Project Title:	Full-scale Testing and Numerical Analysis of Innovative Measures for Minimizing Infiltration and Internal Erosion in Soil Slopes due to Leakage from Pressurized Buried Pipes
Principal Investigator:	Prof. Limin ZHANG
Project ID:	CICR/04/15
Research Institution:	The Hong Kong University of Science and Technology
Subject Area:	Construction Technologies

Objective

- To analyse the water infiltration zone and slope stability due to leakage from pressurized buried water-carrying services, and the safe distance between a leaking pipe and the crest of a soil slope;
- To carry out full-scale evaluation of innovative drainage designs for buried pipes;
- To develope preliminary design guidelines for protecting soil slopes against leakage from buried pipes.

Background

Water pipes could be 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 lead to internal erosion of the surrounding soil. The removal of the soil will further enhance leakage and water infiltration, and may eventually lead to pipe bursts and catastrophic consequences. Very often, pipes are laid in soil slopes or road embankments. The infiltration of leaked water in the embankment slopes will cause the loss of soil suction and increases in pore water pressure, which in turn causes the decrease of soil shear strength and, in severe cases, the slope failures. Between 1984 and 2004, 206 landslide incidents involving water-carrying services in the vicinity of the slopes of concern were reported. Only a limited fundamental research has been performed to study the leaking mechanisms and soil response in the vicinity of leakage of pressurized buried water-carrying services (BWCS).

Methodology

Centrifuge Model Tests

Four mainlaying schemes were proposed to mitigate the captioned catastrophic consequence, which include: (a) Geotextile enclosure; (b) Geomembrane enclosure; (c) Sleeved pipeline; (d) Sheathed pipeline. In total, seven centrifuge model packages were developed to verify the effectiveness of three selected engineering measures for protecting BWCSs, and to evaluate the performance of the current Hong Kong mainlaying practice when subject to leakage of pressurized BWCS.

Laboratory Tests

Since geomembrane is a major material in two of the proposed mainlaying schemes, its durability, water tightness, quality of seaming and maximum sustained pipe pressure are of concern. These parameters were tested rigorously in the laboratory through pressure tests. Another laboratory test was developed to study the internal erosion process. The loss of fine particles was modelled using table salt to replace some soil particles to achieve designated degrees of erosion.

Numerical Simulations

Detailed numerical analysis was conducted to investigate the infiltration process due to leakage of pressurized BWCS. The analysis consists of two parts. In the first part, a preliminary analysis was carried out to comprehensively study the influence of leakage pressure on the evolution of pore-water pressure distributions. The second part of the analysis targets to determine a safe distance between a buried pipe and the soil slope crest.

Results and Findings

Results of Centrifuge Model Test

The results of the 7 centrifuge model tests are presented in this section. The test results are summarized in the Table below.

Test	*Surface rupture and erosion*	*Deep-seated slope failure*	*Pipe pressure at onset of failure*	*Failure time (prototype)*
Current Hong Kong practice (wide trench, slot, pointing upward)	Yes	No	100 kPa	-
Current Hong Kong practice (narrow trench, hole, pointing horizontally)	Prevented	Yes	100 kPa	126 days
Current Hong Kong practice (narrow trench, hole, pointing upward)	Prevented	Yes	100 kPa	109 days
Geotextile enclosure	Prevented	Yes	35 kPa	18 days
Geomembrane enclosure	Prevented	Prevented	-	-
Sheathed pipe	Prevented	Prevented	-	-
Sleeved pipe	Prevented	Prevented	-	-

Results of Laboratory Tests

- The test demonstrated that the sheathed DI pipe can sustain a leakage pressure of 640 kPa.
- The wetting deformations of the samples could be ignored for simplicity.
- Both the peak friction angle and the critical friction angle decrease with an increasing amount of loss of fine particles.

Numerical Simulations

- The simulated values of the pore-water pressures at the pore-pressure transducers (PPT) locations are in good agreement with the centrifuge test readings.

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Recommendations

Safety Distance

A safe separation distance of twice the slope height for a CDG soil with a relative compaction (RC) = 95% or nearly three times the slope height for a CDG soil with a RC = 85% is recommended.

Mainlaying Schemes

In comparison with the safety distance, applying protection measures to the buried pipe during the mainlaying stage enables higher flexibility of the routing, as well as less susceptibility to the in-situ soil properties. The applicability of the proposed mainlaying schemes are summarized in Table below.

Proposed protection measures	***Flat-ground***	***Slope***
Current Hong Kong practice (wide trench, slot, pointing upward)	X (Frequent surface rupture/erosion)	X (Slope failure sometimes)
Current Hong Kong practice (narrow trench, hole, pointing horizontally)	X (Frequent surface rupture/erosion)	✓ (Reduced chance of slope failure)
Current Hong Kong practice (narrow trench, hole, pointing upward)	X (Frequent surface rupture/erosion)	✓ (Reduced chance of slope failure)
Geotextile enclosure	✓ (Effectively prevent surface rupture/erosion)	X (Slope failure may occur)
Geomembrane enclosure	✓ (Effectively prevent surface rupture/erosion)	✓ (Effectively prevent slope failure when sealed properly)
Sheathed pipeline	✓ (Effectively prevent surface rupture/erosion)	✓ (Effectively prevent slope failure when sealed properly)
Sleeved pipeline	Equivalent to geomembrane enclosure	Equivalent to geomembrane enclosure