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Improvement effect of composite geomaterial by utilization of plastic wastes

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ABSTRACT: Recycle of plastic wastes has not proceeded smoothly, so that it is expected to build up the recycling system of the wastes from geotechnical point of view. As one of the methods in reuse of the wastes, it is considered to mix pieces of plastic waste with soil. This method enables to recycle plastic wastes stably for a long term. In order to clarify improvement effect on mechanical properties of composite geomaterial with plastic pieces, unconfined compression test and tensile splitting test were performed for two kinds of soils, cement-treated soil and air-formed lightweight soil, and the effectiveness is confirmed for various plastic wastes. Furthermore, the application to surface stabilized ground is discussed based on the results of model loading test and deformation analysis.

1 INTRODUCTION

The amount of wastes has increased year by year and the disposal becomes a serious problem in Japan. Particularly, recycling ratio of the plastic wastes in life and industry is low and many of them have been reclaimed for the reason of unsuitable ones for incineration. It is necessary to utilize the wastes effectively with technical development in each field. From view point of geotechnical engineering, it is considered that geomaterial mixing small pieces of plastic such as PET bottle is one of the methods (Omine et al 1996). In this paper, the improvement effects of the strength of cement-treated soil and air-formed lightweight soil due to mixing pieces of plastic wastes are investigated based on the results of unconfined compression test and tensile splitting test. Furthermore, an application of composite geomaterial with plastic pieces to surface stabilized ground is verified by the model loading test and the result of deformation analysis on bearing capacity of the surface stabilized ground.

2 MECHANICAL PROPERTY OF COMPOSITE GEOMATERIAL WITH PLASTIC PIECES

2.1 *Cement-treated soil*

(a) Soil sample and testing method

First, plastic sheet for the card case (the thickness of 0.4mm, the density of 1.38g/cm^3) is used in place of the PET bottle. The plastic sheet is cut in the length of 48mm and the width of 3mm. Kaolin clay (w_L=50.6%, I_p=19.6 and ρ_s=2.70g/cm^3) is used as a soil sample. After adding Portland cement to the sample with water content of 100%, the plastic pieces are mixed with it. The cement content C is 50, 100, 200, 300kg/m^3 and the plastic content M is 0, 2.5, 5.0, 7.5% in volume fraction. The specimen of unconfined compression test is in the width of 100×100mm and the height of 200mm, and that of the tensile splitting test is in the diameter of 150mm and the height of 75mm. After curing those specimens during 7 days in the thermostatic chamber of 20°C, each test is performed. Furthermore, other plastic wastes, fishing net (nylon thread) and plastic film for agriculture (soft vinyl sheet), are also used for clarifying the differences in kind of plastic material.

(b) Deformation-strength property

Figure 1 shows the relationship between compressed stress and axial strain on the cement-treated soil with plastic pieces in the case of cement content 100kg/m^3, which is obtained from the unconfined compression test. Maximum compressive strength of the cement-treated soil with plastic pieces increases with increase in the plastic content. In addition, after reaching to peak strength, softening of the cement-treated soil becomes small due to mixing plastic pieces and the brittle behavior has been improved. Such improvement effect of the strength has been also confirmed under the triaxial compression stress condition. On the other hand, the result of the tensile splitting test is shown in Fig.2. The vertical and horizontal axes represent a tensile stress and a compression ratio, respectively, where the compression-

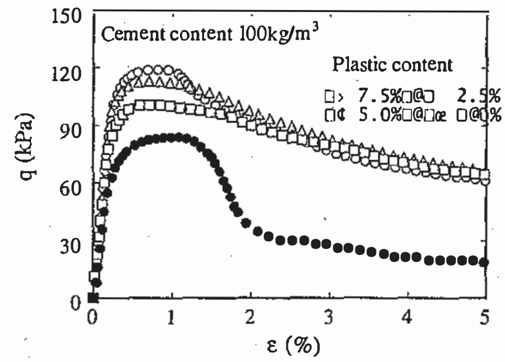

Figure 1. Relationship between compressive stress and axial strain of cement-treated soil with plasitc pieces

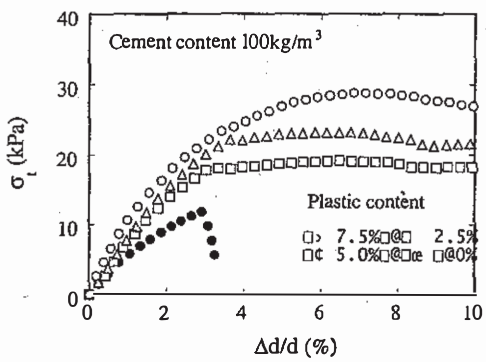

Figure 2. Relationship between tensile stress and compression ratio of cement-treated soil with plasitc pieces

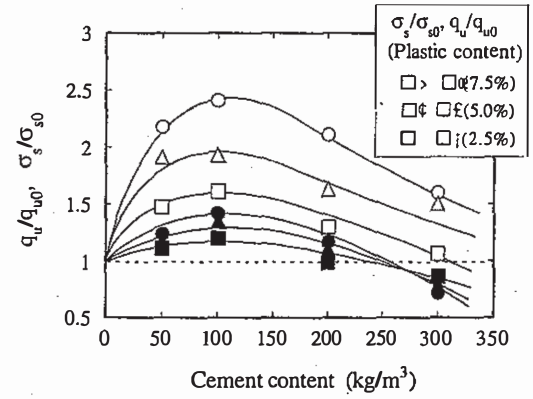

Figure 3. Influence of cement content on Improvement effect for unconfined compressive and tensile strengths

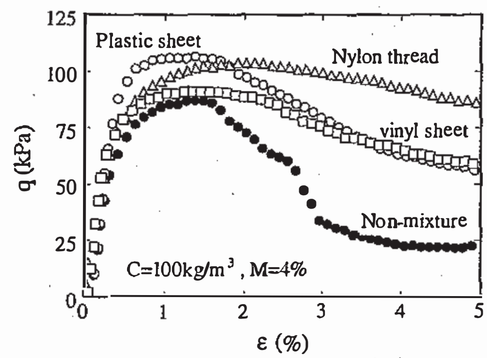

Figure 4. Relationship between compressive stress and axial strain of cement-treated soil with various plasitc wastes

ratio is defined as the value of compressive deformation divided by specimen diameter. The cement-treated soil without plastic occurs a brittle failure suddenly after reaching to the peak strength, whereas the tensile strength in the case of mixing plastic pieces increases remarkably and the high residual strength sustains after reaching to the peak strength.

As an index of the improvement effect of the strength due to mixing plastic pieces, the strength ratio of the cement-treated soils with plastic pieces and without it is used. The improvement effects for the unconfined compressive strength and the tensile strength, q_u/q_{u0} and σ_s/σ_{s0}, are shown in Fig.3, where subscript "0" means the case without plastic piece. As shown in the figure, the effect for tensile strength is large in comparison with the unconfined compressive strength. In addition, the maximum value is seen at the cement content of approximately 100kg/m^3. It is considered that the improvement effect of strength is not decided meaningfully by only cement content, and it depends on curing period and other factors. On the other hand, when the cement content becomes large, the improvement effect decreases. It should be noted that there is a limitation of the application for the large cement content. It is suggested that this method of mixing plastic pieces is effective for subsurface stabilization of soft ground, because it enables to improve tensile strength considerably.

Next, the figure 4 shows the test result of the unconfined compression test on the cement-treated soil mixed with various type of plastic wastes under the conditions of the cement content of 100kg/m^3 and plastic content of 4%. When each plastic waste is mixed, the maximum compressive strength has become large in comparison with it in the case of non-mixture. Softening after peak strength is small in the case of the cement-treated soil with plastic pieces, and it changes to ductile material. The improvement effect is shown in Fig.5 as a relationship between the q_u/q_{u0} and the cement content. The clear improvement effect has appeared in the case of the cement content of 100~200kg/m^3. This tendency is seen for each type of plastic material. The effectiveness is in order of the nylon thread, plastic piece and vinyl sheet. The reason is considered that the surface of the nylon thread is rough and the friction is large, and the vinyl sheet has smooth surface and small rigidity.

2.2 *Air-formed lightweight soil*

Not only the cement-treated soil but also air-formed lightweight soil has a brittle behavior. In order to confirm the improvement on strength of the light

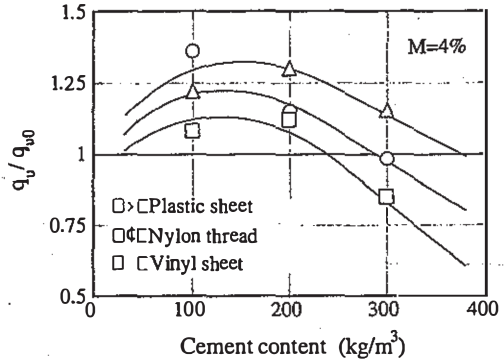

Figure 5. Improvement effect for unconfined compressive strength of cement-treated soil with various plastic wastes

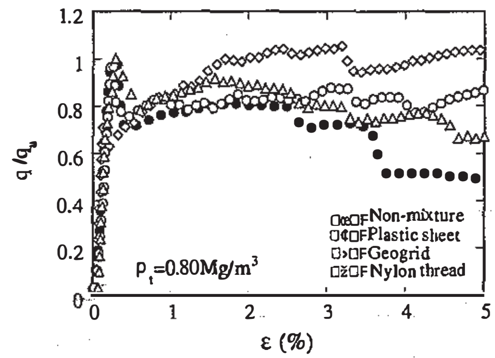

Figure 6. Relationship between normalized compressive stress and axial strain of light-weight soil with various reinforcement materials

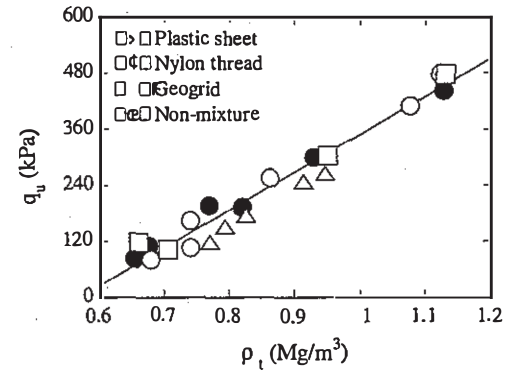

Figure 7. Relationship between unconfined compressive strength and density of light-weight soil with plastic pieces

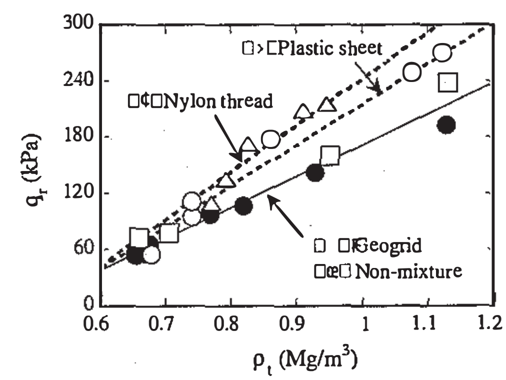

Figure 8. Relationship between residual strength and density of light-weight soil with plastic pieces

weight soil, the unconfined compression test is performed.

(a) Soil sample and testing method

Soil sample is prepared by mixing Kaolin clay and silica sand (ρ_s=2.63g/cm^3) in dry weight ratio of 7:3. After adding Portland cement into the sample with water content of 56%, plastic pieces and air form are mixed. The specimen is made in a mould for curing of 7 days. For comparing the difference of improvement effect, the unconfined compression test on the lightweight soil lying 4 sheets of Geogrids in horizontal direction is also performed.

(b) Deformation-strength property

Figure 6 shows the result of the unconfined compression on the air-formed lightweight soil with plastic pieces in a density of approximately 0.8 g/cm^3. In consideration of scatter for density of the specimen causing by a difference of mixing condition, the normalized compressive stress by the unconfined compressive strength is represented in the vertical axis of the figure. The lightweight soil without plastic piece shows the maximum strength at small axial strain, and after that, the stress decreases suddenly. It is found that such brittle failure of the lightweight soil is improved by mixing plastic pieces. Next, the improvement effects on peak strength and residual strength of the lightweight soil are discussed. Figure 7 shows the relationship between the unconfined compressive strength and the density of the lightweight soil. As shown in this figure, it is understood that the improvement effect for the peak strength at the same density does not appear clearly in mixing each plastic waste. Because the air-formed lightweight soil includes many air bubbles and Poisson's ratio is approximately 0.1, it is considered that tensile stress does not work in the plastic pieces and the improvement effect does not appear. On the other hand, concerning the improvement effect of the toughness, the relationship between the residual strength and the density of the lightweight soil are shown in Fig.8. Herein, the residual strength is de fined as the compressive stress at the axial strain of 5%. The residual strength of the lightweight soil with plastic pieces is larger than that in the case of non-mixture at the same density. Namely the improvement effect due to mixing plastic pieces has appeared in residual strength. It may be said that the tension stress of the plastic pieces works when the large deformation of the lightweight soil causes after reaching to peak strength.

Thus, when a number of the reinforcement material in a thin and long shape such as plastic piece ornylon thread are mixed, it is found that the im provement effect appears clearly for residual strength of the air-formed lightweight soil.

3 APPLICATIONS TO SURFACE STABILIZED GROUND

3.1 *Deformation analysis of surface stabilized ground*

In order to clarify the property of bearing capacity of the surface stabilized ground with plastic pieces, the deformation analysis with two dimensional elasto-plasticity is done using finite element method in consideration of the strength property of the improved soil. Usually, crack occurs in the surface stabilized ground when it reaches bending failure with increase of loading stress. Because this crack is a factor to influence the bearing capacity, it is important to consider the occurrence of the crack in the analysis. The model of stress-strain relationship on the element with yield is shown in Fig.9. Type-A supposes the model without the crack for the cement-treated soil with plastic pieces and Type-B supposes the model with the crack for that of non-mixture. Figure 10 shows the failure envelop on the basis of the failure criteria of Mohr-Coulomb. The maximum tensile stress in the element follows the bending strength σ_{by} and the maximum shear stress follows the undrained shear strength c_u (=q_u/2). The parameters for the analysis are shown in Table 1 and these values were obtained from the unconfined compression test and the bending test of the lightweight soil with density ρ_t =1.0 g/cm^3. The mesh used in FEM analysis is shown in Fig.11. The cases of the analysis are as follows;

Case-1: Surface stabilized ground without reinforcement (Type-B)

Case-2: Reinforcement by laying a sheet of Geogrid in the surface stabilized ground (Type-B+Bar element for Geogrid)

Case-3: Mixture of plastic pieces in the surface stabilized ground (Type-A)

Figure 12 shows the relationship between loading stress and settlement at the central point based on the analysis. The arrow in the figure represents the elastic limit which means yield stress. In the case-1 without reinforcement, it reaches to brittle failure at a small loading stress. In the case-2 with the bar element, yield stress of the stabilized ground increases somewhat due to tensile stress of the Geogrid, but the brittle behavior is not improved. However, in the case-3 with plastic pieces, yield stress of the stabilized ground increases and the material property changes from the brittle behavior to the ductile behavior.

From these results of the analysis, it became clear that the property of bearing capacity of surface stabilized ground is improved considerably for the increase of toughness due to mixing the plastic pieces.

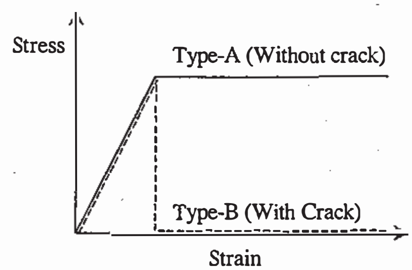

Figure 9. Model of stress-strain relation on the element

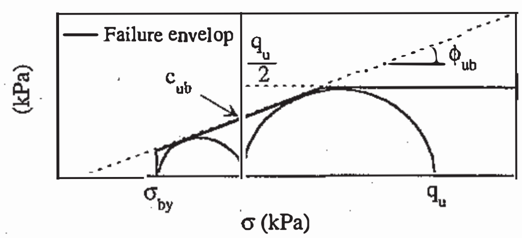

Figure 10. Failure envelop line used for the cement-treated soil

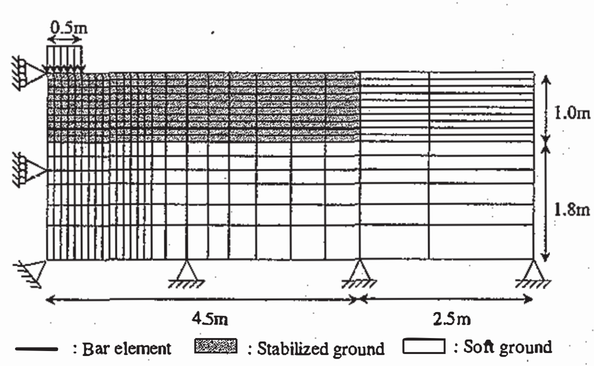

Figure 11. Mesh for deformation analysis

Table 1. Parameters used in deformation analysis

		stabilized ground		soft ground
Plastic piece		Non-mixture	Mixing	-
Size	Width (m)	4.5	4.5	7.0
	Depth (m)	1.0	1.0	1.8
Young's modulus E (kPa)		148000	160000	100
Poisson's ratio ν		0.1	0.2	0.3
Shear modulus G (kPa)		67300	66700	65
ϕ_{ub} (°)		30.8	27.9	45.0
c_{ub} (kPa)		126	145	1000
q_u (kPa)		444	480	-
Bending strength σ_{by} (kPa)		143	174	-

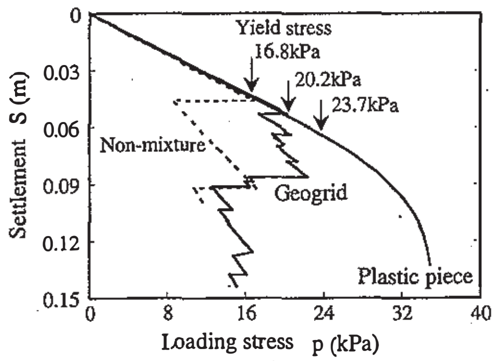

Figure 12. Relationship between loading stress and settlement at the center (Result of analysis)

3.2 *Verification by model loading test*

(a) Testing method and test results

Figure 13 shows the apparatus of model loading test. Soft ground has been supposed as the Winckler model gathering of the spring. The stabilized ground is prepared using mould by the same method in the section 2.1. Size of the model ground is the length of 1.09m, the depth of 0.3m and the depth of 0.1, 0.15, 0.2m. Soil sample is Kaolin clay and the cement content is $100kg/m^3$. Loading stress is applied at the center of the model ground using rigid plate in the width of 0.1m under displacement control condition of 1mm/min, and the settlement is measured at 11 points on the one side from the center.

The relationship between normalized settlement *S/B* at the center and loading stress *p* on the stabilized ground in the thickness of 0.1m is shown in Fig.14, where *B* is width of the loading. The stabilized ground shows almost proportional relation between the *S/B* and the loading stress until yield stress independent of plastic content. Concerning the property of bearing capacity, the stabilized ground in case of *M*=0% shows brittle behavior with clear failure, but that in case of *M*=5% has a ductile property without clear failure. When the yield stress is defined at the largest curvature point for the case of *M*=5%, it is clear that the yield stress increases due to mixing plastic pieces. The sketch of the stabilized ground after the test is shown in Fig.15. When the plastic piece is not mixed, the large crack occurs at the both edges of the loading plate. On the other hand, in the case of *M*=5%, several small cracks occurs and the excessive crack is restricted by mixing plastic pieces. The same results have been obtained for the stabilized ground in the thickness of 0.15 and 0.2m. Therefore, it became clear from the experiments that the bearing capacity of surface stabilized ground is improved considerably by mixing plastic piece.

(b) Comparison between calculation and test results

The FEM analysis for the loading model ground is done by the same way of section 3.1. Figure 16 shows the comparison between calculation and test results on the yield stress of the surface stabilized ground with different thickness. The parameters used in the analysis are shown in Table 2. These values of the parameters were decided from the unconfined compression test and the bending test of the cement-treated soils with or without plastic pieces. Predicted yield stress corresponds well with the test results. It is said that the FEM analysis is ef-

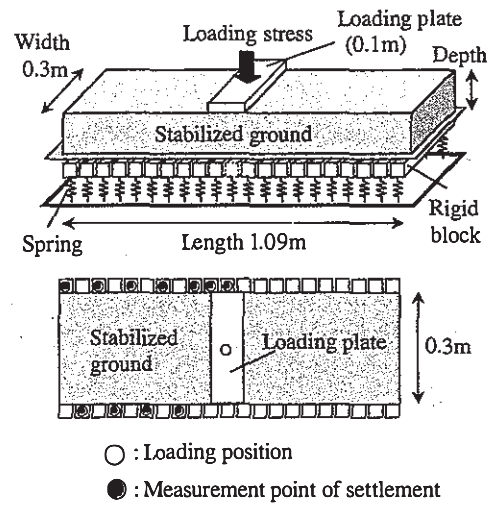

Figure 13. Model loading test apparatus for surface stabilized ground

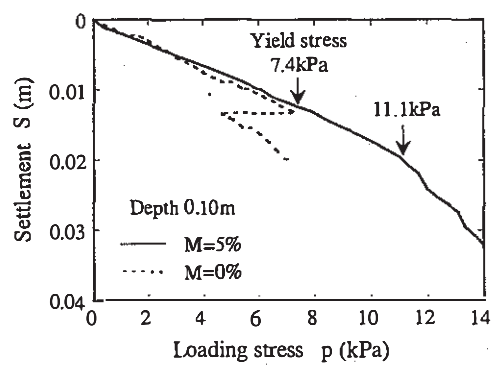

Figure 14. Relationship between loading stress and settlement at the center (Test result)

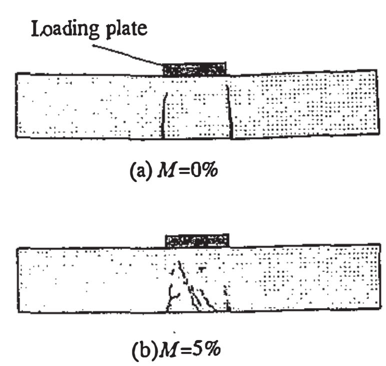

Figure 15. Failure pattern of surface stabilized ground

Table 2. Parameters used in deformation analysis for model test

		stabilized ground		soft ground
Plastic content		M=0%	M=5%	-
Size	Width (m)	0.55		0.55
	Depth (m)	0.1, 0.15, 0.2		0.15
Young's modulus E (kPa)		40000	63000	100
Poisson's ratio ν		0.3	0.3	0.3
Shear modulus G (kPa)		26000	40950	65
ϕ_{ub} (°)		22.8	21.7	45
c_{ub} (kPa)		27.9	38.5	1000
q_u (kPa)		84	84	-
Bending strength σ_{by} (kPa)		37	52	-

fective for such surface stabilized ground with bending failure. In addition, it is also possible to evaluate settlement behavior of surface stabilized ground by the analysis considering the occurrence of the crack as indicated before section.

4 CONCLUSIONS

The main conclusions obtained from this study are as follows:

1) The unconfined compressive strength and tensile strength of the cement-treated soil are increased by mixing the plastic pieces. The improvement effect of the strength depends on the cement content and the optimum condition exists.

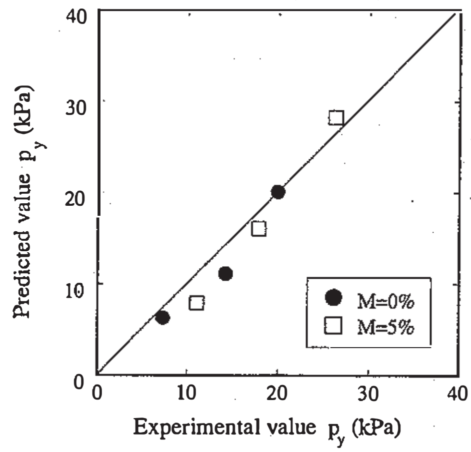

Figure 16. Comparison between calculation and test results on the yield stress

2) Mixing plastic pieces enables to increase residual strength of the air-formed lightweight soil and the brittle behavior is improved.
3) The toughness and yield stress of the stabilized ground are increased by mixing plastic pieces.
4) Composite geomaterial mixing plastic wastes such as PET bottle or fishing net is effective for the utilization of the wastes.

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