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Physical Modelling in Geotechnics

A laboratory apparatus and PIV analysis method to characterize the horizontal displacement of backfill materials

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ABSTRACT: The Coulomb and Rankine earth pressure theories do not fully describe the actual behavior of in-situ soil, which is anisotropic and non-homogeneous material, but current understanding treats the soil as a single medium with constant characteristics. In this study, a physical modelling test was performed to verify the lateral earth pressure and the failure shape of the soil due to rotation around the base (active displacement) of a frictionless Rankine wall supporting a sandy soil backfill. For the model test, the lateral earth pressure distribution was measured by fabricating a soil box having a tiltable wall with load transducers and earth pressure gages embedded. The displacement and particle movement of backfill sand was analyzed using image analysis method (PIV). As a result of the test, the earth pressure at rest shows a triangular shape distribution increasing linearly with the depth which is in accordant to existing understanding. As the wall rotates, the simultaneous lateral earth pressure and failure shape variations have been measured adequately using the real time load-pressure measurement data and PIV analysis results.

Keywords: Backfill, Failure shape, Lateral earth pressure, Particle image velocimetry (PIV), Physical modelling test

1 INTRODUCTION

In general, the classical earth pressure theory of Coulomb (1776), the soil wedge theory, and Rankine (1857), the micro-earth element theory, are used in the design of retaining walls (Fig. 1.). If some assumptions, such as wall shape, friction, and sliding failure lines, violate these requirements, Rankine and Coulomb's earth pressure theory restricts a reasonable earth pressure estimate. The earth pressure problem cannot be handled without taking into consideration all of the various soil characteristics, but soil is an anisotropic and non-homogeneous material, making it difficult to estimate the earth pressure using only the given soil parameters. Therefore, earth pressure theories and mechanical models are used after determining applicability through field observations and measurements, as well as experience and experiments.

In general, the retaining wall displacement mode is classified into three types: translation, rotation around the top, and rotation around the base (Fang et al. 1986, 1994). Because of its adequate drainage and shear strength characteristics, well-graded sand is generally preferred as a backfill material for retaining walls. As a result, a physical modelling test was performed in this study to assess the lateral earth pressure and the variation in failure shape caused by the rotation of the wall in the sandy soil.

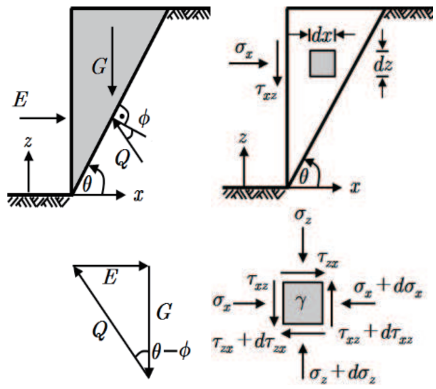

Fig. 1. Coulomb and Rankine earth pressure theory (Lee, 2017) .

2 EXPERIMENTAL SETUP AND INSTRUMENTATION

2.1 Experimental setup

As shown in Fig.2, the soil tank used in this study has dimensions of 980 mm (length) × 300 mm (width) × 900 mm (height). The soil tank was constructed with a transparent acrylic plate so that the soil movement behind the wall could be observed from the outside. A glass plate was attached between the soil and the acrylic plate to reduce friction between the soil and the acrylic plate. The soil tank was constrained to the exterior by a steel frame to avoid distortion.

The rigid wall system used in this study is shown in Fig. 3. A total of 7 separate plates (300 mm in length × 20 mm in width × 100 mm in height) were constructed using lightweight and high-rigidity acrylic. Two load transducers (a total of 14) and an earth pressure gauge (a

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total of 4) were embedded on the inner side of the plates to measure the lateral earth pressure according to depth, avoiding eccentricity from acting on each plate. The reaction wall is constructed of highly rigid acetal and steel, which minimizes the effects of deformation caused by earth pressure and compression induced by the gearbox reaction force. The model ground was composed by installing a hinge at the base of the wall and adjusting the verticality of the wall. The gearbox was controlled at 0.01°/min to provide the rotation (active state) of the wall.

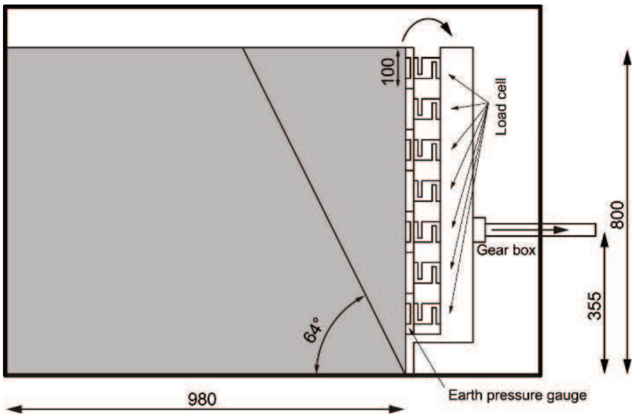

Fig. 2. Physical modeling test schematic .

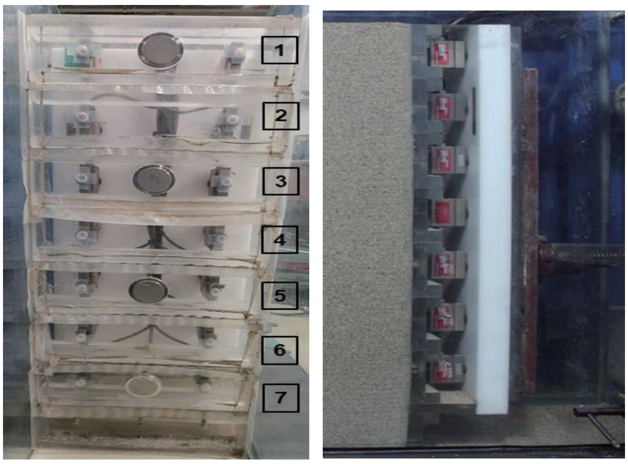

Fig. 3. Lateral earth pressure measurement wall.

2.2 Characteristics of soil

The model ground was composed using dry Jumunjin sand, and the soil properties are provided in Fig. 4 and Table 1.

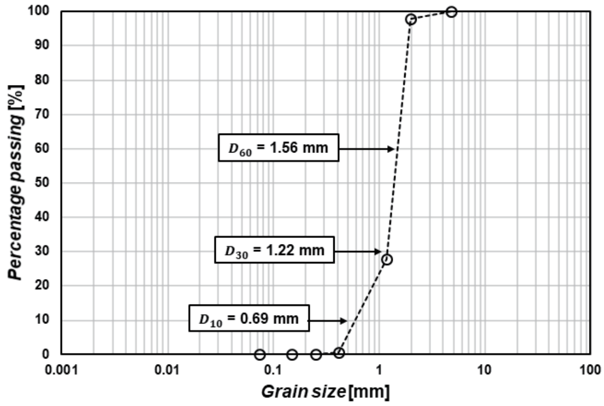

Fig. 4. Particle size distribution of Jumunjin sand.

Table 1. Results of soil properties.

USCS	γ_d (kN/m^3)	D_r (%)	∅ (°)	C (kPa)
SP	17.2	78.2	38	0

2.3 Sample preparation process

A pluviator capable of spraying a certain amount of sand was used to construct a model ground with a constant relative density from a fall height of 700 mm. The rail on which the pluviator moves is isolated from the soil tank when the model ground is built to decrease the effect of vibration induced by the pluviator movement. In addition, at the bottom of the pluviator, a roller was installed to allow horizontal movement on the rail without vibration or friction (Fig. 5).

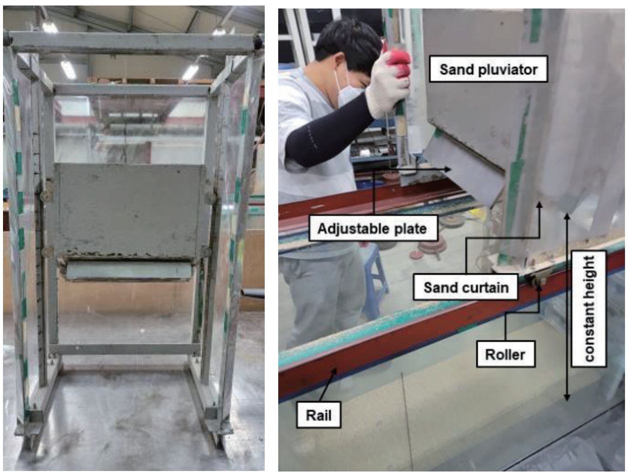

Fig. 5. Pluviator and model ground composition.

Fig. 6. Model ground composition completed.

3 PARTICLE IMAGE VELOCIMETRY(PIV)

GeoPIV is a Matlab-based software for deformation analysis in geotechnical experiments. GeoPIV is a two-dimensional digital image correlation approach for determining the displacement distribution of a plane by computing the moving distance of a specific area (pixel subset) of an image. The GeoPIV image analysis approach can be used to obtain information about the displacement vector, x-y-axis displacement, and shear strain of the ground in terms of contour and surface. The failure shape of the ground induced by the rotation of the wall was analyzed using the GeoPIV image analysis method for this study.

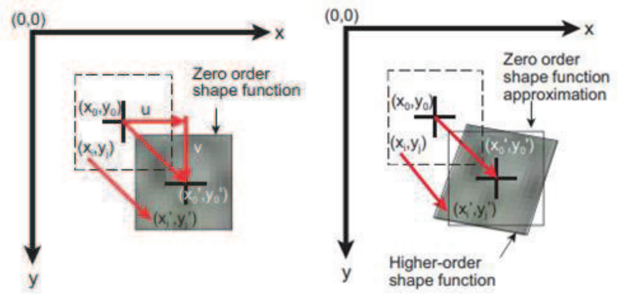

Fig. 7. GeoPIV image analysis principle (Take, 2015).

4 RESULTS AND DISCUSSION

In this study, a wall was built to support the sandy soil, and a physical modelling test was performed to generate the wall's lower rotation. When the wall rotates in the homogenous sandy ground, the background soil linearly ruptures and moves along the sliding failure line. The lateral earth pressure caused by the rotation of the wall was measured, and the variation in the failure shape of the ground was analyzed using GeoPIV image analysis.

4.1 Earth pressure at rest

After the model ground was built and before the wall displacement was generated while the wall was vertical, the earth pressure at rest was measured. The lateral earth pressure grows linearly with depth in a triangular distribution at rest, which is comparable to the theoretical Jaky's equation (K_o =1-sinϕ). The earth pressure at rest coefficient in the test is 0.36 and 0.38 in the Jaky's equation, which is comparable (Fig. 8).

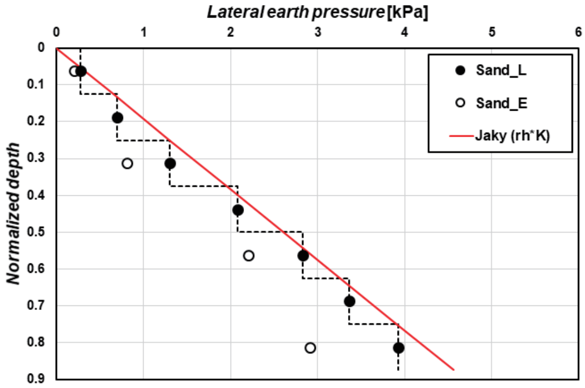

Fig. 8. Earth pressure at rest distribution.

4.2 Lateral earth pressure distribution by wall rotation

The lateral earth pressure distribution was investigated using the lateral earth pressure ratio (active earth pressure/earth pressure at rest) and GeoPIV image analysis in relation to wall rotation and ground failure shape. The intersection with the test result was also determined as the limit displacement, which included Bishop's equation (K_a/K_0-ϕ) (1958).

The lateral earth pressure rapidly decreases when rotational displacement (active displacement) occurs in the at rest condition. The horizontal displacement (Δx/h) is 0.06 %, which is within the theoretical limit state wall displacement range of 0.05-0.1%, as shown by the intersection with Bishop's equation (1958) (dense soil). The lateral earth pressure decreases linearly in proportion to the wall displacement after the limit displacement occurs (Fig. 9).

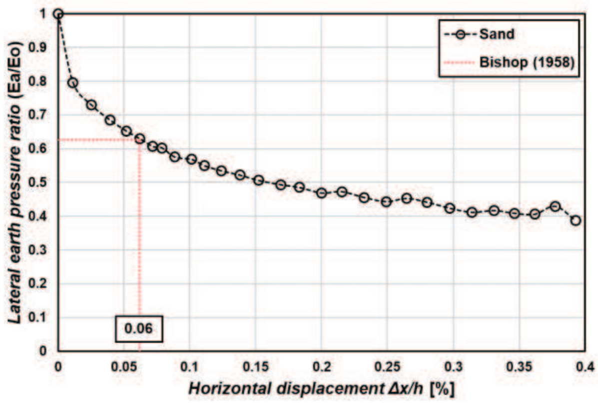

Fig. 9. Lateral earth pressure ratio (E_a/E_o) according to wall rotation.

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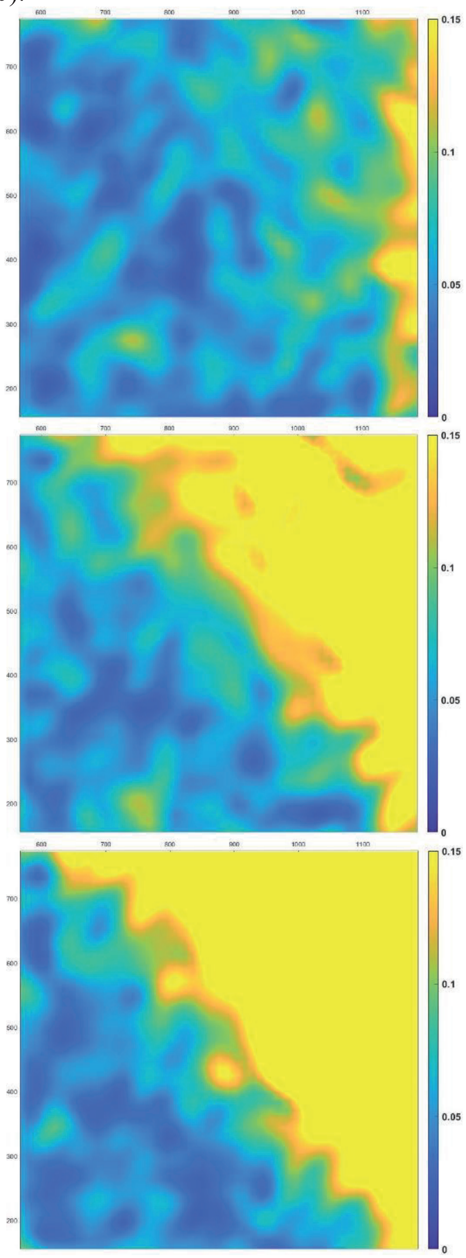
The failure shape according to the rotation of the wall was verified by shear strain using the GeoPIV image analysis method. The limit displacement was determined to be the horizontal displacement that forms a complete failure shape (triangular wedge).

As a result of GeoPIV image analysis, the model ground is a homogeneous sandy soil, and when the wall rotates, a triangular failure shape occurs in the backfill according to the Coulomb theory. The wedge failure pattern was observed in the 0.05-0.1% horizontal displacement (x/h) range. After that, the wedges shape remains constant in proportion to the rotational displacement of the wall, and its size seems to expand (Fig. 10).



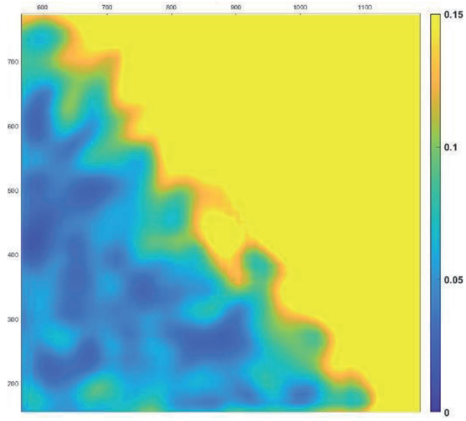


Fig. 10. GeoPIV image analysis (maximum shear strain) (Δx/h 0.05, 0.1, 0.15, 0.2%).

5 CONCLUSIONS

This study drew the following conclusions after conducting a physical modelling test to validate the lateral earth pressure and failure shape generated by rotation around the base of the wall. At rest, the earth pressure is distributed in a triangle pattern that increases linearly with depth. The lateral earth pressure diminishes rapidly and then linearly as the wall rotates (active displacement). Following the occurrence of the limit displacement, GeoPIV image analysis reveals a triangular failure shape, confirming that the wedge shape is constant and that the size expands in proportion to the rotational displacement.

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