Centrifuge Modelling of Slope Instability Due to Leakage of Buried Pipes

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Abstract. Buried water mains, sewers and storm water pipes are critical infrastructures in the urban environment. In Hong Kong, a great number of pipes are buried in slopes, and catastrophic consequences due to landslides may happen upon pipe leakage. This study aims to investigate the infiltration process of leakage water with respect to the current Hong Kong mainlaying practice and explores its impacts on slope stability using geotechnical centrifuge modelling. Test results indicate that deep-seated slope failure, and surface erosion induced by concentrated flow of leaked water may occur when the pipes are subject to leakage.

Keywords: Buried pipe · Mainlaying · Slope stability · Leakage Erosion

1 Introduction

Buried water mains, sewers and storm water pipes are critical infrastructures in Hong Kong. During their service, pipes may become defective and water may leak from the pipes. The leaked water will infiltrate into the surrounding soils. Since the pipe pressure for fresh water mains can be up to 400–600 kPa, the hydraulic gradients in the soil can be very high and hence internal erosion of the soil surrounding the pipe can happen.

After the 1994 Kwun Lung Lau landslide (Hui et al., 2007), the Code of Practice on Monitoring and Maintenance of Water-carrying Services Affecting Slopes (ETWB 2006) was published in response to the recommendations made by Morgenstern (2000). Water Supplies Department (2012) and the new code of practice (ETWB 2006) stipulate on pre-operation tests, inspections, and maintenance. Although attempt has been made to inspect and detect potential problems, pipe bursting still occurred frequently.

Only a limited research (Zhang and Li 2007) has been performed to study the infiltration process around a leaking pipe, the effects of leakage from pressurized BWCS on slope stability, and designs against slope failures caused by leaking BWCS. Therefore, it is necessary to investigate the slope stability upon leakage, as well as the infiltration process.

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2 Centrifuge Model Testing

2.1 Centrifuge Model Package

Three centrifuge model packages were developed to investigate the effects of trench width, fracture type and fracture orientation of the pipe on slope stability and infiltration process upon leakage of the buried pipe. All centrifuge model packages were successfully tested on the HKUST 400 g-ton geotechnical centrifuge. Figure 1 depicts a typical centrifuge model package with required monitoring instruments.

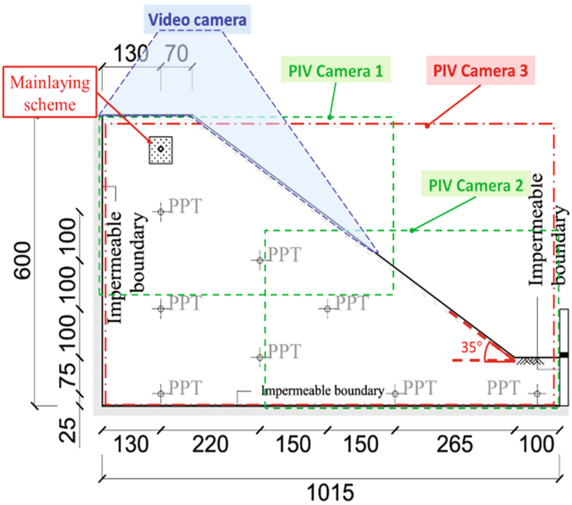

Fig. 1. Typical centrifuge model package with monitoring instruments. Dimensions in mm.

The dimension of the 1/30th-scale slope model was chosen to represent a 15 m high slope in prototype when it was tested at 30 g. The slope angle was 35°. Two trench widths, two types and two orientations of pipe fracture have been considered. The corresponding cover-to-main was 65 mm (1.95 m in prototype), which is measured from the ground surface to the crown of the buried pipe.

Completely decomposed granite (CDG) was adopted as the soil type in all centrifuge models. Particles larger than 2 mm were scalped to minimize the particle size effects. The soil was compacted to a relative compaction of 95% at a water content of 11.5% (dry density of 1757 kg/m^3) using the under-compaction method. Each layer of soil was 25 mm. The CDG soil around the pipe and up to 10 mm (300 mm in prototype) above its crown was compacted to 85% relative compaction (RC) (dry density of 1572 kg/m^3) in accordance with the Hong Kong Manual of Mainlaying Practice (WSD 2012). Beyond the 85% RC region, the CDG soil was compacted to 95% RC.

Figure 2 presents the details of the "mainlaying scheme" region for all model packages. Test 1 evaluated the effects of narrow trench with a slot-type fracture pointing upward; Test 2 considered a wide trench with a slot-type fracture pointing horizontally to the sloping surface; and Test 3 adopted a wide trench with a slot-type fracture pointing upward.

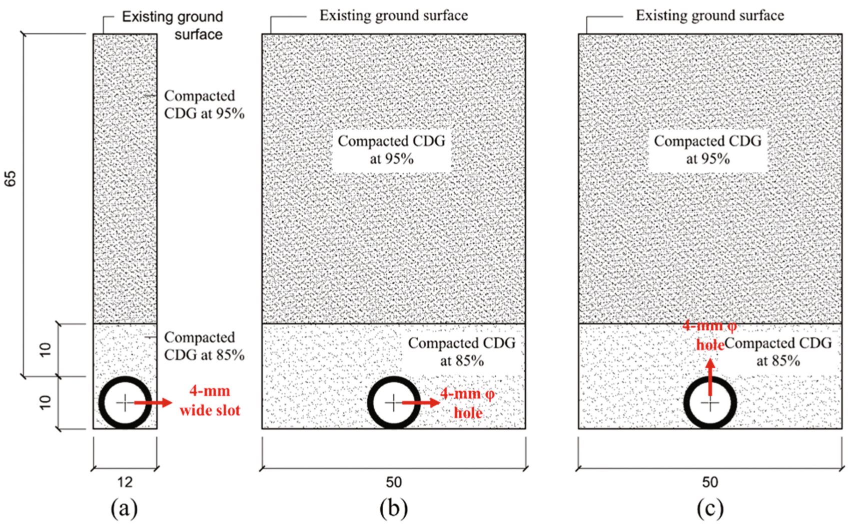

Fig. 2. Details of the “mainlaying scheme” regions for the model packages: (a) Test 1; (b) Test 2; (c) Test 3.

2.2 Test Procedures

In order to simulate leakage from a pressurized-buried water main, a water supply system is required. The water supply system utilizes generated hydrostatic pressure by controlling the water level difference. Water was continuously supplied to the water tank from outside the centrifuge. As a result, a relatively constant water pressure can be generated, and the pressurized water can be continuously supplied to the buried pipe to simulate the leakage process. The centrifuge tests were performed in five steps: swing up (rising g-level); generating sufficient pipe pressure; applying pipe pressure and simulating leakage; increasing pipe pressure; and swinging down the centrifuge and post-failure investigation.

3 Observations and Test Results

Leakage-induced surface erosion was observed in Tests 1 and 3, whereas deep-seated slope failure was observed in Test 2. In both Test 1 and 3, the fracture was oriented horizontally to the sloping surface. An erosion hole emerged at the ground surface and the leaking hole was exposed (Fig. 3(a)). After that, the majority of the leaked water was discharged through this erosion hole, gradually forming an erosion gully. At the end of the experiment, no significant signs of landslide and no deep-seated failure were observed. Nevertheless, in Test 2, the excavation trench was wider, and the fracture was oriented upward, and finally deep-seated failure occurred (Fig. 3(b)). Erosion holes were also observed during the test, but the surface discharge was not as much as that in Test 1 and 3. Most of the leaked water still infiltrated into the slope, causing water level rises. This was the main reason of the occurrence of deep-seated failure. Test 3 was conducted to differentiate the significance of trench width and fracture orientation effects. The only change was the fracture orientation, which was oriented horizontally to the sloping surface. No deep-seat failure was observed but leakage-induced surface erosion and concentrated surface flow.

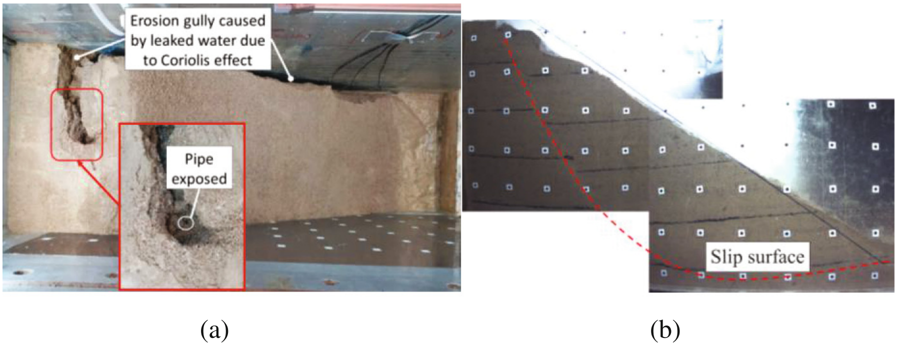

Fig. 3. Different modes of slope failure: (a) erosion failure; (b) deep-seated failure.

4 Conclusions

The current Hong Kong mainlaying practice with different trench widths, fracture types and fracture orientations were successfully studied through centrifuge modelling technique. The test results gave us some insight that the mode of slope failure due to leakage of BWCS may be dependent on the fracture orientation, fracture type and trench width.

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