# FINAL REPORT

# MODEL INVESTIGATION

## of the

# SEDIMENT EJECTOR

## FOR THE

# TRIMMU-SIDHNAI LINK CANAL

## INDUS BASIN PROJECT
## WEST PAKISTAN

Prepared for

Tipton and Kalmback, Inc.
Consulting Engineers
Denver, Colorado

Colorado State University Research Foundation
Civil Engineering Section
Hydraulics Laboratory

December 1961

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ERRATA

# A FINAL REPORT ON A MODEL INVESTIGATION OF THE SEDIMENT EJECTOR FOR THE TRIMMU-SIDHNAI LINK CANAL

By S. S. Karaki

| Page | |
|---|---|
| Front Cover | Spelling error - Kalmback should be spelled Kalmbach. |
| vi | Definition of suspended bed material should follow definition of bed material. |
| 4 | End of second line. Figure 43 should be Figure 46. |
| 8 | End of second paragraph, line 12. Upper regime flow should be upper flow regime. |
| 9 | Third paragraph. Remove the comma after: There is,. . . . . |
| 10 | Table 1. Remove the horizontal lines in the left column. All of the bed forms pertain to lower flow regime. |
| 17 | Table 2. Second column. $D_r$ should be $d_r$ . |
| 20 | Second line. $y_r$ should be $h_r$ . |
| 20 | Table 4. In the second line of the second column under nomenclature. $y_r$ should be $h_r$. |
| Fig. 2 | The ordinate identification should be Bed Material Concentration in place of Total Sediment Transport. |

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## DEFINITIONS OF TERMS

Alluvial channel studies involve use of many terms which are ambiguous to the reader and appear to have multiple meanings. The following is a list of definitions of terms pertaining to this study. All of the terms do not appear in this report but are included for purpose of of clarification. The writer is aware that some of these definitions are not universally accepted. It is anticipated, however, that there will be little difficulty in interpreting the contents of this report if the definitions given below are carefully studied.

Sediment - Fragmental material that originates from weathering of rocks and is subject to transport by water.

Suspended sediment - The sediment that at any given time is moving in suspension in the water-sediment mixture above a specified height above the channel bed and is maintained in suspension by the upward components of turbulent currents or by colloidal suspension. In this report the height above the channel bed is specified as 0.1 foot in the model.

Material - Connotes division of sediment by size or source (not origin) and is used with another term to designate size division; for example, coarse material or bed material.

Bed material - Denotes division of sediment by sizes. In this report it includes all sediment sizes coarser than 0.074 mm. By general definition it includes all sediment coarser than the largest standard separation size at which no more than 10 percent of the bed material is finer. The standard separation size used in this report is the U.S. Standard sieve No. 200 which has an opening of 0.074 mm.

Load - Connotes sediment in transport. The term should not be used interchangeably nor confused with concentration or discharge. The word is used to separate sediment according to mechanics of transport.

Wash load - Denotes sediment sizes transported in suspension, and division of suspended sediment by sizes, In this report it includes all sediment sizes smaller than 0.074 mm. By general definition it includes all sediment finer than the largest standard separation size at which no more than 10 percent of the bed material is finer. The standard separation size used in this report is the U.S. Standard sieve No. 200 which has an opening of 0.074 mm.

Suspended bed material - Bed material sizes suspended in the flow.

Bed load - Sediment that moves along essentially in continuous contact with the channel bed. In this report, sediment within 0.1 foot of the bed in the model is construed as being essentially in continuous contact with the channel bed.

Total load - All sediment transported by the flow.

Discharge - The volume, or weight of the water, water-sediment mixture, or sediment which passes through a section of flow in a unit of time. The section may include the total section, a unit width and/or unit depth.

Suspended sediment discharge - Weight of all the suspended sediment which passes through a section of flow in a unit of time. In this report section denotes the total cross-section of the waterway.

Bed-load discharge - Weight of bed load which passes through a section of flow in a unit of time. In this report section denotes the total cross-section of the waterway.

Bed-material discharge - Weight of bed material which passes through a section of flow in a unit of time. In this report, section denotes the total cross-section of the waterway.

Total-sediment discharge - Weight of all sediment which passes through the total cross-section of the waterway in a unit of time. It is the sum of suspended sediment discharge and bed load discharge.

Sediment concentration - The ratio of weight of sediment to the weight of water-sediment mixture in parts per million. A part per million is a unit weight of sediment in a million unit weights of water-sediment mixture.

Bed-material concentration - Concentration of bed material without regard to mode of transport.

Suspended-bed-material concentration - Concentration of bed material sizes in the suspended sediment.

Total sediment concentration - Concentration of sediment without regard to sizes or modes of transport.

Lower flow regime - A category for flows having bed forms of ripples, ripples on dunes, or dunes.

Upper flow regime - A category for flows having bed forms of plane bed with sediment movement, standing waves, or antidunes.

Bins or hoppers - Prismatic sediment collection receptacles of the ejector system. Pipes with valves are connected to the bottom to flush out the sediment.

Ejector efficiency - A ratio of bed-material discharge, or quantity, through the ejector to the bed-material discharge in the canal upstream of the ejector, or quantity transported to the ejector, in the same units and expressed as percent.

Water ejection ratio - A ratio of water discharge through the ejector to water discharge in the canal upstream of the ejector in the same units and expressed as percent.

Intermittent operation or ejection - Opening of the valves in the pipe lines connected to the bins in a periodic manner to flush the sediment out of the bins.

Continuous operation or ejection - Continuous discharge of water and sediment through the ejector bins.

Inside shore - The shore of the canal nearest the radial center of the circular canal curve.

Longitudinal row of bins or longitudinal bins - Refers to a row of bins along or adjacent to the inside shore line of the curve essentially parallel to the direction of flow in the canal.

Lateral row of bins, or lateral bins - Refers to a row of bins located transversely across the bed of the canal essentially normal to the flow in the canal.

## LIST OF SYMBOLS

| Letter | Units | Reference |
|---|---|---|
| A | $ft^2$ | Cross-sectional area of the canal. |
| B | dimensionless | Ratio of bed load discharge to bed material discharge per unit of width. |
| b | dimensionless | Subscript denoting bed load. |
| C | lb/lb | Sediment concentration. |
| $C_T$ | lb/lb | Bed-material concentration. |
| d | mm | Median sieve diameter of sediment particles. |
| F | dimensionless | Froude number of the flow $F = \frac{V}{\sqrt{gh}}$. |
| f | - - | Lacey's silt factor. |
| $G_e$ | lbs/hr | Bed material discharge through the ejector bins. |
| $G_T$ | lbs/hr | Bed material discharge in the canal upstream of the ejector. |
| g | $ft/sec^2$ | Gravitational acceleration. |
| h | ft | Average flow depth in the canal. |
| K | - - | Constant in generalized Manning's equation. |
| L | ft | Length. |
| m | - - | Subscript to denote a model quantity. |
| N | - - | Subscript used to refer the similarity index to slope. |
| P | ft | Wetted perimeter. |
| p | - - | Subscript to denote a prototype quantity. |

| Letter | Units | Reference |
|---|---|---|
| $Q_e$ | $ft^3/sec$ | Water discharge through the ejector bins. |
| $Q_T$ | $ft^3/sec$ | Canal discharge upstream of the ejector. |
| $q_b$ | lbs/hr/ft | Bed load discharge in the canal per unit of width. |
| $q_T$ | lbs/hr/ft | Bed material discharge in the canal per unit of width. |
| r | - - | Subscript used to denote the quantity as a ratio of prototype to model as: $$V_r = \frac{V_p}{V_m}$$ |
| S | ft/ft | Hydraulic gradient. |
| s | - - | Subscript used to denote suspended sediment. |
| $t_1$ | sec | Hydraulic time. |
| $t_2$ | sec | Sedimentation time. |
| V | ft/sec | Average velocity of water-sediment mixture. |
| W | ft | Bed width of the canal. |
| $\Delta$ | - - | Similarity index. If prototype and model parameters are equal, $\Delta = 1$. |
| $\delta$ | - - | Subscript used to refer the similarity index to the thickness of the laminar sublayer. |
| $\eta$ | - - | Ratio of bed roughness to total roughness. Total roughness is bed roughness plus grain roughness. |
| $\rho_f$ | $\frac{lb - sec^2}{ft^4}$ | Fluid mass density. |
| $\rho_s$ | $\frac{lb - sec^2}{ft^4}$ | Sediment mass density. |

## REPORT SUMMARY

A model study of a sediment ejector system for the Trimmu-Sidhnai link canal was conducted at the Hydraulics Laboratory of Colorado State University. The study was conducted for the consulting engineering firm of Tipton and Kalmbach, Inc., of Denver, Colorado.

The Trimmu-Sidhnai canal is one of several link canals in the Indus Basin Settlement Plan that link rivers in the Indus Basin. The Plan provides for waters from the Indus River and its tributaries to be delivered to lands presently under irrigation. These lands currently face problems of water supply due to the location of the boundary between West Pakistan and India. The Trimmu-Sidhnai canal links the Chenab to the Ravi river. Because of the nature of the materials through which the channel is to be constructed and because of the concentration of bed material which is expected to enter the canal, provision for adequate control of the bed-material discharge must be made near the upstream end to maintain a regime canal.

The purpose of this study was to develop and test a sediment ejector system to protect the Trimmu-Sidhnai canal from excessive bed-material concentrations downstream from the ejector. Based upon available information at the time of this study (1961), the median diameter of the bed-material in the Trimmu-Sidhnai canal was assumed to be about 0.23 mm and bed-material concentrations could vary between 50 and 400 ppm depending upon sediment excluder efficiency at the headworks and sediment concentration in the river. These assumptions are based on available current and past data and it is possible that as future data are taken in the field both bed material sizes and concentrations could differ from these assumed values by significant amounts. The maximum flow available for waste has been assumed to be 10 percent of the discharge in the canal upstream of the ejector.

The bed-material concentration in the canal at regime flow was calculated by a revised Einstein method to be about 100 ppm. In this study only bed material was used in the model. Since wash load was not present, the term total load is not used in this report to avoid confusion with field conditions where wash load is present. Furthermore, reference to all of the bed material in the model flow, whether in suspension or bed load will be stated as bed material and not total bed material in order to avoid confusion with total load.

The preliminary design of the ejector included a system of 28 bins, each 30 x 30 x 9 feet deep placed in two adjacent rows of 14 bins along the inside shore line of a curve in the canal. The radius of the curve was 3,600 feet and the curve length was about 840 feet along the center line. The purpose of the curve was to create secondary circulation to shoal the bed load along the inside of the curve. By appropriate location of the ejector the shoal could be intermittently flushed out of the bins through pipe lines back into the river downstream of the Emerson barrage. Although the delta formation of the ejector outfall in the river could create a problem of river control, solution of this problem was not considered in this study.

The model tests showed that ejector efficiency with intermittent ejection of the shoal by all 28 bins was about 15 percent. Continuous ejection through four ejector bins in the shore line row improved the ejector efficiency. The four bins were spaced every third bin apart, beginning with bin No. 10 as shown in the numbering scheme in the model of Fig. 11. The efficiency curve for the model ejector is shown in Fig. 28 with the corresponding probable prototype efficiency curve shown in Fig. 43. The relationship between the model and prototype curves are discussed more fully in the text of this report. Based upon these curves the improvement in efficiency can be seen by the tabulated values below:

| | Ejector Efficiency Percent | |
|---|---|---|
| Water Ejection Ratio Percent | Model | Prototype |
| 3 | 30 | 20 |
| 5 | 40 | 30 |
| 7 | 50 | 38 |
| 10 | 60 | 45 |

By assuming a water ejection ratio of 10 percent and ejector efficiency of 45 percent, the longitudinal arrangement of four hoppers should be adequate if the bed-material concentrations entering the canal do not exceed 200 ppm.

Installation of a row of eight lateral bins across the bed of the canal in the model, with continuous operation of these bins only, resulted in greater model efficiencies. Ejector efficiencies of the lateral row were also dependent upon water ejection ratios as shown in Figs. 31 and 35 through 38 of this report. The composite data are plotted in Fig. 42. Based upon the average curve through the composite points, the ejector efficiencies were:

| | Ejector Efficiency Percent |
|---|---|
| Water Ejection Ratio Percent | Model and Prototype |
| 3 | 25 |
| 5 | 40 |
| 7 | 55 |
| 10 | 70 |

The scatter of data is about ± 10 percent with some points beyond this range. Scatter of model data of this magnitude with alluvial channel studies is common. By assuming a water discharge ratio of 10 percent and ejector efficiency of 70 percent, the ejector should operate satisfactorily with a bed-material concentration in the canal of about 400 ppm.

The recommended ejector arrangement is shown in Fig. 45. The principal ejection system consists of a lateral row of eight bins which should be operated with continuous ejection with the water discharge regulated as necessary to remove the desired portion of the bed-material discharge. It is recommended that the sizes of bins in the preliminary design be adopted for the final design. During periods of extremely high river level at the ejector outfall, that is, when the river level at the outfall of the ejector pipe line is equal to or higher than the canal water level at the ejector, the ejector gates will probably be closed. As long as the river level at the outfall remains below the canal water level at the ejector some discharge through the ejector is possible. To intercept as much of the bed load as possible during these periods it is recommended that the curve as originally designed be retained in the final canal alignment so that the bed material which may by-pass the closed ejector bins could shoal along the inside shore of the curve. The shore line row of bins are thus recommended for removal of the shoal. The model study indicated need for only four bins to be spaced about 90 feet apart in the prototype, center to center dimension, along the shore if continuous flow is permitted through these bins. Four bins would also be satisfactory for removal of the shoal provided sufficient time and quantity of water is available for waste. The required time and waste water will depend upon the canal discharge, the size of the sand bar and the rate at which the ejector gates can be opened. The lateral row of ejector bins may be located anywhere upstream of the longitudinal bins to a section about 1500 feet downstream of the headworks.

A suggested alternate ejector system is to construct two rows of lateral bins spaced approximately 1000 feet apart as shown in Fig. 43. The alternate system is predicated on the assumption that more than 10 percent of the canal flow upstream of the ejector is available for waste through the ejectors even though it was assumed in the study that no more than 10 percent water ejection was allowable. From the model study the indicated efficiency of a single row of lateral bins with 10 percent water ejection ratio is about equal to or slightly greater than the combined efficiencies of two rows with five percent water ejection in each row. Thus with water ejection greater than five percent in each of the two rows, the combined efficiencies would correspondingly be greater. The bins along the shore in this system also is recommended for removal of the shoal in the canal curve but may be reduced to four, as quick removal of the shoal is not essential since adequate waste water is assumed available. Desirability of this alternate ejector scheme would depend upon the bed-material concentration in the canal and available waste water.

# 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 adequate irrigation water. With the creation of Pakistan as an independent nation, the boundary between West Pakistan and India was established in a north-south direction and 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 Pakistan 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 new barrages will be constructed, and some existing barrages will be reconstructed. Construction of the various works will be financed from a fund created and administered by the World Bank. The West Pakistan Water and Power Development Authority (WAPDA) will administer the design and construction of the engineering works.

## Trimmu-Sidhnai Link Canal

The Trimmu-Sidhnai (T-S) link is the first of the new canals in the settlement plan scheduled for construction. The link originates at the existing Emerson barrage on the Chenab River at Trimmu and terminates at the Ravi River about eight miles upstream of the existing Sidhnai headworks. The T-S link parallels the existing Haveli canal for most of its 44-mile length.

The design of the T-S link is based on the regime equations of Lacey, and the designers recognized from the outset that the canal would require effective sediment control to operate satisfactorily and maintain its geometry. Control of sediment inflow is to be effected at the headworks by an excluder and suitable river training works and as further insurance for proper operation, some type of ejector system was planned for the canal downstream from the headworks.

Sediment Problem

There is little information available on bed material, distribution of bed material sizes and concentrations either in the Chenab River at Emerson barrage or on the T-S canal. From available limited information [1,2], it has been assumed that the bed-material size distribution will be approximately as shown in Fig. 1. In the figure the median diameter is equal to 0.23 mm.

The total sediment discharge in the canal will consist of wash load and bed material load. It is not desirable to remove the wash load from the flow as the presence of the wash load adds to the stability of the banks and increases the apparent viscosity of the water-sediment mixture and in turn slightly reduces the fall velocity and the fall diameter of the bed material. It is the fall diameter, not sieve diameter, that is important in establishing a suitable Lacey silt factor to use in the regime equations. This report uses sieve diameter, however, to conform with the practices of Tipton and Kalmbach and WAPDA. The ejector is concerned only with removal of the bed material. The wash load will be transported through the canal without difficulty.

Observations on sediment concentrations at the Trimmu headworks [3] with particular reference to the efficiency of the silt excluder of the Haveli Canal indicated the concentrations of sediment in the canal varied from about 60 to 360 ppm of coarse and medium sizes (ppm refers to parts of sediment per one million parts of water and sediment by weight). The Pakistan Irrigation Research Institute Reports for the years 1952, 1954 and 1956, reports the Haveli canal sediment concentrations to be about 120 ppm of

[1] "Hydraulic Design of Unlined Canals," by Tipton and Kalmbach, Inc., Denver, Colorado. April 1961.

[2] 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 by Tipton and Kalmbach, Inc., Denver, Colorado.

[3] Table of silt observations at Trimmu headworks extracted from the Punjab Research Institute Report, 1941, made available to Colorado State University by Tipton and Kalmbach, Inc., Denver, Colorado.

coarse and medium sizes[4]. The particle size designations above have the following size references:

Fine: Less than 0.074 mm
Medium: Between 0.074 and 0.20 mm
Coarse: Greater than 0.20 mm

Computations were made to determine the approximate[5] bed-material discharge the T-S link could transport in the regime canal using various methods currently (1961) available [6, 7, 8]. Computations by a revised Einstein method were used in plotting the graph of Fig. 2. The computations in tabular form are included in the Appendix. Because of variations of the T-S link from waterways used in the development of portions of Einstein's empirical relationships, a "variation" envelope is expected about the curve of at least ± 50 percent. Nevertheless, the figure indicates "the order of magnitude" of the bed-material concentrations the Trimmu-Sidhnai canal may be expected to transport without serious deviation in canal geometry. At maximum canal discharge of 11,000 cfs the bed-material concentration may be between 70 and 100 ppm. At 8000 cfs the concentration may be about 60 ppm.

Boundary Forms and Modes of Sediment Movement in the T-S Canal

The flow in the Trimmu-Sidhnai link canal will be tranquil-turbulent flow or is sometimes stated as the lower flow regime. Tranquil flow prevails when the Froude number is less than 1 . Froude number is defined as

$$F = \frac{V}{\sqrt{gh}} \quad ,$$

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[4] "Hydraulic Design of Unlined Canals," by Tipton and Kalmbach, Inc., Denver, Colorado. April 1961.

[5] Computations of total sediment loads are necessarily approximate since the mechanics of sediment transport are not yet fully understood. Many researchers have attempted theoretical treatment but the complexities of the problem have necessitated, by the large, empirical solutions.

[6] Einstein, H. A., "The bed-load function for sediment transportation in open channel flows," USDA Tech. Bull. No. 1026. September 1950.

[7] Meyer-Peter, E., and Müller, R., "Formulas for Bed-Load Transport," Report on the Second Meeting Int. Assoc. Hyd. Struct. Research, Appendix 2, Stockholm, 1948.

[8] Bishop, A. A., "Sediment Transport in Alluvial Channels - A Critical Examination of Einstein's Theory," Ph.D. Thesis, Colorado State University, Fort Collins, Colorado. July 1961.

where

$F$ = Froude number
$V$ = Average velocity of flow
$g$ = Gravitational acceleration
$h$ = Average flow depth.

If boundary shear or Froude number is adequately varied, (which is not the case in regime channels) several forms of bed roughness occur with the sizes of bed material shown in Fig. 1. These forms are shown in Fig. 3 as ripples, dunes, and transition[9]. They develop in the indicated order with increasing Froude number. The transition bed form is washed-out dunes and is the bed roughness that occurs between dunes and plane bed or between lower and upper regime flow.

The bed forms are functions of the properties of the bed material, the wash load and the flow, and cannot be predicted in terms of shear or Froude number.

With the beginning of particle movement on alluvial channel beds, ripples begin to form. Ripples have amplitudes on the order of 0.01 to 0.1 foot and spacings of 0.5 to 1.5 feet from crest to crest. There is generally very little bed material in suspension at this stage of flow. The sediment moves in more or less continuous contact with the bed by rolling over the crest of the ripples and coming to rest on the foreplane. The sediment particle does not move again until it becomes exposed on the upstream face of the ripple as the general movement of the ripple progresses downstream. The surface of the water is smooth. As boundary shear is increased by an increase in depth and/or slope, movement of the bed material speeds up, the ripples change to ripples superposed on dunes, or dunes. The height of dunes may range from 0.1 foot to many feet depending upon the depth, velocity of flow, and properties of the bed material, the wash load and the water. Dunes up to three feet in height with spacings from 30 to 40 feet may be expected in the canal upstream from the ejector when large concentrations of bed-material enter the canal for prolonged periods.

Dunes move in essentially the same manner as ripples except that movement of the individual particles are accelerated. The smaller dunes travel relatively faster than the larger dunes and as a result overtakes the larger dunes. This results in a still larger combined dune with a velocity less than either dune. The average velocity of a large dune may be between

[9] Simons, D. B., and Richardson, E. V., "Resistance to Flow in Alluvial Channels," ASCE Proc. Hyd. Div. HY5, May 1960, Proc. Sep. 2485.

0.05 and 0.2 foot per minute. The larger the dune height the greater the sediment storage capacity within the dune and the slower the dune velocity for a given bed-material concentration. With dunes on the bed the water surface will show definite signs of disturbance described in the figure as boils. The concentration of the suspended bed material in the dune range will increase to about 40 to 60 percent of the bed material concentration. As the suspended-bed-material concentration increases the median diameter of the bed load will tend to become slightly coarser. Considering the assumed bed material for the T-S canal the median diameter can be expected to increase from 0.23 mm to about 0.26 mm with slightly smaller range of particle sizes. The difference in median diameter for suspended bed material and bed load will be small and tend to become smaller as the suspended-bed-material concentration increases.

In the transition zone the bed form will appear as washed-out dunes and the suspended bed-material concentration increases to about 60 to 80 percent of the bed-material concentration. Movement of the sediment particles on the bed will appear practically continuous since few dunes are formed and little sediment is stored.

There is, an approximate relationship between form of bed roughness and bed-material concentration. It will be qualitatively helpful to tabulate the relationship within broad limits as in Table 1. With experience, an individual may estimate the bed-material concentration by observation of sediment sizes and flow conditions.

TABLE 1

Changes in Bed Forms
with
Variation of Bed Material Concentrations[10]

Assumed Bed Material Size in the Trimmu-Sidhnai Canal, d = 0.23 mm

| | Forms of Bed Roughness | Bed Material Concentration ppm | Remarks |
|---|---|---|---|
| Tranquil-Turbulent Flow Regime | Ripples | 1 - 100 | Forms with some sediment particle movement. |
| Lower Flow Regime | Dunes | 100 - 1200 | With sediment having a median diameter of about 0.23 mm ripples will nearly always be superposed on dunes. |
| | Transition | 1200 - 3000 | Transition from lower flow regime to upper flow regime. |

[10] Simons, D. B., and Richardson, E. V., "Studies of Flow in Alluvial Channels - Basic Data From Flume Experiments." USGS, Colorado State University Publication CER61EVR31. May 1961.

# THE PROPOSED SEDIMENT EJECTOR

Consideration was given by the engineers and others concerned with the design of the Trimmu-Sidhnai canal to various types of sediment ejectors. Included among them were the so-called Punjab-type, the vortex tube, a desilting basin with dredge and the ejector investigated in this model study. In order for the vortex tube[11] to operate efficiently, the Froude number of the flow in the canal should be near 1.0 in the section of the canal containing the vortex tube. This generally necessitates some form of contraction in the canal to locally accelerate the velocity and decrease the flow depth. The desilting basin may be practically designed to any size dictated by the reduction in turbulence necessary for settlement of the smallest sediment particle size desired for removal. The dredge for removal of the settled sediment from the basin may vary in capacity or in number depending upon the sediment discharge in the canal and size of basin. The Punjab-type ejector consists of a tunnel which extends across the bed of the canal with an open vertical upstream face to intercept the bed load. In principal it may be designed with any height of vertical opening depending on the flow and type of bed form expected in the canal. In practice, however, the ejector may be innundated by large dunes unless sufficient water is ejected through the tunnel since the ejector is essentially a line sink. If the ejector openings are above the canal bed, local turbulence created at the vertical face will reduce ejector efficiency. If the ejector openings are below the canal bed, possibility of innundation by the dunes becomes greater particularly with small water ejection discharges.

The ejector conceived for the T-S canal (see Figs. 4 and 5) was expected to utilize to some extent the secondary circulation and difference in boundary shear stresses along a curve in the canal to transport the bed load to the inside of the curve and be deposited there as a sand bar or shoal. 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 shorter radius or longer length of curve. There were two adjacent rows of 30 x 30 x 9 feet deep bins placed along the inside shore of the curve to enable intermittent removal of the shoal by pipes back into the river downstream of the Emerson barrage. The bins in the two rows were offset in

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[11] Robinson, A. R., "Vortex Tube Sand Trap," Proc. ASCE Irrigation and Drainage Division, Separate No. 2669, December 1960.

a manner shown in Figs. 4 and 5 to permit pipes to be connected to the individual hoppers. The large size of the bins would collectively provide for about 2.9 acre-feet of sediment storage capacity, discounting the shoal formation above the bins. Because of the lack of fundamental knowledge on the shoaling process, it was considered essential that a model study be made to establish the size, number and location of bins in the canal curve and to determine the efficiency of the ejector. Although formation of a delta at the ejector outfall could create a problem of river control, solution of this problem was considered to be outside the scope of this model study.

# 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 of modeling, 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 scale ratios for movable bed models[12,13,14,15,16,17]. Among the most comprehensive of these has been the work of Einstein and Ning-Chien. 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:

---

[12] Einstein, Hans A., and Ning-Chien, "Similarity of Distorted River Models with Movable Beds," Transactions ASCE, v. 121, 1956.

[13] Allen, J., Scale Models in Hydraulic Engineering, Longmans, Green and Co., London, 1947.

[14] Bogardi, J., "Hydraulic Similarity of River Models with Movable Bed," Research Inst. of Water Economy, Budapest, Hungary, June 1958.

[15] Inglis, C. C., "The Behaviour and Control of Rivers and Canals," Central Waterpower, Irrigation and Navigation Research Station, Poona, Research Pub. No. 13, Part II, Chapter 13.

[16] Sybesma, R. P., and De Vries, M., "Conformity between Model and Prototype - A Symposium," Transactions ASCE, Vol. 109, 1944.

[17] Blench, T., "Scale Relations Among Sand-Bed Rivers Including Models," Proc. ASCE, Separate No. 667, April 1955.

1. Friction (Manning's),

$$V_r^{\,2}\ d_r^{\,2m}\ S_r^{\,-1}\ h_r^{\,-1-2m}\ K_r^{\,-2} = \Delta_V$$

2. Froude,

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

3. Bed load discharge,

$$q_{b_r}\ (\rho_S - \rho_f)^{-3/2}\ d_r^{\,-3/2} = 1$$

4. Channel stability,

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

5. Laminar sublayer,

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

6. Bed-material discharge to bed load discharge,

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

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 implies that if sediment densities in model and prototype are equal, sediment size should be identical in model and prototype and the bed load discharges should be equal. From the studies of Simons and Richardson[18], this means that approximately the same form of bed roughness and equal bed-material concentrations must be created in the model as exists for 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

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

[18] Simons, D. B., and Richardson, E. V., "Forms of Bed Roughness in Alluvial Channels," ASCE Hyd. Div. Jour., v. 87, No. HY5, May 1961.

It was recognized by Blench[19] that these scales should be used as a means of constructing the model, but once the model was constructed the scales should be redetermined on the basis of model reproduction of prototype phenomena.

Methods used by Inglis[20] in his studies have been based principally on trial and error, the model being first constructed according to the scales developed by the foregoing regime relationships but thereafter disregarded.

Description of the Models

Three models were used in this study:

1. Initially a small scale model 1 foot wide was constructed to determine if the degree of the curvature selected for the canal bend was sufficient to create the secondary flow required to transport the bed load to the inside of the bend, and to approximate the location of the shoal. This qualitative model was not constructed to scale.

2. A large scale model was constructed outdoors because of its size and area. This model included the canal bend.

3. Some studies were made in an existing straight 8 foot wide indoor flume of the lateral row of ejector bins.

The outdoor model. -- The outdoor model was initially designed using scales developed by the Einstein-Ning-Chien method, and independently checked by the regime technique. The preliminary scales are tabulated below:

[19] Blench, T., Regime Behaviour of Canals and Rivers, London. Butterworth's Scientific publications. 1957.

[20] Inglis, C. C., "The Behaviour and Control of Rivers and Canals," Central Waterpower Irrigation and Navigation Research Station, Poona. Research Publication No. 13, Part II, Chapter 13.

TABLE 2

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 |

A schematic diagram of the outdoor model is shown in Fig. 6. The width of the canal and radius of the bend in the model was related to the prototype Trimmu-Sidhnai canal as shown in Fig. 4. It will be noted that the model canal bend was oriented as a mirror image of the prototype. This orientation was to suit the conditions at the laboratory. There was approximately 60 feet of straight channel in the model upstream of the bend which included the transition from the head box to the trapezoidal section. There was also 40 feet of straight channel in the model which extended downstream from the end of the curve and terminated at the tail box.

Water was recirculated by a 14 inch turbine pump through the channel. The flow was measured by an orifice meter located in the pipeline between the pump and head box. Sediment in the system, which in this study included only bed material, was also recirculated, but through a separate system from that of the water. The quantity of sediment introduced into the flow

*Einstein-Ning-Chien method.

+Regime method.

per unit time was measured and controlled by a feeder (wet feed process) upstream of the head box. The sediment mixed with the flow in the pipeline ahead of the head box to assure uniform distribution with respect to flow width. The bed material settled out in the tail box and was then pumped through a centrifugal pump into a settling tank. There the sediment was separated from the water and conveyed mechanically back to the feeder. A general photograph of the entire model is shown in Fig. 7. Other photographs of the various components are shown in Figs. 8, 9, and 10.

Results from the tests of the longitudinal bins indicated the desirability to investigate a system of lateral bins across the entire canal bed. The location and arrangement of these bins as installed in the model are shown schematically in Fig. 11. The lateral row of bins was installed on a diagonal so as to facilitate pipe arrangement and was located at the upstream end of the longitudinal rows.

The indoor model. -- The indoor model was used to study the lateral sediment ejector bins. A schematic diagram of the model facilities is shown in Fig. 12. The flume used was eight feet wide, two feet deep and 150 feet long with an average sand bed depth of about 0.6 foot. Eight lateral bins approximately one-foot square (30 feet square in the prototype) were installed normal to the axis of the flume. A two-foot length of clear plastic wall was installed on one side of the flume at the ejector for observation of bed-material movement.

The water and sediment were recirculated through the flume. A steady bed-material discharge was established by maintaining continuous flow in the flume for a period between 25 to 50 hours, depending upon the bed-material concentration. The various concentrations were changed by varying the flow depth and bed slope. Although the flume was supported on adjustable jacks, the bed slope was allowed to adjust itself to the flow conditions since only very minor changes in slope were necessary to satisfy the various bed-material concentrations.

Water ejected through the bins was measured by a weir at the end of the sediment return flume. The bed material ejected from the bins was trapped in the return flume, measured volumetrically, bed-material discharge $G_e$ through the ejector was then calculated. Since the quantity of sediment required for each ejector test amounted to a maximum of only eight cubic feet, and the sand retained during each test was returned to the circulation system within 30 to 60 minutes, the bed-material concentrations were assumed to be unaffected by the sand retention.

Water flow was measured through a calibrated orifice in the system, and bed-material concentrations were measured with a width-integrating nappe sampler at the end of the flume.

# MODEL RESULTS

## Preliminary Study

At the beginning of the study, a curved one-foot wide flume was constructed with a plywood bottom and sheet metal sides for the purpose of visually observing the effectiveness of the curved channel in moving the bed load towards the inside shore of the bend. The geometric ratios of radius of curvature, R, to width of canal, W, and length of the curve, L, to width of canal were used to represent the prototype T-S link. No other scales were used. The values of these two ratios were varied as shown in Table 3.

TABLE 3

Curve Variations in One-Foot Model

Comparison to Prototype

| Model Condition | $\frac{R}{W}$ | $\frac{L}{W}$ |
|---|---|---|
| 1 | 10 | 2 |
| 2 | 15 | 3.5 |
| 3 | 20 | 5.0 |
| Prototype | 15 | 3.49 |

The respective values of the ratios for the prototype are also shown in the table above.

The results of these preliminary studies in the small flume showed that:

1. The bed load moves to the inside of the channel curve.

2. There was no observable difference between model conditions 1, 2, and 3 so far as bed load movement was concerned.

3. Sufficient justification was evident for further study of the proposed ejector in a larger scale model.

Outdoor model. -- The outdoor model was constructed to the calculated scales of $L_r = 35$ and $y_r = 10$ as indicated previously. After construction, some test runs indicated need to adjust the scales slightly to reproduce the proper bed form with the desired bed-material concentration. It is worth repeating at this time, that similarity between model and prototype was based on equal bed-material concentrations for given hydraulic conditions; that condition being maximum design flow[21] with bed-material discharge of 400 ppm. Comparison of calculated and adjusted scales are given in Table 4.

TABLE 4

Adjusted Model Scales for $Q_T = 12{,}000$ cfs $C_T = 400$ ppm

| Item | Nomenclature | Scales | |
|---|---|---|---|
| | | Calculated | Adjusted |
| Length | $L_r$ | 35 | 35 |
| Depth | $y_r$ | 10 | 11.9 |
| Slope | $S_r$ | .286 | .214 |
| Discharge | $Q_r$ | 1106 | 1043 |
| Velocity | $V_r$ | 3.16 | 2.39 |
| Sediment Density | $(\rho_s - \rho_f)_r$ | 1 | 1 |
| Sediment Diameter | $d_r$ | 1 | 1 |

[21] 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.

Sediment size, distribution and density. -- A comparison of the material used in the model and the sediment assumed for the prototype is shown graphically in Fig. 13. The size distribution curve shown for the model was established from sieve analyses of a number of samples taken from the bed. The data are tabulated in the Appendix. The curves show the sediment size and distribution are practically identical as required by model scale. 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 was approximately 2.65.

Removal of the sediment shoal. -- In order to locate the group of ejector bins effectively, several trial runs were made with $Q_T$ equal to 12,000 cfs and $C_T$ equal to about 400 ppm to determine the location of the shoal. The notation $Q_T$ denotes the total canal discharge and $C_T$, the concentration of bed material upstream of the ejector. Model discharge to simulate 12,000 cfs prototype flow was 11.5 cfs. The shoals were surveyed and contoured. Photographs of the shoal are shown in Figs. 14 and 15 with contours of the bed shown in Fig. 16. Based upon the contours, the ejector bins were then located to eject as much of the shoal as possible. Beginning from station 75.35 (station 2 + 825 prototype) the ejector bins extended 12 feet (420 feet prototype) downstream along the inside shore.

It was assumed initially that the shoal would be permitted to form, then be removed periodically through the bins provided. The quantity of sediment thus removed was calculated from contours of the bed after ejection, compared to the bed before ejection. The quantity of sediment removed was then determined by planimeter measurements of the contours and adding the bed material stored in the bins. In order to determine the percentage of bed material removed from the canal with $C_T$ = 400 ppm, the quantity of bed material removed from the canal through the ejector was compared to the quantity of bed material transported to the ejector during a given time interval. The time interval was selected as that necessary for all 28 hoppers to be filled. In the model, the time interval was 11.5 hours (approximately 184 hours prototype). From these tests it was determined that the ejector was approximately 15 percent effective in removing the bed material discharge when $C_T$ = 400 ppm. This means that 60 ppm would be removed and 340 ppm, on a time average, would flow down the canal which would exceed the computed bed-material concentration the regime channel could sustain. Ejector efficiency as used in this report is defined as the ratio of bed-material discharge, or quantity, through the ejector to the bed-material discharge in the canal upstream of the ejector, or quantity transported to the ejector, expressed in the same units and indicated in percent.

Continuous flow through the ejector. -- Although the efficiency was low for intermittent operation, the efficiency can be improved if water and sediment are discharged through the bins continuously. (This procedure is hereinafter termed continuous operation.) When water flows through an ejector bin at the bed of the canal, the flow lines in the vicinity of the opening change as can be proved by the theory of sinks in potential flow, and so alter the flow pattern over a considerable adjacent area of the bed. Two adjacent bins, Nos. 9 and 10 as shown by the bin numbering scheme in Fig. 11 were operated continuously. The ejection efficiency increased to about 36 percent. Conditions at the bed after ejection were as shown in the photograph of Fig. 17 and the bed contours appeared as shown in Fig. 19. During this test, there were no grates on the tops of the bins, hence, the turbulence induced above the bins caused the adjacent bins downstream to scour excessively. Therefore, grates were installed over the bins, to reduce the downstream scour. The effectiveness of the grates is demonstrated in Fig. 18. The ejector efficiency with the same bins at about the same ratio of water ejection was about 38 percent. Water ejection ratio is defined as the flow through the ejector bins divided by the total flow in the canal upstream of the ejectors expressed in percent. Test results are summarized in Table 6.

When the ejector system was initially conceived, it was assumed that bed vanes might aid in directing flow of bed load towards the ejector and also increase secondary circulation. Surface vanes were also contemplated as a means of increasing secondary circulation. Tests were made in the model to determine if improvement might result because of these vanes. Several different locations and angles of the bed vanes were tried, and all resulted in the significant decrease of efficiency by about 50 percent as compared to efficiency without bed vanes. In the model, the turbulence induced by the bed vanes more than offset the advantage of increasing the amount of secondary circulation and movement of bed material to the inside shore of the curve. In test run 15, two eight-foot long vanes were installed at the outside shore line of the canal. The vanes extended from the bank of the canal to about the center line at an angle of about 25 degrees. The photograph of Fig. 20 shows the vanes in the model. The height of the vanes above the bed was one-fourth the depth of flow or about 0.21 foot in the model. The resulting conditions after a test were as shown in Fig. 21. The scour downstream of the vanes along the bank was due to excessive turbulence over the vanes and form drag of the vanes. The vane angle was reduced to about 10 degrees and other locations and arrangements were tested as shown in the photographs of Figs. 22 to 25 inclusively. The results of these tests are summarized in Table 6.

Tests were made with bed vanes and surface vanes in combination and with a surface vane alone. No significant increase in ejector efficiency was detected due to the presence of the surface vane. Fig. 26 shows the resulting bed condition at the ejector using the combined vanes and Fig. 27 shows the surface vane as used in the model. The surface vane consisted of a two-inch V-formed sheet metal rail attached to the bottom of the floating board. Tests with vanes, both bed and surface, were terminated because they did not indicate positive effects.

Increase in efficiency of continuous operation over intermittent operation of the ejector bins directed the study toward determining a more efficient combination of ejector bins. Various combinations were attempted along the two rows of longitudinal bins. Bin combinations were staggered, grouped together at either end of the row, and spaced evenly on each row. The results of tests with various combinations of open bins in the longitudinal rows are tabulated in Table 6. Water ejection ratio was maintained at about 5 percent for the various combinations. The results were:

1. Bins grouped at the downstream ends of the rows were about 20 percent more effective than those grouped at the upstream ends. Compare runs 34 and 33 which showed ejector efficiencies of 50 and 28 percent respectively.

2. Four bins spaced evenly in a row were about 20 percent more effective than two adjacent bins with about the same water ejection ratio. Compare runs 31 and 32 which showed efficiencies of 58 and 38 percent respectively.

3. The bins spaced evenly along the shore line row were about 10 percent more effective than the corresponding bins in the adjacent row towards the center of the canal. Compare run 30, 50 percent; run 31, 58 percent; and run 35, 40 percent.

The results of these studies indicated that four hoppers open along the shore line row of bins spaced the distance of two bins apart (about 90 feet center to center in the prototype), namely 10, 16, 22, and 28 were most effective. Studies were then made to determine the effect of water ejection ratio on ejection efficiency. The results of this study are shown graphically in Fig. 28. Although there is considerable scatter about the curve, there is a trend of increasing efficiency with increasing water ejection ratio. Water ejection ratios greater than 10 percent were not studied because it was understood that more water could not be ejected from the prototype canal. The highest efficiency indicated was about 60 percent with 10 percent water ejection ratio. From these studies, it would appear that if the bed-material concentration in the canal upstream from the ejector was about 400 ppm, about half, or 200 ppm, would be transported past the ejector.

Lateral ejector bins. -- A study was made of a row of bins extending laterally across the canal. The size of bins were the same as those for the longitudinal rows, thus eight bins were required. For convenience six additional bins were installed adjacent to bins 1 and 2 as shown in the schematic diagram of Fig. 11. Photographs of these bins are shown in Figs. 29 and 30. There was no technical reason why the lateral bins had to be located in the bend of the canal. Although not tested in the outdoor model, this ejector system would operate equally well located elsewhere in the canal, provided there was adequate distance downstream of the headworks for stabilization of the flow.

The test results of the lateral bins are shown graphically in Fig. 31. The ejector efficiency was increased to about 70 percent with water ejection ratio near 10 percent. Little difference of efficiencies was noted between the longitudinal and the lateral rows when the water ejection ratio was 5 percent. The reason is that at larger water ejection ratios the downstream velocity components created in the flow above the bins are greater by virtue of the greater sink effect of the discharge through the bins. The greater downward velocity component draws some of the suspended load through the ejector system.

Increased sediment concentration. -- The bed-material concentration in the model canal was increased to 850 ppm with simulated canal discharge maintained at 12,000 cfs by increasing the slope. The longitudinal bins along the shore, Nos. 10, 16, 22, and 28 were tested to determine efficiency under this condition. The results are shown in Fig. 32 and tabulated in Table 6. Because of the changed hydraulic conditions, the model scales readjusted slightly as shown in Table 5.

Only continuous operation of the ejector bins 10, 16, 22 and 28 along the longitudinal row was studied. The efficiencies were significantly lower for the higher bed material concentration due principally to:

1. Greater velocities in the model canal.

2. A larger percent of the bed material discharge was suspended.

Further studies of the lateral ejector system were conducted in the indoor model.

TABLE 5

Readjusted Model Scales

| Item | Nomenclature | Scale | |
|---|---|---|---|
| | | Calculated | Readjusted |
| Length | $L_r$ | 35 | 35 |
| Depth | $h_r$ | 10 | 13.6 |
| Slope | $S_r$ | .286 | .208 |
| Discharge | $Q_r$ | 1104 | 1043 |
| Velocity | $V_r$ | 3.16 | 2.09 |
| Sediment Density | $(\rho_s - \rho_f)_r$ | 1 | 1 |
| Sediment Size | $d_r$ | 1 | 1 |

Indoor model results. -- Photographs of the ejector bins as installed in the indoor flume are shown in Figs. 33 and 34. Studies were made of ejector efficiencies with bed-material concentrations of 1200 ppm, 550 ppm and 170 ppm with $Q_T$ of 12,000 cfs prototype (a model discharge of 12 cfs). An average canal flow of $Q_T$ = 8000 cfs (prototype) and $C_T$ = 300 ppm were also studied. The results of these studies are shown graphically in Figs. 35 to 38 inclusively. The curve on these graphs are intended to be trend lines only and the experimental data are shown as dotted circles. The indicated ejector efficiencies were between 60 and 80 percent at a water ejection ratio of 10 percent. Although the data are not extensive it can be seen that the trend of increasing ejector efficiency with increasing water ejection ratio is established. Some additional photographs of the indoor facility during an ejection study are shown in Figs. 39 and 40. The photograph of Fig. 41 shows pictorially the difference in bed form upstream and downstream from the ejector. In the background of the photograph, upstream from the ejector, there existed dunes with some ripples superposed, while only ripples prevailed downstream from the ejector. The ripples are significant of reduced bed-material concentration.

A composite graph, including data from both indoor and outdoor models, showing the efficiencies of the lateral row of ejectors is compiled in Fig. 42. This composite graph indicates a majority of data is included within a range of ± 10 percent about an average curve through the points and only few points are outside this range. This range in scatter of data can be expected in a study of this nature involving alluvial channels.

TABLE 6.

Model Results
(For location of hoppers and hopper numbers refer to Fig. 11)

| Run No. | Condition of Tests | $Q_T$ Prototype cfs | $C_T$ Prototype ppm | Bin Numbers used to eject Sediment | Ejection Effic. % | Water Ejection Ratio % | Remarks |
|---|---|---|---|---|---|---|---|
| | OUTDOOR MODEL | | | | | | |
| 5 | Intermittent operation | 12,000 | 400 | All 28 bins | 15 | --- | Bins were emptied after the last bin, No. 28 was filled. |
| 13 | Continuous operation | " | " | 9,10 | 36 | 6.2 | No grates over hoppers. |
| 32 | " | " | " | 9,10 | 38 | 5.3 | With grates. |
| 15 | " | " | " | 9,10 | 16 | 5.9 | Bed vanes at beginning of curve. |
| 21 | " | " | " | 9,10 | 13 | 6.0 | Bed vanes at beginning of bins. |
| 24 | " | " | " | 1,16,28 | 17 | 4.8 | Bed vanes at beginning of bins. |
| 27 | " | " | " | 1,2,3 | 12 | 3.7 | Bed vanes at beginning of bins. Surface vanes at point of curve. |
| 31 | " | " | " | 10,16,22,28 | 58 | 5.1 | Surface vanes only at beginning of curve. |
| 49 | " | " | " | 10,16,22,28 | 51 | 5.0 | Repeat of above. |
| 30 | " | " | " | 10,16,22,28 | 50 | 5.3 | No vanes. |
| 33 | " | " | " | 2,4,6,8 | 28 | 5.1 | " " |
| 34 | " | " | " | 22,24,26,28 | 50 | 5.4 | " " |
| 35 | " | " | " | 9,15,21,27 | 40 | 5.4 | " " |
| 36 | " | " | " | 3,9,15,21,27 | 50 | 6.7 | " " |

TABLE 6 - Continued:

| Run No. | Condition of Tests | $Q_T$ Prototype cfs | $C_T$ Prototype ppm | Bin Numbers used to eject Sediment | Ejection Effic. % | Water Ejection Ratio % | Remarks |
|---|---|---|---|---|---|---|---|
| 37 | Continuous operation | 12,000 | 400 | 3,9,15,21,27 | 46 | 7.3 | Repeat of above. |
| 47 | " | " | " | 1,2,29-34 | 65 | 7.8 | Lateral bins were tested in the model. |
| 48 | " | " | " | 1, 2, 29-34 | 30 | 5.1 | Lateral bins. |
| 49 | " | " | " | 1, 2, 29-34 | 51 | 5.0 | " " |
| 50 | " | " | " | 1,2,29-34 | 34 | 3.6 | " " |
| 51 | " | " | " | 1,2,29-34 | 76 | 10.2 | " " |
| 52 | " | " | " | 10,16,22,28 | 30 | 3.0 | Longitudinal bins. |
| 53 | " | " | " | 10,16,22,28 | 55 | 10.1 | " " |
| 54 | " | " | " | 10,16,22,28 | 64 | 10.0 | " " |
| 56 | " | " | 850 | 1,2,29-34 | 75 | 7.6 | Lateral bins. |
| 57 | " | " | " | 10,16,22,28 | 33 | 10.0 | Longitudinal bins. |
| 58 | " | " | " | 10,16,22,28 | 35 | 7.5 | " " |
| 60 | " | " | " | 10,16,22,28 | 29 | 2.8 | " " |
| 61 | " | " | " | 10,16,22,28 | 29 | 5.1 | " " |
| | INDOOR MODEL | | | | | | |
| 201 | " | " | 740 | Lateral bins | 63 | 7.8 | |
| 202 | " | " | 1200 | " " | 52 | 3.7 | |
| 203 | " | " | " | " " | 30 | 4.7 | |
| 204 | " | " | " | Total bins | 55 | 6.6 | |
| 205 | " | " | " | " " | 53 | 3.1 | |
| 207 | " | " | " | " " | 31 | 5.1 | |
| 208 | " | " | " | " " | 74 | 7.3 | |

TABLE 6 - Continued

| Run No. | Condition of Tests | $Q_T$ Proto-type cfs | $C_T$ Proto-type ppm | Bin Numbers used to eject Sediment | Ejec-tion Effic. % | Water Ejection Ratio % | Remarks |
|---|---|---|---|---|---|---|---|
| 209 | Con-tinuous operation | 12,000 | 550 | Total bins | 61 | 8.4 | |
| 210 | " | " | " | " " | 56 | 3.9 | |
| 213 | " | " | 170 | " " | 55 | 8.3 | |
| 214 | " | " | " | " " | 47 | 7.8 | |
| 215 | " | " | " | " " | 25 | 3.4 | |
| 216 | " | " | " | " " | 51 | 5.3 | |
| 218 | " | " | 550 | " " | 73 | 8.7 | |
| 219 | " | " | " | " " | 49 | 7.5 | |
| 220 | " | " | " | " " | 37 | 5.4 | |
| 221 | " | " | " | " " | 37 | 3.2 | |

# INTERPRETATION OF MODEL RESULTS TO PROTOTYPE

## Discussion of Model Conditions

Distortion of the vertical scale in the model has resulted in a model width-depth ratio of 10 as compared to 20 for the prototype. As a result of this distortion, it is expected that the distribution of boundary shear stresses around the bend is greater for the model than for the prototype. Hence, movement of bed load towards the inside of the curve will be greater in model than for the prototype and, consequently, ejector efficiencies in the model will be greater than for the prototype. There is insufficient data available, either from this study or earlier studies by other researchers to predict quantitatively the magnitude of the difference. A more thorough knowledge of scale effects and shear stress distribution in curves of various sizes of channels, and effect of depth would be required.

The form of bed roughness in the model was established similar to that expected in the prototype in order to produce comparable bed-material concentrations. Although it was initially intended to relate the bed load discharges, the bed-material concentration was a more useful value. With equal bed-material concentrations, suspended bed-material and bed load concentrations in model and prototype can be expected to differ slightly because the velocity gradient differs with depth, and the intensities of turbulence differs at corresponding levels in the flow depth. In model flumes, (both indoor and outdoor models had about the same hydraulic conditions) the suspended bed-material concentrations were about 40 to 60 percent of the bed-material concentrations between 100 to 1200 ppm respectively. Although data were not taken in this study, studies by other researchers using the same material in an eight-foot wide flume with similar discharges and flow depths reported these results[22]. Considering that between 40 and 60 percent of the bed-material concentrations is in suspension in the model, the efficiency curves show that the sediment ejector intercepts all of the bed load, and a significant percentage of the suspended load near the bed when water ejection ratios are greater than about five percent. This will be accentuated in the prototype because the 30-foot length of each bin provides greater length for interception of suspended bed material very near the bed where concentration is greatest. Therefore, prototype results of ejector efficiencies could be greater than indicated by the model.

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[22] Simons, D. B. and Richardson, E. V., "Studies of Flow in Alluvial Channels - Basic Data from Flume Experiments," USGS, Colorado State University, May 1961. Report No. CER61EVR31.

Application of Results. -- The efficiency of the sediment ejector for the longitudinal row of bins along the inside shore of the curve, obtained from the model should be reduced when applied to the prototype because the effect of secondary circulation with change in the width-depth ratio of the flow in the canal is relatively unknown and was not studied in this model. Certainly the results should apply to one-half the prototype canal width, or where the width-depth ratio is equal to this model, and can reasonably be expected to apply to more than one-half of the total width, to about the three-quarter point. With this crude assumption, the efficiency curves for the longitudinal bins for the prototype would likely be as shown in Fig. 43. Basically this is a one-fourth reduction of the efficiency indicated by the model.

The efficiencies for the lateral row of ejector bins for the model can be used for the prototype. For the reasons stated in the previous section, prototype efficiencies are probably greater than that indicated by the model. However, it would be unwise to assume increased efficiencies for the prototype.

## Qualitative Analysis of Flow at the Ejector Bins

The flow at a bin of the ejector investigated in this model study is illustrated schematically in Fig. 44. The elevation of the top of the bin may be placed at any practical depth at or below the downstream bed level. There should be no acceleration of flow above the bin and in fact some deceleration is preferable. There is no opportunity to increase the turbulence above the tops of the grates, if the grates are installed with the longitudinal bars parallel to the flow. Thus, there is no opportunity to entrain more bed material in suspension from the bed. All the bed load will be intercepted so long as the discharge through the pipe line at the bottom of the bin is sufficiently large to eject all the material falling into the bin. In the deceleration zone above the bin, downward velocity components are created because of the flow through the ejector. The greater the ejector flow the greater will be the downward component of the flow and the greater will be the probability of ejecting some of the suspended bed material in the flow close to the channel bed. The decelerated flow above the bin also provides opportunity for some settlement of the suspended bed material, particularly the coarser particles, and some quantity will be intercepted depending upon the length of the ejector bin. Because the bed load is removed at the ejector, there is no opportunity for turbulent exchange of sediment between suspension and bed load above the bins, and some of the suspended particles will be settled in the ejector bin.

Because probably all of the bed load can be intercepted in the bin-type ejector system, the canal slope will be flatter downstream and some of the suspended bed-material passing will tend to settle out on the bed, in accordance with the changed flow condition. Since the median size of the suspended bed material will be slightly less than the median size of the bed load upstream of the ejector, the resulting median diameter of the bed load downstream of the ejector will tend to be slightly less than 0.23 mm, assumed for the prototype. Although in the model little if any reduction of median size was noted downstream of the ejector because of the shallow depths of flow and small bin length, the reduction of median diameter that must occur in the prototype will mean reduction of effective diameter, Lacey's silt factor and regime slope. The magnitude of the anticipated reduction in median diameter cannot be determined quantitatively except by field tests.

# CONCLUSIONS

The model studies have shown that a curve in the canal with the radius and length as originally designed[23], (see Fig. 4) will create a shoal or sand bar deposit along the inside shore of the curve. Although a smaller radius of curvature and longer length of curve would help to create a stronger secondary flow and thus tend to move more of the bed load to the inside of the curve, topographic limitations of the particular site prevent significant change in the selected canal alignment.

Two longitudinal rows of ejector bins along the inside shore of the curve have been proven capable of removing the sand shoal once formed, but the efficiency of sediment ejection by this method was only 15 percent. The model study indicated that if four ejector bins, spaced 90 feet apart center to center along the inside shore of the curve, were permitted to flow continuously with a relatively small water ejection ratio ejection efficiency of the bed material could be significantly increased to about 45 percent. The most effective arrangement of ejector bins for continuous ejection was found to be eight bins placed in a lateral row across the bed of the canal. The efficiency of this arrangement was 70 percent with a water ejection ratio of 10 percent. The efficiency curve for the lateral bins is shown in Fig. 42. The efficiency increases with increasing water ejection ratio. Grates over the bins were found to be necessary to prevent scour above and immediately downstream of the bins. The grate bars must be placed parallel to the flow for greatest effect.

The longitudinal arrangement of the bins along the inside shore with 45 percent ejector efficiency would operate satisfactorily if the bed-material concentration does not exceed 200 ppm. The lateral row of bins would be satisfactory for bed-material concentrations in the canal to 400 ppm. If the longitudinal bins were operated intermittently in conjunction with the lateral bins, slightly larger bed-material concentrations in the canal could be ejected. A small quantity of bed material by-passing the ejector in excess of the transport capability of the canal could be balanced seasonally with periods of moderately large and small bed-material concentrations.

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[23] Reference is made here to the canal design as originally shown in Vol. II of the "Contract Documents for Construction of Trimmu-Sidhnai Link Canal and Haveli Relocation." Tipton and Kalmbach, Inc., Denver, Colorado, June 1961.

## RECOMMENDATIONS

The type of sediment ejector studied was basically a bed load ejector. This applies to the longitudinal row of bins as well as to the lateral ejection bins. It is recommended that an ejector system consisting of eight lateral bins, and ten longitudinal bins be considered for the prototype Trimmu-Sidhnai link canal as shown in Fig. 45.

The principal ejection system consists of the lateral row of eight bins which should be operated with continuous ejection with the water ejection ratio regulated as necessary to remove the desired amount of the bed material. To intercept as much bed load as possible during periods when it becomes necessary to close the lateral ejectors, it is recommended that the curve as originally designed be retained in the final canal alignment so that the bed load by-passing the lateral ejectors will shoal along the inside shore of the curve. The longitudinal row of bins as a result are recommended for removal of the shoal. The model study indicated need for only four bins spaced 90 feet apart along the shore for continuous operation and these four bins would satisfactorily eject the shoal provided sufficient time and ejection water is available. The ten bins recommended permit more rapid removal of the shoal. The lateral row of ejector bins may be located at any position upstream of the longitudinal row of bins to a section about 1500 feet downstream of the headworks.

A satisfactory alternate ejector system arrangement, although not tested in the model, may be to construct two rows of lateral bins spaced approximately 1000 feet apart as shown in Fig. 46. This system is predicated on the assumption that more than 10 percent of the canal flow is available for waste through the ejectors. From the model study results of only the single lateral row, the indicated efficiency of one row could be greater than the combined efficiencies of two lateral rows in tandem if less than 10 percent of the total discharge in the canal is available for waste and the total ejector flows are equal through the two systems. The number of bins along the shore for this system may be reduced to four as quick removal of the shoal is not essential in this system since adequate waste water is assumed to be available. There will be some loss of storage capacity with the reduction in the number of bins in the longitudinal row. Desirability of this alternate ejector scheme would depend upon the bed-material concentration in the canal and available waste water.

The level of the tops of the bins should be placed approximately 1 to 1.5 feet lower than the average bed level downstream of the ejector.

If the lateral ejector bins are placed at the canal bend, consideration should be given to the difference in bed level at the outside of the bend in placing the bins. The difference may be as much as two to three feet. The size of the ejector bins as originally designed is considered adequate, although minor alterations may be made to suit the final design.

The pipeline leading from the individual hoppers may be reduced in size from that shown in the original (preliminary) plans. The reduction in size may be calculated using the discharge computed from the selected water ejection ratio and canal discharge. The concentration of sediment in the outflow pipe will not be a factor in calculating the head losses.

Consideration should also be given to installation of a small pipe line around the valve which regulates the flow through the bins to permit some flow through both ejector pipeline and outfall pipe line to keep both lines from becoming clogged.

Colorado State University engineers are cognizant of the sediment problem at the outfall of the ejector system in the river, and to a very large extent the success of the recommended ejector system depends upon successful removal of the delta by the river. However, this problem is considered to be outside the province of this model study.

## ACKNOWLEDGEMENTS

The model study was conducted with considerable guidance from and consultation with Dr. D. B. Simons of the U. S. Geological Survey at Fort Collins, Colorado. Valuable assistance was also obtained from Dr. A. R. Chamberlain and E. V. Richardson. Graduate students, E. A. Cecil, R. M. Haynie and Dr. N. Yotsukura assisted throughout the model study program with design of the model and data-taking. The shop staff constructed the model and offered many helpful suggestions throughout the study.

Special acknowledgements are due Mr. B. F. Kelly and F. R. Redfern and their staff of engineers of Tipton and Kalmbach, Inc., for their assistance and many helpful suggestions in the performance of this study and in preparation of this report.

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# FIGURES

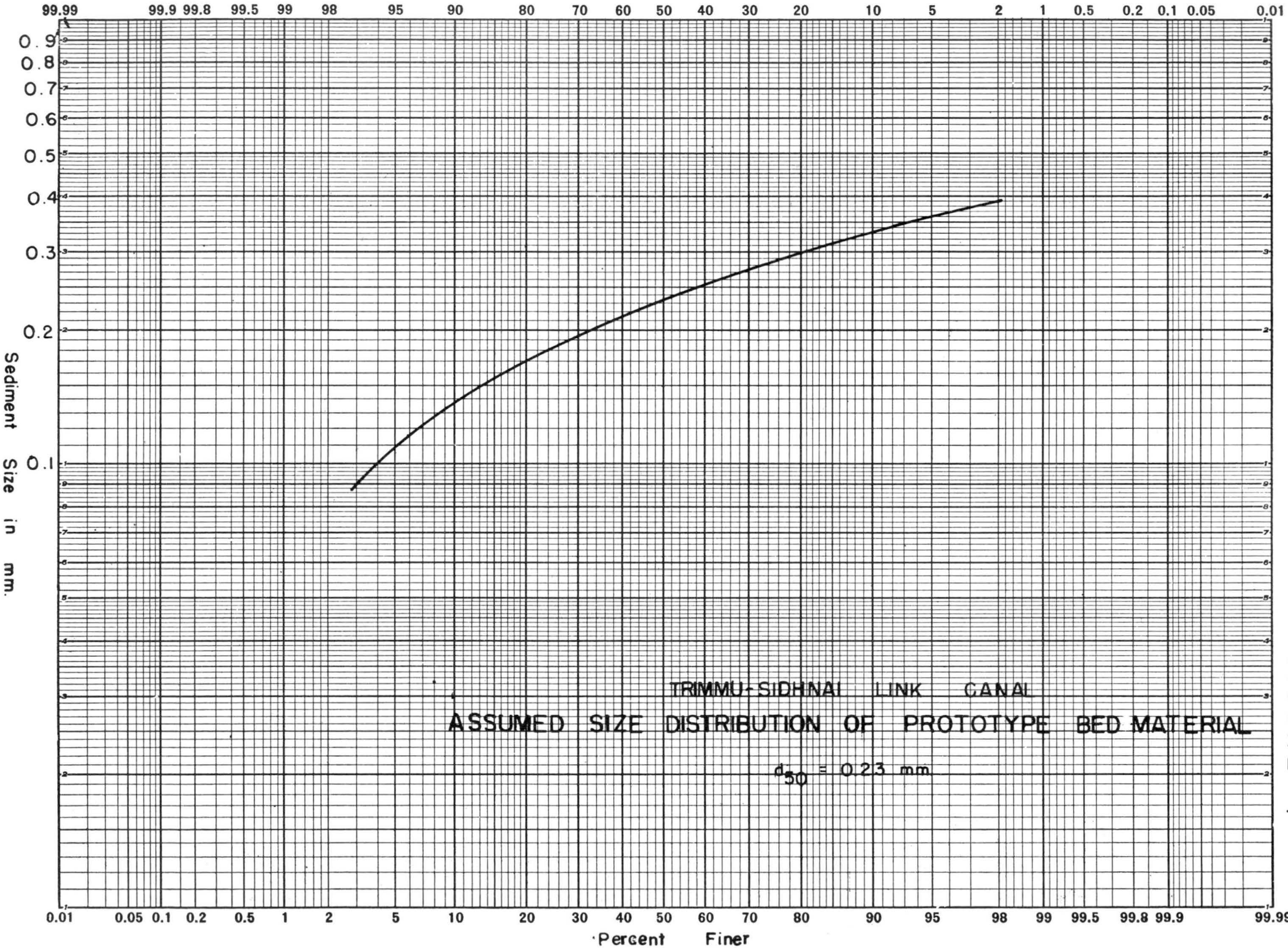
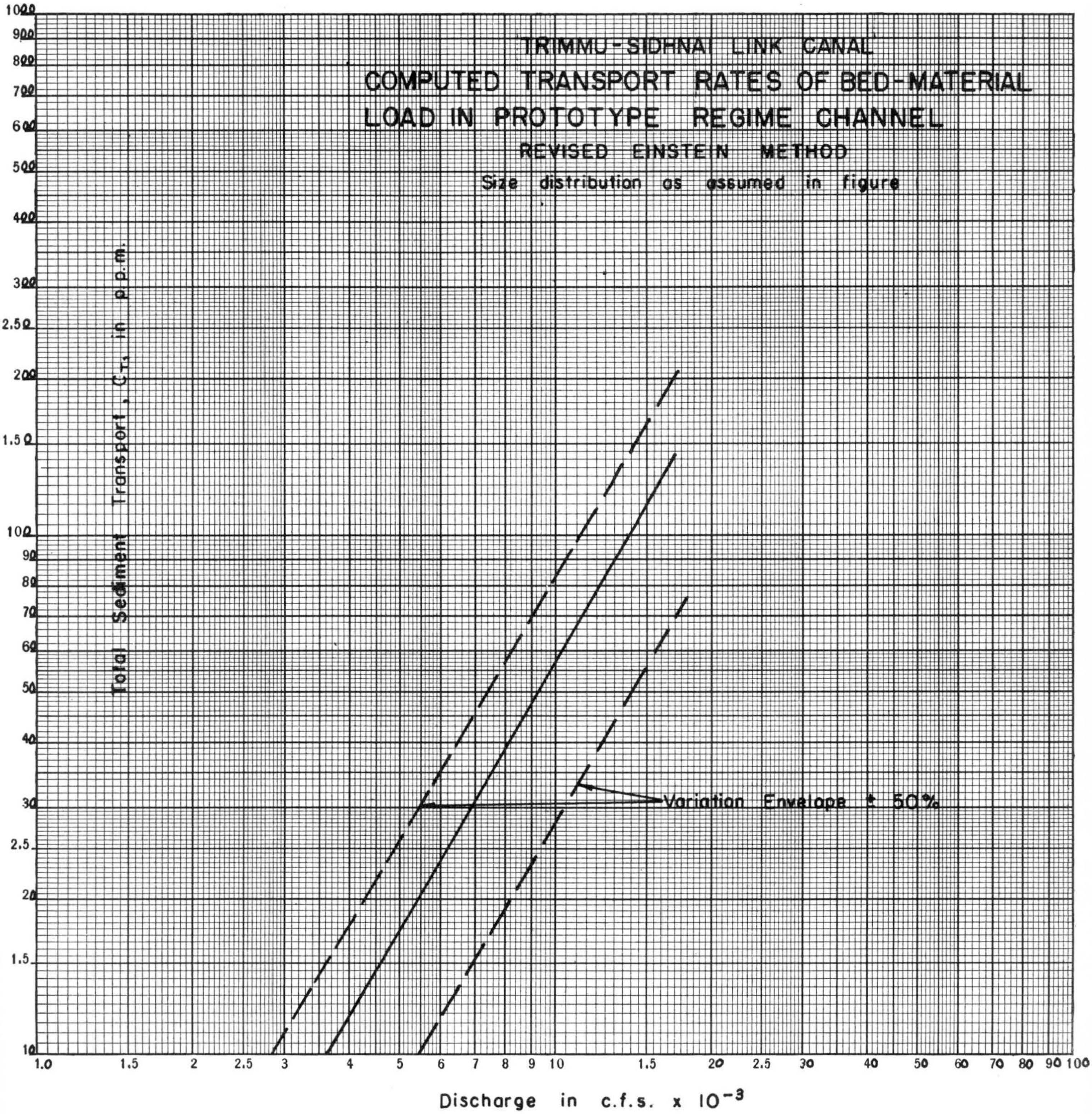

TRIMMU-SIDHNAI LINK CANAL
ASSUMED SIZE DISTRIBUTION OF PROTOTYPE BED MATERIAL
$d_{50}$ = 0.23 mm
Sediment Size in mm.
Percent Finer
99.99 99.9 99.8 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.05 0.01
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.5 99.8 99.9 99.99
0.9 0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1

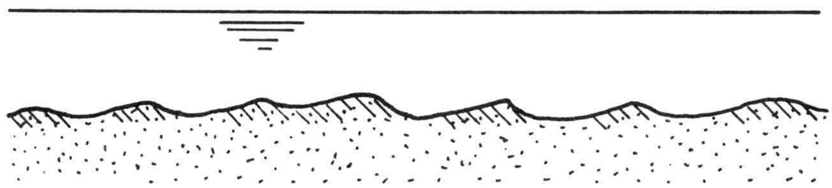
FIGURE 1

FIGURE 2

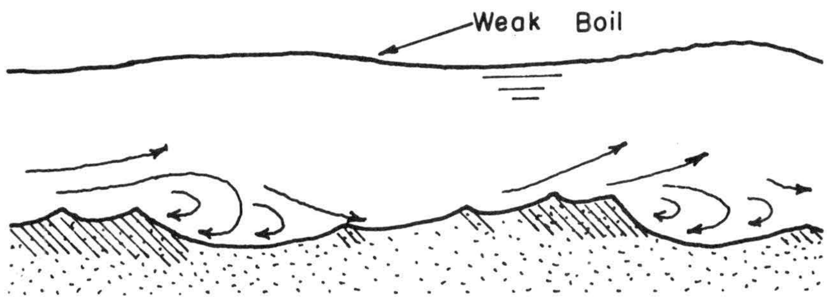

TRIMMU-SIDHNAI LINK CANAL
COMPUTED TRANSPORT RATES OF BED-MATERIAL
LOAD IN PROTOTYPE REGIME CHANNEL
REVISED EINSTEIN METHOD
Size distribution as assumed in figure
Variation Envelope ± 50%
Total Sediment Transport, $C_T$, in p.p.m.
1000
900
800
700
600
500
400
300
250
200
150
100
90
80
70
60
50
40
30
25
20
15
10
1.0
1.5
2
2.5
3
4
5
6
7
8
9
10
15
20
25
30
40
50
60
70
80
90
100
Discharge in c.f.s. x $10^{-3}$

TRIMMU-SIDHNAI LINK CANAL

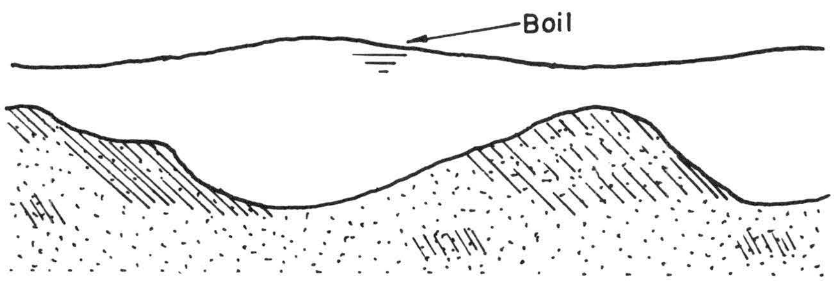
## BOUNDARY FORMS IN THE LOWER FLOW REGIME AND TRANSITION TO UPPER FLOW REGIME d = 0.23 mm.



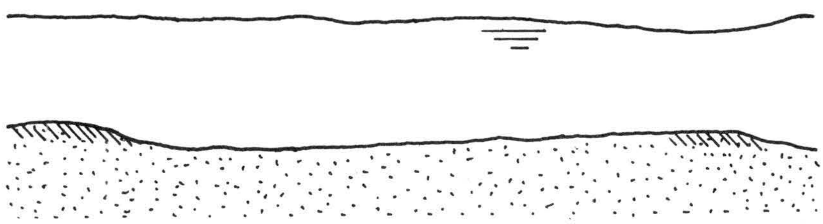
(a.) Ripples. Small amount of sediment movement.




(b.) Dunes with ripples superposed.

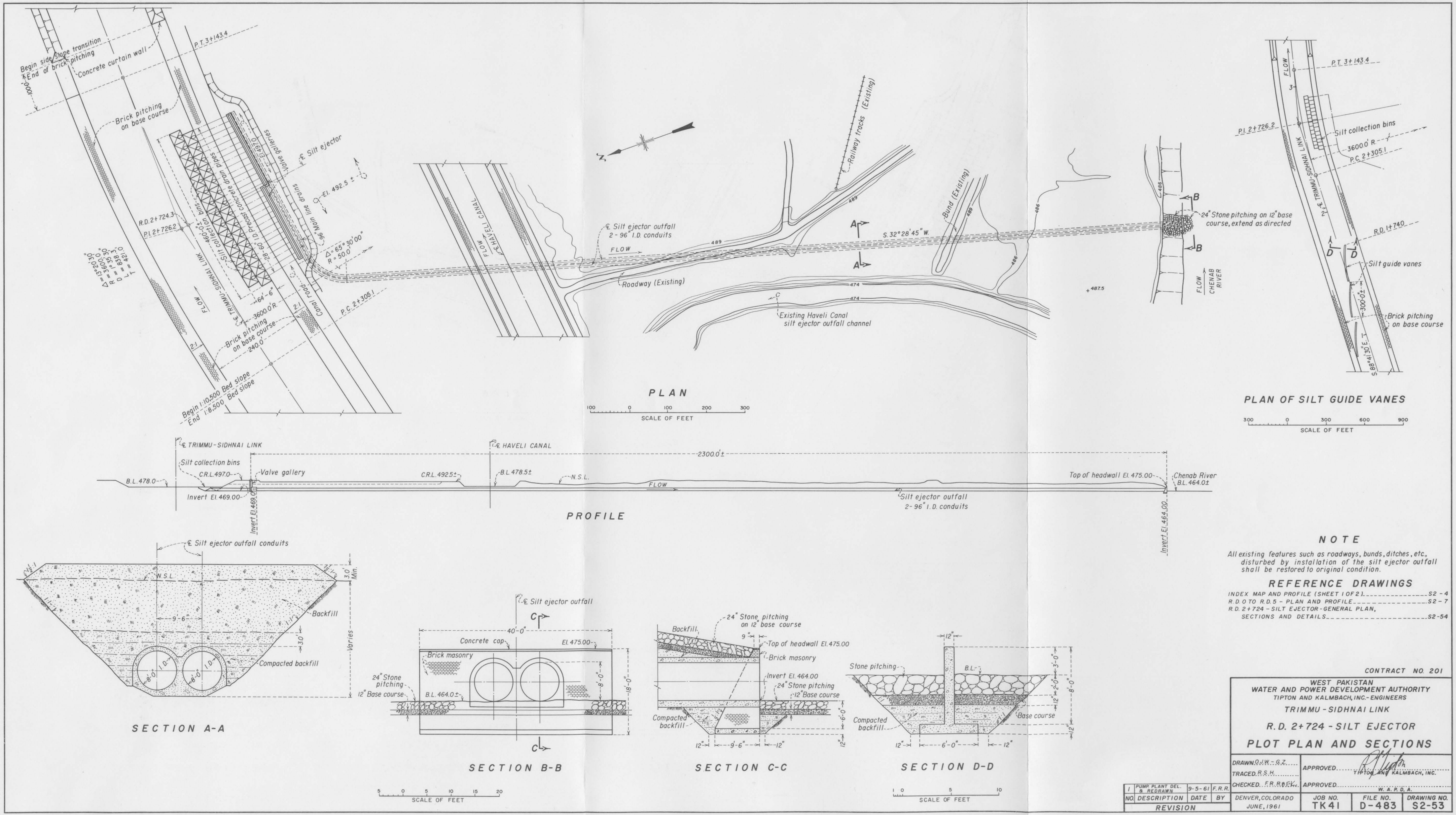



(c.) Dunes.

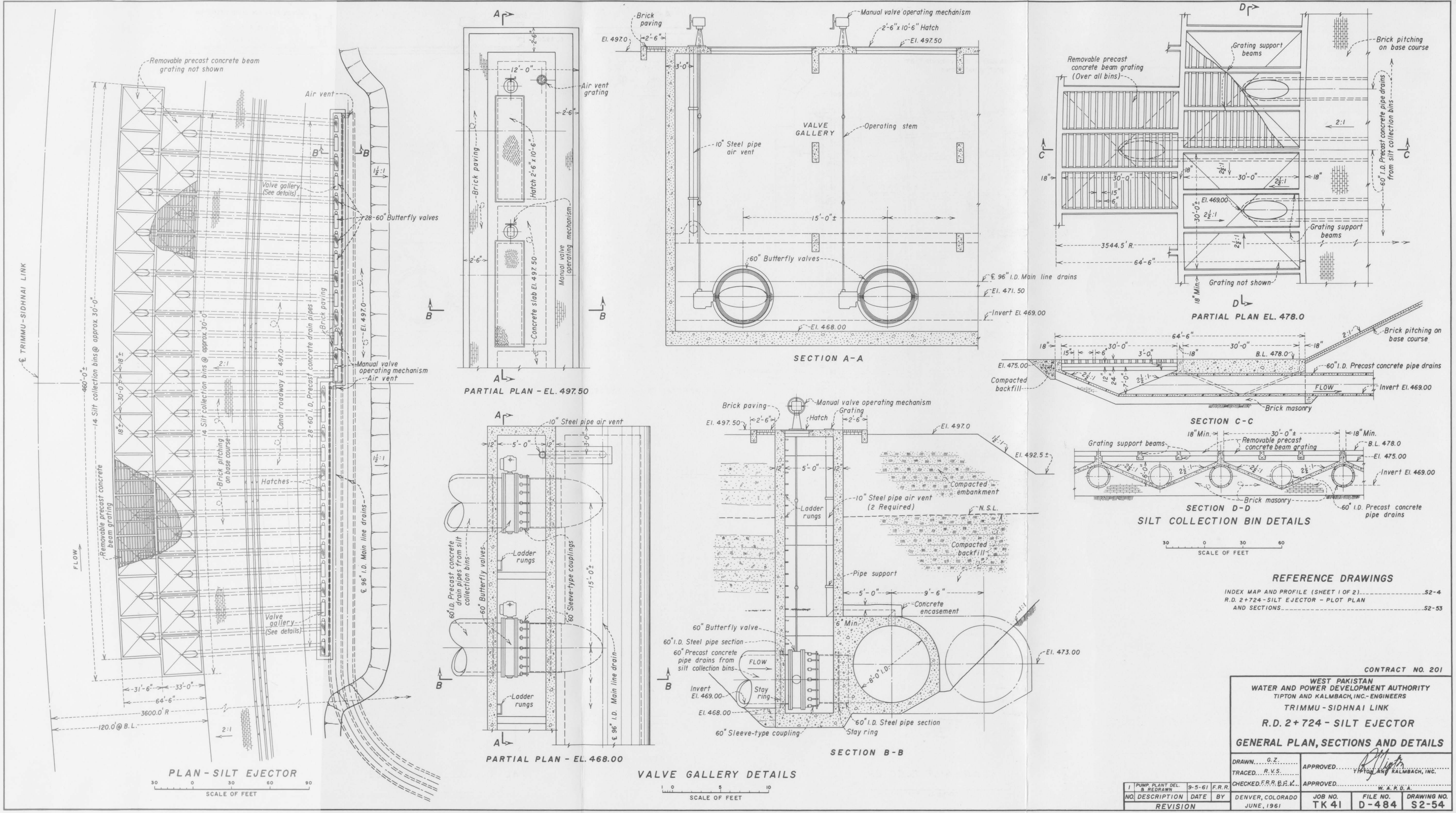


(d.) Transition washed-out dunes.

FIGURE 4



PLAN
SCALE OF FEET
Begin side slope transition
End of brick pitching
Concrete curtain wall
Brick pitching on base course
P.T. 3+143.4
R.D. 2+724.3
P.I. 2+726.2
P.C. 2+305.1
Silt collection bins
28-60" I.D. Precast concrete drain pipes
Valve galleries
℄ Silt ejector
El. 492.5 ±
96" Main line drains
Δ = 65°30'00"
R = 50.0'
℄ TRIMMU-SIDHNAI LINK
Canal road
3600.0' R.
240.0'
Begin 1:10,500 Bed slope
End 1:8,500 Bed slope
FLOW
℄ HAVELI CANAL
℄ Silt ejector outfall 2-96" I.D. conduits
Roadway (Existing)
Railway tracks (Existing)
Bund (Existing)
S. 32°28'45" W.
Existing Haveli Canal silt ejector outfall channel
24" Stone pitching on 12" base course, extend as directed
CHENAB RIVER
PLAN OF SILT GUIDE VANES
Silt guide vanes
R.D. 1+740
S 88°41'30" E.
PROFILE
℄ TRIMMU-SIDHNAI LINK
℄ HAVELI CANAL
Silt collection bins
C.R.L. 497.0
Valve gallery
C.R.L. 492.5±
B.L. 478.5±
N.S.L.
B.L. 478.0
Invert El. 469.00
Invert El. 469.0
2300.0'±
Top of headwall El. 475.00
Chenab River B.L. 464.0±
Silt ejector outfall 2-96" I.D. conduits
Invert El. 464.00
SECTION A-A
℄ Silt ejector outfall conduits
N.S.L.
3.0' Min.
Varies
Backfill
Compacted backfill
9'-6"
8'-0" I.D.
SECTION B-B
℄ Silt ejector outfall
40'-0"
Concrete cap
El. 475.00
Brick masonry
24" Stone pitching
12" Base course
B.L. 464.0±
18'-0"
SECTION C-C
Backfill
24" Stone pitching on 12" base course
Top of headwall El. 475.00
Brick masonry
Invert El. 464.00
24" Stone pitching
12" Base course
Compacted backfill
9'-6"
SECTION D-D
Stone pitching
B.L.
Base course
Compacted backfill
6'-0"
SCALE OF FEET
NOTE
All existing features such as roadways, bunds, ditches, etc., disturbed by installation of the silt ejector outfall shall be restored to original condition.
REFERENCE DRAWINGS
INDEX MAP AND PROFILE (SHEET 1 OF 2) ........ S2-4
R.D. 0 TO R.D. 5 - PLAN AND PROFILE ........ S2-7
R.D. 2+724 - SILT EJECTOR - GENERAL PLAN, SECTIONS AND DETAILS ........ S2-54
CONTRACT NO. 201
WEST PAKISTAN
WATER AND POWER DEVELOPMENT AUTHORITY
TIPTON AND KALMBACH, INC. - ENGINEERS
TRIMMU-SIDHNAI LINK
R.D. 2+724 - SILT EJECTOR
PLOT PLAN AND SECTIONS
DRAWN O.J.W. - G.Z.
TRACED R.S.H.
CHECKED F.R.R.
APPROVED TIPTON AND KALMBACH, INC.
APPROVED W.A.P.D.A.
1 PUMP PLANT DEL. & REDRAWN 9-5-61 F.R.R.
NO. DESCRIPTION DATE BY
REVISION
DENVER, COLORADO JUNE, 1961
JOB NO. TK41
FILE NO. D-483
DRAWING NO. S2-53




## REFERENCE DRAWINGS

INDEX MAP AND PROFILE (SHEET 1 OF 2) ........ S2-4
R.D. 2+724 - SILT EJECTOR - PLOT PLAN AND SECTIONS ........ S2-53

CONTRACT NO. 201

WEST PAKISTAN
WATER AND POWER DEVELOPMENT AUTHORITY
TIPTON AND KALMBACH, INC. - ENGINEERS
TRIMMU-SIDHNAI LINK

R.D. 2+724 - SILT EJECTOR

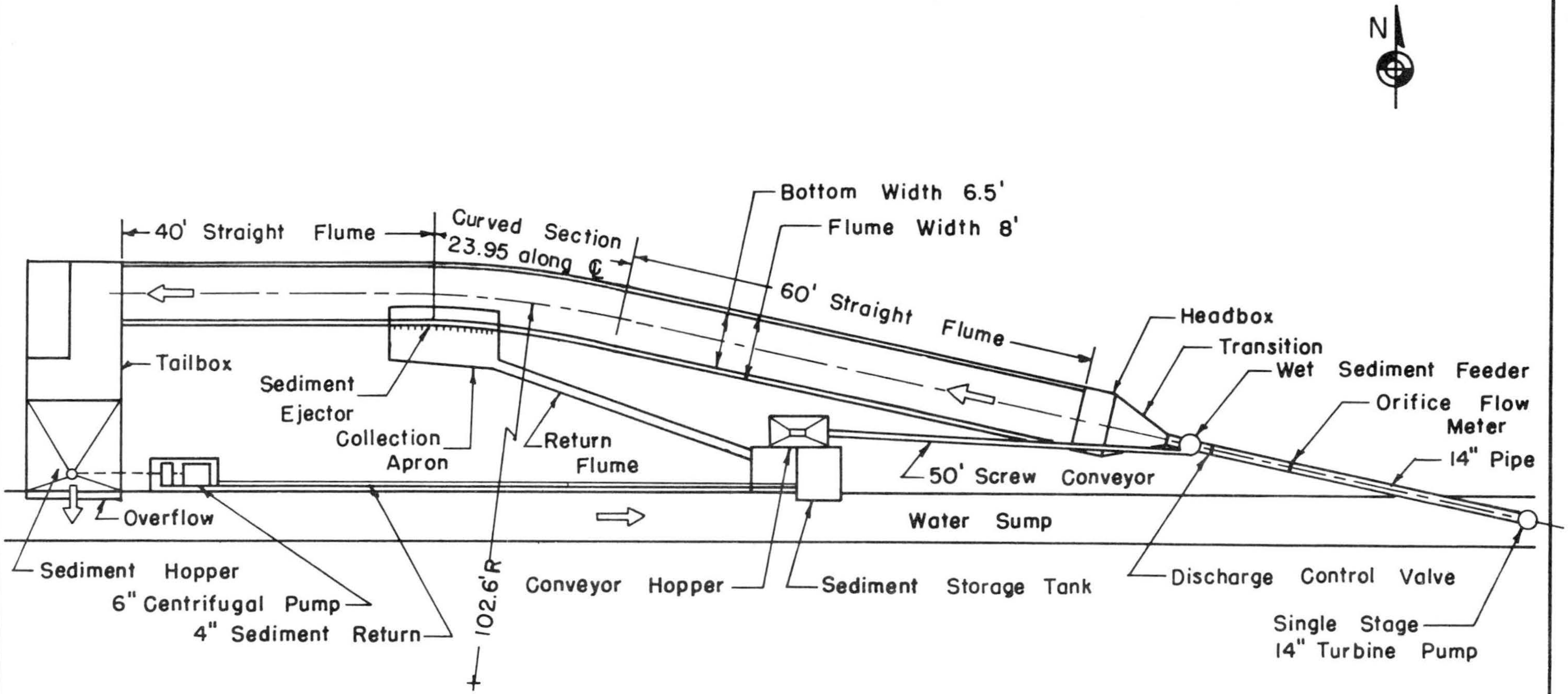
GENERAL PLAN, SECTIONS AND DETAILS

| NO. | DESCRIPTION | DATE | BY |
|---|---|---|---|
| 1 | PUMP. PLANT DEL. & REDRAWN | 9-5-61 | F.R.R. |

REVISION

DRAWN G.Z. — TRACED R.V.S. — CHECKED F.R.R. — APPROVED TIPTON AND KALMBACH, INC. — APPROVED W.A.P.D.A.

DENVER, COLORADO JUNE, 1961 | JOB NO. TK 41 | FILE NO. D-484 | DRAWING NO. S2-54




Note: Canal curve in model is mirror image of the prototype. Model was arranged in this manner because of convenience to the existing facilities.

TRIMMU-SIDHNAI SEDIMENT EJECTOR

SCHEMATIC DRAWING OF OUTDOOR MODEL

FIGURE 6

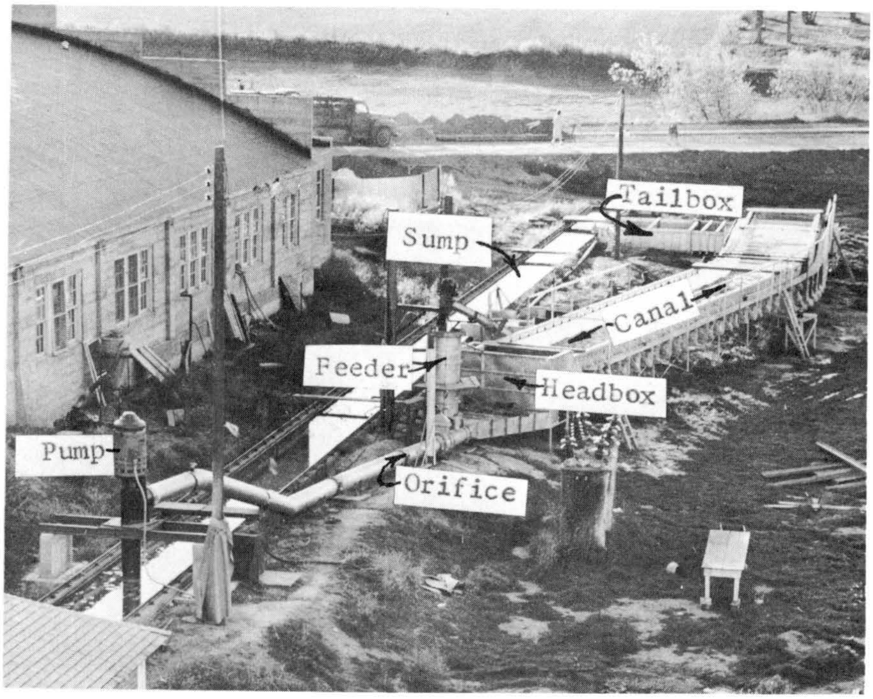



Fig. 7. General photograph of the model.

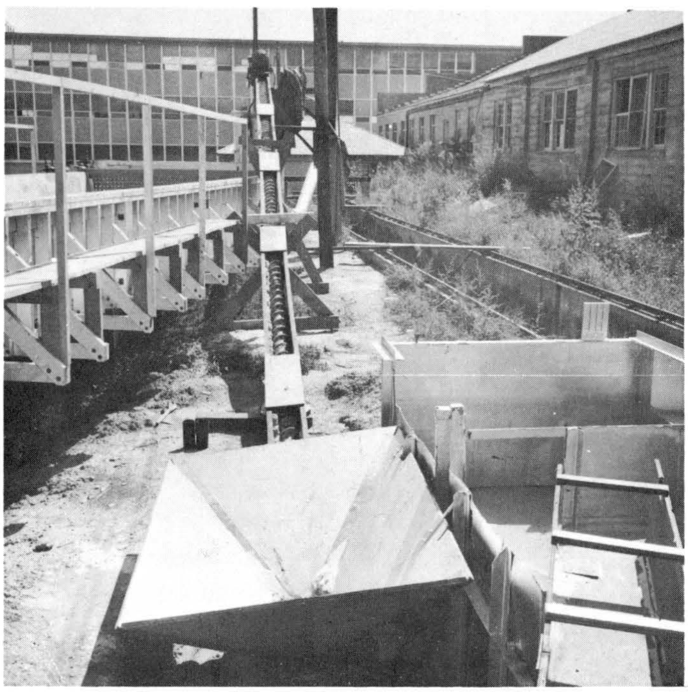


Fig. 8. Screw conveyer.
From sediment storage tank to feeder.

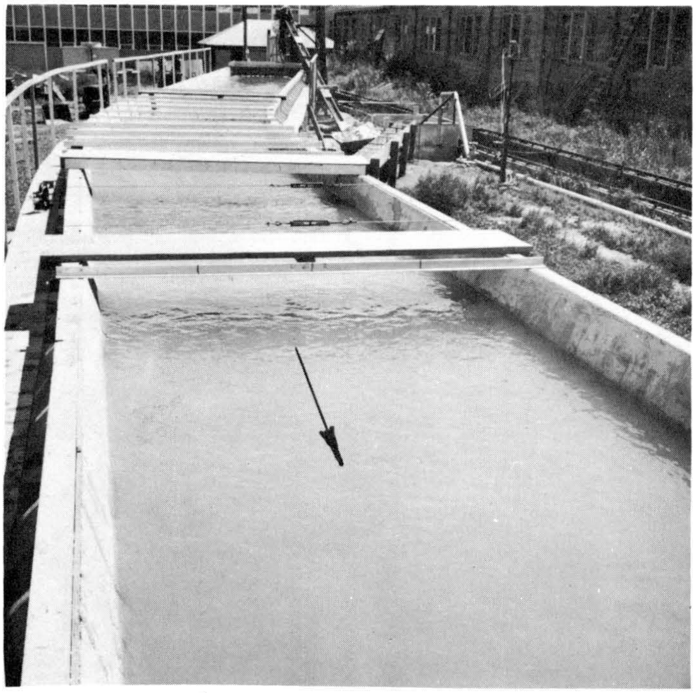
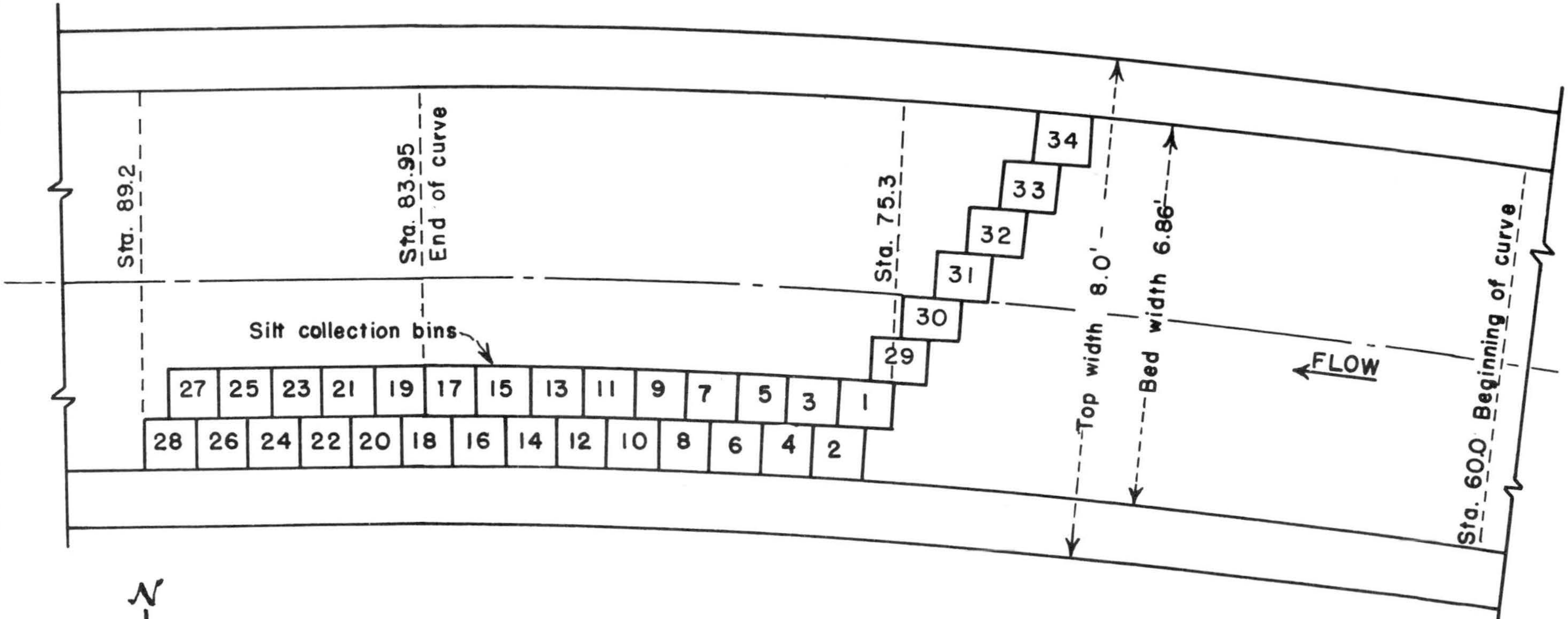


Fig. 9. Upstream view of the model and canal bend.

Fig. 10. Tail box.
Made purposely large to settle
bed material.





PLAN

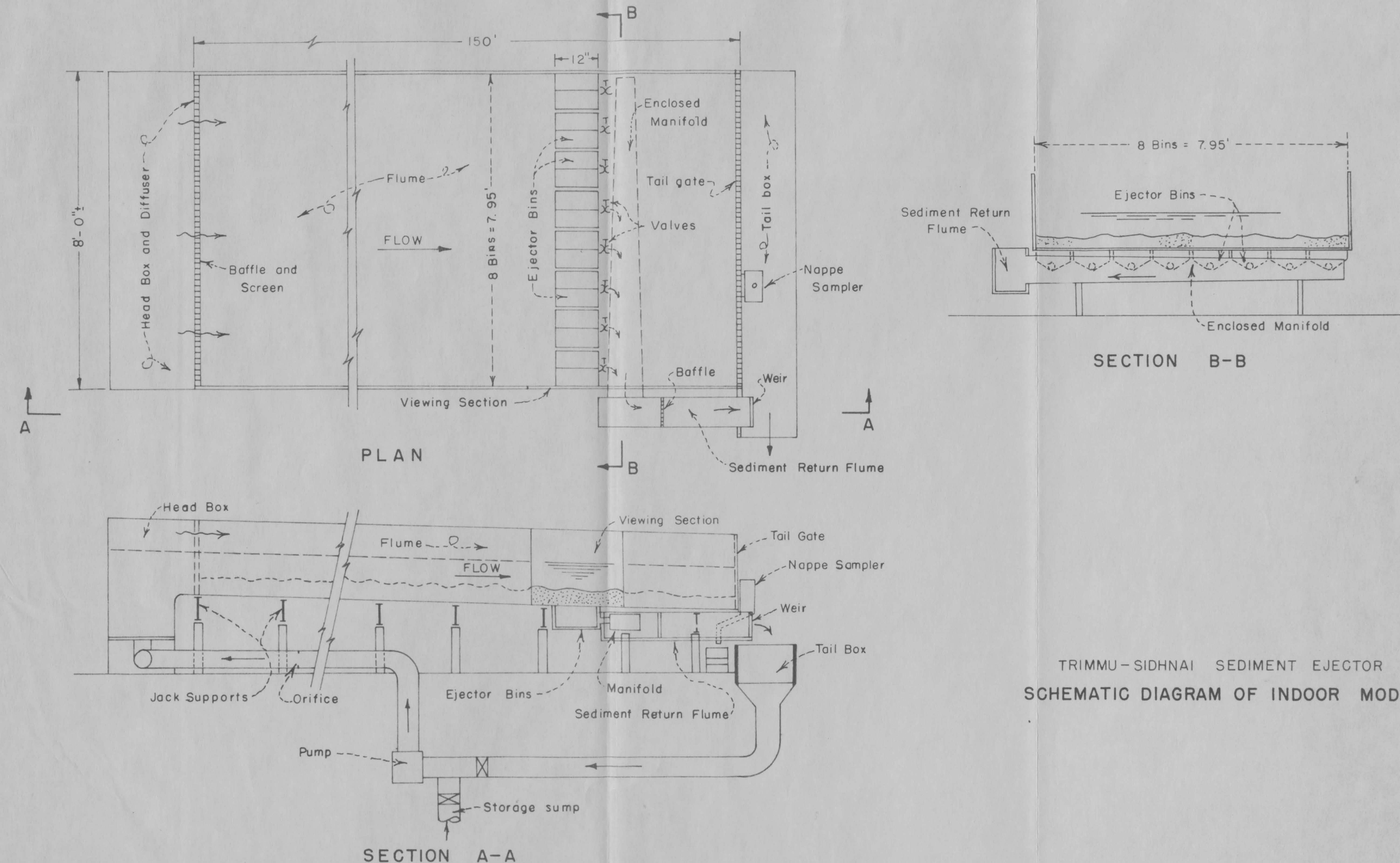
TRIMMU-SIDHNAI SEDIMENT EJECTOR

OUTDOOR MODEL

LOCATION OF EJECTOR BINS AND NUMBERING SCHEME

FIGURE 11

FIGURE 12




TRIMMU-SIDHNAI SEDIMENT EJECTOR

**SCHEMATIC DIAGRAM OF INDOOR MODEL**

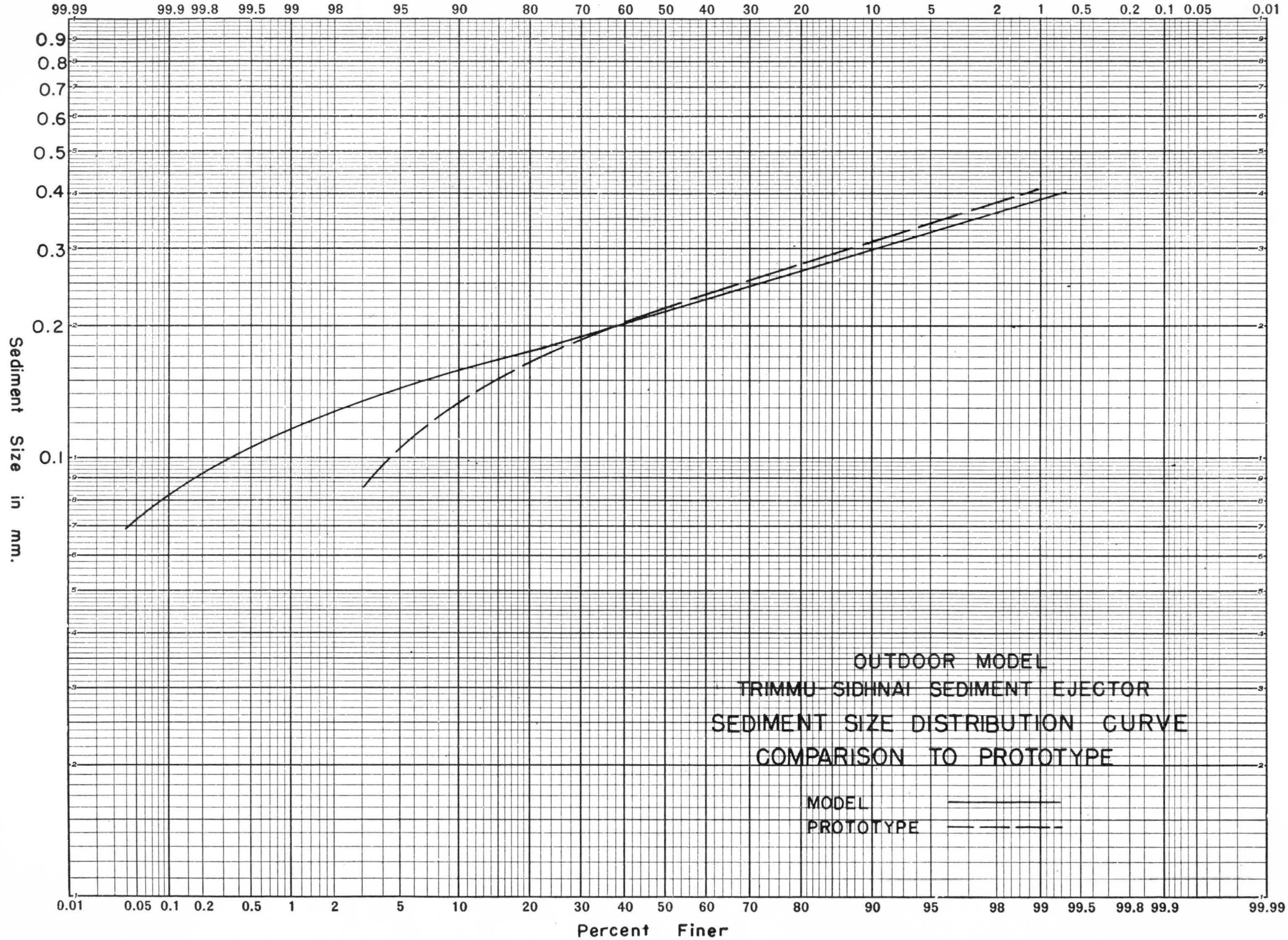

99.99 99.9 99.8 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.05 0.01
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
Sediment Size in mm.
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.5 99.8 99.9 99.99
Percent Finer
OUTDOOR MODEL
TRIMMU-SIDHNAI SEDIMENT EJECTOR
SEDIMENT SIZE DISTRIBUTION CURVE
COMPARISON TO PROTOTYPE
MODEL
PROTOTYPE

FIGURE 13

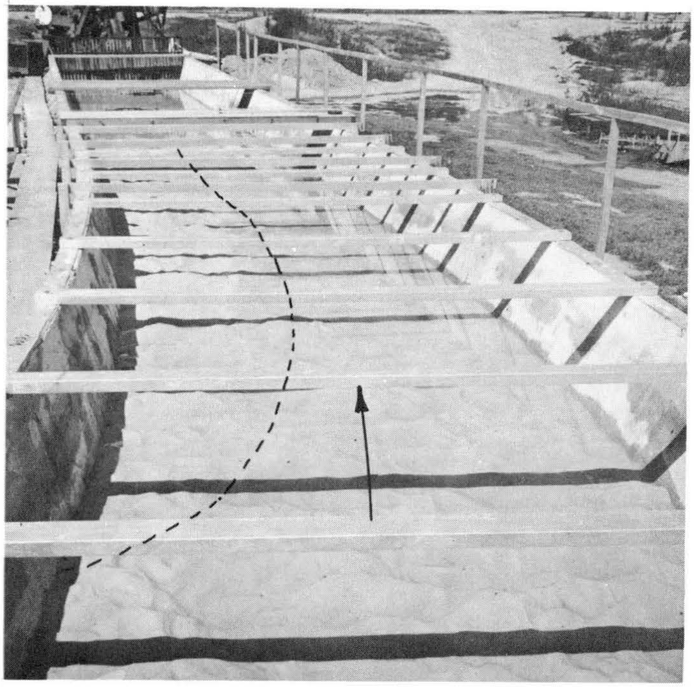
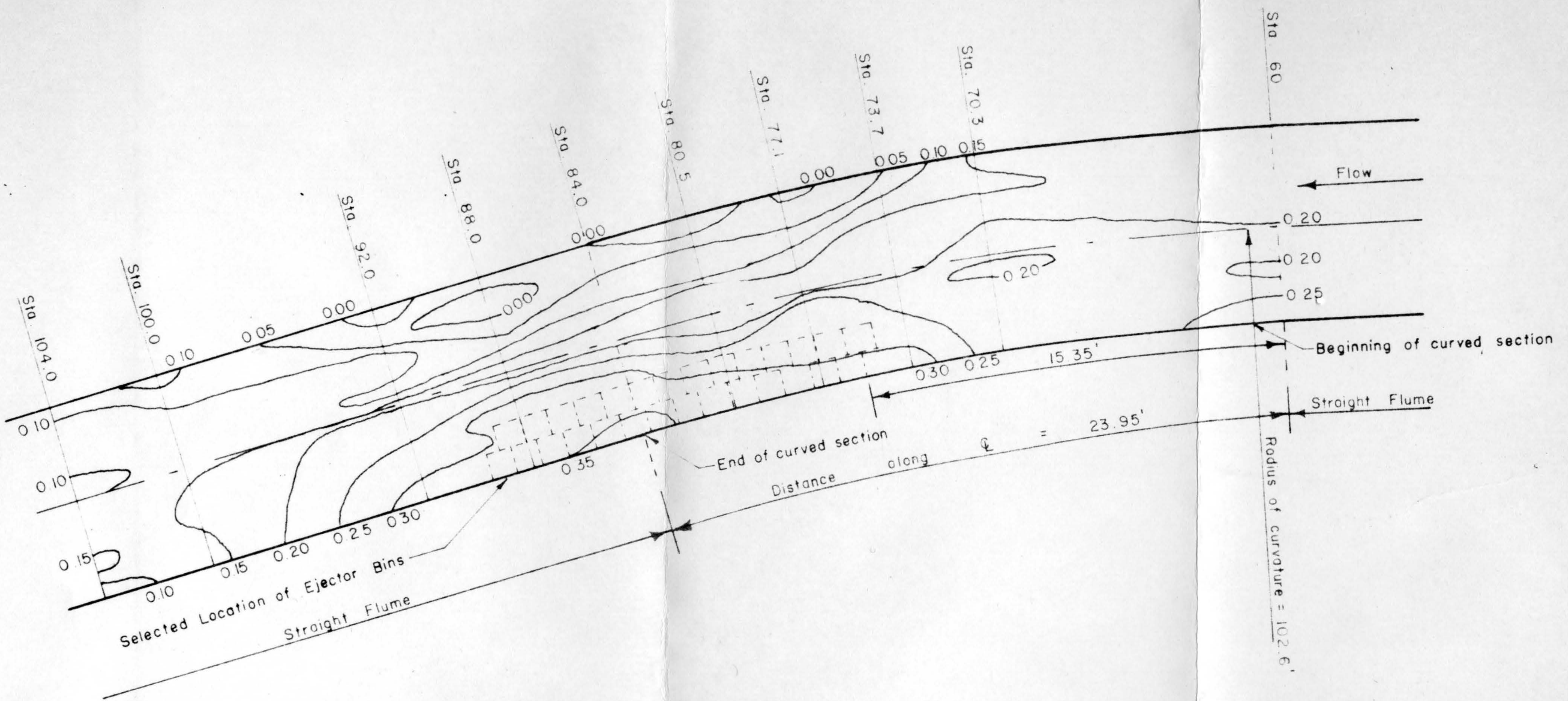


Fig. 14. Approximate location of the shoal in the canal bend. View is downstream.

Fig. 15. Shoal formation in canal bend. Same run as Fig. 14. View is upstream.




NOTES

1. All dimensions and contours are in feet.
2. The lowest contour is arbitrarily denoted 0.00.

Scale 1" = 4'

TRIMMU - SIDHNAI SEDIMENT EJECTOR
OUTDOOR MODEL

BED CONTOURS IN MODEL CANAL BEND SHOWING LOCATION OF SHOAL

Test Run 5
$Q_{Tm}$ = 11.5 c.f.s.
$C_{Tm}$ = 400 p.p.m.

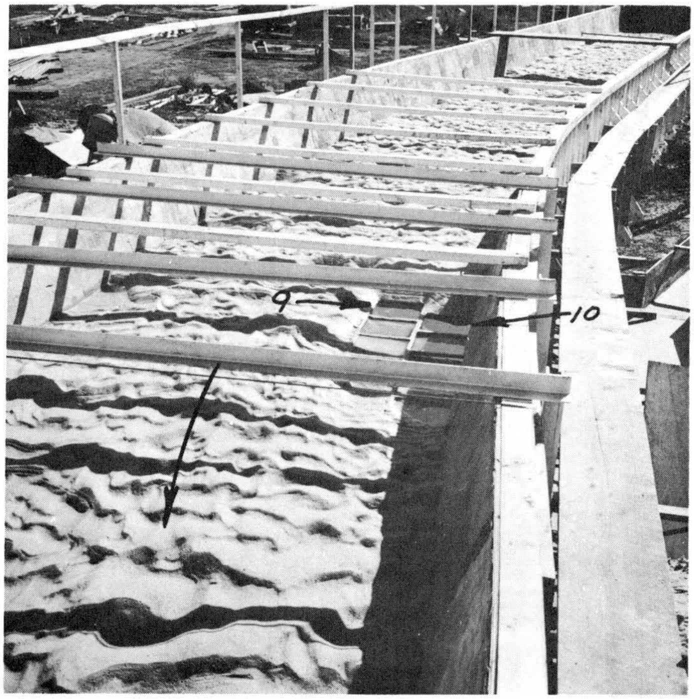



Fig. 17. Canal bed after Test Run 13 with ejectors 9 and 10 ejecting continuously. Note some scour of the downstream bins.

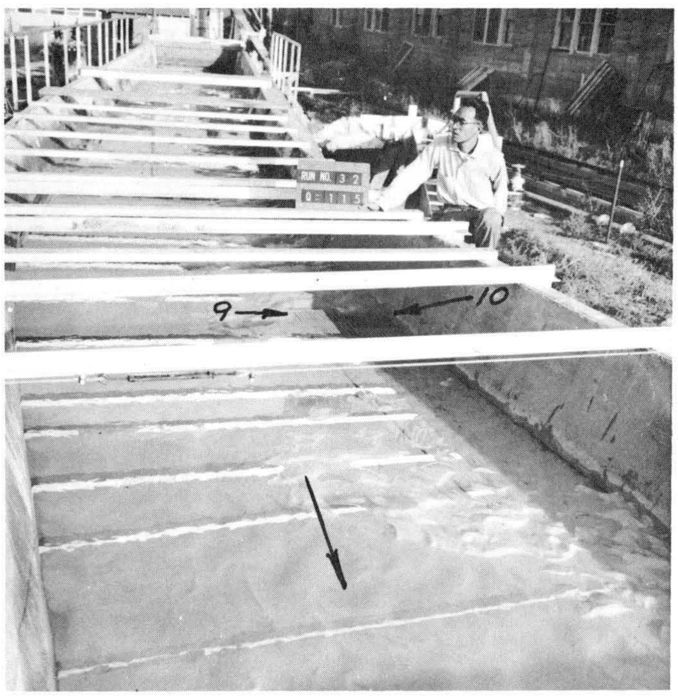
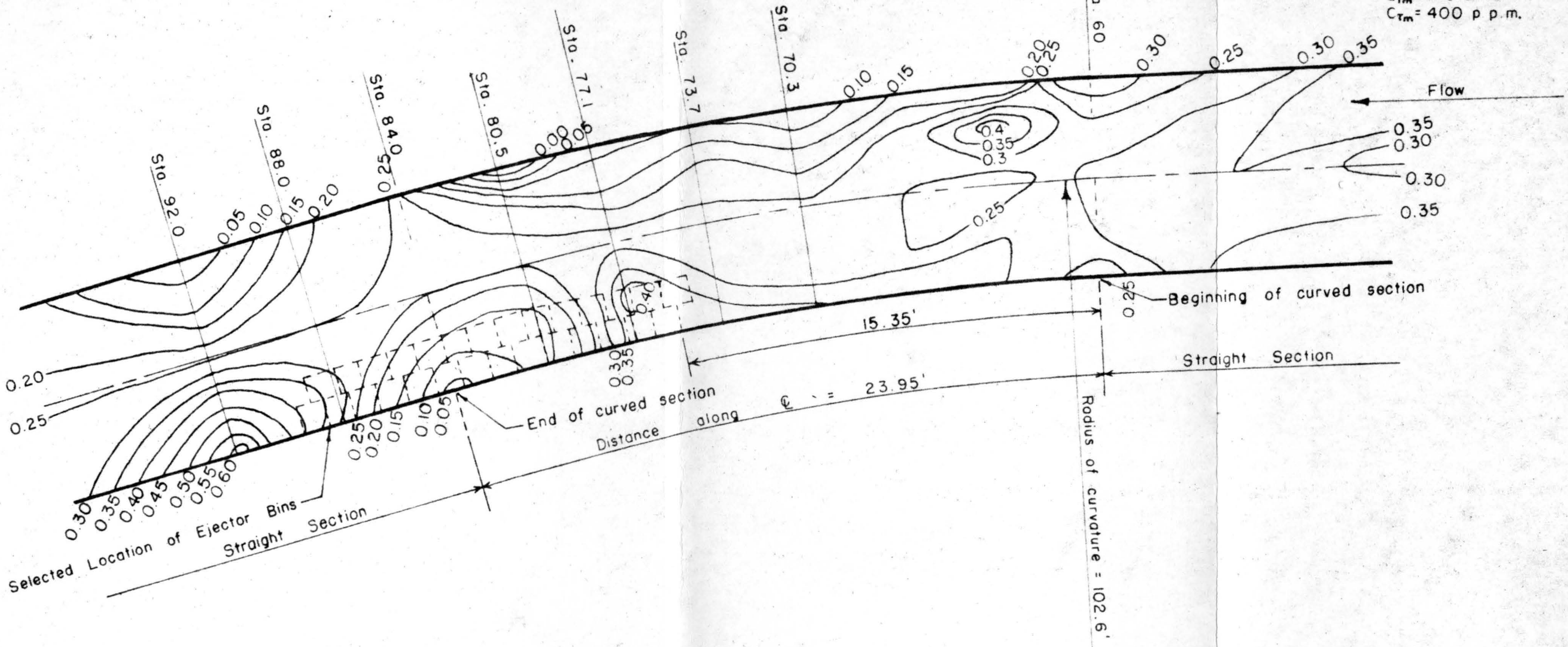



Fig. 18. Effect of grates over bins on reduction of scour. Compare with Fig. 17.

TRIMMU - SIDHNAI SEDIMENT EJECTOR
OUTDOOR MODEL

## BED CONTOURS IN MODEL CANAL BEND AFTER EJECTION THROUGH BINS 9 & 10

Test Run 13
$Q_{Tm}$ = 11.5 c.f.s.
$C_{Tm}$ = 400 p.p.m.




Scale : 1" = 4'

NOTES

1. All dimensions and contours are in feet.
2. The contour elevations correspond to Figure 16.


Fig. 20. Bed vanes at beginning of curve. Preparation for Run 15. Note large angle of vanes with respect to canal bank.

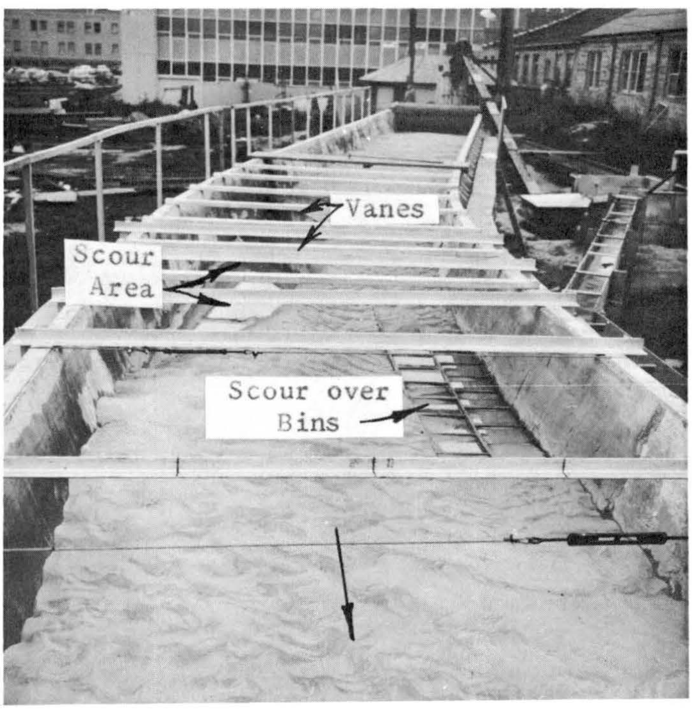



Fig. 21. Resulting bed condition at the ejector with bed vanes of Fig. 20. The scour immediately downstream of the vanes is an exaggerated model condition due to turbulence and form drag of the vanes.

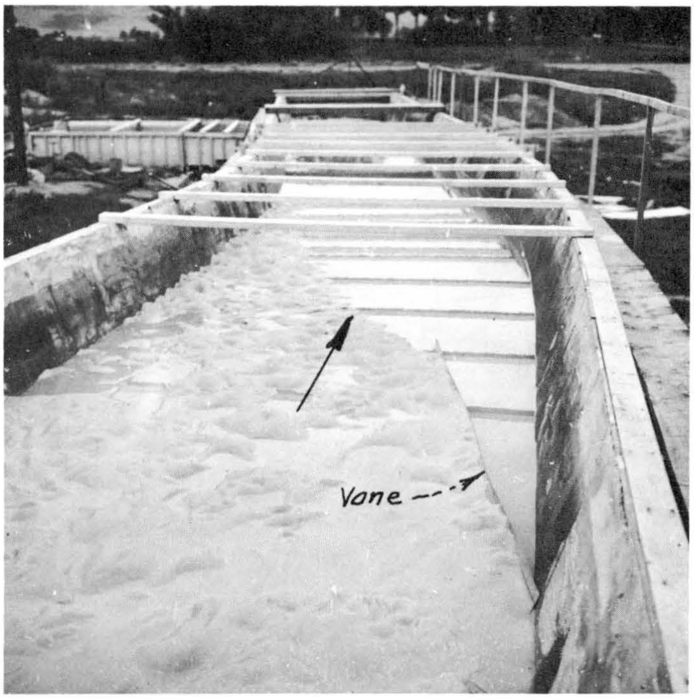



Fig. 22. Single bed vane upstream of the canal curve at angle of about $10^0$ with canal bank.

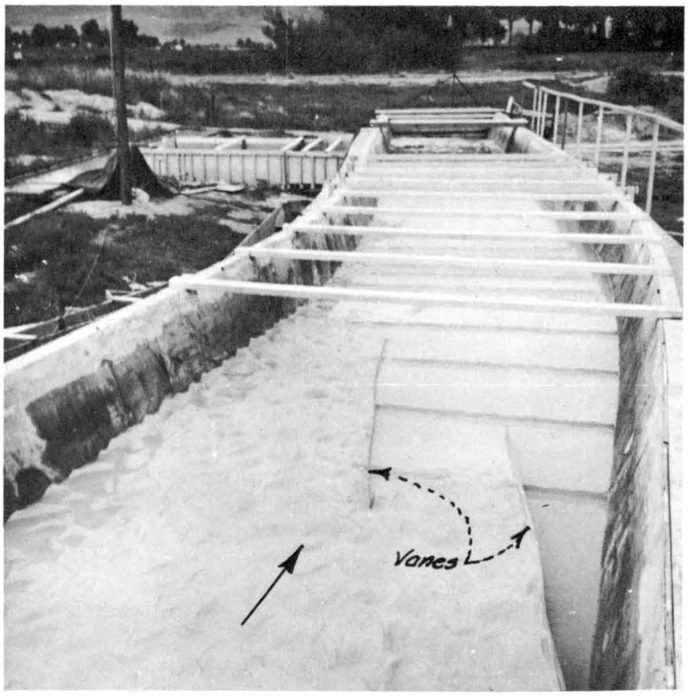



Fig. 23. Two bed vanes upstream of the canal curve.


Fig. 24. Two bed vanes in canal curve terminating near the bins. No ejection during this run.


Fig. 25. Two bed vanes in the canal curve. Note scour over bins and downstream of vanes.

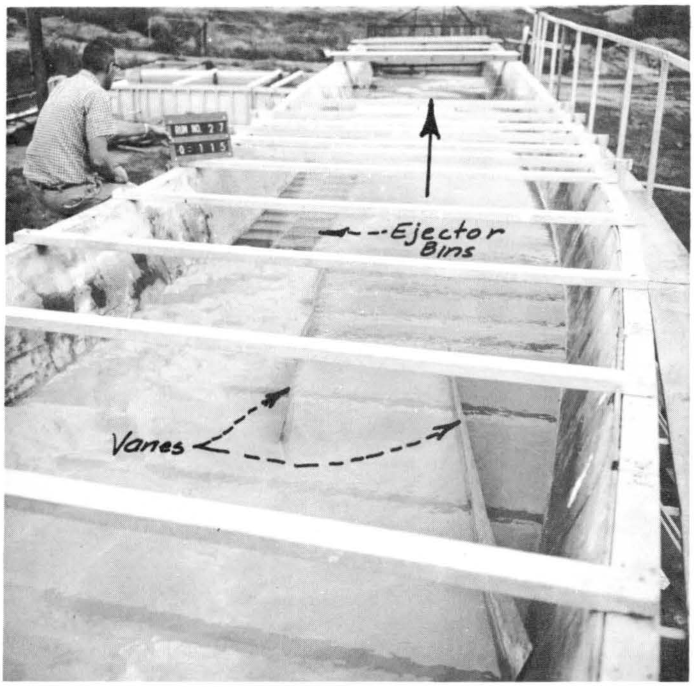
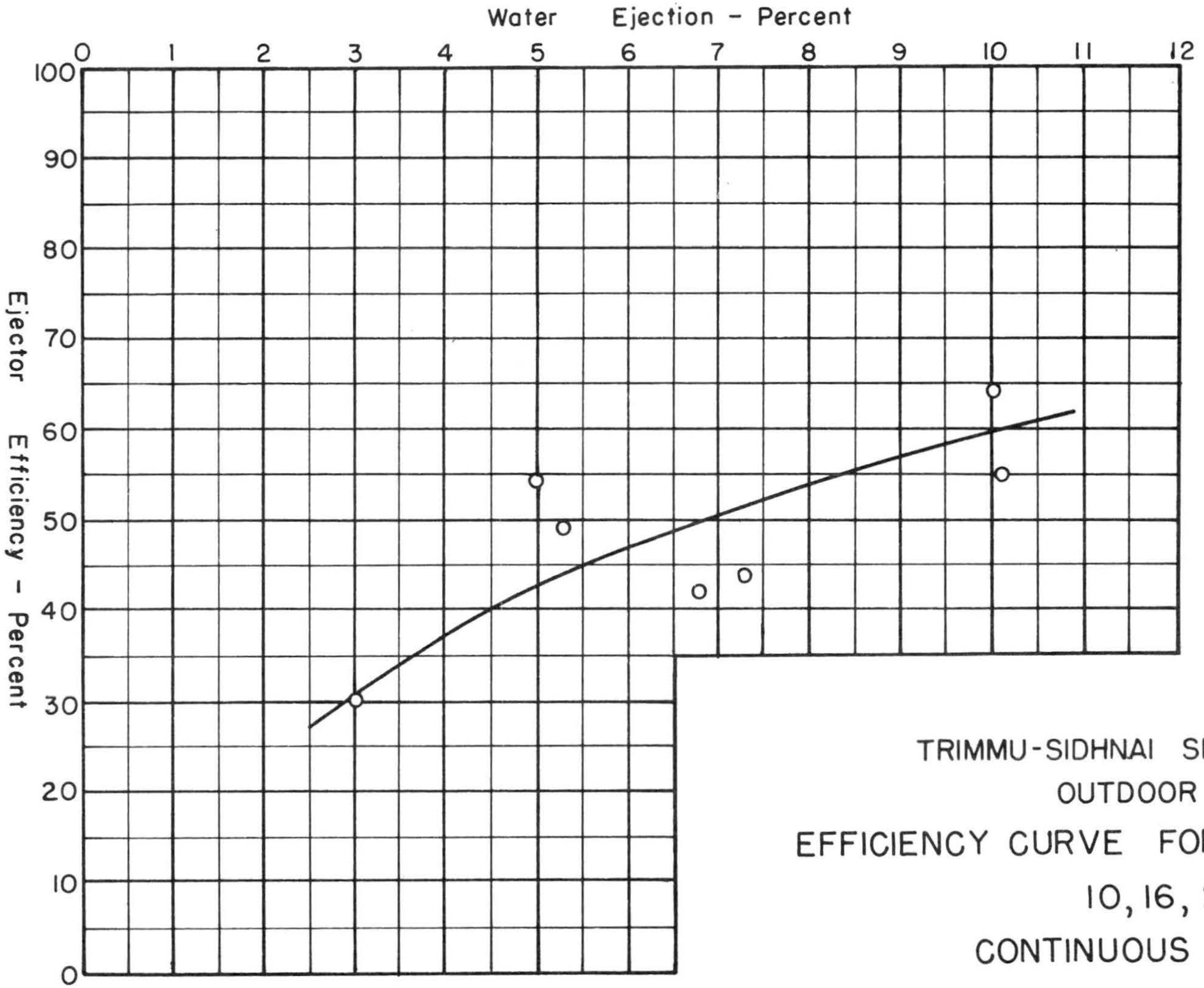



Fig. 26. Test with one surface vane and two bed vanes. Surface vane not shown.

Fig. 27. Surface vane upstream of canal curve. The angle of the vane with respect to canal bank was large for this test.




TRIMMU-SIDHNAI SEDIMENT EJECTOR
OUTDOOR MODEL
EFFICIENCY CURVE FOR LONGITUDINAL BINS
10, 16, 22, 28
CONTINUOUS EJECTION

$Q_T$ = 12,000 c.f.s.
$C_T$ = 400 p.p.m.

FIGURE 28


Fig. 29. Lateral ejector bins in canal curve.

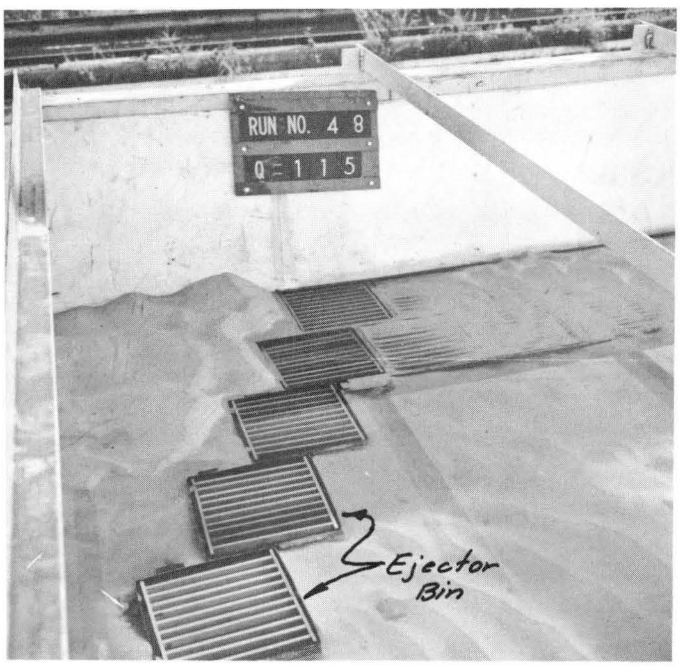
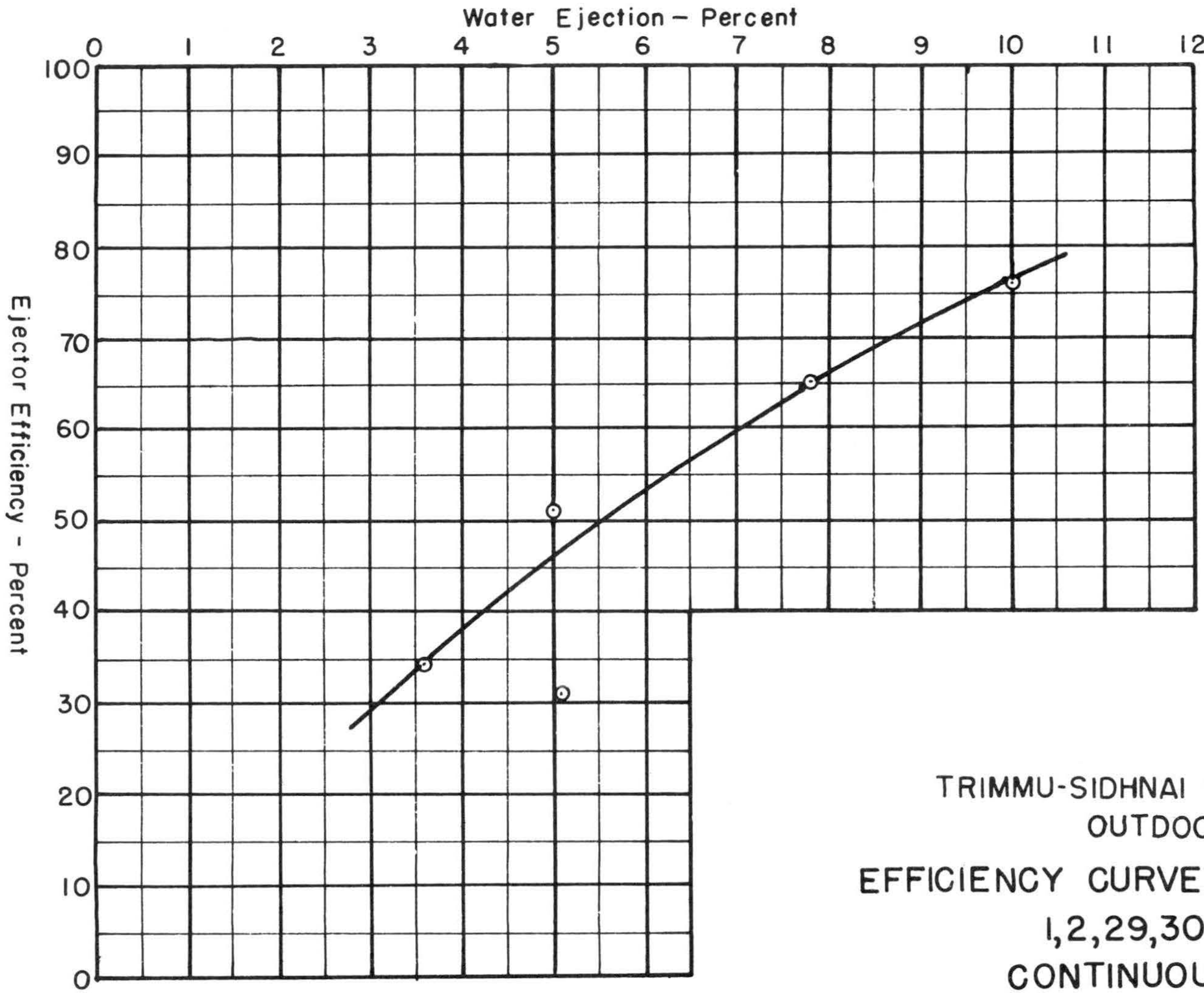



Fig. 30. Detailed view of lateral row of bins. Note bin arrangement and grates.




TRIMMU-SIDHNAI SEDIMENT EJECTOR
OUTDOOR MODEL

EFFICIENCY CURVE FOR LATERAL BINS
1,2,29,30,31,32,33,34
CONTINUOUS EJECTION

$Q_T$ = 12,000 c.f.s.
$C_T$ = 400 p.p.m.

FIGURE 31

TRIMMU-SIDHNAI SEDIMENT EJECTOR
OUTDOOR MODEL
EFFICIENCY CURVE FOR LONGITUDINAL BINS
10, 16, 22, 28
CONTINUOUS EJECTION

$Q_T$ = 12,000 c.f.s.
$C_T$ = 850 p.p.m.

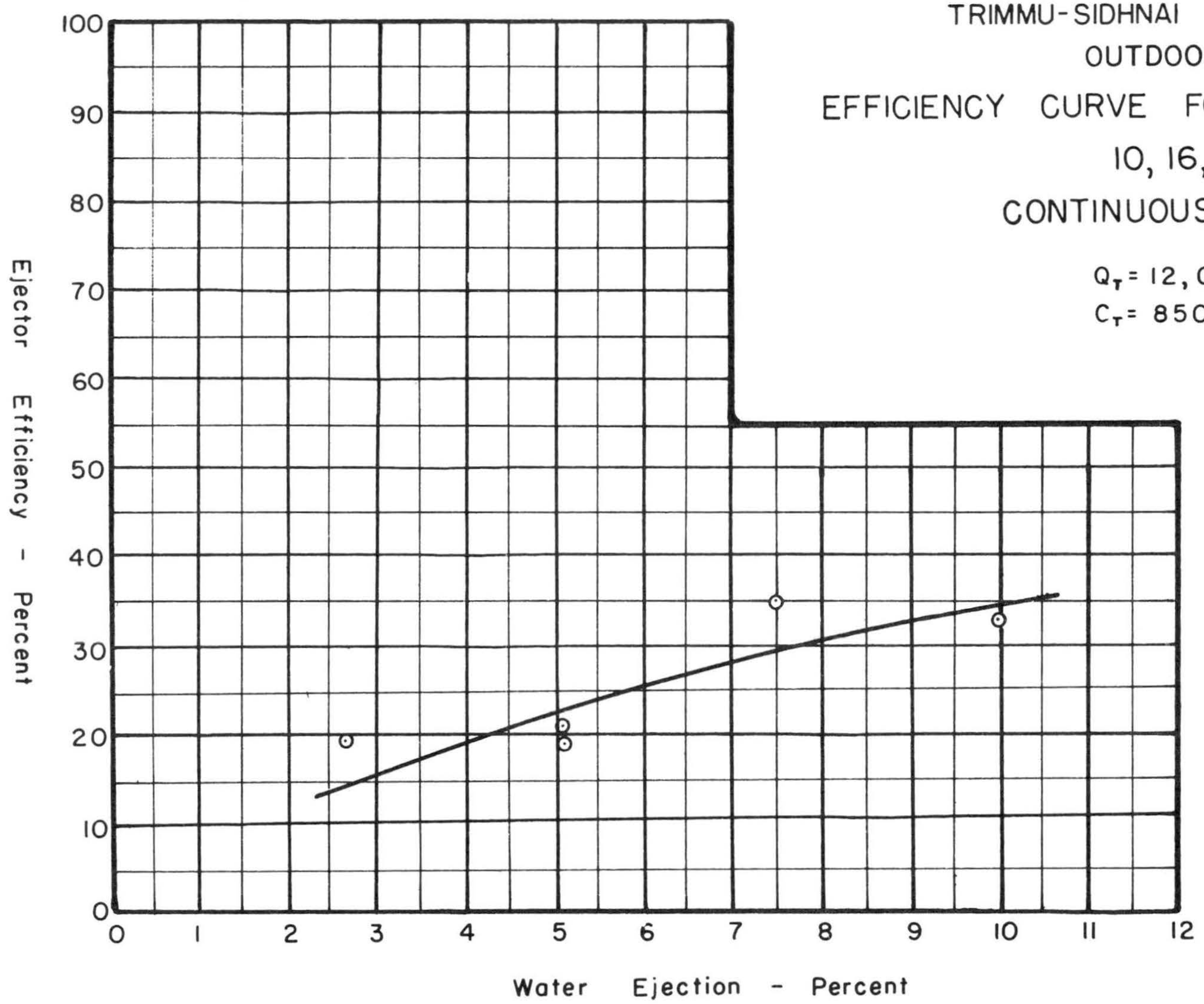



FIGURE 32

Fig. 33. Lateral row of ejector bins in the indoor model.

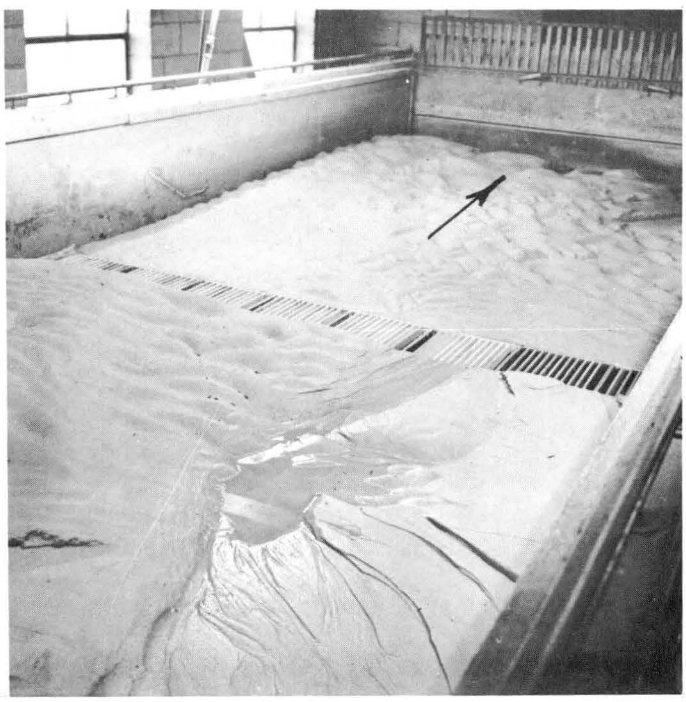
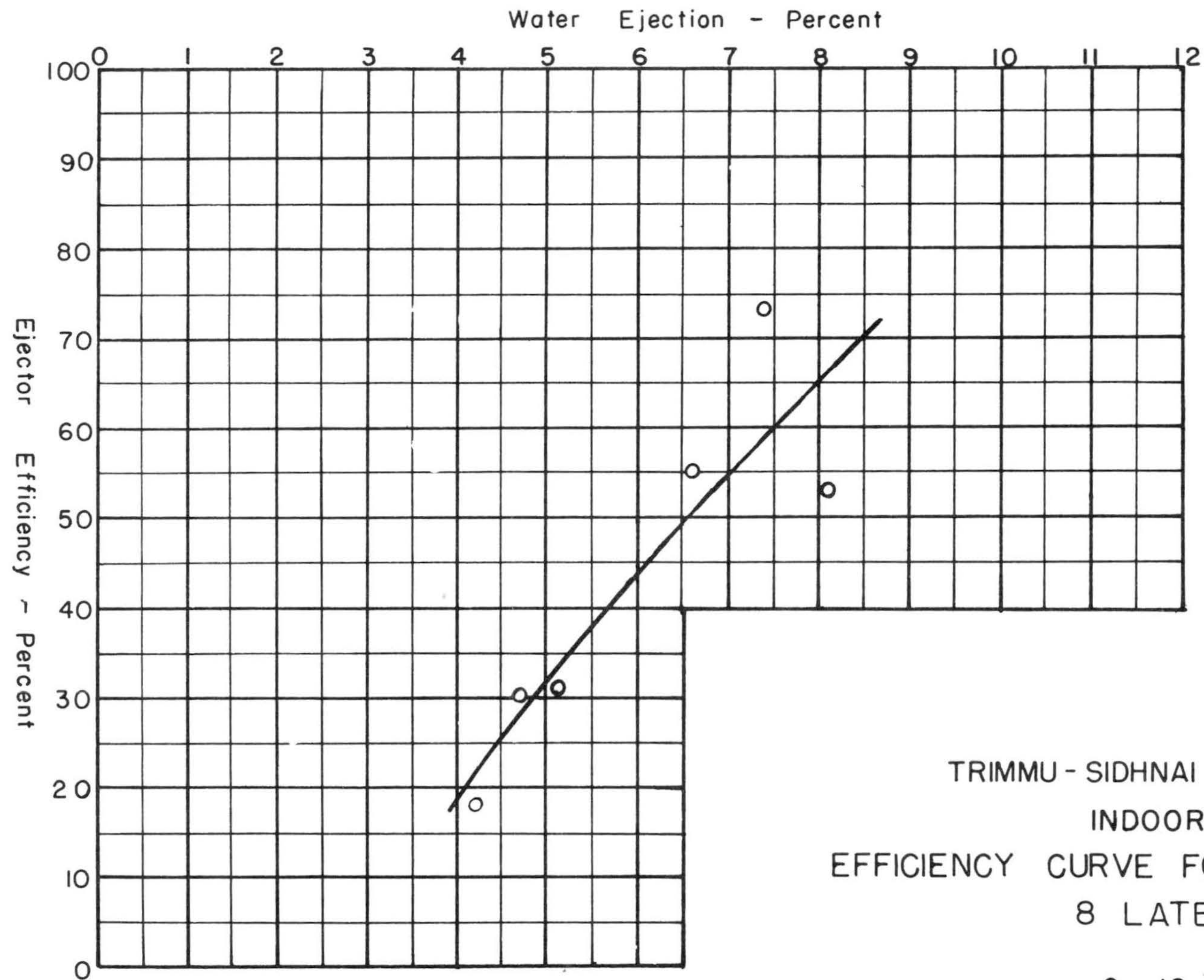


Fig. 34. Downstream view of indoor model. Arrow indicates flow direction.




TRIMMU - SIDHNAI SEDIMENT EJECTOR

INDOOR MODEL

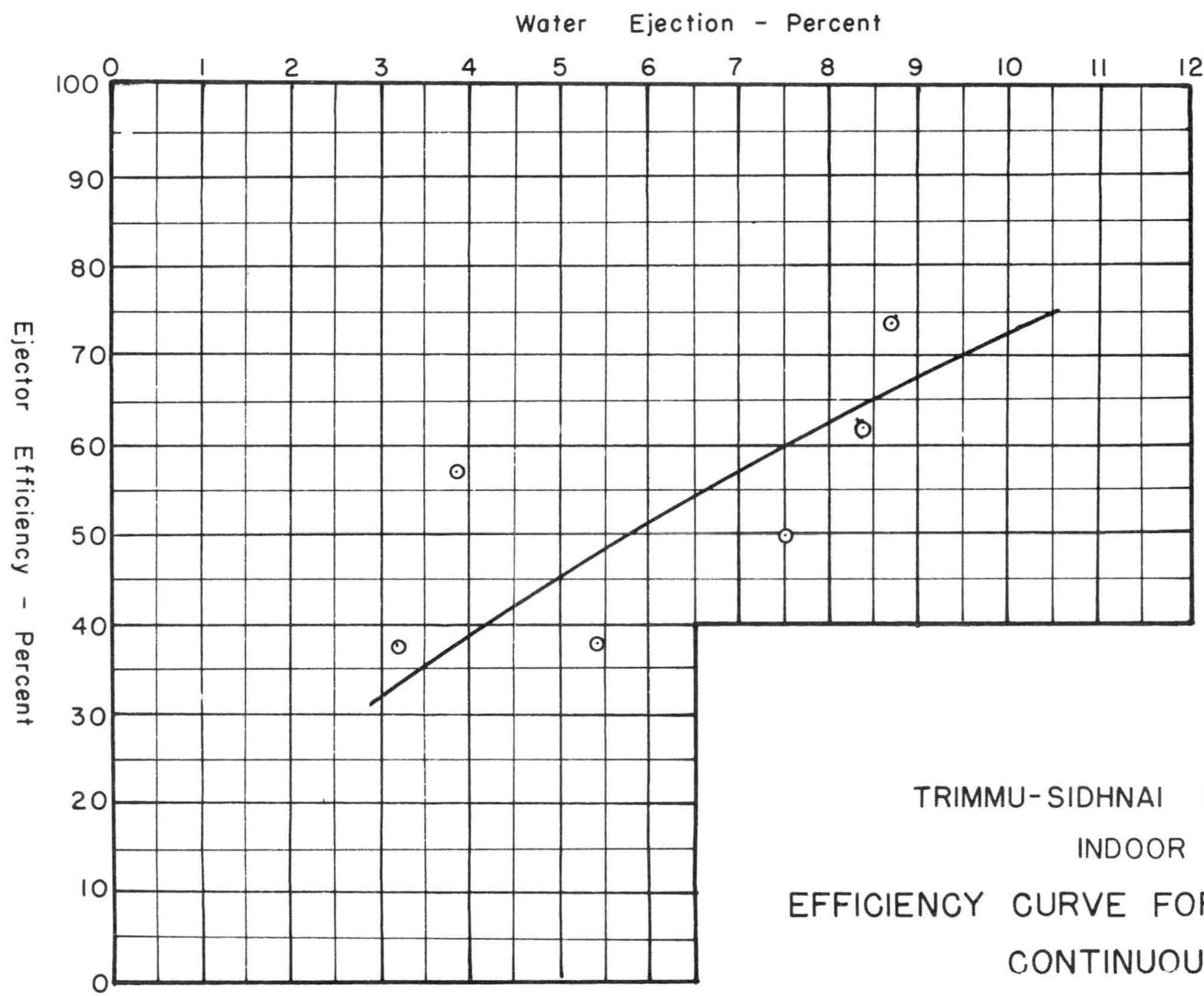
EFFICIENCY CURVE FOR CONTINUOUS EJECTION

8 LATERAL BINS

$Q_T$ = 12,000 c.f.s.

$C_T$ = 1200 p.p.m.

FIGURE 35




TRIMMU-SIDHNAI SEDIMENT EJECTOR

INDOOR MODEL

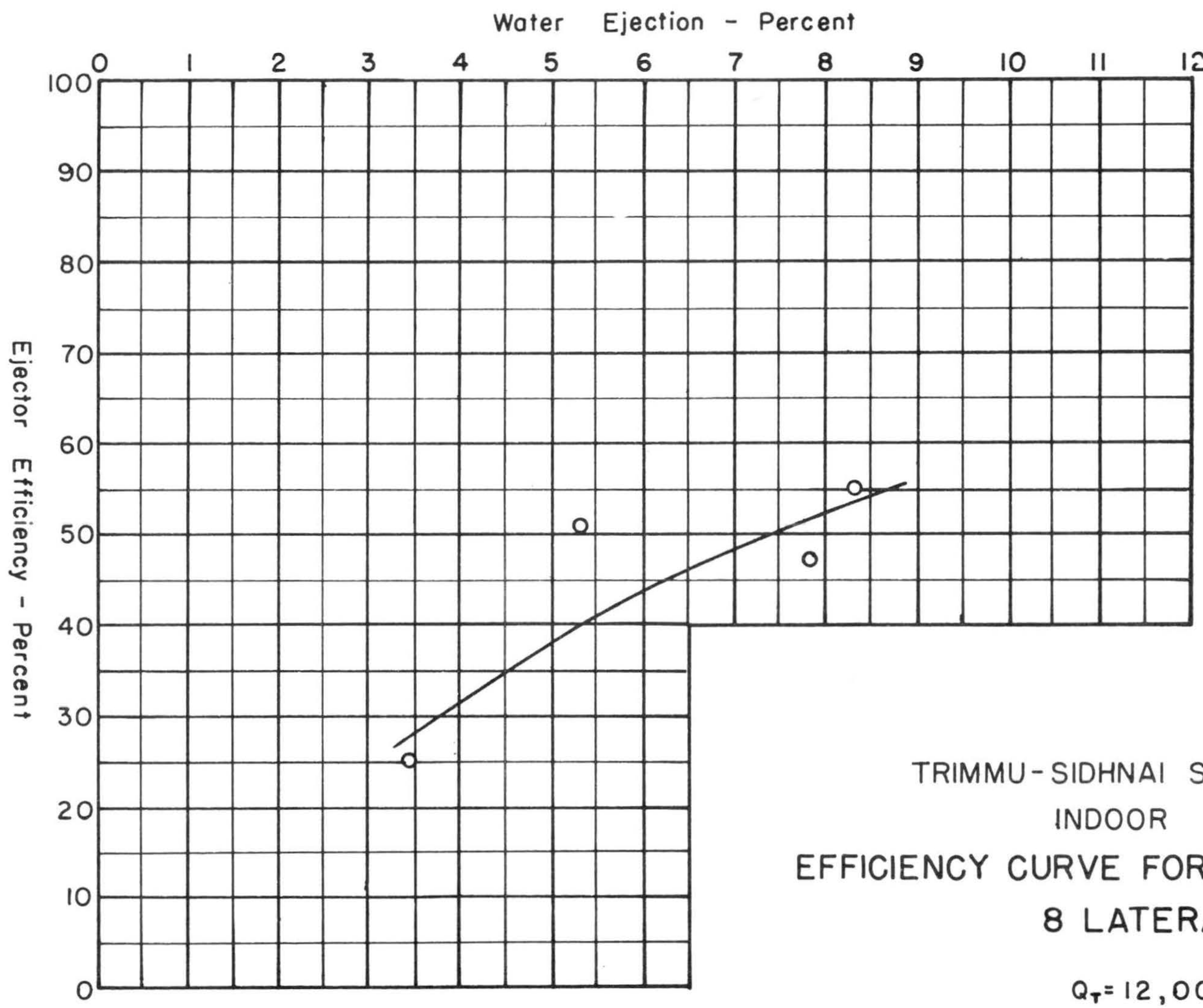
EFFICIENCY CURVE FOR ALL EJECTORS OPEN

CONTINUOUS EJECTION

$Q_T$ = 12,000 c.f.s.

$C_T$ = 550 p.p.m.

FIGURE 36




TRIMMU-SIDHNAI SEDIMENT EJECTOR

INDOOR MODEL

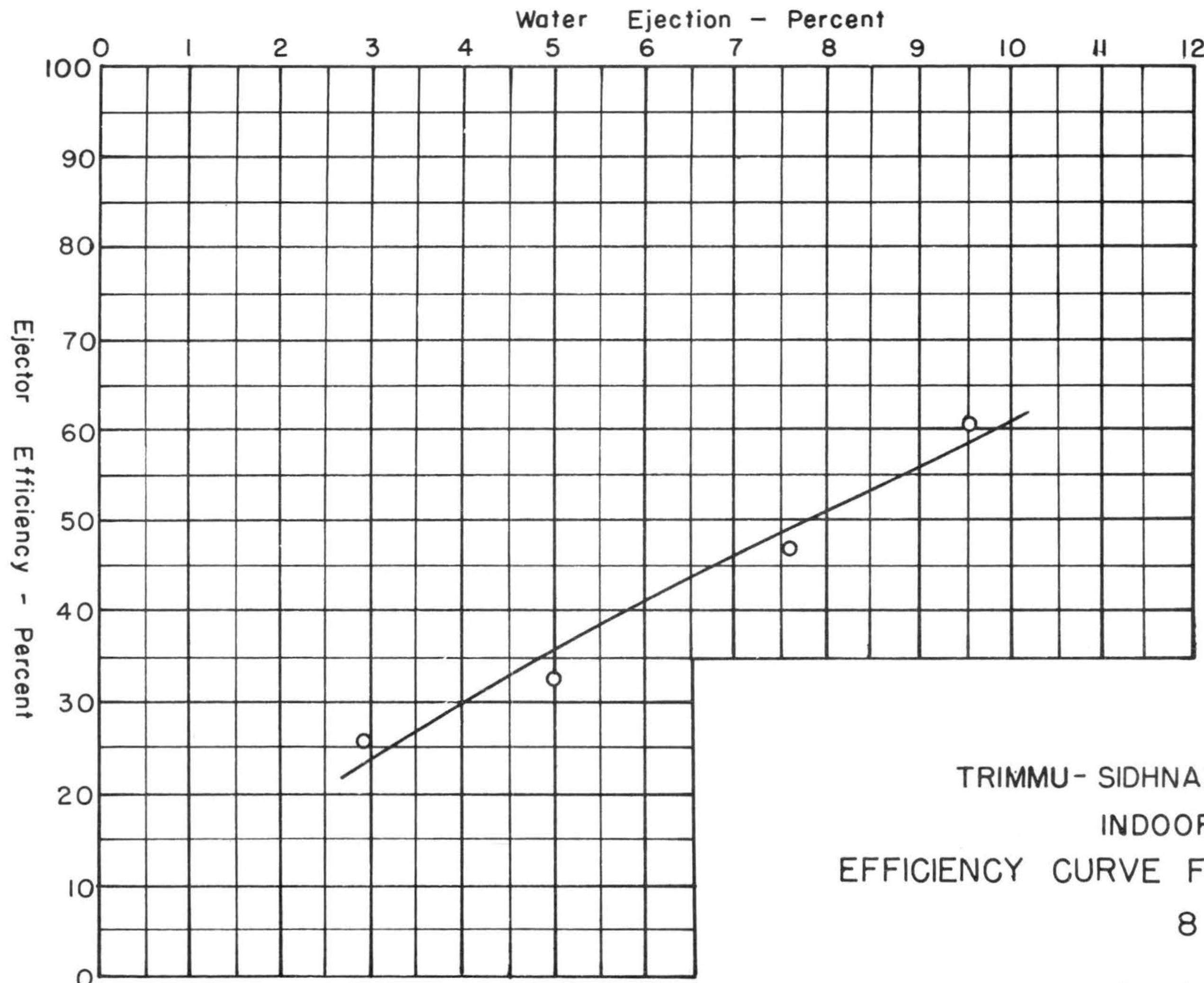
EFFICIENCY CURVE FOR CONTINUOUS EJECTION

8 LATERAL BINS

$Q_T$= 12,000 c.f.s.

$C_T$= 170 p.p.m.

FIGURE 37




TRIMMU-SIDHNAI SEDIMENT EJECTOR

INDOOR MODEL

EFFICIENCY CURVE FOR CONTINUOUS EJECTION

8 BINS

$Q_T$ = 8,000 c.f.s.

$C_T$ = 300 p.p.m.

FIGURE 38

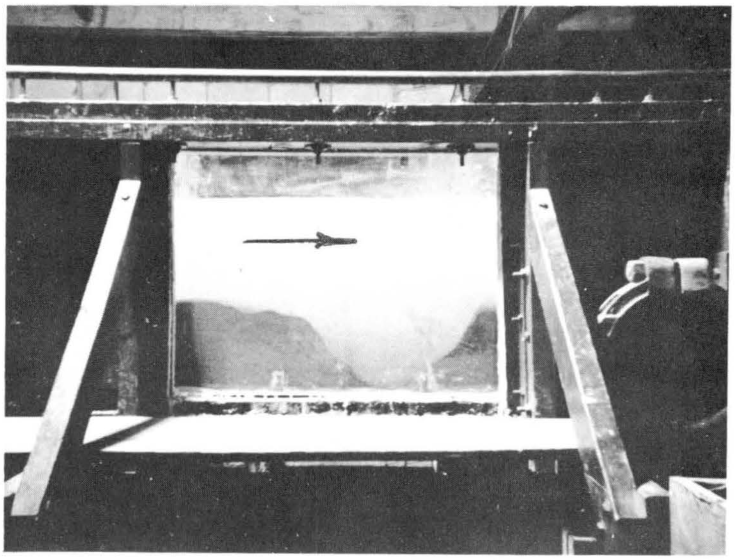


Fig. 39. Ejection of bed material in indoor model - transient condition immediately after opening of valve.


Fig. 40. Indoor model. Channel bed condition during ejection.

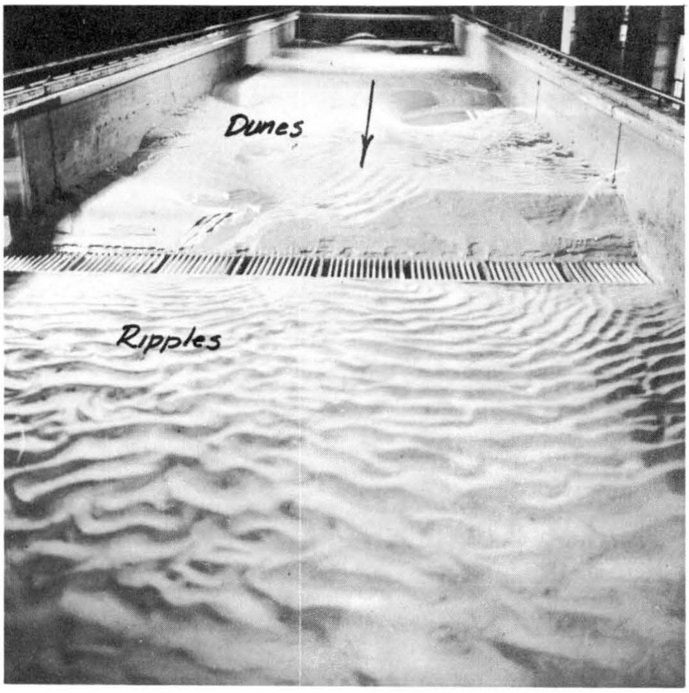
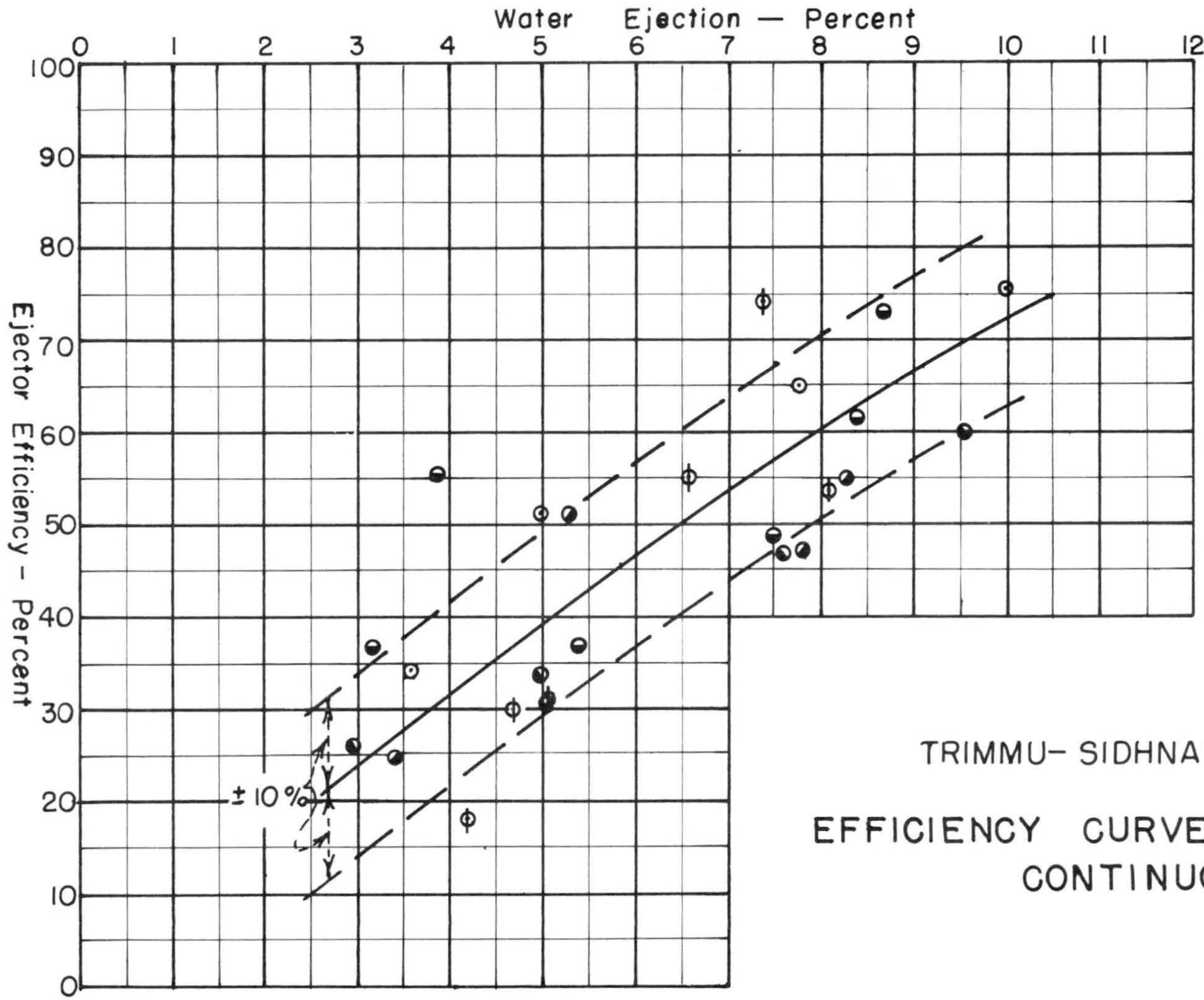



Fig. 41. Channel bed conditions upstream and downstream from the ejector after Test Run 205. $Q_T$ = 12,000 cfs $C_T$ = 1200 ppm. Note dunes upstream and ripples downstream from the ejector. Arrow indicates flow direction.




LEGEND

| | $Q_T$ c.f.s. | $C_T$ ppm |
|---|---|---|
| ϕ | 12,000 | 1200 |
| ⊙ | 12,000 | 400 |
| ◒ | 12,000 | 550 |
| ◕ | 12,000 | 170 |
| ◐ | 8,000 | 300 |

TRIMMU- SIDHNAI SEDIMENT EJECTOR

EFFICIENCY CURVE FOR LATERAL BINS
CONTINUOUS EJECTION

FIGURE 42

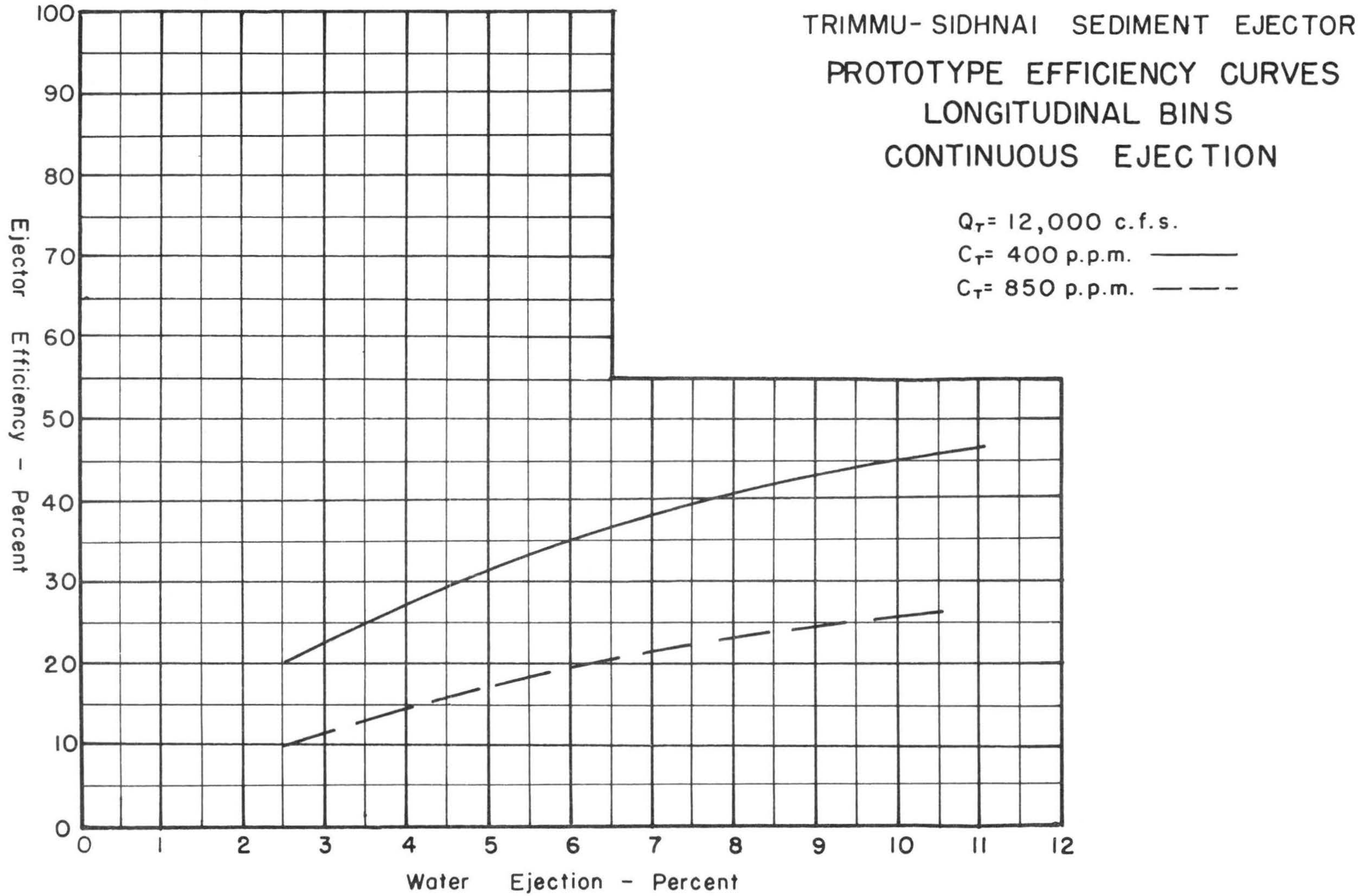
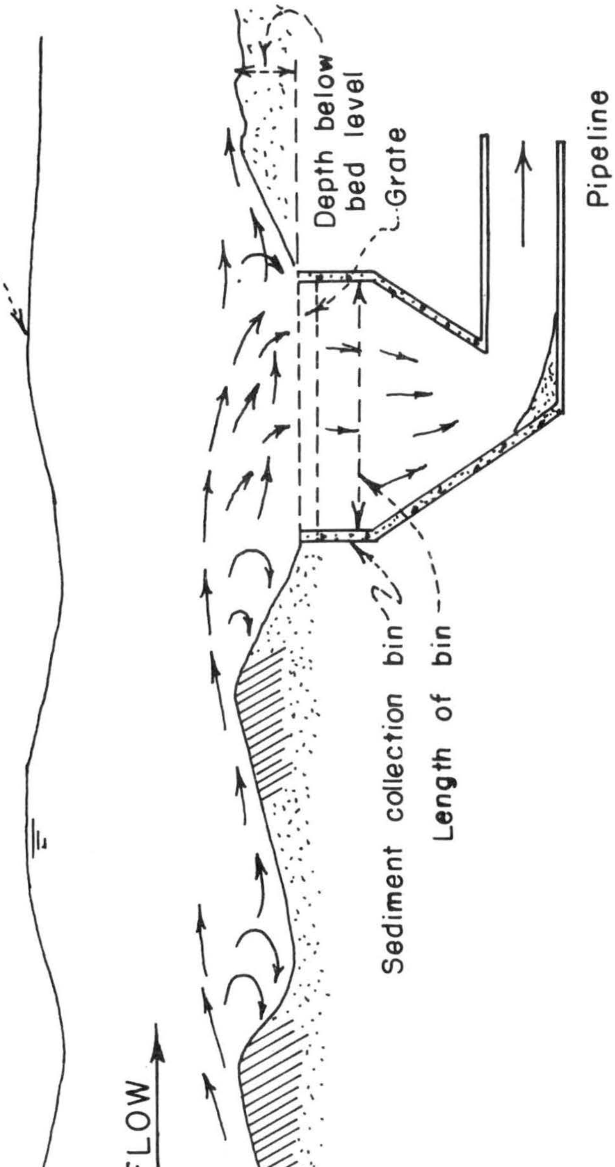

TRIMMU-SIDHNAI SEDIMENT EJECTOR
PROTOTYPE EFFICIENCY CURVES
LONGITUDINAL BINS
CONTINUOUS EJECTION
QT= 12,000 c.f.s.
CT= 400 p.p.m.
CT= 850 p.p.m.
Ejector Efficiency - Percent
Water Ejection - Percent
0
10
20
30
40
50
60
70
80
90
100
1
2
3
4
5
6
7
8
9
10
11
12

FIGURE 43

FIGURE 44

TRIMMU-SIDHNAI SEDIMENT EJECTOR

## SCHEMATIC DIAGRAM OF FLOW AT AN EJECTOR BIN



TRIMMU-SIDHNAI SEDIMENT EJECTOR

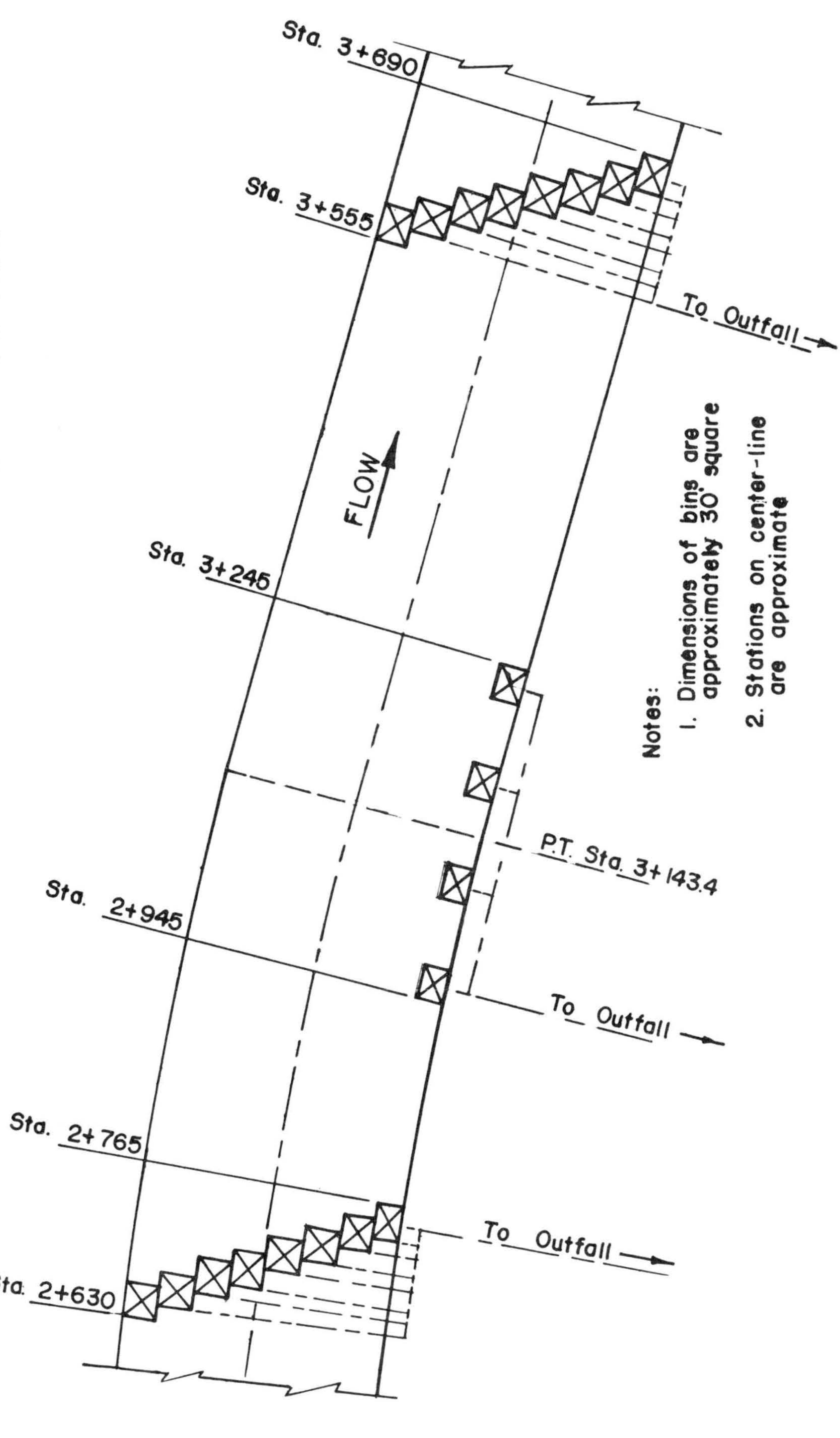
RECOMMENDED ARRANGEMENT AND LOCATION


FIGURE 45

FIGURE 46

TRIMMU-SIDHNAI SEDIMENT EJECTOR

**SUGGESTED ALTERNATE ARRANGEMENT AND LOCATION**



# APPENDIX

TABLE A-1

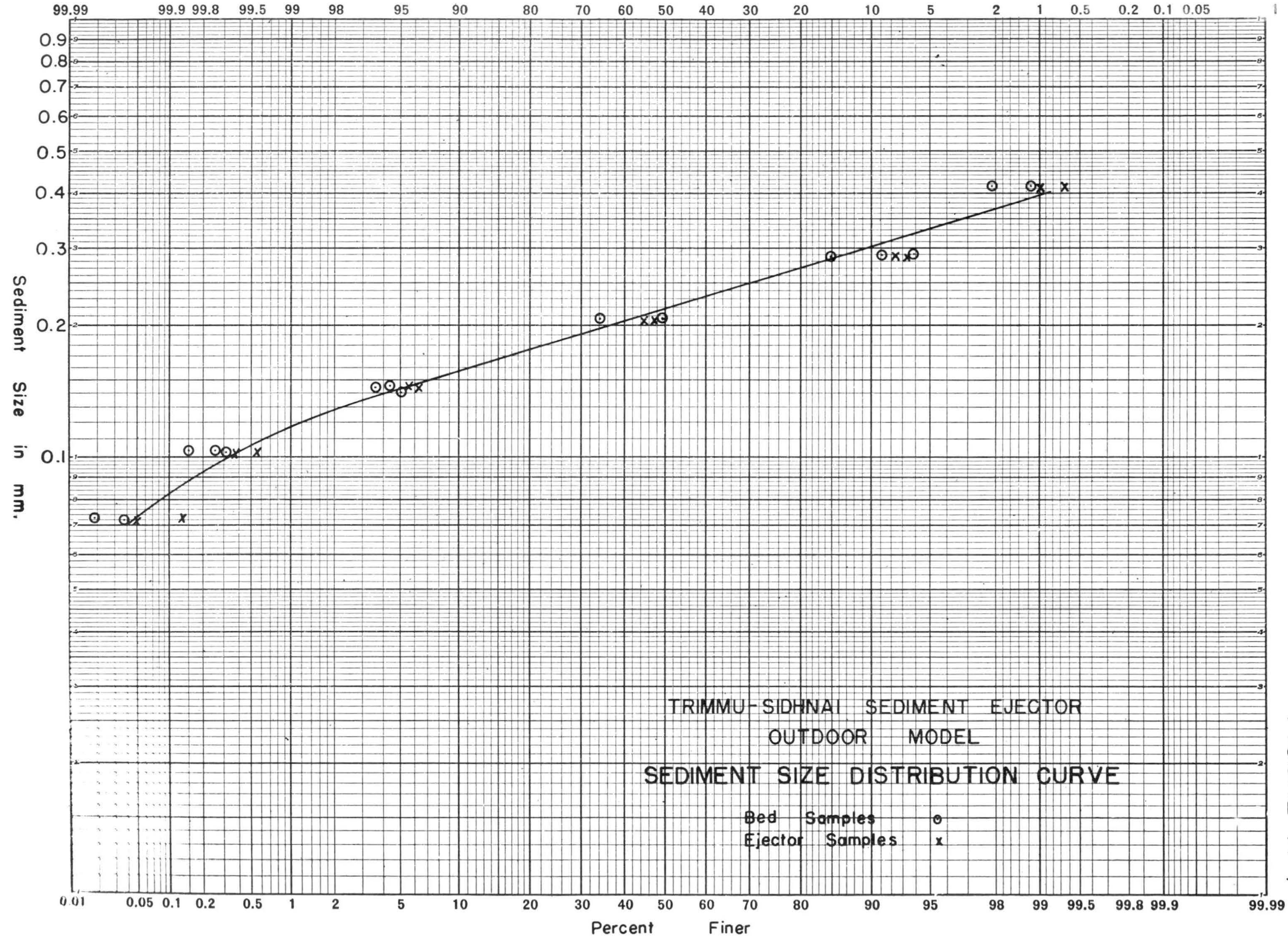
SIEVE SIZE ANALYSES OF SAND IN THE OUTDOOR MODEL

Bed Samples

| Sieve | | Percent Finer | | |
|---|---|---|---|---|
| Mesh | Opening (mm) | Sample 1 | Sample 2 | Sample 3 |
| 35 | 0.417 | 99.03 | 97.99 | 98.91 |
| 48 | 0.295 | 91.53 | 85.44 | 94.06 |
| 65 | 0.208 | 48.88 | 35.44 | 49.61 |
| 100 | 0.147 | 4.68 | 3.84 | 5.36 |
| 150 | 0.104 | 0.27 | 0.16 | 0.31 |
| 200 | 0.074 | 0.04 | 0.04 | 0.02 |

Ejection Samples

| Sieve | | Percent Finer | |
|---|---|---|---|
| Mesh | Opening (mm) | Sample 1 | Sample 2 |
| 35 | 0.417 | 99.26 | 99.00 |
| 48 | 0.295 | 92.55 | 93.68 |
| 65 | 0.208 | 48.85 | 45.08 |
| 100 | 0.147 | 5.65 | 6.38 |
| 150 | 0.104 | 0.36 | 0.58 |
| 200 | 0.074 | 0.13 | 0.05 |



Sediment Size in mm.
Percent Finer
TRIMMU-SIDHNAI SEDIMENT EJECTOR
OUTDOOR MODEL
SEDIMENT SIZE DISTRIBUTION CURVE
Bed Samples ⊙
Ejector Samples x


FIGURE A-1

TABLE A-2

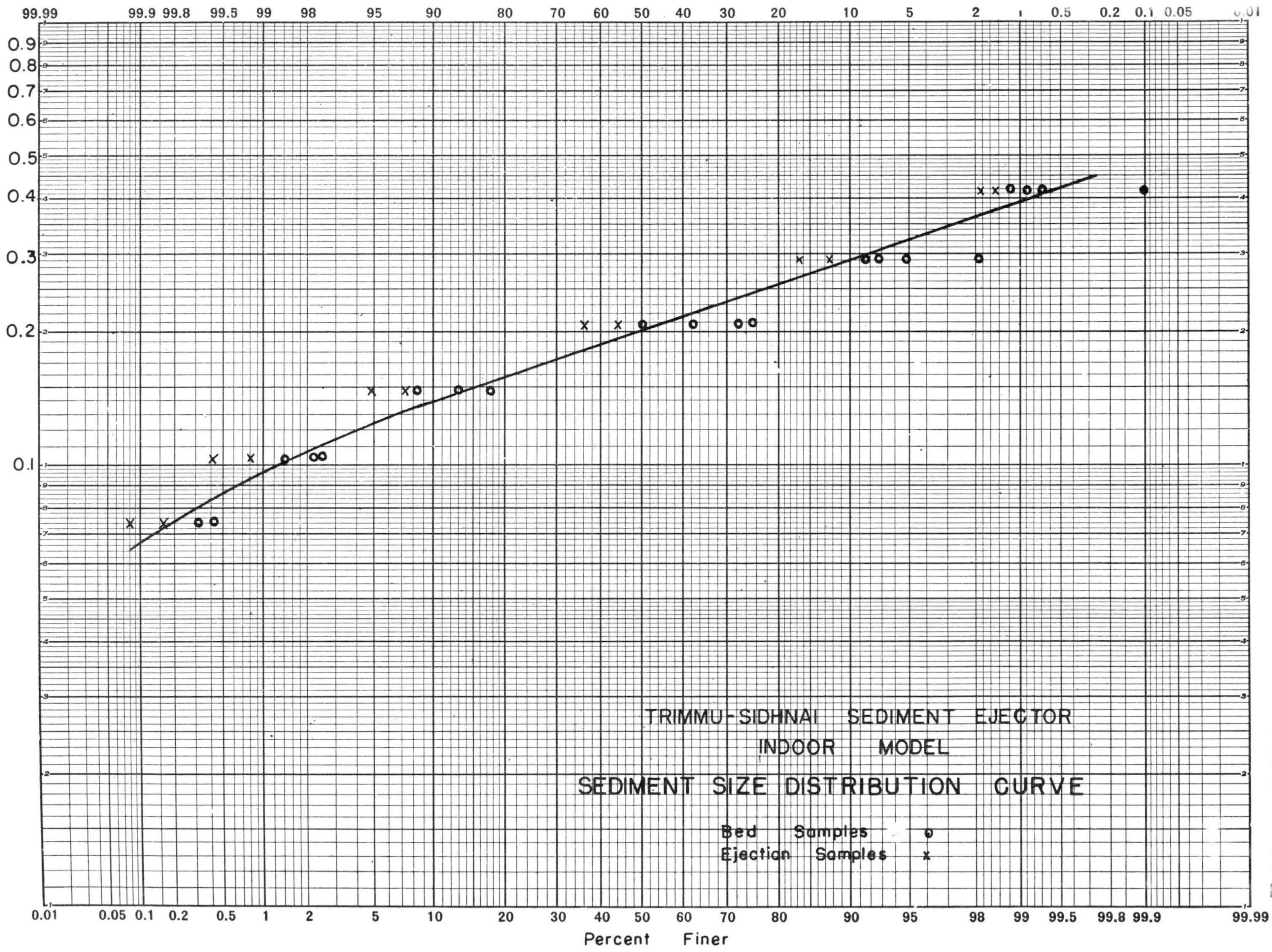
SIEVE SIZE ANALYSES OF SAND IN THE
INDOOR MODEL.

Bed Samples

| Sieve | | Percent Finer | | | |
|---|---|---|---|---|---|
| Mesh | Openings (mm) | Sample 1 | Sample 2 | Sample 3 | Sample 4 |
| 35 | 0.417 | 98.82 | 99.05 | 99.88 | 99.29 |
| 48 | 0.295 | 92.75 | 91.60 | 98.06 | 94.85 |
| 65 | 0.208 | 62.17 | 50.11 | 74.70 | 72.43 |
| 100 | 0.147 | 13.54 | 8.22 | 13.14 | 17.59 |
| 150 | 0.104 | 2.07 | 1.36 | 1.42 | 2.48 |
| 200 | 0.074 | 0.43 | 0.40 | 0.16 | 0.32 |

Ejection Samples

| Sieve | | Percent Finer | |
|---|---|---|---|
| Mesh | Opening (mm) | Sample 1 | Sample 2 |
| 35 | 0.417 | 98.45 | 98.13 |
| 48 | 0.295 | 87.17 | 83.08 |
| 65 | 0.200 | 44.13 | 36.14 |
| 100 | 0.147 | 7.06 | 4.75 |
| 150 | 0.104 | 0.80 | 0.42 |
| 200 | 0.074 | 0.16 | 0.08 |



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
0.9 0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1
Sediment Size in mm.
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
Percent Finer
TRIMMU-SIDHNAI SEDIMENT EJECTOR
INDOOR MODEL
SEDIMENT SIZE DISTRIBUTION CURVE
Bed Samples o
Ejection Samples x


FIGURE A-2

## TABLE A-3

### COMPUTATION OF BED MATERIAL DISCHARGE IN TRIMMU-SIDHNAI CANAL
by Revised Einstein Method

Note: The symbols used in the following tables conform with those of Einstein in his Report: "The Bed-Load Functions for Sediment Transportation in Open Channel Flows," USDA Tech. Bull. No. 1026. Sept. 1950.

The symbols were purposely unchanged for ease in referring to the curves of the above report which is necessary for a complete solution. The symbols as used here, may or may not conform to those listed at the front of this report.

PART I. Computation of $R_b'$ and $R_b''$

| $\overline{U}$ | $\frac{\overline{U}}{\sqrt{gK_s S}}$ | $\overline{U}^3$ | $\frac{\overline{U}^3}{g\nu S}$ | $\frac{\overline{U}}{U_*'}$ | $U_*'$ | $R_b'$ | $R_b$ | $R_b''$ | $U_*''$ | $\frac{\overline{U}}{U_*''}$ | $\psi$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.82 | 1010 | 6.02 | $1.59 \times 10^8$ | 25.6 | .071 | 1.33 | 3.85 | 2.52 | .098 | 18.6 | 7.10 |
| 2.44 | 1355 | 14.50 | $3.82 \times 10^8$ | 26.7 | .091 | 2.18 | 5.67 | 3.49 | .115 | 21.2 | 4.33 |
| 2.99 | 1660 | 26.8 | $7.05 \times 10^8$ | 27.7 | .108 | 3.06 | 7.44 | 4.38 | .129 | 23.2 | 3.08 |
| 3.48 | 1930 | 42.2 | $1.12 \times 10^9$ | 28.45 | .122 | 3.91 | 9.14 | 5.23 | .141 | 24.7 | 2.41 |
| 3.96 | 2200 | 62.5 | $1.65 \times 10^9$ | 28.75 | .138 | 5.01 | 10.81 | 5.80 | .148 | 26.7 | 1.88 |

TABLE A-3 Continued:

COMPUTATION OF BED MATERIAL DISCHARGE IN TRIMMU-SIDHNAI CANAL
by Revised Einstein Method

PART II Computation of parameters for Figures.

| $R_b$ | X | Y | $\beta_x$ | $(\beta/\beta_x)^2$ | P | $U_*'$ | $\delta$ | $K_s/\delta$ | $\chi$ | $\Delta$ | $\Delta/\delta$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $x10^3$ | | | | | | $x10^3$ | | | $x10^3$ | |
| 3.85 | 2.26 | .465 | 1.597 | .413 | 12.20 | .071 | 1.63 | .523 | 1.41 | .605 | .37 |
| 5.67 | 1.78 | .61 | 1.528 | .451 | 12.71 | .091 | 1.28 | .667 | 1.53 | .558 | .44 |
| 7.44 | 1.50 | .73 | 1.471 | .485 | 13.03 | .108 | 1.07 | .798 | 1.59 | .537 | .50 |
| 9.14 | 1.32 | .80 | 1.421 | .520 | 13.28 | .122 | .95 | .899 | 1.61 | .530 | .56 |
| 10.81 | 1.17 | .83 | 1.370 | .560 | 13.44 | .138 | .84 | 1.015 | 1.615 | .528 | .63 |

TABLE A-3 - Continued PART III. Computation of bed material discharge

| $10^3 d$ ft | $10^2 i_b$ | $\kappa_b'$ | $\psi$ | $D/X$ | $\xi$ | $\psi_*$ | $\phi_*$ | $i_B q_B$ $x10^3$ | $10^3 A$ | Z | $I_1$ | $-I_2$ | $PI_1 + I_2 + 1$ | $i_T q_T$ $x10^3$ | $\frac{i_T Q_T}{i_b}$ $x10^3$ | $i_T Q_T$ T/D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.41 | 1.78 | 1.33 | 14.8 | .624 | 2.15 | 6.11 | .38 | .43 | .732 | 6.26 | .04 | .29 | 1.20 | .52 | 29.2 | 5.40 |
| | | 2.18 | 9.05 | .792 | 1.41 | 3.50 | 1.35 | 1.52 | .497 | 4.89 | .05 | .41 | 1.29 | 1.96 | 110. | 20.3 |
| | | 3.06 | 6.44 | .940 | 1.20 | 2.74 | 2.03 | 2.29 | .379 | 4.11 | .06 | .53 | 1.36 | 3.12 | 175. | 32.4 |
| | | 3.91 | 5.05 | 1.07 | 1.11 | 2.33 | 2.60 | 2.94 | .309 | 3.64 | .08 | .635 | 1.45 | 4.26 | 240. | 44.1 |
| | | 5.01 | 3.94 | 1.20 | 1.06 | 1.94 | 3.30 | 3.73 | .261 | 3.22 | .1 | .755 | 1.59 | 5.93 | 334. | 61.5 |
| 1.08 | 20.0 | 1.33 | 11.35 | .478 | 4.2 | 9.16 | .13 | .37 | .561 | 4.92 | .054 | .405 | 1.25 | .46 | 2.3 | 4.8 |
| | | 2.18 | 7.93 | .607 | 2.3 | 5.02 | .70 | 2.0 | .381 | 3.85 | .076 | .58 | 1.386 | 2.77 | 13.8 | 28.7 |
| | | 3.06 | 4.94 | .720 | 1.6 | 2.80 | 2.1 | 6.03 | .291 | 3.24 | .098 | .74 | 1.536 | 9.26 | 46.3 | 95.9 |
| | | 3.91 | 3.86 | .820 | 1.36 | 2.18 | 3.1 | 8.90 | .237 | 2.87 | .116 | .92 | 1.62 | 14.4 | 72.0 | 149.2 |
| | | 5.01 | 3.01 | .924 | 1.22 | 1.71 | 4.2 | 12.05 | .200 | 2.54 | .143 | 1.11 | 1.81 | 21.8 | 109.0 | 226.0 |
| .755 | 50.0 | 1.33 | 7.94 | .334 | 10.5 | 16.0 | .015 | .187 | .392 | 3.47 | .088 | .65 | 1.42 | .26 | .5 | 2.74 |
| | | 2.18 | 4.85 | .424 | 5.8 | 7.72 | .225 | 2.80 | .266 | 2.71 | .128 | .98 | 1.65 | 4.62 | 9.2 | 47.8 |
| | | 3.06 | 3.45 | .503 | 3.65 | 4.45 | .90 | 11.2 | .203 | 2.28 | .172 | 1.32 | 1.92 | 21.5 | 43.0 | 223 |
| | | 3.91 | 2.70 | .571 | 2.65 | 2.98 | 1.85 | 23.0 | .165 | 2.02 | .218 | 1.67 | 2.22 | 51.0 | 102.0 | 528 |
| | | 5.01 | 2.11 | .645 | 2.0 | 1.96 | 3.55 | 44.1 | .140 | 1.78 | .285 | 2.10 | 2.73 | 120.4 | 240.8 | 1248 |
| .427 | .248 | 1.33 | 4.49 | .189 | 40.0 | 34.5 | .0 | -- | .222 | 1.56 | .385 | 2.60 | 3.10 | -- | -- | -- |
| | | 2.18 | 2.74 | .240 | 23.5 | 17.7 | .006 | .017 | .151 | 1.22 | .63 | 3.95 | 5.06 | .09 | .04 | .89 |
| | | 3.06 | 1.95 | .285 | 15.6 | 10.75 | .062 | .16 | .115 | 1.02 | 1.7 | 8.50 | 14.70 | 2.35 | 9.46 | 24.3 |
| | | 3.91 | 1.52 | .324 | 11.3 | 7.15 | .25 | .65 | .094 | .91 | 2.75 | 12.2 | 25.3 | 16.5 | 66.5 | 171 |
| | | 5.01 | 1.19 | .365 | 8.5 | 4.70 | .73 | 1.9 | .079 | .80 | 5.10 | 19.3 | 50.3 | 95.5 | 385. | 987 |

| $\kappa_b'$ | Tons / Day $\Sigma i_T Q_T$ |
|---|---|
| 1.33 | 12.9 |
| 2.18 | 97.7 |
| 3.06 | 375.6 |
| 3.91 | 892.3 |
| 5.01 | 2522.5 |