Behavior of soft plastic in illegally dumped solid waste according to effective stress changes

Seiji Kawai\textsuperscript{i)}, Takayuki Shimaoka\textsuperscript{ii)} and Shinya Sakaguchi\textsuperscript{iii)}

\begin{flushleft}
i) Assistant Professor, Research Institute for East Asia Environments, Kyushu University, 744 Motoooka Nishi-ku Fukuoka 819-0395, Japan.  
ii) Professor, Department of Urban and Environmental Engineering, Faculty of Engineering, Kyushu University, 744 Motoooka Nishi-ku Fukuoka 819-0395, Japan.  
iii) Maeda Corporation, 2-14-1, Hakatahigashi Hakata-ku Fukuoka 812-0013, Japan.  
\end{flushleft}

\section*{ABSTRACT}

The soft plastic mixed into solid waste landfills exhibits a reinforcing effect similar to that of geotextiles and significantly affects the assessment of slope stability. However, little research has focused on the reinforcing effect of soft plastic. In this study, the tension force generated on soft plastic under effective stress changes caused by gas pressure or pore water pressure was measured using strain gauges. The tension force corresponded with Terzaghi's principle with respect to the increasing or decreasing tendency; however, the relationship between the tension force and effective stress decreased parabolically with decreasing effective stress. In particular, tension force decreased rapidly after the effective stress decreased by half.

\textbf{Keywords:} solid waste landfill, soft plastic, tension force, strain, effective stress

\section*{1 INTRODUCTION}

A large amount of solid waste mixed with plastic, which was formed by the illegal dumping or improper disposal of industrial waste, exists in Japan. Due to many factors, these waste landfills maintain stable conditions despite their steep slopes; in some cases, waste is deposited vertically without slope failure (Fig. 1). However, these waste landfills have the potential to fail over the long term. Therefore, it is necessary to evaluate their medium- to long-term geotechnical stability appropriately to facilitate the monitoring and effective use of these landfill sites in the future. Because incineration has been adopted as the principal method of intermediate waste treatment and most waste in Japan is disposed of as incinerated ash, the mechanical properties of solid waste landfills mixed with plastic have not previously been well researched.

Overall, the solid waste landfills in Japan are similar to the final disposal landfills formed by municipal solid waste (MSW) in many areas overseas. A number of shear testing studies with MSW have been conducted in the past; however, most of those test results have indicated no peak, and shear stress continued to increase up to the displacement limit of the test apparatus\textsuperscript{3).} These shear properties of MSW are considered to be due to the tensile resistance exerted by fibrous materials such as paper and plastic. Furthermore, some reports have indicated that the Mohr-Coulomb failure envelope would not be valid because the evaluation of the triaxial compression test would not deliver a correct Mohr envelope\textsuperscript{3).} Taking this background into consideration, the authors focus on the reinforcement mechanism of the soft plastic included in solid waste landfills and attempt to develop a new method that differs from a conventional shear test. This paper aims to investigate the behavior of soft plastic, which significantly affects the slope stability evaluation of solid waste landfills, under effective stress changes caused by increasing gas pressure or pore water pressure.

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{Fig_1.png}
\caption{Illegal dumping site exhibiting a slope failure crisis.}
\end{figure}

\section*{2 REINFORCEMENT MECHANISM OF SOFT PLASTIC}

Various shapes of soft plastic are contained in waste landfills; however, the authors assume that soft plastic pieces, several tens of centimeters in size, primarily
Because of the reinforcing effect similar to that of geotextiles [4], the reinforcement mechanism of geotextiles is as follows. When the soil is deformed by an increase in vertical stress, the geotextile is elongated due to the friction between the soil and its surface, and tension force is generated. This tension force generated on the geotextile will behave as a confined stress for the soil particle, and the generation of tension force depends on the strength of the geotextile’s tendency to return to its original length. Therefore, the geotextile must be elongated to exert its reinforcing effect in the soil. Soft plastics have a similar reinforcement mechanism, and they must also be elongated within the landfill (Fig. 2). In other words, the elongation or shrinkage of the soft plastic in a solid waste landfill will result in an increase or decrease in the tension force generated on the soft plastic. Here, the elongation or shrinkage of soft plastic in solid waste landfills was measured using strain gauges. The measured data can be used as an indicator of the relative elongation conditions of soft plastic. As vertical stress increases, soft plastic is elongated along the uneven surface of waste particles due to the particles becoming denser by compression [5]. In this paper, an increase or decrease in the strain (tension force) on the soft plastic under changing effective stress caused by increasing gas pressure or pore water pressure will be reported.

![Fig. 2. Schematic representation of the reinforcing effect exerted by soft plastic.](image)

### 3 MATERIALS AND METHODS

Waste specimens were collected from an illegal dumping site (Fig. 1) located in the Kanto Province of Japan, and the composition of the specimens was analyzed. Although plastic is usually classified as one item, in this study, plastics were divided into soft and hard plastic. Soft plastic is easily elongated by hand and is a sheet or band, including film and sheets of packaging material. Conversely, hard plastic is difficult to elongate by hand and has a three-dimensional structure, including plastic containers. In this paper, "plastic" is used to indicate both soft and hard plastic. Non-plastic specimen components included the materials that could pass through a 4.75 mm screen, which was predominantly soil in the specimen. Paper and kitchen waste were not included. Glass was included, such as debris from glass bottles; however, this was classified as gravel and rubble in this study. The proportions of each specimen component by dry weight are shown in Fig. 3. Specimens were dried using an incubator at 110°C for 24 hours. After drying, some soil was still attached to the plastic, and this was removed as much as possible by hand. As a result, gravel and rubble accounted for 49.1% of the specimen, hard plastic 5.9%, soft plastic 1.5% and other materials 35.4%. These four categories accounted for 91.9% of the total specimen weight. Soft plastic, the focus of this study, appeared to represent a larger percentage of the specimen by volume than by weight. However, no method for the volume measurement of soft plastic has been established, so these values could not be measured precisely.

![Fig. 3. Composition of waste specimen.](image)
were supplied by Tokyo Sokki Kenkyujo Co. Ltd. The strain gauges were attached at 3 positions on each piece of soft plastic: the center and 75 mm left and right of the center. The pieces of soft plastic were placed at the same depths as the water pressure gauges (Fig. 5).

The waste specimen was compacted in four lifts containing 100 pieces using a 2.5 kg ram and a free fall height of 30 cm. The properties of the waste specimen in the container are shown in Table 1. The wet density was equal to the in situ wet density, which ranged from 1.07 to 1.29 g/cm³. The test procedure is summarized in Table 2. After the specimen was placed in the container, the loading was increased to 80 kPa in stages using the air jack. Then, the air pressure supplied by the compressor was substituted for gas pressure, which was gradually increased to 80 kPa under a constant loading. Subsequently, the gas pressure was lowered to 0 kPa, and CO₂ was injected to increase the saturation (injection pressure 20 kPa). After that, degassed water was injected from the bottom of the container with an initial water level 90 cm, and the pore water pressure was increased to 80 kPa in stages. The changes in the loading from the air jack, gas pressure or pore water pressure occurred every 30 minutes. The measured strain of the soft plastic was corrected for the influence of temperature change caused by the infiltration of CO₂ and degassed water.

Table 1. Properties of the waste specimen in the container.

| Property          | Unit | After filling of waste specimen | After infiltration of degassed water |
|-------------------|------|----------------------------------|-------------------------------------|
| Wet density       | g/cm³| 1.23                             | 1.58                                |
| Dry density       | g/cm³| 1.04                             | 1.09                                |
| Moisture content  | %   | 18.5                             | 44.7                                |
| Density of soil   | g/cm³| 2.43                             | 2.43                                |
| Void ratio        |      | 1.34                             | 1.23                                |
| Saturation        | %   | 33.4                             | 88.5                                |

Table 2. Test procedure.

| Step | Operation               | Elapsed time (hours) |
|------|-------------------------|----------------------|
| 1    | Increase of vertical stress | 0.0 – 4.1            |
| 2    | Increase of gas pressure | 4.1 – 8.1            |
| 3    | Maintenance of vertical stress | 8.1 – 19.3          |
| 4    | Infiltration of CO₂      | 19.3 – 22.4          |
| 5    | Infiltration of degassed water | 22.4 – 25.5       |
| 6    | Increase of pore water pressure | 25.5 – 29.5       |

4 TEST RESULTS

The change in the effective stress in the container over elapsed time is shown in Fig. 6. The effective stress was calculated as \( \sigma = \sigma' - u \) (\( \sigma' \): effective stress, \( \sigma \): total stress, \( u \): pore water pressure) and was based on the assumption that solid waste landfills comply with Terzaghi’s principle. Total stress was obtained from the self-weight of the material and the vertical stress, which was measured by the compression indicator attached to the loading plate. The pore water pressure in the container was obtained from the average of the three water pressure gauges. In this study, the effect of suction was ignored, and gas pressure was obtained using the water pressure gauges in the same way as pore water pressure.

The change in the strain on the soft plastic over elapsed time is shown in Fig. 7. The estimated strain on the middle layer presents negative values because the soft plastic was elongated in the transverse direction and the longitudinal direction when measuring the strain and was subjected to compression force by Poisson deformation. The estimated strain differed among the three layers because the size of the uneven surface between the waste particles and soft plastic was different in each location. Although the increasing or
decreasing tendencies of the strain and the effective stress were basically the same, the change in the strain caused by CO\textsubscript{2} infiltration (step 4) was not clear. Temperature changes caused by CO\textsubscript{2} infiltration and the effects of upward gas flow should be suspected; however, the measured strain on the soft plastic was corrected for the influence of temperature changes, and the change in effective stress due to CO\textsubscript{2} infiltration was approximately 3\%. Furthermore, the upward gas flow was also negligible because the exhaust CO\textsubscript{2} from the outlet of the loading plate could be easily blocked with a finger.

5 DISCUSSION

The effects of change in effective stress on the ratio between strain and effective stress (strain/stress) in step 1 and step 6 are shown in Figs. 8 and 9, respectively. The results showed that in step 1, the increase in strain/stress was approximately proportional and linear with a monotonic increase in effective stress (Fig. 8). By contrast, the results for step 6 revealed a parabolic decrease in strain/stress with decreasing effective stress (Fig. 9). The tension force generated on the soft plastic (measured strain) corresponded with Terzaghi’s principle with respect to its increasing or decreasing tendency; however, the curve of the decrease was parabolic rather than linear. The tension force decreased particularly rapidly after the effective stress decreased by half. The effective stress between waste particles will decrease in accordance with an increase of gas pressure or pore water pressure. Furthermore, the decrease in the tension force exerted on the soft plastic will also cause a decrease in the effective stress between waste particles. As a result, solid waste landfills will destabilize rapidly, particularly after the effective stress decreases by half.

6 CONCLUSIONS

Based on the results obtained, the following conclusions can be drawn:

1) The tension force generated on soft plastic corresponded with Terzaghi’s principle with respect to its increasing or decreasing tendency.

2) The tension force on soft plastic exhibited a parabolic decrease with decreasing effective stress. The tension force decreased particularly rapidly after a decrease in the effective stress by half.

![Fig. 7. Strain on the soft plastic at different depths over elapsed time.](image1)

![Fig. 8. Effective stress and ratio of strain to effective stress (step 1).](image2)

![Fig. 9. Effective stress and ratio of strain to effective stress (step 6).](image3)

ACKNOWLEDGEMENTS

The work presented here was funded by the Environment Research and Technology Development Fund (ERTDF) under Grant No. K2401 provided by the Ministry of the Environment, Japan.

REFERENCES

1) Stark, D. T., Huvaj-Sarihan, N. and Li, G. (2009): Shear strength of municipal solid waste for stability analyses, Environmental Geology, Vol.57, pp.1911-1923.

2) Bauer, J., Koelsch, F. and Borgatto, V.A., A. (2008): Stability analysis according to different shear strength concepts exemplified by two case studies, Proceedings of The 5th Asian-Pacific Landfill Symposium, Sapporo, Hokkaido, Japan.

3) Kawai, S., Shimaoka, T. and Yamawaki, A. (2014): Geotechnical Stabilization of Illegally Dumped Solid Waste Mixed with Soft Plastics: Eurasia2014 Waste Management Symposium, pp.467-474.

4) Kawai, S., Shimaoka, T. and Yamawaki, A. (2014): Fundamental study on the reinforcing effect exerted by soft plastic in landfill, Geosynthetics Engineering Journal, No.19, pp.169-176.