STUDY ON STRENGTH ESTIMATION OF SOIL CEMENT USED IN THE EMBEDDED PILE METHOD BY ELECTRICAL RESISTIVITY MEASUREMENT

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ABSTRACT: Problems caused by poor quality control and quality assurance of the pre-boring embedded pile construction, such as on domestic apartment house are still occurring nowadays. An adequate consideration for invisible risks inside or below the ground is important in pile foundation construction therefore the demand for advanced and reliable quality assurance is increase in the future. In this research, to understand the quality of the construction at early stage, the compressive strength of cement-soil mixture of pile construction after 28 days is estimated using electrical resistivity value of the mixture. More accurate measurement for electrical resistivity value is conducted by inserting the electrodes without using potassium chloride solution as a catalyst. The result showed that there is a certain tendency in the electric resistivity value at the early age regarding to the type of soil (sand, clay) mixed in. The most accurate estimation was achieved from the electric resistivity value at the first day and several days onwards, and from the compressive strength after 3 days.

Keywords: Soil cement, Embedded pile, Electrical resistivity, Quality control

1. INTRODUCTION

The purpose of this research is to study the utilization of electrical resistivity measurement to predict compressive strength and to perform quality control of cement slurry used in bored precast pile construction technique [1][2][4][5]. This paper consists report and recommendation for electrical resistivity measurement technique [3], quantification and estimation technique of electrical resistivity, compressive strength estimation formula based on electrical resistivity value and quality control method using strength prediction of cement slurry through indoor/laboratory and field examination [3][4][5]

2. LABORATORY EXPERIMENT OF SOIL CEMENT MIXTURE

The electrical resistivity measurement methods were decided prior to laboratory examination. The following three patterns of electrical resistivity measurement methods were performed at the same time and suitable method is studied.

Method1 : At 28 days from pouring without removing cell and no pore water.
Method2 : Only measure bleeding water at early stage by making hole with diameter same as cell in specimens. After that stage, 0.1% KCl solution is used as pore water.

Table 1 Method for measuring electric resistivity value

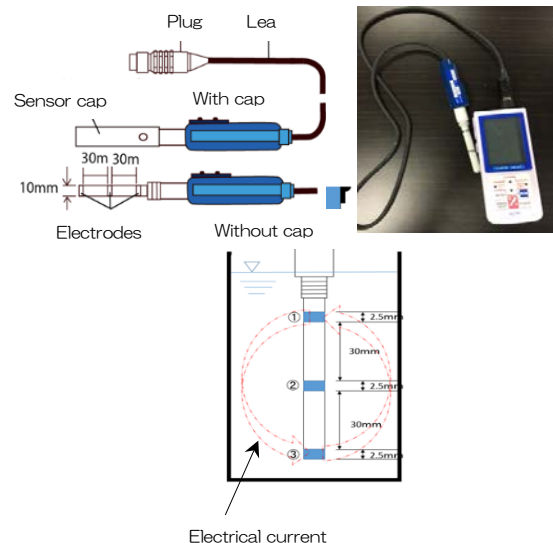| days	Method1		Method2		Method3	
	Pore water	Reseat	Pore water	Reseat	Pore water	Reseat
0	bleeding water	no	bleeding water	yes	bleeding water	yes
1	bleeding water	no	0.1% KCL	yes	X% KCL	yes
2	bleeding water	no	0.1% KCL	yes	X% KCL	yes
3	bleeding water	no	0.1% KCL	yes	X% KCL	yes
7	no water	no	0.1% KCL	yes	X% KCL	yes
28	no water	no	0.1% KCL	yes	X% KCL	yes

X% is determined by measurement

Fig.1 Electrical conductivity meter and measurement

Method3 : Using X%KCl solution with the same electrical resistivity value as specimen right after poured into cell. After that stage, the same procedure as Method2.

Considering actual soil configuration, cement slurry only, cement with sand, cement with clay and cement with sand and clay, three variants of mixture is used for laboratory examination. Electrical conductivity meter and schematic view of measurement are shown in Figure 1.

2.1 Laboratory Examination Mixture Using Cement Slurry

Electrical resistivity value change with time shown by Figure 2 gives information that electrical resistivity value is tends to be the same regardless of mixture and cement amount. For mixture curing age of one day, electrical resistivity value is greatly affected by pore water for method number 1 and number 2, therefore, method number 1 is recommended for electrical resistivity measurement. In addition, temperature change also influences electrical resistivity value.
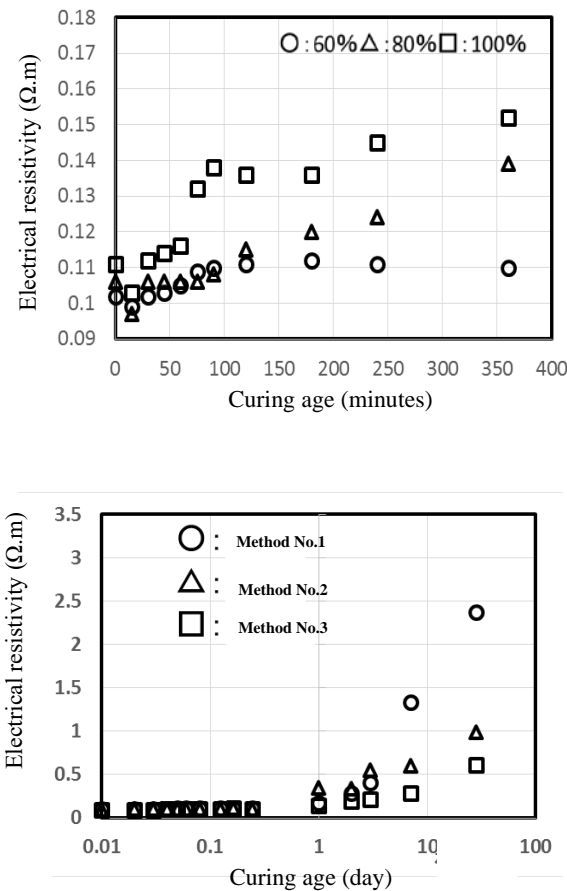

Fig. 2   Electrical resistivity value change with time

Relationship between compression strength and electrical resistivity value measured by method number 1 as shown by figure 3 resulted to conclusion that relation between qu_{28}/ρ_{28} and qu_3/ρ_3 was more correlative than $\Delta qu/\Delta\rho$ and qu_3/ρ_3. In other hand, measurement methods number 2 and 3 also had similar result, therefore, compression strength estimation formula using relationship between qu_{28}/ρ_{28} and qu_3/ρ_3 is recommended. Here, qu is compressive strength, ρ is electrical resistivity and subscript number indicates specimen curing age in day(s) unit.

Method 1 :
$$qu_{28} = \{0.1058 \cdot (qu_3/\rho_3) + 8.8964\}\rho_{28} \quad (1)$$
Method 2 :
$$qu_{28} = \{3.3823 \cdot (qu_3/\rho_3) - 63.551\}\rho_{28} \quad (2)$$
Method 3 :
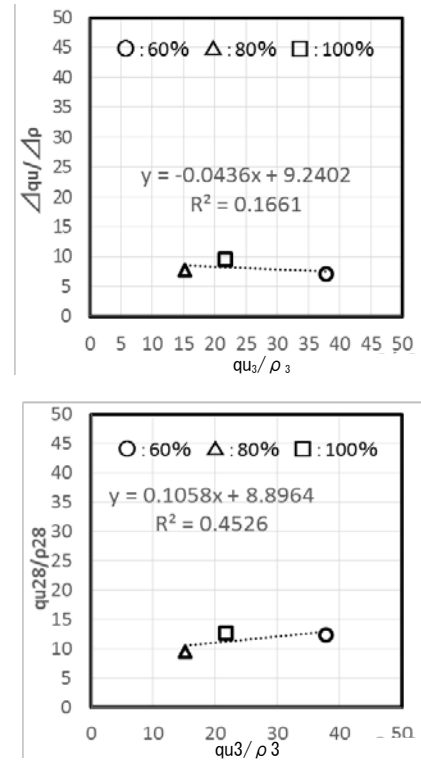$$qu_{28} = \{0.5807 \cdot (qu_3/\rho_3) + 9.3560\}\rho_{28} \quad (3)$$

Fig. 4   Relationship between $\Delta qu/\Delta\rho$ and qu_3/ρ_3, qu_{28}/ρ_{28} and qu_3/ρ_3

Since electrical resistivity value tends to change regarding to time (curing age), compressive strength can be estimated using ρ value from early curing age until reached final curing age (28 days). Electrical resistivity changes due curing age is observed to decide the suitable time for estimating the compressive strength as shown by figure 4. Relationship between ρ_3 and ρ_{28} recommends equation 4, equation 5 and equation 6 for estimating ρ value. In addition, considering ρ value at early age

and onwards due to pore water existence, relationship between ρ_0 and ρ_3 is used for measurement method 1 and ρ_1 vs ρ_3 for method 2 and 3 recommends equation 7 ~ equation 9 for estimating ρ value. Therefore, equation 4 ~ equation 9 is used for estimating electrical resistivity value (ρ).

Method 1 :
$$\rho 28 = 7.8687 \cdot \rho 3^{1.5779} \tag{4}$$
Method 2 :
$$\rho 28 = 0.8950 \cdot \rho 3^{0.153} \tag{5}$$
Method 3 :
$$\rho 28 = 3.5787 \cdot \rho 3^{1.1367} \tag{6}$$
Method 1 :
$$\rho 3 = 0.0015 \cdot \rho 0^{-2.483} \tag{7}$$
Method 2 :
$$\rho 3 = 1.8722 \cdot \rho 1^{1.1642} \tag{8}$$
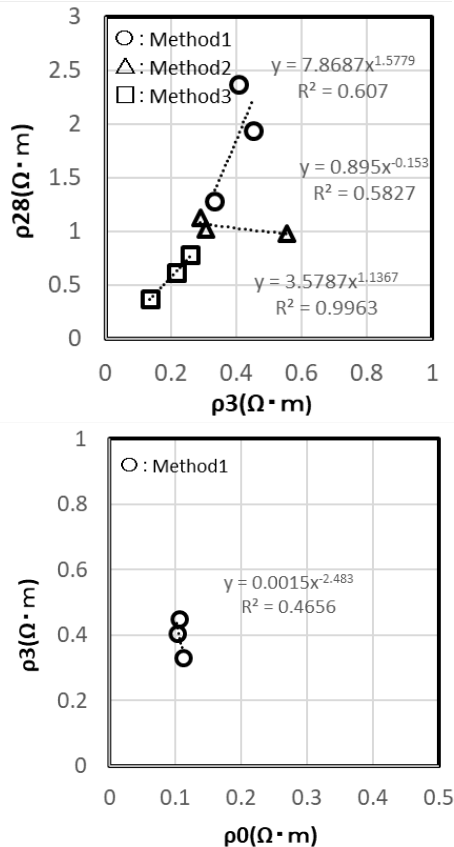Method 3 :
$$\rho 3 = 4.0211 \cdot \rho 1^{1.5936} \tag{9}$$

Fig. 4 Relationship between ρ_3 and ρ_{28} and ρ_0 and ρ_3

Subsequently, estimation formulation for compressive strength prediction was also attempted. Equation 10 is formulation recommended by Japan Society of Civil Engineering (JSCE) [6], is used and applied for laboratory examination in this research.

Where α and β is material constants and t is specimen's curing age. Calculation of performed by linear interpolation of $q_u(28)/q_u(t)$ vs t recommended by JSCE (Figure 5) and listed in Table 1.

Table 1 Laboratory experiment mixture condition

Sample condition (W/C)	α	β
60%	0.84	4.86
80%	0.68	9.53
100%	0.79	6.08
Average	0.77	6.62

$$qu(t) = qu(28) \times \frac{t}{\alpha \times t + \beta} \tag{10}$$

Estimation of compressive strength using equation 1 to equation 9 and laboratory compressive strength test are attempted and the result is compared as shown by figure 6. Estimated value and measured value are nearly consistent for measurement method 1. Estimated value is larger than measured value for method 2 while Measured value is larger than estimated value for method 3. Hence, method 1 is possible and recommended for estimating electrical resistivity value.
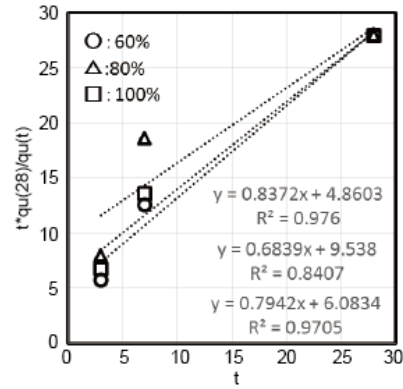

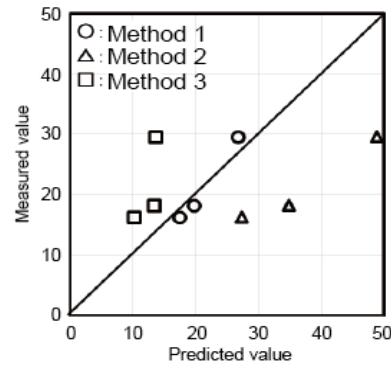Fig. 5 Relationship of t and $t.q_{u28}/q_{ut}$

Fig. 6 Comparison of measured vs predicted value of compressive strength (right)

2.2 Laboratory Examination Mixture Using Sandy Soil and Clayey Soil

Laboratory examination for sandy and clayey soil assumption are performed and the procedures are shown by figure 7 and mixture condition listed in table 2. Electrical resistivity value changes by material age (time) for sandy soil is different from cement only and cement with clay soil due to precipitation influence. For clay soil, specimen is expanding and cracks occurs during curing process causing variation in electrical resistivity value.

Furthermore, for clay soil, the viscosity of the soil cement slurry was very high therefore the compressive strength test could not performed as shown by figure 8.
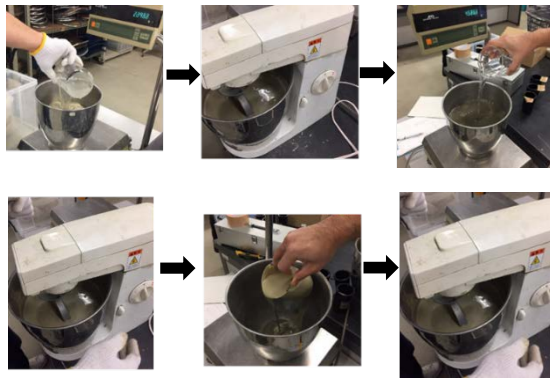

Fig. 7   Soil cement mixing procedure

Table 2   Sandy soil assumed mixture condition

W/C ratio (%)	Mud water ratio	Cement milk : mud water		Replacement soil percentage (%)
60	1.5	1:3	A	30
60	1.5	1:5	B	20
60	1.5	1:10	C	10
100	1.5	1:2	D	50
100	1.5	1:2.5	E	40
100	1.5	1:2	F	30

Compressive strength estimation for sandy soil specimen are also conducted using the same procedure as cement slurry only specimen and recommended formulation, equation 11 ~ equation 19 and equation 10, and comparison between measured and estimated value is shown by figure 9.

As a result, for every measurement method, compressive strength prediction is possible even when sand is mixed. There was specimen with large error of compressive strength value, however, bleeding water effect during curing process might cause this phenomenon.

Method 1 :
$$qu_{28}=\{0.2514 \cdot (qu_3/\rho_3)+0.6748\} \cdot \rho_{28} \qquad (11)$$

Method 2 :
$$qu_{28}=\{0.451 \cdot (qu_3/\rho_3)+0.5002\} \cdot \rho_{28} \qquad (12)$$

Method 3 :
$$qu_{28}=\{0.9578 \cdot (qu_3/\rho_3)+2.9513\} \cdot \rho_{28} \qquad (13)$$

Method 1 :
$$\rho_{28}= 0.2807 \cdot \rho_3^{-2.071} \qquad (14)$$

Method 2 :
$$\rho_{28}= 0.7269 \cdot \rho_3^{-0.2769} \qquad (15)$$

Method 3 :
$$\rho_{28}= 0.9634 \cdot \rho_3^{0.572} \qquad (16)$$

Method 1 :
$$\rho_3= 0.5048 \cdot \rho_0^{0.2804} \qquad (17)$$

Method 2 :
$$\rho_3=0.0946 \cdot \rho_1^{-0.599} \qquad (18)$$

Method 3 :
$$\rho_3=0.7643 \cdot \rho_1^{0.7377} \qquad (19)$$

Fig. 8   Experiment on clay soil

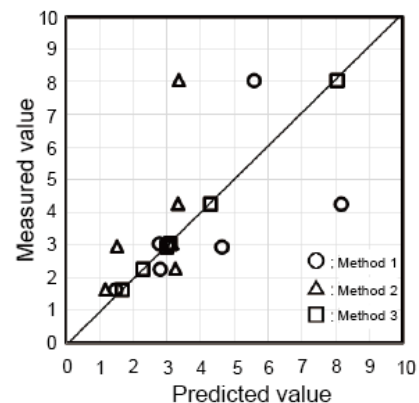## 2.3 Laboratory Mix Examination Assuming Actual Ground

Fig. 9   Predicted vs measured value

Laboratory mixing experiment assuming actual soil condition was performed using sand and clay mixed together with mixing conditions listed in table 3. The experiment results lead to inconsistent change of electrical resistivity value with time along with large variation. Similar method to predict compressive strength of the specimen using relationship between qu_{28}/ρ_{28} and qu_3/ρ_3 also applied in this procedure and came to results that equations 20~28 are recommended for compressive

strength prediction. Comparison between predicted value and measured value shown by figure 10.

Method 1 :
$qu28\{0.2662(qu3/\rho3)+1.9764\}\rho28$
(25)
Method 2 :
$qu28＝\{4.1042(qu3/\rho3)-81.007\}\rho28$
(26)
  Method 3 :
  $qu28＝\{2.8788(qu3/\rho3)-51.029\}\rho28$
(27)
Method 1 :
$\rho28 =3.2724\rho3^{0.6215}$ (28)
Method 2 :
$\rho28 =66.139\rho3^{3.2056}$ (29)
Method 3 :
$\rho28 = 278.01\rho3^{4.227}$ (30)
Method 1 :
$\rho3 =0.5048\rho0^{0.2804}$ (31)
Method 2 :
$\rho3 =0.7679 \rho1^{0.7792}$ (32)
Method 3 :
$\rho3 =0.4656 \rho1^{0.4635}$ (33)

Table 3   Sand with clay soil assumed mixture condition

W/C ratio (%)	Mud water amount ratio	Cement milk : mud water		Sand : clay	Replacement soil percentage (%)
60	1.6	1:1	G	3:7	100
60	1.6	1:1	H	6:4	100
60	1.6	1:1	I	8:2	100

Measurement method 1 and 2 gives prediction with high accuracy, however not with method 3. It is understood that the mixture of sand and clay has moderate density and reduce bleeding process, therefore increase accuracy in measuring electrical resistivity and improves accuracy of prediction formulation.
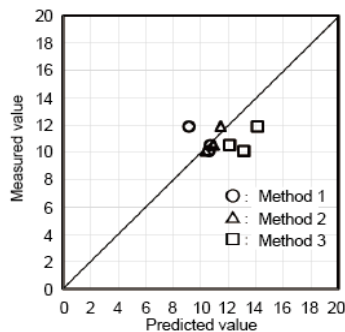

Fig. 10   Predicted vs measured value for sand with clay soil assumed specimen

3.   OUTDOOR EXPERIMENT

3.1   Examination of pile hole at the construction site

Bored pile construction site in Arahama, Kashiwa city of Niigata prefecture is selected for outdoor experiment. The specifications were bored pile hole with diameter of 530mm, depth of 20m and with W/C ratio of 60%. Collection of unsolidified sample was carried out from overflow and mortar plant and the universal water sampler shown in figure 11 and was conducted from depth of 2.5m, 5.0m, 10m, and the specific resistance value on the ground are Measured. Soil until depth of 15m was sandy soil. At the same time, electrical resistivity value near depth of 5.0 m was also measured using custom made electrical conductivity meter with cord length of 30 m.

Fig. 11   Tools and sample collection

Changes of electrical resistivity value was rapid as shown by figure 12. It is believed that summer season condition caused the acceleration of specimen curing process. Figure 12 also shows that the temperature rise is extremely low inside the hole, the influence of the outside air is small at the depth of 5.0m and the influence on the quality by the temperature is not significant.

The result of compressive strength value using prediction equation is shown as listed in table 4. An Accurate strength prediction performed by sample collected from inside the bored hole. In addition, it is possible to predict the compressive strength with an error of about 1.0 N / mm² for safety consideration. However, for sample collected from the plant gives more variation as effect of temperature change is believed to cause this large margin of error.
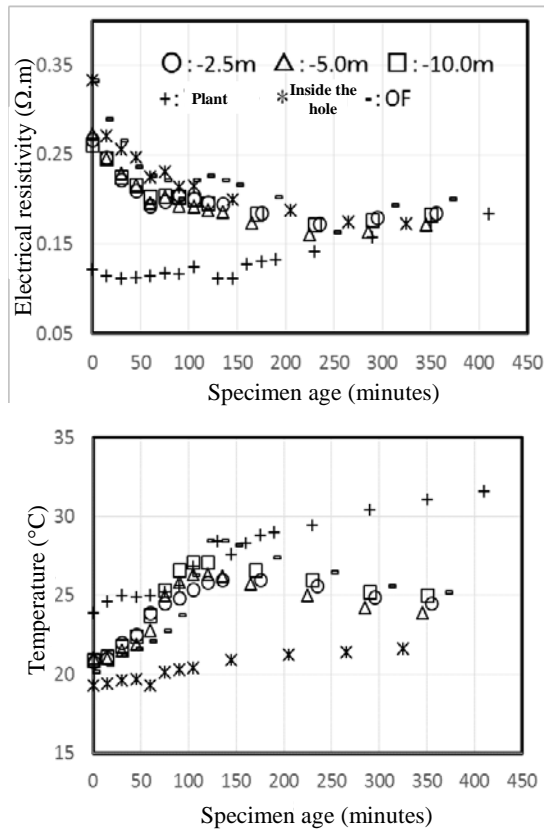
Fig. 12   Electrical resistivity value and temperature change

3.2   Laboratory mixing experiment using site soil

Soil sample also collected from the same construction site in Arahama, Kashiwazaki-shi, Niigata prefecture. Sample was taken using from the bored hole depth of 21.0m (sandy soil) and 51.0m (gravel ground) and cement milk with water cement ratio 60%. Similar mixture experiment was conducted and the condition is listed in table 5. Electrical resistivity value is shown in figure 13 and mixture P and Q has different initial electrical resistivity value compare other mixture. The influence of variation in gravel size of site soil is believed as a factor and temperature also has significant effect.

Table 4 Compressive strength of specimen at each collection location

	Plant	Depth = 0m	Depth = 2.5m	Depth = 5.0m	Depth = 10.0m	Inside the hole
qu_{28} (pr)	11.1	3.036	4.43	4.24	4.64	3.04
qu_2 (me)	29.52	4.282	4.28	4.28	4.28	4.28
ρ_0 (me)	0.122	0.333	0.273	0.273	0.261	0.333
Eq.	1.2.7.A	10.13.16.A	10.13.16.A	10.13.16.A	10.13.16.A	10.13.16.A

Table 5   Compressive strength of specimen at each collection location

W/C ratio (%)	Soil class	Mud water	Cement milk : mud water		Replacement soil percentage (%)
60	Sand	1.6	1:1	J	100
60	Sand	1.6	1:1.5	K	150
60	Sand	1.6	1:2	L	200
60	Gravel	1.7	1:1	P	100
60	Gravel	1.7	1:1.5	Q	150
60	Gravel	1.7	1:2	R	200

Compressive strength was also calculated using prediction formulation (equation 25 to equation 31) and obtained the same results for every mixture sample. This is believed caused by large error of predicted value when assumed ρ_0 was larger than soil electrical resistivity value. Based on this result, it is necessary to collect more data on the electric resistivity value estimation formula and modify it to an estimation formula incorporated to actual soil conditions.
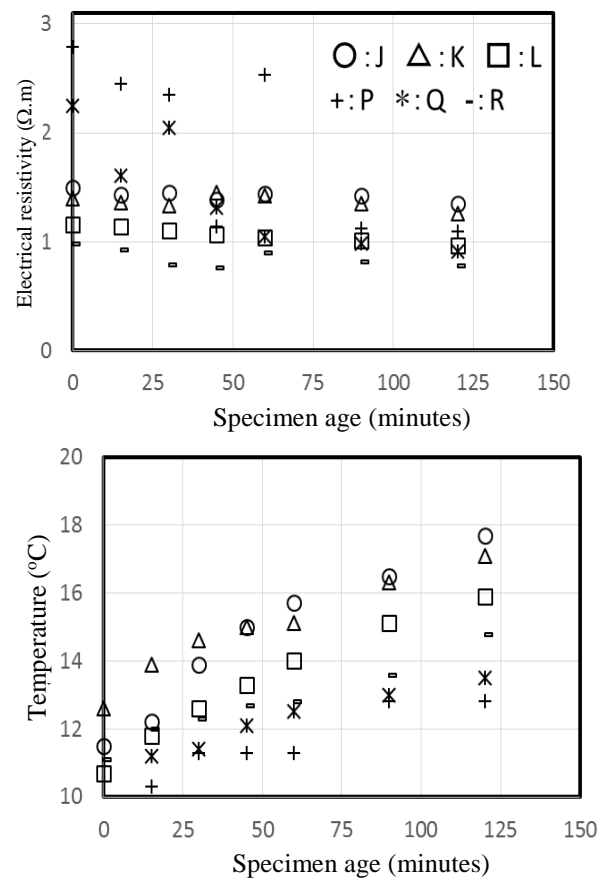

Fig. 13   Electrical resistivity value and temperature change with time

4. Electrical Resistivity Measurement Based of Strength Prediction Recommendation

Based on performed laboratory experiment in this research, prediction formulation for compressive strength of bored pile construction using electrical resistivity measurement procedure is recommended by following diagram shown by Figure 14.

5. CONCLUSIONS

1. Electrical resistivity measurement method 1 was the most suitable method to predict compressive strength of cement milk or cement soil mixture

2. Electrical resistivity value of specimen at early age tends to be consistent regardless to mixture configuration and cement amount if the particle size of soil is uniform to some extent

3. The temperature change of the specimen is greater than Atmospheric temperature has more influence to temperature change of the specimens rather than the heat emission due to the hydration reaction.

4. The relationship between qu_{28}/ρ_{28} and qu_3/ρ_3 is better than $\Delta qu/\Delta\rho$ and qu_3/ρ_3

5. It is possible to use measurement method 2 and 3 for laboratory experiment, however correction process is necessary.

6. Based on outdoor experiment, temperature change does not have significant effect to compressive strength.

7. It is necessary to perform another experiment to understand the influence of soil classification and particle size of soil to electrical resistivity value.

8. Equation 1 to equation 33 may be applied to predict compressive strength of actual condition, however accurate electrical resistivity measurement and measurement data accumulation is necessary.

6. REFERENCES

[1] Tsuchiya T. and Kuwabara F., A study on the compressive strength of the base bulb of bored piles affected by construction methods, Aij Journal of TECHNOLOGY and Design 18(40), Architectural Institute of Japan, 2012, pp.883-888.

[2] Tsuchiya T., A study on the soil properties and the compressive strength of soil-cement in enlarged base of bored piles, Architectural Institute of Japan Summaries of technical papers of annual meeting 2014(Structure I), 2014, pp.463-464.

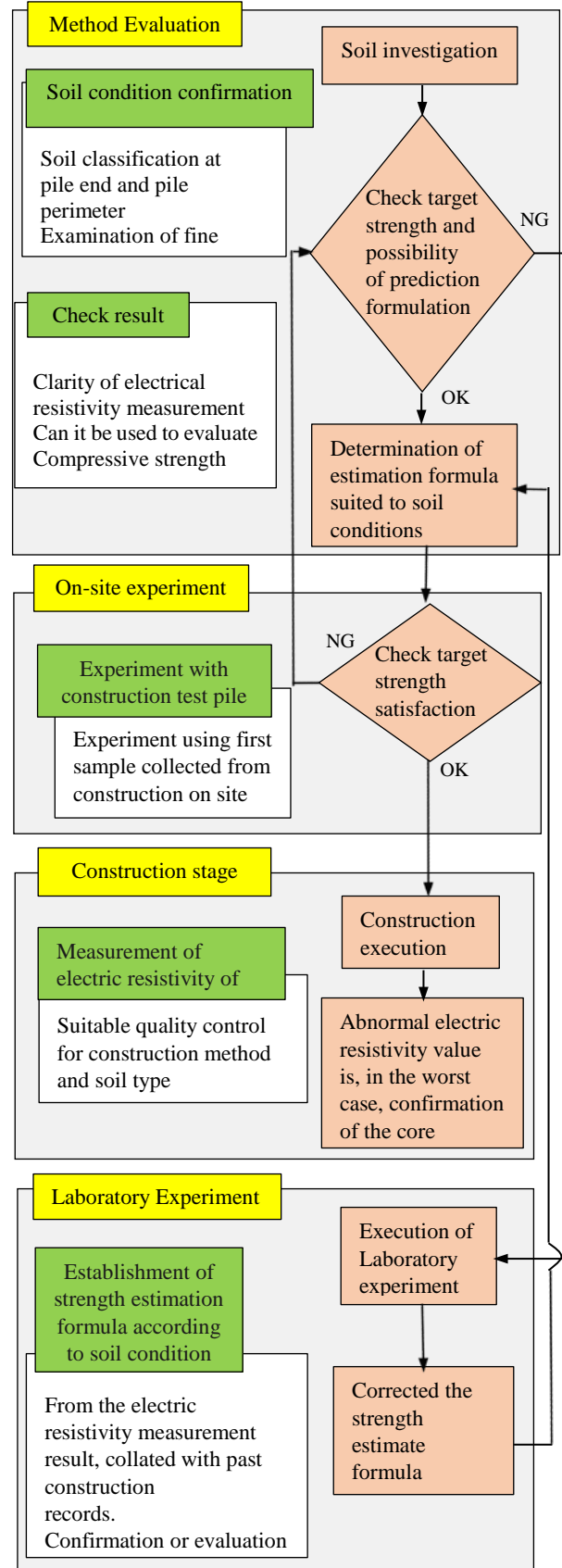[3] Komatsu G., Tamura M., Sakai Y., Fujii M., Kuwabara O. and Kato Y., Quality evaluation

Fig. 14   Recommendation procedure for compressive strength prediction soil cement mixture

for the foot protection part of the bored precast pile using the electric resistivity, Architectural Institute of Japan Summaries of technical papers of annual meeting, 1998, pp. 621-622.

[4] Sakai R., Mochida Y. and Fujii M., Estimation of compressive strength due to the electric resistivity of study 1) Cement milk regarding construction quality control of pile circumferential fixative buried piles using electrical resistivity survey, Architectural Institute of Japan Summaries of technical papers of annual meeting, 2016, pp. 845-846.

[5] Matsuura M., Mochida Y. and Fujii M., Estimation of compressive strength due to electrical resistivity of at Study 2) Sandy soil about construction quality control of pile circumferential fixative buried piles using electrical resistivity survey, Architectural Institute of Japan Summaries of technical papers of annual meeting, 2016, pp. 847-848.

[6] Mochida Y. and Fujii M., Electrical resistivity survey methods and findings in Study 3) construction site regarding construction quality control of pile circumferential fixative buried piles using electrical resistivity survey, Architectural Institute of Japan Summaries of technical papers of annual meeting, 2016, pp. 849-850.

[7] Kato Y., Kawamura M., Fujii M. and Tamura M., Basic study on strength of pile fixed portion of embedded pile, Architectural Institute of Japan Summaries of technical papers of annual meeting, 2000, pp. 755-756.

[8] Tomita K., Fujii M., Senzaki M., Kuwabara F., Hayashi T., Kawano F., and Komatsu G., Quality evaluation of solidified body of pile fixing solution, Architectural Institute of Japan Summaries of technical papers of annual meeting, 2001, pp. 693-694.

[9] Society of Civil Engineers: Concrete Standard Formulation Established in 1996 [Construction Edition].

[10] Mochida Y. and Tsukamoto M., Development of ground improvement method using soil fluidization process due to local material and cement solidification (part1.Construction and management method), Aij Journal of TECHNOLOGY and Design 19(42), Architectural Institute of Japan, 2013, pp.485-490.