Finite Element Modeling of Raft & Pile Foundation on Soft Ariake Clay Ground subjected to Embankment Loading

Saga University ○S.Mem.P. Poungchompu, S. Hayashi, D. Suetsugu, Y.J. Du, S.Mem Y. Miyoshi and T. Umeda

Introduction

This paper proposes a new foundation method for an embankment on soft subsoil to reduce the deformation of embankment by using all natural-non polluting materials. The newly proposed method is called raft & pile method, Since the raft and pile are made of the surplus tree trunks, which are available at no cost with transportation cost only, the method is cost attractive. Since the timber is a natural material, the raft will not pollute the environment when compared to other methods, in which the artificial geometerials are used. Field investigation has shown that even after more than one thousand years, brush wood reinforcement under the Mizuki embankment in north Kyushu, Japan, still have high durability with “under water table condition” (Hayashi and Du, 2005).

Road constructions are being planned along the Ariake Sea Gulf of Japan, where surplus tree trunks in adjoining hilly areas are available. By using the finite element code Plaxis, in order to investigate the effectiveness of raft & pile method for highway embankments construction on soft Ariake clay. The results indicate that the raft & pile foundation improves the overall behavior of the soft ground. The flexible raft distributes the embankment load uniformly and at deeper depths inside subsoil, thus reducing vertical displacements and making them more uniform. The lateral deformations are also reduced significantly.

Boundary conditions and model parameter

In finite-element analysis, the plane strain condition was assumed. The model range was 30 m deep from ground surface, and horizontally 80 m away from the embankment center line see Fig 1. The displacement boundary conditions were as follows: at bottom both vertical and horizontal displacements were fixed, and for left and right vertical boundaries, the horizontal displacement was fixed. The adopted drainage boundary conditions were as follow: the ground surface and bottom line (sand layer) were drained. The left and right boundaries were drained. Fig 1 show the finite element mesh for the cross section of embankment

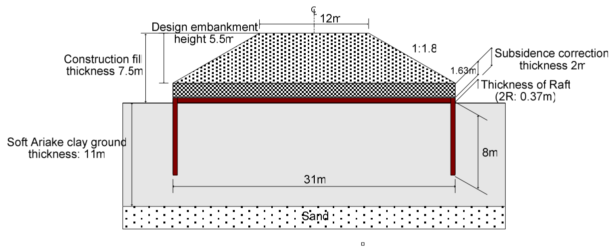


Fig. 2 Cross section of embankment

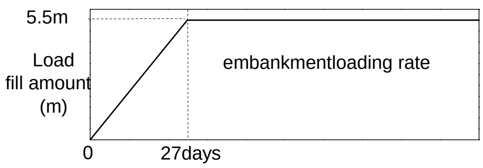
(Fig 2) and the construction history is also indicated in the figure. The mechanical behavior of the clay layers was represented by soft soil model and the sand layers were

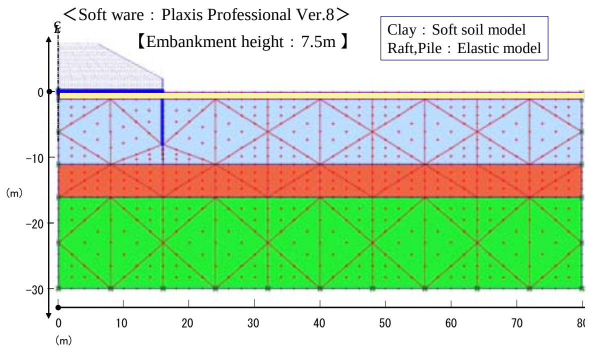
Table 1 Material properties

Linear Elastic		Sand (11m-16m)	Dense Sand (16m-30m)	timber
γ_{unsat}	[kN/m³]	15.50	19.00	4.70
k_x	[m/day]	0.251	0.251	1.000
k_y	[m/day]	0.251	0.251	1.000
e_{init}	[-]	0.500	0.500	0.500
E_{ref}	[kN/m²]	10000.00	30000.00	100000000.00
ν	[-]	0.200	0.200	0.330
G_{ref}	[kN/m²]	4166.667	12500.000	37593984.962

Mohr-Coulomb		Fill
γ_{unsat}	[kN/m³]	16.00
k_x	[m/day]	1.000
k_y	[m/day]	1.000
e_{init}	[-]	1.000
E_{ref}	[kN/m²]	8000.000
ν	[-]	0.300
G_{ref}	[kN/m²]	3076.923
φ	[°]	30.00

Soft-Soil		Weathered crust (0m-1m)	Soft clay (1m-11m)
γ_{unsat}	[kN/m³]	15.00	14.50
k_x	[m/day]	0.010	0.005
k_y	[m/day]	0.007	0.003
e_{init}	[-]	0.50	2.00
λ	[-]	0.250	0.147
κ	[-]	0.025	0.015
c	[kN/m²]	6.00	0.00
φ	[°]	32.50	30.00





Typical Finite-Element Mesh（A main each element has 15 nodes internally, The number of all nodes: It is analyzed by dividing into the element by 2,270.）

Fig. 1 Typical finite-element mesh

Table 2 Test cases

Test case	No. layer of rafts	thickness of raft (m)	Width of Raft	diameter of piles(m)	spacing of pile (m)	installed depth of piles (m)
without Raft & Pile	-	-	-	-	-	-
2R8P (with Raft & Pile)	2	0.37	31	0.2	-	8

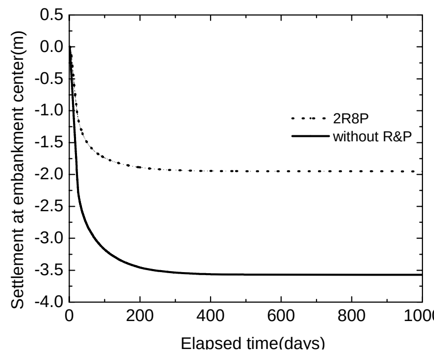
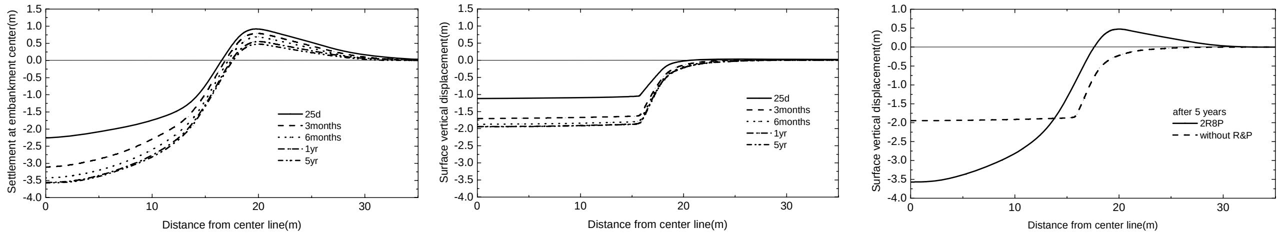


Fig. 3 Setllement at embankment center

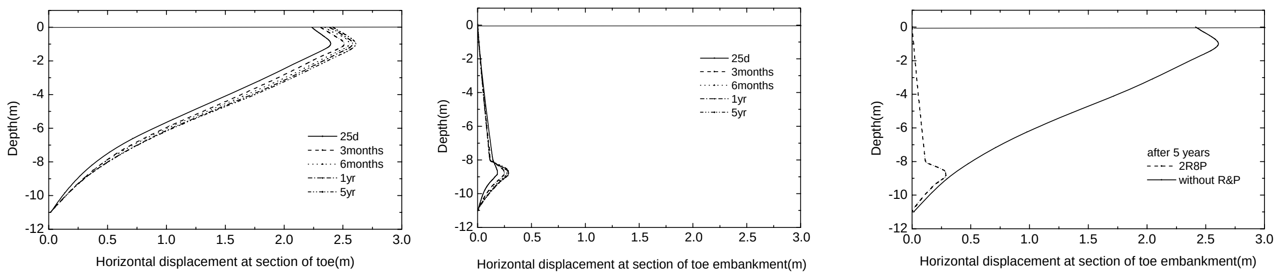
assume to be elastic. The determined model parameters for subsoil (Chai et al 1999) and material properties are listed in Table 1. Timber for Raft & Pile foundations were assumes to be elastic (K.J.Kim, WWW.hitasca.co.th). The ground –water level was the same with ground surface. The mechanical property of the fill material was represented by Mohr-Coulomb (PlaxisV.8). The conditions of the two model tests are summarized in Table 2.

lateral displacement of about 2.7m occurs for case without any support at a depth of 1m and steadily decreases to zero at a depth of 11m. For Raft & Pile foundations, the maximum lateral displacement of about 0.25m occurs at a depth of about 9 m and steadily reduces to zero at a depth of 11m. For the case of Raft & Pile foundation, the lateral displacement, increase with depth and maximum at 0.25m of lateral displacement up to a depth of 8.5m and steadily



(a) (b) (c)

Fig. 4 Surface vertical displacement (a) case without Raft & Pile (b) case 2R8P (c) comparison of case without Raft & Pile and case 2R8P after 5 years.



(a) (b) (c)

Fig. 5 Lateral displacement (a) case without Raft & Pile (b) case 2R8P (c) comparison of case without Raft & Pile and case 2R8P after 5 years.

Result and Discussions

Deformation behavior of the ground with and without any support was studied to obtain the basic data for evaluating the effectiveness of the raft and pile method of the ground improvement. The vertical and lateral displacement behavior of the ground is discussed.

Settlement at Embankment Center

Figure 3 presents the settlement at the embankment center with the applied pressure. As shown in the figure, two cases without any Raft & Pile maximum settlement were noticed after 5 years of about 3.5m. Raft & Pile resulted in a settlement of about 2m. From the above it is seen that the effectiveness of Raft & Pile foundation is evident.

Fig 4a, b, and c show the settlement pattern without any extra support (Fig 4a), with support of Raft & Pile (Fig 4b) and comparison in Fig 4c. It is seen from fig 8a that, the settlement maximum at center of about 3.5m after 5 years. Beyond the toe, the heave is noticed of about 0.8m and the heave slowly reduced to zero at a distance of 35 m from center line. For the Raft & Pile (fig 4b), the surface heave beyond toe and the settlement at center got reduced significantly (of the order of 2/7). This is a very significant advantage. Fig 4c shows the Raft & Pile foundation case. It is seen that beyond toe, there is no heave is monitored.

Fig 5a, b, and c show the lateral displacement for case without any extra support (Fig 5a), with support of Raft & Pile, (Fig 5b) and comparison in Fig 5c. The maximum

decreases to zero at a depth of 11m. It is thus seen that Raft & Pile foundation functions satisfactorily from lateral displacement considerations effectively.

Conclusions.

Based on the calculation result the following conclusions can be drawn:

Embankments loading on the soft Ariake clay without any extra ground support large deformation occur.

With the addition of Raft & Pile Foundation, vertical settlements have reduced significantly. Lateral movement of toe embankment also gets reduced to almost negligible levels.

Reference

Chai, J.C., Miura, N., and Shen, S.L. (2002). *Performance of embankments with and without reinforcement on soft subsoil. Canadian Geotechnical Journal*, 234-435.

Hayashi, S., Du, Y.J. (2005). Geotechnical analysis of Mizuki embankment remains. *Soils and Foundations*, 45(6), 43-53.

K.J. Kim of the north Carolina department of Transportation on the design of foamed concrete embankment supported by timber piles for the U.S. 64 widening project in Tyrrell Country, North Carolina, WWW.hcitasca.co .th.