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Study on stability evaluation of steel slag as road embankment material focused on the improvement effect of low quality soil

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Abstract. In this study, based on field measurements conducted during the period from the start of embankment launch to dismantling, based on the results of the indoor tests on the sampled samples, the deformation and strength characteristics of the embankment receiving the traffic load and rainfall Etc., the performance of the steel slag mixed soil as an embankment material was evaluated by paying attention to the hydraulic characteristics of the embankment. As a result, by mixing and stirring the steelmaking slag and the earth at an appropriate ratio and properly compacting, it is possible to withstand deformation even under traffic load, and it is possible to suppress leaching of high alkaline water from the embankment by rainfall to some extent It could be confirmed. Therefore, it was found that there was no practical problem concerning the concern factor when slag was used as the embankment material.

INTRODUCTION

Embankments are earth structures that are commonly used in road and railway construction, and residential land development. They are important social infrastructure. Despite their widespread use and importance, embankments are not yet sufficiently resistant to natural disasters. The materials that have been used for embankments are natural sand and crushed stone. With decreases in the availability of high-quality natural resources, recycled materials have been increasingly used in construction. For example, cement-treated soil is created by mixing soil removed from construction sites that often contains a large portion of fine fractions with cement to improve grading, and the resulting soil has been used as a substitute material for natural sand and crushed stone. From the viewpoint of preserving natural resources, the realization of increased use of recycled materials is environmentally friendly and reduces construction costs.

This study addresses the use of steel slag as an improvement material that can substitute for cement. Steel slag is generated in large quantities as a by-product of iron and steel production. Steel slag has hydraulicity and high bearing capacity as a construction material. It has been used as a subgrade material in road construction. And it has been used as a material for earthworks and as a soil improvement material for sand compaction piles because of its high angle of shear resistance and density [1]. In recent years, the effectiveness of steel slag in grading improvement has been demonstrated by its use as an additive to dredged soil for backfilling in sea areas [2 - 3]. However, the use of steel slag requires attention regarding its components and properties, which differ depending on the stage of steel production process from which the slag is generated. If slag with a potentially high environmental load is misused in earthworks, the slag may affect the surrounding environment. When the slag is used as an embankment material, one must consider not only its strength as a material but also the pH of the leachate from the embankment.

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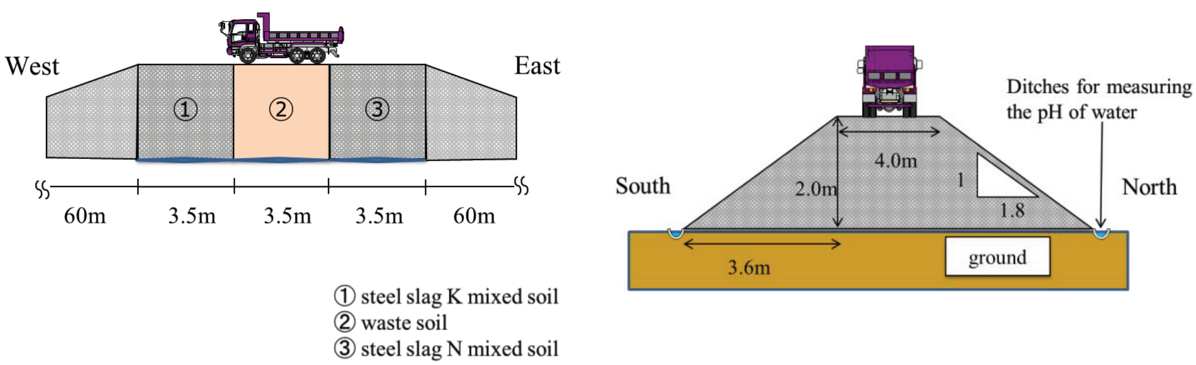
We have been examining the physical and mechanical properties of steel slag mixed soils by various laboratory tests, and it is confirmed that there is an appropriate steel slug mixing ratio in terms of strength and deformation characteristics [4]. Based on the above results, there were constructed a full-scale embankment using steel slag mixed soil. Examinations investigated the deformation of the embankment under traffic load, such as of large trucks, and the influence of alkaline leachate from the embankment after rainfall on the surrounding environment. To make the embankment quake-resistant and to minimize the outflow of alkaline leachate from the soil material of the embankment, the authors explored the optimum mix proportion of steel slag and appropriate construction techniques.

THE CONSTRUCTION METHOD OF THE TEST EMBANKMENT

The test embankment was constructed in three sections by using three types of materials: waste soil, steel slag K mixed soil, and steel slag N mixed soil. The mix proportion of steel slag for the two types of mixed materials was 25%. Each embankment section was 3.5m in length, 2m in height (the thickness of each levelled layer was 25cm; a total of 8 layers) and 4m in crown width. The slope gradient was 1:1.8. The constructed embankment is diagrammed in Figure 1. As shown in Figure 1, the three sections of the embankment were divided with wood planks. To measure the pH of the leachate, ditches were made at the embankment toe. Sloped approach roads of 70m long each were constructed using slag roadbed material before and after the road section constructed on the experimental embankment.



(a) Side section (b) Cross section

FIGURE 1. The constructed embankment.

Table 1 show the physical property values of materials used for embankments. The embankment was constructed based on the Guideline for Road Earthworks, and 90% compaction was the target. Figure 2 shows the results of the onsite density test at completion of construction for each embankment section. For the embankment section constructed with waste soil only, over-compaction was feared, and roller compaction was used without vibration; however, vibration was employed for the third layer and above, because the resulting compaction up to the second layer did not satisfy the lower limit for specified compaction. The target degree of compaction was not attained even after increasing the number of roller compactions. Therefore, from the 5th layer on, the thickness of the layer for levelling and compaction was reduced to 12.5cm/layer, which is half that of the lower layers. The 7th layer and higher layers were compacted by using dampers, because the embankment became too high for the vibrating roller to access the crown. The damper compaction was carefully done so to make the layers as dense as possible. The degree of compaction of the steel slag mixed soil (slag K and slag N) became low in the 4th layer. Compaction for the 4th layer and the layers above of steel slag mixed soil was done by increasing the number of rolling compactions.

About 20,000 dump trucks passed over the top of the embankment in about two years from the time of construction. We conducted various in-situ tests such as cone penetration test and pH measurement, and examined the strength of the embankment and the influence of alkaline leachate.

TABLE 1. Physical properties of the above three materials.

	Steel slag K	Steel slag N	Waste soil
Soil density, ρ_s (g/cm^3)	3.294	3.051	2.694
Water content, w (%)	5.2	11.6	30.9
Liquid limit, w_L (%)	NP*	NP	38.4
Plastic limit, w_P (%)	NP	NP	31.0
Initial pH (%)	11.3	10.8	8.8
Maximum dry density, $\rho_{d\ max}$ (g/cm^3)	2.32	1.85	1.41
Optimum water content, w_{opt} (%)	11.3	18.9	29.3

*NP : non plastic

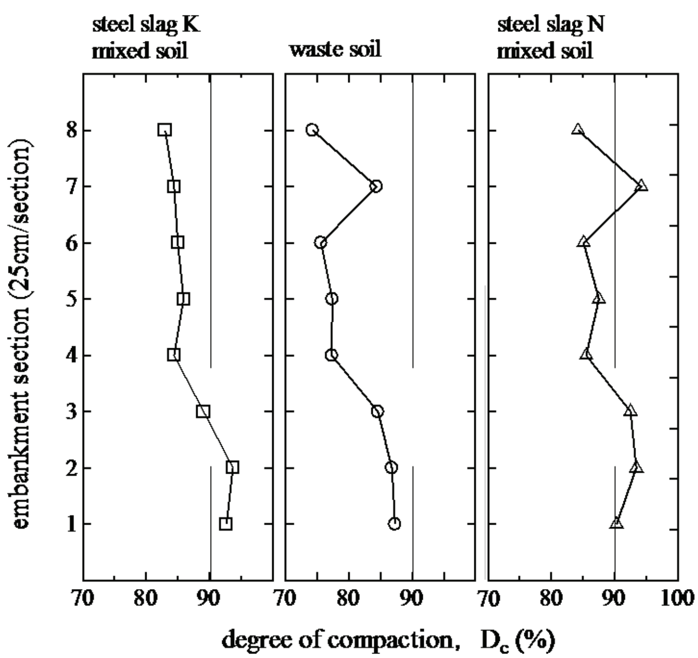


FIGURE 2. Results of the onsite density test at completion of construction for each embankment section.

RESULTS AND DISCUTTION

Strength and deformation of the embankments

Figure 3 shows the results of the penetration tests done at the crown of each embankment section. The figure shows curves for the results of the penetration tests done immediately after construction completion of each embankments and those done one month, six months, one year and two years after the road section was opened to large truck traffic. The N-value of embankment that constructed by waste soil shows low about 10 to 15 at any time. On the other hand, the embankment constructed with steel slag mixed soils increased in N-value with the lapse of time, and one year after construction, the N value was more than 50 from the surface layer. From these results, it can be seen that the strength of the embankments constructed with steel slag mixed soils increased due to hydraulic hardness of slag. In addition, it is considered that the increase of the strength was converged at about 1 year, since the N-value of the embankments constructed with steel slag mixed soils does not differ between 1 year and 2 years.

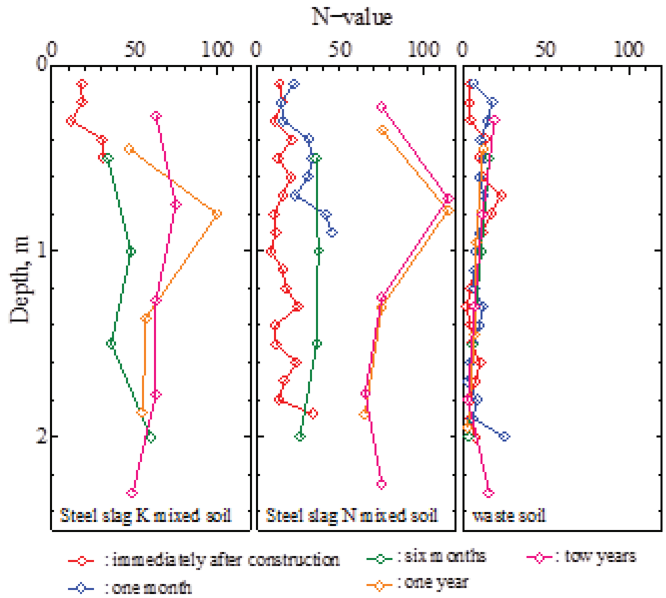


FIGURE 3. Results of the penetration tests.

Figure 4 shows the deformation for crown of embankment from immediately after construction completion to 1.5 years. Unmanned aerial vehicle (UAV) was used for the measurement of displacement. As a results, crown of embankment constructed by waste soil settled down to about 150mm within the period of the measurement. On the other hand, settlement amount of the crown of embankment constructed by each steel slag mixed soil were 50 mm or less within the period.

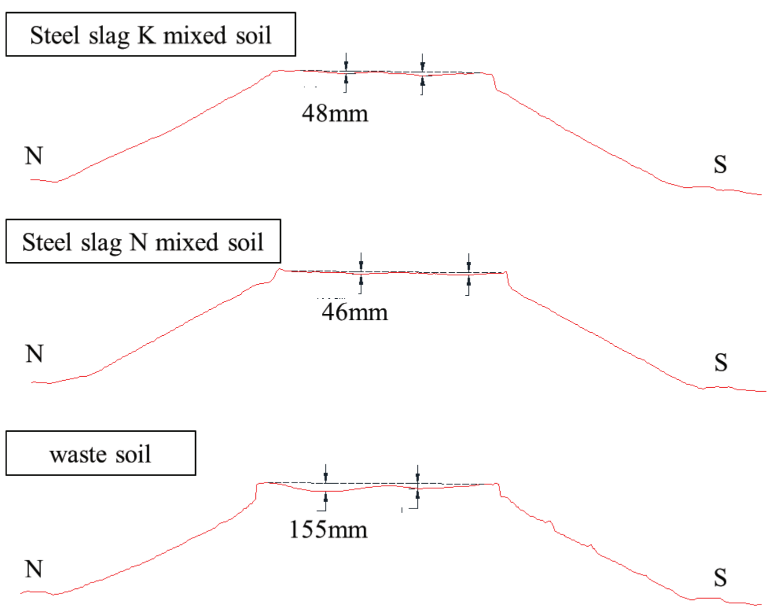


FIGURE 4. The settlement amount of the crown of embankment.

Measurement of pH values inside and outside the embankments

Figure 5 shows the pH values of water taken from the north side ditches of the embankment. The side ditches were installed on the south and north sides of each embankment section, and covers were installed over the ditches to prevent rainwater from directly entering the ditches. The pH in general was around 9, regardless of embankments. Figure 6 shows the pH values of water collected from inside embankment after construction after construction. It is noteworthy that the pH values inside embankment constructed by steel slag K and N mixed soil were almost same as the initial pH value. Therefore, it was found that very little rain water infiltrated into the embankment about one and two years constructed with steel slag mixed soil, and that leachate did not flow out from the embankment. The water in the side ditches of the embankment was thought to be the rainwater that flowed over the slope of the embankment.

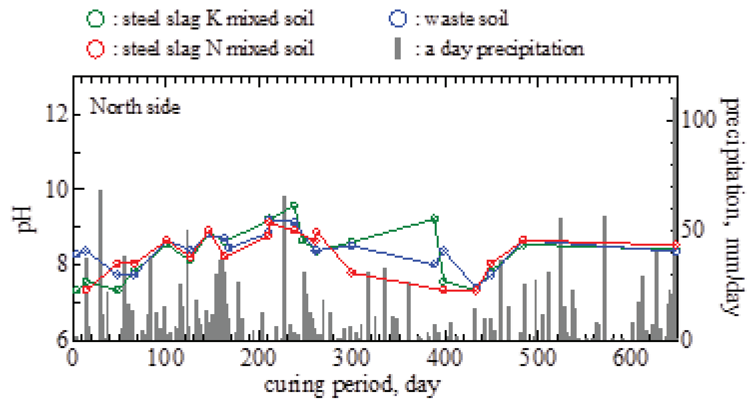


FIGURE 5. The pH values of water taken from the north side ditches of the embankment.

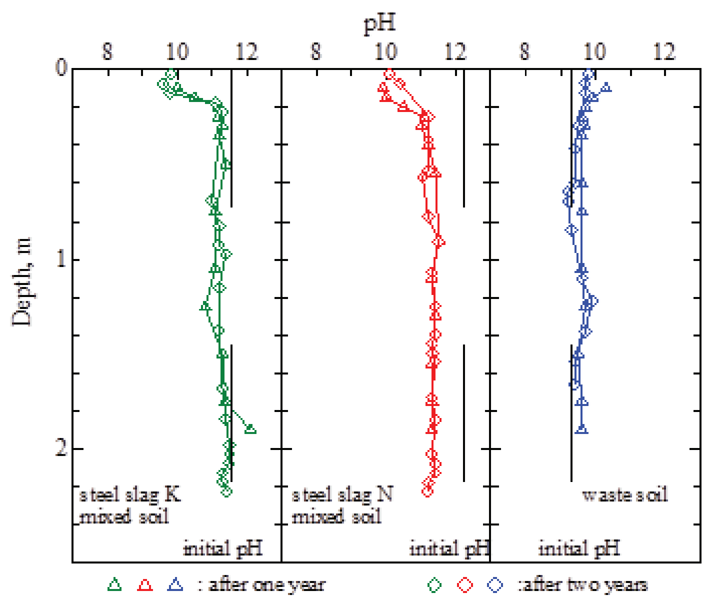


FIGURE 6. The pH values of water collected from inside embankment.

CONCLUSIONS

In this study, an embankment was constructed by using the steel slag mixed soil, and changes in the environmental load of alkaline leachate and the deformation of the embankment under traffic load with time were investigated. The following are the findings of this study.

The degree of compaction of the three embankment sections constructed using construction waste soil only and steel slag mixed soil were uniform. About 1 month after the road section was opened to large truck traffic, the road section on the embankment constructed with construction waste soil only started to have greater deformation than that on the embankments constructed with steel slag mixed soil. The experiment revealed that the embankment constructed with steel slag mixed construction waste soil was stronger than that constructed solely with construction waste soil.

Based on the pH values of water pooled in the side ditches, it was verified that the leakage of highly alkaline water from inside the embankment was controlled by sufficiently compacting the embankment.

ACKNOWLEDGMENTS

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