SEDIMENT TRANSPORT AT LOW CONCENTRATIONS IN PIPES. VOLUME III: LITERATURE REVIEW, ON SEDIMENT EXCLUSION IN SMALL CANAL STRUCTURES

by

V. M. Ponce
Y. H. Chen
J. K. Rivero

Civil Engineering Department
Engineering Research Center
Colorado State University
Fort Collins, Colorado 80523

August 1980

CER80-81VMP-YHC-JKR3

SEDIMENT TRANSPORT AT LOW CONCENTRATIONS IN PIPES. VOLUME III: LITERATURE REVIEW, ON SEDIMENT EXCLUSION IN SMALL CANAL STRUCTURES

Prepared for

USDA SCIENCE AND EDUCATION ADMINISTRATION-
AGRICULTURAL RESEARCH
Fort Collins, Colorado

Prepared by

Civil Engineering Department
Engineering Research Center
Colorado State University
Fort Collins, Colorado 80523

V. M. Ponce
Y. H. Chen
J. K. Rivero

August 1980

CER80-81VMP-YHC-JKR 3

TABLE OF CONTENTS

PREFACE

This volume is the third of a series, entitled "Sediment Transport at Low Concentrations in Pipes," Volume III: Literature Review on Sediment Exclusion in Small Canal Structures." It contains the summary of progress on the second phase of the project "Water Energy Management: Development of a Theory of Gravity Pipeline Design and Operation to Avoid Harmful Sediment Deposition." The project is a cooperative agreement between Colorado State University and USDA Science and Education Administration-Agricultural Research, aimed at research studies on the improvement of surface irrigation practices in the Grand Valley, Colorado. Dr. E. Gordon Kruse is the USDA Project Officer.

LIST OF FIGURES

I

INTRODUCTION

The deposition of water-borne sand and silt has long been recognized as a troublesome problem incident to the operation and maintenance of irrigation canals. Nearly all of the difficulties which confront the irrigation canal engineer are directly or indirectly related to the sediment brought in with the water.

There are two ways to approach the problem: first, to locate an exclusion structure at the canal offtake; and second, to place the exclusion structure in the canal itself. Usually, the exclusion structures at the canal offtake are fairly large and expensive, while the structures located in the canal are relatively small.

At the farm level, very often it is necessary to provide sediment exclusion devices, especially if the distributaries consist of irrigation pipelines. The large number of locations precludes the use of elaborate and expensive sediment exclusion devices. Therefore, the need for simple yet reliable sediment exclusion techniques is recognized.

This report constitutes a summary of the work on the literature review on sediment exclusion in small canal structures. It is to be used as the foundation for developing future strategies on sediment exclusion. The devices identified during the literature review, and which are extensively treated here are:

1) Vortex tube sand trap;
2) Guide vanes;
3) King's silt vanes;
4) Gibb's groyne; and
5) Curved wing with silt vanes.

II

LITERATURE REVIEW

Sediment ejectors usually consist of slots or apertures in the bed of a canal through which coarser material moving as bedload can be removed along with a small quantity of the flow.

Tests of the vortex tube sand trap along with a riffle deflector device were first reported by Parshall (12). The vortex tube sand trap was described as a tube with an opening along the top and placed in the bed of a canal at a angle of about 45° to the direction of the flow. As flow passed over the opening, a spiral motion was set up within the tube. Material traveling along the canal bed was drawn or dropped into the tube and carried to an outlet where it was discharged into a return channel. The device was observed to be very effective in removing large material even to the size of cobblestones.

The riffle deflector sand trap was described as consisting of a series of curved metal plates, each of the shape of the quadrant of a circle fastened to the channel floor. Bedload was caused to move to one side of the channel where it was removed through an opening. A combination of riffles and tubes was also tested with considerable success and was considered the most promising sand trap. In general, this device consists of a series of curved riffles placed on the bed of the channel, whereby the bedload is moved laterally to the side of the channel where it is taken off through small vortex tubes outletting into a common compartment that is provided with an outlet which carries the total trap load back to the river downstream or deposits it in basins as waste material. The riffles in plan are parabolic and since they are identically curved in plan, they are placed one against the other. This type of trap is flexible in that it can be readily adapted to either narrow or wide channels and for flows ranging from less than 10 to more than 2000 ft^3/sec.

Parshall (13) stated that the optimum action of the vortex tube occurred when the water passing over the lip was at or near critical velocity. He also stated that field installations of the device had been both successful and unsuccessful. In installations that were ineffective it was noted that the velocity in the canal was low and the tube was set below channel grade. Trapping efficiencies of 90% were claimed for the device when operating properly.

A tube 0.2 ft in diameter with one-quarter of the circumference cut away and installed in a flume 2 ft wide was studied by Koonsman (8). The sand used for the tests had a size range of 0.4 to 1.1 mm with a median diameter of 0.7 mm. Concentrations of sand ranged from 0.09 to 0.68 in percent by weight (velocity of flow varied from 1.3 to 5.5 fps while depth ranged from 0.2 ft to 0.6 ft). Results from these tests showed that: (1) highest trapping efficiences (92%) were noted near a Froude number of 1.0; (2) efficiencies decreased as the depth of flow increased; (3) efficiencies decreased as concentration was increased beyond a certain point depending also on the depth of flow; (4) optimum operation was noted when the lips were at the same elevation; and (5) percentage of flow removed from the tube varied from 2.7% to 15.5% depending on velocity and depth of flow over the tube. The reason given for the apparent decrease in efficiency with increasing depth was that greater quantities of sediment were being moved and more of this material was in suspension at the greater depths.

A study of the factors influencing the efficiency of vortex tube sand traps was done by Brown (2). A dimensional analysis was performed on the problem and a factor, hitherto neglected, was included in the list of variables, namely, the circulation of the fluid inside the tube. The analysis yielded the conditions which must be satisfied for dynamic similarity to exist between the fluid motions in model and prototype traps. These conditions were verified over a wide range of stream velocities and tube sizes. The stream velocities ranged from about 0.3 fps to just over 2 fps, while the tube sizes were varied from 3/4 in to 1½ in dia. In this way, a method was found by which prototype vortical actions could be predicted from model tests. An important conclusion arising from these tests was that the fluid motion in the tube is virtually independent of viscosity. The outflow through the tube is generally affected by lowering the surface of the water in the sedimentation basin relative to the surface in the channel. The experiments showed that if the downstream lip of the tube was lower than the upstream, the maximum efficiency was found to occur when the Froude number in the channel was slightly less than unity. They showed that the tube became very inefficient over longer lengths and that, as a result, a single tubed trap could not be successfully utilized to remove the bedload from a wide channel. Brown (2) concluded, for a given slot width and tube diameter, that the minimum outflow required to remove the trapped material from the tube over a given width of channel, occurs when the tube is set at 90° to the channel wall. However, an inclined tube will generally have a greater trapping efficiency than the tube placed at 90° to the channel walls. Therefore, no general rule can be stated regarding the inclination of the tube to effect maximum efficiency. Finally, he said that each case must be considered on an individual basis.

Rohwer (16) reported the results of tests conducted on vortex tubes installed in channels 8 ft and 14 ft wide. The tubes used were 4 in and 6 in in diameter set at various angles to the flow. Conclusions from these tests were given as follows: (1) the tubes were most active when the depth of water in the channel was slightly less than critical; (2) straight or tapered tubes were equally efficient in removing sand; (3) angle of tube for angles less than 90° to the direction of flow had little effect on efficiency; (4) efficiencies of trapping were conspicuously better when elevations of the upper and lower lips were the same; (5) the tubes would remove from 70% to 90% of bedload carried by the flume; (6) tubes in a channel that was 8 ft wide seemed to be more efficient in sand removal than the ones installed in a channel 14 ft wide; and (7) when the Froude number of the flow immediately upstream from the tube exceeded 1.3, a considerable amount of sand and gravel was thrown out of the tube and reentered the channel.

The amount of flow from the tube was regulated for some of these tests. This was accomplished by controlling the water level at the tube outlet so that the percentage of flow removed could be varied. It was found that the wasted flow could be reduced by 40% to 50% with a corresponding smaller reduction in the trapping efficiency.

Measurements of velocity of translation and rate of rotation of the flow within the vortex tube were attempted. The maximum translation velocity was found to be approximately 0.4 times the mean velocity in the channel. Because of the number of variables introduced into the study, it was not possible to determine the relationship of translation velocity and rotation to other factors.

Further tests on the vortex tube are also reported by Rohwer (15). For these tests, tube shape was varied as well as size of sand. The tubes were installed at an angle of 45°. By testing a number of tubes, a shape was found that gave the highest trapping efficiency. This efficiency varied with the size of material, being near 90% for material with a median diameter of 1.75 mm and 45% for 0.38 mm median diameter sands. These efficiencies were nearly constant for a range in Froude numbers from 0.4 to 1.3 (velocities 2.3 to 7.9 fps). The percentage of total flow removed by the tube varied from 3.8 to 13.0.

The amount of flow from the tube was also controlled in a limited number of tests. It was found that a reduction of tube discharge of 40% to 50% caused only a slight decrease in trapping efficiency. In both series of tests reported by Rohwer (15,16) the sand was instantaneously dumped into the channel; thus, a constant rate of sediment inflow was not maintained.

Further studies on silt exclusion have been carried out by H. W. King (7) who in 1933 designed a device with curved vanes on the channel bed which would prevent heavier silt entering an offtake. This device works on the principle that the water near the bed of the parent canal or channel contains a relatively high silt charge which should, therefore, be deflected away without disturbance. Silt vanes are hardly suitable for cases in which the discharge of the offtaking channel is more than one-third that of the parent channel. He said that the correct design of silt vanes, though still largely a matter of common sense, nevertheless requires some knowledge and experience of their effect; and since at present they are almost invariably incorrectly designed, it is necessary to lay down some principles and rules evolved from a careful study of the subject for the guidance of engineers desiring to use them. Silt vanes if properly designed, built, and correctly positioned are surprisingly effective; they will usually cause a very heavily silting channel to scour severely; but, on the other hand, if badly designed or built, or incorrectly positioned, their effect may be small, or in extreme cases they may actually cause more silting in the offtaking channel. For example, if the upstream ends are built vertical or nearly vertical so that they arrest jungle, the effect of the vanes is completely discounted and may do more harm than good. Rules are given in order to effect a good design of silt vanes. The minimum radius around which water (at the velocity which has usually to be dealt with) can be guided without undue afflux, may be taken to be 25 feet. If any silt vane has a radius of less than 25 feet, the water guided by it and the silt therein will tend to jump the vane. The minimum possible radius depends on the velocity; therefore low vanes which only control bottom water with a low velocity may have a smaller radius than high ones. Obviously also, the greater the radius, the more efficient the vane will be. A radius of 40 feet or more should therefore usually be aimed at for the shortest vane, in small or medium sized channels. The downstream ends of the vanes should be tangential to lines which are at an angle with the centre line not less acute than 2 to 1 (about 27°). If this does not cause the vanes to extend far enough downstream they should be extended in straight lines at an angle of 2 to 1 with the center line. Now, in order to decide how many vanes are required, how high, and how far apart, it must be remembered that enough top water must pass over the vanes to fill the offtaking channel with plenty to spare. Ordinarily, if the width of parent channel covered by the upstream ends of the vanes is half the width of the offtaking channel, it will be found to be sufficient with respect to the height of the vanes, they may ordinarily be made 1/3 to 1/4 of the depth of the parent channel for strong effect; but as a rule less is sufficient. More is very rarely necessary. The width of the channels between the vanes should ordinarily be about 1½ times the height of the vanes.

A study was made of the probable value of bottom and surface guide vanes in connection with a model study (5) of sediment diverters for the Socorro main canal headworks. Although the guide vanes were not adopted as a solution to the sediment problem existing at this location, the potential usefulness at other locations was recognized.

The Socorro main canal begins at San Acacia Diversion Dam on the Rio Grande approximately 60 miles south of Albuquerque, New Mexico. The dam was built in 1936 by the middle Rio Grande conservancy district to divert water for irrigation. The dam contains 29 river gates 20 ft wide by 7.5 ft high. The equal intake, as originally designed, was located in a sluiceway channel placed near the right bank of the river. The canal was designed for a maximum discharge for 265 cfs.

In the winter of 1957-1958, the USBR modified the right bank diversion structure. A low flow channel was constructed parallel to the river channel to salvage water by concentrating the flow from the wide meandering river to a narrow and relatively straight channel. This channel, having a capacity of 2,000 cfs, saves an estimated 54,000 acre-ft of water annually in the 60-mile reach between San Acacia Diversion Dam and Elephant Butte Dam.

The low flow channel headgates and Socorro main canal headworks were located approximately 135 ft and 255 ft, respectively, upstream from San Acacia Diversion Dam. The existing channel headworks located downstream from the dam was left intact and used to divert water into the low flow channel that was designed to carry the inflowing sediment. No provisions were made to eliminate sediment from the Socorro main canal headworks.

When the Socorro main canal headworks was put into operation under this designed scheme, an excessive amount of sediment accumulated in the canal decreasing its flow to 35 cfs. This is substantially less than the canal design capacity of 265 cfs. A hydraulic model (3) was prompted as a result of this initial operating experience. The model study entailed an examination of the applicability of bottom and surface guide vanes. This type of vane appeared adaptable to the sediment problem that had developed at the Socorro main canal headworks. Several test runs were made in the model study, and the results were compared on a basis of the concentration, R, wich is equal to Cc/Cc_{us}. The value Cc in the concentration of sediment in the water entering the canal headgates and Cc_{us} is the concentration of sediment in the water upstream from the canal headworks. Concentration is measured in parts per million by weight. Lower values of the ratio indicate there is a greater exclusion of sediment from the canal intake. To establish a base for comparison, control tests were run using a standard discharge of 8760 cfs in the river and 174 cfs in the canal. An average concentration ratio of 2.38 obtained from the tests was the base used to determine the comparative improvement resulting from the various arrangements of the guide vanes.

Respect to the bottom vanes, four test were made to determine a satisfactory spacing for them (3). Other tests were run for the determination of location, spacing, length, angle, depth, number, and cross-sectional shape of the vanes. It was demonstrated that the spacing of the vanes was the important factor, the other characteristics not having any appreciable effect on sediment control.

The study indicated that bottom vanes provide an effective means of reducing heavy sediment inflow to a canal supplied with water diverted from a river. The most efficient bottom vane scheme was a group of four, each measuring 50 ft long, installed upstream from the intake at an angle of 45° to the direction of flow to divert bottom water away from the canal intake. The vanes were spaced 26 ft on centers with the lower most tip of the downstream vane being located 5 ft 7 in upstream from the center line of the canal intake structure. This arrangement reduced the concentration ratio for the test discharge from 2.38 to less than 0.1, indicating that the bottom vanes allowed only 1/23 of the usual amount of heavy sediment to enter the canal.

With respect to the surface vanes, a number of tests was also made on surface vanes. These vanes were as effective and about as efficient as bottom vanes in reducing the heavy sediment inflow to a canal supplied with river diverted water.

As found from the bottom vane tests, the dimensions of surface vane variables-location, spacing, height, angle, length, and number-also were not critical with respect to the excellence of performance. Installed in the same relative position as the bottom vanes, except they are angled to divert the top water into the canal intake, the surface vanes produced nearly the same results.

The vanes were not used in the prototype, however, because of the anticipated problem of having to remove brush and debris from them. Rather, a special design was adopted constructing conduit to flumes across the low flow channel to the Socorro main canal. Although the design was less efficient in sediment exclusion, it was more economical from an operation and maintenance standpoint.

Probably another form of silt excluder is the "curved wing" or "Gibb's groyne" (7). This device consists of an extension of the downstream wing wall of the offtaking channel into the parent channel in an upstream curve. It is very effective in preventing the deposit of silt at the head of a channel, but it is not generally realized that it actually excludes silt. After the curved wing has been constructed it forces all the surface water as well as the bottom water into the offtake, which consequently then takes off exactly the same proportion of silt in its water as the parent channel carries, so that the effect of the curved wing is actually to reduce silt entry.

There is no doubt about the effectiveness of the device; it has been tested and proved, but its effect is obviously limited. It may be used in cases where the offtaking channel has, by virtue of its gradient, etc., the same silt-carrying power as the parent channel.

The effect of silt exclusion can even further be increased (7) by using, in conjunction with the silt vanes, the curved wing device described in the previous paragraphs. When the effect of a curved wing (Gibb's groyne) alone is not strong enough to control the entry of silt into the offtake canal, King's vanes may be added to enhance the performance of the curved wing.

III

TYPES OF SEDIMENT EXCLUSION

The purpose of this chapter is to present the various sediment exclusion techniques available to the design engineer. Five types of devices for controlling the entry of silt into offtake canals are listed below:

VORTEX TUBE SAND TRAP

GUIDE VANES

Bottom Vanes

Surface Vanes

KING'S SILT VANES

GIBB'S GROYNE

CURVED WING WITH SILT VANES

3.1 VORTEX TUBE SAND TRAP

Laboratory studies have been made in an attempt to develop practical means for ridding channels of bedload deposit. The investigation of this problem has been carried on primarily by the Division of Irrigation, USDA Soil Conservation Service, in cooperation with the Colorado Agricultural Experiment Station. Various schemes have been investigated and emerging from these investigations have come practical means of solving the problem of protecting channels from bedload deposits, namely, the vortex tube and the riffle deflector-vortex tube sand trap. They are capable of catching the bedload as it is moved along by the flowing water.

The main feature of the vortex tube sand trap, as shown in Fig. 1, is a tube with an opening along the top side. As the water flows over the tube, a shearing action across the open portion sets up a vortex motion within and along the tube. This whirling action catches the

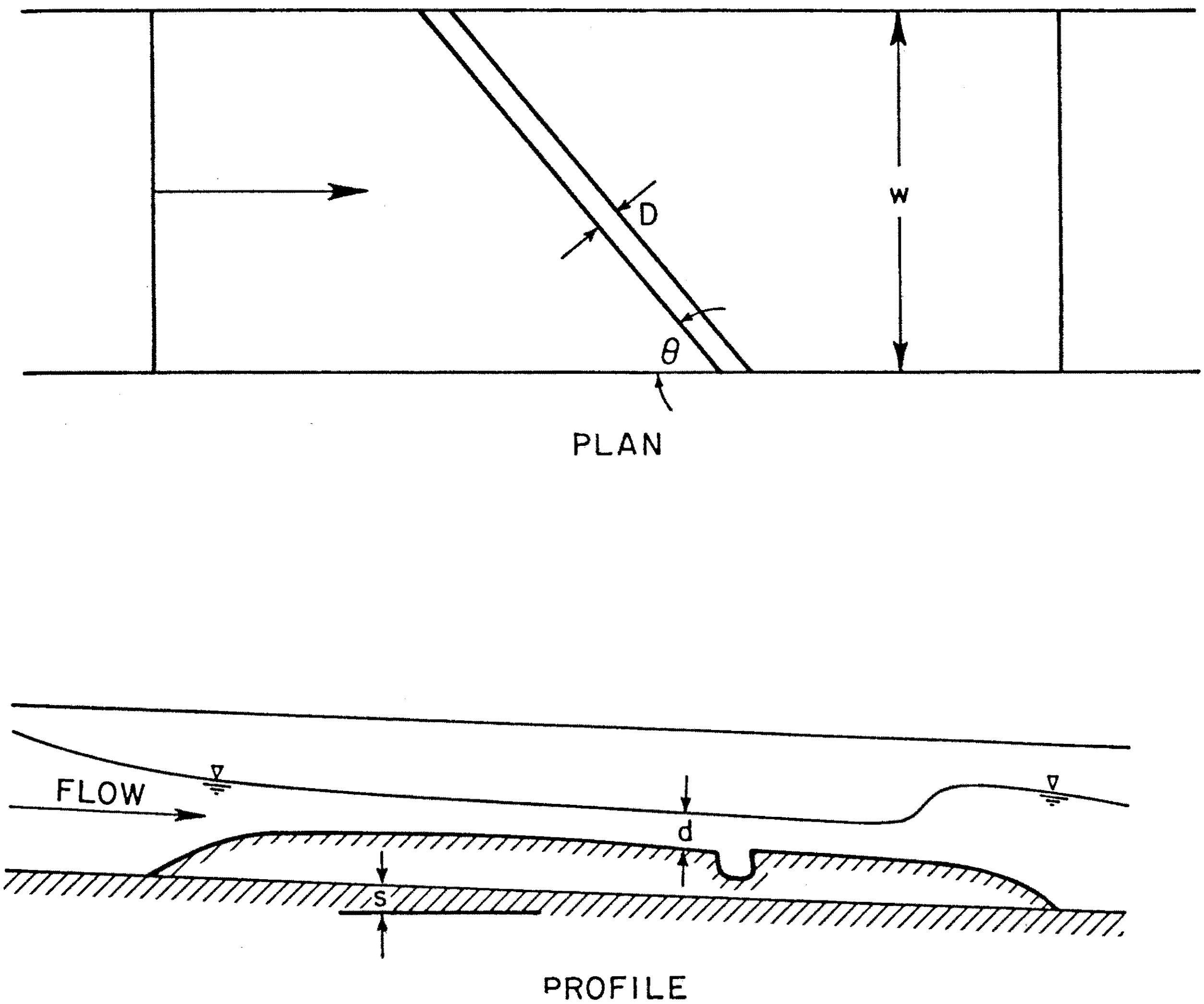

Fig. 1. Vortex tube sediment ejector.

bedload as it passes over the lip of the opening and carries the sediment to the outlet at the downstream end of the vortex tube.

Review of past studies indicates that the vortex tube type of sand trap has been found to be superior to other types of sediment ejectors. The following design features are indicated based on the findings of previous investigators:

(1) Experiments have been conducted with vortex tubes tapered along the length. It has been concluded that straight tubes are equally efficient in removing sediment.

(2) The shape of the tube does not seem to be particularly important as long as this shape is such that material entering the tube is not allowed to escape back into the channel. Conventional cylindrical pipe with a portion of the circumference removed seems to operate as well as other prefabricated shapes.

(3) The elevation of the upstream and downstream lips of the tube opening should be the same for the best overall performance.

(4) The vortex tube angle, θ, should be 45°, although for many experiments the angle had little effect between 45° and 80°.

(5) Maximum efficiency is obtained when the Froude number over the vortex tube is due to the bed form in the dune range. As dunes advance along the canal bed, the vortex tube can be completely covered by sand and become inoperative. The stream power, and hence Froude number, can be determined which will yield a plane bed thus eliminating the problem of sand dunes. To obtain the preferred stream power the bed of the canal should be raised, as opposed to contracting the channel width. Contraction of the flow will induce enough turbulence to cause much bed-load to temporarily go into suspension and thus decrease the efficiency of the vortex tube.

(6) The pipe diameter should be equal to the water depth in the channel at a Froude number equal to 0.8.

(7) The slot width affects the trapping efficiency, though no correlation has been found.

(8) Experiments and practice have shown that vortex tubes become very inefficient over long lengths; as a result, a single vortex tube could not be successfully utilized to remove the bedload from a wide channel. A vortex tube that is too long will tend to get partially clogged at the end farthest from the outlet.

(9) Up to a point the efficiency of the ejector remains fairly constant, after which the efficiency decreases rapidly. Observation has shown the reduction resulted from plugging of the tube, i.e., sediment arriving at the tube faster than it can be carried away. The critical point depends on the extractor ratio, where extractor ratio is defined as the ratio of discharge ejected to the discharge in the channel upstream from the tube.

(10) The percentage of flow removed by the vortex tube usually ranges from 5 percent to 15 percent of the total flow in the channel.

(11) With the foregoing design specifications, the vortex tube can be expected to remove approximately 80 percent of the sediment sizes greater than 0.50 mm. The trapping efficiency of smaller sizes will be considerable lower.

Finally, some further suggestions are given by Robinson (14) and need to be discussed and closely analyzed.

If the vortex tube is assumed to be a type of circular orifice, then the ejected discharge is:

$$Q_T = C \, A_T \, \sqrt{2gH} \qquad (1)$$

and the extractor ratio is:

$$R = 100 \left(\frac{Q_T}{Q}\right) = \frac{100\ C\ A_T\ \sqrt{2gH}}{A \cdot V} \qquad (2)$$

in which:

R = extractor ratio in percent: ratio of the ejected discharge to the channel discharge upstream from the vortex tube area;

Q, Q_T = channel and vortex tube discharges, respectively;

A, A_T = channel and vortex tube cross-sectional area, respectively;

H = effective head on the tube;

V = average velocity in the channel; and

C = a constant.

Through a sequence of substitutions, Robinson attempted to show the relationship between the extractor ratio, R, and the tube and channel flow variables. By simplification, another variable is:

$$C' = \frac{100C\sqrt{2}}{\left(\frac{DL\sin\theta}{A_T}\right)} \qquad (3)$$

But, by analyzing the results of all the vortex tube experiments available, an empirical relation was introduced:

$$C' = 100 \left(\frac{A_T}{DL\sin\theta}\right) \qquad (4)$$

Substituting (4) in (3) and simplifying:

$$C = \frac{1}{\sqrt{2}} = 0.707 \qquad (5)$$

Instead of determining an interrelationship, Robinson found only that the extractor ratio was dependent on the tube cross-sectional area:

$$R = \frac{Q_T}{Q} = \frac{0.707 A_T \sqrt{2gH}}{Q} \qquad (6)$$

In practice, caution must be exercised since the value $C = 0.707$ was obtained only for tubes discharging freely at the side wall of experimental flumes. Also, H was taken as the sum of the water depth and half the tube depth. This is correct if the discharge end of the tube is not submerged and the length of the return pipe between the channel wall and its discharge end is small. When the length of the return pipe between the channel wall and discharge end is large, friction losses must be accounted for in determining the effective head on the vortex tube. Finally, if the discharge end of the return pipe is submerged, then the effective head on the vortex tube is taken as the difference in water surface elevation, with pipe friction losses being considered when necessary.

Many investigators have performed experiments with the vortex sediment ejector. The investigations had inherent shortcomings in that the reported results are applicable quantitatively only for field flow conditions similar to the experimental flow conditions. The actual hydraulics of the flow of the water-sediment mixture through the vortex tube has not been determined; hence, a conceptual approach and design is not possible. Investigations have provided qualitative guidelines and cautions, but no concrete information is available which would allow a design engineer, knowing the field conditions, to design a vortex tube and confidently predict its performance. The design engineer has at his disposal only experience with existing vortex tubes, comparison with experimental studies, and the various guidelines that have been suggested.

3.2 GUIDE VANES

In a continuing effort to develop inexpensive maintenance-free sediment exclusion methods, both channel bottom and water surface guide vanes have been investigated. As with most exclusion structures, the purpose of the guide vanes is to produce favorable secondary currents for sediment removal. Both bottom and surface vanes induce secondary currents which divert the bottom water containing a heavy sediment load away from the canal headworks, and upper water containing a relatively light sediment load can be diverted through the canal headworks.

The U.S. Bureau of Reclamation has investigated guide vanes (3,5) for a limited range of variables. The flow patterns caused by guide vanes are depicted in Figs. 2 and 3. The study was limited to straight guide vanes and one river discharge with a corresponding single diversion discharge.

To develop a satisfactory set of vanes for the standard test discharge and having set the restriction of straight guide vanes and one test discharge, a test program was set up to evaluate the effect on sediment exclusion of:

1) vane spacing,
2) vane angle,
3) vane position,
4) vane length,
5) vane elevation,
6) vane number, and
7) vane cross section.

3.2.1 Bottom Vanes

Four tests were made to determine a satisfactory spacing for bottom vanes arranged as shown in Fig. 2. From these tests it was concluded that bottom vanes are effective in reducing heavy-sediment intake into a canal supplied by water diverted from the river.

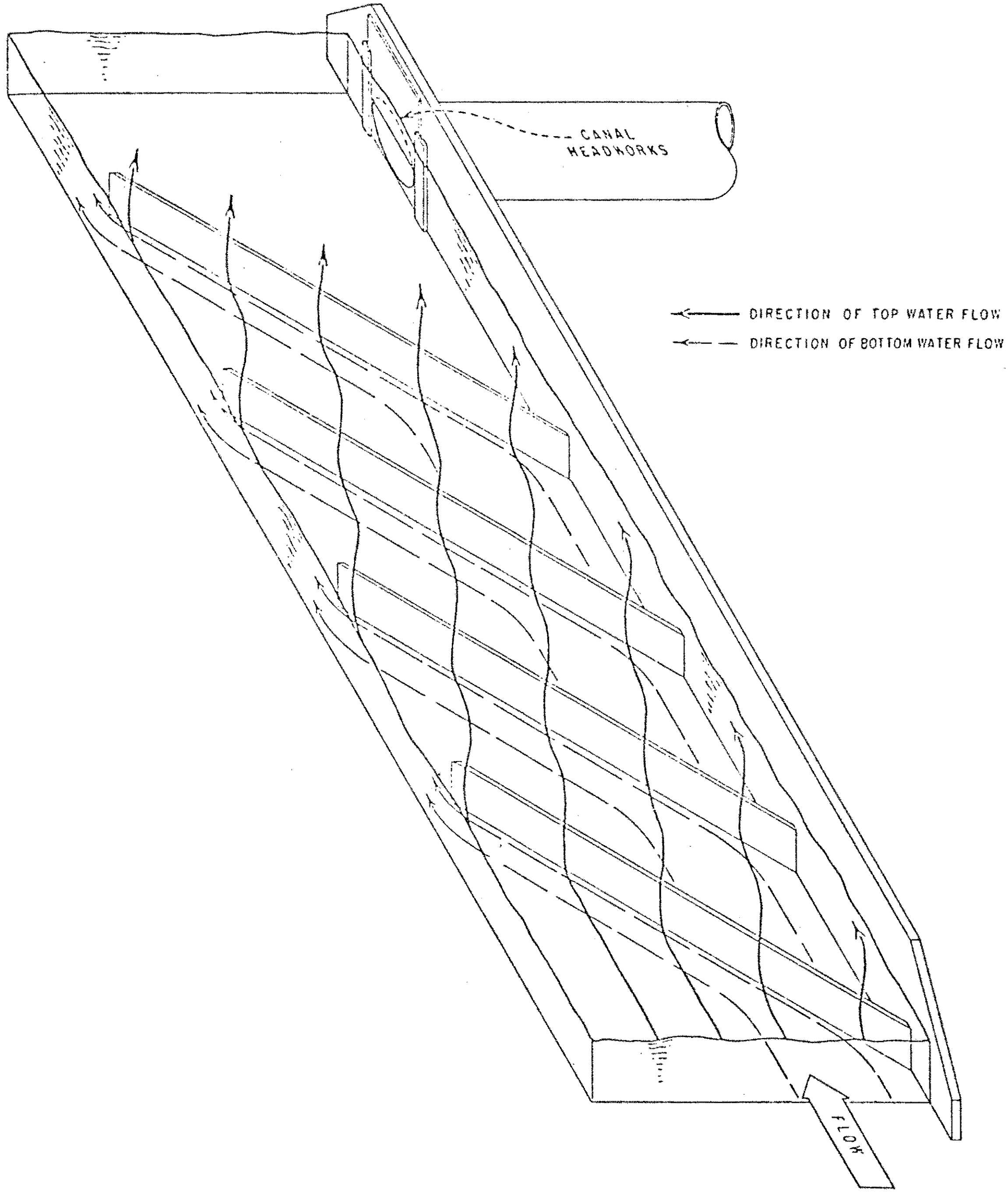

Fig. 2. Bottom guide vane method of producing secondary currents sediment control.

The most efficient bottom vanes developed were a group of four 50-foot-long vanes installed upstream from the intake at an angle of 45° to the direction of flow. The vanes were spaced 26 feet on centers, the downstream tip of the downstream vane was located 5 feet 7 inches upstream from the canal headworks centerline. This arrangement reduced the concentration ratio for the test discharge from 2.38, the average for the test with no vanes in place, to less than 0.1. This ratio reduction means, in effect, that the vanes allowed only 1/23 of the usual amount of heavy sediment to enter the canal.

Considering only the standard test discharge used in these tests, the dimensions of the variables, location, spacing, angle, length, depth, number, and cross section were not critical with respect to performance. Minor changes in the dimensions tested could be made without changing their performance significantly. Surface vanes were next investigated to determine whether they were more or less efficient than bottom vanes.

3.2.2 Surface Vanes

A number of tests were also made on surface vanes. Vane arrangements for the tests are showed in Fig. 3.

Four vanes 50 feet long and 2 feet 8½ inches deep were placed; vane tops were at the normal water surface. The vanes were placed at an angle of 140°, (measured from the same reference as the bottom vanes), with the downstream end of the downstream vane of the canal headworks centerline.

The test ratios all showed considerable improvement over the 2.38 average concentration ratio of the control tests, and indicated that the concentration ratio was not greatly affected by the spacing of the

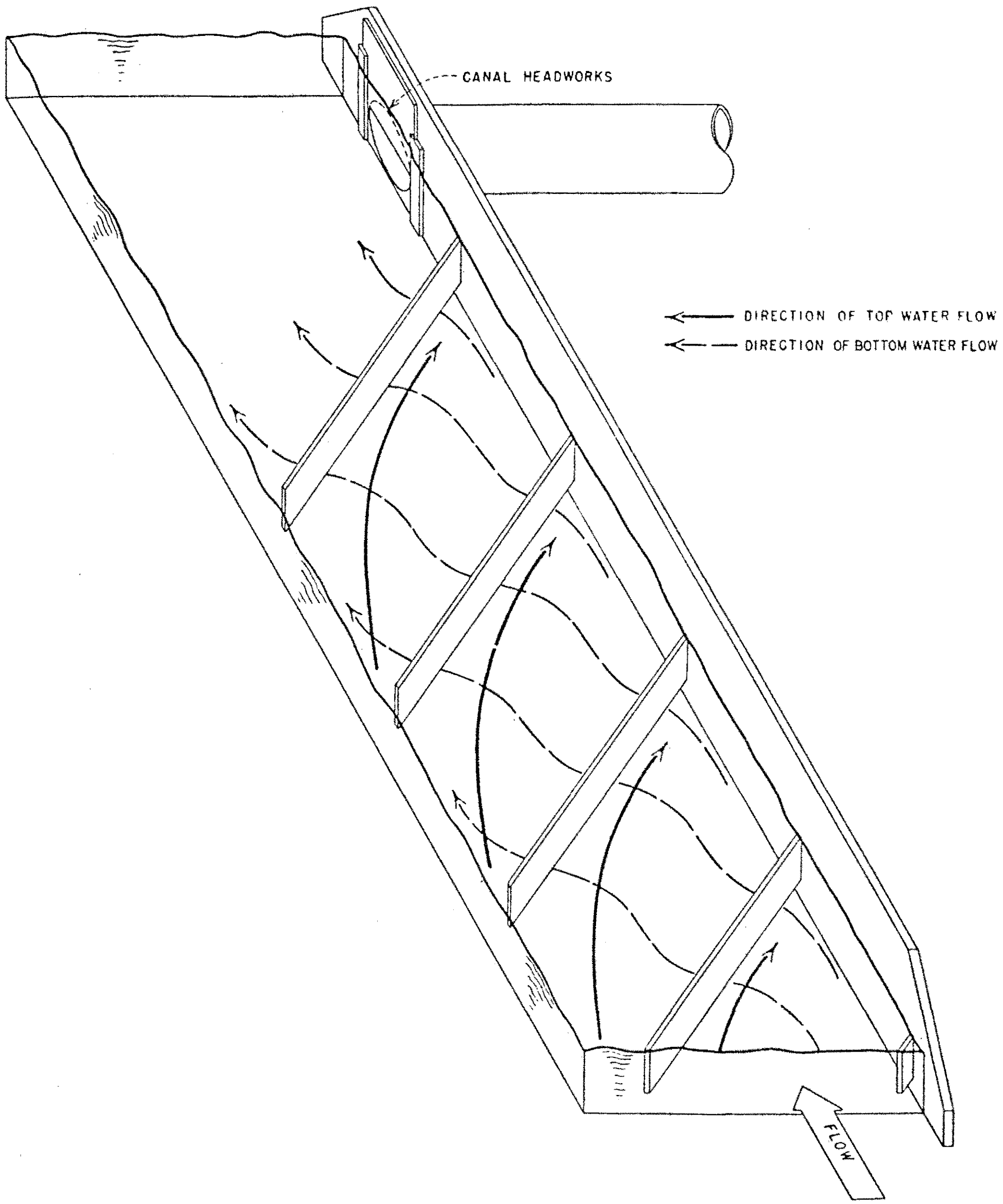

Fig. 3. Surface guide vane method of producing secondary currents for sediment control.

vanes. However, a multiple correlation of the data showed that a spacing of approximately 18 feet 4 inches would be the most efficient for these vanes. From this series of tests it was concluded that surface vanes could be used to effectively reduce the sediment entering a canal headworks.

From the tests with surface vanes, it was concluded that surface vanes are effective in reducing heavy sediment intake into a canal supplied with water diverted from a river, and are about as efficient as bottom vanes. The dimensions of the vane variables, location, spacing, height, angle, length, and number were not critical with respect to the performance of the set of vanes. Installed in the same relative position as the bottom vanes, but angled so as to divert top water into the canal headworks, they produced approximately equivalent results, and reduced the concentration ratio for the test discharge from 2.38, the average for the control tests, to less than 0.1.

A summary of conclusions and recommendations presented by the U.S. Bureau of Reclamation (3) is summarized as follows:

1) Both the surface and bottom vanes were equally effective in reducing the sediment intake into the canal.

2) For both types of vanes the concentration ratio of sediment entering the canal was reduced from 2.38, measured in control tests which used no vanes, to less than 0.1. In other words, the sediment entering the headworks was only 1/23 of the amount which entered when no vanes were used.

3) The most effective set of bottom vanes tested consisted of four 50-feet-long vanes installed upstream from the canal headworks and were placed at an angle of 45° to the direction of the flow.

4) Vane spacing for surface vanes was 26 feet on center, and the downstream tip of the downstream vane was located 5 feet 7 inches upstream from the canal headworks centerline.

5) The most effective set of surface vanes, indicated by tests, included either three or four vanes 40 to 50 feet long placed near the canal headworks and were installed at an angle of 140° (same reference datum as bottom vanes).

6) Vane spacing for bottom vanes was 18 feet 4 inches on centers and vane height was 1 foot 11 3/4 inches.

In general, the Bureau of Reclamation found both bottom and surface vanes to be extremely valuable in helping to gain control of heavy sediments by creating localized secondary currents to reduce the sediment intake into a canal. Consideration should be given to their use where flow conditions are similar to those tested by the Bureau of Reclamation. For example, where a relatively small discharge is being diverted from a relatively large flow, and it is desired that the small discharge have a relatively light sediment load, either bottom or surface vanes may be employed using the dimensions (or proportional dimensions) given in the reports (3,5). However, further investigation in a model should be made if discharges are significantly different than those tested.

3.3 KING'S SILT VANES

In a series of papers H. W. King (6,7) discussed the design of a device with curved vanes on the channel bed which would prevent heavier silt entering an offtake. This works on the principle that the water near the bed of the parent canal or channel contains a relatively high silt charge which should, therefore, be deflected away without disturbances, at an angle of about 30° from the direction of the flow. King presented some general directions to be followed by avoiding incorrect use of the vanes. The layout plan of the vanes is shown in Fig. 4. The dimensions of the silt vanes are given in Table 1. See Fig. 5 in order to identify x1, x2 and R. The length and position of the longest vane and the vane spacing are thus determined. The characteristics of King's silt vanes are given below:

1) The height of the vanes is one-third to one-quarter of the depth of the parent canal.

2) The thickness of the masonry vanes is 12 cm for a height up to 0.36 m, and for greater heights the thickness is 24 cm. However, for efficiency the thinner the better.

3) The width of channels between the vanes is normally 1½ times the height of the vanes.

4) The upstream ends of the vanes beyond the line OQ (Fig. 5) must be finished off to a slope of 1 vertical to 3 horizontal in a v-shaped to act as cutwaters (Fig. 4).

5) The downstream end of the vanes should be vertical.

6) The channels between the vanes and the vanes themselves should be plastered.

7) The bed of the parent canal covered by the vanes, and for a distance of 15 m to 30 m upstream of the vanes, must be smoothly pitched and it should be 15 cm higher than the normal silted bed level. The upstream 4.5 m of the pitching should be built at a slope of 1 in 10.

8) The side slope of the parent canal on the side of the offtake must be pitched up to the length of the pitched floor.

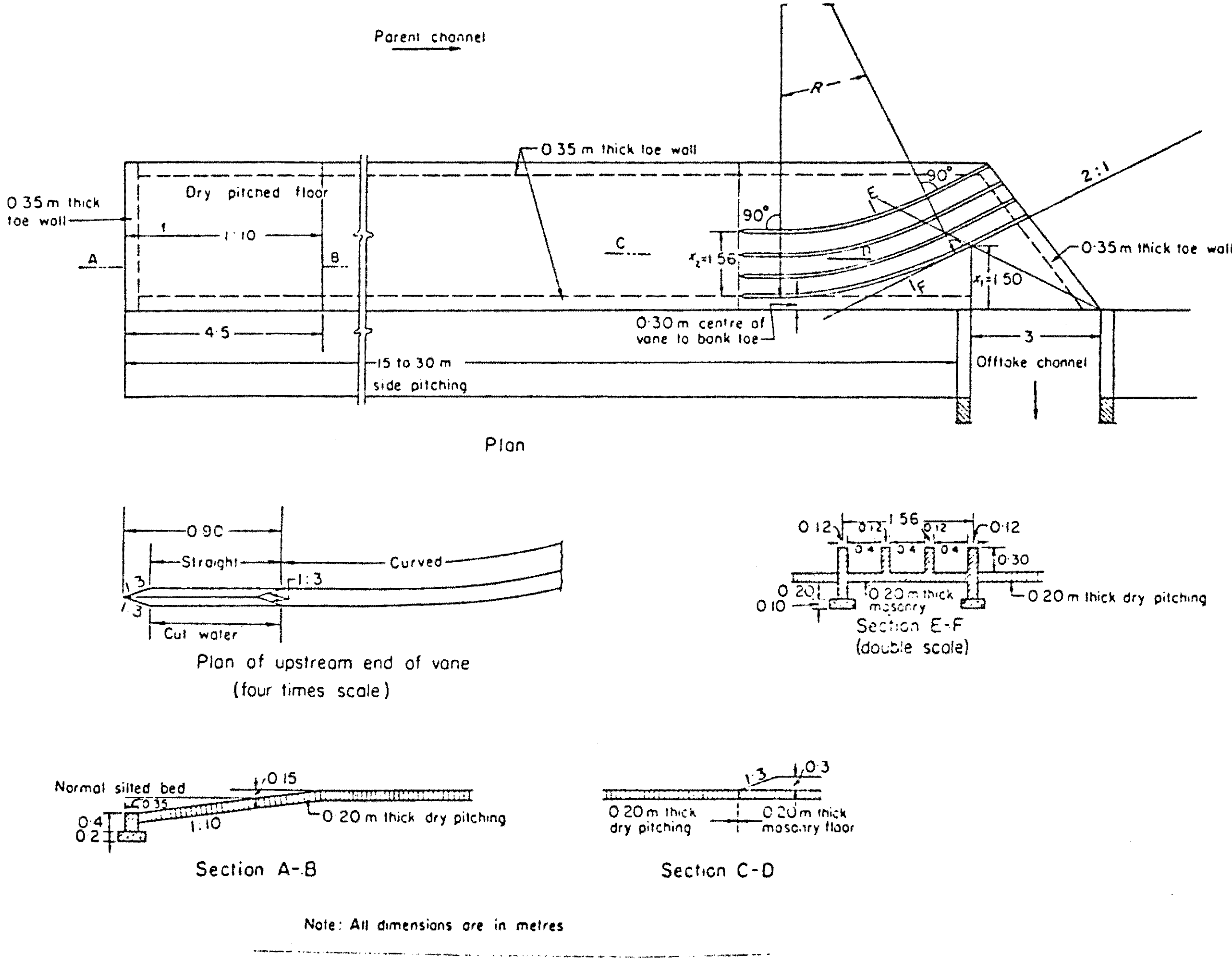

Fig. 4. King's silt vanes, layout plan of the vanes.

TABLE 1

Width of offtake channel = B_2 in meters		0.6	1.2	1.8	2.4	3.0	3.6	4.8
For strong effect	Value of X_1	1.2	1.5	1.8	1.8	2.1	2.4	2.4
	Value of X_2	0.6	0.9	1.2	1.5	1.8	2.4	2.7
	Value of R^2	9.0	10.5	12.0	12.0	13.5	13.5	15.0
Cheaper design (less effect)	Value of X_1	0.9	1.2	1.2	1.5	1.5	1.8	1.8
	Value of X_2	0.6	0.6	1.2	1.2	1.5	1.5	1.8
	Value of R^2	7.5	9.0	9.0	9.0	9.0	9.0	10.5
Minimum dimensions recommended	Value of X_1	0.9	0.9	1.2	1.2	1.5	1.5	1.8
	Value of X_2	0.6	0.6	0.9	1.2	1.5	1.5	1.8
	Value of R^2	7.5	7.5	9.0	9.0	9.0	9.0	10.5

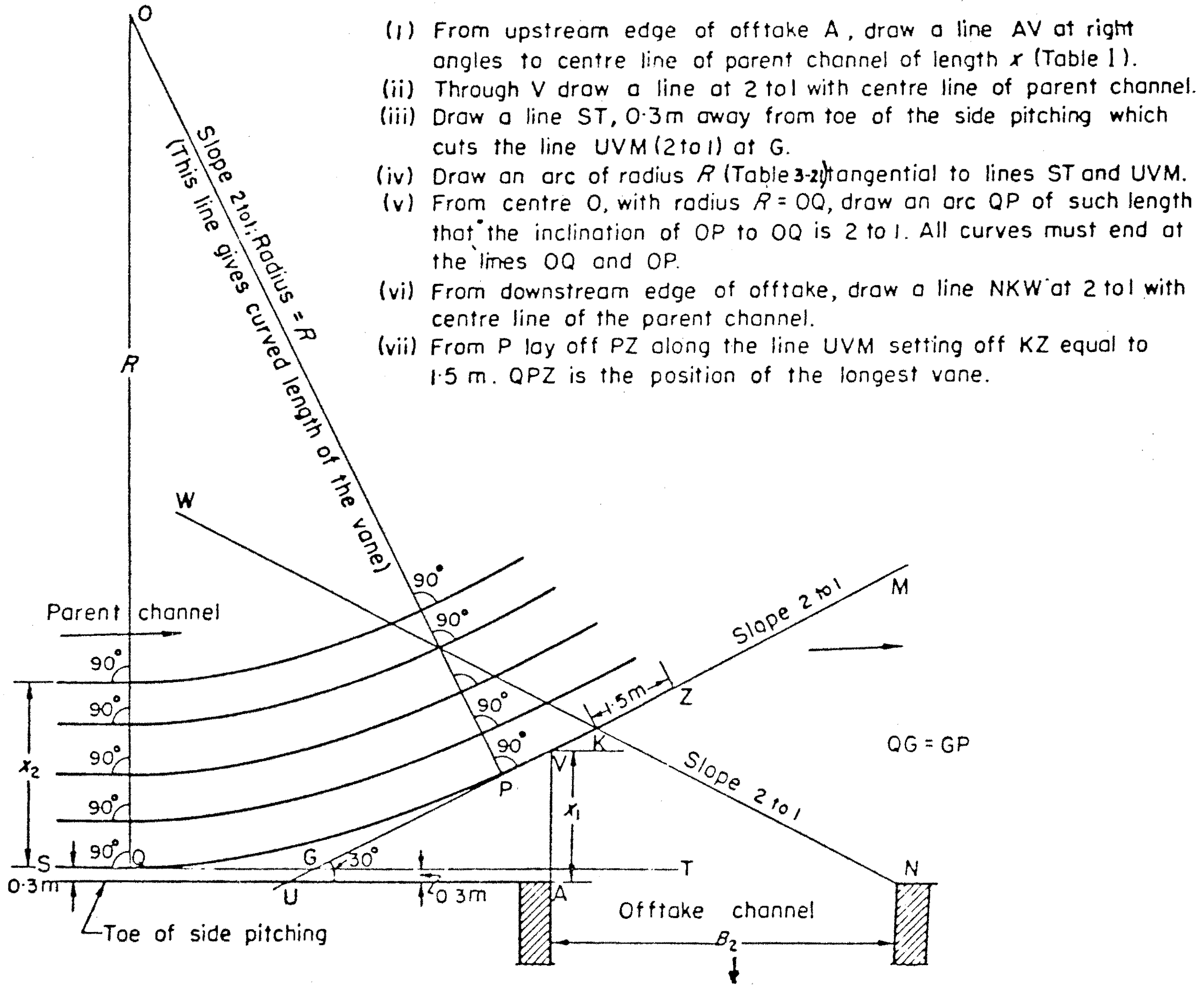

Fig. 5. King's silt vanes details of layout.

It should be noted that King's silt vanes are not suitable in the following situations:

1) Where the offtake canal discharge is more than one-third of that of the parent canal;

2) Where the offtake canal is very small and takes off from a deep parent canal;

3) Where the parent canal does not have adequate width; and

4) Where a violent approach with a strong "draw" towards the intake head exists.

The conclusions drawn regarding King's vanes are the following:

1) They can exclude practically the whole of the bedload for a single discharge;

2) Their efficiency depends to a marked extent on the vanes being in line with the oncoming current. This cannot be assured if there is a range of discharges or a widely varying proportion of the discharge is drawn by the offtake;

3) When they tend to give unsatisfactory results due to a sand bank forming downstream of the vanes, and where flow is not under complete control, they tend to throw coarse material into suspension and may give highly unsatisfactory results; and

4) Where discharge conditions are relatively steady, they can be used, especially if complete exclusion is required. However, under varying flow conditions their use should be avoided.

There are many cases, usually in small distributaries, where it will be found that there is insufficient room in the parent channel for the construction of silt vanes according to the design recommended here. In such cases either this design must be modified, bearing in mind the principles on which it is based or if, as sometimes occurs with small channels, the silt vanes device is entirely unsuitable, then some alternative design must be implemented.

In order to decide the width of the parent channel which should be covered by the vane pitching, it must be remembered that enough top water must pass over the vanes to fill the offtaking channel with plenty to spare; otherwise, severe eddies will be set up and silt tend to be sucked up from between the vanes. Ordinarily, if the width of parent channel covered by the upstream ends of the vanes is half the width of the offtaking channel, it will be found to be sufficient. A greater width of vaned pitching will usually be required for small offtakes, proportionally, than for large.

3.4 GIBB'S GROYNE

Probably one of the best types of silt excluder is the "Gibb's Groyne" (curved wing). This device is fairly well known, but neither its effect, nor the reason for that effect is fully understood. It consists of an extension of the downstream wing wall of the offtaking channel into the parent channel in an upstream curve, see Fig. 6.

The Gibb's Groyne wall is used in cases where the offtaking canal, on account of its gradient, has the same silt carrying capacity as the parent canal. The Gibb's groyne ensures more or less proportional silt distribution to the offtaking canal.

This device is very effective in preventing the deposit of silt at the head of a channel; but it is not generally realized that it actually excludes silt. After the curved wing has been constructed, it forces all the surface water as well as the bottom water into the offtake, which consequently then takes off exactly the same proportion of silt in

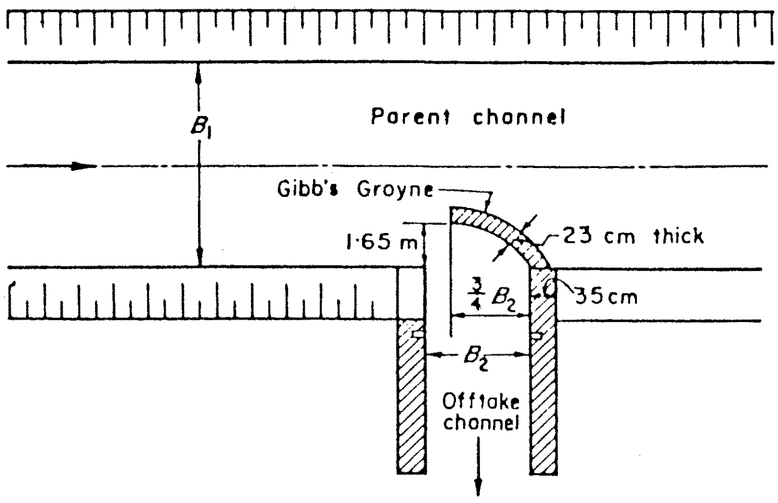

Fig. 6. Gibb's groyne, general layout.

its water as the parent channel carries, so that the effect of the curved wing is actually to reduce silt entry. In addition to this, the curved wing causes the water to be introduced into the offtake with a considerable velocity so that the normal tendency to drop silt in the head reach is obviated. The pitching of the bed and sides is not necessary in this form. As to the extent to which the wing shall project into the parent channel, ordinarily it would project far enough to enclose enough of the discharge of the parent to fill the offtaking channel when the parent is running the lowest supply at which it is desired to run the offtaking channel full. This need by no means necessarily fix the amount of its projection in every case.

As to how far upstream the curve is to be taken, it need not necessarily extend to opposite the upstream abutment of the offtake, but should extend a good way up, say up to 3/4 of the width of the offtake. To take it the whole way up to opposite the upstream abutment would be better, but may in some cases not be convenient.

It is not necessary that the curved wing be exactly tangential to a line parallel to the center line of the parent nor the downstream end tangential to the center line of the offtaking channel. These last two considerations will be decided by the radius of the curve that it is desired to give the wing.

There is not doubt about the effectiveness of the device; it has been tested and proved, but its effect is obviously limited. It might be used in cases where the offtaking channel has, by virtue of its gradient, etc., the same silt-carrying power as the parent. If the offtaking channel has less silt-carrying power, it is better to use some other silt excluder device.

A variation of the device is to leave openings at the foot of the curved wing, so that the bottom water can escape and flow off downstream into the parent channel. This is probably an improvement, but would clearly necessitate the cutting off more water by the curved wing, i.e., making the wing extend further into the parent channel.

3.5 CURVED WING WITH SILT VANES

As stated in Section 3.3, the effect of silt vanes is marked. However, that effect can further be increased by using, in conjunction with the vanes, the curved-wing (Gibb's groyne) device described in Section 3.4.

The effect of this design is that not only is all the surface water enclosed by the curved-wing forced into the offtake, but a considerable portion of the upper layers of water (not necessarily quite at the surface) outside the curved wing is also deflected and forced in. The reason, of course being that the place of the bottom water which is forcibly deflected by the vanes must be taken by the upper water, creating the rotary effect. This effect could be further accentuated by constructing the curved wing so as to enclose a greater portion of the discharge of the parent channel that is required to fill the offtake.

Such drastic action as the curved-wing with silt vanes arrangement will very rarely be necessary. Ordinarily, only in cases where the offtaking channel takes off a large proportion, say 1/3 or 1/4, of the discharge in the parent; or where the parent is too narrow for the ordinary design, and when it has to be resorted to, it must be remembered that the proportion of silt passing down the parent will be very much increased and steps will probably be necessary to enable the parent to carry it on. The most satisfactory arrangement of the curved-wing with silt vanes is seen in Fig. 7.

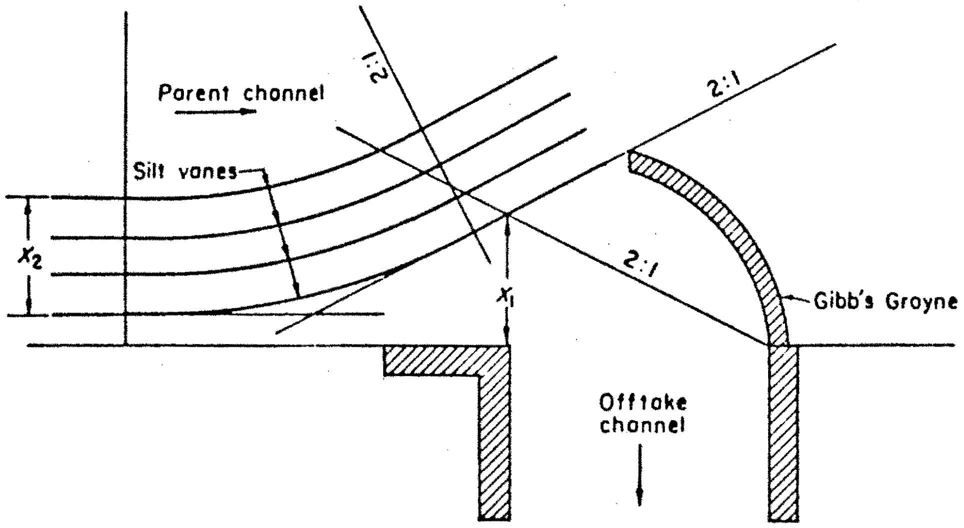

Fig. 7. Curved wing with silt vane, general layout.

The silt vanes must be built with great caution. The best plan is first to try the effect of the curved-wing alone and if the effect is found not to be strong enough, low silt vanes may be constructed, the height of which can be increased later if still more silt is to be excluded.

Probably the most awkward case is where a large channel breaks up into several branches or distributaries at one site, and it is desired to exclude silt from one of the branches, without putting all the silt thus excluded entirely into any one of the other branches. The silt vanes must be designed in such cases with great caution; as their effect is very marked. Low vanes should be constructed at first, perhaps 0.4 or 0.8 ft high, which can be raised later if desired.

In conclusion, when the effect of a curved wing along is not strong enough to control the entry of silt into the offtake canal, King's vanes may be added to enhance the performance of the curved wing. The curved wing in this case is terminated at the 2:1 line of the longest vane, see Fig. 7.

IV

ANALYSIS AND DISCUSSION

4.1 VORTEX TUBE

With respect to the vortex tube, it was found (14) that the percentage of flow removed was a function of tube geometry and angle, as well as of depth and velocity of flow across the section. Parameters describing the tube were the length, width of slot, and area. With the other factors that affect the sediment removal characteristics of the tube being considered, it was noted that tubes with values of C' in the range of 4.6-7.6 were most successful. Robinson (14) also pointed out that the parameter L/D should not exceed a value of 20 for optimum operation and that successful field structures exist with L/D values as low as 11.

The variation of tubes shapes was demonstrated to be very effective by Rohwer and Robinson. Those made from commercially fabricated pipe seem as effective as the others and are easily constructed. Rohwer (16) noted that material was frequently thrown out of these, particularly at the higher channel velocities. This would result in material returning to the channel.

Tests made to determine the efficiency of trapping when the outflow was controlled indicated that the efficiency would be reduced to some extent with a reduction in outflow. The reduction in velocity was not in direct proportion to the reduction in percentage of flow removed. Therefore, if the flow was reduced by one-half, the velocity was only reduced a portion of this. Also, with lower concentrations of bedload, it is possible that there was sufficient movement within the tube so that high removal efficiencies were maintained.

The effect of material size on efficiency of trapping was noteworthy. Under optimum operating conditions, material of a size greater than 0.83 mm was effectively trapped and removed. For material less than 0.30 mm, the trapping efficiency was very low, usually less than 35%. In general, those sizes greater than 0.50 mm will be removed.

The effect of velocity and depth of flow on the trapping efficiency are interrelated. Tests by Koonsman (8), indicated that the highest efficiencies existed near a Froude number of unity, that is at critical depth. The studies by Rohwer (16), show that the efficiency generally increased as the Froude number increased.

A relationship of efficiency to depth of flow for a range of Froude number is presented by Robinson (14). For lower values of Froude number, efficiency decreased rapidly as depth increased. For F in the range of 0.8 through 1.0 efficiency seemed to be almost independent of depth.

4.2 GUIDE VANES

Guide vanes placed near a headworks or sluiceway entrance have been used as one effective method of controlling sediment movement near the intake. They are used to control localized secondary currents by diverting bottom water with its relatively heavy sediment load away from the canal headworks, and top water with its relatively light sediment load through the canal headworks. The Bureau of Reclamation developed a hydraulic model in order to study the optimum arrangement of bottom and surface guide vanes. Five tests were conducted without vanes, but with a 160-foot by 40-foot 3-inch slab, at elevation 4661.0, near the canal headworks on which the bottom vanes were later constructed. The standard discharges were used in the control tests and the river discharge was passed through all the river gates which were opened equally. The duration of the five control tests averaged approximately 6 hours, and the control tests were spaced throughout the overall testing period. The average concentration ratio obtained from the control tests was 2.38. This value was therefore the datum used to determine the improvement resulting from the various guide vane arrangements.

Four tests were made to determine a satisfactory bottom vane spacing. For these test 4 vanes were used having 50 feet long, their top elevation was at 4665.0 feet, and they were placed at an angle of 40° to the direction of flow with the downstream end of the downstream vane on the canal headworks centerline. In these tests the concentration ratio was considerably improved from the 2.38 average of the control test. The highest concentration ratio obtained in this test series is not great when compared to the control concentration ratio of 2.38.

Three test were done to determine a satisfactory angle between the bottom vanes and the direction of flow, and the 45° angle was considered to be most satisfactory. However, all angles tested indicated considerable improvement in the concentration ratio compared to the ratio obtained when no vanes were installed.

Three tests were utilized to determine a satisfactory placement or location of bottom vanes with respect to the canal headworks. Visual observations of trial locations indicated that placing the vanes either farther upstream or downstream from the canal headworks would reduce the efficiency of the vanes. The analysis of the three tests indicated that placing the vanes 5 feet 7 inches upstream from the canal centerline was the most satisfactory arrangement.

According with the bottom vane length, three tests were used to determine a satisfactory vane length. The analysis of the results indicated the 50-foot vane length to be most satisfactory. The results showed a considerable improvement over the average concentration ratio of 2.38 with no vanes in place.

Four tests were used to establish a satisfactory vane top elevation for the test discharge. Analyses of the results indicated the most satisfactory surface elevation to be between 4665.9 and 4666.2 feet. The elevation selected as most satisfactory was 4666.1 feet.

One test was used to establish whether fewer than 4 vanes would produce sufficiently strong secondary currents to reduce sediment intake into the canal. From visual observations, it was concluded that 4 vanes produced a more satisfactory concentration ratio than 3 vanes.

Two tests were used to determine the effect of vane cross section on the concentration ratio. The canal discharge remained constant during both runs and the resulting average of concentration ratio was 0.094, using a rectangular vane cross section.

With respect to the tests with surface vanes, 4 tests were used to determine the effect of spacing. From this series of tests it was concluded that surface vanes could be used to effectively reduce the sediment entering a canal headwork.

Four tests were used to determine the effect of surface vane angles. Although the concentration ratio was not very sensitive to the angle at which the vanes were placed, the analysis indicated the 130° angle to be most satisfactory.

Three tests were used to determine surface vane location. Visual observations indicated that moving the surface vanes farther upstream or downstream would have reduced their efficiency.

Three tests were used to show the effect of varying the length of surface vanes on their efficiency in controlling sediment movement. The analysis indicated that a surface vane longer than 40 feet did not improve the concentration ratio, and that a vane less than 40 feet long was slightly less efficient.

With respect to surface vane height, 4 tests were used to establish a satisfactory height of surface vanes. In all the cases, the vanes were effective, but an analysis indicated the most effective depth to be 1 foot 11-3/4 inches.

One test was conducted to establish the effect of fewer than 4 vanes on the number of surface vanes. The standard discharges were tested and the resulting concentration ratio was 0.074.

Both bottom and surface vanes were found to be extremely valuable in helping to gain control of heavy sediments by creating localized secondary currents to reduce the sediments intake into a canal. Consideration should be given to their use where flow conditions are similar to those tested. For example, where a relatively small discharge is being diverted from a relatively large flow, and it is desired that the small discharge have a relatively light sediment load, either bottom or surface vanes may be employed using the dimensions (or proportional dimensions) given by the Bureau of Reclamation.

4.3 KING'S SILT VANES

With respect to the King's silt vanes, this is very useful in distributaries where constant supervision and clearance of debris is not possible. The only objection to silt vanes is that the silt exclusion from the offtaking channel is not easily controllable; they are therefore, entirely unsuitable in their simple form for use in a headwork, where the control of silt entry rather than the mere exclusion of depositing silt is necessary.

In cases where boulders and shingle are carried in the river at a headworks, it is more than likely that guides of the nature of silt vanes would be extremely effective because total exclusion of shingle and boulders from the canal would be aimed at, and there would be no question of "adjusting" the shingle entry into the canal. The vanes or guides in such a case would of course have to be made strong enough to resist the impact of boulders, etc. Also the curves would have to be more gentle on account of the high velocities obtained, etc., but the system is one which certainly should be tried as the possibilities of success are very great.

It is true that all the silt excluded from an offtaking channel has to go down the parent stream; but it has been found by experience that this has not the marked effect in silting up the parent stream or the other distributaries taking off from it downstream of the silt vanes that might be expected; and it is ordinarily quite safe to introduce silt vanes fairly freely for changes that silt. The extra silt thus put into the parent channel is distributed between the distribution which had not hitherto silted and which are obviously better able to deal with the extra silt than the distributary treated; and the additional silt which each distributary has to take is usually so small that it will not make any appreciable difference to those channels.

4.4 GIBB'S GROYNE

As mentioned in paragraph 3.4, the curved wings or Gibb's groyne is one of the best form of silt excluder. The effectiveness of the device has been tested and proved, but its effect is obviously limited because the offtake takes off exactly the same proportion of silt in its water as the parent channel, so that the effect of the curved wing is actually to reduce silt entry.

4.5 CURVED WING WITH SILT VANES

With respect to the combination of curved wing with silt vanes, the effect can further be increased. This combination is useful when the effect of a curved wing alone is not strong enough to control the entry of silt into the offtake canal.

V

SUMMARY AND CONCLUSIONS

Control of sediment is a major concern of investigators interested in devices for ejection.

With respect to the vortex tube, in the analysis of flow from the tube, it was mentioned that the percentage of flow removed was a function of tube geometry and angle, as well as depth and velocity of flow across the section. Also, past studies have indicated that an angle of 45° for the tube is desirable, and with the range of factors known, it is possible to compute the area of tube needed, Robinson (14).

A study of the data revealed that there was no discernible difference when having the two lips of the tube at the same level, or the downstream lip lower. It was noted that, when the downstream lip was higher, the trapping efficiency was materially reduced. For simplicity in construction then, it is recommended that the two will be at the same elevation.

Many of the existing field structures contain tubes that are tapered along the length L. According to Rohwer (16), straight tubes are equally as efficient in removing material. Straight tubes are simpler to construct and install; therefore, these are recommended.

With respect to the effect of material on efficiency of trapping, only that material that is moving at or near the bed will be trapped by the device. The amount of sediment moving as bedload is of importance in the operation of the tube only for high concentrations. When the flow depth is large relative to the width of opening, the concentration should not exceed 0.20% (2,000 ppm) if optimum operation is to be maintained for shallower depths, the concentration may reach 0.45%. In channel when the load may exceed these values, two parallel tubes should be installed.

By considering the Froude number it would seem that the range should be from 0.6 through 1.0 values lower than this might result in the tube being inoperative whereas those higher would result in material being thrown out of the tube as well as the problems of scour downstream from the structure due to higher exit velocities.

The section containing the vortex tube should be designed so that flow conditions are in the regime in which plane bed type of sediment movement will exist. This was found to be in a Froude number range of 0.6 to 0.7 for material with a mean size of 0.45 mm. Indications are that, for larger material, the Froude number must be increased to maintain the plane bed. For sand sizes >0.50 mm, it would seem that the velocities and depths of flow in the section should be in a range of Froude numbers between 0.7 and 0.9. Because most operating canals will generally have depths that are large relative to the slot opening, it would seem that the section should be designed to maintain the 0.8 through 1.0 range.

With respect to design and location of the vortex tube section, most of the structures now in existence have been located near canal headworks.

Problem may arise in determining the amount of rise to be provided in the bottom of the vortex tube section in order to maintain the Froude number of the flow near 0.8. For a canal that operates at almost constant stage, the problem is simplified. For those in which the flow varies widely, a design flow should be selected that will exist for a greater portion of the time. The normal amount of rise in the floor can then be determined for this design flow and normal depth.

A summary of the guidelines presented by Robinson (14), follows:

1) The Froude number should be approximately equal to 0.8;

2) The percentage of flow removed (about 5% to 15% of the total) is a function of the depth and velocity of flow in the channel as well as width of opening, area, angle, and length of tube;

3) The width of opening should usually be in the range of 0.5 ft to 1.0 ft;

4) The ratio of length of tube to width of opening (L/D) should not exceed 20 with the maximum length of tube being approximately 15 ft;

5) The tube angle should be 45%;

6) Straight tubes operate as well as tapered ones;

7) The elevation of the upstream and downstream lips of the tube can be the same rather than having the downstream one lower;

8) The shape of the tube does not seem to be particularly important as long as this shape is such that material entering the tube is not allowed to escape back into the channel;

9) The required area of the tube can be approximated by the relationship: $A_T = 0.06DL\sin\theta$; and

10) With the foregoing design specifications, the tube can be expected to remove approximately 80% of the sediment with sizes greater than 0.50 mm. The trapping efficiency of smaller sizes will be considerably lower.

The control of sediment using the guide vane device has been a major concern of the Bureau of Reclamation. Therefore, the following conclusions and recommendations have been obtained from their studies on bottom and surface guide vanes.

It was found that both the surface and bottom vanes were equally effective in reducing the sediment intake into the canal. For both types of vanes the concentration ratio of sediment entering the canal was reduced from 2.38, measured in control tests which used no vanes, to less than 0.1.

The most effective set of bottom vanes tested consisted of four 50-foot long vanes installed upstream from the canal headworks. The vanes were placed at an angle of 45° to the direction of flow. Vane spacing was 26 feet on centers, vane top elevation was 4666.1 feet, and the downstream tip of the downstream vane was located 5 feet 7 inches upstream from the canal headworks centerline.

The most effective set of surface vanes, indicated by the tests, included either three or four vanes 40 to 50 feet long placed near the canal headworks. The vanes were installed at an angle of 140°. Vane spacing was 18 feet 4 inches on centers and vane height was 1 foot 11 3/4 inches.

Both bottom and surface vanes were found to be extremely valuable in helping to gain control of heavy sediments by creating localized secondary currents to reduce the sediment intake into a canal. Consideration should be given to their use where flow conditions are similar to those tested by the Bureau of Reclamation. Either bottom or surface vanes may be employed using the dimensions (or proportional dimensions) given by the USBR. However, if discharges are significantly different than those tested by the USBR, further investigation in a model should be made.

Further research should be conducted to determine the general performance of vanes in confined spaces and their possible use in increasing sediment loads in canal sluiceways. The effect of varying discharges should also be investigated.

With respect to King's silt vanes, it is true that they are hardly suitable for cases in which the discharge of the offtaking channel is more than one-third of the parent channel.

A summary of rules is given below in order to effect a good design of silt vanes:

1) The minimum radius around which water can be guided without undue afflux, may be taken as 25 feet. Obviously also, the greater the radius, the more efficient the vane will be;

2) The downstream ends of the vanes should be tangential to lines which are at an angle with the centerline not less acute than 2 to 4 (about 27°);

3) It is sufficient if the width of the parent channel covered by the upstream ends of the vanes is half the width of the offtaking channel;

4) The height of the vanes, may ordinarily be made 1/3 to 1/4 of the depth of the parent channel for strong effect; and

5) The width of the channels between the vanes should ordinarily be about 1 1/2 times the height of the vanes.

With respect to the "curved wings" or Gribb's Groyne," it is very effective in preventing the deposit of silt at the head of a channel, but it is not generally realized that it actually excludes silt. This device may be used in cases where the offtaking channel has, by virtue of its gradient, etc., the same silt-carrying power as the parent. As to how far upstream the curve is to be taken, it should extend a good way up, say up to 3/4 of the width of the offtake. Also, it is not necessary that the curve be exactly tangential to a line parallel to the centerline of the parent nor the downstream end tangential to the centerline of the offtaking channel.

The effectiveness of silt exclusion can further be increased by using, in conjunction with the silt vanes, the curved wing device. Therefore, the same design considerations for each one should be made when they are used together.

APPENDIX I. - REFERENCES

1. Ahmad, M., "Design of Silt Excluders and Silt Ejectors," Golden Juilee Publication, West Pakistan Engineering Congress, October 1963, Part II, pp. 85-120.

2. Brown, D. R. M., "A Study of Factors Influencing the Efficiency of Vortex Tube Sand Traps," Proceedings of the Institute of Civil Engineers, London, England, June 1964, Vol. 28, Paper 6715, pp. 197-200.

3. Carlson, E. J. and Enger, P. F., "Hydraulic Model Tests of Bottom and Surface Guide Vanes to Control Sediment Inflow into Canal Headworks," Hyd. Lab. Rept., August 1962, HYD-499.

4. Dominy, F. E., "Design Considerations in the Economic Handling of Sediment in Irrigation Systems," Sixth Congress on Irrigation and Drainage, New Delhi, 1966, Question 20.

5. Enger, P. F. and Carlson, E. J., "Hydraulic Model Study to Determine a Sediment Control Arrangement for Socorro Main Canal Headworks-San Acacia Diversion Dam, Middle Rio Grande Project, New Mexico," March 1952, Hyd. Lab. Rept. n HYD-479.

6. King, H. W., "Silt Vanes," Punjab Engineering Congress, Vol. 8, 1920.

7. King, H. W., "Silt Exclusion from Distributaries," Punjab Engineering Congress, Vol. 21, Paper 169, 1933.

8. Koonsman, G. L., "Efficiency of a Vortex Tube Sand Trap," M.S. Thesis, Colorado State University, Fort Collins, Colorado, June, 1950.

9. Koonsman, G. L. and Albertson, M. L., "Design Characteristics of the Vortex Tube Sand Trap," Proceedings of the 4th General Meeting of the International Association for Hydraulic Research, Bombay, India, 1951, pp. 317-323.

10. Kraatz, D. B. and Mahajan, I. K., "Small Hydraulic Structures," Water Resources Development and Management Service, Land and Water Development Division, Vol. 26/1, 1975.

11. Melone, A. M., "Exclusion and Ejection of Sediment from Canals," M.S. Thesis, Colorado State University, Fort Collins, Colorado, November, 1974.

12. Parshall, R. L., "Control of Sand and Sediment in Irrigation, Power, and Municipal Water Supplies," Annual Meeting, Water Works Association, Denver, Colorado, October 1933.

13. Parshall, R. L., "Model and Prototype Studies of Sand Traps," Transactions of the ASCE, Vol. 107, 1952, p. 204.

14. Robinson, A. R., "Vortex Tube Sand Trap," Transactions of the ASCE, Vol. 127, 1962, pp. 391-422.

15. Rohwer, C., Code, W. E., and Brooks, L. R., "Vortex Tube Sand Trap Tests for 1933," Fort Collins, Colorado.

16. Rohwer, C., "Effect of Shape of Tube on Efficiency of Vortex Tube Sand Traps for Various Sizes of Sand," Fort Collins, Colorado, 1935.

17. Uppal, H. L., "Sediment Excluders and Extractors," Proceedings of the 4th General Meeting of the International Association for Hydraulic Research, Bombay, India, 1951, pp. 261-315.