The Study of Meandering Phenomenon on the Basis of Stream Power

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Abstract: On the basis of stream power, the phenomena including regime channel establishment and river meandering can be studied. So, previous researchers have suggested and developed the stream power theory and believed that stream power minimization affects these phenomena. In this paper, the stream power theory and a criterion for meandering river modeling will be studied. Then the conclusion of case study of Ghezel Ouzan River and obtained relationships in relation to non-dimensional unit stream power will be mentioned. The Study of Meandering Phenomenon on the Basis of Stream Power.

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Preface

Power is the consumed energy in unit of time. Since energy is force times distance, consumption stream power in unit of length can be written as eq.1. [1].

$$P_l = (\gamma BD)SV \qquad (1)$$

Where, P_l - stream power in unit of length, γ - volume weight of fluid (water), B- average width of stream, D- depth of stream, S- channel slope, V- velocity of stream.

In sediment transport theories, other interpretations are also used for stream power.

A) Stream power in unit of bed area, P_a:

$$P_a = \frac{P_l}{B} = \gamma DSV = \tau_0 V \qquad (2)$$

Where, τ_0 - bed shear stress, which, for wide channels is equal to γDS .

B) Stream power in unit of length and weight of fluid (water) or unit stream power (USP), P_ω :

$$P_\omega = \frac{P_l}{\gamma BD} = SV \qquad (3)$$

Several researchers, based on the theory of stream power, have introduced functions for calculating the total load of sediment, which we can point to the names as: Bagnold 1966; Engelund & Hansen 1972; Ackers & White 1973; Yang 1973, 1984; velikanov, 1954. [2].

For example Bagnold's theory (1966) is based on stream power in unit of area, P_a and Yang's formulation (1973) is based on unit stream power, P_ω . [1].

Results of evaluations show that sediment transport is basically depended on the rate of dissipated energy in transport process and the hypotheses based on this basis are more general and precise compared to other hypotheses which consider the sediment transport rate as a function of discharge, average velocity, slope of energy line, and shear stress. [2]. In order to explain the dissipated energy rate in the process, so far several opinions have been offered:

A) Opinions on stream power by Bagnold (1966), Engelund & Hansen (1972), and Ackers & White (1973).

B) Opinion on unit stream power by Yang (1973)

C) Theory of gravitational power by Velikanov (1954)

Theory of stream power is based on general physical concepts and has been simply derived from basic theories of fluid mechanics. Accuracy and generality of stream power hypothesis is the main reason that equations by Engelund & Hansen (1972), Ackers & White (1973), and Yang (1973, 1979, 1984) compared to other equations, give more accurate results. As another reason, all of the parameters used in these equations are non-dimensional and therefore aren't sensitive to the small dimension of experimental flumes compared with natural rivers.

More over, the theory of unit stream power not only hasn't been based on experimental Results but also has been derived from basic hydromechanical theories and turbulent flows. From theoretical point of view, bed load, suspended load or total load amount is directly proportional to unit stream power.

The unit stream power equations are more precise than the other presented relationships for the purpose of evaluating the rate of alluvial sediment transport specially considering non-adhesive sediments under different conditions in natural channels and experimental flumes. It is mainly due to generality of the assumptions used in development of unit stream power equations, non-dimensional parameters used in the equations and the extensive range to calibrate and adjust the parameters. [2].

Hydraulic Geometry changes of river channels

Adequate physical relationships must be used to determine the hydraulic geometry of river channels. Generally, four groups of equations concerned with dynamics of flow, sediment transport, bank stability, and dynamic balance can be used. Due to dynamics balance, the two phases of liquid-solid conform together and form the channel pattern. Generally, the two following conditions must be satisfied in order to a reach be stabilized (chang 1988).

1) Along a reach, the sediment load must be constant; otherwise in the reach erosion or sedimentation will occurred.

2) Considering other limitations of river, the stream power in unit of length (γQS), must be minimized.

Chang defined this assumption as following [3]: In an alluvial river, the necessary and adequate conditions for reaching equilibrium, considering other limitations, is minimization of stream power in unit of length (γQS). In other words, in an alluvial river, Q-discharge, Q_S-sediment load and type of particles in bed and walls as independent variables regulate the width, depth, and bottom slope of river so that considering other limitations, the value of γQS to be minimized. Since Q is a known parameter, minimization of γQS happens when the slope of the channel is minimized. The hypothesis of stream power has been derived from the low of virtual work and the results based on it, are accurate for various conditions from sand to gravel channels.

Meander River Modeling

To study river meandering, physical models are more informative than mathematical models $[5]$.

In order to simulate the global variation of a meandering river, caused by a change in flow discharge, sediment supply, upstream or downstream boundary condition, etc., a so-called meandering river model has to be adapted. The meandering river model is actually a kind of loose boundary model, which is free to change both its banks and bed, subjected to the flow erosion.

Conventionally the following parameters are used in mobile bed models:

$$\theta = \frac{\tau_0}{g(\rho_s - \rho)D_s} \text{................}(Shields..Parameter)\text{...................}(4)$$

$$\text{Re}_* = \frac{U_* D_s}{\nu} \text{..............}(Particle..Reynolds..Number)\text{................}(5)$$

$$\phi = \frac{q_s}{\rho_s g\sqrt{\Delta D_s^{\,3}}} \text{................}(Einstein..Parameter)\text{....................}(6)$$

Where τ_0 = bed shear stress;

ρ and ρ_s = density of water and sediment respectively;

$\Delta = (\rho_s - \rho)/\ \rho$ relative density parameter;

Case study

Ghezel Ouzan River, the second longest river in Iran, is a meandering river located in northern part of the country. After field surveys, an alluvial meandering reach of the river was selected and by using of its data, 33 experiments were carried out in a 14-meter-long, 1.5-meter-width, 0.8-meter-depth flume in the hydraulic laboratory of Watershed Management Research Center of Iran. The process of establishment and development of meandering pattern was observed and investigated. On the basis of non-dimensional unit stream power (NDUSP) and shields parameter (θ), the results were analyzed and interpreted.

According to these experiments, for very fine gravel materials (on the basis of ASCE classification method) and NDUSP at least between 5.5 to 6.5 and shields parameter between 0.01 to 0.03, the meandering pattern establishment was occurred. In the other word the initial channel which contains the mentioned values of NDUSP and θ is capable to produce a meandering pattern. After regime channel establishment, stream power decreases; because, in the situation the river dissipates its excess power due to bed and walls erosion. By the experiments, it was found that if equation (…) is confirmed between (NDUSP) and (θ), meandering pattern will be formed.

$$\theta = 0.013 \times (NDUSP)^{0.58} \text{.........................}(..)$$

With the increase os discharge, Q, the value of NDUSP increases. Also with increasing of discharge, Q, both hydraulic radius, R, and shear stress $(\tau_0 = \gamma RS)$ will increase. Since $\theta = \dfrac{\tau_0}{(\gamma_s - \gamma)D_s}$, the value of θ will also increase; i.e. both NDUSP and θ will increase [4].

In the regime situation, P_l will minimized; i.e. for any discharge, the characteristics of channel will change in a way that P_l be minimized; since Q and

λ are constants, the changes in channel will continue until S be minimum.

Results

The theory of stream power which is based on general physical concepts and has simply been derived from basic theories of fluid mechanics, can be used for quantitative and qualitative analysis of meandering phenomenon. Non-dimensional unit stream power, which shows the importance of relation of "stream power" to "side resistance", is a ruling parameter in meandering process.

For simulating a meandering river in a model with loose boundaries, the amounts of non-dimensional unit stream power in model and prototype must be the same.

It seems unlikely to be able to replace this scaling criterion with other criteria of movement threshold of particles. The criterion of non-dimensional unit stream power as well as the shields parameter are adequate to geometrical similarity of planform.

On the basis of non-dimensional unit stream power and shields parameter it can be said whether a channel with known specifications can be meandered or not. In regime situation, minimizing of stream power in unit of length is obtained by minimizing of channel slope (for constant discharge and volume weight).

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