Estimation of Sediment Transport in Rivers Using CCHE2D Model (Case Study: Karkheh River)

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Abstract

Rivers are one of the most important sources of water which are continuously changing. Calculation of sediment load in rivers is one of basic issues in designing hydraulic structures and dam power plants. It is very important to identify and recognize factors which affect the behavior and morphology of the rivers such as the form of river, waterway geometry, the shape of the river bed, discharge and the profile of the river. In particular, these factors are valuable for Meander Rivers which have unsteady flow patterns. In this study, the unsteady pattern of Karkheh River flow in Iran from Paypol to Abddolkhan (the area near the Shahid Najian Bridge in the city of Susa) that has a sinusoidal-like turn is analyzed using CCHE2D. Besides, variation of parameters like velocity, Froude number, shear stress, river bed elevation and total sediment deposits of the river are calculated and discussed.

Keywords: Sediment transport, Unsteady flow, Karkheh River, CCHE2D

1. Introduction

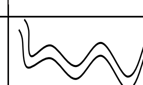
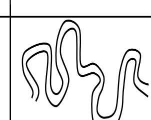
River is a dynamic process and its behavioral pattern is changing all the time. These changes greatly affect the river morphology and the hydraulic condition of the river flow. Understanding of river characteristics has many applications in planning, designing and constructing hydraulic structures in the river. Unlike many countries, Iran has very limited water resources and therefore right and planned utilization of the rivers is very crucial. Different kinds of studies have been done on Iranian rivers, such as water resources management, flood control and sediment balance.

The hydrodynamic simulation of the unsteady flow pattern in a river is studied in [1]. The place of a lateral intake in the extrados (outer curve of an arc) of the river is identified using the CCHE2D model in [2]. Also, [3] uses the same model to simulate the flow and sediment pattern in rivers with the assumption that the flow is unsteady. In [4], the numerical simulation of flow in an arch with a 90 degree angle is conducted using the CCHE2D model. The simulation of flow and sedimentation patterns around the river cutwater in an arch with a 180 degree angle is done in [5]. The effects of the isles made within the river Karun on flood discharge is studied in [6] by the CCHE2D model.

In an unsteady flow, time parameters also interfere and the changes in the flow toward the time are contradicted to zero. In unsteady flows within waterways, at least one value of two main parameters (i.e. depth and flow discharge) change together with the time. This change could happen because of natural events, planned factors or incidents and these events consist of frequent waves, tidal flows and flood as a result of dam breakage. Every unsteady flow is a wave that is changed according to the situation like depth, discharge or both of them. These two factors change from place to place and time to time. Unsteady flows fall into two categories: gradual variable and rapidly variable. Examples of gradual variables are flood waves, tidal waves and waves that are made by slow operations of the flow control structures. Rapidly variable flows can be made by sudden opening and closing of flow control structures.

In river morphology, rivers are three types according to their figures: straight, meander and braided. This classification was made by Leopold and Lemon in 1957 as is shown in Table 1. They used two factors: winding factor and the scale factor between width and depth of the flow to create these categories. When the winding factor is higher than 1.4 or 1.5, the river is swirly (winding) and the lower factors indicate the straightness of the river.

Table 1. *Turning factor for different types of river meanders*

Turning factor	1-1.05	1.06-1.25	1.25-2	Higher than 2
River figure				
River type	Straight	Sinusoidal	Meander	Extreme Meander

2. Materials and Methods

2.1 Equations for Modeling

Equations which are used in CCHE2D software are the equations for flow and sediment in open channels and rivers as the followings. Equations for wave dynamic model in an open channel are Saint Venant equations. Equation 1 is the Continuity equation and Equation 2 is the Momentum equation.

$$\frac{\partial A}{\partial t}+\frac{\partial Q}{\partial x}=q \qquad (1)$$

$$\frac{\partial}{\partial t}\left(\frac{Q}{A}\right)+\frac{\partial}{\partial x}\left(\frac{\beta Q^2}{2A^2}\right)+g\frac{\partial h}{\partial x}+g(S_f-S_0)=0 \qquad (2)$$

In these equations, x and t represents time and place axles. A is flow space, Q is flow discharge, h is flow depth, S_0 is steep of the river bed, b is correction factor of momentum factor, g is gravity speed, q is discharge to width unit and S_f represents frictional steep. In the dynamic wave method, we use the complete momentum equation. Complete momentum equation together with the continuity equation can be only solved by numeric methods.

The momentum equation for wave spreading model is Equation 3. The equation for non uniform sediment transport is Equation 4.

$$\frac{\partial h}{\partial x}+S_f-S_0=0 \qquad (3)$$

$$\frac{\partial(AC_{tk})}{\partial t}+\frac{\partial Q_{tk}}{\partial x}+\frac{1}{L_s}(Q_{tk}-Q_{t*k})=q_{lk} \qquad (4)$$

Where C_{tk} is the mean (average) of sediment density for the size of k units, Q_{tk} is the rate of actual carried alluvia for the size of k units, Q_{t*k} is the capacity for carrying sediments, L_s the length of the distance that sediment is carried inconstantly and q_{lk} the side discharge or output sediments in width unit

In order to estimate the sediment, this software uses four methods as follows: Modified Equation of Eakers, and White, Modified Equation of Angelond and Henson, Equation of Woo et al., Equation of Yan.

2.2 CCHE2D Model

CCHE2D is an aggregated software package created in 2005 by Wang, Jia and San in the National Centre of Calculation and Hydraulic Engineering (NCCHE) under the supervision of University of Mississippi, USA. This model is a two dimensional hydraulic model that is created for analyzing and simulation of flow hydraulic, sediment transport and morphology processes in open flows. The model uses average equations of Reynolds for solving flow area in depth. Two zero models of parabolic distributed equations and the prantels mix length model and also the model of two equations *k-ε* are used for modeling of distributed flow. The network used in this model is curved and not orthogonal. This model is applicable for both steady and unsteady flow. Based on [7, 8 and 9], we used effective Element method (a kind of limited Element), the control volume for solving the equations and dry surfaces method for simulation of unsteady flows and border motions

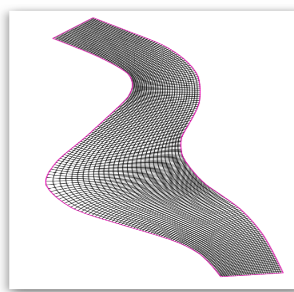
The CCHE2D has two important categories: CCHE2D Mesh generator and CCHE2D GUI (Graphical User Interface). The Mesh generator allows the user to introduce the geometric condition and structures of environment to the model and then proceeds to create the structure's network. Then, using the GUI model, user can observe hydraulic parameters of flow, sediment, boundary condition, parameters needed for simulation and also the output results.

This research is made in the area of Karkheh River around Shahid Najian Bridge. This area is two kilometers upstream the bridge. In this software, five stages should be followed: mesh making, flow ridge condition adjustment, flow initial adjustment and/or sediment adjustment, model execution and illustrating of the program execution results.

River Geometry and Networking

This stage is the first step in flow simulation and it is important because creating an appropriate network increases the accuracy of final results. In desirable mesh making, the areas locations are specified thoroughly in networks and the relation between them will be preserved. Created cells are almost uniform with equal aggregation. Input and output ridges of flow must be far enough from the center spots so that the flow becomes normal (balanced). Mesh lines must be as flat as possible and must not be vertical towards each other. The mesh lines should also go the same as the flow direction as illustrated in Figure 1.

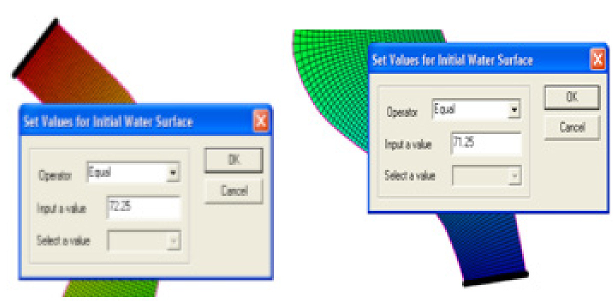
Fig.1. *The created mesh*



Assigning Initial Flow Parameters

To assign initial parameters we set 72.25 for the input value of initial water surface and 71.25 for the output value of initial water surface in the related windows (boxes) as shown in Figure 2. After model calibration the manning coefficient is set to 0.035.

Fig.2. *Assigning initial flow parameters for input and out borders*



Boundary Conditions

In order to determine the border flow conditions, 25-year and 50-year flood hydrographs (Figure 3) are made as the upstream condition and the rating curve (Figure 4) is made as the downstream condition.

Fig.3. *Flood hydrograph*

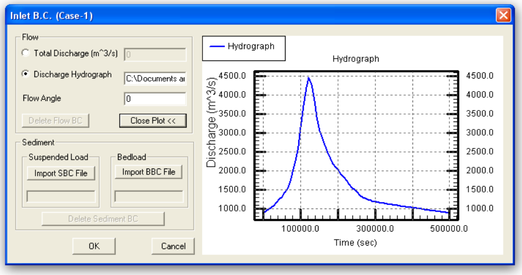
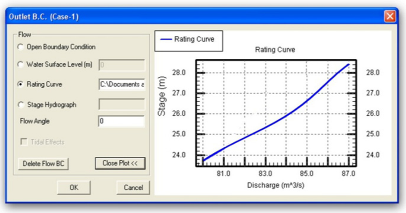


Fig.4. *Rating curve*



Executing the Model

Considering the flood crossing time in the studied area (496.800 seconds), the simulation time is set equal to 496.800 seconds. The calculated time scale is specified from currants number equal to 8 seconds. After completing other adjustments and inserting necessary information, the software starts getting two runs for 25-year and 50-year floods.

3. Results and Discussion

After introducing geometric and hydraulic specifications of flow to the model and running the model, one can observe the modeling results in different forms. In this research, the effects of parameters like velocity, shear tension, water surface profile on the bridge range and river arch will be studied. The results of velocity distribution and their values for the 25-year flood are shown in Figure 5.

Fig.5. *Velocity results of the studied area*

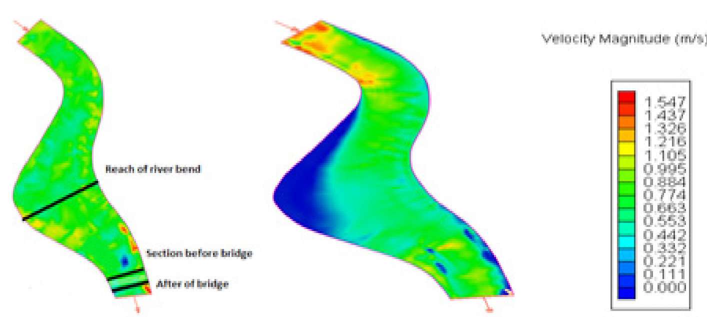


Table 2 shows the results for both 25-year-old and 50-year-old floods. It is seen that velocity, Froude number and shear tension for the 50-year flood are more than the 25-year flood.

Table 2. *Results of flow simulation*

	25-year-old flood results	50-year-old flood results
Average shear stress in the extrados (N/m^2)	0.1	1
Average shear stress in the intrados (N/m^2)	8	20
Average shear stress in the whole area (N/m^2)	10.6	16.7

Particle curves of suspended sediment, bed sediment, suspended sediment discharge and bed load discharge were entered to software. Initial conditions and sediment boundary conditions were determined for the software and the sediment load was analyzed. The results of sediment analysis are shown in Table 3. Due to flood passing time through study length (496800 second), simulation time allocate equal to 496800 second. Stop time was calculated based on currants number, estimated about 8 seconds. Finally, after determination of essential boundary conditions at the restriction of the bridge and the river curves, the model runs twice (for the flood with 25 years and 50 years return periods). It is observed that suspended sediment, bed load discharge, sediment deposit and erosion volume for the flood with 50 years return time are more than the flood with 25 years return time. The dominant phenomenon in the 50-year flood is erosion while the 25-year flood causes sedimentation.

Table 3. *Results of sediment simulation*

	25-year-old flood results	50-year-old flood results
Velocity (m/s)		
Average of velocity variations in the river arc (out)	0.64	0.5
Average of velocity variations in the river arc (in)	-0.43	-0.15
Average of velocity variations in the river arc (all arc)	0.33	-0.433
Average of velocity variations in the bridge area	0.09	-0.433
Sediment		
Suspended Sediment (kg/m^3)	0.95	1.15
Bed local discharge (kg/s)	0.07	0.27
Sediment deposit (m^3)	116845	195585
Erosion volume (m^3)	2957	293257
Effective phenomena (m^3)	113887 - Sedimentation	97671 - Erosion
Area of study	519414	519414

The river bed elevation before and after the 25-year and 50-year flood events are shown in Figure 6 and 7, respectively. Longitude river bed profile before and after these flood events are illustrated in Figure 8 and Figure 9.

Fig.6. *River bed elevation before and after the 25-year flood*

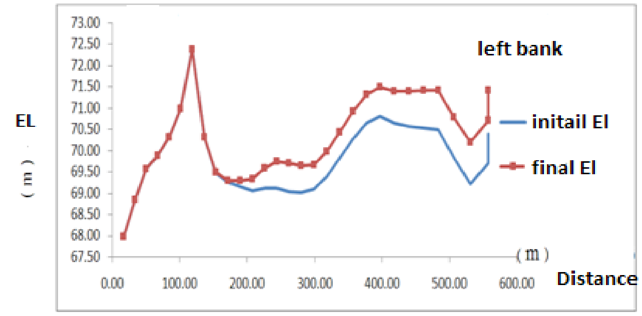


Fig.7. *River bed elevation before and after the 50-year flood*

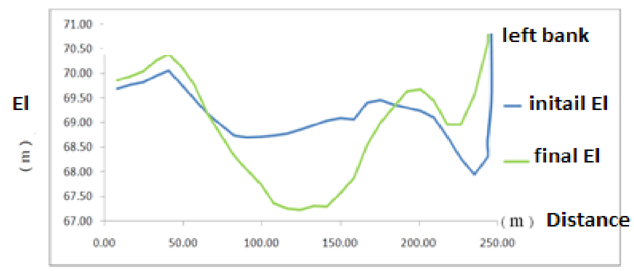


Fig.8. *Longitudinal river bed profile for 25-year flood*

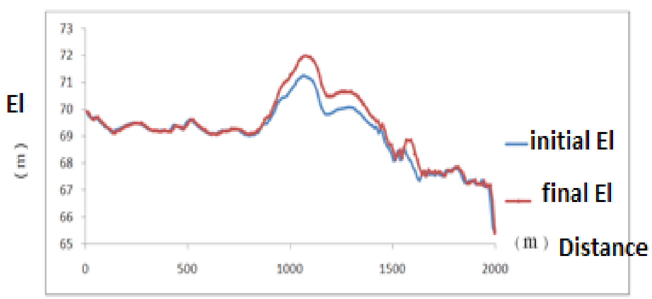
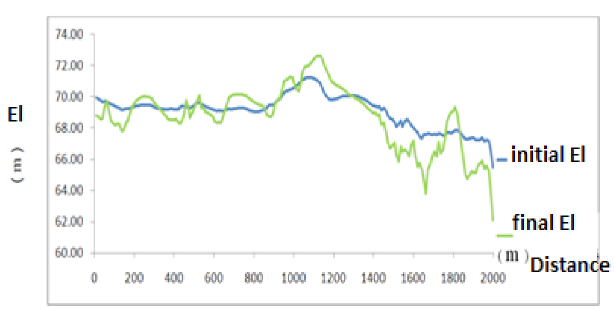


Fig.9. *Longitudinal river bed profile for the 50-year flood*



4. Conclusion

This paper investigates the unsteady pattern of Karkheh River flow in Iran as well as variations of river bed elevation and sediment transport due to two flood events using CCHE2D. It was found that velocity, Froude number and shear stress for 50-year flood are more than 25-year flood. It was also found that suspended sediment, bed load discharge, sediment deposit and erosion vol-ume for the 50-year flood are more than that of the 25-year flood. The dominant phenomenon in 50-year flood is erosion while the 25-year flood causes mainly sedimentation.

5. References

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