Committee Report : JCI- TC074A

Technical Committee on Quality Control Testing Method to Access the Certainty of Construction

Toshiki AYANO, Tsuyoshi MARUYA, Masarou KOJIMA, Kimitaka UJI,
Keiichi IMAMOTO, Shinji URANO, Ken-ichirou NAKARAI, Yasumichi KOSHIRO,
Koichi TAKAHASHI

Abstract

The Committee conducted research to elucidate the current state of test methods to confirm the certainty of construction execution. Availabilities of the test methods to assess that the performance of placed concrete actually meets the designed performance was investigated. Test methods to evaluate the property of concrete and their adequate timing to be applied in each execution stages were also researched. Furthermore, a questionnaire survey was conducted and summarized particularly regarding new test methods to evaluate the properties of concrete and test methods to confirm if various specifications agreed upon before execution are actually secured. Field tests were conducted as well to investigate the effect of execution on the in-situ qualities of concrete.

Keywords: certainty of execution, concrete in the structure, filling capability, quality of cover concrete, quality test method

1. Introduction

The performance of concrete in a built structure may not always meet the performance requirements established at the design stage. The limit state design method is assumed to consider possible differences by material factors. In actual construction, however, efforts are made to minimize the difference between the strength of specimens and the in-situ strength by careful execution in accordance with various guidelines at each stage of transportation, placement, consolidation, finishing, curing, and form/shoring removal. In view of the current design technology and the state of execution, it is vital to develop assessment test methods to accurately confirm the achievement of the established specifications at each stage of execution along with the development of techniques to determine detailed material factors. At the stage of form removal, for instance, it is important that the attainment of an in-situ compressive strength of 5 N/mm^2 can be accurately confirmed by an appropriate test method.

For this reason, the Committee aims to investigate the current state of quality assessment test methods required for each stage of execution, as well as to elucidate the test methods to evaluate the property of concrete and their adequate timing to be applied in each execution stages, so as to ensure the execution of concrete having the performance intended in the design.

Table 1: Members of the Committee

Chairman of Committee	Toshiki AYANO	Okayama University
Secretary of Committee / Manager of Subcommittee	Tsuyoshi MARUYA	Taisei Corporation
	Masarou KOJIMA	Takenaka Corporation
Manager of Subcommittee	Kimitaka UJI	Tokyo Metropolitan University
Secretary of Subcommittee	Keiichi IMAMOTO	Tokyo University of Science
	Shinji URANO	Shimizu Corporation
	Ken-ichirou NAKARAI	Gunma University
Committee Member	Michitoshi IWATA	East Japan Railway Company
	Yoshiaki KATO	The University of Tokyo
	Takehiro KAMAMOTO	Nippon Expressway Research Institute Co.,Ltd.
	Toshinobu YAMAGUCHI	Kagoshima University
	Kazuhisa YODA	Kajima Corporation
	Jun LIANG	Taisei Corporation
	Yoshiki UNO	Sato Kogyo Co.,Ltd.
	Yasumichi KOSHIRO	Obayashi Corporation
	Koichi TAKAHASHI	Hachiyo Consultant Co.,Ltd.
	Makoto TANIMURA	Taiheiyo Cement Corporation
	Masaki OHSHIMA	BASF Pozzolith Ltd.
	Shusuke KUROIWA	Taisei Corporation
	Kuniaki SAKURAI	Obayashi Corporation
	Hisashi SUGIYAMA	Building Research Institute
	Hiroshi WATANABE	Public Works Research Institute

Table 1 lists the committee members. Concretes having the same slump may show different resistances to segregation, passabilities through spaces between reinforcing bars, etc. Working Group (WG) 1 for adequate test methods for concrete performance assessment (Manager: Kimitaka Uji) conducted research on the test methods proposed for selecting adequate mixture proportions of concrete and instances of reflecting the results to execution. WG 2 for performance assessment based on execution methods (Manager: Masaro Kojima) investigated test methods to appropriately assess the required performances at the stages of consolidation, curing, and form/shoring removal, including the possibility of simple

additional tests. WG 3 for comparison with test methods overseas (Manager: Tsuyoshi Maruya) conducted a survey on the current state of techniques overseas for testing the qualities of concrete during execution to clarify the differences between foreign and Japanese standards.

The Committee also conducted a questionnaire survey on test methods to confirm whether the various specifications established before execution are actually ensured, particularly regarding those originally developed in respective companies and those practiced based on experience. Execution tests were conducted as well, assuming the cases with or without adequate execution carried out based on concrete quality assessment test results. The committee activities also included tests on column and wall members to investigate the effects of execution methods on the qualities of concrete in the structure.

2. Requirements of standards/guidelines and their backgrounds

This section describes the requirements related to the qualities and execution of concrete in civil engineering and architectural fields as well as their grounds and backgrounds. **Table 2** gives the requirements related to execution in both fields. The requirements for the workability, placement, and curing of concrete specified in JASS 5 in the architectural field are introduced as an example as follows:

As to the proportioning conditions, the maximum water-cement ratio (W/C) and minimum cement content are specified to ensure the required performance including workability and uniformity. For normal portland cement, the W/C and cement content are required to be not more than 65% and not less than 270 kg/m^3, respectively. The requirement for the time limit from the beginning of mixing to the end of placing was established to prevent large difference in the slump and air content over time.

The time limit between two layers of concrete was established, from the value of penetration resistance in the range of preventing a cold joint, as the time during which re-vibration of preceding concrete is possible. For consolidation, the vibrator is required to be inserted vertically, with the tip reaching below the surface of the preceding layer, until the paste appears on the surface of the placed layer. The insertions should be distributed at intervals not larger than 60 cm, which was established based on the radius of influence of an internal vibrator with a nominal diameter of 45 mm.

For curing, the sheathing retention time, moist curing, and curing temperature are specified. Moist curing includes covering with sheathing, watering/spraying, and the application of a curing compound, for each of which the curing period is specified. When concrete strength reaches 10 N/mm^2, curing may be terminated even before the end of the specified curing period. The curing periods were established because the strength development is inhibited to a greater extent and carbonation is accelerated as the early moist curing period decreases. However, if a strength of not less than 10 N/mm^2 is ensured, then the subsequent strength development and carbonation depth will become comparable to the case with a sheathing retention time of 7 days. The time to form removal, which is included in the moist curing period, is specified for each cement type and mean temperature range. When the strength reaches 5 N/mm^2, sheathing may be removed even before the end of the specified retention period. This is the minimum strength to be resistant to early frost damage and loads and impacts from subsequent construction work. After removing sheathing, watering/spraying should be continued until the end of the specified moist curing period. Shoring should be removed after confirming the attainment of the design strength to prevent deleterious bending cracks/deflection. The curing temperature is stipulated in Article 75 (Curing of concrete), Order for Enforcement of the Building Standards Act as "The concrete temperature shall be maintained at not less than 2°C during placing and for five days after placing, and concrete shall be cured so that the setting and hardening of concrete would not be impaired by drying and vibration." It has been proven that concrete made of normal portland cement can achieve a strength of 5 N/mm^2 in five days, if its temperature is maintained at not less than 2°C.

Table 2: Requirements related to execution

Item		Requirement
JSCE Standard Spec.	Workability	A standard slump is specified depending on the cross-sectional area and bar arrangement.
	Placement	Drop distance: 1. Depth of a layer: 40 to 50 cm Maximum time between layers: 2.5 air temp. of 25°C or less, 2 h with an outdoor air temp. exceeding 25°C
	Consolidation	Intervals between vibrator insertions: 50 cm Depth of insertion: 10 cm into the preceding layer Vibration time: 5 to 15 sec
	Form retention period	Until a compressive strength of 3.5, 5, or 14 N/mm^2 is achieved depending on member type
	Moist curing	A period is specified for each cement type.
JASS 5	W/C	Maximum value of W/C
	Cement content	Minimum value of cement content
	Time limit from mixing to the end of placement	Within 2 h with an outdoor air temp. of less than 25°C Within 1.5 h with an outdoor air temp. of 25°C or more

	Consolidation	Intervals between insertions: Not more than 60 cm Apply vibration until paste appears on the concrete surface.
	Time limit between layers	As a rough guide, 2.5 h with an outdoor air temp. of less than 25°C and 2 h with an outdoor air temp. of 25°C or more, assuming a transportation time of 1 h.
	Sheathing retention period	Sheathing: A specified period or not less than 5 N/mm² Shoring: Not less than the design strength
	Moist curing	A specified period or not less than 10 N/mm²
	Curing temperature	Maintain the concrete temp. at not less than 2°C for 5 days or more after placing

3. Quality assessment test methods for concrete during execution

3.1 Quality assessment methods employed for proportioning

Concrete is roughly classified into three types from the aspect of fluidity and deformability: normal concrete, high fluidity concrete, and (extremely) stiff consistency concrete, with test methods being proposed to assess their properties. **Table 3** shows the assessment test methods for the filling capability of normal concrete (fluidity and segregation resistance) as an instance, including those extracted from the responses to the questionnaire conducted by the Committee. The fluidity is assessed by applying vibration or impact. Refer to the Committee Report for details.

Methods of assessing the filling capability of cement grout mortar, which has been used as a filling material for various uses, have been proposed and put to practical use. The fluidity of grout for prestressing concrete, for instance, is assessed by the J-funnel test specified in a JSCE standard, while it is assessed in NEXCO, for instance, by its original test methods assuming the construction conditions of actual structures.

Table 3: Fluidity/segregation resistance test (normal concrete)

Type	Test method
Vibratory methods	U-shaped filling apparatus + spud vibrator Box-type tester for passability through spaces + spud vibrator L-shaped flow tester + spud vibrator Shaking L-shaped flow tester Box-type apparatus + spud vibrator Vibration flow tester Passing test through flow-blocking bars on slump board
Impact methods	Spread (DIN flow) Tamping, etc.

3.2 Acceptance inspection of fresh concrete

The prerequisite for a test method to be adopted for acceptance inspection is a capability to measure in a short time with the required accuracy. Among the number of methods for assessing the filling capability of concrete introduced in section 3.1, such simple methods as spread (DIN flow) testing and dumping testing are realistic for normal concrete from the aspect of routine control/inspection, aside from the slump testing, the standard test method currently in practice. The establishment of the assessment/judgment criteria for these tests is therefore anticipated.

A number of test methods have been proposed and put to practical use for measuring the unit water content, which is an important test item for ensuring durability. The air meter method appears to have been predominantly used because of its simplicity.

3.3 Confirmation of consolidation

Normal concrete should be consolidated with a length of time and spacing suitable for its consistency to construct a concrete structure with no placing-related defects. A test method for assessing the compactibility focusing on the consolidation energy has been proposed as a technique for this purpose[1]. In this method, the energy necessary for consolidating concrete proportioned identically to the concrete to be placed is determined beforehand by the apparatus and evaluation method shown in **Fig. 1**. The consolidation time and spacing are examined at the stage of placement planning based on the test results.

Vibrators capable of detecting the energy imparted to concrete have also been developed to be useful for judging if the required consolidation has been carried out at the time of actual placing. Efforts are being made to place sensors at appropriate points on reinforcing bars to detect and confirm the filling of concrete[2], while the application of devices for detecting the state of filling from the outside of formwork is also being examined[3].

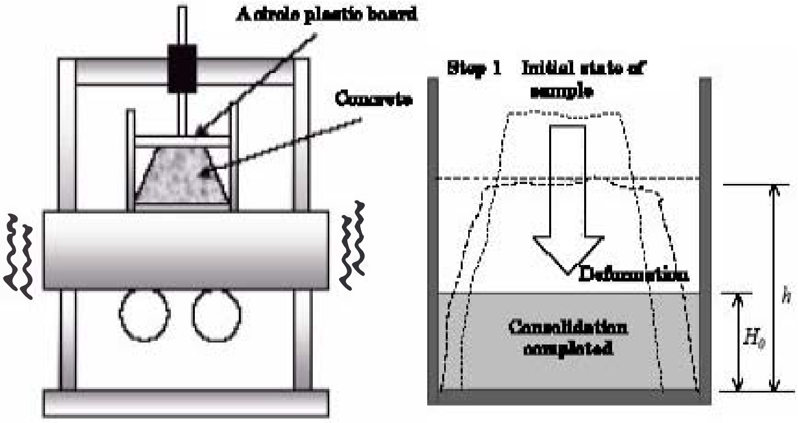


Figure 1: Vibratory consolidation testing apparatus[1]

3.4 Strength confirmation for permitting form removal and terminating curing

Strength confirmation tests are classified into three types: nondestructive methods, semi-destructive methods, and methods using indirect specimens. In this section, those newly studied and developed recently are briefly introduced.

Scratch testing[4], which is classified into the nondestructive group, is a method whereby the surface of concrete is scratched with a constant force using a simple tester to assess the concrete strength from the width of the scratch. The investigation so far has revealed that the effects of cement type, W/C, and concrete age are relatively weak.

Penetration tests, which fall in the semi-destructive category, began with the ECL method in shield tunneling. Attempts are currently being made to apply this method to the judgment of the time for form/shoring removal from secondary lining concrete for mountain tunnels. In this method, a penetration testing machine is pressed onto concrete under a force of 300 N, and the diameter of the resulting indentation is measured to estimate the compressive strength. There is another method whereby the strength is estimated from the relationship between the compressive strength and the Windsor pin penetration resistance value. Though this method was originally developed for low strength old concrete, it is reported to be applicable to the judgment of the time for formwork removal at an early age.

In the BOSS (Broken off specimens by splitting) specimen method, which is a method using indirect specimens, rectangular solid 'BOSS' specimens molded simultaneously with the structural concrete are split from the structure and subjected to quality testing. The benefit of this method is direct inspection of the in-situ concrete without damaging the structure. The problem of repairing the structure after taking specimens is marginal.

Table 4: Strength confirmation tests

Type	Test method
Non-destructive	Ultrasonic pulse velocity test, rebound test, scratch test, etc.
Semi-destructive	Soft coring, drilling, penetration test, Windsor pin penetration test, etc.
Indirect specimen	Method using sealed specimens, method using BOSS specimens, etc.

3.5 Confirmation of properties after hardening

Table 5 lists test methods applicable to confirmation of the cover depth and qualities of cover concrete other than strength.

Air permeability test methods for confirming the quality of cover concrete include the drilling method in which a small hole is drilled in concrete, capped with a plastic plug, and depressurized to determine the time required for the pressure change; the single and double chamber methods in which the chamber is depressurized to determine the time required for the pressure change.

Water absorption/water permeability tests include the surface method with spontaneous water absorption; drilling method with spontaneous water absorption; and pressurized water permeability method. The surface method/spontaneous water absorption is a method in which an acrylic cap is attached to the concrete surface and a hydraulic head pressure is applied to grasp the water-absorbing property of concrete. The drilling method with spontaneous water absorption is a method in which the water absorption of concrete is assessed by the time to the specified water absorption through a drill hole. Drill holes used for air permeability testing can be used for this method. The pressurized water permeability method also uses a drilled hole and introduces pressurized water into a surface chamber to calculate the water permeability coefficient of concrete.

Table 5: Tests to confirm the properties after hardening

Type	Test method, etc.
Curing of specimens	Standard curing, seal curing on site, water curing on site, etc., to the specified ages in consideration of the scale of the structure and construction environment
Quality of cover concrete	Air permeability tests (drilling method, single chamber method, double chamber method), water absorption/permeability tests (surface method + natural absorption, drilling method + natural absorption, pressurized water permeability method), etc.
Cover depth	Electromagnetic induction method, electromagnetic wave radar method, etc.

4. Experiment

4.1 Outline of experiment

Various test methods that are considered effective in evaluating the properties of fresh concrete and changes in the qualities of hardened concrete due to post-placement execution conditions were selected from the literature and the results of the questionnaire survey. Their applicability was examined by the following two series of experiments.

In series I, test methods that are considered effective in evaluating the properties of fresh concrete during material selection and proportioning were extracted. Their effectiveness was assessed by applying them to fresh concretes proportioned with two
three levels of consistencies: standard, viscous, and rough.

In series II, the above-mentioned concretes with different fresh properties were placed in forms for column and wall members and subjected to different conditions of consolidation, form removal, and curing to examine if various test methods can detect tbe resulting changes in their qualities. Also, test methods proven to be simple and to provide effective results were applied to the acceptance inspection for series II to assess the properties of fresh concrete delivered from a ready-mixed concrete plant.

Table 6 lists the factors and levels of experiment in each series. The standard, viscous, and rough consistencies of fresh concrete were adjusted by changing the ratio of fine to coarse grains of fine aggregate and tbe ratio of fine aggregate to total aggregate.

Table 6: Factors and levels of experiment

Series	Factor	Level
I,	Slump	8 cm,
I, II	Concrete consistency	Standard, viscous, rough
II	Member type and bar arrangement	Column: Main bars: D25 bars at 100 and 150 mm spacing
		Wall: Horizontal and vertical D13 bars at 150 mm spacing
II	Consolidation time	5,
II	Demolding age	1 day, 3 days
II	Duration of moist curing	To demolding age, 7 days

4.2 Assessment of test methods for fresh concrete employed during material selection and proportioning (series I)

Tests in series I were conducted in a laboratory using a forced mixing-type mixer with a nominal capacity of 200 liters. **Tables 7** and **8** give the test metbods under assessment and mixture proportions, respectively.

Figure 2 shows the relationship between tbe energy imparted to concrete by consolidation and the degree of consolidation. When compared by the energy required to the completion of consolidation (degree of consolidation: 99.5%), concrete witb a standard consistency required the lowest energy, followed by concrete with a viscous consistency and that with a rough consistency in this order for both target slumps. It is tberefore found that the energy required to obtain densely consolidated concrete widely varies depending on the material and mixture proportions.

Test methods were then assessed as to how these differences in the properties of concrete are expressed by each method, as well as the simplicity of judgment and time required for testing. **Figure 3** shows typical scenes of testing. The assessment results of the test methods are summarized in **Table 9**. The test methods expressed the differences in the properties of fresh concretes under test due to differences of the materials and mixture proportions from various aspects, such as viscosity, passability through reinforcing bar spaces, and proneness to segregation. Refer to the Committee Report for details of the applicability of these test methods.

Table 7: Various tests conducted

Test type		Test method	Series
Fresh properties/ Filling capability	Basic tests	Slump test	I, II
		Air content test	
		Slump flow test	
	Assessment tests for fluidity/ segregation resistance	U-shaped filling devise + spud vibrator	I
		L-shaped flow tester + spud vibrator	
		Passing test through obstacles on slump board	
		*Rotational viscometer	
		Vibrated L-shaped flow test	I, II
		Spread (DIN flow) test	
		Passability test (box type)/segregation test	
		Vibration flow test	
		Tamping flow test	
		*Consolidation energy test	
	Tests for filling capability/ consolidation	Filling detector	II
		*Vibration acceleration of concrete in member	
		*Unfilled area ratio on formed member surfaces	
		*Core density/aggregate area ratio/void percentage	
Placement-induced changes in performance	Strength confirmation for demolding/ terminating curing	Scratch test	II
		Compressive strength of specimens	
		Various tests on drilled cores	
	Qualities of structure (cover concrete)	Rebound test	
		Various tests on drilled cores	
		*Pore size distribution	
		Air permeability (Torrent method, single chamber method, drilling method, RILEM method)	
		*Accelerated carbonation test	
	Cover depth	Electromagnetic induction method	
		Electromagnetic wave radar method	
		*Chipping test	

Table 8: Mixture proportions used for tests

Mixture No.	Concrete type	Target slump (cm)	Target air content (%)	W/C (%)	Fine-total agg. ratio (%)	Unit water content (kg/m3)
1	Standard	8	4.5	57.5	46.0	285
2	Viscous				46.0	
3	Rough				42.5	
4	Standard	18			46.0	313
5	Viscous				46.0	
6	Rough				42.5	

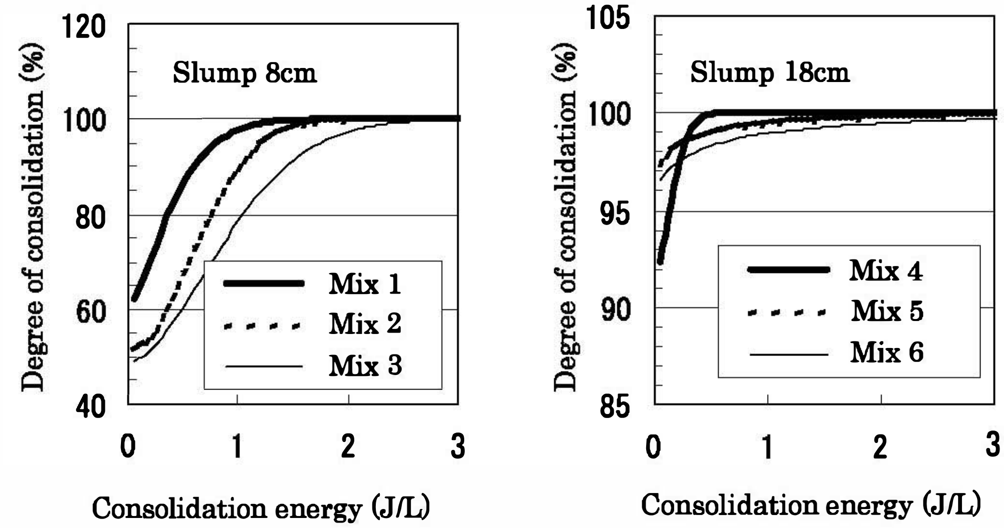


Figure 2: Consolidation energy test results

Figure 3: Views of tests

Table 9: Assessment of test methods for fresh concrete

Test	Subject	Measurement index	Applicable mixtures (No.)		Time required (min)
Spread (DIN flow)	Viscosity/ workability (ease of	Degree of spread by impact	1, 2, 3, 6	Suitable for small slump	0
Tamping			1, 2, 3		20

L-shaped flow + spud vibrator	consolidation)	Time to flow or deform to a specified distance under vibration	-	Difficult to obtain a specific tendency	10
Vibrated L-shaped flow			1, 2, 3	Suitable for small slump	7
Vibration flow			4, 5, 6	Suitable for large sump	7
U-shaped filling device + spud vibrator	Passability through rebars/ segregation resistance	Time to a specified height through rebar obstacles, spread under specified vibration, passing speed	-	Difficult to conduct, as many mixtures do not reach the specified height	10
Simple placeability assessment by passability test through flow obstacles		Changes in coarse aggregate content in addition to the above	1, 2,	Applicable to both small and large slumps	25
Passability through spaces (Box type)					30

4.3 Execution tests using concretes having different properties (series II)

For the execution tests in series II, concretes were produced at a commercial ready-mixed concrete plant using the same materials and mixture proportions as series I. Column specimens with a shape and dimensions shown in **Fig. 4** were placed using 8 cm-slump concretes with a standard, viscous, and rough consistency (columns A, B, and C, respectively). Wall specimens with a shape and dimensions shown in **Fig. 5** were placed using 18 cm-slump concretes with a standard, viscous, and rough consistency (walls D, E, and F, respectively). After being subjected to the tests for the fresh properties selected based on the results of series I, concretes were placed in each form in three layers using concrete buckets. For consolidation, a high frequency internal vibrator 45 mm in diameter was inserted after placing each layer and operated for 5, 10, and 15 sec for the first, second, and third layers, respectively. The test methods given in **Table 7** were conducted. During the consolidation process, the vibration acceleration was measured, and the state of filling and consolidation were checked using the filling sensors fixed to reinforcing bars beforehand. When consolidation was completed, the state of filling was non-destructively examined from the outside of the forms. Part of the test results are presented in the following sections. Refer to the Committee Report for details.

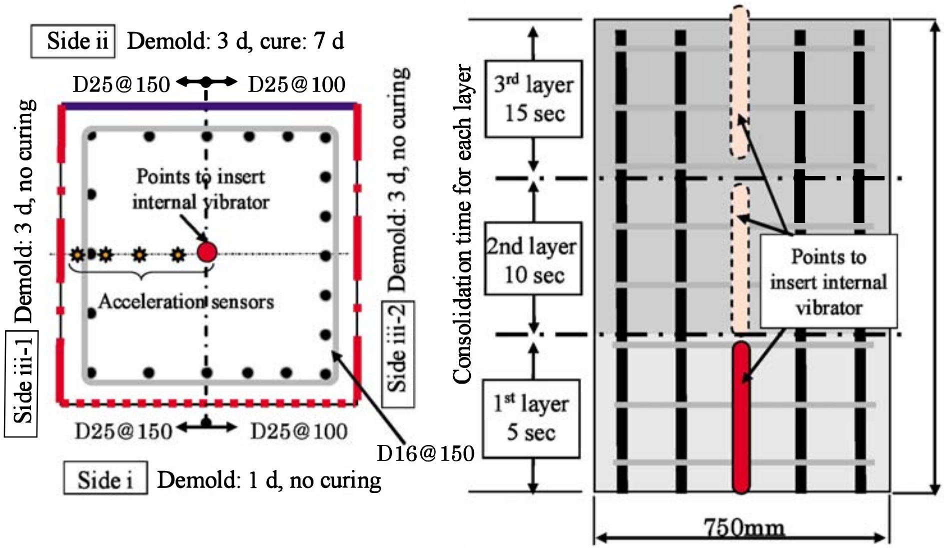


Figure 4: Outline of column specimen

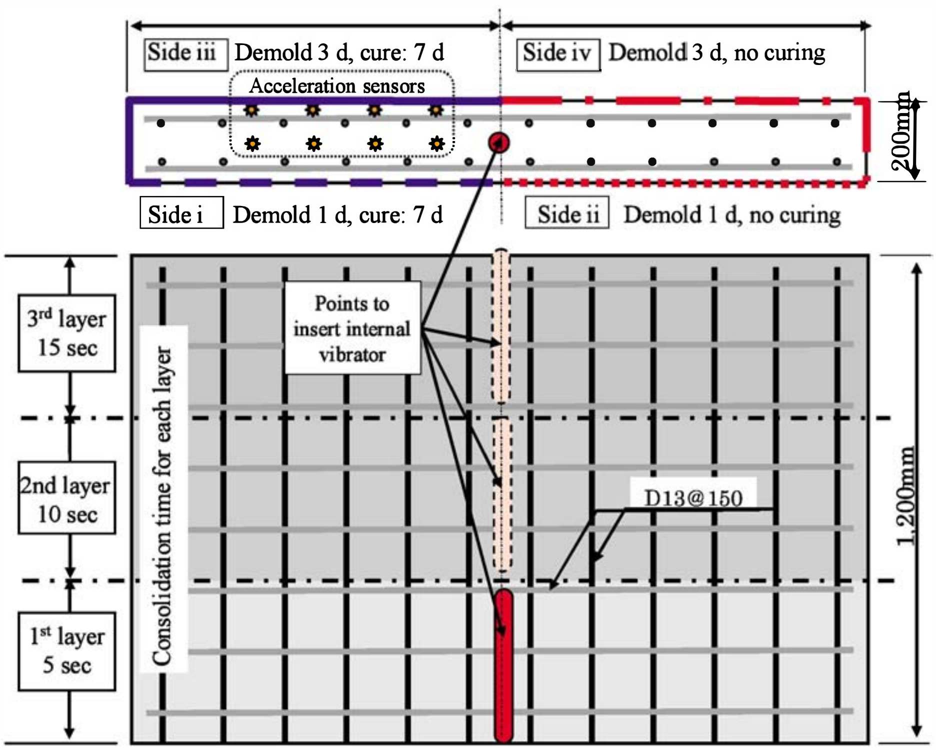


Figure 5: Outline of wall specimen

(1) Acceptance inspection of fresh concrete

Figure 6 shows typical results of fresh concrete assessment by new test methods conducted at the time of delivery. The differences in the properties of concretes, despite the same slump and strength, due to different materials and mixture proportions were expressed by these tests. The results of placing in terms of the unfilled area ratio and concrete qualities were then examined in relation to the as-delivered properties of fresh concrete obtained in the acceptance tests and the placing conditions (consolidation time and spacing).

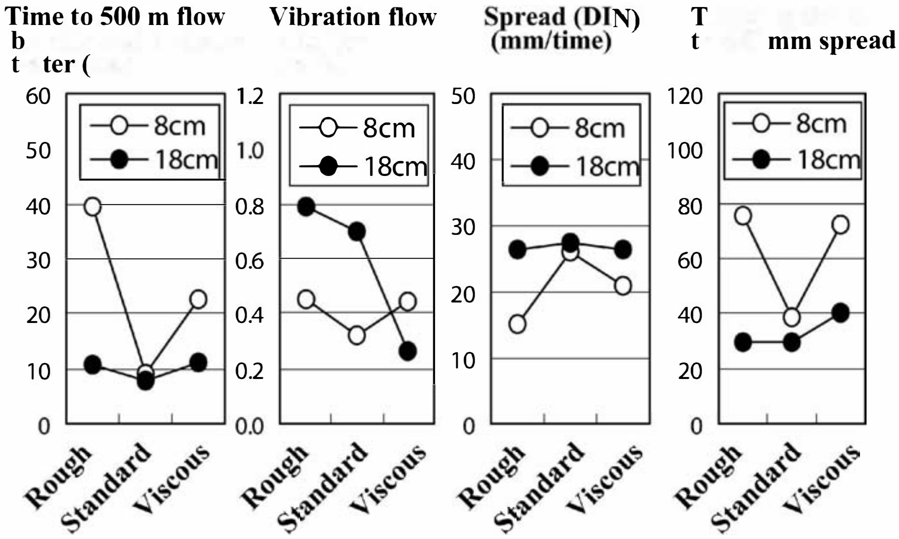
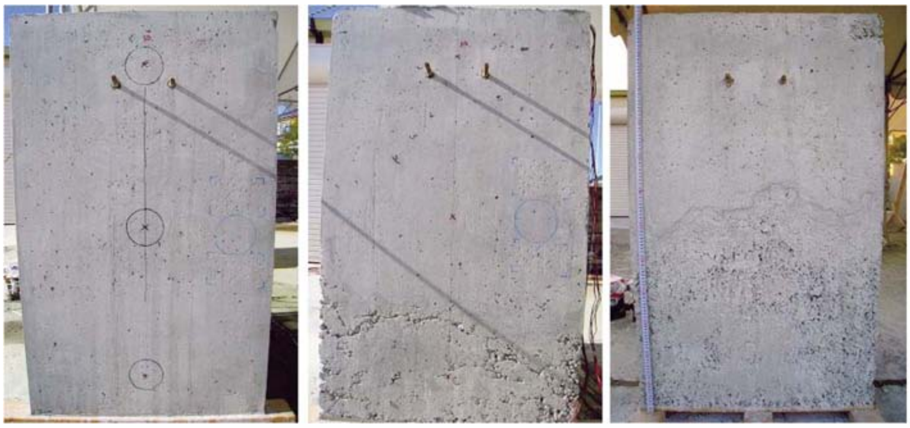


Figure 6: Evaluation test results of concrete at acceptance inspection

(2) Confirmation of consolidation/filling

Figs. 7 and **8** show typical appearances of fabricated specimens and the unfilled area ratios of layers consolidated for different lengths of time, respectively. The unfilled area ratio, which is the ratio of the sum of the area of projection with no concrete and the area of honeycombs, was determined from binalized images made by marking the unfilled area while checking the actual surface. In column specimens with a slump of 8 cm, the unfilled area ratio was greater in the first layer with the shortest consolidation time, but this is not necessarily the case with wall specimens with a slump of 18 cm. This can be because the vibration for consolidating upper layers was propagated through the forms, affecting the state of consolidation of lower layers, as concrete with a large slump can be filled with a low vibration energy.



Column A (Standard) Column B (Viscous) Column C (Rough)

Figure 7: Side of specimen

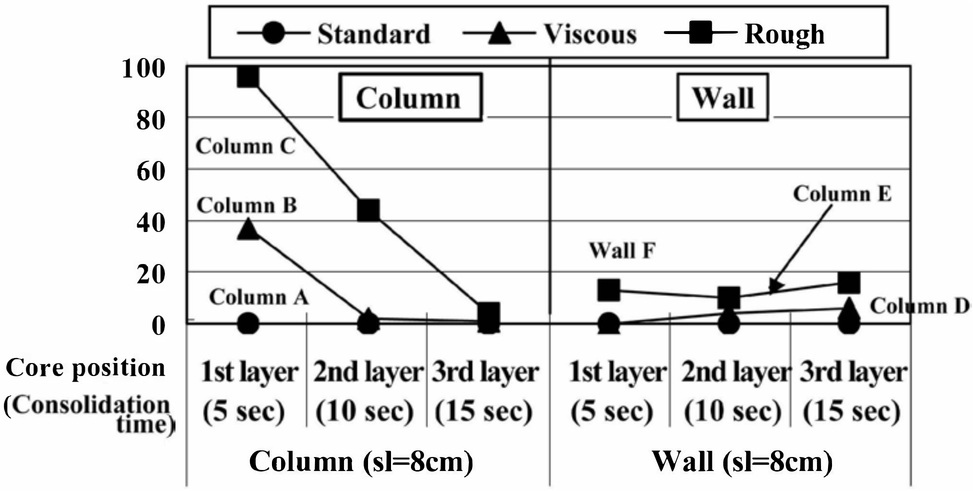


Figure 8: Unfilled area ratio of each layer

Despite the same consolidation conditions for all consistencies, the rough consistency concrete led to the largest unfilled area ratio, followed by the viscous consistency concrete and standard consistency concrete, in this order, regardless of the member type (slump). **Figure 9** shows the relationship between the time to 500 mm flow by vibrated L-flow testing and the unfilled area ratio on the specimen surface as an example of the relationship between the fresh properties and the filling ratio. In regard to the present specimen size and consolidation conditions, it was found that an 8 cm-slump concrete with a time to 500 mm flow of around 10 sec and 20 sec can be thoroughly filled to form surfaces of a column by consolidation for 5 sec and 10 sec, respectively. Also, an 18 cm-slump concrete with a time to 500 mm flow of around 8 sec can be thoroughly filled to the form surfaces of a wall.

Figure 10 shows typical results of sensing the state of filling through the form surface immediately after consolidation. Sensing was conducted at specified points, and the appearances of the points were visually observed after hardening to compare with results. As a result, the nondestructive sensing agreed with the visual observation by a ratio exceeding 90%, proving to be capable of judging the

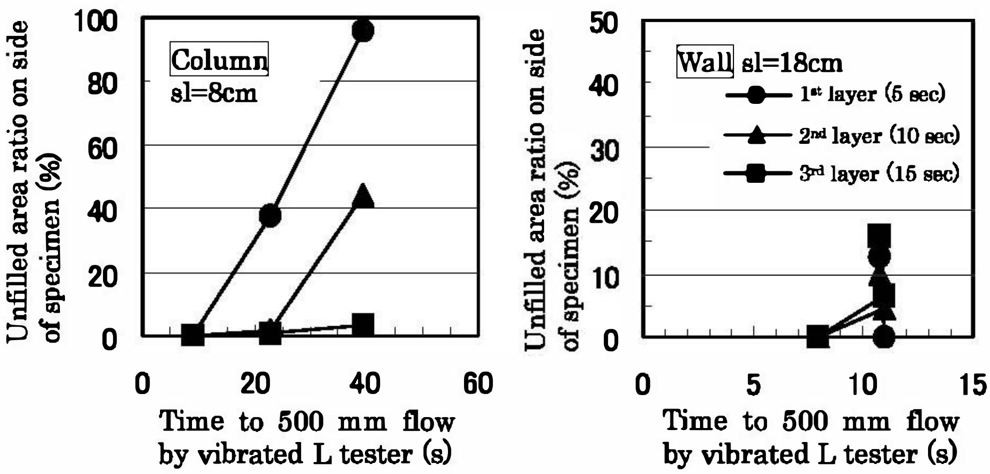
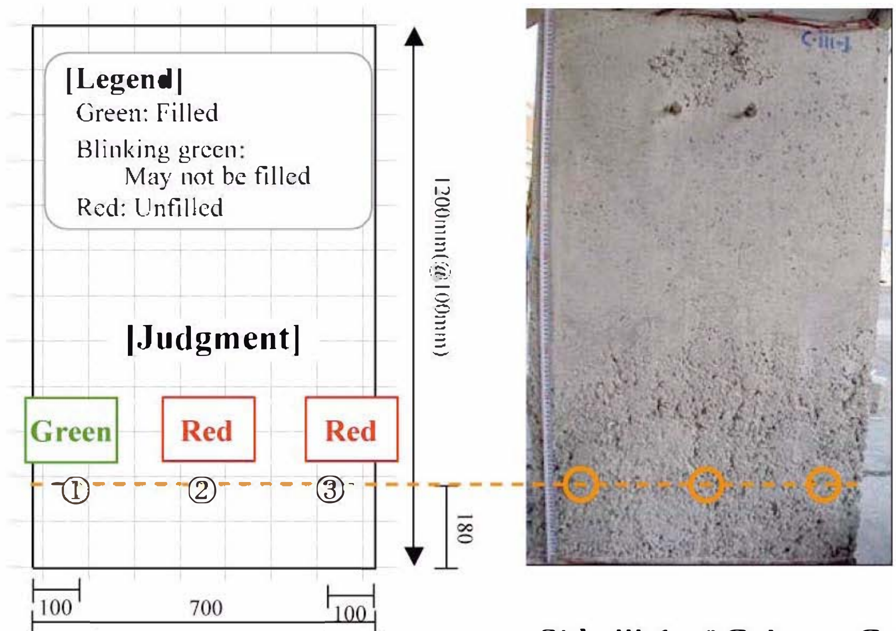


Figure 9: Relationship between the evaluation of fresh properties and unfilled area ratio



Side iii-1 of Column C

Figure 10: Example of filling detection

(3) Confirmation of strength development

The judgment of the strength for form removal is generally made by confirming that the strength of cylindrical specimens water-cured or seal-cured on site exceeds 5 N/mm^2. In the present experiment, the strengths for form removal and termination of curing were confirmed by using a 'scratch tester' proposed by the Japan Society for Finishing Technology along with strength testing on cylindrical specimens seal-cured on site. A scratch was made on the side of each seal-cured cylinder before strength testing to examine the relationship between the scratch width and the compressive strength. As a strong correlation was confirmed between them, scratch tests were applied to the surfaces of the column and wall specimens to estimate the surface strength, with the results being shown in **Fig. 11**. When compared with the compressive strength of cores drilled from the upper portions (near the centers of the third layers), the strength estimated from the scratch, i.e., the surface strength, was slightly lower. This agrees with the tendency of compressive strength distribution from the surface inward determined using cores 25 mm in diameter. This method of estimating the compressive strength from a scratch width can be effectively utilized, as it provides the strength of concrete surfaces, which should be assessed in the judgment of the time for form removal and allows a conservative judgment for the termination of curing.

Figure 12 shows the compressive strength of cores drilled from the centers of specimens in ratios to the strength of seal-cured specimens. The strengths of the top and middle layers were lower than those of the bottom layers in both column and wall specimens. In the present tests, the compressive strength was affected more by densification under the weight of the upper layers than by the consolidation time. The relationship between the consolidation time and the compressive strength therefore remained unclear.

The differences in the surface concrete strength due to differences of form removal time and curing were investigated by drilling cores 45 mm in diameter and 90 mm in length from the surfaces (**Fig. 13**). When compared in ratios to the strength of concrete stripped at an age of 3 days and cured to an age of 7 days, the strengths of surfaces with curing (surface ii of columns and surface iii of walls) were higher than those of surfaces without curing (surface i of columns and surface ii of walls) both in the columns and walls. Concrete surfaces with and without curing were thus found to lead to different surface structures, reaffirming the importance of early curing.

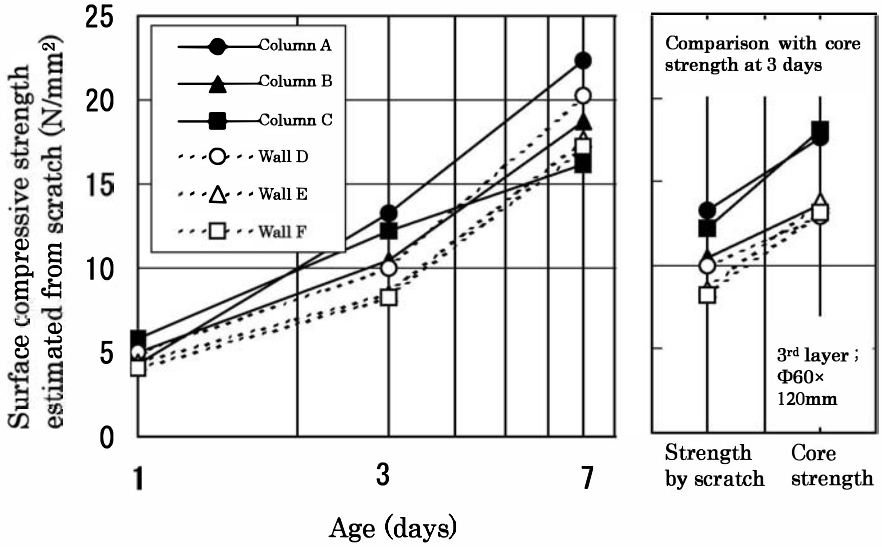


Figure 11: Compressive strength estimated from scratch

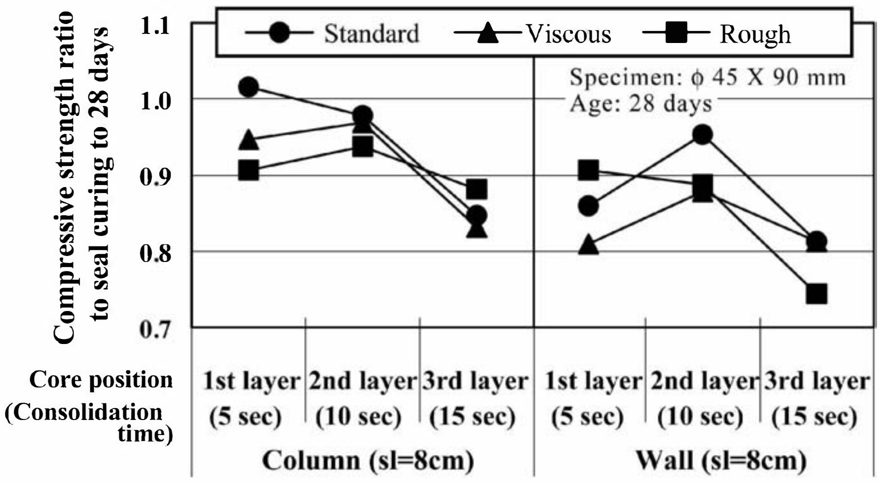


Figure 12: Effect of compaction time

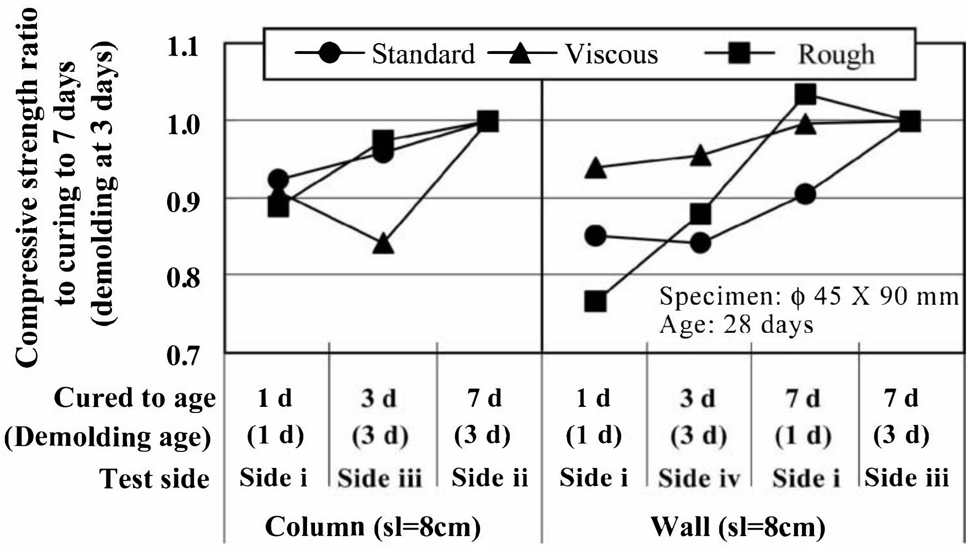


Figure 13: Effects of form removal age and curing condition

(4) Qualities of cover concrete

The effects of the properties of fresh concrete and the execution method on the qualities of cover concrete were investigated from the aspects of surface air permeability and strength properties.

According to the estimation by scratch testing, the compressive strength of the concrete with a standard consistency (A and D) was the highest, followed by a viscous consistency (B and E) and rough consistency (C and F) in this order both in columns and walls. This tendency agreed with the tendency of the unfilled area ratio. **Figure 14** shows the relationship between the compressive strength estimated by scratch testing and the surface air permeability. When tested by the Torrent method and single chamber method, the estimated compressive strength roughly tended to decrease as the air permeability increased, though with a slight scatter.

Figure 15 shows the relationship between the compressive strength estimated by rebound hammer testing and the surface air permeability. The test results of the medium layer consolidated for 10 sec are shown to represent each specimen. According to rebound hammer testing, the compressive strengths of wall specimens (D to F) were lower than those of column specimens (A to C) regardless of curing. This agrees with the tendency of the compressive strength of drilled cores 100 mm in diameter. Correlation is recognized between the air permeability coefficient of columns by the Torrent method and single chamber method and the estimated compressive strength, while no particular correlation is found for wall specimens or the data by the drilling and RILEM methods.

Accordingly, the experiments in the two series showed the possibilities of quality assessment tests to detect fresh concrete properties that have not conventionally been assessed and quality differences derived from differences of execution conditions. These will contribute to ensuring certainty of execution.

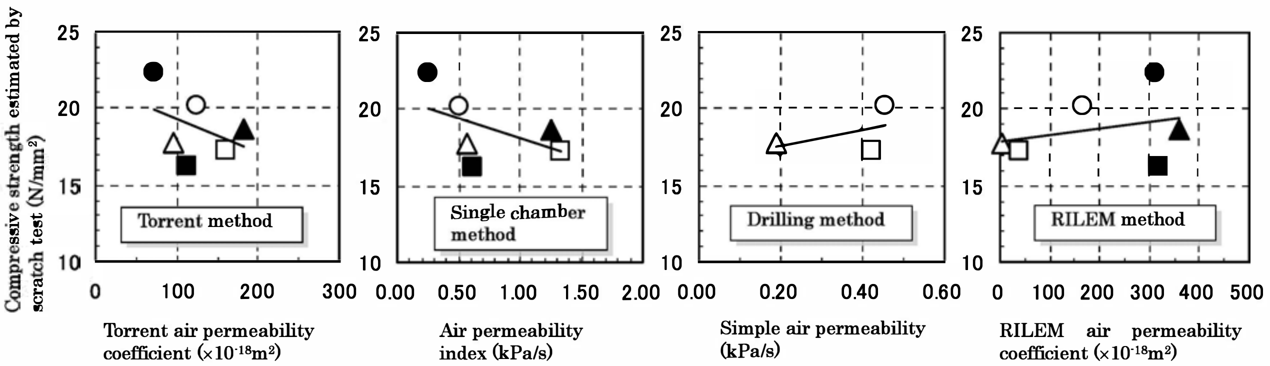


Figure 14: Relationship between air permeability by different test methods and compressive strength estimated by scratch test

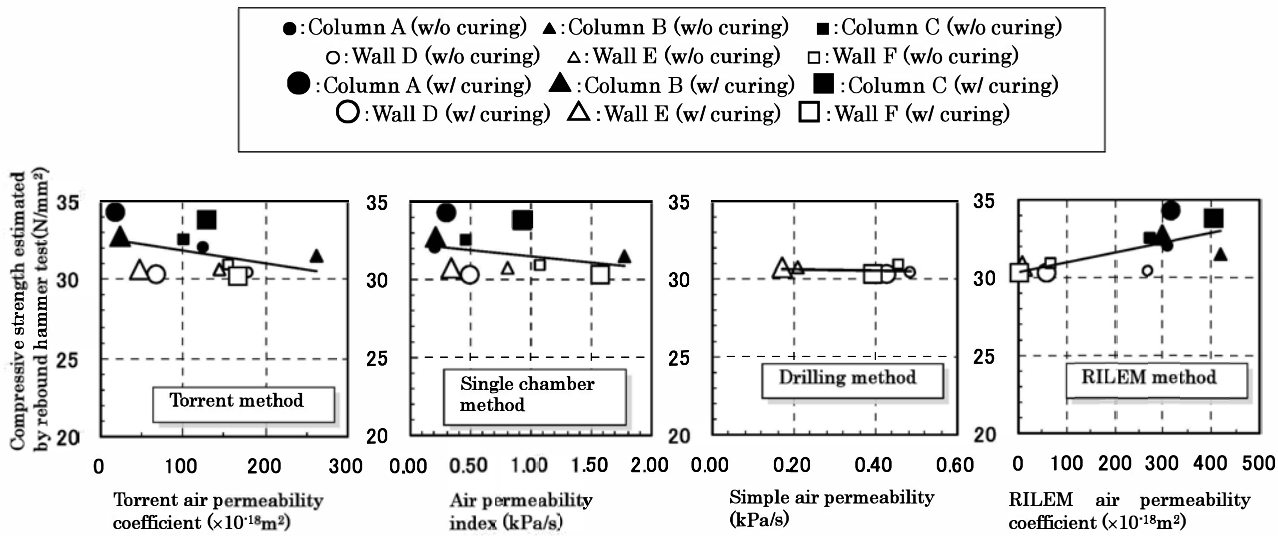


Figure 15: Relationship between air permeability by different test methods and compressive strength estimated by rebound hammer test

5. Comparison between test methods in Japan and abroad

Various test methods have been established to inspect concrete at the stages of production and acceptance as to whether or not the concrete will meet the performance requirements set at the design stage during execution and after hardening. In Japan, most such test methods are specified in JIS. Standards and specifications of respective countries, communities, and groups of related countries are also available overseas. Meanwhile, the recent globalization has been advancing the ongoing development of ISO standards, with efforts being made to maintain consistency between ISO and local standards including JIS. Eurocodes have also been developed in Europe. Differences still exist among these standards.

In this section, similar standards overseas are compared with JIS requirements in regard to six test methods for evaluating the performance of fresh concrete, in order to analyze the differences among these standards. Standards under analysis are ASTM (American), EN (European), and ISO (international). It was considered appropriate to compare these major standards of developed countries, as many developing countries use these standards. Note that this investigation follows JIS's method of comparison, as JIS explicitly tabulates comparisons between JIS and ISO.

(1) Sampling

The JIS, ASTM, EN, and ISO standards were compared in regard to the method of sampling concrete. Though with slight differences in values among the standards, points to consider in concrete sampling are summarized in common as follows: Use sampling apparatuses made of non-water-absorbent materials; take multiple portions from separate points to form a representative sample; take a sufficiently larger amount of sample than required for testing; and carry out the test immediately after sampling to prevent quality changes over time.

(2) Slump test

At present, slump tests are most widely used to rate the consistency (softness, fluidity) of concrete. A comparison among JIS, ASTM, EN, and ISO reveals differences in the scope of application, method of filling concrete, time for lifting the slump cone, and slump measuring point.

(3) Vebe test

A Vebe test, which is a method of evaluating the consistency of fresh concrete, was provided in BS. No similar test method is available in JIS. Fresh concrete is molded with a slump cone set in a larger cylindrical container. After the cone is raised similarly to normal slump testing, a clear disc is placed on top of the concrete, and the time to remolding of the concrete in the cylinder under vibration from the table is measured. EN and ISO include nearly the same Vebe test methods.

(4) Consolidation factor test

Consolidation factor testing, which is one of the methods of evaluating the consistency of fresh concrete, was provided in BS and NF (French) but is not included in JIS. Concrete is filled to the top edge of a specified container and subjected to consolidation by vibration from the shaking table or an internal vibrator until the reduction in the volume of concrete settles. The distance of subsidence is measured to calculate the consolidation factor.

(5) Slump flow test

Slump flow testing is more widely used than slump testing for the consistency evaluation of high fluidity concrete and high strength concrete. The methods of flump flow testing are standardized in JIS, ASTM, ISO, and other standards. In ASTM, a slump cone is used both in a normal manner (Procedure A) and inverted (Procedure B).

For the consistency evaluation of concrete with a slightly large slump, flow table testing (also referred to as flow testing, spread testing, and DIN flow testing) developed in Germany is standardized in European countries but not included in JIS.

(6) Bleeding test

Bleeding testing to measure the amount of bleeding water from concrete is standardized in ASTM and JIS. When comparing both, a difference is found in the method of filling concrete in the test container. ASTM includes a method in which a concrete sample is placed in the container by vibratory consolidation (Procedure B) in addition to a method of filling concrete using a tamping rod similarly to JIS (Procedure A).

As stated above, comparison was made between Japanese and foreign test methods, revealing that similar methods may vary in details. This suggests a possibility that the results of test methods with the

evaluating the consistency of fresh concrete include Vebe testing and consolidation factor testing, which are not provided in JIS. Though slump testing has been widely used in Japan as a simple index to the ease of concrete placing, slump may not be sufficient for adequate assessment depending on the mixture proportions. It is therefore necessary to devise test methods that can incorporate the actual situation of material availability in consideration of test methods overseas, as well as to investigate the standard values.

6. Questionnaire survey on the test methods for confirming the certainty of execution

In actual execution, efforts are made not only to prevent defects but also to ensure the qualities of concrete in actual structures by meticulous formulation of an execution plan and execution control in accordance with various guidelines. It is hoped that techniques to ensure the qualities and secure "certainty of execution" on the job site will be developed. Such techniques will enable engineers to accurately confirm the fulfillment of the requirements at each stage of execution. At the time of form removal, for instance, the development of a technique to confirm that the in-situ strength has unfailingly reached the required compressive strength is anticipated.

With this as a background, the Committee conducted a questionnaire survey regarding new test methods for assessing the properties of concrete and confirming if the various specifications established before execution are actually secured. The questionnaire asked, for each control item, if the respondents employ test methods originally developed by respective contractors or purchasing organizations (including those eventually adopted and included in the guidelines of academic societies) or those practiced based on experience. The results were analyzed to grasp the current situation of test methods actually conducted for appropriate quality assessment necessary for each stage of execution.

Among the 37 responses obtained, the number of test methods originally developed (including those included in guidelines) was 28. The other 9 answered that they carry out normal test methods for unloading/acceptance instead of original methods. **Figure 16** shows the numbers and percentages of respondents by the purpose of testing.

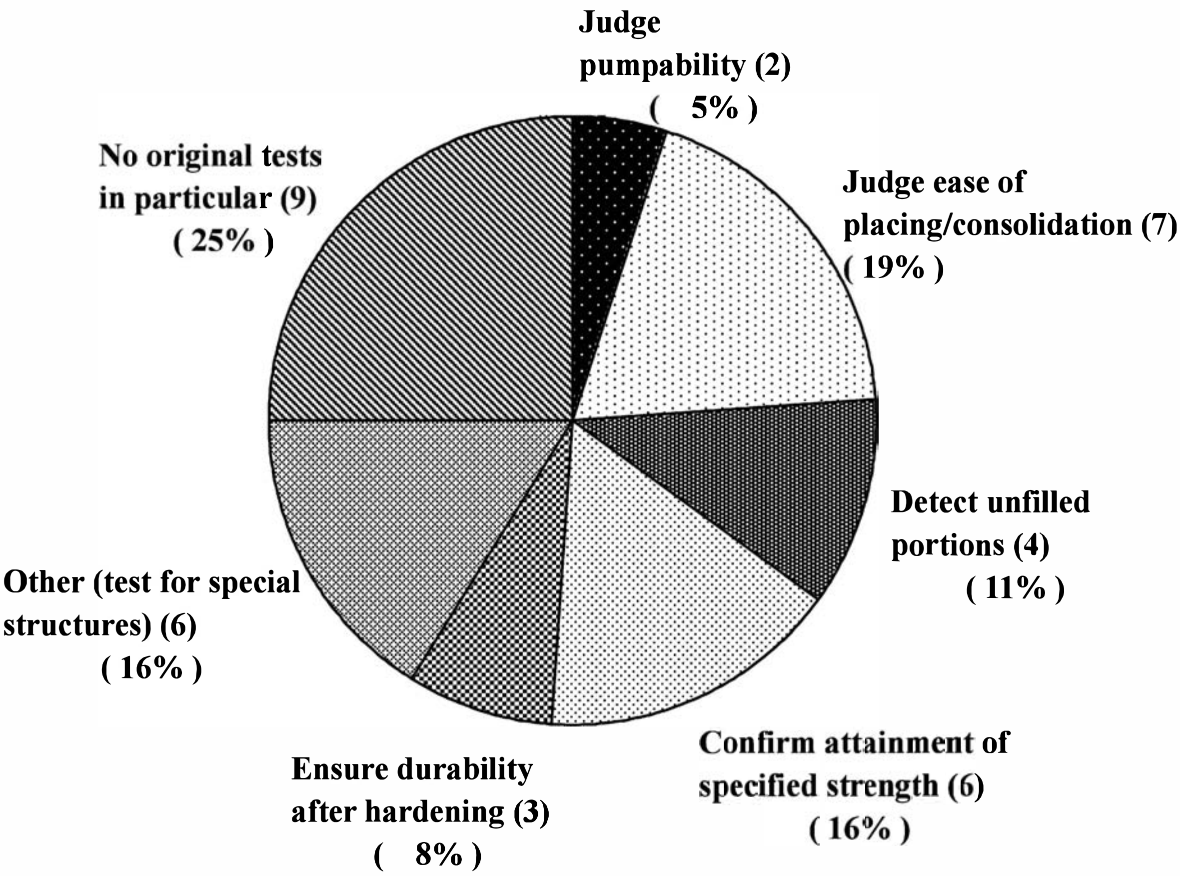


Figure 16: Results of questionnaire survey on test methods to confirm certainty of execution

In regard to fresh concrete, many respondents answered that they employ their own test methods for quality assessment at the stages of trial mixing and proportioning. These include new test methods to grasp the difference in the workability when vibration is applied. This is presumably because, with the recent high degree of freedom in proportioning and material selection, engineers are exploring test methods, other than slump testing, that allow them to distinguish between mixtures showing the same slump but having different fresh properties, within the range of ensuring segregation resistance. In these test methods, however, judgment is currently made qualitatively by comparison between different mixture proportions. It is hoped that evaluation will be made in regard to the relativity with the ease of actual placing and consolidation.

Regarding methods of detecting the presence/absence of filled concrete, methods using sensors have been reported. Apparatuses for this purpose have also been applied to the detection of the degree of consolidation, timing for placing the following layer, early strength development, and internal defects, promising future development.

For the purpose of judging the achievement of the specified strength, which covers a wide range from a very early strength level to compressive strength at later ages, nondestructive test methods are adopted in many cases for measuring the strength of in-situ concrete instead of specimens.

Even where no original tests are conducted, the following practice is reported in the answers where skilled technical workers capable of judging the properties of concrete by visual observation are available:

- Rate the degree of segregation resistance by tapping the surfaces of concrete with a tamping rod after raising the slump cone during the slump testing of trial mixtures or as-delivered concrete. When the concrete is deformed without crumbling, it is judged as plastic, having good workability. Alternatively, concrete is tapped with a mallet in some cases.
- Visually check the condition of concrete discharged from an agitating truck. Judge the properties of concrete from the state of concrete falling from the chute.

These are considered to be practiced where skilled workers having experiences through many different job sites are available. Such practice is important from the aspect of preventing flaws and early defects, but it does not necessarily secure certainty of execution.

As stated above, original and practiced test methods for fresh concrete regarding pumping, placing, consolidation, and filling accounted for more than 30% of all responses to the questionnaire. This is because a new method of evaluating the workability of fresh concrete instead of slump testing is needed to evaluate the placing performance of concrete in the context of the depletion of good aggregate resources and widening variety of concrete materials, which led to differences in the placing performance that are not evaluable by slump testing alone.

7. Summary

There has been a remarkable progress in the development of new materials in Japan as well as worldwide as represented by self-compacting concrete and high strength concrete. For the design of concrete structures, the limit state design method is used, which involves not only analysis techniques with enhanced accuracy but also safety factors precisely allocated to materials and loads, as well as to uncertainty of calculation techniques and dimensional errors unavoidable in the execution. In regard to execution, mechanization and systematization proceed as a result of the decreasing number and aging of site workers. Despite the significant progress in systematization (mechanization) for repeating work following procedures stored in the memory, no device, or robot, is available that is so intelligent as to be capable of keeping operation while judging the adequacy of the work situation by itself. Concrete technology has been developed by mutual influences of the material, deign, and execution sectors. A number of problems remain unsolved in the rationalization and laborsaving of construction technology. The Committee has conducted research into test methods, particularly those necessary for secure execution. One of the goals of this research is to make execution intelligent in the near future.

The activities of the Committee have revealed that the judgment of the adequacy of the work situation still depends on the experience of site workers. At the beginning, the Committee was faced with an argument that an extra test reduces the work efficiency. However, uncertain execution can cause defects, which will trouble not only the purchaser, designer, material suppliers, and contractors, but also users of the structure.

Even if two concretes have the same slump, their placing performances may widely differ depending on such factors as viscosity. If executed by different methods, the differences in their qualities after hardening will become even wider. It is hoped that, in the near future, test methods to grasp their effects will be established and a system to reflect the test results to actual execution will be formulated, so as to assure the certainty of execution in the performance-oriented design and construction of structures.

Acknowledgment

The Committee extends its gratitude to Toyo Construction Co., Ltd. and Ube-Mitsubishi Cement Corporation for their cooperation in the experiment and Assoc. Prof. Noboru Yuasa of Nihon University for his valuable advice regarding scratch testing. We are also grateful to associations, companies, and construction engineers who responded to the questionnaire conducted by the Committee for their active cooperation.

References

1) J. Liang, K. Kokubu, K. Uji, A. Ueno : Study on the Test Method for Compactability of Fresh Concrete, Doboku Gakkai Ronbunshu E, Vol. 62, No. 2, pp.416-427, 2006 (in Japanese)

2) M. Kaneko, M. Yasuda : Concrete Infill Detection System and the Applied Technology, Concrete Joumal, Vol.44, No.5, pp.98-101, 2006 (in Japanese)

3) S. Seko, K. Mitsui, H. Yuki et al.: Detecting concrete defect by measuring of high-frequency capacitance on the surface of the form, Proceedings of the Japan Concrete Institute, Vol.29, No.2, pp.697-702, 2007 (in Japanese)

4) N. Yuasa, Y. Kasai, I. Matsui : Testing Method for Surface Strength of Concrete from the Width of a Scratch Remaining, Summaries of Technical Papers of Annual Meeting Architectural Institute of Japan, A-1 Materials and Construction, pp.677-678, 1999 (in Japanese)