

Evaluation of the Maximum Bending Moment of an Embedded Cantilever Flood Wall Measured by Distributed Strain Sensing Fibers

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1 INTRODUCTION

Understanding the structural behaviour of flood retaining walls is critical for ensuring safety against catastrophic failure, maintaining serviceability limits to protect adjacent infrastructure, and optimizing economic efficiency during design. The structural response of these systems to environmental loads is inherently complex, governed by multiple factors including soil-structure interaction, gap formation between the wall and adjacent soil, deformation limits, and likelihood of plastic behaviour under extreme loading. Wall flexibility strongly influences soil-structure interaction, with increased stiffness significantly reducing lateral deflections (Bourne-Webb et al, 2007).

Geotechnical centrifuge modelling has emerged as a critical experimental tool for simulating prototype-scale stress conditions, enabling researchers to validate theoretical design methods by replicating full-scale wall behaviour in controlled environments. This is particularly useful for flood inundation of retaining walls owing to the extreme environmental loading required and scarcity of well instrumented test sites. Traditional instrumentation methods to capture structural response, particularly foil strain gauges, provide only discrete data points that may miss critical areas of strain concentration. This study addresses these limitations by implementing fiberoptic strain sensing using Optical Frequency Domain Reflectometry (OFDR) based on Rayleigh backscatter. This technology provides continuous, high-definition strain measurements along the entire fiber length, making it ideal for capturing complex bending profiles in retaining structures (Eichhorn & Haigh, 2024).

To validate the centrifuge modeling approach, this work compares results with the E99 Sheet Pile Wall

Field Load Test, conducted on a sheet pile wall in Louisiana's East Atchafalaya Basin Protection Levee (Jackson, 1988). The E99 tests subjected their test wall to a simulated flood loading of up to 2.4 m of head relative to the ground surface. Strain measurements indicated peak moments ranging from 22,370 N-m to 34,030 N-m at depths of 3.4 to 3.7 m below ground surface.

This study has two primary objectives: first, to detail the successful instrumentation of a model retaining wall with optical fiber for in-flight strain measurement; and second, to analyze the strain and bending data obtained during centrifuge testing to directly understand the structural response compared to the E99 field test results.

2 EXPERIMENTAL DESIGN

The experimental series conducted for this study consisted of two 50g centrifuge tests (denoted Test 4 and Test 7 hereon) in which a cantilever wall was installed at different depths and exposed to a simulated flooding event. Figure 1 provides a cross-sectional view of the model set-up.

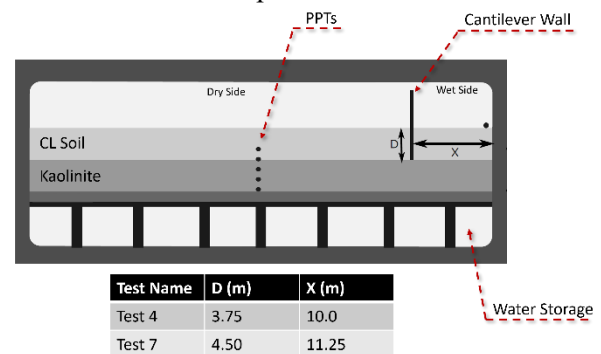


Figure 1. Model set-up for cantilever wall centrifuge tests.

A two layered soil model consisting of a kaolinite base overlain by a homogenous CL soil was created in the centrifuge container and consolidated under g . The soils had an estimated unconfined compressive strength, based on triaxial tests, of 29.3 and 18.96 kPa, respectively. In comparison, the soil used in the E99 tests was a normally consolidated, highly plastic clay with a reported shear strength varying between 9.6 and 23.9 kPa.

Upon consolidation, a rectangular model cantilever wall was driven into the soil to a depth of 3.75 m in Test 4 and 4.5 m in Test 7 (reported at prototype scale). The cantilever wall in the E99 tests was embedded at a depth of 7.0 m (Figure 2). The model cantilever wall was comprised of a 4.75 mm thick aluminium plate that spanned the entire width of the centrifuge container. This material was selected so as to provide a wall bending stiffness and area moment of inertia that were comparable to the PZ-27 sheet pile wall used in the E99 full-scale tests. The reader is referred to Table 1 for a summary of the E99 and model wall properties. Note that lengths are reported in this table following the per unit meter designation used by the manufacturer to ensure correlation with the model wall.

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High-definition fiber optic sensors (HD-FOS) were applied to the aluminum plate to continuously monitor wall strain throughout the experiments at a high spatiotemporal resolution. Shallow linear grooves were etched into the surface of the aluminum plate to designate one vertical and two horizontal sensing segments on each side of the plate where the fiber was to be installed (Figure 3a). The vertical sensing segments were aligned along the wall centroid on both the tension and compression faces, enabling curvature and bending response to be computed from differential strain measurements. Etching helped improve bonding between the low-viscosity cyanoacrylate adhesive applied to the fiber and the plate. A single 5 m long fiber was placed into these grooves with gently curved redirects (Figure 3b) to create a continuous series of linear sensing segments. The fiber's length was sufficiently long so as to provide a 'flying lead' that ran from the model to the optical interrogator. After bonding, a two-part epoxy was applied over the fiber

to provide mechanical protection and ensure durability during centrifuge testing.

A fifth horizontal segment was included on the flood side of the cantilever wall. This segment of fiber was placed within a clear furcation tube to mechanically isolate it from structural strains, allowing temperature measurements to be made. These data

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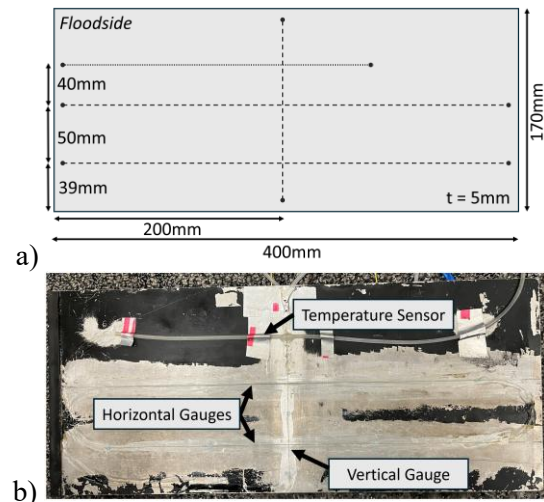


Figure 3. a) schematic of floodside of wall with fiber instrument locations and dimensions and b) final fabricated model cantilever wall with fiber setup.

3 BENDING MOMENT ANALYSIS

The bending moments were calculated from the strain measured on the model wall and compared to the full scale E99 Tests which can be seen in Figure 2. Comparatively the magnitude of bending was similar testing however, the location of the peak bending moment was significantly higher on the wall than the full-scale equivalent. Possible explanations for this difference can be linked to differing soil strengths or the possibility that the model wall rotated more than the prototype. In the case of the latter, the self-weight of the wall would add an additional moment to the structure. Additionally, the E99 tests only had one strain gage above ground at each of the piles and it is possible that the actual behaviour was not fully captured.

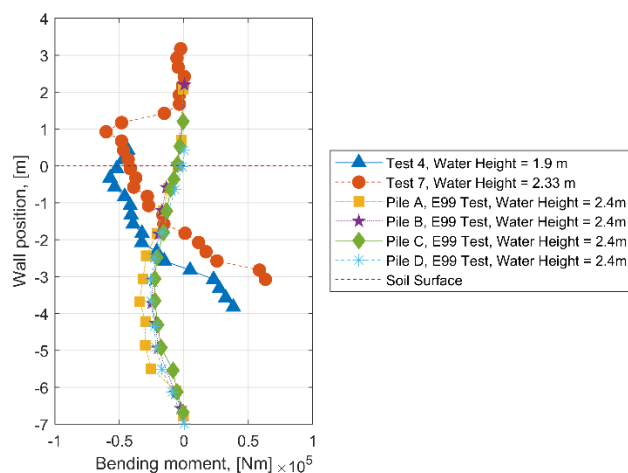


Figure 2. Comparison of wall performance due to hydraulic loading across Test 4 and 7 to the Full Scale E99 results.

4 CONCLUSIONS

Fiber-optic distributed strain sensing provided valuable insight into the structural response of a cantilever flood wall subjected to hydraulic loading conditions. The high spatial resolution of the measurements enabled detailed characterization of strain distribution and deformation patterns that are difficult to capture with conventional instrumentation. These results demonstrate the effectiveness of fiber-optic sensing for evaluating wall performance and highlight its potential to improve understanding of soil–structure interaction mechanisms in earth-retaining systems. The findings support the use of distributed fiber-optic sensors as a robust tool for future physical modeling, validation of numerical analyses, and advancement flood wall design and assessment methodologies.

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