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ANALYSIS ON ROLLER-BOX OF HIGH PRESSURE ROLLER GATE AND DISPERSED FLOW

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SYNOPSIS

New roller gate named NDF roller gate (Non Dispersing Flow) has been developed by authors since 1981. Some actual gate systems with NDF roller gate are designed and one of them is going to be constructed in this year. This paper is written as the summary of the results of experiment and theoretical analysis for this NDF roller gate under the developing process. The main analysis is about the dispersing flow at the gate roller slot. Authors find that the phenomenon of this dispersion of outflow is strongly related to the profile of water surface and derive the equation which gives the relation of dispersing angle and angle between the water surface and channel bed. By using this equation, designers can make a design of NDF roller gate without the model test.

PREFACE

There are more than five types of high pressure regulating gates, such as radial gate, jet flow gate,slide gate and some kinds of valves.

Recently the jet-flow gate and the radial gate are generally used for this purpose in the Japanese dams, while the roller gate is rarely used, because of its inferiority to the radial gate in hydraulic performance. When the roller gate is operated,the high pressure flow spreads and brings about a violent upward flow in the gate slot. This kind of flow frequently causes an erosion of concrete wall and also it makes a vibration of roller and gate. But the roller gate is superior to the radial gate in the respects that an operating system is simpler and its weight is reduced to 90% of total system.

Therefore, the roller gate has been needed to be improved so that the high pressure water may not flow into the gate slot at any gate opening.

Then, a new roller gate which is named NDF roller gate (Non Dispersing Flow), and in which high pressure water does not flow into the gate slot, has been developed by authors in the last three years.

This report summarizes the results of experiments and theoretical analysis obtained in this developing proces.

EXPERIMENT ON DISPERSING WATER FLOW

Experiments on the dispersing water flow from a roller gate under high pressure head, have been done in the order of three steps described below.

The first step is to obtain the relations between the dispersing angle of water flow and the shape of gate port, which is given by the length from gate lip to the front of roller box and the height of drop of the channel bed made at the front side of roller box. (Fig.1)

The second step is to find the relations between the dispersing water flow in the roller box and the opening width of roller box.

When the opening width of roller box is wider, high pressure flow of high velocity more easily comes into the roller box and causes the disturbance of water surface in the box.

The third step is to determine the critical width of roller box in which the high speed water does not come into the box. This is able to be determined from the relations between the dispersing angle of the flow and the offset length of channel wall which is given by widening the channel.

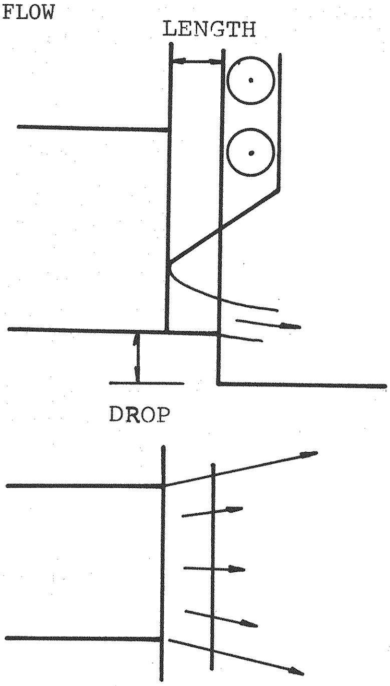


Fig.1 Definition of LENGTH and DROP

SLOPE 15° DROP 0
LENGTH 6 OPEN 80

	○ Head 1 X	Y	SITA	△ Head 2 X	Y	SITA	◇ Head 3 X	Y	SITA
Main	0	0	0.066	0	0	0.093	0	0	0.065
	37.9	3.3	0.093	39.6	3.7	0.097	38.0	2.5	0.067
Sub	0	0	0.162	0.3	0	0.219	0.7	0	0.182
	19.0	2.9	0.53	19.4	4.1	0.572	22.0	4.1	0.532
	37.6	13.8	0	39.2	16.9	0	37.4	12.7	0

In cm,Radian

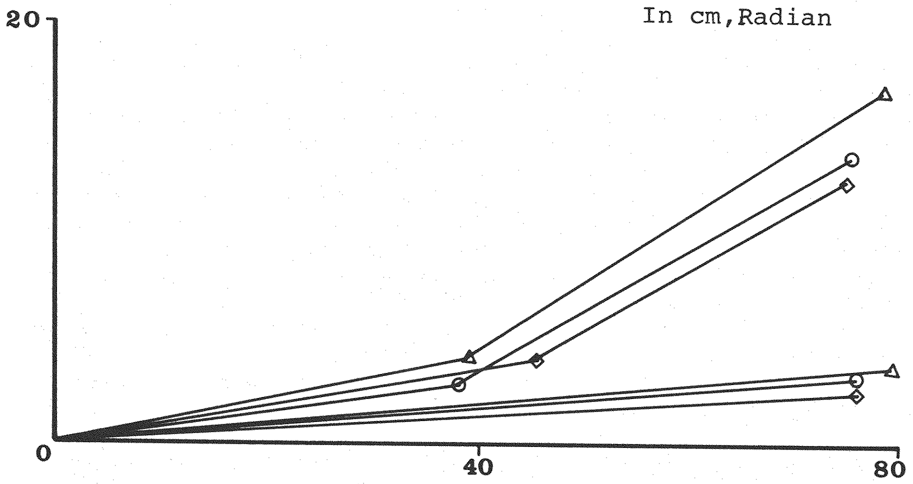
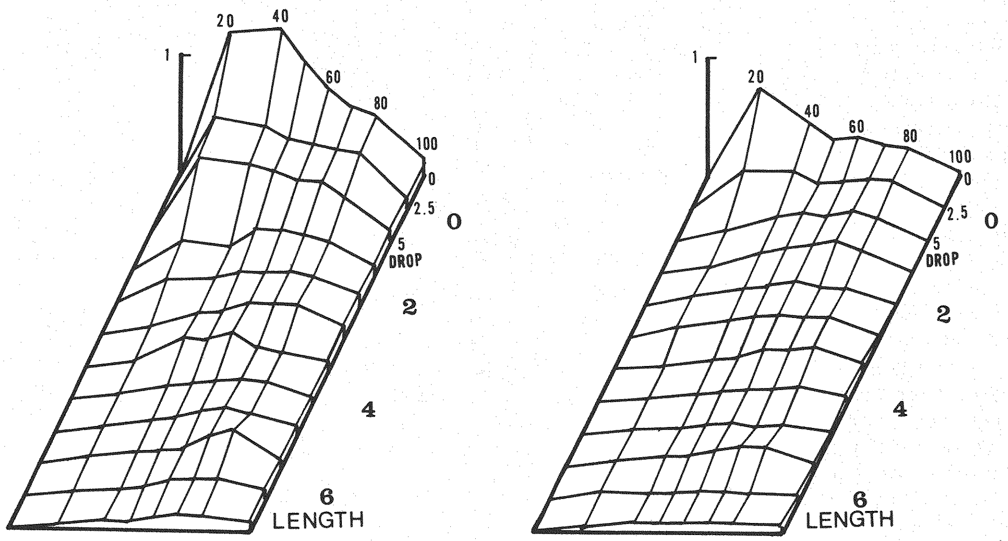


Fig.2 Flow dispersion

(1) Dispersion of high pressure water flow from the gate

It can be easily supposed that the degree of disturbance of water surface in the roller box is closely related to the rate of discharge of water flow into the roller box



Slope 0°

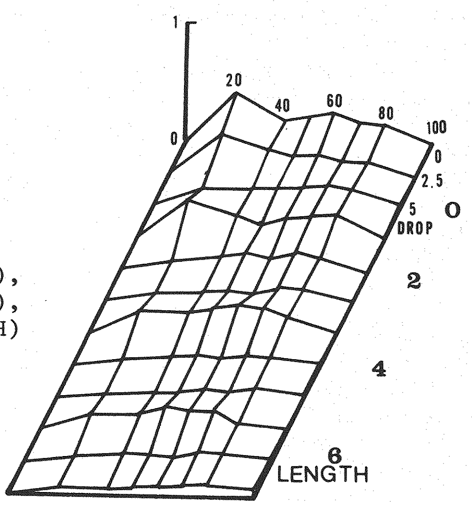
Slope 15°

(1)

(2)

Fig.3 Relations between dispersing angle and the other factors

(3)



Slope 30°

But it is not clear what factors are predominant for the lateral dispersion of water flow released from the gate lip.

When the water flows out from the gate, the high pressure in the conduit is release suddenly at the gate portion. The rate of pressure release is related to the shape of gate lip and the shape of the channel.

Therefore the factors relevant to this phenomenon may be considered to be pressure head at the upstream of the gate(HEAD), gate opening(GATE OPENING), distance from the gate lip to the front side of the roller box (LENGTH), drop of the channel bed at the roller box (DROP), slope of channel(SLOPE), width of channel (WIDTH) and height of the channel(D).

Among these factors ,WIDTH may not be so important because LENGTH is smaller than WIDTH and also this phenomenon occurs in very short distance from the gate lip.

And the flow at the centeral part of the channel is hardly contributive to dispersion of the flow, because lateral dispersion is due to only side part of the flow.

The measurement of dispersing angle of high pressure water flow behind the gate is made by the photograph which is taken from the upper part of the channel. In these photogaraphs the dispersion of the flow can be given as straight line, which is measured by the desitaizer of computer system MELCOM COSMO 700 III in Toyo University and plotted to the graphs as shown in Fig.2. In this graph two angles of both main and sub dispersing water flow are shown. The latter one is observed at surface part of flow and its dispersing angle is larger than that of the main flow.

Coordinates and angles of this dispersing water flow are shown at the upper part of this figure.

The relation between the dispersing angle and the other factors is shown in Fig.3 by three coordinates system.

The ordinate shows the dispersing angle in radian and the abscissa shows the gate ratio.

The graphs are written for 0,2,4 and 6 cm of LENGTH from behind to the front, each of which has three cases of DROP as 0,2.5 and 5.0 cm.

Dispersing angle is largest when LENGTH is 0 and it becomes smaller as LENGTH becomes larger.

The largest dispersing angle appears when the gate ratio is between 20 and 40 % and LENGTH is 0. In other cases of LENGTH, larger angle is shown between 60 and 80 % of gate ratio.

The same tendancy is observed in the effect of DROP, namely the angle is larger in the case of 0 DROP.

In this case the water is directly dispersing from

Fig.4 Equi-dispersing angle diagram

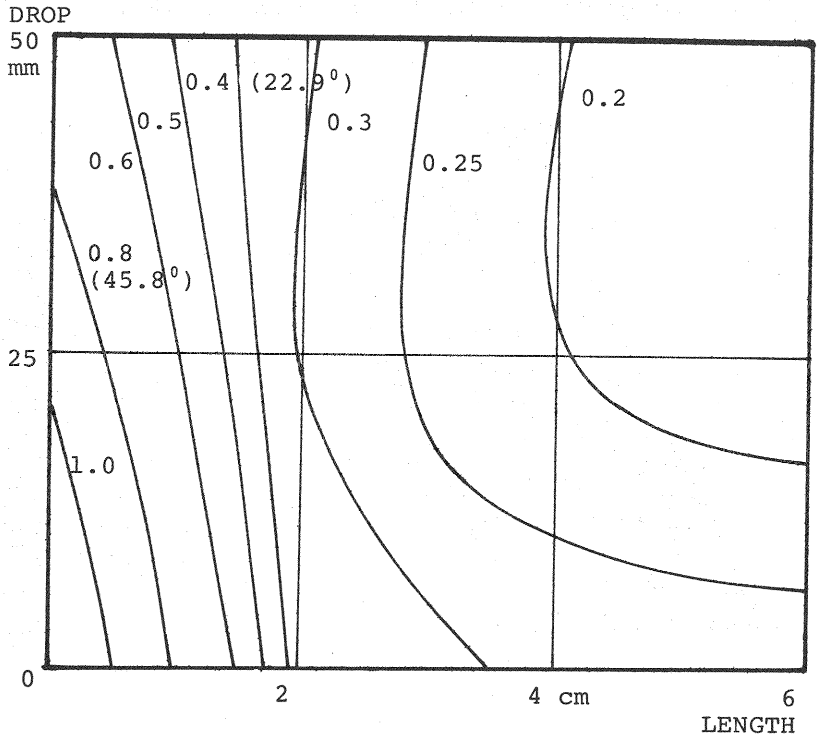
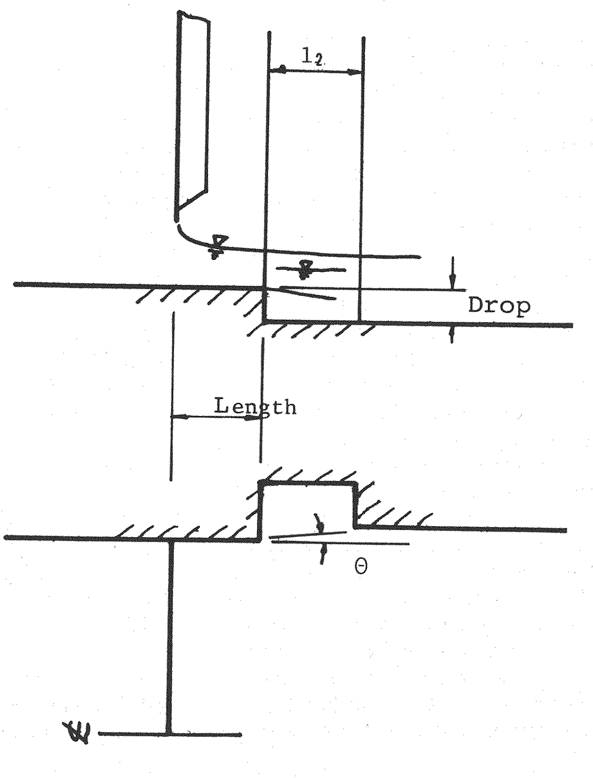


Fig.5 Critical opening



the point of gate lip and in other cases the dispersion occurs after the water drops on channel bed.

The similar characteristics are recogniged for any bed slope(SLOPE) and its angle becomes smaller as the slope becomes larger.

The largest dispersing angle at each gate ratio is picked up in all cases and the equi-dispersing angle graph is made as shown in Fig.4.

This figure is written in the case of zero slope by use of relation between two factors of DROP and LENGTH and the dispersing angle, and it shows that the effect of LENGTH is remarkable in the range of its smaller values. On the other hand, DROP has efficiency only for larger value of LENGTH to obtain smaller dispersing angle.

After this result, the dominant factor to make the dispersing angle smaller is LENGTH and the secondary one is DROP.

Fig.6 Relations between critical opening and the other factors

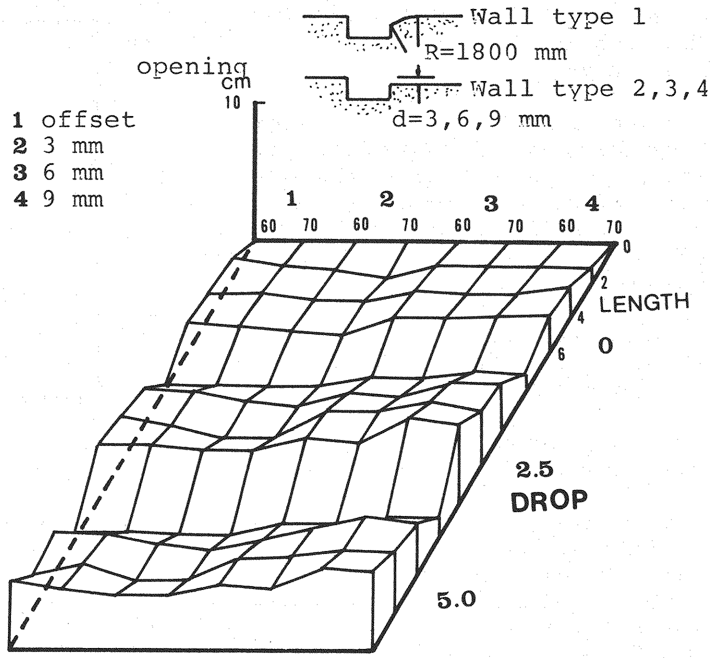
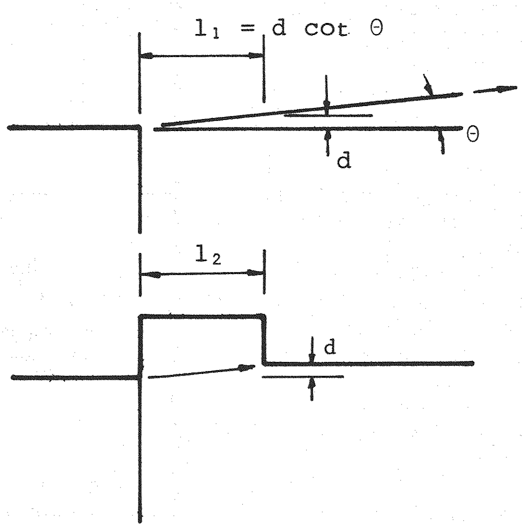


Fig.7 Definition of l_1 and l_2



(2) Relations of opeing of roller box and dispersing water flow

For applying two factors of DROP and LENGTH to the actual gate, the experiment has been done to determine the critical condition which the dispersing water does not flow into the roller box.

For convenience this is given by the condition that the water level in the roller box is the same as the outside water level of main channel and its critical parameter is given by the opening of roller box (l_2 in Fig 5) corresponding to this condition.

Measurement has been done in the most dispersing case of 60 to 70% gate ratio and four types of wall downstream of the roller box are used. Those are 1) offset; circular wall which has 180 cm radius, 2) Straight wall; which is set off by 3mm, and 3) and 4) are set off by

6mm and 9mm respectivly.

The results are shown in Fig.6 by three coordinate system, the ordinate shows opening of the gate box and the abscissa denotes the gate ratio for each wall type.

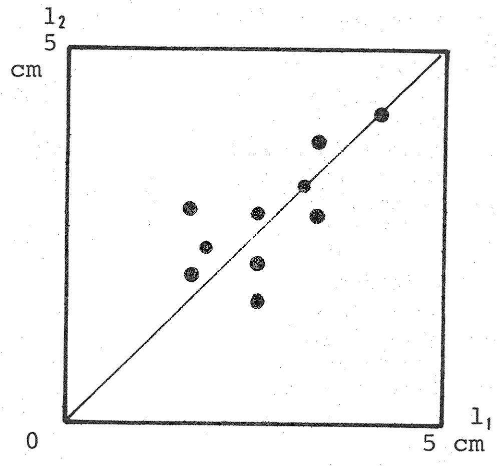
Graphs are written backward to frontside as DROP is 0 to 5cm and each DROP has four case of LENGTH 0, to 6cm.

Larger value of l_2 gives the better condition in which dispersing water is hard to flow into roller box.

From Fig.6, best conditions are given in cases of both LENGTH and DROP are larger.

And little difference of l_2 is observed among four types of wall. So, any type of wall can be applied to actual structures.

Fig.8 Relation of l_1 and l_2



(3) Critical opening of roller box and dispersing angle of water flow

It is well understood that the opening of roller box at critical condition becomes narrower when the dispersing angle is larger.

So, the result of two experiments above mentioned can be combined by the opening length l_2 and l_1 determined by equation(1).

$$l_1 = d \cdot \cot \theta \quad (1)$$

Here d is the widen offset length and θ is the dispersing angle as shown in Fig.7.

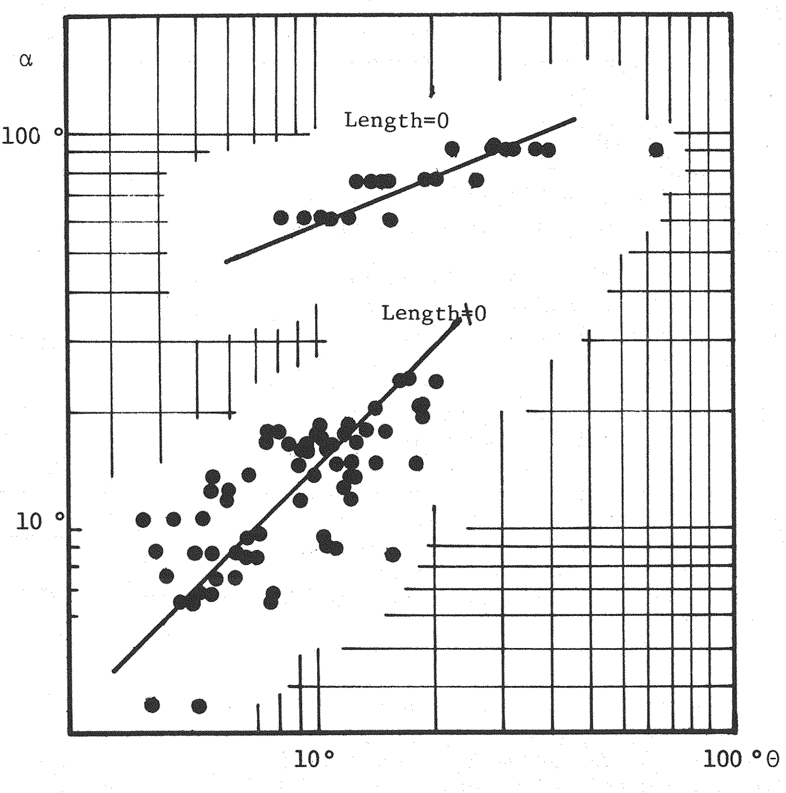
The relations between l_1 and l_2 are shown in Fig.8 and they have a good correlation.

The ratio of these values are as follows.

DROP=0 l_2/l_1 =1.0-1.7
=2.5 =2.0-2.7
=5.0 =2.2-3.2

From this fact the critical opening can be determined as to be larger as DROP

Fig.9 Relations between dispersing angle and angle of watersurface



becomes larger. This is because the water flows out from the bottom of the gate slot when the drop is made.

Therefore a designer can select the suitable ratio of these lengths for the actual gate. But the dispersing angle to determine the length l can be determined only by experiment.

DETERMINATION OF DISPERSING ANGLE

It is not clear how water dispersion occurs at the gate and what factors controle this three dimensional phenomenon. But the authors watch the curvature of water surface of outflows, because water does not flow into the roller box when the gate ratio is below 10% or over 90% and in these cases water surface is parallel to the channel bed at the section of roller box.

This means that water does not flow into the roller box when the radius of curvature of water surface is large.

As mentioned before, when water surface is parallel to the channel bed, dispersing water does not flow into the roller box.

Then, inclination of water surface to the channel bed can also be taken as a parameter instead of radius of curvature.

This point is very important for designer because inclination of water surface can be measured more easily than radius of curve. The relations between inclination of water surface (α) and dispersing angle of water flow (θ) are shown in Fig.9. There are two curves in this figure, in the case of which LENGTH is zero and not zero.

These two curves show extremely different values each other and lower curve is used for N.D.F roller gate to reduce the water dispersion.

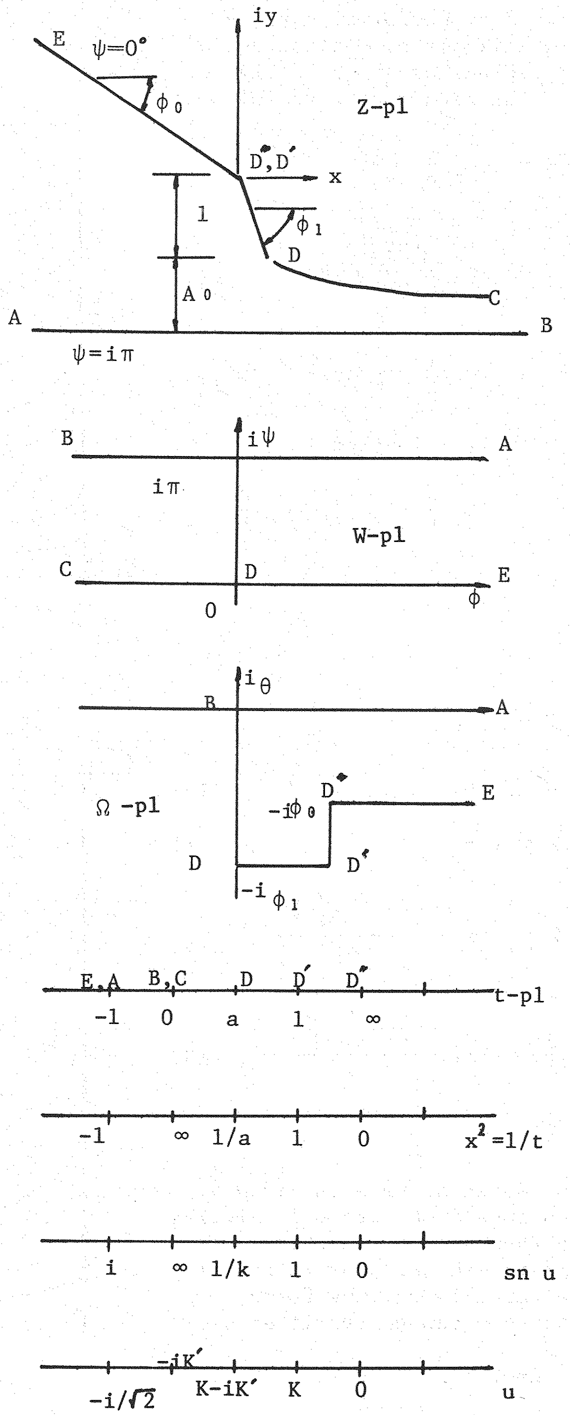
The curves in Fig.9 are represented by the following equations.

$$\theta = 4.02 \cdot \alpha^{\frac{5}{2}} \cdot 10^{-4} \qquad \text{(LENGTH=0)}$$

$$\theta = 4.29 \cdot \alpha^{\frac{5}{4}} \cdot 10^{-1} \qquad \text{(LENGTH}\neq\text{0)} \qquad (2)$$

From Eq.2, the dispersing angle can be determined by the inclination of water surface. Then, how to calculate the inclination of water surface should be discused.

Fig.10 Relations of conformal mapping planes



THEORETICAL EQUATION OF WATER SURFACE

Curve of water surface downstream of the gate is derived by comformal mapping between W-plane, Ω-plane, u-plane and t-plane as shown in Fig.10.

The results are as follows;

$$W = \log\left[\frac{t}{a}\,\frac{a+1}{t+1}\right] \qquad (3)$$

$$\Omega = A\log\frac{\Theta_4\left[\frac{u-a}{2K}\right]}{\Theta_4\left[\frac{u+a}{2K}\right]} + Bu + C \qquad (4)$$

$$A = \frac{\phi_0}{\pi} = \frac{1}{n}\,,\quad B = i\frac{(\phi_0-\phi_1)}{K} \qquad (5)$$

$$C = -i\phi_0 - \log(1/q_0)$$

$$= -i\phi_0\left(\frac{a}{K}+1\right) - (\phi_0-\phi_1)\frac{K'}{K} \qquad (6)$$

$$x = \frac{1}{t} = \mathrm{sn}^2 u \qquad (7)$$

$$a = k^2 \qquad (8)$$

$$\Omega = \log\left(\frac{dz}{dW}\right) = \log\left(\frac{1}{q}\right) + i\theta \qquad (9)$$

$$W = i\psi + \phi \qquad (10)$$

$$z = x + iy \qquad (11)$$

$$\Omega = \log\frac{\exp\left[-\frac{\phi_1}{\pi}\,\frac{u}{K}\,i\pi\right]}{q_0} \qquad (12)$$

$$\frac{dz}{dW} = \log\frac{\exp\left[-\frac{\phi_1}{\pi}\,\frac{u}{K}\,i\pi\right]}{q} \qquad (13)$$

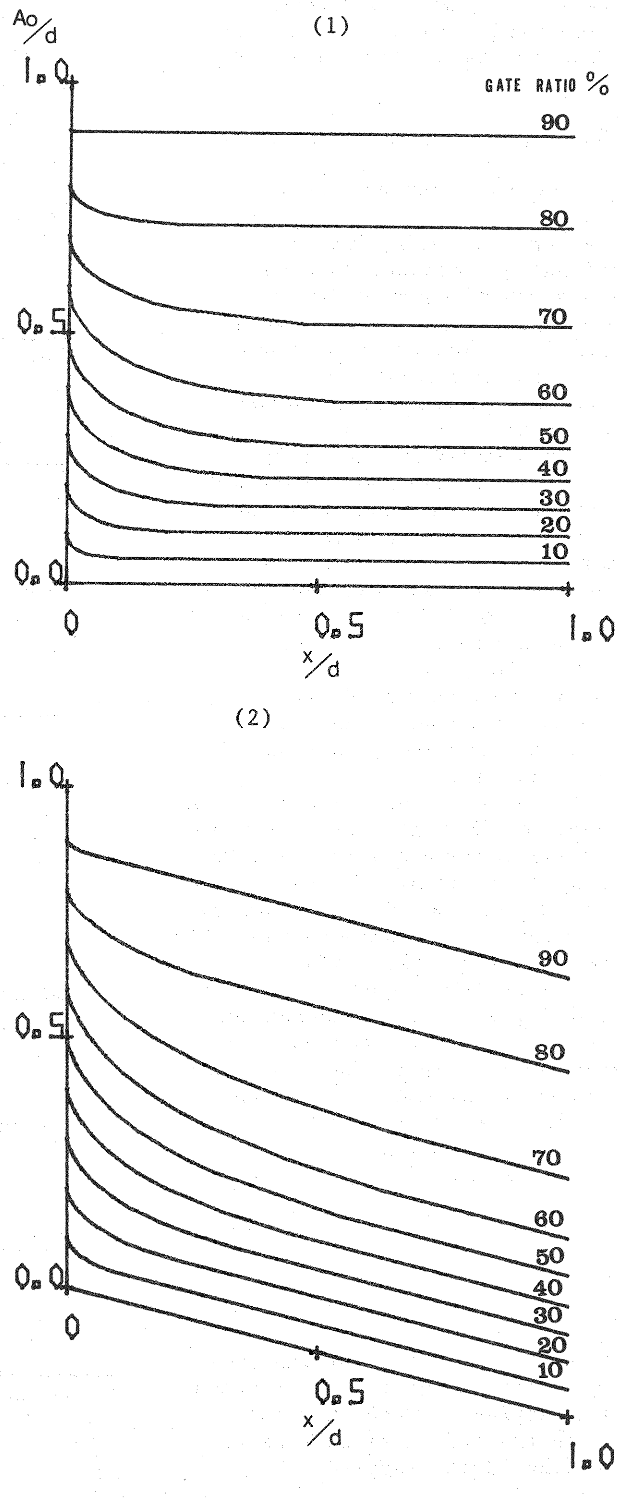
$$\frac{dW}{dt} = \frac{1}{t(t+1)} \qquad (14)$$

Water surface is given by the range from D to C in Fig.10, and then value of u changes from $-iK'$ to $-iK'+K$. Now introducing new variable u2, the former equations can be rewritten as,

$$u = -iK' + K - u_2;\quad u_2 = 0 \text{ to } K \qquad (15)$$

$$t = k^2\,\frac{\mathrm{cn}^2 u_2}{\mathrm{dn}^2 u_2} \qquad (16)$$

Fig.11 Profiles of water surface by theoretical analysis



$$\frac{dW}{dt} = \frac{1}{t(t+1)} \qquad (17)$$

$$dz = [\cos\phi_1(1-\frac{u_2}{K}) - i\ \sin\phi_1\ (1-\frac{u_2}{K})]dW \qquad (18)$$

Curve of water surface is calculated by the following steps;
1) assume u2,
2) calculate t and dt by Eq.16
3) calculate dW by Eq.17 and
4) derive dz by Eq.18.

Inclination of water surface is calculated by dy/dx, and dy and dx can be derived from imaginal and real part of dz.

The calculated curves of water surface as shown in Figs. 11 and the longitudinal variation of inclination of water surface is shown in Figs. 12 for each gate ration.

The experimental values of water surface are plotted in Fig.11 (3) only in the case of 60% gate opening. A good agreement between the theoretical and experimental results is recognized not only in this case but in other cases.

(3)

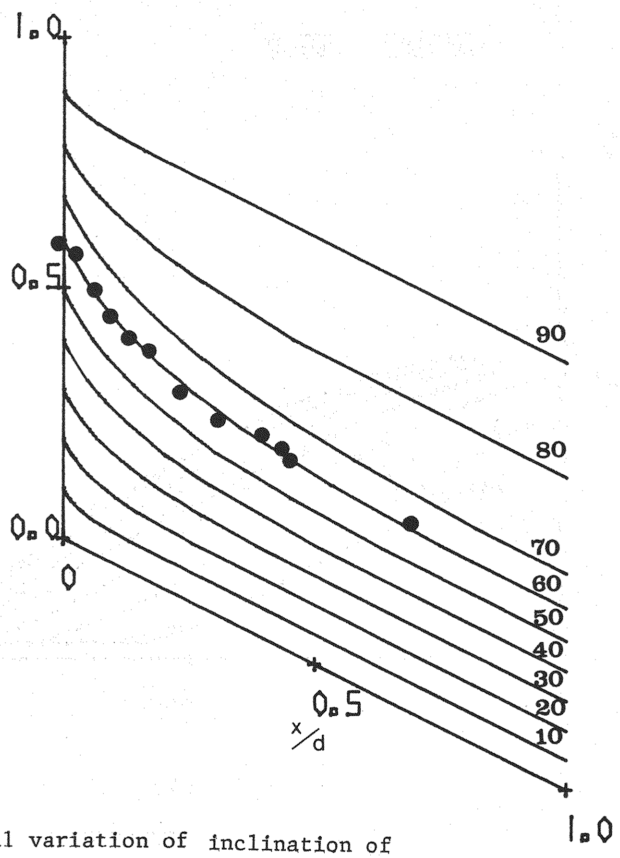
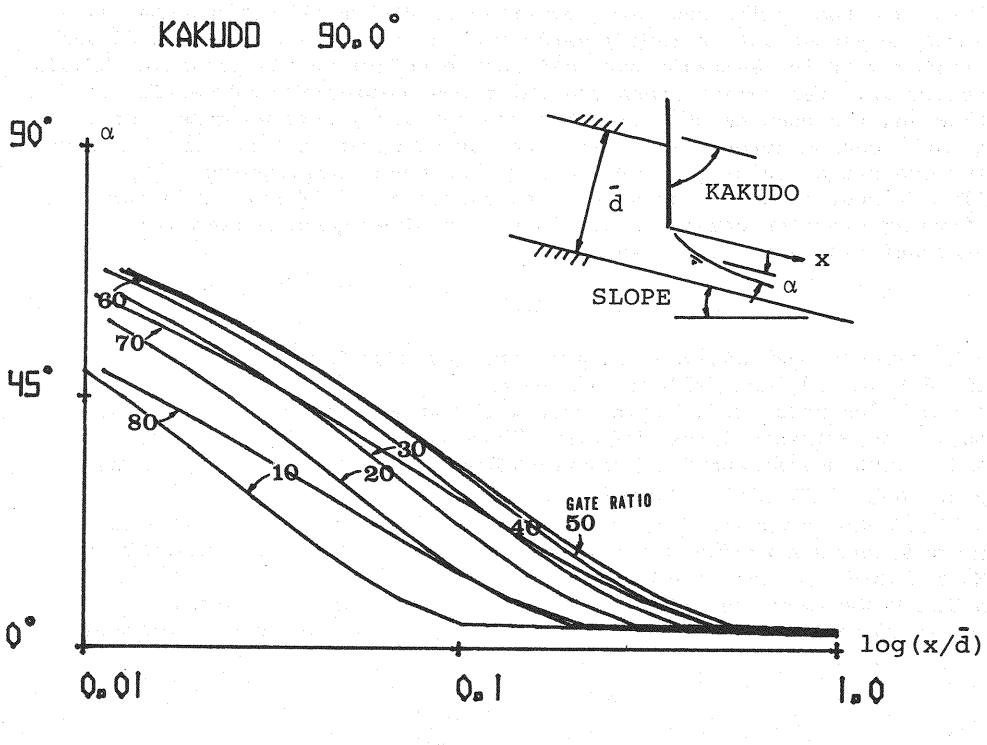
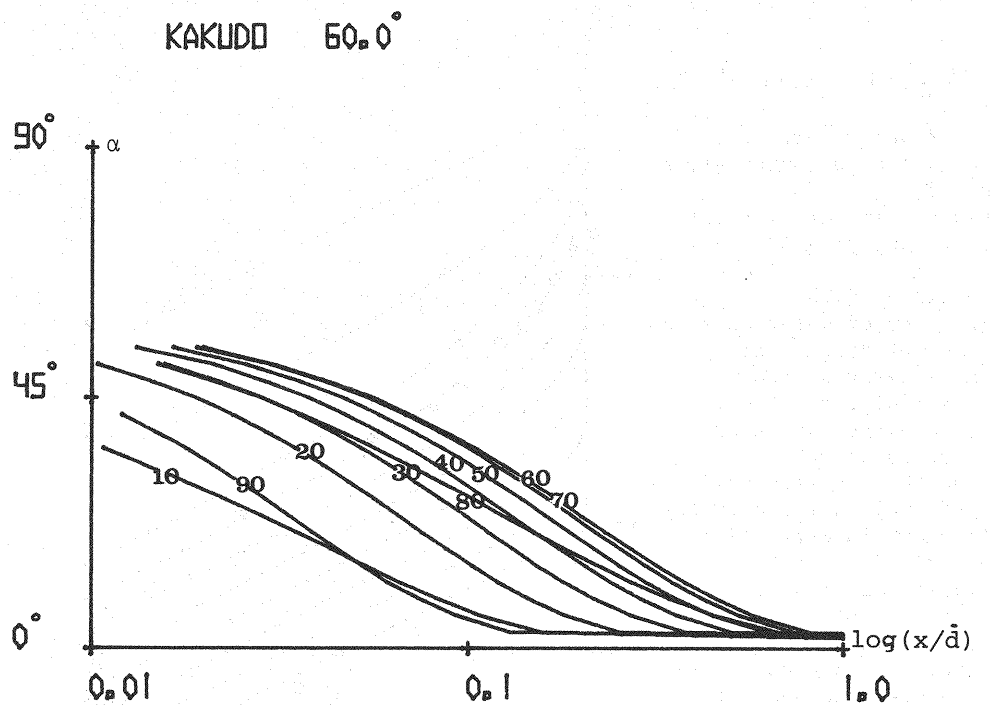


Fig.12 Longitudinal variation of inclination of water surface

(1)





(2)

CONCLUSION

Basic data for designg new roller gate (N.D.F roller gate) in which water does not flow into the roller box, are summarised. Whether the dispersing water flows into roller box or not is mainly determined by two parameters, LENGTH and DROP. Paticularly it is desirable for designer to determine the parameter LENGTH without experiment. For this purpose the relations between the dispersing angle of water flow and the opening of roller box are derived. Further more, the dispersing angle can be determined by inclination of water surface and the curve of water surface are calculated theoretically from comformal mapping.

Finally, it must be attentioned that the parameter of DROP is effective for aeration of water near the channel bed. This also gives good results for cavitation errosion on channel bed and wall.

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APPENDIX - NOTATION

The following symbols are used in this paper:

- A = gate opening;
- d = offset length;
- $\overline{d}$ = height of conduit;
- l = length of gate;
- l_1 = calculated length from offset length and dispersing angle;
- l_2 = opening width of gate slot;
- x = distance from gate lip to down stream side;
- W = complex potential;
- z = complex variable;
- α = angle between water surface and channel bed;
- θ = dispersing angle of water flow; and
- Ω = $i\phi + 1/q$.