Investigation of Efficiency and Labor Saving by Utilizing ICT in Ground Improvement Work

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ABSTRACT

In Japan, i-Construction using ICT has been executed since April 2016 as a way to increase efficiency and save labor. ICT has been introduced as construction control by earthmoving and paving work, quality as-build management, volume management, compaction management and construction support by machine control and guidance in backhoe, bulldozer and motor grader. In the future ICT must be introduced and applied to the construction of foundation work strongly linked to the ground and of ground improvement work etc. in order to perform civil engineering works more efficiently with less labor. In this thesis, we introduce the construction management method in ground improvement work as a countermeasure against soft ground with many applications in Japan, and examples of construction support by ICT, and ICT in the future ground improvement work.

Key words: *Soft ground, Soil improvement, Management method, ICT*

1. Introduction

Embankments, which are one kind of earthwork structure, are constructed on soft ground, and the countermeasures are necessary. The present soft-ground countermeasures often use ground improvement technologies that apply hardening agents such as cement in order to cut costs and shorten work periods. The deep mixing method, a ground improvement method which uses hardening agents, achieves high strength by strengthening improved bodies and lowers cost of construction by lowering the improvement ratio. But lowering the improvement ratio in order to further cut costs and shorten the work period of ground improvement increases unequal settlement of embankments, resulting in it becoming more difficult to ensure stability of earth-work structures. Therefore, at work sites where soft ground countermeasures are needed, combining the deep mixing method with the sand mat method or the geotextile method under embankments and other earth-work structures often reduces the quantity of unequal settlement. The Public Works Research Institute has proposed compound ground improvement technology that combines the surface mixing method which is used to ensure trafficability with the deep mixing method as a way to control unequal settlement.

This paper reports on a survey of documents conducted to clarify construction machinery and construction methods which would benefit from the compound ground improvement technology, in order to clarify measurement items and control methods needed when executing the shallow and deep mixing methods already being executed in Japan. The paper also introduces examples of construction management methods based on mixing in hardening agents and ICT based construction support found in the results of the survey, and describes methods of using ICT to further improve efficiency and save labor in future ground improvement works.

2. Ground improvement technology

Many methods of executing ground improvement technology have been developed to achieve various required effects. In recent years, many consolidation methods using hardening agents to cut costs and shorten work periods in addition to achieving total settlement reduction effects have been adopted. The deep mixing method, which is one consolidation method, is often adopted as a soft ground countermeasure in anticipation of it providing secondary effects in addition to the total settlement reduction effect. Compound ground improvement technologies presumably reduce unequal settlement of embankment structures by combining the surface mixing method with the deep mixing method.

Present technologies related to the deep mixing method and the surface mixing method which are now in use, and to the medium mixing method which is executed at depths between the depths where these 2 methods are executed were surveyed. **Fig. 1** is a schematic diagram showing differences between the construction depths of these three mixing methods.

The deep mixing method is a technology used to build improved bodies by stirring a hardening agent with or spraying a hardening agent onto in-situ ground. Mixing methods are categorized as mechanical mixing using mixing blades, as spray mixing which sprays a hardening agent, and the mechanical mixing plus spray mixing method which combines the former two methods. The spray mixing method basically uses a slurry type hardening agent, but mechanical mixing can also use powder type hardening agents. The improved body shape is columnar, but is also executed as pile improvement or block improvement. So mechanical mixing or spray pipes are often executed as double or triple methods in order for the improved columns to overlap, and the construction depth is generally down to about 50 m.

The surface mixing method is executed in order to improve trafficability. Mixing methods are categorized as the in-situ mixing method which is mixing in in-situ ground, and the removal mixing method, which is transporting materials from in-situ ground, mixing it, then returning it to the site. Hardening agents are slurry and powder, similarly to the deep mixing method. The powder method is executed by mixing in the powder with a stabilizer or back-hoe bucket mixer. The slurry method

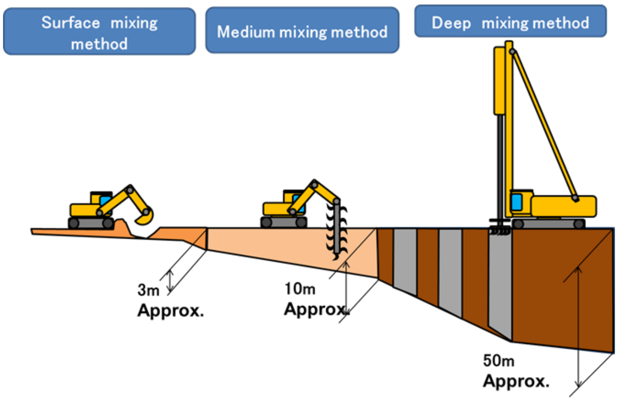

Fig. 1 Differences between various mixing methods based on construction depth

Table 1. Number of technologies surveyed

Method categories	Method types	Number of technologies
Deep mixing method	Mechanical mixing method	33
	Spray mixing method	31
	Mechanical mixing + spray method	18
Surface mixing method	Mechanical mixing method	13
Medium mixing method	Mechanical mixing method	24
	Mechanical mixing + spray method	1

Table 2. Construction machines and improvement depths

Method categories	Base machines	Number of technologies	Improved depth (m)	
			Min.	Max.
Deep mixing method	Boring machine (stationary)	36	20	80
	Pile driver	28	22	55
Surface mixing method	Backhoe	8	1.8	5
Medium mixing method	Backhoe	10	4	13

means mixing by a rotary or trencher installed mainly on backhoes.

The medium mixing method is a technology that deepens the construction depth of the surface mixing method by extending the component that supports the trencher or rotor. There is also a technology that combines a spray mixing technology that is executed by the deep mixing method and which is a hybrid of the shallow mixing method and deep mixing method.

Three methods now used as mixing method technologies were abstracted as 120 technologies and surveyed and categorized based on the surveyed documents. **Table 1** shows the surveyed technologies by method. **Table 2** shows the principal construction machines and improvement depths used for each work method. Backhoes have often been used for the surface mixing method and the medium mixing method. The maximum construction depths of construction machines are 22 to 55 m for pile-drivers and 20 to 80 m for boring machines. And the maximum construction depths for surface mixing backhoes are from 1.8 to 15 m, and for medium mixing backhoes are 4 to 13 m. The applicable soils for mixing technologies are sandy soil, gravel, cohesive soil, humous, and sludge. Sandy soil (N<20) and cohesive soil (N<4) which have low N values can be executed by all the technologies. Humous and sludge can be executed by 60 technologies, which are about half of all technologies, and gravel can be executed by 20 of the technologies.

3. Construction management methods

Construction management in ground improvement work is executed in conformity with work progress control standards and quality control standards for the ground improvement – consolidation method as powder spray mixing works, high pressure spray mixing works, slurry mixing works, slaked lime pile works in Civil Engineering Work Construction Management Standards Draft announced by the Ministry of Land, Infrastructure, Transport, and Tourism.

Work progress control standards are set with their measurement items as "standard height", "position/interval", "pile diameter", and "depth". Under quality control standards, "strength" of the improved body is set as the result of an unconfined compression test. "Strength" is an item needed to perform particularly strict control to improve soft ground. Quality control standards specify that, "testing is done a total of 3 times—once each at the top, middle, and bottom—of each improved body", requiring that strength be ensured uniformly in each improved body. So construction management is necessary along with elements needed to ensure not only the "strength", but also uniformity of an improved body. Construction management items necessary for construction quality are presumed to be the six items: "standard height", "position/interval", "pile diameter", "depth", "strength, and uniformity". The standard values of work progress control standards are shown in **Table 3**

Table 3. Standard values of work progress control criteria

Measurement items	Standard values	Measurement criteria
Standard height ▽	-50mm	100/1 location Less than 100, 2 locations measured At 1 location, four measurements
Position/interval w	Within D/4	
Pile diameter D	Design value or higher	
Depth L	Design value or higher	All L＝ℓ1－ℓ2 ℓ1: depth of tip of improved body ℓ2: depth of crest of improved body

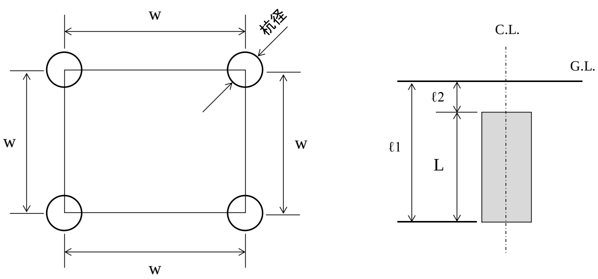

Fig. 2 Measurement locations of work progress control items

Table 4. Standard values of quality control criteria

Test items	Test method	Standard values	Test criteria
Unconfined compression test	JIS A 1216	[1] Test results of each specimen at least 85% of improved ground design strength. [2] Results of 1 test at least improved ground design strength. And 1 test is shown as the average value of test values of 3 specimens.	Less than 500 improved bodies, 3. And every 250 improved bodies above 500 bodies, 1 is added. A total of 3 tests--1 top, 1 middle, and 1 top bottom--are done on each improved body. But if the design strength varies in one improved body, it is 3 times for each design strength. In a case where site conditions, size etc. make it difficult to comply with the above, as instructed by a supervisor.

and work progress control item measurement locations are shown in **Fig. 2**. And the standard values of quality control standards are shown in Table 4.

4. Construction management items

Construction management items apply to 80 technologies—the 120 technologies surveyed as ground improvement technologies excluding similar technologies—and items which workers actually control using Construction management devices installed on construction machines were surveyed. Construction management items are categorized as material quantities including speed (m/s), pressure (Pa), time (s), quantity injected (m3) angle (º), and length (m) which are measured values, as confirmation of construction location and grounding as primarily measurement of change of current

Table 5. Cause-and-effect relationships of construction quality with each of the construction management

Content of execution control of machines		Cause-and-effect relationship of execution control items with execution quality	Related execution quality
Type	Execution control items		
Speed	Insertion speed, pull-up speed, creation speed	Controlling insertion, pull-up, and creation so they are within the specified speeds ensures the uniformity of the improved body by slurry mixing and improved body mixing.	Uniformity
	Rotation speed	Controlling mixer rotation speed so it is the specified speed or higher ensures uniformity of the improved body.	Uniformity
	Chain speed Cumulative length of chain	Controlling the blade cut rotations based on chain speed and cumulative length of chain of the trencher ensures uniformity of the improved body.	Uniformity
Pressures	Discharge pressure, super high pressure water pressure, air pressure	By controlling the slurry discharge pressure, super high pressure water pressure and air discharge pressure so they are at least the specified pressure ensures uniformity of the improved body.	Uniformity
	Pressure in the ground	Controlling pressure in the ground regulates and absorbs mud that is discharged, and reduces the impact of irregularities of the ground accompanying injection and mud discharge and ground settlement on the state of the ground and surrounding structures.	Others
Time	Spraying time, execution time, pull-up time	Controlling the quantity of improving agent that is injected based on injection time and quantity injected per unit of time (liter/min.) ensures the strength of the improved body.	Strength
Quantity injected	Total quantity injected	Controlling the quantity of improving agent (slurry) injected ensures the strength of the improved body.	Strength
	Quantity injected per unit of time	Controlling the quantity of improving agent injected per unit of time ensures the strength of the improved body.	Strength
	Quantity of admixture	Controlling the quantity of solidifying agent injected (kg/m3) ensures the strength of the improved body.	Strength
	Quantity of silica sand injected	Controlling the quantity of fine aggregate ensures the strength of the improved body.	Strength
		Controlling the quantity of silica sand injected obtains adequate ground excavation energy and ensures pile diameter D of the improved body.	Pile diameter
Angles	Verticality	Controlling the verticality of the improved body ensures the standard values of position and interval W in the work progress control criteria to the improved body depth.	Position/interval
	Oscillation angle	The oscillation angle of high pressure spray (spray angle) determines the shape of the improved body (related to work progress control)	Position/interval
Length	Insertion depth, creation length	Measuring the length (depth) of creation of the improved body controls the depth L of work progress control.,	Depth
Position	Execution position	Measuring the execution position controls the standard hight, position/interval, and depth L of work progress control.	Standard height Position/interval Depth
Grounding	Grounding on bearing stratum	Controlling current value, torque, and pressure during insertion ensures that the improved body reaches the bearing stratum.	Strength
Others	Rotation rate/mixer rotations	By controlling mixer etc. rotation speed ensures uniformity of the improved body.	Uniformity
	Air flow rate	By controlling the compressed air flow rate so it is at least the specified flow rate ensures uniformity of the improved body.	Uniformity

value of rotating parts and others (rotation rate, mixing frequency, air flow rate). Many ground improvement technologies measure the quantity of hardening agent that is injected or added, the penetration speed, and the rotation speed of mixing blades. And three construction management items are not only used for confirmation during construction, but also saved as construction records. Construction management items are also organized according to the cause-and-effect relationships with 6 items necessary in Construction management standards. **Table 5** shows the cause-and-effect relationships of construction quality with each of the construction management items which have been organized. Measurement data items related to the qualities of improved bodies, "strength" and "uniformity" are relatively numerous, while those related to work progress, "standard height", "position/interval", "pile diameter", and "depth" are few.

5. ICT based Construction management method

Construction management devices that are installed on construction machines can use measured construction management items to confirm "depth", "strength" and "uniformity" which are present work progress control and quality control items.

"Standard height", "position/interval", and "pile diameter" other than depth have not been confirmed under construction management items that can be measured by construction management devices that are installed on construction machines. So under present circumstances, these must be confirmed by repeated measurements. And depth can also be measured and verified by controlling the rod penetration status using construction management devices, photographs and so on. In the future, it will presumably be possible to perform construction location and a work progress control by installing measurement devices on construction machines. As this method, it is possible to propose the use of computerized construction devices which are used for machine control or machine guidance. The surface and medium mixing methods mainly use backhoes as the base machine, so it is thought to be possible to achieve work progress control using computerized construction devices.

Under quality control standards, it is necessary to confirm by again performing unconfirmed compression testing of the improved body that has been built by the construction. As the strength test, only 3 of every 500 improved bodies are tested. It is, therefore, difficult to clarify the state of the entire construction. In the future, it will be possible to estimate the strength of improved bodies that were not strength tested by comparing construction management items which are related to strength with the results of strength testing. And it is also thought that it will be possible to also estimate the state of construction management with regards to “uniformity” which is related to “strength” by comparing data obtained by measurement of the improved bodies tested by unconfirmed compressive testing with measurement data for other improved bodies. Construction management items are the information with an important role in confirming the construction quality of all improved ground, so it is believed that it is necessary to collect measurement data as supervision items.

Among ICT based Construction management methods for ground improvement, three are registered as New Technology Information Systems (NETIS).

The first technology is a system that guides ground improvement machinery to the center of the improved body while executing the deep mixing method. With this technology, a GNSS antenna is installed on the construction machine and the operator sitting in the driver’s seat monitors, indicates, and guides the machine to the center of the pile to be executed. Figure 3 shows a sample screen of the guidance system. This technology has only a guidance function, but by measuring the construction location and calculating its relationship with the pile center it can measure the work progress items, “standard height” and “position/interval”. Therefore, if a method of measuring “pile diameter” and “depth” were

Fig. 3 Sample screen of the guidance system

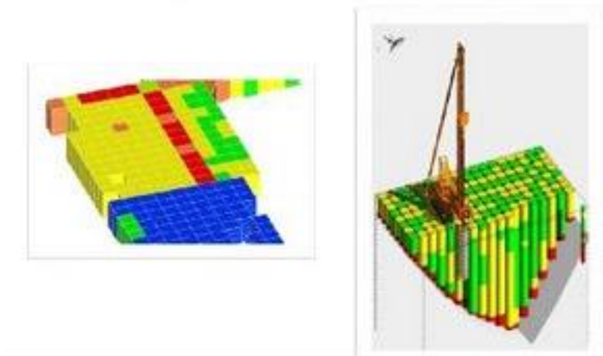

Fig. 4 Example of three-dimensional visualization

added to it, it could also automate the measurement of work progress.

The second technology is a system that three-dimensionally visualizes a series of information from planning deep and medium mixing to construction results. **Fig. 4** shows an example of three-dimensional visualization. Using this system, in addition to the construction location that was measured, the quantity added, the rotation speed, grounding of the bearing stratum (current value) which are measured and collected by Construction management devices, and which were formerly transcribed on paper, are displayed on screen in three dimensions. It is, therefore, possible to visualize the work progress items, or “uniformity” of the state of the work in real time to easily confirm the state of the work. But, this system can only be applied to specified ground improvement methods, so it will be necessary to eventually be able to apply the same method with other ground improvement works.

The third technology is a system that adds a function that visualizes and records construction information to the

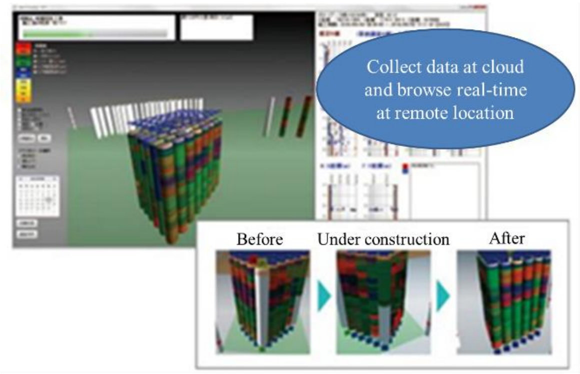

Fig. 5 Example of construction management screen

function that guides to the center of the improved body in the first technology. Construction management information permits acquisition of the construction location, depth, slurry quantity, and ground shape. This system also permits the sharing of Construction management information outside of construction sites through a network. **Fig. 5** shows an example of construction management screen.

6. Conclusion

The ICT Introduction Council that discusses i-Construction reports on "the application of construction history to the supervisory inspections" as a future initiative in March 2018. As object work types, taking ground improvement work as a representative work type, it achieves work progress control and quality control based on the construction machine history data. And similarly, it discusses the rationalization of supervisory inspections from remote sites using "remote construction such as staged confirmation etc. through the use of high speed communications".

The Public Works Research Institute surveyed present ground improvement technologies in order to clarify construction machines or construction methods that are required by compound ground improvement technologies. We believe that it will be possible to perform ground improvement works more efficiently with fewer workers in the future by using computerized construction devices installed on backhoes and technologies registered in NETIS. First, as more efficient work progress control, it is essential to define demanded functions as a system which, instead of applying post-construction measurements as in the past, can use position information obtained from computerized construction devices on construction machines to measure the "position/interval", "standard height", and "depth" of improved bodies. And in order to perform supervisory inspections more efficiently, we want to prepare work process control instructions using ICT and to perform supervisory inspections remotely using network functions.

In addition to more efficient work progress control, we also want to provide an environment in which it is possible to obtain construction management items that are measured by construction machinery by defining data exchange standards. Data for construction management items which have been obtained can be treated as big data by organizing the relationship of ground data obtained during planning or before construction boring data with data for "strength" based on unconfined compressive testing done after construction. Big data for ground improvement work can be counted on to be used for theoretical analysis such as the establishment of a method of estimating the N-value of in-situ ground. And the results of theoretical analysis of big data can realize automatic operation by optimizing the quantity of hardening agent injected and the penetration speed, which in turn, will permit more efficient construction management by fewer workers.

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