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Channel adjustments in a gravel-sand bed reach owing to upstream damming

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ABSTRACT

Upstream damming can greatly alter the flow and sediment conditions entering downstream reaches, leading to remarkable channel adjustments. Especially in a gravel-sand bed reach, the adjustments are more complicated owing to bed-material coarsening process. In order to quantify the adjustment characteristics of a total reach, a reach-averaged method was adopted to calculate the reach-scale bankfull channel dimensions firstly. Then the effects were investigated respectively of the altered flow-sediment regime and the bed-material coarsening degree on the variation in bankfull channel geometry. The results show that the effect of the altered flow-sediment regime on channel adjustments was lower in a coarsening bed reach than a less-coarsening one, because bed-material coarsening limited channel incision and led to a weaker response of channel adjustments to the variation in flow and sediment regime. Moreover, bed-material coarsening also had a significant influence on the adjustments in bankfull channel dimensions, with greater correlations being obtained in the reach suffering higher degree of bed-material coarsening. Therefore, a comprehensive hydraulic geometry relation was proposed to describe the channel adjustments in a gravel-sand bed reach, with these two influencing factors being considered. The obtained correlations were higher than those obtained from the simple relation that solely considered a single influencing factor.

1. Introduction

Upstream damming can significantly alter the natural flow and sediment regimes entering downstream rivers, which usually leads to important consequences for channel adjustments (Williams and Wolman, 1984; Batalla et al., 2004; Ma et al., 2012; Scorpio and Rosskopf, 2016; Smith et al., 2016). In addition to hydrodynamic conditions, channel adjustments are also influenced by the coarsening process of bed material, especially in a gravel-sand bed reach (Galay, 1983; Luo et al., 2007; O'Hare et al., 2010; Tanny et al., 2011; Grant, 2012; Wang et al., 2016). This process can limit the degree of channel incision (Galay, 1983; Luo et al., 2007; Grant, 2012; Wang et al., 2016), and it can also increase the in-channel water levels owing to an increase in bed roughness degree (O'Hare et al., 2010; Tanny et al., 2011). Therefore, it is of great significance to investigate the channel adjustments in a gravel-sand bed reach owing to upstream damming.

Channel adjustments caused by a dam usually cover the adjustments in planform geometry, cross-sectional geometry, grain-size distribution, and channel slope (Simon et al., 2002; Grams et al., 2007; Grant, 2012; Xia et al., 2014b; Scorpio and Rosskopf, 2016; Smith et al., 2016; Liro, 2017). For example, upstream damming may influence channel migration and change river sinuosity, or cause bank erosion in downstream rivers (Simon et al., 2002; Xia et al., 2014b; Liro, 2017). Moreover, upstream damming also initiates significant channel incision and great changes in channel width and cross-sectional area (Grams et al., 2007; Scorpio and Rosskopf, 2016; Smith et al., 2016). It should be noted that cross-sectional geometry under the bankfull level (usually defined as bankfull channel geometry) can reflect the magnitude of flood-discharge capacity, and it's also one of the key parameters in the contexts of river engineering and geomorphology (Julien, 2002). Many researchers have investigated its variation by developing empirical relations between bankfull channel dimensions and the incoming flow-sediment conditions (Leopold and Maddock, 1953; Parker et al., 2007; Wu et al., 2008; Shibata and Ito, 2014). For example, Leopold and Maddock (1953) expressed the hydraulic geometry relations for a channel in the form of power function of discharge. Shibata and Ito (2014) developed empirical relationships between the bankfull channel widths and different characteristic discharges in Japanese rivers using the hydrological and geomorphological data at 368 sites. Wu et al. (2008) developed a relation for the prediction of bankfull cross-

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sectional area, which accounted for the cumulative effect of previous years' flow and sediment conditions on the channel adjustments in the Lower Yellow River. However, adjustments in channel geometry are the result of a set of complex processes that depend on both in-channel hydrodynamic conditions and bed-material properties (Piegay et al., 2005; Bartley et al., 2008; Xia et al., 2014c). Therefore, Wilkerson and Parker (2011) improved the hydraulic geometry relation, with the bed-material composition also being considered. Nevertheless, most of the relationships were developed for sand-bed reaches, and a hydraulic geometry relation is required to describe channel adjustments in gravel-sand bed rivers. In addition, these studies mainly concentrate on channel adjustments at specified cross-sections, and the results cannot be representative of a total reach. So a reach-averaged method is required to investigate the channel adjustments at reach scale (Harman et al., 2008; Xia et al., 2014a). The reach-averaged method means a way to calculate the mean values of bankfull channel dimensions at all cross-sections included in a study reach.

The Yizhi reach (YZR), a typical gravel-sand bed reach immediately downstream of the Three Gorges Dam (TGD), is selected as the study region for the practical application. The planar variation is insignificant in this reach, and the special attention of the current study is paid to the adjustments in cross-sectional geometry. The main purposes are to: (i) adopt a reach-averaged method to calculate the reach-scale bankfull channel dimensions for describing channel adjustments of a total reach; (ii) investigate the impacts of the altered flow-sediment regime and the bed-material coarsening degree on the variation in bankfull channel geometry; and (iii) propose a comprehensive hydraulic geometry relation, which can be used to predict the adjustment tendency of channel geometry in a gravel-sand bed reach.

2. Study area and data collection

2.1. Study area

The Yizhi reach (YZR) in the Middle Yangtze River is a typical sand-gravel bed reach and it is selected as the study area. This reach is located about 43 km downstream of the Three Gorges Dam (TGD), covering the region between Yichang and Zhicheng (Fig. 1). With the boundary at the Yi69 section, the total reach is divided into two sub-reaches (Fig. 1), which are termed Reach 1 and Reach 2 according to the difference in bed-material composition. The riverbed in Reach 1 is mainly composed of gravel and fine sand with a thin sand layer, while the riverbed in Reach 2 comprises predominantly fine sand with a thick sand layer of about 10 m and a subordinate layer of gravel, and the proportion of gravel in bed material decreases gradually along the reach (CWRC, 2016). In addition, the riverbanks of the YZR are mainly controlled by low hills and terraces, as well as the bank-protection works with a length of 6.8 km along the reach (Cao and Wang, 2015).

2.2. Data collection

In order to calculate the section- and reach-scale bankfull channel geometry of the YZR and investigate the effects of the altered flow-sediment regime and the bed-material coarsening degree, the following data sources (CWRC, 2016) were collected.

(i) Hydrological data were collected from the Changjiang Water Resources Commission (CWRC) to analyze the changes in the flow-sediment conditions entering the YZR. These data cover the daily mean discharge and sediment concentration at the hydrometric station of Yichang since 1950, as well as the daily mean water level at the stations of Yichang, Honghuatao, Yidu and Zhicheng in 2002–2015. The locations of these stations are shown in Fig. 1.

(ii) The grain-size distributions of bed material at specified cross-sections (17 cross-sections in Reach 1 and 6 cross-sections in Reach 2) from 2002 to 2010 were used to analyze the bed-material coarsening process.

(iii) Topographic data of the YZR were collected to determine the variation in bankfull channel geometry. The data include the bathymetric map with a scale of 1:10000 measured in 2002 and the post-flood cross-sectional profiles at 50 cross-sections in 2002–2015, with the section numbers of 40 and 10 in two sub-reaches. The distance between two consecutive cross-sections ranges from 0.37 to 3.55 km, with mean spacing of about 1.20 km.

3. Methods

In the following study, the procedure for calculating bankfull channel dimensions (Xia et al., 2014a) and the method for developing hydraulic geometry relations are presented as follows.

3.1. Procedure for calculating bankfull channel geometry

3.1.1. Determination of section-scale bankfull channel geometry

The bankfull channel geometry commonly includes the bankfull width, depth and cross-sectional area. To determine these dimensions, the bankfull level at a cross-section needs to be identified first. The lower level of the lip tops of an active floodplain on both sides is usually defined as the bankfull level at a cross-section, and the distance between two lips is defined as the bankfull width (W_{bf}^{i}). The main passage area under the bankfull level is defined as the bankfull cross-sectional area (A_{bf}^{i}), and the average bankfull depth (H_{bf}^{i}) is equal to the ratio of area to width.

At some sites (for example at Yi41 (Fig. 1) in the YZR), the

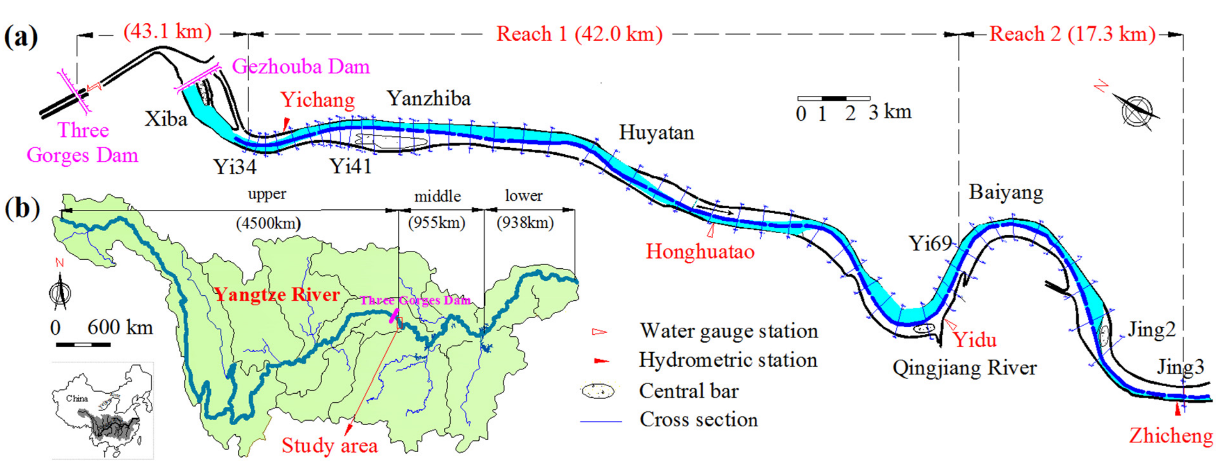

Fig. 1. Sketch of the Yizhi reach in the Middle Yangtze River.