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# PROMOTION OF ICT UTILIZATION BY ELECTRIC RESISTIVITY MANAGEMENT IN FLUIDIZATION TREATMENT PROCESS FOR GROUND IMPROVEMENT

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**ABSTRACT:** This research introduced a new method for monitoring the quality of a ground improvement body by measuring the electrical resistivity of the body using an ICT device attached to the bucket mixer. This method shows engineers the unevenness of the electrical resistivity of the ground improvement body, which indicates imperfections in the mixing process or inconsistency of the compound within the ground improvement body. The monitoring is intended to perform real-time two-dimensional cross-section observation of the ground improvement body. The experiment yielded results enabling engineers to observe the mixing condition of the cement–soil mixture within the ground improvement body by monitoring the level of unevenness of the electrical resistivity of the body, and provides a very accurate quality control process. Quality assurance using wet grab sampling was performed and a uniaxial compressive strength test was conducted and the experimental results showed that the compressive strength of the ground improvement cement–soil mixture at any curing age could be predicted. The quality control and quality assurance method introduced in this research could minimize uncertain judgments in the current methods.

*Keywords: Ground improvement, electrical resistivity, shallow foundation, ICT*

## 1. INTRODUCTION

In the application of the fluidization treatment method for ground improvement work, the most common method to make the final decision to ensure the performance of the ground improvement body is by confirming the rotation number or mixing device's tachometer and the flow value of the stirrer control, and also through visual observation by engineers on the color and consistency of the mixture [1]. However, it is difficult to confirm the condition of the whole ground improvement body and there is a definite possibility of an inhomogeneous mixture inside the body [2][3][4].

With the use of ICT (Information and Communication Technology), and performing a management procedure by attaching an electrical resistivity sensor onto the bucket mixer and measuring the electrical resistivity of the ground improvement body, it has been possible to monitor and determine the unevenness of the ground improvement body mixture and understand the performance of the body in real time [4][5][6].

The use of electrical resistivity measurement also makes it possible to advance the quality assurance method [6][7][8][9][10]. The quality of a ground improvement body should be understood from the early stage to reduce the waste of material as well as the construction cost. This can be done by predicting the compressive strength from the measured electrical resistivity value.

## 2. FLUIDIZATION TREATMENT METHOD OF GROUND IMPROVEMENT

Figure 1 shows the flowchart of the ground improvement work. The first step is to perform a feasibility study such as the building shape, necessary loads to be transferred directly to the foundation, and soil properties in order to perform the design process for ground improvement. Subsequently, an indoor compound examination should be performed using local materials and determining the design for the compound to be used in the ground improvement work. Subsequently, construction plans should be implemented at the execution stage, such as the construction order and quality control, and continued by the inspection stage and completion of the construction process.

Figure 2 shows the flow chart of the execution stage, which is described as follows.

1. Confirmation of ground improvement position by planting steel rods in the boundary area.
2. Removing excess and unsuitable soil layer for construction by excavation work.
3. Excavation of soil within the boundary area of the ground improvement site to the expected depth.
4. Verify the support soil/ground by measuring

the geometry of the cavity. Determine the volume of fluidization treatment agent to be used, based on the calculated cavity volume.

5. Decide the reference line on the ground improvement area range using a backhoe with the backhoe's tip as the reference.

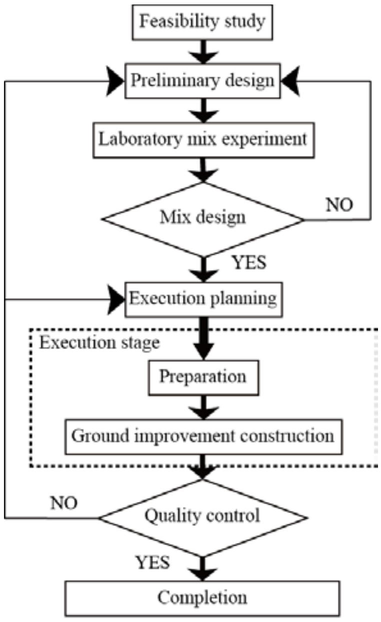



Fig. 1 Ground improvement work flow

6. Fluidization treatment process (construction)
7. Confirm the improved level of the ground improvement body.
8. Electrical resistivity measurement.
9. Sample collection for laboratory test.
10. Completion of the process.

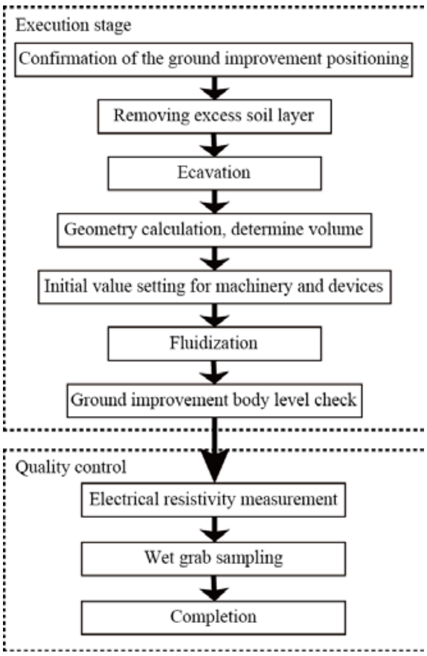



Fig. 2 Execution stage

## 3. ELECTRICAL RESISTIVITY APPLICATION

### 3.1 The Degree of Mixing Process by Electrical Resistivity Measurement

This investigation method uses the measurement of the electrical resistivity of the soil and the solidifying agent compound and estimates the degree of mixing from the change of the electrical resistivity of parts of the ground improvement body.

Electrical resistivity is the opposite of electric current flow, and expresses the resistance to electric current. Cement, waterglass injection, bentonite clay, etc., are the main materials used to construct the ground improvement. If the ion concentration of these materials is high, the electrical resistivity becomes lower and changes because of the mixing process with the soil. Therefore, if the compound is perfectly stirred/mixed, the electrical resistivity becomes lower, whereas when there is a high value of electrical resistivity it may indicate that there are slumps or incompletely stirred compound in that area. This method allows engineers to verify the degree of mixing of the ground improvement body in a shorter time.

### 3.2 Electrical Resistivity Ratio

According to Ohm's law, electric resistance ρ is described by Equations (1) with the following measurement units: voltage (V): V, resistance (Ω): R, and electric current (A): I.

$$\text{Voltage}: E(V) = R \times I$$
$$\text{Electric current}: I(A) = \frac{E}{R}$$
$$\text{Resistance}: R(\Omega) = E/I \qquad (1)$$

Figure 3 shows the cone-type sensor (four-electrode) that was used in the mixing investigation. This cone-type sensor flows electric current (A) from two of the four electrodes (outside electrodes), while the two electrodes located inside measure the voltage. Knowing the value of the current and voltage, the electric resistance and electrical resistivity can be calculated.

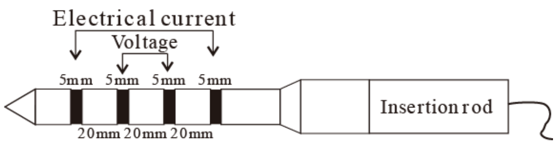



Fig. 3 Cone-type sensor (four-electrode type)

The cone-type sensor has a diameter of approximately 25mm, the length of the sensor unit is 100mm, the electrode thickness is 5mm and the spacing between electrodes is 20mm.

### 3.3 Measurement Method (Insertion Rod Measurement Method)

Measurements of the electrical resistivity are performed immediately after completion of the stirring process or after the expected rotation counter number is satisfied, by sinking the cone sensor at certain points in the depth direction. The investigation is performed by suspending the sensor on the hydraulic shovel available at the construction site, and penetrating at a constant speed. Two or three points are investigated in one area and controlled by determining the relationship between the average moving value and depth distribution and between the average electrical resistance value and the depth distribution. The interval of measurement points is set to 10cm, while one side of the investigation point is decided using a 1 meter length triangle ruler marker and three investigation points are decided using the range of a 50cm equilateral triangle ruler.

### 3.4 Application Example of Construction Management by the Electric Resistivity Utilization Method

The examination was conducted in five locations with different types of soil; Kanto loam soil at two locations (Chofuyagumodai-Tokyo, Tokorozawa-Saitama Prefecture), sandy silt soil at one location (Nagai-Yamagata Prefecture), decomposed granite (DG) soil at one location (Koriyama-Fukushima Prefecture) and clay soil at one location (Nagaoka City-Niigata Prefecture).

A cement-based solidifying material was used for the ground improvement as an additive material with the addition of sandy silt and Kanto loam soil in an amount of 200~350 kg/m$^3$. The basic process for ground improvement in this research is by performing a solidifying process on several soil layers that need to be improved, and finally performing the fluidization treatment process on the entire part of the ground improvement body. A vessel test was performed at each position in order to set the target value for the mean electrical resistivity value due to the fluidization process.

According to the vessel test results (Figure 4), the target electrical resistivity value of the improved body was set as 10 ~ 20 (Ω · m) and the average resistivity value of each investigation point satisfied the expected value. The examination results in DG soil in Fukushima Prefecture and Kanto loam in Tokyo show a large difference of the average electrical resistivity value. Thus, there was some imperfection in the stirring process, but the value changed into the expected range after further stirring.

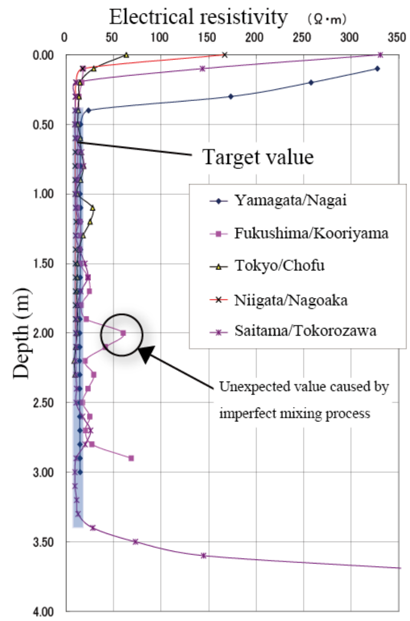



Fig. 4 Vessel test result

### 3.5 Variation of Electrical Resistivity of the Final Stage in the Ground Improvement Work

Figure 5 shows the relationship between the strength of the ground improvement body and the coefficient of variation of the electrical resistivity value of the site core. Local soils were selected for the experiment from a total of 31 locations: sandy soils (sand from three locations, DG soils from one location, fine sands from one location), clay group (clay from 11 locations, sandy silt from six locations, silt from three locations) and loam (Kanto loam from six locations). The strength of the ground improvement body mixture in the site core was calculated using the coefficient of variation of unconfined compressive strength after curing (aged for 28 days). The coefficient of variation of electrical resistivity is defined as the coefficient of variation based on the electrical resistivity value where the sample for the compressive strength test was taken.

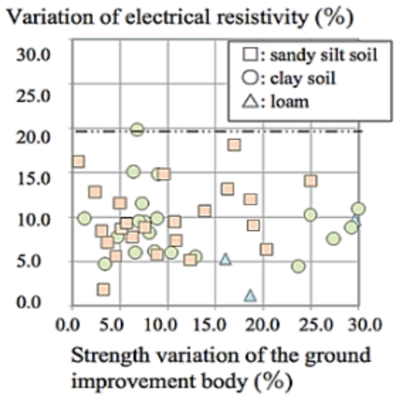



Fig. 5 Relation between electrical resistivity value and amount of cement

In this construction method of ground improvement, the coefficient of variation for the compressive strength was set at 30% as a target, and the experimental results satisfied the target. On the other hand, the trend of the coefficient of variation of the electrical resistivity was not due to the soil type, and the result satisfies the value of 20%.

### 3.6 Relationship between Compression Strength of Ground Improvement Body and Electrical Resistivity Value of Field Core

Figure 6 shows the relationship between the compressive strength of the ground improvement body and the electrical resistivity of the core sample. The strength of the ground improvement body on a full-length core is based on the uniaxial compressive strength after curing (28 days), and the electrical resistivity of the location where the sample for uniaxial compressive testing was taken is used for the electrical resistivity value. If the linear approximation formula and regression analysis in each of the three types of soil is calculated, the following formula is derived:

$$(Sand) \quad y = -989.1x + 22321 \qquad (2)$$
$$(Clay) \quad y = -12.7x + 3272 \qquad (3)$$
$$(Loam) \quad y = -42.3x + 3087 \qquad (4)$$

Increase of the compressive strength as the electrical resistivity value increases is the trend identified for every type of soil. In particular, this tendency is significant when sandy soil (Equation 2) is compared with clay and loam soil.

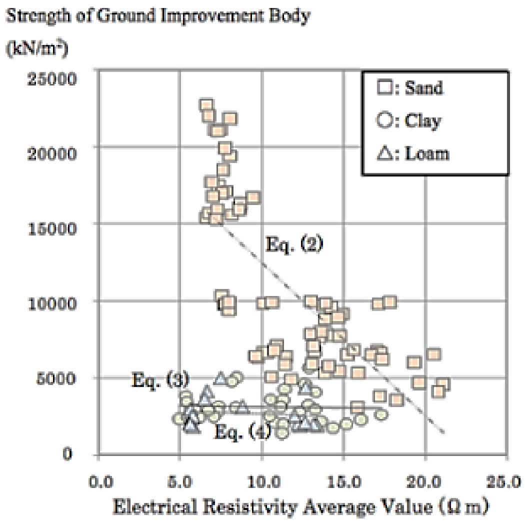



Fig. 6 Relation between electrical resistivity value and compressive strength of ground improvement body

## 4. ELECTRICAL RESISTIVITY APPLICATION AND ICT UTILIZATION IN CONSTRUCTION MANAGEMENT

Electrical resistivity measurements in past research gave examples of how to understand the ground properties by gathering the electrical resistivity value at a specific location using the installed electrical resistivity measurement sensor. The technology used in this research provides a method to understand the ground properties on a two-dimensional cross-section of a ground improvement body by measuring the compound's electrical resistivity using an electrical resistivity sensor attached to the moving bucket mixer used to perform the stirring process. This paper shows the basic concept of promoting ICT technology as follows.

- Makes it possible to observe a visually invisible underground situation
- Speeds up the performance identification by utilizing the electric signal
- Allows instant observation by a display method.

Therefore, this technology application is capable of identifying with greater certainty the ground improvement performance by eliminating the lack of the information on performance in the conventional method using human visual observation, and it improves productivity by eliminating the ambiguous judgment involved in the method based on the stirring rotation counter number. Finally, this technology is expected to reduce misjudgments in the management process arising from a recent lack of skilled engineers.

### 4.1 Fluidization Treatment Process of Ground Improvement Construction Management

Figure 7 shows a diagram of the wireless communication system and Figure 8 shows a diagram of the electrical resistivity sensor attached to the pail part of the bucket mixer. The mixing rotor and solidifying material liquid discharge device configure the pail part of the bucket mixer device to be used in this construction method. The pail part is equipped with a depth gauge, tachometer, and an electric resistivity sensor, which has the function of transmitting the mixing situation of the mixture inside the ground improvement body to the surface.

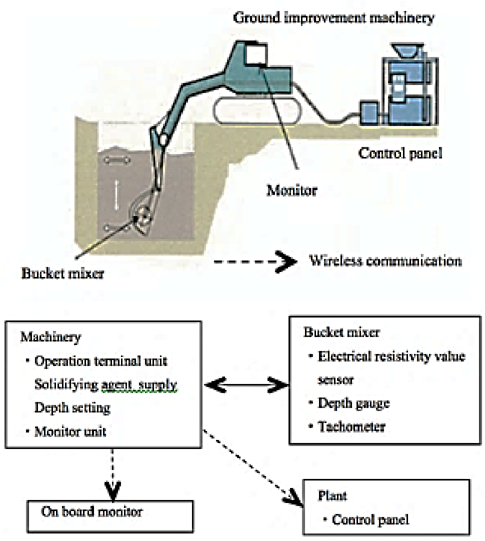



Fig. 7 Wireless communication system

The monitoring procedure is conducted by the operator using the electric signals sent from the equipment attached onto the pail to the control unit. The operator judges the compound mixture condition of the ground improvement body based on the information displayed on the monitor and is able to understand the shape and the compound's degree of uniformity in the ground improvement body. The measured electrical resistivity value will be displayed in different colors according to its value on the monitor screen, which divides the ground improvement body into a 25cm x 25cm grid.

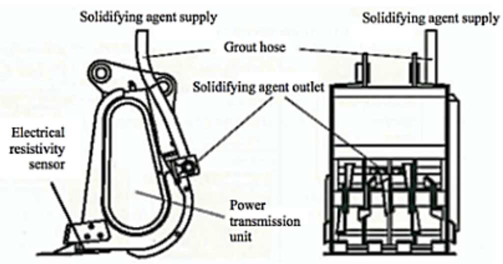



Fig. 8 Bucket mixer configuration

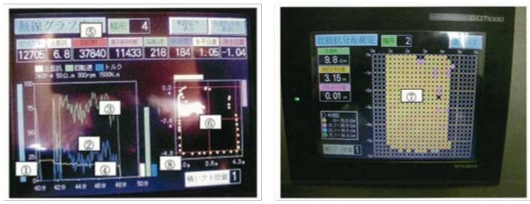
### 4.2 Calibration Standard

The calibration procedure for the method and equipment are described as follows.

1. Put distilled water in the mud balance instruments to manage the specific gravity of the solidifying material liquid, ensuring the specific gravity value is 1.0. Measure the specific gravity of the solidifying material liquid measured in the mud balance instruments and ensure the specific value is 99%. Ensure the pail of the bucket mixer is the predetermined shape.
2. Store the solidifying material liquid in the vessel and ensure the value of electrical resistivity is less than 10Ω.
3. Inspect the horizontal position movement and orientation of the bucket mixer by actual measurement and monitor the observation as a reference, ensuring the difference is ± 5cm in a 2 meter horizontal movement. In addition, for inspection of vertical movement, the difference is ± 5cm in a 1 meter vertical movement.

### 4.3 Monitoring

Data including the compound uniformity level are displayed on the monitor in real time to be used for evaluating the process. The monitoring situation and electrical resistivity distribution are shown in Photograph 1. The electrical resistivity distribution in the entire ground improvement body is displayed in different colors according to its value. The ground improvement body is displayed in cross-section view in 25cm x 25cm grid form and the measured electrical resistivity appears in a colored-dot shape. The stirring process is completed if the electrical resistivity distribution is displayed uniformly in pink or yellow dot indicators.



1. Quantity of solidification materials
2. Rotation torque
3. Rotation speed
4. Electrical resistivity value
5. Propeller blade rotation counter
6. Improvement trace
7. Electric resistivity value distribution
8. Ground improvement depth

Photograph. 1 Monitoring and the electric resistivity value distribution

### 4.4 Control Device

Figure 9 and Figure 10 show the depth gauge used for measuring the coordinates of the pail part of the bucket mixer and ground improvement traces monitoring. The coordinate management procedure is described as follows.

1. Set the position of the pail from the length and angle of each arm using an inclination sensor.
2. Define a reference line using one side of a backhoe inside the area for ground improvement and set the tip of the bucket mixer pail in this position.
3. From this position, calculate the bucket position by the angle and length of each arm and display the trajectory.
4. Input the dimensions of the ground improvement area and depth calculated from the reference line, and display them on the monitor.

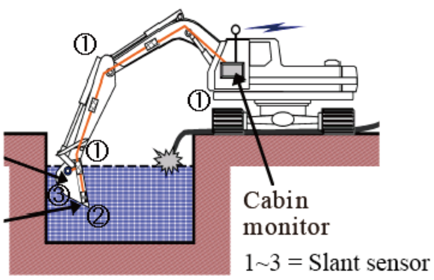



Fig. 9 Coordinated measurement

The ground improvement trajectory shows the outer periphery of the body and it is assumed as the maximum trajectory. It must be ensured by observing the monitor that this maximum trajectory sufficiently satisfies the ground improvement body geometry. Quality control is performed by measuring the electrical resistivity inside the ground improvement body using the electrical resistivity sensor attached to the tip of the bucket mixer pail. The ground improvement cross-section is displayed in the 25cm x 25cm grid pattern and the electrical resistivity will be measured continuously at each grid so that the change of its value can be observed in real time. The construction control procedure is described as follows.

1. Electrical resistance measurement of solidifying agent liquid.

The value is able to express the compound stirring state. Measure the solidifying agent resistivity prior to examination and assume it as the minimum value.

2. Electrical resistivity measurement of ground improvement body.

Measure the electrical resistivity value of the entire ground improvement body using a sensor attached to the pail part of the bucket mixer, and perform the monitoring process.

3. Monitor observation.

Electric signals transmitted by the sensor to the control unit cabin are monitored. The operator can understand the stirring state of the ground improvement body compound by judging its condition based on the information displayed on the monitor.

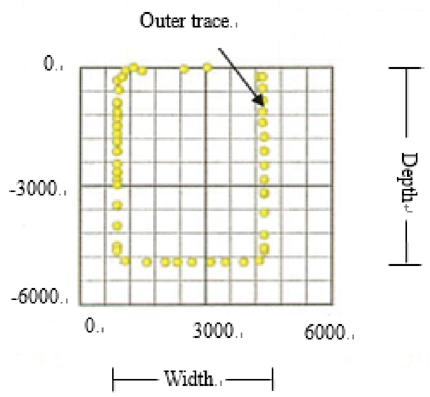



Fig. 10 Ground improvement trajectory

The electrical resistivity value varies depending on the soil type, but in the homogeneous stirring/mixing state converges within 7 ~ 20Ωm. Hence, the maximum value is set as 20Ωm. If the measurement value exceeds 20Ωm or significant variation is seen in the resistivity value of the measurement in the depth direction, the existence of an incompletely stirred part becomes a concern. In this case, a re-stirring process must be performed immediately until the electrical value is uniformly distributed within the expected range. Subsequently, a quality control process is performed by measuring the electrical resistivity value in the depth direction by inserting an electrical resistivity sensor using an insertion rod into the ground improvement body.

## 5. QUALITY CONTROL OF UNSOLIDIFIED SPECIMENS

Quality investigation of the ground improvement mixture due to the fluidization treatment process is commonly conducted by performing an unconfined compressive strength test of the specimens taken from the solidified ground improvement body using a core cutter or core boring. This method allows engineers to determine the performance of the ground improvement body at an early stage and decide on the next progression.

However, in this research, samples were collected by collecting unsolidified specimens from the ground improvement body. The specimens could be collected both by using a remixing mold core and by inserting a mold core. Subsequently a comparison of the compressive strength of the remixing method of core samples and insertion method of core samples was performed, and the strength of the boring core was estimated based on the remixing core. This showed that the proposed method of collecting the sample using the mold core was reliable.

### 5.1 Experiment to Confirm Performance of Unsolidified Sampler

The experiment to confirm the performance is conducted in a total of 9 locations: loam in 6 locations, sandy silt in 1 location, silt in 1 location and sandy clay in 1 location. The terms and conditions of each of the ground improvements are W/C = 80 ~ 150 (%), additive amount of 250 ~ 300 (kg/m$^3$), design strength criterion of 450 ~ 1050 (kN/m$^2$) and the thickness of the ground improvement body from 1.6 m to 4.5 m. As a reference, 3 of the 9 locations were selected, with the boring core (48 ϕ ~ 72 ϕ), remixing core (50 ϕ) and inserted core (100 ϕ). Both the boring core and mold core were subjected to a compressive strength test in moist air (20°C± 3°C) based on the Japanese compressive test standard (JIS A 108).

### 5.2 Strength Comparison of Boring Core and Mold Core

Figure 11 shows the comparison of the average compressive strength between the mold core (remixing core) and boring core. The average compressive strength of the mold core is considered to be roughly 80% of the average compressive strength of the boring core.

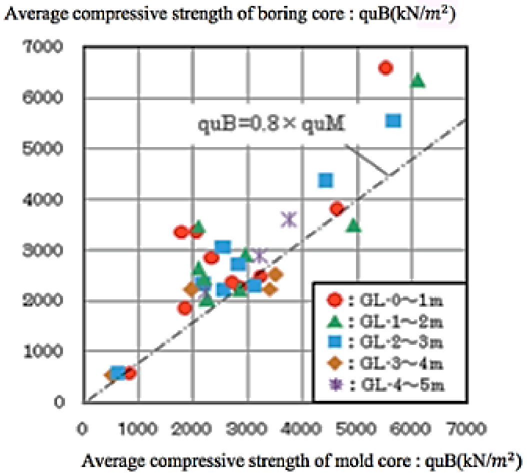



Fig. 11 Comparison of average compressive strength between mold core and boring core (remixing mold core)

### 5.3 Strength Comparison of Remixing Core and Insert Core

Figure 12 shows the comparison of the average compressive strength of the mold (remixing, insert core) and boring core. As shown in previous research on the compressive strength of the concrete core, the compressive strength and coefficient of variation of the core's strength increase with decrease in the core diameter, and in a concrete core with the maximum aggregate size (5–20 mm), its compressive strength decreases with increasing core diameter. The compressive strength test result in this research also shows the trend that the compressive strength of the insert core varies more and the compressive strength of remixing core has the highest value.

## 6. CONCLUSION

This research showed an example of the practical use of ICT technology in construction management by investigating the use of two-dimensional cross-section monitoring to observe the degree of mixing of the entire ground improvement body in real time by measuring the electrical resistivity value using devices attached to the pail part of a bucket mixer. The technology aims to realize an improved production by adding a user-friendly device to prevent ambiguous judgments or inaccurate observation results being made by the engineers when verifying the ground improvement body stirring states.

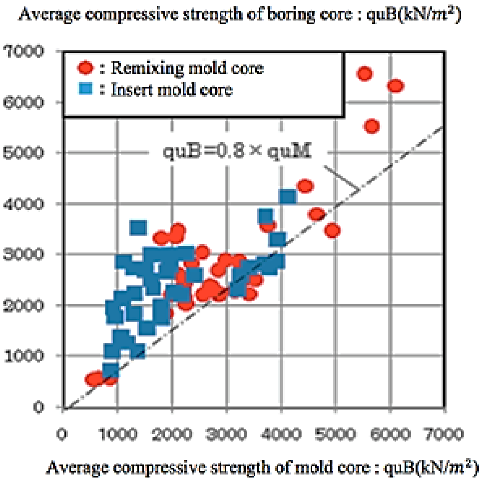



Fig. 12 Comparison of average compressive strength between mold core (remixing, insert core) and boring core

This research has proved that quality control using the electrical resistivity measurement of the ground improvement body provides great accuracy due to the two-dimensional monitoring of the ground improvement body along with colored indicators of the electrical resistivity value of the ground improvement body mixture.

Furthermore, by understanding the differences in the electrical resistivity value due to the soil type, the relationship between the amount of cement and the electrical resistivity value, and the relationship between the strength of the ground improvement body and the coefficient of variation of electrical resistivity, this method has satisfied the targeted value of 30% for both the coefficient of variation and quality control.

In addition, by using a mold core on an unsolidified sample of the ground improvement body and performing a compressive strength test at an early stage, with the sample taken at any depth, engineers are able to estimate the strength of the ground improvement body at any material age.

## 7. AUTHOR'S CONTRIBUTIONS

This research is based on experiments conducted by Indra Hardi. The experimental data were analyzed and interpreted by Indra Hardi under the supervision, review and approval of Prof. Mochida Yasuhide.

## 8. ETHICS

The authors declare that this paper is an original work and there are no conflicts of interest regarding the publication of this paper.

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