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To cite this article: Jun Wang *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **472** 012090

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Mechanical Properties of Riverbank Soil in the Jingjiang Reach and the Characteristics of Flow in Pocket Collapse Area

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Abstract. Based on analyzing the field data and the experimental results, Mechanical properties of riverbank soil in the Jingjiang Reach and the characteristics of flow in the region of pocket collapse are discussed. It is calculated that riverbank of the Jingjiang Reach is characterized by a typical composite structure, covering the low liquid limit cohesive upper layer and the sandy lower layer. The cohesion of the cohesive soil increases first and then decreases with the increase of water content. The internal friction angle generally decreases with the increase of water content. The flow structure in pocket collapse area shows the intensive three-dimensional characteristics. The surface and vertical average velocity, the range and strength of the reflux increase with the increase of upstream flow discharge. Under different conditions of flow discharge, the vertical average velocity in pocket collapse area has a distributed feature of nearly linear or tiny oscillation along the relative direction of water depth. The research can provide the technical support for prevention measures of bank collapse.

1. Introduction

Bank failure is a main disaster in the Yangtze River. In 1998, more than 330 cases of large-scale collapse occurred in the middle and lower reaches of the Yangtze River, of which 17 occurred in the middle reach of the Yangtze River and 39 occurred in the lower reach [1]. And about 655 dangerous cases of bank failure occurred in the main stream of middle and lower reaches of Yangtze River during 2003 to 2010. In both 2002 and 2005, bank retreat occurred in Wencunjia reach more than 300m width. A continuous bank failure occurred at the right bank of the Jing98 section, which is located downstream of the apex of the Beimenkou bend, with the cumulative retreat width reaching 332m during the period from 2002 to 2010. In Oct.2012, a case of large-scale collapse, which was about 400m wide and 500m deep, occurred in the Zhenyang Reach. The damage caused by bank collapse is serious, especially pocket bank collapse has the characteristics of large scale, rapid development and great harm, which may decrease the stability of riverbank, the safety of embankments, the development and utilization of coastal line along the river and the safety of people's lives and property.

The Jingjiang Reach is located between Zhicheng and Chenglingji in the Middle Yangtze River, with a length of 347.2km. Bank failure often occurs in the Jingjiang Reach during the flood season and the dry season [2]. The types of bank failure can mainly be divided into the nest collapse (including general nest collapse, pocket bank collapse and isolated collapsing), strip collapsing and washed



collapsing in the Yangtze River[1]. The three phases of fluvial process of the pocket collapse, including the riverbed change near shore, sharp scour and relative equilibrium. And the special factor of the forming the pocket bank failure is preliminarily studied in the flow and boundary condition [3].

In view of the previous researches, this paper studied mechanical properties of riverbank soil in the Jingjiang Reach by soil test and the flow structure of pocket collapse by the experiment of the flume model.

2. Soil Composition And Mechanical Properties of the Jingjiang Reach

Based on the investigation and sampling of the bank soil in the typical collapse area of the Jingjiang Reach, laboratory soil tests, including the soil composition, physical and mechanical properties of the cohesive soil, were determined by the Geotechnical Test Method (GB/T 50123-1999).

2.1. Soil Composition of the Bank

Field exploration indicates that the riverbanks of the Jingjiang Reach are characterized by a typical composite structure, covering the cohesive upper layer and the non-cohesive lower layer, a thin sandy layer can be found between two cohesive layers at some sections. Figure 1 shows the vertical stratification structures of typical riverbank soils at Guan39 section and the failed bank profile at Jing178 section. The laboratory tests indicate that the cohesive upper soil layer of bank is mainly composed of clay and silt-clay, and the non-cohesive lower soil layer is mainly composed of fine sand and silt. The plasticity index I_p of the cohesive upper layer ranges from 9.0 to 23.8, and liquid limit ω_L and plastic limit ω_p are both lower than 50%, so it is regarded that the riverbank of the Jingjiang Reach is a composite structure, covering the low liquid limit cohesive upper layer and the sandy lower layer, and the soil composition along the river bank is almost the same.

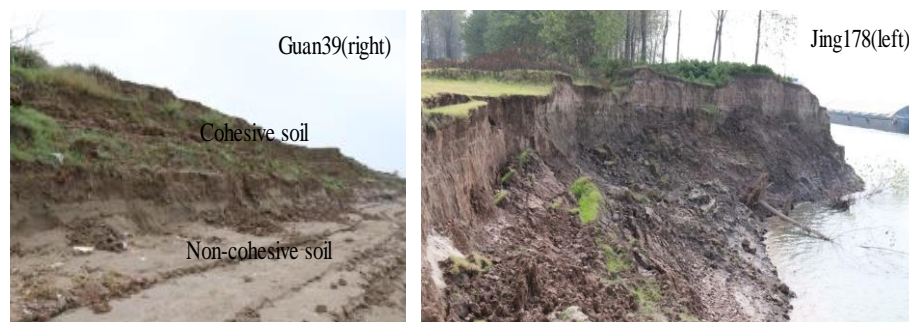


Figure 1. Failed bank profiles at typical sections (2018.10)

2.2. Mechanical Properties of the Bank Cohesive Soil

The mechanical properties of the cohesive soil can often be represent by its shear strength and tensile strength, For the cohesive riverbank of the Jingjiang Reach, its shear strength which includes the parameters of cohesion (c) and the angles of internal friction (ϕ) was studied. The results of laboratory soil tests indicate that water content ranges from 30% to 43%, cohesion ranges from 5kPa to 22.2kPa and the internal friction angle ranges from 6.8° to 16.8° in nature.

According to the results of direct shear test, the relationship between water content and shear strength of cohesive soil (remolded) are shown in Figure 2, it is obvious that the cohesion of the cohesive soil increases first and then decreases with the increase of water content, and there is a critical water content, which makes the cohesion reach the peak value. The internal friction angle generally decreases with the increase of water content [4].

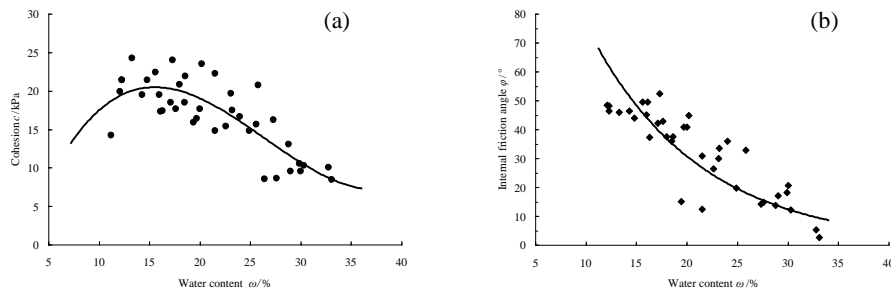


Figure 2. Relationships between shear strength parameters and water content: (a) cohesion and (b) internal friction angle.

3. Flume Model Test

3.1. Model Design

The total length of the experiment flume is 49m. In order to simulate the natural pocket collapse of composite structure, the collapse process of the natural and composite riverbank is simulated by the different particle size of the new type of compound plastic sand (adding adhesive of the appropriate proportion 1% to the upper layer) through the indoor generalized model tests. The median size of the lower layer made of compound plastic sand is 0.2mm. The median size of the upper layer is 0.058mm.

3.2. Test Content

The riverbank change and movement characteristics of flow and sediment in the made pocket collapse (thickness ratio of the upper layer to the lower layer is 2:1; the slope of the river bank is 1:1) are simulated under the different flow conditions (when the design water depth is 0.4m, the design discharge are $0.1\text{m}^3/\text{s}$ and $0.2\text{m}^3/\text{s}$). Horizontal width and vertical width ratio is 1:1, the entrance width is about 1m.

During the experiment, the incoming flow discharge is controlled by the electromagnetic flowmeter. The water level in the tail gate is controlled automatically by the WEL-II-type content gauge developed by the Wuhan University. The typical cross section topography is measured by the CY-I-type silting meter. The velocity is measured mainly by the 3D acoustic Doppler velocimeter (ADV), while the surface velocity is measured by the Rotary pulp type current meter.

4. Flow Characteristics in Pocket Collapse Area

4.1. Reflow Characteristics

By the role of the reflux, the flow structure in the pocket collapse shows the intensive three-dimensional characteristics. Reflux in different strengths generate in the interior of the pocket collapse by the function of turbulent shear stress and gravity around the separation and interface of the water. Separation of flow and collapse zone boundaries is the immediate cause for the flow subregion of the primary and secondary streams, and turbulent shear stress which caused by lateral mixing of large-scale and small-scale vortex body in the interface of mainstream and reflux is the power source of the form of the reflux in the region of the pocket collapse. The water near the entrance in the region of the pocket collapse moves forward by the role the turbulent shear stress, following the mainstream. Then the water moves to the reflux area along the entrance downstream sidewall. The water level in the inside of the reflux area rises, resulting in the surface transverse slope. Water and sediment in the reflux area of the pocket collapse and that in mainstream area are going a mass, momentum and energy exchange through the entrance interface. Flow momentum exchange in both sides of mainstream and reflux cross interface not only include mixing of particles and eddy transferring, but also direct convective transfer of large-scale vortices. So it intensifies turbulent mixing of the water, which makes the flow more unstable in the region of the pocket collapse, and aggravates the exchange of material on both sides of the interface simultaneously.

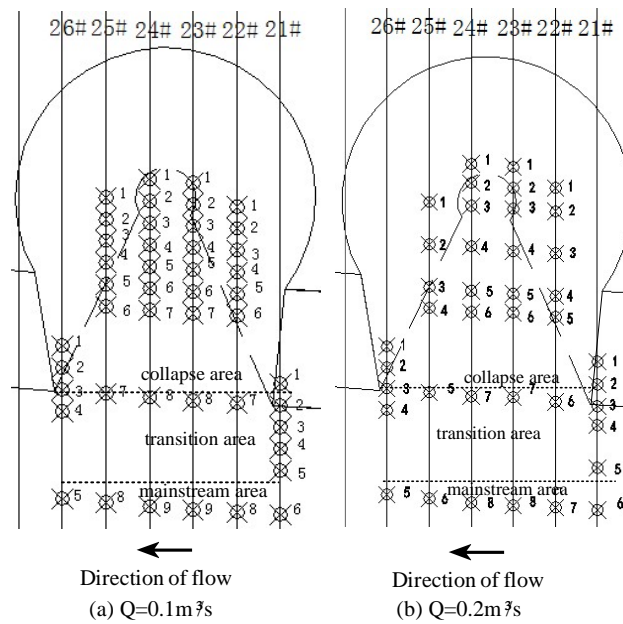
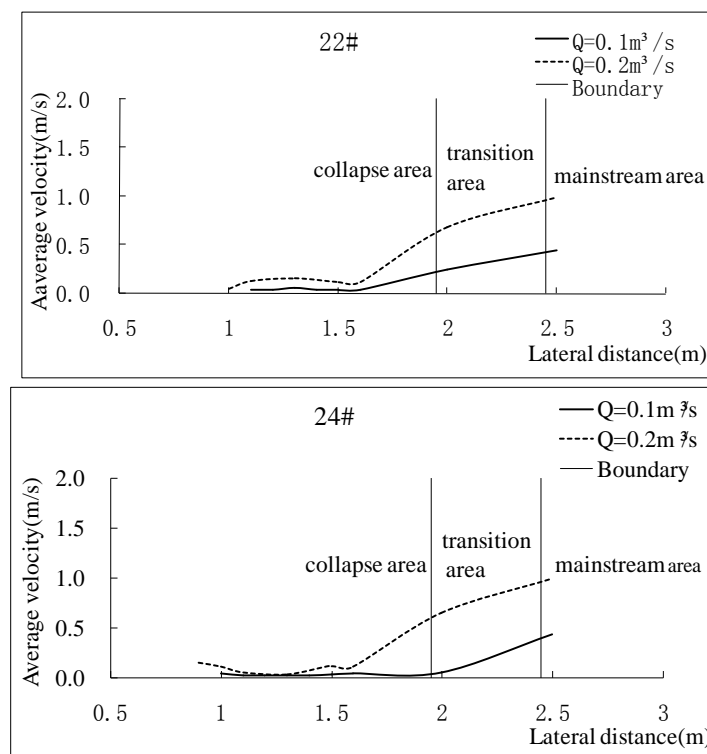


Figure 3. Layout of measurement of flow points of pocket bank collapse.

The reflux flow lines in the pocket collapse appear as multiple concentric circles of varying sizes when flow lines in general nest collapse are multiple irregular ovals and there are many independent of scale size varying vortex. Moreover, the water surface arise irregular distortions. Surface velocity and the range and intensity of the reflux increase with the increase of upstream discharge.

4.2. Velocity Distribution Characteristics

As showed in Figure 4 and Table 1, survey area can be divided into collapse area, transition area and mainstream area according to different measuring point location in the pocket collapse.



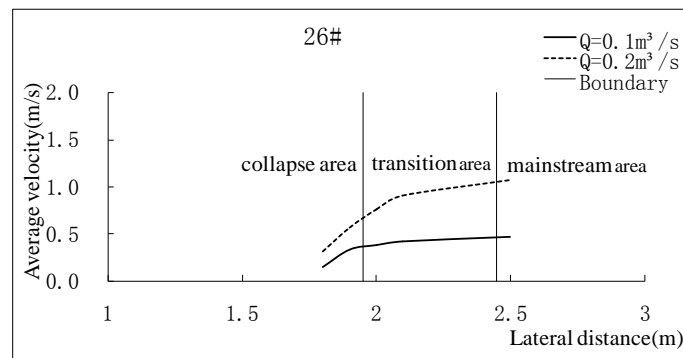
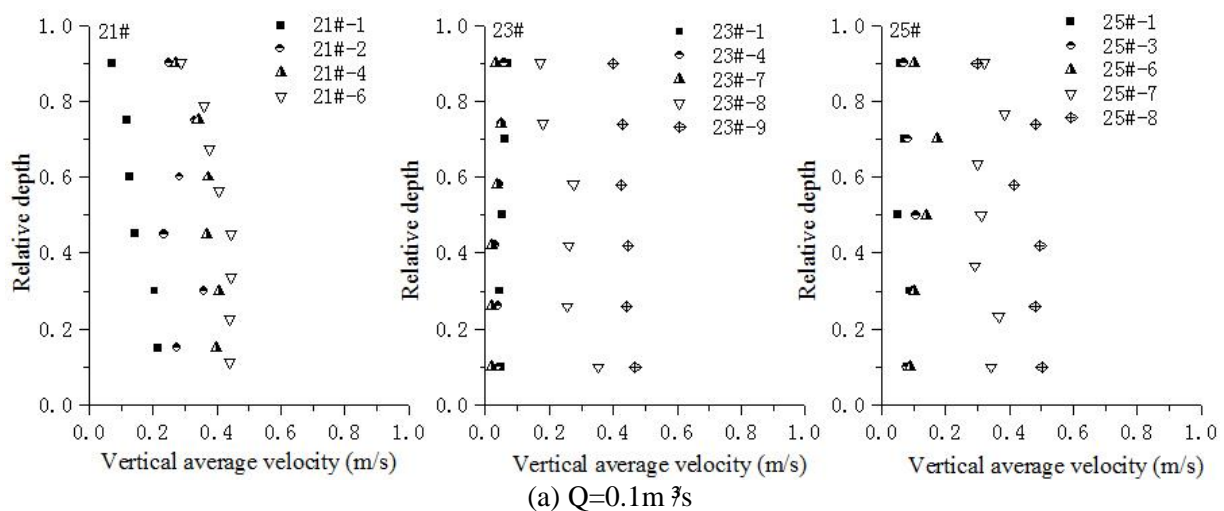


Figure 4. Distribution of average velocity of typical cross-sections of pocket bank collapse.

Table 1. Classification and arrangement of measuring points in pocket collapse area.

Discharge(m^3/s)	Collapse area	Transition area	Mainstream area
0.1	Measuring points except transition and mainstream area	22#-7, 23#-8, 24#-8, 25#-7, 26#-4	22#-8, 23#-9, 24#-9, 25#-8, 26#-5
0.2	Measuring points except transition and mainstream area	22#-6, 23#-7, 24#-7, 25#-5, 26#-4	22#-7, 23#-8, 24#-8, 25#-6, 26#-5

As showed in Figure 4, affected by flow instability in side wall of collapse area, separation zone of mainstream and reflux interface and recirculation zone, the regularity of lateral distribution form of offshore vertical average velocity of typical cross sections in the pocket collapse is not strong, and velocity distribution in the transverse direction is different. Flow velocity is in the range of 0.29m/s to 0.42m/s, and 0.76m/s to 1.00m/s, when discharge are 0.1 m^3/s and 0.2 m^3/s , respectively. Consequently, the larger is the upstream flow, the greater is the average velocity in the pocket collapse. The average velocities of typical cross sections of the pocket collapse in collapse area are minimal, and the largest in mainstream area, while transition area is between the two.



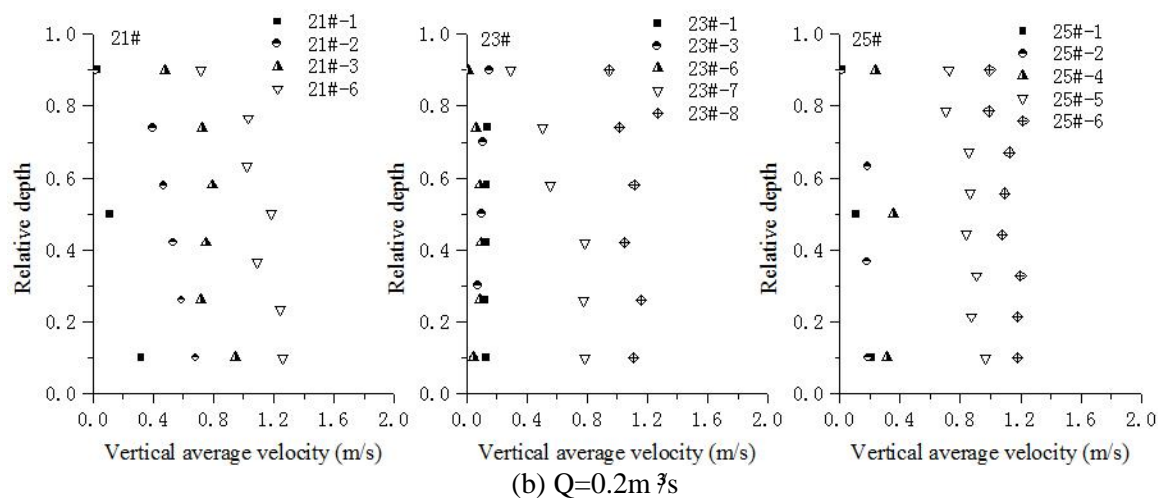


Figure 5. Distribution of vertical average velocity on typical cross-sections.

As seen in Figure 5, the vertical average velocity of various sections of the pocket collapse in collapse area are minimal, and the largest in mainstream area, while transition area is between the two. Under various discharge, mean velocity on a vertical of each measuring point is close to each other near the central area of collapse area, such as sections of 3#-1, 23#-4, 23#-7. And the velocities are significantly less than these in the transition region (23#-8) and in the mainstream area (23#-9). The average vertical velocity distribution characteristics are that the variation of vertical average velocity is small along the direction of the relative depth and the distribution is the approximate linear or small shocks. When flow increases to $0.2\text{m}^3/\text{s}$ from $0.1\text{m}^3/\text{s}$, the law of vertical velocity distribution is similar but different in size, and the vertical average velocity distribution of various sections along the direction of the relative depth are more distributed.

5. Conclusions

(1) Riverbanks of the Jingjiang Reach are characterized by a typical composite structure, covering the low liquid limit cohesive upper layer and the sandy lower layer. The cohesion of the cohesive soil increases first and then decreases with the increase of water content. The internal friction angle generally decreases with the increase of water content.

(2) During the development of the pocket collapse, suffered by the reflux, the upstream and downstream of the entry both are scoured and collapsed seriously. The flow structure in the pocket collapse occur strong three-dimensional characteristic.

(3) With the increase of the upstream flow discharge, the surface and vertical average velocity both increase. The range and strength of the reflux are both bigger. Under the different flow discharge, the vertical average velocity distribution in the region of the pocket collapse has a distributed feature of nearly linear or tiny congestion along the relative direction of water depth. After the flow discharge increasing, it makes the vertical average velocity distribution in every measurement point more dispersed along the relative direction of water depth.

Acknowledgements

Project supported by the National Natural Science Foundation of China (51479008) and basic scientific research fee of commonweal scientific research institutes at central government level (CKSF2016018/HL).

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