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INTEGRATION OF INFORMATION AND COMMUNICATION TECHNOLOGY (ICT) INTO CEMENT DEEP MIXING METHOD

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ABSTRACT: In the deep mixing improvement method, soil-cement columns are installed in to an invisible ground, therefore it is impossible to visually confirm the circumstance of the constructions process. As the results, the inadequacy of construction data management and quality control of the constructed soil-cement columns may happen following re-construction of the columns, and structures failures/damages in some cases. By incorporating the Information and Communication Technology (ICT), authors have invented and developed a system to visualize the construction process of the deep mixing work in real-time, namely “3D Pile Viewer”. This system consists of two functions that are the positioning guidance and the visualization of the construction information. The former has been developed by using the combination of the Global Navigation Satellite System (GNSS) or the Total Station (TS), and the tilt sensor. The latter is to create three-dimensional model of all information during construction such as depth, electrical current value, amount of slurry, rotation speeds, etc., then sharing via internet. By introducing the newly developed system to various actual construction sites Japan and oversea, the practical performance of the system and its advantages have been confirmed.

Keywords: Deep mixing method, Soil-cement column, Information communication technology, Construction information modelling, 3D Pile Viewer (3DPV).

1. INTRODUCTION

Developing new infrastructure on a soft ground often faces many difficulties. To ensure the stability of the structure, reduce the large settlement, and mitigate liquefaction, the soft ground is normally required to strengthen. Among numerous soft ground improvement methods have been developed and applied worldwide, the cement deep mixing method that is a deep in-situ soil stabilization technique using cement as a binder is one of the most effective method. This method was mainly developed and practiced in Japan and Nordic countries until the end of the 1980s, but became very popular over the world recently [1].

Generally, the method consists of a deep mixing machine and a binder plant. The deep mixing machine is composed of one or several mixing shafts with a motor and gear box are installed at the top, and a set of mixing blades are mounted at the bottom. As for supplying cement slurry, a swivel joint is installed at the top of the shaft(s) for slurry supply and set of outlets is made at the bottom for binder injection. A mixing execution procedure ordinarily includes penetration of the mixing blades into the ground while rotating the mixing shaft(s) until designated depth, and then withdrawal of the mixing blades to the ground surface, the slurry could be injected to the ground during the penetration stage or withdrawal stage, or both. After one execution, a column shaped of treated soil-cement is constructed in the invisible ground. When implementing the construction work, the stabilized soil-cement columns must be installed to satisfy both geometric plan including location, depth, verticality, and the quality specified in the design. In order to ensure that operational parameters such as penetration and withdrawal speeds, rotational speed, amount of slurry and current value must be monitored and displayed continuously in control room and cabinet of machine during soil-cement installation [1]. However, those quality control parameters could be evaluated only after finishing working day and limited inside the construction area. If the construction parameters are properly recognized, displayed, shared, and evaluated in real time among related parties, then get the feedback immediately, the failure of column installation could be early fixed and prevented from repetition. Furthermore, a great amount of labor is required to collect the necessary information from a huge amount of numerical data to properly evaluate the construction process and then make the daily report.

On the other hand, the application of Information and Communication Technology (ICT) become very popular recently in the construction industry. Ehab and Ali [2] divide the application of ICT in the construction industry into 10 categories. There are techniques to input the design data into the construction machines, then using these data for guidance or controlling the machines have been developed and applied in the practices [3-4]. Additionally, the Japanese Ministry of Land, Infrastructure, Transportation and Tourism (MLIT) has been positioned "1st for the productivity revolution" from 2016 onward, and has begun efforts to promote "i-Construction" to improve the productivity by incorporating ICT into all processes of construction including investigation, survey, design, construction, inspection, maintenance and so on [5]. In which, the ground improvement work by the deep mixing method is not out of the scope.

Based on the above-mentioned background, we have invented and developed a system called "3D Pile Viewer" [6] that is able to visualize all operational control parameters in three dimensions and share real-time information among related parties even during the execution. This paper will introduce configuration of the system and its up-to-date practical application on construction sites, both in Japan and oversea.

2. CONSTRUCTION INFORMATION VISUALIZATION SYSTEM (3D PILE VIEWER)

As shown in Fig.1, the system has two main functions which are (1) positioning guidance and the (2) three-dimensional data visualization.

2.1 Positioning Guidance Function

The function is configured by using Global Navigation Satellite System (GNSS) or Total Station (TS), and tilt sensor measurement data to ensure the soil-cement columns are installed correctly as per the geometric plan as in the design, and the verticality is within the specification. At the beginning, three-dimensional geometric designed data of the columns including coordinates, depth, and diameter are registered into the system, then positioning work of every column is guided by GNSS or TS, and its verticality is controlled by tilt sensor during the construction process. Fig.2 shows the deep mixing machine attached with the facilities and instruments, two GNSS receivers are installed at the top and one tilt sensor (2 axes) is set at the bottom of the leader, and one computer and data communication antenna are mounted in cabin. During the construction execution, the current position of casing rod(s) or mixing shaft(s) is displayed in comparison with the pre-registered designated position, and the other operational parameters are also presented in the computer monitors located in both cabin and control room, an example is shown in Fig.3. In which, the blue circles filled with green are designed position of the soil-cement columns, while the red circles are the position of mixing shafts at the time of the execution. The function is not only allowing to avoid geometric miss-installation often caused by human errors but also monitoring the verticality of the column instantaneously.

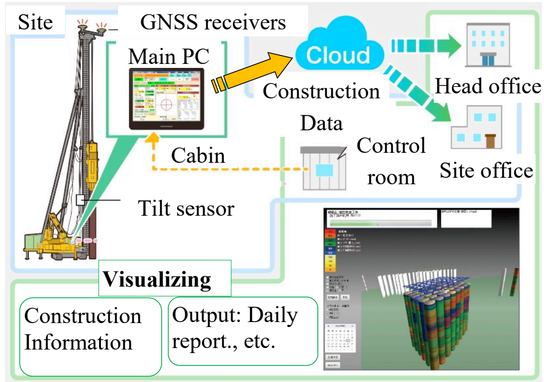

Fig.1 Configuration of the system

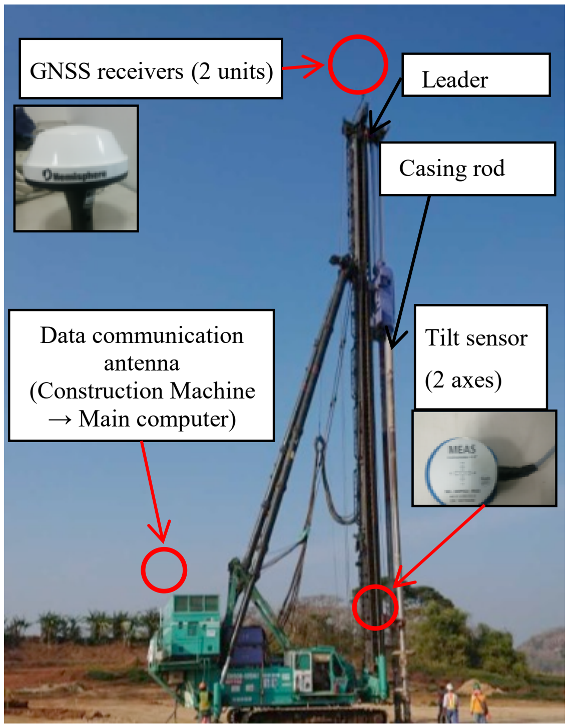

Fig.2 Construction machine with attached facilities and instruments

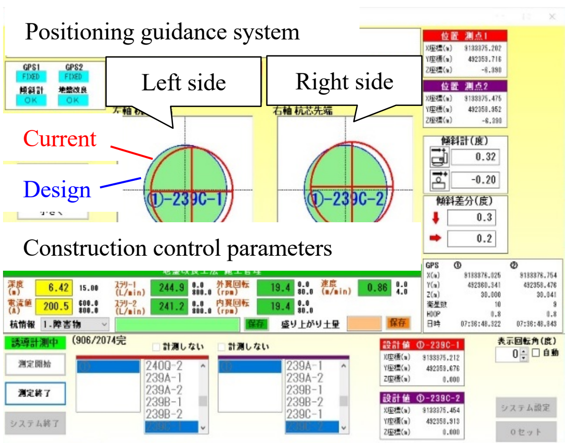

Fig.3 Monitor screen in the machine cabin

2.2 Information Visualization Function

The second function of the system allows three-dimensional visualization and immediately evaluation by seeing the kinetic measurement construction management data such as penetration/withdrawal depth, velocity, discharge amount of slurry, rotation speed of mixing blades, current value generating in the motor, ground properties, etc. In the meantime, the information is uploaded in to a Cloud from the main computer set up in the control room via internet. Consequently, all the construction measuring information are shared in real time among the parties related to the project. An example of the visualization screen is shown in Fig.4, in which, the soil-cement columns are displayed in three-dimension on the left side. All the columns have been geometrically arranged conforming to the designed layout, the measured information of the columns have been constructed and the done part of the ongoing column are categorized and represented in a range of color. The columns and a part of column that are in white color have not been constructed. On the right side, all the distribution with depth of the recorded data of any target column are plotted in corresponding graph. By incorporating the ICT such as the Cloud and internet services, the construction situation and the changing of the ground properties are clearly visualized and evaluated in real-time; therefore, it is able to provide instruction then obtain feedback instantly during the construction process.

3. APPLICATION AT THE CONSTRUCTION SITES

The above construction information visualization system has been introduced in several real construction projects in Japan, and oversea. The practical performance of the system is discussed here.

3.1 Katagishi High Coastal Embankment

As a restoration work after the Great East Japan Earthquake and Tsunami in 2011, an embankment of 800m long and 14.5m high as shown in Fig.5 is being built in Katagishi coastal zone in Iwate prefecture to prevent from the similar level of tsunami in the future [7]. A soft ground consisting of lose sand, and soft to medium silty clay is existing underneath the embankment.

In Fig.6, a complex ground improvement work including sand drain method and cement deep mixing method have been illustrated. The sand drain used at the center part to accelerate the consolidation settlement. The cement deep mixing method is performed at the embankment edges to increase stability, against liquefaction and to reduce settlement amount. In the design, the soil-cement columns with diameter of 2.0m are installed until maximum of 33.6m below the ground surface. The designed strength of the treatment soil-cement columns is different between sea side and land side. Moreover, the soil-cement columns were divided in to three patterns, the 1st pattern is a wall block type of soil column arrangement with 20cm overlapping up to the end of the upper lose sand layer as for liquefaction countermeasure, the 2nd pattern containing the columns are installed until the end of the upper silty clay layer against instability, and the tip of columns belonging to the 3rd pattern is set to reach the bearing layer to reduce settlement. Fig.7 illustrates the geometric arrangement of soil-cement columns.

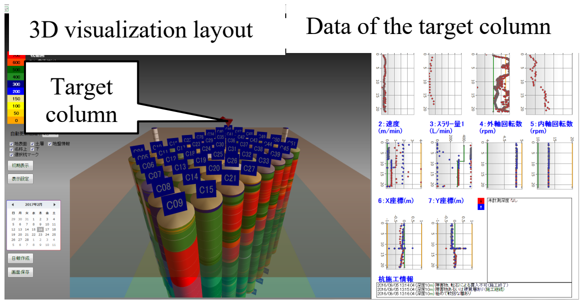

Fig.4 The screen representing the visualization function of the system

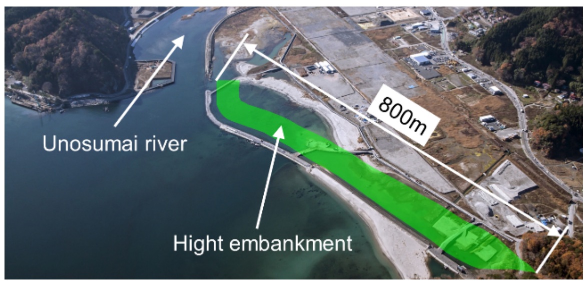

Fig.5 Location of the embankment

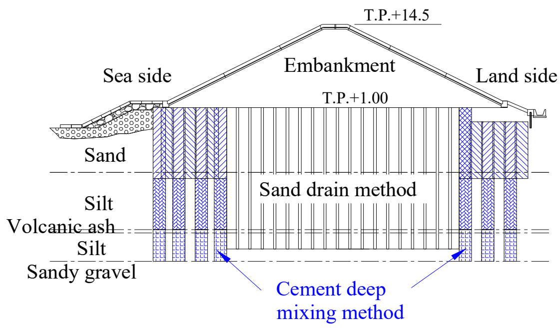

Fig.6 Typical cross-section of embankment

To conform to the above-mentioned design specification, Deep Cement Stabilization method (DCS) has been selected. The DCS method has advantages in construction of large diameter and extreme depth, as well as suitable for the ground containing sand and gravel layers [7].

As previously mentioned, the deep mixing work is quite complicated in this project. It is a challenge for controlling the quality during construction, therefore, the newly developed construction information visualization system has been introduced. Fig.8 shows the captured screen of the system presenting the construction information of deep mixing work in this project. Since the designed layout and depth of all soil-columns were registered into the system in advance, so it is easy to guide the soil-cement columns to install correctly, and to be ensure overlapping between the columns have been made. Besides that, the soil-cement columns have been constructed in high quality without any mistake relating to the designed strength because all construction parameters are monitored in real-time allowing the engineers to control, evaluate, and give further instruction instantly during construction stage.

3.2 Yokokan Minani-Sakae Interchange and Junction

This is a construction project of substructures of Yokokan Minani-Sakae Interchange (IC) and Junction (JCT) on the National Route No. 468 as shown in Fig. 9. The structure foundation is placed on a ground containing a high-water content peaty soil with N-value of 0 from the ground surface to 7.0m depth, under that layer is the soft silt layer up to 18.0m depth with N-value range from 0 to 2, and below that is mudstone with N-value lager than 50 considering as the bearing stratum. Boring investigation results are presented in Fig.10.

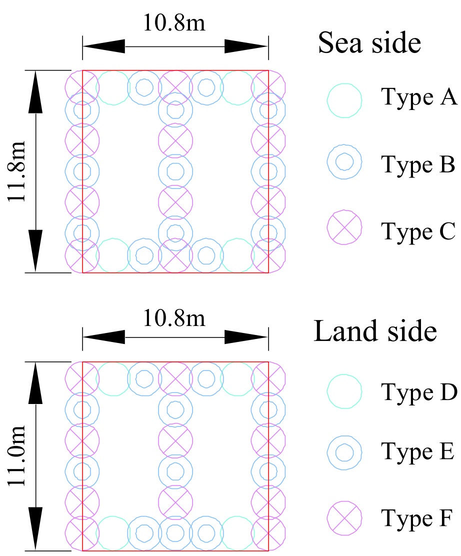

Fig.7 Layout of soil-cement columns

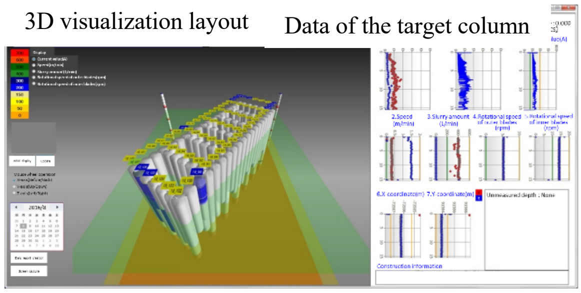

Fig.8 The screen of visualization system applied in the Katagishi embankment.

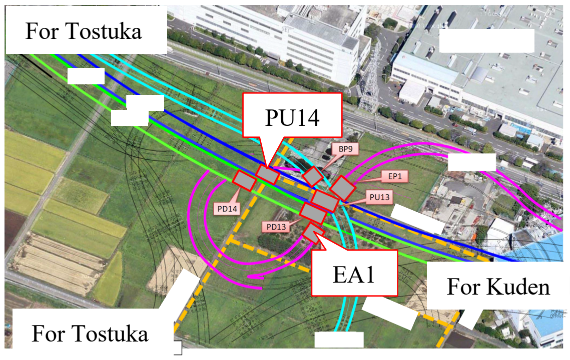

Fig.9 Plan view of the project.

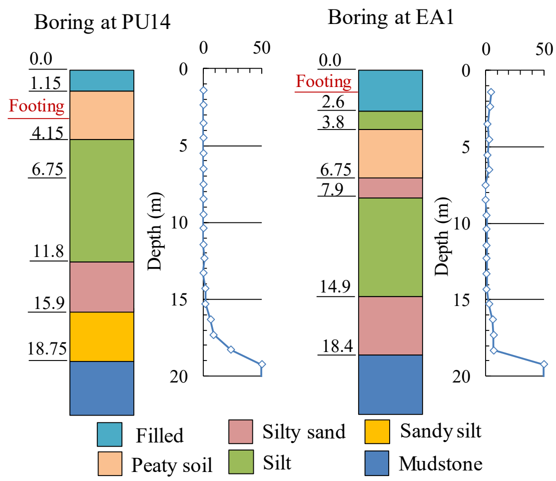

Fig.10 Boring investigation results

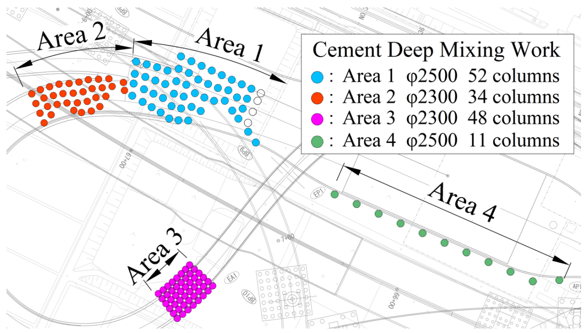

Fig.11 The ground improvement plan

In order to increase the stability and reduce the consolidation settlement of the ground under the embankment of the IC and ramp sections, the ground improvement by cement deep mixing (DCS method) was adopted. In Fig.11 and Table 1, the cement deep mixing work was designed to perform in four areas with different geometric arrangement, quantity and specification soil-cement columns. The overlap among the columns was particularly designed in the area 3. In the design, the soil-columns are required to install to the designate depth or approach the Mudstone stratum. The penetration depth where the current value of motor is over 700A, or speed of the penetration is 10cm/minute is judged as the bearing stratum.

To comply with the design and the judgment specification, it would be not easy and takes time and effort to manage quality during construction process when applying the conventional construction management method, because the construction process is required to control uninterruptedly with high accuracy. For this reason, the new development construction information visualization system was introduced to overcome the difficulty as well as enhance the construction control more reliably and efficiently. The application of the system, for instance, is presented in Fig.12. It is clearly seen that the deep mixing work had finished in the area 3, is ongoing in the area 4, and have not started in the area 2 and 1 yet. In addition, when the measurement current value data is chosen to illustrate in the three-dimensional screen, the parts having current value larger than 700A occur not only at the bottom but also in the upper parts of many columns. According to the specification, the construction of those columns might be ended shallowly. However, when that abnormal high current value was shown in the construction information visualization system the previous soil investigation data and others related information are checked immediately. After that, the inhomogeneous ground strata were confirmed, then resulted in continuation of the improvement works in those columns until the designed depth.

In conjunction with visualization of the construction information, a formula converts current value measured during construction to the N-value was included in the system to instantaneously estimate the N-value of the ground at the point where the soil-cement column installation was implemented. The conversion formula is established by doing statistical analysis on the soil investigation boring data and the construction information of the test column nearby. The conversion has been validated for the ground consisting of peaty, clayey, and silty soil [6,8].

Through this project, the accuracy of the system was confirmed by comparison with the conventional management method, the geometrical installation deviation due to human error could be prevented, and the construction execution could be smoothly carried out providing that all the quality control information is visible in real-time. On the other hand, for the 1st time it came into notice that the data communication did not operate normally due to orientation of the construction machine and the antenna. The shortcoming was addressed properly confirming the alignment in the setting manual.

3.3 Wonogiri Multi-Purpose Dam

Recently, the construction of closure dikes is being implemented in Wonogiri multi-purpose dam in Center Java, Indonesia with the aim of reducing sedimentation that are dramatically increasing every year and might cause serious effects on the intake. The outline of the project is presented in Fig.13, the closure dikes are constructed to prevent sediments inflow from the Kudwan River into the Wonogiri dam reservoir and to discharge the sediment to the downstream side via the new flushing spillway. The top elevation and the height of closure dikes are EL+140.0m and approximately 7.0m, respectively. Since the foundation of the closure dike A mainly consists of very soft to soft clay, silty clay sediment deposited in the dam reservoir, the ground improvement by the Cement Deep Mixing method (CDM) is applied to secure stability against sliding and consolidation settlement. The cement deep mixing machine for on-land works having two mixing shafts is adopted in this project.

Table 1 Quantity and specification of soil-columns

Location	Diameter (mm)	Design strength (kN/m^2)	Length (m)	No. of columns
Area 1	2500	600	18.5	52
Area 2	2300	600	17.7	34
Area 3	2300	1000	18.7	48
Area 4	2500	600	19.5	11
Total				145

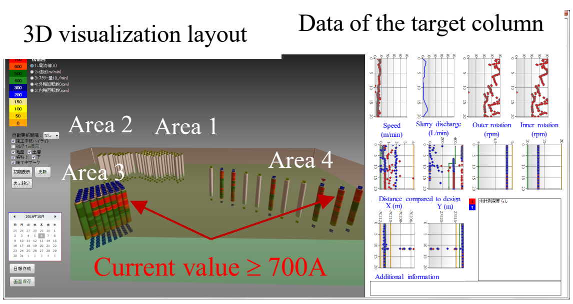

Fig.12 The application of the visualization system

The layout of the soil-cement columns and longitudinal profile of closure dike A are shown in Fig.14. The improvement ratio of 32.0% was required resulting in more than 5000 soil-cement columns are necessary to be installed. Because the depth of soft clay layer varies from 0.0 m to 24.0m in longitudinal section, the largest depth of soft clay layer is at the center of the closure dike A, and it reduces toward both left and right sides. Therefore, the improvement depth was designed from 6.0m to 24.0m corresponding to the changing of the soil profile. The typical cross-section of the deep mixing soil improvement is shown in Fig.15.

In addition to the ordinary operational parameters, the soil-cement column finished depth that is embedded 0.5m into the bearing layer must be strictly controlled in the construction process. In general, the bearing layer is specified when the current value is larger than 300A continuously for at least one minute. To deal with that high criterion, the newly invented and developed three-dimensional construction information visualization system is introduced to the project.

Because of the overseas project, is not convenient for engineers to visit the site frequently. Therefore, the engineers calibrated the GNSS system, sensor, installed the system, trained local staffs, and confirmed the operation at the first visit. After that, the system was operated by the local staffs and supported by the engineers via remote-control technology.

Fig.16 is an example of the capture screen of the system, in which, only the soil-cement columns belonging to the section 267 are chosen to display. Although all the columns in the section were designed to end at the same depth, the different finished depth of each column was constructed actually in reality is clearly recorded and presented. Moreover, abnormal increasing of electrical current value at middle of 10 columns in the right side was recognized while it did not occur in the left. If the construction visualization system had not been adopted, those columns in the right would have been judged to end at the middle. However, similarity to the Yokokan Minami-Sakae IC and JTC, the inhomogeneous geological condition was evaluated immediately, and then the construction process continued until reaching the real bearing stratum. The additional two borings positioned in each side were carried out instantly to clarify the abnormality. The boring investigation results as illustrated in Fig.17 indicates that there is a thin layer of dense silty sand to gravely sand with N-value of 30 exists at 5.0 to 7.0m deep.

The advantage of the construction information visualization system incorporating ICT could be confirmed successfully through this project. The construction progress and change in bearing layer depth, as well as the alteration of soil profile were easy visualized and shared among the involved parties in real-time via internet and the Cloud service. On the contrary, the issue in the operation of the system and sharing (uploading/downloading) data due to huge number of soil-cement columns and the internet environment is not fast enough as in Japan have been found. Additionally, it is barrier to local staffs operating the system because only Japanese language version is available at the current state.

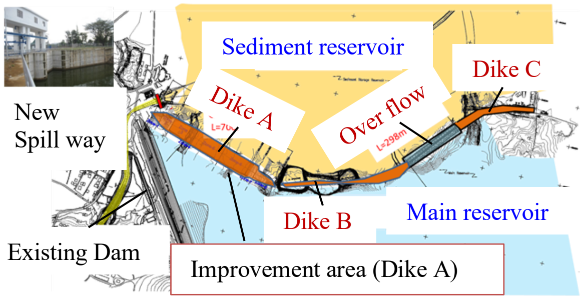

Fig.13 Outline of closure and overflow dikes in Wonogiri Multi-Purpose dam.

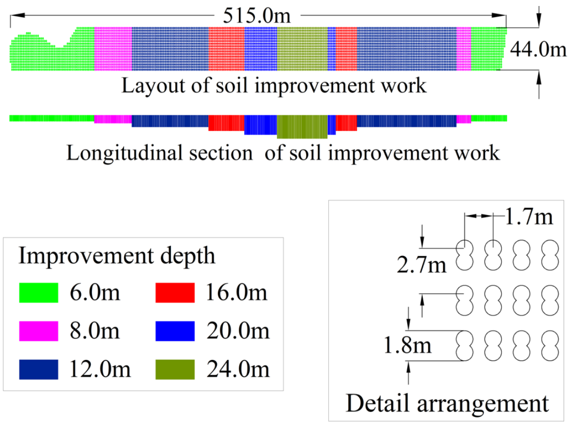

Fig.14 Layout and longitudinal profile of the soil improvement work in the closure dike A.

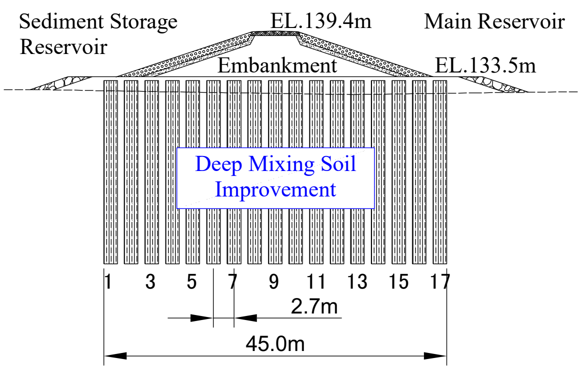

Fig.15 Typical cross-section of the closure dike A

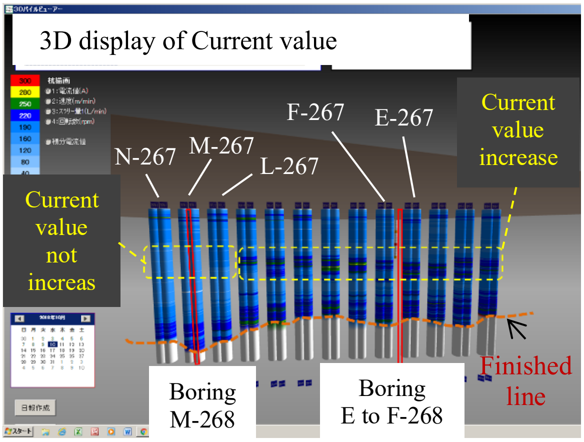

Fig. 16 The screen capture of the system

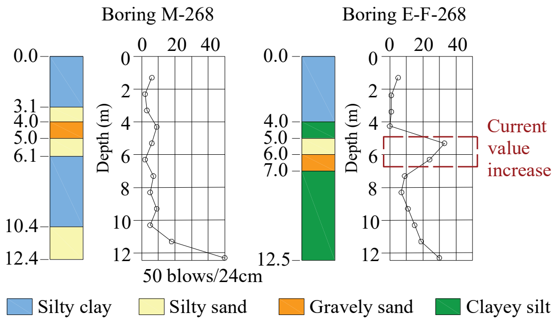

Fig. 17 Soil profile at the section 267~268

4. CONCLUSION

By actively introducing ICT to develope the three dimensional visualization system for the deep mixing method, then applying in the real construction sites, the following advantages can be acquired.

1. The quality magament parameters/information obtaining during the construction process is visually displayed in three dimension and sharing in real time making it more easy to understand the construction situation and the alteration of the original ground condition to compare with conventional magament method.
2. It is expected that accurancy and efficiency of the construction management will improve. The human errors can be minimized and amount of labor for making daily report has been reduced drastically.
3. It raises the awareness of the contractor regarding the quality control and management, results in providing highly reliable products.

However, some shortcomings still remains in the application at the actual construction sites. For example, the system needs to improve to operate smoothly when large amount of treated columns are registered, and operating in the weak internet enviroment. Futhermore, the location of the tip of the column is calculated using measurment data of the tilt sensors attaching on the leader with the assumption that the leader and the mixing shaft(s) are integrated based on the position leader on the ground surface. In reality, there is a certain play between the two, and as the depth increases, there is a possibility that the deviation from the measured value increases.

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