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STUDY ON THE PERFORMANCE OF SHALLOW SOIL MIXING WITH CEMENT

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ABSTRACT: Shallow Soil Mixing (SSM) method with a low dosage of cement can be used to create a sufficiently strong platform for quick access onto grounds that have been recently reclaimed with soft clays. The effectiveness of the SSM method is dependent on the type, dosage and dosing method of cement, the mixing blade design, and the mixing sequence. Hence, a laboratory-scale SSM apparatus was developed to simulate SSM in the field. The early strength development and uniformity of Cement Mixed Soil (CMS) were evaluated by taking into consideration (a) Type of cement: CEM I vs CEM III/A, (b) Dosage of cement: 7% vs 3%, (c) Dosing method: 1-layer vs 2-layer mixing, and (d) Mixing blade design: without overlap between mixing blades vs overlapped mixing blades. Shear strength test results demonstrated that the shear strength development of CMS at an early stage is affected by the type, dosage, and dosing method of cement, while the uniformity of the CMS is affected by the dosage and dosing method of cement and the mixing blade design. From the laboratory test results, it is recommended that CEM III/A cement with 7% cement dosage, 2-layer of dosing method and overlapped mixing blades design parameters be used for SSM in the field to achieve high early strength gain and good uniformity cement soil mix.

Keywords: Shallow soil mixing, Early strength development, Uniformity

1. INTRODUCTION

In land reclamation, water bodies are usually reclaimed using fill materials such as sandy soils [1]. However, due to the limited sources of sandy soil in some country, such as Singapore, soft clays are used as the fill material instead [2]. The major problem of using soft soils as the fill material is that it will undergo a substantial amount of settlement when loaded. Hence, ground improvement must be carried out to accelerate the consolidation and reduce post-construction settlement in the soft soil layer for the newly reclaimed land to gain enough strength for future use. However, to carry out ground improvement work on reclaimed land is also a great challenge as the ground improvement works also need a sufficiently strong working platform for machinery access.

One method of constructing the working platform for machinery access is to treat the top layer of the soft clay by mixing it with cement and creating a layer of CMS. Some methods of introducing cement into the soft soils include Shallow Soil Mixing (SSM), jet grouting and Deep Cement Mixing (DCM). SSM and DCM both improve the geotechnical properties of soil by improving their undrained shear strength (Cu) and lowering compressibility [3]. SSM, however, is used to improve a large treatment area to a shallower depths (Fig.1a), while DSM is used to treat soft soil to a greater depths with a smaller treatment area using column-by-column treatment arrangement. Fig. 1 illustrates this difference.

In the application that this study is concerned, since treatment to only the top shallow layer of soft soil is required, the use SSM to create a working platform for machinery access on the ground recently reclaimed with soft soils will be discussed.

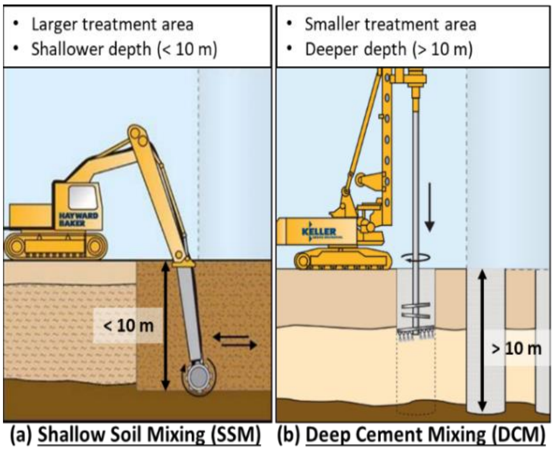

Fig.1 Schematic illustration for Shallow Soil Mixing (SSM) and Deep Cement Mixing (DCM) [4].

1.1 Effectiveness of the SSM

The early strength of the CMS is very important for field implementation, as faster strength gained in the CMS will allow early machinery access to the site. Existing literature reports that the parameters such as type of cement and dosage of cement affect the early strength development of CMS. Mixing uniformity is another key criteria for successful field implementation. A uniformed CMS will ensure uniformity in strength gained across the treatment area. The cement dosing method and mixing blade design are believed to be the parameters that will affect the uniformity of the CMS.

Hence, this study focuses on investigating the effect of the mentioned parameters on the early strength development and the uniformity of the CMS through a series of laboratory scale-SSM test.

1.1.1 Type of cement

The two major standards used globally to categories cement are (a) ASTM International standard, and (b) British Standard European Norm (BS EN). As early strength development is needed for the discussed application (which is the working platform at the shallow depth of soft soils), the type of cement mentioned in the two standards that are related to the early strength gain is as follows.

Referring to ASTM C150/150M, ASTM Type I cement is used for general purposes, while Type III is a rapid hardening cement with relatively high early strength gain. Fig. 2 shows the rate of strength development for various cement types according to ASTM, with higher the Tricalcium Silicate (C_3 S) content in the cement composition providing higher early strength gain.

In the BS EN 197-1:2011, cement type is categorized based on the type of additional materials in the cement composition. The type of cement that provides high early strength gain is Portland cement (CEM I) and Silica fume cement (CEM II/A-D) as shown in Fig. 3. CEM I consists of 95-100% clinker, while CEM II/A-D consists of 90-94% of clinker and 6-10% of silica fume.

Blastfurnance cement (CEM III/A and CEM III/B) provides high long term strength development instead of high early strength gain. CEM III/A consists of 35-74% clinker and 36-65% granulated blastfurnance slag (GGBS), while CEM III/B consists of 20-34% of clinker and 66-80% of GGBS.

1.1.2 Cement dosage

The effect of cement content on the unconfined compressive strength of Singapore Marine Clay is shown in Fig. 4. The strength of cement-treated clay increases with the amount of cement until a “saturated limit”, beyond which there is no strength increment observed with additional cement. For the current study, lightly cemented-clay with cement dosage ≤ 10% is adopted.

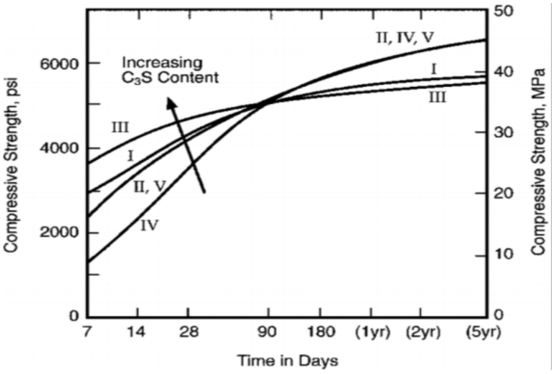

Fig.2 Rates of strength development for concrete made with cement classified according to ASTM standard [5].

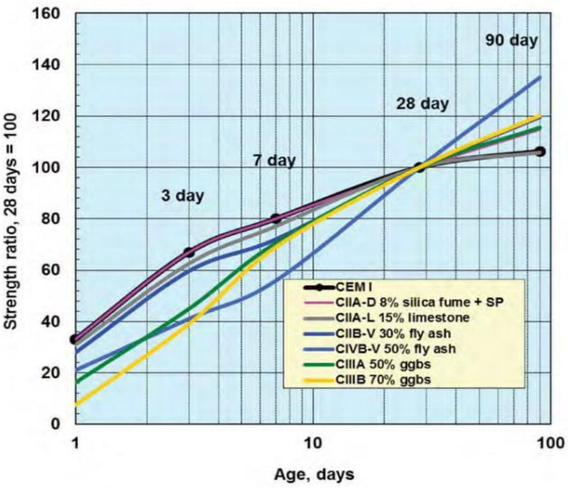

Fig.3 Rates of strength development for concrete made with cement classified according to BS EN standard [6].

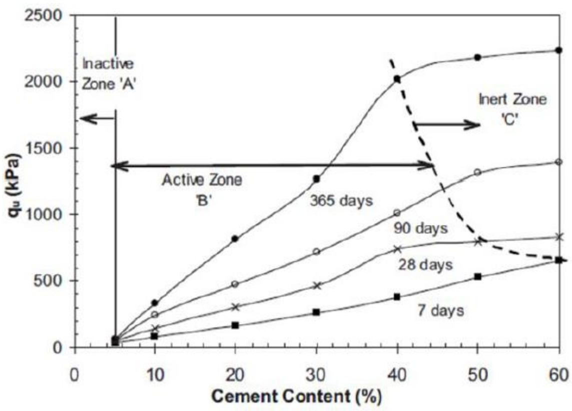

Fig.4 The effect of cement content on the unconfined compressive strength of Singapore Marine Clay [7].

1.1.3 Cement dosing method

The effect of the number of cement layers placed in the soil specimen on the unconfined compressive strength of the CMS was earlier studied [8]. The study reported that the initial cement distribution is one of the dominant factors affecting the uniformity of the soil mix and demonstrated by the distribution of the strength of the CMS.

1.1.4 Mixing blade design

Several studies were carried out to investigate the operation techniques (e.g. mixing blade design) on the quality of the CMS [9]. Fig.5 shows the influence of the number of mixer shafts on the strength of the CMS, where CMS improved by four mixer shafts show similar 7-day strength and higher 28-day strength compared to CMS improved by single mixer shaft.

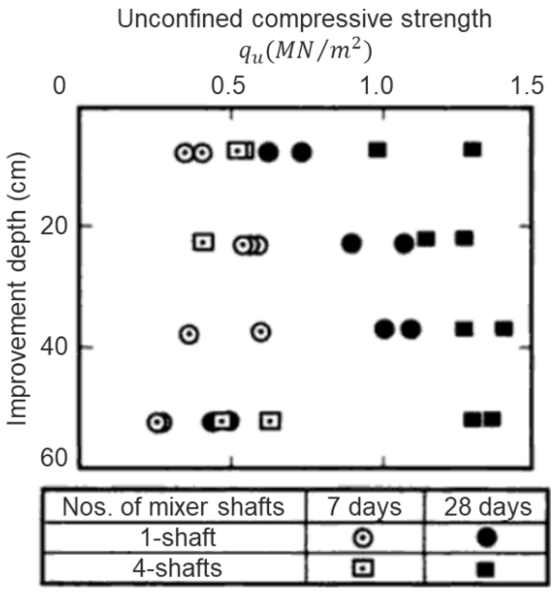

Fig.5 Unconfined compressive strength achieved using a different number of mixer shafts [9].

2. MATERIALS & TEST SETUP

The materials and apparatus used in the laboratory-scale SSM test are elaborated in this section.

2.1 Properties of Soil

Kaolin Clay and Past Infilled Materials (PIM) were the two types of soils used in this study. PIM refers to excavated soils collected from construction activities that had been temporarily dumped into offshore containment sites and now dredged to be used as an alternative infill material for land reclamation.

The particle size distributions and the soil index properties of the soils used are shown in Fig.6 and Table 1, respectively. It can be seen that while Kaolin clay is a uniform soil of silt-sized, PIM is well-graded sandy-clayey silt.

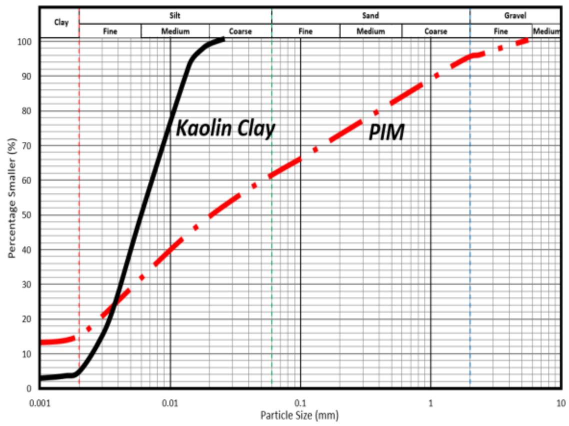

Fig.6 Particle size distribution of Kaolin Clay and PIM.

Table 1 Soil index properties of Kaolin Clay and PIM

Properties	Kaolin Clay	PIM
Plastic Limit (PL)	40 %	28 %
Liquid Limit (LL)	80 %	67 %
Plasticity Index (PI)	40 %	39 %

2.2 Type of Cement

As Singapore adopts the BS EN standard, Cement CEM I and CEM III/A were used in this study. Although it was proven that the CEM I has a higher early strength gain, the use of CEM III/A is more environmentally friendly and cost-effective. There is approximately 11% reduction in the cost of concrete per 1 MPa of strength gained was documented when CEM III/A cement was used instead of CEM I cement [10].

2.3 Laboratory Scale SSM Apparatus

A laboratory-scale SSM apparatus was designed to model the SSM in a controlled environment. Fig.7 shows the SSM apparatus consists of two major components: (1) a 1200mm (length) x 400mm (width) x 400mm (height) rectangular soil container, and (2) motor-powered mixing blades. Three mixing blades were attached at equal spacing across the width (400mm) of the soil container, and each of the mixing blades had four cutting arms.

Fig.8 illustrates two different lengths of the cutting arms (62mm and 75mm) attached on the mixing blades. It was postulated that a more extended cutting arm could provide a better overlap between the blades and result in a more uniformed mix.

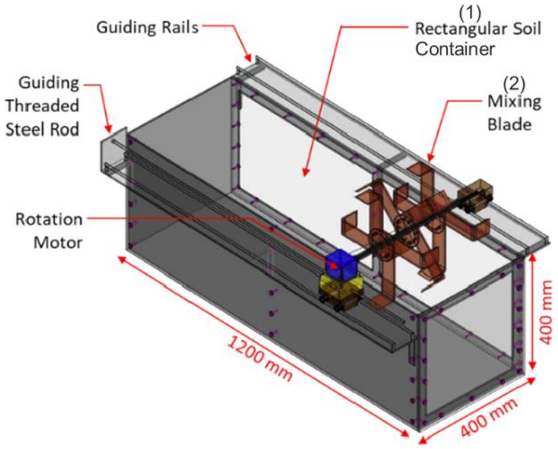

Fig.7 Schematic diagram of the laboratory-scale SSM apparatus.

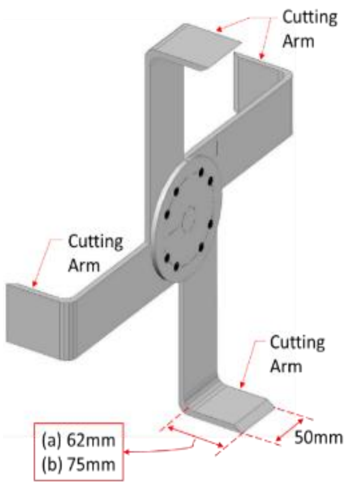

Fig.8 Different lengths of cutting arm on a mixing blade.

3. TEST PROCEDURE

Two dosing methods with slightly different test procedures were studied: one (1)-layer method and two (2)-layer method.

3.1 One (1)-layer Method

Soil was prepared to a water content of 1.2x its Liquid Limit (LL) and poured into the soil container. The cement slurry is then sprayed evenly onto the surface of the soil. The motor-powered mixing blades with the rotating cutting arms were subsequently activated to move back and forth the container eight times.

3.2 Two (2)-layer Method

The effective treatment depth of 100mm in this study is to be divided into two layers. The first batch of the prepared soil (with a water content of 1.2x its LL) was poured into the soil container until the 50mm mark from the top of the container. The total amount of cement slurry was also divided into two equal portions, and the first portion of cement slurry was sprayed onto the first layer of soil surface.

Subsequently, the remaining batch of prepared soil was added to the top of the container. The second portion of cement slurry was then added onto the top surface of the soil. Finally, the motor-powered mixing blades were used to mix the soil uniformly, similar to the 1-layer method.

4. TEST PROGRAM

The first test series used Kaolin Clay (KC) with the 62mm cutting arms on the mixing blades. Effect of the dosing method of 1-layer vs 2-layers was studied in this phase. The second test series used PIM with the 75mm cutting arms on the mixing blades. In this phase, the effect of different dosing percentage was studied and evaluated. The parameters used in the first and second test series are listed in Table 2(a) and Table 2(b), respectively.

Table 2(a) First test series (Kaolin Clay and 62mm cutting arm).

Cement	Cement Dosage	Dosing Method	Test no.
CEM I	10%	1-layer 2-layer	KC-1 KC-2
CEM III/A	10%	1-layer	KC-3

Table 2(b) Second test series (PIM and 75mm cutting arm).

Cement	Cement Dosage	Dosing Method	Test no.
CEM I	7%	1-layer	PIM-1
	3%	1-layer	PIM-2
CEM III/A	7 %	1-layer	PIM-3
	3%	1-layer	PIM-4

5. RESULTS & DISCUSSIONS

The performance of the laboratory-scale SSM test is evaluated by the development of the undrained shear strength (Cu) of the CMS over time.

Vane Shear Tests (VST) and miniature Cone Penetration Tests (CPT) were used to ascertaining the 3-day and 7-day Cu of the CMS at different locations in the soil container, as shown in Fig.9. The 28-day strength was not included as this study is concerned primarily with the early strength gain of CMS.

The undrained shear strength (Cu) obtained for the Kaolin Clay CMS with depth at various locations for each test series are shown in Fig. 10(a) to Fig. 10(c).

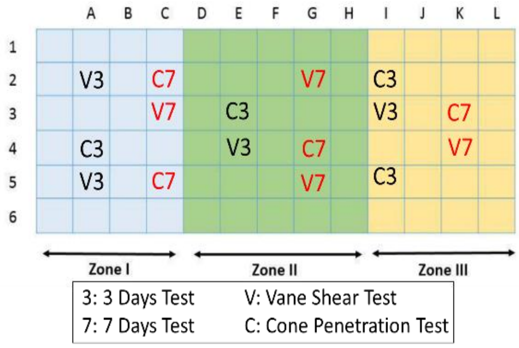

Fig.9 Plan view for VST and CPT test points in soil container

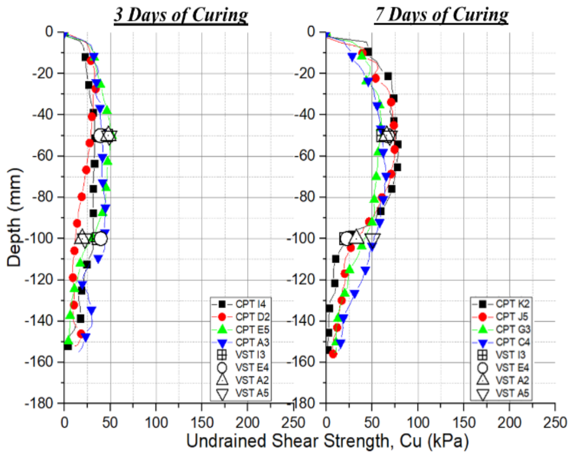

Fig.10(a) Undrained shear strength, Cu, with depth of CMS for Test KC-1

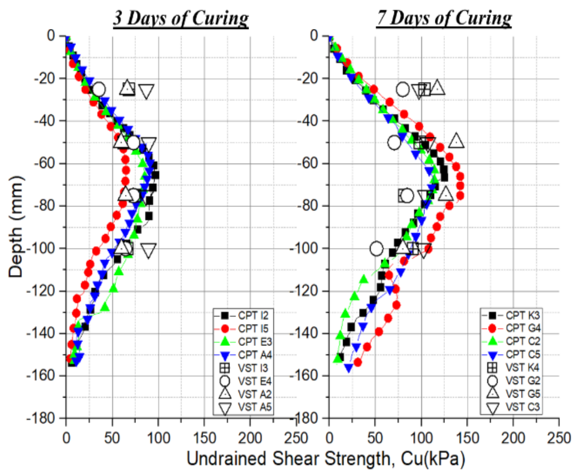

Fig.10(b) Undrained shear strength, Cu, with depth of CMS for Test KC-2

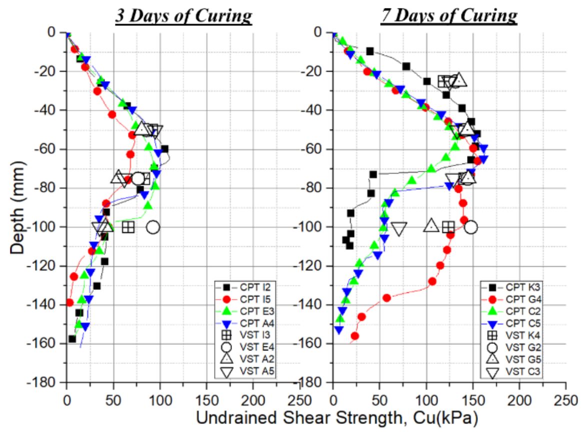

Fig.10(c) Undrained shear strength, Cu, with depth of CMS for Test KC-3

The undrained shear strength (Cu) obtained for the PIM CMS with depth at various locations of each test series are shown in Fig. 11(a) to Fig. 11(d).

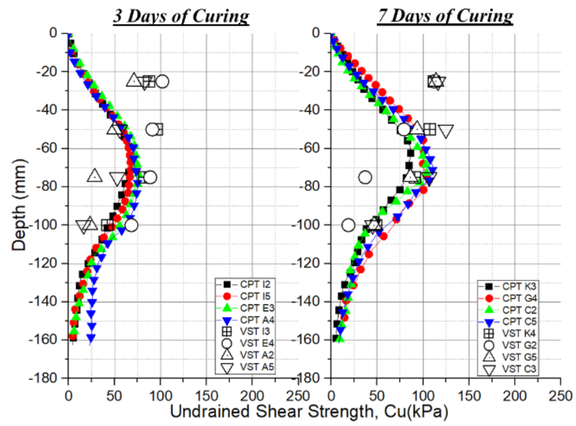

Fig.11(a) Undrained shear strength, Cu, with depth of CMS for Test PIM-1

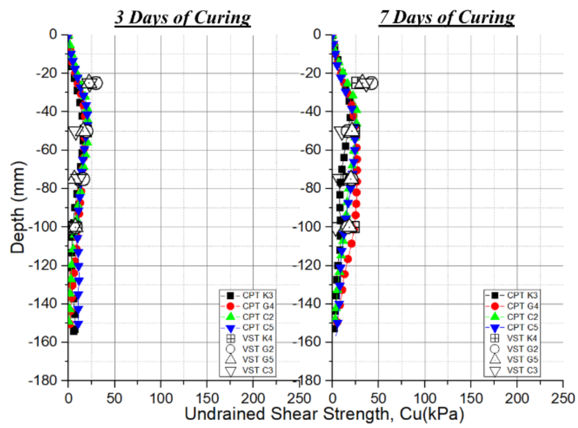

Fig.11(b) Undrained shear strength, Cu, with depth of CMS for Test PIM-2

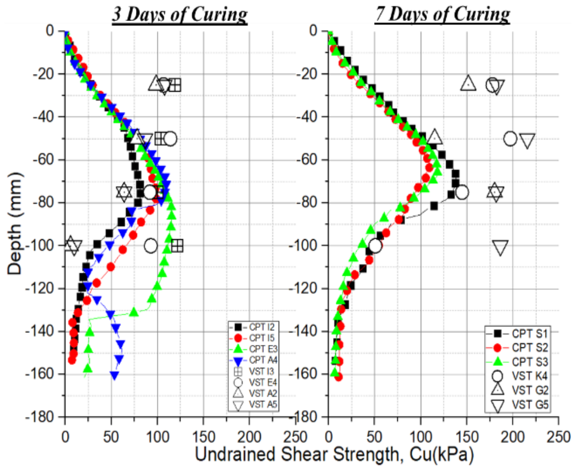

Fig.11(c) Undrained shear strength, Cu, with depth of CMS for Test PIM-3

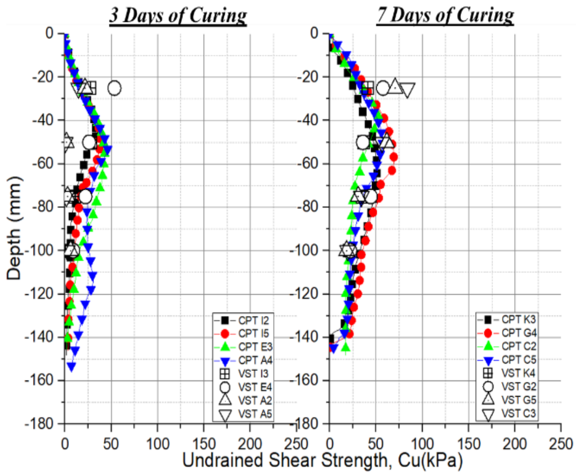

Fig.11(d) Undrained shear strength, Cu, with depth of CMS for Test PIM-4

5.1 Effect of Cement Type

The effect of cement type on strength development can be observed by comparing the Cu distribution with depth in Test KC-1 and KC-3. In general, the 3-day Cu and 7-day Cu distributions of KC-3 are higher than in KC-1. Similar trends are observed in PIM-1 compared with PIM-3, and PIM-2 with PIM-4, where the Cu distribution of CMS with CEM III/A consistently have higher values compared to CEM I.

5.2 Effect of Cement Dosage

By comparing the Cu distributions with depth in PIM-1 with PIM-2, and the Cu distributions with depth in PIM-3 with PIM-4, it can be observed that using a higher dosage of cement gives a higher strength gain, which is expected.

5.3 Effect of Dosing Method

The results of higher Cu values observed in Test KC-2 as compared to KC-1 indicate that using the 2-layer dosing method provides more uniform strength gained in the CMS.

5.4 Effect of Mixing Blade Design

The first test series used 62mm cutting arms, while the second test series used 75mm cutting arms. Apart from differences in the cutting arms, a higher cement dosage was used in Test KC-1 than that in PIM-1.

Although a higher cement dosage was used in KC-1, PIM-1 unexpectedly obtained higher Cu values at the corresponding location and time than that in KC-1. This proved that the increase in the uniformity of CMS is affected by the blade design, such as the amount of overlap of the mixing blades.

6. CONCLUSION

A series of laboratory-scale SSM test was conducted successfully. In the study, CEM III/A cement shows more rapid strength development in the CMS as compared to CEM I cement, and that a higher cement dosage is an advantage for the development of strength gain. It was also concluded that the dosing method and mixing blade design are important in providing uniformed cement mixed soil. Therefore, for the cost-effectiveness of the SSM method to create a working platform at the top layer of soft soils, the cement dosing method and mixing blade design must be carefully planned as these two parameters impact the uniformity of CMS, which directly increase the overall strength gain across a large treatment area.

7. ACKNOWLEDGEMENTS

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