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OPTIMIZATION OF CONCENTRATING STRUCTURES FOR RIVER REGULATION WITH THE USE OF CFD

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Abstract: *Currently, a project to improve navigation conditions on the Elbe River downstream the Střekov waterwork is preparing. Concentrating structures are important elements in this concept from the 19th century. This paper describes an optimization of newly designed concentrating structures in the frame of the Elbe regulation with the use of computational fluid dynamics (CFD). Analysis is also based on experiences with historical spur dikes. The results were compared with measurement on the physically based model and in situ.*

Keywords: ***concentrating structures, spur dikes, computational fluid dynamics***

1. Introduction

In technical terms, two basic methods for achieving navigability of watercourses can be discriminated (Novak et al., 2007). The first one is waterway channelisation, when the design width of the waterway and the navigation depth are achieved by regulating interventions and construction of concentrating structures−spur dikes. The other method, canalisation, is concerned with the construction of a cascade of weirs and locks. This paper focuses on proposals for concentrating structures as well as spur dikes, in the form of longitudinal or transverse dikes within the riverbed designed to ensure sufficient navigation depths even at low flow rates. Requests by environmental organisations resulted in the need to ensure that the space between the spur dikes and the banks are not gradually slogged up with sediments for environmental reasons. The objective is to safeguard the space as a living environment for aquatic organisms and populations living on rocky bottoms. Following a research using a 3D mathematical model, a suitable design of the spur dikes has been devised and optimised, and subsequently verified using a physical model developed by a hydraulic laboratory (Fosumpaur et al., 2010).

2. Methods

To simulate flow conditions for different types of spur dikes a turbulent *k-ε* model was used (Wilcox, 1998). In practical applications, *k-ε* turbulent model is used that belongs to the most favourite at the present time due to its relative simplicity and sufficient reliability of the solution for the majority of engineering tasks. To assess the risk of sedimentation of particles in the space behind the spur dikes the fall velocity has to be calculated. Final values of the fall velocity for different hydraulic conditions according the Reynolds number and particle diameter describe following equations (Miedema, Vlasblom, 1996). For the laminar regime for particles with diameter $d \leq 0{,}1$ mm the reduced Stokes equation was used:

$$w = 424\frac{(\rho_p - \rho)}{\rho} d^2 . \tag{1}$$

For the particles with diameter $0{,}1 \text{ mm} < d < 1$ mm a Budryck equation is valid:

$$w = \frac{8{,}925}{d}\sqrt{1 + 95\frac{(\rho_p - \rho)}{\rho} d^3} - 1 , \tag{2}$$

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and in the turbulent regime for particles with diameter $d > 1$ mm the Rittinger equation was used:

$$w = 87\sqrt{\frac{(\rho_p - \rho)}{\rho}d}. \quad (3)$$

where d is the diameter of the the particle, ρ_p is the density of the particle (~2700 kg.m^{-3}) and ρ is the density of the fluid (1000 kg.m^{-3} for water).

3. Results

The final design for the flow-through spur dikes was optimised in accordance with simulations of flow-rate fields between the Elbe riverbank and the spur dike. The objective was to determine the shape of spur dikes that would prevent sedimentation of clay and suspended silt particles behind the spur dikes. Individual spur dikes feature a longitudinal section 70 to 100 meters long and an oblique part forming an angle with the riverbank of 45°, at a length of approximately 50 metres. The crest of the longitudinal spur dike section is at the water achieved at volumetric flow rate of Q_{180d}. The area behind the spur dikes is washed by water fed by a localised drop in the crest height at the transverse segment, achieved by means of a shallow ditch across the crest. The shallow ditch slopes at a rate of 1:5 from the level of Q_{180d} to Q_{345d}, the width of the overflow edge of the shallow ditch is 10 m. The cross-section of the rock-formed spur dikes is of a trapezoid shape with a width at the crest of 1 m and slopes of 1:5 towards the riverbank and 1:3 towards the watercourse axis. The risk of sedimentation was assessed in a simplified form using a comparison between the sedimentation and dragging velocities. If the resultant for the sedimentation velocity w and the flow velocity u for the water current intersects the bed behind a spur dike between two feeding shallow ditches sedimentation will occur, and vice versa. The drag velocity was estimated as the current velocity according to the simulation using the 3D mathematical model.

4. Conclusions

The research focused on designing a suitable shape of concentrating spur dikes with a view of improving navigability at the lower Elbe below the planned Děčín barrage to the state border between the Czech Republic and Germany. The key purpose of spur dikes is to ensure sufficient navigation depth even under conditions of low volumetric flow rates on the Elbe. An important requirement in the research was the reduction of sedimentation of suspended clay and silt particles in the area between the spur dikes and the riverbank. Historical spur dikes at the lower Elbe had been designed for the most part to lead to complete targeted aggradation. The initial inspiration for the research was therefore taken from spur dikes near Nebočady where partial washing of the riverbed behind the spur dikes is ensured at flow rates exceeding Q_{180d}. The shape of the spur dikes was further optimised using a 3D mathematical modeling. Initial pilot spur dike projects were constructed in the target area of the lower Elbe in 2010, with a currently ongoing evaluation of their function in terms of river navigation and sedimentation of small suspended particles. The initial results of the measurements fully support the proposed solution.

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References

Fosumpaur, P., Kralik, M. & Zukal, M. (2010) Physical and numerical modeling in the research of hydraulic structures, in: *Proc. of the Int. Conf. on modeling and simulation*, CTU in Prague.

Miedema, S.A. & Vlasblom, W.J. (1996) Theory for Hopper sedimentation, in: *Proc. 29th Annual Texas A&M Dredging Seminar*. New Orleans.

Novak, P., Moffat, A. I. B., Nalluri, C. & Narayanan, R. (2007) *Hydraulic structures*. Fourth edition, Taylor and Francis, 2007.

Wilcox, D.C. (1998) *Turbulence Modeling for CFD*. 2nd edition, DCW Industries Inc., California.