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LOCAL SCOUR DOWNSTREAM HYDRAULIC CONSTRUCTIONS

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Abstract:

Downstream a hydraulic construction the original bed of a watercourse is usually protected against scour. This scour is caused by changes of the watermovement due to the construction. Nevertheless scour occurs downstream this protection. The scouring process can be described by an empirical relation. The most important parameter of this relation has to be determined by means of model investigation, which can be a considerable effort. This paper reveals another method to determine this key parameter.

1. INTRODUCTION

To describe the problem of local scour downstream a construction, the definition sketch figure 1 is introduced. In the Netherlands it is common practice to use a bed protection with a length greater than the reattachment length.

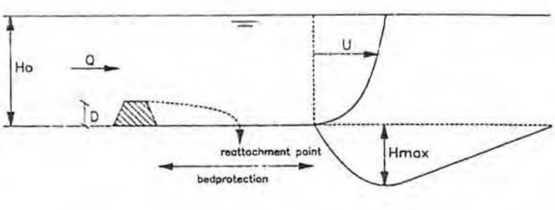

Figure 1 Definition sketch

The time development of the scour hole depth can be formulated by the empirical relation [Breusers, 1965, vd Meulen and Vinje 1975, de Graauw and Pilarczyk 1980].

$$\left[\frac{Hmax}{Ho}\right] = \left[\frac{t}{t1}\right]^{\gamma} \qquad (1)$$

$$t1 = \frac{330\ \Delta^{1.7} H_o^{2.0}}{(\alpha\ U - Ukr)^{-4.3}} \qquad (2)$$

- Hmax = maximum depth of scour hole (m)
- Ho = original waterdepth (m)
- t = time (hr)
- t1 = point of time at which Hmax reaches the value of Ho (hr)
- γ = empirical coefficient, for two dimensional constructions this parameter varies between 0.3 and 0.4. (-)
- Δ = relative density of bed material (-)
- α = empirical scour parameter (-)
- U = mean velocity (m/s)
- Ukr = critical velocity of bed material (m/s)

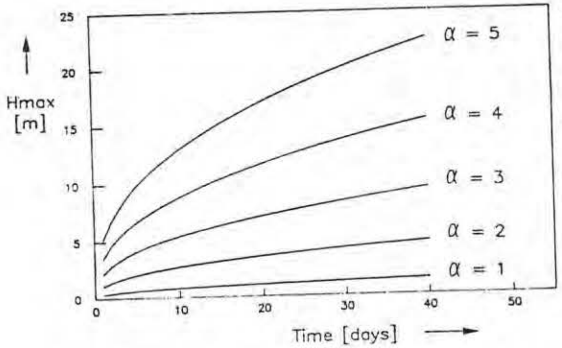

Figure 2 Influence of α

All parameters of this formula are relatively simple to determine, except for the empirical scour parameter α. In order to find this scour parameter it is necessary to use scale model investigation. It is very important to know the correct value of α, because this parameter plays a significant role in the time development of the scour depth. Figure 2 illustrates this role.

2. RELATION BETWEEN α AND THE CONSTRUCTION

In the past years many results of model investigations have been collected. This collection contains many values of for various constructions. These constructions can be divided into two types:

- two-dimensional structures, which cause only a vertical constriction of the watercourse.
- three-dimensional structures, which cause both a horizontal and a vertical constriction of the watercourse.

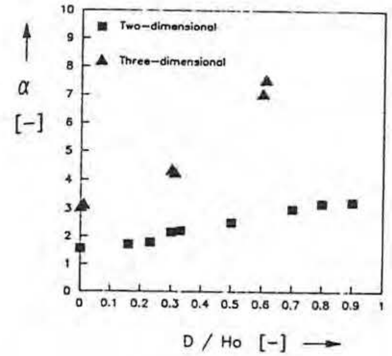

Figure 3 α versus vertical constriction

In figure 3 a set of α-values is presented as a function the vertical constriction. This set is derived from two extensive modelinvestigations by the Delft Hydraulics Laboratory [Investigation nrs. M648/M863, 1972 and M847, 1972]. These α values are valid for a bed protection length of ten times the original waterdepth. This figure produces a too wide range of values for α to be useful as a designers' instrument. It is therefore necessary to review the set existing data in order to create an useful design graph.

3. REFINED DEFINITION OF α

In the original definition the parameter α is linked with the mean velocity, averaged over the total cross section of the water course. This means that every deviation of the local velocity from the mean velocity causes a variation in α. When the parameter α is linked with the local velocity (depth averaged), this variation is prevented. This is illustrated by figure 4.

Now the scour parameter is linked with the depth averaged U_l and called α_l. Relation (2) is changed as follows.

$$t1 = \frac{330.\ \Delta^{1.7} .\ H_o^{2.0}}{(\alpha_l U_l - Ukr)^{-4.3}} \qquad (2a)$$

- U_l = local depth averaged velocity (m/s)
- α_l = local scour parameter (-)

According to this refined definition of the scour parameter figure 3 can be adapted for α_l. This is shown in figure 5.
Allthough the result has improved, it does not yield a reliable α_l value for a certain vertical constriction.

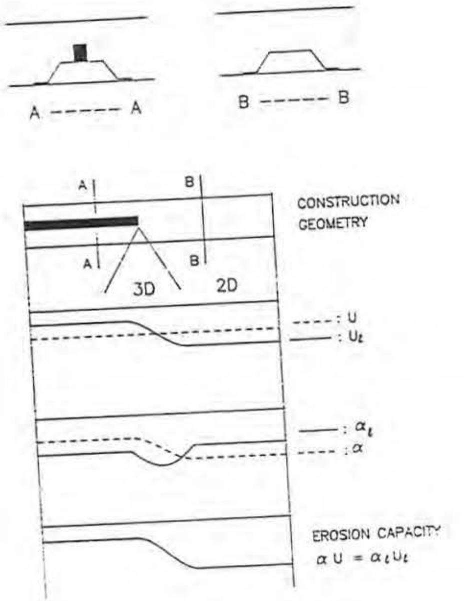

Figure 4 Definition of α_l

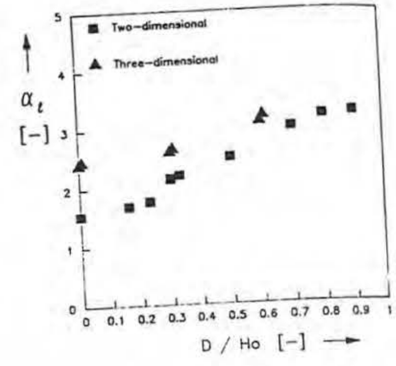

Figure 5 α_l versus vertical constriction

4. RELATION BETWEEN α_l AND WATER MOVEMENT

In order to create a design graph for hydraulic constructions and scour protections the following assumption is made.

"The rate of scour downstream a hydraulic construction is very much influenced by the turbulence of the watermovement downstream the hydraulic construction."

The rate of turbulence is enlarged by the construction. Over the length of the bed protection this turbulence is reduced by dissipation. The rate of turbulence can be defined as follows.

$$r = \frac{U_l}{\bar{U}_l} \qquad (3)$$

- U_l = depth averaged standard deviation of U_l (m/s)
- $\bar{U}_l$ = depth averaged time averaged local velocity (m/s)

In order to investigate the relation between α_l and r at the end of the bed protection, it is necessary to determine the relation between r and the construction.

5. TURBULENCE AND CONSTRUCTION

By means of a combination of a mathematical model [Jorissen, 1988] and model measurements [Investigation nrs. M648/M863, 1972 and M847, 1972] the relation between r, the vertical constriction and the length of the bed-protection is investigated. For two-dimensional constructions Jorissen [1988] used the boundary layer approach and developed a mathematical model to calculate the velocity distribution downstream of a vertical constriction. This model solves the continuity equation and the momentum-equation for two dimensional flow (4,5).

$$\frac{\delta u}{\delta x} + \frac{\delta v}{\delta y} = 0 \qquad (4)$$

$$u\frac{\delta u}{\delta x} + v\frac{\delta v}{\delta y} + \frac{\delta}{\delta y}\left(\nu_t \frac{\delta u}{\delta y}\right) + \frac{1}{\rho}\frac{\delta p}{\delta x} = 0 \qquad (5)$$

For the turbulent viscosity a parabolic formulation is used, which means a considerable simplification. This however is tolerable, because the aim of the model is to predict the velocity at a considerable distance from the construction, beyond the reattachment point. This is confirmed by the comparision of the results from the mathematical model and measurements [Delft Hydraulics Laboratory, investigation nr. M1536, 1988], figure 6.

The next step in the mathematical model is a simplified turbulence model. According to Kay and Nedderman a balance equation for the turbulent energy k can be discribed as follows.

$$\frac{Dk}{Dt} = \nabla_i(\nu_t \nabla_i(k)) + \nu_t(\nabla_i(v_j))^2 + (\nabla_i(v_j))*(\nabla_j(v_i)) - \frac{C_D k^{3/2}}{L} \qquad (6)$$

Assuming a two-dimensional situation and neglecting all terms with a vertical velocity and the diffusion of k, yields equation (7).

$$u\frac{\delta k}{\delta x} = \nu_t \left[\frac{\delta u}{\delta y}\right]^{2.0} - \frac{C_D k^{3/2}}{L} \qquad (7)$$

This equation describes the balance of convection, production and dissipation of turbulent energy. When the velocity field is known, this equation can simply be solved. From the distribution of k the relative turbulence r can be calculated with equation (8).

$$r = C \frac{k^{1/2}}{u} \qquad (8)$$

In this equation a value of 1.0 has been used for the parameter C. For a fully developed boundary layer a value of 0.8 is commonly used.
The calculated rate of turbulence is shown in figure 7 for a bed protection length of ten times the original water depth (dotted line). Some two-dimensional model measurements [Delft Hydraulics Laboratory, investigation nr. M648/M863, 1972] have been added, which seem to confirm the validity of the mathematical model. Also, some three-dimensional model measurements have been added [Delft Hydraulics Laboratory, investigation nr. M847, 1972]. The three-dimensional measurements indicate a greater turbulence if the vertical constriction is rather small. The difference in turbulence between two- and three-dimensional constructions seems to diminish when the vertical constriction becomes larger. This indicates that the turbulence caused by the vertical constriction becomes dominant.

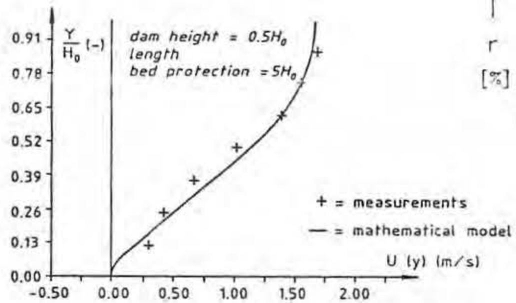

Figure 6 Results mathematical model (velocity)

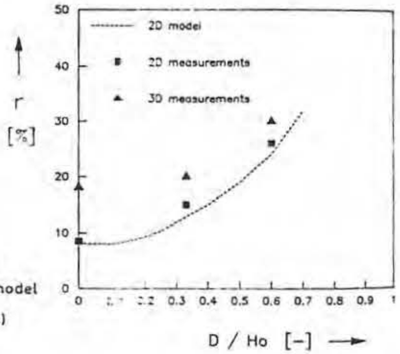

Figure 7 Results mathematical model (turbulence)

6. SYNTHESIS

Combining the data from the figures 5 and 7 yields a relation between α_l and the turbulence r. It can be stated, that the relation according to figure 8 produces an unique value for α_l for a certain value of r, without any variation due to the type of the construction (two- or three-dimensional). To improve the validity of this figure some extra data has been added. This data is derived as well from model investigations by the Delft Hydraulics Laboratory [Investigation nr. M731, 1963] as from prototype measurements at the Storm Surge Barrier in the Eastern Scheldt [Report Q635, 1988].
The investigation nr. M731 gives information about the scouring rate, when a relative short bed protection is applied (four times the waterdepth). The mathematical model is used to calculate the turbulence. At the Storm Surge Barrier - for reasons of extreme safety - a much longer bed protection was applied : about twenty times the waterdepth, which means 600 meters !

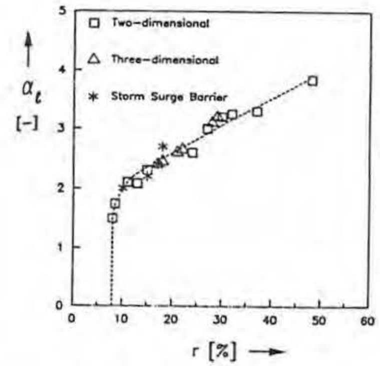

Figure 8 α_l versus r

7. CONCLUSIONS

- the relation between the scour parameter α and the vertical constriction is not unique. The value of α is influenced by the type of the construction.

- by redefining the scour parameter α_l on the local velocity the prediction of this parameter can be improved. The relation between α_l and the vertical constriction is however still not unique.

- by introducing the turbulence as a reference parameter an uniform relation for α_l can be obtained. Therefore it is possible in future to determine a correct value for α_l without scale model investigations. A calculation of the velocity and the turbulence field with a mathematical model is sufficient. This means a considerable saving on design effort. This relation is valid for various bed protection lengths, beyond the reattachment point.

8. LITERATURE

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