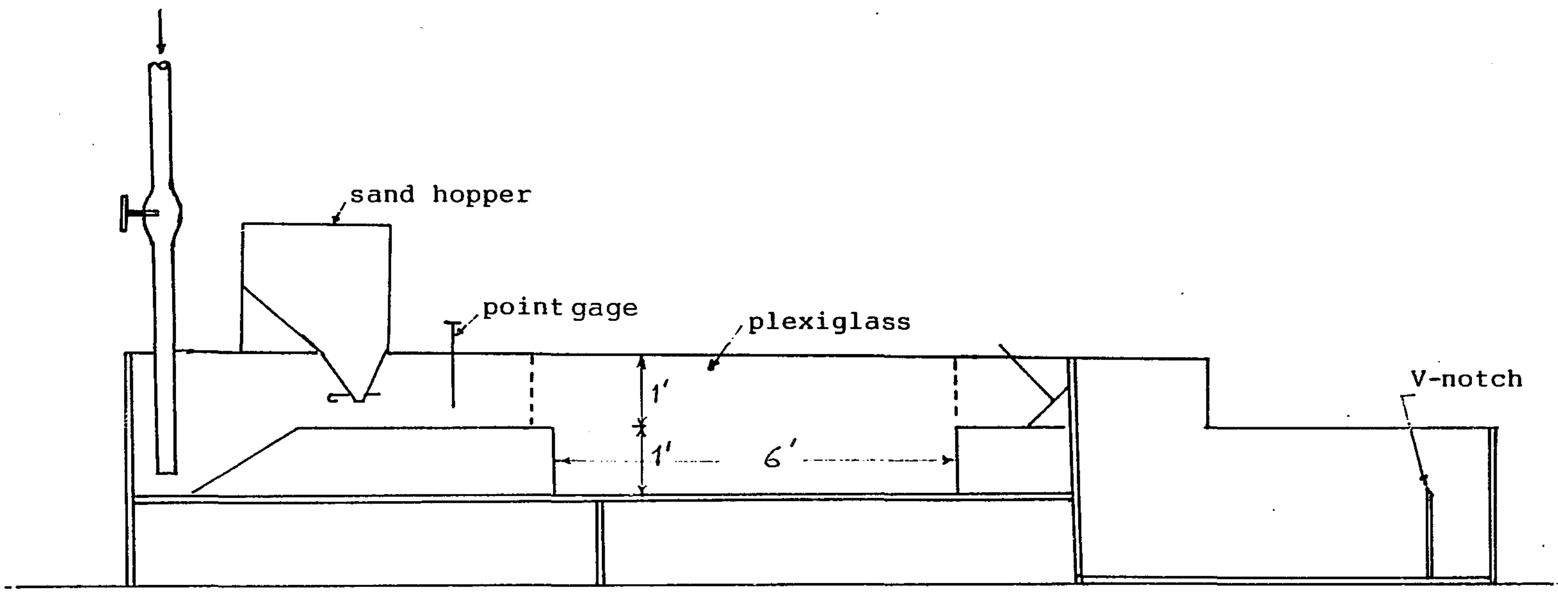

Figure 1. Laboratory Equipment

Laboratory Procedure

The tests were conducted using different combinations of velocity and depth and length of the trap. Depth was measured in the approach channel and at the end of the trap with point gage vernier scales attached to the flume. The rate of sand feed was kept low to minimize deposition of sand on the bed of the approach reach.

The rate of sand feed was noted before and at the end of each run, and the product of total time of run and rate of sand feed gave the total amount of sand introduced in a particular run. The sand that settled on the bed of the approach flume and in the trap was collected and dried separately. The difference between the weight of sand introduced and the sand which settled in the approach gives the total sand that could possibly be trapped. The weight of sand in the trap is used to compute the efficiency of the trap.

The sediment used in the test was natural river bed sand with d_{50} of 0.23mm. The size distribution of the sediment is shown in Figure 2. It was free from cohesive clay particles.

The rate of sand feed was kept as low as possible because the main difficulty in testing was to maintain constant depth of water in the approach section. Because of limitations due to flume size, the depth of water was chosen to be 1.5 inches or 3.0 inches in the approach.

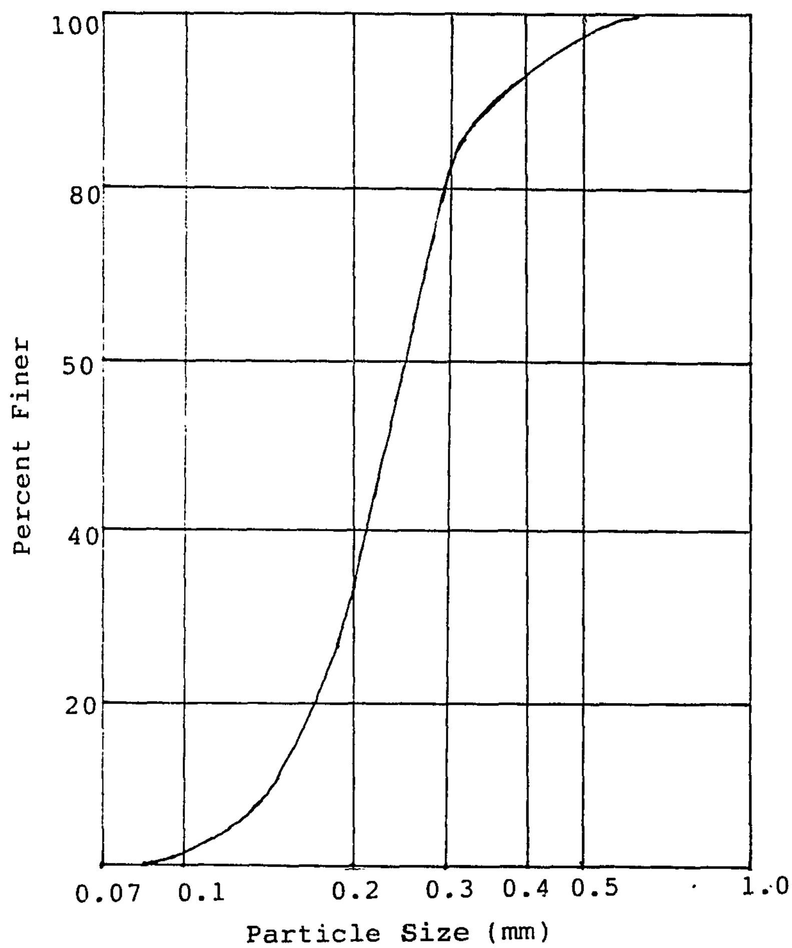

Figure 2. Size Distribution of Sand Used in Tests

Even a small quantity of sand settled in the approach has a tendency to change the depth as well as the velocity.

Flow Pattern

The flow in the approach to the trap is standard uniform open channel flow with a velocity distribution generally assumed to be logarithmic. As this flow continues across the top of the trap, the zero velocity at the channel bed becomes some positive value, and the water in the upper part of the trap is entrained by the momentum exchange due to the turbulence of the flow. The dividing streamline diverges as the velocity of the throughflow above decreases (Figure 3). The turbulence created along the dividing streamline is a larger scale turbulence than that created in the normal channel flow. In the trap there is one large-scale eddy and some other secondary flow features. There are currents in an upward direction near the entrance and exit of the trap. The body of water in the middle portion of the trap is almost calm.

The main eddy, the secondary flow patterns, and the turbulence have some effect on the trapping efficiency, but are not of great concern.

Settlement Pattern

In the approach to the trap, there is sediment moving both as bed load and suspended load. If the trap

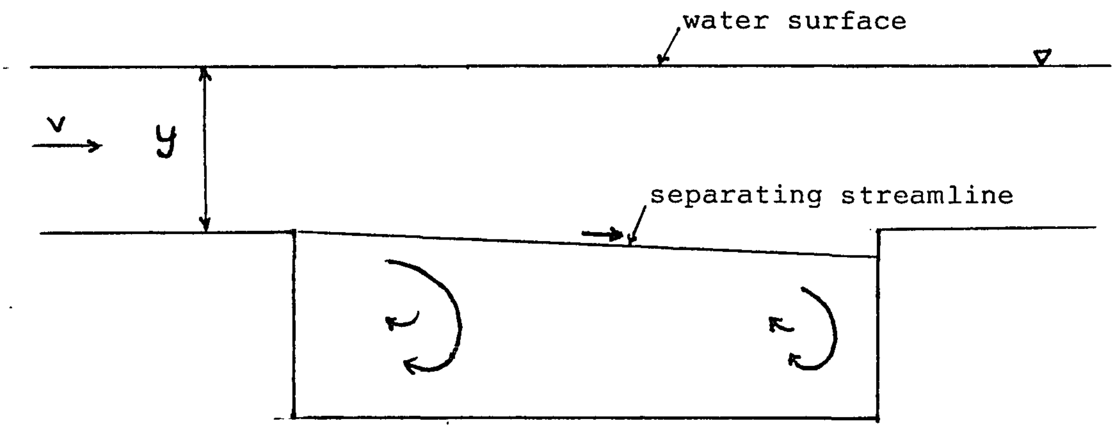

Figure 3. Flow Pattern in the Trap

is long enough to trap all of the suspended load (or at least most of it), it will be more than long enough to trap all of the bed load. The bed load that consists mostly of sands and gravels, but also includes some fines, will fall into the trap and form a triangular deposit at the angle of repose starting at the bottom upstream corner of the trap (Figure 4). The suspended load, on the average, will fall from any specific elevation above the upstream corner of the entrance to the trap down to and through the dividing stream line at an angle determined by the velocity of the flow and the fall velocity of sediment particle. This will not be an absolutely straight line of fall because the velocity of flow varies with elevation and distance from the entrance to the trap.

It should be noted also that the fall velocity is not a simple thing. For a natural sediment particle, it is less than for a sphere of the same weight (size). How much less depends on the shape. The fall velocity also depends on concentration and on turbulence of the fluid in which it is falling. It should also be noted that the size of sediment particles is not easy to measure, especially if the particles are small, and tends to be operationally arbitrary.

These difficulties are largely overcome if the trapping process is described and analyzed qualitatively,

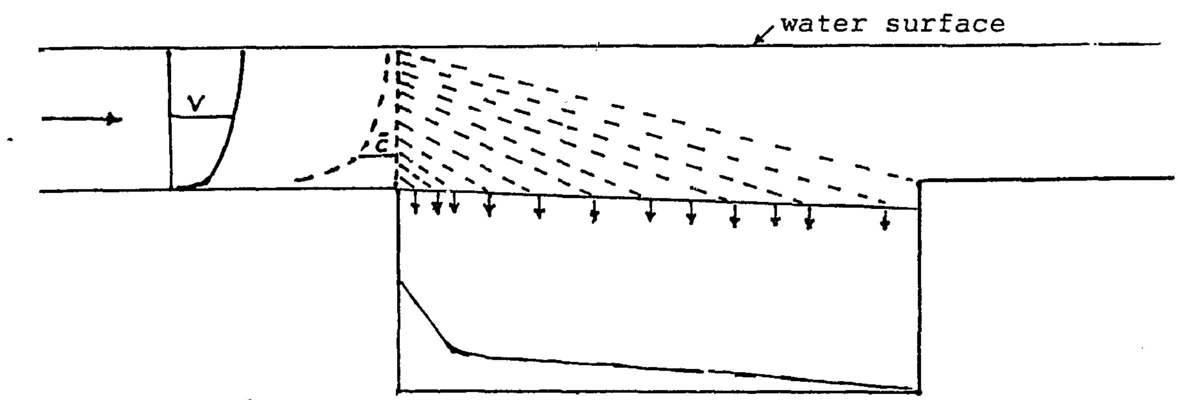

Figure 4. Particles settling from Different Depths

correctly, and if the final results are validated by model and/or prototype measurements.

Because the suspended concentration distribution is greater near the bed of the channel than it is near the water surface, the amount of sediment falling through the dividing streamline is more near the entrance than near the end of the trap. Indeed if the trap is very, very long, all the sediment will be trapped before the end of the trap. This first approximation of the settlement pattern is modified by the effect of the turbulence of throughflow. In general, all particles falling from a certain elevation above the beginning of the trap do not follow the same path (Figure 5). Because of the random nature of the turbulence, some particles reach the dividing streamline closer to the beginning of the trap than the average, others farther than the average.

Only for these particles which on the average reach the dividing streamline at or near the end of the trap, does the effect of the turbulence matter. For these particles, greater than the normal turbulence in the layer of the high shear near the dividing streamline, and the upward component of the throughflow at the end of the trap are also important. However, in a well designed trap only half or less of the particles in a small fraction of depth (near the water surface) with the least concentration should escape the trap.

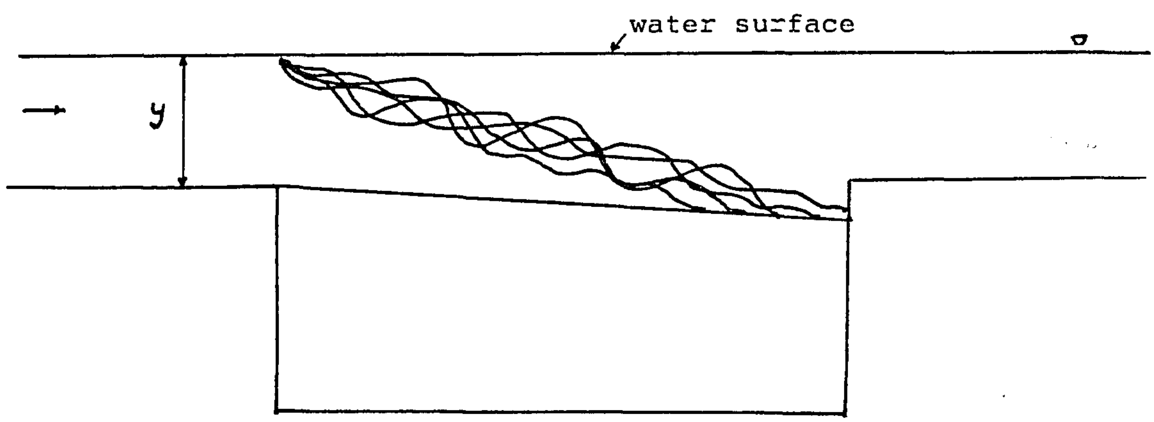

Figure 5. Particles Settling from the Same Point Following Different Paths

The previous discussion suggests that the sediment will almost all be trapped if the length is chosen as in Figure 6.

$$L/y = v/w$$

where, L = length of the trap,

y = depth of approaching flow,

v = velocity of approaching flow,

w = fall velocity of the particle.

or, possibly,

$$L'/y = k\ v/w$$

where k is not much greater than unity to account for the effect of secondary currents and turbulence and the errors in the value of fall velocity.

This is the expected performance of this simple trap and the tentative solution for designing a trap. The experiments presented are an attempt to verify the behavior of the trap and to check the tentative solution (Figure 6).

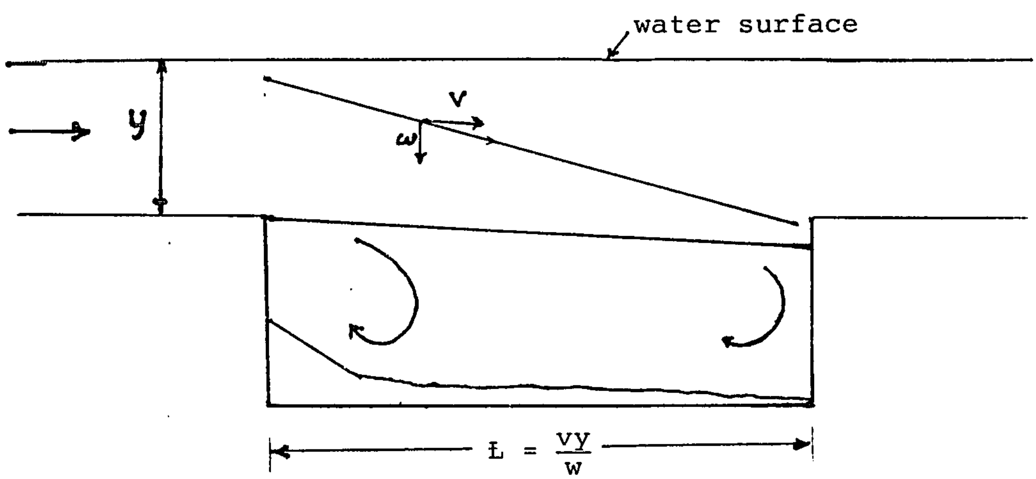

Figure 6. Length of the Trap

CHAPTER 4

RESULTS AND DISCUSSION

Results of tests using various combinations of velocity and depth of flow are tabulated in the Appendix. Sand concentration was arbitrarily kept low to avoid excessive deposition in the approach section of the flume and to keep the desired velocity and depth unchanged. It was found difficult to maintain a constant rate of sand flow from hopper to the flume in the first few tests, and results were unsatisfactory because of excessive settlement in the approach resulting from the high sediment concentrations used. The decrease in the depth and increase in the velocity resulted in a different approach condition than desired. Therefore, in the following tests, a vibrating buzzer was attached to the hopper to ensure a continuous and constant sand feed at the low rate required.

Suspended sediment can damage hydro-mechanical equipment if allowed to pass through the penstock or conveyance tunnel to a turbine. Operating experience indicates (but it has not been shown theoretically) that particles less than 0.1mm diameter do not cause excessive detrimental abrasion of the turbine. The principal purpose of these tests was to determine effective settling tank dimensions to trap sediment. Trapping of particles 0.125mm and smaller diameter particles was emphasized in the tests; the arbitrary size of 0.125mm was chosen because it is the opening of the U.S. standard number 120 sieve, and because finer sediment in small concentrations should not be too damaging. Particles larger than 0.125mm were trapped more efficiently.

After determining the sediment concentration throughout the depth of the approach flow, the length of the settling tank was approximately sized for 100 percent deposition. The summary of the results in Tables 1 and 2 and Figure 7 shows that the percentage of sand <0.125mm deposited does not fully agree with the analytical calculation, but results may have practical importance in an economical design of a settling tank for fine particles, and derivations from the simple theory can be explained. Sand particles >0.125mm were trapped to a higher efficiency. Therefore, if the trap is designed to trap the fine material, it will be more than long enough for the coarse material.

Although it appears unlikely that one can establish design curves or a relationship to be used to design settling tanks that would truly be 100 percent efficient, it has been shown that settling efficiency of a tank is mainly dependent on velocity and depth of approach flow, the fall velocity of the sediment, and length of the trap.

Table 1. Deposition of Fines as a Function of Approach Conditions.

Depth of approach flow, ft	Length of sediment trap, ft	Velocity ft/sec	Percent of <0.125mm sand deposited
0.25	6	0.86	85
		0.70	93
		0.60	100
0.125	6	0.86	99
		0.70	100
		0.60	100
0.25	3	0.86	31
		0.70	45
		0.60	55
0.125	3	0.86	83
		0.60	95
		0.45	100

Table 2. Percent Deposition as a Function of (L/v w/y).

Length of trap L, ft	Depth y, ft	Velocity v, ft/sec	Lw/vy*	Percent settlement of <0.125mm sand
6	0.25	0.86	0.84	85
		0.70	1.03	93
		0.60	1.20	100
	0.125	0.86	1.67	99
		0.70	2.06	100
		0.60	2.40	100
3	0.25	0.86	0.42	31
		0.70	0.51	45
		0.60	0.60	55
	0.125	0.86	0.84	83
		0.60	1.20	95
		0.45	1.60	100

* The fall velocity, w, was taken as 0.03 fps.

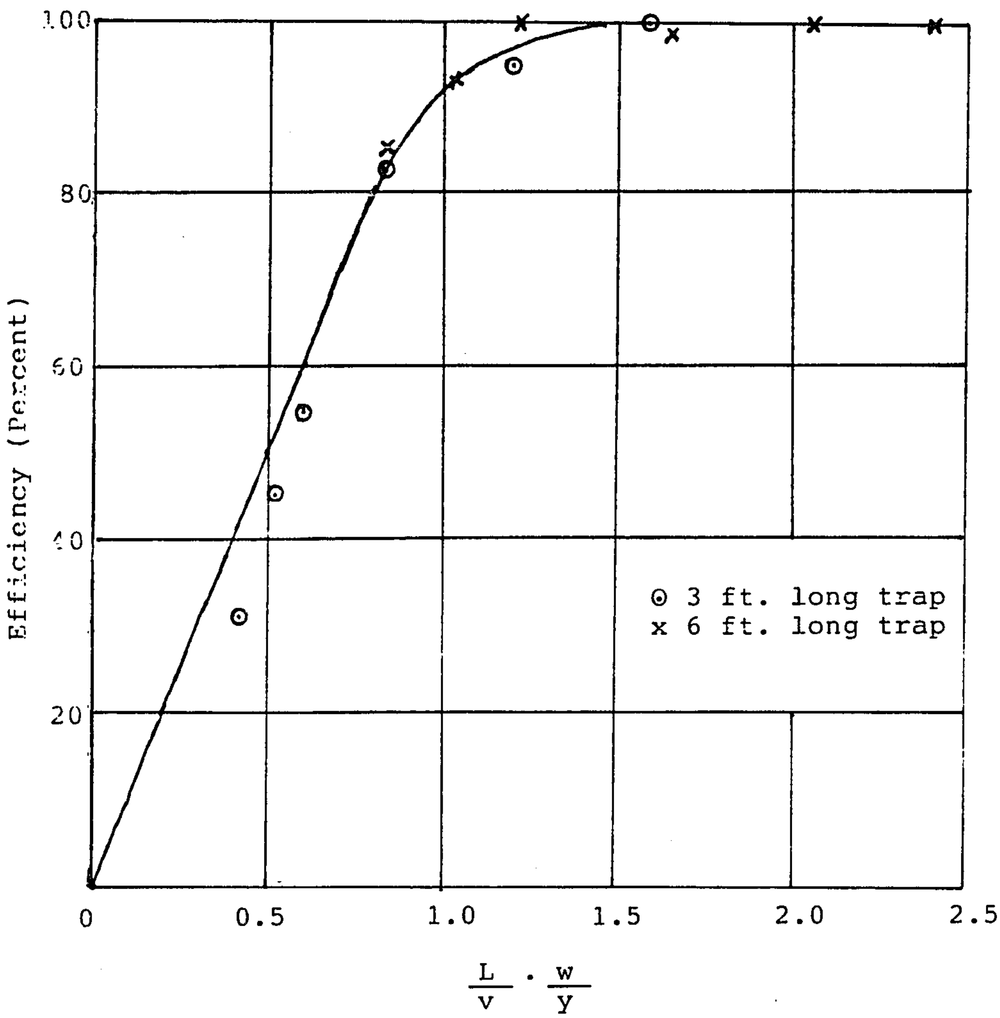

Figure 7. Efficiency of trapping <0.125mm sand

For the test with 0.86 ft/sec velocity and 0.25 ft. approach depth, the 6-ft. long trap had an 85 percent efficiency. Keeping the size of the trap the same, the efficiency was determined at lower velocities and depths. At a value of Lw/vy = 1.2 the efficiency seemed to reach 100 percent. Less than total trapping is due to the following:

1. The fall velocity was calculated as that of a quartz sphere of diameter equal to the sieve diameter; real fall velocity would be less than that. It should also be noted that some of the sand that was not trapped would pass the 200 sieve which has an opening of 0.074mm.
2. The effective length of the trap is less than the actual length due to high turbulence and secondary flow at the upstream and downstream ends of the trap.
3. Some of the fine particles did not pass through the surface tension of water and floated past the trap.
4. Since the streamline separating the flow and turbulence zones inclines downward and the depth of flow increases towards the end of the trap, particles moving near the surface have to fall through a greater depth than the initial depth at the entrance.

Data in Tables 1 and 2 and Figure 7 show that the test results for particular combinations of velocity and depth with a 3-ft. long trap are similar to those for the 6-ft. long trap. Considering the concentration distribution, efficiency of the 3-ft. long trap should have been more than 50 percent for a velocity of 0.86 ft/sec and depth of 0.25 ft. depth; measured efficiency was 31 percent. This shows that the effect of turbulence is more severe for the shorter trap than for the long trap. By comparing the efficiency for various velocities at the same depth it is evident that efficiency decreases more rapidly as velocities increase than as depths increase. This is due to increased turbulence and the shorter transit time required with higher velocities. As the depth increases, only the transit time decreases.

The weight of suspended sediment deposited per square foot of trap was observed to decrease from the entrance to exit of the trap. Mean diameter of the deposited sediment also decreased with increasing distance from the entrance. This illustrates that even fine particles moving near the bed settle into the trap sooner than those moving near the surface. By adjusting only the length of the trap it is possible to achieve the required decreased concentration in the out-going flow. However, at some sites it might be advantageous to adjust the width (usually to be wider) in order to adjust the depth of flow without changing the velocity. Mountainous sites are likely to be very site specific, and the designer should be able to vary any trap dimension if necessary. But then the other dimensions will have to be adjusted to insure the desired trap efficiency. If the trap is wider than the canal, it may be necessary to guide the flow in the approach with vanes.

CHAPTER 5

CONCLUSIONS

Since the tests were conducted in a short flume, the length available for the sediment trap was limited and variation in trap length was constrained. In order to obtain higher trap efficiency, combinations of small depth (1.5 inches to 3 inches) and low velocity (0.45 to 0.864 ft/sec) were used. Sand settling in the approach reach upstream of the trap seriously disrupted velocity and depth. Increased velocity during the test, due to decreased depth in the approach, affected settlement of the suspended particles. Higher velocity also increased the turbulence effect, thereby decreasing the effective length of the trap.

However, considering the above difficulties and for similar conditions of velocity, depth, and trap length, it can be expected that percent deposition will be higher for actual field conditions than in the experimental setup. Therefore, the following conclusions can be safely made:

1. The velocity and depth of the approach flow are the main dominant factors in the settlement process of a suspended particle.

2. A settling basin for fine particles can be safely designed based on the relationship, $L\,w/y\,v = 1.5$.

By providing a depression (trap) of a suitable length in a straight reach of a channel, fine particles can be removed from the flow. The depth of the depression required depends on the method and frequency of removal of settled material from the trap and on the concentration of suspended particles in the river.

Decreasing the approach velocity and depth shortens the required length of a settling basin, but both cannot be achieved at the same time for a particular flow without changing the width and slope of the channel. In a power canal, head loss is minimized by setting the canal at a mild slope; the resulting low velocity thus obtained requires a relatively larger section. The large section can be obtained either by increasing the width or increasing depth. Larger depth requires a longer sediment trap. The width, depth, and velocity of flow in the canal and length of the settling basin can be economically optimized for any specific site conditions.

APPENDIX

OBSERVATIONS AND EXPERIMENTAL RESULTS

Test Condition 1

Length of the trap = 6 ft.

Depth of the flow = 0.25 ft.

Velocity = 0.86 ft/sec

Run time = 60 minutes

Rate of sand inflow = 38.00 gm/min

Total amount of sand inflow = 2280 gm

Sediment settled before trap = 1843 gm

Sediment settled in the trap = 390 gm

Size Distribution of Sand after Experiment

U.S. Standard Sieve	Opening mm	Percent Finer Before Trap	In Trap
35	0.5	99.0	100.0
60	0.25	45.0	88.6
100	0.149	22.0	36.0
120	0.125	0.2	13.0
200	0.074	--	--

Amount of particles <0.125mm diameter

in total inflow of sand = 2280 x 0.0322 = 73.4 gms

Particles <0.125mm settled in the approach = 12.32 gms

Particles <0.125mm in suspension = 74.4 - 12.32 = 61.08

Particles <0.125mm settled in trap = 52.0 gms

Percentage of particles settled = 52.0/61.08 = 85%

Test Condition 2

Length of the trap = 6 ft.

Depth of the flow = 0.25 ft.

Velocity = 0.7 ft/sec

Run time = 70 minutes

Rate of sand inflow = 25.6 gm/min

Total amount of sand inflow = 1792 gms

Sediment settled before trap = 1437.7 gms

Sediment settled in the trap = 341.0 gms

Size Distribution of Sand after Experiment

U.S. Standard Sieve	Opening mm	Percent Finer Before Trap	In Trap
35	0.5	99.3	100.0
60	0.25	52.0	89.3
100	0.149	21.0	42.7
120	0.125	0.4	13.5
200	0.074	--	--

Amount of particles <0.125mm diameter

in total inflow of sand = 1792 x 0.0322 = 57.7 gms

Particles <0.125mm settled in the approach = 5.74 gms

Particles <0.125mm in suspension = 57.7 - 5.74 = 51.96 gms

Particles <0.125mm settled in trap = 48.24 gms

Percentage of particles settled = 48.24/51.96 x 100 = 93%

<u>Test Condition 3</u>

Length of the trap = 6 ft.

Depth of the flow = 0.25 ft.

Velocity = 0.6 ft/sec

Run time = 95.0 minutes

Rate of sand inflow = 12.5 gms/min

Total amount of sand inflow = 1187.5 gms

Sediment settled before trap = 877 gms

Sediment settled in the trap = 306 gms

Size Distribution of Sand after Experiment

U.S. Standard Sieve	Opening mm	Percent Finer Before Trap	In Trap
35	0.5	99.0	100.0
60	0.25	49.0	95.0
100	0.149	20.0	49.0
120	0.125	0.4	12.0
200	0.074	--	--

Amount of particles <0.125mm diameter

in total inflow of sand = 1187.5 x 0.0322 = 38.23 gms

Particles <0.125mm settled in the approach = 5.75 gms

Particles <0.125mm in suspension = 32.48 gms

Particles <0.125mm settled in trap = 39.0 gms

Percentage of particles settled = 39.00/32.48 x 100 = 100%

Test Condition 4

Length of the trap = 6 ft.

Depth of the flow = 0.125 ft.

Velocity = 0.86 ft/sec

Run time = 60 minutes

Rate of sand inflow = 29.8 gms/min

Total amount of sand inflow = 1788 gms

Sediment settled before trap = 1209 gms

Sediment settled in the trap = 565.2 gms

Size Distribution of Sand after Experiment

U.S. Standard Sieve	Opening mm	Percent Finer Before Trap	In Trap
35	0.5	99.0	100.0
60	0.25	44.0	94.0
100	0.149	19.0	46.0
120	0.125	0.5	9.0
200	0.074	--	--

Amount of particles <0.125mm diameter

in total inflow of sand = 1788 x 0.0322 = 57.57 gms

Particles <0.125mm settled in the approach = 4.84 gms

Particles <0.125mm in suspension = 52.73 gms

Particles <0.125mm settled in trap = 52.0 gms

Percentage of particles settled = 52.0/52.73 x 100 = 99%

Test Condition 5

Length of the trap = 6 ft.

Depth of the flow = 0.125 ft.

Velocity = 0.7 ft/sec

Run time = 65 minutes

Rate of sand inflow = 22.1 gms

Total amount of sand inflow = 1430.0 gms

Sediment settled before trap = 1176.4 gms

Sediment settled in the trap = 247.8 gms

Size Distribution of Sand after Experiment

U.S. Standard Sieve	Opening mm	Percent Finer Before Trap	In Trap
35	0.5	99.0	100.0
60	0.25	66.0	91.2
100	0.149	22.0	48.1
120	0.125	0.7	17.3
200	0.074	--	--

Amount of particles <0.125mm diameter

in total inflow of sand = 1430 x 0.0322 = 46.05 gms

Particles <0.125mm settled in the approach = 8.23 gms

Particles <0.125mm in suspension = 37.8 gms

Particles <0.125mm settled in trap = 42.8 gms

Percentage of particles settled = 42.8/37.8 x 100 = 100%

Test Condition 6

Length of the trap = 6 ft.

Depth of the flow = 0.125 ft.

Velocity = 0.60 ft/sec

Run time = 75 minutes

Rate of sand inflow = 14.5 gms/min

Total amount of sand inflow = 1087 gms

Sediment settled before trap = 886 gms

Sediment settled in the trap = 198.7 gms

Size Distribution of Sand after Experiment

U.S. Standard Sieve	Opening mm	Percent Finer Before Trap	In Trap
35	0.5	99.1	100.0
60	0.25	51.6	95.0
100	0.149	20.2	49.6
120	0.125	0.6	16.0
200	0.074	--	--

Amount of particles <0.125mm diameter

in total inflow of sand = 1087 x 0.0322 = 35.5 gms

Particles <0.125mm settled in the approach = 5.32 gms

Particles <0.125mm in suspension = 29.68 gms

Particles <0.125mm settled in trap = 30.8 gms

Percentage of particles settled = 30.8/29.68 x 100 = 100%

Test Condition 7

Length of the trap = 3 ft.

Depth of the flow = 0.25 ft.

Velocity = 0.86 ft/sec

Run time = 60 minutes

Rate of sand inflow = 28.6 gms/min

Total amount of sand inflow = 1716 gms

Sediment settled before trap = 1350.0 gms

Sediment settled in the trap = 141.2 gms

Size Distribution of Sand after Experiment

U.S. Standard Sieve	Opening mm	Percent Finer Before Trap	In Trap
35	0.5	99.0	100.0
60	0.25	46.0	90.0
100	0.149	21.0	32.0
120	0.125	0.2	12.0
200	0.074	--	--

Amount of particles <0.125mm diameter

in total inflow of sand = 1716 x 0.0322 = 55.25 gms

Particles <0.125mm settled in the approach = 2.7 gms

Particles <0.125mm in suspension = 55.25 - 2.7 = 52.55 gms

Particles <0.125mm settled in trap = 16.6 gms

Percentage of particles settled = 16.6/52.55 x 100 = 31%

Test Condition 8

Length of the trap = 3 ft.

Depth of the flow = 0.25 ft.

Velocity = 0.7 ft/sec

Run time = 70 minutes

Rate of sand inflow = 27.3 gms/min

Total amount of sand inflow = 1911.0 gms

Sediment settled before trap = 1532.3 gms

Sediment settled in the trap = 166.6 gms

Size Distribution of Sand after Experiment

U.S. Standard Sieve	Opening mm	Percent Finer Before Trap	In Trap
35	0.5	99.0	100.0
60	0.25	51.0	90.0
100	0.149	22.0	40.0
120	0.125	0.3	15.0
200	0.074	--	--

Amount of particles <0.125mm diameter

in total inflow of sand = 1911 x 0.0322 = 61.11 gms

Particles <0.125mm settled in the approach = 4.6 gms

Particles <0.125mm in suspension = 61.11 - 4.6 = 56.51 gms

Particles <0.125mm settled in trap = 25.4 gms

Percentage of particles settled = 25.4/56.51 x 100 = 45%

Test Condition 9

Length of the trap = 3 ft.

Depth of the flow = 0.25 ft.

Velocity = 0.6 ft/sec

Run time = 90 minutes

Rate of sand inflow = 14.0 gms/min

Total amount of sand inflow = 1260 gms

Sediment settled before trap = 932.2 gms

Sediment settled in the trap = 183.57 gms

Size Distribution of Sand after Experiment

U.S. Standard Sieve	Opening mm	Percent Finer Before Trap	In Trap
35	0.5	99.5	100.0
60	0.25	50.0	90.0
100	0.149	20.0	37.0
120	0.125	0.4	11.0
200	0.074	--	--

Amount of particles <0.125mm diameter

in total inflow of sand = 1260 x 0.0322 = 40.57 gms

Particles <0.125mm settled in the approach = 3.73 gms

Particles <0.125mm in suspension = 36.84 gms

Particles <0.125mm settled in trap = 20.2 gms

Percentage of particles settled = 20.2/36.84 x 100 = 55%

Test Condition 10

Length of the trap = 3 ft.

Depth of the flow = 0.125 ft.

Velocity = 0.86 ft/sec

Run time = 60 minutes

Rate of sand inflow = 32.5 gms/min

Total amount of sand inflow = 1950 gms

Sediment settled before trap = 1623 gms

Sediment settled in the trap = 223 gms

Size Distribution of Sand after Experiment

U.S. Standard Sieve	Opening mm	Percent Finer Before Trap	In Trap
35	0.5	99.0	100.0
60	0.25	54.0	95.0
100	0.149	21.0	51.0
120	0.125	0.5	17.0
200	0.074	--	--

Amount of particles <0.125mm diameter

in total inflow of sand = 1950 x 0.0322 = 62.79 gms

Particles <0.125mm settled in the approach = 8.11 gms

Particles <0.125mm in suspension = 54.68 gms

Particles <0.125mm settled in trap = 45.51 gms

Percentage of particles settled = 45.51/54.68 x 100 = 83%

Test Condition 11

Length of the trap = 3 ft.

Depth of the flow = 0.125 ft.

Velocity = 0.6 ft/sec

Run time = 75 minutes

Rate of sand inflow = 13.5 gms/min

Total amount of sand inflow = 1012.5 gms

Sediment settled before trap = 663.8 gms

Sediment settled in the trap = 292.93 gms

Size Distribution of Sand after Experiment

U.S. Standard Sieve	Opening mm	Percent Finer Before Trap	In Trap
35	0.5	99.0	100.0
60	0.25	41.0	97.0
100	0.149	19.0	50.0
120	0.125	0.4	9.7
200	0.074	--	--

Amount of particles <0.125mm diameter

in total inflow of sand = 1012.5 x 0.0322 = 32.60 gms

Particles <0.125mm settled in the approach = 2.65 gms

Particles <0.125mm in suspension = 29.95 gms

Particles <0.125mm settled in trap = 28.4 gms

Percentage of particles settled = 28.4/29.95 x 100 = 95%

Test Condition 12

Length of the trap = 3 ft.

Depth of the flow = 0.125 ft.

Velocity = 0.45 ft/sec

Run time = 80 minutes

Rate of sand inflow = 9.6 gms/min

Total amount of sand inflow = 768.0 gms

Sediment settled before trap = 598.6 gms

Sediment settled in the trap = 163.4 gms

Size Distribution of Sand after Experiment

U.S. Standard Sieve	Opening mm	Percent Finer Before Trap	In Trap
35	0.5	99.0	100.0
60	0.25	51.0	97.0
100	0.149	23.0	52.0
120	0.125	0.4	14.0
200	0.074	--	--

Amount of particles <0.125mm diameter

in total inflow of sand = 768 x 0.0322 = 24.7 gms

Particles <0.125mm settled in the approach = 2.39 gms

Particles <0.125mm in suspension = 21.31 gms

Particles <0.125mm settled in trap = 23.0 gms

Percentage of particles settled = 23.0/21.31 x 100 = 100%

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