Committee Report: JCI-TC144A

Technical Committee on Establishment of PDCA Cycle for the Construction of High Quality Concrete Structures

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Abstract:

The committee examined the ideal framework of the PDCA cycle in construction to increase the reliability of the current construction, which is based on the concrete quality management using the slump and air content as criteria, with the use of test methods newly proposed. To be more specific, the committee sorted and examined the technologies that can be used at each PDCA stage through a discussion of ideal framework of the PDCA cycle at two levels: site-level PDCA cycle where the concrete used in the site is verified to see whether it meets the construction performance specified at design time, and correction is made in case the concrete is out of the specifications; and planning-level PDCA cycle where constructed structure according to the construction plan that is prepared based on the construction performance specified at design time is verified at the time of completion, and an improved construction plan is suggested at the next construction.

Keywords: Quality test method, construction reliability, filling properties, structure concrete, and PDCA

1. Introduction

Concrete work is carefully executed in each stage of transportation, placing, compaction, finishing, curing, and removal of formwork and support, to ensure that the stracural concrete has the quality specified during design time. Also, to ensure the required quality, a large number of test methods for quality management are suggested to check whether the specifications specified at each stage of execution of work are ensured, for example, whether the strength of 5 N/mm2 is ensured at the removal of the formwork. Numerical simulation technologies for

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verifying the concrete filling condition in the formwork prior to the execution of work have also made progress. This committee was set up with the aim to examine the ideal framework of the PDCA cycle in concrete work required for the construction of higher-quality structures by using these test methods and numerical simulation technologies.

Table-1.1: Committee Structure

Chairman: Toshiki Ayano (Okayama University) Vice-Chairman: Tsuyoshi Maruya (Taisei Corp.) Secretary-General: Yoshitomo Yamada (University of the Ryukyus) Secretary: Yasumichi Koshiro (Obayashi Corp.), Hiroshi Minagawa (Tohoku University)
[WG1: PDCA Cycle Examination WG]○ Head of WG ○ Yasumichi Koshiro (Obayashi Corp.), Shinya Ikehata (Central Nippon Expressway Co., Ltd.), Ichiro Iwaki (Nihon Univ.), Naoko Tsuchiya (NILIM), Masaro Kojima (Takenaka Corp.), Tsuyoshi Maruya (Taisei corp.), Tadashi Watanabe (Nihon Univ.) [WG2: Simulation WG]○ Head of WG ○ Yoshitomo Yamada (University of the Ryukyus), Shinji Urano (Shimizu Corporation), Yoshiyuki Kurokawa (Kagoshima University), Kohji Teranishi (Meijo University), Naoki Mishima (Mie University), Takashi Watanabe (Tokushima University) [WG3: Test Method Standardization WG]○ Head of WG ○Hiroshi Minagawa (Tohoku University), Yoshikazu Ishizeki (Obayashi Corporation), Shogo Osawa (East Japan Railway Company), Masaki Oshima (BASF Japan), Jun Liang (Taisei Corporation), Shinichiro Hashimoto (Fukuoka University), Kosuke Minami (Maeda Corporation), Koichi Takahashi (Hachiyo Consultant Co, Ltd.)
Advisor: Kimitaka Uji (Tokyo Metropolitan University)

The members of the committee are as shown in Table-1.1. The committee consisted of the following three working groups for carrying out activities:

WG1 (PDCA Cycle Examination WG): Examine specific methods for implementing the PDCA cycle in construction using test methods for verifying the reliable construction.

WG2 (Simulation WG): Examine the applicability of the construction with numerical simulations based on a rheological theory to the PDCA cycle.

WG3 (Test Method Standardization WG): Draft standards on fresh concrete test methods to be utilized for implementing the PDCA cycle.

2. Activities of PDCA Cycle Examination WG

This WG carried out activities aiming to describe the PDCA cycle for concrete work. This report first describes what the PDCA cycle is, and then the need of the PDCA cycle for concrete work, followed by the explanation of cases where the PDCA cycle has been used and the technologies contributing to the PDCA cycle in past literatures. The last section presents a PDCA cycle for concrete work proposed by the committee.

Table-2.1 is the draft table of contents of the report for which this WG is responsible.

Table-2.1: Draft Table of Contents of the Report for Which PDCA Cycle Study WG is Responsible

PDCA Cycle Examination WG
1. PDCA Cycle Proposed by this Committee for Concrete Work
1.1 What The PDCA Cycle is
1.2. Need of the PDCA Cycle for Concrete Work
1.3. PDCA Cycle Proposed by this Committee
2. Concrete work cases where the PDCA Cycle is implemented
2.1 Case Where the PDCA Cycle is implemented
2.2 Methods/Tools for Checking Quality and Conditions
2.3 Technologies Making Direct Contributions to Quality Improvement
3. Summary

2.1 PDCA Cycle

The Plan-Do-Check-Act (PDCA) Cycle is one of the methods to facilitate the control in business activities, such as production control and quality control. In this cycle, a job or management action in an organization starts with planning, the job/action is done in accordance with the plan, and the result is checked. If there is a difference between the plan and the result, the target and/or the method are improved for the next job. Efforts to continually improve operations by repeating the four-stage cycle of Plan, Do, Check and Act, as shown in Fig.-2.1 are collectively called the "PDCA Cycle". These four stages are performed in sequence, and upon completion of one cycle, the last "Act" is linked to the next PDCA cycle. “Spiraling up a cycle” in every round in this way leads to continual improvement of operations. This idea has been employed in international standards including the International Organization for Standardization (ISO) 9000 series and ISO 14000 series, and Japanese standards such as JIS Q 15001. The Occupational Safety and Health Management System also utilizes the PDCA cycle for continual risk reduction by identifying the main causes of danger and performing risk assessments.

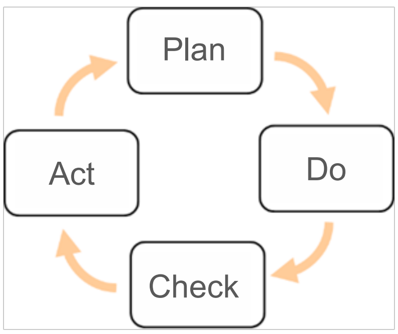

Fig.-2.1: PDCA Cycle

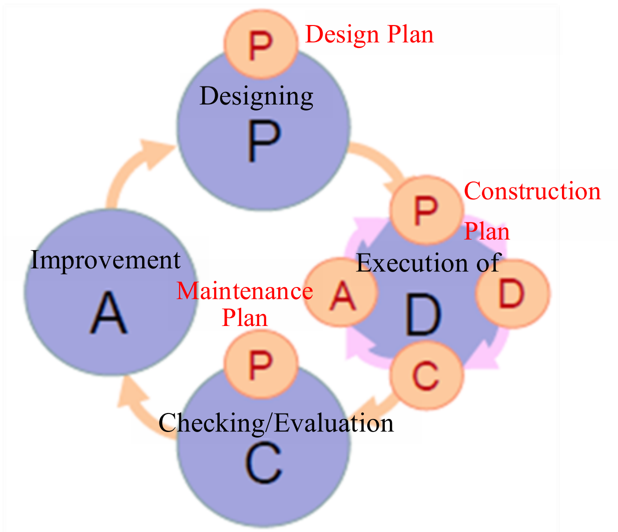

Fig.-2.2: PDCA Cycle for A Group of Concrete Structures

2.2 Need of the PDCA Cycle for Concrete Work

While concrete work has been experiencing cutting-edge technological developments, such as the utilization of ICT technology in the construction management and such as chemical admixtures in the concrete materials, there have been concerns about a decline in the basic technological abilities for the execution of work and management. To provide high-quality concrete structures with limited investments and human resources, as the birthrate declines and the population ages, the PDCA cycle must be used in the cycle of the execution of work of concrete work. A system should be established that allows anyone to construct concrete structures of proper quality as planned, without being imposed a heavy burden, by properly implementing the PDCA cycle.

Fig-2.2 illustrates the PDCA cycle for (a group of) concrete structures examined by this WG. It has a flow of P (designing), D (execution of work), C (checking/evaluation in maintenance), and A (improvement), and reflection of this flow in the next plan for a concrete structure leads to the spiral-up of the cycle. Each of these P (designing), D (execution of work), and C (checking/evaluation in maintenance) corresponds to the Design, Execution, and Maintenance of the Standard Specifications for Concrete Structures compiled by Japan Society of Civil Engineers. Each of these stages further has a PDCA cycle.

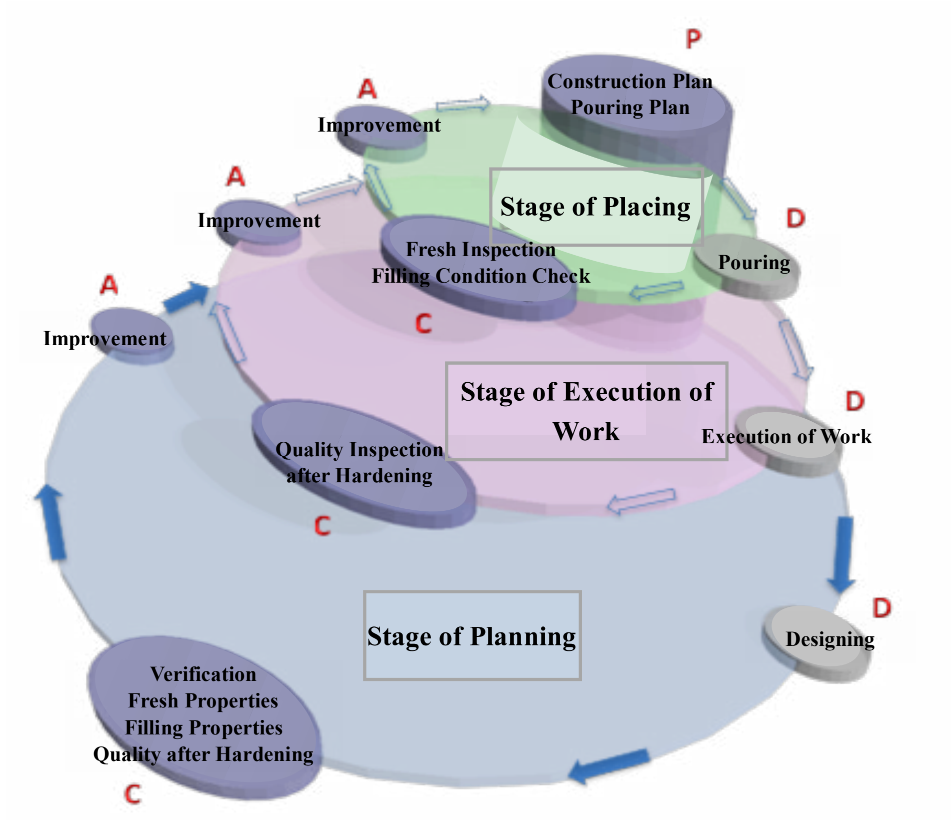

Fig.-2.3: Need of the PDCA Cycle for Concrete Work

Fig-2.3 illustrates the PDCA cycle for concrete work examined by this WG. The flow in the illustrated PDCA cycle starts from the stage of planning, located at the outermost position, proceeds toward the stage of execution of work, and then to the stage of the one-time placing. The cycle is designed in such a way that the feedback resulting from A (improvement) is reflected in both the upper stage of designing and the lower stage of placing without remaining in the same stage.

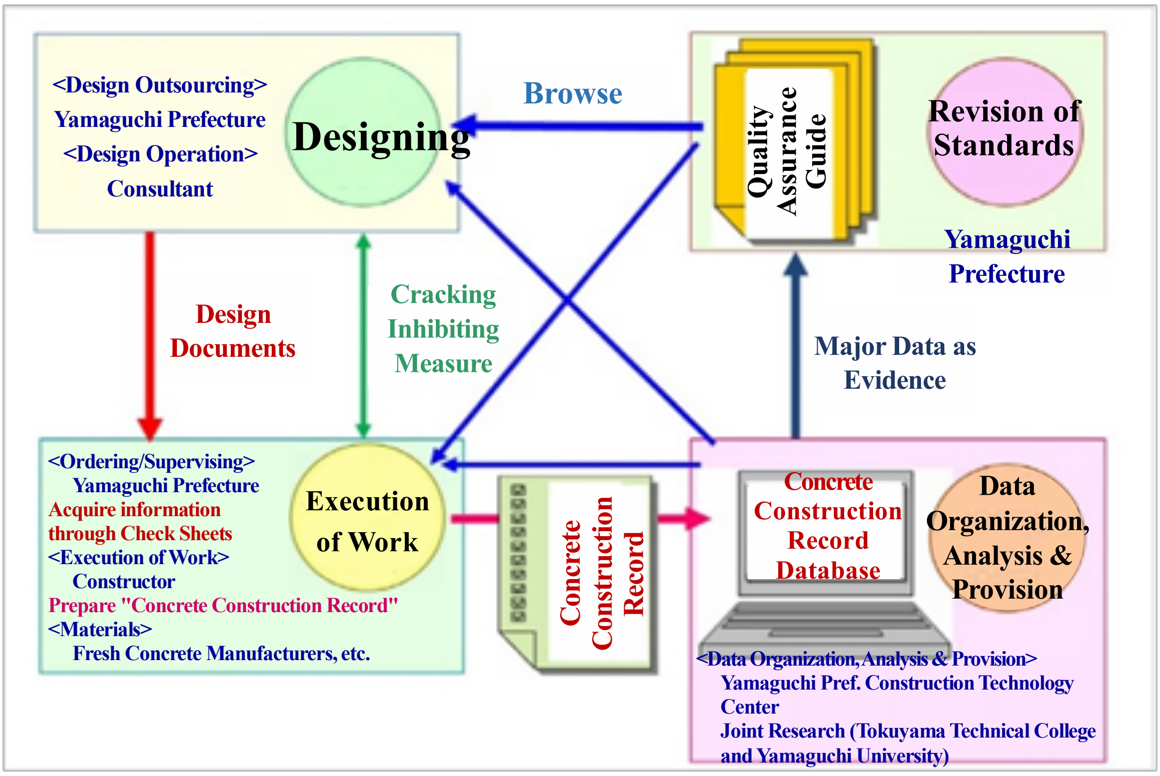

Fig.-2.4: "Cracking Inhibiting System" in Yamaguchi Prefecture[1)]

2.3 Concrete Work Cases Where the PDCA Cycle is implemented

(1) Case Where the PDCA Cycle is implemented

This section introduces a project of Yamaguchi Prefecture as one of the cases where the PDCA cycle is implemented for construction of concrete structures. Yamaguchi Prefecture has established a system to inhibit cracking of concrete structures in collaboration among the industry, academia, and local government. This "Cracking Inhibiting System" of Yamaguchi Prefecture, as shown in Fig-2.4, has established the PDCA cycle, where the work is executed (Do) in accordance with the design (Plan), and the results of data organization and analysis (Check) are reflected in the cracking inhibiting measures (Act). The system is characterized by its "Check Sheet" and "Concrete Construction Record". The Check Sheet has 27 items to be checked for observing the basic rules of construction, and the supervisor uses this sheet for checking and recording. The Concrete Construction Record is used to gather information on concrete materials, cracking inhibiting measures implemented, conditions for placing, history of concrete temperature changes after placing, and cracking generated, and has been published as database on the website of Yamaguchi Prefecture. When a problem occurs, the analysis of this Check Sheet and the data base of the Construction Record enables examination of the cause of the problem, and the item considered to have caused the problem can be improved for the next construction using the lift. Using such Check Sheets and Construction Records shared between the owner and the constructor rotates the PDCA cycle as the cracking inhibiting measure, and leads to the spiral-up.

This idea is followed by the Reconstruction Road (Reconstruction Assistance Road) project proceeded with by the Tohoku Regional Development Bureau after the Great East Japan Earthquake.

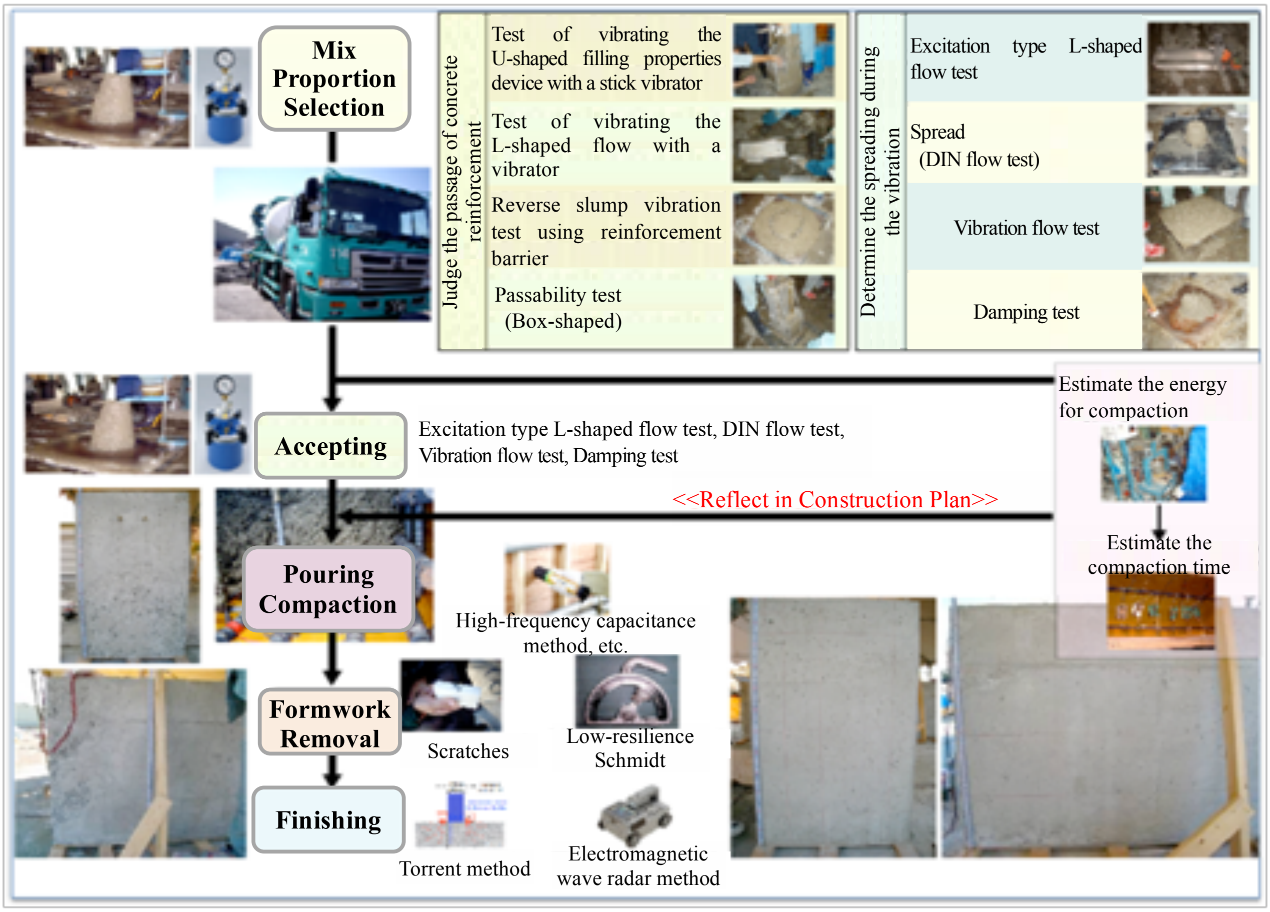

Fig.-2.5: Relation between Concrete Quality Evaluation Test Methods and Concrete Work

(2) Cases Where Methods/Tools for checking are used

Fig-2.5 is a concrete work cycle diagram illustrating the quality evaluation test methods of concrete during the execution of work which were examined in a technical committee of FY 2007 to 2008, "Test Methods for Reliable Construction Technical Committee" (Chairman: Toshiki Ayano, Okayama University)[2]. All of these quality evaluation test methods serve as the methods for checking the quality of concrete and the filling conditions in "C" of the PDCA cycle for concrete work illustrated in Fig.-2.3.

This report introduces cases where the methods/tools for checking the quality of concrete after each stage of trial mixing, accepting, pre-placing, and post-placing in concrete work.

(3) Cases of Technologies for improving Quality

This section describes cases where the quality of concrete is directly improved in D (placing stage) of the PDCA cycle for concrete work. Although there are not so many cases, a case of a high-performance vibrator and a case of the surface layer quality improvement by a special sheet are described.

2.4. Proposed PDCA Cycle for Concrete Work

Fig.-2.6 illustrates the PDCA cycle proposed by this committee for concrete work. The PDCA cycle diagram contains not only concrete work but also a series of flow from design, construction, inspection, and maintenance. Each of these stages also has a PDCA cycle. The stage of construction has a PDCA cycle of construction planning, execution of work, inspection, and improvement. The stage of execution of work has a PDCA cycle for work instruction formulation, placing, inspection/quality control, and improvement. It is important to spiral up the cycle in a series of such flow, aiming to construct high-quality concrete structures. Although each of "P", "D", and "C" of the PDCA cycle has guidelines, standards and/or cases to refer to, for "A (Improvement)", there is no guideline for reference. For proper implementation of "A", what is important is that responsible persons at different positions, for example, the owner and constructor, or an attendant on the site and operator, evaluate ("C") each other based on the common understanding, and provide feedback (“A”) in the same direction based on the shared evaluation results. To this end, the evaluation method and interpersonal communication based on it are critical. Future research and development concerning concrete work should also be approached considering how the action of improvement can be successful.

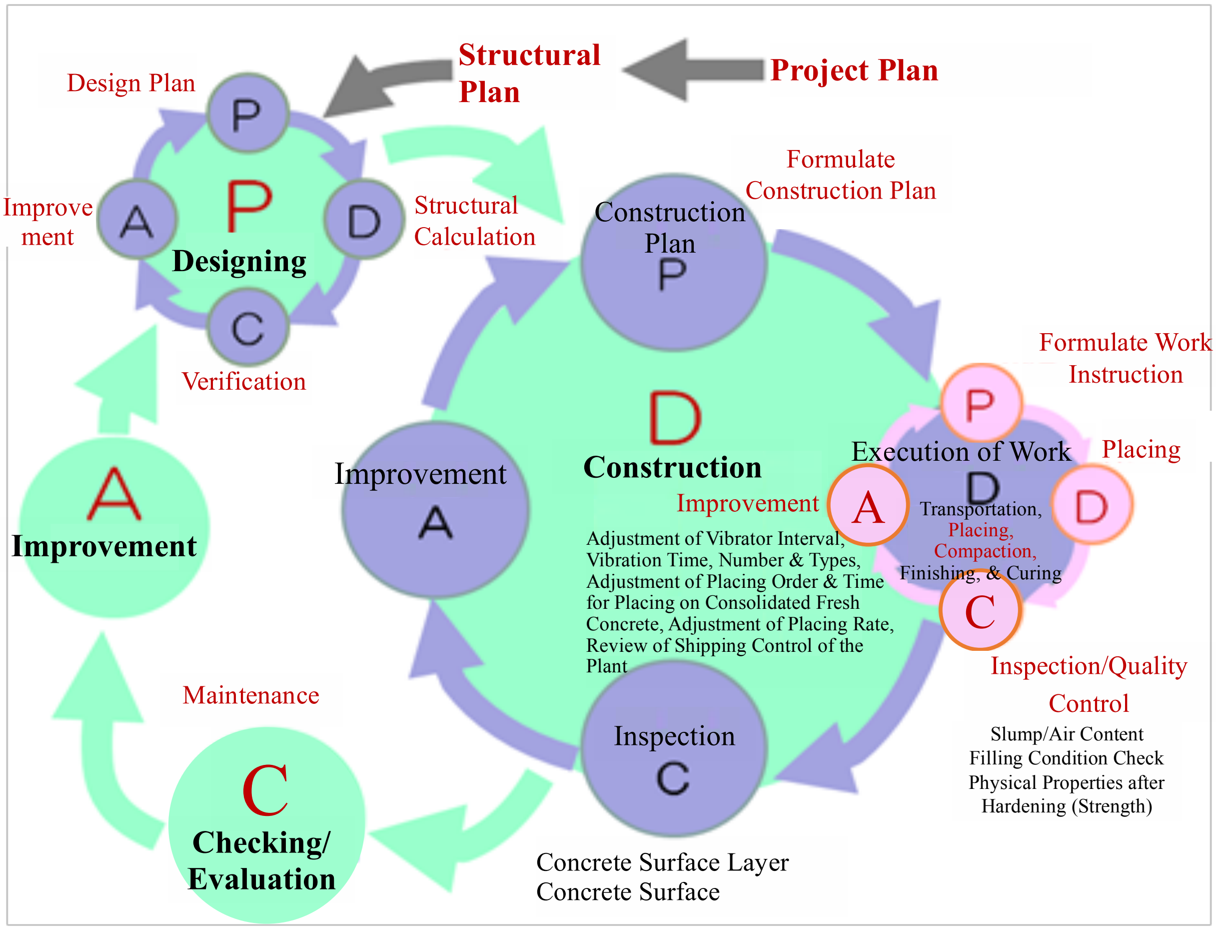

Fig.-2.6: PDCA Cycle Proposed by this Committee for Concrete Work

3. Examination by Simulation WG

In recent years, concrete work sites are experiencing an increase in structures with congested reinforcement arrangement, members with reduced thickness, shortage in high-quality aggregates, increased use of various admixtures (fly ash, granulated blast-furnace slag fine powders, and air-entraining and high-range water-reducing admixtures, etc), as well as a tendency of reduction in the number of experienced technicians, and it would become difficult to evaluate the workability based on empirical rules in the future. In addition, the evaluation of the workability with slump tests assumes the normal construction conditions, and to determine the workability under special conditions, full-size construction experiment using models reconstructing the conditions of real construction may be required, needing excessive costs and time.

Table-3.1: Draft Table of Contents of the Report for Which Simulation WG is Responsible

1. Flow Analysis of Fresh Concrete for Making Use in the PDCA Cycle
1.1. Introduction
1.2 Role of Flow Analysis in the PDCA Cycle
1.3 Issues for Using Flow Analysis in the PDCA Cycle
2. Examination of Past Researches on Flow Properties of Fresh Concrete
2.1 Past Researches on Pouring/Vibration Consolidation
2.2 Past Researches on Segregation
2.3 Past Researches on Pump Pumping Capacity
2.4 Problems and Tasks to be Achieved
3. Constitutive Equation of Fresh Concrete
3.1 Continuum Models
3.2 Discontinuous Models
3.3 Other Models
3.4 Problems and Tasks to be Achieved
4. About Flow Analysis Methods for Fresh Concrete
4.1 Introduction
4.2 Classification and Features of Flow Analysis Methods
4.3 Analysis Cases
4.4 Tasks and Prospects for Flow Analysis
5. For Establishment of the PDCA Cycle Using Flow Analysis with BIM/CIM
5.1 Outline of BIM and CIM
5.2 Role of Flow Analysis in BIM and CIM
5.3. Tasks for Establishment of the PDCA Cycle Using BIM/CIM and Flow Analysis
6. Summary

Solving these issues require development of the technology to forecast the placing filling of concrete from simulations.[3)] Therefore, Simulation WG of this committee examined the flow models of fresh concrete and Flow Analysis methods, and investigated attempts to perform concrete filling simulations using Building Information Modeling (BIM)[4] and Construction Information Modeling (CIM)[5] which are increasingly used in the construction and civil engineering fields in recent years, and Flow Analysis.

With the use of BIM (CIM), the reinforcement arrangement can be examined through the visualization prior to the construction, entering operations of filling analysis can be performed efficiently, and the filling analysis results can be archived as records. Therefore, the filling simulations using BIM (CIM) and Flow Analysis will rationalize concrete work, and allow the information to be shared not only with the construction side but also with the design side, thus are expected to be used as a tool for the PDCA cycle for creating higher quality of concrete structures.

Table-3.1 is the draft Table of Contents of the report for which Simulation WG is responsible.

3.1 Investigations on Flow Models

When modeling the properties concerning the flow of fresh concrete, models are classified into the following two types: continuum model where concrete is viewed macroscopically and treated as a spatially differentiable substance; and discontinuous model where concrete is treated as a composite material comprising coarse aggregates and matrix mortar, and each the contact of coarse aggregates and the deformation of matrix mortar is treated with separated dynamical models. The following sections briefly explain the flow and discontinuous models.

(1) Outline of Continuum Models

The characteristic of fresh concrete is that it flows above a certain stress and ceases below that. One of the flow models representing fluids that have this characteristic is Bingham model. Many studies have attempted to represent the flow properties of fresh concrete with Bingham model[6].

The problem with Bingham model is that the shear stress is uncertain as the strain rate remains zero until the shear stress exceeds the yield value. In order to avoid this problem, numerical analyses on computers use models close to Bingham model such as the ones called bi-viscosity model[7] and regularized Bingham model[8] (refer to Fig.-3.1). These models are featured by the fact that they treat non-fluid concrete as a fluid of very high viscosity.

Bingham model also has a problem when representing complicated behavior unique to fresh concrete. Therefore, models where the coefficient of internal friction is introduced to consider the pressure dependence[9], non-Bingham models where softened flow curves and hardening characteristics can be considered[10], and even the thixotropy model[11], the dilatancy model[12], and models with which multiple affecting factors can be considered[13] have been suggested.

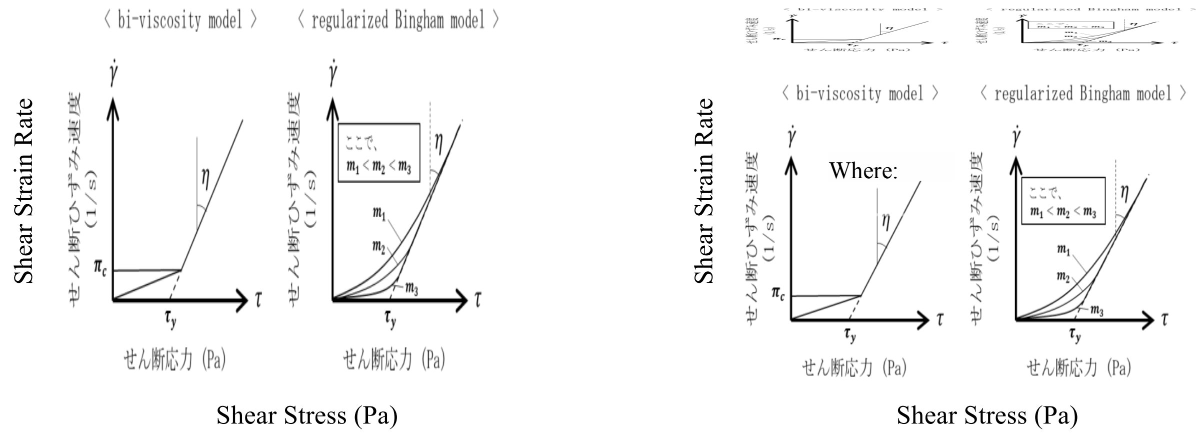

Fig.-3.1: Approximation of Bingham Model

For fresh concrete, there is a possibility of segregation as it is a composite material. While it is difficult to deal with this phenomenon of segregation using flow models, a flow model in which the pressure difference inside fresh concrete changes the ratio of coarse aggregates and mortar to represent the locally uneven distribution of the coarse aggregates and the change in the flow properties[14] has also been suggested recently (refer to Fig.-3.2).

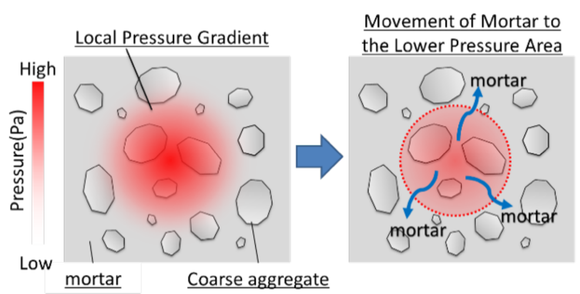

Fig.-3.2 Models of Segregation Driven by Internal Pressure[14]

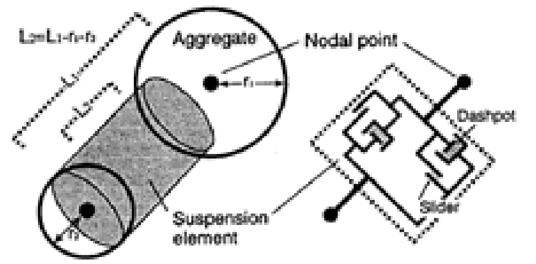

Fig.-3.3 Models of Element Nodal Points of Non-Flow Models[15]

(2) Outline of Discontinuous Models

The characteristics of non-flow models[15], [16] are that most of them are based on two-phase material fresh concrete modeling composed of coarse aggregates and matrix mortar, and that the movements of the contact of coarse aggregates and the visco-plastic deformation of the matrix mortar part are represented with the combination of dynamic models including springs, dash pots, and sliders (refer to Fig.-3.3).

Discontinuous Models, which facilitate contact and separation between coarse aggregates, are expected to analytically reproduce the generation of local defects of concrete, such as segregation and blockage issues. Furthermore, a recent study reports a model that treats the movement of course aggregates as non-fluid, and the movement of mortar as fluid, and couples both movements[17]. Attempts to reproduce blockages caused by course aggregates around reinforcing bars have been made.

Table-3.2: Classification of Flow Analysis Methods

Fluid Model-Based Analysis Method					Non-fluid Model-Based Analysis Method
Finite Element Method		Difference Method	Particle Method	Meshless Method	Visco-Plastic Suspension Element Method
Partitioning of Objects	Partitioning of Space				
Visco-Plastic Finite Element Method	Visco-Plastic Space Element Method	MAC Method	SPH Method	Free Mesh Method	Distinct Element Method
	Marker Particle Visco-Plastic Finite Element Method	VOF Method	MPS Method		Coupled Analysis in Granular and Fluid Model [VOF Method (Fluid) + Distinct Element Method (Non-fluid)]
Visco-Plastic Finite Element Method					
	Euler Finite Element Method				

3.2 Investigation on Flow Analysis Methods

Flow Analysis methods are broadly divided into two groups: those that use constitutive equations formularized based on the flow models described in the previous section, i.e. the finite element method, difference method, particle method, and meshless method; and those that use element note point models based on non-flow models, i.e. the visco-plastic suspension element and distinct element method. The classification of these methods is as shown in Table-3.2. Note that this table classifies the analysis method that couples both non-fluid and fluid as a non-fluid-based analysis method.

Analysis methods that partition objects with the finite element methods, and the free mesh method are insufficient to analyze the concrete filling, as they can cover deformations like slump only. However, other analysis methods are considered to work for the filling analysis. Especially, the MPS Method[18], one of particle methods and was developed by Koshizuka, has many advantages as flow analysis methods of fresh concrete, as unlike the finite element method and difference method, it does not require elements nor cells, and it can handle issues such as finite deformation problems and fluid segregation. The characteristics of this MPS method are utilized in analyses including the segregation analysis around reinforcement and the acceleration transmission analysis with vibrators[19].

Furthermore, there is the coupled analysis in granular and fluid model, which analyzes the movement of coarse aggregates with the distinct element method, and that of matrix mortar with the VOF method, and couples both dynamic transactions, in which the results of this analysis are compared with those of the flow analysis for the excitation box filling test[17]. Fig.-3.4 illustrates the conditions of the coarse aggregates in concrete in eight seconds after the passage between reinforcing bars for each bar arrangement condition. It shows that the filling properties get poor as reinforcing bars increase, compared to the plain concrete.

3.3 Trial Filling Simulation Using BIM (CIM) and flow analysis for Fresh Concrete

BIM (CIM), whose expanded use is expected also for concrete construction, is a system that enables a series of efficient workflow of investigation, design, construction, and maintenance by combining the three-dimensional form geographical data and attribute data. The use of BIM (CIM) is expected to further enhance the information sharing between the design side and construction side, and be useful for reinforcement arrangement verification in the parts with dense reinforcement arrangement [20].

The use of three-dimensional reinforcement arrangement data created by this BIM (CIM) in the filling simulation of concrete in the parts with dense reinforcement arrangement is considered to contribute to the rationalization of concrete work.

Fig.-3.5 shows the result of a concrete filling simulation performed in a column-beam connection, as an example of concrete filling simulations using BIM and the MPS method[21]. The figure shows that the placing was proceeded with from the left to the right. The analyzed concrete is high-fluid concrete with a slump flow of 65 cm (yield value: 50 Pa, plastic viscosity: 300 Pa・s), and the analysis used the bi-viscosity model. The placing of concrete was performed from both ends of the beam.

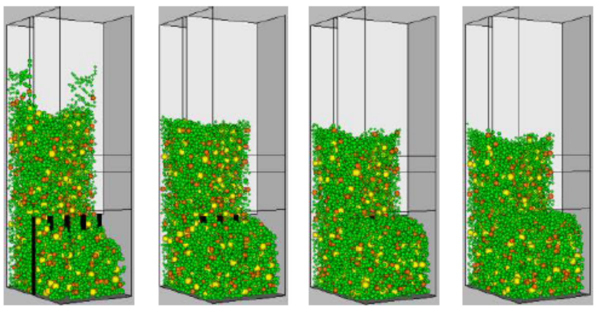

Fig.-3.4: Coarse Aggregate Model Flow Analysis Result for Each Reinforcement Arrange Condition[17]

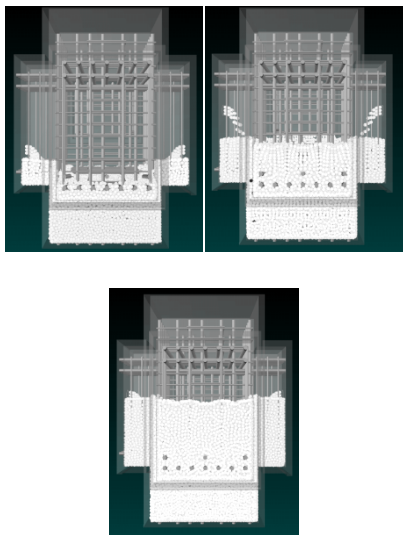

Fig.-3.5: Filling Simulations by BIM and the MPS Method

The result shows that with this level of density, using high-fluid concrete allows easy filling in a column-beam connection. In this experiment, Vectorworks2015 was used for the BIM software, and Particleworks from Prometech Software was used for the MPS method flow analysis software.

Concrete filling simulations are expected to confirm the blockage and segregation, and the conditions of filling and consolidation of slump-type normal concrete done by vibrators. As described in the previous section, the development of these analysis methods is also ongoing, but they need more verification. Further research development is awaited.

If further research and development improve reliability of the flow models and flow analysis methods for concrete, the combined use of BIM (CIM) and filling simulations will make the judgments on the workability and filling properties quantitative and visible, getting rid of the conventional judgments made qualitatively based on empirical rules (refer to Fig.-3.6).

The use of BIM (CIM) will enable the centralization of information about concrete work and the simplification of the data entry of shapes/positional information of members and the parameter information of materials required for flow analysis, and allow the filling analysis results to be archived as records. As the information about concrete work can be shared not only by the construction side but also with the design side, the concrete filling analysis system using flow analysis with BIM (CIM) can be expected to be used as a tool for the PDCA cycle to create concrete of higher quality.

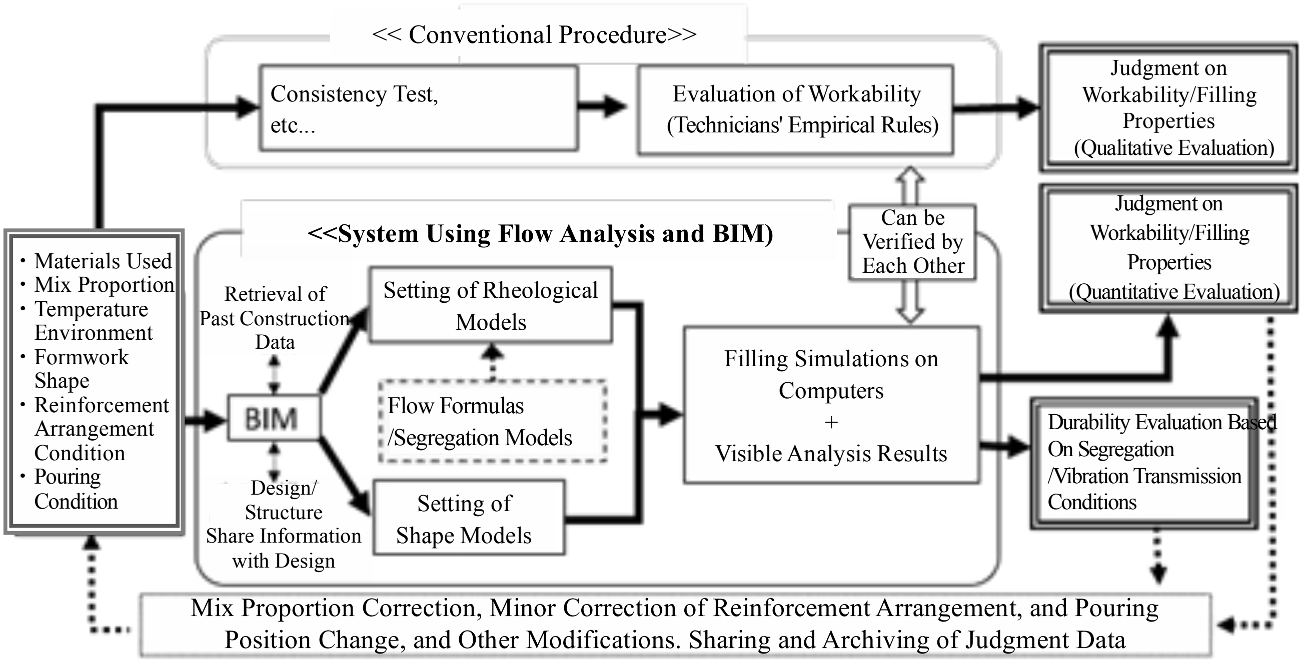

Fig.-3.6: Outline of Concrete Filling Analysis System Using Flow Analysis with BIM/CIM[21)]

Table-4.1: WG3 Table of Contents

3. On-the-Site Experiments of Tests Required for the PDCA Cycle for Reliable Construction
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3.2. Outline of the Fresh Concrete Test Method Evaluated by this Committee
3.2.1. Simplified Test Method for Deformation of Post-Slump Concrete by Tapping Slump Plate (Draft)
3.2.2. Tilt Flow Testing
3.2.3. Round Penetration Tester Testing
3.2.4. Excitation Deformation Testing
3.3. Evaluation of Characteristics of Fresh Concrete by Each Test Method
3.3.1. Experiment Outline
3.3.2. Experiment Results
3.4. Outline of On-the-Site Experiment evaluated by JCI-TC074A Committee and Follow-Up Study
3.4.1. Outline of On-the-Site Experiment
3.4.2. Results of Follow-Up Study
3.5. Summary of this Chapter
Simplified Test Method for Deformation of Post-Slump Concrete by Tapping Slump Plate (Draft) and Explanations
[Annex]
X.1 Introduction
X.2 Test Method for Evaluating Compaction Completion Energy
X.3 Tilt Flow Testing
X.4 Round Penetration Tester Testing

4. Examination by Test Method Standardization WG

The purpose of Test Method Standardization WG is to establish the test methods that serve as the "C: Check" in the PDCA cycle for construction. To achieve this, this WG used the results of the activities of JCI-TC 074 Committee ("Test Methods for Reliable Construction Technical Committee" Chairman: Toshiki Ayano) as a basis, and performed: (1) preparation of new evaluation and draft standards for the methods of testing fresh concrete, and (2) a follow-up study on the on-the-site experiment carried out by JCI-TC 074 A Committee.

In the above (1), "Simplified Test Method for Deformation of Post-Slump Concrete by Tapping Slump Plate" was examined as a test method of fresh concrete for civil engineering structures, information necessary for the standardization was collected/organized, and the draft standards were prepared. In addition, standardized tests were performed for "Tilt Flow Testing", "Round Penetration Tester Testing", and "Excitation Deformation Testing" as test methods of fresh concrete for architectural constructions. In parallel to the above-mentioned examinations, the WG also discussed the clarification of the functions and performance required for the test methods of fresh concrete, the roles of the test methods, the capabilities to be tested, the range of application, and the capabilities to be finally guaranteed, and sorted the information primarily on the history of the changes in the test methods for evaluating the workability.

In the activity (2), the physical properties of 7-year exposed specimens of the construction experiment performed by JCI-TC 074 Committee were evaluated.

The main focus of this committee report is on the activity (1).

4.1 Methods for Evaluating Fresh Concrete

In the 1930s, three types of tests were prescribed as concrete workability tests for evaluating the consistency: slump test, flow test, and dropping test. However in the 1950s, only the slump test was prescribed in JIS. After that, various kinds of test methods were prescribed as standard in JIS and other standards including those of Japan Society of Civil Engineers as times changed. For example, there are eight types of standardized test methods only for the evaluation of the consistency. In the Committee Report, the history of these changes in the test methods is sorted out, and the background to frequent use of slump test is explained.

Then, there was a discussion that, as the functions/capabilities required for the test methods, "testing and measurements should be easy for anybody and require short time for testing", "no special devices or tools are required, and the testing should be easily implemented even in the construction site", "evaluation/judgment should be possible based on quantitative values", "measurement results should be able to be visually checked", "test devices should be trouble-free or hardly cause trouble". The currently available test method that best satisfies these requirements is the slump test.

At the time when only a small number of types of aggregates and chemical admixtures were used, there were less factors affecting the properties like the segregation resistance properties of fresh concrete, and indirect evaluation of workability was possible through the consistency required by the slump test. However, the increase in the variety of materials for concrete caused by the running out of aggregates of good quality and the promotion of the use of a wide variety of admixtures, as well as multifunctionality of chemical admixtures, have made it difficult to evaluate the workability of concrete only by the slump test.

In the evaluation results of JCI-TC074A, this WG therefore focused on the test to deform the specimen after the slump test by beating a flat board, as a test to evaluate the compaction and filling properties, and aimed at the JCI standardization of that test (Simplified Test Method for Deformation of Post-Slump Concrete by Tapping Slump Plate (Draft)). Although the range of application of this test was the mix proportion for civil engineering structures, the tilt flow testing, round penetration tester testing, and excitation deformation testing were added as additional targets for testing with the mix proportion for construction.

4.2 Simplified Test Method for Deformation of Post-Slump Concrete by Tapping Slump Plate (Draft)

In the construction site, at the completion of the slump test, the segregation resistance properties of the concrete are often judged by tapping a flat board for the slump test and observing the concrete deformation conditions. While effects of tapping a flat board is equivalent to those of vibrating concrete for compacting, the degree of tapping deemed to produce the condition of compaction completion, and the criteria for evaluating the segregation resistance properties have not been quantified yet.

For examining this (draft) test method, "the condition where inside a plain container of a certain capacity, the density of fresh concrete has reached the theoretical density for the mix proportion, or an equivalent density thanks to the compaction by vibrations" was defined as "compaction completion", and "the energy required for the completion of compaction" as "compaction completion energy". Then the test method was aimed at easily providing the specimen immediately after the slump test with the vibrations that are equivalent to the compaction completion energy by tapping a flat board for the slump test, and at easily checking the unity of the fresh concrete at the time of the compaction by vibrations based on the conditions of the specimen at the time of tapping. With the mix proportion of high viscosity, where the segregation hardly occurs, the test method was aimed at providing energy that is larger than the compaction completion energy by further tapping the flat board, and at relatively comparing the degree of the viscosity among two or more specimen based on their dimensions and observation of the changes in the conditions of the specimen at the time of tapping.

Detailed procedure of this (draft) test method is described in Committee Report (to be published in September, 2016). This section outlines the procedure as follows:

1) Fill the slump corn with the specimen in the same manner as in the slump test, and level the upper surface of the concrete carefully using a tool like a trowel.
2) Spray phenolphthalein solution to color the upper surface of concrete in reddish purple. This colored area is referred to as colored face.
3) Calmly pull up the slump corn vertically in the same manner as in the slump test. Measure the slump at this time.
4) Continue tapping the flat board for the slump test with a wooden hammer, and deform the concrete until the diameter of the specimen reaches somewhere between 450 and 550 mm due to the vibrations. Beating the flat board until the diameter of the specimen reaches 450 to 550 mm provides the specimen with the vibrations equivalent to the compaction completion energy[22), 23), 24)].

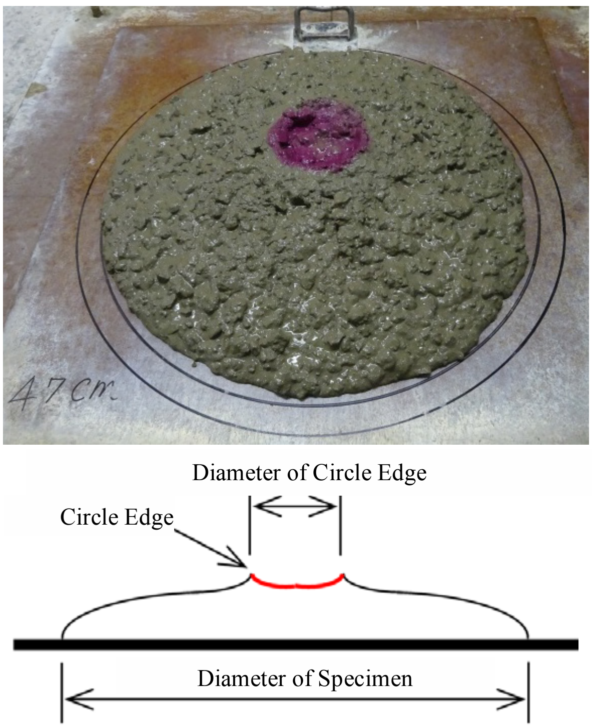

Fig.-4.1: Specimen With Circle Edge

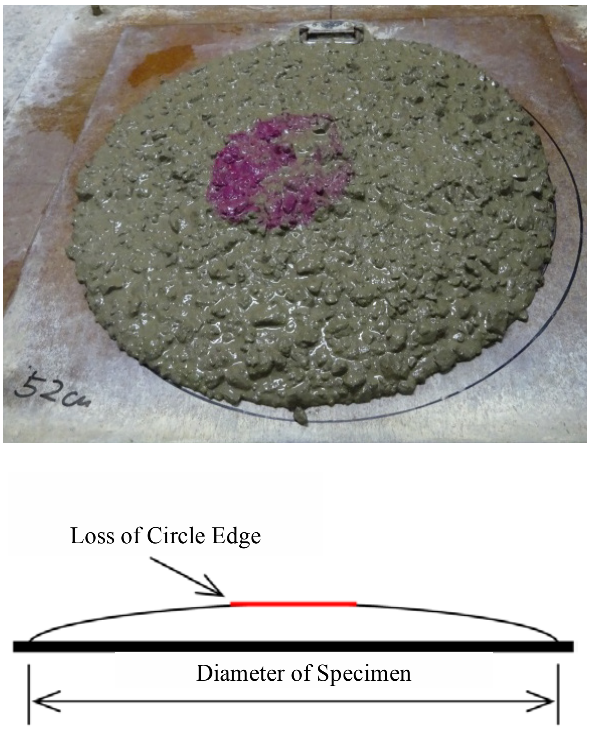

Fig.-4.2: Specimen Without Circle Edge

5) Then, observe the colored face to verify if there is a circle edge on the circumference as shown in Fig.-4.1 or Fig.-4.2, and measure the diameter of the circle edge. Measure the diameter of the specimen at this time.

The Committee Report includes the purpose and history of establishment, matters under special deliberation, supplementary matters with regard to the applications and to the usage, and basis for prescribed elements, as well as applied cases where this (draft) test method can be utilized and a sample flow for selecting the mix proportion. For drafting the test method, a discussion arose on the effects of the way of supporting the flat board for the slump test on the test results, and an experiment was performed for confirmation. The result confirmed that the way of supporting the flat board is unlikely to have a significant impact on the test results. The experiment also indicated the matters to be noted for enhanced reliability, which will be described in the draft.

4.3 Evaluation of Test Methods for Mix Proportion for Construction

The tilt flow testing[25)], round penetration tester testing[26)], and excitation deformation testing[27)] were newly examined as test methods for determining mix proportion. In the standardized tests, concrete with the normal mix proportion, for the fresh properties with higher viscosity, and for coarser fresh properties was prepared by adjusting the fineness modulus, fine aggregation ratio, water content per unit, and chemical admixtures, with the target slump of 18 cm and 21 cm. The results confirmed that, for example, in the tilt flow testing, even with the mix proportions for the same slump, the apparent yield value τ_y acquired was different for each mix proportion. This shows that this test method can evaluate the concrete with the same slump but with different fresh properties.

4.4 Follow-Up Study of On-the-Site Experiment Performed by JCI-TC074A Committee

JCI-TC074A ("Test Methods for Reliable Construction Technical Committee" Chairman: Toshiki Ayano), the predecessor of this committee, carried out the following experiments to verify: whether the concrete actually applied in the construction has the performance specified at design time; and the reliability of the construction.

Series I: When selecting the materials and mix proportions, test methods considered to be effective for evaluating the characteristics of fresh concrete were chosen, to apply to the concrete with the fresh characteristics that are normal, high in viscosity, and coarse, for each of two types of slump, and their effectiveness was evaluated.

Series II: Column specimens and wall specimens made of the above-mentioned concrete with different fresh properties were prepared, to investigate whether the various types of test methods can detect the quality change in the concrete when changes are made to a series of the construction conditions of placing, compaction, formwork removal, and curing.

This WG carried out a follow-up study on the specimen that had been created in the Series II and exposed to outdoor for about seven years. The examination items were: estimation compressive strength by test hammer, compressive strength by core sample, neutralized thickness, salinity penetration depth, surface air permeability, surface water absorption test, and conductivity.

Among the test results, for the neutralized thickness for example, in the column-shaped specimens prepared with the slump of 8 cm, the average neutralized thicknesses for each of normal and high-viscosity concrete were almost the same, 8.1 mm and 7.0 mm, respectively. The result for the coarse concrete was the largest, 11.6 mm. On the other hand, the coefficient of variation of the neutralized thickness for the normal concrete was smaller than that of the coarse and high-viscosity concrete. The wall specimens made of the concrete with the slump of 18 cm also had the same tendency.

These results suggest that the average quality of the hardened concrete and its variance vary depending on the difference in the fresh properties even with the same slump.

5. Summary

This committee makes it clear how important both the ideal framework of the PDCA cycle for enhancing the quality assurance and details of each of the four stages, P, D, C, and Aby summarizing the importance of rediscovering the significance of rotating the PDCA cycle are. One of the characteristics of the PDCA cycle proposed by this committee is that it is a hierarchical structure comprised of the PDCA cycle for the entire concrete work and that for the execution of work on concrete, to clarify that the PDCA cycle is to be rotated while concrete is being placed. In view of further spiral-up of the PDCA cycle, the committee has actively incorporated the cutting-edge analytical technologies and newly developed concrete-evaluation-technology with regard to the fluidity and filling properties of concrete in each of P, D, C, and A as appropriate. The hope of the committee is that this outcome will lead not only to the rotation of the PDCA cycle but also to the reliable concrete construction realized by the spiral-up of the PDCA cycle.

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