Simple estimation method of in-situ strength of sedimentary solid waste ground

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ABSTRACT

In-situ direct shear and earth pressure tests were developed for estimating strength of solid waste materials (SWM). Strength properties of solid waste materials were investigated in different sites. Strength parameters of cohesion of frictional angle are obtained from the in-situ direct shear and earth pressure tests. The in-situ earth pressure test was conducted by putting several bars in a line. Strength parameters are evaluated from test results of the in-situ earth pressure test in different embedded length of pile. Cohesion and frictional angle obtained from the in-situ direct shear and earth pressure tests are correlated respectively. The in-situ earth pressure test is very simple method. It is therefore that the strength property of solid waste materials can be estimated as an approximate value.

Keywords: solid waste material, strength, in-situ test, direct shear, earth pressure

1 INTRODUCTION

There are many improper disposal sites and illegal dumping sites in Japan. Some of them are made in a steep slope and endangered condition in collapse. It is therefore that evaluation on stability of SWM slope is an important problem to be solved in geotechnical engineering.

Generally, stability of SWM slope was calculated on soil mechanics in past study (Koelsch, 2009; Zekkos, 2010; Bray, 2009; Towhata, 2010), however there were few data about in-situ shear property of SWM and almost all experiments were performed in laboratory on specific condition. In-situ shear property of SWM has not been solved. Furthermore, the differences of the shear property between in-situ and laboratory test has not been clarified adequately. The authors have investigated shear property of SWM using in-situ direct shear test apparatus (300mm × 300mm in shear plane) on the improper disposal site in Japan (Miyamoto et al., 2011). The direct shear test in laboratory has been also conducted using SWM sampled from the same site. The differences of shear properties between undisturbed (in-situ) and disturbed (laboratory) SWM were investigated. In-situ shear property of SWM is considered by test results. The differences of shear properties of SWM for undisturbed (in-situ) and disturbed (laboratory) structure conditions are clarified in consideration of differences of depositional structure of plastic wastes.

In this study, for estimating the strength of solid waste material in a simple method, a new type of in-situ earth pressure test is developed. The in-situ earth pressure test is conducted by putting several bars in a line. Strength parameters are evaluated from test results of the in-situ earth pressure test in different embedded length of pile. In-situ direct shear and earth pressure tests are performed on several types of grounds. The validity of this method is confirmed based on the test results.

2 IN-SITU DIRECT SHEAR TEST

2.1 Developed shear test apparatus

A new in-situ direct shear test apparatus was developed for measuring shear strength of SWM as shown in Fig.1. The size of shear box is 300mm×300mm in plan of view and 180mm high. The test is performed under displacement rate of 1mm/min manually. A load lever is attached and actual applied load becomes ten times. Anchoring is done by pile of anchor (220mm length and diameter of 50mm).

![Fig. 1. In-situ direct shear test apparatus.](http://doi.org/10.3208/jgssp.JPN-056)
Test site on improper disposal site in Japan shown in Fig. 1, and undisturbed site was selected for in-situ direct shear test. The ground was excavated and in-situ direct shear test was performed in depth of 2m (GL-2m) and 4m (GL-4m). Furthermore, composition of waste materials in test site is shown in Figs. 2 and 3. It is indicated that the SWM contain a lot of soil and gravel in weight, however soft plastic materials are prominent in volume visually. In-situ density test was performed in the test site. In-situ density was measured and wet density was 0.95 Mg/m$^3$, because SWM contain a lot of soft plastics, and water content $w$ is approximately 20 %. In-situ direct shear test was performed in different normal stress at GL-2m test site and a normal stress at GL-4m test site.

### 2.2 Test results

The direct shear test in laboratory has been also conducted using SWM sampled from the direct shear test box of GL-2m on same site in Japan. Specimen was prepared in the shear box with three layers under normal stress of 20 kN/m$^2$ for 1 minute for each layer. Specimen was made in the same density of the in-situ test. The same normal stress of in-situ test was also applied for the direct shear test in laboratory. Difference of two direct shear tests was undisturbed or disturbed specimens. Shear property of SWM is investigated by differences of these two test results. Figure 4 shows a comparison of shear strength between undisturbed and disturbed specimens. It is found that

the values of shear strengths are almost same.

Shear tests at the site of GL-2m and GL-4m were performed under the conditions of three normal stresses (5.14, 10.9, 16.35 kN/m$^2$) and a normal stress of 10.9 kN/m$^2$, respectively. Relationships between shear stress and shear displacement under the ground level of 2 m and 4 m on the improper disposal site are obtained from this test. Test result indicates that shear stress of SWM in each test condition increases linearly with increase of shear displacement and a peak shear stress is not appeared. Furthermore, the SWM dilates as the shear displacement increases and this tendency becomes clear at larger normal stress condition. In comparison of the same normal stress of 10.9 kN/m$^2$, shear stress and vertical displacement of SWM at the site of GL-4m are larger than those of the SWM at the site of GL-2m at the same shear displacement. However, the wet density of GL-4m site was slightly low compared with that of GL-2m. This may indicate that shear property of SWM depends on not only density but also stress history.

### 3 IN-SITU EARTH PRESSURE TEST

#### 3.1 Idea for earth pressure test

As mentioned in previous chapter, strength of solid waste material can be measured using the developed direct shear test. However, it takes a time for cutting and preparing the rectangular–shaped specimen. It is therefore that a simple method for estimating in-situ strength of the SWM is required. A new type of earth pressure test was developed for this purpose. When three or more values of passive earth pressures are measured using this type of in-situ test in different embedded length, strength parameters of cohesion and frictional angle are estimated based on the theory of coulomb earth pressure.

Idea of application for earth pressure test on inclined ground is shown in Figure 5. Equilibrium of moment for total passive pressure, $P$, and pull-out force, $T$, is shown as Eqs. (1) and (2).
where, $K_P$: coefficient of passive earth pressure, $c$: cohesion of soil, $H$: embedded length, $L$: distance from ground surface to pull-out force, $B$: effective width of earth pressure, $s$: distance from ground surface to fixed point, $R$: total entire length of bar, $\gamma$: weight per unit volume of soil, $\theta$: angle of inclination of bar, $i$: angle of inclination of ground surface, $d$: friction angle of wall.

Left-hand side of Eq. (1) can be obtained from pull-out force, $T$, and other test conditions such as length of bar. When we perform several tests in different embedded length of bar, a linear relation between $Y$ and $H$ is obtained. Intercept and inclination of Equation 1 are represented as $0.81 \times 2c(K_p)^{1/2}$ and $\gamma K_p / 2$, respectively. As a result, $K_P$ can be calculated using weight per unit volume of soil $g$. Furthermore, cohesion is also obtained from this equation. Equation 2 is a coefficient of passive earth pressure in the theory of coulomb earth pressure considering inclination of ground surface.

### 3.2 Test results

In this study, in-situ earth pressure test was applied to solid waste ground. Figure 6 shows a situation of in-situ earth pressure test. Seven steel bars with length of 1m are used and these bars are installed into the ground in 50 mm distance. After connection of these bars, the ground was deformed until passive earth pressure condition. Inside earth pressure of just five bars is measured in consideration of influence of friction for edge. Effective width of earth pressure in this test was 270 mm. When the bars are inclined, self-weight of the bars is also considered in the calculation of equilibrium force. From several test results, inclination of angle of bar, $\theta$, at maximum earth pressure is approximately 100-110°. It is assumed that angle of inclination of ground surface is $i=0$ and friction angle of wall is $d = (2/3) \phi$.
Figure 7 shows the relationship between pull-out force and inclination of the angle of the bar. Clear peak value of pull-out force is found in the conditions of different embedded length.

In order to confirm the validity of this method, in-situ earth pressure and direct shear tests were applied to various grounds. Three kinds of grounds were selected, namely, building land ($\gamma_t = 1.678$ Mg/m$^3$), two sites of SWM without plastic waste ($\gamma_t = 1.964$ Mg/m$^3$) and SWM including plastic waste ($\gamma_t = 1.678$ Mg/m$^3$). Relationship between shear strength and vertical stress on each ground is shown in Figure 8. On the other hand, relationship between $Y$ in Eq. (1) and embedded length on each ground is shown in Figure 9. From intercept and inclination in a linear relation of Figure 9, cohesion and frictional angle of the ground are calculated.

Figure 10 shows the comparison of strength parameters obtained from in-situ direct shear and earth pressure tests. Cohesion calculated from the earth pressure test is relatively small in comparison to that obtained from the direct shear test. On the other hand, frictional angle calculated from the earth pressure test is larger than that obtained from the direct shear test. This may be caused by a difference of confining stress. As shown in the figures (a) and (b), these have a linear relation. In other words, cohesion and frictional angle obtained from the in-situ direct shear and earth pressure tests are correlated respectively.

**CONCLUSION**

In this study, a new type of in-situ earth pressure test was developed. Strength parameters are evaluated from test results of the in-situ earth pressure test in different embedded length of steel bar. Cohesion and frictional angle obtained from the in-situ direct shear and earth pressure tests are correlated respectively. The in-situ earth pressure test is very simple method. It is therefore that the strength property of solid waste materials can be estimated as an approximate value.

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