

# A review of deep mixing methodology in geotechnical projects

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**Abstract**— The Deep Soil Mixing method (DSM), further developed by Keller, was invented in Japan and Scandinavia. Its use is growing across the world in strengthening and sealing weak and permeable ground. The method helps to achieve significant improvement of mechanical and physical properties of the existing soil, which after mixing with cement or compound binders becomes the so-called soil-mix (or soil-cement). The stabilised soil material that is produced generally has a higher strength, lower permeability and lower compressibility than the native soil. Although the DSM technology is based on simple principles it requires, on the one hand, having significant experience and expertise in associated planning stages, involving soil-mix and geotechnical design, and execution. On the other hand it also requires the use of specialised rigs and mixing tools to meet specifications imposed by ongoing quality assessments and performance monitoring procedures. In this paper, several types of DM column, Such as CDSM and T-shaped DM (TDM) column, was designed and used as an alternative to the large-area-replacement-ratio DM columns employed in the field.

**Index Terms**— Deep Soil Mixing, soil stabilization, TDM, CDSM.

## 1 INTRODUCTION

Deep mixing methodology (DMM) is an innovative in situ soil stabilization technique that delivers cement and/or lime additives, in either slurry or powder form, into the ground to be mixed with the native soil, using blades that form a hard treated soil column in different block, wall, lattice, and column configurations. Deep mixing methodology was first used in Japan and the Nordic countries in the mid-1970s, and then later spread to Thailand, China, the United States, the United Kingdom, and several other parts of the world [Coastal Development Institute of Technology (CDIT) 2002; Bhadriraju et al. 2008]. The objectives of DMM are to reduce settlement of soft ground, minimize heaving of expansive soils, seismically retrofit civil infrastructure, enhance the stability of embankments or slopes, and solidify contaminated soil media (Porbaha 1998; CDIT 2002; Madhyannapu et al. 2010). Deep mixing methodology was introduced to China in the late 1970s and spread rapidly throughout the country in the late 1990s (Han et al. 2002). Soil cement deep mixed (DM) columns were widely used in China to strengthen highway and railway embankments built over soft clayey soils (Lin and Wong 1999; Chai et al. 2002a; Han et al. 2002). A detailed discussion of the use of DM columns in ground improvement projects in China can be found in Han et al. (2002).

Case histories indicate that settlement of surrounding untreated soil is always greater than settlement of DM soil under embankment loading conditions (Bergado and Lorenzo 2002). This is attributed to the different compressibility behavior of DM and untreated native soils. The difference in settlement between treated and untreated soils can be as high as 8 to 20% of the average settlement at the ground surface (Bergado et al. 2002). This differential settlement is highly problematic because it can cause embankment instability and also pavement distress in the form of longitudinal cracking. For high-speed rail embankments, where tolerance is further restricted, differ-

ential settlements between treated and untreated soil zones needs to be carefully evaluated.

Jasperse And Ryan in 1987 To protect the Jackson Lake dam, Wyoming, from damage due to earthquake induced liquefaction, a series of honeycomb cells to contain the soil was specified. Deep soil mixing was the chosen construction method, ahead of jet grouting, on cost and efficiency grounds. A fluid water cement grout mix is injected into the ground using an auger drill. The construction of containment walls using this technique, and their applications to in situ treatment of contaminated soils are discussed.

Evaluation of soil mixing in the field and in the laboratory has been done before by many researchers around the world (Bergado et al., 1996; Locat et al., 1996; Feng et al., 2001; Chew et al., 2004; Lee et al., 2005; Shen et al., 2008; Kamnuzzaman et al., 2009; Duraisamy et al., 2009; Jongpradist et al., 2011; Con soli et al., 2011 and Pakbaz and Alipour, 2012). In these research activities the cement or lime was introduced to the soil either in the form of slurry (wet method of mixing) or in the form of powder (dry method of mixing). Also in the field both dry and wet applications are used (Islamand Hashim, 2004). A comparison between wet and dry method of mixing for both cement and lime treated soils with high initial water content has not been done so far. In this study, the behavior of the soil samples with the initial high water content treated with lime, cement and lime-cement in different percentages using dry and wet methods is examined and compared.

Zhang et al in 2012 were investigated on Simulation of Excess Pore Water Pressure During Deep Soil Mixing Columns Installing, that In order to find methods to predict and simulate the excess pore water pressure during DSM column installation, the complicated dissipation and buildup of excess pore water pressure through in-situ test are studied in this paper. In-situ test was conducted in soft clay near the Huangpu River

in Shanghai. The pore water pressure was investigated by an automatic monitoring system. Test results indicate that the excess pore water pressure induced by one DSM column installation is composed of the compaction pressure and the reversing pressure. The empirical equations of excess pore water pressure dissipation and buildup were built by mathematical fitting methods. A compound method is proposed to simulate the excess pore water pressure due to DSM installation. Using this method to predict the excess pore water pressure in the situ test, results show a well agreement between the prediction and the measurements.

Wang et al in 2015 were investigated on time-dependent performance of soil mix technology stabilised/solidified contaminated site soils. Their paper presents the strength and leaching performance of stabilised/solidified organic and inorganic contaminated site soil as a function of time and the effectiveness of modified clays applied in this project. Field trials of deep soil mixing application of stabilisation/solidification (S/S) were performed at a site in Castleford in 2011. A number of binders and additives were applied in this project including Portland cement (PC), ground granulated blastfurnace slag (GGBS), pulverised fuel ash (PFA), MgO and modified clays. Field trial samples were subjected to unconfined compressive strength (UCS), BS CN 12457 batch leaching test and the extraction of total organics at 28 days and 1.5 years after treatment. The results of UCS test show that the average strength values of mixes increased from 0-3250 kPa at 28 days to 250-4250 kPa at 1.5 years curing time. The BS EN 12457 leachate concentrations of all metals were well below their drinking water standard, except Ni in some mixes exceed its drinking water standard at 0.02 mg/l, suggesting that due to varied nature of binders, not all of them have the same efficiency in treating contaminated soil. The average leachate concentrations of total organics were in the range of 20-160 mg/l at 28 days after treatment and reduced to 18-140 mg/l at 1.5 years.

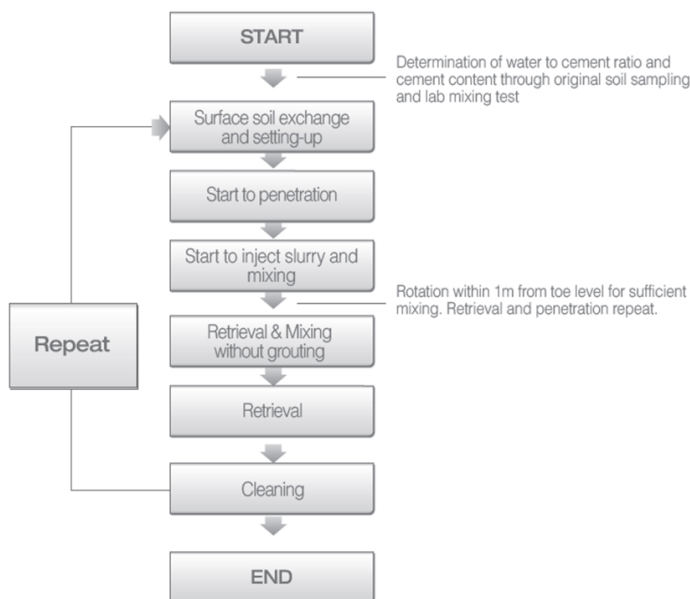


Figure 1-Construction Sequence Chart

In addition, organo clay (OC)/inorgano-organo clay (IOC) slurries used in this field trial were found to have a negative effect on the strength development, but were very effective in immobilising heavy metals. The study also illustrates that the surfactants used to modify bentonite in this field trail were not suitable for the major organic pollutants exist in the site soil in this project. Thus, Construction Sequence Chart of mixing showed in figure1.

## 2 INTRODUCING SOME DEEP MIXING METHOD

CDSM is a process whereby soil is improved by injecting grout through one or more augers that simultaneously mix the soil, forming in-place soil-cement columns as shown in Figure 2.

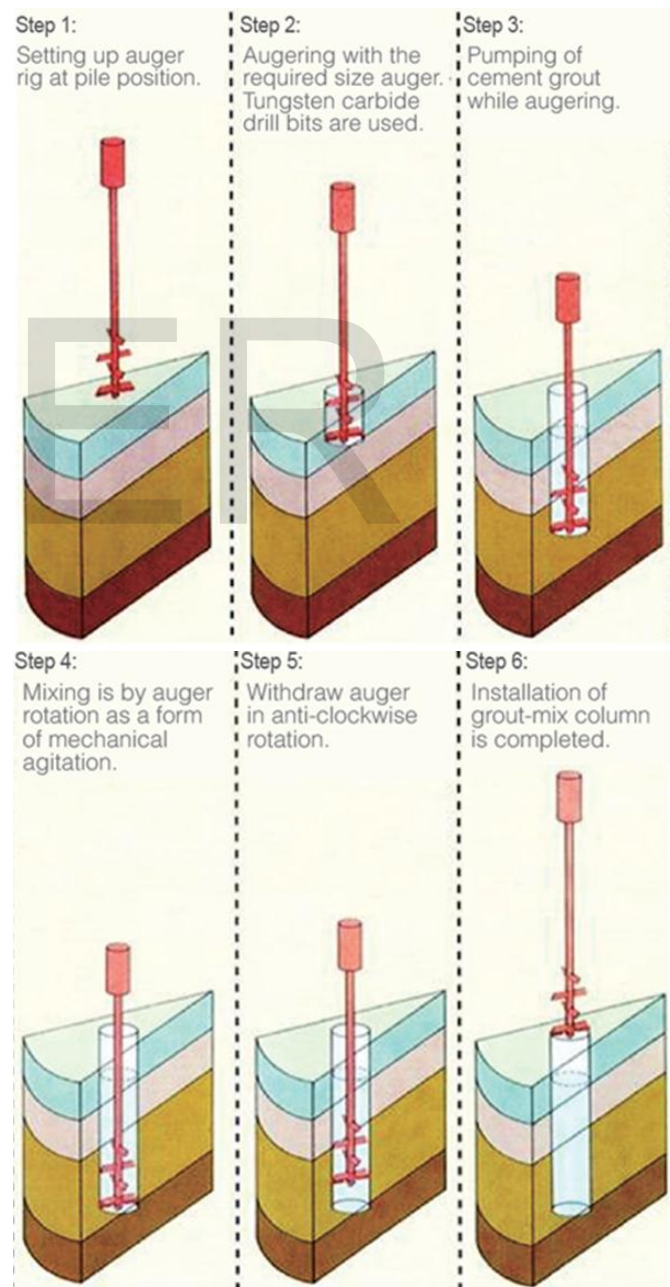


Figure 2. CDSM Construction Procedure

The CDSM would need to be performed in a regular grid of in-place columns to effectively improve the target soils. Level benches would have to be cut into the embankment in order to operate the CDSM rig. The grid would have to be designed to provide subsurface drainage paths to minimize buildup of groundwater behind the soil cement columns.

Advantages of CDSM include:

1. High strengths can be achieved in the final soil cement product.
2. CDSM has been used on similar projects to address seismic stability issues associated with significant strength loss, such as the Jackson Lake Dam and the Clemson Upper and Lower Diversion Dams. It has also been used on several projects within the Bay Area, such as at the Port of Oakland.
3. The zone of improvement can be controlled more effectively than jet grouting.
4. Proven confirmation testing methods exist for assuring quality.
5. The process would have a low impact on reservoir operations.

Disadvantages include:

1. Temporary construction benches would have to be cut into the embankment during installation.
2. The process generates spoils that must be used onsite or hauled offsite.

Recently, for construction of DM columns for highway engineering in China, a new type of soil cement DM column, called T-shaped deep mixed (TDM) column, was proposed (Liu et al. 2007a). The diameter of the TDM column is larger in diameter at shallow depth (enlarged column cap) than at greater depths (deep-depth column), resulting in a column shaped like the letter "T" (see Figure. 3). The area replacement ratio of TDM columns- supported ground at shallow depth is much higher than that of conventional DM column-supported ground. Therefore, at greater depths, TDM columns can be installed at wider intervals than can conventional DM columns, reducing the amount of cement used in the construction project.

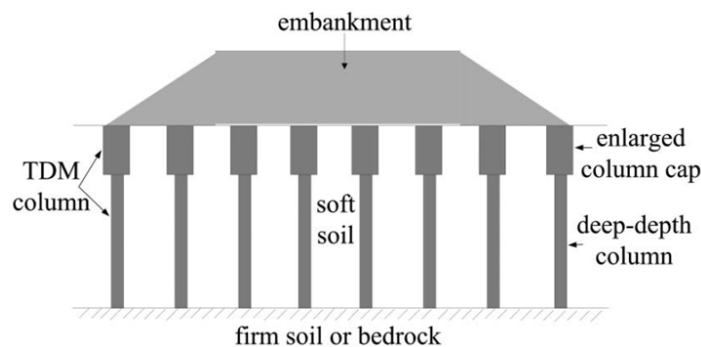


Figure. 3. Illustration of TDM column-supported embankment

The enlarged column cap in the TDM column-supported embankment is somewhat similar to the pile cap in the rigid pile-supported embankment except that the former is less rigid

and greater in length than the latter. It should be noted that the area replacement ratio of the TDM column-supported embankment is generally higher than that of the rigid pile-supported embankment. It is hypothesized that the load transfer mechanism of a TDM column supported embankment is somewhat closer to that of a rigid pile-supported embankment because of the similarities in their geometrical configurations. Both the higher column efficacy of TDM columns and the lower additional stress on surrounding soil under embankment loading are expected because of the higher area replacement ratio used in shallow TDM column-supported ground.

The column area replacement ratio ( $a_s$ ) is defined as the ratio of the column area to the whole area of the influence unit cell, expressed as (Bergado et al. 1996)

$$a_s = \frac{A_c}{A_c + A_s} \tag{1}$$

where  $A_c$  = horizontal area of a column; and  $A_s$  = horizontal area of the soil surrounding the column. For the triangular pattern, the area replacement ratio is calculated as (Bergado et al. 1996)

$$a_s = \frac{\pi}{2\sqrt{3}} \left(\frac{D}{S}\right)^2 \tag{2}$$

where  $D$  = column diameter; and  $S$  = column spacing (from column center to column center).

For TDM column-supported ground, there are two values of  $a_s$ : one at shallow depth and the other at greater depth. Both values

### 3 CONCLUSION

Deep Soil Mixing was selected as the preferred alternative to mitigate a potentially weak foundation. The results of this study have shown the beneficial effects of deep soil mixing. Therefore, On the basis of literature survey carried out following concluding remarks are made:

- 1- both total settlement and postconstruction settlement of TDM column-supported ground would be lower than with conventional DM column-supported ground.
- 2- CDSM has been used on similar projects to address seismic stability issues associated with significant strength loss, such as the Jackson Lake Dam and the Clemson Upper and Lower Diversion Dams. It has also been used on several projects within the Bay Area, such as at the Port of Oakland.
- 3- High strengths can be achieved in the final soil cement product.

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