A COMPARATIVE STUDY ON INFLUENCE OF SOFT CLAY PROPERTIES FOR DEEP SOIL CEMENT MIXING IN THE DELTAS OF MEKONG AND MISSISSIPPI

NOZU M., NAKAI. N.
Fudo Tetra Corporation, Tokyo, JAPAN

ABSTRACT: In the southern port region of Vietnam, many deep mixing (DM) columns have been installed to increase the stability of slopes and mitigate ground settlement. Prior to DM production, laboratory mixing tests should be executed carefully. In fact, there is significant variation in cement dosage due to the required performance (UCS, criteria), soil condition and local cement property. This paper describes the clay property and considers a case study of a laboratory mixing test using the local clay deposited at major river deltas in the South of Vietnam and the Southern United States, and considers differences with Japanese clay mixing results. In addition, deformation characteristics associated with DM installation is considered based on the measured data.

INTRODUCTION

In South Vietnam, based on many references and standards (Miki, 1998, JGS, 2000, Kitazume et.al., 2001, BS 2005, Nozu 2005), deep mixing (DM) has been used in recent years for soft clay improvement to increase the stability of slopes and to reduce consolidation settlement.

Prior to DM production, laboratory mixing tests need to be executed carefully. Actually, cement dosage can vary considerable due to the required performance (UCS, criteria), soil condition and local cement property.

This paper begins with a description of clay properties and a case study of laboratory mixing tests using the local clay deposited in the big river delta in Vietnam and the United States, and considers differences with Japanese clay mixing results.

It is well known that DM has some deformation influence on surrounding ground. By injecting stabilizing agent into soft ground, the ground will heave to some extent and expand horizontally. In Vietnam, however, the authors have observed larger ground deformation due to DM installation compared with Japanese measured data. This paper therefore also investigates the major factors in the large deformation and considers an appropriate response.

SOIL PROFILE

The soil profile at two large river deltas where DM method has been applied is shown in Table 1.

In the South of Vietnam, marine clay is deposited to a thickness of around 20 to 30 m without a sand seam. (The shear strength of marine clay is typically around cu=10+1.5z, kPa.) The coefficient of consolidation (cv) is also rather low at around 10-60 cm^2/day because of its fine clay particles. This suggests that a consolidation acceleration method like a plastic board drain is likely to be difficult to use in this area.

The Mississippi river delta, in the United States, has soft clay layers such as a "peat" layer with a thickness of 4 to 5 m, at a depth of 5 m, and a "fat clay" layer with a thickness of 10 to 15 m, at a depth of 10 m. In fat clay, the natural water content is approximately 20% lower than the liquid limit so that it is hard to make it fluid and hard to mix it with cement (see Figure 6, Nozu 2010).

X-ray diffraction analysis

X-ray diffraction analysis (see Figure 1) has been performed to investigate the micro structure of these clays. The analysis has revealed montmorillonite crystals, made by metamorphic tuff, to some extent in both Vietnam marine clay and U.S. fat clay.

Montmorillonite readily absorbs water. Subsequently, mixing with cement may be difficult because of local gel reaction and the lack of a separation property (Figure 3). Montmorillonite has an octahedron-type crystal structure in which water is readily included. This crystal is very rare and is not deposited in soft ground in Japan.

Table 1 Soil conditions in major river deltas in Vietnam and the United States

		Cc (%)	LL (%)	Ip	wn (%)	Density (g/cm3)	Su (kPa)	Su/p	cv (cm2/day)	pH
South Vietnam		40-70	75-100	35-64	65-95	2.67-2.78	20-60	0.2-0.25	10-60	5.4-5.8
U.S. (Mississippi)	Peat	-----	-----	-----	99-500	-----	15-20	-----	-----	5.0-7.6
	Fat clay	60-80	60-80	20-60	45-60	2.67-2.78	10-40	≒0.2	10-50	7.0-8.0
Japan(Ariake-kai)		50-55	55-140	50-80	42-200	2.58-2.66	8-40	0.25-0.45	50-200	6.5-7.5
Japan(Hachirogata)		40-70	150-200	54-77	74-100	2.65	130-160			

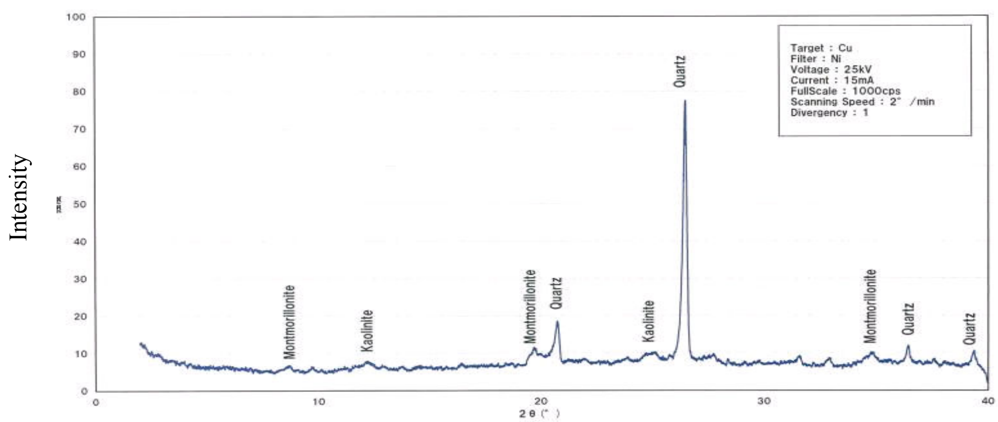

Figure 1 X-ray diffraction analysis results of South Vietnam marine clay

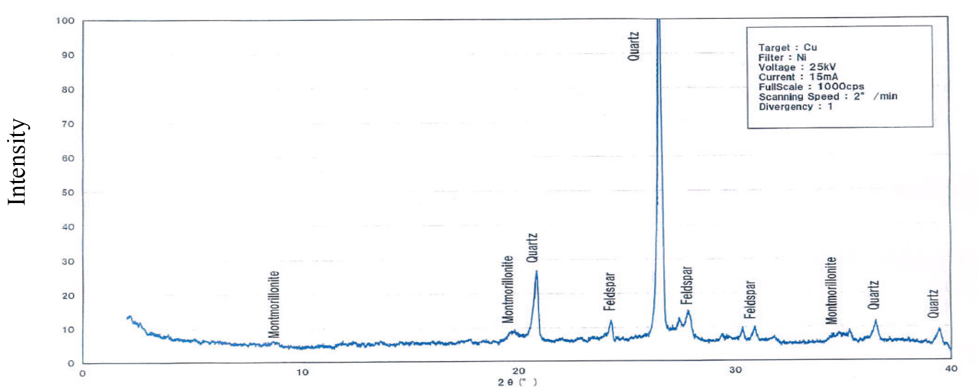

Figure 2 X-ray diffraction analysis results of Mississippi delta clay

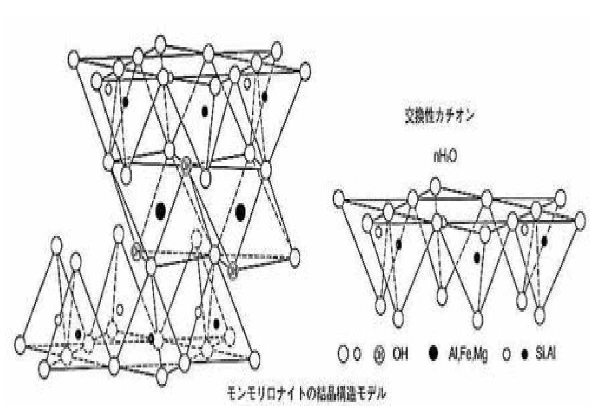

Figure 3 Crystal structure of montmorillonite

Element quantitative analysis

Table 2.2 shows the results of element quantitative analysis obtained using a fluorescent X-ray device.

Table 2 Results of element quantitative analysis

(%)	South Vietnam	New Orleans
SiO_2	53.5	65.0
Fe_2O_3	17.6	9.3
AL_2O_3	11.8	8.6
SO_3	9.0	4.4
K_2O	3.4	5.1
TiO_2	2.3	1.6
CaO	1.9	5.4
MnO	0.2	0.2

Electric conductivity

Table 2 shows the electric conductivity of each kind of soil, in which the electric conductivity of South Vietnam and New Orleans fat clay is comparatively high, such as 230-992 micro Siemens/cm.

Table 3 Electric conductivity of suspended soils

	South Vietnam	New Orleans	Japan
Electric conductivity(mS/cm)	992	230	0.06-4.5
pH	8.0	10.0	
Ignition loss (%)	11.5	6.1	

Ion exchange capacity

Table 4 shows the cation exchange capacity (CEC) and each cation amount.

Table 4 CEC and Cation amount

(meq/100g)	South Vietnam	New Orleans
CEC	18.4	20.2
Ca^{2+}	39.6	40.0
Mg^{2+}	17.8	14.2
Na^{+}	37.2	11.7
K^{+}	3.3	2.2
Total	97.9	68.1

Table 5 Cement content in each region

		Vietnam		U.S.	Japan		
					JIS R 5210		JIS R 5211
		OPC	PBFC	OPC	NP*1)	HEP*2)	PBFC B*3)
Specific surface (cm^2/g)		3780	3970	3790	≧2500	≧3300	≧3000
Setting time	Initial (min)	110	165	96	≧60	≧45	≧60
	Final (h)	2h45min	3h55min	3h58min	≦10		
Chemical(%)	MgO	-----	-----	2.9	≦5.0	≦5.0	≦6.0
	SO_3	2.1	2.4	2.9	≦3.0	≦3.5	≦4.0

*1) NP: Normal portland cement

*2) HEP: High early strength portland cement

*3) PBFC B: Portland blast furnace slag cement (Type B)

CEMENT PROPERTY

Cement content in each region is summarized on Table 3.1. Both Vietnam and the United States have Ordinary Portland Cement (OPC) and Portland Blast Furnace Cement (PBFC). However, the fineness of each cement type is significant and hydration time is short in comparison with Japanese cement.

In the Vietnam cement standard, fineness values such as 3780 cm^2/g for OPC and 3970 cm^2/g for PBFC are relatively high. This means that it is easy to obtain a hydration reaction at early stage when using Vietnam cement.

LABORATORY MIXING TEST RESULTS

Figure 4 shows a comparison of the cement dosage and 28-day UCS strength relationship for each region.

Figure 5 shows the cement dosage and UCS relation for peat and fat clay in the United States. It is clear that with PBFC, a higher UCS is obtained at all regions and in both the United States and Vietnam relatively low UCS is obtained in comparison with the Japanese case. The reasons for the low UCS are believed to be as follows:

(1) Relatively low pH value in Vietnam clay,

(2) Small clay particles compared with cement particle,

(3) Mixing hardness; Photo 4.1 is the filling condition for a mold in the United States. The clay readily absorbs mixing water so it is hard to fill the mold.

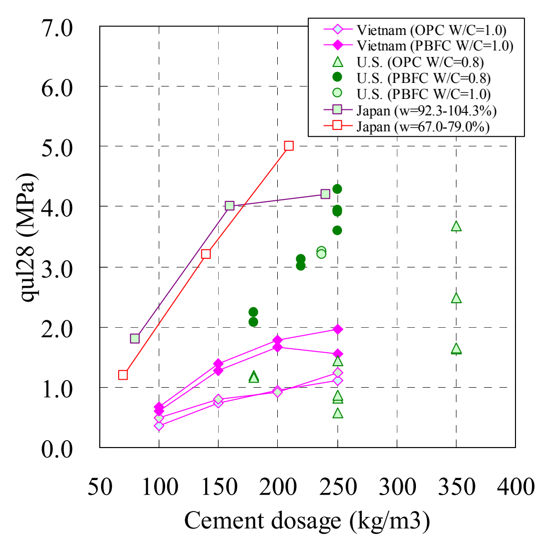

Figure 4 Cement dosage and 28-day strength at each region

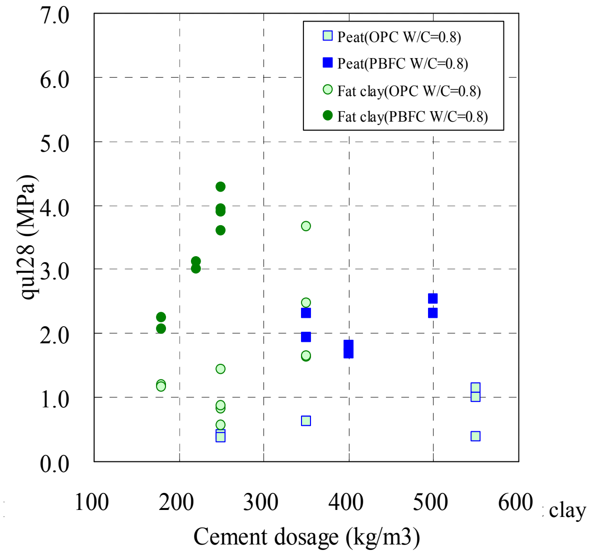

Figure 6 Mold filling conditions

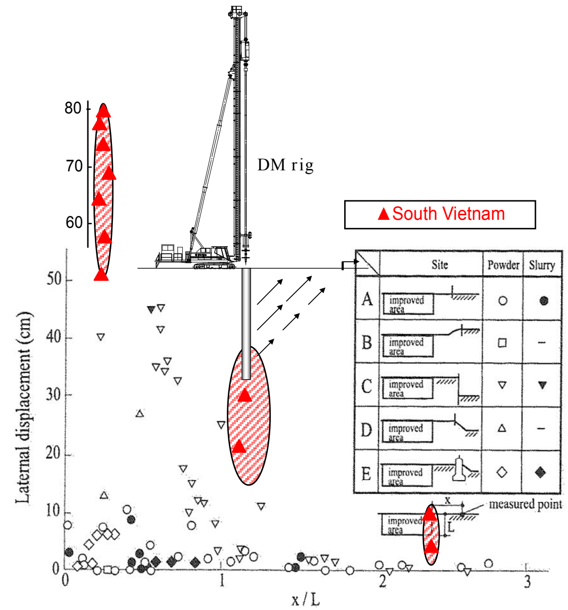

Figure 7 Lateral deformation and distance observed at Vietnam site plotted in Japanese results (Kitazume et.al. 2001)

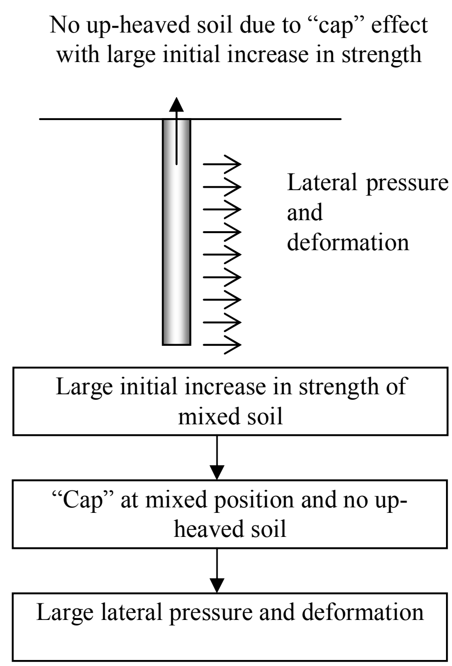

Figure 8 Cause of large deformation

DEFORMATION DUE TO DM INSTALLATION

In Figure 7, ground deformation data due to DM installation in Vietnam were plotted in red in the relationship between x/L (distance divided by depth of DM column) and lateral displacement, which have been observed at Japanese construction sites for around 30 years. The red color plot was clearly larger in comparison with previous experience in Japan.

As a result of injecting stabilizing agent into soft ground, the ground surface will heave to some extent. The extent of the up-heaved ground is not uniform but will depend on many factors such as the soil profile, the thickness of the improved layer, the improvement area ratio, and the workflow sequence.

According to accumulated field experience, the total volume of up-heaved soil is almost equivalent to that of the cement slurry injected, and the up-heaved volume within the improved ground area is approximately 70% of the volume of the cement slurry injected.

In this Vietnam site, however, some up-heaved soil was observed during the DM mixing. It is indeed an unusual situation in comparison with the Japanese experience.

It is thus considered that no up-heaved soil induces the large lateral pressure and deformation of the surrounding area. The reason for the absence of up-heaved soil will be considered subsequently. From the precise observation at the site, the large initial increase in the strength of mixed soil seems to have a "cap" at the mixed position, disrupting the up-heaving of soil. Consequently, the reason for the large initial increase in the strength of mixed soil should be estimated next (Figure 8).

There seem two main reasons for the large initial increase in the strength of mixed soil, as follows:

- High temperature

- Initial condensation effect

1) High temperature

Figure 9 shows the observed temperature of used water for making cement slurry at the site.

As shown in the figure, the water temperature in the slurry plant has already reached 35 degrees, which is very high. This means that the hydration reaction will accelerate and cause high initial hardening.

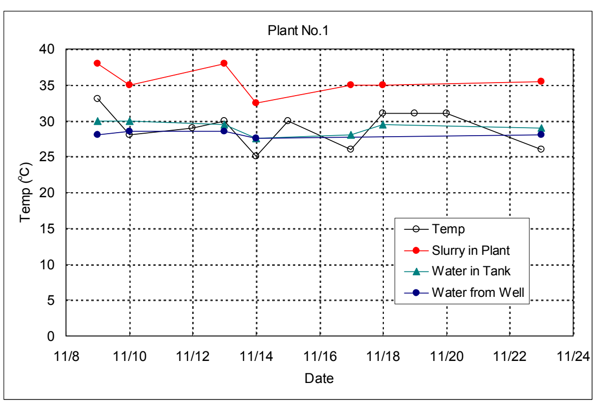

Figure 9 Observed temperature of water used for making cement slurry on site.

2) Initial Condensation effect

In general, natural clay is charged with negative ions and cement is charged with positive ions due to Ca^{2+}. Therefore clay and cement is likely to be pulled together and have a condensation object due to ion exchange, if there are many minerals and a high number of cations (high electric conductivity, see Figure 3) in the clay (Figure 10).

In an environment with many minerals like marine clay, condensation objects tend to connect in a network and become large bodies.

This seems to be the main reason why the "cap" effect is observed at an early stage in the ground. In that case, a special additive already developed to mitigate the condensation is effective.

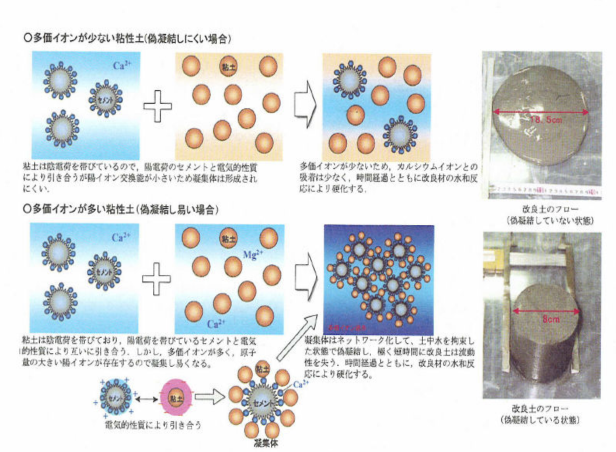

Figure 10 Condensation process (Aoyama, 2002), with the upper example showing no condensation and the lower case showing condensation objects generated.

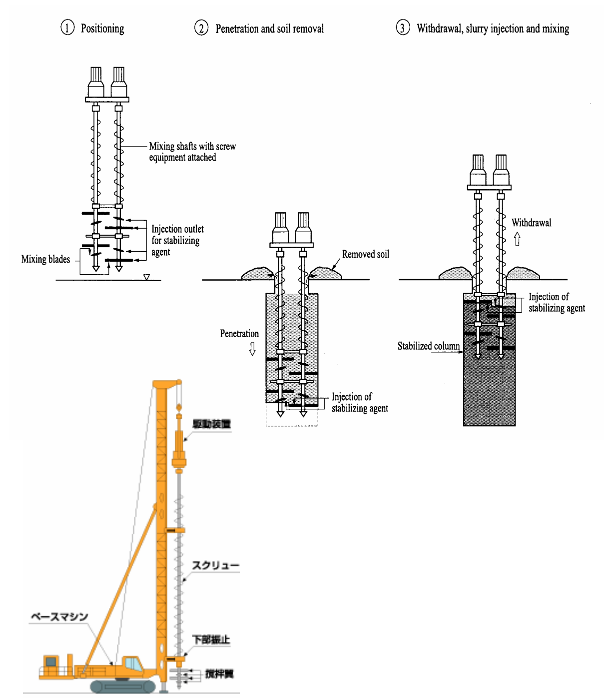

Figure 11 Work procedure of CDM-LODIC (Kitazume, 2001)

CONCLUSION

The strength characteristics in a laboratory cement mixing test are investigated with using Vietnam delta clay and

Mississippi delta clay. Each local soil and cement property should be carefully considered to ensure good quality at the deep mixing site.

In addition, the cause of large deformations caused by DM installation observed in Vietnam is considered. To reduce this lateral deformation, the CDM-LODIC method (Figure 11, Sugiyama, 2002) is effective based on our experience in South Vietnam.

REFERENCES

Aoyama K., et.al,: (2002). Influence of physical and chemical property of soil against initial condition and strength of cement mixed soil, *Journal of Geotechnical Engineering,* Japanese Society of Civil Engineers, No.721/VI-57,pp.207-219, 12-2002.

British Standard, Execution of special geotechnical works-deep mixing, BS EN 14679:2005.

Japanese Geotechnical Society, (2000). Practice for making and curing stabilized soil specimens without compaction, JGS 0821-2000, *Japanese Geotechnical Society* (in Japanese).

Kitazume, M. and Terashi, M. (2001), The Deep Mixing Method, A.A. Balkema Publishers.

Miki, H. and Nozu, M. (1998), Manual for Design and Construction of Cement Column Method*, (JICA, Public Works Research Institute (MOC))-THAILAND* (Department of Highway), Joint Study on Soft Clay Foundation.

Nozu, M. (2005). Regional Report in Asia, Deep Mixing ’05 in Stockholm, May 2005.

Nozu, M. and Nakai, N., (2010). Strength characteristic at laboratory cement mixing test using soft clay deposited at the mouth of long rivers, *Vietnam Geotechnical Day*, June 2010.

Sugiyama K, (2002) The CDM-LODIC method–outline and application–,” *Proc. Deep Mixing Workshop* 2002, Tokyo, 2002.