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STUDY ON DEVELOPMENT OF SOIL IMPROVEMENT PILE METHOD USING RECYCLED SOIL

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ABSTRACT: With the development of building technology in recent years, the effect on environmental degradation has been a major concern. This study was conceived in a bid to further promote environmental sustainability through reasonable resources consumption pattern in line with The United Nation sustainable development goals. The purpose of the study is to examine the feasibilities and efficiency of developing a ground improvement method using recycled construction sludge. The paper describes an environmentally friendly construction method in which reclaimed soil obtained by drying sludge from construction sites can be used for soil improvement piles. Although the occurrence of excessive bleeding and inadequate methods of evaluating the compressive strength during curing remains a prominent issue in the proposed use of this recycled material, from the results of this study it was deduced that with the addition of 2% sodium bicarbonate additive to the resulted concrete mix, the amount of bleeding was adequately controlled. The use of an ICT device for measuring electrical resistivity for enhanced quality control and quality assurance was also introduced for adequate prediction of properties such as strength at any curing age of the improved soil. The study will adequately recommend the use of the new improved soil for improvement piles in residential buildings.

Keywords: Resources consumption, Recycled construction sludge, Ground improvement, Electrical resistivity, Concrete bleeding.

1. INTRODUCTION

World consumption pattern has been a global issue lately. The current production, consumption and resources management pattern is incommensurable. With the world population growing at about 1.1% annually, material consumption of natural resources is increasing, particularly within Eastern Asia. Aside other sectors such as agriculture, manufacturing and production, construction activities dominate material resources consumption globally. Such materials include sand, gravel and crushed stone. The United Nation in its Sustainable development goals cautioned that "should the global population reach 9.6 billion by 2050, the equivalent of almost three planets could be required to provide the natural resources needed to sustain current lifestyles".

Construction activities generate a considerable amount of waste which are sometimes poorly managed. Construction wastes are recognized as by-products that results from different construction processes either during a new construction or renovation works. Most constituent includes soil, clay (construction sludge), concrete, wood, steel and plastics. Construction sludge consists of sand particle, mud, and water in colloidal form. In Japan's waste disposal law, construction sludge is categorized and treated as industrial solid waste. Within this standard, fine-particle mud with high water content and a cone-index under 200KN/M^2 are regarded as Construction sludge. They are generated during the process of underground excavation and other building projects, especially in areas with expensive soil. Recycling of construction sludge consist of various succeeding processes and leads to the production of primary materials such as sand, gravel and mud which can further be treated into improved soil.

While considering their environmental effects and economic viability, most developed Nations have implemented adequate construction waste management practice through the 3-Rs concept of Reduce, Reuse and Recycle in accordance to global guidelines. While transforming used materials into new products, recycling is instrumental in curtailing wastage and also reduces the depletion of fresh resources and energy use.

Although various researches have been conducted on the possibilities of recycling concrete waste, only little has been achieved in the reuse of construction waste such as construction sludge. The need to develop technologies that can treat low quality soil with low cone index is imperative as a measure to promote the recycle and reuse of construction sludge.

The purpose of this study is to promote an environmentally friendly construction method using reclaimed and improved soil obtained from the treatment process of construction sludge.

2. LITERATURE REVIEW

The Japanese government through the local authorities is making frantic effort towards regulating sludge treatment and recycling before eventual disposal. During this process, materials such as sand, gravel and mud are produced. These materials can be further treated to be recycled and reused for construction purposes such as backfill and also as embankment material [1]. This will be instrumental in conserving natural resources, promote reasonable resources consumption and also encourage healthier environment [2]. Over the past 15years, technology has been more modified to carry out the separation and treatment process of construction sludge in a more compact system. This has also ensured that when the need arises, construction sludge can be treated faster to meet up with the growing demand for the produced primary materials.

In the past two decades, the Japanese Government has facilitated stakeholders in the construction industry to develop techniques that will encourage the use of construction by-product. This includes the utilization of liquefied stabilized soil as material in backfilling and other underground structures. Liquefied stabilized soil are formed by evenly mixing cohesive soil with stabilizing agent and increased moisture content to produce a saturated mixture that cannot be compacted. This mixture can be adequately placed into a form due to its liquidity property and it attains its strength when hardened. With the increasing use of these by-products in Japanese construction industry, it is imperative to note that there is an urgent need to create more use for the recycled materials generated from treating construction sludge.

From previous researches, experimental results reveal that amongst other factors, excessive bleeding affects the quality assurance and effectiveness of using the recycled improved soil for construction purposes. It was reported that by adding 2% sodium bicarbonate additive to the resulted concrete mix, the amount of bleeding was adequately controlled while improving the quality.

Improved soils are basically stabilized soil that was initially separated and treated from construction sludge. The quality of the dewatered and dehydrated floc is enhanced and recycled by mixing with lime type or cement type solidifying material in a self-propelled soil improving machine. The amount of solidifying agent added to the floc can be regulated to produce a regenerated soil with 800KN/m^2 cone index or more.

The objective of this study is to develop an environmentally friendly construction method of ground improvement using improved recycled soil. This study is aimed to promote the reuse of construction waste particularly construction sludge. Using the concept of initial electrical resistivity and compressive strength, the appropriate mixing ratio of the improved soil was determined. A method of estimating the compressive strength of the resulting construction material within 28 days was also proposed using the same concept. Furthermore, the viability of using baking soda in controlling excessive bleeding of the material was also emphasized.

3. MATERIALS

This study was conducted in two parts, the first part focused on the regeneration of improved soil while, the other phase is predominantly on the control of excessive bleeding in the concrete mix. Materials used for both phases include cement, water, additives and improved soil.

Table 1 Details of the samples in the first phase

	Weight（kg）						W/C (%)	B/C (%)
	Water	Improved soil	Ordinary Portland cement	Cement-based solidifying material	Baking soda	Total		
No.1	4	0.75		5	0.1	9.85	80%	2%
No.2	4	1.5		5	0.1	10.6	80%	2%
No.3	4	0.75	5		0.1	9.85	80%	2%
No.4	4	1.5	5		0.1	10.6	80%	2%

Table 1 shows the samples in the preceding part of the experimental evaluations, four specimens were created using a combination of water, sodium bicarbonate, solidifying material, and the improved soil. The baking soda cement ratio (B / C) was maintained at 2%, and the water-cement ratio (W / C) at 80%. The improved soil (corn index 200 KN / m²) was altered at 15% and 30% weight ratios were mixed with cement-based solidifying agent and ordinary Portland cement. Bleeding test was conducted for each specimen while the temperature, electrical resistivity, and PH were initially measured every 15 minutes.

When the change in electrical resistivity became quite minimal, the data were recorded every 30 minutes and subsequently every 1 hour. Uniaxial compression test was conducted on each specimen on the 1,3,4,8,15,22 and 28 days.

Subsequently, experiments were conducted using cement milk with three types of additives, baking soda, magnesium carbonate, and bentonite. A case Specimen was also prepared without the use of any addictive. During the study, the water cement ratio (w/c) was alternated between 60%, 80% and 100% as shown in Table 2. In each case, the mixed samples were placed in about 5cm wide and 50cm long polyethylene bag and the initial weights were measured using a graduated cylinder containing 300 cc of water.

Using the same method, the weights of the samples was measured every 15minutes within the preceding 2 hours of the study and every 30minuties in subsequent hours. A uniaxial compression test was conducted on the 28th day.

Table 2 Details of the samples in the second phase

Symbols	PL			BS1%			BS2%			PP			Be5%			Be10%		
Additive	Plain			Baking Soda						Magnesium carbonate			Bentonite					
M/R(%)	−	−	−	1	1	1	2	2	2	1	1	1	5	5	5	10	10	10
W/C	60	80	100	60	80	100	60	80	100	60	80	100	60	80	100	60	80	100

4. EXPERIMENTAL EVALUATIONS

4.1 Bleeding Test

Bleeding plays an important role during concrete setting as it replaces evaporated moisture and thus prevents excessively early hardening. Excessive bleeding leads to strength loss by producing laitance at the surface of the concrete. This also leads to wear resistance and poor bonding between the layers of the concrete.

Table 3 Bleeding test in the first phase of the study

	volume			Bleeding	
	Initial value	After 3 hours	After 20 hours	After 3 hours	After 20 hours
No.1	600	590	585	1.70%	2.50%
No.2	560	550	550	1.80%	1.80%
No.3	595	520	520	12.60%	12.60%
No.4	620	560	560	9.70%	9.70%

Table 3 shows the results of bleeding experiments in the first phase of the study. With both the baking soda cement ratio (B / C) and water cement ratio (W/C) kept constant, it was observed that after the initial 3 hours of the study, bleeding was quite pronounced in the samples with Ordinary Portland cement compare to cement based solidifying material. These observations persisted even after monitoring the samples for 20 hours. However, in both cases of solidifying materials, samples with higher quantities of improved soil showed a better rate of bleeding. This clearly indicates that the addition of improved soil plays a role in controlling bleeding in the concrete mix. In the other phase of the bleeding experiment, as shown in detail in Table 2, the percentage mix ratio of additives was altered variably to ensure a wide scope of coverage in the study.

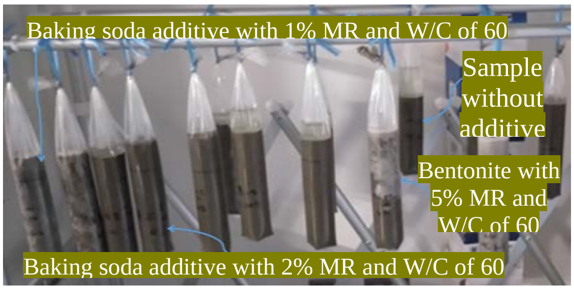

Fig. 1 Showing the samples.

Figure 2 further emphasized the relationship between the additives and the bleeding rate of the samples. The samples displayed a more stable and viable bleeding rate at w/c of 60% compare to others. It was also observed that although the specimen with 10% bentonite additive shows a considerably stable rate of bleeding, samples with baking soda displaces a better control. It was noticed that the sample with 2% backing soda content shows the most appropriate bleeding rate. This evidently clarifies the efficiency of using baking soda as an additive to control bleeding in concrete compare to other viable additives.

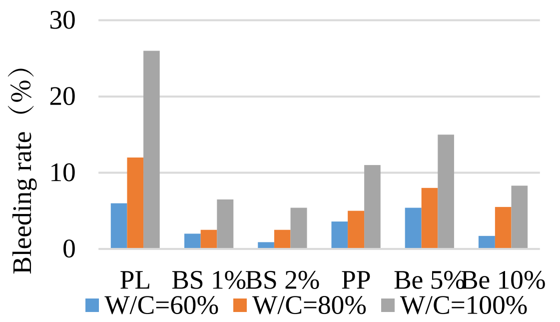

Fig. 2 Relationship between additives and bleeding

4.2 Uniaxial Compressive Test

In the preceding phase of the study, compressive strength test was conducted on each sample daily with focus on the impact of the varying amount of improved soil of each sample. Considerably equal values of compressive strength were recorded for all the samples at the initial stage of the study irrespective of the improved soil content. However, quite evident changes in values were observed towards the 5th day. The sample containing the higher amount of improved soil and cement based solidifying material recorded the better compressive strength. It is quite interesting that each sample showcased a uniform increment rate in compressive strength with respect to the ages of the samples however; both samples 1 and 2 showcased higher compressive strength on the 28th day of the study.

In the other phase of the experiment, compressive test was conducted on the sample on the 28th day. Compared to others, magnesium carbonate had the least desired effect. In cases of the altered ratios of bentonite, little differences were noticed in all w/c ratios except at 60% w/c ratio where there compressive strength increased by about 14% compared to the plain sample. The sample with 2% baking soda content showed a more desired result at 60% w/c ratio with about 30% increment in compressive strength. This further emphasized the relevance of baking soda as a viable additive.

4.3 Relationship between Temperature, PH and Electric Resistivity

Figure 3 shows changes over time in temperature, PH, and electrical resistivity in the first phase of the study. All values were relatively stable within the initial 15 hours of the study. The electrical resistivity values of each samples increased steadily until the 28th day, while the sample with the first sample recorded the most value.

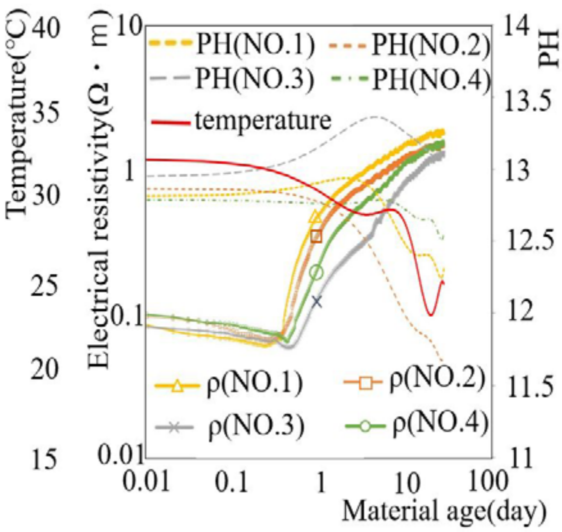

Fig. 3 Changes over time in temperature, PH, and electrical resistivity

In the contrary, the PH values of each sample were stable for the initial 72 hours of the experiments after which the values took a downward turn. However, the sample with ordinary Portland cement and more improved soil content proved to be more stable while the sample with cement solidifying material attained the peak value of PH. In the same vein, the temperature attained peak value at the commencement of the study with minimal decrease within the initial 15hours. This pattern is quite similar in each case of the specimens.

5. EXPERIMENTAL EVALUATION

With reference to the evaluation method of the past research [3] and bearing in mind that this study was focused on efficiently predicting the strength of the materials at varied time, the strength development observed in the solidifying materials was different from the previously used Eq. (1); there were few disparities between the properties exhibited by cement-based solidifying material and the ordinary Portland cement. Therefore, the initial equations were further modified to cater for each type of solidifying material. Equation (2) was adequate for cementitious solidification agent while equations (3) and (4) are suitable for ordinary Portland cement.

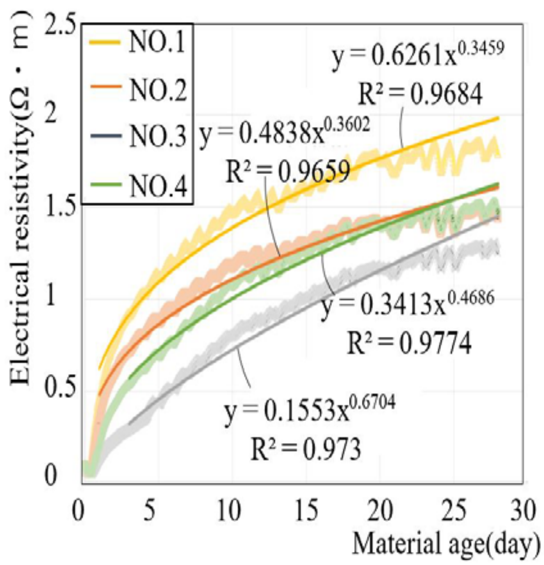

Fig. 4 Evaluation of material age and electrical resistivity

Figure 4 shows the relationship between material age and electrical resistivity. While further affirming the preceding studies, the increasing tendency is almost linear therefore it was expressed as an approximate expression of Y= aXb based on the material age and the specific resistance value (X: Material age, Y: specific resistance value).

An average value of **a** was used since B/C is constant in all the samples. The value of b was predicted using an approximate expression from the tendency of the slope.

$$\rho(X) = aX^b + \{\rho(1) - \rho(1AVE)\} \quad (1)$$

ρ(X) : Electric resistivity at age X day (Ω·m)
ρ(1) : Measured electrical resistivity at day 1 (Ω·m)
ρ(1AVE) : the average value at day = 0.4175[Ω·m]
a=0.55495 b=0.35305

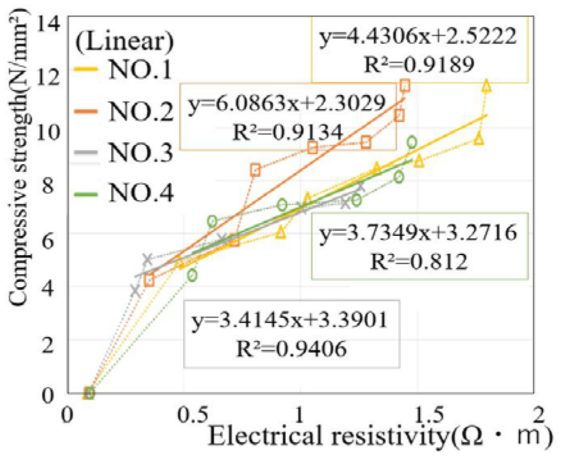

Fig. 5 Relationship between electrical resistivity and compressive strength

Figure 5 shows the relationship between electrical resistivity and compressive strength. The electrical resistivity at day 1 shows a uniform value regardless of the weight ratio of the improved soil. However, the specific resistance values and the compressive strength ratios changed in each specimen relative to the material age. From these findings, the linear relationship between electrical resistivity and compressive strength in form of coefficients K1 and K2 was used to propose Eq. (2) which is suitable for cement-based solidifying materials.

$$qu(28) = K1 \times \{\rho(28) - K2\} + qu(1)\} \quad (2)$$

qu(28): Compression strength at day 28 (N/mm2)
qu(1): Measured compression strength of the material at day 1 (N/mm2)
ρ (28): Estimated electrical resistivity of the material at day 28 (Ω·m)
K1: Linear relationship between electrical resistivity and compressive strength = 5.25845{N/mm2·(Ω·m)}
K2: ρ(1)

In case of Ordinary Portland cement, the measured values of electrical resistivity and the compressive strength within the initial 72 hours was used to generate the expression in Eq. (3).

$$\rho(X) = cXd + \{\rho(3) - \rho(3AVE)\} \quad (3)$$

ρ (3) : Measured electrical resistivity at day 3 (Ω·m)
ρ (3AVE)=0.4145[Ω·m]
c=0.2483 d=0.5695

$$qu(28) = K3 \times \{\rho(28) - K4\} + qu(3) \quad (4)$$

qu(3): Measured compressive strength at day 3 (N/mm2)
K3: 3.5747{N/mm2·(Ω·m)},
K4: ρ(3)

6. SUMMARY AND CONCLUSION

To wrap up the study, Table 4 shows comparison between the estimated values using the proposed equations and measured values of electrical resistivity at the 28th day of the experimental samples. More so, Fig. 6 shows the correlation between the measured values and the estimated values of compressive strength at 28th day of the material samples.

Table 4 Comparison between estimated and measured electrical resistivity values

	No.1	No.2	No.3	No.4
Estimated value	1.865	1.734	1.533	1.778
measured value	1.797	1.446	1.257	1.477

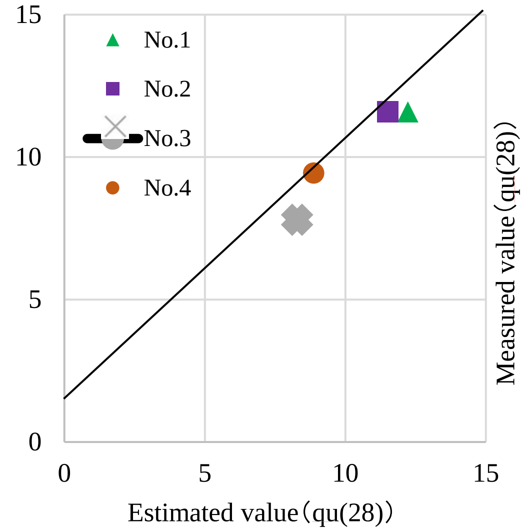

Fig. 6 Comparison between estimated and measured Compressive strength values

With the electrical resistivity values of the materials at 28th day estimated from Eq. (1) and (3) using electrical resistivity values of the materials at day 1 and 3 respectively, the two comparisons suggest a highly reliable relationship. Although previous studies had indicated this assertion, this study further proves the viability of using improved soil as a fine aggregate in the cement milk.

Furthermore, the possibility of estimating the compressive strength of the cement mil at 28 days of age with Eq. (2) and (4) using the measured compressive strengths at ages of 1 and 3 days, respectively was upheld.

In addition, cement contains atoms such as calcium, silicon, aluminum, and iron, and reacts with water to produce hydrates. Equation (1) shows the chemical reaction between cement and water.

$$3CaO \bullet SiO_2 + 2.17H_2O \rightarrow 2CaO \bullet SiO_2 \bullet 1.17H_2O + Ca(OH)_2 \quad (5)$$

Aside other additives, the impact of baking soda as a suitable fit was established in the other phase of this study. As shown in the equations below, $NaHCo_3$ undergoes a hydrolysis reaction in water.

$$NaHCo \Leftrightarrow Na^+ + HCo^-{}_3 \quad (6)$$

$$HCo^-{}_3 + H_2O \Leftrightarrow H_2CO_3 + OH^- \quad (7)$$

$$Na^+ + H_2O \Leftrightarrow NaOH + H^+ \quad (8)$$

This hydrolysis reaction increases the number of anions also present in the cement hydrate. The anion has a function of accelerating the hydration reaction by stimulating the cement particles. Therefore, as a result, the concrete setting time was shortened and concurrently, bleeding was reduced. In future study, the laboratory intend to conduct more tests on the possibilities of using other additives with improved soil to further verify the viability of recycling construction sludge in form of improved soil for construction purposes particularly ground improvement. This is in a bid to adequately encourage reuse and recycling in the construction industry towards, promoting advocacy for reasonable resources consumption and environmental conservation.

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