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Execution Control System of the Deep Mixing Method for House Construction in Japan

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ABSTRACT

This research concerns the execution management system in the deep mixing method of soil stabilization for small-scale buildings such as detached houses. In this paper, we describe the current situation in Japan and pick up subjects that require considerations. Two kinds of execution data management methods are reported; one is the execution data information system, and the other is the data display system. Case study is performed in order to confirm validity of the display system. Furthermore, the simplified management system, which can evaluate the performance of ground improvement, is discussed.

KEY WORDS: Execution management; quality control; ground improvement; deep mixing method; detached house.

INTRODUCTION

Most big cities in Japan are located in coastal areas, where ground surface strata consist of weak alluvium. Consequently, pile foundations or ground improvements are required even for small-scale buildings such as detached houses because they are prone to trouble from ground settlement. In 2004, 480,000 houses are built in Japan, and some ground reinforcement is performed in about 25 % of those. And the deep-mixed soil cement column method is adopted in about 25 % of the reinforcement work.

The authors have been working on the development of a construction management system, which would allow the quality control of each execution unit as well as the whole work, and would be applicable to the performance-based approach (Tamura and Watanabe, 2000, Kawamura and Tamura, 2001, Tamura and Hibino, 2002). In this paper, firstly, we report on the new execution data information system, which can confirm the working condition immediately. Secondly, we describe the case study for taking the execution data display system (Sato and Kouda, 2002, Tamura and Sato, 2003) into consideration. And then, we discuss the properties of the torque values on mixing rod and relationship with quality of the soil cement columns in order to propose a simplified execution management system.

PRESENT CONDITION OF EXECUTION MANAGEMENT SYSTEM IN JAPAN

Detached houses in Japan have two-storied timber structures and are built on comparatively narrow land, of which building areas are 100 - 150 m^2. In the case of performing deep-mixing soil stabilization, the

Table 1. Executing control items

General Items	Execution time, Column length, Level of column top, Column diameter, Position of column center, Verticality of column
Soil Stabilizer	Quantity of cement and water, Total amount of cement slurry, Cement slurry amount per unit length
Mixing Machine	Excavating speed, Total number of blade rotation, Rotation number per unit length
Load of Machine	Mixing torque, Excavating axial load

Photo 1. Execution machine

Photo 2. Soil stabilizer plant

depth of soil cement columns is 3~6 m and the diameter of the columns is generally 60 cm. Since the width of entry roads may be 4 m or less, small-scale execution machines are used as shown in Photo 1. It is important for construction management to guarantee the quality of stabilizing materials and to sufficiently control stirring and mixing of slurry with soil. Many control items and those specifications are established as shown in Table 1. In the preparation process of cement slurry, a plant that can load onto a small truck as shown in Photo 2 was developed, and slurry of stable quality came to be supplied. On the other hand, in the construction process of the soil-cement columns, there are some subjects that require more investigation. The execution machine is provided with various kinds of monitors, and the operator can work by checking those values. However, the operator has difficulty checking all the control values strictly because there are so many of them and machine capability is limited. Therefore, the operator pays attention only to confirming total rotation number of the mixing rod, and other items are checked by intuition which depends on his experience. In order to shift to the management method based on the quality and performance after construction, it is necessary to discuss following matters;

i) Simplification of the control items.
ii) Automation of the control method.
iii) Preservation of the execution information, and feedback.
iv) System for identifying the execution condition.

EXECUTION DATA INFORMATION SYSTEM

The execution machine has indicators that show mixing conditions. The indicated items are execution time and speed, depth of mixing blade, inclination of mixing rod, discharge amount and pressure of cement slurry, blade rotation number and speed, penetration load and mixing torque and so on. However it is very difficult to judge the executing condition accurately, because the ordinary indicator shows only those values separately. Accordingly, a new execution data information system, which can display visually and comprehensibly, has been developed. Photo 3 shows a snapshot of the monitor, and Photo 4 shows the situation in the operator cab. Critical items, such as inclination of the mixing rod, execution depth, speed, and slurry discharge amount, are displayed largely on left side of the 10-inch monitor. And slurry discharge rate per 1 m depth, blade rotation number, average torque, and penetration load (axial load) are displayed with animation which shows execution situation. The main feature of this system is that it can send the screen view to other locations by radio. The supervisor and/or the foreman can monitor the same screen simultaneously and confirm the construction process of the soil-cement columns in the construction office or in a car (Photo 5). This range of radio is about 100 m. Another feature is to display a graph, which shows the change of the slurry discharge, the rotation number, the penetration load and the mixing torque. When some troubles are suspected, detailed check can be performed immediately using the execution data display system, which will be mentioned later, because

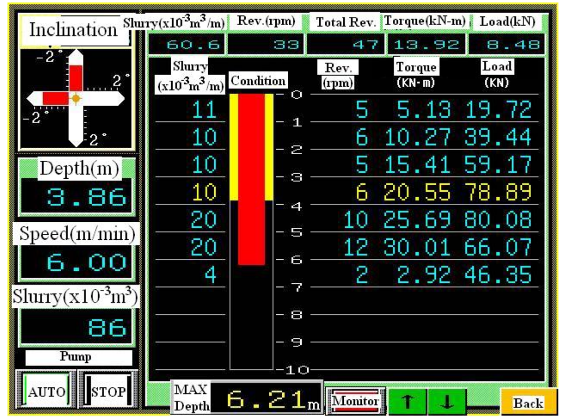


Photo 3. Snapshot of monitor

Photo 4. Operator cab

Photo 5. Radio monitoring

the data is transmitted in real time.

EXECUTION DATA DISPLAY SYSTEM

In order to guarantee the quality after construction, it is necessary to examine not only each construction condition of the soil-cement column but uniformity and variation of the whole construction site. However, the execution data, which involve huge quantities and complicated contents even in small-scale ground improvement projects like detached houses, are distributed over underground 3-dimensional space. The authors proposed the execution data display system (Sato and Kouda, 2002). The system is based on simplifying and visualizing the execution data about arbitrary vertical sections and horizontal sections within the execution space. The summary and case study are given bellow.

Summary of the display system

The execution data display system operates on the spreadsheet software Microsoft Excel®, and the processing program is created using macro language of the software, VBA® (Visual Basic for Applications).

First, various kinds of execution information are measured and recorded per column. Although it is better to collect as many data as possible in order to perform suitable analysis, in this stage it does not matter if the record intervals and the number of data are arbitrary.

Next, data are extracted for every certain depth determined as 1 m or 0.5 m, etc. and the various amounts per unit depth (added value, average value, etc.) are computed. Required 2-dimensional data (the horizontal section; X-Y plane, or vertical section; X-Y or Y-Z plane) are cut off from these 3-dimensional data (Fig. 1), and outputted to a new worksheet by fitting the data coordinates to the worksheet cell coordinates. Furthermore, each cell of the worksheet is colored by the size of the numerical value of those data so that it may be easy to judge execution information visually. Moreover, if needed, statistical analysis results, such as average of the various amounts, distributions, and

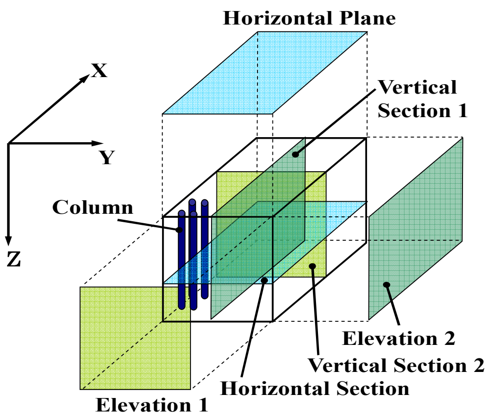


Fig. 1 Execution data display system

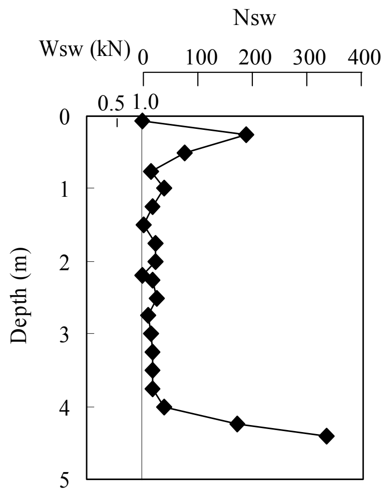


Fig. 2 SWS results

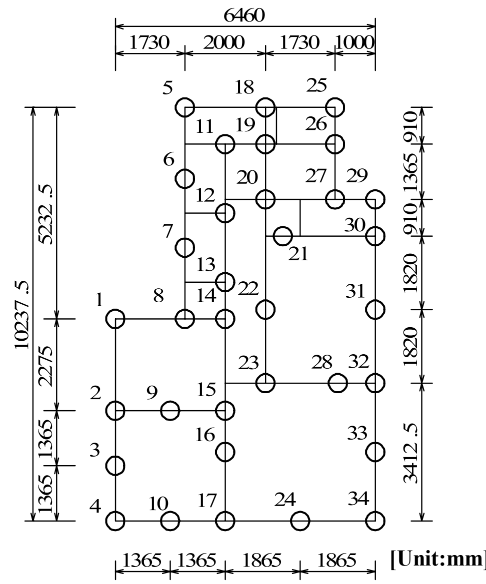


Fig. 3 Layout plan of columns

Table 2. Control items and defined values

Column Diameter	D	D = 0.6 (m)
Column length	H	H = 4.5 + 0.2 (m)
Amount of cement slurry	V_T	$V_T > 340 \times 10^3$ (m^3)
Amount of cement slurry per 1m	V	$V > 76 \times 10^3$ (m^3/m)
Total blade rotation number	R_T	$R_T > 450$ (revs.)
Blade rotation number per 1m	R	R > 90 (revs./m)

standard deviations, are added, or are expressed by graph.

The future goal of this system is to realize display of synthetic execution results including soil investigation results or quality control results (execution accuracy, strength examination, etc.). At the present time, a system that only presents the information has been created as the first step of development.

Case study of the display system

Soil improvement construction was carried out in a city facing Tokyo-bay using the deep-mixing soil-cement column method. Fig. 2 shows the result of Swedish Weight Sounding (SWS). According to the SWS, a weak layer was found between 1.5 m and 2.0 m depth when Wsw < 1 kN, and it was decided to improve the soil using the deep-mixing method up to 4.5 m depth.

The layout plan of the columns is shown in Fig. 3. Construction control items and those standard values are shown in Table 2. The double mixing method was used as the mixing technique.

Confirmation of standard control values

Figs. 4~5 show the outputs of the system concerning the total amount of cement slurry discharge and the total number of mixing blade rotations. These outputs show the representative values of each improved column, and give outlines about the mixing work. From these charts, we can recognize that the mixing process was carried out well without large dispersion.

Interruption of work by obstacles

Fig. 7 shows average execution time per unit length of each column. It is understood that most of the columns are constructed in 26 to 35 seconds per 1 meter except for Nos. 29 and 34. The cells of No. 29 and

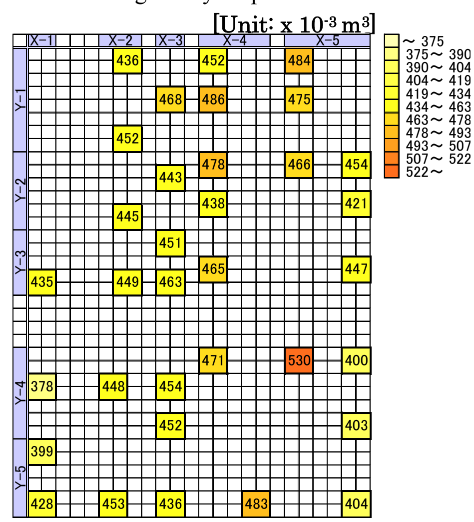


Fig. 4 Total amount of cement slurry discharge

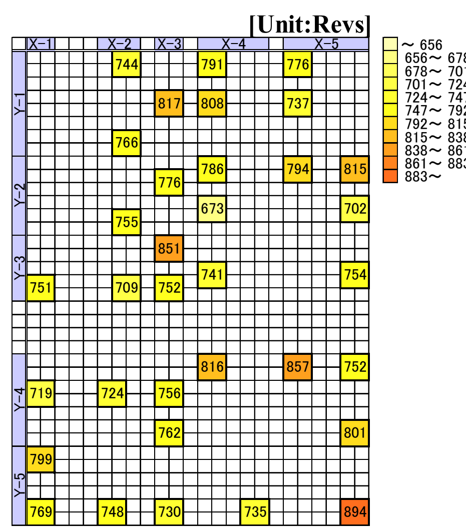


Fig. 5 Total number of mixing blade rotations

35 are colored dark and numerical data are also large.

Fig. 8 shows the output concerning the vertical section of average execution time concerning No. 25 to 34, and Fig. 6 shows the relationship between mixing depth and time. The cells with dark color in Fig. 7 are the spots where the mixing rod was stuck due to obstacles such as rock or mudstone.

When penetration speed is changed, the amount of cement slurry and number of mixing rotations are also changed. Particularly, if those

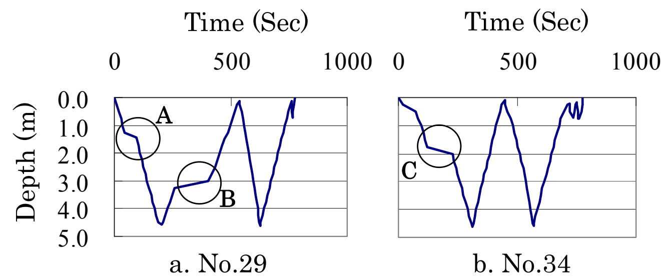


Fig. 6 Relationship of mixing depth and time

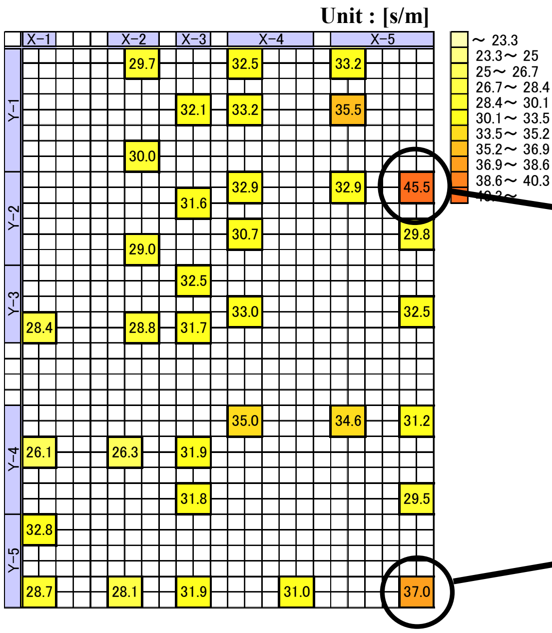


Fig. 7 Execution time per 1 m (plane view)

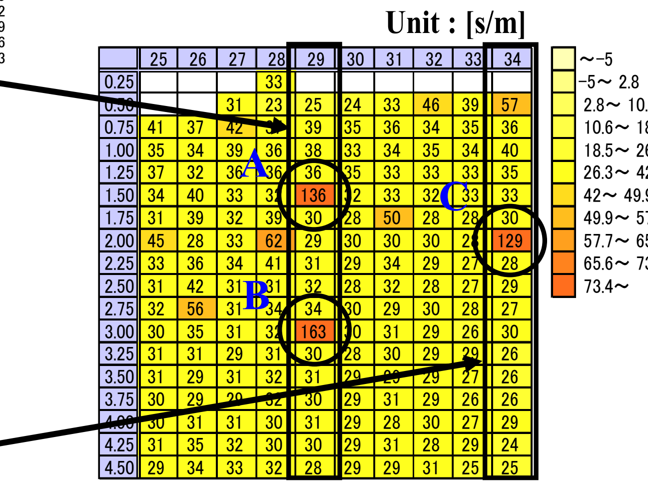


Fig. 8 Execution time per 1 m (vertical section, No.25 - 34)

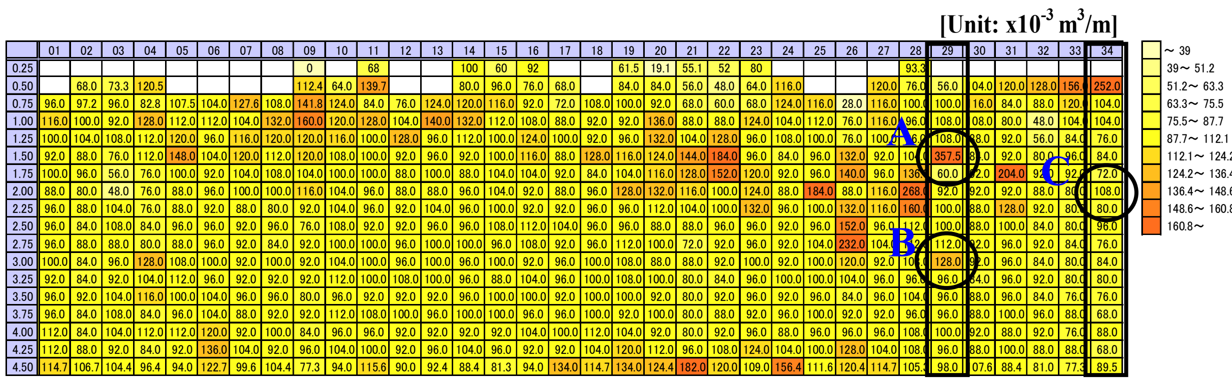


Fig. 9 Amount of the cement slurry discharge per 1 m (for all section)

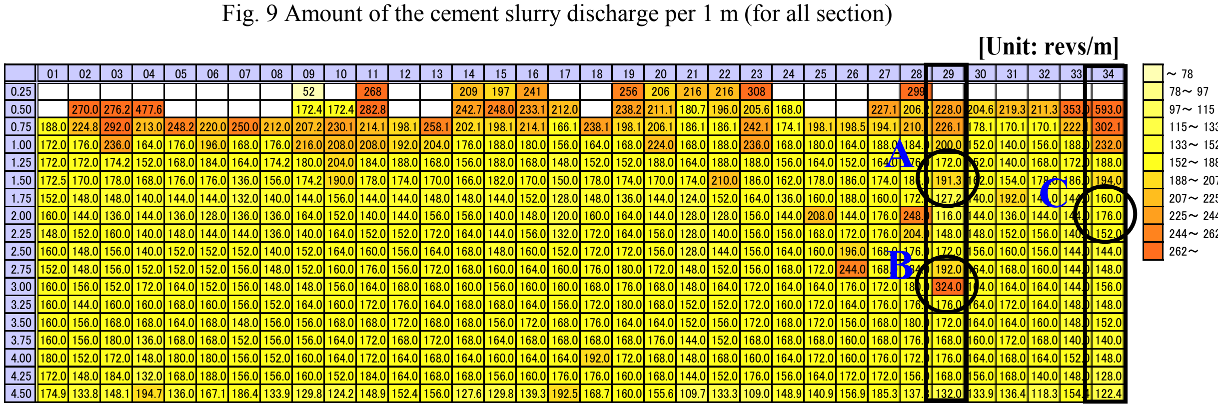


Fig. 10 Number of blade rotations per 1 m (for all section)

values fall below standards, execution quality may deteriorate. Vertical sections of all columns are shown in Figs. 9~10, which are output by the system concerning the amount of the slurry and number of mixing rotations per unit depth. The cells where the mixing rod was stuck show nearly the same or larger values than in the surrounding area. Accordingly, it is confirmed that the execution work has been done appropriately in all improvement areas

DISCUSSION OF MANAGEMENT METHOD

Change of the mixing torque

By discussion of some case studies using the execution data display system, we found out that the resistance of mixing torque became small with progress of the mixing process, and the change of the torque decreased also. Fig. 11 shows the change of the torque in the retrieval process on the cohesive soil and the sandy soil. On the cohesive soil, the coefficient of variation (Cv) of the first retrieval process is about 50, and it decreases to about 30 in the second retrieval process. On the sandy soil, the Cv value already reaches to about 30 in the first retrieval, and it decreases to about 20 in the second retrieval.

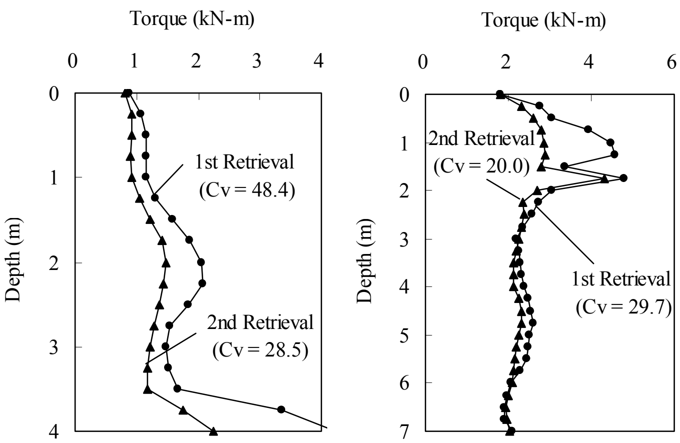
Generally, the deep mixing soil improvements for detached houses are performed on simple stratum because the column length is relatively short such as 3~6 m. Therefore, showing small Cv values of torque means that the construction has been performed homogeneously and precisely. Then, we will examine to adopt the Cv value of the mixing torque as the indicator of the execution management. Since the convergent tendencies of Cv values differ with cohesive and sandy soil, it is understood that the standard value should be arranged according to the kind of ground.

Unconfined compressive strength of improvement body

Fig. 12 shows the unconfined compressive strength (q_u) of specimens extracted from the improvement bodies executed on cohesive and sandy ground. The specimens were extracted from 2 m depth after the first and second retrieval processes. The tests were performed after 4 weeks (28 days). The q_u values of all improvement bodies are designed by 0.6 MN/m^2 and the standard blade rotation numbers is 450. The q_u values of cohesive soil after the first retrieval process, when the blade rotates about a half of the standard, do not satisfy the designed values. With sandy soil, the qu reaches the designed value by about a half of the standard rotation number. The blade rotation number must be established taking the safety factor into consideration. Nevertheless, it is understood that more standard numbers are required for cohesive soil than for sandy soil.

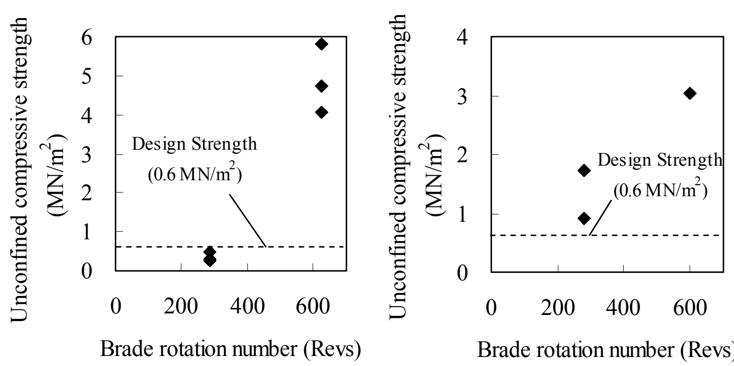
Laboratory test of improved soil

Laboratory test was carried out in order to investigate basic character of improved soil. The test mold, 100 mm in diameter and 200 mm in height, was filled up with kaolin clay (the liquid limit = 65%, the water



a. Cohesive soil b. Sandy soil

Fig. 11 Change of the mixing torques



a. Cohesive soil b. Sandy soil

Fig.12 Unconfined compressive strength (q_u) of impressive bodies

Photo 6. Mixing equipment used in laboratory test

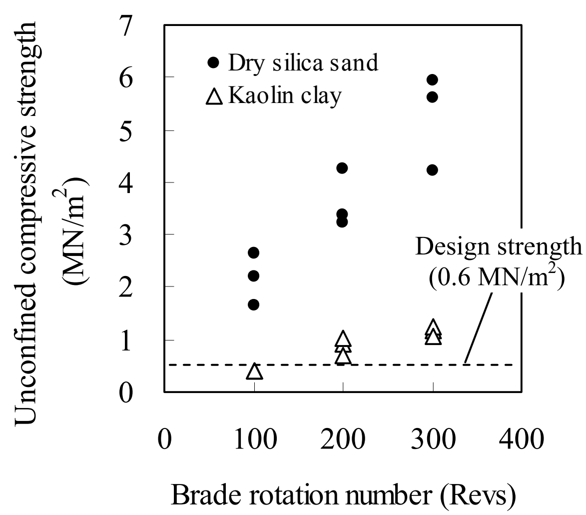


Fig. 13 Unconfined compressive strength (q_u) of laboratory test

ratio = 60%) or dry silica sand (D_{50} = 0.15mm). And a cylindrical void was made to the central part of the specimen and cement slurry was poured into it. Stirring and mixing was performed using the rotation and fluctuation equipment shown in Photo 6, and the unconfined compressive test was carried out after 4 weeks.

Fig. 13 shows the result of the test. With clay, q_u increases in proportion almost to the mixing number, and q_u exceeds 0.6 MN/m^2 when the mixing number reaches 200. With dry sand, q_u increases in linearly as well as clay, however, q_u exceeds $600kN/m^2$ with the minimum mixing number.

Revising the management method

The authors would like to argue that the present management method of deep mixing soil stabilization for detached houses should be revised to so that it can evaluate the quality after execution. The basic concepts of revision are as follows;

i) A new standard number of blade rotations should be established: The number should be the minimum one which can warrant the strength of the column. And the number is formulated with typical character of soil such as the fine fraction content.

ii) The allowable Cv value of the mixing torque should be set up: The mixing work must be executed until Cv value on retrieval process becomes smaller than the allowable one. It is surmised at present stage that the Cv value will be around 20 irrespective of the kind of soil.

In order to apply the mixing torque as a management indicator, many more case studies and strength tests in various kind of soil should be carried out. And it is necessary to quantify the minimum blade rotation number and the Cv value of the mixing torque for every typical soil. The management method using the mixing torque is connected to the quality of the improvement construction directly rather than the method of using the blade rotation number. The formulated indexes with typical soils will enable a construction project that matches the actual circumstances, and the execution performance will also progress.

CONCLUSION

The execution data information system is able to display the construction data of a single improvement column intelligibly. The system is available for large-scale residential land development because the data is transmitted to the administration office in real time. The execution data display system is applicable not only to the deep mixing method but other foundation work, such as pile foundation and the sand compaction pile method. The management method using the mixing torque as the indicator will be developed to the quality control method based on the performance.

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