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Applicability of molding procedures in laboratory mix tests for quality control and assurance of the deep mixing method

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Abstract

The deep mixing method (DMM) has been applied in many construction projects. The laboratory mix test is essential to the quality control and quality assurance (QC/QA) of deep mixing methods. The procedures used for the preparation of specimens in the laboratory mix test greatly affect the physical and mechanical properties of the stabilized soils. Different procedures are applied in different countries/regions. With the increasingly globalized DMM market, it is desirable that a common understanding of the nature of the laboratory mix test and internationally accepted guidelines to conduct it be established in order to guarantee the QC/QA of DMMs. As part of an international collaborative study, the influence of different molding techniques for the laboratory preparation of specimens was studied. Five different molding techniques were tested in four organizations. The results showed that the molding techniques considerably influenced the magnitude and variation of the unconfined compressive strength and the wet unit weight of the stabilized specimens. The applicability of the molding techniques was discussed in terms of their undrained shear strength and the liquidity index of the soil and binder mixture, and the usefulness of the techniques was demonstrated.

Keywords: Molding technique; Stabilized clay; Cement; Lime; Laboratory tests; Unconfined compressive strength; Deep mixing

1. Introduction

The deep mixing method (DMM), an in-situ admixture stabilization technique using cement and/or lime as a binder, has been applied in many construction projects for various improvement purposes (Kitazume and Terashi, 2013). The DMM was put into practice in Japan and the Nordic countries in the middle of the 1970s to improve soft deposits, and then spread into the USA, China, South East Asia and, recently, to other parts of the world.

The quality of deep-mixed soil (improved soil by in-situ mixing) depends upon a number of factors including the type and condition of the original soil, the type and amount of binder, and the production process. The practice of quality control and quality assurance (QC/QA), which focuses upon the quality of deep-mixed soil, was originally established in Japan and the Nordic countries and has been accepted worldwide for more than three decades. It is comprised of a laboratory mix test, field trial installation, monitoring and control of construction parameters during production and verification by measuring the engineering characteristics of

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the deep-mixed soil either by unconfined compression tests on core samples or by sounding. The diversification of application, soil type, and execution system, together with an improved understanding of the behavior of deep-mixed ground over the past two decades have made a revision of the current QC/QA practice necessary. A previous literature review and International Collaborative Study have revealed the similarity and differences in the QC/QA procedures employed in different parts of the world (Kitazume and Terashi, 2009; Kitazume et al., 2009a; 2009b).

Laboratory mix tests are essential to the QC/QA of deep mixing methods. The procedures used for the preparation of specimens in the laboratory mix test greatly affect the physical and mechanical properties of the stabilized soils. Different procedures are applied in different countries/regions (e.g. Japanese Geotechnical Society, 2009; EN 14679, 2005; EuroSoilStab, 2001; Carlsten and Ekström 1997; Åhnberg and Holm, 2009). In an increasingly globalized DMM market, it is desirable that a common understanding of the nature of the laboratory mix test and internationally accepted guidelines to conduct it be established, in order to guarantee the QC/QA of DMMs.

As part of an international collaborative study, the influence of different molding techniques for the preparation of specimens has been studied. This is one of the major themes currently being studied with the purpose of establishing common understanding of the key issues involved in the QC/QA of deep mixing works (Terashi and Kitazume, 2009; 2011). This part of the collaborative study was undertaken in four organizations, the Tokyo Institute of Technology, the Sapienza University of Rome, the University of Coimbra and the Swedish Geotechnical Institute, referred to as TIT, UR, UC and SGI, respectively, hereinafter.

The laboratory mix tests were carried out on regional soils with regional binders which were available in the collaborating organizations. The soil and binder mixtures with different initial water content and binder amounts, which changed their consistency, were molded using five molding techniques. Unconfined compression tests were performed on the specimens produced. The results showed that the molding techniques considerably influenced the magnitude and variation of the unconfined compressive strength and the wet unit weight of the stabilized specimens. The applicability of the molding techniques was analyzed by using two indices: the undrained shear strength and the liquidity index of the soil and binder mixture. The study showed that these indices may be useful tools to evaluate the applicability of the techniques. The test results have been partially presented earlier by each collaborator (Kitazume, 2012; Grisolia et al., 2012, 2013, Marzano et al., 2012, Åhnberg and Andersson, 2011, Miguel, 2011; Venda Oliveira et al., 2012). A more general picture covering a variety of soils and binders is presented and discussed in this paper in order to evaluate the applicability of the indices.

2. Testing program

The collaborating organizations, the Tokyo Institute of Technology, the Sapienza University of Rome, the University of Coimbra and the Swedish Geotechnical Institute, prepared stabilized soil samples using their own materials, binders and facilities and molded by some of the five molding techniques, namely tapping (*TP*), rodding (*RD*), dynamic compaction (*DC*), static compaction (*SC*) and no compaction (*NC*). The soil, binder and testing procedure adopted by each collaborating institution are briefly presented in the following sections.

Table 1
Geotechnical properties of Kaolin Clay.

Specific gravity, G_s	2.61
Liquid limit, w_L(%)	77.5
Plastic limit, w_P(%)	30.3
Plasticity index, I_P	47.2
Compression index, C_c	0.56
Swelling index, C_s	0.10
K_0	0.6
c_u/σ'_{vo}	0.24

2.1. Tokyo Institute of Technology (TIT)

2.1.1. Soil materials and binder

A Kaolin clay was stabilized and tested in unconfined compression, with ordinary Portland cement (OPC) (Japanese Industrial Standard, 2009) as a binder. The geotechnical properties of the Kaolin clay tested are summarized in Table 1.

2.1.2. Test procedure and program

In preparing the samples of stabilized soil, the soil was first homogenized thoroughly with the prescribed initial water content, $w_i = 120\%$. The dry form of the binder was then mixed with the soil for 10 min to make a uniform mixture. Immediately after mixing, the water content of the mixture was measured, and the undrained shear strength of the mixture was also measured using the hand vane apparatus. The stabilized clay was placed into plastic molds (cylindrical shape, 50 mm in diameter and 100 mm in height) in 3–6 layers. Four different molding techniques were used, as shown in Fig. 1:

(1) Tapping (*TP*) (see Fig. 1(a))
For each layer, the mold was tapped about 50 times against the floor, which followed the standard specified by the Japanese Geotechnical Society (2009).

(2) Rodding (*RD*) (see Fig. 1(b))
Performed using an 8 mm diameter steel rod and consisted in slowly tamping down (30 times) the mixture with the rod for each layer and, if necessary, pushing down the material attached to the rod.

(3) Dynamic compaction (*DC*) (see Fig. 1(c))
Each layer was compressed by the weight of a rod (1.6 kg) and compacted by a falling weight (0.6 kg) using a special apparatus. The fall height was set to 10 cm, and the number of blows to 5.

(4) Static compaction (*SC*) (see Fig. 1(d))
Each layer was statically compressed by the weight (4.82 kg, corresponding to a vertical pressure of 25 kPa) for 10 s using a heavy rod.