Transverse Flow characteristics in the Meandering Compound Channels

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ABSTRACT

Natural channels always form meanders along their path, and it is important to consider the effect of this meander on the flow characteristics pattern. When a flood occurs, the water level crosses the main section of the river and enters its floodplains. In this case the river crossing becomes a compound cross section. In this study, using the Flow3D software, powerful software in the field of computational fluid dynamics, we investigated the vortex rotational power and transverse flow in the meandering compound channel under the influence of relative depth and Sinusoidal Change. For this purpose, six channels with different sinuosity and three relative depths were used. The results of numerical simulation show that the maximum rotational power of vortices increases with an average of about 195% by increasing the sinusoidal rate from 1 to 1.209. The maximum rotational strength of the vortices and the transverse flow rate occur at a 45 degree angle to the central arc and a sinusoidal value of 1.209. In the main cross section of the meandering compound channel, for all sinusoidal values, by decreasing the relative depth, the vortex and transverse rotation strengths are increased and the rate of change in transverse current power relative to relative depth changes decreases with increasing sinusoidal rate.

KEYWORDS

Meandering Compound Channel, sinusoidal, relative depth, transverse flow, Vortex.

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1. Introduction

Natural rivers are rarely in direct flow because of regulating the energy grade-line, and usually have a curved path to which it is referred to as "meandering channels". After the appearance of meandering rivers, with the passage of time and the lateral movement of the meanders, the external bending progression and the sinusoidal or curvature is increased. In the meandering channels, the curvature of the meandering sections with a dimensionless number can be defined as the sinusoidal which is the ratio of meander length of the main channel to the floodplain length. By increasing sinusoidal slope number, flow velocity and river discharge capacity decrease. As a result, the risk of flood has increased significantly and during floods the water level exceeds to the main river boundary and enters to the floodplains. In this case, due to the interaction between higher velocities in the main channel and the slower velocities in the floodplains and the exchange of the momentum between these two regions, the flow profile is constantly changing. The central angle of the curve (2θ) is used as a measure to divide the development curve of a river. Kornise(1980) has presented a division according to Table1 to express the quality of development and progress of curvature in rivers by considering the central angle of the arc [1].

Table 1. The types of alluvial rivers based on central angle

Shape of river	Central angle (deg.)
Straight	Undifined or zero
Semi Meander	$0 < \alpha \leq 41$
Undeveloped meande	$41 < \alpha \leq 85$
Developed meander	$85 < \alpha \leq 158$
More developed meander like river	$158 < \alpha \leq 296$
River ox-bow (serpentine arc)	Up to 296

According to the studies of the meandering rivers, it is observed that a large part of the rivers are located in the developed and undeveloped area. Considering the risks of floods along the meanders and the diversity of rivers with different sinusoidal rates, it seems necessary to study the flood flows of the meandering compound channels. By reviewing the studies performed on meandering compound channels, in this research, the rotational strength of vortices and secondary flow power in meandering compound channels have been evaluated according to the change in sinusoidal rate and relative depth.

2. Methodology

In this research, using FLOW3D software, which is a powerful one in the field of computational fluid dynamics (CFD), an investigation takes into account the rotational strength of vortices and secondary flow power in meandering compound channels under the influence of sinusoidal rate change and relative depth. For this purpose, six channels with different sinuosity and three relative depths were used (Figure1&Table2). According to studies performed on compound channels, the RNG turbulence model has better adaptation to laboratory data, so in this research, this turbulence model has been used in modeling. In this study, the boundary conditions applied to the numerical model are for the upstream boundary of the channel, the Volume Flow Rate and for the downstream boundary of the Outflow. To apply the boundary conditions in the side walls and the floor of the channel, the boundary condition of the wall was used. The upper surface of the flow field was also defined as symmetry boundary conditions in this modeling. Laboratory data of Liu et al. (2014) were used to validate and control the results extracted in the present study[2,3&4].

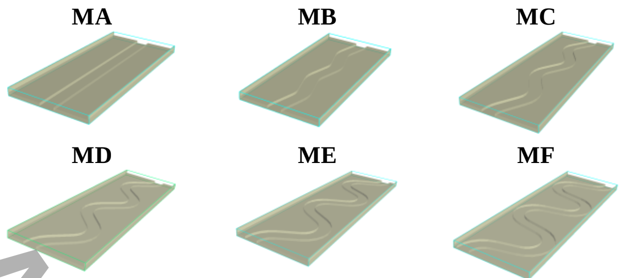

Figure 1. Channels used in this research

Table 2. meandering compound channels parameters

Case	channel sinuosity	θ
MA	1	0
MB	1.026	15
MC	1.096	30
MD	1.209	45
ME	1.381	60
MF	1.641	75

In order to investigate the secondary flow power in the meandering compound channels due to changes in sinusoidal rate and relative depth, shukry(1950) relations have been used. Shukry, by conducting studies on the flow in the river arch, by explaining the mechanism of secondary flow, in order to quantitatively study this phenomenon, has introduced Equation (1) for the power of secondary flow [5].

$$S_{yz} = \frac{K_{lateral}}{K_{main}} \tag{1}$$

This criterion in a cross section is the ratio of lateral flow kinetic energy to mainstream kinetic energy, which is calculated according to Equation (2).

$$S_{yz} = \frac{(\frac{V^2_{yz}}{2g})}{(\frac{V^2}{2g})} \tag{2}$$

The values of V_{yz} and V can be calculated according to equations (3) and (4).

$$V_{yz} = (v^2 + w^2)^{0.5} \tag{3}$$

$$V = (u^2 + v^2 + w^2)^{0.5} \tag{4}$$

In these equations u, v and w are the velocity components in the x, y, z and g directions of gravity acceleration.

Also, transverse currents in the meandering rivers cause vortices that can be evaluated using the vortex rotational power criterion.The net counterclockwise rotation rate of an element with dimensions Δy * Δz about the x-axis is defined in Equation (5) as Figure (2).

$$\vec{\omega}_x = \frac{1}{2}(\frac{\partial w}{\partial y} - \frac{\partial v}{\partial z}) \tag{5}$$

In this relation, ω_x is the value of rotation about the x, v and w axes of the velocity components in the direction of the y and z axes.

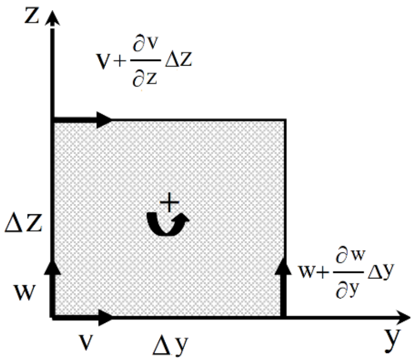

Figure 2. Rotation diagram of an element around the x-axis

3. Results and Discussion

In this section, the secondary flow power in the main channel of the CS1 section is calculated according to Figure 3 with respect to the change in sinusoidal value and relative depth. As shown in this figure, the maximum secondary flow power occurs at a 45-degree angle to the central arc and a sinusoidal magnitude of 1.209 (Case MD).The reason for the increase in secondary flow power due to the increase in sinusoidal rate is the increase in transverse velocity of the current(v) and the decrease in the longitudinal velocity(u).

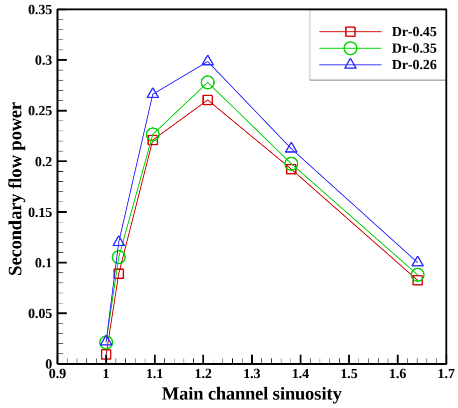

Figure 3. Maximum value of secondary flow power due to changes in sinusoidal magnitude and relative depth

In order to investigate the trend of changes in the Vorticity parameter in the meandering compound channels due to the change in sinusoidal magnitude and relative depth, this parameter is calculated in the cross section of CS1 according to Figure 4. According to Figure 4, the sensitivity to change the rotational power of vortices is higher at relatively low depths. For example, for the MD channel, the rate of change in the rotational power of the vortices increased from a relative depth of 0.45 to 0.35 by 4%, while from a relative depth of 0.35 to 0.26, it increased by 52%.

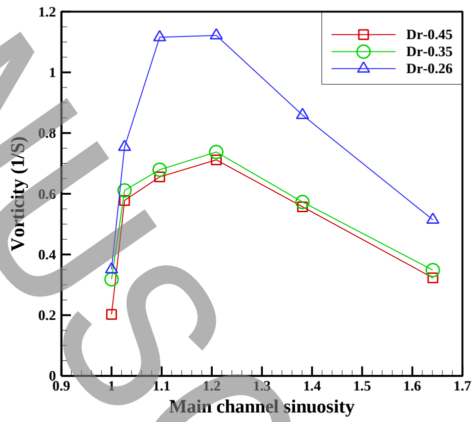

Figure 4. Maximum value of rotational power of vortices due to changes in sinusoidal rate and relative depth

4. Conclusion

In this study, the rotational power of vortices and secondary flow power as generators of secondary currents in the meandering compound channels due to changes in sinusoidal rate and relative depth were investigated using numerical modeling and the results are as follows:

- The maximum secondary flow power and rotational strength of vortices occurs at a 45 degree angle to the central arc and a sinusoidal magnitude of 1.209.(case MD)
- In a straight compound channel (MA) the amount of secondary flow power in the center of the main channel is very small.
- By decreasing the relative depth, the amount of secondary flow power increases. The sensitivity of the secondary flow power to the relative depth change in the MA channel is the highest.
- In the main channel of the meandering compound channels, for all sinusoidal values, the rotational power of the vortices is increased by decreasing the relative depth.
- The sensitivity to change of rotational strength of vortices is higher at relatively low depths.

5. References

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