

## HYDRAULIC CALCULATION METHOD FOR SEA BOTTOM SPILLWAY SEWERS

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*Within the scope of the present article the problem of interaction of sea and waste water at inflow reaches is considered and formulae to calculate the maximum dimensions of salinity wedge intrusion into bottom spillways are established. These formulae foresee end slopes of spillway bottoms which must be necessarily considered in hydraulic engineering construction, especially in the Black Sea regions of Georgia.*

### INTRODUCTION

The problem of interaction of sea and waste water at inflow reaches, bottom spillway structures or sea sewage collectors is one of the problems associated with the hydrodynamics of coastal regions. On the one hand, the salinity wedge (halosol) intrudes into the river inflows, non-pressure or pressure discharge structures at long range, impedes with the exploitation of water-supply and sewerage systems of coastal settlements, stimulates load sedimentation and holm formation in stream canals, reduces the discharge capacity of collectors, creates threats of flooding coastal territories, causes marine pollution (which is especially dangerous for the Black Sea recreation zones of Georgia), etc.

Accordingly, the practical importance of specifying the dimensions of salinity intrusions in inflow reaches and sewage collectors and studying the diffusion and range zone of impure water streams, which intrude into the sea from storm sewers and sewage collectors, is obvious.

At present, these issues have been more or less precisely studied for cases where the sea bottom has a gentle slope. As for the Black Sea regions of Georgia, the slopes of inflow reaches and the ones of the sea bottom are so steep that it's inadmissible to disregard them. The steep slopes of the sea bottom also determine the location and dimensions of a waste water flow section opening into the sea. It's practically impossible to place an ending section of a spillway on the sea bottom, 13 km away from the shore, which is required by normative documents, because of deep lead sea (200-500 mm) in the Black Sea regions of Georgia. If a spillway is arranged at a shorter distance, it's necessary to substantiate environmental safety, which directly depends on the study of expansion of impure waters by wave and convection flows directed at the shore, etc. However, in the present article we confine ourselves to just specifying the dimensions of the salinity wedge intrusion into bottom spillway structures, on which the capacity of whole spillways depends immediately.

### CALCULATION METHOD FOR SALINITY WEDGE INTRUDED INTO BOTTOM SPILLWAY STRUCTURES

In a water pipeline fresh and salt waters are divided by a horizontal surface which simultaneously with the displacement of salt water by fresh one from a pipeline gradually comes down to the ending section without deformation [12]. As soon as it reaches the ending section, the fresh water flows out into the space occupied by salt water and the dividing surface loses its initial

horizontality and warps. Besides, depending on the size across of the spillway pipeline and pipeline decline, in a certain range of fresh water flow the fresh water still remains on the bottom of the pipeline, the depth and length of which are easily determined on the basis of the calculation pattern given on the figure 1.

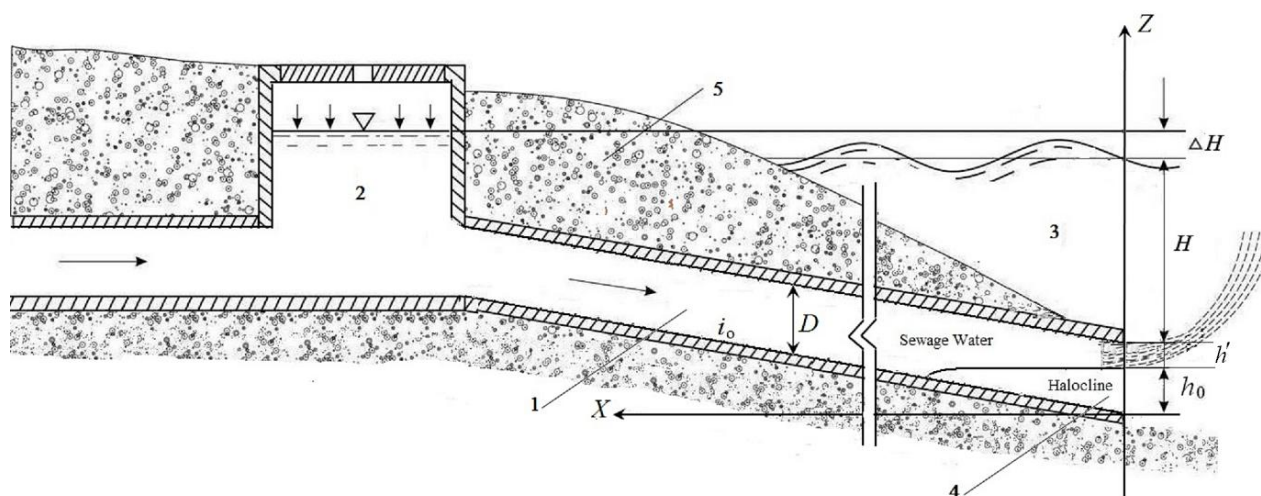


Fig. 1. Halosol Intrusion calculation Pattern for Sea Bottom Spillway

1 – spillway collector; 2 – storm-water – observation well; 3 – the sea; 4 – halosol; 5 – shore

Let's first assume that a spillway has a prismatic section, or discuss a plane problem. A halosol in a sea bottom spillway may be considered as a long internal wave prevented by a fresh water flow, above which the fresh water velocity reaches the critical value calculated according to the following relation [1, 2]:

$$V_{\text{critical}}^2 = g \frac{\rho - \rho'}{\rho'} h', \quad (1)$$

where  $\rho$  and  $\rho'$  are sea and fresh water densities;  $h'$  is the depth of the fresh water in the ending section above the halosol.

If we represent the fresh water velocity by means of the reduced discharge at the ending section of the bottom spillway and the height (depth) of the waste water height, on the basis of the (1) equality, we may write

$$\frac{q^2}{(D - h_0)^2} = g \frac{\rho - \rho'}{\rho'} (D - h_0), \quad (2)$$

where  $q = Q/B$  is the reduced discharge of the waste water at the ending section;  $Q$  – total design flood;  $B$  – spillway width;  $h'$  – fresh water depth at the ending section,  $h' = D - h_0$ ;  $D$  – spillway height;  $h_0$  – the sought-for depth of the salt water.

According to the relation (2), the depth of the sea salt water at the ending section is

$$h_0 = D - \left( \frac{q^2 (1 - \sigma)}{g \sigma} \right)^{1/3}, \quad (3)$$

where the following notation is introduced  $\sigma = 1 - \gamma'/\gamma$ .  $\gamma'$  and  $\gamma$  are specific weights of waste and sea waters, ( $\gamma' < \gamma$ ). According to the relation (3), the sea water statically occupies the whole ending section of the bottom pipeline, when the river water flow equals zero, i.e.,  $h_0 = D$  when

$q=0$ . On the other hand, the sea water will be completely displaced from the pipeline when the reduced fresh water flow exceeds the critical value

$$q_{\text{critical}} = \left( \frac{\sigma}{1-\sigma} g D^3 \right)^{1/2} \quad (4)$$

i.e., when  $q > q_{\text{critical}}$  the depth of salt water at the ending section of the  $h_0 = 0$ .

Assume that the river water flow which enters the bottom spillway is less than the critical value. Let's determine the length of the salinity wedge intruded in the spillway for this case. For this purpose we may use Euler equation and according to the calculation pattern admit that the coordinate of the surface dividing the salt and fresh waters in the pipeline is

$$z = z'' \quad (5)$$

Then the water flow pressure on the yet unknown dividing surface will be represented as a sum of hydrostatic pressure and pressure caused by water velocity

$$p' = \gamma'(H + \nabla - z'') + \gamma' \frac{q^2}{2g(z'_0 - z'')^2}, \quad (6)$$

where  $H$  is the depth of the sea above the ending section of the pipeline;  $\nabla$  – level of river water in the observation;  $z'_0$  – coordinate of the spillway ceiling edge.

In consideration of the representations (5) and (6), Euler equation for statistic balance of salinity wedge in the pipeline becomes the following:

$$\left( 1 - \frac{\gamma'}{\gamma} \right) \frac{dz''}{dx} + \frac{\gamma'}{\gamma} \frac{q^2}{2g} \frac{d}{dx} \frac{1}{(z'_0 - z'')^2} = 0. \quad (7)$$

Let's change in the equation (7) the coordinate of the surface dividing the salt and fresh waters  $z''$  by the sum

$$z'' = z_0 + h, \quad (8)$$

where  $z_0$  is the coordinate of the spillway bottom and  $h$  is the halosol depth in any section. Then, if we also take into consideration that

$$\frac{dz_0}{dx} = i_0 \quad \text{and} \quad z'_0 - z_0 = D \quad (9)$$

where  $i_0$  is the slope of the spillway bottom, the equation (7) will become the following

$$\sigma \frac{dh}{dx} + \sigma i_0 + (1-\sigma) \frac{(q')^2}{2g} \frac{d}{dx} \frac{1}{(D-h)^2} = 0. \quad (10)$$

Integration of the equation (10) results is

$$\sigma h + (1-\sigma) \frac{(q')^2}{2g} \frac{1}{(D-h)^2} = -\sigma i_0 x + C. \quad (11)$$

To exclude  $C$  (constant of integration), we may use an adjacent condition  $h = h_0$ , when  $x = 0$ , where  $h_0$  is the initial depth of the halosol of the ending section of the spillway. Then in result of a simple transformation the equation (11) will turn into

$$(h_0 - h) + \frac{1-\sigma}{\sigma} \frac{q^2}{g} \left[ \frac{1}{(D-h_0)^2} - \frac{1}{(D-h)^2} \right] = i_0 x. \quad (12)$$

It is obvious that in the spillway, where the depth of the salt water  $h = 0$  linear coordinate  $x$  represents the maximum intrusion of the halosol or the length of the halosol, which, according to on the basis of the representation (12) is calculated by means of the formula

$$L = \frac{1}{i_0} \left\{ h_0 + \frac{1-\sigma}{\sigma} \frac{q^2}{2g} \left[ \frac{1}{(D-h_0)^2} - \frac{1}{D^2} \right] \right\}. \quad (13)$$

In (13)  $h_0$  must be preliminarily determined by means of the relation (3).

In case of bottom spillways with circular sections, the calculation patterns are relatively complicated and lead to insignificantly different results as compared with the results of the relations (3) and (13), if we consider  $D$  to be the pipeline diameter and calculate the reduced water flow by means of the formula

$$q = \frac{Q}{\omega^{1/2}} = \frac{2Q}{D\pi^{1/2}} = \frac{1.13Q}{D} . \quad (14)$$

Thus, in consideration of this assumption, we may also use the formulae (3) and (13) to calculate the salinity wedge in bottom spillways with circular sections.

### NUMERICAL EXAMPLE OF CALCULATION

Let's assume that we need to define the possibility of wedge intrusion into a sewage collector with a circular section and its dimensions on the basis of the following data:

$D=0.63$  m;  $\rho'=1$  t/m<sup>3</sup>;  $\rho=1.008$  t/m<sup>3</sup>;  $i_0=0.0125$ ;  $Q=0.006$  m<sup>3</sup>/sec;

We preliminarily calculate the values

$$\sigma = \frac{\rho - \rho'}{\rho} = 1 - \frac{\gamma'}{\gamma} = 1 - \frac{1}{1.008} = 0.008 .$$

From the formula (4) we'll obtain  $q_{\text{critical}} = (9.8 \times 0.008 \times (0.63)^3)^{1/2} = 0.14$  m<sup>2</sup>/sec; and from the formula (14) –  $q = 1.13 \frac{0.006}{0.63} = 0.0108$  m<sup>2</sup>/sec.

As far as  $q < q_{\text{critical}}$ , salt water will intrude into the sewer pipeline from the sea. According to the formula (3), the depth of the sea water equals

$$h_0 = 0.63 - \left( \frac{0.0108^2 \times 0.9921}{9.8 \times 0.0079} \right)^{1/3} = 0.63 - 0.114 = 0.52 \text{ m},$$

and according to the formula (13), the length of the sea water intrusion into the sewer pipeline is

$$L = \frac{1}{0.0125} \left\{ 0.52 + \frac{1}{0.008} \cdot \frac{0.010^2}{2 \cdot 9.8} \left[ \frac{1}{(0.63 - 0.52)^2} - \frac{1}{0.63^2} \right] \right\} = 46 \text{ m/s}.$$

This distance must be measured from the ending section of the pipeline up the stream.

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