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Development of a laboratory-scale test apparatus for evaluating pipe wear for slurry shield TBM

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ABSTRACT

Inspection and maintenance of pipe wear are critical for ensuring efficient muck transportation and minimizing downtime in slurry shield tunnel boring machine (TBM) operations. In this study, a laboratory-scale test apparatus was developed to investigate pipe wear caused by slurry flow containing excavated materials. The tests were conducted using granite particles as the excavated soil at various concentrations. Pipe wear was evaluated in two distinct sections of the test apparatus, a straight section and a bending section, by comparing the pipe weights before and after testing. The results showed that the wear rate was higher in the bending section than in the straight section and increased with higher granite particle concentrations. These trends were consistent with findings from previous studies. Therefore, the developed test apparatus demonstrates strong potential for exploring additional factors affecting pipe wear during slurry flow containing excavated soil and rock fragments.

1. INTRODUCTION

With the growing demand for underground infrastructure, slurry shield tunnel boring machines (TBMs) have become widely used in tunnel construction. In this method, pressurized bentonite slurry is supplied at the excavation face to stabilize it, while the excavated material, mixed with the slurry, is transported through discharge pipelines to ground-level slurry treatment facilities (Fang 2023). During muck transportation, the pipelines are continuously exposed to abrasion from solid particles, leading to wear and, potentially, unintended failures. Pipe leaks can cause costly operational standstills and require time-consuming repairs, making timely inspection and maintenance of pipe wear critical for ensuring efficient material transport and

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minimizing downtime in slurry shield TBM operations.

Numerous studies have investigated the factors contributing to pipe wear due to slurry erosion, including the properties of the excavated materials, slurry characteristics, and flow conditions (Arabnejad 2015; Tang 2015; Xie 2015; Alam 2016). To examine these factors, various laboratory-scale testing methods have been developed, such as pot erosion testers, jet erosion testers, and whirling arm erosion testers (Gupta 1995; Al-Bukhaiti 2007; Karthik 2021). While these methods have yielded valuable insights, they fall short in realistically reproducing the actual flow conditions within discharge pipelines.

To address this limitation, the present study developed a laboratory-scale test apparatus designed to simulate the flow conditions encountered in slurry shield TBM operations. Pipe wear tests were conducted using granite particles at three different concentrations. Wear was evaluated in both a straight and a bending section by measuring the pipe weights before and after the tests. The results were compared with findings from previous studies to validate the applicability of the proposed apparatus for investigating pipe wear under slurry flow conditions.

2. Experimental studies

2.1 Test setup

The laboratory-scale test apparatus was designed to simulate pipe wear caused by slurry flow under conditions similar to those in discharge pipelines during slurry shield TBM operations. As shown in Fig. 1, the setup includes a centrifugal pump, a buffer tank, an electromagnetic flowmeter, a programmable logic controller (PLC), and a closed pipe loop. The pump is equipped with an 80 mm suction inlet and a 50 mm discharge outlet. The buffer tank has a capacity of 200 liters and supplies slurry to the system. The electromagnetic flowmeter measures the volumetric flow rate, while the PLC, connected to both the pump and the flowmeter, controls the pump speed and records flow rate data at one-second intervals. The test loop consists of 50 mm-diameter pipes, with two designated test sections: a 700 mm straight section and a 235.5 mm bending section. These dimensions were selected to reflect key flow geometries and assess differential wear behavior under realistic operational conditions.

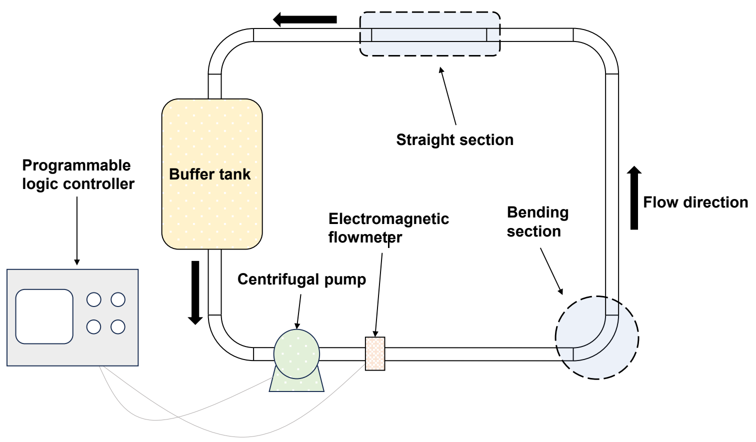

Fig. 1 Schematic of laboratory-scale test setup

2.2 Materials

Granite particles were used as the erodent material to induce pipe wear. The particle size distribution was controlled through sieving. The pipe loop was fabricated using carbon steel. A bentonite suspension, prepared by mixing sodium bentonite with tap water, was used as the carrier fluid.

2.3 Test procedures

After preparing the bentonite suspension, the programmable logic controller (PLC) was used to control the pump's rotation speed to achieve the target volumetric flow rate of 28 m^3/h, as measured by the electromagnetic flowmeter. Granite particles were then introduced into the buffer tank, and the pipe wear test was conducted for 30 minutes. Upon completion, the test apparatus was flushed and cleaned by circulating fresh water and discharging it four times. This process was repeated at least eight times for each test case. After the series of tests for each case, the two pipe sections were weighed using a digital scale to evaluate pipe wear. Three pipe wear test cases were performed using granite particle concentrations of 1.5, 3.0, and 6.0 wt.%.

3. Results and discussion

Table 1 summarizes the results of the pipe wear tests conducted at the three granite particle concentrations. Pipe wear was quantified by calculating the wear rate, defined as the weight loss per wetted surface area of each test section per unit time. The results consistently showed higher wear rates in the bending section compared to the straight section. Additionally, wear rates in both sections increased with higher granite particle concentrations. This trend is in good agreement with previous studies that employed different testing methods to evaluate slurry erosion wear (Turenne, 1989; Chandel, 2012; Singh, 2017). These findings suggest that the developed test apparatus is well-suited for investigating slurry-induced pipe wear under controlled conditions.

Table 1. Wear rates of the two test sections in the pipe wear tests

Test case No.	Particle concentration (wt.%)	Wear rate (g/(h·m^2))	
		Straight section	Bending section
1	1.5	0.73	3.78
2	3.0	3.00	7.02
3	6.0	7.00	16.21

4. Conclusions

This study developed a laboratory-scale test apparatus designed to replicate the flow conditions in discharge pipelines during slurry shield TBM operations, with the aim of investigating pipe wear caused by slurry flow containing excavated materials. To evaluate the reliability of the apparatus for assessing pipe wear, tests were conducted using varying particle concentrations, one of the primary factors influencing erosion wear. Pipe wear was assessed in two test sections, a horizontal straight section and a bending section, by comparing the weight before and after the tests. The results confirmed that wear was more pronounced in the bending section than in the straight section. Additionally, wear increased with higher concentrations of granite particles, consistent with findings from previous studies. These results demonstrate that the developed test apparatus is suitable for further investigations into factors influencing pipe wear during slurry shield TBM operations.

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