Study on basic properties of soil-slag mixtures and applicability as a fill material to improve aseismicity of embankment

Kyungbeom Jeong[1], J. Baek[1], J. Hur[2], and S. Shibuya[1]

[1] Graduate school of Civil Engineering, Kobe University, #, 1-1, Rokkodai-cho, Nada-ku, Kobe, 657-8501, JAPAN.
[2] Kyowa sekkei Co., Ltd., #, S2-1-34, Ushitora, Ibaraki-shi, Osaka, 567-0877, JAPAN.

ABSTRACT

Bearing in mind that the demand to use fine-grained local soil mixed with steel slag as fill material in geotechnical engineering practice has recently been increasing in Japan. Accordingly, engineering properties of the mixture of a fine-grained soil with various kinds of steel slag, which is a by-product of steel industries, were thoroughly examined in the laboratory. In this study, the samples were prepared using a fine-grained natural soil mixed with each of three types of steel slag, together with Ashstone, the light-weight granular material consisting of flyash and Portland cement. The physical properties of the various mixtures with different content of the fine-grained soil were in detail examined. The compaction characteristics and the shear strength were also measured for each mixture. It was found that the shear strength were greatly improved when considering the use as fill material. In addition, it is manifested in pseudo-static limit equilibrium analysis that aseismicity is improved by using the mixture of Ash Stone & GBFS with the soil for embankment.

Keywords: soil-slag mixtures, compaction characteristic, shear strength, embankment, aseismicity

1 INTRODUCTION

Construction of high-rise buildings for habitation and other large-scale civil structures, such as dams and road embankments, are increasing every day to fulfill the need of growing urbanization. Accordingly, there is high demand of granular earthfill materials and practicing engineers are striving for finding suitable and economical alternatives. On the other hand, almost 40 million tons of various types of steel slag, a by-product of steel industries, is produced in Japan every year and is being recycled for various purposes (Ministry of the Environment in Japan 2013). Besides the use in cement production as a raw material, civil engineering fields, such as sea walls, dams and road embankments, are the primary area of concurrent use.

Recently, locally available fine-grained soils may need to be used in embankments. However, requirements for gradation, strength, permeability are hardly satisfied in natural conditions. Accordingly, there is a need to improve the fine-grained local soil properties by mixing with some alternative coarse-grained geomaterial. To cater such needs by using a natural coarse-grained geomaterial would be difficult not only in terms of the cost but also the quality control. On the other hand, the steel slag that is by-product in the process of producing steel is much cheaper and can be well controlled in quality and therefore, their potential applicability is examined in this research. Steel slags may serve the purpose of natural gravels and therefore, can be the preventive solution of many environmental problems that is induced by excessive harnessing of the natural resources.

In this paper, a locally available silty soil is mixed with various proportions of slags and fly-ash products. And, grading, compaction and strength characteristics were examined in the laboratory. In addition, pseudo-static limit equilibrium analysis was carried out in order to examine the aseismicity of the embankment with each mixtures, bearing in mind of their potential applicability as a fill material in geotechnical engineering practice.

2 PHYSICAL PROPERTIES

The three types of steel slag used in this research are Steelmaking slag (SM slag), Electric Arc Furnace slag (EF slag) and Granular Blast Furnace Slag (GBFS). The SM slag and EF slag are heavier in weight. On the other hand, the GBFS resembles to a natural-sand in the physical properties. The other two fly-ash products, named here as “Ash Stone A” and “Ash Stone B”, procured from two different makers were also tested for a comparative study. These Ash Stones are the mixture of light-weight fly-ash with the Portland cement. A silty soil, for which the evaluation of engineering properties enhancement is investigated in this study, is originated from a river dike in Kyoto. Fig. 1 shows the pictures of these materials.

Table 1 shows the primary properties (natural water content, particle density, water absorption ratio, liquid limit and plastic limit) of all the tested materials. Note that the particle densities of Ash Stones A and B, 2.393g/cm^3 and 2.410g/cm^3 respectively, are lighter in weight as compared to natural soils. The absorption rate was irrationally high with the value as high as 40%. The particle density of GBFS (i.e., 2.691g/cm^3) was found to be similar to those of natural sands. However, the maximum and minimum void ratios (e_{max}=1.431, e_{min}=0.999) were quite high as compared to the natural sand (n.b., e_{max}=0.977, e_{min}=0.597 for standard Toyoura sand). The particle density of SM and EF slags, 3.167g/cm^3 and 3.601g/cm^3 respectively, are seemingly high when compared to other naturally available soils. In contrast to Ash Stone, the absorption rate shows a very low value of 2.7%. In other words, Ash Stones are lighter in weight with a high absorption rate, the steel slag is heavier in weight with a low absorption rate, and the GBFS resembles to natural sand in terms of the physical properties.

Fig. 2 shows the grain size distribution curves of all the materials tested. Three type of Ash stone-silt mixes were prepared from each Ash stone, A and B, at the weight ratio of 100%, 70% and 50%. The maximum particle size of all of these materials was 75mm or less. A glance in Table 1 shows that GBFS is poorly-graded type and have a coefficient of uniformity, Uc value of 3.9 and coefficient of curvature, Uc' value of 0.66. Whereas, Ash stones and the silt fall under well-graded category. The fines content (<0.075mm) was below 20% for all except the silt. The Uc values shown in the Fig. 2 shows that the grain size distribution of the silty soil has improved on mixing with Ash stone, the extent of which depended on the weight ratio.

3 COMPACTION CHARACTERISTICS

It is well-known that the compaction characteristics depend greatly on the grading of soil particles. Table 2 shows the compaction method employed according to JIS A 1210 'Compaction Test'. The 'A-c method' recommends a 2.5kg rammer, the fall height of 30cm, the mold of inside diameter 10cm and 1000cm^3 volume, compaction in 3 layers with 25 blows per layer and the permitted maximum grain size of 19mm. The 'B-c method' differs from the former one in the mold 15m in diameter, 2,209cm^3 in volume, necessary compaction per layer (55 blows) and the permitted maximum grain size of 37.5mm. Both of these compaction methods followed non-repetitive soil use method so, the soil once used for compaction was not reused.

The compaction curves for all the samples, showing the relationship between the maximum dry density and the optimum water content are drawn in Fig. 3. Also drawn alongside are zero air void curves (Z.A.V.C.). The maximum dry density, ρ_{dmax}, of EF slag, steel slag, GBFS and Ash Stone A, B was 2.300g/cm^3, 2.239g/cm^3, 1.455g/cm^3 and 1.173g/cm^3, 1.019g/cm^3, respectively.

Fig. 1. Pictures of materials tested

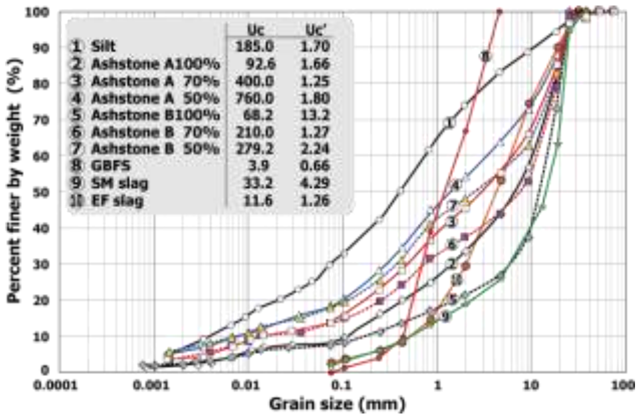

Fig. 2. Grain size distribution curve

Table 1. Basic properties of tested materials

Division	Ash Stone A	Ash Stone B	GBFS	SM slag	EF slag	Silt
Water content (%)	45	40	4.2	3	0.35	17.1
Particle density (g/cm3)	2.393	2.410	2.691	3.167	3.601	2.667
e_{max} e_{min}	-	-	1.431 0.999	-	-	-
Water absorption ratio (%)	45.6	39.7	-	2.7	-	-
Liquid limit (%) Plastic limit (%) Plastic Index	NP	NP	NP	NP	NP	33.9 20.8 13.1
Uc	92.6	68.2	3.9	33.17	11.59	185
Uc'	1.66	13.2	0.66	4.29	1.26	1.7
D_{max} (mm)	26.4	19	4.75	37.5	31.7	37.5

As for the mixture of slag and silty soil, the optimum moisture content increased as the blending proportion of Ash Stone or GBFS was increased, whereas the ρ_{dmax} went down. These trends can clearly be seen in Fig. 3. It is certainly attributed to the nature of lighter unit weight of Ash Stone and GBFS. The SM slag behavior was vice versa. The compaction curve showed a tendency to become more flat when the proportion of SM slag, Ash Stone or GBFS was increased, suggesting that the in-situ compaction work may be less influenced by the weather conditions and can sometimes be taken as a great advantage in engineering practice.

Table 2. Compaction tests performed

Sample			Type (Wet and Non-iterative method)
EF slag			A-c
Silt			B-c
SM slag	Mixture ratio	50%	A-c
		70%	
		100%	
GBFS	Mixture ratio	50%	A-c
		70%	
		100%	
Ash Stones A and B	Mixture ratio	50%	B-c
		70%	
		100%	

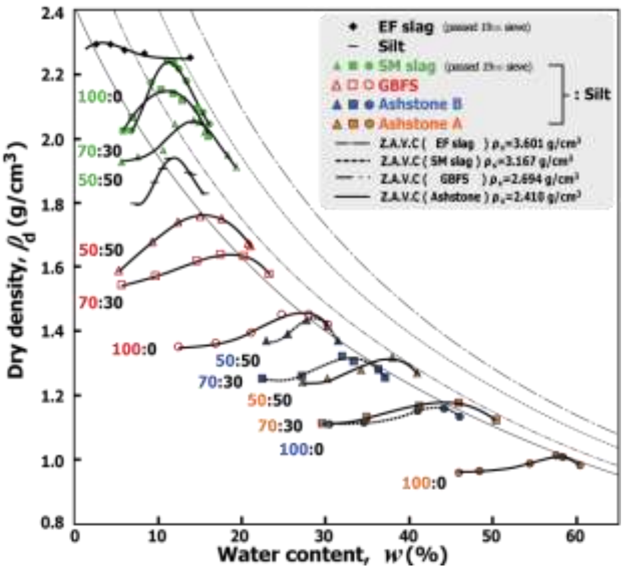

Fig. 3. Compaction curves

4 SHEAR STRENGTH

The strength when subjected to confined conditions was evaluated by using samples prepared from Ash Stones A and B and GBFS in the triaxial compression test. The silty soil was mixed with various proportions (100, 70, 50 and 0%) of slags and Ash stones by dry weight. Considering the maximum grain size of the material, two specimen sizes (i.e., a large specimen, 150mm in diameter and 300mm in height and a small specimen, 50mm in diameter and 100mm in height) were prepared. Testing conditions are given in Table 3.

Table 3. Triaxial compression test performed

Sample	Mixture ratio (dry weight) Ash Stone : Silt		Degree of compaction D_c (%)	Confining pressure σ' (kPa)	Strain rate (%/min)
Ash Stone mixed soil	0% : 100%	CU	98	50, 100, 150	0.05
	50% : 50%	CD	95	50, 100, 200	0.1
	70% : 30%				
	100% : 0%				
Sample	**Mixture ratio (dry weight) GBFS : Silt**		**Relative density Dr (%)**	**Confining pressure σ' (kPa)**	**Strain rate (%/min)**
GBFS mixed soil	100% : 0%	CD	95	49.05, 98.10, 196.20	0.3
	70% : 30%				
	50% : 50%				

Table 4. Results of triaxial compression test

Sample	Mixture ratio (dry weight) Ash Stone : Silt	γ_t (kN/m^3)	c_d (kN/m^2)	ϕ_d (°)
Ash Stone A mixed soil	0% : 100%	19.20	0.0	35.4
	50% : 50%	12.51	49.3	42.3
	70% : 30%	11.23	21.5	48.8
	100% : 0%	9.68	7.7	45.4
Ash Stone B mixed soil	0% : 100%	19.20	0.0	35.4
	50% : 50%	13.79	19.8	46.6
	70% : 30%	12.68	17.7	46.7
	100% : 0%	11.14	65.4	44.9
Sample	**Mixture ratio (dry weight) GBFS : Silt**	**γ_t (kN/m^3)**	**c_d (kN/m^2)**	**ϕ_d (°)**
GBFS mixed soil	0% : 100%	19.20	0.0	35.4
	50% : 50%	16.72	28.0	38.4
	70% : 30%	15.58	28.0	37.0
	100% : 0%	13.82	21.0	36.7

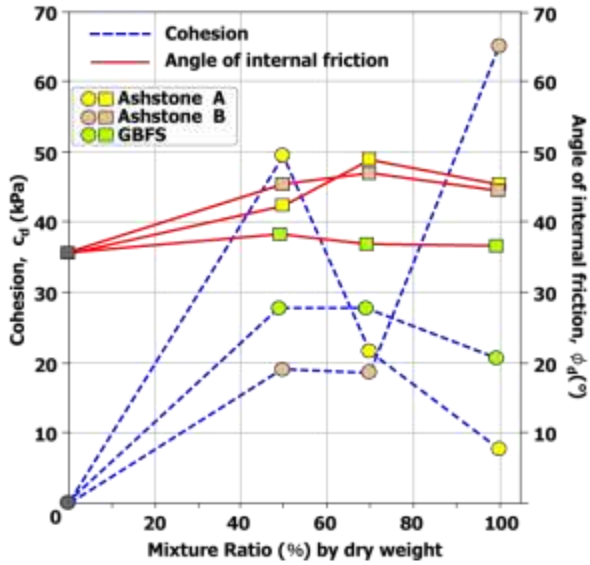

Fig. 4. Strength parameter by Mixture ratio of Ash Stone & GBFS

Table 4 shows strength parameters by mixture ratio of Ash Stone & GBFS. Variation of cohesion, c_d, as well as the angle of internal friction, ϕ_d against the mixture ratio is shown in Fig. 4. Note that the ϕ_d of the mixture of Ash Stone with the silt continuously increased to above 40° along with the increase in mixing ratio. In case of the mixture of GBFS with silt, the ϕ_d stayed more or less constant at around 38° but slight increase in c_d can be noticed when the mixing ratio is increased. In general, the trend of strength enhancement (c, ϕ increase) of the silty soil was achieved by adding slags as well as the Ash stone.

5 PSEUDO-STATIC LIMIT EQUILIBRIUM ANALYSIS

In order to examine the aseismicity of embankments which are constructed with the mixture of various kinds of steel slag with fine-grained soil, a pseudo-static limit equilibrium analysis is carried out. Fig. 5 shows a model embankment used in this analysis which is 5m-height. The groundwater condition was not considered. The material properties evaluated by triaxial compression test listed in Table 4 are used. The analysis was performed along the circular slip by following the modified Fellenius slice method to find out factor of safety under earthquake. In this analysis, horizontal seismic coefficient (k_h) is used as 0.16.

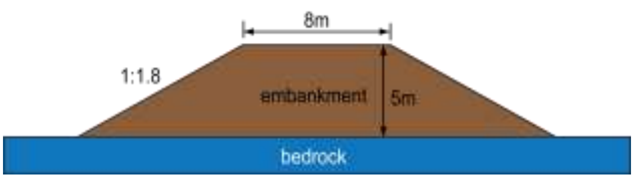

Fig. 5. Model embankment

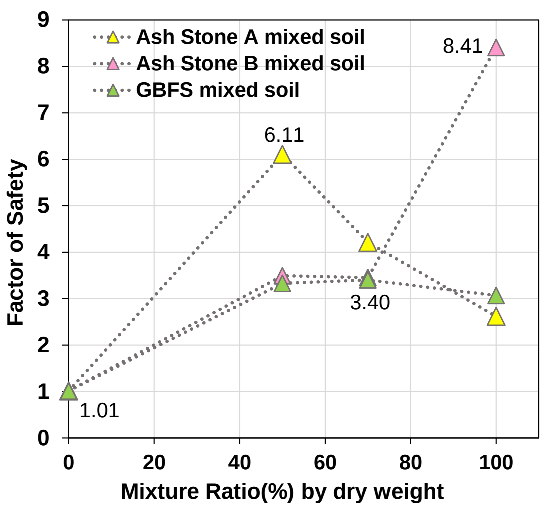

Fig. 6. Factor of safety by Mixture ratio of Ash Stone & GBFS

Fig. 6 shows factor of safety of embankments constructed with the soil and each the mixture of Ash Stone & GBFS with the soil. Similar to the result of triaxial test, it was confirmed the effect of increasing factor of safety i.e., the aseismicity by using the mixture of Ash Stone & GBFS with the soil to construct embankment.

6 CONCLUSION

Ash Stone and GBFS are lightweight granular materials compared with ordinary soil. Conversely, steel slag and EF slag is heavy. As for GBFS, the maximum and minimum void ratio was high possibly due to bubbles entrapped in the particles (Coastal Development Institute of Technology 2007). The absorption rate of Ash Stone was very high (about 40%). In addition, the compaction curve is flat against the water content at sample preparation. Therefore, in the field, Ash Stone may mixed with silty soil even in wet conditions without loosing much strength.

In the triaxial compression test, the angle of internal friction, ϕ_d of the mixture of Ash Stone with silt increased gradually above 40° when the mixing ratio was increased. On the other hand, the mixture of GBFS with silty soil, the ϕ_d stayed more or less constant at around 38° and the c_d slightly increased as the mixture ratio went up. The point to be noted here is that the maximum dry density was smaller for higher mixing ratio. Thus although being lighter, the strength aspect is being maintained or slightly going up. In other words, the strength of fine-grained silty soil was greatly improved by adding GBFS, result in increased the factor of safety of embankment under earthquake. The same trend of soil-improvement was confirmed for the silt-Ash Stones soil mixtures. As a result, it is expected to improve the aseismicity of embankment by using the mixture of Ash Stone & GBFS with the soil as the fill material.

ACKNOWLEDGEMENTS

The authors are grateful to Dr. Tara N. Lohani, Kobe University for his valuable comments given in the course of this research.

REFERENCES

Ministry of the Environment, Government of Japan (2005). Utilization of by-products of the steel industry. <www.env.go.jp/council/former2013/04recycle/y040-25/ref03.pdf> (in Japanese).

Coastal Development Institute of Technology (2007). GBFS use technology manual in a harbor / the airport, No.27, pp.4~5, pp.25~26 (in Japanese).