VISCOSITY EVALUATION OF AIR FOAM MIXED SOIL FOR FOAM INJECTION SHIELD TUNNELING METHOD

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ABSTRACT

Foam Injection Shield Tunneling Method has many advantages. Excavated soil obtains smooth flow performance of excavated soil mixed with air foam. Using this technique, stability of face pressure in the excavation chamber and smooth discharge of the excavated soil from the chamber are improved in the shield machines. It is very important to evaluate properties of the excavated soil mixed with air foam. Purpose of this research is to develop the evaluation methods which can be easily mobilized to the actual sites under tunnel construction.

In this research, two simple methods were developed. One is "Cylinder slump test" using a small slump cylinder, and another one is "Shear test" using a multiple shear device. In the slump test, viscosity according to shear velocity was evaluated from the observation of self-weight deformation of the material cylinder. In the shear test, initial shear stress when just the material begins a deformation was evaluated.

1. INTRODUCTION

Air foam mixed soil is applied for Foam Injection Shield Tunneling Method. Excavated soil obtains smooth flow performance and it improves the efficiency of transportation by mixing air foam. Behavior of air foam mixed soil is very complicate and this sometimes makes it difficult to evaluate the properties using conventional equipment. In this study, advanced new evaluation methods were developed.

Air foam mixed soil is made from soil, water and foam agent. The property changes by evaporation of water and dissipation of bubbles. In this research, a polymer material (Viscotop producted by KAO and is used as the additive to the concrete) was used. This material has non-Newtonian properties similar with foam mixed soil and the properties are not changeable for the long duration. Also viscosity of this material is easily controlled with changing water rate.

2. EXPERIMENTAL APPARATUS AND CONSIDERATION

2.1 Rotational viscometer

Various viscometers are applied to evaluate material viscosity, e.g. Rheometers, Brookfield viscometers, and various optical techniques. Especially, the Brookfield viscometers (Rotational viscometer) are frequently used to evaluate viscosity of high viscous fluid. In this equipment, a spindle is inserted in the object material and it is rotated at high speed by motor. Material's viscosity is evaluated from torque resistance of spindle. 5 samples of viscotop with different water rate were evaluated using this equipment. Results are shown in Fig.1 (shown as Sample A). Each sample of viscotop showed different viscosity. The result shows that viscotop has a typical property of pseudoplastic fluid. This result was obtained using same spindle. The Brookfield viscometer, however, sometimes requires changing spindles according to the shear speed. In the case of non-Newtonian fluid, it was found that this measurement method could obtain un-continuous data when the spindle was changed as shown in Fig.2.

Viscosity of air foam mixed soil was also evaluated using same equipment. Result is shown as Sample B in Fig.1. As a result, shear stress didn't change with shear speed. The reason is considered because slip occurred between the spindle's bob and material. As the result, it was found that high speed rotation was not suitable to the measurement of viscosity for the complicate property materials such as air foam mixed soil. Therefore, new deformation method to evaluate the properties of the air foam mixed soil have devised.

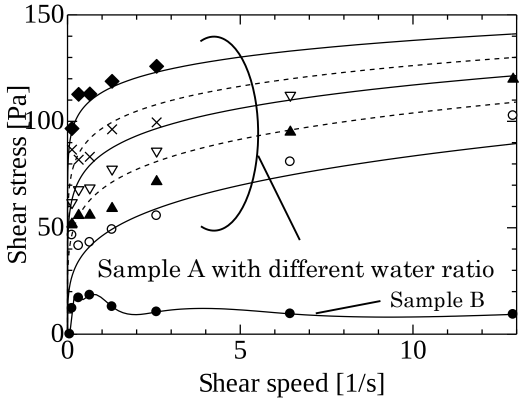


Fig. 1 Shear stress vs Shear speed

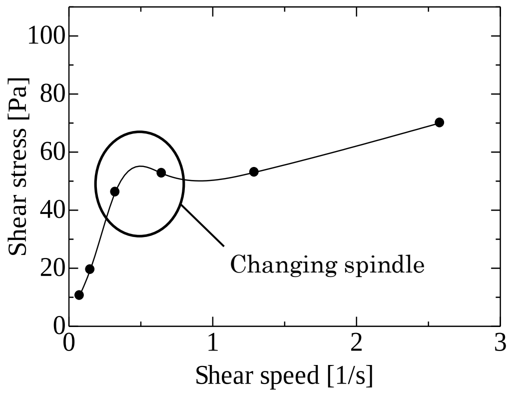


Fig. 2 Error by different spindle

2.2 Cylinder slump test

This test has a mechanism that can make slow deformation to the target materials. In this method, materials spread by its own weight, and its deformation speed is changed during the process. It enables to obtain a stress curve vs. deformation speed by only one test. This is one of the advantages which this test has over the conventional slump test.

In the cylinder slump test, stress is expressed by the following formula,

$$\sigma = \frac{W}{A} \tag{1}$$

where σ is stress, W is force of weight [N], and A is spread cross-section area [m]. W is rewritten as,

$$W = \rho V g \tag{2}$$

where ρ is density [kg/m^3], V is volume [m^3], and g is acceleration of gravity [m/s^2]. A is also rewritten as,

$$A = \pi/_4 d^2 \tag{3}$$

where d is cross-section's diameter. Since material is spread, d has relation to time t [s]. From the formulae (1) to (3), σ is described as follows.

$$\sigma = \frac{\rho V g}{\pi d^2} \tag{4}$$

Here right side has only one variable d(t). σ is able to get by d. In particular, d is calculated by observing cross-sectional change from the bottom with a camera. Height at each time y is

$$y = V/_A \tag{5}$$

From the formula (3),

$$y = \frac{V}{\pi/_4 d^2} \tag{6}$$

Height at each time y is calculated by cross-sectional area, and the deformation speed is defined as divided by the displacement of the height by time. Test result of sample A is shown Fig.4. The result shows similar pseudoplastic behavior as obtained by rotational viscometer. It was found that Cylinder slump test enables evaluation of material viscous behavior accurately.

Comparing Fig.1 and Fig.3, the horizontal axis order is very different. Shear speed in Fig.1 is around $10^0 \sim 10^1$, and is around $10^{-4} \sim 10^{-3}$ in Fig.3. Cylinder slump test is assessable with slower speed than rotational viscometer. (Here, shear speed and deformation speed are assumed as same parameter.)

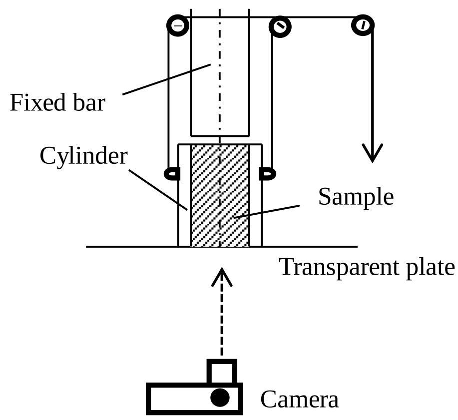


Fig.3-1 Outline of equipment

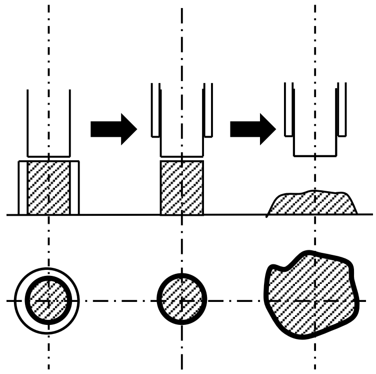


Fig.3-2 Outline of equipment

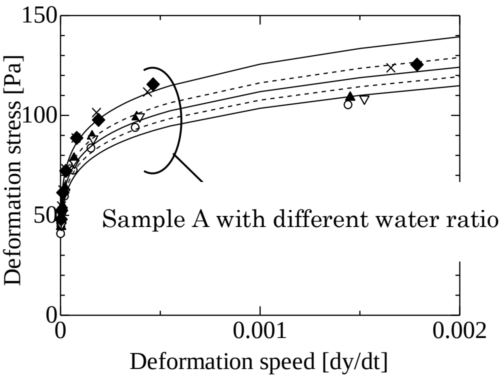
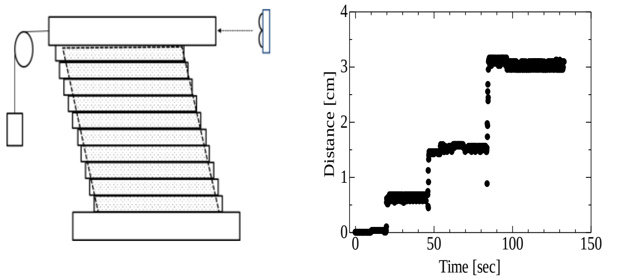


Fig.4 Stress vs speed spread



(a) Outline of equipment (b) Example of test result

Fig.5 Multiple shear stress test

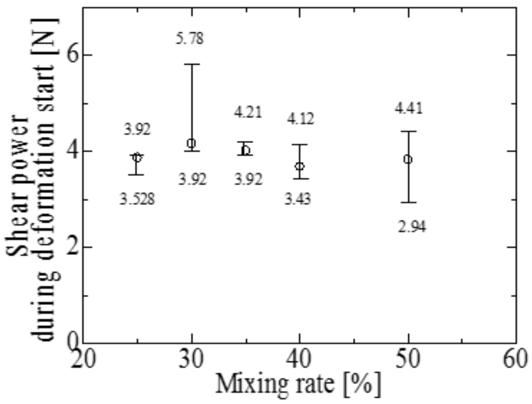


Fig.6 Shear stress vs mixing rate

2.3 Shear test

Cylinder slump test can evaluate in a fluidized zone. However, this test cannot evaluate the yield point. Rheometer is often used for search the point, but it doesn't check whole behavior. In this method, constant load and the starting point of deformation is observed. This equipment has a lot of shear planes, and shear stress is amplified. The equipment and an example of the test results are shown in Fig.5. As shown in Fig.6, total weight at the point the device starts the motion is regarded as the shear stress of yield point. As a result, it was found that Viscotop had the yield point. This method was considered useful for evaluating the yield point.

3. CONCLUSION

As the result of present research, it was found that the conventional rotational viscometer was not suitable for non-Newtonian or some other materials such as air foam mixed soil due to lack of integrity in different spindles and too large shear speed of the rotating spindles. Therefore, an advanced method, the Cylinder slump test, was developed. This test doesn't require to use rotating spindles and it enabled to evaluate viscosity with much lower shear speed. It was confirmed that Cylinder slump test can provide the same result with the rotational viscometer in reliable conditions, and also that it enables to provide a stress curve vs. deformation speed by only one test. Shear test was also developed as an effective experiment method to evaluate the yield point. We confirm that the above-mentioned developed tests are able to show one of the possibility to evaluate fluid properties of complicated materials such as high viscous fluid and non-Newtonian fluid.

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