Research status of riverbed evolution

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Abstract

Riverbed evolution refers to the process of scouring and silting in the riverbed under natural conditions and the construction of rehabilitated buildings. In recent years, many sediment researchers have carried out a lot of research on the theme of river evolution and have achieved fruitful results, some of which have also been applied in practical projects and have made great contributions to the development of sediment disciplines. From the analysis of the current research status of riverbed evolution, this paper summarizes the theory and research methods of riverbed evolution and the calculation method of river channel erosion and siltation, which helps to analyze the evolution mechanism of river course, predict the evolution trend of rivers and provide scientific reference for future projects designs, shipping safety flood prevention planning.

Keywords

Riverbed evolution; sediment movement; river scouring.

1. Introduction

Rivers are not only an important component of the Earth's life circle, but also provide basic resources for humans' survival and development. The development of humans and their social systems is closely related to the river and is closely connected in the historical process. Rivers have the water environment on which humans depend and humans also promote social progress and development through the development and utilization of rivers. With the current global climate changes and the rapid development of regional economy, the contradiction between supply and demand of water resources in various countries is more prominent, and river sediment research will face new challenges.

Natural rivers are always in the process of constant development due to natural conditions and humans' production and life. After the construction of water conservancy projects, river management projects or other projects on the river, the riverbed will undergo significant changes due to the disturbances from the buildings [1-3]. In the process of developing and utilizing river resources, human beings must effectively eliminate the disadvantages and adopt remediation measures. However, the riverbeds of natural rivers are complex in shape and the evolution laws differ dramatically. Therefore, the remediation methods implemented are often different. In order to remedy rivers effectively, we must fully understand the basic principles of riverbed evolution and the special evolution laws of various riverbeds. Only by studying the law of riverbed evolution deeply can we avoid the serious consequences of irrational development and enable rivers to better serve humans and promote social and economic development better.

In recent years, a large number of domestic and foreign scientific research scholars have been braved enough to innovate and promote the development of sediment disciplines, thus contributing to the progress of river remediation projects. Duboys P 's bed movement theory [4], Gilbert GK sink test

[5], Shields A's Shields curve [6], Rouse H's Rouse formula [7], Einstein H A's Einstein sediment transport function [8], etc., the launch of which marks the formation of the theoretical system of river sediments. Since the 1950s, the classical sediment transport theory [9-12] based on particle dynamics or continuum mechanics and the dynamics of two-phase flow of water and sand [13-15] have been greatly developed around the different states of sediment movement (stationary, starting, migrating and floating). The same is true in the field of riverbed evolution.

Riverbed evolution is an important river surface process, which depends mainly on the interaction of water flow and its sedimentary sediments and riverbed sediments [16]. When the hydrodynamic force is enhanced, the water flow is increased, the sediment is frequently started and the riverbed is prone to erode. When the hydrodynamic force is weakened, the sediment flow is decreased, the sediment is silted and the riverbed is prone to silt up. By analyzing the research status of riverbed evolution, this paper summarizes the theory and research methods of riverbed evolution, helps to analyze the evolution mechanism of rivers, predicts the evolution trend of rivers, and provides scientific reference for future engineering design, shipping safety and flood control planning.

2. Theoretical study on river bed evolution

There is a relatively stable relationship between climate, runoff and sediment yield in the basin under natural conditions. The evolution of rivers includes changes in river channel ratio, morphology, and composition of riverbed materials. In terms of its evolution, riverbed evolution can be divided into two categories: lateral evolution and vertical evolution and the two mutually restrict and influence each other. Analysis of riverbed evolution, the main research factors include riverbed plane morphology, river evolution and sedimentation and siltation of riverbeds in sandy rivers, etc. The theory of riverbed evolution is basically based on the balance and non-equilibrium of riverbed erosion and sedimentation. If the riverbed material and watershed do not change much in the water, the river pattern often tends to a certain relative balance; if the riverbed material and the basin come to the river to change greatly, the river will form an automatic negative feedback mechanism during the evolution of the riverbed, which will make the evolution of the riverbed to equilibrium [17].

At present, there are mainly several kinds of equilibrium theory of riverbeds. From the perspective of energy consumption, Dou Guoren [18] proposed the minimum activity hypothesis of river evolution, and believed that under certain conditions of incoming water and riverbed conditions, the evolution of riverbed to the least active section. Many scholars have proposed the minimum energy consumption hypothesis that the riverbed will be adjusted according to the change of incoming water and sand to minimize energy consumption. In addition, there are the maximum sediment transport efficiency hypothesis [24], the minimum variance hypothesis [25], the maximum drag coefficient hypothesis [26], and the river raft theory [27], the above hypotheses can be transformed into each other in essence. The above river bed evolution theory is based on the "equilibrium channel", the river is in equilibrium, and its water and sediment transport process has reached a dynamic balance [28].

3. Riverbed evolution research method

3.1 Method of data analysis

The method of data analysis is the most commonly used and the earliest method with high credibility. The analysis of measured data mainly includes the following three aspects [29]:

Analysis of the topographic observation data of the river section. With the development of science and technology, several underwater terrain observations are carried out every year in important river sections of many important rivers. It is of great value to sort out these data to analyze the historical evolution of the river section, its recent evolution, its development trend and the river improvement plan.

Analysis of the geological data of riverbed. When the geological composition of the riverbed is loose sand, the riverbed will change sharply and the riverbed will be unstable; when the geological

composition of the riverbed is soil, the process of riverbed evolution is slow and the riverbed is relatively stable. When analyzing the geological conditions of the riverbed, the geological profile is generally drawn according to the geological exploration data and then the geological conditions of different parts are analyzed to obtain the erosion and deposition of the riverbed.

Analysis of water and sand factors. The change of river bed's erosion and siltation is closely related to the change of incoming water and sediment volume. The actual exploration and observation in the field is usually the beginning of people's understanding of various changes in the river system. With the modernization of observation methods, data acquisition methods, observation accuracy, and data volume have been greatly improved. A comprehensive analysis of a large amount of measured data which is collected, so that people gradually understand the regularity of the evolution of riverbed geomorphology, which has always been one of the commonly used means of studying rivers. With the development of modern mathematics, modern mathematical methods such as function, probability theory, mathematical statistics, mathematical logic, and cybernetics have been gradually applied to data analysis, which further promotes the application of data analysis methods.

In recent years, many scholars have used the measured analysis method to explore the changing laws and trends of riverbed evolution. Wal Daphne Van der et al. [30] used nautical charts and on-site topographic observations to clarify the long-term geomorphological evolution of the Ribble estuary in the UK and explain the similarities and differences between the scouring and silting conditions in different periods. Ciaran Harman et al. [31] analyzed the uncertainty and variability of the flat beach flow in the 114 river sites in southeastern Australia and established a prediction error analysis model. Yang et al. [32] summarized the evolution law of the Nantong River section of the Yangtze River through the measured hydrological and topographic data. It is believed that most of the Han section of the river section is relatively stable in the near future, which is represented by deep chaos and the collapse of the beach of local river sections. Xu et al. [33] used the measured section and river topographic data to reveal that the riverbed erosion in the middle and lower reaches of the Yangtze River intensified from “slot flushing to silt” to “slot flushing” after the Three Gorges water storage operation. Tang et al. [34] used the years of measured underwater topographic data of the Anshan section to analyze the evolution of the riverbed in the river section, and the right bank of the section was relatively stable, and the left bank would be greatly adjusted. In response to the evolution of the riverbed in the Yangtze River estuary, Chen [35], Wu [36], Guo [37] et al. have carried out a large number of researches based on measured data. Li et al. [38] used the measured underwater topographic data of the Yangtze River estuary to construct the water depth-cumulative area curve and the calculation of the scouring and silting flux and the sediment transport with the Three Gorges Reservoir and Datong Station, indicating that the Three Gorges water storage has a controlling effect on regional evolution of the Yangtze estuary after 2007. The measured research is not only conducive to understanding the laws and trends of riverbed evolution, but also provides a lot of valuable basic data for further exploration of riverbed evolution, which laid a solid foundation.

3.2 GIS technology and DEM model method

As early as the 1960s, Shreve [39] used stochastic theory to try to simulate the geomorphology of water system. With the continuous development of science and information technology, GIS technology has come to maturity. From the perspective of technology and application, GIS is a tool, method and technology for solving spatial problems. GIS has the functions of acquiring, storing, presenting, editing, processing, analyzing, outputting and applying spatial data. GIS not only provides a solution for the integrated management of a large number of river topographic information, but also provides an automated, fast and reliable analysis method for the river bed time and space change process. In addition, GIS has a spatial visualization function that enables 3D modeling and 3D analysis of river terrain, making the riverbed evolution analysis process more intuitive and specific. Therefore, geographic information systems (GIS) and digital elevation models (DEM) are gradually being applied to the study of riverbed evolution.

Delpont G. et al. [40] used high-resolution satellite imagery and aerial photographs to monitor the dynamic topographic changes at the Tech and Tet estuaries along the Roussillon coast of France from 1942 to 1986 and concluded that changes in estuaries and shorelines in the region were mainly affected by flooding. Wu et al. [41] used the GIS and digitizer to establish the underwater digital elevation model of the Yangtze River estuary in different periods based on the data of the 1842-1997 Yangtze River Estuary. And based on this, the study was carried out from the perspectives of the river channel plane shape and the horizontal and vertical sections. The problem of beach trough evolution, shoreline erosion, and sand island evolution in the Yangtze River estuary sand area is also calculated by calculating the volume change of the river channel. Li et al. [42] used GIS and DEM technology to study the process of scouring and silting in the Jiujiang section of the Yangtze River in the past 40 years. It was found that the overall performance was sedimentation from 1963 to 1972, and the overall performance was scouring from 1972 to 2002. Wang et al. [43] used GIS technology to establish the underwater DEM of the North Port of the Yangtze River estuary from 1973 to 2003. The relative scouring and siltation distribution of the riverbed in different periods was obtained. The evolution of the scouring and silting of the river channel in the North Port of the Yangtze River estuary in the past 30 years was analyzed and the sedimentation and scouring volume of the river was calculated. Based on GIS technology, Bai et al. [44] studied the river channel shape and erosion and deposition sites in the Jiangsu section of the Yangtze River, revealing that the deep channel was dominated by scouring before 1995.

It can be seen from the above research results that the combination of GIS and DEM can consider the qualitative and quantitative analysis of riverbed erosion and siltation, which makes the evolution of riverbed become highly visible, which is a relatively mature and highly reliable method in the study of riverbed evolution characteristics.

3.3 River model experiment

The river model test method is an early method for river simulation research [45-49]. Initially, the control was manually adjusted and the simulation accuracy of the model was also low due to the backwardness of the test and measurement methods. After entering the middle of the 20th century, the measurement methods have been significantly improved, the river model test has also been greatly developed, and the method of model test is constantly improving. From the normal fixed bed model test, to the metamorphosis, and then to the subsequent dynamic bed model test. With the development of modern science and technology and sediment research, especially the emergence and rapid development of computers, the research of river model has made significant progress from design method to experimental technology in the past 10 years. The model test method has undergone tremendous changes, and digital acquisition and control under computer control has been realized. For example, the boundary tide tidal unsteady flow data automatic control, acquisition and monitoring system and the river model intelligent acquisition control system developed by Hohai University [50]. The development and application of these systems not only saves material and manpower, but also improves the quality of the test results, and the control interval between two adjacent measurements in the model can be quite short, reaching about 1 second, which can be basically possible to track prototype changes in real time. New theoretical and simulation methods are also proposed in the aspects of model ratio secondary metamorphosis, geometric variability, model sand selection, and wide-scale non-uniform sand simulation. Li et al. [51] and Zhang et al. [52] proposed the river comprehensive stability index as the river similarity criterion for the Yellow River and other models, and better reconstructed the evolution characteristics of the prototype. Dou et al. [53] proposed the minimum water depth scale criterion of the model to ensure that the model water flow is in the square zone of resistance.

The scale of the model test is also expanding, and large-scale models such as China Three Gorges Dam, the Yangtze River estuary renovation project, and Gezhouba dam have emerged. Therefore, the research on the scouring and siltation of important shoal sections and the research on remediation engineering measures must be applied to the river model test so far.

3.4 Mathematical model

The mathematical model of riverbed deformation evolution can be divided into one dimensional model, two-dimensional model and three-dimensional model according to the detailed degree of consideration of the problem [54]. The preliminary work on the numerical simulation study of sediment movement began in China in the 1960s. Xu and Zhu et al. [55] studied the deformation problem of one-dimensional suspended sand riverbed in the equal-width river channel, and adopted the concept of balanced sediment transport, and obtained the basic equations of riverbed deformation under balanced sediment transport conditions and solved the riverbed deformation equations by the characteristic line method. Dou et al. [56] first analyzed the riverbed deformation problem of alluvial rivers and estuaries with the concept of unbalanced sediment transport. Han et al. [57] established an unbalanced sediment transport model for one-dimensional non-uniform suspended sediment based on the statistical theory of sediment movement. The model has a wide application range and is verified by the measured data of several river sections. The SUSBED-2 model developed by Yang et al. [58] is a nested non-uniform sand model for one-dimensional constant equilibrium and unbalanced sediment transport. It can be used to calculate water and sediment changes and riverbed deformation in reservoirs and rivers. The basic equations used in the one-dimensional sediment mathematical model are the water flow equation, the water flow continuous equation, the sediment continuous equation and the riverbed deformation equation [59]. As early as the 1990s, two-dimensional and three-dimensional mathematical models of sediment were successively proposed due to the many insurmountable shortcomings of the one-dimensional model, in which the planar two-dimensional sediment mathematical model was used to solve the sediment movement and riverbed deformation on the plane, which has been rapidly developed. The two-dimensional sediment mathematical model of Zhou et al. [60] and Dou et al. [61] has been successful in practical engineering applications.

In general, domestic scholars have studied the one-dimensional sediment mathematical model in the evolution of riverbed and applied it more widely. The research on two-dimensional and three-dimensional sediment mathematical models started late, but the development is faster and there are also many models [45].

4. Calculation method for river channel erosion and deposition

The calculation of river channel discharge is an important aspect of sediment research and an important part of riverbed evolution. A large number of mathematical models, solid models and prototype water and sediment control results are very important. A very important evaluation criterion is the accuracy of the calculation of the amount of erosion and deposition. The speed of scouring and silting directly reflects the speed of riverbed evolution. The distribution of scouring and silting is directly related to the shape of the river channel. Therefore, the riverbed scouring and silting rate can also be used as a representative parameter to study the evolution law of riverbed. The calculation method of scouring and silting amount and the multi-time scale characteristics of scouring and silting velocity are of great significance for studying the evolution law of riverbed.

There are three main methods for calculation of riverbed erosion and siltation: sectional topography [62-63], sediment transport balance method [64] and digital elevation model method [65]. The sediment balance method is simple, but the calculation error is large, which can be used to estimate the erosion and deposition characteristics of the river section. The section topographic method has a large amount of calculation and a small calculation error. In the past studies, there were comparisons between the advantages and disadvantages of the section topographic method and the sediment transport balance method. Li et al. [66] pointed out that the calculation of the water level has a great influence on the results of the section topography. If the same water level is considered, the results of the above two calculation methods are consistent. Duan et al. [67] explored different calculation methods (section topography, grid topography and sediment transport balance method) for alluvial rivers from the aspects of calculation principle, influencing factors and error analysis, and combined

with the above three calculation methods in the downstream of the Three Gorges Reservoir dam, systematically studied its accuracy and influencing factors. The section topographical method is more focused on calculating the scouring and silting of the river channel under a certain water level (especially the level of the flat beach). It is difficult to calculate the scouring and silting of the river channel land. The sediment transport balance method is limited by the fact that the inlet and outlet of the study section must have sediment measurement data. Otherwise, the method is difficult to apply. In addition, the cross-sectional topography and sediment transport method are difficult to describe the internal spatial characteristics of river channel erosion and deposition distribution.

5. Conclusion

The study of riverbed evolution has made significant contributions to river flood control safety and regional social and economic development. At present, with the rapid development of science and technology, sediment research is inclusive and interspersed with hydrology, ecology, geography, informatics and other disciplines, showing mutual vitality. This paper introduces the basic theory of riverbed evolution, and selects the measured data analysis method, GIS technology and DEM model method, river model experiment method and mathematical model method in the riverbed evolution research method as the typical research method. The basic concepts of these research methods, the practical application and the inadequacies were introduced. Based on these riverbed evolution research methods, the mechanism of river evolution was discussed and the research status of river evolution was analyzed. At the same time, some methods for calculation of river channel erosion and siltation are introduced, which will help to analyze the evolution mechanism of river channels, predict the evolution trend of rivers, and provide scientific reference for future engineering design, shipping safety and flood control planning. In the future, with the joint promotion of national needs and disciplines, research on riverbed evolution will be further deepened, making greater contributions to building a harmonious society and promoting the sustainable development of the regional economy.

Acknowledgements

The authors express their appreciation to the College of Hydraulic & Environmental Engineering (Science and Technology Project of Undergraduate Students), China Three Gorges University for financial support of this work.

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