Amirkabir Journal of Civil Engineering

Amirkabir J. Civil Eng., 51(4) (2019) 241-244
DOI: 10.22060/ceej.2018.13948.5517

1D Numerical Modeling of Sediment Pattern in Settling Basins

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ABSTRACT: Settling basins are one of the most important structures, which are commonly used for deposition of sediment particles in water and wastewater systems in order to prevent the damage of sediment particles. The purpose of this study was to provide a one-dimensional numerical model for simulating flow and sediment in a rectangular settling basin. The governing equations are depth averaged equations of flow and sediment transport. In order to the numerical solution, the finite difference method has been used. The model can be used for non-uniform flow and non-uniform particles and may predict important information such as removal efficiency, thickness, and distribution of particle size of sludge. Comparison of the results of the proposed numerical model with the results of other researchers stated the acceptable accuracy of the proposed model, so that in all cases the error rate was less than 3%. The results of the sensitivity analysis showed that more than 50% of suspended sediment was deposited at the first 5 meters of the basin; therefore, the increase in the dimensions of the rectangular reservoir was not the best way to improve the performance of the pond. In fact, increasing the removal efficiency can be achieved by reducing the depth of the settling basin, increasing the cross-sectional area of flow and reducing the surface loading rate.

Review History:

Received: 11 January 2018
Revised: 3 June 2018
Accepted: 4 June 2018
Available Online: 11 June 2018

Keywords:

Rectangular Settling Basin
Sediment
Removal Efficiency
Numerical Model
Sludge

1- Introduction

The settling basins (which often have rectangular cross sections and in some cases have trapezoidal sections), decrease the sediment transport capacity of flow by reducing the water velocity and deposit a considerable portion of the sediment. The design, construction and maintenance of these structures significantly depend on the precision of the prediction of removal efficiency, the thickness of deposits sediment and the distribution of particle size from the basin, which are one of the important issues of hydraulic engineers.

The purpose of this study was providing a simple one-dimensional numerical model with a grouping of sediment particles that can deliver useful information to designers and users of these types of basins. The ability of the proposed model will be evaluated in the predictions.

2- Methodology

One-dimensional Saint-Venant equations are used for numerical modeling of flow [1]:

$$\frac{\partial h\bar{u}}{\partial x} + \frac{\partial h}{\partial t} = 0 \tag{1}$$

$$\frac{1}{2g}\frac{\partial \bar{u}^2}{\partial x} + \frac{\partial H}{\partial x} + \frac{n^2\bar{u}^2}{ghR^{1/3}} = 0 \tag{2}$$

Where R is the hydraulic radius, n is Manning roughness coefficient, ū is depth averaged horizontal velocity, h is depth of water in the settling zone, x is location variable and t is the time variable. As shown in Fig. 1, H is the water level and z_b is the total level of the basin bed. The transfer and sediment continuity Equation are as follows [2]:

$$-h\bar{u}\frac{\partial \bar{s}}{\partial x} = \beta\omega\left(\bar{s} - s^*\right) = \rho_d \frac{\partial z_s}{\partial t} \tag{3}$$

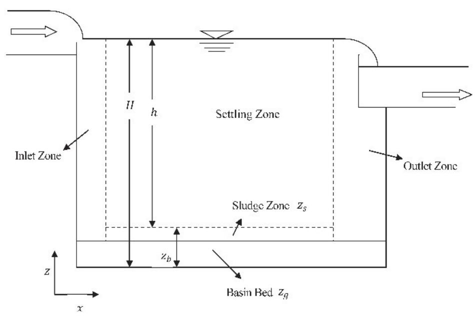

Figure 1. Schematic of the basin

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Where z_s is the sediment thickness settled in basin bed, $\bar{S}$ is the cross-sectional depth averaged of the sediment concentration, β is the ratio of the sediment concentration of the bed to the depth averaged sediment concentration at the cross-section, ω is the average deposition velocity of the sediment and s* is average sediment transport capacity [2]. Equation (2) can be solved by using a finite difference discretization as below:

$$H_{i+1} - H_i + \frac{Q^2}{2gB^2}\left(\frac{1}{h_{i+1}^2} - \frac{1}{h_i^2}\right) + \frac{\Delta x Q^2 n^2}{2gB^2}\left(\frac{1}{h_{i+1}^3 R_{i+1}^{1/3}} + \frac{1}{h_i^3 R_i^{1/3}}\right) = 0 \quad (4)$$

Where i is the node number, Δx is the spatial step between the nodes, Q is the constant flow of the inlet and B is the width of the rectangular basin. The water level at the outlet can be determined at the design phase. Consequently, the water level for each node along the length of the rectangular settling basin could be calculated by moving backwards from the output to the input. In the initial time step, the profile of the water depth was equal to the water level profile. After calculating the first time step, the water depth profile returned to the start of the calculation loop. For the next step, the depth profile of the water was corrected using the thickness of deposited sediment calculated in the previous step. This computational loop was repeated until the final time step is reached.

In the next step, by integrating Equation 3 along the flow from the input to the outlet, the suspended sediment concentration at the next section (i + 1) at the time step j for each group (p) can be calculated as follows:

$$\bar{s}_{i+1,p}^{j} = \left(1 - \frac{\Delta x\, \beta\omega_p}{q}\right)\bar{s}_{i,p}^{j} + \frac{\Delta x\, \beta\omega_p}{q} s_{i,p}^{*j} \quad (5)$$

Where q is the flow rate in unit width, $\bar{s}_{i,p}=\varsigma_p\ \bar{s}_i$ and $s^*_{i,p}=\varsigma^*_p\ s^*_i$ are the percentage of the group particle (p) in the sediment transport capacity. After the same calculation process was applied to all particle groups at time step j, the results were stored for use for subsequent computational steps. The total suspended sediment concentration at section i can be determined by summation the suspended sediment concentrations of all groups at the same section. By determining the above parameter, the thickness of the sludge, the sludge sediment distribution (SSD), the particle size distribution (PSD) in the outflow stream, and finally the important parameter of the efficiency of removal (RE) of the basin can be obtained.

3- Results and Discussion

As the first verification, the results of the proposed model were compared with the model of Swamee and Tyagi [3]. In the model, the removal efficiency for the rectangular settling basin was considered 85% that in order to achieve this number, the length of the basin was calculated 38 m. According to the proposed model, to achieve the removal efficiency of 85% with the same width of the basin, the length of the basin should be 39 m, which has a slight difference with the results of the Swamee and Tyagi model [3].

For the second verification, the input data of the proposed model was selected from the Guo model [4]. Figure 2 showed that the removal efficiency of the Guo model and the proposed model are very close to each other, with an error less than 1%. According to the Figure 2, more than 50% of suspended particles were deposited in the first 5 m of the deposition area; hence, increasing the length of the settling basin was not appeared economical for improvement of the overall removal efficiency.

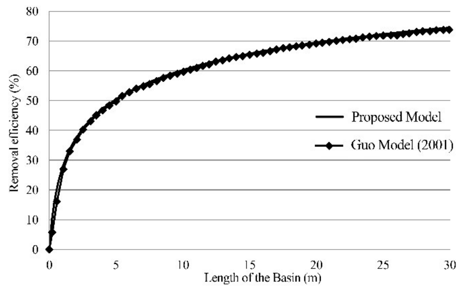

Figure 2. Removal efficiency along the length of basin.

In order to the sensitivity analyze of the model, the effects of key parameters of detention time (T), overflow rate (q_v) and basin dimensions on total removal efficiency were evaluated. The results showed that under constant detention time and constant volume of the basin, total removal efficiency were reduced by increasing the overflow rate. For cases where the flow rates were the same, the removal efficiency was roughly equal and the lengths of the basin and detention time were not important. Therefore, increasing the dimensions of a rectangular sedimentation basin was not an effective and economical way to increase the removal efficiency. In the constant water depth and the width of the basin, the removal efficiency was increased by increasing the length of the basin. Furthermore, for the fixed surface area of the basin, the removal efficiency had an inverse relationship with the depth of water, so reducing the depth of the sedimentation basin was not effective on the efficiency, but reduces the required cost and space. It seems that the effect of water depth on the efficiency of the basin is more important than the length of the settling zone.

4- Conclusions

In this research, a one-dimensional numerical model was presented to simulate suspended sediment transport in a rectangular sedimentation basin. The depth averaged flow equation along with the sediment transport equations were employed to construct the proposed model. The finite difference approximation was also utilized to solve the governing equations. In order to validate the proposed model, Swamee and Tyagi model [3] and the Guo model [4] were used. The results are briefly summarized below:

- The length of the basin in the removal efficiency of 85% of the Swamee and Tyagi model and the proposed model were close to each other with an error of about 2.5%, indicating the accuracy of the proposed model results.

- The removal efficiency and the particle size distribution at the output for Guo model [4] and the proposed model were very close to each other. This result means that the proposed suspended sediment transport model can provide respectable results in agreement with existing numerical models.
- More than 50% of suspended particles in the first 5 meters of the settling zone. This means that a large amount of deposition occurs in the inlet area and an increasing the length of the settling zone will contribute a little to increasing the deposition rate.
- From sensitivity analyzes, it can be concluded that during a constant overflow, the increase in detention time had no significant effect on the increase in total efficiency. Conversely, with the constant detention time, the flow rate was the most important factor affecting the performance of rectangular settling basins. Therefore, the removal efficiency can be increased by reducing the depth of the settling basin. In the other words, the removal efficiency could be increase by decreasing the depth of basin, increasing the cross-sectional area in the direction of flow and reducing the flow rate.

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Please cite this article using:

H. Sarveram, F. Rostami, M. Shahrokhi, 1D Numerical Modeling of Sediment Pattern in Settling Basins, *Amirkabir J. Civil Eng.*, 51(4) (2019) 781-792.

DOI: 10.22060/ceej.2018.13948.5517