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Risk analysis of slope instability of levees under river sand mining conditions

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Abstract: Levees are affected by over-exploitation of river sand and river adjustments after the formation of sand pits. The slope stability is seriously threatened, drawing wide concern among experts and scholars in the area of water conservancy. This study analyzed the uncertainties of slope stability of levees under river sand mining conditions, including uncertainty caused by interest-driven over-exploitation by sand mining contractors, and uncertainty of the distance from the slope or sand pit to the bottom of the levee under the action of cross-flow force after the sand pit forms. Based on the results of uncertainty analysis, the distribution and related parameters of these uncertainties were estimated according to the Yangtze River sand mining practice. A risk model of the slope instability of a levee under river sand mining conditions was built, and the possibility of slope instability under different slope gradients in a certain reach of the Yangtze River was calculated with the Monte Carlo method and probability combination method. The results indicated that the probability of instability risk rose from 2.38% to 4.74% as the pits came into being.

Key words: *sand mining; levee; risk analysis; slope instability; Monte Carlo method; probability combination method*

1 Introduction

Sand resources are abundant in some rivers, such as the Yangtze River and Pearl River in China. Sand is one of the components of the riverbed and also a construction material with high economic value. Since the beginning of the last century, illegal sand mining activities have been rampant in many rivers in China, which have caused a serious threat to the safety of levees. Take the Chiding reach of the Xijiang River in Guangdong Province of China as an example: its levee is an earth embankment with a total width of 6 m and a 5-m-wide concrete pavement. Illegal sand mining activities taking place before 2000 seriously corroded the lower part of this levee, and its bottom was heavily incised, which threatened the safety of the levee. Under these circumstances, a landslide finally took place in February of 2001, causing a 100-m-long levee to slip into the river (Wang et al. 2004). The largest river in South India, the Pamba River, also encountered similar incidents (Padmalal et al. 2008). In recent years, local

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governments in different places, on the one hand, have attacked the illegal activities of sand mining, and, on the other hand, have utilized river sand resources scientifically and rationally with sand exploitation planning as guidance. But there still exist two problems: first, sand mining contractors always try their best to over-exploit beyond the scope or depth, driven by their interests, and even under strict supervision; and second, the state of river flow changes after sand mining pits come into being, corroding the river bank or the slope of the levee. Experts and scholars are paying close attention to the heavy risk of slope instability caused by these two factors.

River sand mining affects not only the levee of the reach containing the pit, but also the upper reaches of the pit in both vertical and horizontal directions, which causes incision deformation of riverbed. In the Chiding reach of the Xijiang River levee in Guangdong Province, after sand mining caused a sand pit in 1998, the riverbed was cut down by almost 2 m (Wang et al. 2004). Macdonald (1988) conducted systematic analyses of riverbed recovery in the sand mining reach of the American Naugatuck River and the floodplain near it. He predicted that channel recovery to pre-mining morphology was expected to require up to several hundred years for instream sites and longer for riparian pits. Mao (2003) simulated and studied the secondary flow problem of sand mining pits in natural rivers with the anisotropic three-dimensional algebraic stress turbulent model. The result demonstrated that sand mining changed the original steady state of the river, caused a vertical vortex along the mainstream direction, and scoured the upper edge of the sand pit, while the transverse secondary flow in the sand pit caused transversal erosion. Research on turbulent characteristics has indicated that sand mining have some negative influences on riverbed stability. Li (2008) indicated that sand mining lowered the upstream water level, and the height of the pit played a decisive role. Transverse circulation took place in some parts of the pits and scoured the lateral riverbed. The deeper the pit was and the larger the area was, the stronger the circulation flow would be. The speed of backward erosion was very fast, but the influencing distance was limited, and the stream-wise erosion downstream did not scour deeply, but the influencing distance was relatively large and deposition phenomena occurred after scouring. Consequently, in this study on the instability risk of levees under river sand mining conditions, we mostly focus on levees in reaches containing pits and in reaches upstream of the pits, as well as the instability risk caused by the uncertainty of slopes or levees.

To study the instability risk of levee and dam projects, Wang et al. (1998) calculated the risk taking into account the physical and mechanical indices of the soil body under uncertain flood-preventing water levels, and calculated probability using the Monte Carlo (MC) method. By combining the reality of safe operation and management of the levee, Wu and Zhao (2003) proposed a risk estimation model and solution method based on the reliability theory with consideration of slope stability and seepage stability. The model was applied to the risk estimation system of parts of the Yangtze River levee. Cao (2006) and Srivastava and