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Research papers

The dynamic capacity calculation method and the flood control ability of the Three Gorges Reservoir

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ABSTRACT

To evaluate the flood control ability of a river-type reservoir, an accurate simulation method for the flood storage, discharge process, and dynamic capacity of the reservoir is important. As the world's largest reservoir, the storage capacity and flood control capacity of the Three Gorges Reservoir (TGR) has attracted widespread interest and academic debate for nearly 20 years. In this study, a model for calculating the dynamic capacity of a river-type reservoir is established based on data from 394 river cross sections and 2.5-m resolution digital elevation model (DEM) data of the TGR area. The storage capacity and flood control capacity of the TGR were analysed based on the scheduling procedures of a normal impoundment period. The results show that the static capacity of the TGR is 43.43 billion m^3, the dynamic flood control capacity is 22.45 billion m^3, and the maximum floodwater flow regulated by the dynamic capacity at Zhicheng is no more than 67,700 m^3/s. This study supply new simulation method and up-to-date high-precision data to discuss the 20 years debate, and the results reveal the TGR design is conservative for flood control according to the Preliminary Design Report of the Three Gorges Project. The dynamic capacity calculation method used here can provide a reference for flood regulation of large river-type reservoirs.

1. Introduction

The most important parameter that reflects the flood control ability of a reservoir is the flood control capacity; quantifying and calculating the floodwater flow is essential for analysis of dynamic reservoir capacity and for planning and implementation of flood control (Li et al., 2010, 2014). During flood events, the flood water gradually rises in the reservoir and the water surface deviates from horizontal. The flood capacity of the reservoir, called the dynamic capacity, is calculated as the sum of the static capacity below a horizontal plane close to the water surface and the wedge capacity, defined as the volume between the horizontal plane and the actual water surface. Many factors influence the wedge capacity, including water inflow, outflow, and reservoir shape (Cai et al., 2005). The greater the inflow, the higher the reservoir water level and the greater the wedge capacity will be. Generally, the wedge capacities of lake-type (i.e. level-pool) reservoirs are small, but they are relatively large for river-type reservoirs, especially those with a wide tail. In traditional methods of flood regulation involving static capacity, the flood is regulated based only on calculations of the static capacity curve, ignoring the flood propagation process in the reservoir area and the wedge capacity (Fiorentini and Orlandini, 2013). In more accurate methods of capacity estimation for river-type reservoirs, the wedge capacity is included (Chen et al., 1999; Ai et al., 2002; Tong and Zhou, 2003).

The Three Gorges Reservoir (TGR) (Fig. 1) is a typical river-type reservoir with a length of up to 600 km, which has a surface area of about 1080 km^2, an average width of about 1100 m, a mean depth of about 70 m and a maximum depth near the dam of about 170 m; thus, the dynamic capacity method should be used to estimate the floodwater flow through the TGR for flood regulation. Over the past two decades, many studies examined various methods of estimating the dynamic flood control capacity of the TGR (Cai et al., 2005; Ai et al., 2002; Tong and Zhou, 2003; Changjiang Water Resources Commission, 1992; Wang and Hu, 2006; Zhou et al., 2013; Zhang et al., 2016; Zhong et al., 2010; Lu et al., 2010; Cai, 2011; Min et al., 2011; Zheng, 2016; Wang et al., 2013, 2005; Hayashi et al., 2008). According to the Preliminary Design Report of the Three Gorges Project (PDRTGP) (Changjiang Water Resources Commission, 1992), the normal water level is 175 m, with a corresponding capacity of 39.3 billion m^3, and the flood control water

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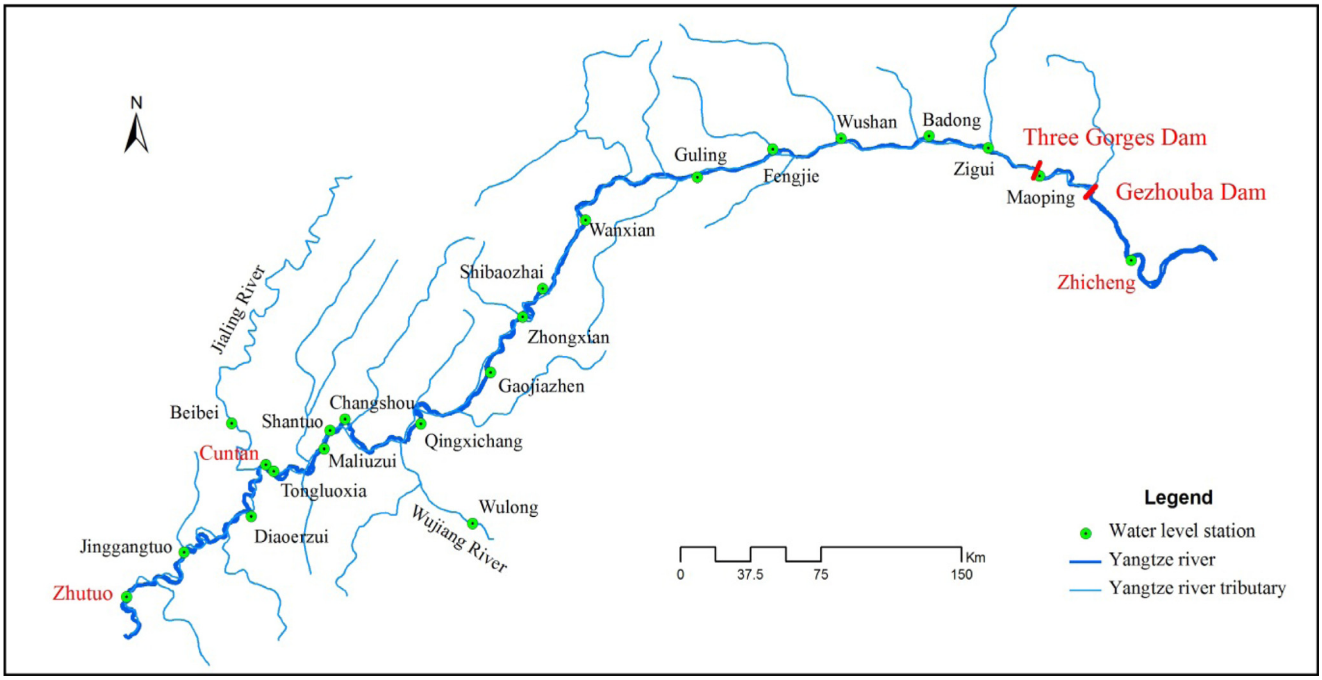

Fig. 1. The Yangtze River and its tributaries and water level stations of the study area. The TGR has great significance to the flood control of the Jingjiang reach of the Yangtze River, and the discharge of Zhicheng is used to show the flood control effect of the TGR. A total of 394 cross sections and 2.5-m resolution Digital Elevation Model along the river from Zhutuo to the dam were used to simulate the dynamic capacity of the TGR.

level is 145 m with a flood control capacity of 22.15 billion m^3. Zhou et al. (2013) used the dynamic capacity model to calculate the flood regulation capacity of the TGR (Tong and Zhou, 2003; Wang and Hu, 2006; Zhang et al., 2016) and showed that the flood control capacity is 17.9 billion m^3 (with a discharged flow of 60,000 m^3/s), only 81% of the preliminary design capacity. Researchers at the Design Institute of Changjiang Water Resources Commission, Nanjing Hydraulic Research Institute, and Wuhan University also studied this issue (Cai et al., 2005; Zhong et al., 2010), using the methods of instantaneous water surface line, Priessmann's model of implicit difference, and the three-level river network algorithm, respectively, as well as other methods to estimate the dynamic capacity for flood regulation, and concluded that the dynamic capacity for flood control of the TGR is 20.81–21.49 billion m^3, with a corresponding dam discharge flow of 68,000–69,000 m^3/s, and a controlled flow at the Zhicheng monitoring station of 70,000 m^3/s.

These studies used the data prior to 2005 when the TGR was not complete to verify their dynamic capacity model (Cai et al., 2005). The studies lacked data on the normal operating conditions; therefore, the conclusions require further verification. Moreover, the models in the foregoing studies only used data of large cross sections across the river and the capacity curves of important tributaries, and lacked consideration for the channel storage role of river bends, small tributaries and so on. Therefore, the effect of such channel storage on reservoir capacity still needs to be evaluated. Studies conducted in recent years have focused on the reservoir operation process in 2010 (Lu et al., 2010; Cai, 2011; Min et al., 2011) and used data from the normal storage operation period; however, there are no clear conclusions or detailed simulation methods that provide an estimate of the total dynamic capacity of the TGR.

The TGR began normal storage operation in 2008; further studies and discussions on the accurate capacity of flood control in the TGR have great significance and, with better data support, can produce more accurate results. The main objective of this paper is as follows. (1) The one-dimensional unsteady flow calculation method is optimized to better reflect the effect of the real terrain on the calculation. And based on the high precision DEM data and the optimized calculation method, the dynamic capacity calculation model of river-type reservoir is established. (2) According to the existing flood-control procedures, the flood control schedule of TGR in a 100 and 1000-year flood events is calculated and the corresponding static capacity and dynamic capacity are calculated. Based on the calculation, the flood control capacity of the TGR is discussed to clarify the controversial issue of reservoir capacity to provide a reference for downstream flood control planning.

2. Study area and data

The TGR project, which began in 1993, is a major development scheme for harnessing China's longest river – the Yangtze River. The region downstream from the TGR contains the plains of the middle and lower reaches of the Yangtze River, which is one of the most populous and developed areas in China and is also subjected to the most frequent and disastrous floods in the country (Xia et al., 2016; Xie et al., 2012). With a length of up to 600 km and an average width of about 1100 m, the TGR retains the long narrow belt shape of the original river section and is a typical river-type reservoir (Li et al., 2010; The Executive Office of the Three Gorges Project Construction Committee, 2015). The water storage in the TGR was implemented in three stages. The water level first rose from 70 m to 135 m in June 2003, then was raised to 156 m in October 2006. In November 2008, the water reached 172.3 m for the first maximum storage testing, and in October 2010 a level of 174.9 m was reached. Currently, the reservoir's water level is maintained at about 175 m for power generation and navigation during winter (from November to February), and gradually lowered to 150–170 m for downstream irrigation and navigation in the spring (March–May), then maintained at 145 m for flood control during most of the monsoon season (June, July, and August). Storage starts again at the end of the flooding season in September each year (Wang et al., 2011; Wang et al., 2014).