MODEL INVESTIGATION
OF THE
SILT EXCLUDER SYSTEM
FOR THE
TRIMMU - SIDHNAI LINK

INDUS BASIN PROJECT
WEST PAKISTAN

Prepared for

Tipton and Kalmbach, Inc.
Consulting Engineers
Denver, Colorado

Colorado State University Research Foundation
Civil Engineering Section
Hydraulics Laboratory

October 1962

CER62SSK58

MODEL INVESTIGATION
OF THE
SILT EXCLUDER SYSTEM
FOR THE
TRIMMU-SIDHNAI LINK

INDUS BASIN PROJECT
WEST PAKISTAN

Prepared for
Tipton and Kalmbach, Inc.
Consulting Engineers
Denver, Colorado

by
S. S. Karaki
and
R. M. Haynie

Colorado State University Research Foundation
Civil Engineering Section
Hydraulics Laboratory

CONTENTS

FIGURES

TABLE

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 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.

REPORT SUMMARY

A model study of modifications to the existing silt excluder of the Haveli Link Canal headworks to meet the needs of silt control at the Trimmu-Sidhnai headworks was performed 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 head regulator of the Haveli Canal is located on the Chenab River at Emerson Barrage immediately downstream from the confluence with the Jhelum River. The head regulator of the proposed Trimmu-Sidhnai Link Canal will be adjacent to and upstream of existing works. Preliminary model studies conducted in Pakistan indicated that with the existing sediment excluder, when the Trimmu-Sidhnai Link was installed, the sediment load entering the Haveli Link could be expected to increase significantly. This observation was verified in the subject model study. Existing conditions in the Haveli Link are such that no appreciable increase in the sediment load is permissible and sediment load in Trimmu-Sidhnai (T-S) Link is to be minimized. Therefore, this study was undertaken in an attempt to arrive at some scheme of modifying the existing excluder system which would be satisfactory to both canal systems.

The study was conducted in a distorted sectional model including approximately one-fifth of the total barrage. The horizontal scale of the model was 1:120, model to prototype, and the vertical scale was 1:25. The various modifications of the sediment excluder in the model were compared with the same river discharge and pond level.

Based upon the laboratory data and observations of sediment movement in the vicinity of the silt excluder, assuming:

1. that the centerline of the Trimmu-Sidhnai head regulator structure, normal to the canal centerline, will be along the same line as the centerline of the Haveli regulator, and
2. that the centerlines of the two canals will be 330 ft apart,

it is recommended that:

1. the existing intermediate divide wall be removed;
2. the outer existing wall remain intact;
3. the exclusion (sluice) tunnels should be extended upstream in the manner shown in Fig. 25. The top of the tunnel roof slab of the extension should be maintained at elevation 481 with a horizontally curved shape with a radius of 415.79 ft as shown in the figure;
4. subdivisions of the four main tunnels in the extended section resulting in eight under-sluices will not hydraulically alter the performance of the silt excluder if structurally this should be desirable. If possible the main tunnels should be maintained at four to permit positive sluicing of the tunnels;
5. the existing island immediately upstream of the silt excluder structure be removed to improve the approaching flow pattern so that much of the sediment (bed load) can be transported away from the silt excluder structure and the head regulators;
6. the left guide wall in the river approach to the Trimmu-Sidhnai head regulator, recommended by the Pakistan model study, is satisfactory provided a wing wall at the entrance to the head regulator is constructed above elevation 485. The left guide wall shown in Fig. 7 is basically a curved wall, below the water surface extending only to elevation 485. The wing wall at the entrance is shown in Fig. 25.

As an alternative to the recommended silt excluder, it is suggested that simpler construction could be effected by extending under-sluices 1 and 2 only as shown in Fig. 22. The extension of only two sluice tunnels does not create the same advantageous approach flow pattern as the recommended structure with regard to transporting bed load toward the barrage. Sediment will tend to deposit upstream of sluices 3 and 4 and probably will require more frequent flushing than the recommended structure to minimize sediment entry into the links. The chief difference in location of sediment deposit between the recommended structure and the alternative would mean less sediment entry into the canal.

INTRODUCTION

The Trimmu-Sidhnai (abbreviated hereafter as T-S) link canal will be constructed with the head regulator adjacent to the existing Haveli Canal. Because of desirable operational procedures of the canals, although the two canals are adjacent to each other, a separate head regulator will be constructed for the new T-S link. Increase in offtake discharge from the river requires alteration of the head works, specifically the silt excluder, if sediment problems are to be minimized in both canals. A greater offtake discharge generates greater local approach velocities in the river which in turn will transport greater quantities of sediment into the existing Haveli Canal unless a structure is constructed to reduce sediment entry into the canals.

Some studies conducted in Pakistan in a small scale model of the entire Emerson Barrage and the approach river section on a 1:250 horizontal scale (model to prototype) distorted vertical scale model indicated that unless some specific alteration was made to the existing excluder structure the Haveli sediment load would increase very appreciably by addition of the T-S canal.

A sectional model of only the head regulators and approximately one-fifth of the total Emerson Barrage was constructed at the Hydraulics Laboratory of Colorado State University to study in greater detail the silt exclusion problem for the combined Haveli - T-S headworks to arrive at a favorable solution for minimizing sediment (bed-material load) entry into the two canals. In general, the objective of the study was to maintain or possibly minimize the sediment load in the Haveli Canal compared to existing conditions and to develop an effective excluder for the combined headworks.

THE MODEL

Distortion of a river model is often a necessity. By geometric distortion it becomes possible to effectively reproduce turbulent flow conditions which would not easily be possible to attain in a comparably sized undistorted model. Distortion of the model permits greater flow velocities necessary for movement of sediment. When a model is geometrically distorted, unavoidably other distortions are introduced. In order to reproduce prototype conditions as nearly as possible it is often expedient to make the other necessary adjustments through trial and error procedures.

A distorted model was deemed necessary for this study. The horizontal scale of 1:120 (model to prototype) was determined on the basis of available space and necessary physical coverage of the river. The vertical scale was then selected so that depth, and subsequently velocity of flow in the model would be sufficient to create favorable flow velocities for movement of sediment.

A sectional model was constructed, primarily because of limited space. However, since the problem was localized at the canal head regulators, it was deemed prudent to construct only that portion of the river, and canal head works including Emerson Barrage necessary for the study, particularly since a complete model of the river and diversion works had been constructed and were under tests in Pakistan. The tests in Pakistan included other phases of the total problem. The limits of the model are shown as a portion of the general plan of the site in Fig. 1.

In order to control flow direction in the sectional model a system of gates and baffles was devised so that the discharge through each section of the model could be regulated independently. There was no specific effort to reproduce flow patterns of the prototype exactly because (a) no prototype data were available with regard to flow velocities or direction, (b) discharge distributions around the island were not known, and (c) barrage gate regulation procedures were not specified. An attempt was made however to establish flow direction in accordance with pictoral views of the Pakistan model for similar discharges used in this model.

The various excluder schemes were studied by comparison with the existing structure and with other excluder schemes. Results are comparable only at similar discharges and although flow distribution into the model at a particular discharge was maintained the same for the various schemes, flow patterns in the model varied because of the effects of the various structural alterations in the vicinity of the excluders. The alterations included removing of existing divide walls, removal of the island, introduction of a new left guide wall and introduction of the Trimmu-Sidhnai head regulator. A schematic plan of the model is shown in Fig. 2.

The model was constructed with pumped recirculated clear water. The bed of the model was

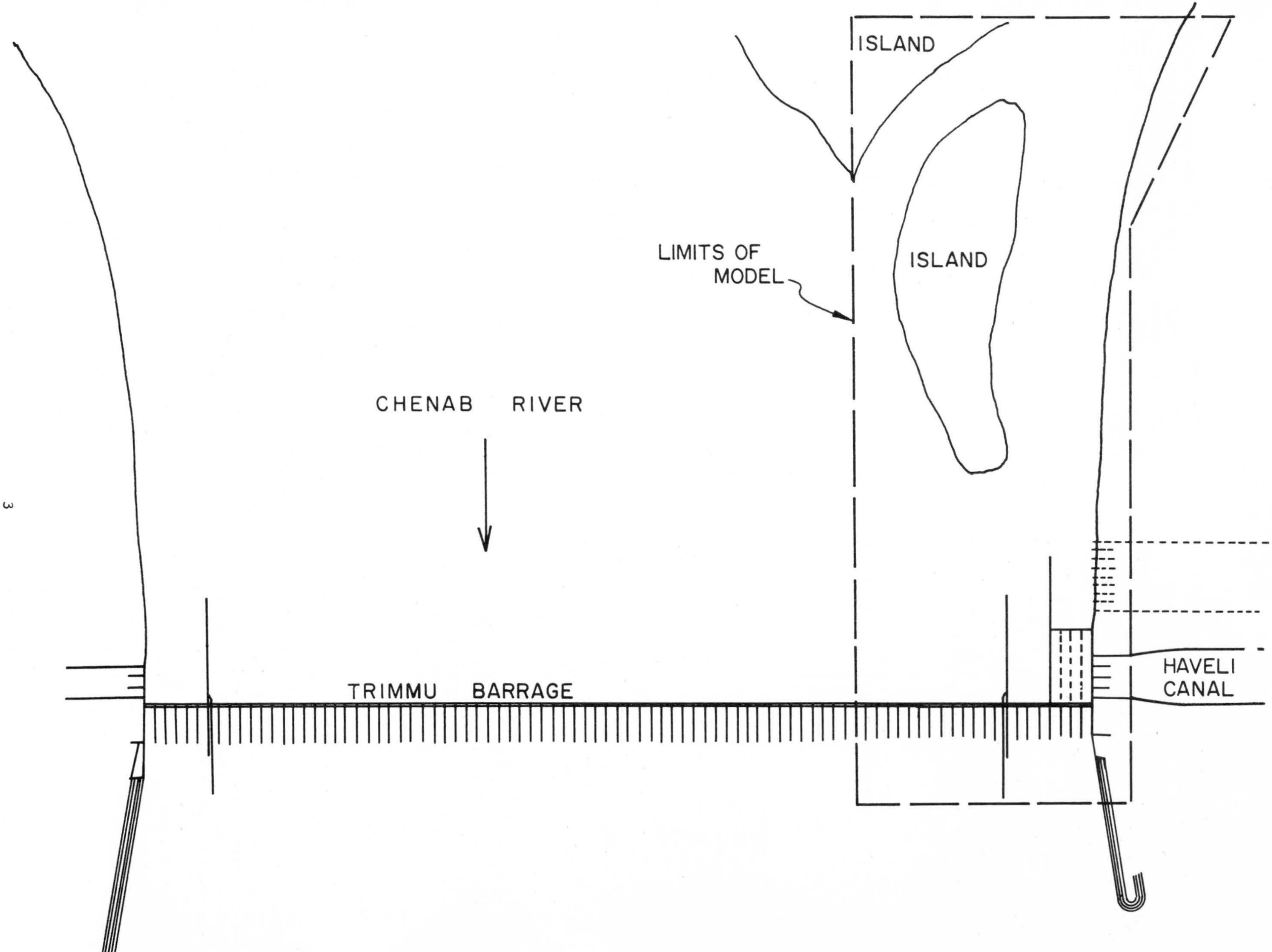
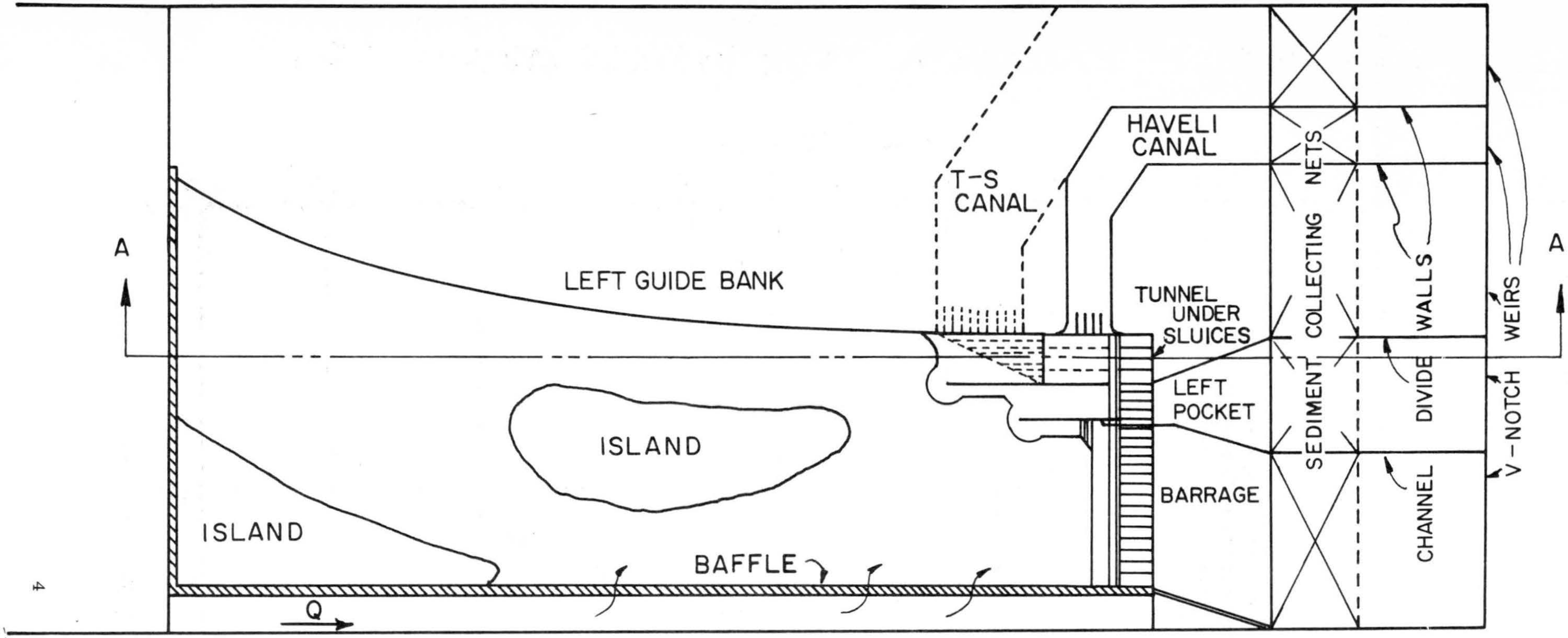
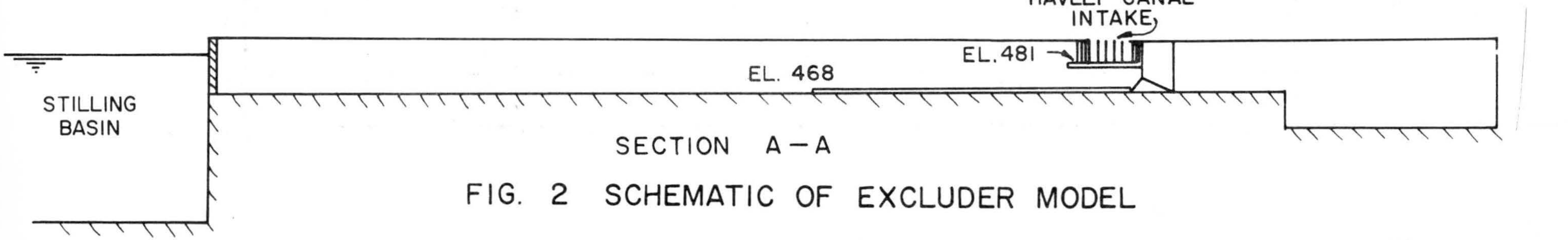


FIG. 1 EXTENT OF MODEL COVERAGE





SECTION A — A

FIG. 2 SCHEMATIC OF EXCLUDER MODEL

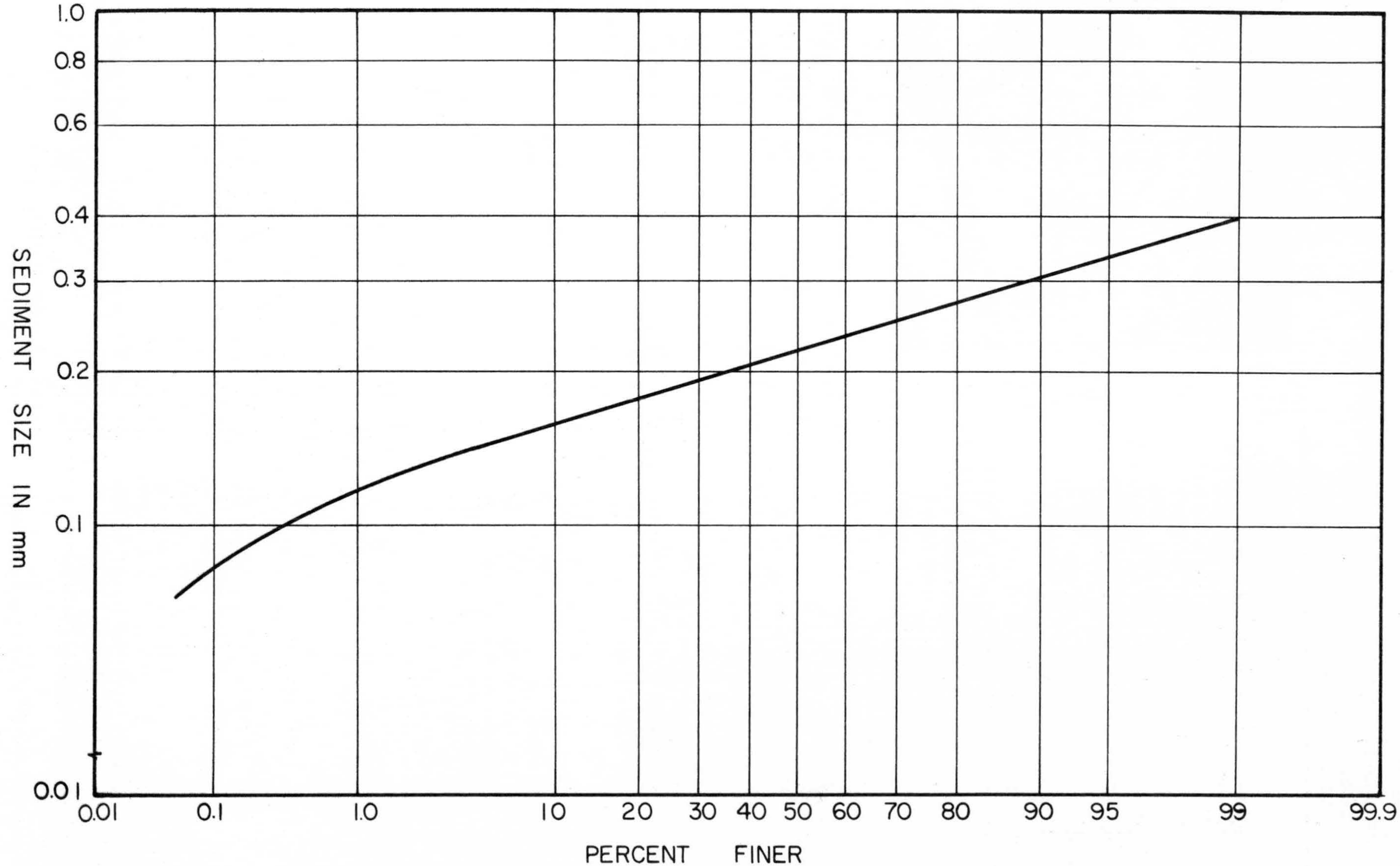


FIG. 3 SEDIMENT EXCLUDER MODEL SEDIMENT SIZE DISTRIBUTION CURVE

formed of fine sand having a median diameter of 0.23 mm. A size distribution curve for the sand is shown in Fig. 3. Although the quantity of sand movement was purposely designed to be small, the sand bed provided a moveable boundary and local points of scour and deposition were better identified. Plastic pellets, cylindrical in shape, 1/8" in diameter and 1/8" long were used to represent the bed material load in the river. The specific gravity of the pellets was about 1.05, varying between 1.04 and 1.06. Because of the light weight of the plastic particles, some floated on the water surface due to surface tension, other particles remained suspended in the flow and portions were transported as bed load. The plastic pellets were introduced into the model by regulated mechanical feeders shown in Fig. 4 and reclaimed downstream of the model from a screened trapping device. To prevent excessive quantities of the plastic particles from floating, the pellets were soaked in an offline container for a period between 48 and 72 hours before use. Reclaimed pellets were re-admitted to the soaking vats for re-use. Even with this precaution preliminary tests resulted in excessive floating particles because individual pellets dried out while in the hoppers of the mechanical feeders. The problem was satisfactorily solved by placing a screen in front of the line of feeders as seen in Fig. 4, and applying a mist of spray of water upstream of the screen. The screen necessitated the pellets to flow below the water surface and the spray wetted the pellets upstream of the screen to ensure submergence.

Flow into the model was measured by an orifice meter, and flow out of the model, divided into five separate channels shown in Fig. 2 was measured over V-notch weirs. This enabled separate control and measurement of flow through the T-S head regulator, the Haveli head regulator, the four under sluice gates, the four gates adjacent to the under sluice tunnel and the flow through the barrage. The gates in each of these segments were raised equally as possible to prevent arbitrary flow distribution in the river approach not directly comparable from one test to another. The quantity of sediment passing through each of the five flow channels were collected individually and weighed. The amount of sediment flowing into the canals was expressed as a percentage of the total sediment collected during the test period. The effectiveness of the individual excluder schemes were determined by comparison with other schemes.

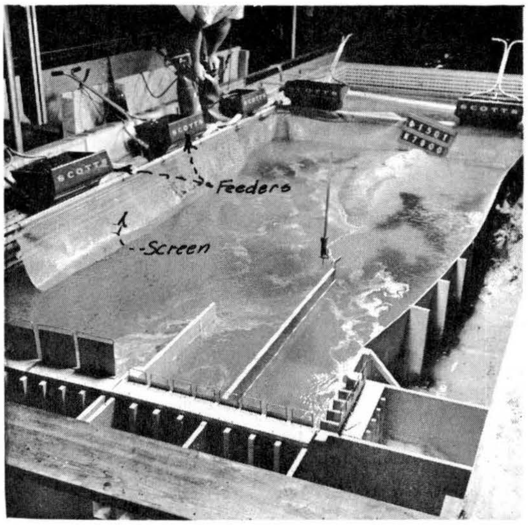


Fig. 4. View of sediment feeders used in model and screen in front of the feeders to ensure submergence of plastic particles.

Three river discharges were represented in the model at 75,000, 150,000 and about 250,000 cfs. To determine model discharges, it was necessary to assume that total river flows, less the off-take discharges, flowed over the barrage with the left and right under sluices and pockets normally closed. One-fifth of this flow plus the flow in the Haveli and when applicable the Trimmu-Sidhnai Canal, was added to make up the model flow. Pond levels were varied initially between elevation 487 and 493, however, most comparative results for the various excluder schemes were made with pond level at elevation 490. Canal discharges were also initially varied, however when significant differences were not evident between different canal discharges, the discharges were set at 7000 cfs for Haveli and 12,000 cfs for the T-S link.

MODEL TESTS AND RESULTS

In this study a number of different sediment excluder schemes were investigated. Some of the minor changes were studied and discarded after observation. All of the major changes, however, were studied in detail.

Existing Conditions

To provide a basis for comparing the effectiveness of the various excluder schemes a sequence of tests were made with existing river and headworks conditions. River discharges of 75,000, 150,000 and 250,000 cfs were tested with pond levels at elevations 487, 490, and 493. For each combination of these variables, the discharge in the Haveli Canal was varied at 7000, 5000 and 3000 cfs. The amount of sediment flowing into the Haveli canal based upon the total amount of sediment flowing through the model in the same test period is presented in the form of percent in the bar charts of Fig. 5. A photograph

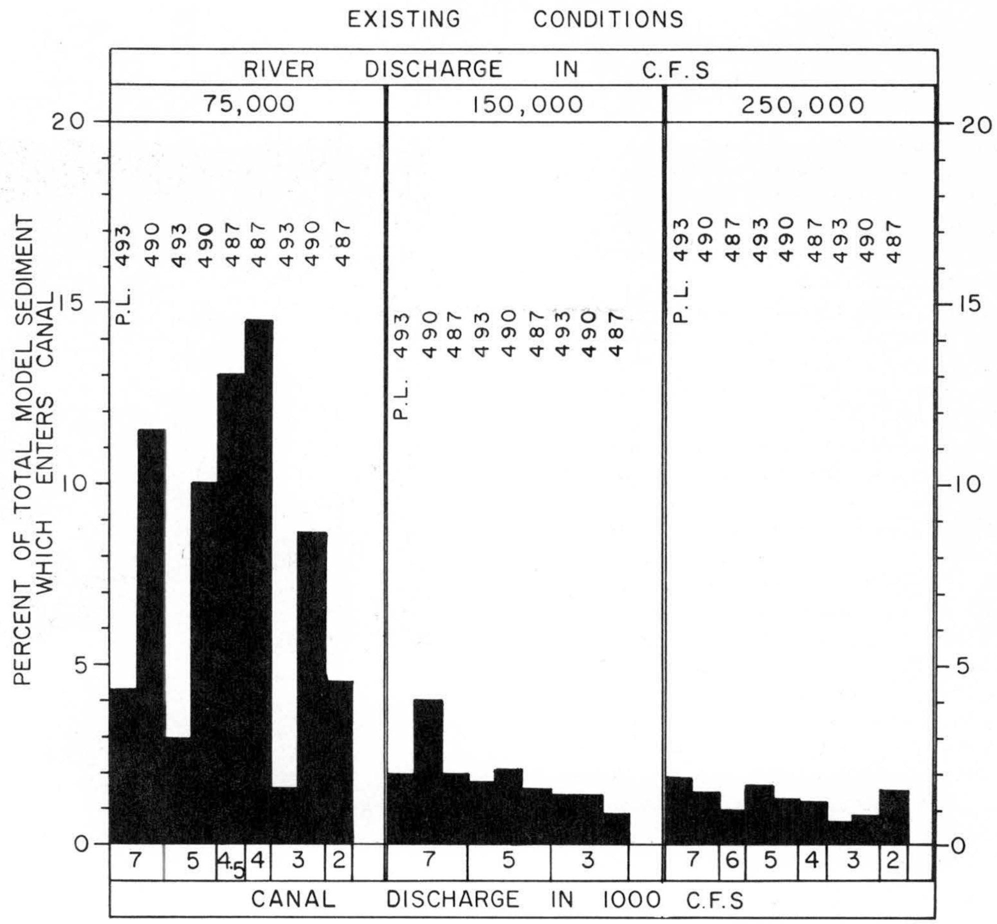


FIG. 5 PERCENT OF TOTAL SEDIMENT INTRODUCED IN THE MODEL ENTERING HAVELI CANAL

of a typical test is shown in Fig. 4 and a drawing of the existing conditions is shown in Fig. 1. The test data of all comparative schemes are tabulated in a summary table at the end of this section.

Scheme A (Contract Documents)

Scheme A refers to the plan for silt exclusion shown in the contract documents prepared by Tipton and Kalmbach, Inc. as drawing No. S2-39. It is redrawn in this report in Fig. 2 shown in dashed lines. A photograph of the model for this scheme is shown during a test in Fig. 6. The centerline of the head regulator for the T-S link is along the same centerline for the existing Haveli head regulator with the distance between centerlines of canals set at 330 ft. The only difference between the model scheme and that shown in the contract documents is that the top of the intermediate divide wall was lowered to elevation 481 instead of elevation 483 as shown in the documents. The existing sluice tunnels are extended to meet the head regulator of the T-S canal with additional internal tunnel divide walls to create 8 tunnels where formerly there were four.

From observation of the results of tests with the existing condition, it was decided to make comparison tests of the various schemes with river discharge of 150,000 cfs and pond level of elevation 490. Haveli discharge was set for 7000 cfs and the Trimmu-Sidhnai discharge at 12,000 cfs.

The tests were run first with the island in place as it presently exists but with the flow obstructed to the left of the island. Additional tests were then performed with the island removed and with a left guide wall as shown in Fig. 7. The first series involved tests with the outer divide wall undisturbed and then with the outer divide wall reduced in length to 155 ft from the weir centerline. The second series involved an additional test with the under sluice

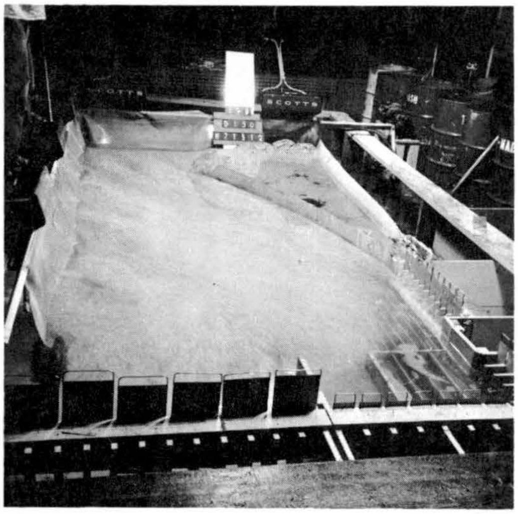


Fig. 6. Photograph of Scheme A contract documents during test. Tunnel tops were constructed of clear plastic.

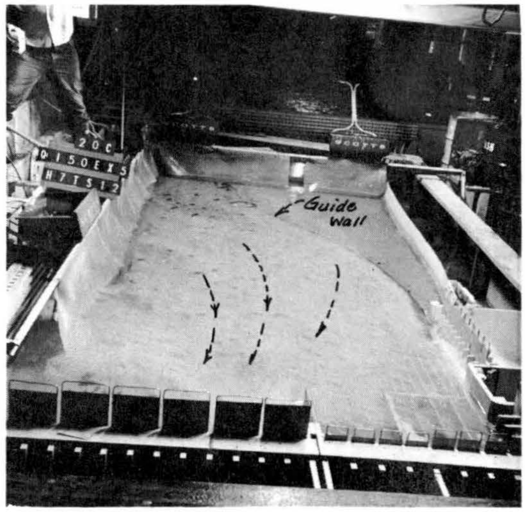


Fig. 7. Left guide wall installed in accordance with Pakistan model results. Arrows show pattern of bed-load movement.

discharging 5000 cfs. The various amounts of sediment entering both canals are shown in bar graph form in Fig. 8.

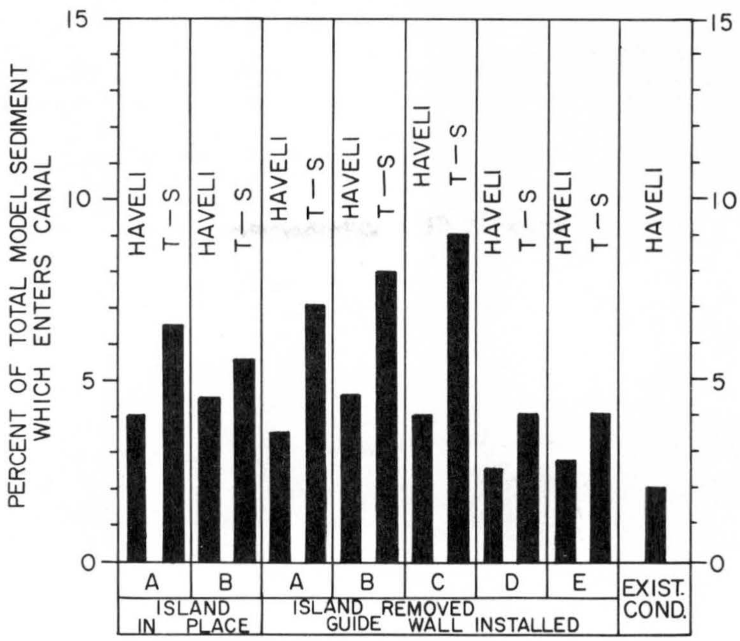
The island very definitely formed an obstruction to the canal approach. It would appear not only desirable but necessary to remove at least part of the island to develop a more favorable approach flow pattern.

The left guide wall to the head regulators as developed in the Pakistan model and tested in the second series indicated a very definite change in the flow line approach to the head regulators. By creating a greater flow approach area, the velocities in the vicinity of the outer divide wall were reduced, less sediment was suspended, and thus less material was transported into the canals. It was evident that a proper approach to the head regulators is a factor to be considered integrally with the silt excluder structure itself. With the island in place, the percent of total model sediment entering Haveli amounted to about 4 percent, while with an improved flow approach, the sediment entry was reduced to about 3.5 percent. Sediment entry into the T-S canal however was not materially altered. A decrease in length of the outer divide wall served to increase the sediment entry into Haveli by about 1 percent and decreased sediment entry into the T-S link by about the same amount. Operation of the sluice tunnels increased sediment entry into both canals by about 1/2 percent, resulting largely from the greater approach flow velocities in the river which suspended a greater amount of sediment in the flow. In all tests the sediment entry into Haveli increased slightly in comparison to the tests with existing conditions.

A curtain wall, 4 ft in height installed across the openings of the tunnels from elevation 481 to elevation 477 proved to reduce the amount of sediment entering both canals. The effect of the curtain wall was to provide a flow deflector which created a pronounced curvature in the approach flow and with it development of a strong secondary current which carried the bed load away from the head regulator toward the barrage at the right of the outer divide wall. A photograph which attempts to show the surface flow pattern is shown in Fig. 9.

SCHEME A (Contract Documents)

RIVER DISCHARGE - 150,000 C.F.S.



EXPLANATION OF CODE LETTERS

A. Existing outer divide wall

B. Outer divide wall reduced to 155 ft.

C. Outer wall reduced to 155 ft.
Sluices 1 – 4 discharging 5000 c.f.s.

D. 4 feet drop curtain across tunnel openings with existing outer divide wall

E. 4 feet drop curtain with 155 ft. outer wall

FIG. 8 COMPARATIVE EFFECTS OF ALTERATIONS TO SCHEME A (Cont. Documents)

Scheme A Modification I

This scheme differs from the contract documents only in the shape and elevation of the tunnel extension roof slab as shown in Fig. 10. While the existing roof slab of the sluice tunnels is at elevation 481 this modification lowered the extension to elevation 475. A photograph of the model for this scheme is shown in Fig. 11.

The modification resulted in reduced sediment entry into both canals as indicated in the bar graph Fig. 12. The improvement was largely due to reduced velocities above the tunnel roof in the immediate vicinity of the T-S head regulator, causing less suspension of bed material and less carry-over into both canals. The extremities of the sluice tunnels with respect to the outer divide wall also was significant in that it permited the approach flow to be

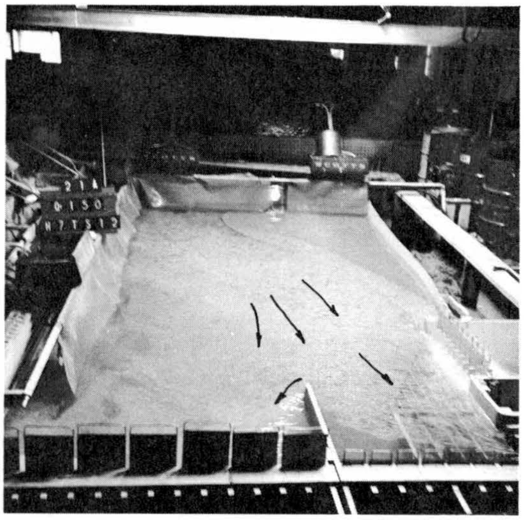


Fig. 9. Surface flow pattern of Scheme A (Cont. Doc.) with 4' drop curtain and existing outer wall.

diverted causing greater flow curvature and stronger secondary current. With a stronger secondary current more bed load was transported over the barrage away from the head regulators. Reduction in the length of the outer divide wall resulted in slightly increased sediment load into Haveli and reduced sediment load into the T-S canal.

With the elevation of the tunnel extension at 475, there was a greater tendency for deposition of sediment on the tunnel roof slab, which in operation may require some method of determining when sluicing would be necessary. If the sediment is allowed to deposit in quantity above the extended sluice tunnels, the sediment load into the canals would increase. The difference in elevations between the existing tunnel roof slab and the tunnel extension namely 6 ft from 481 to 475, would enable sluicing of the deposit on the tunnel extension. Sluicing, that deposit of sediment however, would not be completely effective because the area of the roof slab and distance from the opening at the beginning of the tunnel extension is large.

Some modifications involving upstream bed vanes, and surface vanes were attempted but from visual observations and comparisons it was concluded that vanes of either type would not be materially effective in directing the bed material away from the head regulators. In fact in some cases sediment load into the canals increased because of the increase in turbulence over, around and under the vanes, which created greater suspension of sediment in the flow.

One of the alterations to the basic scheme attempted was to place a sill on the extension roof slab to a height of elevation 481 as shown in Fig. 10, with the hope that this would tend to increase the secondary circulation of flow in the vicinity of the silt excluder, hopefully to direct more of the bed load over the barrage. The result however was to increase the sediment into both the canals because the sill created turbulence and material which normally would have deposited on the roof slab was suspended in the flow and carried into the canals. The effect is shown in Fig. 12 C as compared to A.

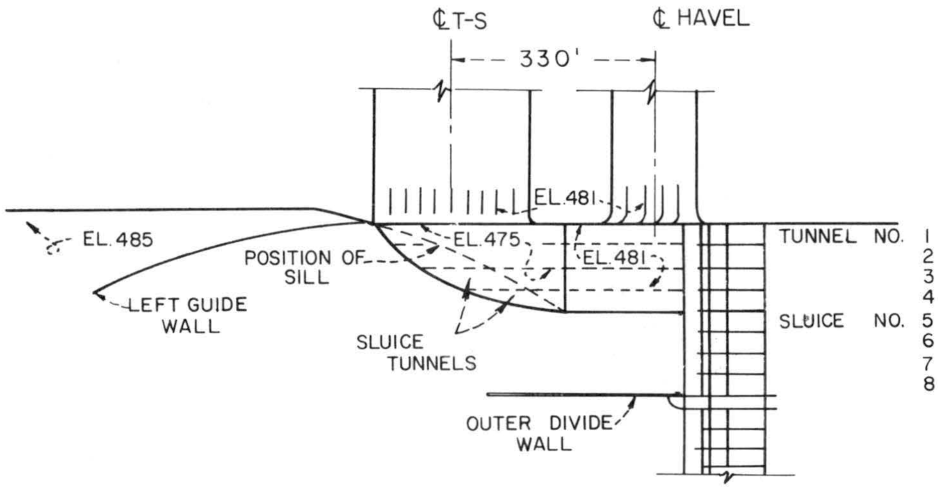


FIG. 10 SCHEME A MODIFICATION I CURVED TUNNEL TOP

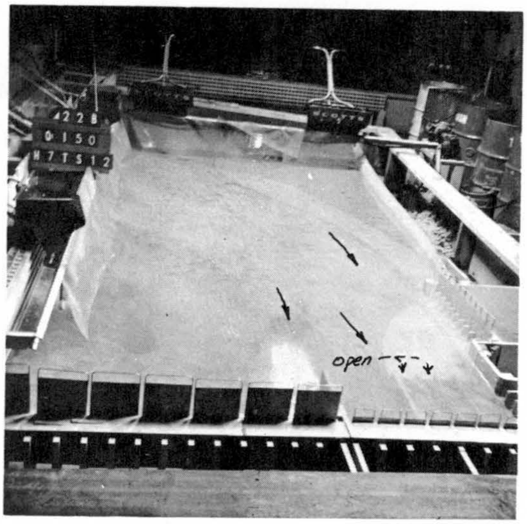


Fig. 11. Scheme A Modification I during test with shortened outer divide wall. The difference in tunnel top elevation between the extension and existing sluice tunnels can be seen.

Operation of the sluice tunnels did not effectively reduce sediment entry into the canals. As in the tests of Scheme A, contract documents, the increased velocities of approach in the river produced increased sediment entry into the Haveli Canal.

Scheme A Modifications II and III

The tunnel extension roof of Modification I of Scheme A was raised successively in Modifications II and III to elevation 478 and 481 respectively. Photographs of the model arrangements are shown in Figs. 13

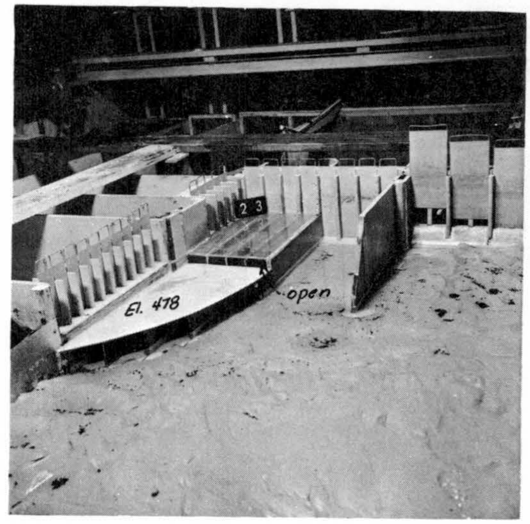


Fig. 13. Scheme A Modification II. Tunnel extension roof raised to elevation 478.

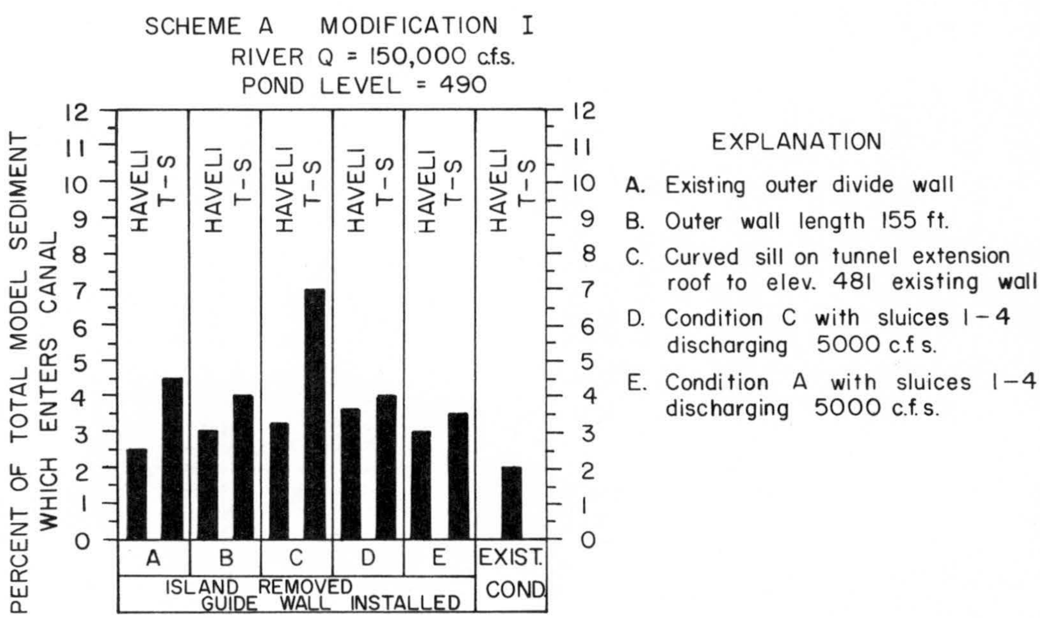


FIG. 12 COMPARATIVE RESULTS OF SCHEME A MODIFICATION I. REDUCTION OF SEDIMENT IN CANALS COMPARED TO FIG. 11

and 14. Modification II resulted in reduced sediment entry into both canals when compared with Modification I. The sediment entry into Haveli was less than that recorded for the existing condition. The percent of sediment into the T-S canal was approximately twice that in Haveli, or about 2 to 2.5 percent of the total sediment introduced into the model. This compares with about 2 percent entering Haveli with the existing conditions.

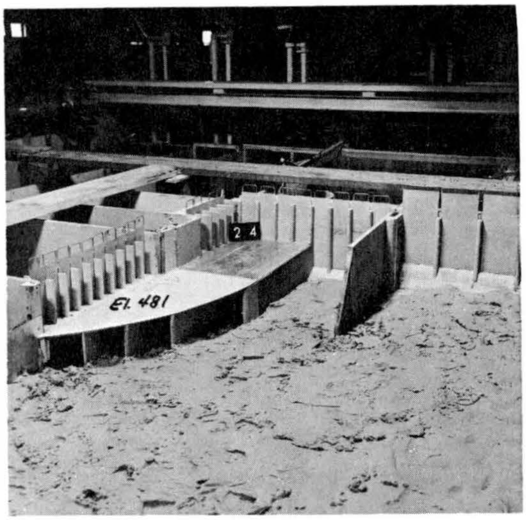


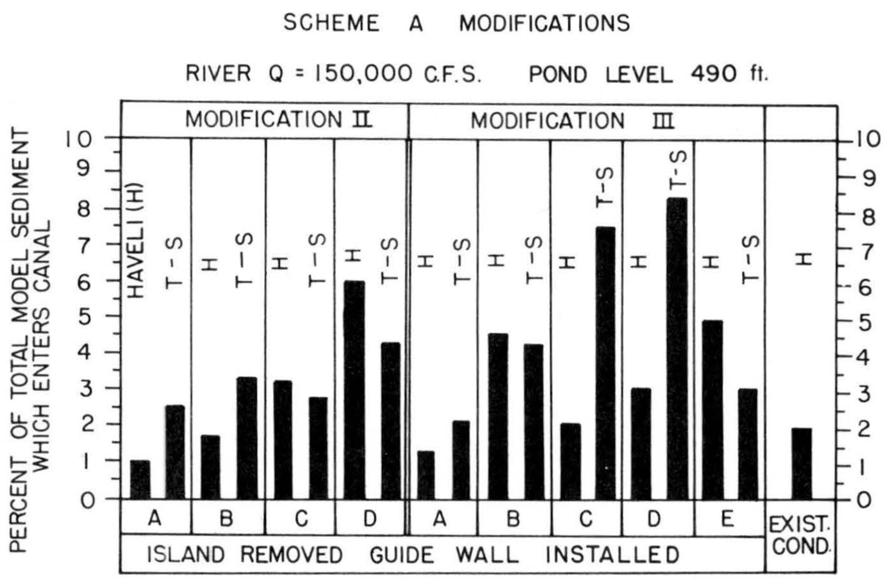
Fig. 14. Scheme A Modification III. Tunnel extension roof raised to elevation 481.

The basic difference between Modifications II and III was that Modification III resulted in greater flow deflection at the silt excluder, creating in turn greater secondary circulation. This secondary circulation directed more of the bed material load in the river away from the head regulators toward the barrage. The results of the modifications are depicted in the bar graphs of Fig. 15. The left guide wall was installed as recommended from the Pakistan model study. Reducing the length of the outer divide wall to 155 feet increased the sediment load into both canals. Opening either set of sluice gates, 1 to 4 or 5 to 8 served only to increase the sediment into the canals. Under these circumstances it may be advisable to reduce the discharge rates in both canals while sluicing deposits of sediment from the vicinity of the exclusion structure.

Figure 16 shows schematically the difference in the effect of the height of the tunnel extension on the deflection of bed load toward the barrage. The higher elevation of Modification III deflected the bed load toward the barrage from a point further upstream than Modification II. The solid arrows indicate the trend in bed-load movement with Modification III.

Scheme A Modification IV

A series of tests were conducted with the centerline of the T-S head regulator set back 50 ft from the head regulator of Haveli with the basic



EXPLANATION :

A. Basic modification with existing outer divide wall

B. Outer divide wall reduced to 155 ft.

C. Existing outer wall with sluices 1-4 discharging 5000 ft.

D. Existing outer wall with sluices 5-8 discharging 5000 ft. sluices 1-4 closed

E. Lowered outer wall to El. 485

FIG. 15 RESULTS OF SCHEME A MODIFICATION II AND III REDUCTION OF SEDIMENT IN CANALS COMPARED TO EXISTING CONDITON

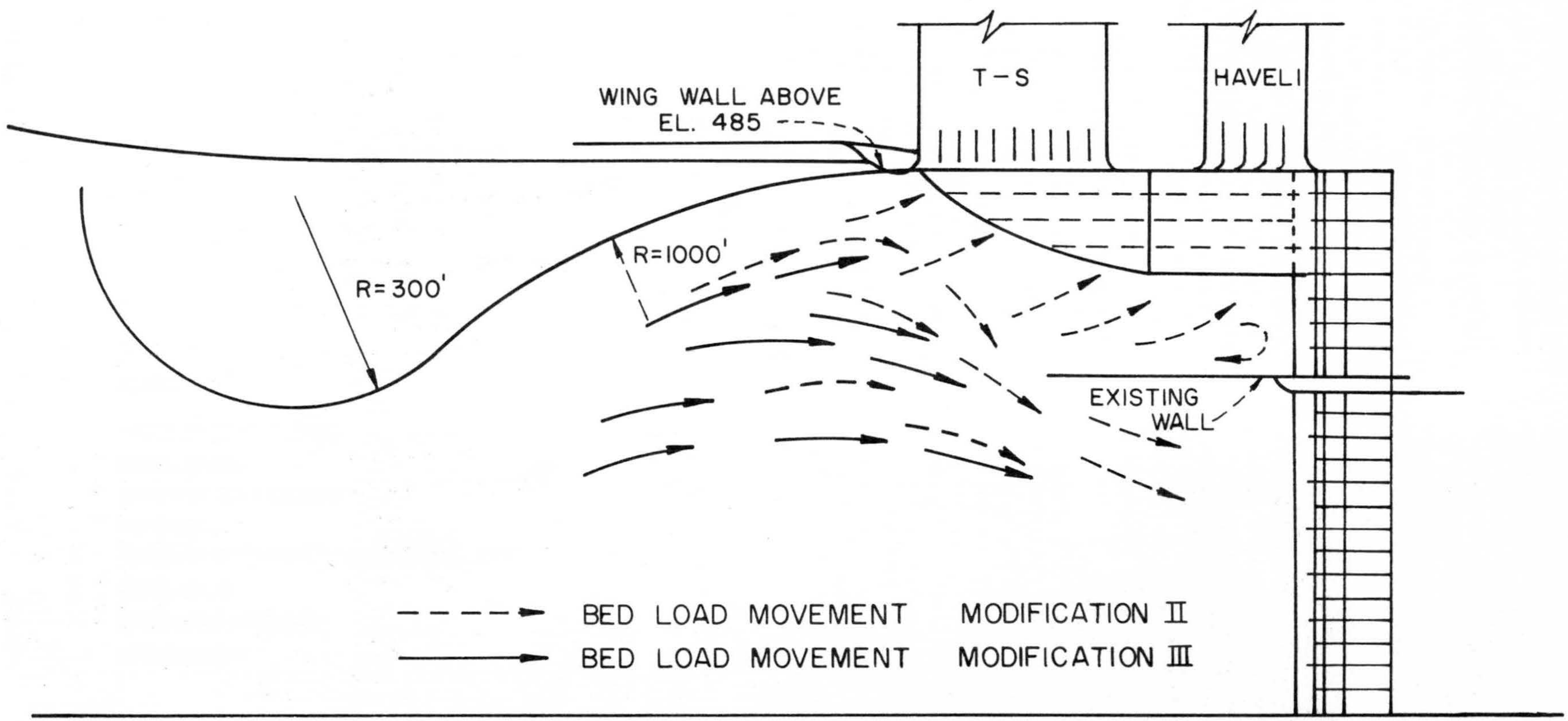


FIG. 16 COMPARATIVE BED LOAD MOVEMENTS WITH MODIFICATIONS II AND III. NOTE THAT BED LOAD TURNS FARTHER UPSTREAM WITH MODIFICATION III BECAUSE OF GREATER DEFLECTING EFFECT OF THE HIGHER TUNNEL TOP ELEVATION

Modification I of Scheme A. Although the sediment percentages into the canals are not directly comparable to Modification I because the island was not removed, visual observations indicated no significant improvement with the head regulator set back. The slightly greater approach flow area created by the set back of 50 feet would create slightly less river approach velocities, but the effect on deposition of suspended sediment would not be significantly different from say Scheme A Modification I, II or III.

The results of this series of tests are comparable to the tests of Scheme A, contract documents, (Fig. 8) with the island in place. In this comparison there was little or no significant difference in the percentage of sediment entering the Haveli while sediment in the T-S increased markedly. The sediment into Haveli was approximately twice that of the existing conditions.

In an attempt to increase the flow area immediately upstream of the T-S head regulator, thus reduce velocities and increase sediment deposition there, the tunnel extension was removed. As the result in Fig. 17 shows, they did not decrease sediment entry into the canals significantly. The opening in the sluice tunnel created by the difference in elevations of the existing tunnels and the extensions were closed off. This did not decrease sediment in the canals. Observations of sediment movement in the model during these tests tended to confirm that the greatest silt exclusion could be effected by creating a favorable curved flow pattern in the river approach, with as simple an exclusion structure as possible to prevent flow disturbance and unnecessary suspension of bed material which could be conveyed into the canals.

Extension of Excluder Tunnels to Outer Divide Wall

The excluder tunnels were extended laterally across sluice gates 1 through 8 to the outer divide wall. The change is shown pictorially in Fig. 18. The top of the tunnel slab was set at elevation 481. This scheme resulted in favorable movement of bed load toward the barrage in the river approach channel but did not compare favorably with canal sediment load of Scheme A Modification III. The percent results of the tests are given in Fig. 19. Because of the lack of improvement over, say, Scheme A Modification III the larger structure in comparison is unjustified.

No Exclusion Tunnel Extension

Tests were conducted with a structural arrangement of the excluder involving removal of the intermediate divide wall and no sluice tunnel extension beyond the existing length. The results are shown in Fig. 20. Without the tunnel extension the curved flow pattern and favorable secondary circulation near the head regulators was not pronounced and the pattern of bed-load movement indicated the change. Sediment load in both canals increased. The photograph of Fig. 21, taken during a test run with the existing length of outer divide wall shows, by arrows, that the bed load was transported past the T-S head regulator and almost to the existing sluice tunnels before turning. This path or pattern provides more

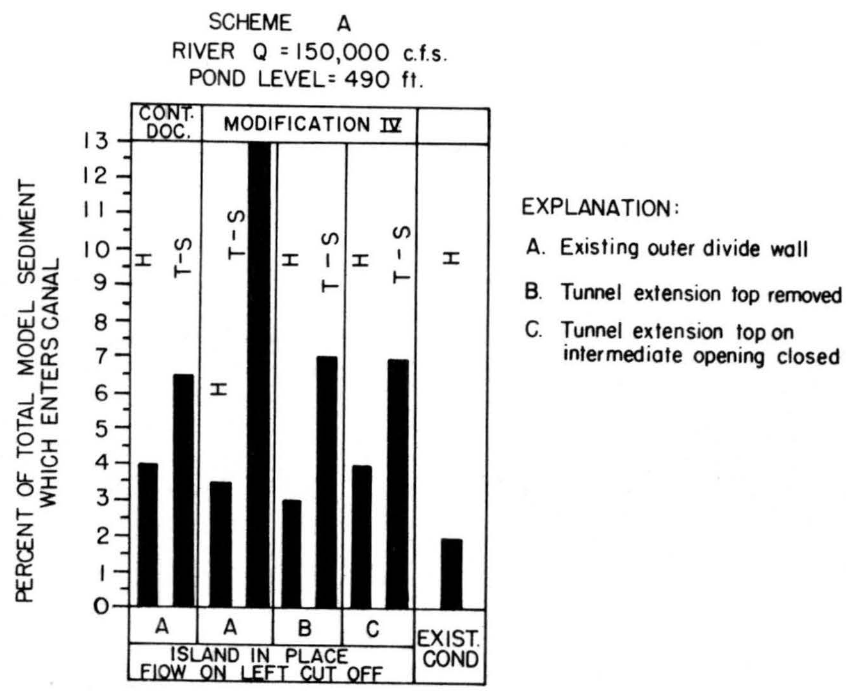


FIG. 17 SCHEME A MODIFICATION IV. T-S CANAL SET BACK 50 ft.

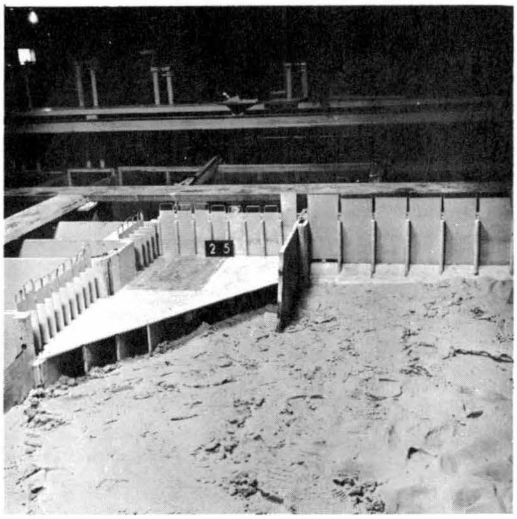


Fig. 18. Sluice tunnels extended to include left pocket area.

opportunity for transport of bed material into the canals than the pattern created by Scheme A Modification III.

Extension of Tunnels 1 and 2 Only

In the interest of providing the least structure necessary for the greatest silt exclusion possible, tunnels 1 and 2 only were extended in a manner shown in Fig. 22. Tunnel 1 was extended to the upstream, or left side of the T-S head regulator and Tunnel 2 was 40 ft shorter. The tops of both tunnels were at elevation 481, the same as the existing level.

The movement of bed load away from the head regulators was not so pronounced as in Scheme A or its modifications and as a result sediment entry into Haveli was greater than the previous schemes. At the same time, sediment entry into the T-S Canal was less, as less turbulence was created near the entrance to this head regulator. The pattern of bed-load movement is shown in Figs. 22 and 23. The

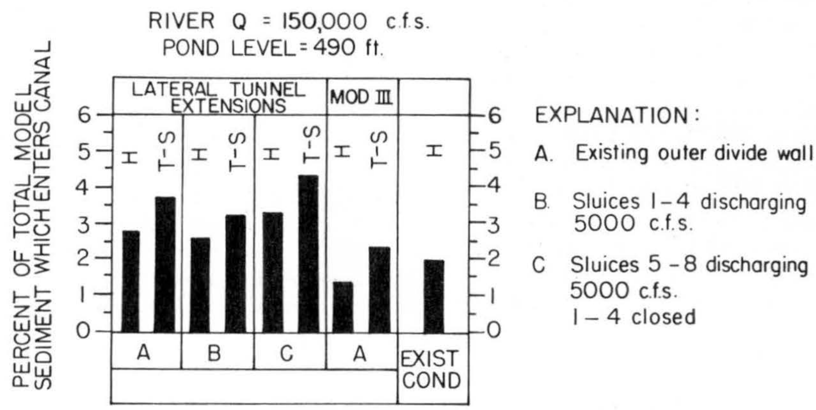


FIG. 19 RESULTS OF TUNNEL EXTENSIONS LATERALLY TO INCLUDE SLUICES 5 TO 8

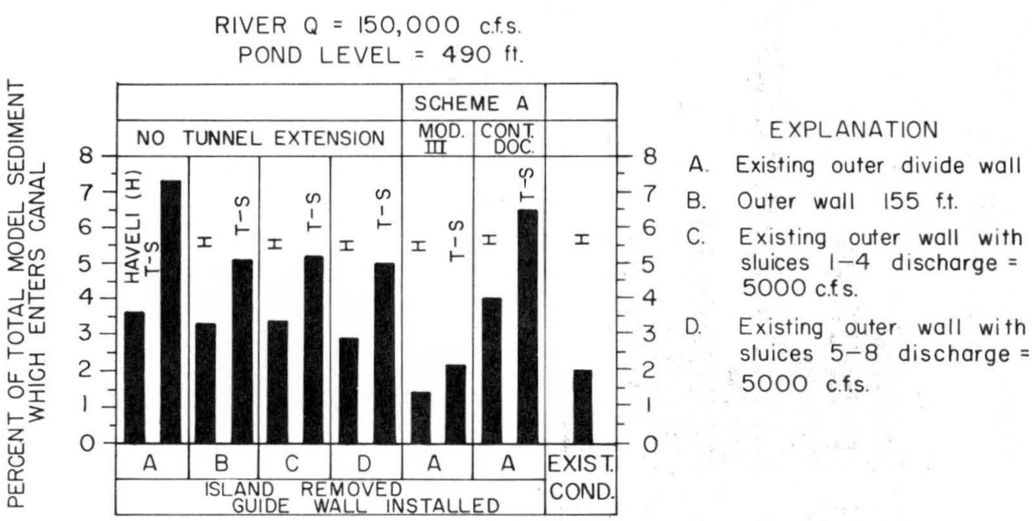


FIG. 20 COMPARATIVE RESULTS OF CHANGES IN EXISTING STRUCTURE WITH NO TUNNEL EXTENSION, WITH SCHEME A CONTR. DOC. AND WITH MODIFICATION III

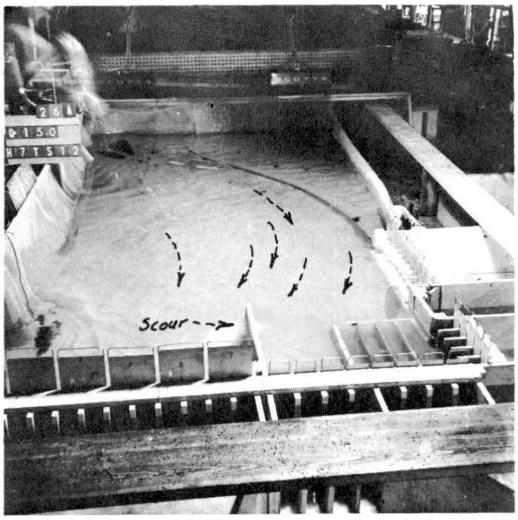


Fig. 21. Intermediate wall removed. No sluice tunnel extension.

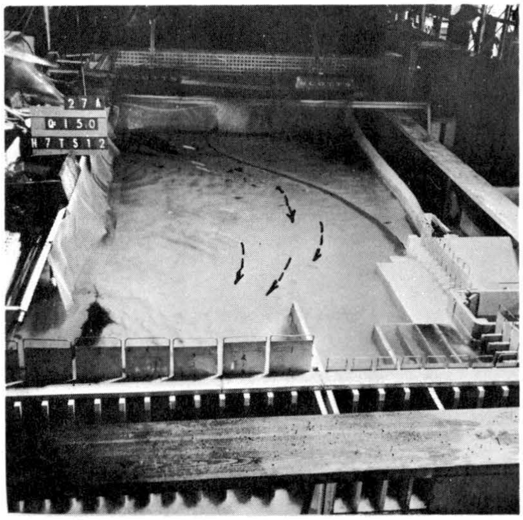


Fig. 23. Pattern of flow with existing outer divide wall and no sluices operating.

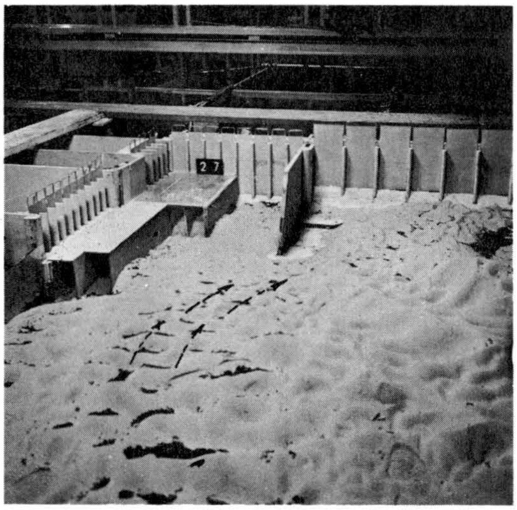


Fig. 22. Extension of tunnels 1 and 2 only. Tunnel No. 2 is set back 40 ft from the end of Tunnel 1. Tunnel 1 is even with the end of the T-S head regulator.

scheme was not as favorable as Scheme A Modification III but the slight increase in sediment load into Haveli which is offset by the reduction in cost of construction may be worth consideration as an alternative to Scheme A Modification III. The results are graphically shown in Fig. 24 with a comparison to Scheme A Modification III.

Comparative Summary

The results of all of the various schemes and modifications are tabulated for ease in comparison and reference is made directly to the various schemes. In addition to results previously shown in graphical forms, other test results are also given in the table.

General Observations

The results of this model study should not be attempted to be scaled to prototype. The model was designed and tested to compare relative improvement or advantages of various excluder structures and head regulator positions. Further, the test results of different river discharge conditions are not comparable one from another, for the sediment quantities in this sectional model are not necessarily in proper proportion to the prototype. The recommended silt excluder is based as much upon observation of flow conditions and sediment movement as it is on recorded data of the kind shown in the figures and table of this report.

It is to be noted in comparing the results of tests with different river discharges that the percentage of sediment entry into the canals at 75,000 cfs river discharge is greater than with river discharge of 150,000 cfs. This is misleading because it is known that sediment quantity entering the canals with lower river discharge is less than at higher river discharges. Actually the quantity of sediment introduced into the model at the representative river discharge of 75,000 cfs is greater than its proportionate amount when compared to 150,000 cfs. This was purposely done in this model to enable better sediment measurement in the canals.

SUMMARY TABLE OF RESULTS

Scheme	Pond level	Water Discharge in 1000 cfs			Total Model feed rate of Sediment	Sediment in % of Total Model		Remarks	See Fig.
		River	Haveli	T-S	#/hr	Haveli	T-S		
Existing Conditions	493	75	7	-	35	4.3	-		5
	490		7	-		11.4			
	493		5			2.9			
	490		5			10.0			
	487		4.55			13.0			
	487		4			14.3			
	493		3			1.4			
	490		3			8.6			
	487		2			4.6			
	493	150	7	-	295	2.0	-		5
	490					4.0			
	487					2.0			
	493		5			1.7			
	490					2.0			
	487					1.5			
	493		3			1.4			
	490					1.4			
	487					0.7			
	493	250	7	-	1100	1.8	-		5
	490					1.3			
	487		6			1.0			
	493		5			1.6			
	490					1.1			
	487		4			1.1			
	493		3			0.4			
	490					0.8			
	487		2			1.5			
A Contract Documents	490	150	7	12	35	4.0	6.5	Existing outer wall	8
						4.5	5.5	155' long outer wall	
						3.5	7.0	Island removed Existing wall	
						4.5	8.0	155' long outer wall Island removed	
						4.0	9.0	Same as above Sluices 1-4 Q = 5000 cfs	
						2.5	4.0	Curtain wall 4' across tunnel openings Existing wall	
						2.7	4.0	Same as above 155' outer wall	
A Modification I Rounded tunnel Extension with top elev. at 475.	490	150	7	12	40	2.5	4.5	Existing outer wall	12
						3.0	4.0	155' long outer wall	
						3.2	7.0	Curved sill on top of tunnel Ext. See Fig. 10	
						3.6	4.0	Same as above with Sluices 1-4 Q = 5000 cfs	
						3.0	3.5	Sill removed with Sluices 1-4 Q = 5000 cfs	

SUMMARY TABLE OF RESULTS (Continued)

Scheme	Pond level	Water Discharge in 1000 cfs River	Haveli	T-S	Total Model feed rate of Sediment #/hr	Sediment in % of Total Model Haveli	T-S	Remarks	See Fig
A Modification II Tunnel extension roof raised to elev. at 478	490	150	7	12	40	1.0	2.5	Existing outer wall	15
						1.7	3.3	155' long outer wall	
						3.2	2.8	Existing outer wall Sluices 1-4 Q = 5000 cfs	
						6.0	4.3	Existing outer wall Sluices 5-8 Q = 5000 cfs	
A Modification III	490	150	7	12	43	1.3	2.2	Existing outer wall	15
						4.6	4.3	155' long outer wall	
						2.1	7.6	Existing outer wall Sluices 1-4 Q = 5000 cfs	
						3.1	8.4	Existing outer wall Sluices 5-8 Q = 5000 cfs	
						5.0	3.1	Lowered outer wall to Elev. 485.	
A Modification I with T-S head regulator set back 50 ft.	490	150	7	12	40	3.5	13.	Existing outer wall	17
						4.0	6.0	Sluices 1-4 Q = 5000 cfs	
						3.5	5.0	Sluices 1-4 Q = 12,000 cfs	
						5.0	5.0	Sluices 5-8 Q = 10,000 cfs Sluices 1-4 closed.	
	490	150	7	12	35	3.0	7.0	Tunnel Top removed Ends of former tunnel openings closed.	
						3.4	10.0	Same as above with 155' outer wall	
						4.0	10.0	Same as above with Sluices 1-4 Q = 5000 cfs	
						4.0	7.0	Tunnel Top replaced, ends open, intermediate openings closed.	
T-S Head Regulator in line Lateral Extension of Tunnels. Roof Elev. 481	490	150	7	12	40	2.8	3.7	Existing outer wall	19
						2.6	3.2	Sluices 1-4 Q = 5000 cfs	
						3.3	4.3	Sluices 1-4 closed Sluices 5-8 Q = 5000 cfs	
No Tunnel Extensions	490	150	7	12	40	3.7	7.3	Existing outer wall	20
						3.3	5.1	155' long outer wall	
						3.3	5.2	Existing outer wall Sluices 1-4 Q = 5000 cfs	
						2.9	5.0	Existing outer wall Sluices 5-8 Q = 5000 cfs	

SUMMARY TABLE OF RESULTS - Continued:

Scheme	Pond level	Water Discharge in 1000 cfs			Total Model feed rate of Sediment #/hr	Sediment in % of Total Model		Remarks	See Fig.
		River	Haveli	T-S		Haveli	T-S		
Extensions of Tunnels 1 and 2 only	490	150	7	12	40	3.3	2.1	Existing outer wall	23
						2.9	3.0	155' long outer wall	
						2.2	4.4	Existing outer wall Sluices 1-4 Q = 5000 cfs	
						3.1	2.8	Sluices 5-8 Q = 5000 cfs	
A Modification II Repeat	490	150	7	12	40	1.5	3.2	Existing outer wall	
						1.7	3.3	155' long outer wall	
						2.5	3.7	155' wall with sluices 1-4, Q = 5000 cfs	
	490	75	7	12	15	37	14	Existing outer wall	
						13	18	155' long outer wall	
						40	6.5	Existing outer wall with Sluices 1-4 Q = 5000 cfs	
A Modification III Repeat	490	150	7	12	42	1.1	10	Existing outer wall	
					35	2.9	13	155' long outer wall	
					33	3.3	10.2	Existing outer wall Sluices 1-4 Q = 5000 cfs	
					40	2.5	9.6	Sluices 5-8 Q = 5000 cfs	
	490	75	7	12	9	13.3	46	Existing outer wall	
					13	11.3	28	155' long outer wall	
					11	27	5.2	Existing outer wall with Sluices 1-4 Q = 5000 cfs	
					17	7.2	0.9	Existing outer wall Sluices 5-8 Q = 5000 cfs	
	490	230	7	12	40	1.7	4.4	Existing outer wall	
						2.5	5.1	155' long outer wall	
						2.4	9.6	Existing outer wall with Sluices 1-4 Q = 5000 cfs	
						2.7	7.5	Sluices 5-8 Q = 5000 cfs	
						4.2	9.6	Sluices 1-8 Q = 10,000 cfs	
Intermediate wall reinstalled with Tunnel extension in place	490	150	7	-	35	2.0	-	Existing outer wall	
						0.9		Sluices 1-4 Q = 5000 cfs	
						1.0		Sluices 5-8 Q = 5000 cfs	
	490	75	7	-	6.8	large	-	Existing outer wall	
					3.7	25	-	Sluices 1-4 Q = 5000 cfs	
					4.3	9.4	-	Sluices 5-8 Q = 5000 cfs	
	490	230	7	-	75	3.5	-	Sluices 1-4 Q = 10,000 cfs	
					82	2.6	-	Sluices 5-8 Q = 10,000 cfs	

SUMMARY TABLE OF RESULTS (Continued)

Scheme	Pond level	Water Discharge in 1000 cfs			Total Model feed rate of Sediment	Sediment in % of Total Model		Remarks	See Fig.
		River	Haveli	T-S	#/hr	Haveli	T-S		
A Modification III	490	75	7	12	4.3	38	13	Existing outer wall	
					13	79	11	Sluices 1-4 Q = 5000 cfs	
					12	7	12	Sluices 5-8 Q = 5000 cfs	
	490	230	7	12	61	2	9	Sluices 1-4 Q = 10,000 cfs	
					57	3.2	11	Sluices 5-8 Q = 10,000 cfs	
Extension of Tunnels 1 and 2 only	490	230	7	12	55	2.4	7.4	Sluices 1-4 Q = 10,000 cfs	
						2.5	11.3	Sluices 5-8 Q = 10,000 cfs	
	490	150	7	12	39	1.9	9.4	Existing outer wall	
					35	4.0	8.5	Sluices 1-4 Q = 5,000 cfs	
					35	5.5	10.1	Sluices 5-8 Q = 5000 cfs	
	490	75	7	12	17	70	8.8	Existing outer wall	
					16	50	9.5	Sluices 1-4 Q = 5000 cfs	
					21	9.8	6.7	Sluices 5-8 Q = 5000 cfs	
Existing Conditions	490	75	7	-	13	1.4	-	Existing conditions	
					11	7.8		Sluices 1-4 Q = 5000 cfs	
					12	1.6		Sluices 5-8 Q = 5000 cfs	
	490	150	7	-	24	12.8	-	Existing conditions	
					28	1.9		Sluices 1-4 Q = 5000 cfs	
					24	5.0		Sluices 5-8 Q = 5000 cfs	
	490	225	7	-	58	2.2		Sluices 1-4 Q = 5000 cfs	
					52	7.0		Sluices 5-8 Q = 5000 cfs	

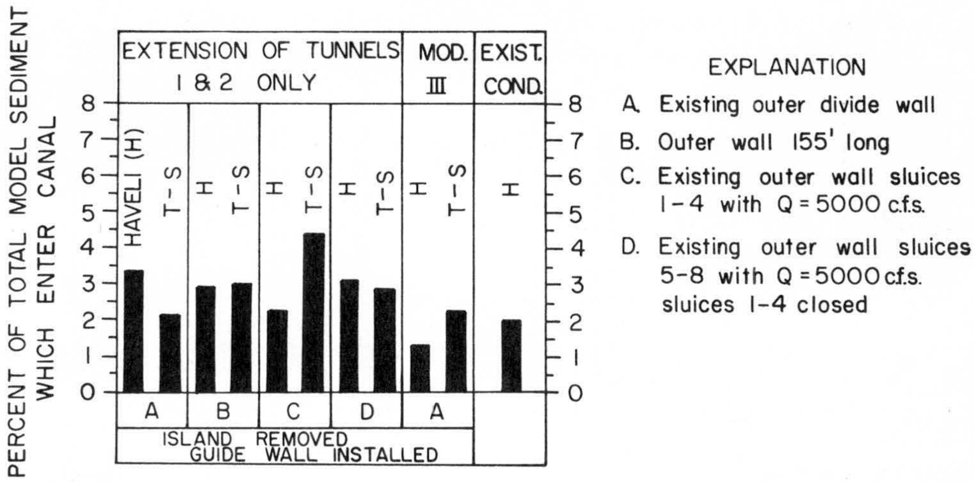


Fig. 24 COMPARISON OF EXTENSION OF TUNNELS 1 AND 2 ONLY WITH SCHEME A MODIFICATION III

The continuous flow of water through the sluice gates does not, in general, reduce sediment entry into the canals. The greater amounts of water flowing toward the head regulators causes greater velocities which in turn creates more suspension of bed material in the flow. Thus while sluicing prevents deposition of sediment in the immediate vicinity of the head regulators it does cause greater amounts of sediment to be transported into the canals. It is better to construct a structure which will direct the bed load toward the barrage away from the head regulators, and provide sluicing devices to remove sizable deposits of sediment which will undoubtedly occur in areas of reduced velocities.

RECOMMENDATION

It is recommended that Scheme A, Modification III shown in plan in Fig. 25 be constructed as the most suitable among those tested to prevent excessive sediment entry into the canals. The recommended structure by its geometry creates a curve in the approach flow favorable to the canal head regulators. The deflection of flow by the silt exclusion structure creates a secondary current and movement of a substantial amount of bed load away from the head regulator toward the barrage to the right of the outer divide wall.

The intermediate divide wall should be removed and it is recommended that the outer divide wall remain unchanged. A shorter outer divide wall will decrease the sediment entry into the T-S link but will increase, in general, sediment entry into Haveli over its present condition. It is recommended further that the island presently obstructing the approach to the canals be removed in part or a total and the left guide wall of the kind recommended from results of the Pakistan model study be provided. One slight modification to this guide wall is suggested at the left side of the T-S head regulator. A wing wall rounded in the form shown in Fig. 16 should be constructed to provide smoother flow entrance in the first and second bays of the head regulator.

The centerline of the head regulators of the two canals should be constructed in the same line with a distance of 330 ft between canal centerlines.

ALTERNATIVE RECOMMENDATION

Should the recommended structure be considered excessive in cost or otherwise difficult to construct and is not acceptable on these accounts, the alternative scheme recommended for construction is extension of tunnels one and two only as shown and described in Fig. 22. The intermediate guide wall should be removed and the outer guide wall should remain intact The Pakistan recommended left guide wall in the approach region is satisfactory provided that a wing wall of Fig. 25 is constructed adjacent to the left side of the T-S head regulator.

This alternative structure will cause greater sediment entry into the Haveli Canal than the recommended scheme.

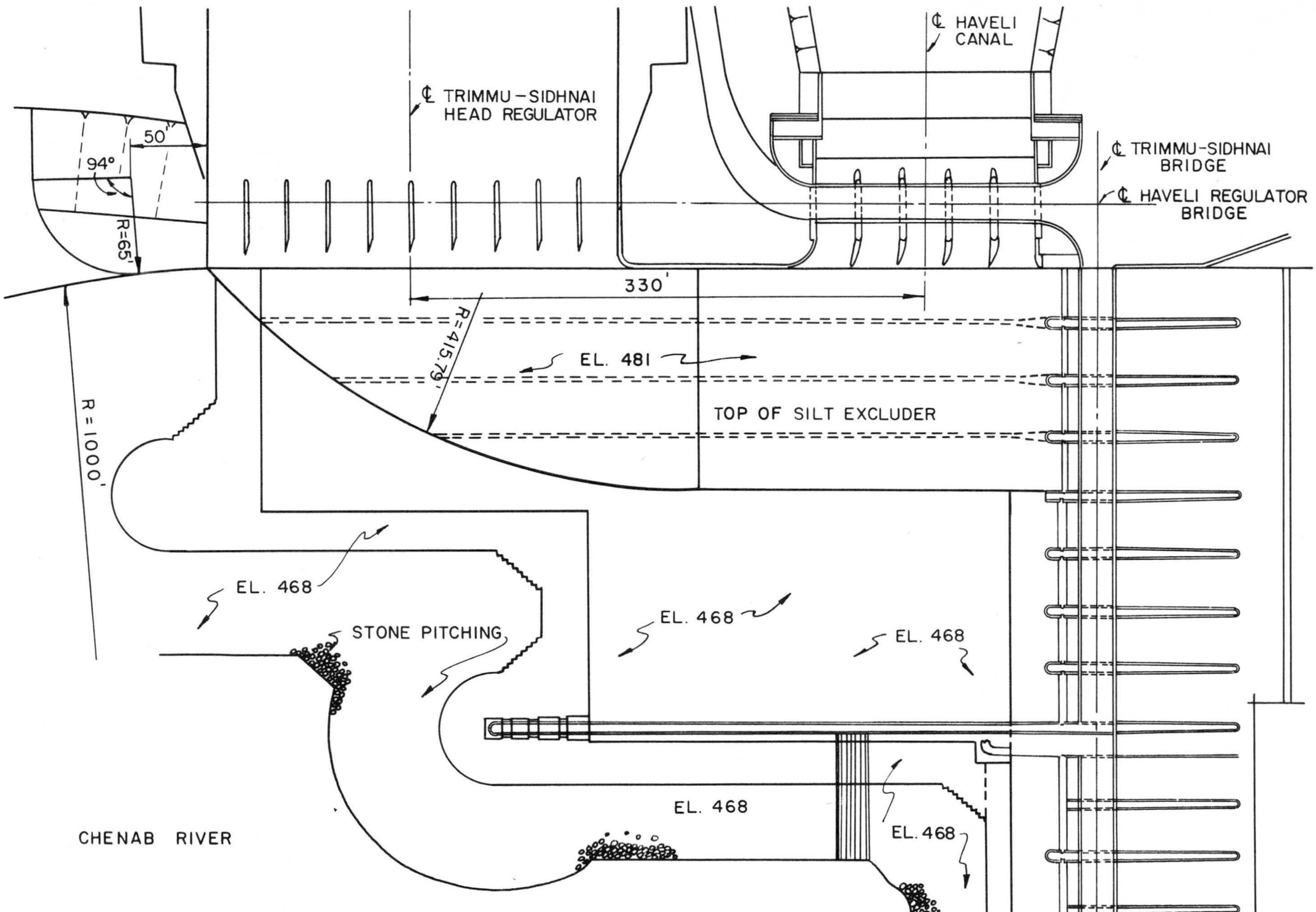


FIG. 25 RECOMMENDED SILT EXCLUDER

ACKNOWLEDGEMENTS

Acknowledgement is due Dr. D. B. Simons for his advice and participation in the model study and in the preparation of this report. The shop staff of the Hydraulics Laboratory at Colorado State University constructed the model and assisted in the operation throughout the study.

BIBLIOGRAPHY

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

Einstein, Hans A., and Hing-Chien, Similarity of Distorted River Models with Movable Beds, Transactions ASCE, Vol. 121, 1956.

Nichols, K. O., Geometric Distortion in Hydraulic Models, Paper No. 2044, Transactions ASCE, Vol. 104, 1944

Blench, T., Scale Relations Among Sand-Bed Rivers Including Models, Proceedings Se. No. 667, ASCE, April 1955.

Hydraulic Models, ASCE Manual of Engineering Practice No. 25, July 1942.