Some Salient Features of Silt Ejector in a Fluvial Channel Based on Hydraulic Model Studies

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CHAPTER I

Introduction.

Sediment carried by natural stream can cause damage in a variety of ways and presents serious difficulties. The sediment can clog a river channel to increase flood heights, silt up a reservoir to reduce the live storage, block a harbour to obstruct navigation, choke a canal to reduce its capacity and may damage power turbines by filling its blades, undermine hydraulic structures due to scour, and cause a host of other problems. The life, utility, efficiency and maintenance cost of hydraulic structures is intimately related to sediment characteristics and flow characteristics.

With a given slope, discharge and cross-section a channel can transport optimum silt in grade and quantity. The silt carrying capacity of some rivers in West Pakistan varies from 0.2 gm/litre to 10 grm/litre in Moonsoon season whereas the Upper limit of sediment load that can be transported without appreciable bank erosion is 0.6 gm/litre. With a heavy silt charge, the channel tends to become shallow, wide and steep, it develops tendency to meander, its discharge carrying capacity is appreciably reduced due to building up of slope and the tillable commanded area is substantially cut off.

When canal withdrawals are heavy and surplus discharge in the river at the site of diversion headworks above requirements of the off-taking canals is reduced appreciably to flush the sediment back to the river ; the exclusion of silt from offtaking canals becomes a very difficult problem. Marala Ravi Link with a head discharge of 22,000 cs. was completed in 1956 and opened the same year for transfer of surplus supply from Chenab to Sutlej river through Balloki Headworks on river Ravi. By the end of

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1960, 252 million cft of silt deposited in its head reach that steepened the slope in the head reach to such an extent that the capacity of the link at designed full supply level is almost nil.

Nara canal draws silt at its intake which is less than its transport capacity and it picks up silt in the reach Sukkur to Jamrao head thereby causing objectionable deposits in Nara Canal system at and below Jamrao head. Upper Jhelum Canal, when it will be fed by clear water from Mangla Dam through Bong Canal, will scour and the Hydraulic structures are likely to be damaged, if canal is not regraded.

The artificial canals and channels should be designed to attain the least annual total maintenance cost and to prevent conditions which would lead to progressive increase in maintenance cost. The silt entering the main canal at its head should be controlled by sediment exclusion and/or ejection structures so that it is equal to the silt carrying capacity of the main channel and that it should be so distributed in the secondary and canals that each draws its due share proportional to its transport capacity and that the setting of cill level of outlets should be such that the entire silt that enters the tertiary canals should move to the Fields.

Any one or a combination of the following methods are gencrally adopted for satisfactory sand exclusion from the ehannels.

1. Reducing the rate of sediment production in the water shed of a stream in head water mountains.

The sediment production in the water shed of a stream can be reduced by proper management of the water shed. As most of the tributaries of Indus river drain the friable, younger, sedimentary rock formation of Siwalik terrain, the annual sediment loads and silt intensity in the Indus and its tributaries is fairly high. Some of the measures that can be adapted for reducing the sediment production in the catchment area check dams, afforstation, soil conservation, restricted grazing and control and elimination of gullies.

2. Sand exclusion at the intake of the Canal.

The silt selective methods and devices for preventing the coarse sediment particles from entering the canal at or before the intake of canal with some reference to basic principles of sediment movement were discussed by the Authors in the papers submitted to West Pakistan Engineering Congress in 1960 and, therefore, are not repeated here.

3. Sand ejection after it has entered the Canal.

Some of the measures that can be adopted are :

(*a*) Silt is cleared by heavy manual labour or mechanical means and the spoil is either unloaded in the river or along the banks of canal. The formations along the canals present unsightly scars on the earth's surface.

(*b*) Sediment is scoured back into the river through a silt ejector.

The ejectors are known to work satisfactorily if sediment is not fine, head available for ejection is sufficient at all stages of river and proper conditions of outfall are available.

Before 1947, almost all the ejectors constructed in West Pakistan were of conventional tunnel type with openings facing the flow. The main tunnels and the sub tunnels were so dimensioned that discharge through all the sub tunnels is almost the same fig. 1. The conventional type of ejectors with front openings had been designed for a wide range of discharge ejections varying from 2 to 40 per cent of canal discharge.

It is very important to get the maximum efficiency at minimum discharge ejection, for, very often there is very little discharge to spare. Model study to improve the vortex tube type silt extractor and to compare it with the frontal type was started in 1954 in connection with the design of Taunsa Barrage Canals. This paper embodies these results.

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CHAPTER II

Design of the Canal Section A review of previous Work.

The design of silt stable channel has been the object of extensive research in this Country. The complete solution of the problem has eluded the man. Different regime equations are only valid for limited range of conditions upon which these are based.

In the earlier days of irrigation Engineers believed in choosing such a relationship between bed width and depth that $\frac{dQ}{dA} = 0$ or the discharging capacity of canal is maximum for a given cube of earth work and thus though the initial capital cost was minimum but sumptuous sums of money were spent on annual silt clearances.

Mr. Kennedy of Punjab Irrigation was the first person to state (On the basis of observations on U.B.D.C. system in 1895 a relation in sandy bedded loose boundry channels. His formula $V = .84\ D^{.64}$ related the mean velocity (V) of the channel to the depth of water (D). The equation can be written in the general form $V = CD^{n}$. The coefficient C and exponent 'n' were a function of both grade and charge and so different canal systems had difierent values of c and n.

Kennedy used Kutter's relation to work out the slope and claimed that channels designed on his formula were in regime i.e. stable neither silting up nor scouring sensibly from season to season and were flowing

within a self deposited envelope of the same sediment as transported. According to Kennedy it is permissible to design a narrow deep channel or wide shallow one to carry the same sand water mix.

Mr. Kennedy was held sacroscent till 1919 when Mr. Lindley had shown (on the basis of 786 observations in the branches of Lower Chenab Canal) that if silt charge and discharge controlled the depth there was no reason why it should not similarly control the width, (regime width depends on lateral transfer of momentum by turbulent mixing) and that if so, a given silt and dischage uniquely determined the channel dimensions including the slope and were fixed by nature. No attempt was made by Lindley to introduce silt charge, silt grade and rugosity in his equations. However his work and his generalised statement of the problem have led to farreaching advances.

The acceptance of the regime concept and its application to the solution of practical problems by engineers had been mainly due to the writing of Mr. Gerald Lacey.

Lacey put some systematic and logical order into the mass of available data on artificial channels and brought forth empirical rules (with round exponants) which constitute mile-stone in the history of the problem.

The mimimum stable wetted perimeter (P) of a canal or river is a variable depending upon the causing agentie the discharge

$$P = 8/3 \quad Q^{\frac{1}{2}} \qquad \ldots \qquad \ldots \qquad \text{I (a)}$$

Lacey claims that the minimum stable perimeter formula appears to be applicable for all discharges upto 2½ million cusecs. A narrow and deep channel is hydraulically more efficient than a wide and shallow channel as it generates greater hydraulic radius and greater velocity, it possesses greater transporting capacity to move materail of larger sizes but the total load transporting capacity is less as there is less bed width for transporting bed load. Leopold and Maddock in U.S.A. have concluded from their study of river data that their derived equation for width in terms of the discharge was indentical to that of Mr. Lacey but did not have the same magnitude of constant and exponant. They stated that channel width varies with. The 26 power of the dischcrge.

(2)

Mr. Altunin of Russia has given the following formula for the stable width :

$$W = (.415 \text{ to } .94)\ x \frac{Q^{.5}}{S^{.2}} \text{ ft.} \qquad \ldots \qquad \ldots \qquad \text{I (b)}$$

(3)

Simon and Alberkan have shown that for sand beds and cohesive banks the wetted perimeter is related to discharge by the formula ;—

$$P = 2.5\ Q^{.51} \quad \ldots \quad \ldots \quad \text{I (c)}$$

They have also shown that the fine sediment load of imperial canals in U.S.A. decreases the stable wetted perimeter.

(4)

Lacey claims that silt grade and silt charge are implicit in the relation :—

$$V = 16.04\ (DRS)^{\frac{1}{2}} \quad \ldots \quad \ldots \quad \text{II}$$

where R is the hydraulic radius and D is depth of Water. The above equation is very usefull for the determination of flood discharge on occasions when it is not possible to determine v by direct methods. This equation does not include solid charge but is valid if sediment load which can be transported is of the order of .4 gm/litre.

The general validity of this equation for Indo-Pak Sub Continent was established by simons and Albertson. They have remarked that :—

(*i*) The permissible average velocity increases as fine silt charge increases.

(*ii*) The value of coefficient in equation II varies from 13.86 to 17.9.

Mr. Lacey also claims that the silt factor $f = \frac{.75\ V^2}{D} = 24.13\ \frac{V^2}{D}$ explicily includes the silt grade and the silt charge and in one of his latest relations he has shown it to be a factor of silt charge $\overline{C}$ and fall velocity of the particle $\underline{(W)}$. Mr. Ning Chen (5) has shown that the Lacey silt factor $.75\frac{V^2}{R}$ has a linear relation with silt charge. In certain main canals carrying excessive silt charge the value of silt factor $.75\ \frac{V^2}{D}$ was considerably less than unity despite the fact that the sediment size is of the order of .4 mm and the slopes are steeper.

(4)

The Lacey equation correlating the discharge, slope and area of across section are given below :—

$$A = \frac{1.26}{f^{\frac{1}{3}}}\ Q^{5/6} \quad \ldots \quad \ldots \quad \text{III}$$

$$S = \frac{f^{5/3}}{1844 \times Q^{1/6}} \quad \ldots \quad \ldots \quad \text{IV.}$$

These equations hold when :—

(*a*) The discharges are within the conservative range 5—5000 cs. and

the silt diameter varies from .15 mm to .4 mm and the bed load is quite less.

(*b*) The silt charges (bed and suspended) are not more than the regime silt charges.

(*c*) When the surcharge of silt is over dunes the lacey relations as given above do not apply. Extra slope generated in the head reach of Jamrao Canal of the Nara Canal System due to duned bed is of the order of 40%.

(*d*) When the material is fine enough to be cohesive other factor will come into play.

The geometry of the channel cross-section is a function of discharge, slope, representative silt diameter, solid charge, wash load and the mode of operation of the channel. It is imperative that sediment characteristics be considered in the design of channel cross-section. The problem of a alluvial channel design can be stated as follows : Given the bed material, what shoved be the width, depth and slope of the channel to accomodate the given discharge and sediment inflow.

CHAPTER III

The Residual silt which cannot be carried by the channel should be ejected through silt ejector.

With a given slope, discharge and cross section of a channel, it can tsansport optimum silt in grade and quantity. Sediment load in alluvial channel varies between wide limits and is a function of fluid properties, flow and sediment characteristics and channel geometry.

Due to increased silt load and progressively coarser bed material entering U.B.D.C. at its head regulator, it was noticed that shingle nodes were travelling at the rate of 1000.0' per annum and the beds of the branches and distributries were rising. The very channels which Kennedy held to be in regime, had slowly widened and become shallowe. Ultimately Salampur extractor had to be constructed besides taking preventive measures at Madhopur headworks.

In case of L.C.C. excessive silt entry at the head had caused the bed of the main canal to rise and was giving great trouble in the branches and the distributaries and so preventive measures which embodied triple decantation of water above the headworks were adopted in the years 1934-35.

Dadupur excluder was completed in 1936 to exclude coarse silt from main branch of Western Jamna Canal which had silted to such an extent that its authorised supply could not be passed without expensive raising of Main Line.

Marala Ravi Link with designed capacity of 22000 cs. was opened in 1956. By the end of 1960, 252 million cft. of silt entered the Link that resulted in raising the bed of the channel and steepening of channel slope in its head reach to such an extent that the capacity of channel at its designed full supply level at its head is almost nil at present.

Thus M.R. Link, designed for Lacey f=1, went out of regime due to excessive silt charge within 4 years. This attracted attention prominently to the importance of the silt charge in Regime concept. Recent works on this aspect are surmised below before giving over own attempt at the analysis of the data available on the subject.

(4)

Lacey in his recent paper has given the following equation involving silt charge.

$$\frac{V^2}{gD} \propto \left(\frac{\overline{C}W}{Vg}\right)^{\frac{1}{3}} \quad \ldots \quad \ldots \text{ I.}$$

Where W=the fall velocity of the particles

D=Depth of water.

γ=Kinemetic viscosity.

$\overline{C}$=Silt charge.

The values of constants in equation I are yet undetermined.

(8)

Professor E.A. Zamarin has given the following two equations (in metric system) involving q_s the transport capacity of channel in kg/cm.

$$qs = \frac{700\ v}{wo} \quad \frac{/\ RS\ v}{m} \quad \ldots \quad \ldots \text{ II.}$$

$$qs = \frac{9000}{-1.25}\ RS \quad \ldots \quad \ldots \text{ III.}$$

Where $\overset{m}{W}_{o}$=2 for m<2 mm.

Where m is diameter in mm.

(9)

Einstem has given the following equation for total load transport in a fluvial channel :

$$\overline{C} = i_B\ q_B\ (PI_1 + I_2 + 1) \quad \ldots \quad \ldots \text{ IV.}$$

Where i B=Fraction of a bed load in a given grain size range.

q B=Rate at which bed load moves through unit width of cross-section. It can be calculated from the relationship given by Ning Chien. (10)

$$\phi_* = (\phi/-.188)^{3/2} \quad \ldots \quad \ldots \text{ IV (a).}$$

where $\phi = \frac{qB}{(g)} \left(\frac{P_f}{P_s - P_f} \right)^{\frac{1}{2}} \left[1/g(m_{35})^3 \right]^{\frac{1}{2}}$ ... ... IV (b).

$$\phi = \frac{\left(P_s - P_f \right)}{P_f} \cdot \frac{m_{35}}{RS} \quad \text{... ... IV (c).}$$

where m_{35} = size of bed material of which 35 percent is finer.

P_s and P_f are the densities of the fluid.

$$I_1 = .216 \frac{A^{Z-1}}{(1-A)^Z} \int_A^f \frac{(1-y)^Z}{y} dy \quad \text{... ... IV (d).}$$

$$I_2 = .216 \frac{A^{Z-1}}{(1-A)^Z} \int_A^f \frac{(1-y)^Z}{y} \log_e (y)\ dy \quad \text{... ... IV (e).}$$

The integral values of I_1 and I_2 are functions of A & Z and plotted by Einstein.

$$A = \frac{2d}{D}$$

$$Z = \frac{W}{.4\sqrt{\frac{}{g}RS}}$$

and $P = \frac{1}{.434} \log_{10} \left(\frac{30.2 \times x}{K_s / D} \right)$ ... IV (f).

Where KS = Roughness of bed and is the size of sediment of which 65 per cent is finer.

$d = \frac{m\ 35}{305}$ i.e. dia of bed material in feet.

of which 35 per cent is finer.

Investigation of the total load was carried out by the Laboratory experiments by Laurson and the equation derived by him is as below.[11]

$$C = iB \left(\frac{T}{T_c} - 1 \right) \left(\frac{m}{D} \right)^{7/6} f(Z) \quad \text{... V.}$$

Where T is the tractive force and T_c is the critical tractive force to

initiate the motion of a particle.

A comparison of Laurson and Einstein methods of computation of (11a)
sediment charge was made in one of the papers presented to this Congress last year and some imperical formula applicable to the Punjab Regime data were also given.

It appears that the problem of bed roughness and silt intensity are similar as both are functions of fluid properties, flow and sediment charactaristics and boundry geometry.

The pertinent variables which the authors consider important are arranged in the functional relationship.

$$C = \phi (q, s, v, B, D, w, d, \mu, \varrho, g)$$

where q = discharge per foot run

s = slope, B = bed width and d = dia meter in feet.

Assuming D, V and ϱ as repeating variables and applying Pi-theorem the interdependence between important non-diamensional parameters is

$$\overline{D} = \phi \left(S, Re, Fr, \frac{B}{D}, \frac{d}{D}, \frac{w}{V}, Cc \right)$$

where Re is Reynold No. Fr i.e. Froud No. and Cd is a drag coefficient. The equation can be simplified by noting that :—

(1) Width-depth ratio is probably of secondary importance.

(2) Cd is implicit in hydraulic parameters.

$$\overline{C} = \phi \left(S, Re, Fr, \frac{d}{D}, \frac{w}{V} \right) \quad \ldots \text{ VI.}$$

The following data was utilized in developing the silt intensity equation as guided by equation VI.

(1) L.C.C. data observed by Irrigation Research Institute in the years 1940-1942. Range of weighted dia of bed particles was .15 mm to .43 mm and the temprature variations were from 9°c to 18°c. Wash load which is defined as the material transported by flow which is not found in appreciable quantities in bed was neglected in computations of silt charge which was averaged out for the months May-September 1941.

(2) Development and Research Division, Karachi conducted hydraulic and silt data observation on 25 sites in Jamrao Canal system in the year 1930-1932 for the months July-October. Wash load (below .02 mm) which was about 2/3rd of total silt load also neglected in this case. The average silt

intensity of the period June-October in the years 1930-1932 is of the order of .7 gm/litre. The average dia of bed silt of the system varies from .052 to .261 mm.

(3) Field data from selected canal reaches in States was taken by [3] D. B. Simons and D. L. Bender during Summer of 1953-1954. A total of 24 reaches were investigated. The magnitude of sediment concentration in the Canals measured by Simons and Bender is of lesser order as compared to Punjab Canals.

(4) D. B. Simons and E.V. Richards on conducted study of roughness in alluvial channels in a tilting recirculating flume 150′ long, 8.0′ wide and 2.0 deep. The median fall diameter of sand was .45 mm. Forty-five runs covering all the conditions of bed varying from ripples to antidunes were conducted by [7] Simons and Richardson. The tests by D. B. Simons with [12(b)] .28 mm. dia were also utilized plotting.

(5) E. M. Laurson conducted flume tests (in 105′ long 36″ wide and 18″ deep flume) with .04 mm. and 1 mm. median dia. sand. This data is unique in that the sediment concentration is relatively high and the bed load was probably not more than 1 % of the total load. [11]

Starting from the data and its analysis presented by the senior author and A. Rehman [11(b)] (paper No. 351 West Pakistan Engineering Congress 1962), the authors of this paper made further attempts, using some more data also, to improve upon the relation derived earlier. The aim kept in view was that the relation may be non-dimention and may give equal or a better fit.

The calculated silt charge as given by the modified non-dimensional is plotted against observed silt charge in gm/litre in fig. 2.

$$\overline{C} = \frac{20}{3}\left(\frac{q}{Y}\cdot\frac{Y}{dw}\right)^{2/3} \cdot S^{3/2}, \frac{V}{D^{\frac{1}{2}}} \quad \text{(Flume data} \quad \ldots \text{ VII.}$$

$$\overline{C} = \frac{200}{3}\left(\frac{q}{Y}\cdot\frac{Y}{dw}\right)^{2/3} \cdot S^{3/2.} \frac{V}{D^{\frac{1}{2}}} \quad \text{(Field data)} \quad \ldots \text{ VIII.}$$

where d is dia in feet.

The L.C.C. and Jamrao Canals yield points that plot quite close to the trend curve. Ravi at Shahdara points nearly lie on the curve. The range of material forming the periphery of canals of Simons and Bender data extends from fine cohesive material to coarse, non-cohesive material but still the trend line is symmertical with respect to Simon & Bender data.

Sediment load with ripples varies from 0 to .09 gm/litre and so estimation of exact silt charge becomes a difficult problem espeeially when the bed material is of the order of .45 mm. In case of rippled bed as the movement of ripples is very slow equilibrium conditions are established after few days and some error in measurement of silt can occrue on account of this fact.

All the parameters on the right hand side of equations VII and VIII are dimensionless. The significant features of the equations are that the silt intensity is ∝ ratio of Reynold No. of flow and that of falling particles, Froude No. and slope.

Although plotted data represent a wide range in silt charge, median dia, depth, slope, mean velocity yet water temperature which effects the silt intensity as given by equation VII and VIII through w, the fall velocity has not been accounted for in the plottings. The eurve of equations VII and VIII is fairly representative trend line of the plotted data. The scatter is fig. 2 can be explained by :—

(1) Effect of fine sediment on roughness of bed.
The reduction in channel resistance is due to damping effect upon the turbulance of heavily loaded laver of water near the bed. The damping effect of the sediment is dependent, on the size of particles, settling velocity and the amount of silt present in flow.

(2) Temperature effects the settling veloeity.
The settling velocity for silt computations was read from the fall velocity and grain size curves given by Rubby, fig. 2b. The velocity is definitely a function of temprature.

(3) Flume data is essentially for two dimensional flows.
Side slippings and by-passing of dunes as in a natural stream is not possible in a flume. In a flume dunes will grow untill their crests are within a certain distance of the water surface. In case of flume the ratio of depth of flow to dune height ranged from 1 to 5. Moreover fine silt contents are a small percentage of the total silt in flume while in channels, the fine part is excessive.

(4) Channel shape effect has been ignored.
It is obvious that share is appreciably affected by the type of natural bank material, the amount and type of bank vegetation. (The plant roots reinforce the berms of canals) and concentration of wash load.

(5) Method of measurement of silt charge.

The technique of observations of stlt charge is important for working out the representative silt samples. In some cases the silt intensities have been measured at .6 depth by bottle sampler and in some case depth integreting sampler have been

used and in some cases samples were collected by width integreting sampler from falling nappe at the downstream end of flume.

In case of Lacey channels the silt charge is approximately given by the equation.

$$\overline{C} = \left[(1844 \times S \times Q^{1/6}) \right]^{3/5 Z} = .75 \frac{V^2}{R} \quad \ldots \quad IX$$

$$\text{Where } Z = \sqrt{\frac{g\ DS}{w}} \quad \ldots \quad X$$

If the silt transporting capacity as given by equation VIII is less than the actual silt intensity in canal the residual silt beyond the carrying capacity of channel can be ejected back into the river through silt ejectors. Equation VIII can also be utilized for aegulating silt at the intake of the canal. In case there is no ejector in the head reach of canal every attempt should be made to disallow silt into the canal beyond the carrying capacity of canal.

Equation VIII can also be utilized for regulating the silt at ejector site.

M. R. Link with a design discharge of 22,000 eusecs, depth of 14.0′ silt diameter of .2 mm. and slope of 1/10000 has a silt carrying capacity of .736 gm/litre as calculated from equation VIII. This increases to 1.0 gm/litre if channel is regarded to a slope of 1/8333 and to 1.387 gm/litre if it is regarded to a slope of 1/7000. The silt intensity (coarse + medium sand) in M. R. Link at its head sluice in moonsoon months varies from 1 gm/litre to 2 gm/litre and it sometimes shoots up to 4 = 7 gms/litre. The equation derived above, therefore, can be used for estimating the silt carrying capacity of a channel over a wide range of silt load. Knowing the silt carrying capacity of the off-taking channel & silt load in the parent stream we get a basis of how much material is to be excluded at the head regulator. Now we deal with the means to achieve this.

CHAPTER IV

BASIC HYDRAULIC PRINCIPLES OF DESIGN OF SILT EJECTORS

(*a*) The location of ejcctor on inside of the curve.

(12)

The investigations described in the paper "Sediment exclusion method and devices at the intake of canals" have unequivocally shown that Nature's method of locating the intake of off-taking canal from parent canal on a well established concave curve towards its downstream end is fool proof, automatic and most reliable method of controlling sand in the offtaking canal.

Similarly experiments conducted in the Institute very well demon-

strated that if silt ejector is located on the inside of curve towards its downstream end, it draws heavily silt laden water as there is concentration of sediment on the inside of the bend. The exact location of the silt ejector, the type of silt ejector and the mode of drawing the water determines the efficiency of silt ejector. Pipe inlets were tried for drawing the sediment from bar on the inside of curve at the offtake point of Power Channel of Rasul Hydel from U. J. C. (Fig. 3). The efficiency of 4 No. pipe inlets was as high as 87 per cent. Vortex tube with its axis parallel to the bank on the inside of bend is also quite offective if effluent tunnel from vortex tube is located at the mid of tube (which is at the downstream end of the curve) and its two ends are closed. If the curve in the channel is mild we can use surface vane (with opening at its bottom) to deflect sediment towards the inside of curve.

(*b*) Drawing heavily silt charged bottom flow through the silt ejector.

The working of the frontal ejectors depends on the fact that the coarse material is carried near the bed and if we could withdraw heavily silt charged bottom flow we can quantitatively reduce the silt charge as more of coarser stuff is carried near the bottom a qualitative reduction in silt charge of the canal will also accrue.

The turbulence concept of sediment suspension is now generaily accepted. Although the flow at the point has a general forward motion, in a short span of time small volumes of flow or eddies fluctuate spontaneously, rapidly and haphazardly in horizontal and vertical directions and the fluctuations follow normal error law. Sediment particles are raised from the stream bed by a shear or tractive force exerted on the boundaries of channels and are moved upward by momentary upward eddy currents. The upward movement of flow and sediment is countracted by the force of gravity and the particles are falling with respect to the fluid surrounding them. Normally the sediment concentration in a stream increases towards the bottom and so upward eddies transport greater sediment than the downward eddies though for reasons of continuity the quantity of water moving in upward and downward eddies past any horizontal plan is the same. The sediment load distributions in a stream vertical is in equilibrium when the downward rate of sediment through any horizontal plane is equal to the upward rate resulting from upward eddy components.

Turbulence or mixing process is lifting or diffusing sediment in the direction of decreasing concentration and if it is assumed that average concentration varies with depth in an orderly manner then the upward discharge of sediment per unit area of horizontal plane is $\delta_s \frac{dx}{dy}$ and corresponding downward discharge of sediment is nw and under statistically steady state equilibrium conditions.

$$nw = -\delta_s \frac{dx}{dy} \quad \ldots \quad 1(a)$$

Where n is concentration at depth y and $\frac{dx}{dy}$ is silt concentration gradient.

If δ_s the intensity of sediment mixing process is equal to δ the eddy viscosity or the rate of fluid exchanges related with shear velocity $\sqrt{To/P}$ by the Prandtle V'on Karman relation

$$\frac{T}{P\delta} - \frac{10}{dy} = \frac{2{\cdot}5}{y}\sqrt{To/P} \qquad \ldots (1)$$

The shear T stream is distributed linearly being zero at water surface or depth D and maximum To at bed.

$$T = To\ \frac{(D - y)}{D} \qquad \ldots (2)$$

The cumbining equations 1 (a), 1 and 2 and integrating we obtain the equation

$$\frac{n}{na} = \left[\frac{(D-y)}{y}\left(\frac{a}{D-a}\right)\right]\frac{2{\cdot}5w}{\sqrt{To/P}} \qquad \ldots (3)$$

Where n_a is the concentration at depth a. Equation 3 represents the Physical law controlling the distribution of the suspended sediment over the vertical. It has been shown by Professor Venoni (13) that equation 3 holds for particles greater than .1 mm as for finer particles the Von Karman Universal constant 2·5 is a function of finer particles.

To increase the efficiency of frontel type silt ejector it is essential that more sediment be thrown in bottom layers which implies that the ratio $\frac{n}{n_a}$ should be as small as possible.

The equation 3 can be written as :

$$\frac{n}{na}\left[\frac{a}{D}\left(\frac{1}{y/D} - 1\right)\right]\frac{2{\cdot}5w}{\sqrt{gDS}} = N^Z \qquad \ldots (3)$$

The objective can be achieved by decreasing the value of S, increasing the value of D and increasing the value of W. At large diametres the weight of the particles becomes too great for the lift forces and the entire solid charge moves over or near the bed. The finer the particles, the more gradual becomes the silt concentration gradient and conversely the coarser the particles the steeper becomes the concentration gradient. The settling velocities of particles smaller than 1/16 mm vary approximately as square of diametres, whereas extremely large particles the settling rates

vary approximately as square roots of the diameters and so in the analysis of sediment in suspension particles of size smaller than 1/16 mm may be ignored. Clay and silt particles are uniformly distributed in a stream.

The increase in the value of D, decrease the value of N as well as Z. The effect of gradual lowering of bed just u/s of frontal silt ejectors conducive to increase the trap efficiency of silt ejectors. It also connotes that the skimming wall works most efficiently in deep water.

The effect of slope is dominent of all otherfactors. If a channel of depth 16·0′ carries a sand of average diametre ·25 mm. the value of the ratio of sediment concentration at ·6 D over the concentration at depth 'a' is $6{\cdot}0\times10^{-6}$, $3{\cdot}5\times10^{-}$ and $4{\cdot}6\times10^{-54}$ respectively for respective slopes 1/10,000, 1/6,666 and 1/1,000 assuming constant depth for all the slopes.

(14)

(*c*) It has been concluded by Danel, Durand and Condolios, that with normal sandy duned-bed formation the bulk of the sediment is transported by saltation. Then the canals carry surcharge of bed sediment by consuming more slope than the regime slope. Thus if the ejectors are constructed in bed of such canals the most of the coarse material in saltation will be drawn by ejector as sand waves are intercepted by the silt ejector.

(*d*) Where there is convergence of currents the concentration increases in the bed layers. Converging currents have greater silt carrying power, Scour or silting up are respectively the results of accelerated and decelerated currents. The vortex ejector utilizes this phenomenon for its efficient performance.

(*e*) If a silt ejector is located on the bed of a channel at its bend, the helicoidal cross-currents generated due to unbalanced pressure at the concave bank as a consequent of centrifugal force (which carry the sediment from concave bank to the convex bar) vitiate the performance of ejector. Any disturbance that causes mixing of filaments supplants the efficiency of silt ejector.

CHAPTER V

Frontal Type Silt Ejector.

Excessive silt entry has invariably resulted in accretion of bed of canal and its sub-branches even in the case when the canal sections are designed on the basis of silt stable regime formulae.

In case of the L.C.C. excessive silt entry at its head had aggraded the bed of the main canal and silting trouble reached in the branches and distributries. Preventive methods in the form of generation of curviliner flow at the intake of regulator of L.C.C. such that the canal supply branched off from the main river current slightly D/S from the summit of the extrados of curve and construction of silt excluder tunnels in pocket to stop bottom currents from entering canal were adopted in the years 1934-1935.

It was noticed that shingle bar was travelling at the rate of 1000.0' per annum in U.B.D.C. and the beds of branches and distributries were consistantly rising and so Salampur extractor had to be constructed besides taking preventive measures at Madhopur Headworks.

Dadupur excluder was completed in 1936 to exclude coarse silt from Main Branch of Westerd Jumna Canalwhich had silted to such an extent that its authorised supply could not be passed without expensive raising of Main Line.

Number of silt extractors were constructed on Upper Jhelum Canal to exclude silt that finds its way into the Canal at the level crossings of Nullahs crossing the Canal. There is no silt trouble in U.J.C. upto offtake of Rasul Power Channel. There is excessive silt entry in Gujrat branch offtaking above Khokhra regulator but it is due fluctuations of water levels and bed levels in Power Channel and Upper Jhelum Canal above Khokhra Regulator.

Haveli Canal which offtakes from left bank of Trimmu Headworks drops into the river Ravi above Sidhnai has no fall in its entire length of 45 miles and is designed with a slope of 1 : 10.500. Steps taken to exclude silt from Haveli Canal consisted of silt excluder tunnels in 4 undersluices bays adjacent to regulator of Haveli Canal extending beyond the left abutment of regulator and two silt ejectors below R.D 2000 of canal to utilize upto 40 percent of canal discharge.

To exclude silt from Thal Canal designed to take 6000 cusecs (at Pond level 692.0) modified Khanki type silt excluder was constructed in two undersluice bays annexed to canal regulator and 5 silt extractors with extraction ratio of 24 % were placed in geomatrical progression at R.D. 500, 735, 1150, 1900 and 3200 below the head regulator. As in fluvial channel carrying silt in suspension the concentration of silt in lower layers is greater than in upper layers, it was assumed if the silt settles into the lower layers of water in compartments of canal between silt extractors, the efficiency of 5 silt ejectors drawing water from the proximity of bed at

5 sections will be more than a single ejector with a discharge escapage equal to total escapage of all the 5 silt ejectors.

It was experienced at Trimmu that when river is high and canal supply is low the silt extractor failed to function and so a regulator at R.D. 3300 was provided D/S of extractors capable of heading up supply in the head reach to pond level and thus enabling the full head across the barrage to be used in the extractors.

The pertinent hydraulic features of frontal silt extractors are :—

(1) Horizontal slab close to the bed of canal (supported over a system of main piers forming the walls of main tunnels and sub-piers acting as the vertical diaphragms of sub tunnels) separaters the stream into two parts, horizontally the upper part containing relatively clear water which continues to flow in the forward direction as canal supply and the heavily silt laden bottom water which escapes through the system of main and sub-tunnels converging towards river side bank of canal back into the river D/S of the weir. The canal width at the entrance is divided into a number of eqnal compartments and each compartments is further sub-divided into a number of sub-tunnels.

(2) To obtain better movement of sediment the floor of sub tunnels is given a slope which is usually along the axis of canal.

(3) To avoid any danger of silting, the velocity in the tunnels must be high without affecting the normal velocity distribution at the inlet of tunnels. The purpose can be achieved by transforming low velocity of the escapage at separating to the high tunnel velocity by gradual contractions and expansions of the sections of the tunnels prior to exit.

(4) The ejector is usually designed to draw uniform discharge per foot of the entire bed width of the canal. The velocity of flow at the intake of sub-tunnels, at the junction of sub-tunnels with main tunnels and the exit of main tunnels should be equal for all the tunnels.

For construction ease and economy in frame work the radii of the vanes under sub-tunnels are usually kept the same and the section of sub-tunnels is adjusted by sloping the bottom of the roof slab to equalise the head losses through all the sub-tunnels. The usual practice is to keep the clear height of main tunnels the same and to equalise the head losses in the main tunnels by adjusting the width of the tunnels.

(5) To confine the turbulance due to transformation of flow bed velocity of canal into higher velocity in sub-tunnels, the roof slab of sub-tunnels is projected beyond the nose of piers. The openings to the entrance of ejector are bell mouthed.

(6) The discharge in main tunnels is regulated by gates at the exit end of tunnels. The gates are usually regulated so that discharge through all the tunnels is the same.

(7) The tail race of silt extractor is designed on a steep slope to carry the heavily silt charged escapage. It can be a lined channel. The escape channel should be designed for full supply discharge with tail water level generated by the dominent discharge of the river.

(8) Trash that collects at the nose of piers and projected edge of

adversly effects the efficiency of silt ejector.

(9) A silting over top of roof slab of ejector equal to half of full supply depth canal may be assumed (when the canal is dry) for designing the slab and piers of the ejector.

(10) During the period when the ejector is out of operation occasional flushing of tunnels is required.

The Model of Dera Ghazi Khan Canal Silt Excluder.

Irrigation Research Institute was entrusted to evolve a suitable silt ejector design for Taunsa Barrage Canal. Series of experiments were conducted to clear up some of the transcedental salient features of the frontal silt ejector at the Hydraulics Field Research Station Nandipur.

The Canal selected for silt ejector studies was Right Bank Dera Ghazi Khan Canal. The model representing 3000.0′ length of D.G. Khan Canal and two silt ejectors were constructed to a geometrically similar scale of 1/20 Fig. 4. A sand feeding machine was installed at the head of model for injecting sand uniformly at a constant rate in an artificialy created standing wave sufficiently above upper silt extractor to secure natural distribution of silt at ejector site. The silt passing into silt extractor and the canal below silt extractor was collected in silt traps of suitable dimensions. The results obtained from the model are discussed below.

Most Effieient and Economical Discharge to be Escaped Through Ejector.

Some of the earlier designers of silt ejector believed that the greater the escapage the greater, the effeciency of silt ejector. Designed escapages for some of the silt extroctars are given below:

Silt Extractor	Canal	D.Canal	D.Discharge	Percent
Bhong	U.J.C.	8000	1260	15.8
Jaba	U.J.C.	8000	1500	18.8
Kasba	U.J.C.	8000	200	2.5
Chak Sikandar	U.J.C.	8000	235	2.9
Dumbiwala	U.J.C.	8000	108	1.3

Silt Extractor	Canal	D. Canal	D. Discharge	Percent
Salampur	Salampur feeder U.B.D.C.	1800	700	39.0
Dadupur	Western Jumna Canal	6400	1400	22.0
5 Extractors of Thal Canal.	Thal Canal	6000	1440	24.0
2 Extractors of Haveli Canal.	Haveli	5249	2200	41.9

Mr. F.F. Haigh an authority on silt excluders and silt ejectors suggested a figure of 20 percent as reasonable. The additional escapage discharge increases the silt entry in canal at its intake and inflates the head regulator cost, conformity maximum effeciency of ejector.

Efficiency of the model silt ejector as determined by the formula given below is plotted as ordinate against extraction ratio of ejector $\left(\frac{\text{escapage discharge}}{\text{canal discharge}}\right) \times 100$ as abcissa in figure (5).

Effcciency $E = (1-Id/Iu)\ 100$

Where Iu = Silt intensity (silt per cusec per hour) in the approach channel to ejector.

and Id = Silt intensity in canal D/S of silt ejector.

It is obvious from interdependence curve between efficiency and extraction ratio that :—

(1) The gradient (slope) of the curve decreases with increase in extraction ratio and the curve is almost parallel to X axis at an extraction ratio of 12.5 %.

(2) The proportional increase in the efficiency of the silt ejector beyond extraction ratio of 12.5—15 % is almost nil. Abnormal draw of discharge through silt ejector results in mixing of filaments at bifurcation point of top and bottom flow, at inlet of tunnels and thus increase of discharge beyond 12.5 % does not contribute in enhancing the silt efficiency of ejector. The optimum ratio of escapage will be a function of sediment grade, silt concentration the incoming discharge in canal and R.L. of the separation point.

When ejector was drawing 12.5 % of the canal flow the silt samples of silt charged at head of model, silt collected in sand traps of extractor and canal were analysed. The results are given in Table I. It will be

seen that whereas 35.4 % of the coarse sediment above .2 mm existed in sample fed in the model only 4 % of this coarse silt was present in sample collected in canal below ejector. Thus with optimum escapage the coarser material above .2 mm will be satisfactorily drawn by the ejector.

Position of a Diaphragm Slab with Respect to canal bed.

The separation of the escapage flow at the U/S edge of diaphragm slab and the U/S edge of this slab itself should not effect the regime of flow in the zone of withdrawal of ejector. The vortex ejector is known to be most efficient at critical flow conditions. To determine optimum position of horizontal slab and the oprimum frouds No. ($V/\sqrt{gd}$) in the ejector flume for the best silt performance of the ejector, it was raised as a whole by 1.0′ in each test. In this series of tests the extraction ratio of silt extractor was fixed at 12.5 per cent and the working head for the ejector was kept constant and rate of feeding the silt in the model was also kept fixed.

With rise in elevation of horizontal slab the water surface wave transforms first into unulatory jump and finally into hydraulic jump at a slab R.L. of 440.01 (fig. 6 a, b). The water s urface profile along axis of ejector flume, velocity distribution in canal section at U/S apron at R.L. 431.0 (for top levels of ejector slab at R.L. 433.01, 437.01 and 438.01) are shown in figure 7. The efficiency of silt extractor against non-dimensional parameter d/D where (d) is the depth of water over slab of ejector and (D) is the normal depth of water of the canal and Froud No. F is plotted in fig. 8 which discerns that the highest efficiency is attained $d/D = .9$ or Froud No. Fr is at .2 and at higher values of Froud No. Fr or d/D ratio the ejector slab starts interfering in the normal distribution of flow.

In normal distribution of silt in suspension in vertical the silt charge and coarseness increase from water surface to the bed of the channel but this distribution is disturbed by permitting too great a velocity over the horizonal slab as a consequent of which the normal pattern of flow gets altered substantially, various filaments of the flow get disturbed and mixed together and the coarse particles rise to the surface. This us edge of horizontal slab sets up turbulence and probably sepration of flow at higher velocities. Thus the main conclusion is that at higher levels the horizontal slab which is meant to deflect the bottom layers charge with a heavy and coarse silt to ejector tunnel without disturbing the top layers itself disturbs the normal silt distribution pattern by deflecting the bottom filaments towards surface.

The approach conditions necessary in the channel for efficient silt exclusion.

The theoretical analysis showed that silt charge and coarseness from water surface towards bed increases with depth of water and so a deep and straight channel of optimum length without any sangs of deformations in bed or sides that may set up turbulance, is a pre-requisite for efficient performance of silt ejector.

The u/s pitched length and its slope is an other parameter effecting the silt distribution in the lower layers of water and smooth entry to the silt ejector tunnels.

Keeping the top of diaphragm slab at R.L. 433.01 i.e. the bed of canal and fixing the extraction ratio at 12.5 percent the u/s pitched length was increased by changing the slope connecting the top of u/s curtain wall (at canal bed level) to the bottom of arifice at the intake of ejector tunnels. The slope of lined or pitched bed approaching the mouth of tunnels was changed on model from 1 : 2 to 1/20. The cross-sections through the ejector for different slopes are shown in fig. 9. The efficiency of silt ejector increased from 55 per cent to 66 per cent as the slope increased from 1 : to 1 : 20 thus vindicating the contention that the slope of the sloping appron to the intake of tunnels improves the entry conditions at the silts ejector. So long as this pitched length remains covered with sand it is immaterial whether it is plastered or pitched but in case the suction of ejector draws this silt cover and the bed is exposed the rough surface generates turbulence and so this portion of bed should be plastered.

CHAPTER—VI

Evolution of the vortex type silt ejector.

Another type of sand trap that can be used to reduce the sediment load entering the canal through its headworks to regime solid load is vortex tube.

It consists of a tube of suitable diameter with a silt parallel to the axis of tube at its top placed orthognally at the bottom of the channel in a transverse direction to the flow and joined at one end with a closed conduct (fitted with a valve or gate at its D/S end) which is taken across the river side bank of canal.

The vortex tube was first developed by Mr. Ralph L Parshall (16) and a detailed study was made by M/S Koonsman and Albertson (17) to appraise the information for its design features and hydraulic conditions in parent channel for its best sediment control. According to them performance of vortex tube is best when :—

(1) Froud No. of the channel is equal to 1 or when there is critical depth over the top of tube.

(2) The dia of tube is the same as the critical depth.

(3) The two lips of the tube are at same elevation.

(4) When tube is at angle with linc of flow.

The investigators claim 90 % efficiency for solids of size greater than .65 mm for 9.5 % extraction ratio.

(18)

Messrs Harold M. Martin and Caurlson of Bureau of Reclamation used a horizontal vane (tapered on the underside towards axis of tube) at a certain height above the wortex tube installed in the crest of regulator of canal u/s of regulator gates at 65° to gate line, The tapered vane increased the velocity directly over the tube causing the vortex in tube to be much stronger than the case when tapered vane was removed and so sediment removed from the tube increased as more sand moved out of the exit of vortex tube. The tapered vane increased the effective length of the tube as without the vane a portion of tube had clogged due to weaker vortex motion in tube.

The salient features of the vortex tube in contradistinction to frontal type silt ejector are :

(*a*) The shearing action across the open top of vortex tube sets up vortices within the tube. The intensity of vortices within the tube increases with velocity of flow at the point ofseparation tube flow from the onward flow. The vortex tube is most efficient at or near the critical flow in parent channel at tube section. The powerful eddies within the tube prevent any deposition of sediment within the tube.

(*b*) The vortex tube obviates any disturbance and consequent mixing of filaments characteristic of horizontal diaphragm of frontal silt ejector. The suction effect of the vortex inside the vortex tube causes downward convergence of flow which helps in increasing the concentration of silt in bottom layers whereas

frontal type causes divergence of flow which is always associated with turbulence. Even if canal is not contracted to accelerate the velocity and decrease the depth the vortex tube ejector is as efficient as frontal type provided it is ensured that the discharge per foot run entering the tube is the almost the same in its entire length.

(*c*) The maximum efficiency of vortex silt ejector is attained at Froude No. .8 — 1.0 but the average Froude No. of Lacey Channel is .19 and so channel cross section has to be tightened by either fluming the channel or by decreasing the depth of flow by vertical constriction or both. Thus gradual reduction in cross-section of channel results in vertical or horizontal or both vertical and horizontal convergence of filaments that throws the sediments in bottom layers thereby increasing the efficiency of vortex ejector.

(*d*) Silt transport capacity of the fluvial channel is given by the guiding relationship as given in equation VIII or Chapter II and as vortex ejector withdraws much of the coarser material near the bottom of channel, the silt transport capacity of the parent channel below the ejector increases. As vortex tube

is more efficient (for excluding coarse silt) than frontal ejector, therefore, the increase in transporting capacity in the canal is more for the vortex tube than in case of Frontal Ejector.

(*e*) For the same escapage the vortex tube is more efficient than the frontal type.

(*f*) If a long vortex tube discharges at one end then the discharge end of tube acts as sluice way, the discharge per foot run entering the tube at all points is not the same and decreases from open and to blind end of tube. In this case the vortex tube gets clogged and its efficiency is vitiated and may be quite less than in case of frontal ejector. Thus it can be gleaned that the efficiency of any type of ejector stems from the requisite that the discharge per foot run withdrawn from bottom of channel should be the same throughout the width of the channel.

Series of tests were made to investigate the design features of the vortax tube and Hydraulic characteristics of vortex ejector flume both in Laboratory flume and full model of D. G. Khan Chanal at the Field Station, Nandipur.

Hydraulic Parameters Affecting Sediment Removal by Vortex Tubes.

The interdependance between various parameters affecting sediment removed tube as worked out from P.1 Theorem which is a handy tool used in solving various problems relating to dimensional homogeneity is :
Where δ = efficiency of vortex ejector

$$\delta = \left[\frac{B}{D}, \frac{I}{D}, \frac{O}{D}, \frac{P}{D}, \frac{Qe}{Q}, \frac{Qs}{Q}, \theta, \frac{V}{\sqrt{gd}}, \frac{\mu}{De\rho}, \frac{W}{V} \right]$$

D = dia of tube

D = depth of flow

I = opening of slit at the top of tube,

O = thickness of slab above the tube.

P = aifference between the U/S and D/S lip levels of aperture of tube.

Qe = vortex tube escapage discharge.

Q = Canal discharge at vortex ejector site.

Qs = Total sediment charge in canal at vortex ejector tube.

θ = Angle between axis of tube and line of flow.

V = Average velocity in silt ejector flume.

$\frac{V}{\sqrt{gd}}$ = Froud No.

Dv = Reynold Number.

efficiently for our canals if Froude number can some how be increased at the ejector site.

To increase the Froude No. at the site the section of the channel can be contracted either by providing vertical construction either by raising the hump at bed of canal or by depressing the surface by breast wall and by fluming the canal at site of vortex ejector. In case of D. G. Khan Canal, flume was provided at ejector site and the vortex ejector was fitted in the crest of flume and experiments were conducted to fix the optimum crest level of flume and the fluming ratio.

For a large canal such as D. G. Khau Canal (Q=14720 cfs B= 300·0′, D=12·99′) experiments showed that single silt across the canal even if placed obliquely does not work equally efficiently for its entire length, as the discharge per foot run entering the slit of vortex tube all along its entire length is not the same, (it being less at blind end and maximum near exit end) as a consequent of which the tube gets partically clogged. Dividing the vortex tube length into two halves equal to half canal width at the section and extracting discharges from each half as shown in Fig. 12 gave the best results. The number of units into which the vortex tabe is to be divided is a function of total length of tube, silt concentration and discharging capacity of exist conduit. Each unit must have its own exit conduit the inlet of which may be bell-mouthed.

Effect of variation of crest level.

In these tests on a model of D. G. Khan Canal to a scale of 1/20, the fluming ratio was kept constant at 66 per cent., the radius of u/s side contraction curves at 50·0′, the crest level of the hump was raised from R. L. 431·0J (the canal bed level) to 436·5 at intervals of ·5′, the water surface profile was observed in each test and the diameter of the vortex tube and exit tunnels was kept equal to observed depth of water in the middle of the crest. In each test discharge equivalent to full supply discharge of canal was run for 10 hours. The water level D/S of ejector was maintained at R. L. 444·0 and silt was injected at uniform rate of ·1 per cent. (by weight) by sand feeding machine and the usual observations of velocity distributions, surface profile, silt collections etc., were made.

The afflux cause by the throated flume which is a measure of decrease in working head across the canal head regulator is given in table below :—

Crest level of vortex silt ejector hump	Water level u/s of silt ejector flume	Afflux
431·01	444·08	·08
432·00	444·14	·14
433·0	444·20	·20
434·0	444·30	·3
435·0	434·38	·38
436·5	444·98	·98

The plot of silt efficiency of silt ejector against extraction ratio of ejector for different crest R. L's of silt ejector flume (figure 13a) showed that the crest R. L. 435·0 was the best elevation for this structure.

The inter-relation between Froude number just upstream of vortex tube and the efficiency for different escapages of silt ejector is maximum for Froude Number in the range ·7 to ·8 (Fig. 13 (b).

The concentrations of sediment at various points on vertical on the axis of flume midway between upstream crest line and axis of vortex tube determined from samples syphoned from the flume through a pippette 5/16" in outer diameter concurrently with Pitot tube Velocity observations with crest levels of hump at R. L. 432 and 435 is plotted in Fig. 13 (c). It can be discorned from Fig. 13 (c) that the silt concentration in bottom layers increases as crest level of silt ejector hump is raised from R. L. 432·0 to R. L. 435 or as the Froude Number increases from ·3 to ·7.

It was noticed on model that depth of flow at the crest of silt ejector just upstream of the vortex tube very nearly conforms to a velocity head given by $\frac{V^2}{50}$.

Effect of fluming of Canal on the performance of ejector.

The efficiency of vortex tube ejector being maximum at Froude No. ·8, the effect of fluming of canal at silt ejector site by 100, 80, 66 and 50 per cent. on the performance of silt ejector without tempering with the optimum value of Froude No. was estimated from model tests. The crest level of the silt ejector flume was determined as detailed below :—

$$\frac{V}{\sqrt{gD}} = \cdot 8 \qquad \ldots \text{(a)}$$

But as $V = \frac{Q}{F \times B \times D}$

$$\therefore \frac{Q}{\sqrt{g.F.B.D.^{\frac{3}{2}}}} = \cdot 8 \qquad \ldots \text{(b)}$$

As the value of Q the canal discharge, (F) the fluming ratio, (B) the width of canal are known the value of D (depth) or water just upstream of vortex tube can be manupolated from equation (b) and the value of velocity (v) at throat can in turn be calculated from equation (a).

The R. L. of the crest of silt ejector flume = Full supply level + velocity head in approach of silt ejector $= \left(D + \frac{V^2}{50}\right)$.

The radius of upstream side wing walls of throated flume was kept equal to $\left(\frac{100-F}{200}\right)$.

The radius of u/s glacis of hump was kept equal to 4 times the theoretical effective depth of water over the crest of hump. Each test for a particular fluming and escapage discharge was repeated thrice (as usual) and the average efficiency obtained from three tests was taken for plotting the results (figure 14 (a).

The conclusions are :—

(1) The curves are almost parallel.

(2) The increase in efficiency of fluming beyond 66% is insignificant which implies that no attempt should be made to increase the contraction of canal section beyond 66 per cent fluming.

(3) The efficiency of silt ejector for an extraction ratio of 5 per cent is 39.5, 55 and 58 respectively for respective ratio fluming of 100, 80, 66 and 50 per cent. It also means that for the same Froude Number the efficiency decreases with the height of crest above canal bed level or the efficiency of silt ejector increases with depth of water over the crest and downward convergence of currents and vice-versa.

Comparison of performance of vortex and frontal silt ejectors.

The withdrawals of vortex (Fluming ratio 66 per cent and Froude No. 8) and conventional type ejectors as percentage of Canal discharge when plotted against efficiency of silt ejector showed (fig. 14 b) that vortex type ejector can be more efficient with less discharge extractions as compared to conventional frontal type ejector. The efficiency obtained with vortex silt ejector is equal to that of frontal type silt ejector at about $\frac{1}{3}$rd escapage of discharge. The maximnm efficiency of Frontal type and Vortex silt ejector is 50 per cent and 60 per cent respectively at respective extraction ratios of 12.5 percent and 7.5 percent,

Operating head across the silt ejector.

If the water escaping through the ejector is thrown in the parent river immediately below the Headworks the river levels especially in accreted conditions will effect the discharge capacity of the ejector and hence its efficiency.

To visualise this effect the outlets of exit tunnels of the vortex silt ejector were made completely free of gates and the level D/S of the silt ejector starting with free fall conditions was raised in a step of 1.0'. The amount of water escaping through the vortex ejector is function of the head operating across the tunnels and the area of cross-section of the tunnels. The silt efficiency of vortex silt ejector is function of escaping discharge only and is not dependent on the head across the ejector tunnel fig. 14c.

Jet Expansion and energy dissipation in the Expanding flume below the ejector.

The problem of jet expansion at Froude No. equal to .8 is very

difficult and so the problem of energy dissipation below the low drop structure. The proper hydraulic jump is formed when kineticity factor (F^2) is 3 or greater than 3.0. In the present case (F^2) is only. .64 and so undulatory jump symptomatic of low drop structure is formed and the flow is very erratic. As recovery of energy is smallest along the sides of the expanding flume the region of flow along the sides is very sensitive hydraulically. There is concentration of flow on the one side and a high intensity return roller on the other side. There is heaving and unbalanced flow. The tail erosion below the work is expected to be devastating. To oviate back swirls and to normalise the flow below the flume structures a number of divices in the form of vanes, breast wall etc. were tried on the model. Satisfactory conditions of flow in expansion and at the end of expansion were secured with the following arrangement.

(1) An aero-baffle wall with top level at the crest of flume is constructed at the toe of glacis. The aero baffle helps in distributing the flow unformly.

(2) D/S wing walls are splayed out parabolically in a splay of 1:4. The apex of parabola is located at D/S end of splay wall and asymptote of parabola is parallel with abutment line.

Model studies for silt ejector shadiwal hydel.

If a Power Channel is transporting sediment the life of the turbine blades will be a function of the sand grade and quanta of silt particles filing the baldes under tremendous velocities and thus to mitigate the baneful effect of sand on turbine blades it is very desirable that harmful silt should be excluded from the flow entering the forebaygates. As each kilowatt of hydel power is very important at the present stage of development of the country, it is imparative that ejector should draw a small percentage of the canal flow and should trap all the harmful silt flowing into the Power channel.

The model comprising lined power channel D/S of R.D. 6000, Forebay, spillway system of Shadiwal Hydel and Bhimber weir was constructed on 1/12 geomatrical scale. To control the flow entering forebay regulator, to maintain pond level at the intake of Power House and to generate velocities in Power Channel simulating to prototype, suitable resistance to flow was provided at the site of wicket gates. The silt entering the silt ejector (discharging into upper most regulator bay of spillway) was collected in a suitably dimensioned settling tank and was measured viumetrically. The solid charge passing into the headrace below the ejector was collected in the silt tran tank below the draft tubes.

As U.C.C water feeding the Hydraulic Research Field Station Nandipur ss charged with different grades of particles with different concentrations in different layers, the U.C.C., water that fed the model was first drawn into 200 cusecs feeder channel which was used as settling tank. Ejector discharge were measured accurately with sharp crested weirs. The sand was injected into the entire section of Power channel at R.D. 7000 with the help

of sand feeding machine at the rate of 1 cft per hour for 8 hours in each test. Each ejector was tested for different escapages.

The percentage escapage through the Frontal and Vortex silt ejectors fig. 15a, b for specific efficiency is as given in the table below and plotted in fig. 16a.

Percentage efficiency of silt ejectors.	Extraction Ratio for Frontal ejector	Extraction ratio for Vortex Ejector.
20%	2	1.1
30%	5.8	2.1
35%	7.5	2.65
40%	9.5	3.5
45%	11.7	4.6
50%	15.0	6.5
55%	This efficiency cannot be attained at any escapage.	9.2
66%	— do —	13.5

It is obvious from the table that to attain the same efficiency (10-50 percent) the escapage of vortex ejector is 35-43 percent of the corresponding escapage for frontal type ejector. The rate of rise of efficiency with escapage through the silt ejector as the extraction ratio increases from 0=5 percent is higher for vortex ejector than with frontal ejector. The most economical extraction ratio is near about 5 percent and for this specific escapage the efficiencies of frontal and vortex silt ejectors are 28 percent and 46 percent respectively.

The total sediment distribution and velocity distribution in the vertical on the centre line of the Power channel just at the intake of the silt ejector for 7-5 percent extraction ratio for the two type of silt extractores are constrasted in fig. 16b which depicts that the percentage silt concentration in bottom layers at the U/S end of aperture of vortex tube is higher than at the inlet of frontal type ejector.

The mechanical analysis of the samplers of sand fed into the model collected from the vortex ejector silt trap and silt trap below the power house for an escapage of 5 percent through the vortex silt ejector is given in the table :—

(*i*) **Mechanical analysis sand fed in head race:**

Mesh No.	Mesh Dia	Percentage finer	Percentage coarser
25	.0236 Inch	98.55 percent	1.45 percent
36	.0166 ,,	92.8 ,,	7.20 ,,
52	.0116 ,,	63.3 ,,	36.7 ,,
100	.0060 ,,	20.8 ,,	79.9 ,,
200	.0030 ,,	14.3 ,,	85.7 ,,

(*ii*) **Mechanical analysis of silt collected in silt taken of silt ejector.**

25	.0236 Inch	97.5 percent	2.5 percent
36	.0166 ,,	90.8 ,,	9.2 ,,
52	.0116 ,,	60.2 ,,	39.8 ;,
100	.006 ,,	20.1 ,,	79.9 ,,
200	.003 ,,	3.0 ,,	97.0 ,,

(*iii*) **Mechanical analysis of silt collected from silt collecting tank below power house.**

Mesh No.	Mesh Dia	Percentage finer	Percentage coarser
25	.0236 Inch	99.3 percent	.7 percent
36	.0166 ,,	98.5 ,,	1.50 ,,
52	.0116 ,,	89.15 ,,	10.85 ,,
100	.006	75.6 ,,	24.4 ,,
200	.0070	37.4 ,,	62.6 ,,

It is apparent from the table that the sand collected in the silt trap of silt ejector is coarser than the sand fed into the model. The 80 percent of sand collected below vortex ejector was coarser than .15 mm whereas the sand coarser than .15 mm escaping in Power House is only 24 percent of the total.

CHAPTER VII

ANALYSIS OF PROTOTYPE DATA FOR THE PERFORMANCE OF SILT EXCLUDERS AND EJECTORS.

The performance of silt excluders.

The prototype data relating to the performance of silt excluders and ejectors does not permit of easy analysis as :—

(1) The number of variables is large and variation is haphazard. The approach to the intake of pocket, Froude No. in the approach channel, the silt concentration and the silt dia vary with stage of the river.

(2) The silt observations are not under controlled conditions.

(3) The increased discharge entering the pocket as a consequent of working of the silt excluders increases the silt entry into the pocket and so it is difficult to determine the absolute efficiency of the excluder. The percentage decrease in the silt entry into the canal (relative to silt conditions in the pocket) in the presence of an excluder as compared to the case when there is no excluder cannot be determined from prototype data unless we have two exactly similar works, with similar approach and entry conditions one having an excluder and the other without it.

(4) Silt moving in the vicinity of the bed which is intercepted by the excluder or ejector tunnels is not accounted for in the analysis as it is not observed in the Field.

Haigh plotted efficiency against water ejection ratio for Dadupur, Slampur, Khani and Jaba and presented results while introducing the paper to the Punjab Engineering Congress in 1368. His analysis had not given conclusive relation between efficiency and discharge ejection.

The efficiency *i.e.* percentage reduction in silt entry for coarse and plus medium silts, S1 (coarse plus medium silt) gm/litre, S2 (Coarse silt) gm/litre ejected through the excluder, S1 and S2 passing into the canal for excluders at Trimmu and Khani are plotted in figures 17 & 18. The following conclusions can be discerned from fig. 17.

(*i*) For Trimmu the efficiency, to start with, was fair being nearly above 50 % on the average.

(*ii*) The difference between the efficiency for coarse and coarse plus medium is not great.

(*iii*) The efficiency observed in 1943 and onwards (observations are available for small periods) is not as high as in the previous years. The reason needs study of actual working conditions.

(*iv*) One of the reasons for high efficiency of excluder in this weir is that the coarse silt actualy present as shown from samples in the excluder and the canal is very little.

From Khanki data it is evident that the efficiency on the average for coarse silt is less than 50 % Khanki excluder is dealing with greater incoming coarse silt charge with higher silt intensity. The Khanki excluder has opening from the sides. It has been observed on the models that side openings in the excluders as in Khanki Excluder decrease the efficiency.

The efficiency against extraction ratio for Trimmu, Khanki, Bong and Jaba silt excluder are plotted in fig. 19. It is difficult to draw a single trend line through the scatter of points. However a family of trend lines can be drawn through the polued points. It is evident from fig. 19 that the efficiency increases with the ejection ratio of the excluders for a particular set of conditions of flow in canal excluders tunnels.

The suction effect of tunnels does not extend very far off from the mouth of the tunnels. The comparison of Trimmu and Khanki excluders shows that the openings of the excluder tunnels should intercept the bottom flow moving towards the regulators of the canals. There is a curvature generated in the pocket itself and so we need not intercept the flow from the outside of the curvature and every attempt should be made to intercept the bottom flow ont he convex side of the curvature.

Data of silt ejectors.

In case of the frontal type silt ejector the entire flow is drawn from open vertical upstream face of the ejector. The height of vertical openings depends on the flow and form of bed expected in the canal. If the ejector slab is above the canal bed the turbulence created at the upstream nose of diaphragm slab throws the silt in suspension. If the ejector openings are below the canal bed the openings are likely to be choked by moving dunes especially at smaller ejection discharges. The rolling bed sediment is sucked through the gap in the form of a slit above the opening of the extractor. The efficiency of Thal Line ejectors (4 in number) against silt intensity upstream of the ejector and the ejection ratio are plotted in figures 20 and 21. It connotes from figure 20 that the efficiency of ejector increases with silt intensity and is maximum at .2 gm/litre and then it falls with further increase in silt intensity in the canal. The efficiencies are significiently lower for higher concentrations as at higher silt intensities in the canal a large percentage of the solid charge is in suspension. The stable value of the efficiency for suspended material increases as we go from extractor at higher R.D. to extractor at lower R.D. It is obvious that as the bed load in the canal decreases from extractor 1 to 4, the efficiency of the extractor with respect to suspended load increases from extractor 4. The suspended load sinks to bottom to cater for the bed load that is ejected out higher up.

The efficiency of four extractors of Thal Canal increases with extraction ratio as is evident from fig. 21. The efficiency of Qasba, Dumbiwala extractors on U.J.C. against silt intensity and extraction ratio is plotted in fig. 21. The trend is the same as for Thal Canal extractors.

The prototype data for extractor of Dargai Hydel is being collected and arrangements are being made by the Institute to collect the data for vortex silt ejector constructed in the head race of Shadiwal Hydel.

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