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A few remarks on the design guide to pile net method

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ABSTRACT: Pile net method has been used increasingly as one of the countermeasures for high organic soil deposits in Hokkaido and for high sensitive soft clay deposits in Kyushu, Japan. Pile net method may often be used in the future, because of its advantages which are a rapidity of construction, a facility of execution management, a large effect of restricting lateral flow and so on. However, at present, the rational design method based on its mechanism has not yet been established. This paper offers the useful knowledge for establishing the design guideline by synthetically examining the results of the in-situ tests executed on the Ariake clay ground, the model experiments and the finite element analysis.

1 OUTLINE AND FEATURES OF THE CONSTRUCTION METHOD

Pile net method is one of the pile works for reinforcing poor ground foundation. The pile net method is a relatively new which was developed in 1976 as the method of reinforcing the banking foundation in the peat deposit in Hokkaido, Japan. It is constructed by connecting the heads of the piles (wood, concrete, or steel) driven in a poor ground with the steel bars arranged in a net form as shown in Fig.2. And sand mats the permeable sheets or wire nets on them so that most of banking load is supported by the pile group as friction piles. The pile net method aims mainly at the increase of bearing capacity and the restriction of subsidence. When fill-loading is made on poor ground foundations, the restriction of ground displacement, the elimination of influence to surrounding structures, and the suppression of the ground vibration due to traffic load must be accounted for also (Sasaki, H. 1982).

The feature of this construction method is to transfer the banking load to deep strata by the flexible structure giving deflection to steel bars and enhanced the effect of pile group. Furthermore, such advantages as the rapid execution is possible, and the maintenance management during and after the execution is easy.

The effect of restricting lateral displacement is large and the subsidence and deformation of the surrounding ground are minimized. It is expected that its adoption as the reinforcing method for the countermeasures to a poor ground will increase in future.

2 CASE RECORDS

The application of pile net method to Ariake clay ground has been carried out since 1981 at three districts in Saga plain for the following three purposes.

1. To study the effect of pile lengths (Ashihara district).
2. To study the effect of restraing lateral flow of the ground (Kutsugu district).
3. To illustrate the use short piles (Futamata district).

2.1 Geotechnical properties of the Ariake clay

The Ariake clay sedimented in Saga plain lies north of the Ariake Sea located in central Kyushu, is to be as one of the most soft clay in Japan. The Ariake clay

layer is sedimented in general 15-20m thick.

The geotechnical features of the Ariake clay are summarized from many investigations (Onitsuka, 1983).

The natural water content (W_n) is as high as 100-170%, and the liquidity index (I_L) is more than 1 and N-value is usually zero, therefore, the resistance to lateral flow is extremely small.

The sensitivity ratio (S_t) is above 16, and sometimes exceeds 100.

The geologic strata of the ground of Ashihara district, consist of the Ariake clay stratum, diluvial stratum that is the deposit of Quaternary and the base rocks (sandstone, shale) belonging to the Tertiary of Cenozoic era. The depth wide distribution of the soil characteristic values is shown in Fig.1. Besides, it has been confirmed that the groundwater level (borehole water level) is around 0.5m below the ground surface.

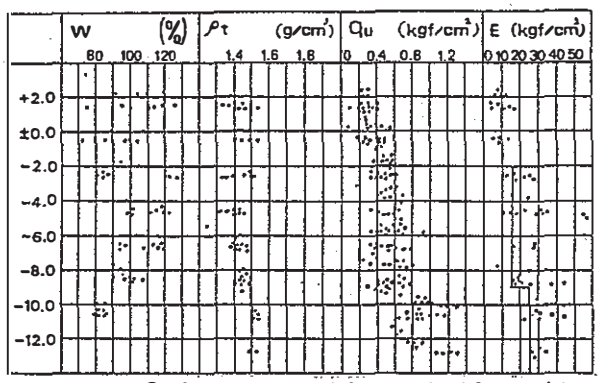

Fig.1 Soil properties at the site (Asihara)

2.2 Construction procedure

The construction procedure of pile net method in Ashihara district is as follows.

1. Driving of piles

As for the piles, pine woods (diameter: 20cm at the tip, length: L=5,7 and 9m) were used, and those were driven in square arrangement at pile intervals of 1.1m, 1.3m and 1.5m, respectively, in the bank bed width of 22.5m. Further, preservative (creosote) was applied once from the pile tops to the depth of 3m.

2. Connection of pile tops

After the piles were driven, by the clamping method shown in Fig.2, the steel bars (SR16, ϕ 16mm) joined by lap welding (one side, thickness 6mm) and pile heads were tied with clamps.

3. Sand mats and the sheets

After pile tops were connected, the sand fill was spread all over by a bulldozer, to a thick up 20cm over the pile heads. Then the sheets (tensile strength higher than 20kgf/cm^2) were laid.

4. Execution of banking

Subsequent filling operation was done at 20cm lift thickness, and leveled and compacted by rolling with a bulldozer.

In the test construction in Ashihara district,the rapid execution in raising up to the final height of banking (3m in 40 days) has been carried out. As to the pile length, the construction for observation of not only 9m but also 7m and 5m, has been carried out continuously since July, 1981, for judging the effect of pile lengths.

2.3 Results of measurement

Taking Ashihara district as an example, the construction in this case used the pile of 9, 7 and 5m in length, and the difference of the construction effect due to the pile length was observed.

The thickness of layer is 16.5m. In this case, observation was carried out about the settlement under banking and the lateral displacement of the surrounding ground, the pore water pressure in the clay, the stress due to banking load, the force acting on the steel bars on pile tops. The arrangements of observational equipments are shown in Fig.3.

The settlement at February, 1987, in the case of the pile lengths of 9,7 and 5m were 22, 34 and 44cm, respectively, and the settlements decreased as pile lengths increased.

The stress acting in the steel bars changed according to pile intervals. As the pile intervals increased, the stresses also increased arose. Its maximum intensity was 200-400kgf/cm^2, equivalent to about 1/3-1/6 of the allowable tensile strength.

The lateral displacement on Feb. 1987 in the case of the pile length of 9. 7 and 5m were about 0.4, 1.0 and 1.2cm at the toe of the embankment slope.

As pile length increased, the lateral displacement decreased.

From the above discussion, we can summarize as follows.

1. The settlement of the embankment is proportional to the thickness of comprresible soil strata below the tip of piles. The settlement between piles in the range where the piles were driven was small, and the settlement in the depth below pile tips was subjective.

2. The lateral displacements tended to decrease as the pile length increased.

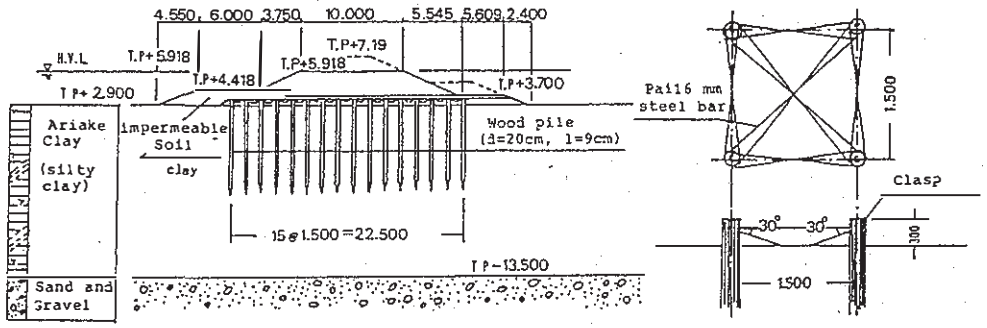

Fig.2 Outline of pile net method (Ashihara)

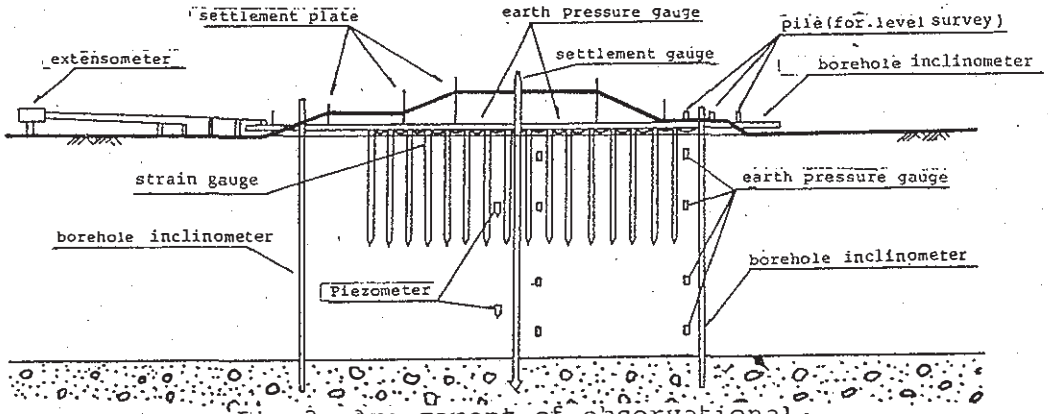

Fig.3 Arangement of observational instruments (Ashihara)

This is because banking load is transmitted to deeper ground through piles, but its relation to pile intervals has not yet been clarified.

3. The stress acting in the steel bars was about 200-500kgf/cm^2 in the case of embankment height less than 4m, amounting to only about 1/3-1/6 of the allowable tensile strength.

As mentioned above, in the pile net method, the effects has been recognized in the restriction of settlement, the prevention of lateral flow and the prevention of sliding failure.
However, as to such effect,particularly the mechanism of increasing the bearing capacity, the condition for the whole pile-net to act as one-body structure have not yet been clarified.

3 MODEL EXPERIMENT

3.1 Outline of experiment

A model experiment was carried out to clarify the bearing mechanism of the pile net method using the Ariake clay.
A soil tank for experiment is a plane strain two-dimensional model tank made of acrylate plate and its dimension is 220*130*60cm.
The model ground and material for the experiment are shown in Table 1.

Table-1 Materials of model test

Model ground soil	W_n	112 ~ 123 %	
	G_s	2.64	
	γ_t	1.34	t/m^3
	c	0 ~ 10 cm	0.10t/m^2
		10 ~ 30	0.13
		30 ~ 50	0.17
		50 ~105	0.20
pile net	sheet mat	paper, tensile strength 0.027~33 kgf/3cm	
	pile	wood ϕ 8mm Young's modulus 190000 ~ 200000kgf/cm^2	
	steel bar	wire (#28 ϕ0.3mm)	

3.2 Experimental results

From the experimental results, it become obvious regarding bearing characteristics of the pile group without net and the pile group with net as shown in Fig.4. The data obtained by Whitaker, T (1961) and Sower, F. (1961) are added in Fig.4.

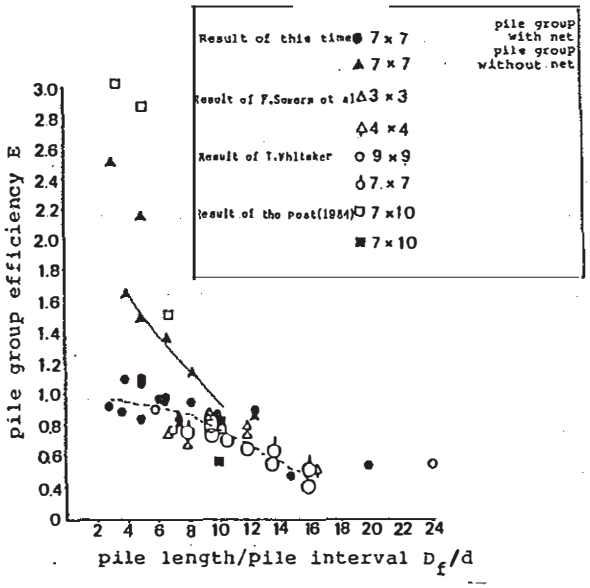

Fig.4 bearing characteristics of the pile group with and without net

(1) Failure type

The block failure where soil inside a pile and pile circumference fails/settle as a unit in a pile interval from 2 to 4 times of a pile diameter is occurred. All piles occur penetration failure that does penetrate in a pile interval over 4 times of a pile diameter.

(2) Pile group efficiency

A pile group efficiency (E) is defined by the bearing capacity ratio of pile group per unit pile to a single driven pile. Bearing capacity (a bearing capacity decrease by stress interference among the piles and also an increase of settlement) decreases by a pile group effect when pile intervals become narrow. A change of this pile group efficiency may also be a pile group that may not be over 1. The unique relation exists between pile length/pile interval (D_f/d) and pile group efficiency (E) as shown in Fig.4.

(3) Stress share between ground and pile top

The structure of a pile-net consists of pile tops connected by reinforcing bars as mentioned before. Because of the hammock effect generated by the reinforcing bar connection, a part of a load is transmitted to the piles. That proportional relation materializes in the interval of pile length/pile interval (D_f/d). As mentioned above, the bearing capacity characteristics of a pile-net can be explained by pile length/pile interval (D_f/d). Large bearing capacity is obtained, by connecting a pile head with reinforcement from this case.

4 CASE ANALYSIS

A slide joint is used to interface model considering the wall surface friction and the sliding. Also, FEM analysis with bi-linear anisotropic elasto-plastic model is carried out for the soil element (Iseda, T. and Tanabashi, Y. 1978). The analytical model is a plane strain condition as shown in Fig.5. The pile element is shown in this figure. The analytical conditions consist of three piling types such as non treated grouped pile, grouped pile and head connected piles by reinforcing bars. The step by step calculations are carried out with combinations of a pile length and a pile interval for embankment height from 0m to 6m.

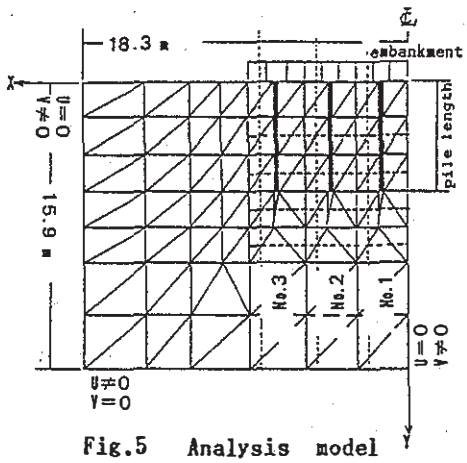

Fig.5 Analysis model

From the results of analysis, the piled zone may be considered as a integrated structure like a caisson. Incidentally, in case of 9m pile length with 3m embankment height, maximum horizontal stress increase between piles were 1.20tf/m^2 as the measured value and 1.45tf/m^2 as the calculated value. The maximum horizontal stress increase under piles were 3.80tf/m^2 as the measured value and 5.85tf/m^2 as the calculated value.

Attaching in the case of pile group construction, a relationship between expansion among three piles and embankment height was obtained by the parameter of the pile length to examine necessity of pile head connection by reinforcing bars in the pile net method (see Fig.6).

Three piles shown in Fig.5. were designated No.1, No.2 and No.3 from one near a load center. Between the bank center and No.1 pile, the reinforcing bar connection is not necessary according to shrinkage having no connection with

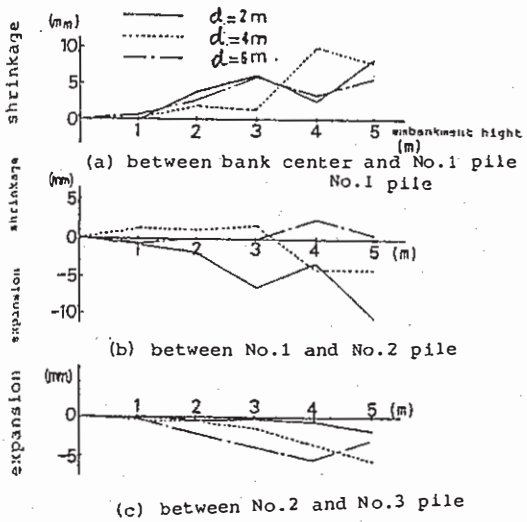

Fig.6 Relation the extension of pile distance and embankment hight

banking height. Between No.1 and No.2 pile, this zone is a transient zone where the compression and expansion occur depending on the combination with embankment height and pile length. Between No.2 and No.3 pile, an expansion was entirely shown without being related to the embankment height as shown in Fig.6. If the hammock effect is not expected and any problem in trafficability has not occurred, it is not necessary to connect the pile heads by reinforcing bars for the total width of the considered piling area.

5 DESIGN GUIDELINES AND CONCLUSIONS

Conventional concepts for the pile net design are summarized in a flow chart as shown in Fig.7. From the results of various model experiments, field observations and case analysis, new design concepts against conventional concepts are presented as follows:

5.1 Pile interval and pile length

A conventional concept is based on Bierbaumer's formula, $d=1.5\sqrt{rD_f}$ where r is a pile radius, D_f is a pile length which is theoretically carried out to determine a pile interval without any stress interference between the piles. However, over and under bearing capacity values by pile group formula may be carried out due to the optional pile interval, pile length, and number of piles. Because of this, it is good to design the pile arrangement plan, by the

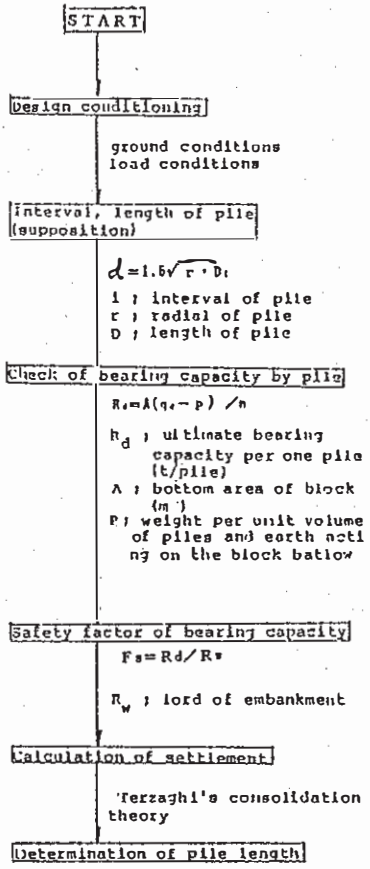

Fig.7 Design flow chart of pile net method

parameter (D_f/d) that is able to explain an actual phenomenon of bearing capacity characteristics.

A pile interval having a good efficiency in present conditions is within from 4m to 9m of D_f/d. In the case that D_f/d becomes small, the pile interval is extended when the pile length is constant. Whether or not this is the case, the structure that deform as a unit becomes a problem. Accordingly, if the pile length is assumed, pile interval may be determined.

5.2 Concept of bearing capacity

The present concept of bearing capacity is the one that regards an entire pile group of a pile-net as one block. With the ratio of a pile interval to pile diameter (5 to 7) usually used, it is clarified by an experiment that the soil between the piles does not integrally moved with piles. Also, the ratio of pile length (D_f) and pile diameter (D) may be indicated by $D_f/D>1$. From this case, in a pile-net, it is conceivable that plastic equilibrium state peculiar to general shear of shallow foundation will not happen.

It is adequate for a pile group of pile-net to handle as a short pile group that became independent individually. Plastic equilibrium condition may be considered as a deep foundation case. Bearing capacity of the pile-net is the bearing capacity of a single pile plus the ground reaction. Here, the ground reaction may be calculated by the relation with D_f/d as that shown in Fig.8. According to an existing experiment, the ground reaction magnitude is estimated to be from 10% to 60% of a pile bearing capacity in a range of D_f/d=5 to 7.

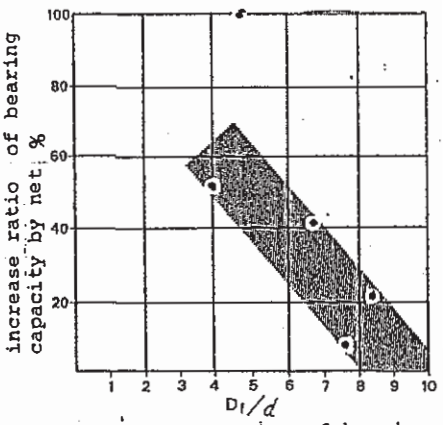

FIg. 8 I ncrease ratio of bearing capacity by pile net miethod

5.3 Settlement due to consolidation

The calculation methods of the settlement generated for the pile net method are as follows: Using overlap of the stress solutions as pile group settlement acting on the semi-infinite elastic body; and using one-dimensional consolidation theory that the stress acts at 1/3 of the pile length from pile point; and using FEM analysis. These methods have strong and weak points. However, as a simplified calculation method, one-dimensional consolidation calculation of Terzaghi with admissible accuracy on practical use may be cited.

5.4 Role of reinforcement

It is explained and clarified above that the ground reaction is added to the pile bearing capacity for the pile-net structure with pile head connection by reinforcing bars. A role of the reinforcement is to transmit the load between piles to the piles by hammock effect. Also, the reinforcements function to distribute stress by structure integration.

On the other hand, from results of the FEM analysis and measurements, stresses that act on the reinforcement reaches from 1/6 to 1/3 of the allowable stress of the reinforcement. Also, the netting width that influences the strength of circumferencial zone may be decreased in proportion to increasing of the ratio of pile length to the layer thickness (L/H). In the future, it is necessary to study the simplification of the pile arrangement and the application of new materials such as polymer grid.

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