4 OUTLINE OF THE MODELS AND TEST CONDITION

4.1 The Model

4.1.1 Range of the Model

The model covers distance of 2.1 km from the upstream-end to the downstream-end centering the Hadwari bund as shown in Fig.-4.1 and Fig.-4.2.

4.1.2 Scale of the Model

Scale of the model is 1/50 considering the design flood discharge (Q = 2,500 m3/sec), accuracy of the model test and limitation of the area of experiment field, etc.

4.2 Similarity

4.2.1 Reduced Ratio by Froude's Law of Similarity

In the model test, Froude's law of similarity is applied for a kinematic similarity for the flow under gravity dominant case.

Table-4.1 shows reduced ratios of geometrical condition and hydraulic factors calculated by the Froude's law of similarity.

Table-4.1 Reduced Ratios by Froude's Law of Similarity

Factors	Dimensions	Reduced Ratio	
		Ratio	Scale
Geometrical Factors			
Horizontal (X)	L	Xr	1 : 50
Vertical (h) (Water Depth, Elevation)	L	hr	1 : 50
Gradient (h / X)	-	$hr \cdot Xr^{-1}$	1 : 1
Area (A)	L^2	$hr \cdot Xr$	1 : 2,500
Volume (Vm)	L^3	$hr \cdot Xr^2$	1 : 125,500
Flow Factors			
Froude's Number (Fr)	-	1	1 : 1
Velocity (V)	$L \cdot T^{-1}$	$hr^{1/2}$	1 : 7.07
Discharge (Q)	$L^3 \cdot T^{-1}$	$Xr \cdot hr^{3/2}$	1 : 17,677.7
Time (T)	T	$Xr \cdot hr^{-1/2}$	1 : 7.07
Pressure (P)	$F \cdot L^{-2}$	hr	1 : 50
Roughness Coefficient (n)	$L^{-1/3} \cdot T$	$hr^{2/3} \cdot Xr^{-1/2}$	1 : 1.92
Discharge Coefficient (C)	$L^{1/2} \cdot T^{-1}$	$Xr^{-1/2} \cdot hr^{1/2}$	1 : 1
Tractive Force (z)	$F \cdot L^{-2}$	Hr	1 : 50
Energy (E)	$F \cdot L$	Hr^4	1 : 6,250,000
Momentum (mv)	$F \cdot T$	$Hr^{7/2}$	1 : 883,882

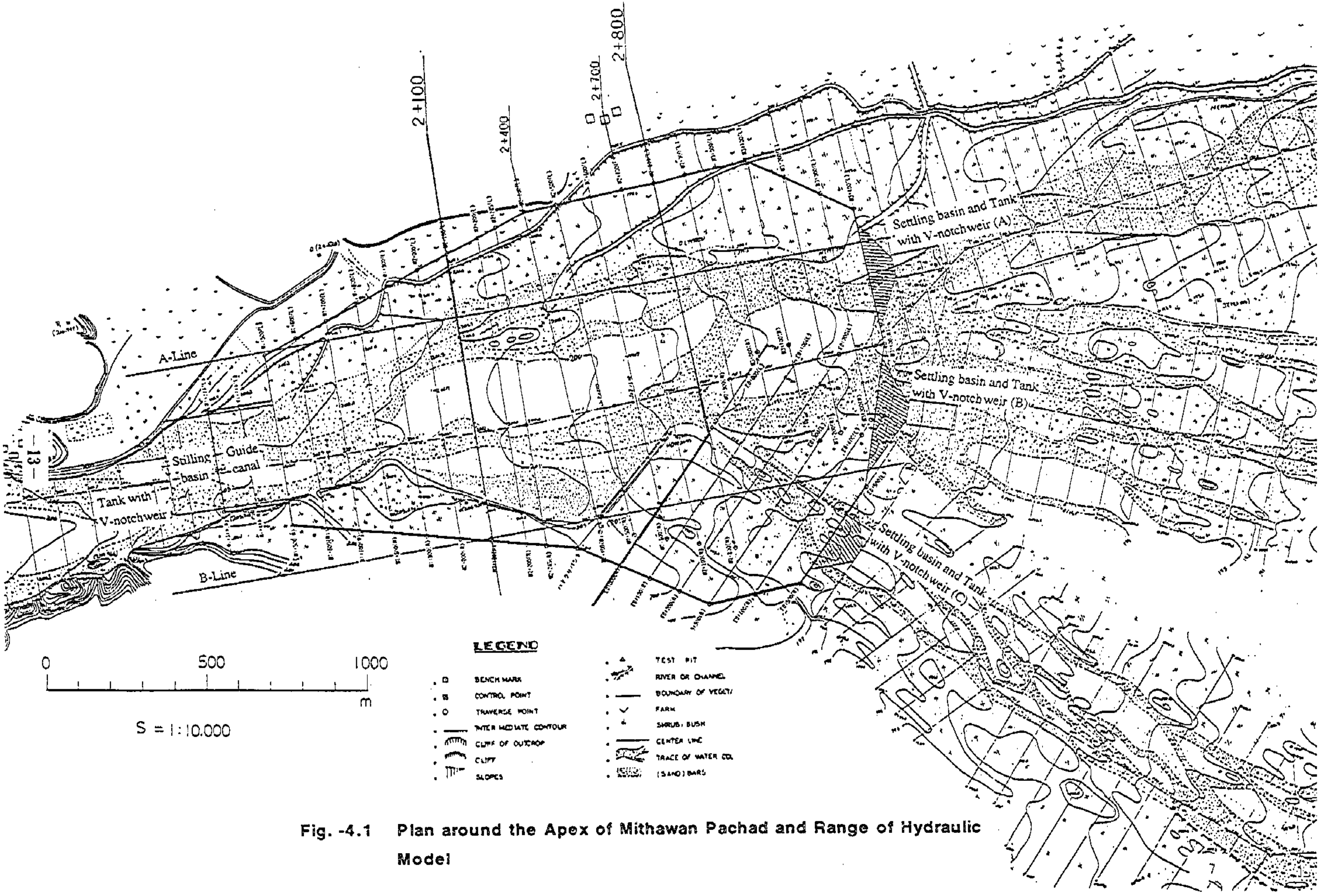


Fig. -4.1 Plan around the Apex of Mithawan Pachad and Range of Hydraulic Model

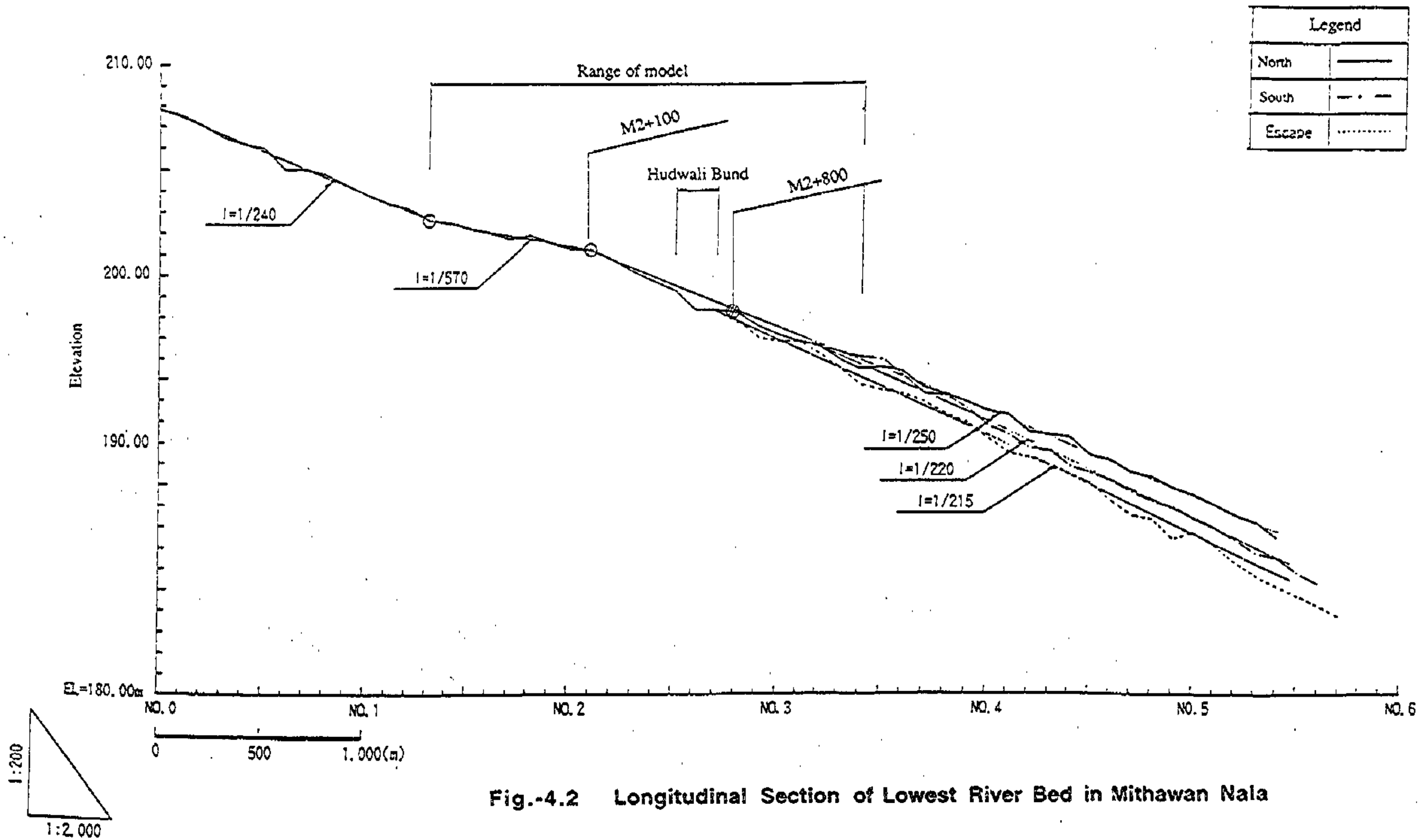


Fig.-4.2 Longitudinal Section of Lowest River Bed in Mithawan Nala

4.3 Condition of the Model Test

4.3.1 Discharge

Discharge for the model test corresponds to the design flood of 2,500 m^3/sec of 25-year return period. A hydrograph for the model test also corresponds with peak discharge of 2,500 m3/sec shown in Fig.-2.1 and Table-2.2 in Chapter 2.

Discharge in the model test was supplied by the modified stepwise hydrograph shown in Fig.-4.1.

Discharges at various return periods is shown in Table-2.1 and the modified discharges by the reduction of the catchment area is shown in Table-4.2 and Fig.-4.3.

Table-4.2 Return period and Discharge (Iwai's method)

Return period year	(a) For 21 data m3/sec (cusec)	(b) For 21 data m3/sec (cusec)	(c) Average((a)+(b))/2 m3/sec(cusec)
25	2,596 (91,496)	2,449 (86,316)	2,523 (88,924)
20	2,439 (85,963)	2,327 (82,016)	2,383 (83,989)
10	1,960 (69,080)	1,944 (68,517)	1,952 (68,799)
7	1,716 (60,481)	1,742 (61,397)	1,729 (60,939)
5	1,485 (52,339)	1,547 (54,534)	1,516 (53,432)
3	1,125 (39,651)	1,233 (43,457)	1,180 (41,589)
2	822 (28,972)	954 (33,623)	1,180 (41,589)
1.1	202 (7,120)	336 (11,824)	269 (9,481)

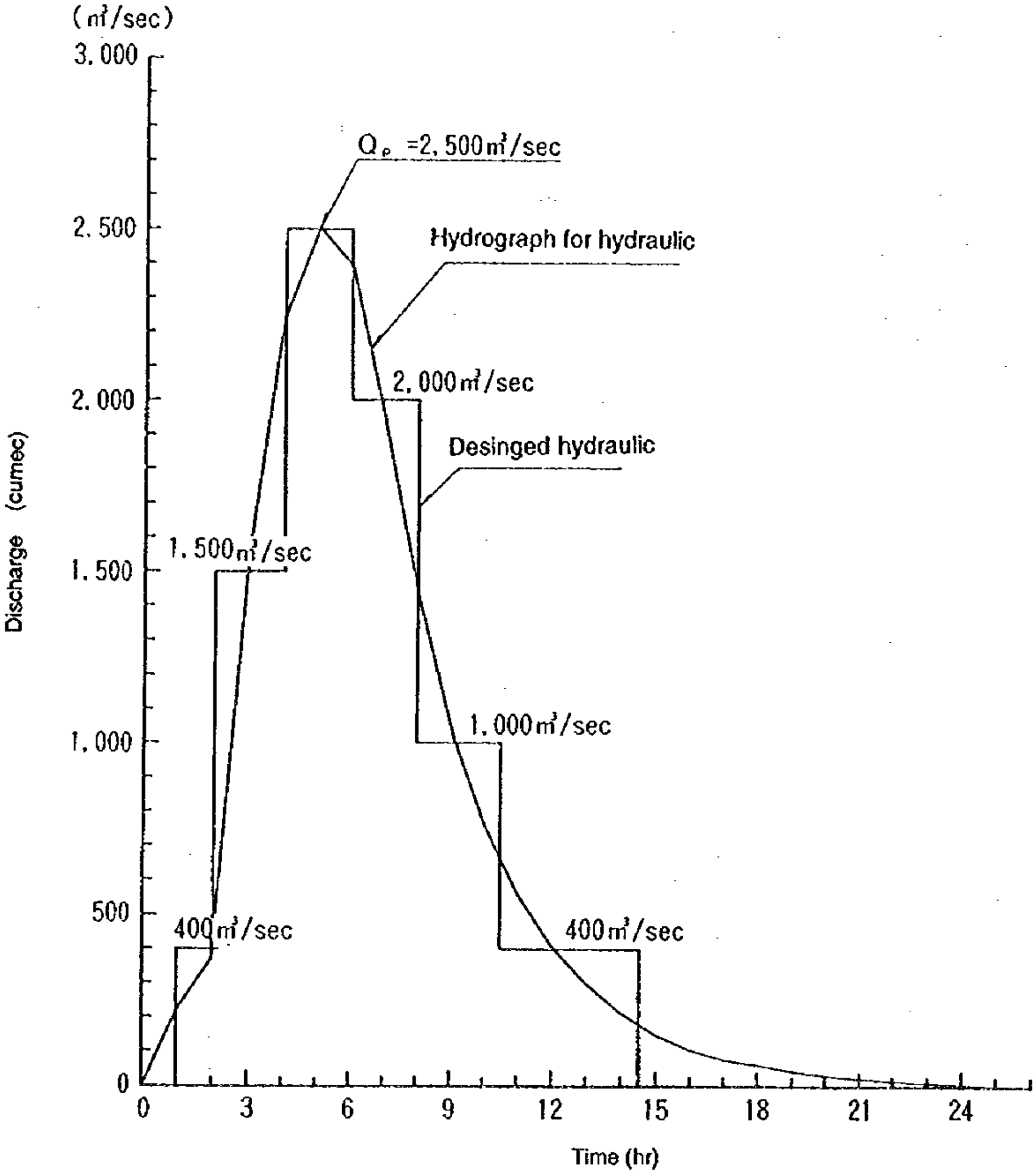


Fig.4.3 Hydrograph for Hydrauli Model Test

4.3.2 Riverbed Material

Since the riverbed material at the site is composed of fine sand of 0.3 mm in average diameter, the bed material in the test should be 0.006 mm in diameter when the reduced ratio of 1/50 is applied. It is supposed that the test using such fine material of clay size must show quite different behaviour from that of the prototype due to the viscosity. Therefore, the washed fine sand of 0.16 mm in average diameter was used in the model test.

4.4.3 Quantity of Supplied Sand

As the bed material is fine sand with its average diameter of 0.3 mm in the prototype, considerable volume of fine sand will be transported as suspended load during flood. In such case, Brown's formula is applied to compute sediment transportation considering suspended load and bed load in the range of high non-dimensional tractive force.

Therefore, Brown's formula has been used to determine the quantity of the sand supplied during the test.

$$q_B/(u_* \cdot d) = 10\left[u_*^2 / \{(\sigma/\rho - 1)\cdot g \cdot d\}\right]^2$$

q_B : Volume of sediment transported per unit time per unit width

u_* : Shear velocity ($\sqrt{(g \cdot h \cdot i)}$, m/sec)

d : Mean Diameter (=0.03 cm)

σ : Density of soil particle in water (=1.65 g / cm^3)

ρ : Density of water (=1.00 g / cm^3)

g : Gravitational acceleration (9.8 m / sec^2)

Maximum quantity of sediment (40,388 m3) which is supposed to be transported in one flood was supplied in the model test.

Table-4.3

Calculating Item Case	Mean Diameter dm (mm)	Width of Wah B (m)	Roughness Coefficient n ($sec \cdot m^{-1/3}$)	Total of Supplied Sand Qs (m^3)
1st	0.3 1)	300	0.030	689,080
2nd	8.0 2)	300	0.030	25,841
3rd	8.0	120 to 300 3)	0.030	28,558
4th	8.0	60 to 150 4)	0.030	40,388

Note
1) Mean diameter of Mithawan nallah bed
2) Mean diameter made by magnifying the size of the Test
3) Width of wah from Regime theory, a=6
4) Width of wah from Regime theory, a=3

Regime Theory

$$B = a \cdot Q^{\frac{1}{2}}$$

Where, B ; Width of Channel, Q : Discharge, a : Coefficient, A : Catchment Area

Catchment Area : A (Km2)	Coefficient : a
$A <= 1$	2 to 3
$1 < A <= 10$	2 to 4
$10 < A <= 100$	3 to 5
$100 < A$	3 to 6

4.4 Particulars of the Model Test

The model test is performed by an extra model using a two-dimensional channel (preparatory test), a rigid bed model (3 cases), and a mobile bed model (2 cases).

4.4.1 Extra Model Test Using Two-dimensional Channel

Preparatory test by a mobile bed model

The function of the distributor and the status of local scouring around it are confirmed by a preliminary test along with observation on the bed configuration using a straight channel of 1.0m wide. Discharge matches that of unit width.

4.4.2 Rigid Bed Model Test

Case 1 (Test at present condition)

It is to confirm the status of flows during flooding at several discharge levels. Two models are tested, with Hadwari bund and without Hadwari bund.

Case 2 (Test with the distributor)

It is to confirm the status of flows during flooding when the distributor placed at Sta. 2+100 which is the point of flow diversion in the channel.

Case 3 (Test with the distributor)

It is examined to confirm the shares of flood distribution when the distributor placed at Sta. 2+800 near the Hadwari bund.

4.5 Mobile Bed Model Test

Case 4 (Test with the distributor)

It is examined to study the variation of the shares of diversion by the bed alteration using a mobile bed model with the distributor at Sta. 2+800.

Case 5 (Test with the distributor)

Using the same model to the Case 4, influence of bed variation to the function of the distributor is confirmed. The test is continued until the bed being in equilibrium under the steady flow condition with supply of sand.

5 RESULT OF THE MODEL TEST

5.1 Extra Model Test by Two-dimensional Channel

5.1.1 Objectives

The size of bed material of the prototype is 0.3 mm in average and silt is also found locally. On the bed composed of such fine sand, various kinds of sand waves may be developed depending on the variation of flow condition as if the gravel bed develops meso-scale bed configuration. The type of sand wave and its extent have close relation with roughness coefficient of the bed condition, so that it is necessary to know the relation prior to the model test.

Following are tested by the extra-model test;

1) evaluation of the function of the proposed distributor,

2) evaluation of the riverbed configuration.

5.1.2 Test Conditions

(1) Model

The extra model test was conducted using a straight channel of 1.0 m wide, 0.45 m high and 15.0 m long at the channel slope of 1/250. Acrylic transparent plates were used for the side walls to observe the flow condition on the weir and its immediate upstream and downstream.

(2) Scale

Scale of the extra-model is 1/50. The sand used in the test of the model is 0.16 mm in average diameter.

(3) Test Conditions

The test conditions are shown in Table-5.1 and the cross section of the weir used in the test is shown in Fig.-5.1.

To keep the similarity of the unit width discharge between the model and the prototype, discharge is determined with the assumption of 500 m of the bed width in the prototype.

Table-5. 1 Condition of Extra Model Test

CASE	River bed Gradient (i)	Return period	Discharge Qp (m^3/sec)	Discharge per unit width q (m^3/sec/m)	Discharge used Test Qm (lit / sec)
1	1/ 250	2 year	1,000	1.0	5.66
2	1 / 250	5 year	1,500	3.0	8.49
3	1 / 250	25 year	2,500	5.0	13.14

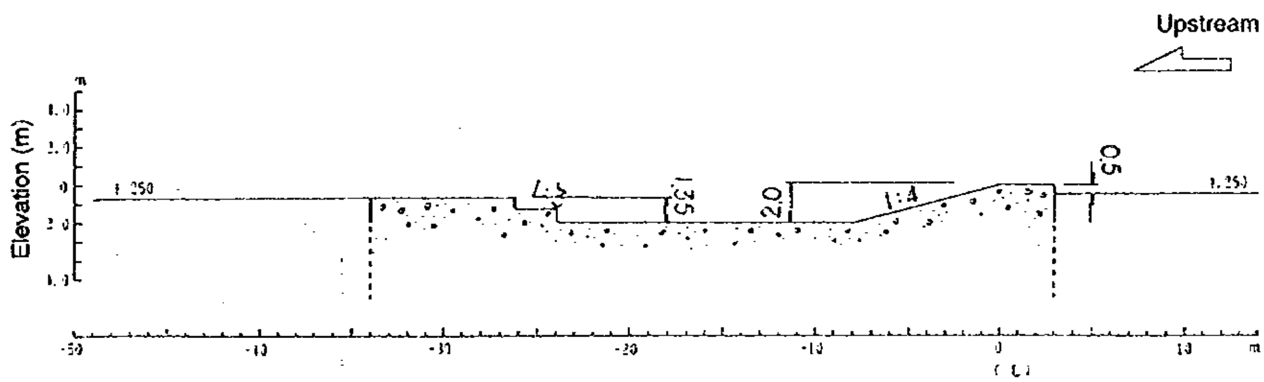
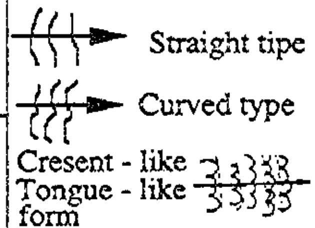
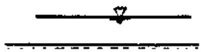
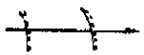
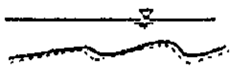


Fig.5.1 Cross Section of Model Supplied for Extra Model Test

Type of Configuration			Pattern of Form and flow: Side View	Pattern of Form and flow: Plan View	Move to	Feature of Sand Wave
Small-Scale Bed Configurations	Lower Regime	Ripples			downstream	Velocity of sand wave is slower than the velocity of water flow. Wave length is 500 to 1,500 times of the diameter of bed mateials.
		Dunes			downstream	Upsteam slope is much gentler than steep downsream slope. Wave length of Dunes is 4 to 10 times of the water depth.
		Transition				Small ripples and dunes in the initial growing stage aredeveloped on the flat bed.
	Upper Regime	Flat Bed				A large amount of sedement is flowing on the flat bed.
		Untidunes			upstream Non moving downstream	Untidunes are sand waves which are synchronous to water-surface wave. They are developed in strong mutual interference with the surface waves.
Meso-Scale Bed Configurations		Alternate Bars			Non moving downstream	Water course meanders in the channel. Waves length of the bars is 5 to 16 times of the width of channel.
		Braided Bars			downstream	
		Multiple Bars (Imbrication Bars)			downstream	Multiple bars are formed in wide a higher of width - depth ratio (B / H). It looks like scales

5.1.3 Result

(1) Function of the Distributor

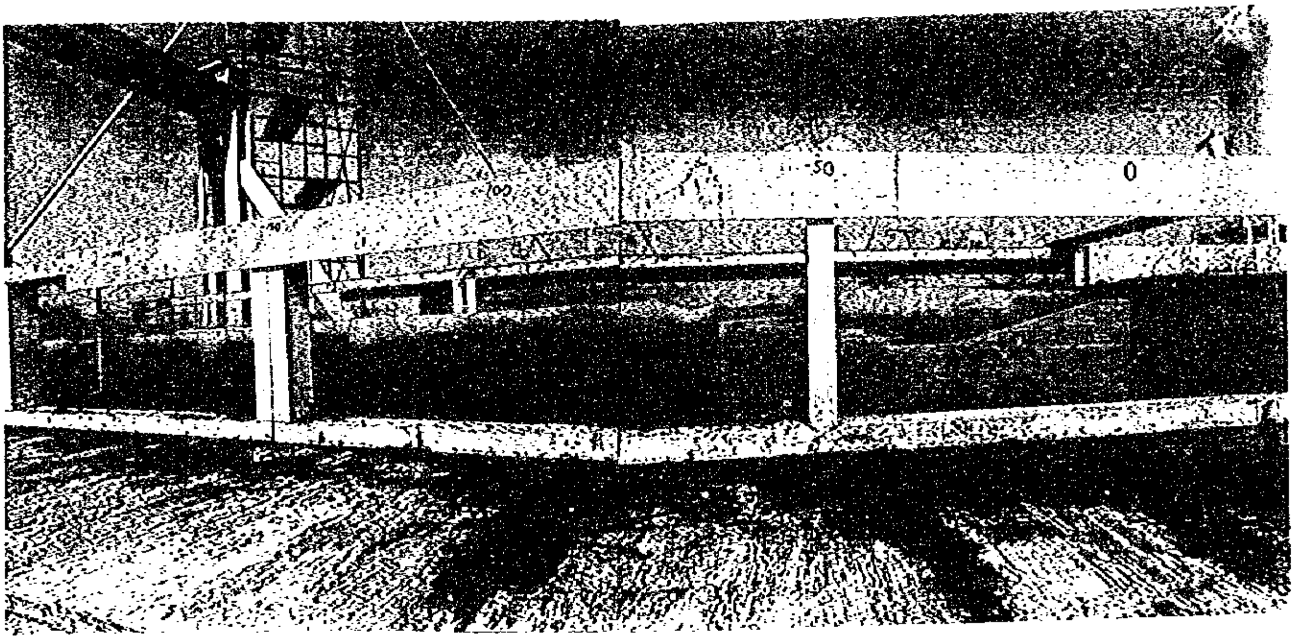
Flow condition is stable and the stilling basin works well (at the discharge of 1,000 and 1,500 cumecs).

Velocity in the stilling basin decreases to about 2.5 m/sec as same as velocity upstream of the cross structure. Therefore, the form of the cross section is confirmed to be suitable for the proposed distributor (shown in the pictures of flow condition).

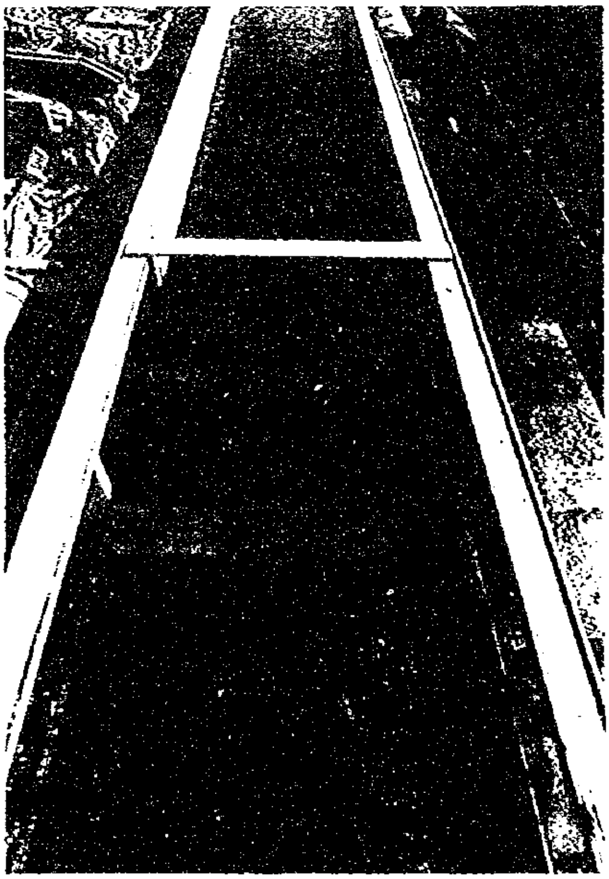
(2) River Bed Configuration

In the two-dimensional model test, ripples are formed on the bed at the discharge of 1,000 m3/sec, 1,500 m^3/sec and 2,500 m^3/sec. It is,however, supposed that the flow condition in the three dimentional model will not be similar to that of the two dimensional model. Because it is forecasted that different hydraulic condition between the two-dimension model and three-dimension model might produce different bed configuration since the flow direction tends to vary lateral and longitudinal in the three-dimension model.

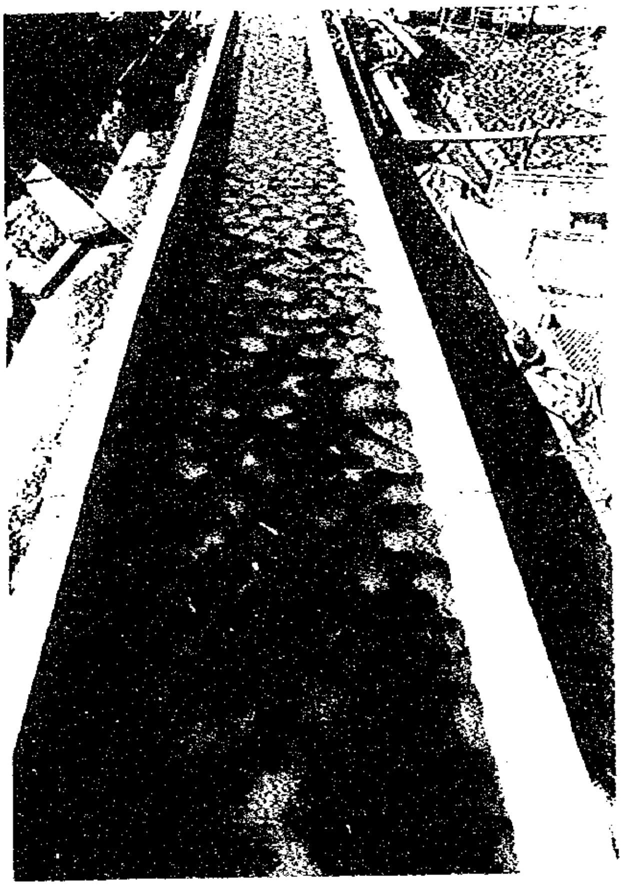
Especially, at the design flood discharge of 2,500 cumecs, bed configuration is difficult to forecast because the hydraulic condition at this discharge belongs to the region of transition from ripples to sand dunes.



View of the flow condition around the cross structure



Flow condition of around
the cross structure



Form of the bed after the test,
ripples are formed.

Photo. 2 **Flow condition at discharge of 2500 m^3 / sec (88,100 cusecs)**

5.2 Flood Distribution at Present Condition (Rigid Bed Model Test:Test 1)

5.2.1 Objectives

1) To confirm the shares of flood distribution to the channels with Hadwari bund and without Hadwari bund.

2) To confirm the point for distributary as the suitable location of the distributor.

5.2.2 Result

(1) Shares of Flood Distribution

The shares of flood distribution with Hadwari bund and without Hadwari bund are tabulated in Table-5.2

Table-5.2 Comparison of the shares of flood distribution to the channels with and without Hadwari Bund

	Share	
	North Branch Escape	South Branch
With Hadwali Bund 13%	54%	33%
Without Hadwali bund 16%	52%	32%
Plan 30%	40%	30%

Inflow to the Escape without Hadwari bund is bigger than with it. As the proposed shares of distribution is North : South : Escape = 30% : 40% : 30%, it is necessary to increase the inflow into Escape by reducing that into North branch.

Because diverted flow directions to the North and the South branches in the model do not change during the test since the riverbed is made of mortar in which bed alteration could not occur.

(2) Point for Distributary

The change of flow direction is examined by analyzing the locus of the flow tracers. The points of distributary are shown in Table-5.3 with Hadwari bund and without Hadwari bund.

Table-5. 3 Points of distributary with Hadwari Bund without

	Major distributed point U/S	Distributed point between North and South Branch	Distributed point between South and Escape Branch
With Hadwali Bund	M2+100 to M2+400	M2+100 to M3+300	M2+500 to E2+300
Without Hadwali bund	M1+900 to M2+285	M2+400 to M3+000	E0+000 to E0+300

The point of distributary is the suitable location for placing the distributor since it is easy to control the direction of flow in the lower reaches of it. The model test shows that the distributary point corresponds with the altering point of bed gradient (show in Fig.-5.2 & 5.3). Most of the case, the altering point of bed gradient is to be the controlling point of bed alteration where deposition of sediment or scouring tends to occur. Therefore, it is a suitable location to construct the distributor from the viewpoint of controlling bed alteration both upstream and downstream of the structure.

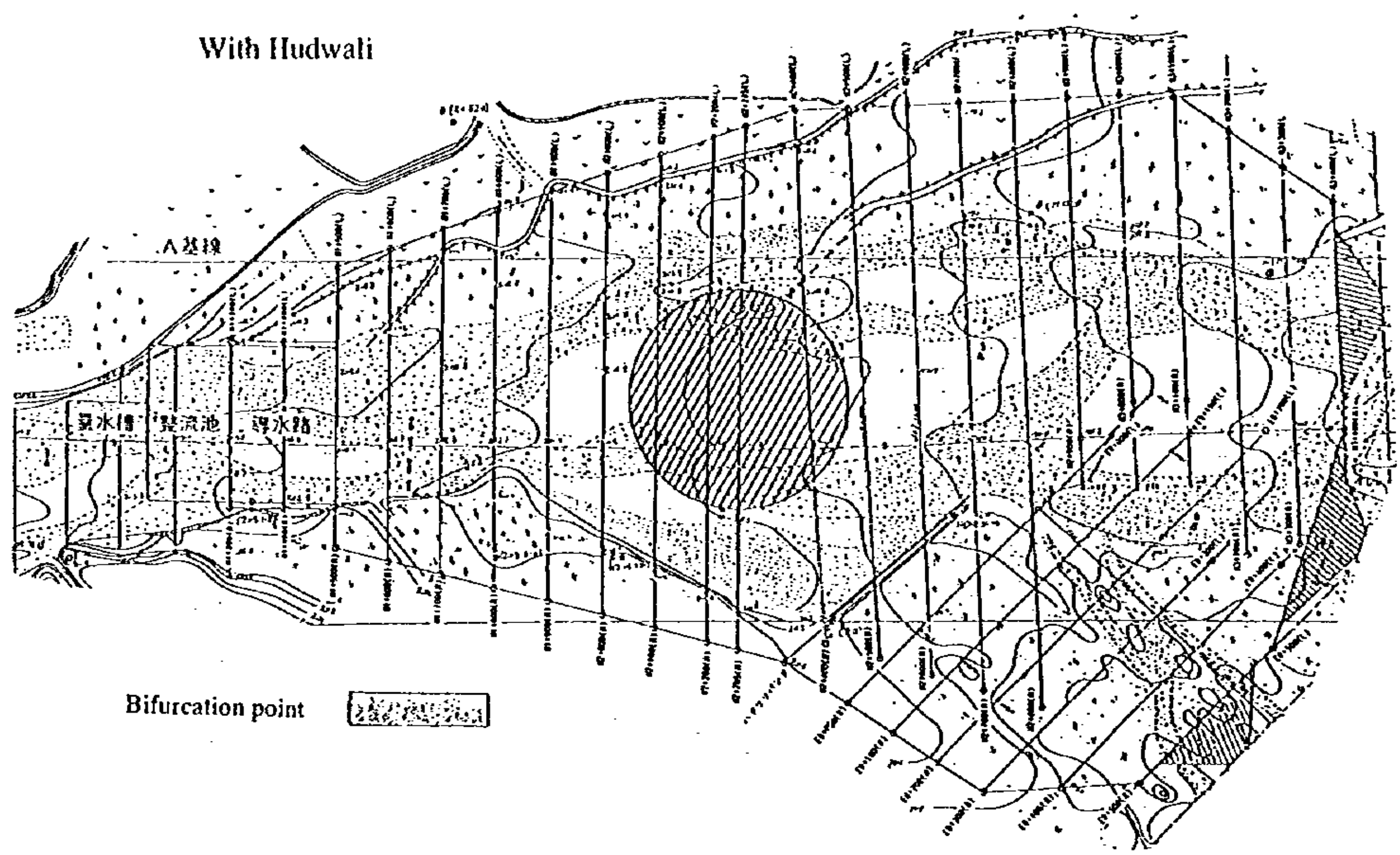
(3) Roughness Coefficient of Rigid Bed of the Model

In the rigid bed model, the surface of the bed is made of mortar. Roughness coefficient changes with discharge, and its estimated values by discharge are as follows.

Q = 400 m3/sec : n = 0.031 - 0.035

Q = 2,500 m3/sec : n = 0.028 - 0.033

Roughness coefficient is determined n = 0.03 for the analysis of the test results consequently.



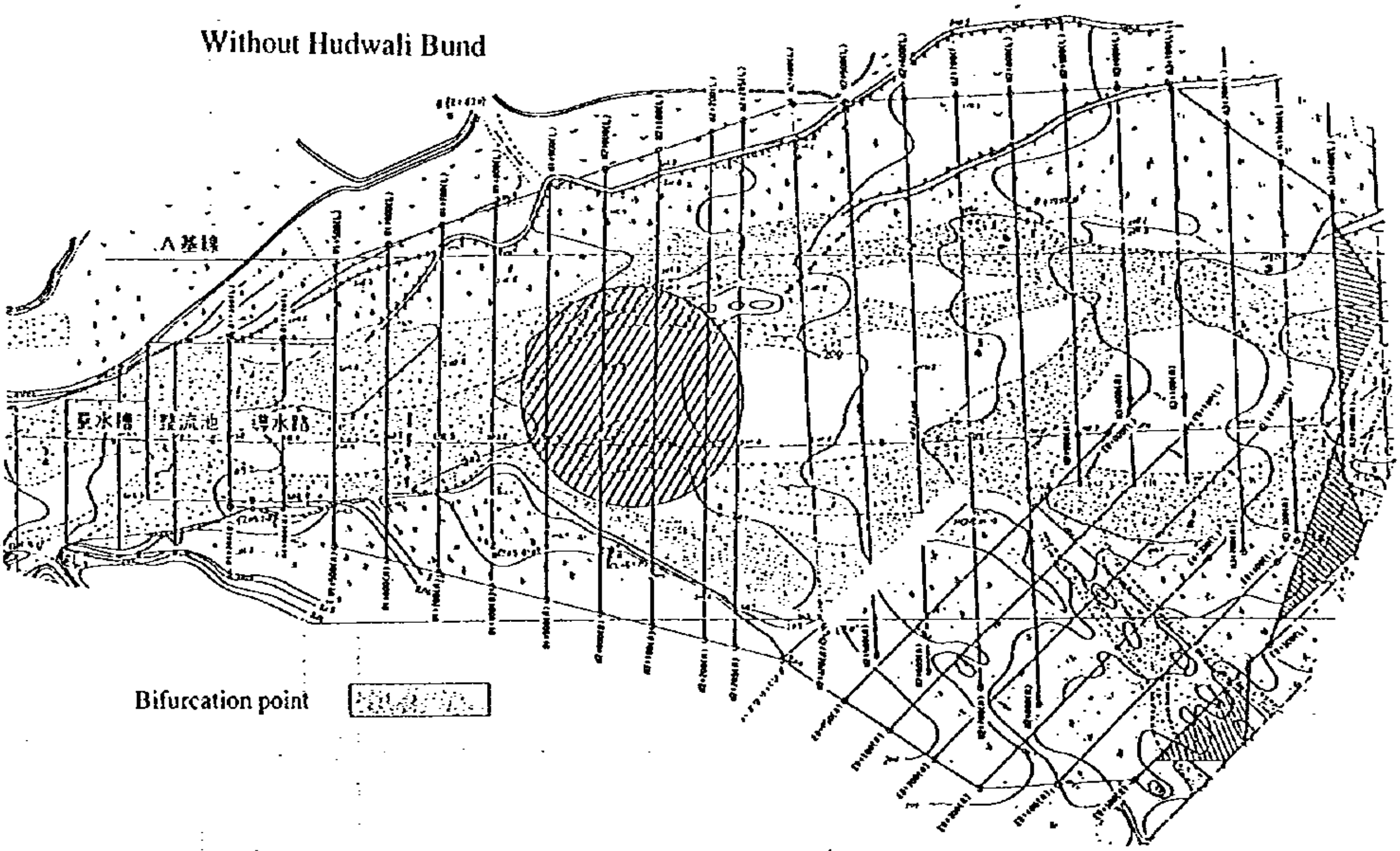


Fig.-5.2 Bifurcation Point of Flow Direction in Existing Mithawan

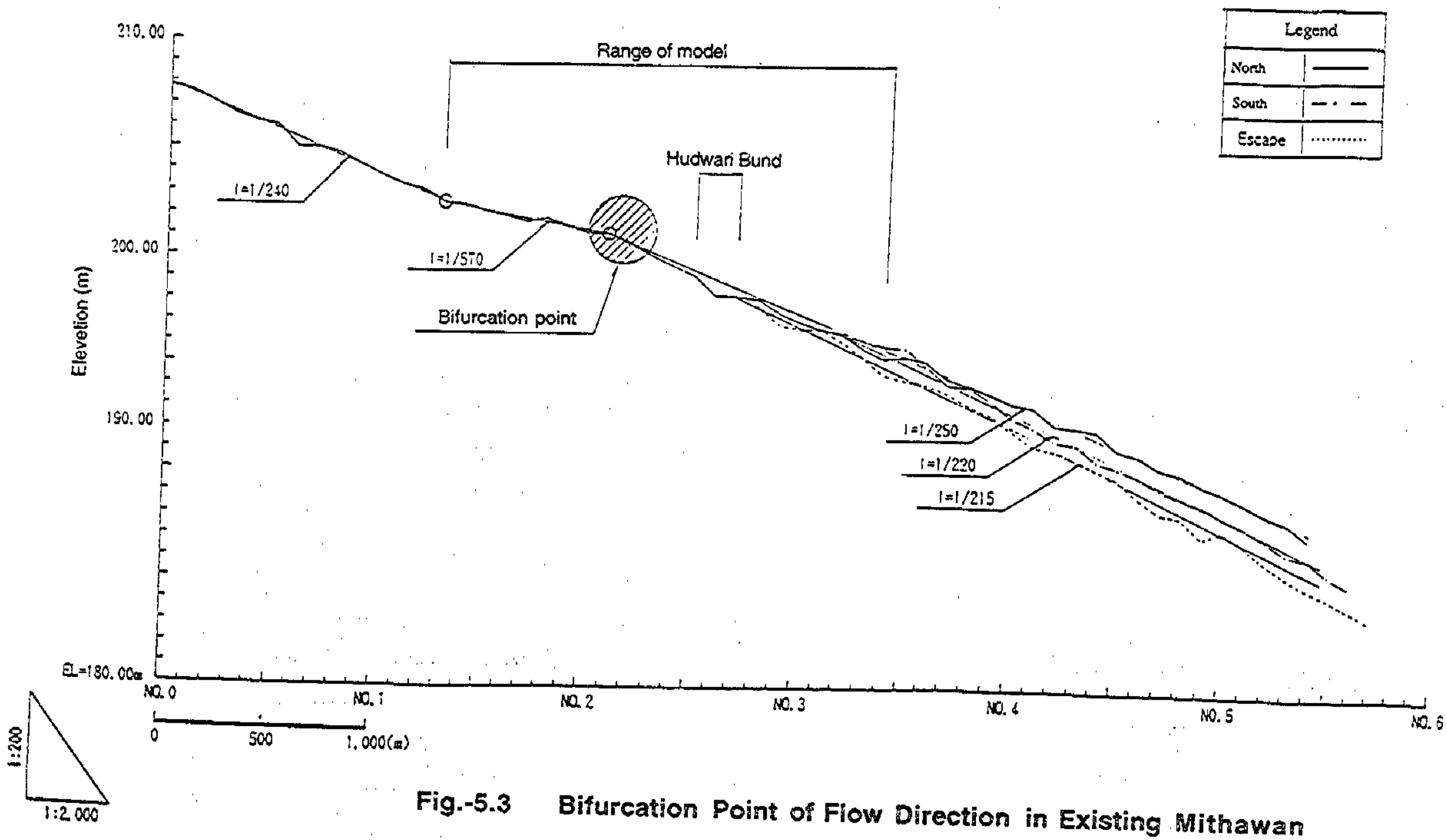


Fig.-5.3 Bifurcation Point of Flow Direction in Existing Mithawan

5.3 Study on the Shares of Distribution with the Distributor at M2+100 (Rigid Bed Model Test: Case 2)

5.3.1 Objectives

1) To confirm the shares of distribution when the distributor placed at M2+100.

2) To evaluate the function of the distributor comparing the shares of distribution by the test and that of by calculation.

5.3.2 Test Condition

(1) Location of the Distributor

The distributor was placed at M2+100 which is the point of distributary as well as the turning point of river bed gradient.

(2) Discharge of the Test

Discharge in the test is 6 levels which are equivalent to 400 (14000), 1000 (35000), 1500 (53000), 1800 (63000), 2000 (70000), 2500 (88000) cumecs (cusecs) in the prototype.

5.3.3 Test Result

Shares of flood distribution to the North branch, the South branch and the Escape are compared in Table-5.4.

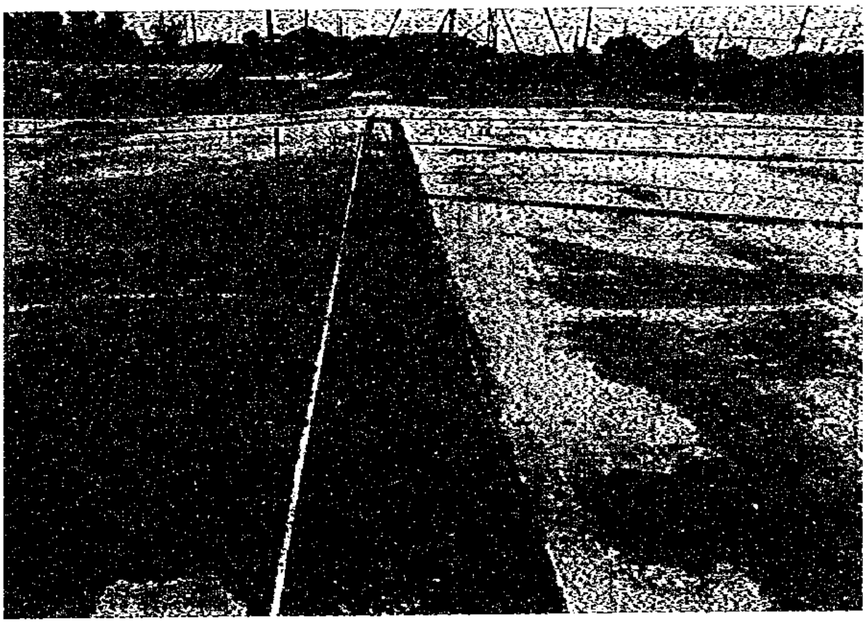
Table-5. 4 Shares of Flood Distribution
(Q=1,500 m3 / sec, 52,868 cusec)

	Shares of Distribution		
	North Branch	South Branch	Escape
Calculation	35%	35%	30%
Test Result	35%	33%	32%
Planning	30%	40%	30%

It was confirmed that the shares of distribution was (North branch+South branch) : Escape = 68% : 32% which is close to that of the plan (70% : 30%).

Distributor with the cross structure and guide walls placed at M2+100

View of the cross structure at M2+100



Flow condition on the cross structure at the discharge of 2500 m^3 / sec (88,100 cusecs)

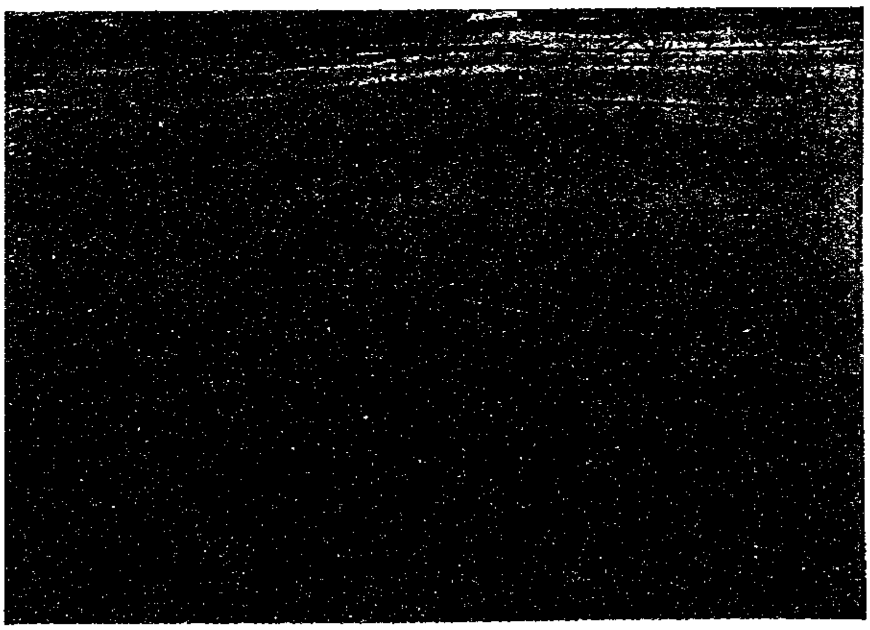
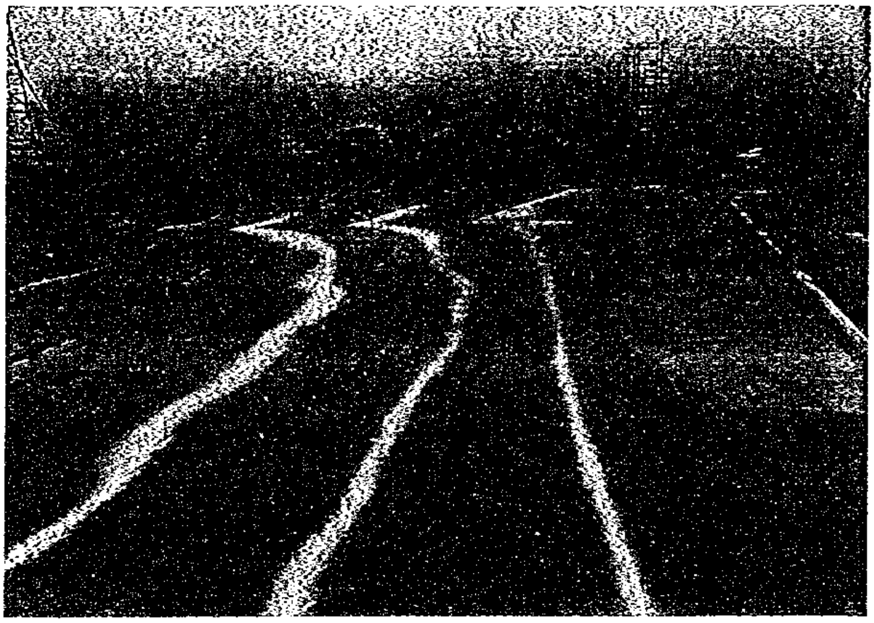


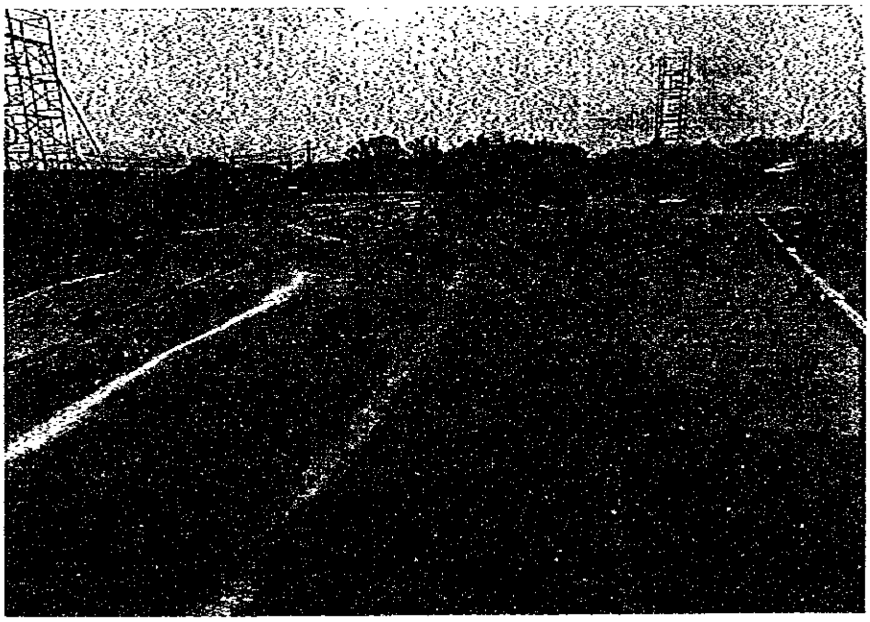
Photo. 3

TEST Case - 2

Q＝４００m³/sec



Q＝1，５００m³/sec



Q＝2，５００m³/sec

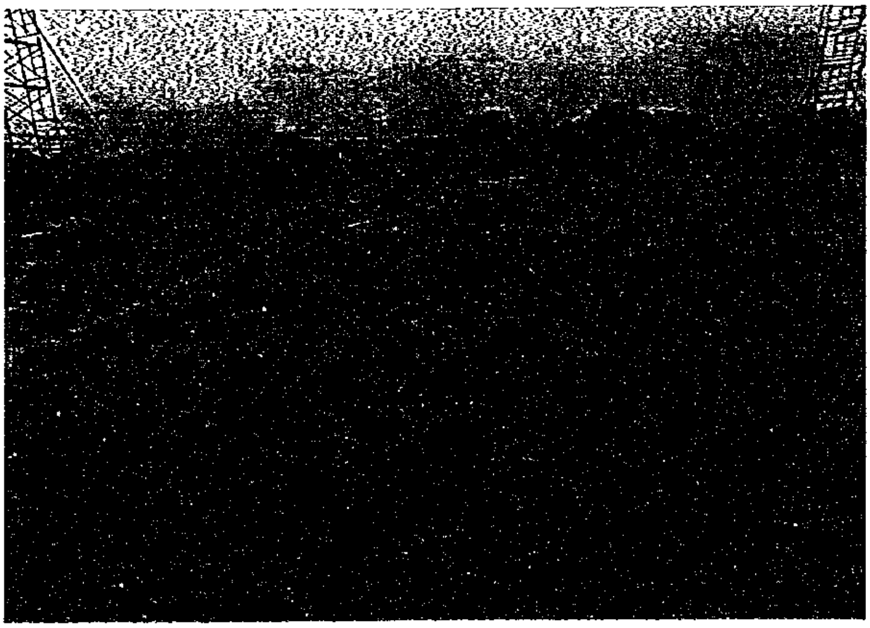


Photo. 4

Stream during flooding upstream cross structure (Case 2)

5.4 Study on the Shares of Distribution with the Distributor at M1+800 (Rigid River Bed Model Test: Case 3)

5.4.1 Objectives

1) To confirm the shares of distribution when the distributor placed at M2+800.

2) To evaluate the function of the distributor by comparing the calculated shares of distribution and that of by the test.

5.4.2 Test Condition

(1) Location of the Distributor

The distributor was placed at M2+800 (near Hadwari bund), which is the diversion point for the North branch and the South branch.

(2) Discharge of the Test

Discharge in the test is 6 levels, which are equivalent to 400 (14000), 1000 (35000), 1500 (53000), 1800 (63000), 2000 (70000), 2500 (88000) cumecs (cusecs) in the prototype.

5.4.3 Test Result

The shares of distribution for each channel is shown in Table-5.5.

Table-5. 5 Shares of flood distribution
(Q=1,500 m3 / sec, 52,868 cusec)

		Share for each Channel		
		North Branch	South Branch	Escape
Design Ratio		30%	40%	30%
Plan - I	by Calculation	35%	46%	19%
	by Test	45%	39%	16%
Plan - II	by Calculation	24%	48%	28%
	by Test	32%	41%	27%

Calculated shares of sum of the North and the South branches and that of the Escape conforms to the shares by the test. But it is difficult to forecast each share to the North branch and to the South branch by calculation. The reason is that the sand bars developed in the upper reaches of the South branch obstruct to produce uniform flow in the pond upstream of the cross structure.

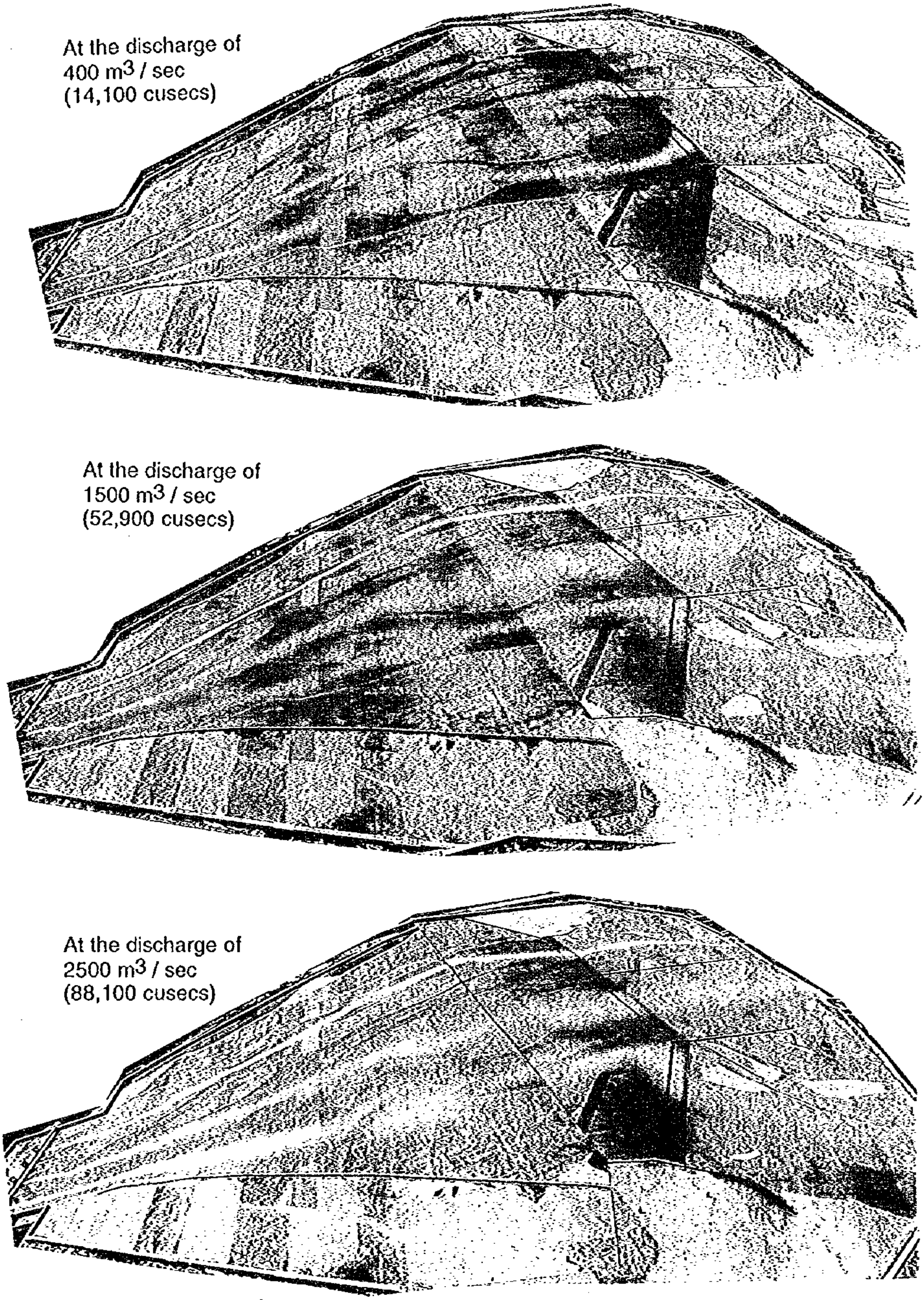


Photo. 5 **Bird's eye view of the stream during flooding (Case - 3; PLAN II)**

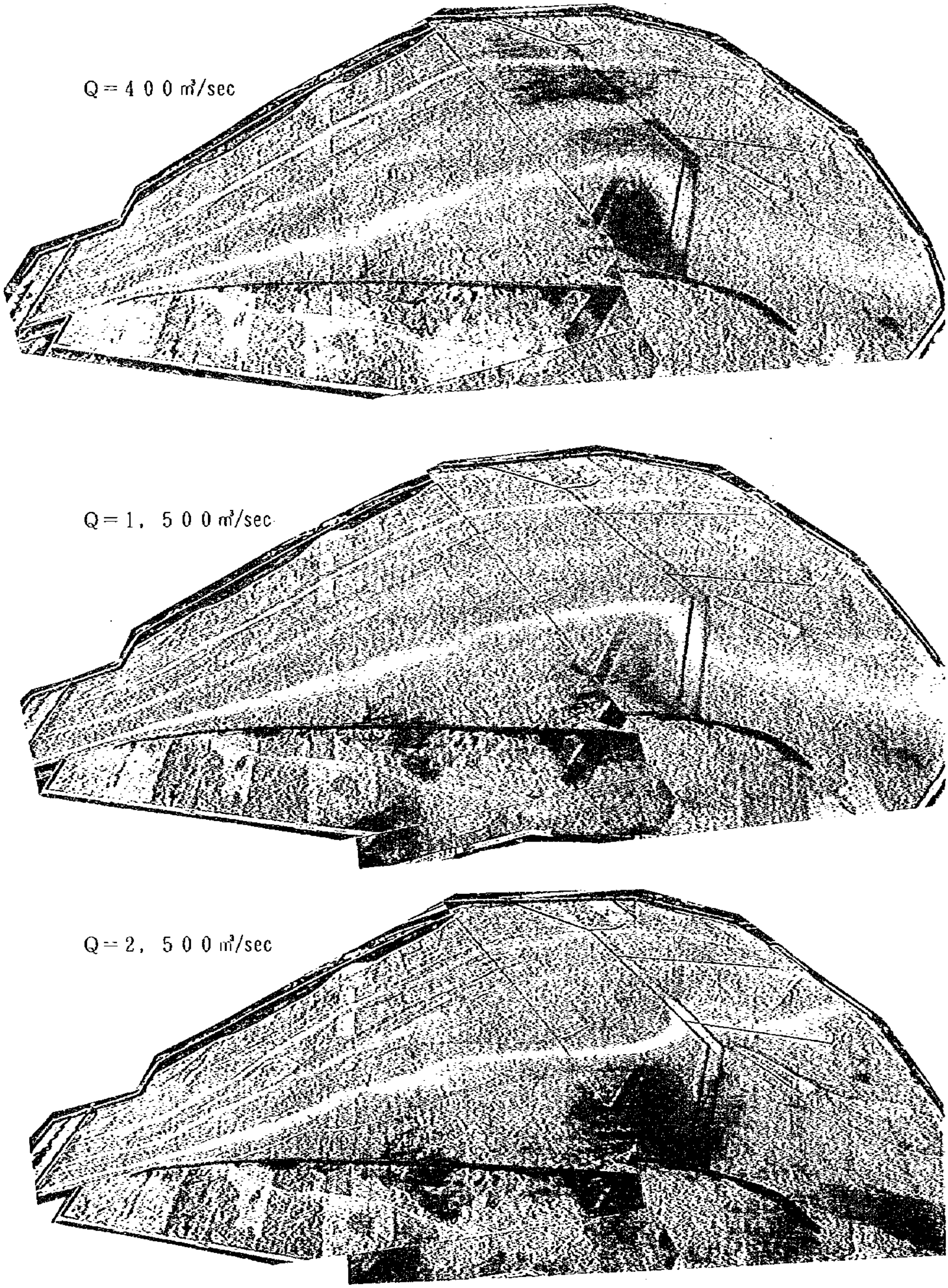


Photo. 6 **Bird's eye view of the stream during flooding (Case - 3;PLAN III)**

5.5 Test for Location of the Distributor and the Shares of Distribution (Mobil Bed Model Test: Test 4)

5.5.1 Objectives

1) To confirm the shares of distribution and the status on the riverbed alteration using mobile bed model,

2) To evaluate sediment transportation upstream of the distributor,

3) To evaluate function of the stilling basin of the distributor and deposition of sediment in it,

4) To perceive the riverbed configuration in the channels, and

5) To perceive the status on the local scouring.

5.5.2 Test Conditions

(1) Location of the Distributor

The distributor is placed at M2+800 at the same point in the Test 3.

(2) Discharge

Discharge is varied following the modified hydrograph with 2500 cumecs (88000 cusecs) at its peak discharge.

(3) Bed material

The bed material used for the test has the diameter smaller than 0.2 mm (average diameter : 0.16 mm).

(4) Quantity of sand supply

The quantity of sand supply was calculated by Brown's formula using the diameter of supplied sand (it is equivalent to 8 mm in average size in the prototype). The total quantity of supplied sand in one test is 40,338 m^3 equivalent to sediment transportation in one flood in the prototype.

5.5.3 Test Result

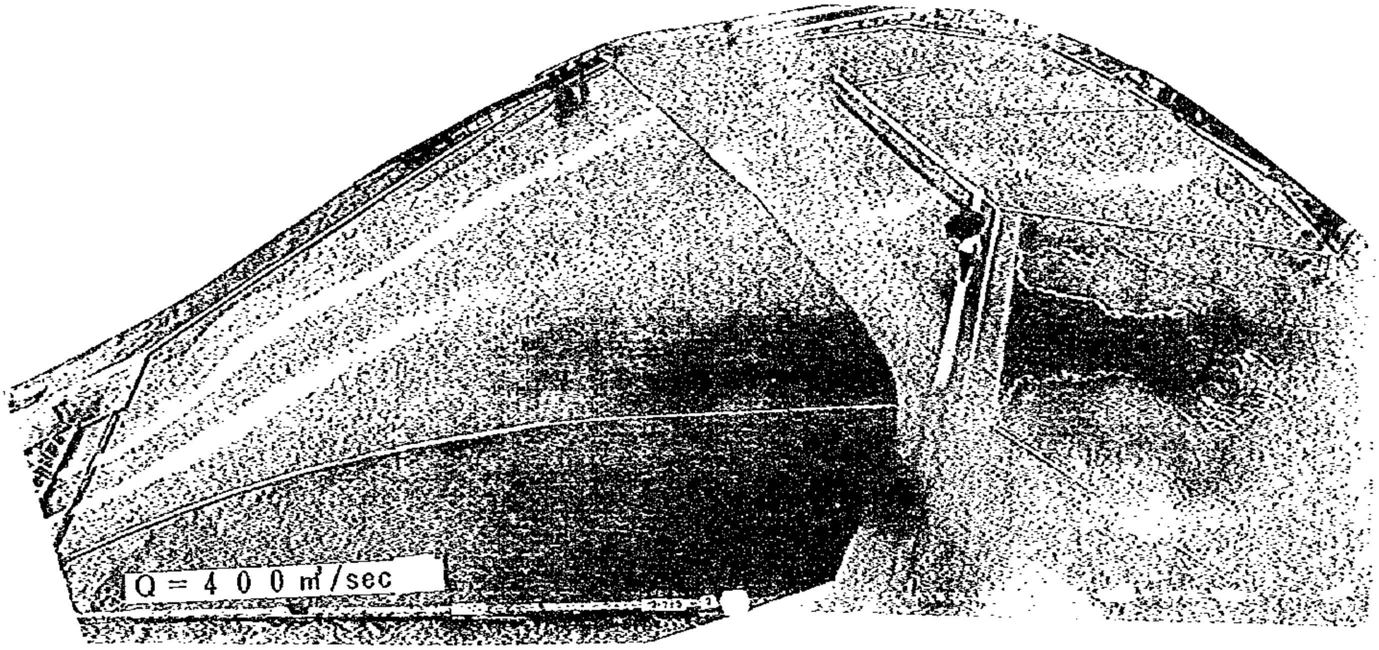
(1) Shares of Flood Distribution

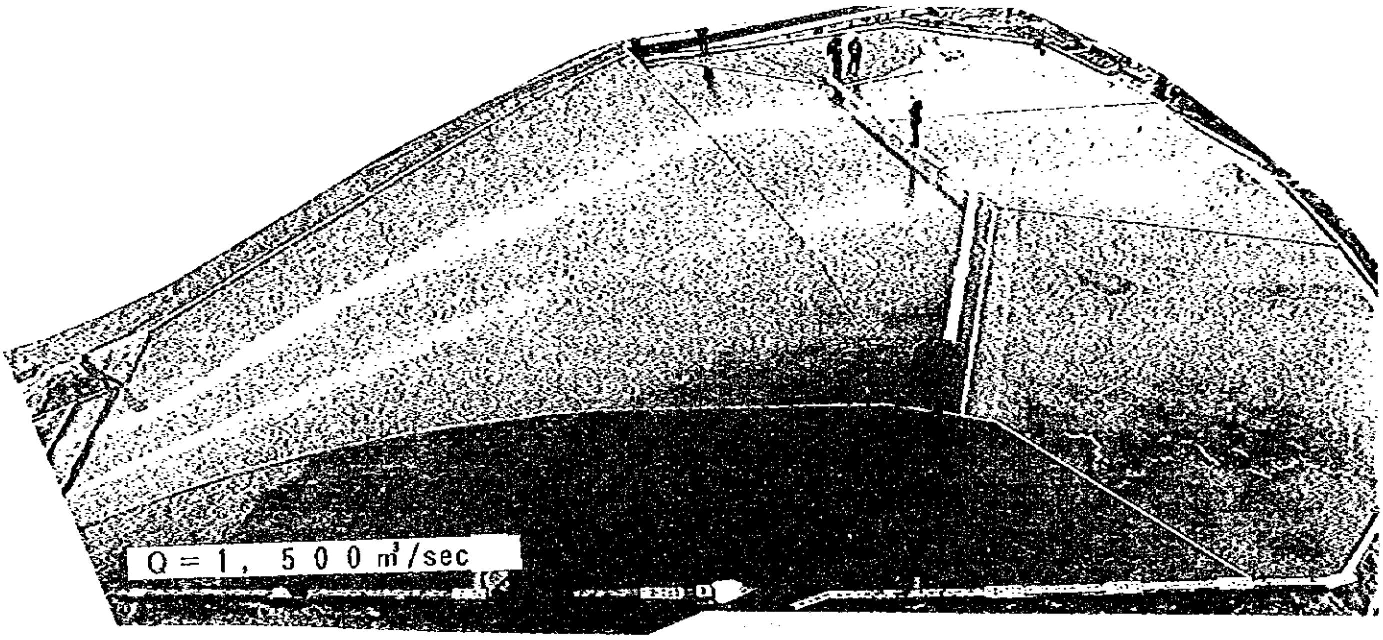
Table-5.6 shows shares of flood distribution by discharge.

Table-5.6 Shares of Distribution by Flood Discharge

Discharge	North Branch		South Branch		Escape	
Q (cumecs) {cusecs}	Q (cumecs) {cusecs}	Share	Q (cumecs) {cusecs}	Share	Q (cumecs) {cusecs}	Share
400 {14,000}	120 {4,229}	30%	185 {6,520}	46%	95 {3,348}	24%
1,000 {35,000}	321 {11,314}	32%	428 {15,085}	43%	251 {8,857}	25%
1,500 {53,000}	418 {14,733}	28%	711 {25,059}	47%	371 {13,076}	25%
2,000 {70,000}	522 {18,398)	26%	846 {29,817}	42%	632 {22,275}	32%
2,500 {88,000}	550 {19,385}	22%	1,236 {43,563}	49%	714 {25,165}	29%
Designed Discharge {1,500 m3 / sec}	450 {15,860}	30%	600 {21,147}	40%	450 {15,860}	30%

The shares of distribution at every discharge level are corresponded to the designed shares. But it is possible that the shares of distribution being changed in the prototype by the riverbed alteration in future because in the test the supplied sand has not reached to the distributor by one flood and sand bars has not formed in upstream of the cross structure.





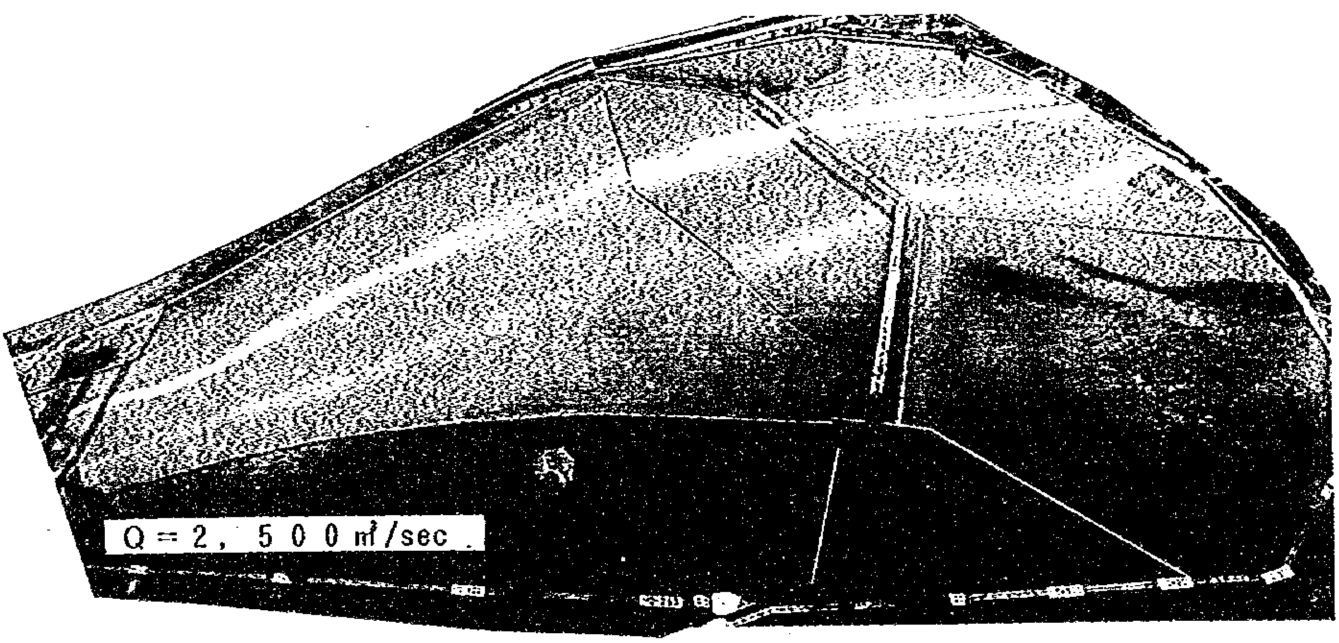
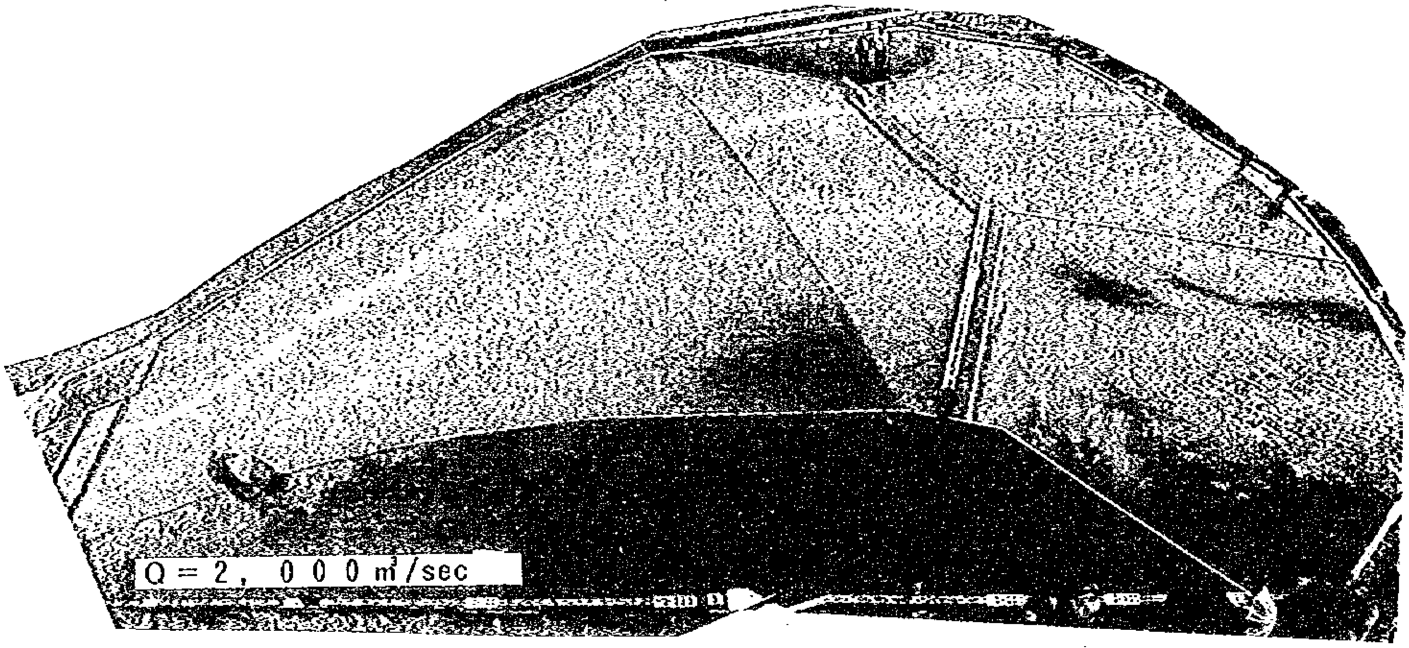
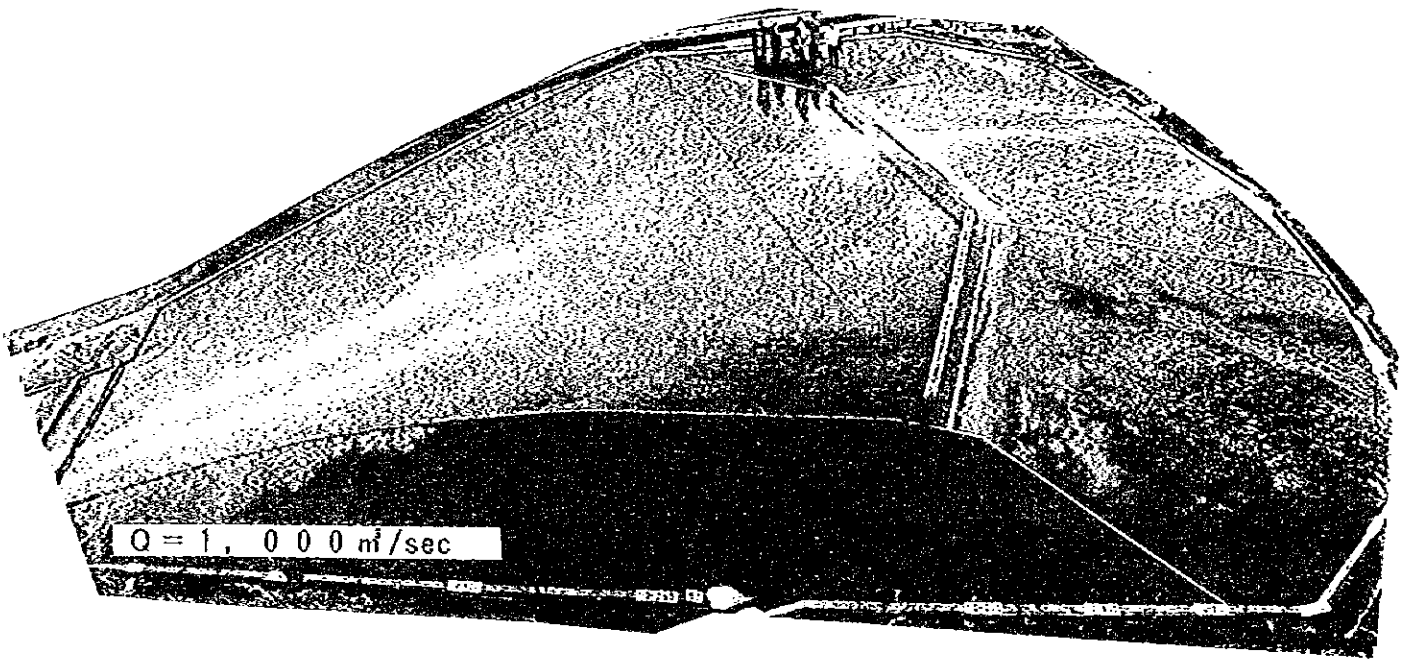


Photo. 7 Bird's eye view of the stream during flooding (Case - 4)





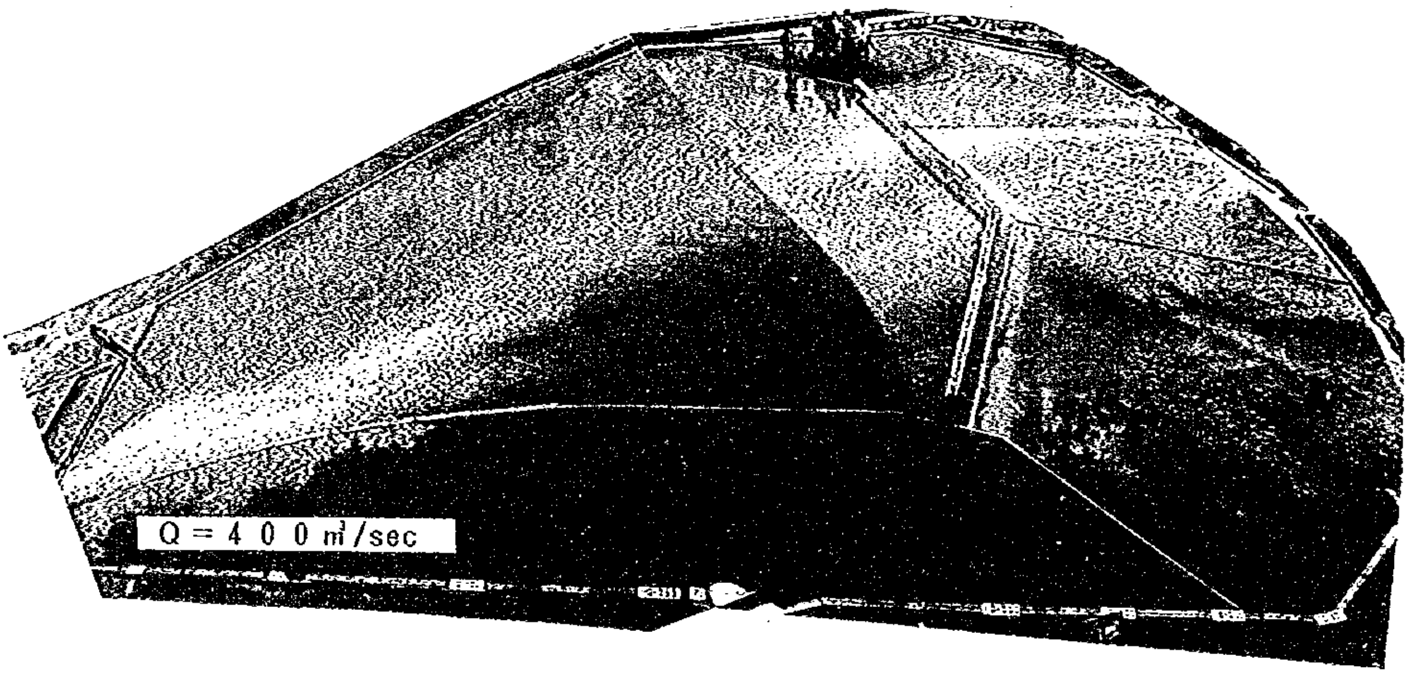
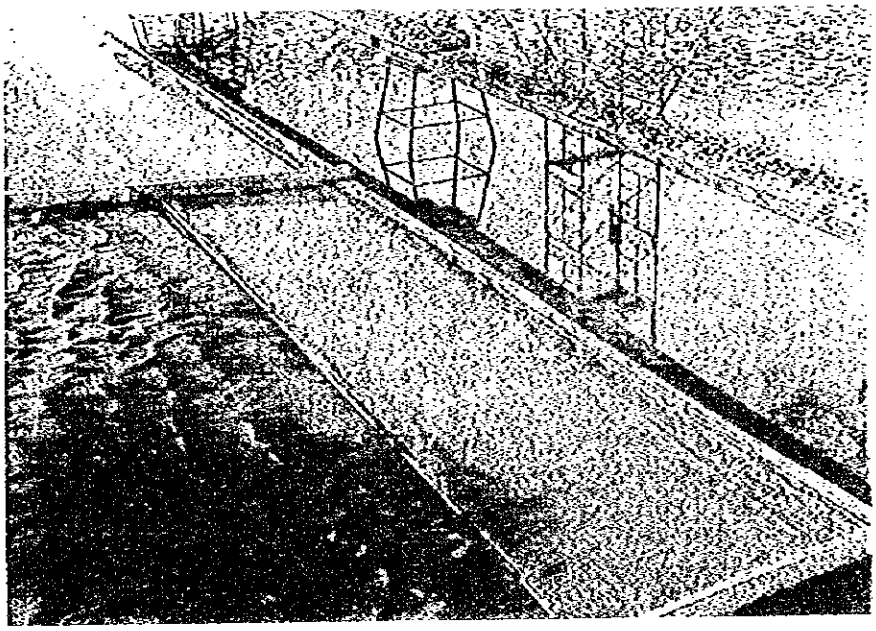


Photo. 8 Bird's eye view of the stream during flooding (CASE - 4)

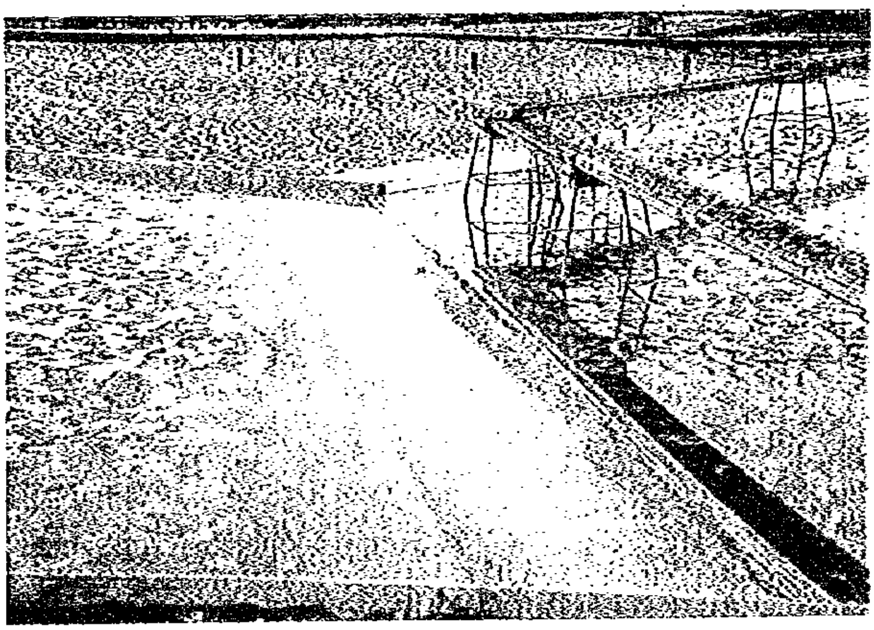
Photo. 9

TEST CASE - 4

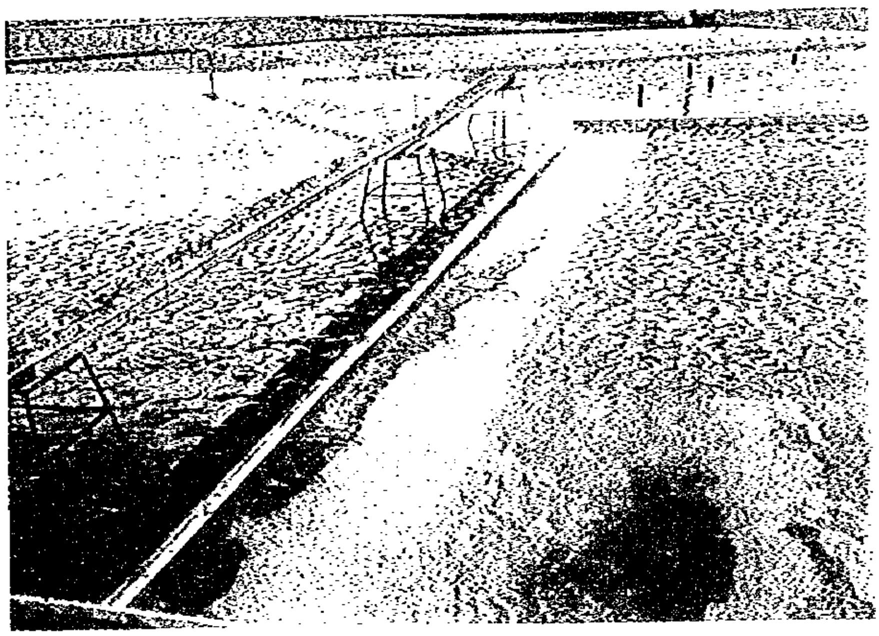
The overflow section to the North branch after the test.
No sedimentation remained in the dissipator,because the sedimentation did not reach to this part of the cross structure.
No local scouring was found immediatedownstream of the cross structure.



The overflow section of the South branch after the test.
A little amount of sedimentation remained in the dissipator.
No local scouring was found immediate down stream of the cross structure.



The overflow section of the Escape after the test.
A considerable amount of sedimentation accumulated in the dissipator, because the sediment reached this part in a short time.
Local scouring was found along the guide wall to the South branch.



(2) Sediment Concentration

Sediment concentration in the Escape is higher than those of other branches, because flow tends to concentrate in the Escape which has steeper bed slope in main water course than other branches.

(3) Change of Bed Condition

Ripples are formed over the channel. Miner local scouring equivalent to less than 1 m deep in the prototype was developed downstream of the cross structure. Supplied sand had not reached to the North branch, but it reached to the South branch and the Escape deposited sediment in their dissipator.

5.6 Test for Evaluation of the Distributor (Mobil Bed Model Test: Test 5)

5.6.1 Objectives

To examine the variation of the shares of distribution by riverbed alteration and to confirm the status of the bed in equilibrium.

5.6.2 The Condition of model test

(1) Location of the Distributor

The cross structure is placed at M2+800.

(2) Discharge

Constant discharge of 2,000 m^3/sec was supplied.

(3) The quantity of sand supply and its concentration

In the Test 4, the quantity of supplied sand was 40,388 m^3 against calculated quantity of sand 689,080 m^3, for one flood. Therefore the shortage of supplied sand of 648,692 m^3 applied at the available maximum concentration of 0.043 % for a long period.

5.6.3 Result

(1) Variation of the Shares of Distribution

As shown in Fig.-5.4 and Fig.-5.5, the shares for the North and the South branches are decreased gradually, on the contrary share to the Escape increased. Finally, flow concentrated into the Escape, because of developing deep channel toward the Escape equivalent to 50 to 75 m wide in the prototype .

(2) Bed Configuration in the Main Water Course

At the end of the test, a channel of 50 to 70 m wide with 4 to 5 m deep developed in the riverbed to the Escape. Riverbed degradation began from local scouring develops main eroded channel and results concentration of flow. The location of the distributor is recommended at the upper reaches of the channel such as M2+100, where the main eroded channel are not developed.

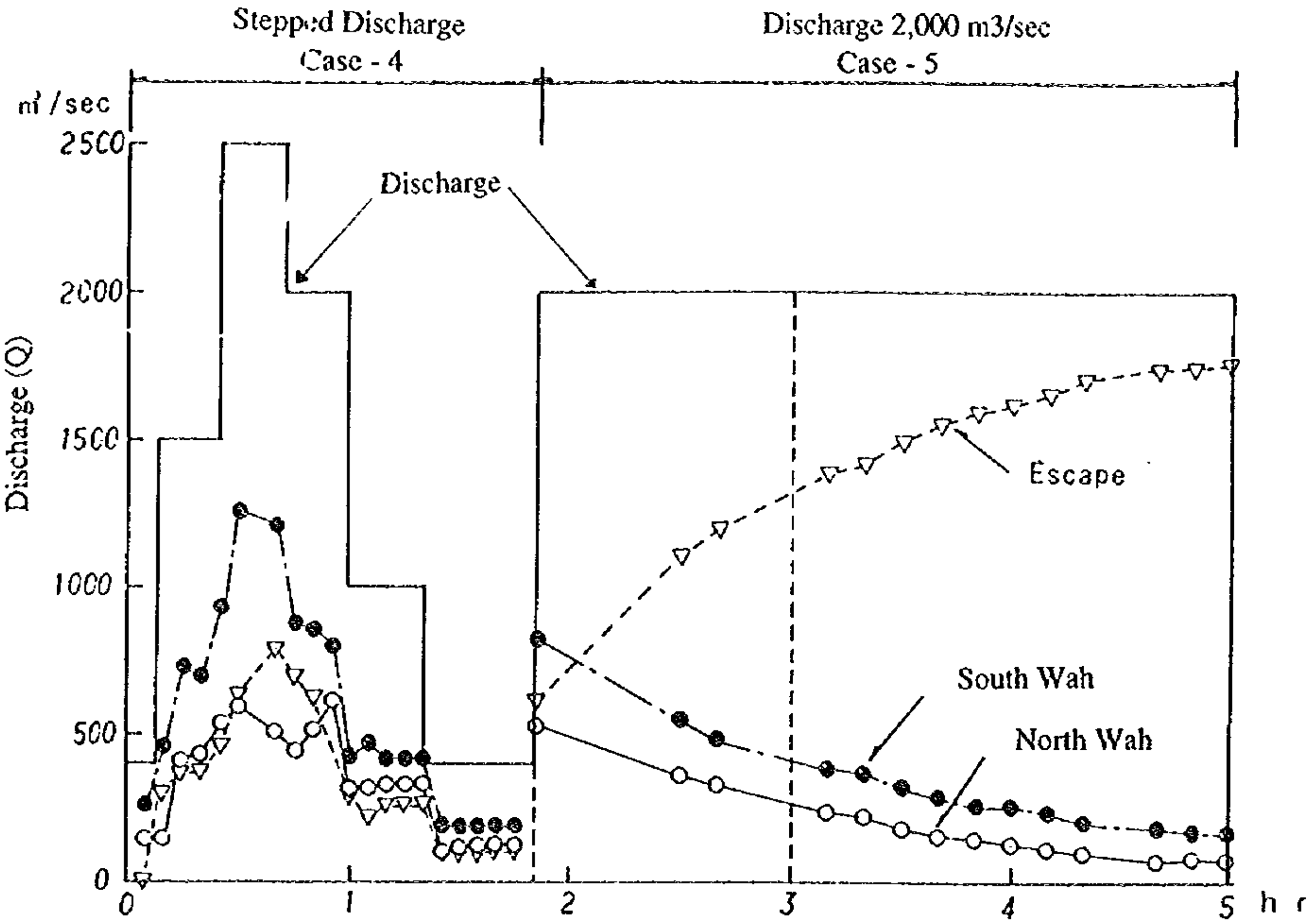


Fig.-5.4 Change of Distributed Dischage in Each Channel with the Passage of Time (Case 4 and 5)

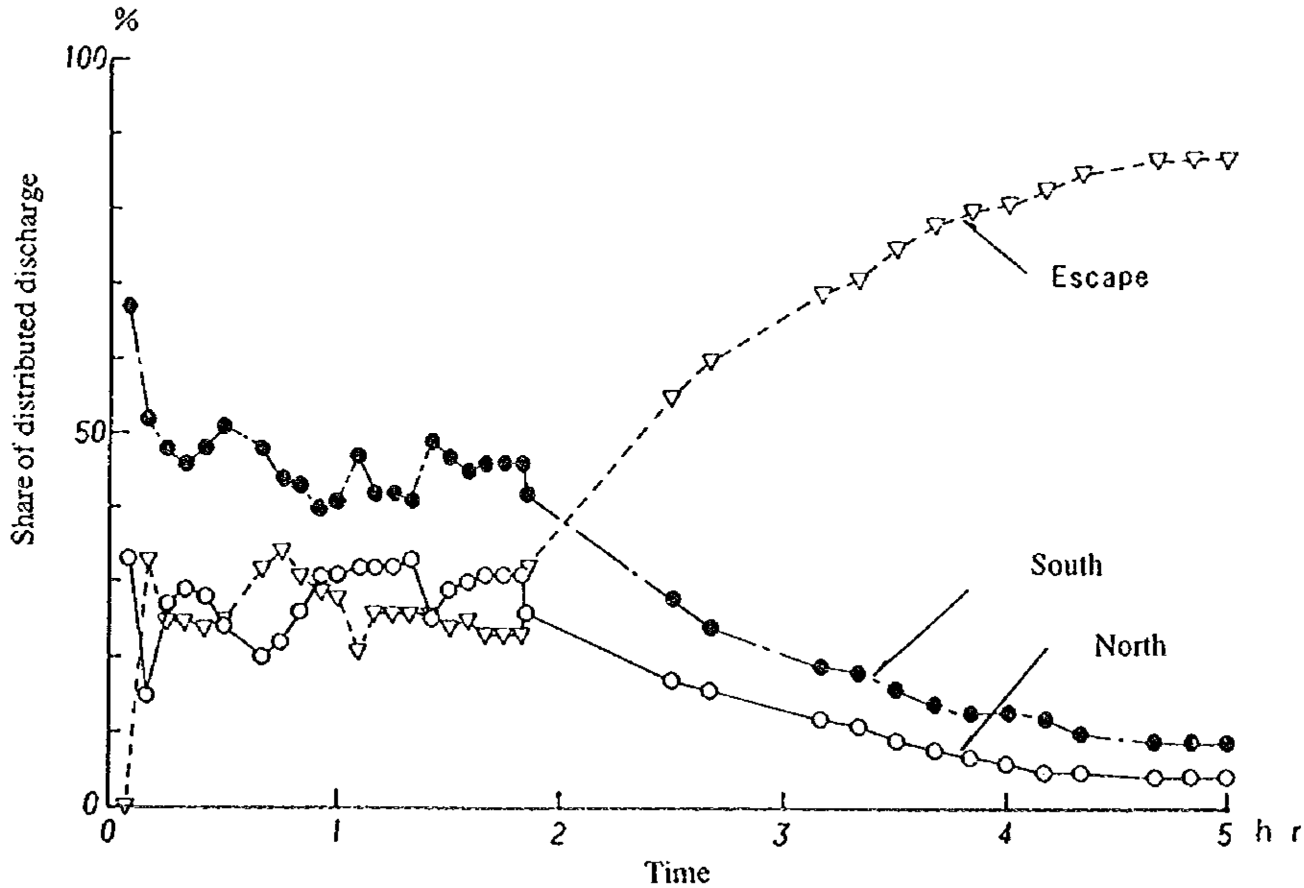
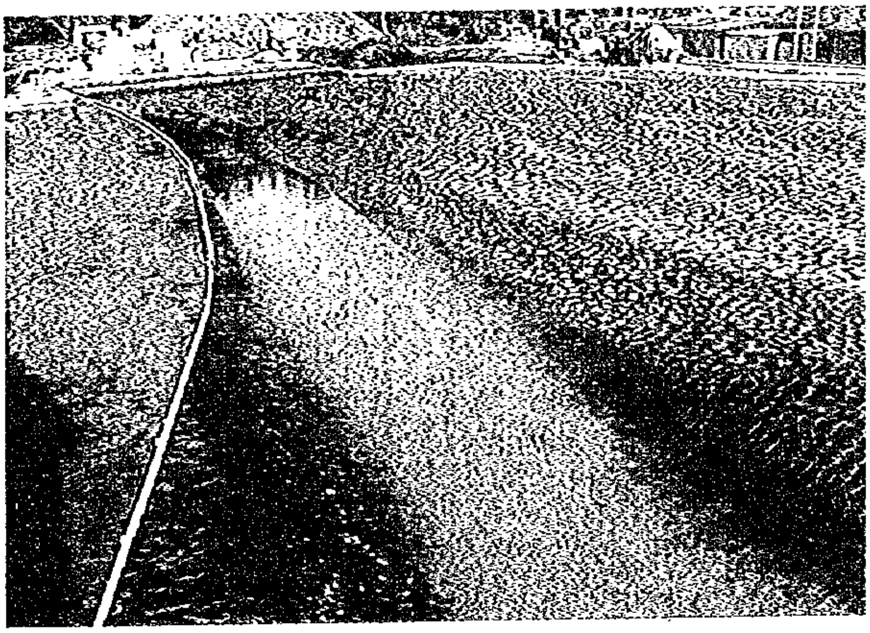


Fig.-5.5 Change of Distributed Discharge in Each Channel with the Passage of Time (Case 4 and 5)

After the test. Deep channel of 50 to 75 m (160 to 250 ft) wide was formed upstream of the Escape.



Scoured depth downstream of the cross structure is less than 1m (3.3 feet), but it reaches about 2 (6.6 ft) deep along the guide wall.

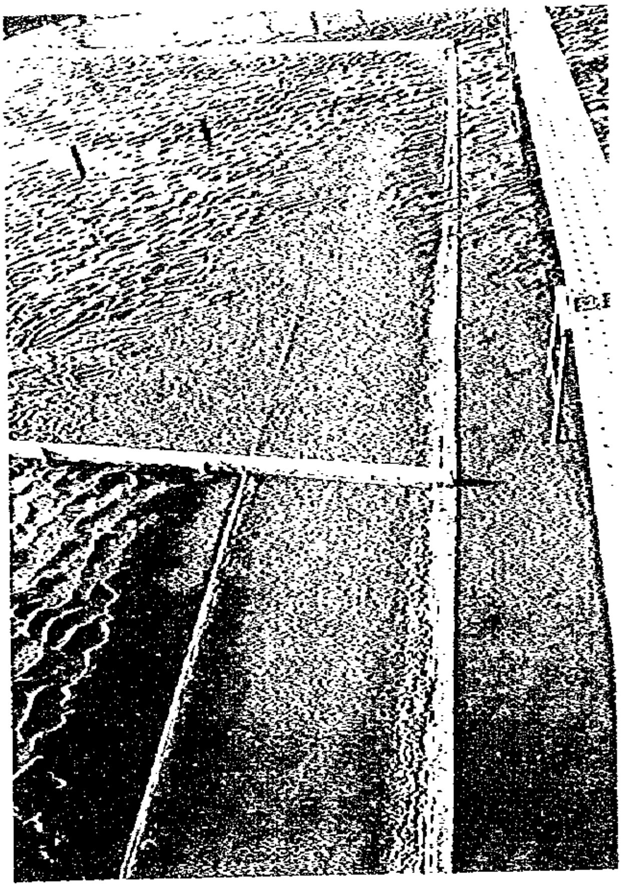
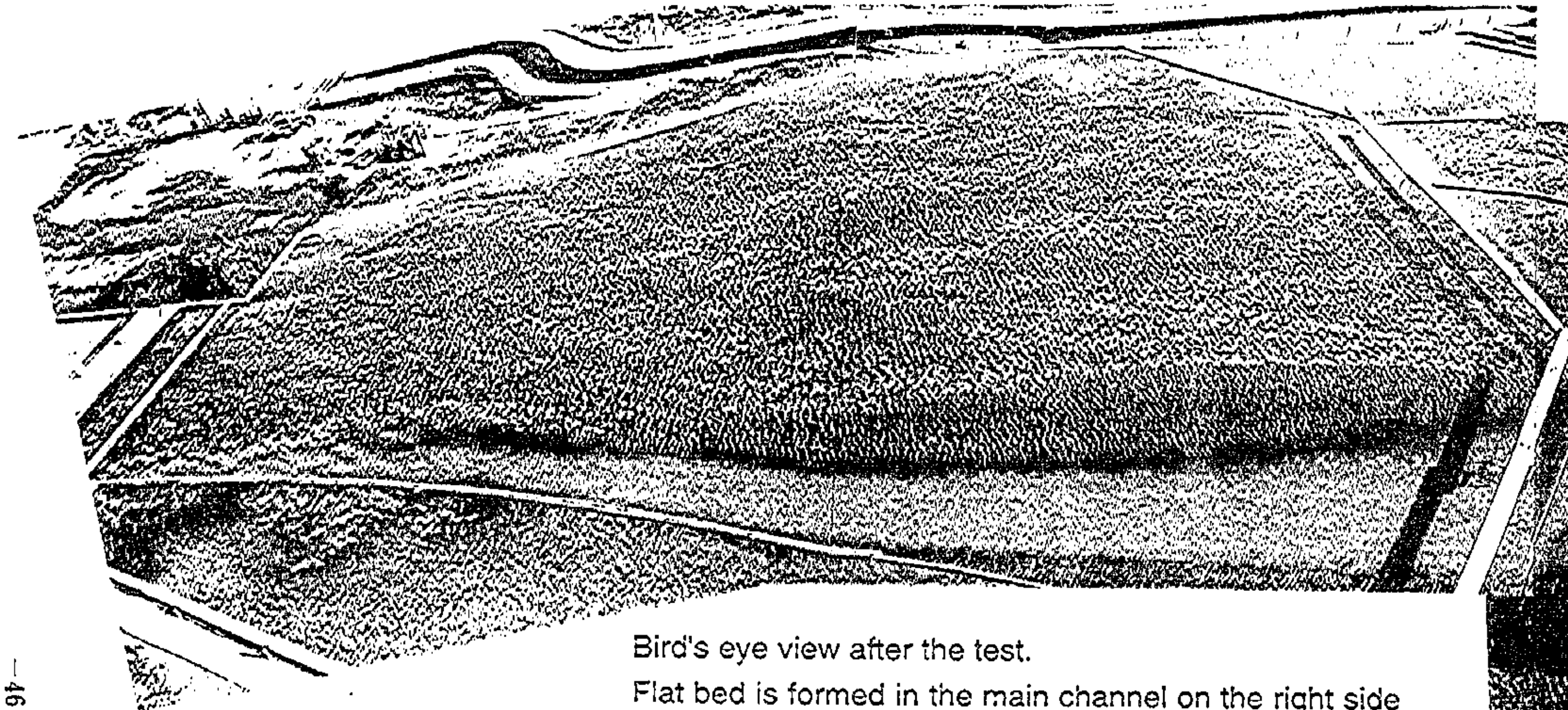
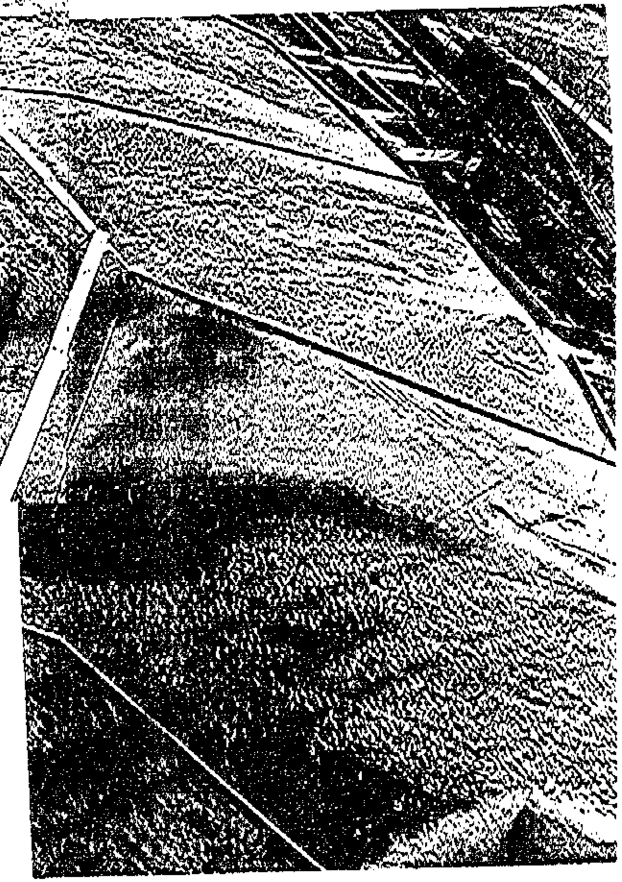
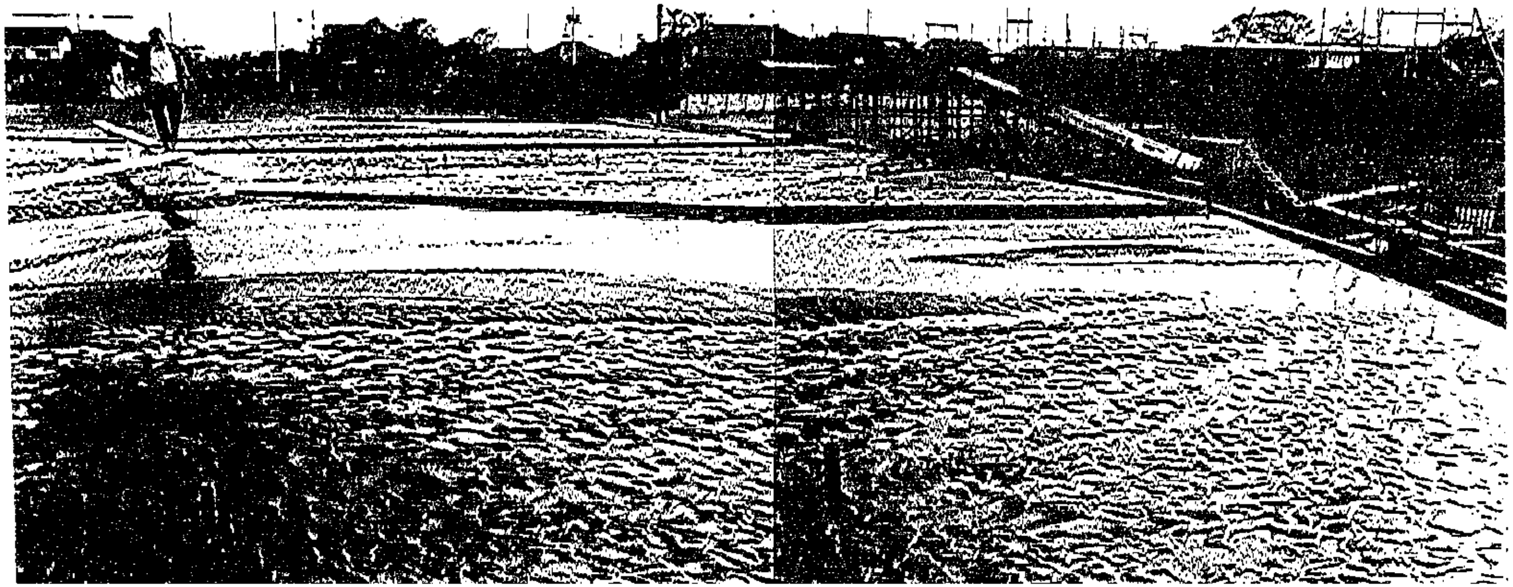


Photo. 10



Bird's eye view after the test.
Flat bed is formed in the main channel on the right side and ripples are formed the remained area of the riverbed.





Riverbed Condition downstream of the over flow section to the Escape.

Photo. 11

6 CONCLUSION

6.1 Difference of Bed Configuration between the Model and the Prototype

It was confirmed that the river bed configuration in the model was different from that of the prototype. Ripple are formed in the model bed, on the other hand, flat bed or dunes must be formed in the prototype.

The difference of bed configuration between in the prototype and in the model means that the similarity on sediment transportation in the model does not conform to that of the prototype. It is recommended to use a distorted model having different reduced scales in vertical and in horizontal for the hydraulic model tests focusing in the similarity of sediment transportation.

6.2 The Hadwari Bund

The distributor is recommended to place at M2+100, where flow direction could be controlled easier than at M2+800. In the test, it was shown that removal of the Hadwari bund would distribute flood flows uniformly over the fan. Additional model test is recommended to confirm the role of the Hadwari bund before its remova.

Table-6. 1 Comparison of the Shares of Flood Distribution with/without Hudwari Bund

	North Branch	South Branch	Escape
Rigid Bed Model test			
With Hudwari Bund	54%	33%	13%
Without Hudwari bund	52%	32%	16%
Mobile Bed Model Test			
Without Hudwari bund	4%	9%	87%

Table-6. 2 Necessary Width of Channel for Distribution without Hudwari Bund

Location of Dispersion Structure	Width of Channel North Branch	South Branch	Escape Branch	Total
M2+100	157 m	209 m	248 m	614 m
M2+800	150m	310m	390m	850 m
Planned Shares	30%	40%	30%	

6.3 Stability of the Distributor

The hydraulic model tests showed that local scouring must develop immediate upstream and downstream of the structure and along the guide banks. Degradation of the riverbed should develop along the right bank/ toward the Escape channel upstream of the structure. Therefore, measures are required to cease the flow concentration or to reduce the partial flow. The crossing structures to minimize bed lowering is also recommendable depending on the erosion in the riverbed.

Construction of crossing structure is recommendable to minimize the development of longitudinal continuing erosion channels in the riverbed.

Report on Hydraulic Model Test (Part 2)

Table of Contents

1. OBJECTIVES OF THE HYDRAULIC MODEL TEST

In the case of designing structure on the alluvial fan, it is necessary to understand the characteristics of river bed variation and to evaluate the stability and the function of the structure. For the purpose, hydraulic model test was conducted to evaluate the bed morphology and local scouring around the structure.

The objectives of this hydraulic model test are as follows.

(1) Determination of applicable equation for sediment transportation

The test aimed to determine the coefficients in the applicable sediment transportation equation and carried out using two-dimensional channel for determining the quantity of supplied sand in the distorted model test keeping conformity with the sediment flow in the prototype.

(2) Evaluation of the bed morphology

The test aimed to confirm the status of bed morphology and shares of flow distribution to the channels downstream using three-dimensional distorted model.

(3) Evaluation of local scouring around the structure

The test aimed to evaluate the extent of local scouring around the proposed distributor to determine the penetration depth of the foundation and the range of protection works against scouring. Non-distorted model was used to examine the extent of scouring quantitatively.

2. TEST CONDITIONS

2.1 Distorted Model

In the distorted model, scales of the model are different in horizontal and in vertical, and it results different flow conditions in the prototype and in the model.

Prior to establish the model, the distortion (a=Hr/Vr), that is the ratio of horizontal reduced scale (Hr) vs. vertical reduced scale (Vr) was studied. Appropriate distortion was determined to keep the similarity on the riverbed configuration in the prototype and in the model by examining change of the riverbed resistance to the flow depending on difference of the scale.

2.1.1 Discharge by each distortion

Considering the area of the experimental field and the capacity of the pumps, three kinds of distortion, a=4, a=5 and a=6, were studied. Table-2.1 shows relation of distortion, horizontal reduced scale, vertical reduced scale and discharges in the prototype and in the model.

Table-2.1 Relation on Distortion, Horizontal and Vertical reduced scale and Discharge

Horizontal Reduced Scale H_r	Vertical Reduced Scale V_r	Reduced Scale Ratio a	Discharge in Prototype Q_p	in Model Q_m
150	25	6	400 to 2,500	21.3 to 133
150	30	5	400 to 2,500	16.2 to 101
150	37.5	4	400 to 2,500	11.6 to 72.6

$H_r=H_{rp}/H_{rm}$, $Vr=V_{rp}/V_{rm}$, $a=H_r/Vr$

Suffix p: prototype, m: model

$Q_r=Q_p/Q_m=V_r^{3/2}\cdot H_r=a\cdot V_r^{5/2}$

2.1.2 Distortion and Reduced ratio of the Hydraulic Factors

Table-2.2 shows the reduced ratio of water depth, roughness coefficient and non-dimensional tractive force, etc. by scale difference.

Table - 2.2 Reduced Scale of Hydraulic Factors by Distortion

Factors	Distortion, a a=4	a=5	a=6
Horizontal length, X_r	150	150	150
Water depth, h_r	37.5	30	25
Gradient, i_r	0.25	0.2	0.167
Discharge, Q_r	34446	24648	18750
Roughness Coefficient, n_r	0.91	0.79	0.70
Non-dimensional tractive force, Tau_r	5.0	3.2	2.22

$X_r=X_p / X_m$, $h_r=h_p / h_m$, $i_r=i_p / i_m$, $Q_r=Q_p / Q_m$, $n_r=n_p / n_m$,

2.1.3 Determination of the Distortion

The factors dominating sediment transportation test results are roughness coefficient, water depth and non-dimensional tractive force. Their reduced ratios are as follows;

Roughness coefficient; $n_r=h_r^{1/6} / a^{1/2}$

Non-dimensional tractive force; $Tau*_r=h_r / (a \cdot d_r)$

where, d_r: reduced ration of the bed material,

$d_r=d_p / d_m=0.3\text{ mm} / 0.16\text{ mm}=1.875$, fixed

In this study, critical part affecting the test result is regarded the upper reaches of the Hadwari bund where the riverbed slope in prototype is $i_p=1/570$ and the channel width is enlarged to $B_p=375$ m, because this place was supposed to be the most difficult to maintain the similarity on the riverbed configuration during the test.

Table-2.3 shows the relation between the hydraulic factors and distortion. Actual bed configuration during flooding must be in the region of flat to anti-dunes at the site, therefore it is necessary to reproduce similar bed configuration in the model test.

Suitable distortion was determined by the Yamamoto's figure (Fig.-2.1). In the case of a=4, non-dimensional tractive force (Tau*) ranges 1.05 to 1.58 at the ratio (H/d) of water depth (H) to bed material diameter (d) of 250 to 350. In other cases, Tau* from 1.63 to 2.48 with H/d from 306 to 469 at a=5, and Tau* from 2.66 to 3.56 with H/d from 369 to 563 at a=6.

Judging by Fig.-2.1, the case of a=4 falls in the range of flat to anti-dunes region and the cases of a=5 and 6 fall in complete anti-dune region. Therefore, similarity of the bed configuration might be kept when the distortion is determined a=4.

Table - 2.3 Roughness coefficient, water depth and non-dimensional tractive force by distortion

Factors		Distortion, a		
		a=4	a=5	a=6
Roughness	n_p		0.030	
coefficient (sec / $m^{1/3}$)	n_m	0.033	0.038	0.043
Water depth	h_p (m)		1.47 to 2.24	
	h_m (cm)	3.9 to 6.0	4.9 to 7.5	5.9 to 9.0
Non-dimensional	Tau_p		5.23	
tractive force	Tau_m	1.05 to 1.58	1.63 to 2.48	2.66 to 3.56
Froude's number	Fr		0.48 to 0.51	
Diameter-Depth Ratio	h_m / d_m	243 to 375	306 to 469	369 to 563

2.2 Reduced Scale in the Test

Based on above discussion, distortion for the hydraulic model test determined a=4. Froude's law of similarity is applied as a kinetic similarity in the test in which gravity and centrifugal force are dominant. Table-2.4 shows the reduced scales used in the distorted model test.

Table - 2.4 Reduced Scales for Basic Factors Froude's Law of Similarity

Items	Dimension	Reduced Scale	
Geometric Factors			
Horizontal	L	H_r	1 : 150
Vertical	L	V_r	1 : 37.5
Gradient		$V_r \cdot H_r^{-1}$	1 : 4
Area	L^2	H_r^2	1 : 22,500
Volume	L^3	$H_r^2 \cdot V_r$	1 : 843,750
Hydraulic Factors			
Froude's number		1	1 : 1
Velocity	L/T	$V_r^{1/2}$	1 : 6.12
Discharge Volume	L^3/T	$H_r \cdot V_r^{3/2}$	1 : 34,445.9
Time	T	$H_r \cdot V_r^{-1/2}$	1 : 24.5

2.3 Quantity of Sand Supply

Quantity of supplied sand in the test is determined by calculation using sediment transportation equation obtained experimentally.

2.4 Reduced Scale of Time based on Bed morphology

The form of riverbed changes with passage of time in a movable bed model test. It is necessary that the riverbed configuration and the rate of its change in the model coincide with that of the prototype during the process of alteration.

Usually reduced scale of time obtained from the bed morphology is different from the time scale by Froude's similarity. It is assumed that reduced time scale based on the bed morphology in the model will correspond with actual phenomena if the flow condition is steady.

Brown's equation, which considers suspended load and bed load, was applied in the study to discuss the reduced time scale based on the bed morphology. It gives reduced time scale t_{sr}=64.1, on the other hand reduced time scale by Froude's similarity (t_{sr}) is 24.5 as shown in Table - 2.4.

3 SEDIMENT TRANSPORTATION EQUATION

3.1 Objectives

Bed configuration in a model must be same to that of a prototype to reproduce the similarity in sediment transportation on a movable bed hydraulic model test. The test aims to determine the quantity of sand supplied in the distorted model test to reproduce similarity on bed configuration between the model and the prototype. It also aims to confirm the minimum discharge which makes similar bed configuration between the model and the prototype in the section having the lowest tractive force.

Followings are examined.

1) Confirming similarity of bed configuration

To determine the discharge which makes a similar bed configuration in the model and the prototype in the section of lowest traction force without supply of sand.

2) Determining the quantity of supplied sand

To determine the quantity of supplied sand which keeps equilibrium of channel bed in the distorted model.

3.2 Test Condition

3.2.1 Model

In the model test, a channel of 15 m long, 1 m wide and 0.45 mm deep is used. The movable layer has 20 cm thick and is composed of sand of 0.16 mm in average diameter.

The section adopted for the test has 1/570 of bed gradient and 375 m of channel width in the prototype. In the test, a distorted model with distortion a=4 is applied. Therefore, the model has 1/143 of bed gradient and 2.5 m of channel width.

3.2.2 Discharge

Four levels of discharge, 100, 1000, 1500 and 2000 cumecs are applied to confirm the similarity on bed configuration at each discharge level. Discharge per unit width agrees in the model and is met to that of unit width assuming the uniform flow over the channel section.

3.2.3 Procedure

The bed condition was observed at each discharge level to confirm the bed configuration. To confirm the bed configuration, sand is not supplied at any levels of discharge.

Flown out sediment is measured at same intervals at the outlet of the channel to know the sediment transportation at the state of riverbed in equilibrium.

3.2.4 Results

Observation on the bed configuration is as follows.

Discharge	Bed configuration	Sediment Concentration at outlet (%)
400	ripples	
1000	flat bed except along the side walls	
1500	flat bed	0.765
2000	flat bed	0.872

3.3 Experiment for determining sand supply

3.3.1 Model

Specification for the channel, size of sand, thickness of movable layer and distortion are same to above mentioned in 3.2.1.

The bed gradient and width are following two kinds.

Prototype		Model	
Bed Gradient	Channel Width	Bed gradient	width
1/570	375	1/143	25
1/240	300	1/60	2

3.3.2 Discharge

Above mentioned result of the experiment (ref. 3.2.4) shows that discharge at 400 cumecs cannot keep similar bed configuration between the prototype and the model. Therefore, three discharge levels of 1000, 1500 and 2000 cumecs are selected in this experiment.

3.3.3 Procedure

To keep the riverbed in equilibrium, sand is supplied continuously during experiment. Flown out sediment is measured at a same interval at the outlet. Quantity of sand supply at the first trial is that of the observed concentration in the preceding experiment mentioned above in 3.2.4. Test continued until sediment concentration of inflow agreed with that of outflow.

Coefficients of the sediment transportation equation is determined by the observed sediment concentration.

3.3.4 Results

Observed sediment concentration of inflow and outflow at various discharge levels are tabulated as follows.

Discharge	Bed Gradient	Sediment Concentration		Status of bed
		Inflow	Outflow	
1,500	1/143	0.765	0.846	Lowering
1,500	1/143	0.846	1.087	Lowering
2,000	1/143	1.872	0.951	Lowering
2,000	1/143	0.951	1.104	Lowering
1,500	1/60	2.2	2.975	Lowering
1,500	1/60	3.5	4.076	Lowering
1,000	1/60	6.0	4.59	U/S sedimentation D/S in equilibrium
1,000	1/60	5.0	3.94	U/S sedimentation D/S in equilibrium

The sediment concentration of outflow is larger than that of inflow except at the discharge of 1,000 cumecs with gradient of 1/60. Relation between inflow and outflow sediment concentration are shown in Fig.-3.1.

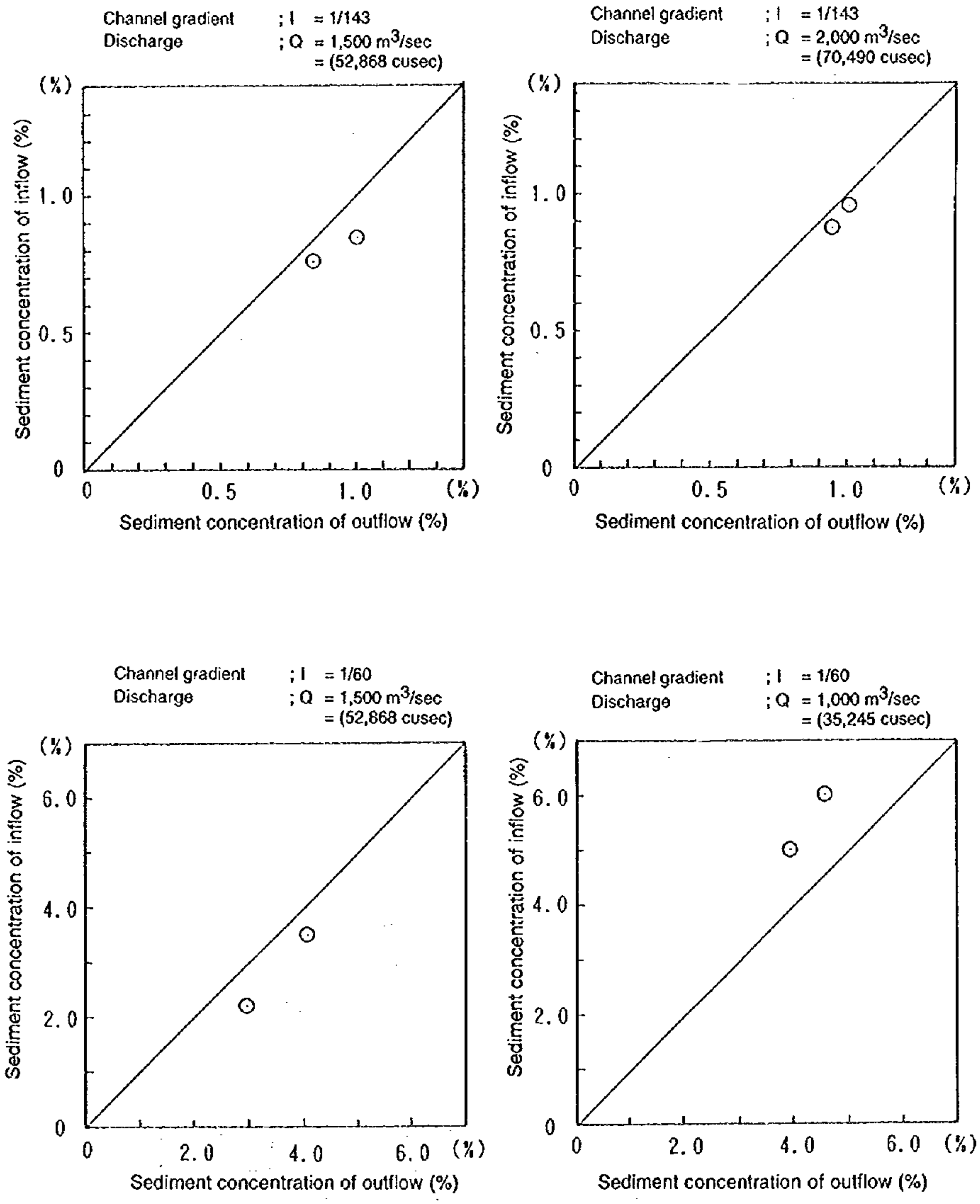


Fig.-3. 1 Relation between Sediment concentration of Inflow and outflow

3.4 Discussion and Conclusion

Bed configuration could be kept similar between the prototype and the model at the discharge of more than 1,000 cumecs in the prototype.

Judging from the above test result, sediment concentration at the riverbed in equilibrium estimated as follows;

No.	Prototype		Model		Estimated Sediment. Concentration at kinetic bed equilibrium in model
	Bed Slope	Discharge (Cumecs)	Bed Slope	Discharge (l/s)	(%)
A	1/570	1,500	1/143	17.4	1.3
B	1/240	1,000	1/60	14.5	5.0

Brown's formula below is adopted since the flow containing a considerable amount of suspended load and bed load.

$$q_s/(u_* \cdot d) = \alpha \cdot \tau_*^\beta$$

Substituting above test result to the equation,

No. A	Quantity of sediment	;	q_s= 0.000556 m3/sec
	Equivalent water depth	;	h=0.049 m
	Friction velocity	;	u_*=0.058/m/sec
	Non-dimensional Tractive Force	;	τ_*^β=1.30
No. B	Quantity of sediment	;	q_s=0.000725 m3/sec
	Equivalent water depth	;	h=0.034 m
	Friction velocity	;	u_*=0.075 m/sec
	Non-dimensional Tractive Force	;	τ_*^β=2.17

Using these values, coefficient of the sediment transportation equation determined. Below equation determines sediment transportation to maintain the river bed in the condition of kinetic equilibrium in the distorted model.

$$\frac{q_s}{u_* \cdot d} = 8.37\tau_*^{1.78}$$

where,

q_s :	Volume of sediment in the unit width, (m^3/sec/m)
u_* :	Function velocity (m/sec)
d :	Mean particle size of bed material (m)
τ_* :	Dimension less tractive force
S :	unit weight of bed material in water (g/cm^3)