



Experimental Study on Mechanical Properties of Dike Fill and Settlement and Deformation of Jingjiang Yangtze River Embankment

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Abstract. Implementing and promoting the governance and protection of the Yangtze River has been a major task for the Yangtze River water conservancy efforts. As an important barrier safeguarding the economic belt along the river, monitoring the mechanical properties and deformation of the embankment project is a key aspect of the operation and management of the Yangtze River. This paper presents a consolidation and drainage shear test on the fill of Jingjiang Yangtze River embankment, along with an analysis of settlement and deformation using data from six measurement points at the top of the embankment. The results indicate that the bias stress and volume deformation of embankment fill increase with axial strain, and the peak stress and volume deformation increase with perimeter pressure. And there are significant spatial differences in the settlement of the river embankment, and the settlement at CJ1 and CJ6 measurement points is minimal, within 3 mm, whereas the settlement at CJ4 and CJ5 measurement points reaches 27.28 mm and 13.64 mm, respectively, suggesting a need for enhanced continuous observation.

Keywords: embankment; consolidation and drainage shear test; settlement and deformation monitoring

1 Introduction

Embankments are water-retaining structures built along the edges of rivers, canals, lakes, coasts, or floodplains, playing an irreplaceable role in maintaining water safety and ecological security. Due to the long history of embankment engineering, some embankments suffer from varying degrees of aging and biological damage, making them prone to seepage, leakage, loose dip, tube surge and other hazards during flooding periods. As the foundation of Yangtze River flood control, the stability of the embankment projects directly affects the safety of people's lives and properties as well as the economic development along the river. Therefore, it is necessary to effectively monitor the safety and stability of the Yangtze River embankments and promptly investigate potential hazards^[1].

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Numerous scholars have conducted extensive research on the stability of river embankments, yielding significant results^[2-8]. For instance, Zhu Qingchuan et al. (2010) analyzed long-term ground settlement data of the embankment of Haihe River main stream and the embankment of lower reaches of Ji Canal, proposing management measures to address embankment damage caused by ground settlement^[9]. Jiang et al. (2024) studied the spatial and temporal evolution of the settlement of the Yangtze River embankment, discovering that the vertical deformation of the entire embankment follows a pattern where the front and end sections of the left line bulge, while the middle section of the left line settles, and the entire right line settles, with the magnitude decreasing from the front to the end of the embankment^[10]. To ensure the safety of the Yangtze River embankments, this study focuses on the Jingjiang Yangtze River embankment (Jiehe section to Lianxing Port section), conducting indoor consolidation and drainage shear tests, and analyzing settlement and deformation. The goal is to provide a reference for the safety monitoring of the Yangtze River embankments.

2 Project Overview

The upper section of Jingjiang Yangtze River embankment is situated on the left bank of the Chengtong section of the Yangtze River in Jiangsu Province, extending 24.4 kilometers from Jiehekou to Paotaiwei featuring a single straight and slightly curved channel as shown in Figure 1. The Jiangyin Waterway is divided into two deep troughs in the south and north by a submerged continent. The northern trough is close to the left bank, and the poor soil structure of the riverbed boundary of the left bank exacerbates the impact, leading to long-term collapses of deep ponds along the Jingjiang embankment banks.

The study area covers the Jingjiang Yangtze River embankment (Jiehe section to Lianxinggang section), with a total length of about 3km, as depicted in Figure 2. Longitudinal cracks have appeared in several places on the pavement at the top of the dike, with height differences on both sides of some cracks and displacements at the construction joints of the local wave protection wall.

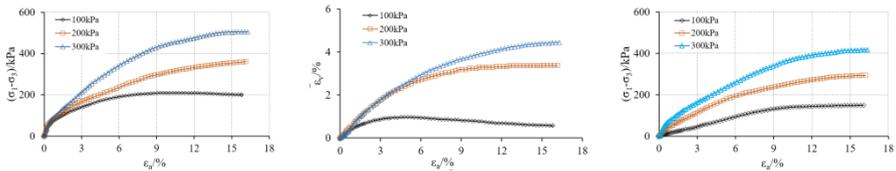
The project team carried out the first crack measurement from August 22, 2023, and measurements were taken every 2 weeks, and a total of 6 crack width measurements have been completed so far. The results show that there are 18 groups of 40 groups of cracks in the concrete surface layer of the embankment top with the change value of crack width more than 1mm, of which the maximum value is 4.64mm and the minimum value is 1.08mm; and the remaining 22 groups of cracks with the change value of crack width are less than 1mm, of which the maximum value of the crack change is 0.94mm and the minimum value of the crack change is 0.28mm. Crack measurements are shown in Figure 3.

Table 1. Triaxial test program for embankment fill soil.

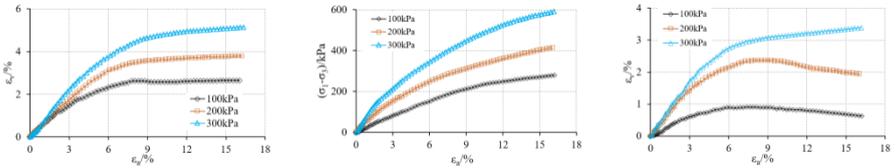
No.	Depth (m)	Dry density (g/cm ³)	Water content (%)	Perimeter pressure (kPa)
J1-1	1.1-1.4	1.44	29.0	
J4-5	7.9-8.9	1.27	40.2	100, 200, 300
J7-6	10.5-11.5	1.29	39.6	
J10-8	9.0-9.8	1.25	40.7	
J13-9	15.7-16.7	1.42	29.2	100, 200, 300, 400

The specimens were consolidated under different peripheral pressures before gradually applying bias stress, with a shear rate set at 0.008 mm/min. The test was conducted in accordance with the *Standard for geotechnical testing methods* (GB/T 50123-2019). For data analysis, the peak point on the stress-strain relationship curve was considered the failure point if a peak was present; otherwise, the point corresponding to a 15% strain was deemed the failure point.

3.3 Test results and analysis



(a) Stress-strain curve for specimen J4-5. (b) Volume change curve for specimen J4-5. (c) Stress-strain curve for specimen J7-6.



(d) Volume change curve for specimen J7-6. (e) Stress-strain curve for specimen J10-8. (f) Volume change curve for specimen J10-8.

Fig. 4. Triaxial Test Curves for Soil Specimens.

Three sets of triaxial test curves for specimens J4-5, J7-6, and J10-8 are presented in Figure 4. Taking specimen J4-5 as an example, Figure 4 (a) and Figure 4 (b) display the bias stress versus axial strain curves and volume deformation versus axial strain curves, respectively. As shown in Figure 4 (a), the stress-strain curve for the 100 kPa perimeter pressure condition exhibits strain hardening, with destructive stress increasing with axial strain and a peak destructive stress of 209 kPa. Under perimeter pressures of 200 kPa and 300 kPa, the maximum bias stresses are 354.0 kPa and 504.0 kPa, respectively, indicating a general trend of increasing bias stress with axial strain. Therefore, the overall bias stress increases with the axial strain. Figure 4 (b) illustrates that under a 100 kPa perimeter pressure, the specimen initially exhibits an increase followed

by a decrease in volumetric deformation during shear. With the increase of the perimeter pressure, the volumetric deformation of the soil specimen during shear increases with axial strain until failure, with volumetric deformations of 0.7%, 3.6%, and 4.5% at failure for the respective pressures.

The shear strength parameters of the specimens obtained from the indoor triaxial CD shear test are as follows: specimen J1-1 (from a depth of 1.1-1.4m) exhibited a cohesion of 5.8 kPa and an internal friction angle of 28.5°; specimen J4-5 (from a depth 7.9-8.9m) showed a cohesion of 19 kPa and an internal friction angle of 25.1°; specimen J7-6 (from a depth 10.5-11.5m) had a cohesion of 6kPa and an internal friction angle of 23.5°; specimen J10-8 (from a depth 9.0-9.8m) demonstrated a cohesion of 16.6kPa and an internal friction angle of 28.2°; and specimen J13-9 (from a depth 15.7-16.7m) exhibited a cohesion of 23.3kPa and an internal friction angle of 27.3°.

4 Analysis of settlement and deformation monitoring of the embankment

4.1 Measuring point arrangement and measurement

Six settlement measuring points (CJ1-CJ6) were established at the top of the embankment. The location of each measuring point is shown in Figure 2, with CJ2 located at the embankment shoulder on the backwater side, and the remaining points situated at the shoulder on the waterfront side.

4.2 Instrument Selection

This monitoring work adopted Japan-made Topcon DL-502 electronic digital level meter, which can quickly obtain stable and reliable observation value and guarantee observation accuracy, and complete all kinds of level measurement and calculation. The instrument is shown in Figure 5.



Fig. 5. Topcon DL-502 electronic digital level meter.

4.3 Measurement results and analysis

Following the determination of the observation section, settlement deformation at the points was measured biweekly from August to November, with the main results presented in Figure 6.

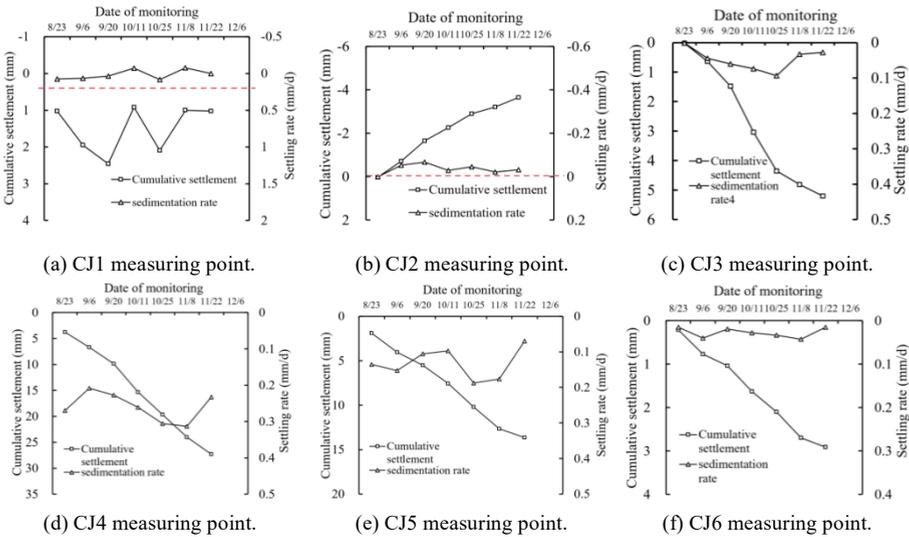


Fig. 6. On-site top-of-embankment settlement monitoring results.

As displayed in Figure 6, the settlements at measuring points CJ1 and CJ6 is minimal, with cumulative settlement within 3mm. Measuring point CJ2, located on the landward shoulder of the embankment, showed a sustained minor uplift, with the amount of uplift within 4mm. Measuring points CJ3, CJ4, and CJ5 demonstrated varying degrees of cumulative settlement, with maximum settlements of 5.20 mm, 27.28 mm and 13.64 mm respectively. Notably, CJ4 and CJ5 showed significant settlement (27.28 mm and 13.64 mm, respectively), warranting reinforced continuous observation in the future.

5 Conclusion

Triaxial CD shear test was conducted on the Jingjiang Yangtze River embankment fill utilizing a triaxial shear test instrument, to obtain the mechanical index of the fill. Settlement deformation was analyzed for the six measuring points on the top of the embankment. The main conclusions are as follows:

(1) The partial stress and volumetric deformation of the embankment fill increase with axial strain. With the rise in peripheral pressure, the shear dilation of the soil specimens gradually diminishes, and the volumetric deformation of soil body gradually increases with axial strain.

(2) Settlement of the embankment exhibits significant spatial variation. CJ1 and CJ6 showed minimal settlements, both within 3 mm; CJ2 displays minor uplift, within 4 mm; and greater settlements occurred at CJ3, CJ4, and CJ5, which are 5.20 mm, 27.28 mm, and 13.64 mm respectively.

(3) Measuring point CJ1 experienced repeated cycles of settlement and uplift, likely influenced by tidal water levels at the time of measurement. The minor uplift at measuring point CJ2 may be attributed to its location on the landward shoulder of the embankment. Greater cumulative settlements were observed at points CJ4 and CJ5, suggesting the need for continuous monitoring at these locations.

Acknowledgments

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