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FIELD DISPOSITION OF THE MARGINAL STRIP OF THE RIVER DIKE UTILISING WOODEN RAFT AND PILE FOUNDATION ON SOFT CLAY

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ABSTRACT: Full scale field experimentations were incorporated along the downstream of the Chikugo River, Saga, Japan in order to observe the effect of wooden raft and pile foundation on the soft clay. In this study, the wooden raft and pile foundation was utilised for the marginal strip to understand the disposition of vertical settlements and lateral displacements of the ground. Cypress wood was taken into consideration in order for constructing raft and pile. Two different types of wooden raft and pile foundations with same dimensions were installed in the ground. The wooden raft installed with single-sided assemblages of wooden piles was configured as Case I. While, the same raft with both-sided assemblages of wooden piles was configured as Case II. A new embankment was constructed embedded with the existed ones on the river dike. The study was carried out for 136 days span of time from the beginning of the embankment construction. The results showed that both side assemblages of wooden piles were more effective to prevent the lateral displacement, reduce the vertical settlement and local deformation of the dike and the surrounding ground with compared to the single-sided installed piles of the similar foundation structure. The test results confirmed that the river dike supported by the wooden raft and pile foundation can be anticipated as more stable on sand layer of the soft ground within the depth of pile length.

Keywords: Wooden raft and pile foundation, marginal strip, river dike, embankment, soft clay.

INTRODUCTION

Deformations of road embankments along the highway have become severe problems when encountered with thickly deposited clay such as the Ariake clay in Kyushu Island. Consequently, large settlements and lateral deformations have brought damages to the civil structures, buildings together with agricultural fields of the surrounding area (Hayashi et al. 1997). Frequent and heavy rains are surplus in lowland and the Ariake Sea coastal basin which are caused to raise the sea levels and subjected to flood hazards. The mitigative measures are essential for such areas associated with thick deposits of soft clays to protect the civil engineering structures built on those low lying areas. In general huge embankments are built to protect over flooding of sea level rises. In this context, current engineering practices are arising to protect the embankment. In this context, Shen and Miura (2001) and Miura and Chai (2000) used deep mixing column methods as a ground improvement techniques. Similarly, Chai et al. (2001, 2002) adopted basal reinforcement techniques and prefabricated vertical drains for ground improvement. Pioneer geotechs Bergado and Teerawattannasuk (2008) practiced steel grid reinforced embankment with advancing the technologies forwards. Similarly, Vootipruex et al. (2011) and Bergado et al. (2012) developed a new type of reinforced stiffened deep cement mixing pile which constituted deep cement mixing pile reinforced with precast concrete core pile which was more effective to reduce settlements and lateral movements with compared to previous methods.

In contrast, utilisations of woods have become an alternative option in the place where artificial forest resources are higher. Saga prefecture has one of the possibilities to use wooden foundation structures. Wood as a chief resources in Japan minimises cost of construction as well as protects the eco-environment in

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the ground when encounter with waters which contains inclusions of several metallic and acidic elements to prevent decaying of foundation structures. Current practices on ground improvement techniques adopting chemical agents to stabilise the soft ground contaminate surface water, sea water as well as groundwater. The salinization can easily deteriorate the ground due to contact of chemically stabilised ground with sea water (Hara et al. 2010, 2013, 2014) which softened the ground and occurrences of leaching can also easily contaminate the groundwater severely (Kamon et al. 1996; Kitazume et al. 2008; Hara et al. 2010). Besides, it is necessary to understand the ground water under global population explosion, it has been pointed out that sustainability of global environment is heading to the crisis of sustainability of global environment and to the one of subsistence of human beings. The preservation of the society of human beings which is sustainable and coexists with an environment with an abundant in nature is the important subject in the 21st century. The shortage of resource is feared, the well-balanced utilization of natural resource is a keyword for global subsistence. Specially, the woods utilisation in consideration of cycle of forest resource is one of the most important topics and is noticed world-wide. Now it is an urgently important issue to discuss the effective woods utilisation to sustain the global environment and to make action immediately (Numata and Uesugi 2006).

Refreshing such advantages of woods utilisations, a full scale field test was performed to maintain and repair the tidal river dike and coastal geo-structures to protect from sea level rise in lowland areas. Furthermore, construction of such embankment with wooden raft and pile foundation protects the over flooding of sea water and reduces salinization of ground water by intrusion through the surface water. Pounchompu et al. (2008, 2010, 2012) and Manandhar et al. (2014) discussed the function and effects of the wooden raft and pile on the soft ground with the combination of raft and pile incorporated herein after as one of the developed method using wood experimented in the field. In the field, a common type of Cypress Wood (also called Hinoki in Japanese) has been incorporated as constructions of raft and pile foundation. The overall average strength properties of Cypress Wood are described in Table 1.

As an engineering practice, an embankment has been built with wooden raft and pile foundation to inhibit from corrosions due to elements contained in the river and saline waters. In this reference, the soft ground measures method have been examined using woods as a source of high durability when penetrated below the groundwater level. The main objective of this study is to observe disposition of full scale experiment of the wooden raft and pile foundation on soft clay. A marginal strip was incorporated to observe the deformations of the ground for this study. Two different types of raft and pile foundation assemblages were considered for the evaluation of vertical settlement and lateral displacement. The foundation piles on the right side only of the raft (Case I) and both sides of the raft (Case II) were built up at the site. It is noticeable that the same dimensions of

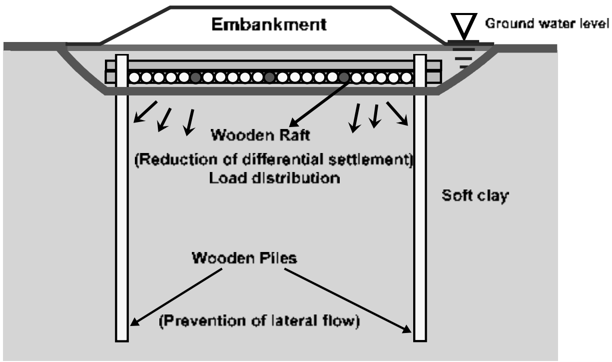

Fig. 1 Concept of wooden raft and pile sub-merged below ground water level

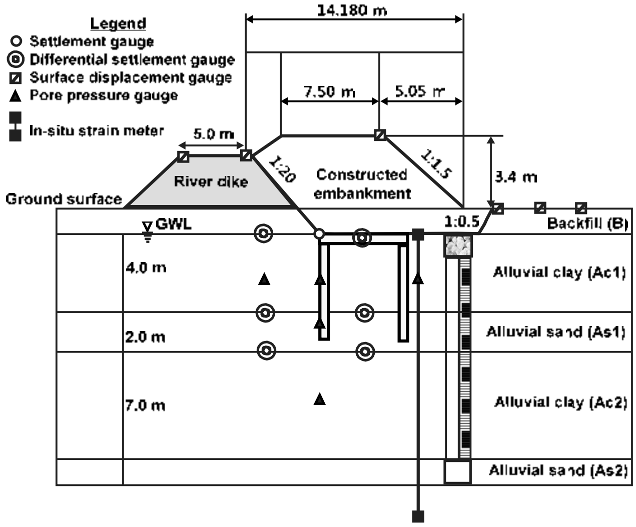

Fig. 2 Cross-section of constructed embankment, soil profice and measurement locations to understand the disposition of wooden raft and pile on soft clay (Figure not to scale)

Table 1 Average properties of Cypress Wood used for raft and pile foundation

Descriptions		Value
Bending elastic modulus,	(MPa)	8826
Compressive strength,	(MPa)	39.29
Tensile strength,	(MPa)	117.7
Bending strength,	(MPa)	73.55
Shear strength,	(MPa)	7.355

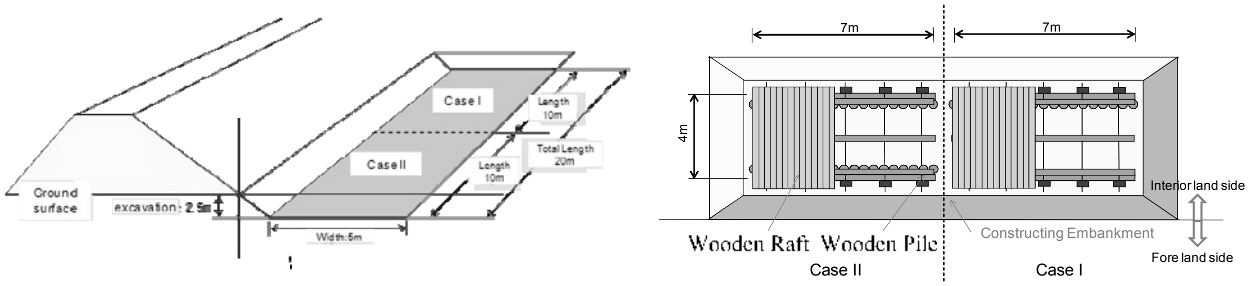

Fig. 3 Plan views of the embankment (left) and construction of the wooden raft and pile for two cases (right) (figure not to scale)

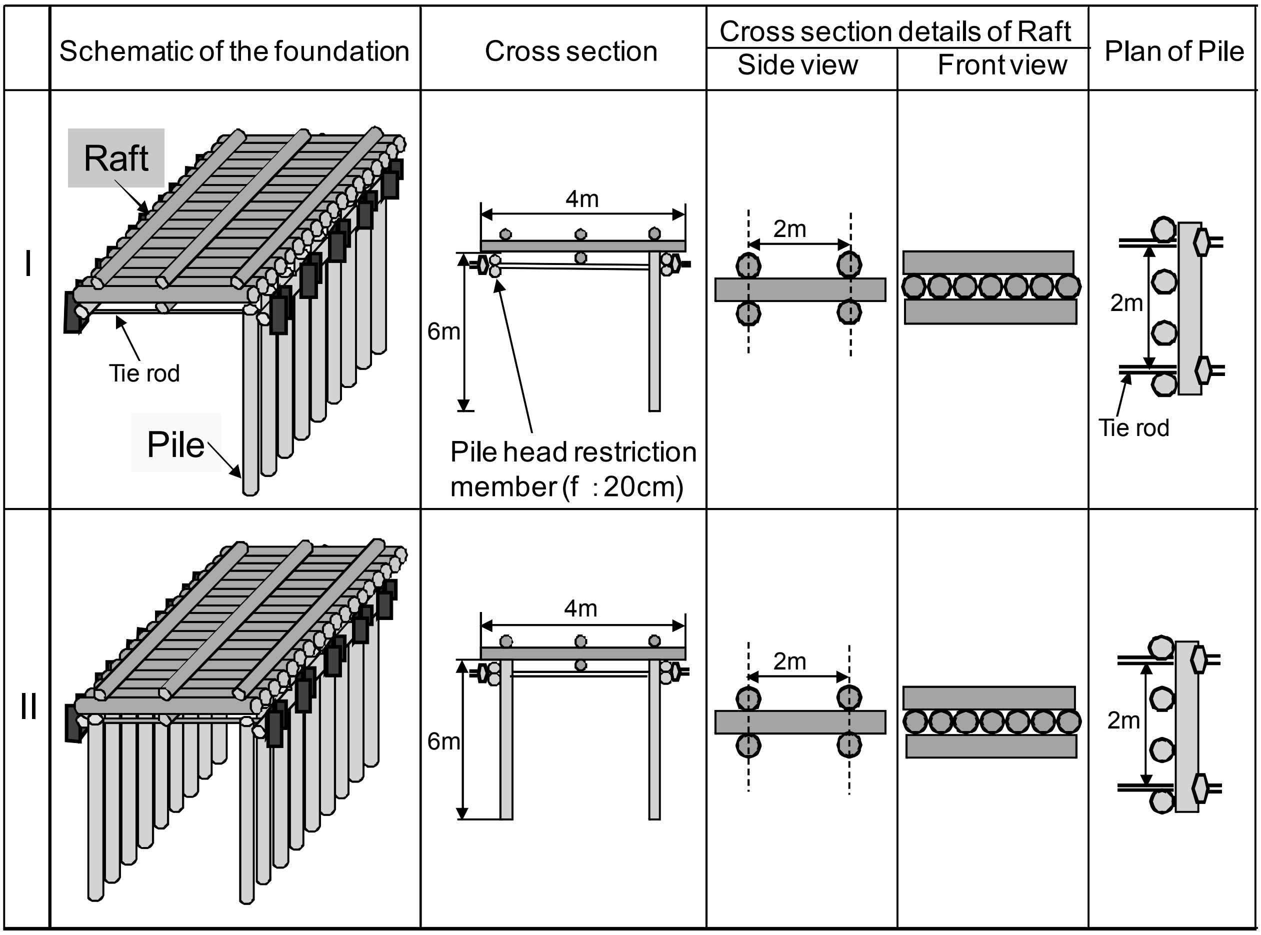

Fig. 4 Representation of schematic diagrams of the wooden raft and pile foundation together with their plan and cross-sectional views (figure not to scale)

the wooden raft and pile are taken into consideration to conduct for the full scale tests in the field.

CONSTRUCTION AND METHODS OF FULL SCALE TESTING

Figure 1 shows a concept of the raft and pile using wood sub-merged below groundwater. It is associated with two separate functions of wooden raft and wooden pile. It is believed that a wooden raft reduces a differential settlement to prevent failures of embankment with distributing uniform loads. In the meantime, a wooden pile prevents lateral flow such that it reduces lateral deformation around the soft clay. As a construction procedure, ground was excavated to meet the groundwater level and assemblages of wooden piles were installed in the ground fixed with a tie rod at the pile head facing each other to prevent from openings of headings of piles due to embankment loading. Then raft

(a) Excavating to meet groundwater level

(b) Installation of wooden piles

(c) Installation of tie rods

(d) Constructions of two sets of wooden rafts

(e) Under backfilling

(d) Constructing new embankment

Fig. 5 Steps of photographs from (a) to (f) representing construction of new embankment adjacent to previously existed river dike with installations of two sets of wooden raft and pile foundation. Cypress Wood (Hinoko in Japanese) is taken into consideration for the test along the downstream of the Chikugo River, Saga Prefecture, Saga Japan

was built up set up and sub-merged into the groundwater level by constructing a surcharge/embankment is constructed. Afterwards, pre-loading was designated with removing the surcharge to encounter the overconsolidation state.

The full scale tests were incorporated at the downstream of the Chikugo River, Saga, Japan. Initially, the site is composed of 3 m gravel layer at the surface interbedded with 4 m thick alluvial clay layer (Ac1), 2 m thick alluvial sand layer (As1) and 7 m thick alluvial clay layer (Ac2) from the top of the ground surface to the bottom. Groundwater level is located at a depth of 2 m from the surface layer. After excavating the ground up to 2.5 m to install wooden raft and piles at the sub-merged condition and filled with backfill (B), the sub-surface profile together with cross-sectional view can be observed as shown in Fig.2. Table 2 represents the physical and strength properties of each sub-surface layer.

At first, surface layer was excavated up to 2.5 m from the surface and piles were installed tying up with rods. Then, rafts were assembled just below the groundwater level in the submerged condition and back filled with sand (B). Afterwards, the embankment was constructed embedded with the existing embankment at the rate of 0.25 m/day. The slope gradient of the embankment for this construction site was built at 1:1.5 ratio having width of 7.7 m and height of 3.4 m which is higher than the existing embankment.

The experiments were conducted for two different cases as shown in Fig.3. At the first case (Case I), assemblages piles were installed at the right side of the raft adopted with raft while in the second case (Case II), piles at both sides of the raft were assembled. Same dimensions of 20 cm diameter wooden raft and piles extracted from Cypress Wood were assimilated as a commercial product for this field experimentation. Sets of 4 m X 6 m long wooden raft and piles were installed at the site at intervals of 15 cm each. The wooden piles have pointed tips and installed at intervals of 2 m (5 numbers of piles/rod) and tied up with rods through the pile head restraint material. A 4 m long wood was tied up at the centre and both ends of raft to prevent from movement of assemblages of raft at the top (Figs. 4 and 5).

A surface displacement gauge was installed at 2.5 m distance from the toe of the constructed embankment as well as the top of slope. Moreover, differential settlement gauge and pore pressure gauge were installed at each layer. Besides, in-situ strain meter was also installed at the top edges of the raft extended below alluvial sand layer (As2) as shown by Fig.2 in order to observe the disposition of marginal strip using wooden raft and pile.

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Figure 6 represents the settlement of sub-surface encountered for each layer with elapsed time from the centre of ground below the wooden raft for both single-sided assemblages and both-sided assemblages of the wooden piles (Cases I and II) respectively. The figure

Table 2 Physical properties of sub-surface ground

Descriptions	B	Ac1	As1	Ac2
Specific gravity, ρ_s (g/cm^3)	-	2.572	2.635	2.603
Wet density, ρ_t (g/cm^3)	1.7	1.423	1.637	1.488
Natural moisture content, w (%)	-	103.2	79.9	86.1
Liquid limit, L_L (%)	NP	112.0	NP	92.2
Plastic limit, L_p (%)	NP	44.9	NP	39.0
Compression index, C_c	-	-	-	1.087
Swelling index, C_s	-	0.163	-	0.096
Internal friction angle, ϕ' (°)	-	25.1	36.4	-
Consolidation yield stress, p_c (kN/m^2)	-	25.1	-	156.57
OCR	-	2.2	-	1.08
Elastic Modulus, E (kN/m^2)	3000	-	1000	-
Poisson's ratio, ν	0.2	0.37	0.29	0.35

shows that the sharp settlement occurred immediately at the top layer Ac1 after 8 days and continued until 21 days to complete the primary settlement for Case I. The settlement for this case is larger enough with compared to Case II where the raft was supported with assemblages of both-sided piles. For the remaining layers, the settlement configurations were insignificant and almost similar with elapsed time. In the same way, Fig.7 shows the settlement of both edge of wooden raft with elapsed time. The settlements at the left side edge were larger compared with right side for Case I. The settlement is higher for free marginal raft which do not have any pile supports at the left side of the raft. When observed the similar phenomena for the Case II in which both margins were supported with assemblages of piles, the raft was subjected to few settlements with compared to the Case I. It seems that immediate settlements have occurred at the point of backfilling and began to rise with elapsed time until 30 days. The raft is leaned towards the side of the embankment. Larger displacement was observed at Ac1 layer below the raft which can be interpreted on account of inclination of raft foundation with compared to the Case II supported by assemblages of piles at both sides of the raft which showed uniform and smaller settlements.

Figure 8 shows the cross-section of the overall embankment, sub-surface lithology embedded with results of lateral displacement and vertical settlements of each sub-surface layer. The result is traced through depth after 136 days from the beginning of the embankment construction. The illustration in the figure shows the lateral displacement of the ground at the assemblages of piles near the side of the embankment for each depth. The settlement on the top layer Ac1 of the existed embankment is larger in the Case I configuration.

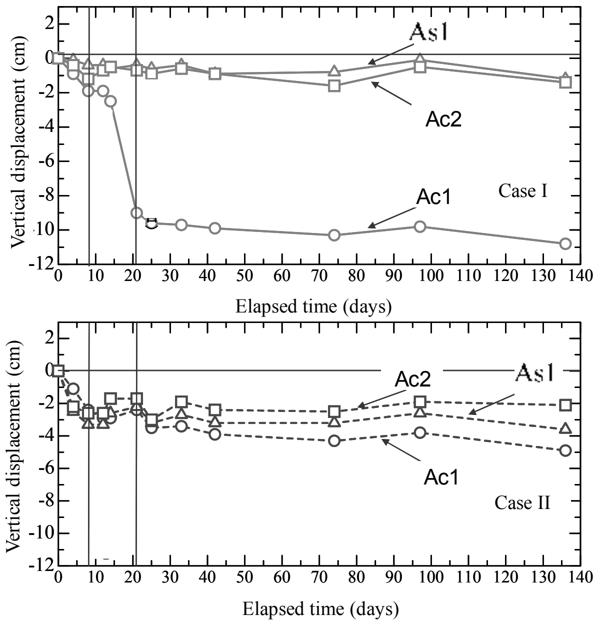

Fig. 6 Settlement behaviour of timber raft for each layer

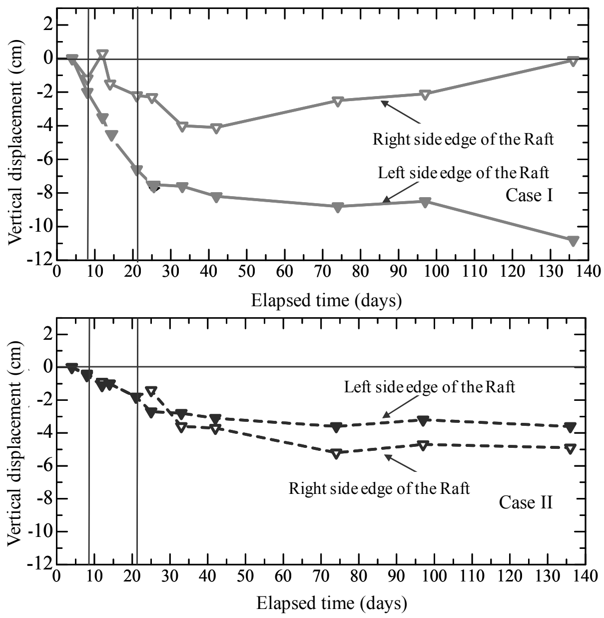

Fig. 7 Settlement behaviour of both edge of the timber raft

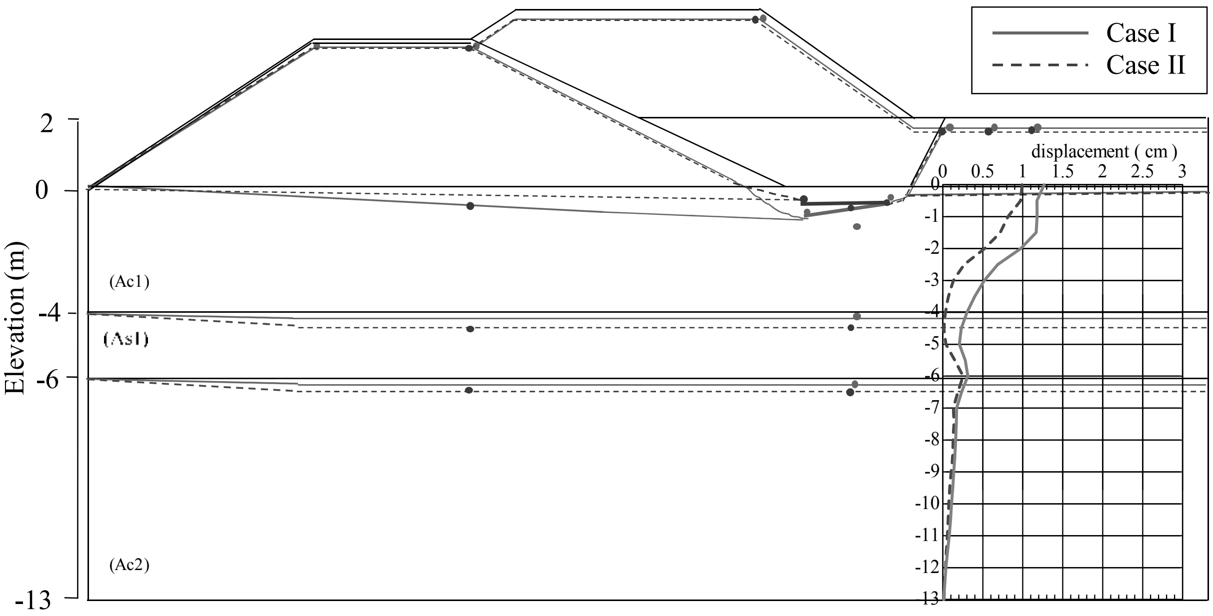

Fig. 8 Dispositions of wooden raft and pile on soft clay representing lateral displacement and vertical settlement of each layers

However, the amount of settlement for the Case II configuration is observed to be slightly greater on As1 and Ac2 layers respectively due to appearance of previously existed excessive slope of the embankment. The peripheral ground of the raft foundation is displaced laterally, locally representing a large horizontal displacement on account of asymmetric load distribution of the raft from the centre of the axis of the raft. It is noteworthy that the lateral displacements of Ac1 layer are larger for both cases just below the side of the embankment. Although, the lateral displacements of the Case I configuration is greater than that of the Case II configuration. The effect of suppressing the lateral displacement was increased and compressed across the raft foundation causing reduction in lateral displacement gradually with increasing depths due to presence of assemblages of piles on the side of the raft. In contrast, on the As1 layer, the lateral displacement for the Case II configuration was increased to meet the value with the Case I configuration. Below the As1 layer, tendencies of lateral displacements for both cases appeared to be gradually decreased and no further lateral displacements were occurred 13 m below the ground surface. The Case II configuration was identified to be the asymmetric load distribution. However, uniform settlements have occurred with spreading loads almost equally on sides of the embankment.

CONCLUDING REMARKS

The marginal strip utilising the wooden raft and pile foundation on soft clay with two different configured assemblages of piles showed that the wooden piles installed on both sides of the raft are more effective for the prevention of large lateral displacement, reduction of vertical displacement and local deformation of the peripheral ground. The full-scale test confirmed that the utilisation of woods in terms of constructing raft and pile can able to predict the soft ground on sandy layer within the depth of the pile length. The monitoring data for the duration of 136 days showed that vertical settlement and lateral displacements of single-sided assemblages of pile governed larger deformation of the ground with compared to the both-sided assemblages of pile configuration of the wooden raft and pile foundation. In this reference, some of the important concluding remarks can be drawn as follows:

1. The observation on the ground shows that the lateral displacement suppression effect becomes larger and compresses into a set of wooden pile at both ends of the raft foundation. The effect of the alluvial sand layer (As1) was considerably greater for this experiment.
2. The results confirm that the embankment can be built and can be durable for long span of time if wooden piles are driven to encounter the alluvial sand layer (As1) for this case.
3. Single-sided assemblages of piles on the raft leaned towards another side with increasing lateral displacement compared to the assemblages of piles on both sides of the raft.
4. Wooden piles installed on both sides of the raft governed asymmetric load distribution at the centre of the wooden raft. Instead of this phenomenon, there appeared uniform settlement with uniform load distributions of ground.

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