International Journal of Sediment Research 31 (2016) 264–270

Contents lists available at ScienceDirect

International Journal of Sediment Research

journal homepage: www.elsevier.com/locate/ijsrc

Original Research

Morph- and hydro-dynamic effects toward flood conveyance and navigation of diversion channel

Min Xu, Li Chen*, Qihui Wu, Dongfeng Li

State Key Laboratory of Water Resources and Hydropower Engineering Science, Wuhan University, Wuhan 430072, China

ARTICLE INFO

Article history:
Received 23 November 2014
Received in revised form
21 September 2015
Accepted 23 September 2015
Available online 22 November 2015

Keywords:
Diversion channel
Bed morphology
Navigation condition
Discharge capacity
Channel design

ABSTRACT

The functions of the diversion channel are usually disturbed by sediment erosion and deposition. Considering the effects of unsaturated sediment flow and narrowed cross section the diversion channel is enormously eroded. The discharge capacity, however, is deteriorated for the local deposition which lessens the water depth to satisfy the minimum navigable flow rate. In this study, the alternative diversion channel with unsaturated sediment flow at Hanjiang River, China, was taken as an example. The impacts of bed morphology for flood events and normal flow conditions were analyzed. The results show that the consideration of bed morphology is essential to design the diversion channel. Even for the unsaturated and eroded channel, the local deposition can reduce the water depth and restrict the navigable requirement under normal flow conditions.

1. Introduction

The diversion channel can divert the river water downstream for navigation, flood control, municipal water supply, or irrigation purposes. According to the water amount flowing from main channel to diversion channel, it can form into a braided or an alternative channel. The braided channel forms when the flow is carried by main and diversion channels. The alternative channel forms when the main channel is totally substituted. The characteristics of sediment-diffluence behaviour and flow structure for the braided river can be applied to the former one. The behaviour of the alternative-channel, including its flow characteristics and riverbed evolution, is different from the original main channel because of the cross section transition.

The confluence of two channels is present in the braided channel. The complexity of the phenomena and process in the confluence flow are considered from the effect of strong interaction of incoming flow and bed morphology. Best and Reid (1984) observed the separation zone near the braided-channel junction and characterised the separation zone shape with the ratio between the width to the horizontal length. Neary and Odgaard (1993) showed that the width of the separation zone along the upstream wall of the diversion is smallest at the bottom and increases towards the water surface. A secondary circulation is created in the diversion which resembles that occurring in bend flows. Huang et al. (2002) applied a numerical investigation on the confluence flow by varying junction angles. The separation zone did not form for a junction angle lower than 30°, and the size of the separation increased with the angle. Liu et al. (2012) found that the development of the separation was also restricted by the discharge ratio. Li and Zeng (2009) applied the numerical model to study the effect of channel width ratio and roughness on channel flow. They predicted the trend of increasing flow in the branch channel with increasing the channel width or decreasing the roughness. The characteristic of this flow is related to the upstream–downstream water depth ratio, discharge ratio of main and diversion channels, angle between two combining channels, and associated energy loss (Cañizares et al., 2007; Meselhe et al., 2012; Willson et al., 2007). The observation showed a lateral sandbar near the junction could increase the sediment–water ratio in the diversion: a larger diversion channel with a more favourable alignment and orientation relative to the flow direction in the river results

* Corresponding author.
E-mail address: chenliwuhee@263.net (L. Chen).

http://dx.doi.org/10.1016/j.ijsrc.2015.09.001
1001-6279/

in a higher sediment–water ratio (Best & Reid, 1984). Allison et al. (2013) had a case study of the 2011 Mississippi River flood analyse the diffluence effect of a channel and resulted in the reduction of stream power, and, thus, in sediment transport capacity. They also observed that huge amounts of sediment were deposited which degrades the navigation conditions.

The width, configuration, and scour-resistance of the alternative-channel are different from the original river. The corresponding adjustments will occur in water–sediment movement and evolution. The stability of the alternative channel is extremely affected by the channel bend and the erodibility of bed materials (Brice, 1983; Chang, 1986). To fulfil the safety issue the width of the channel should increase in proportion to its bank roughness (Firenzi et al., 2000). Kim et al. (2004) showed the response of channelised streams to extreme flooding and demonstrated the inertia-dominant behaviours of channel straitening, widening, and steepening with its channel morphology newly shaped by the extreme flood. Neary et al. (1998) pointed that a channel should maintain its existing energy slope for more frequent flood events with discharges at, or less than, the dominant discharge, thereby maintaining longitudinal sediment equilibrium to ensure flood damage mitigation and navigability. Ramamurthy et al. (2007) indicated that secondary flow in a channel had detrimental effects on bank stability. A diversion channel which only exists in the course of hydro-junction construction differs from a channelized river. Its width is normally narrower than the original river which increases the flow velocity and a greater sediment-transport capability. Even the original river is under in the scouring-depositing equilibrium, pronounced erosion will occur in the alternative channel. The protective measures are always considered to ensure the safety of such channels; however, the morphological influence on channel function (such as, discharge and navigability) is overlooked.

The diversion channel constructed on a river with unsaturated sediment transport often narrows the stream course during the construction period of hydropower projects, such as the diversion channel at the Cuijiaying hydro-junction on the Hanjiang River in this study. The deposition in this diversion channel may occur and directly influence the discharge capacity of the channel as a result. This study, therefore, is to understand the complexity of the diversion channel affected by the bed morphology and the construction of Cuijiaying hydro-junction on the Hanjiang River. The data measured in-situ were utilised to calibrate and verify our numerical modelling. The results can help to supplement the design of the diversion channel.

2. Study area

The Hanjiang River, the largest tributary of the Yangtze River, is located in central China. It plays an important role in the comprehensive utilisation of water resources, especially in the midstream section where there are nine hydro-junctions, including the Cuijiaying hydro-junction, built. The Cuijiaying hydro-junction is 142 km downstream from Danjiangkou hydro-junction, and 155 km upstream from the Yangtze River (at Wuhan) (Fig. 1). Since Danjiangkou reservoir came on-line in 1968, sediment concentration of reaches downstream of the dam (where Cuijiaying hydro-junction is located) dropped dramatically due to the retention of sediment by the reservoir. As a result, the annual mean sediment concentration drops from 3.92 kg/m^3 to 0.4 kg/m^3 (Yang, 1989) and the reach is in an unsaturated sediment transport state.

Construction of the Cuijiaying hydro-junction began in November, 2005, and it was put into operation in August, 2010. During the first phase of construction from December, 2006 to September, 2008, a cofferdam cut off the main channel and an open diversion channel was excavated for navigation and flood discharge in the Fenghuang floodplain on the left bank. The diversion channel has a compound cross-section, with a bottom width of 280 m and an excavated slope of 1:3. A 150-m-wide platform was made at a 60-m elevation on the left bank. Fig. 2 shows positions of the diversion channel, cofferdam, and Han River with the diversion channel profile. Compared with the original channel, the reach from Section C to Section F was excavated in the Fenghuang Floodplain and the river width narrowed significantly, especially near the dam axis (Section E) where the river width decreased from 593 m to 280 m. To prevent erosion from unsaturated flow on both banks and the riverbed near the dam axis, some protective engineering measures were taken in accordance with the result of the fixed-bed river model. According to the design data, the discharge capability and navigation conditions of the diversion channel are demonstrated by fixed-bed model test.

Field inspections of the diversion channel topography, velocity distribution under different flow conditions, water level, and stream gradient were observed during operations. The topography is measured by LeicaTC403, the depth by SDH-13D and velocity by chongqingZSX-4. The riverbed evolution was analysed according to the prototype measurement data. A two-dimensional Delft-3D flow model (immovable bed) of the diversion channel was implemented based on observed topographical data from June, 2008. The riverbed was simulated from Sections A to J then verified with observed velocity and water level data, on the basis of which, flow velocity, water level, and water depth for each section of the diversion channel was calculated ($Q_1 = 470$ m^3/s; $Q_2 = 5500$ m^3/s). By contrasting the design and observed data, this research analysed the influences on discharge capacity and navigation conditions due to riverbed evolution.

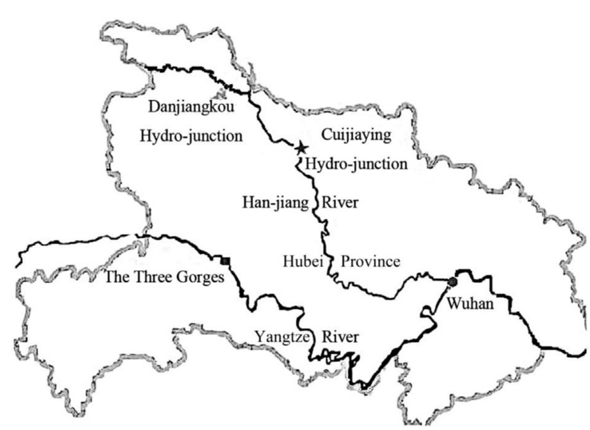

Fig. 1. Location of the Cuijiaying hydro-junction.