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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), the vortex rotational power and transverse flow in the meandering compound channel under the influence of relative depth and Sinusoidal Change were investigated. For this purpose, six channels with different sinuosity and three relative depths were used. The results of the numerical simulation showed that the maximum rotational power of vortices increased 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 occurred 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 increased and the rate of change in transverse current power relative to relative depth changes decreased with increasing sinusoidal rate.

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1. INTRODUCTION

Natural rivers are rarely in the 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 are 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 the 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 the main river boundary and enters 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) presented a division according to Table 1 to express the quality of development and progress of curvature in rivers by considering the central angle of the arc [1].

According to the studies of the meandering rivers, it was observed that a large part of the rivers is located in developed and undeveloped areas. 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.

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

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

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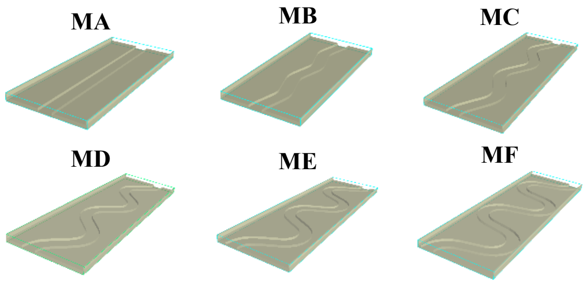

Fig. 1. Channels used in this research

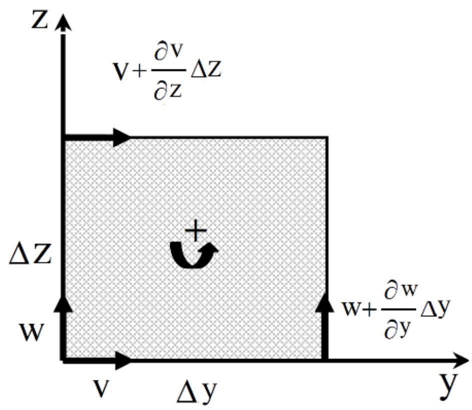

Fig. 2. Rotation diagram of an element around the x-axis

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

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 (Fig. 1 and Table 2). According to studies performed on compound channels, the RNG turbulence model has better adaptation to laboratory data. Therefore, in this research, this turbulence model was 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 the downstream boundary of the Outflow. To apply the boundary conditions in the sidewalls 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 [2-4].

To investigate the secondary flow power in the meandering compound channels due to changes in the sinusoidal rate and relative depth, Shukry's (1950) relations were used. By conducting studies of Shukry on the flow in the river arch, and explaining the mechanism of secondary flow to quantitatively study this phenomenon, Eq. (1) is introduced 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 Eq. (2).

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

The values of V_{yz} and V can be calculated according to Eqs. (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, and z, respectively, and g is the direction 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 $\Delta y * \Delta z$ about the x-axis is defined in Eq. (5), as shown in Fig. 2.

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

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

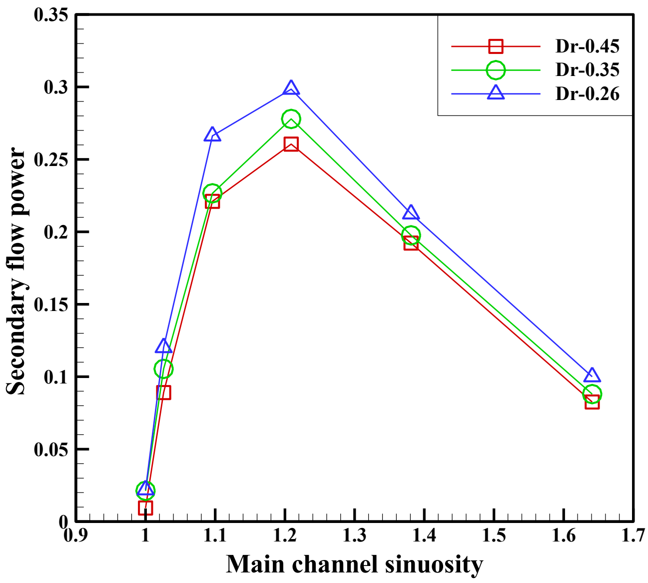

Fig. 3. The maximum value of secondary flow power due to changes in sinusoidal magnitude and relative depth

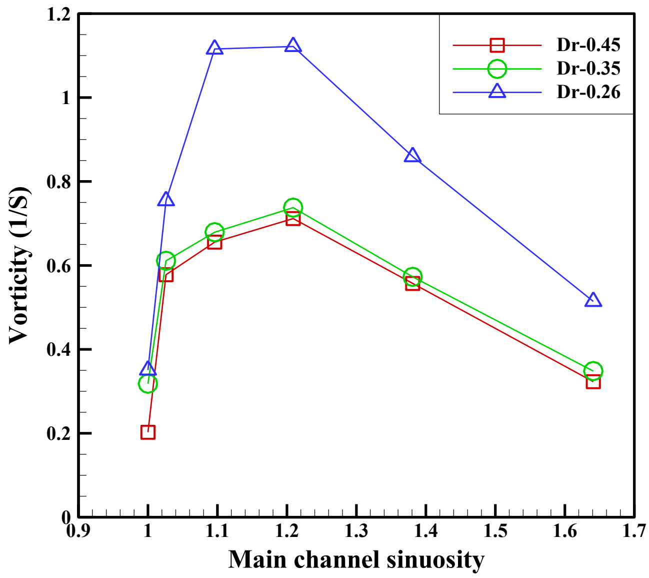

Fig. 4. The maximum value of rotational power of vortices due to changes in the sinusoidal rate and relative depth

3. RESULTS AND DISCUSSION

In this section, the secondary flow power in the main channel of the CS1 section is calculated concerning the change in sinusoidal value and relative depth as shown in Fig. 3. It can be seen that 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).

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 Fig. 4. According to Fig. 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%.

4. CONCLUSION

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

· The maximum secondary flow power and rotational strength of vortices occurred 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 was very small.

· By decreasing the relative depth, the amount of secondary flow power increased. The sensitivity of the secondary flow power to the relative depth change in the MA channel was the highest.

· In the main channel of the meandering compound channels, for all sinusoidal values, the rotational power of the vortices was increased by decreasing the relative depth.

· The sensitivity to change of rotational strength of vortices was higher at relatively low depths.

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