Effects of an angle of mixing paddles on deep mixing in soft clays

Les effets d'un angle de mélanger les pagaies sur le mélange profound dans les glaises molles

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ABSTRACT

The deep mixing soil improvement are commenly used for soft ground improvement and foundation systems for embankments, port and harbor foundations, retaining walls, and liquefaction mitigations. The advantage of this method is that it not only improves the strength of soft ground, but is a superior method for the prevention of settlement. Quality controls of the improved soils affect of the efficiency of this method are not yet properly established. These effects vary depending on the construction environments and operating conditions of the mixing paddle. The strength and shape of the improved column are not unique and these are affected by the mechanical properties of the mixing paddles.

In order to investigate the efficiency of the deep mixing soil improvement on a soft clay, experimental studies are conducted that consider the mechanical properties of mixing paddles; the location of the exit-hole of the admixtures, the angle of the mixing wing. The experiments are conducted with a simulated deep mixing plant at a reduced scale of 1:8 of the real plant. From the results, the sizes and shape of the improved column mass vary depending on the mechanical properties and operating conditions of the mixing paddle. The quality of the column in the shapes and strength is improved when the exit-hole for admixtures is located in the mixing wing, when an angle of the mixing wing is large.

RÉSUMÉ

L'amélioration de sol de mélange profonde est utilisé pour l'amélioration de terre molle et les systèmes de fondation pour les digues, le port et recèle des fondations, des murs de soutènement et des mitigations de liquéfaction. L'avantage de cette method consiste en ce qu'il améliore non seulement la force de terre molle, mais est une method supérieure pour la prevention de règlement. Les commandes de qualité des sols améliorés affectent de l'efficacité de cette méthode ne sont pas encore correctement établis. Ces effets varient selon les environnements de construction et les conditions d'utilisation de la pagaie se mélangeant. La force et la forme de la colonne améliorée ne sont pas uniques et ceux-ci sont affectés par les propriétés mécaniques des pagaies se mélangeant.

Pour enquêter sur l'efficacité de l'amélioration de sol de mélange profonde sur une glaise molle, les études expérimentales sont accomplies qui considèrent les propriétés mécaniques de mélanger des pagaies; l'endroit du trou de sortie des mixtures, l'angle de l'aile se mélangeant. Les expériences sont accomplies avec une usine de mélange profonde simulée à une échelle réduite de 1:8 de l'usine réelle. Des résultats, les grandeurs et la forme de la masse de colonne améliorée varient selon les propriétés mécaniques et les conditions d'utilisation de la pagaie se mélangeant. La qualité de la colonne dans les forms et la force est améliorée quand le trou de sortie pour les mixtures est trouvé dans l'aile se mélangeant, quand un angle de l'aile se mélangeant est grand.

Keywords : Deep mixing method, Ground improvement, Mixing paddle, Soft clay, Admixture

1 INTRODUCTION

A ground improvement method by the deep mixing is that improves the strength of soft ground by forming a soil column using the process-to-solid effect of hydration and pozzolan reaction by uniformly supplying and mixing a stabilizer such as lime or cement into the deep soft ground. Specifically, a hydration reaction occurs when the cement mixes with water, and an ettringitte of capillary crystals is generated since the product of the hydration generates a pozzolan reaction with the clay minerals in the soil as the age increases. Also, this method is effective in preventing the ground settlement of soft ground. In general, the improvement effect of the deep mixing is greater than the improvement effect of soft ground stabilization and enables a significant improvement in strength in the early stage. However, the disadvantage of the deep mixing is that the degree of improvement greatly varies according to the type of soft ground. The improvement effect of this method depends on the degree of stirring and mixing. In addition, the quality of the improved column is strongly affected by how uniformly the stabilizer and soft soil can be mixed. If the stabilizer is handled without care it can be toxic to the human body, or may cause a problem by raising the degree of pH in the surrounding area.

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The deep mixing was introduced as a viable means of achieving columnar inclusion (Broms and Boman, 1975; Okumura and Terashi, 1975, during the 5th ARC in Bangalore, India). The increase in strength with time of the surrounding clay adjacent to the soil cement columns was later experimentally and numerically studied by Miura *et al.* (1998, 2001). Yoon *et al.* (1996) studied the improvement cases by using the jet grouting method, which is a type of the deep mixing, and demonstrated that the diameter of the improved column decreases as the improvement depth increases, and that the shape of the section becomes unsteady. The relationship between soil properties and torque, which is the penetrating resistance on the mixing wing, was investigated using experiments (Hata *et al.*, 1987). It was investigated considering the mechanical properties of the mixing paddle; an angle of the mixing wing and curing time obtained from experiments (Lee *et al.*, 2008).

Related to the deep mixing in both Korea and abroad are carried out using the field test and internal mixing test. Although studies towards the understanding of the shapes of improved columns are mostly carried out by using a geophysical exploration after a cast-in-place process, this is not sufficient to present accurate comparison criteria since it is difficult to standardize the heterogeneous property of the ground and the operation of cast-in equipment.

Also, in studies on the deep mixing, a number of factors that influence the formation of the improved column must be considered, such as the location of the exit-hole for admixtures, the type of mixing paddle wing, the mixing speed, and the gushing method of the stabilizer. These factors can be obtained from studies of the optimizing of the cast-in equipment operation. Accordingly, it is believed that these studies can be performed most appropriately by using an experimental study.

Therefore, in order to investigate the improvement effect of DMM by using cast-in equipment, the intention of this study is to determine the optimal conditions for a cast-in equipment operation by comparing the shape and strength of improved columns that are formed by a variety of conditions. This will be achieved by performing an experimental test using parameters such as the angle of the mixing paddle wing, the mixing velocity, and the curing period.

2 EXPERIMENT

The test device was prepared by reducing the size of the actual deep mixing equipment by a ratio of 1:8, consisting of the experimental box, the mixture injection device and the control unit. Fig. 1 depicts the specifications of the mixing paddle, the dimensions of the mixing paddle, and the location of the exit-hole for the admixtures. The mixing paddle wing within the agitation device as a plate type of wing consists of 3 layers with 3 units in each layer. Here, the total diameter is 60.5mm; the length of the mixing paddle wing is 44.5mm; and the mixing diameter of the mixing paddle wing is 150mm. One injection nozzle with a diameter of 8mm was installed onto the toe of the rod in type-A. Two injection nozzles with a diameter of 5mm were installed onto the three mixing paddle wings positioned at the bottom in type-B. The dimensions of the experimental box were *L*700mm × *B*700mm × *H*1000mm and the effective improvement depth was set at 800mm. The control device was designed so that it could control the mixing speed of the mixing paddle, the injection, and the drawing speed.

Clay with a water content of 60% was used for the sample in this experimental study. The clay sample was uniformly agitated and the ground was stabilized in 9 layers of 10cm each within an experimental box by compaction and consolidation for one month. The properties of the clay used are shown in Table 1. Tables 2 ~ 3 show the physical and chemical properties of the admixture agent. For the admixture agent, the cement and the HWS solidification agent were mixed at a ratio of 9:1 (cement 9; HWS solidification agent 1) and the power state of the solidification agent was converted into a liquid state by re-mixing it at a 1:1 ratio of water to solidification agent.

Table 1. Properties of clay

Cu	Cg	LL (%)	PL (%)	IP	Gs	γ_{dmax} (kg/cm^3)	OMC (%)
93	6.42	27.0	22.2	4.92	2.68	1.45	7.2

Table 2 Physical Characteristics of Admixture

Specific gravity	Surface Area (cm^2/g)	Solidification Initial (hr)	Solidification Final (hr)	Test Method
2.8~3.2	2800over	3~5.5	5.5~8.5	KS L 5201

Table 3 Chemical Characteristics of Admixture

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Ignition Loss	Test Method
20~35	5~15	1~4	40~55	2~4	2~4	1~2	KS L 5120

For the experimental procedures shown in Fig. 2, the mixing paddle was drawn while injecting the mixture at a rate of 0.75 l/min from the point that is drawn at the same velocity after injecting the mixing paddle device within the experimental clay box up to an effective depth. At the real site, the strength of the improved column is increased by injecting and drawing the mixing paddle several times. However, in this study, the comparison task has been made easier by simplifying the experiments whereby the agitation is performed once each for the top and bottom. After performing the cast-in process, the sample was cured in an experimental box for 7 days. It was then cured again in a curing tank under a temperature of 20° and a humidity of 70% for 21 days. After curing, the shape of the improved column is measured, and the uniaxial compression strength test is then performed while loading the weight at the speed of 0.1cm/min by cutting the top and bottom part to a size of 30cm and shaping the test specimen. Table 4 shows the test pattern used in this study for analyzing the uniformity of shape and strength of the improved column according to the diversified conditions in the spread nozzle type. It also shows the age of the improved column and the angle of the mixing paddle wing.

3 RESULTS

Fig. 3 shows the shape of the improved column after 28 days curing time according to the wing angle of the mixing paddle device in type-A, and type-B. Generally, the shapes of the improved columns are uniformly molded when the angle of the mixing paddle wing is increased, and it is irrelevant to the spread type.

Table 4. Pattern of experiments

	Spread nozzle type	Curing time of improved column (day)	Wing angle (°)
Type-A	Nozzle located in toe of rod	7, 14, 28	10, 20, 30, 40
Type-B	Nozzles located in wing	7, 14, 28	10, 20, 30, 40

The diameter of the improved column was measured in this investigation by measuring the upper, middle and lower parts of the improved column. Fig. 4 quantitatively shows the diameter of the improved column in the upper, middle and lower positions of the improved column at varying wing angles. However, this is not related to curing time. Although the upper part appears to be about 2~5% larger than the middle or lower parts, most of the improved columns were evenly formed. The average diameter appears to be about 1~3% smaller than that of

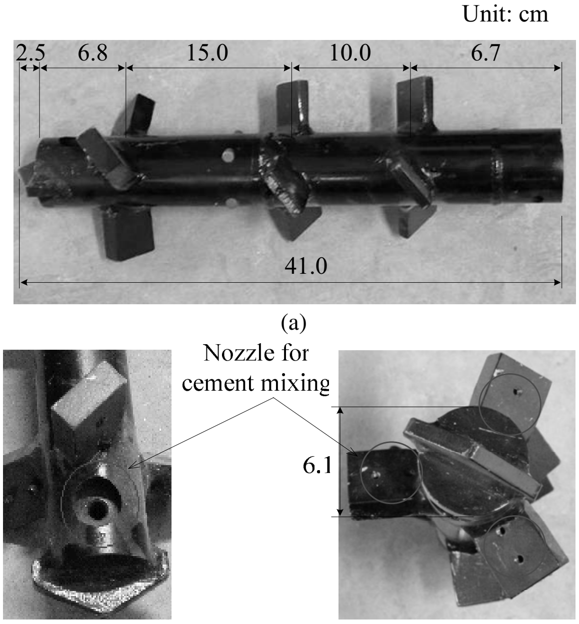


Fig. 1 Specifications of mixing paddle; a) Dimension of mixing paddle, b) Nozzle located in toe of rod (type-A), c) Nozzles located in wing (type-B)

the design specifications (a diameter of 15cm). However, it is assumed that the required diameter of the improved column is smaller due to the lateral earth pressure since this creates an agitation of the ground in the cast-in process for the soft clay specimen used in this study. The shape is variable when the wing angle of the mixing paddle is under 40° in type-A and type-B. However, the uniformity of shape is remarkably good at a 40° wing angle in both types, and it is shown as a dotted line in Fig. 4.

Fig. 5 shows the uniaxial compression strength according to the angle of the mixing paddle at varying curing times. After curing, the uniaxial compression strength test is performed by attaching two test specimens to the upper and lower parts, respectively, of the improved column. Fig. 5 shows the average value of uniaxial compression strength in the upper and lower parts. The strength of the improved column in type-B is stronger than that in the improved column in type-A under all conditions. As shown in the figure, the uniaxial compression strength increases as the curing time increases. The ratio of the uniaxial compression strength of the improved column with 7 days

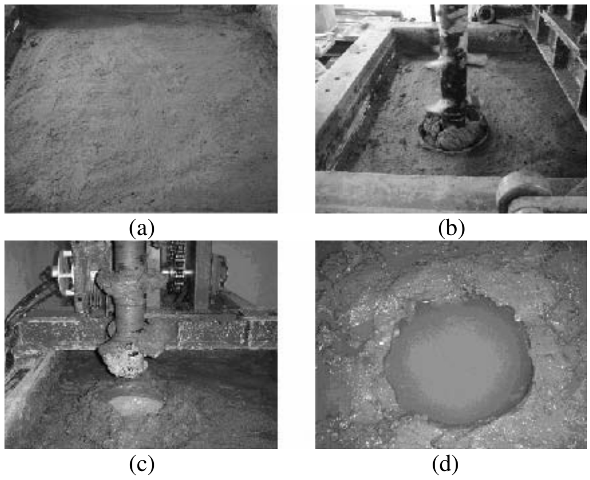


Fig. 2 Test Process; a) Filling soils in container, b) Rotational insertion by the shaft of experimental box, c) Mixing of admixture, d) Curing of improved column

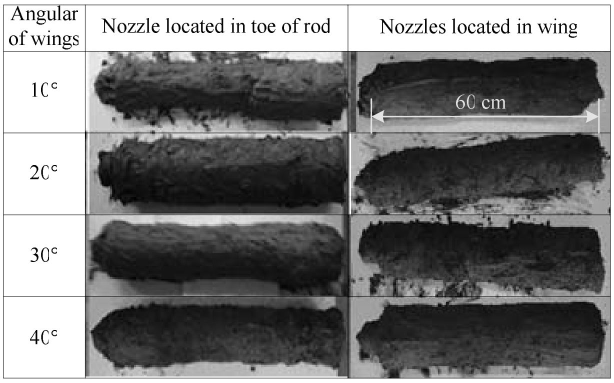
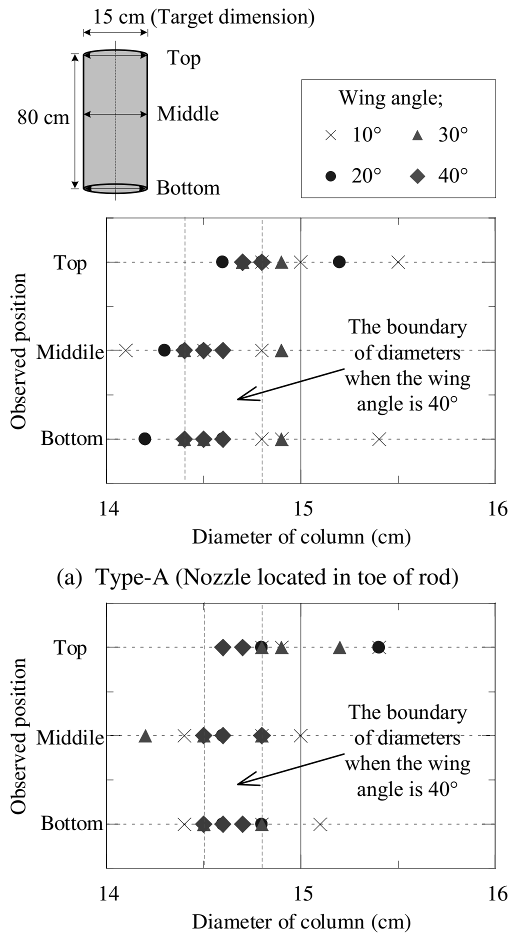


Fig. 3 Shape of improved columns (28 days curing time)

curing time to the uniaxial compression strength of the improved column after 28 days curing time appears to be about 30%. The uniaxial compression strength of the improved column after 14 days curing time was about 60% in all cases. Moreover, the uniaxial compression strength appears to increase as the angle of the mixing paddle wing increases under identical curing periods. As the wing angle increases, the uniaxial compression strength constantly increases. When the wing angle is 40° and the curing time is 28 days, the uniaxial compression strength appears to be greatest at 11.35kg/cm^2 and 14.10kg/cm^2 for type-A and type-B, respectively. However, as the curing time decreases, the difference in the uniaxial compression strength according to the change in the wing angle appears to decrease.

4 CONCLUSIONS

In this study, a bench scale test was performed in order to investigate the effect that various factors (the location of the exit-hole for admixtures, the type of mixing paddle wing) have on the efficiency of the improved column. The following conclusions can be made based on the results of the test:



(a) Type-A (Nozzle located in toe of rod)

(b) Type-B (Nozzles located in wing)

Fig. 4 Diameters of improved column at different positions for type-A and type-B (7 days, 14 days and 28 days curing time)

Diameters of the improved column measured to be about 1~3% smaller than 15.0 cm as the design specification. It is assumed that the improved column is compressed due to the lateral earth pressure during this creates ground agitation in the cast-in process for the soft clay specimen used in this study. In contrast to the quality control for the strength and shape of the improved column obtained by agitating the mixing paddle wing several times in the field, it is assumed that the admixture will gush out by inserting the mixing paddle device into the ground only once by the mixing paddle. As the mixing paddle wing angle and the curing time increase constantly, the uniaxial compression strength increases and about 60% of the uniaxial compression strength could increase according to the increase of the wing angle. Moreover, when the nozzles located in the wing are stronger than those in the improved column, where the nozzle is located in toe of the rod. The strength of the improved column is not related to the other conditions. The shape and strength of the improved column vary considerably according to the wing angle. However, since in the actual field the wing

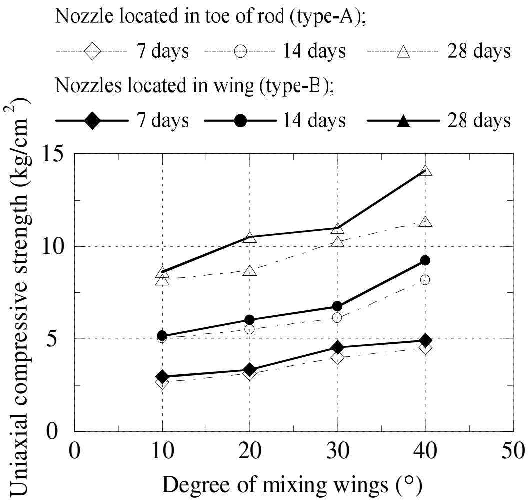


Fig. 5 Uniaxial strength of improved column according to the angle of the mixing wings

angle of the mixing paddle device is generally determined by the motor efficiency, a study whereby various field conditions are considered should be performed in the future in terms of the ground materials. Also, it is recommended that experimental research should be conducted with various operating conditions of mixing peddles.

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