Review on Riverbank Soil Collapse

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Abstract: Bank slope collapse is a kind of natural phenomenon which commonly existed on both sides of alluvial plain rivers. The mechanism of bank collapse is complex, and it is an interdisciplinary frontier research subject. The collapse of the bank slope will lead to the instability of river regime and frequent changes of erosion and siltation, which will cause great harm to river regulation and people’s livelihood. Through review of river bank soil collapse at home and abroad, it is concluded that the main influencing factors of river bank soil collapse are the action of water flow and the soil structure of river bank. In addition, the stability of river bank and the numerical simulation of river bank collapse are also studied by scholars. In view of the above research results, the deficiencies of the current research are pointed out and the research directions that should be followed in the future are put forward.

1 Research background

Alluvial rivers are always in the process of continuous change and development under natural conditions, including the change of vertical erosion and deposition along river bed and river channel transverse deformation (Xie Jianheng, 1989; Jia Dongdong, 2011). Bank collapse is an important manifestation of river channel transverse deformation. It usually occurs in the area directly scoured by water flow, it is an sudden event in the course of river bed evolution that water flow scours, erodes and develops and accumulates on embankments. It belongs to the coupling effect of water and soil boundary (Duan Jinx, 2004; Yu Minghui, 2010; Zhang Xingnong, 2009). Bank collapse is a kind of natural phenomenon on both sides of alluvial plain rivers. The mechanism of bank collapse is complicated, and it is an interdisciplinary frontier research subject. It belongs to the lateral evolution of riverbank in river bed evolution and the stability of bank slope in soil mechanics (Davis, 2012). From the form of river bed evolution, bank collapse phenomenon not only runs through the whole river bed-building process, but also develops continuously according to the inherent law of different river types when the river forms a certain shape. Bank collapse is formed by the interaction between river flow and bank soil. On the one hand, the bank slope becomes steeper and unstable because of the action of water flow on the bank. On the other hand, the soil structure and the physical characteristics of soil composition of the river bank determine the anti-scouring of the river bank to maintain the stability of the bank and resist the formation of bank collapse (Yu Minghui, 2008). There are two kinds of internal and external causes (Wang Yangui, 2013). The boundary conditions of bank slope are internal causes, including river bending rate, soil properties and composition, bank slope height and slope (Yu Wenchou, 2008). The river flow dynamics are external causes, mainly including the change of water level in the river channel (Xia Junqiang, 2014; Deng Shanshan, 2015), the seepage effect within the bank slope (Zhang Xingnong, 2015), the scouring effect of longitudinal flow, the circulation and recirculation of bends. After bank collapse, the sloping soil in the river becomes one of the sources of sediment, which makes the sediment inflow and sediment concentration increase rapidly in a short period of time, changes the conditions of sediment inflow in the original channel, and then causes the evolution and development of the downstream channel (Tang Jinwu, 2012).

Hydrodynamic conditions, especially the scouring effect of longitudinal water flow, which are the most important factors affecting erosion, transport of sediments from the bottom and shore and changing their forms. Bank slope failure is a process of repeated circulation that river scouring bank and bank slope collapse. After the soil at the foot of the bank slope is washed away, the rest collapsed into the river, and water flow continues to destroy the temporary bank slope and makes it retreat (Shen Ting, 2005). Moreover, the soil on the bank slope falling into the river channel causes the riverbed scouring and silting deformation as a sudden sediment source (Nagata, 2000; Darby, 1995).

Material composition of riverbed and bank is complex, and they interact with water flow to form a complex system. Therefore, the form and intensity of bank collapse are different in different rivers or in different sections of the same river. Many rivers in our country often have bank collapse, due to the lack of complete and thorough control, resulting in many unstable river regime, frequent changes
in erosion and siltation, bank erosion and collapse phenomenon is very common and serious in rivers.

Fig.1 River bank collapse

2 Research progress of river bank collapse

Before the mid 1970s, the research on bank collapse is relatively less. Although some progress has been made in explaining the mechanism of bank collapse in recent years, there are still many problems to be further studied (Yu Minghui, 2014; Simon, 2000; Xia Junqiang, 2008). The mechanism and influencing factors of bank collapse are different for riverbanks with different soil properties. The existing research on the mechanism of bank collapse with dual structure are mostly qualitative analysis, the quantitative research is less (Wang Yangui, 2007). From the research results of domestic and foreign scholars on the mechanism of bank collapse, there are many ways and methods adopted by domestic research. Some starting from the analysis of bank stability, establishing mathematical model of bank; some starting from the physical and mechanical properties of river bank soil and the hydrodynamic conditions to study. Foreign scholars do not have many achievements in studying bank collapse directly. They mainly study the stability of riverbanks and the erosion of riverbanks (Yue Hongyan, 2002).

2.1 River bank stability

Many scholars have studied the slope instability characteristics or collapse modes. Darby and Thorne (1995) based on Osman's stretching model, considering the effects of pore water pressure and hydrostatic pressure on bank slope stability, and relaxing the restriction that sliding surface must pass through the foot of slope, the simulation results are close to reality and extended to the stretching model of straight reach. Fukoka (1996) carried out the scouring test by digging method in a binary structure bank on a floodplain of Shinkawa River in Japan. The results show that clay collapse can delay further scouring of slope foot by water flow. Osman (1998) and Thorne (1998) based on the hydrodynamic-soil mechanics method of homogeneous bank slope, proposed a channel broadening model. The model calculates the lateral scour distance of bank slope, and then analyzed whether the bank slope was unstable and collapsed. Huang Bensheng (2002) et al put forward the theoretical model of clayey river bank collapse from the perspective of bank slope stability. Wang Yangui (2003) obtained the similar qualitative knowledge by carrying out the generalized model test; the author (2007) also derived the critical height formula for the first and second collapses of broken-line riverbanks on the basis of the stability analysis of riverbanks. Yu Minghui (2008) et al on the basis of summing up the previous research results on bank collapse in the Yangtze River, analyzed emphatically the characteristics and mechanism of bank collapse in different river types, and put forward the calculation model of bank slide, the slope gradient of stable bank slope, and the prediction method of bank collapse. Zhang Xingnong (2009) et al established a generalized slope model based on the original sediment of typical bank collapse sections in the middle and lower reaches of the Yangtze River, and simulated the erosion mechanism and ultimate stability gradient of slope collapse. Sun Jichao (2010) et al studied the stability of bank under scouring action by means of influence deviation and path damage theory, pointed out the evolution and prediction method of bank stability. Zong Quanli (2013) et al established a bank stability calculation model to analyze bank collapse from the view of water flow erosion or bank slope stability, but did not combine the two methods; the author (2014) also proposed the bank collapse calculation of the binary structure of the upper Jingjiang River in different periods (dry period, high water period and recession period), and analyzed the stability of riverbank in different periods and calculated the stability of riverbank under different conditions.

2.2 Influence of riverbank soil structure on bank collapse

At present, most researches simply studied on the occurrence and development of bank collapse and the critical stability conditions for different riverbank soil compositions (Simon, 2009; Davis, 2012; Stefano, 2003;
2.3 Influence of hydraulic action on bank collapse

Hydraulic action is the main external cause of bank collapse. Osman (1998) analyzed riverbed depth and river bank scour respectively, and judged whether the bank collapsed or not by the safety factor. The results of study show that secondary flow will increase the average shear stress of water depth by more than two times (Papanicolaou, et al, 2007). The formation, development process and relevant mechanical mechanism of slope collapse were studied, the results of simulation show that the main effects of water flow on bank slope are erosion at the foot of slope, bank collapse and slope slowing down (Zhang Xingnong, 2009). Jia Dongdong (2011) established the lateral erosion model of flow-slip bank collapse, and verified it by flume test. Jamieson (2012) et al discussed the effects of turbulence and vortices on bank collapse, and found that vortices and scouring zones are coincide. Six groups of tests were carried out in curved flume, the effect of near-shore riverbed composition on viscous bank slope collapse under the same hydraulic action was studied (Yu Minghui, 2016).

The effect of water flow on bank collapse manifest in the following aspects, on the one hand, the change of bank slope gradient changes the stability of bank slope, and on the other hand, the change of flow structure itself after the deformation of river bed, which further accelerates the occurrence of bank slope collapse and the deposition and transportation of landslides. The positive relation between transverse velocity and river width and water depth is put forward, and it is pointed out that the more concentrated the nearshore velocity, the greater the lateral gradient of the nearshore velocity to the bank, and the steeper the nearshore slope, the more likely the bank slope will lose its stability, and the more likely the bank will collapse (Yu Wenchou, 2008).

The researchers also analyzed the interaction between riparian collapse and riverbed. A series of tests were carried out in curved flume, the interaction process between non-cohesive bank slope erosion and riverbed erosion and deposition and its influencing factors during hydraulic scouring were studied, and the sediment contribution rate of bank collapse and silt bed were further analyzed (Yu Minghui, et al, 2013). Based on the model of bank collapse with binary structure, a series of tests were carried out in curved channel flume, the transport process of shaped collapse at the foot of concave bank slope and its interaction with the stability of non-cohesive bank slope and the erosion and deposition of river bed were studied (Yu Minghui, et al, 2014). Feng Yu (2013) et al also carried out a series of tests in curved flume to study the slope collapse pattern composed of non-cohesive sediment particles and its interaction with river bed erosion and deposition. Wu Songbai (2014) et al studied the difference of erosion and collapse of bank slopes composed of clay and non-clay soils and their deposition on riverbed, and analyzed the accumulative deposition rate of total erosion and collapse on riverbed.

However, bank slope conditions (i.e. bank slope gradient and soil composition) will affect the stability of bank slope and the collapse of bank slope in natural conditions. Aiming at the bank slope and riverbed composition of homogeneous soil, the process of bank slope collapse, collapse body split, fragmentation and transport under the action of hydraulic erosion in curved channel flume was studied, and the interaction law between bank soil transport and riverbed erosion and deposition was further studied (Li Guomin, et al, 2015). Hu Chengwei (2017) et al carried out a series of experiments in curved channel flume to study and analyze the effects of different bank slope gradient and soil composition on nearshore flow structure, bank slope instability and collapse mode, collapse body transport and its interaction with river bed. The test results show that the decomposition and transport of bank slope collapse and collapse body are closely related to the turbulent kinetic energy of nearshore flow.

2.4 Mathematical and analog simulation

From the view of riverbed evolution, bank collapse belongs to the plane deformation of river channel. The phenomenon of bank collapse not only runs through the whole river bed-building process, but also develops continuously according to the inherent law of different river types when the river forms a certain shape. The interaction between beach collapse and riverbed erosion and deposition is complicated and there are many influencing factors. Current research results are relatively simple, or studying riverbank collapse mechanism, or studying riverbed evolution law. In addition, some scholars mostly used mathematical model method to study. Simon (2009) et al simulated and studied the hydraulic process (erosion slope toe) and geological process (gravity collapse) of bank slope erosion with BSTEM model. Sahoo (2011) et al took Jordan Creek River as the research background, attempted to simulate the contribution of riverbank erosion to alluvial channel erosion and
deposition in the lower reaches by combining dynamic basin simulation model and bank erosion model. Xiao Yi (2012) et al established a mathematical model considering the effects of riparian vegetation and deformation to simulate the change of river morphology and the transformation of river pattern.

3 Future concerns

Previous studies have mainly focused on the effects of water flow on sediment transport, and most of them are only from the perspective of soil mechanics; it cannot simulate the impact of water flow on river regime. There is no systematic study on the impact impedance effect of river bank soil on water flow under the different soil, the different soil structure, the different hydrodynamic conditions.

Based on the above research, the author thinks that more attention should be paid to the following aspects in the future. Starting from the different soil structures along the river bank, considering the anti-scour ability of different soil structures to the flow and the influence of different hydrodynamic factors on the bank collapse, the shielding effect of the bank collapse on the toe of slope and the adjustment of the river regime and the influence of the collapsed soil on the downstream river bed morphology evolution should be studied.

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