DESIGN OF FLUSHING PIPES FOR SAND TRAPS

By: **Nils Reidar Olsen**

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SUMMARY

This report is the documentation from the first study of the "flushing pipe", which is designed to remove sediments from sand traps by periodical flushing. A sketch of this design is given on page 2 in this report.

The pipe is placed on the bottom of the sand trap so that the sediment deposits cover the pipe. The general design idea is to keep the entrance of the pipe free from sediments and let most of the flushing water enter here. The sediments enter through slots along the pipe. The cross-section area of the entrance should be about twice the sum of the cross-section areas of the slots to prevent the pipe from clogging.

This report refers model studies of the flushing pipe, and gives the theoretical background for transferring the model study results to prototype conditions. It also contain design guidelines for prototype flushing pipes, with an example. The example is considered to be a typical case for a sand trap, and this gives a flushing water loss of approximately 4 %.

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INTRODUCTION

Sediments can cause problems by depositing in irrigation canals or wearing turbines. When abstracting water from a river that is carrying high concentrations of sediments, a sandtrap is used to exclude some of the coarsest particles. The sediments settle in a part of the canal where the cross-section area is increased. A flushing canal or a flushing pipe can be used to remove the sediments from the sandtrap. However, little research have been carried out to find general guidelines for the design of the flushing systems.

This paper is the third report from the project called "Withdrawal of water from steep sediment-carrying rivers", which is a research program funded by NORAD and administrated by the Division of Hydraulic Engineering at the Norwegian Institute of Technology.

The two previous reports in this program are referred as (3) and (4) in the references. (4) is a general study of the problems encountered when modeling sediments in a physical model. (3) is a test of a previously suggested solution for removing the sediments in a sand trap. However, this solution is only designed for continuous flushing. A solution for periodical flushing is proposed in this report. More detailed work with larger model scales is planned in 1989.

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Mr. S. Halstadtrøen

1. INITIAL MODEL STUDY

In this first phase of the study it was attempted to make a model that worked according to the given criteria. This was that the system should be able to flush out the sediments that had deposited over some time in the sandtrap without getting clogged.

After having tried several solutions, the design shown below was adapted. During the study of this model type, the slot area and entrance area were varied. A solution with four slots of 1x2 cm and an entrance area of 16 cm^2 worked well.

An idea that did not work was to have one slot that extended over the total length of the flushing pipe. The reason why it did not function well was that the sediments closest to the downstream end of the pipe were flushed out first. This caused most of the water to enter here, and not sufficient water entered in the entrance of the pipe.

2. DETAILED MODEL STUDY

After having found one model solution that worked, it was necessary to do a more detailed study to be able to extend the results to prototype conditions.

In chapter 2.1 and 2.2, a laboratory model with a pipe of the following geometrical dimensions is referred:

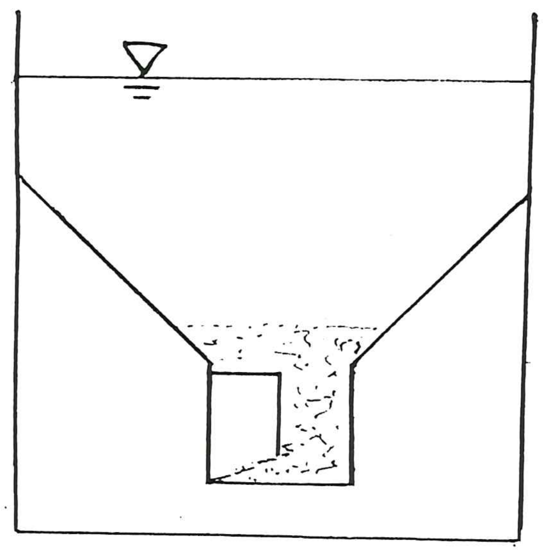
Length: 1.5 meters
Width: 3.7 cm
Height: 7-9 cm

This meant that the cross-section area increased from 26 to 34 cm^2. The entrance of the pipe had a smallest cross-section area of 16 cm^2. The geometrical dimensions indicated a model scale of approximately 1:10.

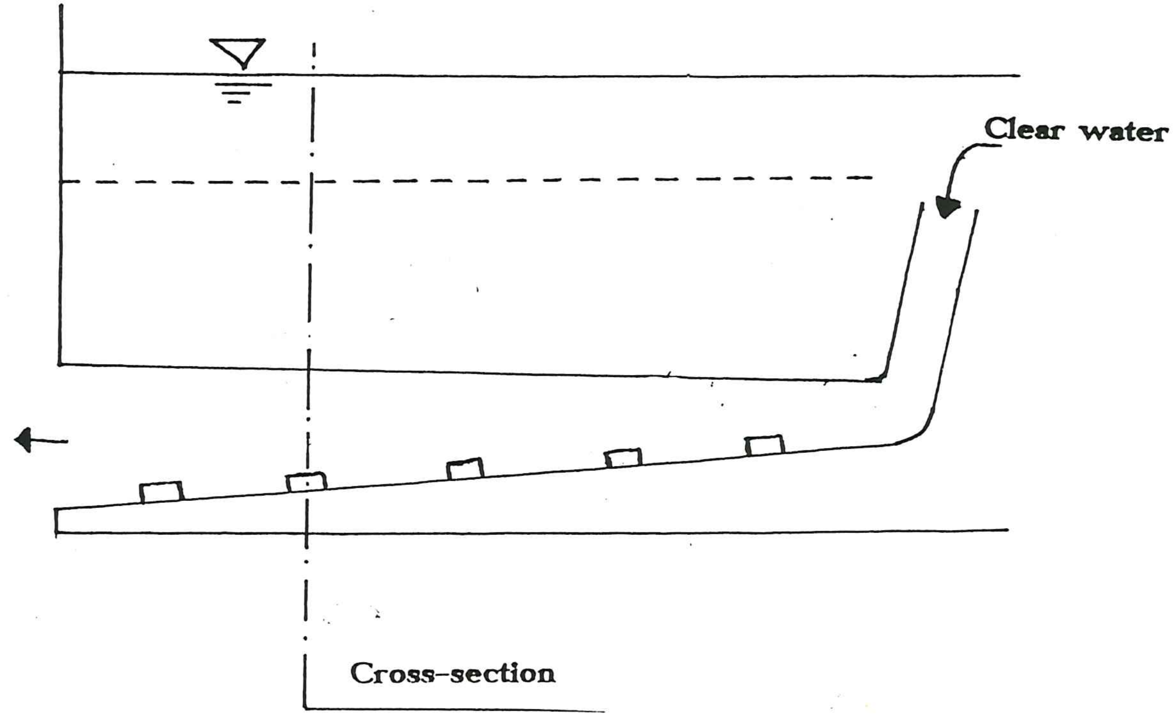
Sketch of sand trap

Sand trap with flushing pipe

Cross section



Longitudinal section



It was possible to measure the pressure head in both ends of the pipe, and also the discharge out of the pipe. This gave the possibility of measuring the head losses in the pipe.

2.1 HEAD LOSS OVER A SLOT

Two tests were carried out to find the head loss over the slots. In both cases two of the four model slots were kept open. In the first test the slot size was 1x2 cm, and in the second test the size was 0.45x0.9 cm.

In both tests the entrance head loss as a function of the discharge was calculated first. This was done while all the slots were closed. The discharge through the entrance as a function of the pressure difference in the entrance could then be obtained. When testing with open slots later, the discharge through the entrance was determined from the entrance head loss.

It was found that the head loss coefficient for the entrance was between 1.0 and 1.5. Because the entrance probably will be shaped differently for each scheme, more accurate results for this model was not considered necessary in this report.

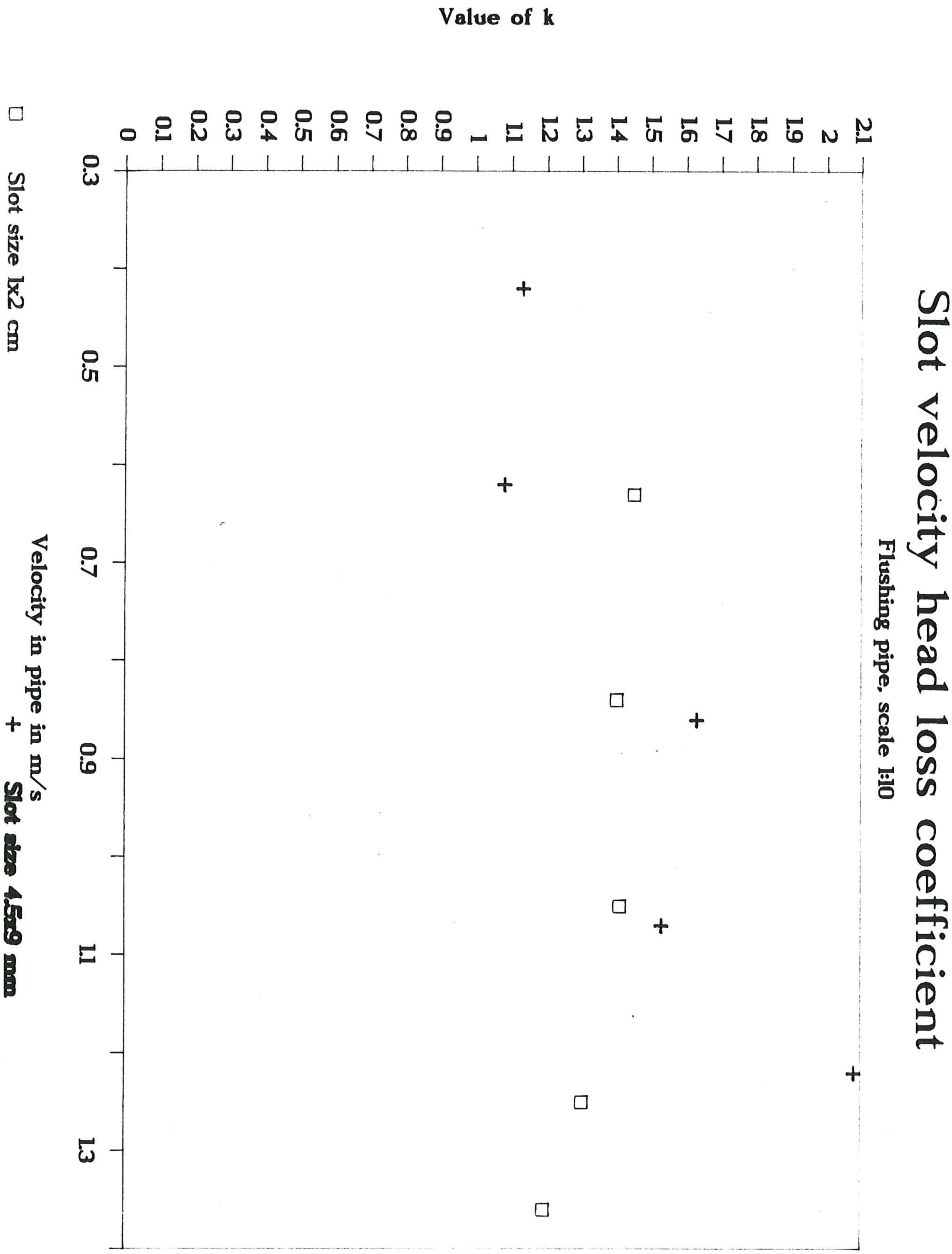
The head loss coefficients were calculated from the following formula:

k = (pressure head - velocity head in pipe) / (V*V/2g),

where V is :

V = (discharge in pipe - discharge in entrance) / (slot area)

The values of k as a function of the velocity in the pipe are given below. As we can see, there are some variations in the results, but a value of 1.5 can be recommended until further results are available. Note that the velocity in the entrance of the pipe and in the slots were approximately equal for both tests.


Slot velocity head loss coefficient
Flushing pipe, scale 1:10
Value of k
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
2.1
0.3
0.5
0.7
0.9
1.1
1.3
Velocity in pipe in m/s
□ Slot size 1x2 cm
+ Slot size 4.5x9 mm

2.2 HEAD LOSS IN PIPE

When the main flow of water in the pipe passes a slot, there will be some contraction of the flow. It was feared that this could cause the friction loss in the pipe to increase. Therefore two tests were carried out to determine this loss. The same models as in chapter 2.1 were used, with slot areas of 1x2 cm and 0.45x9 cm. The head losses were calculated according to a head loss coefficient k, giving the following results:

Slot area :	1x2 cm	0.45x0.9 cm
k :	0.25	0

In the test of the larger slots, the relative discharge through the slots was large compared to the prototype. The smaller slots correspond more to the prototype conditions. Therefore we conclude at the present stage that there is no head loss in the pipe because of the slots. Later model studies with larger scale models will determine more accurate values of k.

2.3 SEDIMENT VELOCITY IN SLOTS

An important design parameter for the flushing pipe is the velocity of the sediments through the slots during flushing. However, it is a problem to determine the sediment velocity in the prototype on the basis of model tests. This is because we lack knowledge of which scale relation to use. Staff at the Division of Soil Mechanics at the Norwegian Institute of Technology indicated that a possibility could be to treat the sediment suspension as a fluid with different density and viscosity than water.

Because of the difficulties with the scaling, a geometrical scale of 1:1 was used in this test. Prototype sand was also used, but this was only laid in a thickness of 0.25 meters. The total head for the test was also only 0.5 meters. In a prototype, we may have sediment thickness of over 1 meter, and heads of over 3 meters.

The result of the test was a velocity of approximately 1 m/s. For clear water, we obtained a velocity of 3 m/s. We therefore assume that the sediment velocity in the slots is approximately 0.5-0.1 times the water velocity. This is however a very rough approximation, which require further studies.

2.4 EFFECTS OF COHESIVE SEDIMENTS

Experience show that the sediments in a sand trap will contain layers of cohesive material. Only sand with no cohesion was used in the present model test. The most important effect of cohesion in the sediments will be to decrease the sediment velocity through the slots. At the present stage the decrease in velocity as a function of the cohesion has not been obtained. This may be done in further studies.

A suggestion to minimize the effects of the cohesive material could be to try to keep the velocity in the sand trap so high that very little cohesive material deposited. However, this may be difficult from a practical point of view.

Cohesive sediments in the sand trap may also be caused by organic material in the river. The behavior and influence of this material is not known at the present stage of the study.

3. DESIGN RECOMMENDATIONS

In this sub-chapter we will try to apply the results from the model study to give guidelines for the design of prototype flushing pipes.

3.1 MAIN DESIGN GUIDELINES

If we look at a sketch of the flushing pipe as given on page 2, we observe that we have two different situations for which we have to assure that the system functions.

SEDIMENTS OVER ALL THE SLOTS

One of these situations is when all the slots are covered with sediments. This means that it is only the water in the entrance of the pipe that will remove sediments. For this situation, we must only ensure that the amount of water in the entrance is sufficient for the flushing needs.

This argument leads to the conclusion that most of the water must enter the entrance of the pipe. We can define a parameter t as:

t = (discharge through slots) / (discharge through entrance)

In the initial model test t was varied, and a value of 0.5 seemed to work well.

SEDIMENTS OVER FEW SLOTS

The other situation is when only one of the slots in the upstream end of the pipe is covered with sediments. Then we have to assure that enough water passes this slot. This means that we must avoid a situation where little water enters the entrance of the pipe, and most of the water enters through the open slots.

The latter argument leads to the conclusion that the size of the slots must be as small as possible, but without clogging. In this study we have assumed that a prototype size of 5x10 cm may be a usable solution.

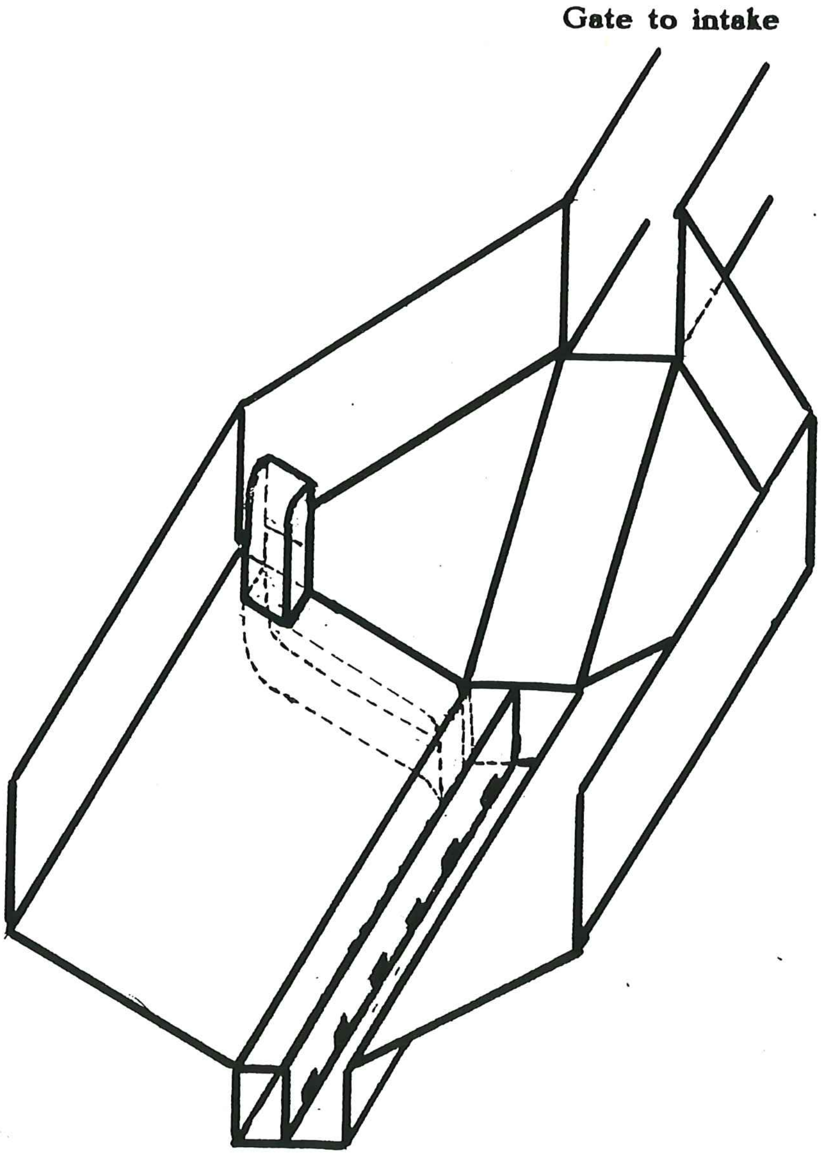
3.2 GEOMETRICAL DESIGN

ENTRANCE

The basic idea of the flushing pipe is to be able to have an entrance that does not clog. Therefore, the entrance must be above the bed of the sand trap. But it must also be lower than the water surface.

Entrance region

Sand trap with flushing pipe



An important point is to try to minimize the head loss through the entrance. Therefore, it should be designed with a large cross-section and all the bends should be hydraulically well shaped to give as small loss as possible.

A suggestion for the design of the prototype entrance is shown on a sketch above. The entrance for the model test was approximately equal, and an entrance head loss coefficient of approximately 1.5 was observed.

CROSS-SECTION

One of the main design charachteristics of this type of pipe is that the slots are located very low in the side wall of the pipe. It is assumed that this will prevent the pipe from being clogged even if there is a considerable amount of sediments above the pipe. However, some sediments will enter the slots and decrease the cross-section area. Because these sediments deposit at the bottom of the pipe, it is important that the height of the pipe is greater than the width. The ratio of height/width was approximately 2 in the model tests, and this value is also recommended for the prototype.

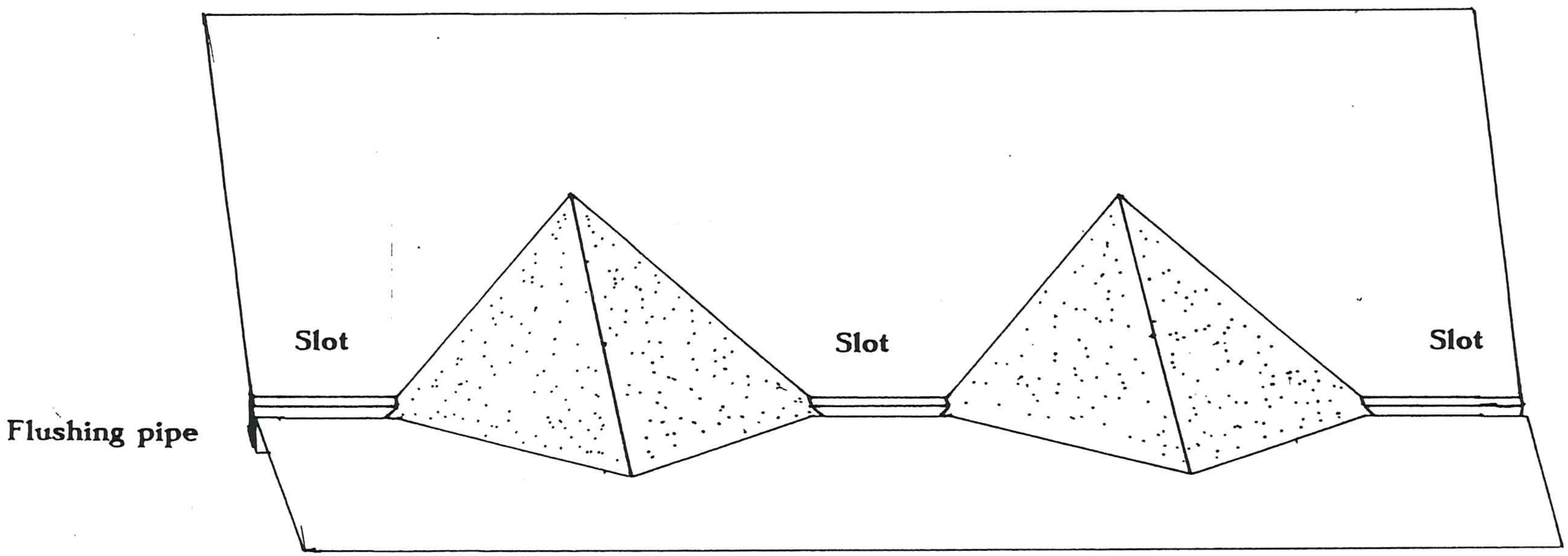
SLOTS

As mentioned in the previous sub-chapter, the recommended size of the slots is approximately a height of 5 cm and a width of 10 cm.

The distance between the slots must be decided for each scheme, but for the design shown on page 2 an initial value of 2-3 meters can be suggested. This distance will decide the magnitude of the sediment deposits on the bottom of the sand trap after flushing. The sketch shown below may explain this better. These sediment deposits will cause a decrease in the cross-section area of the sand trap. They may also cause extra turbulence to be created, and thereby decrease the trap efficiency of the sand trap. This is further discussed in (6).

Sediment deposits after flushing

Sediment trap with flushing pipe



LONGITUDINAL SECTION

The most complicated design aspect is the increase in the cross-section area of the pipe. One main idea is to keep the water velocity approximately constant over the total length of the pipe. If all slots are covered with sediments this will be no problem, but because we may have a situation with only a few slots covered, we will have to assume that the slots are open.

We will make use of the following formulas:

$$Hf = f*(L/D)*V^2/2g = Kf*(V^2/2g) \qquad (1)$$

This is Darcy-Weissbach's formula for friction loss in pipes. The value of Hf can be obtained from Moody's diagram, as given in appendix 1 which is taken from (5). Note that formula 1 also defines a friction loss coefficient for the pipe, Kf.

L = Length of pipe
D = Pipe diameter
V = Velocity in pipe
f = Friction factor from diagram
g = Acceleration of gravity

$$He = Ke*(Ve^2/2g) \qquad (2)$$

He = Head loss trough entrance of pipe
Ke = Entrance head loss coefficient
Ve = Velocity through entrance

We will in the following assume that the cross-section area of the entrance is the same as the upstream part of the pipe. This gives that we have the same velocity through the entrance as in the pipe.

$$Hs = Ks*(Vs^2/2g) \qquad (3)$$

Hs = Head loss through slot
Ks = Slot head loss coefficient
Vs = Velocity through slot

The water velocity in the pipe can be calculated from the following formula based on Bernoulli's equation:

$$V = ((2gH)/(Kf+Ke+1))^{0.5} \qquad (4)$$

H = Available flushing head

The water discharge through the entrance can then be calculated as:

$$Qe = Ae*V \qquad (5)$$

Ae = Cross-section area in the entrance of the pipe

The main difficulty is to find the amount of water that enter through the slots, which also determines the increase in the cross-section area of the pipe. We make use of the following notations:

$$Ao = (Qs+Qe)/V \qquad (6)$$

Ao = Cross-section area in the end of the pipe
Qs = Discharge through all the slots

Bernoulli's equation for the flow trough one slot give:

$$H = V^2/2g + Ks*Vs^2/2g + Kf*V^2/2g*l/L \qquad (7)$$

l = Distance from slot to end of pipe

This equation can be solved for Vs:

$$Vs = (\ (\ 2gH - V^2(1+Kf*l/L)\ )\ /\ Ks\ )^{0.5} \qquad (8)$$

We can rewrite formula 8 using formula 4:

$$Vs = V * ((Ke+Kf(1-l/L))/Ks)^{0.5} \quad (9)$$

Then we have to summarize over all the slots:

$$Qs = As * SUM (Vs) \text{ from } l = 0 \text{ to } l = L \quad (10)$$

When we have obtained this value, we can calculate Ao from formula 6. The calculation of formula 9 and formula 10 can be carried out accurately using a spreadsheet program on a computer. But if this for some reason not is convenient, the following formula can be used for approximate solutions:

$$Qs = As * V * (1 + (2*N*Ks/(3*Kf)) * Z) \quad , \text{ where} \quad (11a)$$

$$Z = (Ke/Ks + Kf/Ks - (Kf/(N*Ks)))^{3/2} - (Ke/Ks)^{3/2} \quad (11b)$$

3.3 ESTIMATED FLUSHING WATER LOSS

When we have calculated the water discharge in the pipe, we can obtain a value for the sediment capacity of the flow. This can be done using the graph in appendix 2, which is taken from (1). From this we obtain a value which we can denote Qfg. But we can also estimate the sediment discharge through the slots from the results of chapter 2.3, and denote this Qfs.

The effective sediment discharge, Qf, will be the smallest of these two values.

If we denote the amount of sediments that we want to remove as S, we obtain the following flushing time:

$$T = S/Qf$$

If we want to find out how much time we want to use for flushing as part of the total time, we can use the following formula:

$p = C*Qi / Qf$

C = Concentration of sediments in the inflowing water
Qi = Water discharge through the sand trap

The amount of flushing water as a part of the total water discharge through the sand trap is:

$r = C / Cv$

Cv = Sediment concentration in the flushing water.

3.4 SUMMARY AND EXAMPLE

In this chapter we will give a step by step guidance for the engineer who want to design a flushing pipe.

SUMMARY OF GEOMETRICAL CALCULATIONS

We will choose a pipe with rectangular cross-section two times as high as the width. After having decided the number of slots, we assume these slots to have a dimension 5x10cm. We then decide for a maximum flushing water discharge, for example 20 % of the discharge in the sandtrap. Then we assume a head loss in the entrance of maybe 1.0 or obtain a better value from experiments or hydraulic literature, for example (5). We also assume an initial friction loss coefficient of maybe 3.0. Formula 4 give the velocity in the entrance on the basis of maximum flushing head, and we can calculate the cross-section area from formula 5. This give us the opportunity to use formula 1 to see if the initially assumed friction loss coefficient is correct. If not, this can be recalculated.

Then we calculate the amount of water through the open slots, using formula 11 or a spreadsheet. This will determine the cross-section area at the end of the pipe.

Note that we will prefer to have Qs < Qe/2, and if this is not satisfied, we will consider increasing the allowable flushing discharge, or reduce the number of slots.

EXAMPLE

We will design a flushing pipe for a discharge of 1.5 m^3/s, and an available head of 5 meter. Initially we assume that 1.0 m^3/s flows through the entrance. We assume a friction loss coefficient, Kf, of 1.5 for the pipe, and an entrance head loss coefficient, Ks, of 1.0.

Formula 4 then give the velocity in the pipe as:

V = SQTR (2*9.81*5 / 1.5+1.0+1.0) = 5.3 m/s

The cross-section area in the entrance of the pipe is then:

Ae = 1 m^3/s / 5.3 m/s = 0.189 m^2

The entrance dimensions of the pipe is:

Width : 31 cm
Height : 62 cm

We are then able to recalculate the friction loss in the pipe using appendix 1 :

Re = D * V / visc. = (0.31 m * 1.25) * 5.3 m/s / 1E-6 m^2/s
= 2 E+6

The relative roughness is calculated as one mm for concrete divided by the diameter of 0.31 m * 1.25. This is 0.0025. The friction coefficient f is then 0.025. The friction loss coefficient for the pipe is:

Kf = f * L / D = 0.025 * 50 m / (0.31m*1.25) = 3.22

We have here assumed a flushing pipe length of 50 m.

Because this coefficient differs from the firstly assumed (1.5), we do all the calculations over again with Kf = 3.22. This give:

V = 4.3 m/s
A = 34 * 68 cm
Re = 1.8 E+6
f = 0.025
Kf = 3.2

This means that we will use the above values for the further calculations. To calculate the discharge trough the slots, we firstly assume Ks = 1.5, and that we have 20 slots.

A spreadsheet program then gives Qs = V * As * 25.44 = 0.55 m^3/s
while formula 11 gives Qs = V * As * 25.22 = 0.54 m^3/s

As we see, there is little difference between the formula and the exact solution for this case.

Initially, we had required that Qe / Qs > 2, while the value for this example is 1.0 / 0.55 = 1.8. This means that we will have to reduce the number of slots if we want this requirement to hold.

However, the value of 2.0 is chosen as a round number, and the value 1.8 is so close that it may be considered to be sufficient.

The cross-section dimension at the end of the pipe is then:

Ao = 1.55 m^3/s / 4.3 m/s = 0.36 m^2

Height : 85 cm
Width : 42 cm

We then want to calculate the flushing water loss for the pipe. We assume that the concentration in the inflowing water is 2 000 ppm (weight). The concentration in the flushing pipe must then be calculated. The capacity of the pipe is calculated from appendix 2, and we use the same notation :

The hydraulic radius is : r = 0.12 meters
The friction loss gradient is : $i_m = Kf/L * V^2/2g = 0.060$
We assume density of sediments, s = 2.65, and size, d = 0.0005 m.

This give: Value of the vertical axis : 0.1
Value of the horizontal axis: 1E+3

The concentration is then : Cv = 0.08 = 8 % (Volume)
$= 0.08*2.65*10^6$ppm = 210 000 ppm

We have here used that Cv is always given as a volume concentration, and that the ppm notation refers to a mass concentration. We have assumed a density of 2.65 kg/dm^3 for the sediments.

The sediment discharge through the slots is:

Qf = 0.1 * 0.55 m^3/s * 1500 kg/m^3 = 83 kg/s

We have here assumed that the sediment velocity trough the slots is 0.1 times the water velocity trough the slots.

This give the following sediment concentration:

Cf = Qs / Q = 83 kg/s / (1.55 m^3/s * 1000 kg/m^3) = 50 000 ppm

We observe that the inflowing sediment concentration is lower than the capacity of the flushing pipe.

The water loss is therefore:

r = C / Cv = 2000 ppm / 50 000 ppm = 4 %

4. RECOMMENDATIONS FOR FURTHER STUDIES.

In this chapter, recommendations for the further work on the project "Withdrawal of water from steep sediment-carrying rivers" are given. This is divided in two parts. One is the design of the flushing pipe and the other is the design of the intake.

STUDIES OF THE FLUSHING PIPE

As we can see from chapter 2, many of the results are not precise. This can be said about the head loss for the main flow of water in the pipe, and for head loss through the slots. Also the sediment velocity through the slots need further research. It is therefore advisable to carry out more accurate model test for these questions, preferably with a model in a larger scale.

Also other problems as cohesive layers in the deposited sediments will be a question of investigation. For the understanding of this problem it may be advantageous to cooperate with the Division of Soil Mechanics at the Norwegian Institute of Technology.

STUDIES OF THE INTAKE

There is also a need to preventing sediments from entering the waterways. This can be studied in a physical model of the intake and intake reservoir.

Another problem is to remove the sediments from the intake reservoir. Different flushing methods may be investigated, and the method described in this report pipe may be transferred to indicate solutions of the reservoir problem.

When carrying out these test, it may be advisable to use light-weight material to model the sediments. Results from (2) and (4) can then be used, and experience from the use of such sediments will be gained.

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