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MEASURED BEHAVIOR OF A TRIAL EMBANKMENT ON FLOATING COLUMN IMPROVED SOFT ARIAKE CLAY DEPOSIT

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ABSTRACT: A 6.5m height trial embankment was constructed on soft Ariake clay deposit improved by the floating soil-cement columns. At the test site, the thickness of the soft soil was about 10 m, and the length of the column was 8.5 m and the area improvement ratio was about 31%. To check both the mechanical and geoenvironmental performance, the embankment was monitored for more than 2 years. The measured results indicate that the behavior of the trial embankment satisfies the performance requirements for constructing a highway around Ariake Sea, in Kyushu, Japan, i.e. settlement and lateral displacement at the toe of the embankment are less than 50 mm, and residual settlement is less than 0.3 m. The observed results also show that the column improvement not only reduced the settlement but also accelerated the consolidation rate of the deposit. The results of groundwater monitoring indicate that at the test site, in terms of groundwater level, flow velocity, pH value and the concentrations of some key ions, there was no effect on the groundwater quality due to the installation of soil-cement columns into the ground.

Keywords: Soft ground improvement, Floating soil-cement column, Trial embankment, Field observation, Environmental monitoring

INTRODUCTION

In Saga plain, a regional expressway named the Ariake Sea Coastal Road has been under construction in the Saga Lowland, where deposits famous soft Ariake clay (Holocene deposit) with a thickness of about 20 m (Shimoyama et al. 2010). Construction of a highway in this region requires thorough understanding of the mechanical properties of the soft ground. It is also necessary to consider the potential effect of construction activity on surface and groundwater quality, which is a sensitive environmental issue (Hachiya et al. 2002).

The Ariake Sea Coastal Road is a 1st grade, 3rd class (MLIT 2003), access-controlled freeway with a design speed of 80 km/h. It was designed as a 20.5 m wide four-lane road. In the first stage a 10.5 m wide two-lane road is under construction (ASCRDO Saga Pref. 2009). Fig. 1 shows the locations of the Ariake Sea Costal Road and the trial embankments. The road is a 55-km-long freeway connecting Omuta in Fukuoka Prefecture and Kashima in Saga Prefecture. Fig. 2 shows a part of the road in Saga Prefecture. For the most part of the road, the design embankment height is more than 5 m. The performance requirements for the embankment are: the vertical and horizontal displacements along the property line of the road should be less than ±50 mm, and after the road entered service, the residual settlement should

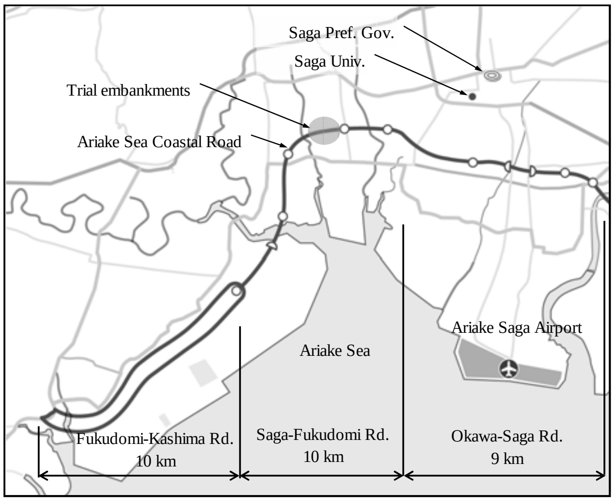

Fig. 1 Site of trial embankments

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Note: Discussion on this paper is open until December 2011

Fig. 2 A Part of the Ariake Sea Coastal Road in Saga prefecture (March, 2011)

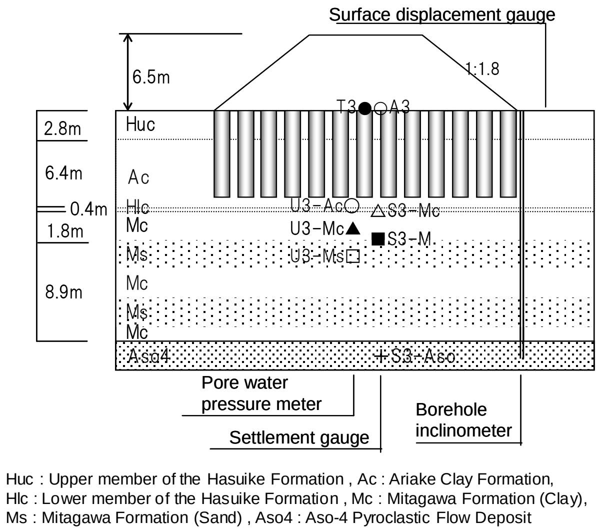

Fig. 4 A cross-section of the trial embankment

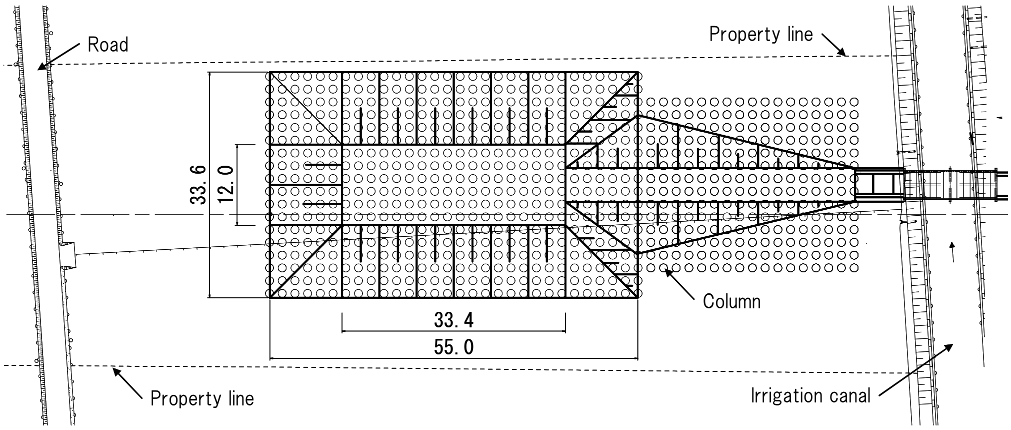

Fig. 3 A plan view of the trial embankment

be within 0.3 m. To satisfy these requirements, soft ground improvement became inevitable. One of the ground improvement schemes selected is improving the soft clayey layer by soil-cement columns. However to ensure that there is no negative impact on the groundwater quality, it has been specified that to leave about 1.0 m thick clayey soil layer above the sand layer (an aquifer) without cement improvement to serve as a barrier. To verify both the mechanical and geoenvironment performance of this ground improvement scheme, a trial embankment was built and monitored for more than 2 years.

This paper presents the details of the trial embankment and field monitored results, in terms of settlements, lateral displacements, excess pore water pressures and groundwater qualities. The effectiveness of the ground improvement method is discussed.

A TRIAL EMBANKMENT ON SOIL-CEMENT COLUMN IMPROVED GROUND

The height (fill thickness) of the trial embankment was 6.5 m. The top dimensions (length × width) of the embankment were 12.0 m × 33.4 m, and the slope gradient was 1:1.8 (V:H). Decomposed granite was used as fill, and the rate of filling was 0.1 m/day. The average value of wet unit weight of the embankment fill was about 18.2 kN/m^3. The ground was improved by soil-cement columns and each of the columns had a diameter of 1.2 m and length of 8.5 m. The columns were placed in a square pattern with a center-to-center distance of 1.9 m, and their design unconfined compression strength is 600 kN/m^2. The amount of a cement based stabilizer free of hexavalent chromium (Cr^{6+}) used was 150 kg/m^3. Slurry mixing method was adopted with a water-cement ratio of 150%. For the purpose of reducing the horizontal

Fig. 5 The state after the soil-cement column improvement

Fig. 6 Completed trial embankment on soil-cement column improved ground

displacement of the ground, wire (2 mm in diameter) mesh with a diamond-shaped grid and 56 mm wire spacing was put at the base of the embankment. A plan layout and a cross-section of the trial embankment are shown Figs. 3 and 4, respectively. Figs. 5 and 6 respectively show the state after the soil-cement column improvement and completed trial embankment. The ground improvement and the embankment construction were constructed from May to December, 2008.

MECHANICAL BEHAVIOR OF THE TRIAL EMBANKMENT

Fig. 7 shows the data obtained from the surface settlement plates placed on the top of the soil-cement column and between the columns, and sub-surface settlement plates under the center of the embankment. All the surface settlements and the sub-surface settlements indicate that ground settlement accelerated while the embankment was being built, and the ground continued to settle after the completion of the construction. However, ground settlement almost ceased by the 150 days after the end of the construction. The final surface settlement was 0.47 m on the top of the column and 0.57 m between the columns, with a difference of about 0.1 m. Ground settlement also took

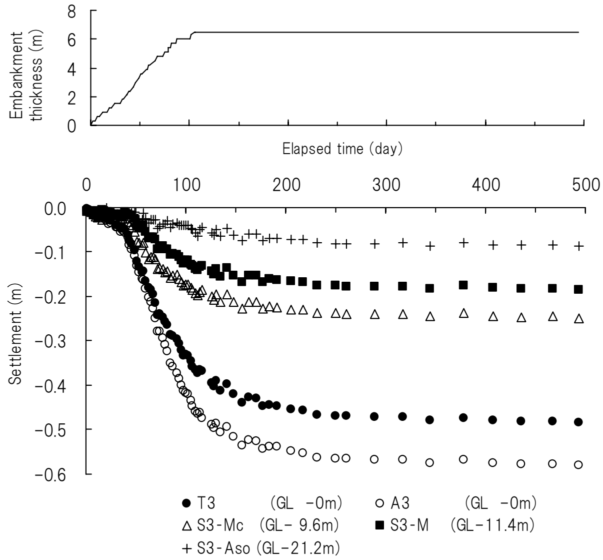

Fig. 7 Measured settlements

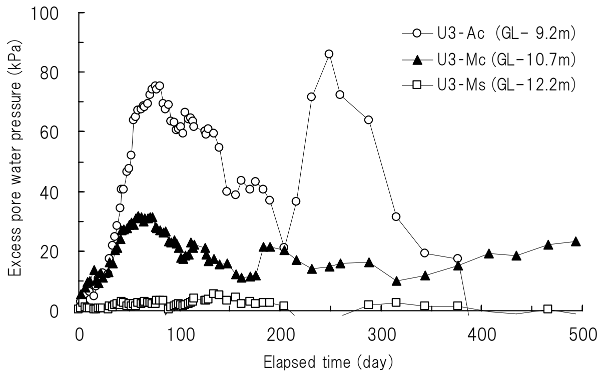

Fig. 8 Measured excess pore water pressure

place below the Ariake Clay Formation. Fig. 8 shows the measured excess pore water pressure variations under the center of the embankment. The excess pore water pressure in the Ariake Clay formation (U3-Ac) increased after the start of the embankment work, peaked at about 80 days of elapsed time, and decreased after that. At 200 days after the start of the embankment work, the measured data show some fluctuations. The reason for this kind of anomalous values is not clear yet. The excess pore water pressure in the clay layer of the Mitagawa Formation (U3-Mc) peaked before the embankment completion. Then it dissipated gradually. From the 200 days after the start of the embankment work, the value remained roughly constant. The excess pore water pressure in the sand layer of the Mitagawa Formation (U3-Ms) almost not increased after the start of the embankment work. Measured maximum excess pore water pressure was 75 kPa corresponding to about

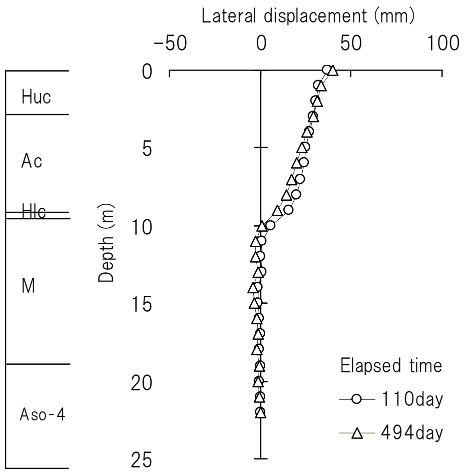

Fig. 9 Measured lateral displacement profiles

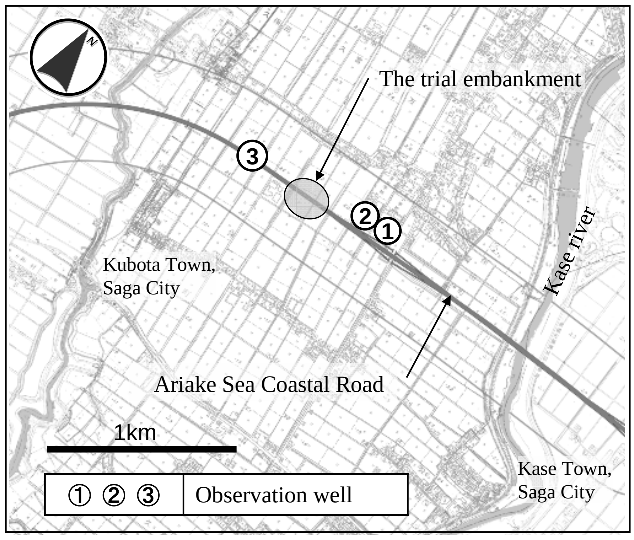

Fig. 11 Locations of groundwater monitoring

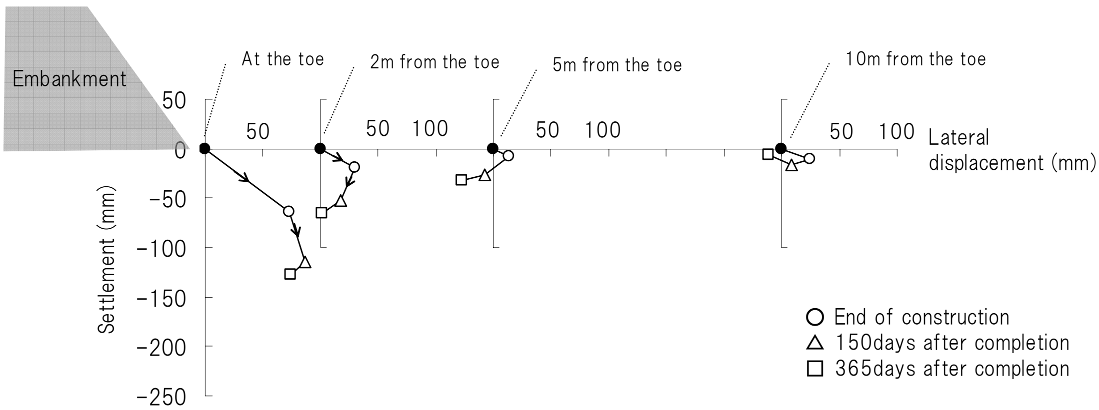

Fig. 10 Measured surface deformation in surrounding area

64% of the fill load of about 118 kPa under the center of the embankment. The reasons considered are the high stiffness of the columns carried more load (stress concentration) and the column also accelerated the rate of consolidation. Fig. 9 shows the measured lateral displacement profiles under the toe of the embankment. The largest lateral displacement occurred at the ground surface, and decreased with depth. There was little displacement below 10 m depth. The lateral displacement increased while the embankment was being built, and not increased after the completion of the embankment. Fig. 10 shows the measured surface deformation in surrounding area of the embankment, at the toe as well as at 2 m, 5 m and 10 m away from the toe of the embankment. The outward surface deformations and the settlement increased while the embankment was being built, and horizontal displacement peaked at the end of embankment construction. After that, the outward deformations decreased with the increase of settlement. The surface deformations decreased with increasing distance from the toe of the embankment. There was little settlement at points 5 m and 10 m away from the toe.

GEOENVIRONMENTAL BEHAVIOR

Fig. 11 shows the locations of groundwater monitoring (ASCRDO Saga Pref. 2010). Note, the observation wells were installed not only for monitoring the geoenvironmental impact of the trial embankment, but also the impact of constructing the road. For the part of the road from the observation well No.1 to the right side in Fig. 11, the ground improvement work was

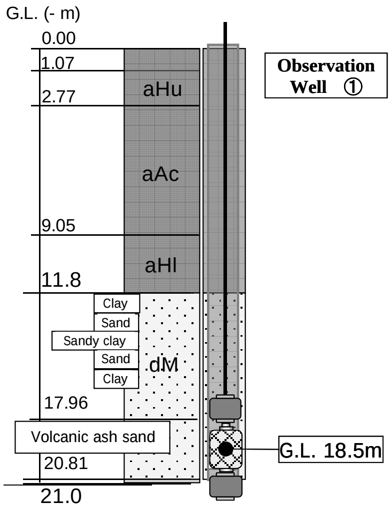

Fig. 12 Groundwater observation well system

Fig. 13 Heat-capacity groundwater flow direction/velocity meter

finished in December 2009. Therefore some of the results given below include the effect of constructing the road. The structure of the groundwater monitoring well is shown in Fig. 12. The heat-capacity groundwater flow direction/velocity meter used is shown in Fig. 13 (Hayami et al. 2009). The observations were made before (October 2007), during (August, December 2008) and after (December 2009) the embankment construction. Tables 1 and 2 show the results of monitored temperature, elevation (level), flow velocity and direction of the groundwater. The results in Tables 1 and 2 show that the groundwater temperature level and flow velocity were not affected by the embankment construction. Table 3 shows the results of groundwater quality monitoring. When the mixing cement into the ground, there is a concern that the cement may affect the groundwater quality. Both before and after the embankment/road construction, the level of hexavalent chromium (Cr^{6+}) was "not detected" (ND) or under the minimum limit of the measurement method used, and no obvious changes were observed with regard to calcium ion (Ca^{2+}), magnesium ion (Mg^{2+}) concentration and pH values.

Table 1 Measured air temperature and groundwater temperature/level

Well No.	Date	Temperature (℃) Air	Temperature (℃) Groundwater	Water level (T.P m)
2	Oct/2007	20.0	17.7	0.82
	Dec/2008	5.7	17.7	0.89
	Dec/2009	10.2	18.1	0.88
3	Oct/2007	20.2	17.4	0.74
	Dec/2008	5.8	15.3	0.76
	Dec/2009	11.3	17.8	0.75

Table 2 Measured groundwater flow velocity/direction

Well No.	Observed depth (m)	Date	Velocity (m/sec)	Direction
1	18.5	Aug/2008	$\sim 10^{-6}$	Southwest
		Dec/2008	$\sim 10^{-6}$	Southwest
		Dec/2009	$\sim 10^{-6}$	Northwest

Table 3 Measured groundwater quality

Well No.	Date	Cr^{6+} (mg/l)	pH	Ca^{2+}, Mg^{2+} (mg/l)
2	Oct/2007	ND	7.4	1,400
	Dec/2008	ND	7.5	1,300
	Dec/2009	ND	7.3	1,400
3	Oct/2007	ND	6.9	1,700
	Dec/2008	ND	6.8	1,800
	Dec/2009	ND	6.8	1,800

CONCLUSION

A 6.5 m height (fill thickness) trial embankment was constructed on soft Ariake clay deposit improved by the floating soil-cement columns. At the test site, the thickness of the soft soil was about 10 m, and the length of the column was 8.5 m with an area improvement ratio of about 31 %. The embankment had a top dimensions of 12 m × 33.4 m and side slope of 1:1.8 (V:H). The embankment was monitored for more than 2 years, and from the measured results, following conclusions can be drawn.

The main purpose of the trial embankment is to find/confirm soft ground improvement scheme for constructing a highway around Ariake Sea, in Kyushu, Japan. The measured results indicate that the behavior of the trial embankment satisfies the performance requirements, i.e. settlement and lateral displacement at the toe of the embankment are less than 50 mm, and residual settlement is less than 0.3 m. The observed results also show that the column improvement not only reduced the settlement but also accelerated the consolidation rate.

The results of groundwater monitoring indicate that at the test site, in terms of groundwater level, flow velocity, pH value and the concentrations of some key ions (Cr^{6+}, Ca^{2+} and Mg^{2+}), there was no effect on the groundwater quality due to the installation of soil-cement columns into the ground. At the monitoring points, the groundwater flow velocity was about 10^{-6} m/sec.

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