INTERIM REPORT

MODEL STUDY OF THE SEDIMENT EJECTOR for the TRIMMU-SIDHNAI LINK CANAL

Prepared for
Tipton and Kalmbach, Inc.
Denver, Colorado

by
S. S. Karaki

Colorado State University
Research Foundation
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INTRODUCTION

General Information

"The Indus Basin Settlement Plan" for West Pakistan is a comprehensive plan involving vast engineering works to provide lands in the Indus River Basin with irrigation water to produce the food necessary to sustain Pakistan's large population. With the creation of Pakistan as an independent nation, the boundary between West Pakistan and India was established in a general north-south direction which crossed the Indus River and its tributaries. The location of this particular boundary developed serious problems in division of waters between the two countries. Lands under irrigation in West Palistan were isolated from canals and headworks of the canals located in India. After many years of study, patient negotiation between the two countries, and arbitration by the International Bank for Reconstruction and Development (World Bank) a treaty was finally consummated for division of the disputed waters, using the final form of the Indus Basin Settlement Plan as its basis.

The "Plan" in brief involves two large storage dams, one on the Indus River and the other on the Jhelum River, and a number of large canals linking the rivers Indus, Jhelum, Chenab, Ravi, and the Sutlej upstream of their normal confluences. Several barrages will be constructed, and some will be reconstructed. Construction of the various works will be financed from a fund created and administered by the World Bank. West Pakistan Water and Power Development Authority (WAPDA) will administer the design and construction of the engineering works.

The Trimmu-Sidhnai Link Canal

The Trimmu-Sidhnai, (T-S) Link is the first of the new canals in the system scheduled for construction. It links the Chenab and the Ravi Rivers with a design flow capacity of 11,000 cusecs. The canal is trapezoidal in shape, 240 feet wide at the base, and 44 miles long on a slope of 1:10,500. For purposes of design, modified equations originally presented by Lacey were used. Their form as adopted by the Central Irrigation Board of India in 1934 and used by Tipton and Kalmbach for design are as follows:

$$S = 0.0005469 \frac{f^{5/3}}{Q_T^{1/6}}$$

$$P = 8/3\, Q_T^{1/2}$$

$$A = 1.260 \frac{Q_T^{5/6}}{f^{1/3}}$$

In the above equations,

S = hydraulic gradient

f = Lacey's silt factor

Q_T = discharge in cfs

P = wetted perimeter in feet

A = cross-sectional area of the waterway.

Available head from the headworks or pond level at Trimmu to Sidhnai at the outlet is very limited. If the canal is to discharge the design flow without change in slope or width, it is necessary that Lacey's silt factor f be approximately 0.89 as used for purposes of design. It would be pertinent to note that the design engineers have made a careful study of the silt factor considered applicable to the site. Detailed explanations and results of their study are found in a separate report[1].

[1] "Supplemental Note on Hydraulic Design of Link Canal with particular reference to the Trimmu-Sidhnai Link," by Tipton and Kalmbach, Inc., Denver, Colorado. April 1961.

The principal factor which affects the value of f is the sediment size of the canal bed. Size of bed material and sediment charge in the canal determines the form of bed roughness for given flow conditions, and the bed form determines the hydraulic gradient. Thus, to control the canal slope it is necessary to control the sediment charge in the canal. This may be done by sediment excluders at the headworks to the canal and by sediment ejectors in the canal located a short distance downstream of the headworks. The subject under study at Colorado State University is the sediment excluder for the T-S Link. More specifically, it is the aim of the study to develop an efficient, practical and economic ejector system which could operate within a wide range of canal flow conditions to safeguard the canal from serious deviations in slope or channel width from design conditions. While it is recognized that sediment which is ejected from the canal and returned to the river will be a by-product of the ejector, the problems which may be created there are outside the province of this study.

THE PROPOSED SEDIMENT EJECTOR

Consideration was given by the engineers and others concerned with canal design to various types of sediment ejectors[2]. Included among them were the so-called Punjap-type, vortex tube, and desilting basins with dredges; but for reasons of efficiency or economy they were considered unsatisfactory. The ejector which was conceived for the T-S Link canal was one which was thought to utilize the boundary shear along a curved channel to transport the canal bed load to the inside of the curve. A curve of 838.3 feet in length was established approximately 2300 feet downstream from the headworks with a radius of 3600 feet. Because of the topographic limitations of the surrounding terrain it was not possible to develop a much sharper or longer curve. There are two adjacent rows of large 30 x 30 x 9 feet deep hoppers, placed along the inside shore line of the curve, staggered in such a way as to permit pipes to be placed to the individual hoppers for ejection of the sediment. See Figs. 1 and 2 for details and dimensions. The intended principle of operation was simply one of utilizing the effect of the secondary flow created at the bend to shoal the sediment along the inside of the curve. The shoal would then be periodically removed through the hoppers by pipes back into the river. Because of the lack of fundamental knowledge of the shoaling process at the inside of the bend, it was not possible to definitively design the size, number, and location of the hoppers with out the aid of a model study. Thus, it was considered essential that a model study be made to study the entire ejector system, with particular application to the T-S Link.

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[2] It is not within the scope of this report to discuss in detail the various other types of sediment ejectors considered.

THE MODEL

General Background

Models are used to solve many hydraulic problems, but there are few models more complex than distorted alluvial or movable bed models. Distortion in geometry is generally necessary for models of wide, shallow waterways to avoid laminar flows or flow conditions in the model unlike the prototype. It is impossible to introduce one distortion in model scale without creating others. To add to the complexity, fundamental laws governing the mechanics of flow in alluvial channels are not yet clearly understood, thus making it very difficult to construct models which are quantitatively reliable in every respect.

Much work has been done to develop scales for movable bed models. Among the most comprehensive of these has been the work of Einstein and Ning Chein[3]. Their method involves nine condition equations to relate ten independent scale ratios; seven distortions are involved. The condition equations are based on the following criteria:

1. Friction, (Manning's)

$$V_r^{\,2} \, D_r^{\,2m} \, S_r^{\,-1} \, h_r^{\,-1-2m} \, C_r^{\,-2} = \Delta_v$$

2. Froude,

$$V_r \, h_r^{\,-1/2} = \Delta_F$$

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3 Einstein, Hans A., and Chein, Ning, "Similarity of Distorted River Models with Movable Beds," Transactions ASCE, v. 121, 1956.

3. Sediment transport

$$q_{b_r} (\rho_s - \rho_f)^{-3/2} D_r^{-3/2} = 1$$

4. Channel stability (zero sediment load)

$$(\rho_s - \rho_f)_r D_r \eta_r^{-1} h_r^{-1} S_r^{-1} = 1$$

5. Laminar sublayer

$$D_r \eta_r^{1/2} S_r^{1/2} h_r^{1/2} = \Delta_\delta$$

6. Total load rate to bed load rate

$$q_{t_r} = B q_{b_r}$$

7. Hydraulic time

$$t_{1_r} V_r L_r^{-1} = 1$$

8. Sedimentation time (duration of flows)

$$q_{t_r} t_{2_r} L_r^{-1} h_r^{-1} (\rho_s - \rho_f)_r^{-1} = 1$$

9. Slope distortion

$$S_r L_r h_r^{-1} = \Delta_N$$

A significant point is noted in the above condition equations when

$(\rho_s - \rho_f)_r = 1$. If all other conditions are satisfied, from condition equations 4 and 5,

$$D_r = 1$$

and from equation 3,

$$q_{b_r} = 1$$

which means that sediment size is identical in model and prototype and the bed load rates are equal and approximately the same form of bed roughness must be created in the model as exists in the prototype.

The regime formulae establish model scales such that if sediment densities are equal in model and prototype, and sizes are approximately equal, then

$$L_r = Q_r^{1/2}$$

$$h_r = Q_r^{1/3}$$

$$S_r = Q_r^{-1/6}$$

and

$$h_r = L_r^{2/3}$$

It was recognized by Blench[4] that these scales are to be used as a means of constructing the model; that once the model is constructed the scales would be redetermined on the basis of model reproduction of prototype phenomena.

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[4] Blench, T. Regime behavior of canals and rivers, London. Butterworth's Scientific publications; 1957.

Methods used by Inglis[5] in his studies have been based principally on trial and error, the model being first constructed on certain basic relationships and thereafter equations and formulae are disregarded.

Description of the Model

The model was initially designed using the method developed by Einstein and Ning Chein, and independently checked by the regime method. The purpose of these computations was to size the model, recognizing that certain trial procedures would be necessary in adjusting the model scales. The preliminary scales are tabulated below.

TABLE 1.

Preliminary Model Scales

Item	Nomenclature	Method 1*	Method 2.+
Length	L_r	35	35
Depth	h_r	10	10.7
Discharge	Q_r	1106	1225
Velocity	V_r	3.16	3.27
Slope	S_r	.286	.305
Sediment Density	$(\rho_s - \rho_f)_r$	1	1
Sediment Size	D_r	1	1

* Einstein and Ning Chein method

\+ Regime method.

5 Inglis, C. C. "The behavior and control of rivers and canals," Central Water Power Irrigation and Navigation Research Station, Paona. Research Publication No. 13. Part II, Chapter 13.

A schematic diagram of the model is shown in Fig. 3 . The width of the canal and radius of the bend in the model is in relation to the prototype Trimmu-Sidhnai Canal as shown in Fig. 1. There is approximately 60 feet of straight channel upstream of the bend which includes the transition from the headbox to the trapezoidal section. The downstream channel extends 40 feet from the end of the curve, terminating at the tailbox.

Water is recirculated by a 14-inch turbine pump through the channel and into the sump. The flow is measured by an orifice meter located in the pipeline between the pump and headbox. The sediment in the system is also recirculated, but through a separate system from that of the water. The rate of sand fed into the flow is measured and controlled by the sediment feeder (wet feed process) upstream of the headbox. The sand mixes with the flow in the pipeline ahead of the headbox to assure uniform distribution with respect to the flow width. The sand settles out in the tailbox and is then pumped through a centrifugal pump into a settling tank. The sand is then separated from the water and conveyed mechanically back to the sediment feeder.

A general photograph of the entire model is shown in Fig. 4. Other photographs of the various components are shown in subsequent figures.

MODEL PROGRESS AND PARTIAL RESULTS

Model Scales

The model scales to be used in this study are not constant, for several of the scales will vary with the flow condition under study. The basis of similarity between model and prototype is the form of bed roughness which is created at different water and sediment discharges. Keeping in mind that it is the prime purpose of this sediment ejector to remove that portion of the bed load in the canal which is in excess of that needed to maintain the canal in regime, it is important that the form of the bed be comparable in the model and prototype under similar sediment loads.

The tests to date have been concerned with maximum canal discharge of 12,000 cfs[6] and expected average total sediment charge of 400 ppm. The model scales determined for these conditions are tabulated below:

TABLE 2.

Model Scales for Q_T = 12,000 cfs G_T = 400 ppm[7]

Item	Nomenclature	Scale Ratio
Length	L_r	35
Depth	h_r	13.9
Slope	S_r	.133
Discharge	Q_r	1043
Velocity	V_r	1.85
Sediment Density	$(\rho_s - \rho_f)_r$	1
Sediment Diameter	D_r	1

6 The T-S Link is designed to flow a maximum discharge of 12,000 cfs from the headworks to the sediment ejector. Downstream from the ejector, the design capacity is 11,000 cfs.

7 G_T is total sediment concentration by weight upstream of the ejector.

Sediment Size, Distribution and Density

A comparison of the material in the model and the sediment assumed for the prototype[8], is shown in Fig. 3a. These curves show that the sediment size and distribution are practically identical. The sand for the model was obtained from a site south and west of Denver, Colorado which exists in nature as loosely cemented sandstone. The specific gravity of the sand in the model is approximately 2.65.

Results of Tests

The results of studies made to date are tabulated on page 12. The effectiveness of the ejector is expressed in terms of efficiency; the quantity of sediment ejected G_e per unit time, divided by the total quantity of sediment transported in the canal per unit time G_T.

Remaining Test Program

The ejector system thus far in the test program appears to operate most satisfactorily using continuous operation of only several bins. The double row of hoppers included in the preliminary design of the ejector system appears unnecessary, and even if intermittent operation should be chosen, the shoal could be ejected with very little additional time using only one row. On the basis of the results of tests tabulated in Table 3, it appears that the row of hoppers along the shore line should be installed.

A lateral row of 8 hoppers was installed in line with hoppers 1 and 2. Tests with this system are aimed at improving the ejector efficiency above the 50 per cent indicated by the longitudinal hoppers.

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8 Size distribution curve of a sample collected from the Trimmu discharge site near the right bank of the river, taken from the Punjab Irrigation Research Institute, 1938, supplied to Colorado State University from Tipton and Kalmbach, Inc.

TABLE 3.

Model Results
(For location of hoppers and hopper numbers refer to Fig. 2)

Condition of Tests	Q_T	G_T	Bin Numbers used to eject sediment	Per cent Ejection Ratio		Remarks
				Sediment	Water	
Inter-mittent operation	12,000	400	All 28 bins	15	---	Bins were emptied after the last bin, No. 28, was filled.
Con-tinuous operation	"	"	9,10	38	6.2	No grates over hoppers.
"	"	"	9,10	38	5.3	With grates.
"	"	"	9,10	16	5.9	Bed vanes at beginning of curve. (Fig. 11).
"	"	"	9,10	13	6.0	Bed vanes at beginning of bins. (Fig. 12).
"	"	"	1,16,28	17	4.8	Bed vanes at beginning of bins.
"	"	"	1,2,3	12	3.7	Bed vanes at beginning of bins. Surface vanes at point of curve.
"	"	"	10,16,22,28	58	5.1	Surface vanes only at beginning of curve.
"	"	"	10,16,22,28	54	5.0	Repeat of above.
"	"	"	10,16,22,28	50	5.3	No vanes.
"	"	"	2,4,6,8	28	5.1	" "
"	"	"	22,24,26,28	50	5.4	" "
"	"	"	9,15,21,27	40	5.4	" "
"	"	"	3,9,15,21,27	50	6.7	" "
"	"	"	3,9,15,21,27	46	7.3	Repeat of above.
"	"	"	1,2,29 - 34	65	7.8	Lateral bins were tested in the model

Note: Per cent sediment ejection is defined as a ratio of the quantity of sediment ejected per unit time to the total quantity of sediment being transported in the canal upstream of the ejector in the same unit of time. Per cent water ejection is flow of water through the ejector divided by the flow of water in the canal upstream of the ejector.

The remaining test program will consist of the following:

1. The lateral hoppers will be tested at $Q_T = 12{,}000$ cfs and $G_T = 400$ ppm.

2. Tests for $Q_T = 12{,}000$ cfs and $G_T = 1200$ ppm will be made

3. The performance of the ejector system will be determined for $Q_T = 12{,}000$ cfs and $G_T = 100$ ppm.

4. Q_T will be reduced to 5000 cfs and G_T at the more critical value observed in the foregoing will be tested.

5. $Q_T = 8000$ cfs will be studied

6. The effectiveness of the ejector system under extremely adverse conditions of sediment charge will be determined. The sediment charge will be increased until the system is considered to fail.

The program outlined above is not intended to be complete in all details. Important factors which are considered of secondary importance at this time, may be added to the tests, and unnecessary tests may be omitted. On the basis of results to date, the proposed sediment ejector shows great effectiveness. Combination of the longitudinal and lateral rows of sediment collection bins appears to be a very satisfactory arrangement for the sediment ejector.

NOMENCLATURE

A = Cross-sectional area of the canal

B = Ratio of total sediment load to bed load

b = Bed load

C = Constant in generalized Manning's equation

D = Sediment diameter

F = Froude number

f = Lacey's silt factor

G = Sediment transport in ppm

h = Depth of flow

L = Length

P = Wetted perimeter

Q_T = Canal discharge in cfs upstream of the ejector

q_b = Bed load per unit of width

q_t = Total sediment load per unit of width

r = Prototype to model ratio

S = Hydraulic gradient

t_1 = Hydraulic time

t_2 = Sedimentation time

V = Velocity in fps

Δ = Similarity index

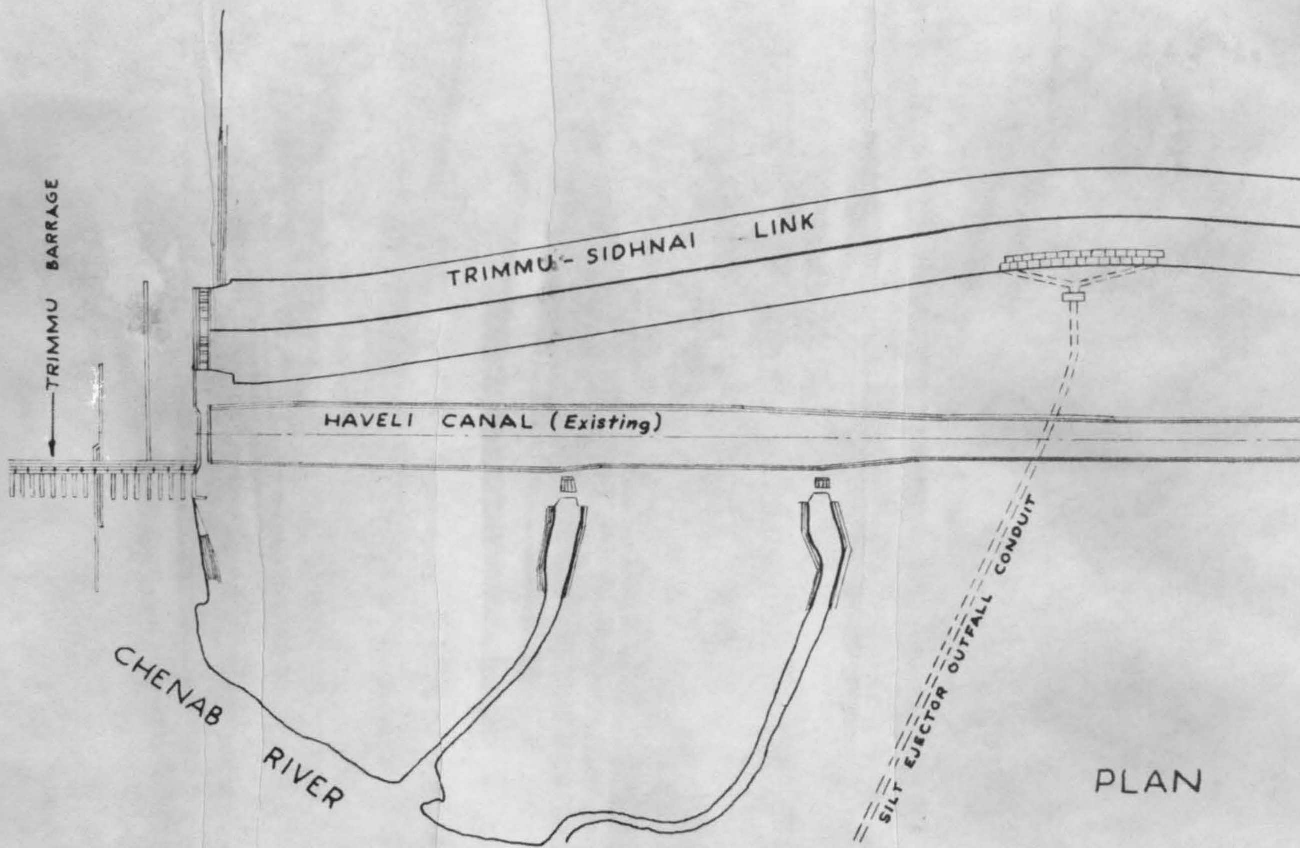
η = Ratio of bed roughness to total roughness

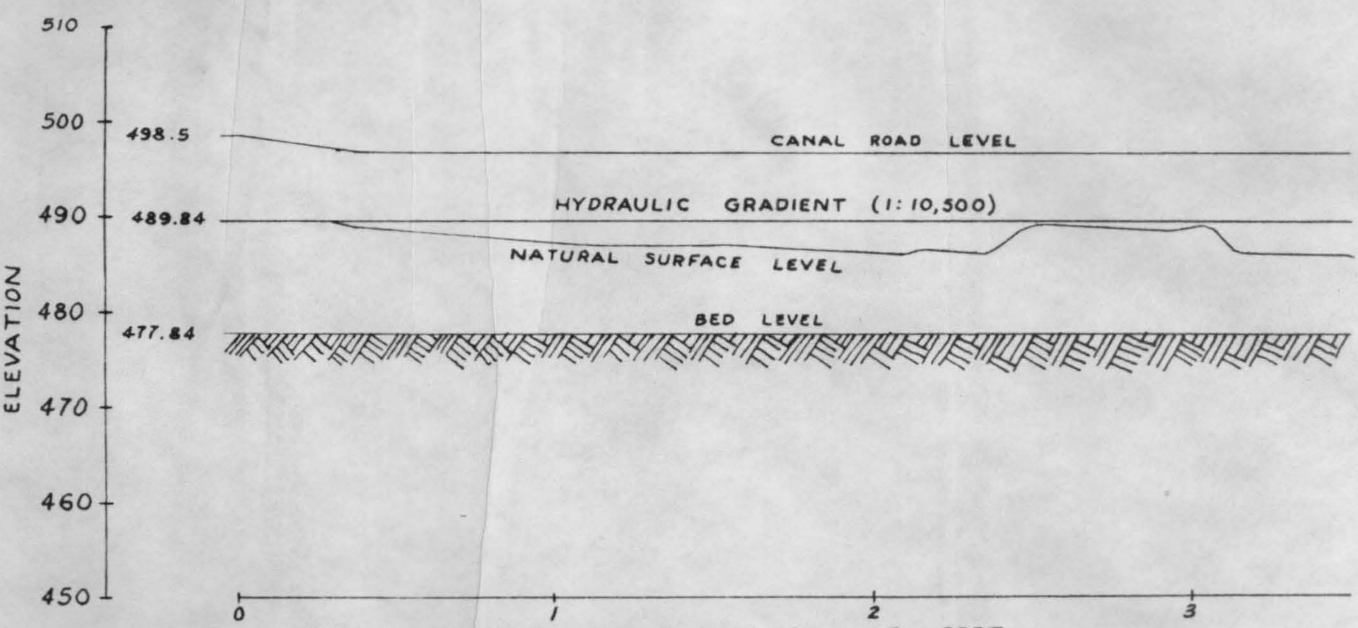
ρ_f = Fluid density

ρ_s = Sediment density

F IGURES

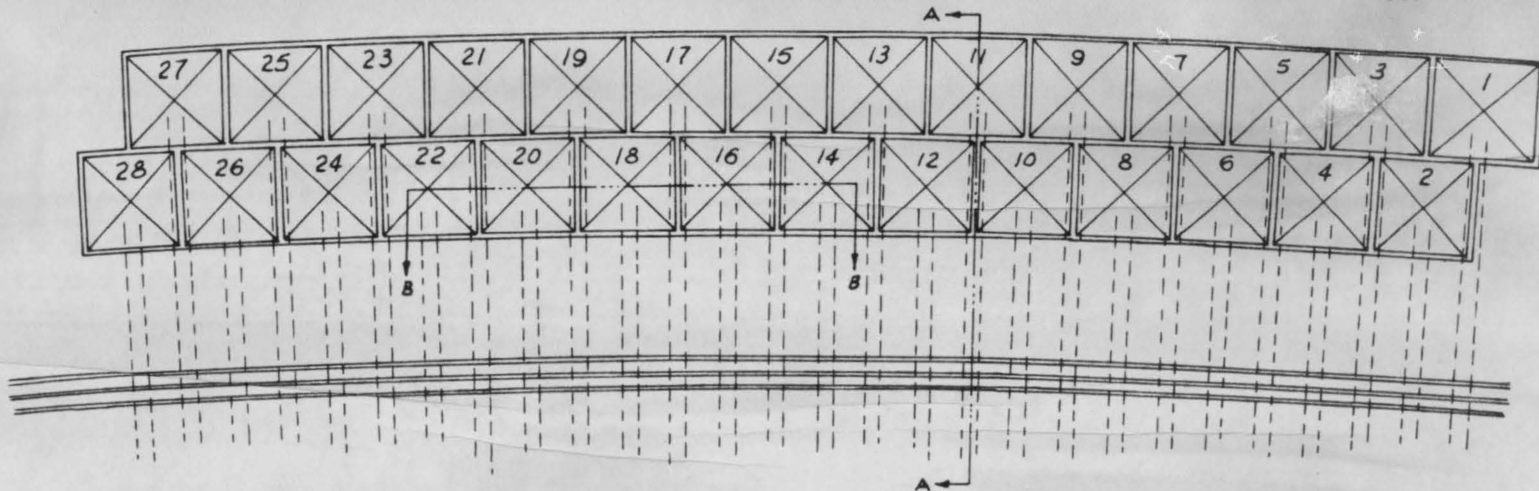
FIGURE 1.



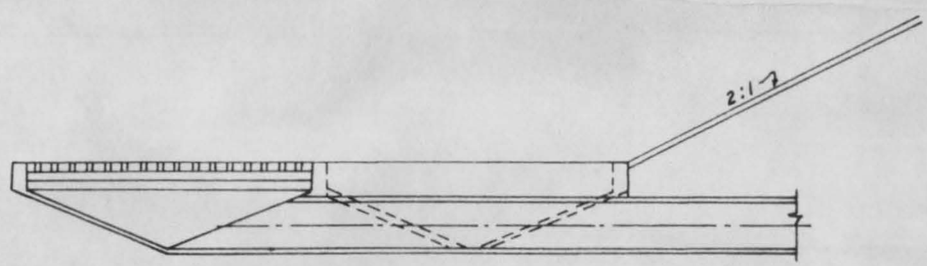


PROFILE

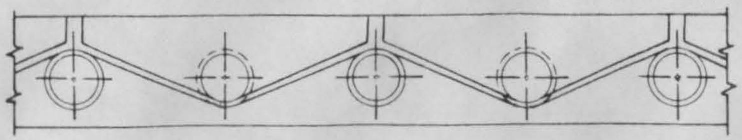
NOTE: GRATES OMITTED ON DRAWING



SILT COLLECTION BINS – NUMBERING SCHEME



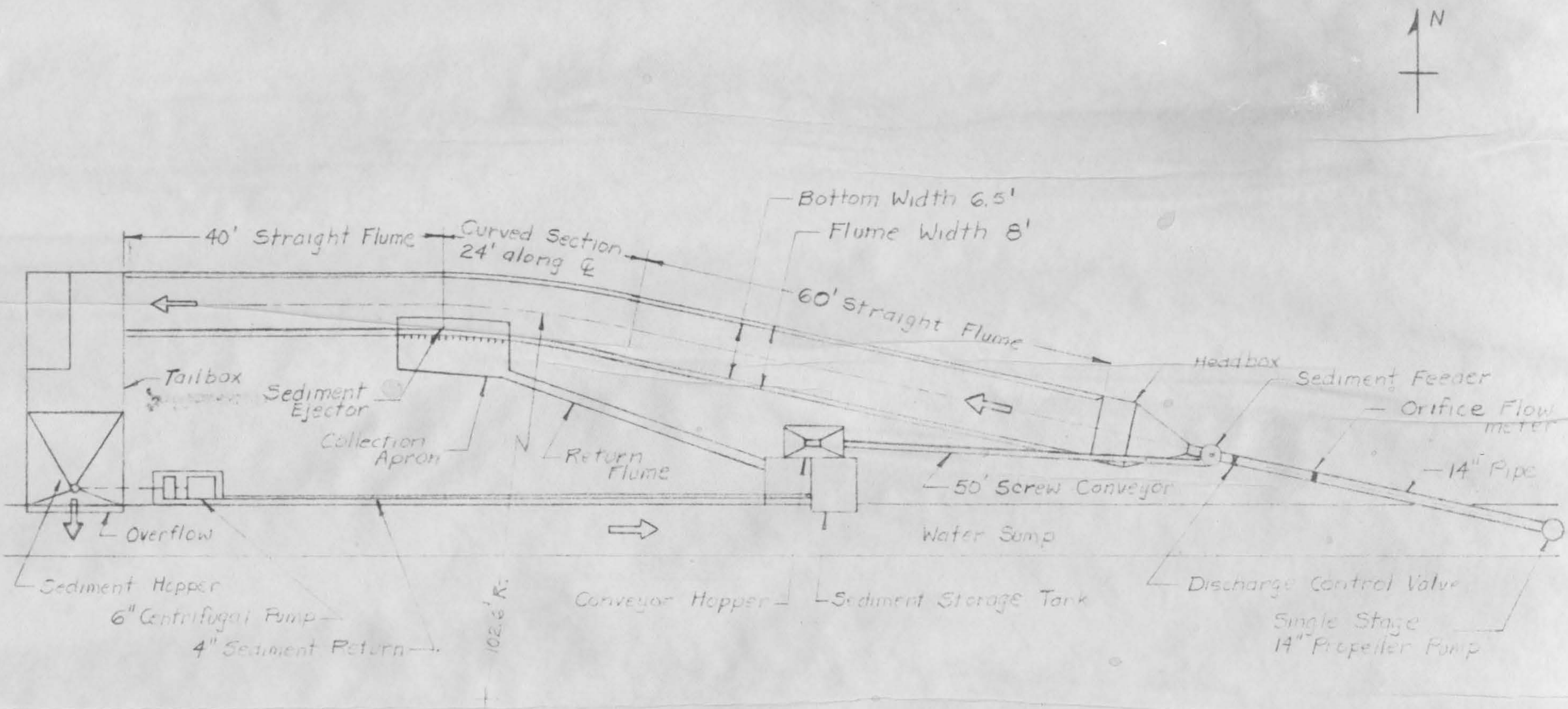
SECTION A-A



SECTION B-B

FIGURE 2

SILT COLLECTION BINS — DETAILS



SCHEMATIC DRAWING OF MODEL

FIGURE 3

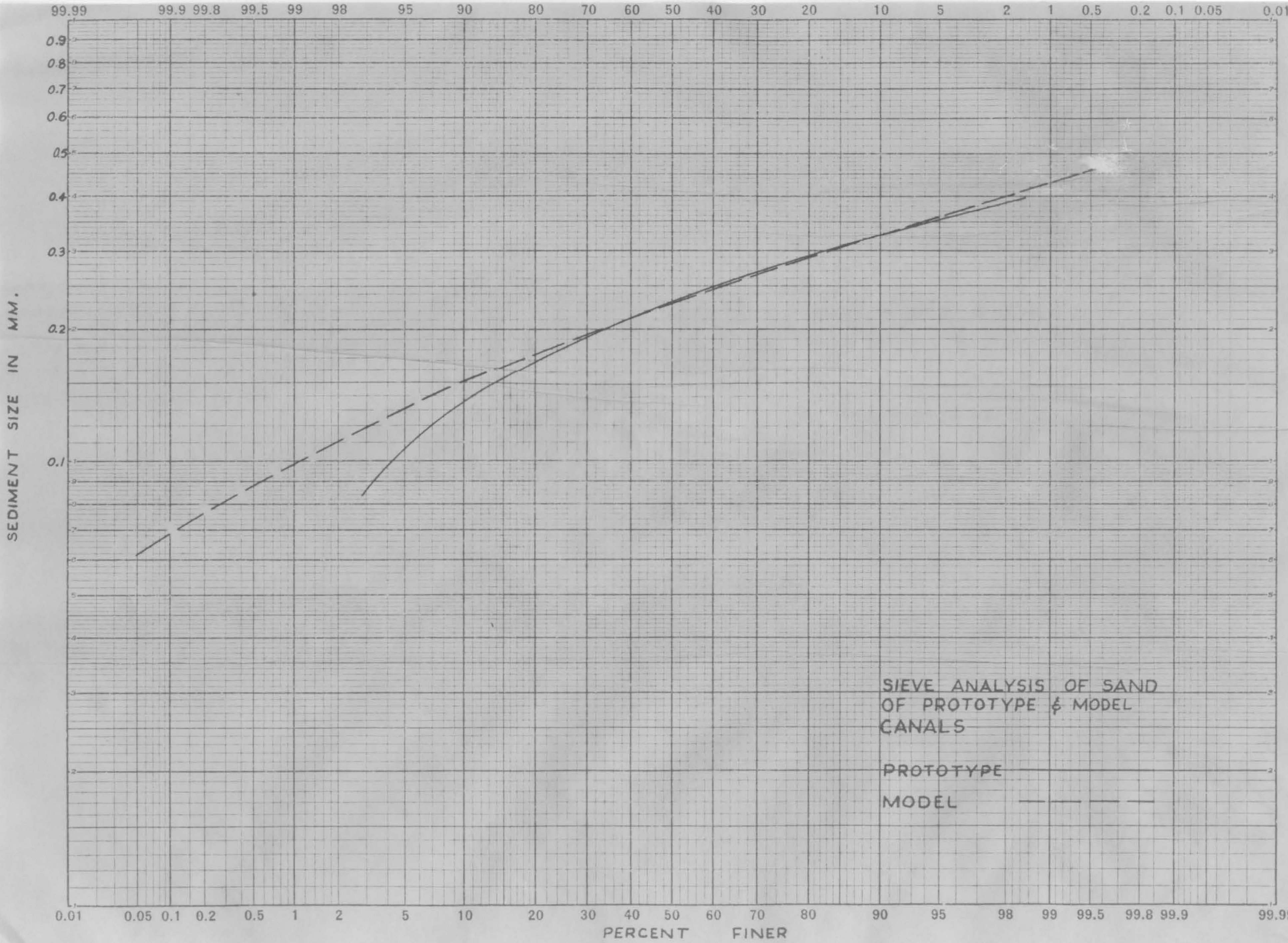

SIEVE ANALYSIS OF SAND OF PROTOTYPE & MODEL CANALS
PROTOTYPE
MODEL
SEDIMENT SIZE IN MM.
PERCENT FINER
99.99 99.9 99.8 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.05 0.01
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.5 99.8 99.9 99.99
0.9 0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1

FIGURE 3-A

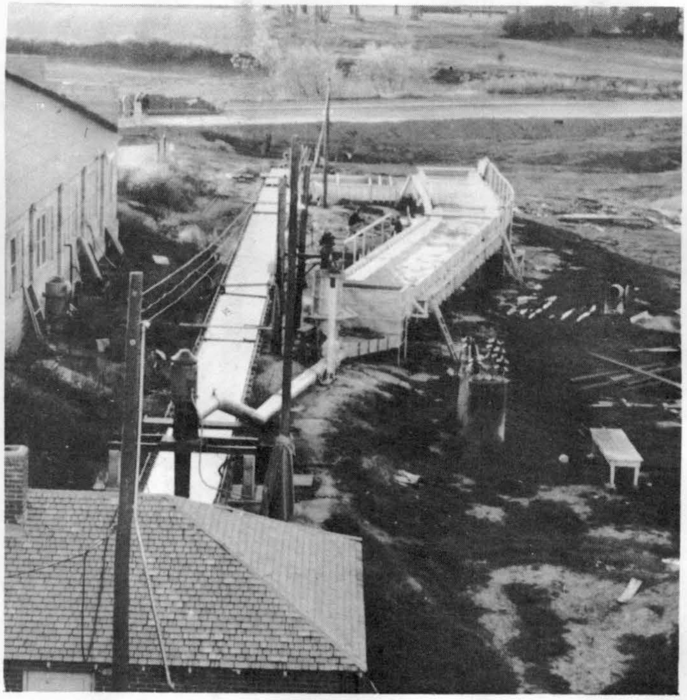


Fig. 4 General photograph of the model.

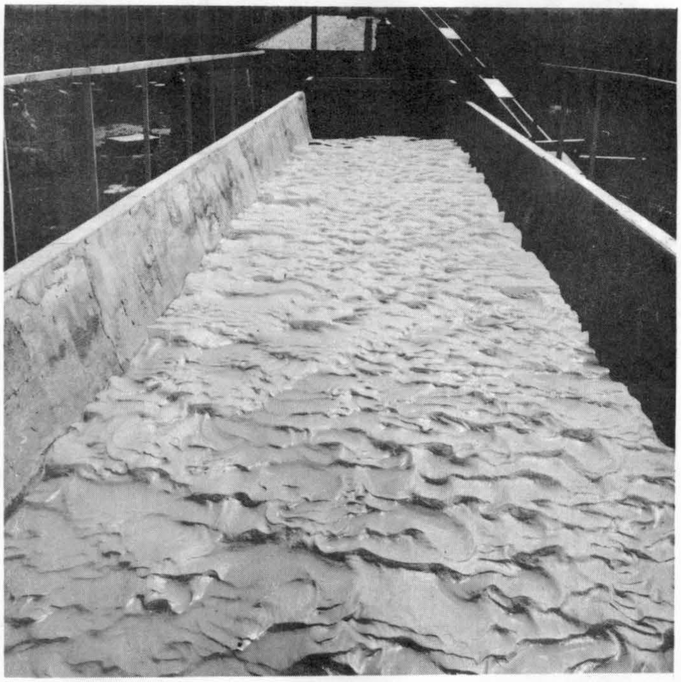


Fig. 5 Photograph of the bed form in the model. Condition is described as ripples on dunes. View is upstream.

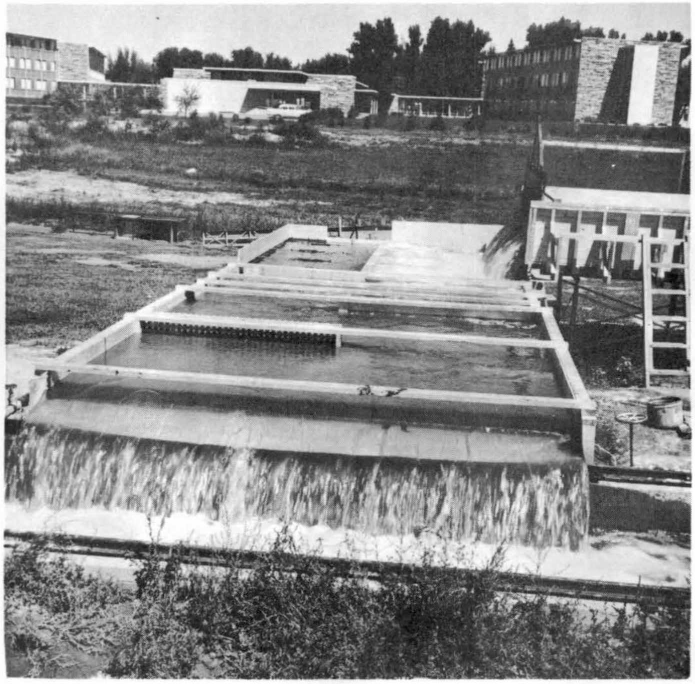


Fig. 6 Photograph of large tailbox for separating sediment and water flow.

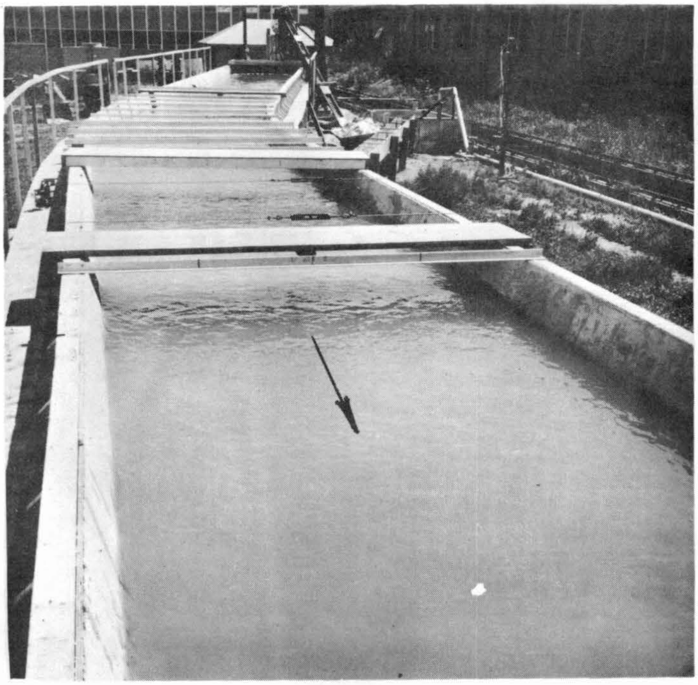


Fig. 7 Photograph of model canal showing curvature. Flume is 8 feet wide at the top. View is upstream.

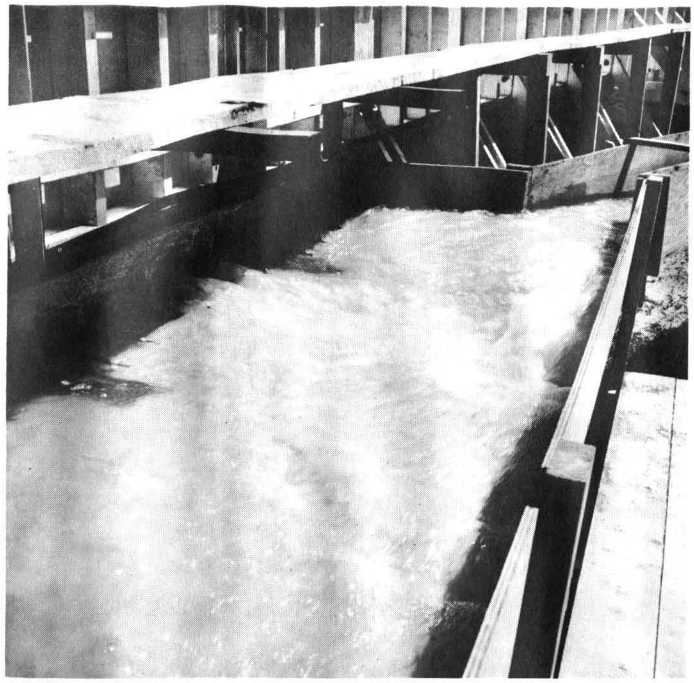


Fig. 8 View of model arrangement of the pipes leading from the ejector hoppers.

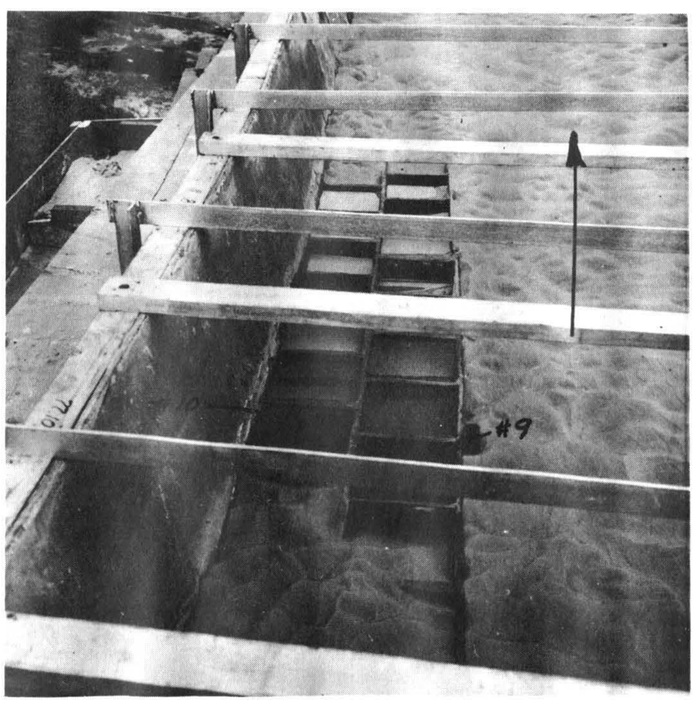


Fig. 9 Photograph shows results of turbulence created over the hoppers without grates. Hoppers nos. 9 and 10 were open for continuous ejection.

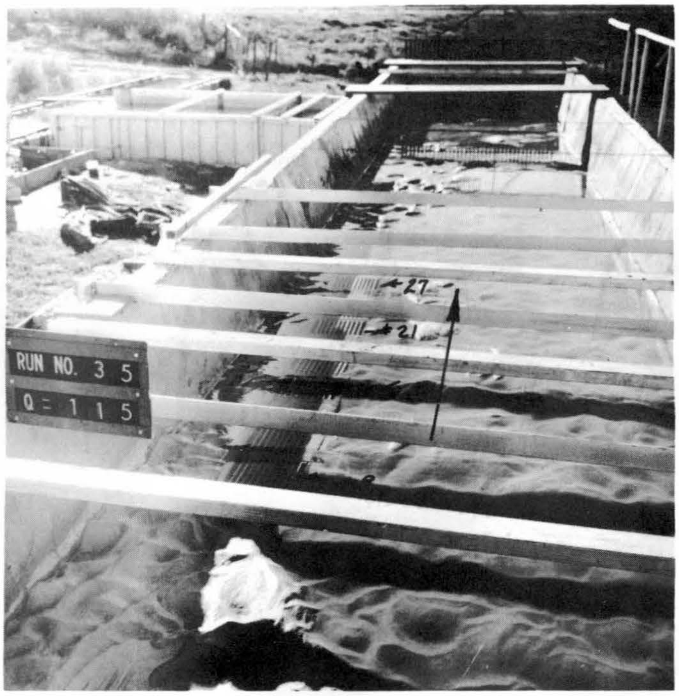


Fig. 10 Turbulence is reduced by the grates. Hoppers nos. 27, 21, 15 and 9 were open in continuous ejection. Flow is towards top of photograph.

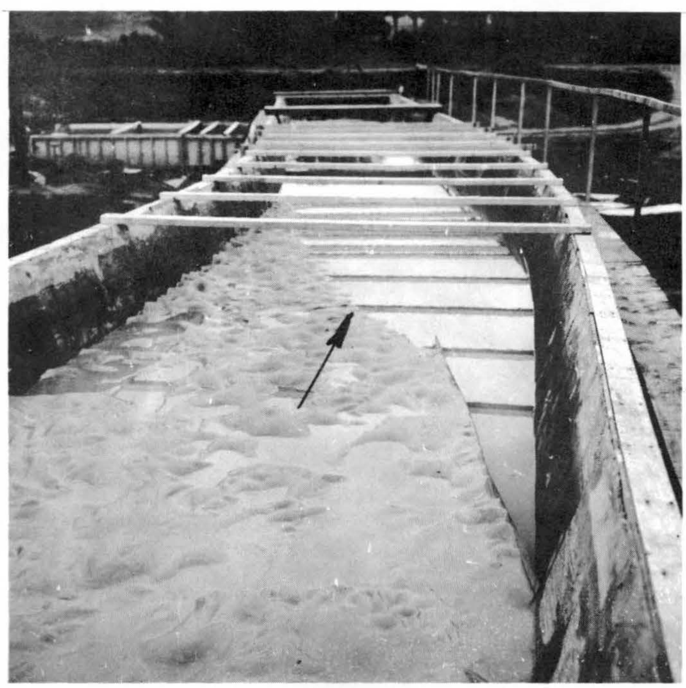


Fig. 11 Bed vane installed in outside of curve at the beginning of curvature. Vane projected one-fourth the depth of flow.

Fig. 12 Bed vanes were installed near the beginning of the hoppers. Vanes projected approximately one-fourth the depth of flow.

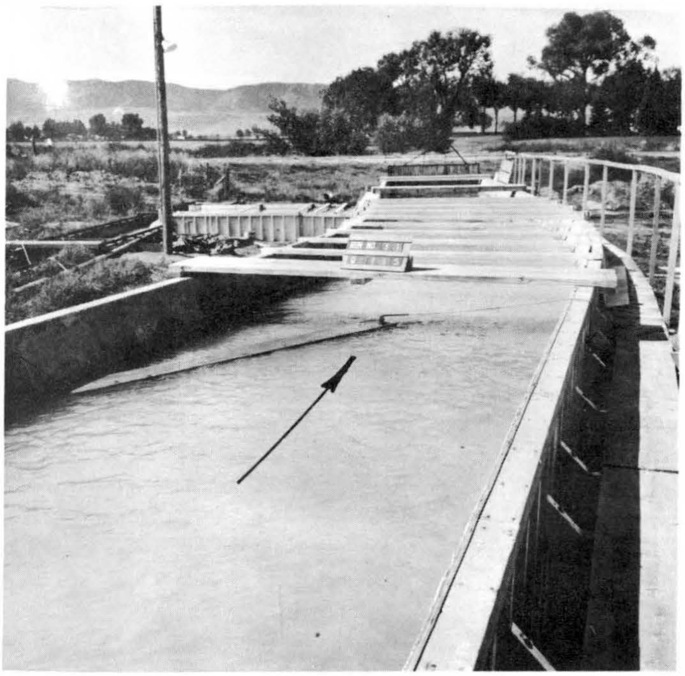


Fig. 13 Surface vane located at beginning of curve.