INTERNATIONAL SYMPOSIUM ON
DAMS FOR A CHANGING WORLD
-Need for Knowledge Transfer across the Generations & the World
Kyoto, Japan June 5, 2012

Introduction of Information and Communication Technology to Main Body Construction of Tono Dam

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ABSTRACT:
In the Tono dam construction project, the river diversion channel and the construction road had been unfortunately damaged by flood, forcing the work on the main dam body to run approximately 3 months behind the schedule. In the midst of the situation where the construction period must be shortened, the information and communication technology (hereafter called the ICT) was introduced for management of filling works with the intension of strengthening the system of work supervision by ensuring efficient progress of construction as well as consistent quality of work. This paper reports the findings from the discussion on the benefits possibly gained from the introduced ICT as well as on supervisory reinforcement and reduced frequency of field tests that should result from the foregoing introduction.

Keywords: information and communication technology, ICT, supervision of construction, and rock-fill dam

1. INTRODUCTION

Construction of Tono dam is under way in the Fukurogawa river upstream area in the river system of Sendaigawa river that runs through Tono, Kokufu-cho, Tottori City. It is the first rock-fill dam of its kind to be built under the jurisdiction of Chugoku Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism with a dam height of 75 m, a dam volume of 2,110,000 m^3, and water volume in the dam lake amounting to 12,400,000 m^3.

Filling works of the dam main body was completed on October 22, 2010 and the initial impoundment was started on March 3, 2011.

The maximum target water level of 194.50 m was reached in the reservoir (Fig. 1) on April 5, 2011, while the initial impoundment was completed on April 25 of the same year. Concurrently, it was confirmed that both the dam and the reservoir had an acceptable level of safety. Although the project has progressed satisfactorily as mentioned above, there was a cumulative rainfall of 185 mm in July 2007 in the catchment area of Tono dam and the resultant flood damaged the river diversion channel and the construction road. This disaster necessitated a restoration work on the damaged channel and road, entailing an interruption of the main body construction for about 3 months.

In such a case, the traditional field tests on compacted fills might have impeded the progress of construction still further. Furthermore, there was a shortage of technical staff in charge of the main dam body construction, with their members about one-third of those stationed at the normal offices under management of the Ministry although the project should be promoted speedily by putting in even extra night work hours. For

Figure 1. The maximum target water level

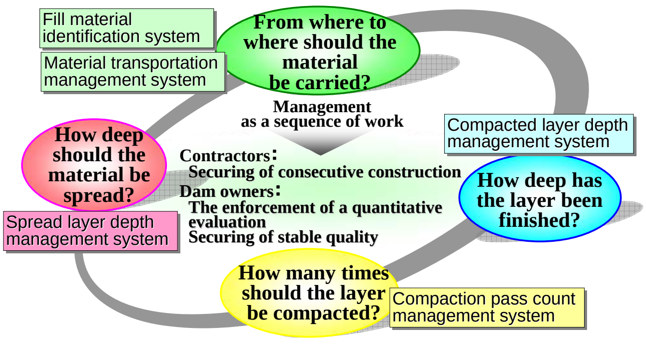

Figure 2. The ICT introduced

such an understaffed office, work supervision and inspection was not an easy task.

Under these circumstances, we introduced 5 construction management systems based on the ICT to supervise the main body construction. (Fig. 2) They were expected to be useful also on the part of the dam owners, who could determine easily whether or not the workmanship meets the specifications without performing strict in-situ supervisions. Therefore, the foregoing systems have been further improved and applied so as to lighten the burdens of the supervisors and enhance their ability at the job site.

2. OVERVIEW AND BENEFITS DERIVED FROM ICT INTRODUCED

The following is a description of the overview and benefits possibly derived from the ICT which was introduced into the main body construction of Tono dam.

2.1. Fill Material Identification System (GPS Method)

We installed a GPS terminal on each dump truck which carries the fill material to the site. Loading and unloading locations (coordinates) and the time of day are recorded while the relevant jobs are done by pressing the GPS terminal buttons that are discriminatively arranged in accordance with the sort of materials.

Forms (Fig. 3) are then created by reference to the recorded data, enabling the personnel to verify that the appropriate material is being carried into the specific zone. The right-hand points on the form indicate the location where the rock I is loaded onto the dump truck, while the left-hand triangular points denote the location where the material is unloaded.

Introduction of this system proves helpful in verifying that the right material is handled at the right location. Furthermore, the fill materials become easily traceable since their loading and unloading locations are readily known.

At the dam construction site, 8 different kinds of materials, i.e., core, filter, rock I, rock 1', rock II, transition, riprap, and random zone, are properly zoned as shown in Fig. 4. It is essential to confirm that every kind of materials has been unloaded into the proper zones.

2.2. Spread Layer Depth Management System

Information on the position of the bulldozer is gained by the GPS receivers (Fig. 5) installed on the blade of the bulldozer operated for spreading work. On the on-vehicle monitor screen is indicated a difference in height between the design spreading position and the operating blade. All that is required for the operator is to move the blade up and down according to the instructions appearing on the monitor screen while moving the bulldozer back and forth. Since the spreading work is done at a given height without installing a fixed ruler, the time otherwise required for installing the ruler is saved, thereby making the job more efficient.

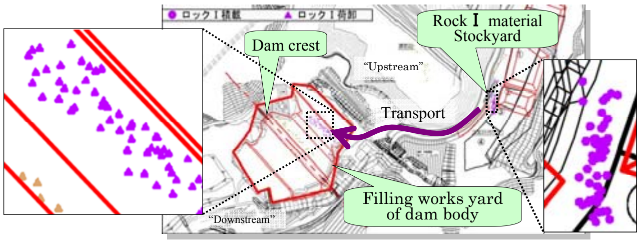

Figure 3. The form of Fill material identification system

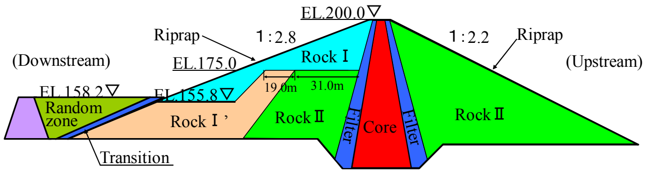

Figure 4 Typical cross section of Tono dam

2.3. Compaction Pass Number Management System

The locus of the vibrating roller is recorded based on the data acquired from the GPS receiver (Fig. 6) installed on the roller. Accordingly, the compaction pass number can be displayed in real time for each management block in the work area. A red-colored area at the center of the on-vehicle monitor screen indicates the location where the designated compaction pass number has been reached. Since the operator can do the job while checking the compaction pass number in real time, necessary compaction is no longer skipped, resulting in an enhanced operating accuracy.

Following completion of compaction, it can be confirmed whether or not the job has been done as specified, referring to the count stated on the form (Fig. 7) printed out of the system.

Blocks colored blue in the upper and lower areas of the form indicate the filter material on which the compaction pass number exceeds 6, while blocks colored brown at

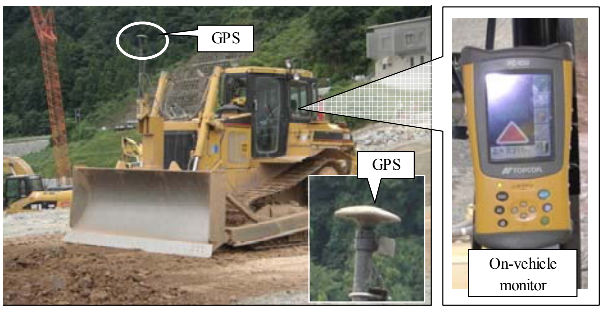

Figure 5. The work situation of spreading

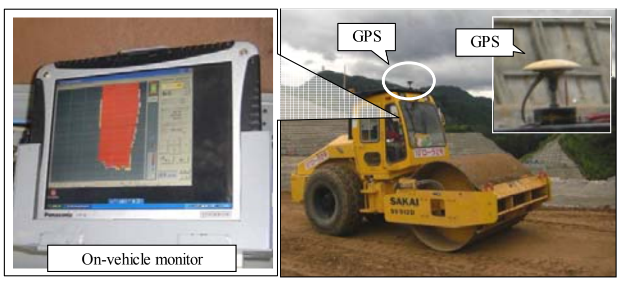

Figure 6. The work situation of compaction

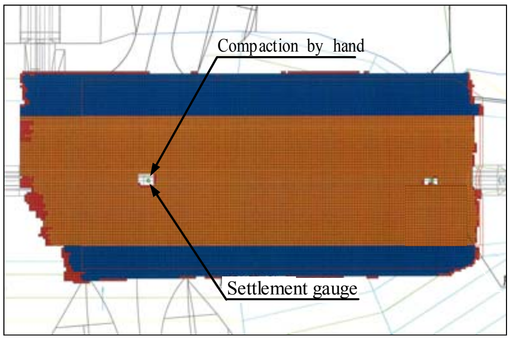

Figure 7. The form of Compaction pass number management system

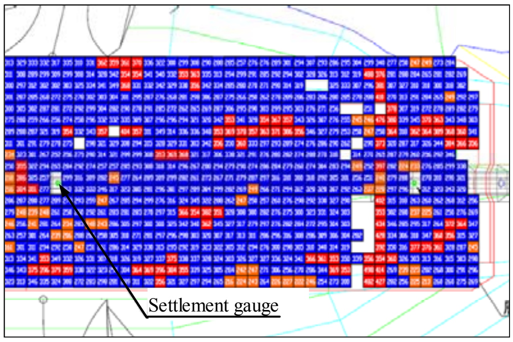

Figure 8. The form of Compacted layer depth management system

the center indicate the core material on which the compaction pass number exceeds 6 in count. Other red blocks indicate area where the compaction pass number is less than 6 in count.

Since compaction is placed under an areal management by use of the output form as described above, the level of compaction uniformity is kept higher than that in the traditional point-to-point field tests. In addition, the presence of the data on compaction passes for all layers concerned will reliably certify that the compaction was performed as specified for each layer.

2.4. Compacted Layer Depth Management System

Thickness of the compacted layer is computed by calculating the difference in elevation between the current and the previous layer by reference to the positional information obtained from the compaction pass number management system. The workmanship of compaction can be known from a finished thickness of the layer stated on the form (Fig. 8) printed out of the system.

On the output form, thicknesses of layers are mentioned using three colors: red for 350 mm or more, blue for 250 to 350 mm, and orange for 250 mm or less. That way of indicating the layer thickness on the form could facilitate the areal management of the layer thickness to be finished. Moreover, it could save the workload required for surveying the finished elevation upon completion of compaction. Additionally, the recorded data on thicknesses of all layers could prove that each layer has its finished thickness as specified.

2.5. Material Transportation Management System

The filter material amounting to approximately 160,000 m^3 in volume was required at the dam construction site. As the filter material, we decided to take advantage of excavated rock waste which occurred in other businesses because of shortage of sand and gravel from the riverbed of the site. It must be carried by sea from Mizushima Port, Okayama Prefecture, to Tottori Port from where it is sent by land to the site.

The dump truck that carries the filter material is provided with the GPS equipment by which the personnel could keep track of the traveling dump truck in real time, while watching the computer screen at the office. An emergency message from the office can be sent quickly to the monitors installed on the trucks.

In an emergency, necessary messages can simultaneously be sent to the monitors as many as 30 trucks a day. The drivers can be kept aware of importance of traffic safety.

3. BENEFITS DERIVED FROM INTRODUCTION OF THE ICT

Each element of the ICT system has advantages of its own indeed. When employed in a well-organized manner in a sequence of operations, the system could offer the following benefits.

3.1. Certification of Quality and The Size of Filling works

Details of the entire construction processes have become all clear to those concerned since the data on a series of operations, including material loading, transportation, unloading, spreading, compaction, and confirmation of layer depth of fill materials, can be recorded through simultaneous introduction and practical use of ICT.

Thus excellent quality and the size of filling works are ensured because of acquisition of all related data in an areal way as against traditional sampling inspection. Strict protection against corner-cutting manner of operation is another contributing factor in this respect.

3.2. Reduction in Workload of Supervision

Creation of the forms based on the foregoing data facilitates review of the history of operations, such as material transportation and compaction. The resultant operational transition to a spot survey at strategic points away from the conventional continuous supervision significantly relieves the supervisor of his workload. Now that necessary data can be collected during night work as in the day and that check based on the print-out form can be made afterward, even a small number of supervisors are sufficient for effective performance of their duty.

4. PROBLEMS WITH THE SYSTEM AND COUNTERMEASURES FOR THEM

It is true that ICT has some problems to be overcome although it gives us many benefits. The following is a description of such problems. The countermeasures for them are suggested at the same time.

4.1. Improvement on Precision of Spread Layer Depth

Variations in precision of the spread layer depth are supposed to have a large impact on the compacted layer depth in relation to the spread depth management system. It is expected that the compacted layer depth will be enhanced in precision by reinforcing the spread layer depth management system with the support of the GPS, such as mmGPS[1], which operates in combination with a laser-applied measurement technology capable of high-precision measurement of height.

4.2. Provision of Data Security

One of the problems that are posed in common among the fill material identification system, compaction pass number management system, and compacted layer depth management system is a falsification of the data or the system software.

Among approaches against data falsification is data acquisition in real time also by the hand of the dam owners. Such an acquisition could enable comparison with the data held by the contractors, possibly resulting in improvement of data security.

As to measures against the system software falsification, it is recommended that a third-party inspector (for tests and audit) be retained so as to prove the integrity of the system software.

5. REDUCTION IN THE FREQUENCY OF FIELD TESTS

The frequency of customary quality verifications (field tests after filling works) could be reduced since the quality of construction has improved due to the introduction of the ICT. In this connection, we first conducted a comparative study on the traditional work and the ICT-applied work with regard to the frequency of field tests. After that, we proceeded to discuss the feasibility of reducing the frequency at the site where construction of Tono dam was under way on the basis of the ICT.

5.1. Our View of The Frequency of Field Tests

While the dam main body is being built, compacted layers are subject to the tests at given intervals with respect to soil density and such to check the level of quality after filling works.

In the process of testing, there may be cases where the filling works must be interrupted for safety of the testing personnel, which retards the progress of the entire work. Such retardation could be avoided if the frequency of filed tests is reduced. Accordingly, it can be said that a given level of quality must be maintained after filling works for the work that should proceed without a delay.

Fig. 9 indicates the view of the frequency of field test. In the traditional work management system, materials to be used are first subject to tests to keep the required level of their quality and then work quality is ensured by inspectors who oversee the filling process (including transportation, spread, and compaction) where machines are used. As the final inspection in the two different areas mentioned above, field tests are performed after the filling works.

Visual inspection and the like are employed to check the workmanship following the sampling test of materials. Since the 100-percent test is not conducted, it is probable that materials or works of poor quality escape the inspector's attention by any chance. Therefore, the personnel in charge are considered to conduct the field tests to check the quality even by partially breaking the compacted layer that is a final product.

In contrast, the ICT system, once introduced, could allow the personnel to easily check if the workmanship of filling works done conforms to the specifications throughout the entire processes, meaning that the 100-percent test has become feasible.

Meanwhile, the technology that could make the 100-% test on the materials for filling works seems to still remain undeveloped.

Such being the case, it is reasonably believed that the ongoing field tests after the filling works cannot be omitted. Since the work quality verification method has significantly improved, the frequency of field tests may be reduced depending on the result. However, if the actual result is found to be below par, the current testing frequency should be maintained.

5.2. Discussion on The Frequency of Core Material Field Tests

Elements of the quality specifications for the core material include grading, in situ coefficient of permeability, in situ soil density (compactness and dry density), and ratio of water content. This paper describes the test results on the in situ density of the core material which is often tested at the site, thereby exploring the

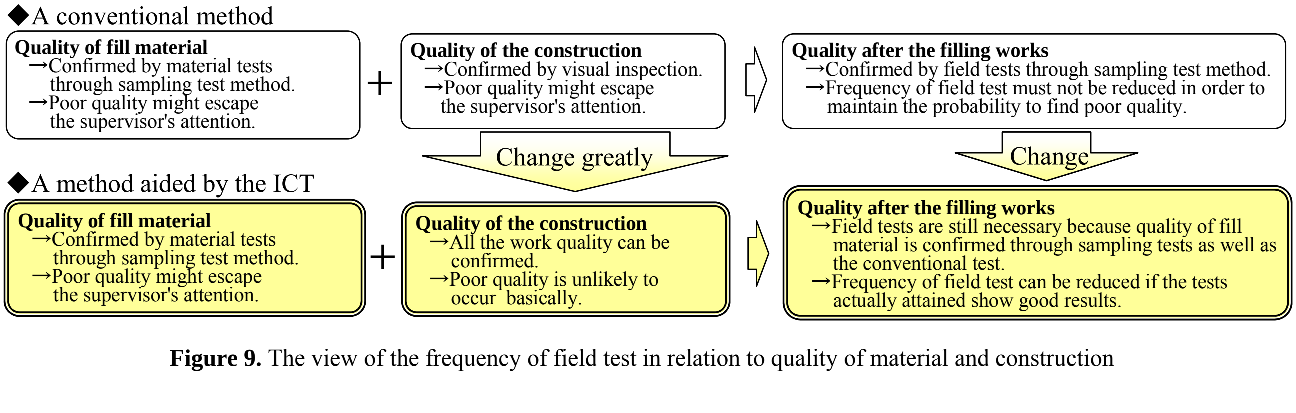

Figure 9. The view of the frequency of field test in relation to quality of material and construction

possibility of reducing the frequency of field tests. Histograms of the results obtained from the field test on density (compactness and dry density) are given in Fig. 10 and 11.

Quality specifications for the core material are: Value D of compactness ≥ 95% and dry density $\gamma_d \geq 1.60$ t/m^3. Whether or not the test results sufficiently meet the quality specifications will be determined according to the "figure of compliance with the specifications" which is defined by Eq. 1 given below. This figure indicates the extent to which the average value of the test results lies apart from the specification in terms of multiples of the standard deviation. The specification and the average value glowingly differ from each other as the figure of compliance increases, indicating that the test results are less likely to deviate from the specification.

If the frequency distribution of the test results is significantly near the normal distribution, the probability of failure in conforming to the specification is approximately 16% when the figure of compliance is 1. The probability is about 2.3% and about 0% when the figure of compliance is 2 and 3.

Figure of compliance with the specifications
(unilateral specification)
= (Average value - Specified value)
/ Standard deviation (1)

The core materials used at the construction site of Tono dam are a mixture of fine and coarse grains, with the coarse grains being composed of two different kinds of materials: grains collected from dam body excavation wastes and grains collected from quarry sites. Since a difference between the two could not be neglected, the evaluation based on Eq. 1 was made separately. As indicated in Fig. 10 and 11, the figure of compliance with the specifications is found to exceed 3 in virtually all cases (the probability of the test results deviating from the specifications is approximately 0%). This finding now leads us to presume with reasonable confidence that the frequency of field tests for the core material used at the Tono dam construction site can be decreased.

6. DISCUSSION ON RULES FOR REDUCING THE FREQUENCY OF FIELD TESTS

As to the process for reducing the frequency of field tests for the filling works, several management rules should be established with respect to the criteria for determining an allowable degree of reduction, defining the yardstick for restoring the initial testing frequency in cases where the collected data is found undesirable, and such. We have discussed some suggestions on such rules by reference to the existing specifications contained in the JIS (Japanese Industrial Standard) on quality control.

6.1. Official View of JIS Quality Control

In the section of the JIS Z 9015 titled "Sampling test standard on enumerated values", we find the view that the frequency of tests may be decreased when the product quality is considered to steadily stay good. There are two reduction means available: "lenient inspection" and "skip lot"[3),4)].

The lenient inspection is intended to conduct a sampling test, using a smaller sample size than usual. On the other hand, the skip lot refers to the test method where whether or not the specific lot of samples is subject to the test is determined depending on the previous test results without reducing the number of samples for each test. In other words, it is assumed that the better the previous test results, the lesser the frequency of testing may be. In order to shorten the construction period, it is better than the former method.

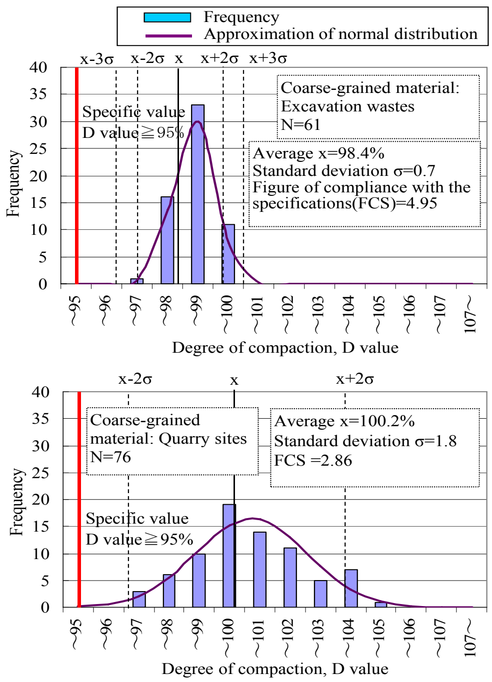

Figure 10. Histogram of field density test result of core material (Specific value: D value = more than 95%)

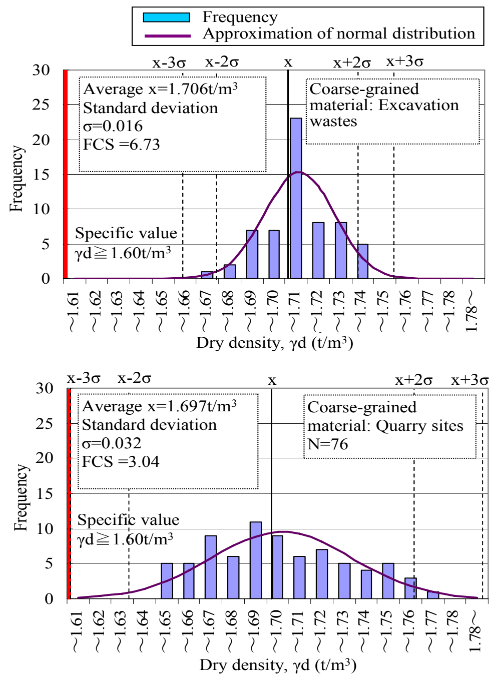

Figure 11. Histogram of field density test result of core material (Specific value: γd = more than 1.6t/m^3)

In order that the frequency of tests may be decreased, the requirement that the product quality be found good at all times must be satisfied. If that requirement is not met, then the initially specified frequency of testing must be restored.

6.2. Proposal of Management Rules (Draft)

Decision on whether or not the frequency of field tests should be reduced is made according to Eq. 1 that yields the figure of compliance with the specifications. The data that is required for finding the average values of the test results as well as the standard deviation should be such that is derived from the test results from the layer where the same material and the same way of work method are adopted. In cases where the grading or the water content ratio largely changes because of variations in the specimen collection site or in the stock pile or where use is made of different construction machinery or methods that are related to the compacted layer depth, computation is performed separately according to Eq. 1, assuming that the test results obtained are different from each other.

Depending on the figure of compliance with the specifications found from Eq. 1, the forthcoming frequency of field tests is determined for the work in which the specific materials and work methods are employed. Each time the field test is conducted, computation is made according to Eq. 1 so as to make the foregoing decisions as many times as required. The flow of that management rule (draft) is indicated in Fig. 12.

6.3. Simulation of Reduction in The Frequency of Field Tests at The Tono Dam Construction Site

An attempt to reduce the frequency of field tests on the core material is simulated in accordance with the management rules (draft) we have established. The findings from the simulation above are such that 14 out of 61 tests can be cut out when the core material contains the coarse grains collected from the excavated dam body. Consequently, an elimination of about 1/4 of the ongoing tests is found justifiable.

7. CONCLUSION

Through introduction of the ICT system to a series of steps of filling works that are followed during supervision of construction, all the necessary sets of data can be obtained in an areal manner. As a result, the size of the works and stable construction quality are ensured in all likelihood. In addition, spot supervision focusing on strategic locations of construction apparently suffices the purpose as against the conventional practice where monitoring over the situation of the local site is continually required. Workload for the supervisors is thus reduced. Assuming that the test results that satisfy the specifications are acquired, it is probable that the frequency of field tests may be reduced in accordance with the management rules (draft) suggested herein, resulting most probably in a curtailment of the work period.

Introduction of the ICT system to the construction site is currently intended to streamline the entire job on the part

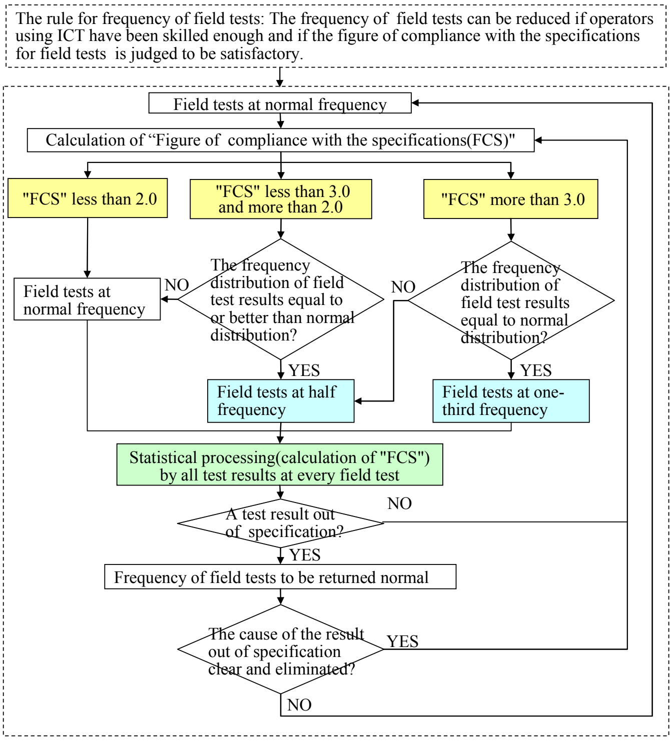

Figure 12. Management rule(draft) for the frequency reduction of field tests

of the contractors. However, it is possible to argue that the dam owners themselves should bend their energies to meet many social as well as industrial demands made in the area of infrastructure for a reduction in cost involved in public works, desirable effects to be realized as early as possible, higher product quality, enhanced competitiveness, and so on.

Amid the situation mentioned above, it can reasonably be said that the current practice of construction and supervision from the viewpoint of the dam owners should be reconsidered, taking full advantage of the ICT system as an effective tool for facing the foregoing challenges.

The authors sincerely hope that not only the contractors but also the dam owners will understand far-reaching benefits that could be derived from introduction of the ICT and that the authors' suggestions made herewith could help diffuse that new technology as a means for promoting an elaborate as well as rational way of construction and supervision.

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