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Numerical simulation of deposition behind the regulatory dam of Dez through application of the 2D software of CCH2D

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Abstract: There are various methods to estimate the procedure of deposition within reservoirs the most important of which are the empirical methods and mathematical models. The empirical methods are usually faster but with less accuracy. Exact prediction of dispersion of deposition is carried out through mathematical models. As computers and new solutions have emerged for the partial differential equations of water flow and sediments, numerous mathematical models with simplified hypotheses and various levels of accuracy have been developed in order to simulate the deposition procedure in dam reservoirs. This research was conducted on the regulatory dam of Dez. This dam was constructed within two Kilometers upstream of the third bridge of Dezful as high as 20 m in order to regulate the irrigation network of Dezful, satisfy the industrial needs and to generate power. The 2D model of CCHE2D was applied to model the deposition process behind this regulatory dam which yielded acceptable results.

Key words: Reservoir deposition; CCHE2D 2D model; Regulatory Dam of Dez

1. Introduction

Restricted water resources and the increasing consumption rate have caused the Water Resource Management Organization to adopt a new approach towards this issue through application of modern scientific methods, an approach aimed at protection and maintenance of water resources which has led to optimized use of resources and removal or decrease of detrimental factors. One of these factors is the deposition of sediments and decrease in capacity of reservoirs causing the long term exclusion of their usage. Construction of dams on rivers inflicts significant effects on the water flow and deposition which could lead to variations in the form of rivers, dam reservoirs and the surrounding environment, thus decreasing the life span of reservoir. Hence, prediction of the amount of sediments flowing into the damn reservoir and the quality of their dispersion throughout the reservoir is of major significance during the utilization period of dams. Deposition in dams is inevitable and it is no secret that it would have severe effects on decrease in life span of reservoir and its installations.

Thus, the complexity and significance of this issue calls for any dam to be comprehensively studied. Lack of information on the state of deposition in reservoir and prediction of methods to control it would decrease the life span of dam and waste large amounts of national wealth. Application of mathematical models based on analysis of equations governing the phenomena affecting the transfer, dispersion, deposition and scouring of sediment has nowadays turned into one of the important means of studying the process of deposition in reservoirs of dams and rivers.

Regulatory dam of Dezful was constructed at the downstream of the reservoir dam for the multi-purpose project of Dez. This multi-purpose project includes reservoir, regulatory and check dams of Dez as well as other irrigation facilities and channel that have been designed and practiced in order to supply agricultural, industrial, potable and power generating water. Construction of regulatory dams is necessary due to variability of power consumption during the day and the resulting variable and irregular discharge of reservoir dams whereby controlled and regulated water may be provided for downstream irrigation network. The effective capacity of reservoir in regulatory dams must be maintained during the life span of reservoir in order to adjust and control the amount of water required for the network.

Therefore, the amount and the manner of dispersion of sediments in the reservoir during the future periods of utilization must be predicted to achieve this purpose so that appropriate methods for controlling of sediments and also proper dredging techniques may be studied with respect to the deposition trend of sediments. Study of depositions in dams is of major significance which is a crucial factor in their design. The effective capacity of reservoir in regulatory dam of Dezful must be to the extent capable of daily adjustment of water in different conditions of utilization in the power plant of Dez dam. Since the regulatory dams are usually

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filled with sediment up to the overflow limits over a few years, therefore their effective capacity is equivalent to the capacity between the top of overflow and the upper edge overflow valves when they are completely jammed.

Today, different mathematical models have been developed for prediction of amount and quality of deposition in dam reservoirs including the Gstars3, HEC-6, fluvial 12 and CCHE2D models. The impact of sedimentation in a dam reservoir is reflected in the decrease of storage capacity of reservoir and only the capacity above the sediment layers is considered as the effective storage of reservoir. The necessity for analysis of deposition and transfer of sediments in reservoirs through 2D models is strongly felt since the deposition procedure in dam reservoirs has already been analyzed through empirical methods or one-dimensional models. The model used in this research is called the CCHE2D which is coupled model that simultaneously performs the calculations of flow and sedimentation. Also, the mesh applied in this research is of preformed type while the equations were implicitly solved through finite difference method.

This model was proposed and developed in 2007 by Yakzine Xhang of the National Center for Computational Hydroscience and Engineering under the supervision of the Engineering and Technical Faculty of the University of Mississippi in U.S. The main purpose of this research is to model the deposition procedure in the dam in 2D format for a limited period and to conduct the sensitivity analysis of the results derived from application of this type of models compared to numerical parameters of model and roughness of bed. Since computer modeling is of more simplicity and speed than the empirical methods, its application may be institutionalized in research on the issues of dams in case acceptable results are obtained. Therefore, the sensitivity of simulation results to the parameters involved in the model must be studied prior to application of such models in practical project. From then on, the model would be practiced for a restricted period. The model may not be calibrated for reservoir conditions and only the sensitivity analysis has been accounted.

2. Instrumentation and methodology

The CCHE2D model was developed by Wang, Sam and Gia in 1997 at the International Water Engineering Center under the supervision of the University of Mississippi in U.S. Generally, this pack consists of two separate models, one is the mesh generating model and the other is the CCHE2D-GUI model. Mesh model generates a grid of intersected lines that create a platform for the equations used in the model of CCHE2D-GUI to become consistent with the numerical method of discrete finite elements. Simulation of sediments (cohesive and granular) is carried out through application of non-equilibrium transfer models. Three different methods are used to simulate the bed load, suspended load and total load. Equations used in this stage are the bed load and suspended load transfer equations as well as the equation for variation of bed elevation. These equations are solved with either exponential differences or effective factors methods. The procedure used in the CCHE2D model is schematically illustrated in Fig.1.

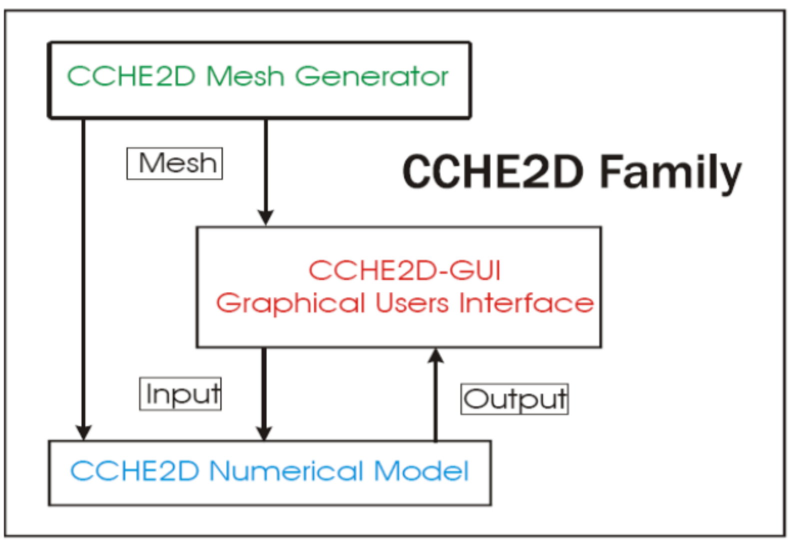

Fig. 1: Simulation procedure in CCHE2D model

A contoured topographical map is used in the current case study to insert the geometry of reservoir into the model which should be converted to required format via other software. The resulting topographic file consists of longitude, latitude and elevation of locations throughout the dam reservoir. In order to develop the grid required by the CCHE2D model, the area has to be first of all converted into a regular mesh with grid points of certain coordinates with the help of CCHE mesh generator. The resulting grid is entered in form of a CCHE2D file and the boundaries are specified. The model is capable of using diverse boundary conditions such hydrograph of discharge at the inflow boundary or water table hydrograph at the exit boundary. The simple condition mode may also be applied.

2.1. Required data for modeling (numerical) of sediment transfer in CCHE2D software

2.1.1. Total load

According to a preconceived classification, the vertical movement of sediments falls into two categories of suspended load and bed load. Bed load is that part of the sediment movement where sediments tumble over the bed. Suspended load is the part where sediments are suspended in depth while the overlying layer is also called the bed load. CCHE2D software is capable of simulating the total load of sediment transfer.

2.1.2. Non-equilibrium transfer

Since the transfer of sediments mostly takes place under non-equilibrium conditions, it is necessary to simulate the suspended load of sediment transfer based on the non-equilibrium transfer model. On the other hand, it is necessary to separately perform the simulation of bed load of sediment transfer under non-equilibrium conditions. The CCHE2D software is capable of simulating sediment transfer under non-equilibrium for both cases. This software uses transfer-dispersion equation for modeling of suspended load and uses the continuity equation for modeling of bed load.

2.1.3. Classification of bed sediments

Classification of bed sediment in vertical direction is quite variable. Hence, the bed sediment overlying the non-erosive layer is divided into several layers. The top layer in Fig.2 represents a mixed layer and the second one represents the subsurface layer. Variations (fluctuations) in classification of bed sediments in the top layer may be estimated through application of partial differential equations while the mass conservation principle is used to estimate the classification of bed sediments in lower layers.

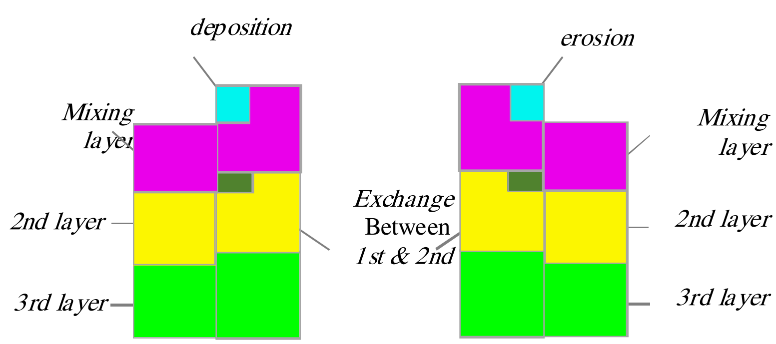

Fig. 2: Classification of sediments

2.1.4. Initial conditions

It is necessary to acquire data on sediment properties, sediment transfer capacity, bed roughness and non-equilibrium length in order to simulate the sediment transfer. Sediment properties include the size of sediments, specific gravity of sediments (presumed to be equal to 2.65), shape of particles (presume value of 0.7) and void ratio of sediments. Sediment transfer capacity, channel roughness and non-equilibrium adaptive length are derived from empirical formulae.

2.1.5. Empirical formulae

The CCHE2D software uses four empirical formulae to model the sediment transfer.

1. VAN RIJN, S Formula (1984)
2. WU ET AL, S Formula (2000)
3. SEDTRA model (Garbrecht et al., 1995)
4. The Ackers and White modified formula (Proffit and Sutherland, 1983) or Engelund and Hansen, s (WU AND VIEIRA 2000).

2.2. Research method

The data required to conduct this research include the initial topographical data of the reservoir and the initial topographical data of sediments whereby the mesh grid would be generated and interpolated to perform the simulation

Development of mesh based on the database provided by topographical data

The database used to develop the mesh is of random type and as it was mentioned earlier, it is specified in format of mesh-x y z in the CCHE2D model. The entire x, y and z values of the region are first derived via AUTOCAD software as illustrated in Fig 3-13 and then converted to Mesh-x y z format via Excel software. The whole aquifer area is first partitioned into blocks in order to create the mesh grid and then the reticulation was carried out based on the already partitioned blocks. The mesh developed based on the particular shape of the reservoir is formed out of two major parts: the main creek and the lake. When the partitioning of blocks is completed, the first step to reticulate the aquifer is to develop algebraic mesh for the aquifer under study. The algebraic mesh is developed as the initial reticulation and is not qualitatively sufficient for simulation process.

The next step is to improve the quality of algebraic mesh through numerical methods. Having carried out some try and failure tests, the method of orthogonal mesh with smoothness controls was recognized as the most appropriate among the available methods due to significant improvement of mesh quality.

The parameters for assessment of mesh quality after the application of numerical method are as follows:

ADO=2.51

AAR=2.88

The first parameter is the average deviation from right angle while the second one represents the average deviation from smoothness. The third step is to interpolate the developed mesh to attribute the bed elevation data to the grid points. In the end, a mesh with geo format was obtained.

2.3. Data of sediments

Data of sediments include the initial condition of sediments, boundary conditions and sediment parameters in the CCHE2D model. The initial conditions of sediment are the erosivity of bed, maximum thickness of erosion and deposition, samples and thickness of sedimentary layers of bed, bed samples based on classification of bed materials. The boundary conditions of sediments include the discharge of suspended sediment, bed sediment, and percentage of classes measured in each one.

Therefore, in order to define the initial and boundary conditions of sediments, classification of particle size distribution must first be determined. Having defined the initial conditions, the boundary conditions and parameters related to flow and deposition are prepared to be practiced. Four classes of grain sizes seem reasonable with respect to the conditions of this project.

The determined classes of sizes in this research are according to table 1. It is assumed that the percentages of classes do not vary in case of various discharge rates of suspended or bed loads.

Table 1: Classification of sediment particle size distribution

4	3	2	1	Class No.
0.00014	0.0000175	0.0000025	0.0000006	Diameter

2.4. Suspended load discharge of sediment

In order to determine the boundary conditions of sediments at the inflow of CCHE2D model, both discharge rates of suspended load and bed load must be given to the model. Since the inflowing stream is not durable, therefore the discharge rate of inflow sediment must also be selected as non-persistent. To this end, flow discharge relationship with discharge of suspended sediment was used. The deposition rate of bed load is considered approximately 20% of that of the suspended load. Therefore, the daily discharge rate of suspended load has been multiplied by 0.2 in order to determine the daily discharge of bed load.

The fitting relationship for the Dez River is as follows:

$$Qs = 0.1463Q^{2.0271}$$

Wherein Q is the water discharge rate in terms of m/s and Qs is the discharge rate of suspended load in terms of tons per day.

2.5. Sensitivity analysis of model

Sensitivity analysis of mathematical models is usually studied from two perspectives. One is the sensitivity analysis of bed roughness and the other is the sensitivity analysis of numerical parameters applied in the model. These two aspects are naturally considered in calibration of models. In order to conduct this research, the purpose is to assess the sensitivity of CCHE2D model to the three parameters of bed roughness, turbulent viscosity ratio and adaptive length. The sensitivity analysis period for each run was 30 days. The conclusion that can be made from the abovementioned sensitivity analysis is that the sensitivity of model to the adaptive length of bed load for a roughness of 0.022 is less than those of other roughness values.

3. Conclusions

The results from a 30-year period comprise the graphically illustrated results of sediment transfer. The graphical results include the plan view of aquifer and the distribution of hydraulic and sedimentary parameters such as velocity, suspended sediment fractional concentration and others within the computational aquifer as shown in Fig. 3 to Fig. 9. These results are further discussed below.

Distribution of suspended load concentration based on classification of sediments: The total concentration of suspended load includes two fine-grained classes of 0.0006 and 0.0025 mm. as figure 5 to 8 show, distribution and development of suspended loads for two classes of 0.0006 and 0.0025 mm is too significant as they flow over the dam. Considering that only the very fine-grained sediments would practically advance to the dam, the overall distribution trend of simulated sediments by the model may be assessed as reasonable and logical. Also, it may be concluded that the concentration of suspended sediments is higher in the trough line and in deep places where the flow discharge is much higher. Additionally, distribution of suspended sediment concentration depends upon the route and alignment of water flow.

Fig. 3: Initial elevations of bed

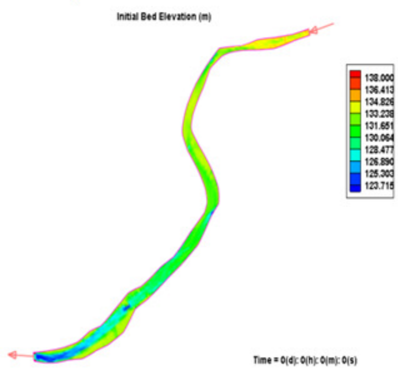

Fig. 4: 30-Year elevations of bed

Development of sediments according to the performed classifications is depicted in graphical results as follows.

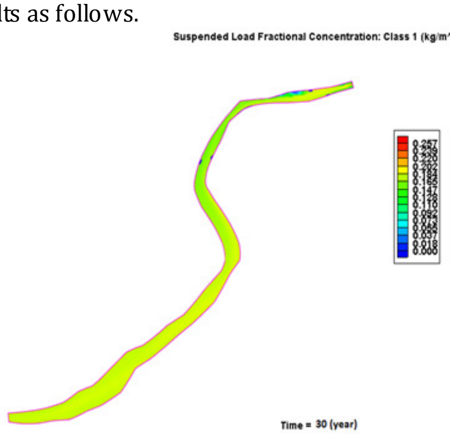

Fig. 5: Suspended load concentration for class2

Composition of materials constituting the bed based on classification of sediments: it could be well-deduced from the results that the fine content of materials in upstream bed is very low and the coarse content is rather significantly high. Low concentration of 0.0006 mm class is in the upstream while it is highly concentrated in downstream. This difference is not mostly due to variation in erosion or sedimentation of fines in upstream and downstream of reservoir.

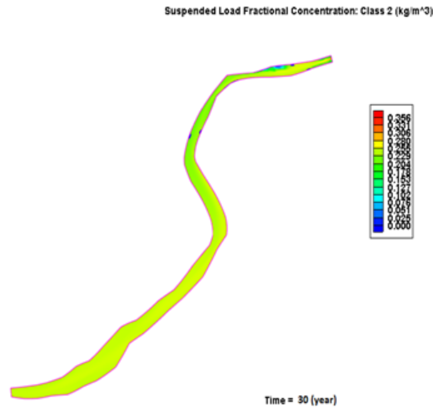

Fig. 6: Suspended load concentration for class 1

Fig. 7: Suspended load concentration for class 3

Fig. 8: Suspended load concentration for class 4

This issue is affected by coverage of bed with larger sized layers of sediments such as silt and others that have overwhelmed the percentage of fine sediments. This analysis also applies to coarse-grained classes while the fine sediments constitute a low percentage of bed materials since they are covered by coarse sediments.

Sedimentation in reservoir: Figures 3 and 4 show the amount of sedimentation in upstream of reservoirs. Soft sandy sediments constitute the major percentage of deposition. Extensive sedimentation in upstream and also the repletion of some voids with sediments due to vortex flows is fairly consistent with these facts.

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