Recommendation for Self-Compacting Concrete

CONTENTS

Chapter 1 General
1.1 Scope ..... 1
1.2 Definitions(Terminology) ..... 4

Chapter 2 Performance of Self-Compacting Concrete
2.1 General ..... 8
2.2 Self-compactability ..... 9
2.3 Other performances ..... 11

Chapter 3 Materials
3.1 General ..... 11

Chapter 4 Proportioning
4.1 General ..... 13
4.2 Proportioning ..... 14
4.3 Form for expressing mixture Proportions ..... 15

Chapter 5 Performance verification
5.1 General ..... 16
5.2 Verification of self-compactability ..... 17
5.3 Verification of other performance items ..... 19

Chapter 6 Production and Control
6.1 General ..... 19
6.2 Production ..... 20
6.3 Quality control during production ..... 21

Chapter 7 Construction and control
7.1.General ..... 21
7.2 Conveying, placing, finishing, curing and joints ..... 22
7.3 Formwork ..... 23
7.4 Quality control during construction ..... 24

Chapter 8 Inspection
8.1 General ..... 24
8.2 Inspection of self-compactability ..... 25
8.3 Inspection of other performance items ..... 26

# Recommendation for Self-Compacting Concrete

## Chapter 1 General

### 1.1 Scope

(1) This Recommendation shall apply to construction of concrete structures using self-compacting concrete.
(2) As to matters not specified herein, the Japan Society of Civil Engineers' Standard Specification for Design and Construction of Concrete Structures shall apply.

[Commentary]
(1) This Recommendation is applicable to concrete having self-compactability with which it can be placed in the every comer of formwork without vibration causing no segregation. The performance evaluation method of fresh Self-Compacting Concrete widely differs depending on whether vibration is given to the concrete during placing. For this reason, the scope of this Recommendation is limited to Self-Compacting Concrete that can be placed without any external forces other than gravity. Accordingly, concrete to which weak vibration is applied to assist the compaction, as in the case of precast product plants, is beyond the scope of this Recommendation.

Self-Compacting Concrete not only increases the reliability of structures but also reduces the number of workers required at the construction site and streamlines the construction. In precast product plants as well, Self-Compacting Concrete is highly effective in reducing the noise as it requires no vibration. This Recommendation specifies its performance, provide methods to verify and inspect the performance, and also hatters that require attention to ensure its performance in selecting materials, proportioning, producing, and placing. In this Recommendation, the term "verification" refers to a judgment for ascertaining the performance before actual placing, and the term "inspection" refers to a judgment at each stage of actual placing as to whether the concrete is acceptable.

The proportioning methods to satisfy the performance of Self-Compacting Concrete specified in this Recommendation are provided in the Manual for Mixture Proportioning; the producing and placing methods in the Manual for Production and Placement. These manuals provide typical methods to ensure the required qualities based on the previous experience, but concrete made by other methods may be used as Self-Compacting Concrete, provided that they are judged as passing the performance verification, inspection and also satisfying the production and p1.acement requirements specified in this Recommendation. Currently the performance verification has to be based on various experiments simulating actual placement, but the work for the performance verification can be simplified by observing the manual based on the previous experience. It should be noted that when applying Self-Compacting Concrete, an engineer who understands its properties and has mastered the technology of using such concrete should manage the procedure at each stage of the mixture proportioning design, production, and placement.

(2) It is important in the case of using Self-Compacting Concrete as well to formulate an adequate structural design and production/placement plan to impart the required properties to the structure and execute the construction in a streamlined manner. This h specifies the performance of Self-Compacting Concrete as a material primarily in regard to the self-compactability. Requirements for the performance and construction work of the structure should primarily be based on the Japan Society of Civil Engineers. Standard Specification for Design and Construction of Concrete Structures (JSCE Standard Specification).

Recommendation

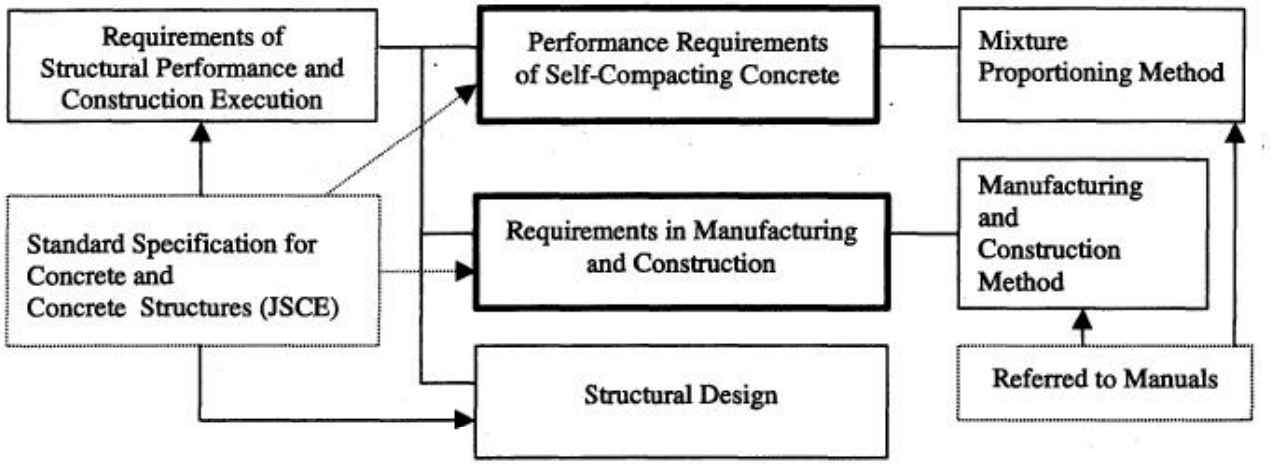


Fig. 1. 1 Scope of Recommendation for Self-Compacting Concrete

As the performance required of a structure, serviceability and safety are set in consideration of the function of the structure and the loads after the structure is put into service and environmental 1oads; the performance of concrete as a material should then be set to satisfy these requirements. In this case, the performance of concrete is required to be adequately set to sa tisfy the performance required of the structure and performance expected of the construction in consideration of the relations with the production/placing methods and details of the structural design, as these also affect the performance of the structure.

Self-Compacting Concrete is characterized by the adoption of a concreting method that does not require vibration during placing. This Recommendation specifies the performance required of Self-Compacting Concrete, primarily the self-compactability, and provide verification and inspection methods. They also provide important requirements in producing and placing Self-Compacting Concrete. The Manuals for Mixture Proportioning and for production/placement provide how to select and proportion materials and how to formulate the production/placement plan, respectively, to fulfill the requirements.

The work flow is as follows: the performance of concrete is determined; concrete is proportioned and the construction plan is formulated referring to the Manuals; the verification is conducted to check if the concrete attains the specified performance; after being confined that all performance requirements are met, the concrete is placed and then inspected. When the concrete does not pass the verification, the concrete is reproportioned and the construction plan is reformulated. When it does not pass the inspection, the construction is not completed.

In regard to matters not specified in this Recommendation, engineers are required to refer to the JSCE Standard Specification. However, items premised on normal concreting with vibration should not be applied to Self-Compacting Concrete. These include the following:

Section 2.3 (2) of the JSCE Standard Specification [Construction] requires that the slump of concrete at the time of placing be not more than 12 cm. This upper limit for the slump is not applicable to Self-Compacting Concrete, as its deformability is significantly increased without impairing the segregation resistance by the addition of admixtures, such as air-entraining and high-range water-reducing admixtures and/or viscosity agents as well as by the proportioning arrangement.

Section 4.7 of the JSCE Standard Specification [Construction] specifies the standard slump. This is

not applicable to Self-Compacting Concrete, as it is not evaluated by slump testing.

Section 7.4.2 of the JSCE Standard Specification [Construction] specifies the standard slump of concrete to be pumped. This is not applicable to Self-Compacting Concrete, as it is not evaluated by slump testing.

Section 7.5.2 (3) of the JSCE Standard Specification [Construction] prohibits lateral transfer of placed concrete within formwork. This is not applicable to Self-Compacting Concrete, as it is expected to fill in formwork by its own weight and is allowed to how to an extent that it does not cause segregation.

Section 7.5.3 of the JSCE Standard Specification [Construction] requires vibration. This is not applicable to Self-Compacting Concrete, which is placed into forms without vibration.

Section 13.5.2 of the JSCE Standard Specification [Construction] requires slump testing for the quality control of fresh concrete. This is not applicable to Self-Compacting Concrete, as it is not evaluated by slump testing.

**1.2 Definitions (Terminorogy)**

The definitions of terms used in this Recommendation are as follows.

(1) Self-Compacting Concrete--Concrete having self-compactability.

(2) Self-compactability--A capability of concrete related to the placeability of concrete, with which it can be uniformly filled and compacted in the every comer of formwork by its own weight without vibration during placing.

(3) Resistance to segregation--A property of fresh concrete to maintain its uniform distribution of concrete ingredients against segregating action induced by gravity and extemal forces.

(4) Deformability--A property of fresh concrete representing ease of being deformed by gravity and external forces.

(5) Passability through narrow spaces-A capability of fresh concrete to pass without causing segregation through narrow spaces, e.g., between reinforcing bars by its own weight using no vibration.

(6) Placeability--A capability of fresh concrete representing ease of transporting, placing, filling, compacting, and finishing.

(7) Viscosity agent--An admixture producing an effect of increasing the segregation resistance of fresh concrete. Some are expected to reduce the fluctuation of the fresh concrete qualities.

(8) Function--The role and service of the structure and its materials to fulfill the purposes of and requirements for the structure.

(9) Performance--Capabilities of the structure to be constructed and its materials demonstrated to fulfill the purposes of and requirements for the structure.

(10) Qualities--Quantifiable properties that the structure and its materials actually possess.

(11) Verification--Judgment at a pre-execution stage as to whether the designed and planed contents satisfy the performance requirements.

(12) Inspection-Examination to judge as to whether the produced or placed concrete, members, or structures satisfy the performance requirements and are acceptable.

(13) Powder-type Self-Compacting Concrete--Self-Compacting Concrete proportioned to provide the required self-compactability not by using a viscosity agent but primarily by reducing the water-powder ratio (in effect increasing the powder content) to impart adequate segregation resistance and using an air-entraining and high-range water-reducing admixture or superplasticizer to impart high deformability.

(14) Viscosity agent-type Self-Compacting Concrete--Self-Compacting Concrete proportioned to provide the required self-compactability by the use of a viscosity agent to impart segregation resistance and air-entraining and high-range water-reducing admixture or superplasticizer to impart high deformability to the fresh concrete.

(15) Combination-type Self-Compacting Concrete-Self-Compacting Concrete proportioned to provide the required self-compactability primarily by reducing the water-powder ratio (in effect

increasing the powder content) to impart adequate segregation resistance and using an air-entraining and high-range water-reducing admixture to impart high deformability. A viscosity agent is also added to reduce the quality fluctuation of fresh concrete, so as to facilitate the quality control of concrete.
(16) Belite-rich portland cement-Portland cement in which the belite (dicalcium silicate) content is not less than 40% and less than 70%, which is higher than in moderate-heat portland cement. Low-heat portland cement specified in JIS is included in this category.
(l7) Limestone powder-Finely ground limestone, whose main component is $CaCO_3$ (calcite). Having low chemical activity, it is not regarded as a binder.
(18) Powder-A generic term for solid materials including cement and those having a fineness equal to or higher than cement.
(19) Unit absolute volume of coarse aggregate-The coarse aggregate content used for producing 1 $m^3$ of concrete divided by the density of the coarse aggregate in a saturated surface-dry condition; in $m^3/m^3$.
(20) Unit bulk volume of coarse aggregate-The bulk volume of coarse aggregate used for producing 1 $m^3$ of concrete. This is determined by dividing the unit coarse aggregate content by the unit weight of the aggregate.
(21) Yield value-One of the rheological constants of fresh concrete, fresh mortar and fresh paste when they are regarded as Bingham fluids. The minimum stress is required for making the fluid flow.
(22) Plastic viscosity-One of the rheological constants of fresh concrete, fresh mortar and fresh paste when they are regarded as Bingham fluids. The magnitude of the change in the applied stress required for changing the unit now velocity.

[Commentary]
(1) The definition of Self-Compacting Concrete used by the Japan Concrete Institute and Architectural Institute of Japan is adopted unchanged. However, this Recommendation deal with only concrete having self-compactability.

(2) Passability through spaces refers to a capability of fresh concrete placed in forms to pass through narrow spaces such as between reinforcing bars only by its own weight without being vibrator-consolidated and without causing segregation. This capability can be evaluated to a certain extent by filling tests using a U-type apparatus or box-type apparatus, or by funnel tests.

(8)-(10) When selecting concrete materials and designing concrete structures according to performance requirements, it is necessary to accurately define such terms as “function,” “performance” and “quality,” which have been used without clear definitions. For this reason, these terms are defined in this Recommendation in regard to concrete materials and concrete structures.

Though the term “high function” is frequently used, such expressions as “high function” or “low function” are not relevant, as “function”. refers to such qualitative ideas as “role” or “service.” Such expressions as "multi-function" and "single function" are appropriate.

Conversely, “performance” is quantifiable, allowing such expression as “high performance."

The difference between “performance” and “quality” is the involvement of human interest. “Performance” is determined according to the purposes or demands people have. Such a nature is more evident when the term “required performance” is substituted. “Qualities” are properties that things possess independent of the purposes and demands people have. The qualities of aggregate can be easily understood by this concept. However, concrete and structures are more complicated, as they are products of proportioning, structural design and production/construction according to the performance selected by people. h this case as well, these qualities of concrete and structures should be understood as the quantifiable properties they possess.

(13) This is a type of Self-Compacting Concrete with segregation resistance increased by the

reduction of the water-powder ratio without using a viscosity agent. As a result, the powder content becomes higher than in normal concrete. The type of powder to be used should be adequately selected in consideration of the purpose of use of the concrete. The use of an air-entraining and high-range water-reducing admixture or superplasticizer is essential. The water-powder ratio by volume and unit absolute volume of powder of the powder-type Self-Compacting Concrete dealt with in the Manual for mixture proportioning are 0.85 to 1.15 and 0.l6 to 0.19 $m^3/m^3$, respectively.

(14) This is a type of Self-Compacting Concrete with segregation resistance increased by the use of a viscosity agent with the powder content being low compared with the powder-type. The mixture proportions of such concrete are relatively similar to those of conventional concrete except that a viscosity agent and an air-entraining and high-range water-reducing admixture or superplasticizer are used.

(15) This is a type of Self-Compacting Concrete having a reduced water-powder ratio and containing a viscosity agent. The difference from the viscosity agent-type is that the purpose Of using a viscosity agent is to alleviate the fluctuation of fresh concrete properties due to the fluctuation of surface moisture content, aggregate grading, etc. The mixture proportion of this type is similar to the powder type except for the use of a viscosity agent.

(16) Belite-rich portland cement is a type of portland cement recently developed for concrete with a high binder content, such as high strength concrete and Self-Compacting Concrete. This type exhibits not only high deformability and high strength development in the low water-cement ratio ranges but also has significantly lower hydration exotherm than conventional portland cement. The properties of strength developing and hydration exothemic properties can be varied by the combination of the belite (dicalcium silicate) content and fineness. Though JIS has standardized this type as low-heat portland cement, belite-rich portland cement available on the market include those out of the JIS specifications and yet have good quality. This h generically refer to portland cement containing not less than 40% and less than 70% belite (dicalcium silicate); including low-heat portland cement, as belite-rich portland cement.

Regarding (17) Limestone powder is limestone, whose primary component is $CaCO_3$ (calcite), pulverized to a specific surface area by Blaine of 2500 to 8000 $cm^2/g$. It can be regarded as being chemically inert, though marginally active. It is often used when a lower hydration heat and/or strength are desired without reducing the powder content. Limestone powder is included in the categories of powder and mineral admixtures, but not included in binders.

(18) Powder is a generic term for cement and other solid concrete materials having a fineness equal to or higher than cement. These include cement, ground granulated blast-furnace slag, fly ash, silica fume, and limestone powder.

(19) and (20) Since the self-compactability and passability through spaces of Self-Compacting Concrete greatly depend on its unit absolute volume or unit bulk volume of coarse aggregate, these should be considered in mixture proportioning. Generally speaking, a lower unit absolute volume or unit bulk volume of coarse aggregate leads to a higher self-compactability and passability through spaces, as well as to a lower modulus of elasticity. An adequate value should, therefore, be established to consider these properties. It should be noted that concrete having the same unit absolute volume of coarse aggregate may have different coarse aggregate contents, depending on the density of the coarse aggregates.

(21) and (22) Both are rheological constants of fresh concrete, fresh mortar and fresh paste when they are regarded as Bingham fluids. Yield values correlate with slump flow and L-type flow values, whereas plastic viscosity correlates with funnel efflux time and time to 500 mm flow when the yield value is constant.

## Chapter 2 Performance of Self-Compacting Concrete

### 2.1 General

The performance of Self-Compacting Concrete shall be adequately established to satisfy the performance requirements of the structure in consideration of the structural, constructional and other conditions.

[Commentary]

The performance of Self-Compacting Concrete should be adequately established so that the performance required of the structure or members can be attained and the requirements for the construction can be satisfied, in consideration of various conditions. These conditions include the structural conditions, such as shapes, dimensions and reinforcement layout and construction conditions, methods of transporting, placing, finishing and curing. Where the performance of Self-Compacting Concrete cannot be established rationally set, the structural conditions and/or construction conditions should be modified. The maintenance plan and recycling plan may also have to be considered, as they affect the required performance of the structure, such as durability. This chapter provides the performance required of Self-Compacting Concrete as a material to satisfy the performance requirement of the structure.

The performance specific to Self-Compacting Concrete is the self-compactability of fresh concrete. This is premised on a construction plan without vibration. Other performances, such as placeability, strength and durability should be established similarly to normal concrete. These performances should be established in accordance with the JSCE Standard Specification.

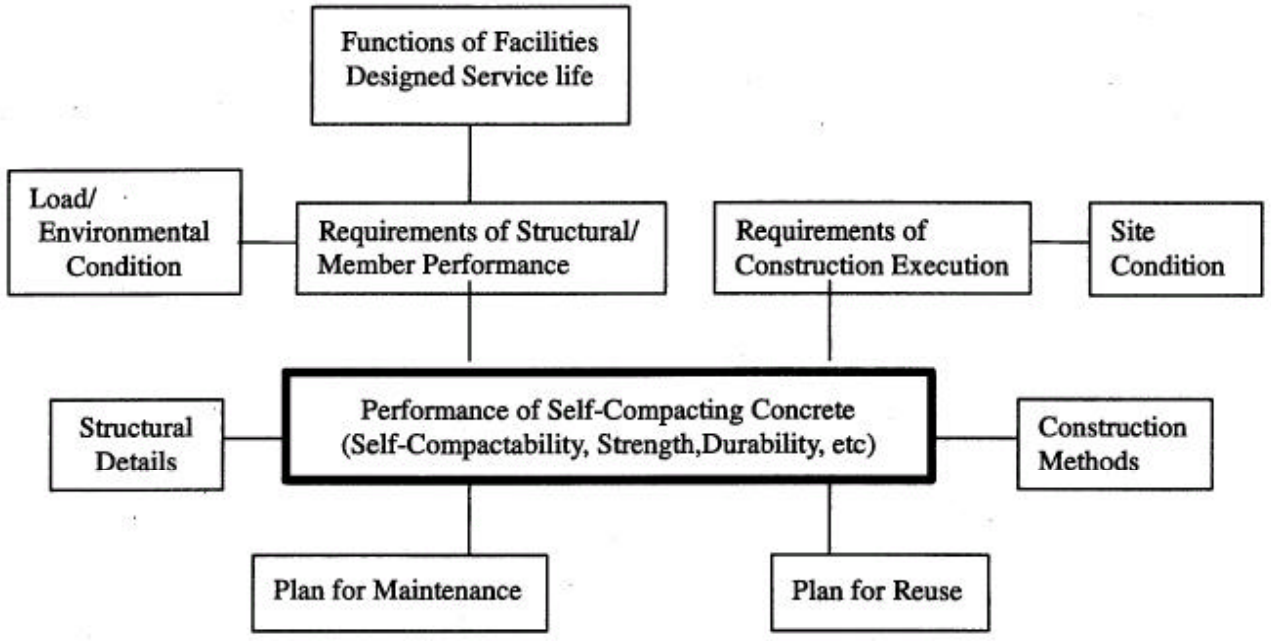


Fig. 2.1 Relations between Performance of Self-Compacting Concrete and Others

### 2.2 Self-compactability

(1) The levels of self-compactability shall be adequately established in regard to concrete immediately just before placing into forms in consideration of the shapes, dimensions and reinforcement conditions of the structure to be placed.

(2) The following three ranks shall be established as levels of self-compactability:

Rank 1: Self-compactability into members or portions having complicated shapes and/or small cross-sectional areas with a minimum steel clearance in the range of 35 to 60 mm.

Rank 2: Self-compactability into reinforced concrete structures or members with a minimum steel clearance in the range of 60 to 200 mm.
Rank 3: Self-compactability into members or portions having large cross-sectional areas and a small amount of reinforcement with a mdnimum steel clearance of more than 200 mm.
(3) It is recommended that the standard self-compactability level of general reinforced concrete structures or members be Rank 2.

[Commentary]
(1) The rank of self-compactability of the required performance varies depending on the shapes, dimensions and reinforcement conditions. The required level of self-compactability can also differ depending on placing conditions, such as the drop height, flow distance and lift height. However, it is rather practical to adequately establish the construction conditions, such as drop height, flow distance and lift height, according to the concrete to be used than to design the concrete according to the construction conditions. Where these conditions are particularly important in the construction plan, they may be included in the performance requirements for concrete.

(2) Ranks 1 to 3 are set as the levels of self-compactability of concrete. These ranks are set based on the dimensions and reinforcement conditions of the structures or members. Rank 2 is defined as the capability of concrete with which it can be self-compacted through minimum bar clearance of 60 to 200 mm. This normally corresponds to a steel content of 350 to 100 kg/m$^3$. Rank 1 is a level on which concrete meets severer requirements than Rank 2, filling the spaces to meet the minimum cover depth and clearance specified in the JSCE Standard Specification. Rank 3 is a level on which concrete meets easier conditions than Rank 2, demonstrating self-compactability where the minimum bar clearance is more than 200 mm and maximum steel content is less than 100 kg/m$^3$.

(3) In normal concrete structures and members, minimum bar clearance is 60 to 200 mm and the steel content is roughly 100 to 200 kg/m$^3$. Therefore a self-compactability level of Rank 2 is selected as a standard for such structures and members. Where the minimum bar clearance is less than 60 mm or the steel content is more than 350 kg/m$^3$, the self-compactability level must be raised to Rank 1.The cover depth and bar clearance should meet the minimum requirements specified in the JSCE Standard Specification. Where the minimum bar clearance is more than 200 mm or less than 100 kg/m$^3$ in terms of steel content, the self-compactability level can be lowered to Rank 3. It should be noted that concrete of a higher self-compactability rank is generally capable of self-compacting under conditions corresponding to lower ranks.

### 2.3 Other performances

Performances of Self-Compacting Concrete other than self-compactability shall be established in accordance with the JSCE Standard Specification.

[Commentary]
In order to satisfy the performance requirements of the structure and construction requirements, it is necessary to select other performances than the self-compactability specific to Self-Compacting Concrete and establish adequate criteria for them. Since these performances are similar to normal concrete, they are required to be in accordance with the JSCE Standard Specification.

It is generally required to establish the placeability for fresh concrete, strength and durability for hardened concrete. The placeability of fresh concrete is a capability required of concrete from immediately after its production through the end of the placement. Concrete having the required placeability can be filled into forms uniformly and densely without causing segregation to construct a structure of the required dimensions with the required accuracy under the planed construction conditions. The performances required of hardened concrete include strength and durability with which it can demonstrate the required performance for the required period.

## Chapter 3 Materials

### 3.1 General

(1) Materials for self-compacting concrete shall be of confT1rmed quality.
(2) When materials for which no quality specifications are provided in JIS or JSCE Standards are to be used, shall be confirmed that the materials satisfy the quality requirements for hardened concrete as well as the self-compactability requirements.

[Commentary]
(1) The use of suitable materials, having the required performance, is necessary for producing self-compacting concrete. Materials specified in the JSCE Standard specification can be judged as those whose qualities have been confT1rmed. Whether a material is suitable can be judged by tests or field experience.

(2) The self-compactability of materials not covered by the JSCE Standard Specification or of those that will be newly developed may be confT1rmed by the verification methods provided in this Recommendation. In this case as well, it should be confirmed that such concrete satisfies the quality requirements for hardened concrete specified in the JSCE Standard Specification.

Amongst the materials not covered by JIS or the JSCE Standard Specification, the following are examples of materials for self-compacting concrete for which sufficient field experience has been acquired:

a) Belite-rich portland cement
This is a type of portland cement developed for concrete proportioned to have a high binder content Low-heat portland cement specified in JIS R 5210 is included in this type. The belite (dicalcium silicate) content of belite-rich portland cement is 40% to 70%, which is higher than moderate-heat portland cement. This type of cement exhibits high deformability and strength development at a low water-binder ratio, and is also characterized by a lower hydration exotherm than conventional portland cement. For this reason, it is used where high strength and/or low heat are required.

b) Binary/ternary system low-heat cement
This is a type of cement made of normal or moderate-heat portland cement mixed with ground granulated blast-furnace slag and/or fly ash. This is used where desired that the hydration exotherm be reduced without reducing the powder content.

c) Limestone powder
Limestone powder is limestone consisting primarily of $CaCO_3$ (calcite) pulverized to a specific surface area by Blaine of 2500 to 8000 $cm^2/g$. It can be regarded inert, though marginally active, and is used where desired that the hydration exotherm and/or strength be reduced without reducing the powder content. For its qualities, refer to the Quality Specification for Limestone Powder for Concrete (draft) published by the Japan Concrete Institute.

d) Viscosity agent
Viscosity agents are classified into two types: those used simply to impart segregation resistance to fresh concrete and those used both for imparting segregation resistance and curbing the effects of fluctuating qualities of the materials. Glycol type and water-soluble amide type liquid viscosity agents are beginning to be used in place of conventional powder types, such as the cellulose type, acrylic type, polysaccharide polymers, biopolymers and inorganic viscosity agents.

## Chapter 4 Proportioning

### 4.1 General

The mixture proportions of self-compacting concrete shall be established to satisfy the performance requirements provided in Chapter 2.

[Commentary]
Self-compacting concrete is a concrete in which two normally incompatible properties of deformability and segregation resistance are both realized to achieve self-compactability by such measures as to increase the powder content and/or use of a viscosity agent. For this reason, a wide variety of formulas are possible for self-compacting concrete satisfying the self-compactability requirements as well as performance requirements for hardened concrete, such as durability required from environmental conditions.

Concretes are therefore proportioned by selecting an adequate combination of materials in consideration of the restricting conditions at production plants and economical efficiency including their availability and transportation cost.

It should be noted that, in this Recommendation, the performance items of self-compacting concrete, other than the self-compactability, are required to conform to the JSCE Standard Specification [Construction].

Self-compactability is classified into three ranks corresponding to structural conditions of structures. When proportioning self-compacting concrete, the self-compactability level is determined from the structural conditions of the structure to which the concrete is applied, and concrete is proportioned to attain this level.

The proportioning methods, to attain Self-compactability of Rank 2 easily, are illustrated in the Manual for mixture proportioning. These methods were formulated on the basis of the field experience of using self-compacting concrete up to now with limited ranges of materials. Therefore, when using materials other than those specified in the Manual, the mixture proportions must be established separately so as to pass the performance verification provided in this Recommendaition.

### 4.2 Proportioning

When proportioning self-compacting concrete, an appropriate type of self-compacting concrete shall be selected. The materials and their contents shall then be determined so that the established performance requirements can be satisfied.

[Commentary]
Self-compacting concrete must be proportioned to achieve filling into every comer of forms to ensure the performance of the structure. To this end, it must be proportioned to attain the required self-compactability immediately before being placed into forms in consideration of the structural conditions, the construction conditions including the method and duration of transportation, placing method and curing method.

Self-compacting concrete is generally proportioned in a sequence as shown in Fig.4. 1. No limitations are put on the technique of proportioning, provided the resulting concrete satisfies the performance requirements.

The proportioning condition examination process in the now chart is a process in which the target performance requirements are established on the basis of the structural conditions and, where required, construction conditions of the structure.

The proportioning examination process in the flow chart is a process in which tentative mixture proportions (initial proportions) are calculated. Generally speaking, a suitable type of self-compacting concrete is selected from amongst the powder type, viscosity agent type and combination type, based on the performance requirements for the concrete, production limitations and economical efficiency. The materials are then selected, and their contents are determined so that the self-compactability and performance of hardened concrete can be attained. Whereas various classification systems are possible for self-compacting concrete, this Recommendation classify it roughly into three categories: the powder type, viscosity agent type and combination type, as mentioned in Chapters 1 and2.

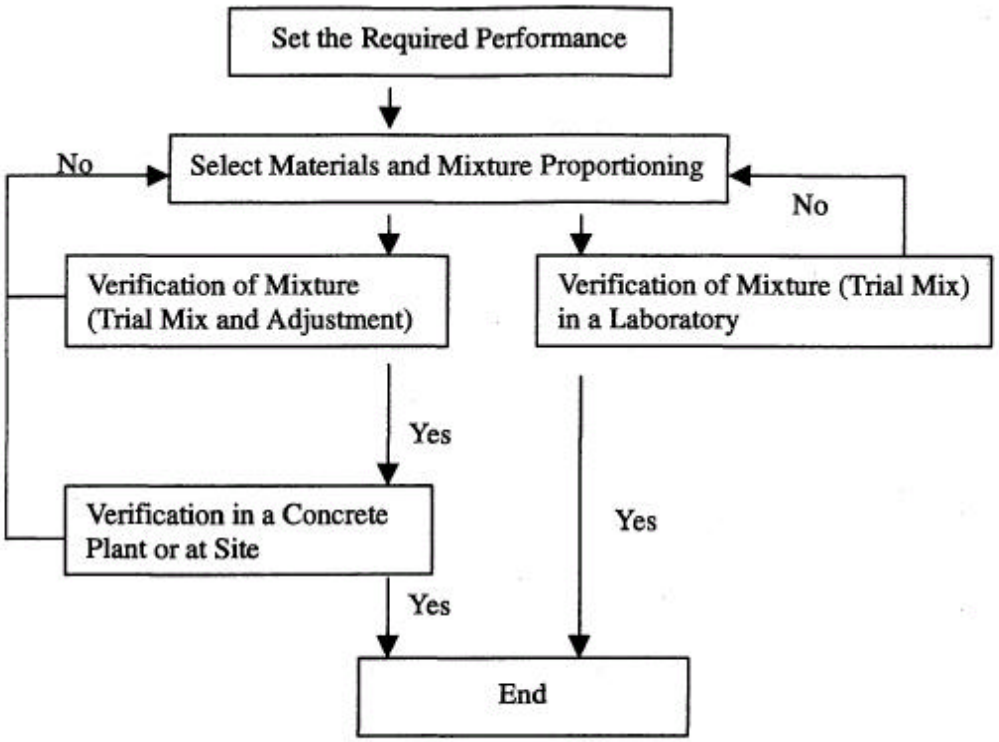


Fig.4.1 Flow Chart of Mixture Proportioning

In the proportioning confirmation Process, the tentatively determined initial proportions are checked if they satisfy the performance requirements. Unsatisfactory proportions are modified. Trial mixtures should, as a rule, be produced to confT1rm the qualities of fresh, hardening and hardened concrete. The self-compactability of fresh concrete may be conf1rmed by the "test method for passability through spaces using a filling tester" described in Chapter 5. Where the verification is possible by laboratory tests, this confirmation process represents the verification process. Where tests using actual equipment or full-scale models are to be conducted, the verification is carried out after this process. This series of processes to determine the materials and their contents is referred to as proportioning.

### 4.3 Form for expressing mixture proportions

The form for expressing specified mixture proportions shall be generally as shown in Table 4. 1.

Table 4. 1 Form for expressing mixture proportioning

| naximum size of coarse aggregate (mm) | rank of self-comapct ability | water to binder ratio (%) | water to powder ratio by volume (%) | air content (%) | unit volume of coarse aggregate ($m^3/m^3$) | unit weight($kg/m^3$) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | water W | cement C | admixture F | fine aggregate S | coarse aggregate G | chemical admixtures | | |
| | | | | | | | | | | | superplasticizer | viscosity agent | others |
| | | | | | | | | | | | | | |

Notes 1) When more than one material of the same kind is used, each shall be indicated in a separate box.
2) The dosage of an air-entraining and high-range water-reducing admixture shall be expressed in $kg/m^3$ and shall be included in the unit water content.
3) The dosage of other chemical admixtures sham be expressed in $ml/m^3$ or $g/m^3$ and shall be indicated undiluted and undissolved.
4) The viscosity agent content shall be expressed in $kg/m^3$.
[Commentary]
The specified mixture proportions shall be expressed as the content of each material in terms of mass per cubic meter of concrete. It should be noted that the water-powder ratio by volume is indicated in addition to the water-binder ratio, as the volume of powder strongly affects the deformability and segregation resistance of self-compacting concrete.

It is desirable that the forms include the type of the structure, type of self-compacting concrete, design strength, age at which the design strength is assured, type of cement, type and physical properties of mineral admixtures, type and physical properties of coarse and fine aggregates and type of chemical admixtures. It is also desirable that it includes the structural conditions of the structure, such as reinforcement conditions, as well as the construction conditions, such as the transportation time, construction methods and seasonal conditions. The inclusion of the slump flow, flow time to 500 mm and funnel efflux time is recommended. These are useful for the control of self-compactability.

## Chapter 5 Performance verification

### 5.1 General

(1) The proportioned self-compacting concrete shall be verified by a suitable method in regard to the attainment of the established performance.
(2) When the attainment of the established performance of the proportioned concrete is not verified, the materials, mixture proportions and/or construction conditions shall be modified, and the resulting concrete shall be subject to reverification.

[Commentary]
(1) It is necessary to verify that the concrete designed in accordance with Chapter 2 possesses the designed performance. This chapter specifies the methods of such verification. The performance requirements of concrete consist of various items. All of these items should as a rule be verified, to the extent that they affect the performance or construction plan of the structure. However, the performance requirements for performance items are differently weighted depending on the structure and construction conditions. In addition, the verification of one item can overlap that of another. For this reason, the items and methods of verification should be adequately selected.

The establishment of non-test verification methods is expected in the future, such as physical estimation and numerical simulation. At present, however, verification by testing and inferring from field experience are more rational and reliable in most cases. The methods of verification

should, therefore, be selected suitably from among these.

(2) When the checking for verification has revealed that the concrete does not satisfy the established performance requirements, the materials should be reselected and the concrete should be reproportioned for reverification. If the concrete cannot be rationally proportioned by this procedure, it may be necessary to review the construction conditions and, where required, structural conditions.

**5.2 Verification of self-compactability**

(1) The self-compactability of fresh concrete shall be verified using full-scale models having similar structural and constructional conditions simulating the actual structure or members.
(2) Where test methods with established correspondence with the actual structural and constructional conditions are available, concrete may be verified by such test methods.
(3) Where standard construction methods are to be applied, concrete may be verified by passability tests using a filling tester with an adequate obstacle setting according to the structural conditions.
(4) In the case of self-compacting concrete with Rank 2 self-compactability, the concrete may be verified by passability tests using a filling tester with obstacle R2.

[Commentary]
(1) Verification of self-compactability of fresh concrete is important for ensuring the performance of structures. The verification should be carried out by preparing full-scale forms of the structure or members or model forms representing the portions where the placing is considered most difficult, placing the proportioned concrete in them according to the assumed construction plan and confirming the state of filling of the concrete.

(2) Where the test methods for the specific structural and construction conditions have already been established on the basis of field experience, the use of such methods for verification is permitted. In regard to the fresh concrete performance, the verification should include confirmation that the concrete can be pumped as planed, that it does not segregate during placing and flowing laterally and filled into every comer of forms without clogging around reinforcement in the structure. It is difficult to confirm these items by a single test method. Therefore, these are generally judged by combinations of multiple test methods, such as passability tests using a filling tester combined with slump flow tests or funnel tests.

(3) and (4) Where the concrete is placed under standard construction conditions, verification by the tests specified in JSCE Standards is permitted. These are passability tests using a filling tester, shown in Fig.5.1, according to the Rank of the concrete established in consideration of the structural conditions. This has been concluded from field experience acquired to date (see the reference). The standard construction conditions referred to here are assumed to be a maximum drop height of not more than 5 m and maximum lateral flow distance of not more than 8 to 15 m. A flow slope of 1/l0 to 1/30 and pumping through 4- or 5-inch pipes not more than 300 m in length are also considered standard.

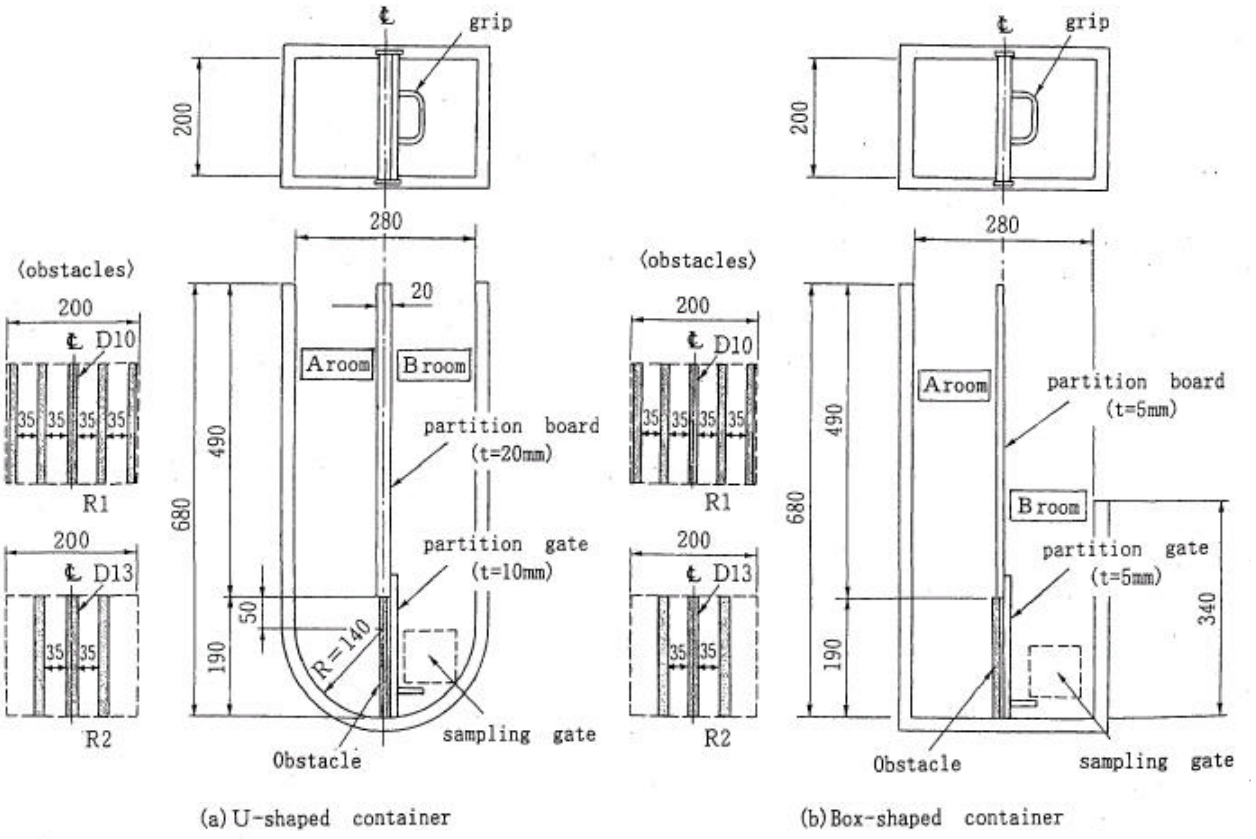


Fig.5. 1 Shapes and Dimensions of Apparatus for Self-Compactability Test

When Rank 2 self-compactability is required, the concrete is judged as satisfying the requirement, if its filling height is not less than 300 mm by a filling tester with obstacle m. When Rank 1 self-compactability is required, the concrete is judged as satisfying the requirement, if its filling height is not less than 300 mm using obstacle R1. The methods for concrete of Rank 3 include testing by a filling tester without any obstacle.

In the case where the self-compactability is verified at a stage other than immediately before placing the concrete in forms, it should be confT1rmed that the changes in concrete qualities after the point of test are sufficiently small. The qualities of fresh concrete tend to change over time, and their properties also change depending on the type and size of mixers. Their qualities may also change after pumping. For this reason, these changes should be thoroughly grasped when tests are conducted at an earlier stage than should be. However, where such changes can be grasped thoroughly by the methods indicated in the Placement Manual or from field experience, the concrete may be verified by laboratory tests.

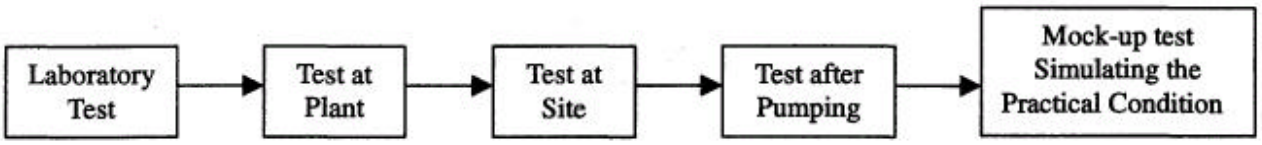


Fig.5.2 Timing of test for verification of Self-compactability

### 5.3 Verification of other performance items

Fulfillment of performance items other than self-compactability shall be verified in accordance with the JSCE Standard Specification.

[Commentary]
Where performance items other than self-compactability are established and are required to be verified, they should be verified at appropriate times by suitable methods. Though the time and method for such verification are not specified in the current JSCE Standard Specification, the performance of concrete can be confirmed, e.g., by the methods given in 13.5 and 13.9 in the JSCE Standard Specification [Construction]. This can be regarded as a substitute for verification.

## Chapter 6 Production and Control

### 6.1 General

Production plans for self-compacting concrete shall be adequately formulated to obtain the required qualities and the production shall be adequately controlled according to the plan.

[Commentary]
Self-compacting concrete differs from normal concrete in the materials and mixture proportions, and particularly in the properties at fresh state. Therefore, the processes of producing self-compacting concrete, such as batching and mixing, should be properly carried out in well-equipped plants so that the required qualities of fresh concrete can be obtained. Also, such production should be adequately controlled so that the expected characteristics of self-compacting concrete can be realized. General items for production should be in accordance with the JSCE Standard Specification [Construction].

### 6.2 Production

(1) The surface moisture ratio shall be adequately measured, and the surface moisture correction shall be ensured.
(2) Self-compacting concrete shall be adequately mixed using equipment with the required efficiency so that the required qualities of concrete can be obtained.
(3) Self-compacting concrete produced at plants shall be tested to conf1rm that it satisfies the established performance requirements for fresh concrete. If it does not satisfy the requirements, the mixture proportions shall be modified.

[Commentary]
(1) Self-compacting concrete is generally more susceptible to fluctuation of unit water content than normal concrete. For this reason, it is necessary to control fluctuation of the surface moisture ratio of aggregate, particularly fine aggregate, in order to produce self-compacting concrete having stable qualities. In order to reduce the adverse effects of such fluctuation, the surface moisture should be measured by an adequate method and its correction should be made accurately and promptly.

(2) Self-compacting concrete is characterized by the low yield value and high plastic viscosity when compared with normal concrete. It should, therefore, be mixed using a mixer with high mixing efficiency and the order of charging materials, batch size and mixing time should be adequately established according to test results or field experience, in order to obtain concrete having the required qualities.

(3) The properties of fresh self-compacting concrete produced using the plant to be used for actual construction may frequently differ from those of self-compacting concrete proportioned in advance in laboratories. This results from different mixing efficiency of the mixer. In such a case the proportions are normally corrected by adjusting the dosage of an air-entraining. and high-range water-reducing admixture. See the Manual for Production and Placement for details of such

adjustment.

### 6.3 Quality control during production

(1) The deformability, segregation resistance and self-compactability of self-compacting concrete shall be controlled as the quality control during production.
(2) Deformability may be controlled by slump flow testing. Resistance to segregation may be controlled by the flow time to 500 mm or efflux time through funnels. Self-compactability may be controlled by tests for passability through spaces using a filling tester.

[Commentary]
Self-Compactability should be controlled in quality control testing of self-compacting concrete in addition to tests for normal concrete, in order to exercise sufficient control over its characteristics. The percentage or amount of bleeding water is an index to static segregation resistance of concrete, and is useful for such quality control. The power consumption of the mixer during mixing can also be used for such control.

Other quality control items and test methods are provided in the JSCE Standard Specification [Construction]. These should be observed accordingly.

## Chapter 7 Construction and control

### 7.1 General

In order to attain the specified quality of the entire structure, an adequate construction plan shall be formulated for self-compacting concrete and adequate control shall be exercised so that construction can be carried out according to the plan.

[Commentary]
There are a number of points of note specific to self-compacting concrete in the concreting work from production to curing after placing. In order to ensure the required quality of the entire structure, including the function, strength and durability, an adequate construction plan should be formulated in careful consideration of these points. Also, control should be exercised so that concreting is carried out smoothly in accordance with the plan. General matters regarding concreting should be carried out in accordance with the JSCE Standard Specification [Construction].

### 7.2 Conveying, placing, finishing, curing and joints

(1) The type and number of concrete pumps and diameter and length of pipelines shall be selected with thorough consideration to the test results and field experience.
(2) The placing rate of self-compacting concrete should be established adequately according to the mixture proportions, geometry of members and reinforcement conditions on the basis of test results and field experience.
(3) The maximum permissible drop height and flow distance should be established in advance for self-compacting concrete with due consideration to the mixture proportions, structural conditions and constructional conditions.
(4) The standard pumping conditions shall be as follows:
Diameter and length of the pipeline: 4 or 5 inches and not more than 300 m, respectively; maximum free drop height of concrete: around 5 m or less; and maximum lateral flow distance: 8 to 15 m or less.
(5) Measures to prevent surface drying should be taken for self-compacting concrete until finishing operation is performed, and care should be exercised not to miss the time for taking such measures.
(6) Treatment at construction joints of self-compacting concrete may be simplified, provided it is confirmed that such joints have attained the required performance.

[Commentary]
When self-compacting concrete is conveyed by pumping, an increase in the pumping rate tends to lead to a greater pressure loss than normal concrete. Also, pumping generally tends to reduce the slump flow of self-compacting concrete. Therefore, the type and number of pumps as well as the diameter and length of pipelines must be selected with thorough consideration to test results and field experience. Pumping through 4- or 5-inch pipes not more than 300 m in length should be the standard pumping conditions.

Excessively quick placing of self-compacting concrete can entrap air or cause defective m1ing in certain structures. It is, therefore, necessary to establish the placing rate adequately according to the mixture proportions, geometry of members and reinforcement conditions based on test results and field experience. When placing into closed spaces, it is important to select the mixture proportions so as to reduce the slope of the flowing concrete and select the placing rate adequately. Though self-compacting concrete is proportioned to provide high deformability and resistance to segregation,segregation can occur when it is dropped or flowed for an excessively long distance. The permissible drop height and flow distance should, therefore, be established in advance in consideration of the mixture proportions and structural and construction conditions. The standard maximum free drop height and maximum lateral flow distance should be around 5 m or less and 8 to l5 m or less, respectively.

Finishing work is difficult to perform on self-compacting concrete, due to its high viscosity and little amount of bleeding water. It is, therefore, necessary to take measures to prevent surface drying until the time of finishing, and care should be exercised not to miss the time to take such measures.

The small amount of bleeding water of self-compacting concrete forms less laitance on the construction joint surfaces than normal concrete. For this reason, the required performance of the joint surfaces can often be attained even with simplified treatment of the surfaces.

**7.3 Formwork**
(1) The lateral pressure of self-compacting concrete acting on the formwork shall as a rule be designed as liquid pressure.
(2) When placing self-compacting concrete into closed spaces, vent holes shall be provided at appropriate positions in the top forms.
(3) For structures whose aesthetic appearance will be jeopardized by surface voids, care shall be exercised when selecting the materials of sheathing and type of form removers.

[Commentary]
(1) The lateral pressure of self-compacting concrete placed in the forms acts similarly to liquid pressure on the forms, due to its high deformability. In addition, the generally longer setting time than normal concrete tends to retain the high lateral pressure for a longer time. Therefore, the lateral pressure of self-compacting concrete on the formwork should as a rule be designed as liquid pressure.

(2) Air in closed spaces should be allowed to escape out of the forms as concrete is filled in them. To this end, vent holes should be provided at appropriate positions in consideration of the placing method and shapes and dimensions of the portions to. be placed.

(3) Self-compacting concrete can leave many voids on the formed surfaces. For structures on which such voids will damage their aesthetic appearance, the materials for sheathing and type of form removers should be selected with care, as these can affect the state of air-voids being left on formed surfaces. Light tapping on the surfaces of forms may be required in certain cases.

**7.4 Quality control during construction**
(1) Quality control during construction shall as a rule be exercised at the time of concrete placing.

(2) Quality control testing on self-compacting concrete may be conducted at the point of unloading taking account of the quality changes during conveying from the point of unloading to the point of placing.
(3) It is recommended that the deformability, segregation resistance and self-compactability shall be controlled for quality control of self-compacting concrete.

[Commentary]
7.4 Though the quality control of self-compacting concrete during construction should as a rule be exercised at the time of concrete placing, testing at the point of placing is often difficult. For this reason, quality control tests are normally conducted at the point of unloading taking into account the quality changes during conveyance from the unloading point to the placing point.

The deformability, segregation resistance and self-compactability should be controlled for quality control of fresh self-compacting concrete. Whether the concrete attains the required self-compactability at the point of unloading can also be judged by placing a passability apparatus between the agitator truck and the mobile pump, with which the passability of the whole truckload can be automatically tested.

Other quality control items for fresh concrete include the air content, temperature, unit mass and chloride ion content. These and other items and test methods of quality control during construction are provided in the JSCE Standard Specification [Construction]. These should be observed accordingly.

## Chapter 8 Inspection

### 8.1 General
Inspection shall be conducted on produced and placed concrete at an appropriate time to check if it satisfies the established performance requirements.

[Commentary]
Even if the performance of concrete satisfies the established requirements at the verification stage, it normally undergoes changes, due to fluctuation in material qualities, fluctuation during production and quality changes during transportation/conveyance. It is, therefore, necessary to conduct inspection at an appropriate time by a suitable method to see if the produced and placed concrete satisfies the established performance requirements.

### 8.2 Inspection of self-compactabilty
(l) The self-compactability of concrete shall be inspected before placing.
(2) The inspection for self-compactability shall be carried out at least once for each 50 $m^3$ or fraction thereof of concrete by passability tests using a filling tester.
(3) If all possible factors for quality fluctuation of concrete are identified and if such factors can be inspected by a test method with established correspondence with passability tests using a filling tester, such tests may substitute for inspection tests.
(4) Concrete rejected in the inspection shall be treated adequately. The causes for such rejects shall be identified to improve subsequent production.

[Commentary]
(1) The performance of concrete produced and transported for actual construction can differ from that of designed concrete. It is, therefore, important to conduct inspection before placing, even if the concrete has been verified at the design stage. It is particularly important to examine before placing that produced and transported concrete attains the established Self-compactability for ensuring reliability of the structure. Since the changes in the temperature and transportation time during the construction can alter the self-compactability from the designed level, it has to be confirmed by a suitable method by the time the placing begins.

The inspection is generally carried out at the point of unloading after production/transportation. In this case, it should be confirmed that the changes in the self-compactability due to conveyance within the site, such as pumping after unloading, are sufficiently small. The time after production and before shipping may be specified for inspection, if it is also confirmed that the transportation after production causes only marginal changes in the self-compactability.

(2) Self-compactability may be inspected by passability tests with a Bl1ing tester used at the verification stage. The obstacle conditions corresponding to the established self-compactability rank should be used for testing. An inspection frequency of at least once for each 50 $m^3$ or fraction thereof of concrete was adopted referring to the frequency of inspection specified for superplasticized concrete.

(3) A simple alternative test method may be applied in place of the inspection, if the possible factors for quality fluctuation of concrete during production are identified and if such a Simple test method is established, whereby correspondence can be established with the criteria for rejection in the inspection by passability tests using a filling tester. Where the measurements during production can be reviewed by printed records and the factors for possible quality fluctuation are limited to the fluctuation in moisture content and high-range water-reducing agent, the evaluation can be made by a combination of slump flow and flow time to 500 mm or funnel efflux time. In this case, it is necessary to establish judgment criteria corresponding to rejection by passability tests using a filling tester.

When self-compacting concrete is applied to general reinforced concrete structures (Rank 2 self-compactability), 100% testing with a passability tester may be applied for inspection. One hundred percent testing with a passability tester can automatically judge if a Rank 2 self-compactability concrete possesses the required self-compactability, having established correspondence with passability testing with a filling tester. The whole truckload can be inspected by installing this tester between an agitator truck containing concrete and a mobile pump to receive it. This type of tester could also be used for concrete of other self-compactability ranks by an adequate setting of the obstacle conditions. Refer to the Manual for Production and Placement for detailed descriptions of 100% test methods.

(4) When an inspection has rejected a concrete for low deformability, the concrete may be added with a high-range water-reducing agent at a dosage in a predetermined range for reinspection. When rejected for segregation, the concrete must not be used. In any case, the causes for rejection must be identified for adequate and prompt remedial measures to improve subsequent production.

### 8.3 Inspection of other performance items

Inspection of performance items other than self-compactability shall be conducted in accordance with the JSCE Standard Specification.

[Commentary]
Where requirements have been established for performance items other than self-compactability, for which inspection is required, it should be conducted at an appropriate time by suitable methods. The time and methods for the inspection should be in accordance with the JSCE Standard Specification.