JSCE Guidelines for Concrete
No.18

STANDARD SPECIFICATIONS FOR CONCRETE STRUCTURES – 2007
"Dam Concrete"

Japan Society of Civil Engineers

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FAX +81-3-5379-2769 E-mail pub@jsce.or.jp
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Preface

Concrete structures have supported our society as infrastructures. The society can only preserve itself in wholesome with tough, beautiful and durable concrete structures. Concrete Committee of Japan Society of Civil Engineers (JSCE), leading organization for investigation, research, technological promotion and education of concrete in Japan, considers the issuance and revision of Standard Specifications for Concrete Structures as its most important activity. Standard Specifications for Concrete Structures (JSCE-SSCS), which show the model for plan, design, execution, maintenance and repair of concrete structures, have been highly recognized in practice and contributed to the development of concrete technology in Japan since its first publication as “Standard Specifications for Reinforced Concrete – 1931.”

In order to cope with the development of concrete technology in Japan and the worldwide trend, Concrete Committee converted all Specifications in JSCE-SSCS namely ‘Structural Performance Verification,’ ‘Seismic Performance Verification,’ ‘Materials and Construction,’ ‘Maintenance,’ ‘Dam Concrete’ and ‘Pavement,’ from the “Prescriptive Code” to “Performance-based Code” and completed the work in 2002.

This revised edition adopts the technological development after 2002 and intends to enhance the performance-based nature in Standard Specifications. For practical efficiency, the three Specifications - ‘Design,’ ‘Materials and Construction’ and ‘Dam Concrete’ present not only general provisions for verification of specified performance requirements but also standard methods as simplified methods to achieve the performance requirements under certain conditions. JSCE-SSCS is ready for practical use as it describes the role of each Specification during the plan, design, execution, maintenance and repair phases as well as the relationship among them. And for the first time, it also describes roles of engineers for construction works. This JSCE-SSCS is yet an ultimate one. There are still remaining tasks, such as inclusion of provisions for scenario of concrete structures during service life. What readers can find in this revised edition is rationality with “the performance-based concept” and the applicability for practice, showing the high level of technology in Japan.

This revised JSCE-SSCS consists of five Specifications; ‘Design,’ which combines the previous ‘Structural Performance Verification’ and ‘Seismic Performance Verification’ together, ‘Materials and Construction,’ ‘Maintenance,’ ‘Dam Concrete’ and ‘Test Methods and Specifications.’ Specification of ‘Test Methods and Specifications’ was issued separately in May 2007. Specification of ‘Pavement’ was published as “Standard Specifications for Pavements – 2007” by the Committee on Pavement Engineering of JSCE, which has taken over the issuance and revision works from JSCE-SSCS.

Finally I would like to show my most sincere gratitude to Prof Taketo UOMOTO and Dr Tadayoshi ISHIBASHI, Chairman and Secretary General of Sub-committee on Revision of Standard Specifications for Concrete Structures as well as its Secretaries, Conveners and Members who devoted themselves continuously despite the tight drafting schedule. My gratitude also goes to Advisors, Secretaries, Executive Members and Members of Concrete Committee, who reviewed the draft.

December 2007

Toyo. Miyagawa

Toyoaki MIYAGAWA, Chairman
Concrete Committee of Japan Society of Civil Engineers

Preface to the English Version

The Japan Society of Civil Engineers' (JSCE) Concrete Committee has been publishing the Standard Specifications for Concrete Structures in Japanese since 1931. The English versions were published twice in 1987 and 2005 when the limit state design and the performance-based concept were introduced in the 1986 and 2002 editions of Standard Specifications for Concrete Structures (JSCE-SSCS) for the first time, respectively.

Since 2004 the Concrete Committee has put efforts to enhance information dissemination overseas by presenting various English publications including the series of "JSCE Guidelines for Concrete." Concrete Committee has also decided to prepare the English version of every edition of JSCE-SSCS. This Sub-committee on English Version of Standard Specifications for Concrete Structures was established in 2008.

Our task is to prepare the English version of four Specifications: 'Design,' 'Materials and Construction,' 'Maintenance' and 'Dam Concrete' of the 2007 edition of JSCE-SSCS. Specification of 'Test Methods and Specifications' of JSCE-SSCS is not included in this English version. However, some of these standard test methods and specifications have been translated for publication in a series of "JSCE Guidelines for Concrete." Please visit the website of Concrete Committee at http://www.jsce.or.jp/committee/concrete/e/index.html for the information on the English publications.

This English version includes most of the contents in the original Japanese version. Utmost efforts have been made to ensure that the translation accurately convey the description in the original Japanese version. If there were any discrepancy between the Japanese and English versions, however, reference should be made to the original Japanese version.

Translation of technical work does not only require expertise but a lot of time and dedication. I am grateful to all the members for their tiring efforts. My heartfelt appreciations go to Prof YOKOTA Hiroshi (Secretary General), Dr SHIMOMURA Takumi (Head, WG for Design), Prof SUGIYAMA Takafumi (Head, WG for Materials and Construction), Dr MAEDA Toshiya (Head, WG for Maintenance), Prof AYANO Toshiki (Head, WG for Dam Concrete) and Dr ISHIZUKA Takayuki who proof-read all the translated Specifications. Without them this English version would not have been published.

December 2010

Tamon Ueda

UEDA Tamon, Chairman

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Application of Standard Specifications for Concrete Structures

Editorial notes for the English Version:

(1) The Standard Specifications for Concrete Structures are a model code which is supposed to be applied in Japan and have no legal bindings.

(2) Therefore, some contents, such as Chapters 2 and 3 of “Application of Standard Specifications for Concrete Structures,” may not fit to practical scheme in construction industry in the other countries.

(3) However, it is hoped that the Standard Specifications for Concrete Structures could be a model code for the other countries after necessary modifications of the contents considering the local conditions.

1. Basic concept concerning the organization of the Standard Specifications for Concrete Structures

The Standard Specifications for Concrete Structures are regularly revised reflecting the state-of-the-art concrete technologies developed in Japan and other countries, and provide standards concerning the technical aspects of concrete structures in a series of phases from planning to design, construction and maintenance.

In this revised edition, the “Standard Specifications for Concrete Structures, Design” is composed of the “Standard Specifications for Concrete Structures, Structural Performance Verification” and “Standard Specifications for Concrete Structures, Seismic Performance Verification” to enhance the convenience of design practice. Durability check and initial cracking check, which should be discussed in the “Standard Specifications for Concrete Structures, Design” have been transferred from the “Standard Specifications for Concrete Structures, Materials and Construction” to “Standard Specifications for Concrete Structures, Design”. The preparation and revision of the “Standard Specifications for Concrete Structures, Pavement” has been handed over to the Committee on Pavement Engineering, JSCE (Japan Society of Civil Engineers). The results are now published separately under the title of the Standard Specifications for Pavement. Thus, the Standard Specifications for Concrete Structures include five components: Design, Materials and Construction, Maintenance, Dam Concrete, and Test Methods and Specifications.

The General Requirements for “Design”, “Materials and Construction” and “Dam Concrete” are described based on the concept of performance-based code. Performance requirements are specified for structures and the methods for checking the compliance with requirements are shown in the General Requirements. In the Standard Methods, standard methods for satisfying the General Requirements under certain conditions are given for more efficient and simpler design and construction. In cases where no conditions specified in the Standard Methods are met, performance verification should be conducted in accordance with the General Requirements. For establishing new standards fitting for structures or regions to which no Standard Methods are applicable, the Standard Methods may be referred to.

Concrete structures are generally constructed for providing services in the phases of planning, design, construction and maintenance in accordance with the respective components of the Standard Specifications. Each type of work is not independent of the others. Data are handed over from an upstream to a downstream phase that are required for carrying out the work downstream to meet the conditions specified upstream. Handing over the data is therefore important to proper implementation of work in respective phases. In the Standard Specifications for Concrete Structures, “Design”, “Materials and Construction” and “Maintenance” are closely interrelated to one another. Then, the required data shown in each Specifications should be accurately handed over to the next phase without fail.

Performance requirements for durability, safety, serviceability and restorability that are specified in the “Standard Specifications for Concrete Structures, Design” are determined in the design phase. Construction and maintenance methods are roughly determined in the phase. The data that affect construction and maintenance should therefore be handed over to the next phase without fail in the form of design drawings.

Construction records that are specified in the “Standard Specifications for Concrete Structures, Materials and Construction” provide important data for assessment, deterioration prediction and implementation of remedial measures in the maintenance phase. Accurate construction records should therefore be handed over to maintenance engineers. Construction plans and various inspection reports should also be provided to engineers as required.

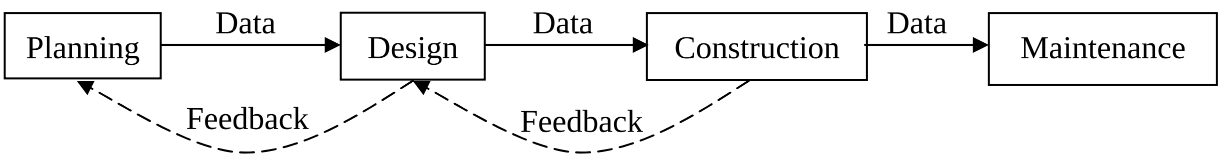


Fig. 1 Flow of work

Figure 1 shows a flow of work from the planning of a concrete structure to service commencement. Data collected in the maintenance phase are not transferred to engineering works in the planning, design or construction phase. It should, however, be taken into consideration that reflecting the data in the maintenance phase in the planning, design and construction of another structure for improvement is important to extend the service life of the structure. The interrelationship is basically the same for design, construction and maintenance described in the “Standard Specifications for Concrete Structures, Dam Concrete.”

Each component of the Standard Specifications for Concrete Structures is described below.

The “Standard Specifications for Concrete Structures, Design” shows standard methods for performance verification of concrete structures such as reinforced concrete, prestressed concrete and steel-concrete composite structures, and stipulates the preconditions for checking and structural details. The revised Standard Specifications for Concrete Structures are not applicable to unreinforced concrete structures. Material design values or other applicable items may, however, be applied to unreinforced concrete structures.

The “Standard Specifications for Concrete Structures, Materials and Construction” provides basic general rules concerning the construction of concrete structures. In the construction phase, the construction method and the performance during the construction work are determined based on the design drawings and restrictions on construction. Then, materials are selected and concrete mix proportions are determined, where a concreting plan is developed so as to meet the requirements for water content, cement amount, cement type and other parameters. Whether the concreting plan meets the construction requirements or performance requirements of the structure or not is verified by an appropriate method. If the requirements are not satisfied, the concreting method is re-specified or the mix proportions are modified as long as the conditions handed over from the design phase are met.

The “Standard Specifications for Concrete Structures, Maintenance” provides general basic principles concerning the maintenance of concrete structures. In the maintenance phase, documents such as the design drawings and maintenance plans handed over from the design phase, and the construction plans, as-built drawings, construction records and inspection reports handed over from the construction phase should be fully used for efficient and effective maintenance work. In cases where the use or functions of the structure change due to social changes, performance verification should be made to verify whether the structure meets the resultant performance requirements or not. If designated performance requirements are not ensured, repair, strengthening or other remedial measures should be considered.

The “Standard Specifications for Concrete Structures, Dam Concrete” stipulates performance and quality requirements for dam concrete, and describes the methods for verifying the compliance with the requirements and the basic design and construction principles. The descriptions concerning design, construction and maintenance in the “Standard Specifications for Concrete Structures, Dam Concrete” are different from the contents of the Standard Specifications “Design”, “Materials and Construction” and “Maintenance” with many respects because of the factors unique to dam concrete such as the unreinforced nature and low or zero slump of dam concrete. The “Standard Specifications for Concrete Structures, Dam Concrete” therefore describes the matters concerning the design, construction and maintenance of dam concrete.

The “Standard Specifications for Concrete Structures, Test Methods and Specifications” lists the Japan Industrial Standards, provisions of JSCE and other standards for the methods mentioned in the other four components of the Standard Specifications. Figures 2 through 4 show work steps in respective phases described in the Standard Specifications for Concrete Structures “Design,” “Materials and Construction” and “Maintenance.”

2. Roles and deployment of responsible engineers

To produce and maintain a reliable structure that meets the performance requirements, the engineers involved should have a capacity to carry out the work and a high level of ethics.

In the planning, design, construction and maintenance of a concrete structure, the engineers should make appropriate decisions under varying work conditions. Therefore, the engineers with required technical skills should be deployed according to the level of difficulty of work. In the planning, design, construction and maintenance, therefore, responsible engineers not only with required technical expertise but also with responsibility and authority should be deployed in organizations of the owner, the consultant and the contractor.

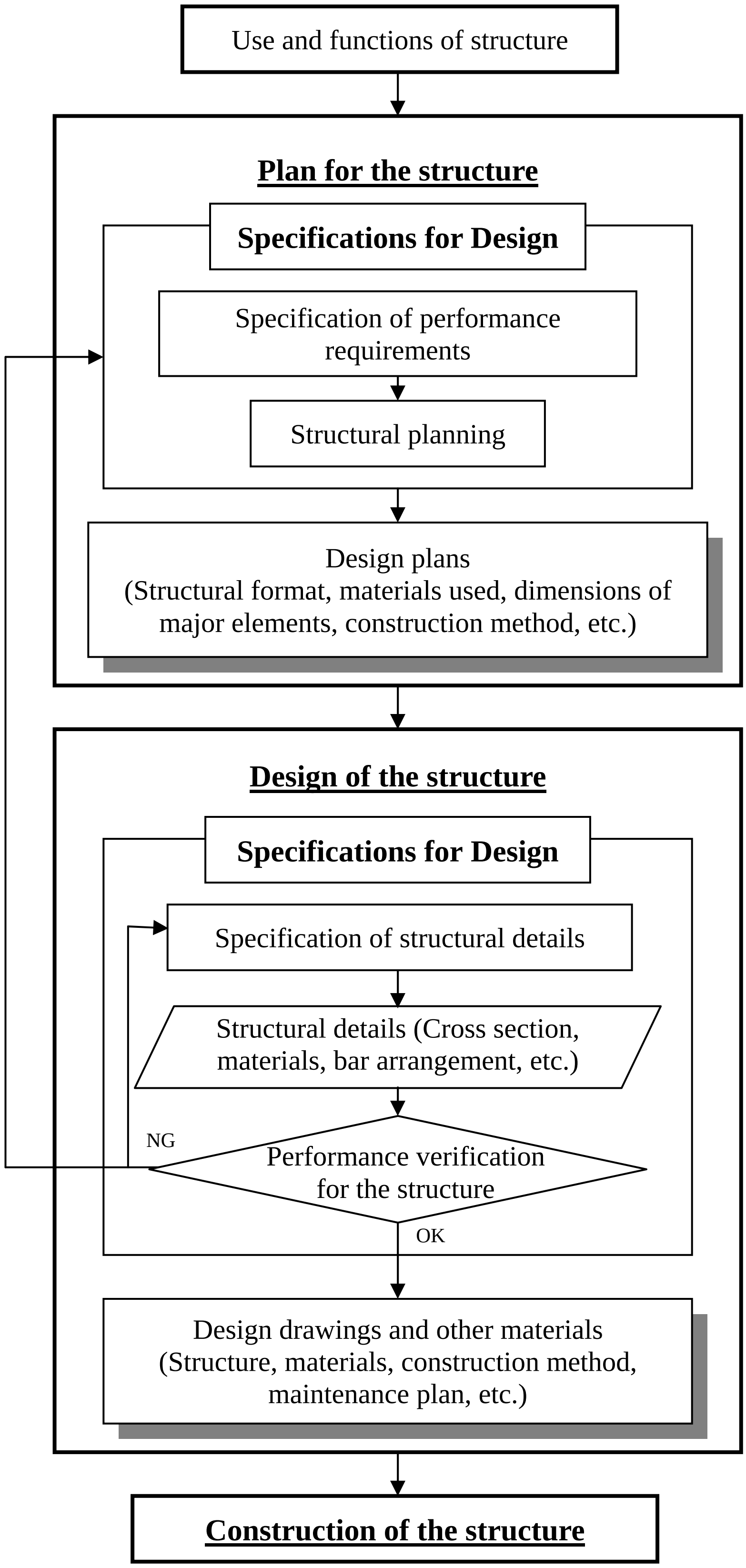


Fig.2 Work steps described in "Specifications for Design"

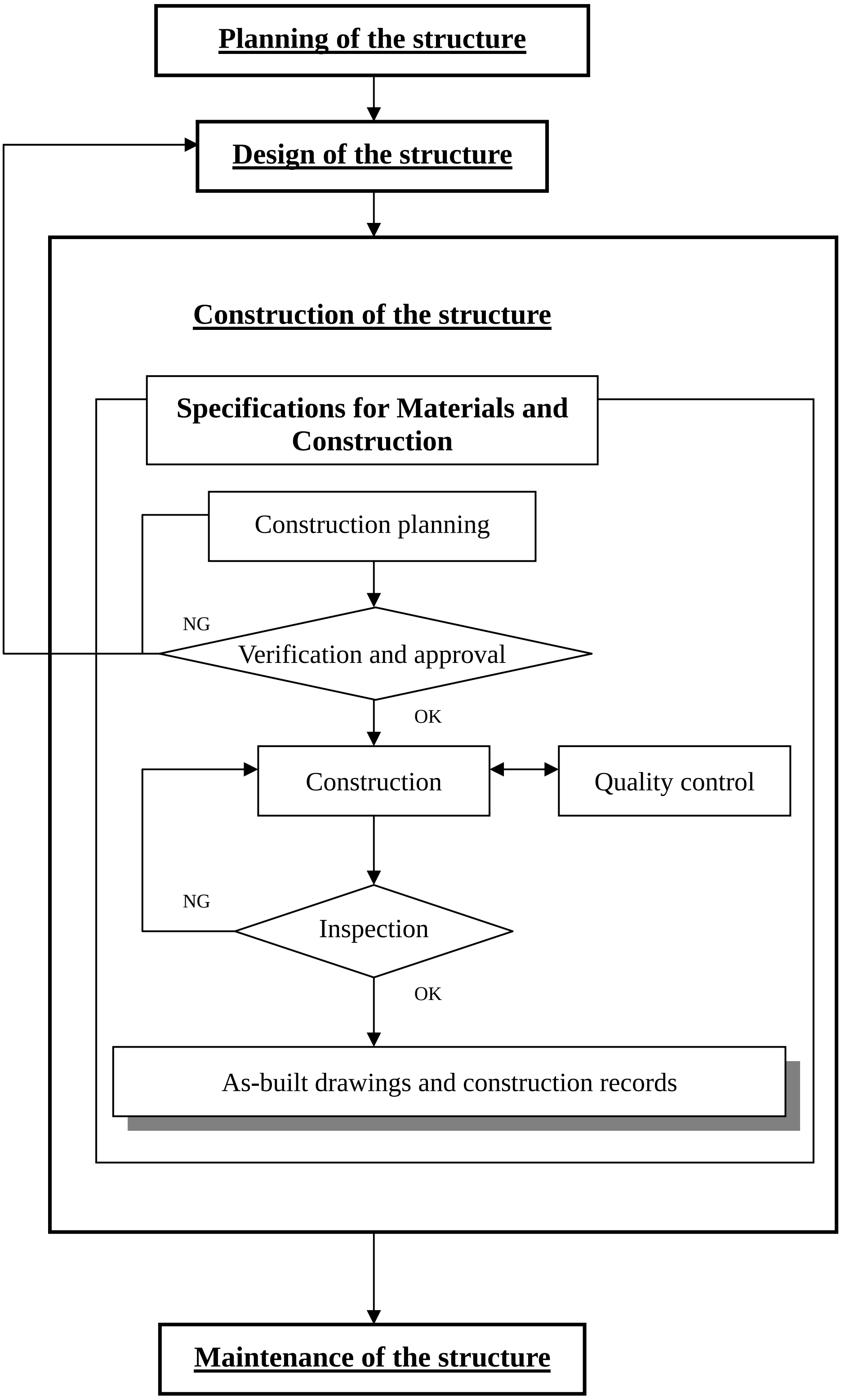


Fig. 3 Work steps described in “Specifications for Materials and Construction”

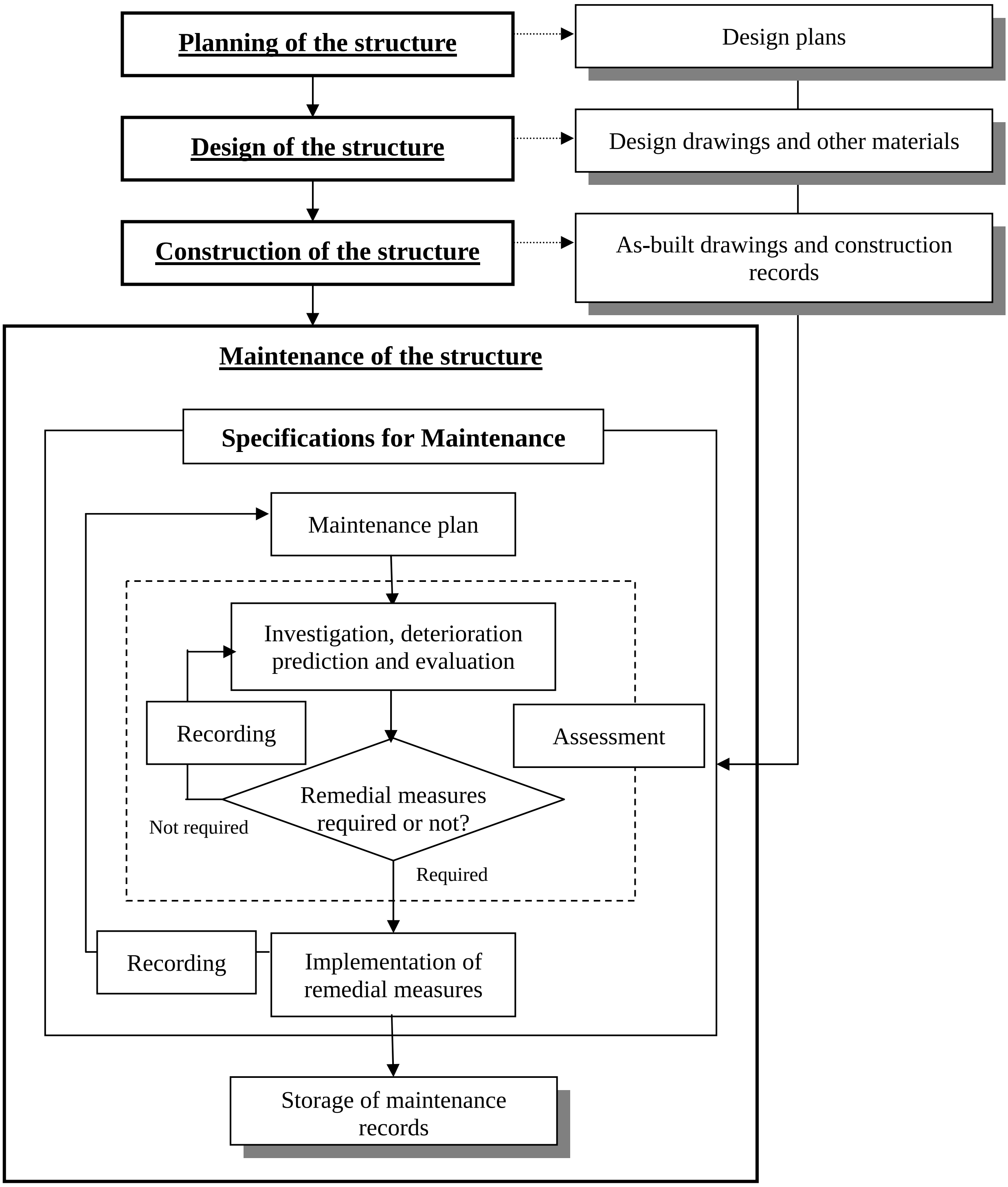


Fig. 4 Work steps described in "Specifications for Maintenance"

The technical skills required for responsible engineers should be defined according to a scale of the work, importance and difficulty of planning, design, construction or maintenance.

As capacity classifications of engineers, engineer qualifications authorized by JSCE are listed in Table 1. The qualifications for the special senior engineers and senior engineers are generally required for responsible engineers.

The JSCE technical qualifications cover several fields. Responsible engineers to be deployed in projects need to have qualifications only for major fields related to the specific project.

Table 1 Engineer qualifications authorized by JSCE

Qualification	Required skills
Executive Professional Civil Engineer	Japan’s leading civil engineer with high-level knowledge and experience in his or her field of specialty, or with comprehensive civil engineering expertise
Senior Professional Civil Engineer	Engineer with high-level knowledge and experience in multiple fields or with comprehensive knowledge on civil engineering who can solve key problems as a leader
Professional Civil Engineer	Engineer with knowledge and experience at least in one special field who can carry out task at his or her discretion
Associate Professional Civil Engineer	Civil engineer with required basic knowledge who can carry out assigned task

3. System for ensuring reliability

Many groups are involved in the planning, design, construction and maintenance of a structure. In order to ensure the high reliability of the structure in each work phase, the organizations involved should play their role providing their know-how and assuming due responsibility.

To ensure reliability in the design (and planning) phase, two independent groups should basically check the design. After the design and check by the design company, engineers of the contractor should re-check the design, or request a third party to check the design. Then, fully skilled engineers should be selected for checking so that safety or other reliability parameters may be satisfied. The design drawings serving as a basis for contracting should carry the signatures of responsible engineers of the two groups that assume responsibility.

In the construction phase, reliability is ensured through the quality management by the contractor and the quality verification by the inspector independent of the contractor. Inspections have generally been conducted directly by the Owner and/or Consultant. Completed structures should be inspected wherever possible. If inspecting completed structures is impossible, inspections should be conducted while the structure is being constructed. If the Owner cannot directly inspect the structure under construction, the Owner may request an agent independent of the contractor. Adopting as many highly reliable methods as possible can reduce the labor required for quality management and inspection. In cases where adopting not so reliable methods is inevitable, the level of quality management should be raised or inspections should be conducted more frequently to improve reliability. Inspection items and decision criteria should be specifically presented at the time of contracting because they greatly affect the quality of the structure and the construction cost.

Ensuring safety requires regular investigations. When defects are detected, decision should be made as to remedial measures. For decision making concerning remedial measures for extremely difficult deformation, listening to the opinions of engineers with high skills who have experienced numerous cases is important.

In order for a system for ensuring reliability to work properly, the people or organization with technical skills fit for the specific work should be granted explicit responsibility and authority and assigned to the work. The compensation for the work and time required for the work should also be provided.

Performance Verification

CHAPTER 1 GENERAL

1.1 Purpose

***The Standard Specifications for Concrete Structures - 2007: Dam Concrete* specify the performance requirements for concrete used in concrete dams (hereinafter referred to as "dam concrete") and methods for verifying and inspecting whether the dam concrete satisfies the performance requirements.**

[Commentary] *The Standard Specifications for Concrete Structures - 2007* (hereinafter referred to as “these Specifications”)*: Dam Concrete* specify the performance requirements for dam concrete so that the required structural performance of a concrete dam should be achieved, and also specify methods of verifying and inspecting whether the dam concrete satisfies the performance requirements. Performance requirements for the dam concrete that are not related to the structural performance of the dam concrete, for example, performance requirements for aesthetics enhancement, are not dealt with here.

Engineering details that are not described in *Part 1, Performance Verification*, need to be judged by the responsible engineers of the Owner and the Contractor.

1.2 Scope

***Part 1, Performance Verification*, describes general rules for verifying the required performance of dam concrete. *Part 2* specifies standard methods of performance verification for conventional dam concrete which has been used in past projects.**

[Commentary] *Part 1, Performance Verification*, specifies criteria of performance verification type in these Specifications: Dam Concrete. As a general rule, mixture design, construction and inspection for dam concrete should be carried out as described in *Part 1, Performance Verification*. Ordinary dam concrete that has been used in past projects. It, however, may be deemed to have the required performance if the procedures specified in *Part 2, Standard Methods*, are followed.

The flow of works such as mixture design, construction and inspection for dam concrete specified in *Part 1, Performance Verification* is shown in Fig. C1.2.1.

The construction of concrete dam in Japan is usually carried out jointly by the Owner’s engineer and the Contractor under the supervision of the Owner. These Specifications: Dam Concrete assume that the works are led by the constructors in the chapters related to the construction works and led by the Owner or its representative in the other chapters.

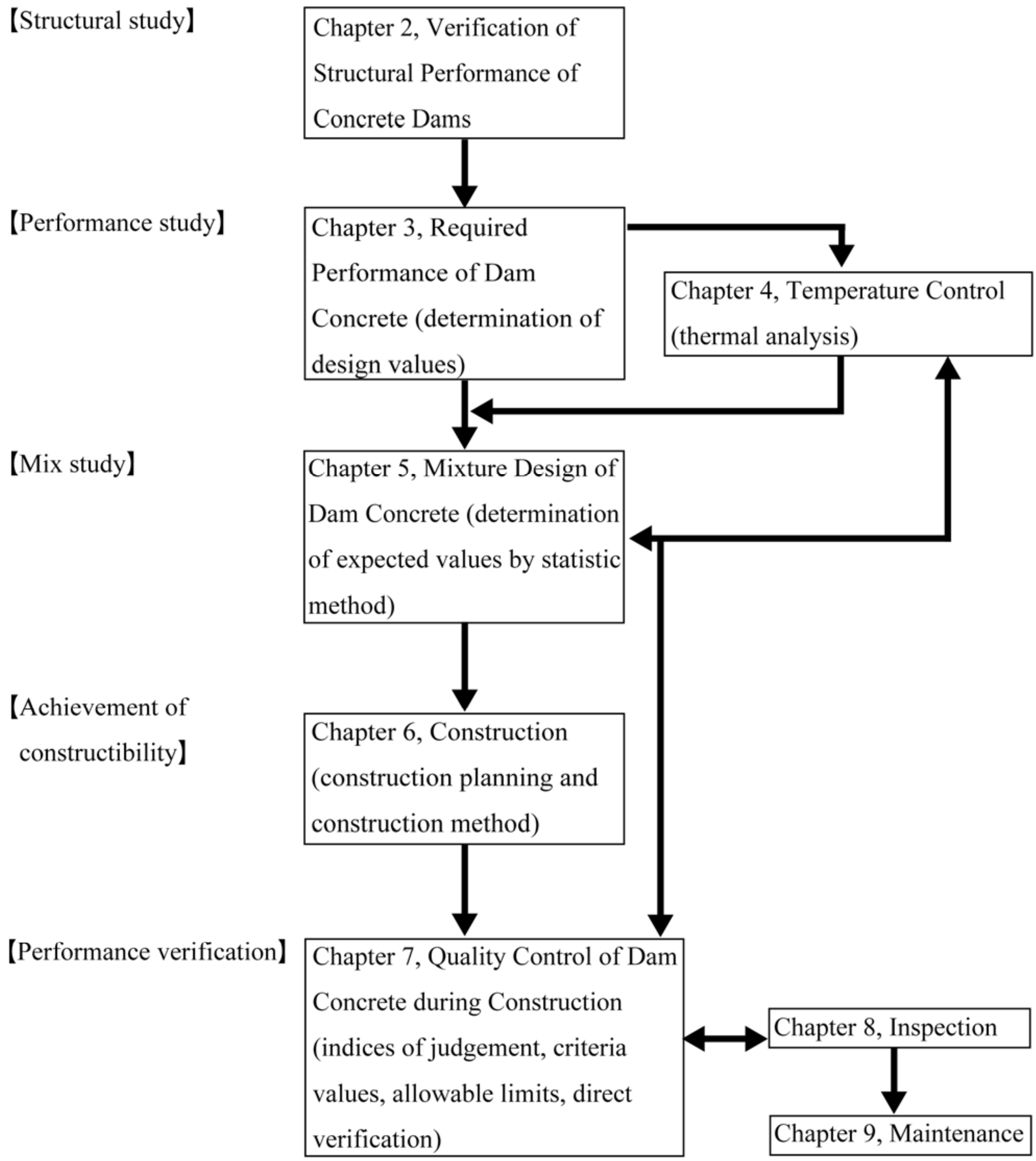


Fig. C1.2.1 Content of *Part 1, Performance Verification* and workflow

1.3 Definitions

Terms used in *Part 1, Performance Verification*, are defined as follows:

Performance – Property of the dam concrete required in the design of a concrete dam or in the mixture design of dam concrete.

Characteristic value – A representing value indicating the performance of dam concrete required in the mixture design of the dam concrete (e.g., specified strength of test specimens).

Allowable limit for characteristic value – A value indicating the lowest or highest allowable level of dam concrete performance required in the mixture design of dam concrete.

Expected value – The average value indicating dam concrete performance required in the mixture design of dam concrete (e.g., required strength).

Index of judgment at the construction stage – An index used to judge whether a characteristic value required for dam concrete is achieved at the construction stage.

Criterion value at the construction stage – A representing value of an index of judgment at the construction stage required for dam concrete.

Allowable value of judgment at the construction stage – The lower or upper boundary of an index of judgment permitted for dam concrete at the construction stage.

VC value – A value indicating the consistency of Roller Compacted Dam-concrete and it is expressed as time (in seconds) obtained by the vibrating-table type consistency test method using a specified container.

Conventional block construction method – A method of constructing a concrete dam by dividing the dam body into a number of blocks with longitudinal and transverse joints.

RCD (Roller Compacted Dam-concrete) Method – A construction method of a dam in which Roller Compacted Dam-concrete is used as the internal concrete and the spread concrete is compacted by vibratory roller in the construction.

Extended layer construction method (ELCM) – A construction method of a concrete dam in which conventional concrete is placed without difference in lift.

[Commentary] The terms defined here are the special terms used in *Part 1, Performance Verification*. The explanations for each term are described below.

Performance: In general, performance-verification-type of standards employ the term "performance" to refer to the physical properties required for a structure or its materials. The term "performance" basically refers to the ability or functions of an object or material. In *Part 1, Performance Verification*, however, "performance" has been defined as the physical properties of dam concrete required in the design of a concrete dam or in the mixture design of dam concrete following the other parts in the previous versions of these Specifications. That is why the term "performance" is used in a broader sense here than in general use and the strength of dam concrete, water-tightness, Young's modulus, Poisson's ratio and so on are included in "performance."

Characteristic value and allowable limit for characteristic value: The performance requirements for dam concrete cannot always be verified in the laboratory. For example, whether dam concrete is capable of maintaining the required strength for as much as 100 years can only be verified by conducting the test in 100 years. In addition, because the state of stress in a dam body is three-dimensional, it is not appropriate to evaluate the failure characteristics of the concrete by the uniaxial compressive strength (or splitting tensile strength) in the strict sense. Furthermore, although the maximum size of aggregate used for dam concrete usually ranges from 80 to 150 mm, the compressive strength is usually tested on the specimens of the concrete from which 40 mm or larger size of aggregates is removed by wet screening because it is not easy to conduct compressive strength test of the concrete with such large size of aggregate. It is therefore not realistic to directly evaluate the required performances and it is necessary to verify it indirectly by testing. For ordinary concrete, design values for the structural design are determined by assuming that the physical properties of the concrete mixed according to the specified mixture proportions are the same as those of the concrete constituting the structure. For dam concrete, various tests should be conducted on specimens of concrete sampled by wet screening as mentioned above. The test data of such sampled concrete may be considered as the physical properties of the dam concrete itself for the convenience following the previous practical engineering judgment. In case of strength, for example, the specified strength of specimens should be considered as the characteristic value of the dam concrete.

Whether dam concrete satisfies the performance requirements should be judged by verifying whether test data of the specimens is larger or smaller than the required value. In reality, however, dam concrete varies in the performance, and it is necessary to judge whether it satisfies the performance requirements by taking the variance into consideration. Evaluation based on probability theory is necessary for that purpose. Criterion for judgment with two levels is adopted for dam concrete. One is a value that must not be realized frequently (a probability of occurrence set up as 15% for example). The other is a value that is not permissible practically (a probability of occurrence set up as 1% for example,). In case of dam concrete, the value that must not be realized frequently should be the characteristic value, and the value that is not permissible practically should be the allowable limit for the characteristic value.

Expected values: The mean value of test data of the physical properties by which the performance of dam concrete is verified at the mixture design stage is referred to as "expected value." According to the definitions, the order of smallness is allowable limit for characteristic value, characteristic value, and expected value.

If uniaxial compressive strength is considered as a performance requirement for dam concrete, the characteristic value and the expected value correspond (though not necessarily equivalent) to the "specified strength" and "required strength" mentioned in *Part 2, Standard Methods*.

Index of judgment at construction stage, criterion value at construction stage and allowable value for judgment at construction stage: Although performance requirements for dam concrete should normally be specified for hardened dam concrete, whether the mixed dam concrete may be placed should basically be judged prior to the placement. That is why index is necessary for judging the propriety of the dam concrete before the placement instead of the performance of the dam concrete itself. The index for that purpose should be the "index of judgment at the construction stage."

For example, the index by which whether the uniaxial compressive strength of conventional concrete satisfies the required value can be judged should be the combination of the water/cementitious material ratio and the slump value. The criterion value (representative value) at the construction stage and the allowable value of judgment (lower or upper boundary) should be the water/cementitious material ratio and the slump value corresponding to the characteristic value and the allowable limit for the characteristic value, respectively.

The relationship among the terms mentioned above along with the examples is shown in Fig. C1.3.1. As mentioned in the commentary on the definitions of the terms related to the characteristic value and the allowable limit for characteristic value, it is difficult to verify that the performance of dam concrete itself. That is why the “required performance” should be evaluated indirectly in terms of the “performance required in mixture proportion stage” as specified in the uppermost section in Fig. C1.3.1. Because they are going to turn out with the progress of the construction work, “index for judgment at the construction stage” should be set up and the propriety be judged promptly. To be more specific, “performances that can be measured in the laboratory” should be set up corresponding to the “original requirements” shown in the middle section in Fig. C1.3.1, and indices related to those requirements, that is, “indices that can be verified at the construction stage” should be chosen. By using those indices, the “verification at the placing site” and “verification of performance in the quality control laboratory” should be conducted to confirm or verify that the performance requirements for dam concrete are satisfied.

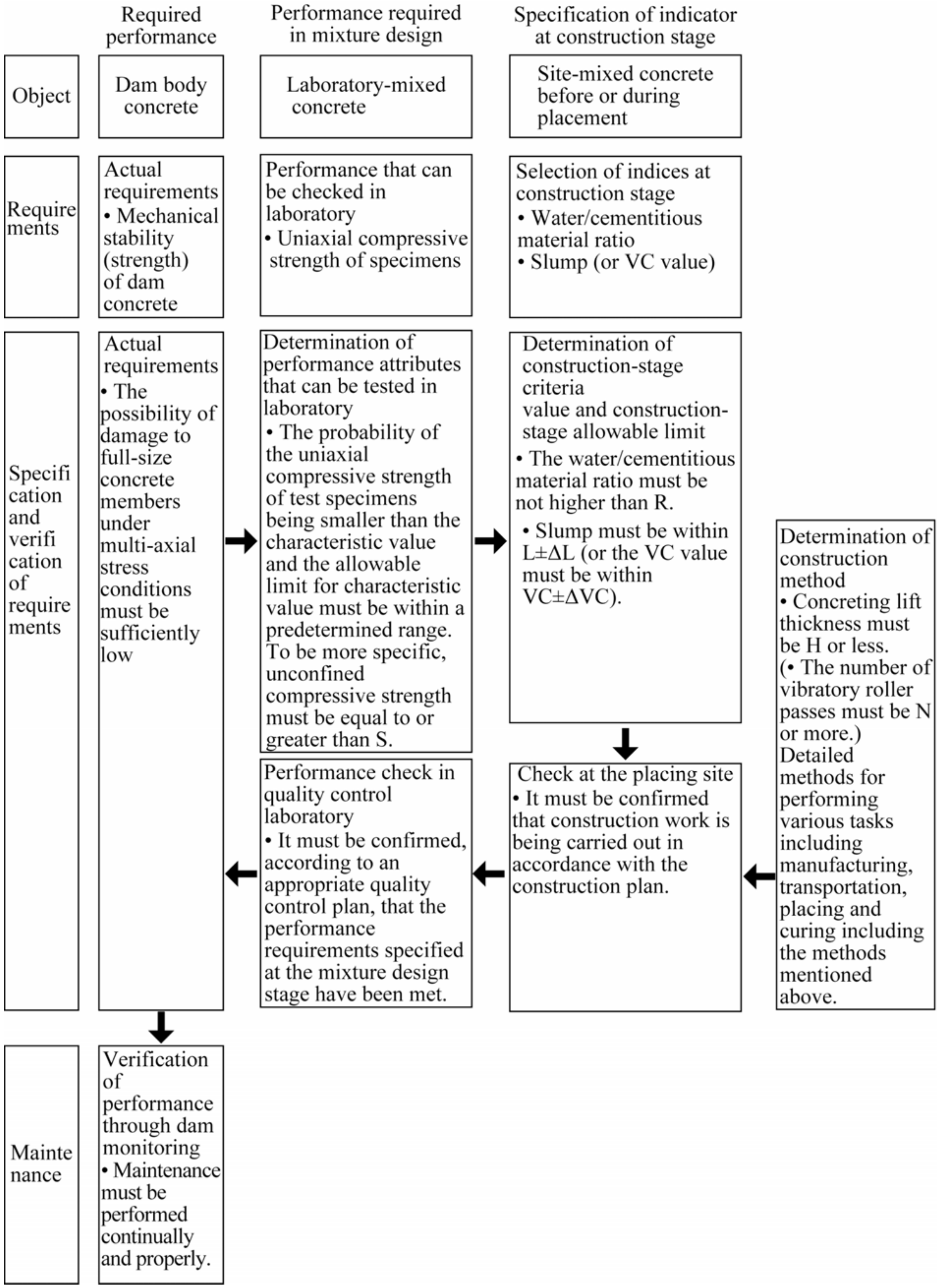


Fig. C1.3.1 Relationship between required performance, performance required in mixture design, and index of judgment at the construction stage (example in which the required performance is "compressive strength")

CHAPTER 2 VERIFICATION OF STRUCTURAL PERFORMANCE OF CONCRETE DAM

2.1 General

Concrete dam shall be designed structurally in principle so that the required structural performance is ensured.

[Commentary] In the structural design of a concrete dam, it is necessary to design the dam so that the required structural performance is not failed when the dam is subjected to assumed loading. The structural performance requirements for concrete dams include safety, serviceability and reparability. These requirements may be considered as follows:

Safety: Safety is ensured so that the stability of a dam is not failed under assumed loading conditions, and that uncontrollable stored water does not cause casualty or property damage in the areas downstream.

Serviceability: The functionality of a dam against assumed loading is achieved.

Reparability: Repairs can be done with applicable technology, at reasonable cost and in a reasonable period of time so that continuous use may be possible.

The “assumed loading” conditions should be determined as described in Section 2.2, Loads.

Structural performance verification should check whether a dam has been designed so that the dam may not lose the expected functions even under the assumed loading conditions.

Sedimentation may impair the water storage function resulting in the reduction in the serviceability. This chapter, however, deals with the verification of structural performance against loads due to sedimentation only.

Serviceability as one of the structural performance of a dam is the ability to retain the water storage function and to keep capable of controlling water storage and release under the assumed load conditions. Serviceability, therefore, is often regarded as one of the structural performance of appurtenant facilities, particularly discharge facilities and control facilities such as gates and valves designed for water storage and release control. For the dam body, structural safety is usually more important than serviceability, which indicates water storage and release control performance. When considering reparability as a structural performance, it is necessary to take not only technicalities associated with safety evaluation but also the social and economic impacts of the impairment of the flood control and water utilization functions of the dam during the repair period into accounted. Since *Part 2, Dam Concrete*, deals with dam concrete used for concrete dam bodies, Chapter 2, Verification of Structural Performance of Concrete Dam, describes safety related to dam bodies as a structural performance of dam concrete to be verified.

2.2 Loads

2.2.1 Load classification

Loads shall be classified into permanent loads, variable loads and accidental loads.

[Commentary] Loads should be classified into permanent loads, variable loads and accidental loads.

The term "permanent load" is defined as a constantly acting load or a load with very low rate of change compared with the average value. Permanent loads also include loads with monotonously increase or decrease until it reaches a certain limit. Permanent loads acting on dams include its self-weight.

The term "variable load" is defined as a load with non-negligible variance compared with its average value and without monotonic changes. Variable loads acting on dams include water pressures during dam operation including those in times of flood, uplift pressures, thermal loads and seismic loads. For variable loads that can be evaluated statistically, effort should be made to indicate probabilistic indices such as the expected value during the return period and the non-exceeding probability.

The term "accidental load" is defined as a load that is difficult to predict statistically but cannot be negligible. Dam-related accidental loads include loads caused by extreme earthquakes or unexpected water pressures such as overflow.

2.2.2 Load combinations

When a concrete dam is designed, appropriate combinations of loads shall be taken into consideration.

[Commentary] Concrete dams should be designed by taking expected load combinations into consideration. Combinations of loads acting on the dam body to be taken into account should be selected from the loads listed below and estimated in suitable level according to such factors as the type of dam and the reservoir level.

(1) Load from water pressure load in the reservoir (e.g., hydrostatic pressure, uplift pressure, earthquake-induced hydrodynamic pressure)

(2) Earth pressure due to accumulated sediment (e.g., static pressure, earthquake-induced dynamic pressure)

(3) Self-weight of dam, earthquake-induced inertial force of the dam body

(4) Thermal loads due to change in weather or reservoir water temperature

(5) Other expected loads

At the construction stage, the following loads need to be taken into consideration:

(1) Gravity: For example, gravity acting on the dam body affects the self-supporting ability of demolded concrete. A concrete arch dam before joint grouting could be in a dangerous state of

stress.

(2) Heat of hydration during hardening of concrete: That load, along with weather-induced loads, may cause thermal cracks in the surface layer and interior of the dam concrete.

(3) Other expected loads

2.3 Safety Verification

In the design of a concrete dam, it shall be verified that the dam has the required level of safety by using a structural analysis method suitable for the structural characteristics of the dam.

[Commentary] Safety against shearing stress generated in the concrete dam body, along the joint between the dam body and in the supporting ground, and stress generated in the supporting ground under expected loads should be verified. Safety against stresses generated in the dam body must also be verified. It should also be verified that vertical tensile stress may not be generated on the upstream surface of a concrete gravity dam.

In addition to the safety specified above, performance of earthquake resistance of a concrete dam to earthquake motion with ranking Level 2 should basically keep the water storage function and have such an appropriate restorationability that can make it possible to restore despite of the damage. Dynamic response analysis should be employed for the verification of the performance of earthquake resistance to the motion ranked Level 2. JSCE defines the earthquake motion ranked Level 2 as one of the most intense one at present and in future at the site.

CHAPTER 3 PERFORMANCE REQUIREMENTS FOR DAM CONCRETE

3.1 General

(1) Appropriate performance requirements for dam concrete shall be determined so that the concrete dam has the required structural performance.

(2) When designing a concrete dam, the design values for the dam concrete performance used as the input conditions shall be either on the safety side or within the design allowable range.

[Commentary] (1) Three main performance of dam concrete required for achieving the structural performance of concrete dam to be taken into consideration in the structural design of a concrete dam should be strength, water-tightness and unit mass. Although durability is originally a concept in which strength or water-tightness is evaluated along the axis of time, it should practically be assumed as one of the independent items of performance by taking its current situation on the practical affairs into consideration.

In addition to strength, water-tightness, unit mass and durability, performance of dam concrete includes placing performance such as workability. However, placing performance is necessary for ensuring the strength, watertightness, unit mass and durability required for dam concrete efficiently or easily. No matter how the placing performance is, it may be allowable on condition that the strength, water-tightness, unit mass and durability meet the requirements finally. That is why the placing performance should not be determined as one of the independent items of performance.

(2) There are various methods of analysis for designing a concrete dam and an appropriate method should be selected by taking the structural characteristics of the concrete dam and the degree of importance of each item of the performance required for the dam concrete into consideration.

Design values for the various performances of the dam concrete are necessary as the input conditions for the design of the concrete dam having the required structural performance by the selected analytical method. For example, the unit mass of the dam concrete is necessary as an input condition in order to examine the mechanical stability in the design of a concrete gravity dam. In the case of a concrete arch dam, the Young’s modulus and Poisson's ratio, etc., of the dam concrete are necessary as input conditions for the calculation of the stress in the dam body because the concrete arch dam is an indeterminate structure. Adiabatic temperature rise, specific heat, thermal conductivity, thermal diffusion coefficient, etc., of the dam concrete are necessary as input conditions for planning temperature restriction for controlling thermal cracking due to the heat of hydration of cement.

As described above, the design values used as input conditions for the design of a concrete dam are necessary for achieving the required structural performance of the dam. The design values used as input conditions for designing a concrete dam, therefore, should be conservative. However, larger or smaller design value for some performance may reduce the structural safety of the concrete dam. The design value should be within the allowable range in such a case.

The flow of the dam concrete mixture proportioning study and the placement of dam concrete after the structural design of a concrete dam is shown in Fig. C3.1.1. Taking compressive strength as an example of a performance requirement for dam concrete, the relationship between the performance required at the mixture design stage (Chapter 5) and the indices (Chapter 7) used at the construction stage is shown. Chapter 3, Performance Requirements for Dam Concrete, describes considerations in determining characteristic values leading up to Chapter 5, Mixture Design of Dam Concrete.

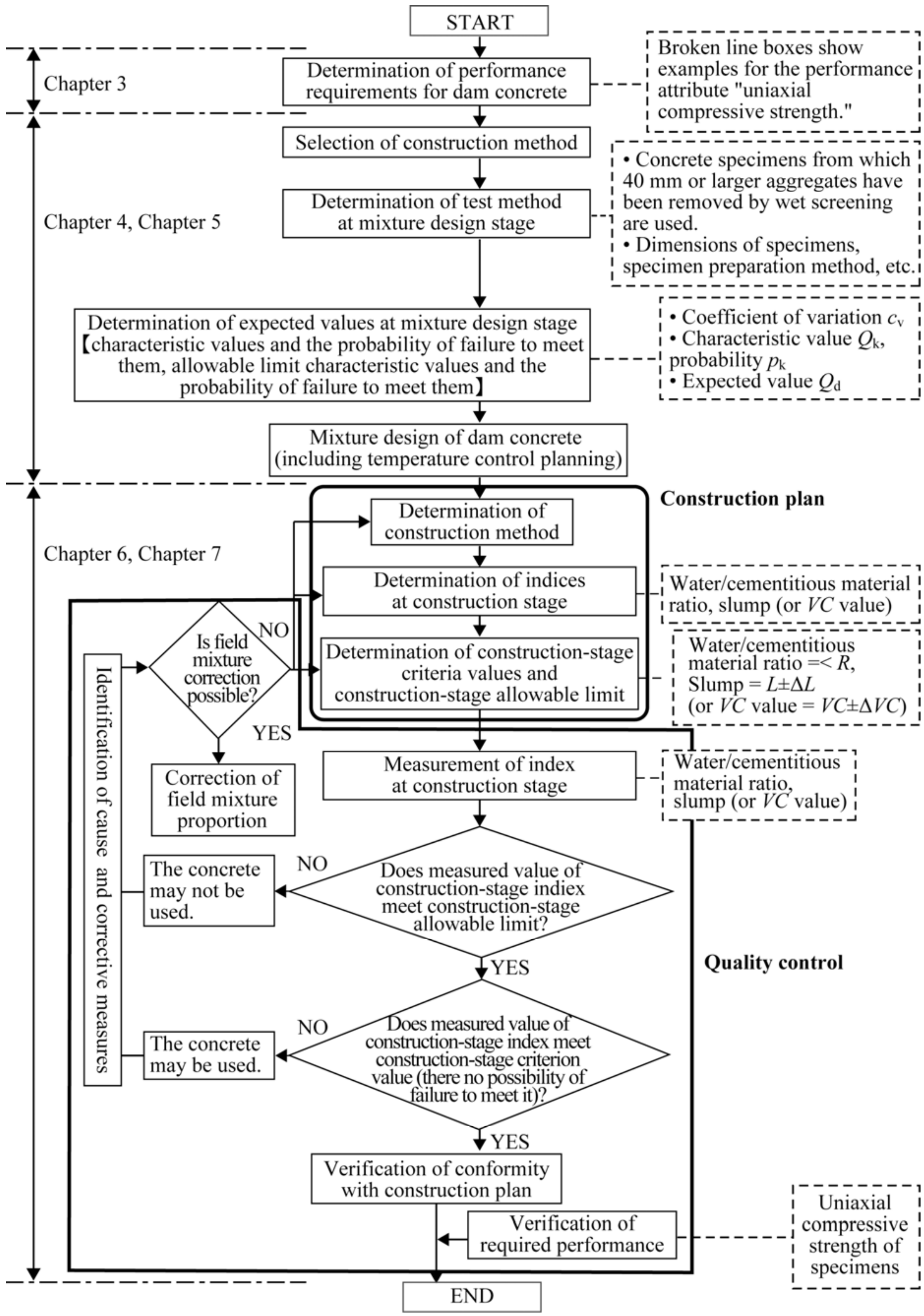


Fig. C3.1.1 Flow of mixture proportioning study and placement of dam concrete (Broken line boxes show examples for the performance attribute of uniaxial compressive strength.)

3.2 Design Values for Required Performance of Dam Concrete

3.2.1 Design values of unit mass

Design values of unit mass required for dam concrete shall be determined appropriately against loads that could be sustained by dam concrete.

[Commentary] Structural performance of dam concrete should be verified by combining loads appropriately as specified in Section 2.2.2, Load Combinations. Design values of the unit mass of dam concrete, therefore, should be determined appropriately so that the values determined in structural performance verification is met.

3.2.2 Design values of strength

(1) Design values of the required strength of dam concrete shall be determined on the basis of the results of the structural performance verification of concrete dam specified in Chapter 2.

(2) If it is judged that the performance other than strength should be used, an alternate design value for the performance may be determined.

[Commentary] (1) Design values of the required strength of dam concrete should be determined so that the probability of the failure of dam concrete under the loads that could be sustained by dam concrete mentioned in the Commentary in Section 2.2.2, Load Combinations, may become sufficiently low. In other words, design values of the required strength should be determined so that an appropriate safety coefficient is achieved. In connection with minor damage such as surface thermal cracking, however, design values of required strength may be determined as less strict in view of the reliability of the methods of repairing such damage.

When considering tensile damage to concrete, it is necessary to set up appropriate tension softening curve. In coming years, there will be many cases of making effective use of existing facilities such as heightening of a dam. In such a case, the (tensile and shear) bond strength between the existing and new concrete should be important.

(2) Strength should be common item of the performance for evaluating whether the dam concrete may be failed or not. However, ductility should be more suitable item for evaluating resistance to thermal cracking rather than the strength in some case. In case of such a judgment, the design values for the ductility may be determined instead of the strength.

3.2.3 Design values of water-tightness

Design values of the required water-tightness of dam concrete shall be determined appropriately so that the water storage function of the concrete dam is achieved.

[Commentary] The level of water-tightness required for dam concrete should be the same as that of the water-tightness of ordinary dam concrete, which is generally regarded as a practically acceptable level of impermeability.

3.2.4 Design values of durability

Design values of durability required for dam concrete against external influences occurring at the dam site shall be determined appropriately.

[Commentary] External influences on the durability of dam concrete include weather action (freezing and thawing action), chemical action and abrasion.

Because the freezing and thawing action is one of the major factors causing the deterioration of dam concrete, it can be said, from the viewpoint of ensuring durability, that resistance to freezing and thawing action is an important performance. For dams constructed in a cold climate, therefore, it is necessary to determine design values such as the relative dynamic modulus of elasticity so that the required freezing and thawing resistance is satisfied.

Deterioration due to alkali–silica reaction (chemical action) may result in a decrease in the strength. If harmful expansion due to the alkali–silica reaction is to be suppressed, there may be cases where it is more appropriate to make evaluation by using an index related to chemical stability rather than the strength. If it is judged that such an index should be used, design values for such items of performance instead of strength should be determined. Other damages caused by aggregates include volumetric changes due to expansion or shrinkage of aggregates containing laumontite or montmorillonite. The design values for such damage should be determined by using indices that are deemed appropriate for each phenomenon.

3.2.5 Design values for other performance

Performance requirements for the dam concrete of dam may be customized to resist loads that occur under conditions to which that the dam is subjected. Design values for the required performance in such a case shall be determined prior to the mixture design of the dam concrete.

[Commentary] It is regarded that Sections 3.2.1 to 3.2.4 should cover all the performance requirements for dam concrete under the normal conditions. Depending on the load conditions to which a particular dam is to be subjected, however, special performance requirements for dam concrete may be specified. The mixture of dam concrete should be designed by taking such special requirements into consideration so that the dam concrete satisfying them may be manufactured. That is why the design value for the required performance should be determined prior to the mixture design of the dam concrete.

CHAPTER 4　TEMPERATURE CONTROL

4.1　General

(1) Prior to the placement of dam concrete, a thermal stress analysis shall be conducted and a temperature control plan shall be settled on according to the analytic results in order to prevent the occurrence of harmful thermal cracks due to the heat of hydration of the dam concrete.

(2) The performance of the dam concrete used for the thermal stress analysis shall be determined on the basis of the performance of the dam concrete to be actually used for the dam construction, or the mixture shall be designed so that the performance of the dam concrete used for the thermal stress analysis is ensured.

[Commentary]　(1) Thermal cracking may occur in mass concrete such as concrete for dam due to the restrain of the volumetric change during the falling of the temperature of the hardened concrete without an appropriate countermeasure resulting in considerable high rise in the temperature of the concrete during hardening. Harmful thermal cracks in concrete dam may impair the structural performance of the dam. That is why a temperature control plan should be settled on the basis of analytic results obtained by an appropriate thermal stress analytic method in order to prevent the thermal cracking.

Temperature control methods include using low-heat cement, reduction in the cementitious material content, adjusting concrete placement schedules, introducing construction joints and pre-cooling of the materials for the dam concrete. The propriety of the employment of the methods listed above should be examined by taking such factors as the size of the dam, weather conditions at the dam site and the construction conditions for the dam into consideration and the result of the thermal stress analysis should be taken into account.

(2) The values for the performance used for the thermal stress analysis such as the adiabatic temperature rise, specific heat and thermal diffusion coefficient should normally be determined on the basis of the performance of concrete in which the materials and the mixture proportions are actually employed so that the effect of temperature control can be evaluated. On the other hand, in case the input data for the thermal stress analysis is obtained from the previous records, the mixture proportions of the dam concrete should be determined so that the values for each performance of the dam concrete is ensured.

CHAPTER 5　MIXTURE DESIGN OF DAM CONCRETE

5.1　Determination of Dam Concrete Performance Requirements and Performance Test Methods

(1) Prior to the mixture design, a concrete dam construction method shall be selected appropriately through a comprehensive study of such factors as construction safety, constructability and economy.

(2) The mixtures shall be designed, after confirming the quality of materials to be used, so that the performance requirements are satisfied.

(3) When the mixtures are designed, performance that can be measured by tests on specimens and their characteristic values shall be identified in order to judge whether the concrete in the concrete dam body meets the performance requirements specified in Chapter 3. The performance measured by tests on specimens shall be the same as or nearly equivalent to the performance required for the dam concrete in the concrete dam body.

(4) If measured values for performance obtained from tests on specimens specified in Item (3) vary depending on the shape and size of specimens, the methods for preparing and curing specimens, the age of specimens and the test method (hereinafter referred to as a “specimen test method”), a specimen test method consistent with the placement method shall be determined prior to the mixture design of dam concrete.

[Commentary] (1) Concrete dam construction methods applicable to the interior concrete include the conventional block construction method, RCD method and the extended layer construction method. The RCD method and the extended layer construction method are concrete dam construction methods developed in Japan to make more effective use of general-purpose construction equipment than in conventional construction methods, rationalize construction, and ensure construction safety. Because large general-purpose construction equipments are used in the RCD method and the extended layer construction method, the advantages of these methods can be demonstrated more effectively in larger construction yard. In the conventional block construction method and the extended layer construction method, conventional concrete is used. On the other hand, extremely stiff consistency concrete is spread by bulldozers and compacted by vibratory rollers in the RCD method. That is why the advantages and disadvantages of the plural numbers of construction methods should be evaluated, and an appropriate construction method for the dam should be selected prior to the mixture design of dam concrete.

(2) The mixture should be designed by using materials that will be actually used. In the construction of a concrete dam, aggregates are usually manufactured from rock for aggregates obtained quarries near the dam site. If the rock for aggregates cannot be quarried near the site, commercial aggregates may need purchasing. The physical characteristics of rock for aggregate in a quarry is not always uniform and its variance may result in the variance of the quality of the manufactured aggregate. Commercial aggregates with stable physical properties also cannot always be provided because the construction period of a dam is long. In addition, low-heat cement that has not been specified by JIS yet is often used for restricting the thermal cracks. That is why the characteristics of materials in use such as aggregates and its variance should be verified for the

mixture design so that the requirement for the performance is satisfied.

(3) The mixtures should be designed so that the performance requirements for the concrete used in a concrete dam body is satisfied. As shown in Fig. C3.1.1 in Chapter 3, Performance Requirements for Dam Concrete, expected values (e.g., required strength for strength) should be set up by increasing the two types of characteristics values properly by taking the variance of quality of the dam concrete into consideration so that the required performance is satisfied in the prescribed probability. The mixture of the concrete should be designed for the expected values. It is usually difficult, however, to directly check whether the performance requirements for the dam concrete are satisfied or not. In such cases, the performance that can be deemed nearly equivalent to the required performance of the concrete in the concrete dam body and that can be measured by tests on specimens, and their characteristic values should be set up. The concrete mixtures should be designed on the basis of those values.

An example of a mechanical performance that can be used to evaluate the mechanical stability of full-size dam concrete under multi-axial stress conditions in a dam body at the mixture design stage is the uniaxial compressive strength of wet screened concrete specimens. There is a correlation between those two strength that can be expressed by a formula under a given conditions. It is difficult to directly grasp the mechanical stability of the dam concrete in a dam body. That is why the mechanical stability of a dam should be evaluated indirectly in terms of the unaxial compressive strength of wet screened concrete specimens. As well as the stability, one of the required performances corresponding to the durability should the relative dynamic modulus of elasticity of wet screened concrete specimens for freezing and thawing test.

One example of performance that can be measured by tests on specimens corresponding to the required performance of the concrete in a concrete dam body is shown below. The performances of full-size dam concrete are shown on the left hand side, and the performances that can be measured by using specimens from wet screened concrete are shown on the right hand side. Since the relationships shown here are some of examples, other performances that can be measured by tests on specimens may be used for the performances mentioned here.

Strength properties under multi-axial stress → Uniaxial compressive strength of specimens

Ductility under multi-axial stress → Young's modulus of specimens

Water-tightness → Coefficient of permeability of specimens for permeability test

(4) In many cases, performances that can be measured by tests on specimens and that can be used to indirectly express the performance of the dam concrete in a concrete dam body mentioned in Item (3) may vary considerably according to the shape and size of specimens, the methods of producing and curing specimens, the age of specimens and the test method. For example, in the case of extremely stiff concrete mixtures such as RCD concrete, the unit mass and strength of the specimen may vary according to the capacity of compaction and compaction time of the specimen. Consequently, even if identical dam concrete mixtures are used, the uniaxial compressive strength measured by tests on specimens cannot be fixed as only one. That is why test method of the specimen should be fixed prior to the mixture design by using performance whose values may vary according to the testing method of the specimen. Test methods of the specimen should be consistent with the actual construction method, or the actual construction method should be consistent with the test methods of the specimen.

It may not generally be easy to judge that the performances required for dam concrete can be expressed in terms of measured values obtained from tests on specimens. The judgement, therefore, should be evaluated by examining whether the method under consideration is widely recognized by taking the previous experiences or actual results into consideration. In case the reliability is low, the characteristic values and allowable limit for the characteristic values should be set up with a sufficient margin of safety.

5.2 Mixture Design with Variance in Dam Concrete Performance

Performance requirements specified at the mixture design stage shall be determined by taking the probability in which the characteristic values should be met and the probability at which the allowable limit for characteristic values should be met into consideration. These probabilities shall be determined in view of the degree of importance of the dam and the degree of importance and reliability of the required performance of dam concrete.

[Commentary] Because of various uncertain factors and variation factors, in practice it is not possible to manufacture dam concrete with required performances constantly. Consequently, the performance of the manufactured dam concrete more or less varies from the expected values of performance. In order to express the expected values of performance requirements, therefore, it is necessary to use a statistical method.

In general, the characteristic of variance of dam concrete performance can be expressed in terms of a probability density function. If the probability density function can be approximated by a normal distribution, its shape can be uniquely expressed in terms of the mean and the standard deviation.

For example, as shown in Fig. C5.2.1, the probability that the compressive strength of the mixture (Mix A) with the mean value of 17.76 N/mm^2 and the coefficient of variation of 15% will fall below 15 N/mm^2 and the probability that the compressive strength of the mixture (Mix B) with the mean value of 21.75 N/mm^2 and the coefficient of variation of 30% will fall below 15 N/mm^2 are both 15%. Since, however, the range of the variance of the compressive strength of Mix A is smaller than that of the compressive strength of Mix B, the probability that the compressive strength of Mix B will fall below 10 N/mm^2 is higher than the probability that the compressive strength of Mix A will fall below 10 N/mm^2. Thus, in order to ensure the required level of reliability for both materials with large and small variance respectively, it is necessary to use the allowable limit for characteristic value as the lowest allowable limit as well as the characteristic value as the lowest limit in an allowable probability from the viewpoint of engineering.

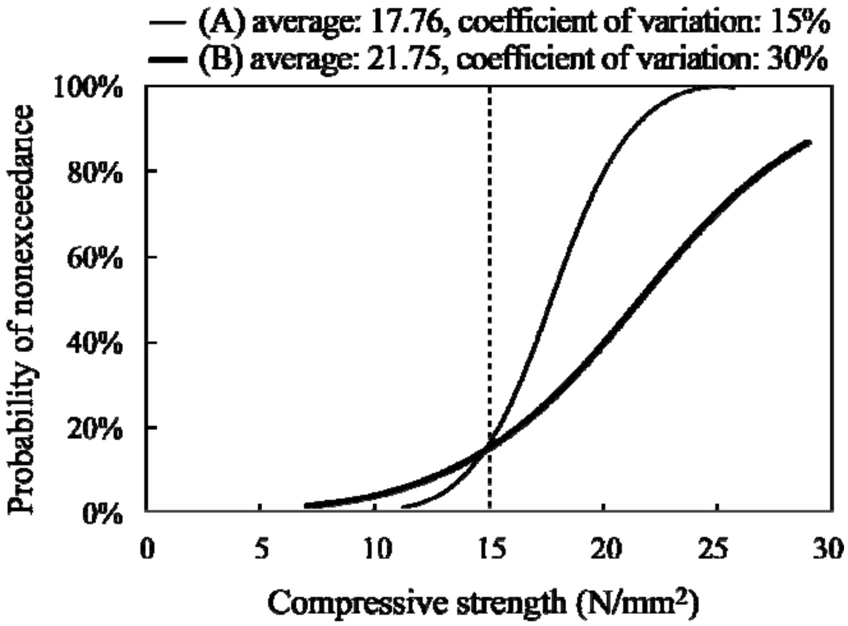


Fig. C5.2.1 Two types of concrete with different ranges of variance in compressive strength

Note: For both types of concrete, the probability that compressive strength will fall below 15 N/mm^2 is 15%. The probability, however, that the compressive strength of Mix B will fall below 10 N/mm^2 is higher than the probability that the compressive strength of Mix A will fall below 10 N/mm^2.

5.3 Determination of Expected Values in Mixture Design of Dam Concrete

In the mixture design of dam concrete, the expected values shall be determined by using a statistical method in view of likely variance in the performance of dam concrete at the construction stage.

[Commentary] When designing the mixture of dam concrete, the variance of the performance of the dam concrete should normally be expressed by the mean value and the coefficient of variance (defined as the ratio of the standard deviation to the mean value).

If the coefficient of variance for the performance of dam concrete is given, the only one expected value to be used as the target value in the mixture design can be determined by using a statistical method. The obtained value is referred to as the expected value Q_d.

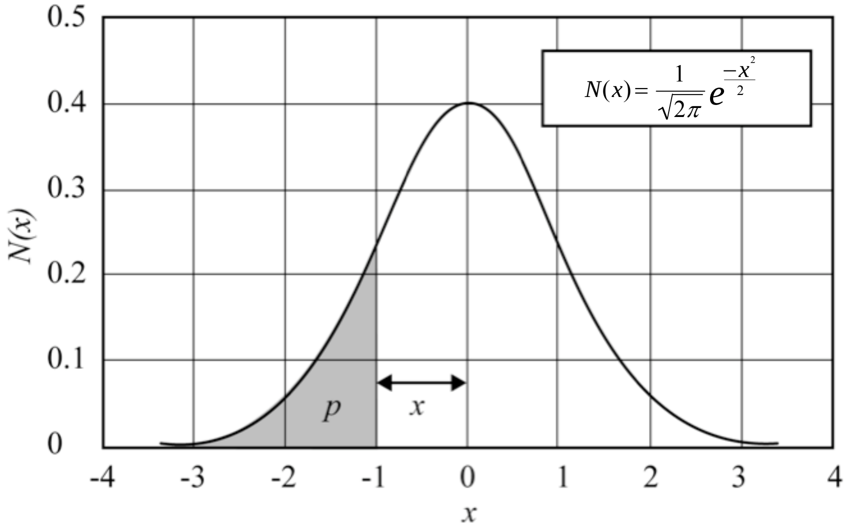
If the coefficient of variance is represented by c_v, the expected value Q_d of, for example, the required strength should satisfy the following inequality, in which the characteristic value Q_k of the performance of dam concrete and the probability p_k of not satisfying it defined in C5.3.1 are used:

$$Q_d \geq Q_k / (1 + F(p_k) \cdot c_v) \quad \text{(C5.3.1)}$$

The expected value Q_d should also satisfy the following inequality, in which the allowable limit for characteristic value Q_a for dam concrete and the probability p_a of not satisfying it defined in C5.3.2 are used:

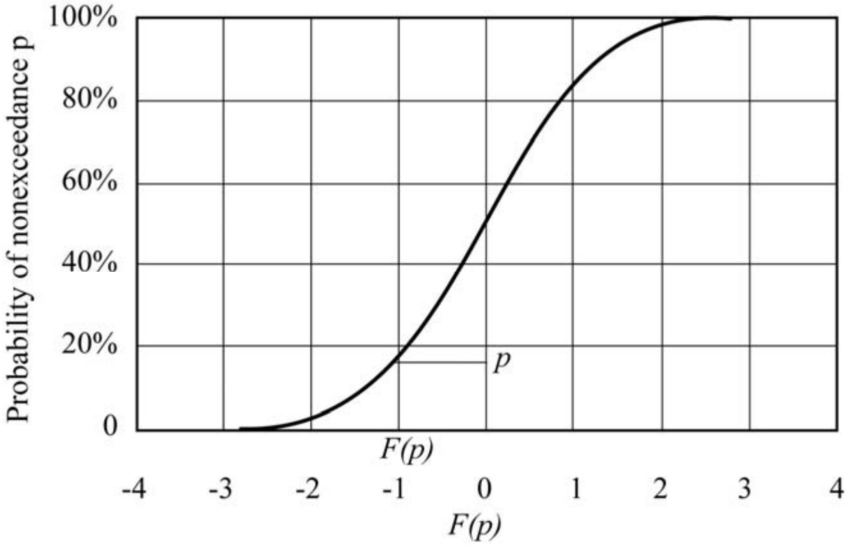
$$Q_d \geq Q_a / (1 + F(p_a) \cdot c_v) \quad \text{(C5.3.2)}$$

where $F(p)$ is a function that expresses the value of x corresponding to the probability of non-exceeding p in the probability density function $N(x)$ for the standard normal distribution.



(a) Relationship between probability of non-exceeding *p* and *x*

Probability density curve: normal distribution (μ = 0, σ = 1)



(b) Relationship between probability of non-exceeding *p* and *F*(*p*)
Probability distribution curve: normal distribution (μ = 0, σ = 1)

Fig. C5.3.1 Relationship between the probability density curve and the probability distribution curve

The relationships among the characteristic value Q_k (or the allowable limit for characteristic value Q_a) the probability that Q_k (or Q_a) will not be satisfied, p_k (or p_a), and the expected value Q_d is shown in Table C5.3.1, where c_v is the coefficient of variance for the material.

Table C5.3.1 Relationship among the coefficient of variation c_v for the material, the probability that the characteristic value Q_k will not be satisfied (p_k), and the expected value Q_d (value of Q_d if the characteristic value Q_k is 1)

		Probability that characteristic value Q_k is not met (p_k)					
		1%	5%	10%	15%	20%	25%
Coefficient of variation c_v	5%	1.132	1.090	1.068	1.055	1.044	1.035
	10%	1.303	1.197	1.147	1.116	1.092	1.072
	15%	1.536	1.328	1.238	1.184	1.144	1.113
	20%	1.870	1.490	1.345	1.261	1.202	1.156
	25%	2.390	1.698	1.471	1.350	1.266	1.203

1) The average values of Q needed to achieve $Q \geq 1$ with a probability of $1 - p_k$ is shown in the table.

2) The relationship between p_k and Q_d, but if p_k is replaced with p_a, the table will show the relationship between p_a and Q_d is shown in the table

5.4 Determination of Mixture Proportions of Dam Concrete

In the mixture design of dam concrete, its mixture proportions shall be determined so that the measured values obtained by tests on the specimens satisfy the conditions for the characteristic values and allowable limit for the characteristic values described in Section 5.2.

[Commentary] At the beginning of the mixture design stage, the variance in the performance of dam concrete are still indeterminate. The mixtures of dam concrete, therefore, should be designed on the basis of an assumed coefficient of variance based on past project data. It is necessary, therefore, not only that the measured values obtained from tests conducted by using specimens of the designed mixtures of dam concrete should satisfy the expected values specified in Section 5.3, Determination of Expected Values in Mixture Design of Dam Concrete, but also that the results obtained by statistically processing the measured values should satisfy the criteria for the characteristic value and the allowable limit for the characteristic value specified in Section 5.2, Mixture Design with Variations in Dam Concrete Performance.

It should also be noted, when designing the mixtures of concrete, that the probability density function assumed at the mixture design stage may differ considerably from the function derived from the measured values obtained at the construction site.

CHAPTER 6 CONSTRUCTION

6.1 General

(1) For the dam concrete works, a construction plan shall be prepared in advance, and the dam concrete shall be placed in accordance with the plan so that the performance requirements for the dam concrete is satisfied.

(2) Prior to the construction of dam concrete, it shall be verified, as appropriate, that the required performance can be ensured by the specified construction method.

(3) In the event that the conditions for construction assumed at the design stage turned out to differ from the actual conditions, the construction plan shall be altered and the construction method reconsidered, if necessary, in accordance with the responsible engineer's instructions so that the required performance is ensured.

[Commentary] (1) Commonly used methods for constructing concrete gravity dams include the conventional block construction method, the extended layer construction method and the Roller Compacted Dam-concrete Method, of which the construction method set up at the mixture design stage is to be used at the construction stage. Mixture proportions and compaction methods differ among these construction methods. In the conventional block construction method and the extended layer construction method, a basic approach is to use conventional concrete and internal vibrators for the compaction. In the Roller Compacted Dam-concrete Method, bulldozers and vibratory rollers are used for the spreading and the vibratory compaction respectively, and extremely stiff concrete mixtures are used because heavy equipments move around on the concrete surface.

Prior to the dam concrete works, a construction plan should be prepared so that the required performance is achieved. Work methods including such details as construction equipments and compaction methods suitable for the construction methods should be determined, and the concrete placement should be carried out under strict quality control. If a problem arises related to the mixture design or construction conditions or so, it is important to solve the problem prior to the actual work by trial constructions, analytical examinations and so on.

Because the scale of construction of dam is large and because the Owner’s engineers are usually stationed at the construction site, it is possible to carry out the construction work by solving the problems related to the design or construction properly. In the construction of dam concrete, it is desirable to reexamine the design or construction plan promptly in case of need by making an effective use of such a merit so that high construction quality may be achieved.

(2) The performance required for dam concrete can be satisfied on condition that the construction work is carried out properly by a method set up beforehand. There are considerable varieties in the quality of concrete in use or construction methods among the conventional block construction method, the extended layer construction method and the Roller Compacted Dam-concrete Method. That is why whether the construction work is being carried out properly in accordance with the methods (e.g., equipment in use, scope of work, lift, compaction time, the number of compaction) set up at the construction planning stage should be verified actually. In addition to the performances required for the dam concrete such as unit mass, strength, water-tightness and durability, the construction method should ensure the unity of the placed concrete.

(3) In order for dam concrete to satisfy the performance requirements, the placement should be

carried out properly in accordance with a construction method assumed at the mixture design stage. There are some cases, however, where the material characteristics or the construction methods assumed at the initial stage vary at an actual construction stage. The performance of hardened concrete may vary according to the degree of the compaction. If the compaction by vibratory rollers is inadequate or it takes a long time to complete the compaction after the mixing due to the reduction in the efficiency of construction at site, it is uncertain that the required performance should be ensured. If the efficiency of construction is low or the required performance of the dam concrete cannot be ensured in accordance with the method set up, appropriate corrective measures should be taken, and the construction plan should be altered or the construction plan be reexamined if necessary. In addition, embodied control systems or methods for the quality and placement of the dam concrete should be determined according to the degree of importance of the concrete dam at the construction stage and the variance in the quality of the materials.

A temperature control plan should be drawn up in order to prevent thermal crack. If conditions assumed at the planning stage cannot be realized at the construction stage, the prevention of thermal crack cannot be assured. The temperature distribution in the dam body, which may cause thermal crack, may vary with the specific heat, heat generation characteristics and thermal conductivity of the concrete in use, lift, placement interval, starting seasons of construction, concrete placing temperature, ambient temperature, and rock temperature near surface or curing methods. In case the conditions at an actual construction differ from that assumed in the temperature control plan, the temperature control plan should be altered if necessary and the construction methods should be reexamined so that the altered temperature control plan is satisfied.

6.2 Determination of Indices for Judgment at Construction Stage

Prior to the construction of dam concrete, indices at the construction stage shall be set up appropriately in order to check the quality of the materials specified at the mixture design stage and judge whether the dam concrete to be placed meets the performance requirements. Indices set up for this purpose shall be ones that can be verified prior to the placement of the dam concrete.

[Commentary] In the construction of concrete dam in which the manufacturing and placement of the concrete continue for a long period of time, the quality of materials in use may vary from that at the mixture design stage. That is why the materials in use should be controlled by taking the variations and variance in the quality into consideration so that the performance required for the dam concrete is satisfied.

The required performance specified at the mixture design stage includes the requirements for hardened concrete. Whether the required performance specified at the mixture design stage is satisfied should be verified before the placement of the dam concrete so that the purpose of the verification is achieved. That is why the verification should be carried out by setting up such indirect indices for judgment that can make it possible to check whether the required performances specified at the mixture design stage is to be ensured at the fresh concrete stage. Examples of indices corresponding to the required performances of the dam concrete are listed below although they are examples and other appropriate indices may be employed.

Unit mass → Unit mass

Uniaxial compressive strength of specimen → Combination of water/cementitious material ratio and slump (or VC value)

Young's modulus of specimen → Combination of water/cementitious material ratio and slump (or VC value)

Coefficient of permeability of specimen for permeability test → Combination of water/cementitious material ratio and slump (or VC value)

Relative dynamic elastic modulus of specimen for freezing and thawing test → Combination of water/cementitious material ratio, density of aggregates, slump (or VC value) and air content

6.3 Set up of Criteria Values at Construction Stage

(1) In case the indices of judgment specified in Section 6.2 are the same as the performances specified in Section 5.1, the characteristic values and allowable limit for the characteristic values at the mixture design stage shall be set up as the criteria values at the construction stage. In that case, the term "characteristic value at the mixture design stage" in Section 5.2 shall be deemed to be replaced with "criterion value at the construction stage," and the term "allowable limit for characteristic value" shall be deemed to be replaced with "allowable value."

(2) In case the indices set up as specified in Section 6.2 differ from the performances specified in Section 5.1, the criteria values and allowable values for judgment at the construction stage shall be set up appropriately so that the judgment may be safety side against the criteria values for the characteristic value and allowable limit for characteristic value at the mixture design stage set up as specified in Section 5.2.

[Commentary] (1) Criteria values at the construction stage of dam concrete should basically correspond to the characteristic values and allowable limit for the characteristic values at the mixture design stage set up as specified in Section 5.2, Mixture Design with Variations in Dam Concrete Performance. In case the indices of judgment at the construction stage are the same as the performance required for dam concrete (in case the unit mass is set up as the index of judgment, for example), therefore, the characteristic values and the criteria values for the allowable limit for characteristic value at the mixture design stage set up as specified in Section 5.2, Mixture Design with Variations in Dam Concrete Performance, themselves should be the criteria values at the construction stage. The quality should be controlled so appropriately that it may not fall below the characteristic value or the allowable limit for the characteristic value in a permissible probability from the viewpoint of engineering.

(2) In case that the indices of judgment at the construction stage differ from the performances set up at the mixture design stage (for example, the uniaxial compressive strength of specimens and the combination of the water/cementitious material ratio and slump (or VC value) listed in Section 6.2, Determination of Indices of Judgment at Construction Stage), indirect criteria values at the construction stage, that is, criteria values and allowable limits should be determined by referring to the results of tests conducted at the mixture design stage or past records so that the result of the evaluation may be safety side. The quality should be controlled so appropriately that it may not fall below those indirect criteria values or the allowable values of judgment at the construction stage in a probability set up for each value beforehand.

CHAPTER 7 QUALITY CONTROL OF DAM CONCRETE AT CONSTRUCTION STAGE

7.1 General

Quality control of dam concrete shall be carried out both before the placement of the dam concrete and after the hardening so that the performance of the dam concrete does not fall below the criterion value at the construction stage set up as specified in Section 6.3 in a probability set up beforehand. The field mixture proportion or construction method shall be reexamined appropriately according to the result of the quality control.

[Commentary] Most of the performances required for dam concrete are related to the hardened concrete and those performances cannot be verified directly when dam concrete is placed except of some items such as the unit mass. That is why the indirect criteria values should normally be set up at the construction stage for the verification of the quality at the placement as the first stage and the quality should be verified again directly after the age at test specified at the mixture design stage as the final stage as specified in Section 6.2, Determination of Indices of Judgment at Construction Stage.

It is important to verify that the concrete is to satisfy the required performances set up for dam concrete at the mixture design stage before the placement in order for concrete dam to have the required performance. That is why the indices for the propriety of fresh concrete should be set up and they should be judged as shown in Fig. C3.1.1 in Chapter 3, Performance Requirements for Dam Concrete and countermeasures be taken without delay if necessary. In the quality control of dam concrete, it is necessary to process measured values statistically and to modify the field mixtures if necessary so that the performance of the concrete may not fall below the characteristic values or the allowable limit for the characteristic values set up as specified in Section 5.2, Mixture Design with Variations in Dam Concrete Performance or below the criteria values or allowable value for judgment at the construction stage in a probability set up beforehand. The measured surface moisture content of the aggregate may affect the unit water content in the concrete remarkably, and the material measurement errors may make it impossible to obtain the target mixture proportion. In addition, the quality of concrete may vary due to such factors as the variance in the particle size distribution or quality of the aggregate or change in the temperature of the mixed concrete. It is therefore necessary to identify the cause of changes in the quality of concrete, examine countermeasures for them and modify the field mixture proportions if necessary.

7.2 Quality Control and Treatments Taken at Construction Stage

(1) Prior to the placement of dam concrete, a quality control plan shall be prepared, and tests shall be conducted with appropriate measurement items at an appropriate frequency so that the quality of dam concrete does not fall below the criterion value at the construction stage set up as specified in Section 6.3 in a probability set up beforehand.

(2) If the test data of index of judgment at the construction stage exceeds the allowable criterion value at the construction stage set up as specified in Section 6.3 in a probability determined beforehand, the concrete shall not be used. However, the concrete may be used on condition that it has been verified that the structural performance of the concrete dam is satisfied. For this purpose, the characteristics of materials, mixture proportions, construction methods, and so on shall be checked, and the mixture proportions, construction methods, or the like shall be reexamined if necessary.

(3) If the test data of index of judgment at the construction stage do not fall below the allowable value for judgment at the construction stage set up as specified in Section 6.3 in a probability set up beforehand but exceed the criterion value in a probability set up beforehand, the concrete may be used on condition that the characteristics of materials, mixture proportions, construction methods, and so on shall be checked, and the mixture proportions, construction methods, or the like shall be reexamined if necessary.

(4) Even if the test data of index of judgment at the construction stage do not fall below the allowable value for judgment at the construction stage set up as specified in Section 6.3 in a probability set up beforehand and if the test data tends to increase or decrease gradually or to vary periodically, the cause shall be identified and the field mixtures or construction methods shall be reexamined if necessary.

[Commentary] (1) It is more difficult to repair concrete dam than ordinary concrete structure in case it becomes defective. That is why it is necessary to draw up the quality control plan beforehand and to carry out the quality control tests with appropriate measurement items at an appropriate frequency so that the dam concrete may satisfy the performance requirements, that reworking may be avoided, and that prompt countermeasures may be taken by judging the propriety of the quality at the construction stage.

(2), (3) and (4) The allowable value for judgment at the construction stage set up as specified in Section 6.3, Set Up of Criteria Values at Construction Stage, should be the allowable lower limit (or upper limit) of the index of judgment at the construction stage of dam concrete. That is why the dam concrete should not be used if the test data of the dam concrete do not satisfy the allowable value for judgment at the construction stage in a probability set up beforehand. It is also necessary to modify the mixture proportions of concrete to be placed appropriately hereafter. If the test data of index of judgment at the construction stage satisfies the allowable value for judgment at the construction stage in a probability set up beforehand but do not satisfy the criterion value for judgment at the construction stage in a probability set up beforehand, the concrete may be placed, but it is necessary to modify the mixture proportions of the dam concrete appropriately so that the criterion value at the construction stage is satisfied a probability set up beforehand.

If the test data is increasing or decreasing continuously or varying periodically, it is necessary to identify the cause and to reexamine the field mixture proportion or construction method so that the dam may not be in defective because there might be a problem in the mixture proportions or construction method.

7.3 Quality Identification of Dam Concrete and Measures

(1) It shall be periodically verified by direct means that the performance of dam concrete does not fall below the characteristic value or the allowable limit for the characteristic value at the mixture design stage set up as specified in Section 5.2 in a probability set up beforehand in case the index of judgment at the construction stage set up as specified in Section 6.2 differs from the required performance set up as specified in Section 5.1.

(2) If it becomes evident that the performance of dam concrete will fall below the criteria values for the characteristic values or the allowable limit for characteristic value at the mixture design stage set up as specified in Section 5.2 in a probability set up beforehand, the mixture proportions, construction methods and so on shall be reexamined, the structural performance of the concrete dam in that state shall be verified, and the structural performance as a concrete dam shall also be verified and necessary measures including repair be taken according to its result.

[Commentary] (1) In case the index of judgment at the construction stage is indirect, the quality control by the criteria values cannot always assure the performances required for dam concrete set up as specified in Section 5.1, Determination of Dam Concrete Performance Requirements and Performance Test Methods. In such cases, it should be verified by a direct method that the performance required for the dam concrete set up as specified in Section 5.1, Determination of Dam Concrete Performance Requirements and Performance Test Methods, is ensured. For example, the index of judgment at the construction stage should normally be the combination of the water/cementitious material ratio and slump or the VC value in case the performance required at the mixture design stage is the uniaxial compressive strength of specimens, and it should be tested periodically.

(2) If it becomes evident that dam concrete will not satisfy the performance requirements for dam concrete set up as specified in Section 5.1, Determination of Dam Concrete Performance Requirements and Performance Test Methods, specific investigations should be carried out on the influence of the condition on the structural performance of the concrete dam. In case it is shown as a result that the structural performance of the concrete dam has no hindrance, the dam concrete may be permissible. If, on the other hand, the structural performance may have hindrance, the cause should be identified and necessary measures including repairs should be taken.

CHAPTER 8 INSPECTION

8.1 General

(1) Concrete dam shall be inspected upon the completion by appropriate methods to verify that the dam is capable of satisfying the performance requirements throughout its service life.

(2) It shall be verified, in the inspection of concrete dam, by test data that the performance does not fall below the criterion value or the allowable value for judgment at the construction stage in a probability set up beforehand.

(3) If the inspection result does not satisfy the required criterion, appropriate measures shall be taken so that the dam satisfies the performance requirements.

(4) The inspection record shall be kept throughout the service life of the dam.

[Commentary] (1) The Owner should inspect a completed concrete dam to judge whether the dam will satisfy the performance requirements throughout its service life.

Inspection is an act of the Owner to verify that the quality of dam concrete manufactured and placed by the Contractor satisfies the criterion for judgment set up beforehand. Type of inspection can be roughly classified into acceptance inspection and inspection during the construction. In these Specifications: Dam Concrete, the Owner's recognition of the Contractor's act of quality control as an act of supervision is also defined as inspection.

Common inspection methods can be classified into four types listed below:

Dimensional inspection: An act to verify whether the position or dimensions of a dam conform to the working form specified in the design documents. The measurable dimensions should be measured and verified on the spot in principle.

Quality inspection: An act to verify whether the quality of materials in use and the quality of construction satisfy the quality requirements specified in the design document by using documents, data, etc., concerning quality control. The judgment should be done by checking written documents and observing the spot or pictures of the construction conditions.

Workmanship inspection: An inspection of the surface of concrete such as crack, appearance or leakage mainly by visual observation.

Destructive inspection: An act to verify whether the performance requirements for dam concrete are satisfied by minimum destruction of the dam body including destructive test such as core sampling if necessary during the construction or after the completion. Destructive inspection is usually conducted according to the non-destructive test results.

(2) Judgment that dam concrete satisfies the performance requirements can be made by verifying that the test data of dam concrete at the construction stage does not fall below the characteristic values or the allowable limit for the characteristic values at the mixture design stage or their indirect indices of the criteria values or allowable value for judgment at the construction stage in a probability set up beforehand. The judgment of pass or fail should be made on the basis

of those criteria values and test data in the inspection.

(3) If, as a result of the inspection, it becomes evident that the dam concrete does not satisfy the performance requirements set up as specified in Chapter 3, Performance Requirements for Dam Concrete, the cause should be identified and appropriate measures including repairs be taken if necessary.

(4) Because the inspection records are useful information for the maintenance during in service, they should be kept together with the construction records throughout the service life of the dam.

CHAPTER 9 MAINTENANCE

9.1 General

(1) Dam concrete shall be maintained throughout the service life so that the structural performance requirements for the concrete dam are satisfied.

(2) The maintenance of dam concrete shall be planned appropriately by taking the characteristics of the concrete dam, site conditions, and so on into consideration and it shall be executed in accordance with the plan.

[Commentary] (1) Safety management should be done through measurement of deformation of the dam, leakage, and so on or visual observations and various deterioration or change of the dam concrete should be grasped by inspection or check and appropriate measures including repairs should be taken if necessary so that a concrete dam may ensure the structural performance and perform the functions sufficiently throughout the service life.

(2) Because the dam body is made of mass concrete, it is easily subject to cracks due to long-term temperature change. In addition, the surface of the concrete in the overflow section is easily subject to change like abrasion due to the running water. It is also necessary to take deterioration due to freezing and thawing into consideration in cold weather regions. That is why the maintenance plan should be drawn up appropriately by taking the characteristics of a concrete dam, the site conditions and so on into consideration. Because it is generally certain that the deteriorations described above seldom cause rapid reduction in the performance of dam concrete resulting in fail of functions of the concrete dam, visual observation is usually conducted at the early stage of deterioration.

Problems on ordinary deterioration factors, methods of maintenance or handling of the records should be based upon these Specifications: Maintenance.

Standard Methods

CHAPTER 1 GENERAL

1.1 Scope

The Standard Specifications for Concrete Structures - 2007, Dam Concrete, Part 2: Standard Methods **describe standard methods for the structural design of concrete dams, the design and construction of concrete used in dam bodies (hereinafter referred to as "dam concrete").** ***Part 2, Standard Methods*****, deals only with ordinary types of dam concrete that have been used in past projects.**

[Commentary] The term "dam" refers to a 15 m or higher river-crossing structure constructed to store or intake river water. Dams can be classified into concrete dams and fill dams according to the type of material for dam bodies. *The Standard Specifications for Concrete Structures - 2007* (hereinafter referred to as "these Specifications"), *Dam Concrete, Part 2: Standard Methods* describes standard methods for the structural design of concrete dams and the design and construction of concrete used in dams, or dam concrete that has been used in past projects.

In almost all cases, dam concrete is manufactured by setting up aggregate plants and concrete manufacturing facilities at the construction site. In recent years, it has also become common practice, in small dam projects, to purchase aggregates or manufacture concrete by using ready-mixed concrete plants. Even in such cases, *Part 2, Standard Methods*, should be followed.

Concrete dams can be classified, according to the type of structure, into gravity concrete dams, concrete arch dams, hollow gravity concrete dams and buttress concrete dams. Most common among the newly constructed concrete dams are gravity concrete dams. Only a small number of concrete arch dams have been constructed, and neither hollow gravity concrete dams nor buttress concrete dams have been constructed in recent years. *Part 2, Standard Methods*, has been written to deal mainly with gravity concrete dams and to cover only essential requirements for concrete arch dams for basic conformance.

Basically, *Part 2, Standard Methods*, avoids duplicating the content of these Specifications, Construction, after giving careful consideration to the special nature of dam concrete. Among the details common to all types of concrete, therefore, those that are not covered in *Part 2, Standard Methods*, should either be determined so as to meet the performance requirements in accordance with *Part 1, Performance Verification*, or be in conformity to these Specifications, Construction.

1.2 Definitions

Terms used in ***Part 2, Standard Methods*****, are defined as follows:**

Classification of mixture proportions – Mixture proportions for dam concrete are determined according to the quality requirements for different parts of the dam body; or a mixture grouping thus determined.

Specified concrete strength –strength used as a reference in the design of dam concrete. Generally it is the compressive strength at 91 days.

Required strength –strength used as the required average strength when determining

the mixture proportions for dam concrete taking account of the probable quality control of the concrete manufacturing process. Generally it is the compressive strength at 91 days.

Specified mixture proportion – Mixture proportion determined at the planning stage, by using possible materials to meet the performance requirements for dam concrete.

Field mixture proportion – Mixture proportion specified at the construction site for materials actually used at the construction stage.

Contraction Joint – Joint provided to prevent harmful thermal cracking caused by the heat of hydration of cement. A joint normal to the axis of dam crest line is referred to as a "transverse joint," and a joint parallel with the axis of dam crest line is referred to as a "longitudinal joint."

Joint grouting – The technique of achieving structural integrity by filling a contraction joint with cement milk.

Lift schedule – Schedule for placing dam body concrete in each of predetermined concrete block of placement.

Lift – The thickness of dam concrete placed continuously in an area or the dam concrete so placed.

Pre-cooling – The technique of cooling some or all the materials of dam concrete before it is placed to lower the placing temperature of dam concrete.

Construction joint – Joint provided between lifts of concrete.

Conventional concrete – Dam concrete compacted by using internal vibrators.

RCD concrete (Roller Compacted Dam concrete) – Zero-slump dam concrete compacted by vibratory rollers.

Embedded pipe cooling – The technique of cooling dam concrete by passing cold water through piping embedded in dam concrete.

Vibrating joint cutter – Equipment for making a joint by cutting fresh concrete with a vibrating blade.

Shear key – Ruggedness-shaped structure provided on contraction joint to transfer shearing force along the joint.

[Commentary] The terms are defined here in addition to those defined in the "Design," "Construction," "Maintenance" and "*Part 1: Performance Verification*" sections of these Specifications.

Required strength: In dam concrete, usually aggregates having a maximum size of 150 to 80 mm are used. When determining the required strength, therefore, aggregates are wet-screened with a 40 mm sieve to prepare test specimens. The required strength is determined according to the strength of specimens wet-screened with a 40 mm sieve.

Specified mixture proportion: In dam construction, concrete mixture proportions chosen at the design stage are used for temperature control planning or other purposes. Mixture proportions are determined by using aggregates made by crushing rock for aggregates taken from trial adits at quarries. They are referred to as "specified mixture proportions."

Field mixture proportion: The characteristics of the aggregate for construction work are not always the same as those for specified mixture proportions. The quality of materials used for dam construction does not necessarily remain constant during the construction period; instead, it is assumed that it may vary during the construction period. When using dam concrete, it is necessary to modify mixture proportions in view of such fluctuation in the quality of materials to make the mixture proportions closer to the specified mixture proportions. For this reason, mixture proportions determined by modifying the specified mixture proportions are referred to as field mixture proportions. Examples of field mixture proportioning are the correction of the amount of coarse aggregates with under-grains, the adjustment of sand percentage, and the estimation for the surface moisture content of aggregates. In cases where it takes time for transportation because the site of placement is far from manufacturing plant and there are considerable variance in the properties of the concrete, field mixture proportioning includes the compensation for such influences.

Conventional concrete: Conventional concrete is ordinary dam concrete other than RCD concrete. Slump ranges from about 2 to 5 cm, depending on the maximum aggregate size and the parts of a dam where the concrete is used. In recent years, there have been cases where self-compacting concrete is used in difficult-to-fill portions such as inspection gallery zones.

RCD concrete: RCD concrete is stiff consistency concrete used as internal concrete of the dam body constructed by the RCD Method. Because of the differences in mixture design methods, construction methods, quality control methods, etc., RCD concrete is defined separately from conventional concrete.

CHAPTER 2 STRUCTURAL DESIGN OF CONCRETE DAM

2.1 Basic Structural Requirements

(1) Concrete dam should be designed so as not to overturn or slide under the expected loading.

(2) Concrete dam should have the strength needed to resist stresses in the dam body caused by the expected loading.

[Commentary] (1) Concrete dams are structures for storing large amount of water for various purposes. Concrete dams, therefore, should be structurally designed not to overturn or slide under applied loads such as water pressure due to water storage.

The safety of a gravity concrete dam against overturning and sliding is evaluated by regarding the dam body as a two-dimensional structure divided by transverse joints. Safety against overturning is examined by checking whether the extended line of resultant force acting on the dam body is located within the middle third area of each horizontal section and in the plane of contact between the dam body and the supporting bedrock. In cases, however, where the dam body is subjected to seismic force directed upstream, the extended line of resultant force may be located outside the middle third area of each horizontal section or contact face between the dam body and the supporting bedrock if the tensile stress occurring in the dam body is within a range permissible for design purposes.

Safety against sliding is checked by ensuring whether the safety factor for shear friction F_S in (C2.1.1) is 4 or greater for the following three types of the contact faces: (1) the horizontal construction joint in the dam body, (2) the plane of contact between the dam body and the supporting bedrock, (3) assumed shear plane in the supporting bedrock.

$$F_S = \frac{\tau_0 l + fV}{H} \tag{C2.1.1}$$

where,

l: length of the sliding surface in the sliding direction

τ_0: shear strength of the sliding surface

f: internal friction coefficient along the sliding surface

V: vertical force per unit width acting on the sliding surface

H: shear force per unit width acting on the sliding surface

In the case of a concrete arch dam, safety against overturning and sliding is evaluated by regarding the dam as a three-dimensional united structure without transverse joints. The shape of a concrete arch dam can prevent it from overturning in the downstream direction due to the water pressure from the reservoir and the safety against the overturning can be automatically ensured. The safety of the dam body subjected to seismic force in the upstream direction against overturning should be judged by checking whether the tensile stress generated in the dam body is less than the allowable tensile stress.

The safety against the sliding is verified by checking that the safety factor F_S in (C2.1.1) or the three-dimensional extended one is 4 or greater for the shear friction between the dam body and the bedrock or the shear friction on any of the assumed shear plane in the bedrock.

(2) A concrete dam should be structurally designed not to overturn or slide and have the strength needed to resist stresses in the dam body caused by the loads. The specified concrete strength is stipulated in Section 3.4.2, Strength.

Because the stress in a gravity concrete dam is relatively low, it can be calculated by such a convenient method as that regarding the design cross section as a cantilever. In such a case, if the extended line of the resultant load acting on the dam body is not located out of the middle third area in any horizontal plane and the contact face between the dam body and the supporting bedrock, all of the stresses occurring in the dam body are compressive. If the dam body is subjected to seismic load directed upstream, low tensile stress may be generated on the downstream side area. However, such tensile stress is permissible if it is not greater than the allowable tensile stress. In general, the allowable tensile stress can be approximately 10% of the allowable compressive stress. The allowable compressive stress is one fourth or less of compressive strength.

The stress generated in a concrete arch dam is an important factor for the design. It should be calculated accurately by using an analysis method such as the trial load method or the finite element method, or the model experiment method. As a concrete arch dam is in the state of the multiple-axis stress and tensile stress may occur. Methods to determine the specified concrete strength under that condition are described in Section 3.4.2, Strength.

To cope with the local tensile stress occurring around the hollow portions in the dam body such as the effluent pipes or the galleries, they are reinforced by steel bars.

The seismic coefficient method is employed in the seismic design for concrete dams in accordance with the Government Ordinance for Structural Standards for River Administration Facilities (No. 199 in 1976) and its enforcement ordinance. If the magnitude of the earthquake is expected to be large, the earthquake resistance can be additionally verified by such a method as the dynamic response analysis.

2.2 Loads

The types and magnitudes of loads used for the structural design of concrete dams should be determined taking the type of dam, the conditions at the dam site and the reservoir water level into consideration.

[Commentary] The assumed loads for the structural design of concrete dams should be determined according to the type of the dam as shown in Table C2.2.1, and the values of those loads should be determined by taking the type of dam and the conditions at the dam site into consideration. The structural design of a concrete dam is carried out for the possible combinations of the loads that can occur in the expected conditions of the water storage.

The condition of the reservoir for the structural design of the concrete dam includes the normal water level, the surcharge water level and the design flood water level. The normal water level is the highest one for the purpose of storing water behind the dam during the non-flood season. The surcharge water level is the highest one for the purpose of retaining water temporarily behind the dam in times of flood. The design flood water level is the one when the design flood discharge for the dam flows the spillway. The design flood discharge for a dam is the largest one of the followings: (1) the flood discharge that is expected to occur once in 200 years at the dam site, (2) the highest historical flood discharge at the dam site, and (3) the flood discharge that could occur at the dam site, judging from the observation records at other sites with the similar hydrological and meteorological conditions.

The normal water level is the condition of the water storage that can occur frequently in ordinary times. For that condition of the water storage, all of the loads listed in Table C2.2.1 are taken into consideration. The surcharge water level is the condition of the water storage that can occur temporarily in times of the flood. For that condition of the water storage, the magnitude of the seismic load may be halved. The design flood water level is the highest one specified to ensure the safety of the dam against the flood. Because the possibility of the conditions of the water storage mentioned above is very low, the seismic load does not need to be taken into consideration at those water levels.

Table 2.2.1 Design loads for concrete dam

Type of dam	Design load
Gravity concrete dam	Self-weight of dam, Hydrostatic pressure of water storage, Silt pressure of sedimentary mud, Uplift pressure due to seepage flow, Seismic inertia force, Hydrodynamic pressure of water storage during earthquake
Concrete arch dam	Self-weight of dam, Hydrodynamic pressure of water storage during earthquake, Silt pressure of sedimentary mud, Uplift pressure due to seepage flow, Thermal load, Seismic inertia force, Hydrodynamic pressure of water storage during earthquake

2.3 Mechanical Characteristics for Structural Design

The Young's modulus, Poisson's ratio, coefficient of thermal expansion and unit mass of the dam concrete necessary for the structural calculation for the concrete dam should be determined experimentally or by other appropriate methods.

[Commentary] Because gravity concrete dams are designed as statically determinate structures, there is no need for the Young's modulus, Poisson's ratio or the coefficient of thermal expansion of the dam concrete for the calculation of the stresses in the dam body. On the other hand, since concrete arch dams are indeterminate structures, the Young's modulus, Poisson's ratio and the coefficient of thermal expansion of dam concrete are necessary for the calculation of stresses in the dam body. The Young's modulus, Poisson's ratio and the coefficient of thermal expansion of dam concrete should be determined through tests for the dam concrete materials and the mixture proportions to be actually used or by other appropriate methods.

At the planning stage before the specified mixture proportions for the dam concrete are determined, the Young's modulus of 25 to 30 kN/mm^2, Poisson's ratio of around 0.2 and the coefficient of thermal expansion of around 1.0×10^{-5}/°C are usually chosen. The unit mass is usually set up as about 2.3 t/m^3 for safety.

CHAPTER 3 QUALITY OF DAM CONCRETE

3.1 General

(1) Dam concrete should have the strength, water-tightness, durability and other qualities to achieve the structural safety and water storage capability of a dam.

(2) For dam concrete, different mixture proportions should be determined for different parts of the dam to meet the performance requirements for each part of the dam.

(3) Dam concrete should have as stiff a consistency as possible within the limits of the sufficient workability.

[Commentary] (1) Dam concrete should have the strength to ensure the structural safety of the dam against various applied loads. Dam concrete should have the water-tightness to achieve the water storage capability of the dam. Also, dam concrete should have the durability to maintain the structural safety and water storage capability of the concrete dam during its service life.

In the case of a gravity concrete dam, the self-weight of the dam body plays an important role in maintaining the structural safety of the dam. Dam concrete, therefore, should have the unit mass to maintain the structural safety of the dam.

(2) The volume of a dam concrete is enormous. It is common practice, therefore, to make an effort to construct a dam economically by assigning an appropriate mixture proportion to each part of the dam body. In the case of a gravity concrete dam, for example, the dam body is led to be wide since the weight of the dam body itself ensures the structural safety. Consequently, the strength of the dam concrete is not needed to be very high. The cement (or cementitious material) content of the internal concrete of the dam with the lower required durability is generally less than that of the external concrete. It leads to the decrease in the heat of hydration of the cement (or cementitious material) causing a temperature crack and economical dam construction.

(3) High-slump concrete with a high water content is used sometimes, when the cement (or cementitious material) content is limited to minimize the heat of hydration. In that case, the water/cement (or cementitious material) ratio may increase and the durability and water-tightness may be lower. Methods for improving the workability without increasing the water content by recent high range water reducing and air entraining agents can be used for carefully selected portions. Since casting areas of dam are typically flat and large, it is not uncommon that construction work is carried out on newly casting concrete. The dam concrete, therefore, should be made as stiff as possible to the extent of securing the workability for successful casting of homogeneous concrete.

3.2 Classification of Mixture Proportion

Mixture proportions of dam concrete can be chosen for each part of the dam body to meet the required quality of the dam concrete.

[Commentary] Dam concrete can be classified for mixture proportion corresponding to different parts of the dam body as shown in Fig. C3.2.1. Classification of mixture proportion and corresponding performance requirements in dam concrete are shown in Table C3.2.1.

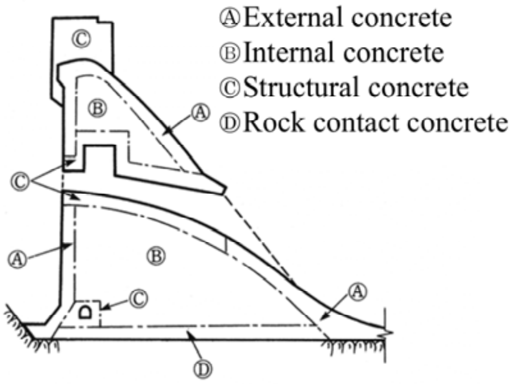


Fig. C3.2.1 Example of classification of mixture proportions for gravity concrete dam

Table C3.2.1 Classification of mixture proportions of dam concrete and corresponding performance requirements

Classification	Name of each part	Function, purpose and performance requirement
Ⓐ	External concrete	Besides the performance requirements for internal concrete, the water-tightness, and resistance to abrasion action and to freezing and thawing are required. Excellent appearance is also required.
Ⓑ	Internal concrete	The capability to resist water pressure and other loads by the self-weight and specified unit mass and strength are required. Because of the large volumes of casting concrete, the low heat of hydration and good placing performance is also required.
Ⓒ	Structural concrete	The strength of reinforced concrete, bond performance between reinforcement and buried structure, and placing performance into narrow spaces between reinforcements and in forms are required. Concrete used in the parts of the dam body that serves as external surfaces should also meet the quality requirements for external concrete. The concrete of this type is used, for example, in portions around galleries.
Ⓓ	Rock contact concrete	Particularly important quality requirements include strong bond performance between rock and concrete and good placing performance with easy casting on rough rock and steady bond. Basically, the functions and purposes of rock contract concrete are the same as those of internal concrete.

3.3 Quality of Fresh Concrete

3.3.1 Consistency

(1) For conventional concrete, the slump should be measured by using wet-screened materials with a 40 mm sieve, and its average should be 2 to 5 cm.

(2) The Vibrating Compaction value of RCD concrete should be measured by using wet-screened materials with a 40 mm sieve, and it should be normally 20 seconds.

[Commentary] (1) It is desirable that the slump should be as low as possible to the extent that the required level of workability is achieved. In recent years, the technology to achieving workability without increasing the water content has been established. The mixture proportions, therefore, should be determined after carefully studying details such as the quality requirements, costs and construction parts of the dam body. The consistency of conventional concrete is usually evaluated through slump test. Its slump is generally measured by using wet-screened materials with a 40 mm sieve and the average is about 2 to 5 cm.

(2) The consistency of RCD concrete is usually evaluated through the Vibrating Compaction test. The Vibrating Compaction value suitable for compaction by vibrating roller is measured by the use of wet-screened materials with a 40 mm sieve. In many cases, the Vibrating Compaction values of around 20±10 seconds are used.

During the period after a dam concrete mixture is prepared and until it is compacted, the consistency of dam concrete changes to some extent under the influence of weather conditions, transportation conditions, time for placement, etc. When placing dam concrete, therefore, it is necessary to pay attention to the prevention of the decline in consistency and take their effects into consideration at the mixture design.

3.3.2 Air content

The air content of concrete used in the parts of the dam body where resistance to freezing and thawing is required should be within the ranges corresponding to different maximum aggregate sizes shown in Table 3.3.1.

Table 3.3.1 Standard values of air content of AE conventional concrete

Maximum size of coarse aggregate (mm)	Air content upon completion of transportation and compaction (%)
150	3.0±1.0
80	3.5±1.0
40	4.0±1.0

[Commentary] Standard values of air content are measured by concrete using wet-screened materials with a 25 mm sieve and should be 4 to 7% to meet the resistance to freezing and thawing as described in Section 3.4.4, Durability. Resistance to freezing and thawing is determined by the air content of the mortar. For aggregates with typical grading curves, standard values of air contents of concrete containing full-size aggregates estimated from the air contents of wet-screened concrete are shown in Table 3.3.1. The values, therefore, shown in Table 3.3.1 should be used as standard values of air content of concrete containing full-size aggregates at the mixture design.

3.4 Quality of Hardened Concrete

3.4.1 Unit mass

The unit mass of dam concrete should be on the safety side of the assumed value or within a permissible variable range of design values.

[Commentary] The unit mass is an important factor for a dam concrete, especially a gravity concrete dam, to ensure the structural safety of a concrete dam. The unit mass, therefore, of dam concrete used for the structural design of a concrete dam should be determined on the basis of the materials and mixture proportions of dam concrete actually used for construction. The unit mass of the dam concrete actually used for construction should also be more conservative than the design value used for the structural design of the concrete dam or within a permissible range of variation of design values.

3.4.2 Strength

(1) The specified strength of dam concrete should be determined by multiplying the designed stress in the dam body by an appropriate safety factor.

(2) The required strength of dam concrete should be calculated by multiplying the specified concrete strength by an appropriate safety factor to allow for variations in the quality of dam concrete at the construction site.

[Commentary] (1) In the design methods based on the seismic coefficient methods, the occurrence of tensile stress is not permitted for a gravity concrete dam. However, it is exceptionally accepted in the portion near the downstream face of the dam subjected to seismic loading in the direction of upstream while the reservoir water level is low or in reinforced portions around hollows in the dam body. The specified strength of dam concrete for a gravity concrete dam, therefore, should be determined depending on the compressive stress occurring in the dam body. The specified concrete strength of the dam body without seismic loading for a gravity concrete dam should be calculated by multiplying the compressive stress occurring at a given point in the dam body by a safety factor of 4 or greater.

For a concrete arch dam, the specified concrete strength should be determined taking into consideration the permission of the occurrence of tensile stress in the dam body and the dam body in a state of the multiple-axis stress. To be more specific, the specified concrete strength of the dam body for the concrete arch dam without seismic loading should be established by multiplying the first principal stress (maximum compressive stress) occurring at a given point in the dam body by a safety factor of 4 or greater and then dividing the obtained value by a modified factor (see Fig. C3.4.1) determined in view of the magnitude of the third principal stress.

For a dam subjected to seismic loading, the specified concrete strength can be obtained by dividing the value calculated by the method described above by a value not greater than 1.3.

These methods can be expressed as follows:

For gravity concrete dam:

$f'_{ck} \geq \sigma_c \times 4$ (under no seismic loading) (C3.4.1)

$f'_{ck} \geq \sigma_c \times 4 \div 1.3$ (under seismic loading) (C3.4.2)

For concrete arch dam:

$f'_{ck} \geq \sigma_c \times 4 \div$ Modification factor (under no seismic loading) (C3.4.3)

$f'_{ck} \geq \sigma_c \times 4 \div$ Modification factor $\div 1.3$ (under seismic loading) (C3.4.4)

where,

f'_{ck}: specified concrete strength, σ_c: compressive stress in dam body

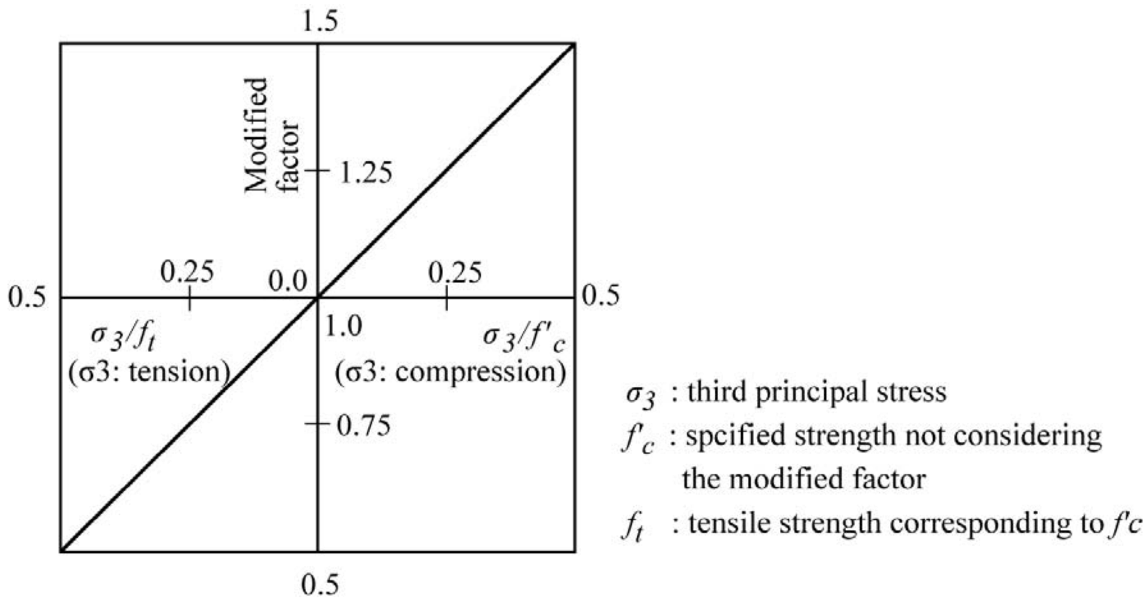


Fig. C3.4.1 Values of the modification factor

(2) Measured compressive strength of dam concrete depend on changes in the quality of cement, mineral admixtures, aggregates and chemical admixtures, material measurement errors, mixing and other construction conditions. Variations in the compressive strength of dam concrete under general control roughly follow a normal distribution.

If there is strong likelihood of the measured compressive strength falling below the specified concrete strength or if the measured strength falls considerably below the specified concrete strength, the structural safety of concrete dam may not be certainly satisfied. The required strength of dam concrete, therefore, should be adjusted so that the following conditions are met:

a. Measured compressive strength do not fall below 80% of the specified concrete strength with a probability of 1/20 or higher.

b. Measured compressive strength do not fall below the specified concrete strength with a probability of 1/4 or higher.

The required strength under these conditions can be determined by multiplying the specified concrete strength of dam concrete by a safety factor for each coefficient of variation of its specified concrete strength. The safety factor can be found from Fig. C3.4.2 or the following equations:

$$c_0 = \frac{0.8}{1-0.0164\,c_v} \qquad (c_v \geqq 18.1\%) \qquad \text{(C3.4.5)}$$

$$c_0 = \frac{1}{1-0.00674\,c_v} \qquad (c_v \leqq 18.1\%) \qquad \text{(C3.4.6)}$$

where

c_o: safety factor, c_v: coefficient of variation

The specified concrete strength and required strength of dam concrete are determined on the basis of the compressive strength at an age of 91 days. It is not advisable to evaluate the quality of dam concrete in terms of early strength partly because of the following reasons; concrete dams do not experience their design loads for a considerably long period after casting and use of low-heat cement or mineral admixtures such as fly ash and ground granulated blast-furnace slag results in low strength at an early age.

The compressive strength of dam concrete is determined in accordance with JIS A 1108:2006, "Method of test for compressive strength of concrete," by the use of wet-screened materials with a 40 mm sieve. The specimens for compressive strength tests are prepared in accordance with JIS A 1132:2006. The specimens for RCD concrete are compacted by vibrating tables, equipments for standard test specimens of RCD concrete, or vibrating tampers. For RCD concrete, it is desirable to check the compressive strength in accordance with following order; A facility for large-scale test specimens is used to make compaction tests under the most realistic conditions possible and boring core samples are taken from specimens with full-size aggregates compacted by that apparatus.

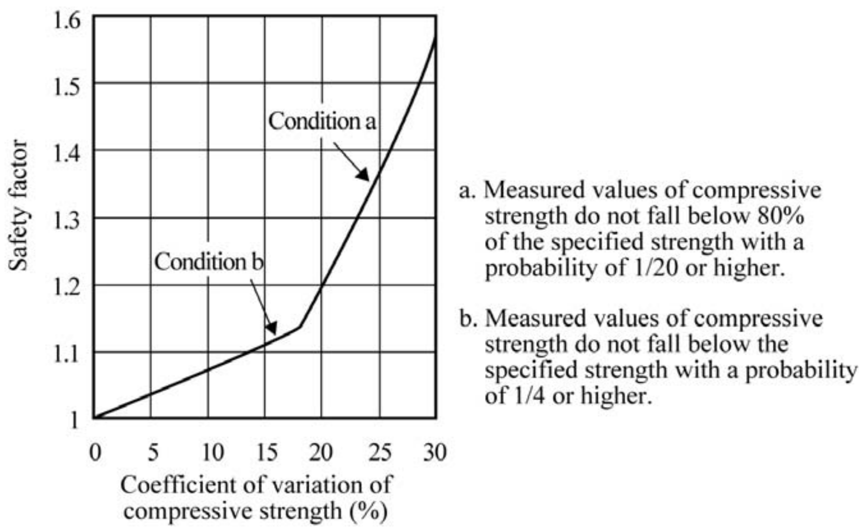


Fig. C3.4.2 Relationship between the coefficient of variation and the safety factor

The tensile strength of dam concrete is determined in accordance with JIS A 1113:2006, "Method of test for splitting tensile strength of concrete," by conducting tests on specimens using wet-screened materials with a 40 mm sieve. At the outline design stage, values equal to about 1/10 of compressive strength are often used as the tensile strength of dam concrete.

The shear strength of dam concrete is not a parameter necessary for design if the dam concrete can be regarded as an isotropic body. When the safety factor against shear friction along horizontal construction joints is evaluated, the shear strength along horizontal construction joints is necessary. The shear strength varies widely depending on the method of treatment of joint. If the construction joints are carefully treated, the shear strength along horizontal construction joints is roughly equal to the shear strength of dam concrete. In this case, the shear strength is about 1/5 of the compressive strength of dam concrete.

3.4.3 Water-tightness

(1) Dam concrete should have the water-tightness to ensure the water storage capability of the dam.

(2) When water-tightness is required, the standard water/cementitious material ratio for the dam concrete should be 60% or less.

[Commentary] (1) The water-tightness of dam concrete increases as the water/cementitious material ratio decreases and as a sufficient paste to fill the voids between aggregates exists. When an internal concrete has a high water/cementitious material ratio and a small quantity of paste like RCD concrete, it is necessary to pay close attention to the water-tightness of the external concrete so that the water-tightness required for the dam body as a whole can be achieved.

(2) In order to achieve the water-tightness, it is necessary to make the water/cementitious material ratio low. When water-tightness is equired, the standard water/cementitious material ratio of the dam concrete should be 60% or less.

For mass concrete like dam concrete, the possibility of the occurrence of thermal cracking due to thermal stress caused by the heat of hydration of cement (or cementitious material) cannot be ignored. Because thermal cracks reduce water-tightness as a structural defect, it is necessary to design, manufacture and construct a dam concrete carefully for the purpose of thermal crack control.

3.4.4 Durability

(1) Dam concrete should be durable enough to maintain the structural safety and water storage function of the dam during its service life.

(2) The water/cementitious material ratio and air content of the concrete used in the parts of the dam body where resistance to freezing and thawing is required should be determined appropriately by using aggregates with the resistance.

(3) The concrete used in the parts of the dam body where durability against chemical attack and abrasion action is required should be treated appropriately.

[Commentary] (1) Dam concrete should be durable enough to maintain the structural safety and water storage function of the dam during its service life. The durability of dam concrete is affected by weather (freezing and thawing), chemical attack and abrasion action and so on. Only less resistance to freezing and thawing can be often required for the internal concrete.

(2) For the concrete required to have resistance to freezing and thawing, it is necessary to use aggregates that have resistance to freezing and thawing in conformity with Section 5.4.3, Durability, and Section 5.5.2, Durability, and control the amount of entrained air appropriately. If a concrete satisfies the following condition, it may have the relative dynamic modulus of elasticity at 300 cycles of much more than 60% in accordance with JIS A 1148:2001, "Method of test for resistance of concrete to freezing and thawing (A method)" and resistance to freezing and thawing as shown in Table 8.4.1 in Section 8.4.1, Freezing and Thawing Damage Verification, of these Specifications, Design; the aggregates with resistance to freezing and thawing are used for ordinary concrete, the air content is kept to be 4 to 7% and the water/cementitious material ratio allowing for the weather conditions, cross-sectional dimensions and surrounding condition to the structure as shown in Table C3.4.1 are satisfied. The standard air content of dam concrete is as shown in Table 3.3.1. To meet the conditions mentioned above, it is necessary to adjust the air content of specimens using wet-screened materials with a 25 mm sieve to 4 to 7%, which are the values indicated in these Specifications, Design. Therefore, the concrete that contains the aggregates with resistance to freezing and thawing and has the required air content and a water/cementitious material ratio of 60% or less can be resistant to freezing and thawing.

If the concrete properly maintain the resistance to freezing and thawing, it is necessary to meet air content requirements stated and additionally check the distribution of air voids. The mixture proportion should be specifically determined in view of the type of the cement and admixture to ensure an appropriate spacing factor of air voids. If the content of type C fly ash cement (fly ash content of less than 30%) exceeds the limit, it is advisable to study the distribution of entrained air voids in advance.

If fine aggregates or coarse aggregates with no resistance to freezing and thawing are used for environmental conservation or economic reason, it is necessary to check the resistance to freezing and thawing of the concrete by carefully studying the mixture proportions and others in advance to achieve the required durability depending on the weather conditions and the parts of the dam body. In such cases, tests for the resistance to freezing and thawing are conducted by applying the materials and mixture proportions same as on construction site, and they are started considering the period before applying the freezing and thawing and strength development properties of the cement. Since dam concrete is often made by using cement with slowly strength development for the purpose of reducing flush of hydration, tests for the resistance to freezing and thawing are started at 91 days. If 91 days are not kept for reasons related to test periods, the tests may be conducted at 56 days. In the case of dam concrete, coarse aggregates with a maximum size of 80 mm or more are often used. When specimens for resistance to freezing and thawing are prepared, they are generally made by using wet-screened materials with the maximum aggregate size of 25 mm or less. These specimens are carefully conducted so that the air entrained by AE agent is not released and the vibration by compaction is not much excessive than on construction site. An alternative method is to adjust the mixture proportion to that with wet-screened materials by removing non wet-screened aggregates of 25 mm or more in advance.

(3) The chemical attack includes alkali–silica reaction, erosion by acidic water, and erosion by sulfate-containing water and so on. The alkali-silica reaction should be prevented by the use of harmless aggregates. If there is no choice but to use the harmless aggregates, it is good practice to replace a part of the cement with other materials such as fly ash or ground granulated blast-furnace slag powder or to keep the total alkali content of the concrete with less than Na_2O equivalent of 3.0 kg/m^3. The durability of dam concrete to erosion by acidic water or sulfate-containing water can be effectively enhanced by using cement with relatively small quantities of calcium or tricalcium aluminate, such as blended cement, or pozzolan that reacts with calcium hydroxide.

The resistance to abrasion by gravels in running water and erosion on the surface of the dam concrete due to impacts or cavitation can be enhanced by, for example, using high-strength dam concrete with a low water/cementitious material ratio or stiff aggregates. There is a limit, however, to the degree of enhancement of dam concrete durability against abrasion or erosion that can be achieved. If these environmental conditions are particularly severe, it is necessary to consider the use of materials other than concrete.

The water/cementitious material ratio of dam concrete used in the parts of the dam body where durability is required should not be higher than the values shown in Table C3.4.1.

Table C3.4.1 Upper limits of the water/cementitious material ratio based on durability

In cases where weather action is severe and freezing and thawing action are repeated In cases where dam concrete is exposed to other equally severe environmental conditions	60%
In other cases	65%

CHAPTER 4　THERMAL CONTROL PLAN

4.1　General

To prevent the occurrence of harmful thermal cracking due to the heat of hydration of dam concrete, an appropriate thermal control plan should be drawn up.

[Commentary]　When concrete hardens, it generates a large quantity of heat due to cement hydration. In the case of mass concrete such as dam concrete, unless appropriate control measures are taken, the concrete temperature rises considerably so that thermal cracks occur upon subsequent cooling of the hardened concrete. The thermal cracks in a concrete dam can impair the water-tightness and durability of dam concrete. At the stage of the mixture design and construction of dam concrete, therefore, an appropriate thermal control plan should be drawn up in order to minimize thermal cracking and prevent the occurrence of harmful thermal cracks. Prior to thermal control planning, thermal cracking should be estimated by thermal analysis.

Methods of thermal control include using cement that does not generate a large amount of heat due to hydration, reducing the cementitious material content, making adjustments to the concrete placement schedule by changing details such as lift thickness and intervals of placement, providing joints, and pre-cooling materials of dam concrete. The thermal control of dam concrete needs to be achieved by using a combination of these methods appropriately in view of such factors as the size of the dam, the weather conditions at the dam site and the construction conditions for the dam. Because assumptions about weather conditions and other factors often turn out to be incorrect, it is necessary to take into consideration possible changes in the construction conditions and weather conditions when drawing up a thermal control plan.

4.2　Thermal Crack Prediction

4.2.1　Thermal properties

The values of adiabatic temperature rise, thermal conductivity, specific heat and thermal diffusivity of dam concrete should be determined experimentally or by other appropriate methods.

[Commentary]　The values of adiabatic temperature rise, thermal conductivity, specific heat and thermal diffusivity of dam concrete are needed to investigate the temperature history of a dam under construction. Thus, they should be determined by conducting tests using the materials and mixture proportions to be used, referring to past data or literature research or carrying out other appropriate methods.

4.2.2　Prediction method

Methods used for thermal crack prediction should be proven methods that are able to quantitatively estimate the possibility of cracking.

[Commentary]　A long practiced method is to estimate the possibility of thermal cracking from the relationship between the amount of restricted strain and the ultimate strain of dam concrete by a thermal stress analysis with the thermal properties of the materials to be used according to the concrete placement schedule. One method that has been used in a growing number of dam projects in recent years is to use a cracking index and perform two-dimensional or three-dimensional finite element analyses for each shape of dam. If the occurrence of cracking is to be predicted, therefore, it is recommended that the constraint intensity matrix method or cracking index method can be used. In the constraint intensity matrix method, the allowable restricted strain for dam concrete is used for cracking control and a value of 100 μ or so is often chosen. In case of the cracking index method, a target cracking index for external restricted stress caused by contact with bedrock can be used as the construction conditions for concrete dams are less uncertain than those for ordinary concrete structures.

4.3 Joints

(1) The body of a concrete dam should be provided with appropriately spaced joints to prevent harmful thermal cracking.

(2) To prevent leakage, transverse joints should be provided with water sealing plates.

[Commentary] (1) The body of a concrete dam should be provided with appropriately spaced joints to minimize the occurrence of harmful thermal cracks caused by the heat of hydration in dam concrete. Usually, the harmful thermal cracking perpendicular to axis of dam crest line can be prevented by providing transverse joints at intervals of about 15 m. In the conventional block construction method, transverse joints are made when constructing forms. In the RCD concrete construction method and the extended layer construction method, transverse joints are made by inserting joint fillers into the cuts by vibrating joint cutters immediately after casting. A dam body is a longitudinal structure, the upstream and downstream surfaces are constantly under the influence of changing ambient temperatures, and the underside of the dam body is contact with the bedrock. Consequently, thermal stresses in the dam body are dominated by tensile stresses in the direction of axis of dam crest line. Regardless of the construction method, therefore, transverse joints should be provided at certain intervals.

In the conventional block construction method, longitudinal joints should be provided at certain intervals because sides (transverse joints) and upper surfaces of the lift are exposed to the air for a long period of time. When lifts of concrete are placed uniformly such as the RCD concrete construction method and the extended layer construction method, longitudinal joints may be omitted because sides (transverse joints) and upper surfaces of the lift are not exposed to the air for a long period of time. If a large dam without longitudinal joints is constructed in long layers, auxiliary thermal control measures such as pre-cooling may be necessary.

The transverse joint and longitudinal joint are provided to prevent harmful thermal cracking. Structurally speaking, however, these joints are a kind of artificial thermal cracks. It is therefore necessary to take some measures to achieve structural uniformity of the dam. Structural design requires that in the case of a gravity concrete dam, the structural uniformity be achieved in the cross section perpendicular to the dam axis and that in the case of a concrete arch dam, the structural uniformity be achieved in the cross section along the dam axis and in the cross section perpendicular to the dam axis. To this end, at longitudinal joints of gravity concrete dams and transverse joints of concrete arch dams, structural uniformity of the dam body should be achieved by joint grouting. In order to carry out the joint grouting, it is necessary to lower the temperature of the dam body concrete to the final stable temperature by embedded pipe cooling. Since the RCD concrete construction method and extended layer construction method have been most widely applied to the construction of recent gravity concrete dams, few longitudinal joints exist. For these gravity concrete dams, embedded pipe cooling is not usually carried out.

(2) Because transverse joints penetrate the dam body from the upstream face to the downstream face, those joints could become leakage routes from the reservoir. Water sealing plates should be installed, therefore, near the upstream end of each transverse joint. In the overflow spillway, water sealing plates should be installed near the downstream end of each transverse joint.

4.4 Concrete Placement Schedule

4.4.1 General

Concrete placement schedules should be prepared after giving careful consideration to the prevention of harmful thermal cracking.

[Commentary] Dam concrete is placed in lifts according to a predetermined plan. If the placement speed is too high, heat radiation from the lift surface is hampered, and the resultant rise in concrete temperature increases the probability of thermal cracking while the dam concrete cools down. If the placement of the next lift of concrete is too slow, a large temperature gradient occurs at the lift surface so as to increase the probability of thermal cracking. In the conventional block construction method, if transverse joints between blocks are exposed to the air for a long period of time, large temperature gradients occur near the transverse joint surfaces so as to increase the probability of thermal cracking. Prior to the construction of a concrete dam, therefore, a concrete placement schedule should be prepared after giving careful consideration to thermal cracking control and the prevention of harmful thermal cracking.

4.4.2 Lift thickness and placement interval

Lift thickness and placement intervals should be determined after giving careful consideration to the prevention of harmful thermal cracking.

[Commentary] In the case of mass concrete such as dam concrete, if the lift thickness is increased, the radiation of heat generated by hydration is reduced and the probability of thermal cracking due to a rise in concrete temperature increases. The lift thickness, therefore, should be determined taking into consideration the characteristics of the dam concrete to be used and the concrete placement schedule. When special measures are not taken and the placing speed of dam concrete substantially exceeds 0.3 m/day, the probability of thermal cracking becomes high.

In cases where new concrete is placed on a bedrock or an existing dam concrete after a long period of time, restraint against deformation due to shrinkage leads to the high probability of thermal cracking. In such cases, therefore, it is common practice to place concrete in a number of thin lifts.

4.5 Pre-cooling

Pre-cooling to prevent harmful thermal cracking should be planned on the basis of an expected concrete placement schedule.

[Commentary] In order to prevent harmful thermal cracking of dam concrete, it is important to lower the highest temperature of the placed dam concrete in order to minimize subsequent temperature falls. The pre-cooling is a method of lowering the highest temperature of dam concrete by directly cooling or cooling part of the spent materials. The pre-cooling should be planned on the basis of the results of thermal analyses and thermal stress analyses according to an expected concrete placement schedule.

Conventional pre-cooling includes the method of using cold water for concrete mixing, the method of replacing part of mixing water with ice and the method of cooling coarse aggregates with cold wind or cold water. Cooling of fine aggregates has been little used because it is difficult to stabilize the surface moisture of fine aggregates. In recent years, however, new technologies for cooling fine aggregates while controlling their surface moisture have been developed. Examples of cooling fine aggregates are the quick method of spraying liquefied nitrogen while mixing fine aggregates and the method of utilizing the heat of vaporization of water by reducing the air pressure in the fine aggregate bins.

The pre-cooling needs to be performed not to have adverse effects on the quality of dam concrete. For example, if ice is used as part of mixing water, it is common practice to use ice in flakes so that the ice melts completely before the end of concrete mixing. When fine aggregates are cooled, it is necessary to carefully control the surface moisture of fine aggregates so that the water content of the mixture proportion does not change.

CHAPTER 5 MATERIALS

5.1 General

The quality of materials should be verified experimentally or otherwise prior to use.

[Commentary] The quality required for dam concrete, such as strength, water-tightness and durability, is heavily dependent on the quality of the materials constituting the dam concrete. The quality of materials should be verified by testing or by other means. For materials conforming to JIS and other quality standards such as the JSCE standards, quality certification at factories may be deemed to be equivalent to the quality verification mentioned above.

5.2 Cementitious Materials

5.2.1 Cement

(1) The cement should not generate a large amount of heat through hydration.

(2) The cement should conform to JIS. Otherwise the quality should be verified experimentally or other suitable methods prior to use.

(3) The quality should be highly consistent.

[Commentary] (1) If cement that generates a large amount of heat through hydration is used for mass concrete such as dam concrete, the temperature of concrete rises considerably to the extent of increasing the possibility of thermal cracking. For dam concrete, therefore, cement that does not generate a large amount of heat through hydration should be used.

For dam concrete, usually moderate-heat portland cement, type B portland blast-furnace slag cement, or type B or type C fly ash cement is used. In the RCD Method and the extended layer construction method, moderate-heat portland cement is used as the base material, and about 30% in mass of that is replaced with fly ash.

When portland blast-furnace slag cement is used, if the ground granulated blast-furnace slag is too fine, autogenous shrinkage may increase, and if the ground granulated blast-furnace slag content is too low, a greater amount of heat may be generated than when normal portland cement is used. The properties and content of slag, therefore, should be carefully checked. When ordinary type B portland blast-furnace slag cement is used, it is necessary to pay careful attention to heat generation characteristics because such cement, when used for mass concrete such as dam concrete, may not fully perform its intended function as low-heat cement.

(2) Portland cement, blast-furnace slag cement and fly ash cement used for dam concrete should conform to JIS R 5210:2003, "Portland cement," JIS R 5211:2003, "Portland blast-furnace slag cement," and JIS R 5213:1997 (Reaffirmed in 2002), "Portland fly ash cement," respectively. Low-heat portland cement hardens slowly, and that slow hardening could affect constructability. It is therefore desirable that low-heat portland cement be used only after it is verified experimentally that the cement meets the constructability requirements. In cases where a cement mix made by replacing part of moderate-heat portland cement with fly ash is used, it should be verified in

advance that the quality requirements are satisfied. In recent years, new types of cement have also been developed, such as mixed cement containing admixtures in percentages exceeding the limit for type C blended cement and ternary cement containing two supplementary cementing materials. Because these types of cement harden more slowly, possibly to the extent of affecting constructability, it is desirable that they be used only after it is verified that they meet the constructability requirements.

(3) If dam concrete with consistent quality is to be made, the quality of cement supplied during construction should be stable. Since the construction of a concrete dam continues for a long period of time, it is necessary to control the quality of cement so as to prevent it from changing during construction. When using blended cement, it is also necessary to pay attention to the quality of the mineral admixtures (supplementary cementitious materials) and the replacement ratio.

5.2.2 Mineral admixtures

(1) Fly ash and ground granulated blast-furnace slag used as part of cementitious materials should conform to JIS A 6201 and JIS A 6306, respectively. Otherwise the materials should be verified experimentally prior to use so that they meet the quality requirements.

(2) If mineral admixtures other than those mentioned in Item (1) above are used, it should be verified experimentally prior to use that they meet the quality requirements.

(3) The quality of mineral admixtures should be highly consistent.

[Commentary] (1) Possible effects of replacing part of cement with high-quality fly ash include the improvement of the workability of dam concrete, reduction in water content, reduction in the heat of hydration, and the prevention of alkali–silica reaction.

The quality of fly ash varies considerably depending on the quality of coal used as raw material, the coal combustion method, and the fly ash collecting method. For this reason, only fly ash that conforms to JIS A 6201:1999 (Reaffirmed in 2004), "Fly ash for use in concrete," or fly ash whose quality has been experimentally verified may be used as part of cementitious materials. Although JIS A 6201, "Fly ash for use in concrete," stipulates four categories (Type I to Type IV) of fly ash classified according to activity index, percent flow, fineness and ignition loss, as a standard requirement Type II fly ash should be used. If lower-grade Type III or Type IV fly ash is used, it should be verified experimentally prior to use that the quality requirements for dam concrete are met.

Possible effects of replacing part of cement with ground granulated blast-furnace slag include the prevention of alkali–silica reaction and the improvement of chemical resistance to sulfates and other substances.

Ground granulated blast-furnace slag that conforms to JIS A 6206:1997 (Reaffirmed in 2004), "Ground granulated blast-furnace slag for concrete," or ground granulated blast-furnace slag whose quality has been experimentally verified may be used as part of cementitious materials. JIS A 6206:1997 (Reaffirmed in 2004), "Ground granulated blast-furnace slag for concrete," specifies three types with specific surface areas ranging from 3,000 cm^2/g to 10,000 cm^2/g, and their activity varies widely. Because ground granulated blast-furnace slag with a large specific surface area undergoes a great amount of autogenous shrinkage and generates heat due hydration fast, it is necessary to pay attention to cracking.

(2) Mineral admixtures other than fly ash and ground granulated blast-furnace slag have not yet been used widely. Those admixtures should be used, therefore, only after it is verified, through careful studies and experiments concerning their effects on the quality of dam concrete, that the quality requirements are met.

(3) If concrete of consistent quality is to be made, the quality of admixtures supplied during construction should be stable. Because the construction of a concrete dam continues for a long period of time, it is necessary to control the quality of mineral admixtures so that the quality of the admixtures does not affect the quality of dam concrete.

5.3 Mixing Water

Mixing water should be clear and should not contain a harmful quantity of oil, acids, organic impurities or other substances that have adverse effects on the quality of dam.

[Commentary] Mixing water should not contain substances that have adverse effects on the setting or strength development of dam concrete or cause the corrosion of steel. Concrete dam construction usually involves the use of river water as mixing water. In such cases, it is necessary to conduct water quality tests to evaluate the usability of the water under consideration.

5.4 Fine Aggregates

5.4.1 Density and absorption

Fine aggregates should have the density and percentage of water absorption (hereinafter referred to as "absorption") required for achieving the required performance of dam concrete.

[Commentary] Because the construction of a concrete dam requires a large quantity of aggregates and it is important to obtain stone to be used as aggregates. It is becoming increasingly difficult to obtain high-density, low-absorption fine aggregates. In view of this situation, density and absorption requirements for fine aggregates should be determined prior to use through careful studies so that the performance requirements for dam concrete are met.

Among the control values used for the quality control of fine aggregates, density and absorption are used as indicators of the physical properties of fine aggregates. These control values are determined for every potential aggregate source for every site. In view of this situation, it is required that density and absorption requirements be determined for every dam either by test reference to past projects and these Specifications, Construction.

5.4.2 Particle size distribution

Particle size distribution of fine aggregates should be such that appropriate workability of dam concrete can be achieved.

[Commentary] By selecting the particle size distribution of fine aggregate appropriately, dam concrete with the required level of workability can be obtained with a low cementitious material content. Therefore, the particle size distribution of fine aggregates should be within the ranges shown in Table C5.4.1. However, even fine aggregates whose particle size distribution is outside the ranges shown in Table C5.4.1 may be used if it has been verified experimentally that by carefully determining mixture proportions, appropriate workability can be achieved. Sieve analyses should be conducted in accordance with JIS A 1102:2006 "Method of test for sieve analysis of aggregates."

Concrete mixtures for the RCD Method are lean mixtures. In order to achieve the required level of workability, therefore, it is advisable to use fine aggregates containing a higher percentage of fine particles than in the case of ordinary dam concrete. Workability might be improved by increasing the content of fine particles passing a 150 μm sieve. Limestone powder is sometimes used to make up for the shortage of the finer particles content of fine aggregates.

Table C5.4.1 Standard grading of fine aggregates

Nominal sieve size	Percent passing (%)	Nominal sieve size	Percent passing (%)
10~5mm	0~8	600~300μm	15~30
5~2.5mm	5~20	300~150μm	12~20
2.5~1.2mm	10~25	150μm or smaller	2~15
1.2mm~600μm	10~30		

5.4.3 Durability

(1) Fine aggregates whose loss in mass as determined in accordance with JIS A 1122:2005 "Method of test for soundness of aggregates by use of sodium sulfate," is 10% or less should be used in the parts of dam concrete to be subjected to freezing and thawing cycles.

(2) Fine aggregates should be hard and chemically and physically stable.

[Commentary] (1) Fine aggregates used for external concrete and structural concrete that could be subjected to freezing and thawing cycles should be sufficiently resistant to freezing and thawing cycles. The soundness of fine aggregates is determined by testing their frost resistance in accordance with JIS A 1122:2005 "Method of test for soundness of aggregates by use of sodium sulfate." The standard upper limit of the loss in mass of fine aggregates determined by the soundness test method is 10%. However, even in cases where the loss in mass of fine aggregates determined by the soundness test method exceeds 10%, if the relative dynamic modulus of elasticity after 300 cycles, determined in accordance with JIS A 1148:2001 "Method of test for resistance of concrete to freezing and thawing" (freezing and thawing in water), is greater than 60%, the fine aggregates may be deemed to be sufficiently frost resistant. Mixture proportions and ages of specimen for freezing and thawing test are as shown in Table C5.4.2. Coarse aggregates for the test should have sufficient resistance to freezing and thawing.

For fine aggregates used for internal concrete, which is seldom subjected to freezing and thawing cycles, the frost resistance evaluation criteria may be relaxed.

Table C5.4.2 Concrete mixture proportions and test conditions for freezing and thawing test

Condition of mixture proportion	Test conditions
• Maximum size of coarse aggregate	20 mm or 25 mm
• Type of cement	Normal portland cement
• Water/cement ratio	55 %
• Slump range	8.0±1.0 cm
• Air content range	4.5±0.5 %
• Curing	Standard curing
• Testing age	28 days

(2) An important consideration related to the chemical stability of fine aggregates is alkali–silica reaction. In cases where stone that could cause alkali–silica reaction is used to make fine aggregates, the chemical stability of the aggregates should be verified in accordance with JIS A 1145:2001 "Method of test for alkali-silica reactivity of aggregates by chemical method," and JIS A 1146:2001 "Method of test for alkali-silica reactivity of aggregates by mortar bar method." In such cases, common practice is to check whether the fine aggregates under consideration are harmless by the chemical method and, if they have been judged not to be harmless, use the mortar bar method. Even fine aggregates that have been judged not to be harmful may be used if (1) the total alkali content of the concrete is kept at or below 3.0 kg/m^3 in terms of Na_2O equivalent, (2) blended cement such as type B or type C portland blast-furnace slag cement or type B or type C portland fly-ash cement is used or (3) low-alkali cement is used.

Minerals that require attention in connection with the physical stability of fine aggregates include montmorillonite and laumontite. These minerals often exist in cracks in rocks, but they may also exist as components of rocks. If fine aggregates containing montmorillonite are used, the setting of dam concrete may be accelerated so as to cause problems in the placement of dam concrete. If fine aggregates containing laumontite are used, expansion crack or pop-out of dam concrete may result. If these minerals have been detected in fine aggregates by X-ray diffraction analysis or by other means, it is necessary to evaluate the usability of the aggregates. There are no specific criteria for the allowable content of montmorillonite or laumontite, but 10% and 1%, respectively, are often used as control criteria.

5.4.4 Content of harmful substances

Standard allowable limits of the content of harmful substances, such as clay lumps, aggregate particles passing a 75 μm sieve and chlorides, should be as shown in Table 5.4.1. The usability of fine aggregates containing organic impurities should be evaluated by conducting tests in accordance with JIS A 1105:2001 "Method of test for organic impurities in fine aggregate."

Table 5.4.1 Standard limits of the content of harmful substances in fine aggregate (percent in mass)

Type	Maximum value
• Clay lumps	1.0[1)]
• Particles passing a 75 μm sieve	
In the case where dam concrete surface is subjected to abrasion	3.0[2)]
In other cases	5.0[2)]
• Chlorides	0.04[3)]

1) Aggregate particles retained in the 75 μm sieve in a test conducted in accordance with JIS A 1103 are used.

2) If crushed sand is used, if the particles passing a 75 μm sieve are crushed stone particles that do not contain clay or silt, the maximum values are 5% and 7%, respectively.

3) Percentage relative to absolute dry mass of fine aggregate; expressed as NaCl equivalent

[Commentary] Because harmful substances contained in fine aggregate affect the quality of dam concrete, their content should be kept within the standard limits shown in Table 5.4.1. Fine aggregates, however, that have exceeded the values shown in Table 5.4.1 may be used if it has been verified experimentally that they do not affect the quality of dam concrete. Tests for the items listed above should be conducted in accordance with JIS A 1137:2005 "Method of test for clay lumps contained in aggregates," JIS A 1103:2003 "Method of test for amount of material passing test sieve 75 μm in aggregates," JSCE C 502-2007 "Test method for chloride ion content of sea sand," and JIS A 1105:2001 "Method of test for organic impurities in fine aggregate," respectively.

5.5 Coarse Aggregates

5.5.1 Density and absorption

Coarse aggregates should have the density and absorption characteristics needed to achieve the required durability and strength.

[Commentary] The density and absorption of coarse aggregates are indicators of various quality attributes including durability and strength. It is therefore necessary to use coarse aggregates with the highest possible density. As a standard requirement, the density and absorption of coarse aggregates in a saturated surface-dry condition should be 2.50 g/cm^3 or more and 3% or less, respectively. In cases where coarse aggregates with an absorption of 3 to 5% are used, it is necessary to follow the rules stipulated in Section 5.5.2, Durability, and conduct a careful study so that the performance requirements for dam concrete are met. Even in cases where the density or absorption of coarse aggregates does not meet the requirements mentioned above, fine aggregates that have been judged to be capable of meeting the performance requirements for dam concrete as a result of a concrete test conducted on the coarse aggregates may be used. The density and absorption of coarse aggregates should be determined in accordance with JIS A 1110 "Methods of test for density and water absorption of coarse aggregates."

5.5.2 Durability

(1) As a standard requirement, coarse aggregates used for dam concrete in the parts of the dam body to be subjected to freezing and thawing cycles meet the requirements shown in Table 5.5.1.

Table 5.5.1 Standard values of frost resistance of coarse aggregates

Specified strength of dam concrete	Standard values of absorption and loss in mass
Lower than 18 N/mm^2	Absorption: 3% or less, loss in mass: 40% or less or Absorption: 5% or less, loss in mass: 12% or less
18 N/mm^2 or higher	Absorption: 3% or less, loss in mass: 12% or less

(2) Coarse aggregates should be hard and chemically and physically stable.

[Commentary] (1) Coarse aggregates used for external concrete and structural concrete that could be subjected to freezing and thawing cycles should be sufficiently resistant to freezing and thawing cycles. It is common practice to evaluate the soundness of fine aggregates by testing their frost resistance in accordance with JIS A 1122:2005 "Method of test for soundness of aggregates by use of sodium sulfate." In this case, standard upper limits of the loss in mass of coarse aggregates are determined according to the design strength of dam concrete and absorptions of coarse aggregates as shown in Table 5.5.1. However, even in cases where the loss in mass of coarse aggregates determined by the soundness test method exceeds the values shown in Table 5.5.1, if the relative dynamic modulus of elasticity after 300 cycles determined in accordance with JIS A 1148:2001 "Method of test for resistance of concrete to freezing and thawing" (freezing and thawing in water), is greater than 60%, the coarse aggregates may be deemed to be sufficiently frost resistant. Mixture proportions and age used for freezing and thawing test are as shown in Table C5.4.2. Fine aggregates used for the test should have sufficient resistance to freezing and thawing.

For coarse aggregates used for internal concrete, which is seldom subjected to freezing and thawing cycles, the frost resistance evaluation criteria may be relaxed according to the case.

(2) Chemical and physical stability of coarse aggregates should be evaluated as described in the Commentary (1) of Section 5.4.3, Durability.

An important consideration related to the chemical stability of coarse aggregates is alkali–silica reaction. In cases where stone that could cause alkali–silica reaction is used to make coarse aggregates, the chemical stability of the aggregates must be verified in accordance with JIS A 1145:2001 "Method of test for alkali-silica reactivity of aggregates by chemical method," and JIS A 1146:2001 "Method of test for alkali-silica reactivity of aggregates by mortar bar method." In such cases, common practice is to check whether the coarse aggregates under consideration are harmless by the chemical method and, if they have been judged no to be harmless, use the mortar bar method. Even coarse aggregates that have been judged not to be harmless may be used if (1) the total alkali content of the concrete is kept at or below 3.0 kg/m^3 in terms of Na_2O equivalent, or (2) blended cement such as type B or type C portland blast-furnace slag cement or type B or type C portland fly-ash cement is used.

5.5.3 Abrasion resistance

As a standard requirement, the abrasion loss of coarse aggregates used for dam concrete as determined in accordance with JIS A 1121:2001 "Method of test for resistance to abrasion of coarse aggregate by use of the Los Angeles machine," is 40% or less.

[Commentary] External concrete needs to be sufficiently resistant to abrasion. Hence, coarse aggregate, which occupies a major portion of the volume of dam concrete, should be highly resistant to abrasion. Tests for the abrasion resistance of coarse aggregate should be conducted in accordance with JIS A 1121:2001 "Method of test for resistance to abrasion of coarse aggregate by use of the Los Angeles machine."

As a standard requirement, the abrasion loss of coarse aggregate as measured by use of the Los Angeles abrasion testing machine is 40% or less. Since, however, abrasion test results may vary by several percent depending on the sampling of specimens, abrasion resistance of coarse aggregate should be evaluated according to not only the test results but also other factors such as the level of abrasion resistance required of dam concrete.

5.5.4 Particle size distribution

The standard particle size distribution of coarse aggregate is as shown in Table 5.5.2.

Table 5.5.2 Standard particle size distribution of coarse aggregate

Particle size range (mm) / Maximum size of coarse aggregate	Percent in mass of different particle sizes					
	150~80	120~80	80~40	40~20	20~10	10~5
150	35~20	-	32~20	30~20	20~12	15~8
120	-	25~10	35~20	35~20	25~15	15~10
80	-	-	40~20	40~20	25~15	15~10
40	-	-	-	55~40	35~30	25~15

[Commentary] The influence of the particle size distribution of coarse aggregate on the properties of concrete is not as great as that of fine aggregate. For dam concrete, however, coarse aggregate having a maximum size of 150 mm is used in some cases. In such cases, the influence of the particle size distribution of coarse aggregate may be great. Table 5.5.2 shows standard particle size distributions of aggregate, but actual particle size distribution does not necessarily fall into the indicated ranges under the influence of such factors as the type of rock used as aggregate and the method of manufacturing aggregate. Such aggregates may be used if the quality requirements for concrete are met.

5.5.5 Content of harmful substances

The standard allowable limits of the content of clay lumps, soft particles fragments and particles passing a 75 μm sieve is as shown in Table 5.5.3.

Table 5.5.3 Standard limits of the content of harmful substances in coarse aggregate (percent in mass)

Type	Maximum value
• Clay lumps	0.25[1)]
• Soft stone fragments	5.0
• Particles passing a 75 μm sieve	1.0[2)]

1) Aggregate particles retained in the 75 μm sieve in a test conducted in accordance with JIS A 1103 are used.

2) If crushed stone is used, the maximum value is 1.5%.

[Commentary] Because harmful substances contained in coarse aggregate affect the quality of dam concrete, their content should be kept within the standard limits shown in Table 5.5.3. Tests for the items listed above should be conducted in accordance with JIS A 1137:2005 "Method of test for clay lumps contained in aggregates," JIS A 1126:2001 "Method of test for content of soft particles in coarse aggregate by scratching" (for soft particles fragments) and JIS A 1103:2003 "Method of test for amount of material passing test sieve 75 μm in aggregates."

5.6 Chemical Admixtures

As a standard requirement, air-entraining agents, water-reducing agents, air-entraining water-reducing agents and air-entraining high-range water-reducing agents conform to JIS A 6204:2006 "Chemical admixtures for concrete." If chemical admixtures do not conform to the JIS, their usability should be experimentally verified in advance.

[Commentary] If used appropriately, air-entraining agents, water-reducing agents, air-entraining water-reducing agents and air-entraining high-range water-reducing agents bring about various beneficial effects such as improved workability, enhanced resistance to freezing and thawing and enhanced water-tightness of dam concrete. A great variety of air-entraining agents, water-reducing agents, air-entraining water-reducing agents and air-entraining high-range water-reducing agents are available on the market, and their quality varies widely. It is necessary, therefore, to use chemical admixtures conforming to JIS A 6204:2006 "Chemical admixtures for concrete," or chemical admixtures whose quality has been verified experimentally.

Chemical admixtures other than air-entraining agents, water-reducing agents, air-entraining water-reducing agents and air-entraining high-range water-reducing agents should be used after not only verifying their quality but also verifying experimentally that they do not adversely affect the quality of dam concrete such as strength and durability. Examples of chemical admixtures of this type are super retarder used to control changes with time in slump of dam concrete made with montmorillonite-containing aggregate.

If mineral admixtures such as fly ash are used, care needs to be taken because the quality of those admixtures could affect the effects of chemical admixtures.

CHAPTER 6 MIXTURE DESIGN

6.1 General

(1) Mixture proportions for dam concrete should be determined so as to meet the performance requirements for the dam concrete.

(2) Mixture proportions for dam concrete should be determined so as to meet the performance requirements for different mixture proportions based on the mixture proportion classification shown in Table 3.2.1.

(3) In cases where mixture proportions are determined by use of wet-screened specimens, as a standard requirement, workability should be checked by using concrete mixtures containing full-size aggregate.

[Commentary] (1) Mixture proportions for dam concrete should be determined so that both the performance requirements for fresh concrete and the performance requirements for hardened concrete are met. A series of tasks performed to determine the mixture proportions for dam concrete is referred to as "mixture design."

To the extent that the level of workability suitable for the tasks to be performed can be achieved, the strength, water-tightness and durability of dam concrete are determined mainly by its water/cementitious material ratio, and as the water/cementitious material ratio of dam concrete decreases, its strength, water-tightness and durability increase. When determining the mixture proportions for dam concrete, therefore, it is necessary to make the water/cementitious material ratio as low as possible to the extent that workability suitable for the tasks to be performed can be achieved.

Since, however, a dam is a mass concrete structure, if the amount of heat generated by hydration when the concrete hardens is large, thermal cracking of the dam concrete causes adverse effects on the storage capability, durability and structural safety of the dam. When determining the mixture proportions for dam concrete, therefore, it is necessary to keep the cement content as low as possible to the extent that the level of workability suitable for the tasks to be performed can be achieved, or to replace part of the cement with appropriate mineral admixtures on an as-needed basis.

The mixture proportions for dam concrete affect temperature control and other aspects of the design of the dam and its construction plan. The mixture design of dam concrete, therefore, is conducted as part of the design of the dam. The mixture proportions determined at the design stage prior to the construction stage are referred to as the "specified mixture proportions." After the aggregate and concrete plants at the construction site are completed, the specified mixture proportions are modified according to the actual construction conditions. The mixture proportions thus determined at the construction stage are referred to as the field mixture proportions. Mixture proportions may be modified by, for example, changing the sand percentage depending on variations of materials during the construction process. Field mixture proportioning at the site includes such modifications. Corrections for the surface moisture content and too small or too large particle sizes are also included in the field mixture proportioning at the site.

(2) Dam concrete can be classified as shown in the mixture proportion classification shown in

Table 3.2.1, but other mixture proportions may be added, if necessary, by changing conditions such as slump, air content or the maximum aggregate size. Mixture proportions for dam concrete for different parts of the dam body need to be designed so that the quality requirements can be met.

(3) The maximum size of coarse aggregate for dam concrete usually exceeds 40 mm, and it is common practice to determine mixture proportions by using specimens wet-screened with a 40 mm sieve. In this case, the standard procedure requires checking the workability of the concrete containing full-size aggregate after the mixture proportions are determined because the workability and other characteristics of wet-screened concrete may differ from those of concrete made by using full-size aggregate. For example, workability can be checked by producing a batch of concrete and casting it into formwork with a known inner volume.

6.2 Maximum Size of Coarse Aggregate

The maximum size of coarse aggregate should be determined in view of all requirements such as making the cementitious material content low enough to reduce the amount of heat generated during the hardening of dam concrete and achieving the level of workability suitable for the tasks to be performed.

[Commentary] In general, as the maximum size of coarse aggregate increases, the required cementitious material content of dam concrete can be reduced so that temperature rise due to heat of hydration can be reduced. In the case of RCD concrete, which is extremely stiff lean mix concrete, it is desirable that the maximum size of coarse aggregate be kept small so as to minimize segregation during the transportation, discharging and spreading of dam concrete. For this reason, the maximum size of coarse aggregate should be determined taking all of these factors into consideration.

For reinforced concrete sections such as structural concrete sections, reinforcement spacing also needs to be taken into consideration in determining the maximum size of coarse aggregate.

6.3 Particle Size Distribution of Coarse Aggregate

The particle size distribution of coarse aggregate should be determined in view of the particle size distribution of the aggregate used so that the level of workability required for the tasks to be performed can be achieved. The standard particle size distribution of coarse aggregate is as shown in Table 5.5.2.

[Commentary] Crushed stone is often used as coarse aggregate of dam concrete. Table 5.5.2 shows the standard range of particle size distribution of coarse aggregate that makes it possible to achieve the level of workability required for the tasks to be performed. It is advisable to determine the grading of aggregate with reference to the grading ranges shown in the table so that the solid content of coarse aggregate becomes high.

In cases where riverbed gravel is used as coarse aggregate, aggregate in the naturally produced condition or aggregate from which too large particles have been removed may be used if it is verified that the quality requirements for dam concrete can be met.

6.4 Sand Percentage

The sand percentage should be determined so that the cementitious material content can be kept low and the required level of segregation resistance can be achieved.

[Commentary] By selecting an appropriate sand percentage of dam concrete, the cementitious material content can be kept low and high segregation resistance can be achieved.

If the sand percentage that minimizes the water content is determined by using specimens wet-screened with a 40 mm sieve, there are cases where the required level of workability cannot be achieved when concrete containing full-size aggregate is used because the quantity of sand is too small. When determining the sand percentage, therefore, it is desirable that verification is made by using concrete specimens containing full-size aggregate.

6.5 Water/Cementitious Material Ratio

(1) The water/cementitious material ratio should be determined so that the quality requirements for different mixture proportion classes of dam concrete are met.

(2) In cases where the water/cementitious material ratio is determined on the basis of compressive strength, the water/cementitious material ratio should be determined experimentally.

(3) The water/cementitious material ratio of external concrete should be determined so that the required water-tightness and durability can be attained.

[Commentary] (1) The quality of dam concrete such as strength, water-tightness and durability is determined mainly by the water/cementitious material ratio. The water/cementitious material ratio, therefore, should be determined so that the quality requirements for each type of mixture of dam concrete, such as strength, water-tightness and durability, can be met.

(2) Even if the water/cementitious material ratio does not change, the compressive strength of concrete can vary widely depending on such factors as the type of cement, the quantities of admixtures used, and the type and quality of aggregate. When the water/cementitious material ratio is to be determined, therefore, compressive strength tests should be conducted on concrete produced by using the materials to be actually used, and the water/cementitious material ratio should be determined according to the test results.

(3) External concrete should meet the durability requirements. When the water/cementitious material ratio is to be determined on the basis of the water-tightness and durability requirements, it is a standard requirement to observe Section 3.4.3, Water-tightness, and Section 3.4.4, Durability.

6.6 Cementitious Material Content

6.6.1 General

The cementitious material content should be made as low as possible to the extent that the required water/cementitious material ratio is attained and the level of workability suitable for the tasks to be performed is achieved.

[Commentary] In the case of a mass concrete structure like a dam, temperature rise due to the hydration of cement should be kept low so that harmful thermal cracking can be prevented. In order to reduce temperature rise due to heat of hydration, the cementitious material content of dam concrete should be made as low as possible to the extent that the required water/cementitious material ratio is attained and the level of workability suitable for the tasks to be performed is achieved.

Requirements for the cementitious material content of internal concrete vary depending on the dam construction method and the capability of the equipment used. According to data on past projects, the cementitious material content of conventional concrete for a gravity concrete dam is about 140 to 160 kg/m^3 for the columnar block method and about 130 to 150 kg/m^3 for the extended layer construction method, and the cementitious material content of RCD concrete is about 120 to 130 kg/m^3. For a concrete arch dam, which requires high compressive strength, the cementitious material content is about 210 to 220 kg/m^3. For a gravity concrete dam, the cementitious material content of external concrete is about 210 to 220 kg/m^3.

6.6.2 Mineral admixture fraction

In cases where part of cement is replaced with a mineral admixture, the admixture fraction should be determined so that the quality requirements for the dam concrete are met.

[Commentary] By replacing part of the cement in the internal concrete with admixtures such as high-quality fly ash, temperature rise in the dam concrete can be reduced without losing the required strength, and workability can also be improved. In cases, therefore, where temperature rise in dam concrete needs to be strictly controlled as in the case of RCD concrete, it is common practice to replace part of the cement with mineral admixtures such as fly ash or ground granulated blast-furnace slag. The admixture fraction should be kept within the range in which the required early-age strength can be attained. In general, the admixture replacement percentage for RCD concrete is about 30% when fly ash is used and about 50 to 70% when ground granulated blast-furnace slag is used.

In cases where part of the cement in external concrete is replaced with an admixture, the admixture fraction should be determined in view of the water-tightness and durability requirements for the external concrete. In general, the admixture replacement percentage for external concrete is 30% or less when fly ash is used and about 50 to 60% or less when ground granulated blast-furnace slag is used.

6.7 Chemical Admixture Content

(1) The chemical admixture content of air-entrained concrete used in the parts of the dam body that are to be subjected to freezing and thawing cycles should be determined so that the required air content is attained.

(2) The chemical admixture content of dam concrete in the parts of the dam body that are not to be subjected to freezing and thawing cycles should be determined so that the required level of workability can be attained.

[Commentary] (1) Because concrete with an appropriate amount of entrained air is sufficiently resistant to freezing and thawing, air-entrained concrete is used as dam concrete for the parts of the dam body that are to be subjected to freezing and thawing cycles. The quantity of an air-entraining agent, air-entraining water-reducing agent or air-entraining high-range water-reducing agent to be used should be determined so that the standard air content of air-entrained concrete shown in Table 3.3.1 can be attained at the placing site. Tests for air content measurement should be conducted in accordance with JIS A 1128:2005, "Method of test for air content of fresh concrete by pressure method," JIS A 1116:2005, "Method of test for unit mass and air content of fresh concrete by mass method," or JIS A 1118:1997, "Method of test for air content of fresh concrete by volumetric Method."

The air content of dam concrete decreases by about 1/4 to 1/6 during transportation and compaction. When determining the air content of dam concrete, therefore, it is necessary to allow for decreases in air content during transportation and compaction so that the air content requirements for dam concrete can be met at the placing site. It is desirable that the degree of decrease in air content due to transportation or compaction should be determined experimentally because it varies depending on the properties of dam concrete and the construction conditions.

(2) It is not necessary to use air-entrained concrete as dam concrete for the parts of the dam body that are not subjected to freezing and thawing cycles such as internal concrete. For conventional concrete, however, the use of concrete with an appropriate amount of entrained air improves workability and is also effective in reducing cementitious material content requirements. It is common practice, therefore, to use air-entrained concrete to improve workability as internal concrete.

For RCD concrete, retarding type air-entraining agents are commonly used to disperse cementitious material and retard setting. In such cases, measured values of air content of freshly mixed dam concrete containing full-size aggregate are often 1.5±1.0%.

The quantities of air-entraining agents, water-reducing agents, air-entraining water-reducing agents and air-entraining high-range water reducing agents added to dam concrete to attain the required level of workability should be determined experimentally.

6.8 Indication of Mixture Proportions

Mixture proportions should be expressed as shown in Table 6.8.1.

Table 6.8.1 Mixture proportions

Maximum size of coarse aggregate (mm)	Slump or VC value range (cm) (sec)	Air content range (%)	Water/ cementitious material ratio *W*/(*C*+*F*) (%)	Admixture content *F*/(*C*+*F*) (%)	Sand percentage *s*/*a* (%)	Unit content (kg/m^3)								
						Water *W*	Cement *C*	Admixture *F*	Fine aggregate *S*	Coarse aggregate *G*				Chemical admixture
										mm ~ mm	mm ~ mm	mm ~ mm	mm ~ mm	

Note: If no admixture is used, the water/cementitious material ratio is expressed as the "water/cement ratio." The quantities of chemical admixtures are undiluted, undissolved quantities.

a: total absolute volume of fine and coarse aggregates (L)

s: absolute volume of fine aggregate (L)

[Commentary] Mixture proportions indicate the mass of each material contained in one cubic meter of dam concrete. The saturated surface-dry condition of aggregate is assumed, and it is also assumed that all of the fine aggregate passes a 5 mm sieve and the coarse aggregate is retained on a 5 mm sieve.

CHAPTER 7 MANUFACTURE OF CONCRETE

7.1 Storage of Materials

7.1.1 Storage of aggregate

(1) The fine and coarse aggregate should be stored separately and the coarse aggregate be stored with the grading classified.

(2) The aggregate storage facilities should be designed so that the aggregate with stable surface moisture content may be provided.

[Commentary] (1) Stable particle size distribution of the aggregate is indispensable for the production of dam concrete. The fine and coarse aggregate, therefore, should be stored separately. Segregation between large and small size of particles may easily occur in coarse aggregate and then it should be stored with separated into three or four classes of the size. The size of the grading of coarse aggregate is usually 150 to 80 mm, 80 to 40 mm, 40 to 20 mm and 20 to 5 mm in case of four classes while 150 to 80 mm, 80 to 40 mm and 40 to 5 mm or 150 to 60 mm, 60 to 25 mm and 25 to 5 mm in case of three classes respectively.

(2) Large fluctuation of surface moisture in the aggregate due to insufficient drying makes it difficult to keep the unit water content in the dam concrete constant and may result in unstable quality of the dam concrete. Large fluctuation of the surface moisture content especially in fine aggregate with much surface moisture may often affect the quality of the dam concrete.

The aggregate storage facilities should be provided with an adequate drainage facility for the stable surface moisture and their capacity should be designed so that the drying time of the aggregate may be sufficient. It is also desirable that fine aggregate especially should be stored with protection from the rain water, that the drainage facilities be designed and that plural number of storage bins be facilitated for drying more than three or four days.

The aggregate storage facilities should be provided with adequate drainage facilities for the stable surface moisture and their capacity should be designed so that the drying time of the aggregate may be sufficient. It is also desirable that fine aggregate is stored with shed for the protection from the rain water, that the drainage facilities be designed and that plural number of storage bins be facilitated for drying more than three or four days.

7.1.2 Storage of cementitious materials

(1) The cementitious materials should be stored by a method that makes it possible to ensure the required quality.

(2) If cement and admixtures are to be mixed at the batching plant, each material should be stored by a method similar to that stipulated in Item (1).

[Commentary] (1) Cementitious materials are weathered if exposed to moisture. The use of weathered cementitious material may result not only in a failure of the required strength of dam concrete but also in the reduction in the durability. The silos for cementitious materials, therefore, should be designed to ensure the required quality.

If stored for a long period time, cementitious materials are weathered due to the moisture. Therefore, the quality of the cementitious materials after the long time of storage should be experimentally verified before using.

Extreme high temperature of cement (or cementitious material and so forth) may cause quick set of the dam concrete during the mixing. Because the temperature of the newly made cement is very high, the use of cement with such high temperature should be avoided by the control on the temperature of the cement at the shipment from the factory or at the acceptance to the mixing plant. The usual regulation temperature of the cement is less than 50 to 60°C at the shipment from the cement plant and less than 40 to 50°C at the acceptance to the mixing plant respectively.

(2) Cement and admixture are normally blended at the cement plant. On the other hand, if cement and admixture are to be mixed at the mixing plant, each material should be stored at the mixing plant by a method similar to that stipulated in Item (1).

7.1.3 Storage of chemical admixtures

Chemical admixtures should be stored by such a method that makes it possible to ensure the required quality.

[Commentary] Chemical admixtures should be stored in places where the stable quality can be ensured, and each type of the admixtures should be stored separately.

The quality of chemical admixtures after a long time of storage may be deteriorated. Therefore, the quality of the chemical admixture after a long time of storage should be experimentally verified before using.

7.2 Batching and Mixing

7.2.1 Batching of materials

(1) The standard accuracy of batching each material for concrete by the use of weighing equipment is shown in Table 7.2.1.

Table 7.2.1 Tolerance for error of batching material

Type of material	Tolerance(%)
Water	1
Cementitious material	1
Mineral admixture	2*
Aggregate	3
Chemical admixture	3

* 1% if used as a portion of cementitious material

(2) Materials should be batched in accordance with the field mixture proportion, into

which the specified mixture proportion be adjusted.

(3) The surface moisture content of aggregate should be measured with an adequate frequency and it should be reflected in the field mixture proportions.

[Commentary] (1) The systematic errors of batching materials for the concrete can be divided into the mechanical errors by the weighing equipment itself and the batching errors in the process of batching the materials. The former, the mechanical errors by the weighing equipments, can be determined by the certification and then they can be reduced through the daily maintenance. The mechanical error of weighing equipment used for the construction is normally about 0.5% of its maximum capacity. On the other hand, the latter, the batching errors, depend on the minimum unit amount by the feeding equipment of the materials and then it is difficult to control the batching error in case of using the feeding equipment with a large capacity. It is therefore necessary to determine the capacity of the feeding equipment so that the amount of the materials used in the usual batch of concrete can be batched accurately. The batching errors of the materials for the target batching weights should be controlled to be less than the values shown in Table 7.2.1.

(2) The specified mixture proportions should be designed on condition that the aggregate is in saturated surface-dry condition and the unit aggregate contents should be obtained on condition that all of the particles of the fine aggregate can pass through and all of the particles of the coarse aggregate can be stopped by the sieve with the size of 5 mm. On the other hand, the exact conditions of the aggregate are different from those mentioned above. The field mixture proportions, therefore, should be modified by taking the surface moisture content in aggregate, the amount of the particles of the fine aggregate stopped by the sieve with the size of 5 mm and the amount of the particles of coarse aggregate passing through the sieve with the seize of 5 mm into accounted. Also, the surface moisture in aggregate and the water used for diluting the chemical admixture should be regarded as a portion of the unit water in the concrete.

(3) Fluctuation of the surface moisture content on aggregate affects the water content in the concrete largely. It is therefore necessary to measure the surface moisture content on aggregate with an adequate frequency and to reflect it in the field mixture proportions.

Because RCD concrete has extremely stiff consistency with the low water content, the surface moisture content on aggregate especially needs accurate controlling. The surface moisture content on the fine aggregate for RCD concrete, therefore, is normally measured for each batching at the batching plant and it is reflected in the adjustment of the water content to be batched. Methods of measuring the surface moisture content on fine aggregate at the batching plant include the methods by measuring the electric resistance or the permittivity, the method using neutrons and the volume method.

7.2.2 Mixing

(1) Mixers used for dam concrete should have adequate mixing efficiency and be designed so that the segregation may occur hardly at the discharge of the mixed concrete.

(2) The order of charging the materials into the mixer and the mixing time should be determined experimentally.

[Commentary] (1) The maximum size of coarse aggregate in dam concrete is large, and the cementitious material content is low. The efficiency of the mixers, therefore, affects the quality of concrete largely. For this reason, the mixer used for dam concrete should have the efficiency needed to produce homogeneous concrete and be designed so that the segregation may occur hardly at the discharge of the mixed concrete.

The mixers include batch mixers and continuous mixers. The batch mixers can be divided broadly into gravity mixers and revolving blade mixers. The batch mixers normally allow easy control of accuracy and are capable of adequate mixing even if the cementitious material content in the concrete is low. The continuous mixers, on the other hand, make it possible to mix large volume of concrete with the use of relatively simple facilities, but it is necessary to take cares in the accuracy of batching of the materials.

The type of mixer should be selected by taking such factors as the scale of the dam and the mixture proportion of the dam concrete into consideration. In the mixing of RCD concrete with extremely stiff consistency and low cementitious material and water contents, the forced mixing type mixers are normally used, which enable the production of homogeneous concrete with short time of mixing and can cause little segregation

The test for the mixing efficiency should be conducted with the mixed concrete in accordance with JIS A 1119:2005, “Methods of test for difference in amount of mortar and coarse aggregate content in mixed concrete” and JIS A 8603:1994 (Recognized in 2006), “Concrete Mixer” and the efficiency should be evaluated in accordance with Table C7.2.1

Table C7.2.1 Mixing efficiency of batch mixers

Item		Mixing volume of concrete	
		Nominal capacity	1/2 of nominal capacity
Difference in unit mass of mortar in concrete		0.8% or less	0.8% or less
Difference in coarse aggregate content in concrete		5% or less	5% or less
Difference with average value	Compressive strength	7.5% or less	-
	Air content	10% or less	-
	Slump	15% or less	-

(2) The required mixing time for producing homogeneous dam concrete depends on such factors as the type of mixer, the order of materials charging into the mixer and the consistency of the dam concrete. The order of materials charging into the mixer and the mixing time should normally be determined experimentally. The experiment should be conducted in accordance with JIS A 1119:2005, “Methods of test for difference in mortar and coarse aggregate contents in mixed concrete by mixer” and the result be evaluated in accordance with Table C7.2.1.

CHAPTER 8 CONSTRUCTION

8.1 Construction Planning

The construction plan of dam concrete should be prepared beforehand to meet the performance requirements and the dam concrete should be placed in accordance with the plan.

[Commentary] It is important to prepare a construction plan beforehand and to place the dam concrete appropriately in accordance with the plan in order for the dam concrete to meet the performance requirements. The construction standards necessary for construction planning are described in this chapter. Items not dealt with in this chapter should be in accordance with these Specifications, Construction.

Because dam concrete is placed in a large volume day and night, the aggregate and batching plants are normally located at the construction site. On the other hand, crushed stone may be purchased or ready-mixed concrete plant may supply with the concrete for small-scale dam mainly for economical reasons. In such cases, it is recommended that the crushed stone plant and the ready-mixed concrete plant should be regarded as an aggregate plant and a batching plant that installed at the construction site respectively and that the construction plan should be drawn up in accordance with *Part 2, Standard Methods*.

The construction of a dam is a large-scale construction work, and in many cases the Owner's engineers are available at the construction site. It is usually easy, therefore, to identify the problems related to the construction promptly and to take corrective measures such as modifying construction methods. By making use of those advantages, it is desirable that both the client and the contractor should discuss and review the design and construction plans appropriately in order to achieve the high quality of construction.

8.2 Formwork

8.2.1 General

Formworks and falseworks should be structurally designed and be tightly installed in the designated position so that they can have the sufficient strength and stiffness for maintaining accurate shape and size of the structure.

[Commentary] Formworks and falseworks should have the sufficient strength and stiffness to resist the applied load and be installed exactly to prevent the error of the shape or size of the dam body.

The formworks used for concrete dam include those on the upstream and the downstream faces, those for the longitudinal and transverse joints, those for the internal structures such as gallery and gate spaces, and those for the external structures such as training wall and pier. The formworks, for the major parts of the dam such as those for the upstream and downstream faces and for the longitudinal and horizontal joints have already been standardized.

In some of the constructions of the dams by the RCD or extended layer construction method, the formworks for the end side along the transverse joint are used, where simple traveling or embedding type of formworks may be employed because high accuracy is not necessary.

In recent years, precast concrete members have been used as the formworks for the internal structures in some projects. In such cases it is difficult to verify the compaction of the concrete. It is therefore necessary to examine the materials and construction methods carefully so that the compaction of the concrete may be ensured.

8.2.2　Formworks

(1) Formworks and falseworks should be designed by taking the appropriate loads according to the construction condition into consideration.

(2) Materials used for the formworks and falseworks should have the required strength and stiffness.

[Commentary] (1) It is possible that formwork for dam concrete is subject to high lateral pressure locally mainly due to the use of powerful vibrators or the existence of large maximum size of the coarse aggregate. Also, it is possible that setting and strength development of concrete may be delayed mainly due to the low cement content or the replacement of cement with admixtures such as fly ash. By taking these factors into consideration, the loads should be set up properly according to the construction conditions.

Self-compacting concrete has been cast to fill up the space around the structures in the dam body in some of the recent dam projects. The lateral pressure of self-compacting concrete to the form should be designed as that of liquid.

It is recommended that the unit mass of the fresh concrete should be set up as about 2.4 t/m^3 for unreinforced concrete and about 2.5 t/m^3 for reinforced concrete respectively in designing load to the formworks or falseworks. In addition, a distributed load of about 2.45 kN/m^2 should be taken into accounted as the live load from the construction machines. The lateral pressure of the concrete should normally be determined in accordance with Fig. C8.2.1. The maximum pressure $P_{\max}$ in the figure can be obtained as

$$P_{\max} = K_A \rho g h_0 \qquad \text{(C8.2.1)}$$

$$K_A = \sin\beta + \cos^2(\phi-\beta)/(\cos\beta + \sin\phi)^2 \quad (\beta \ge 0)$$

$$K_A = \cos^2(\phi-\beta)/(\cos\beta + \sin\phi)^2 \quad (\beta < 0)$$

$$h_0 = 2.30 - 0.048T + 0.0365\beta \quad \text{(m)}$$

Where β : Slope of the form (degree)

ϕ : Angle of internal friction of concrete (≈10 degree)

ρ : Unit mass of concrete (t/m^3)

T : Concrete temperature at the time of placement (°C)

h_0 : Height of concrete at the time of placement(m)

g : Gravitational acceleration (m/s^2)

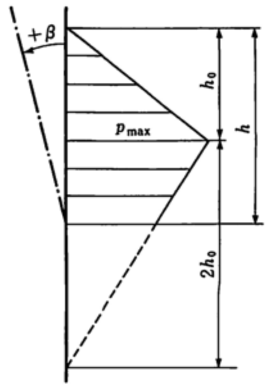


Fig. C8.2.1 Lateral pressure of concrete

(2) Materials used for the formworks and falseworks should have the required strength and stiffness. Because the same forms are used repeatedly in the construction of dam, steel forms are normally used while timber ones are used in the position where the formwork should be adjusted on site such as to the place of the rock surface. The materials for the formworks should be specified by JIS or JAS or should have the equivalent quality or more.

Cantilever-types of formwork are normally used for dam construction. The design and construction of the structure supporting the falseworks such as C-bolts need cares for fear of large distortion of the shape or gap in the position of the form.

8.2.3 Installation and removal of formworks

(1) The formworks should be installed exactly and tightly in the designated positions.

(2) The surface of the weir to face to the concrete should be finished flat, and be cleaned up and coated with the release agent before using.

(3) The holes of the bolts in the concrete used for installing the formworks should be treated by an appropriate method.

(4) The formworks should not be removed unless the concrete has attained the strength sufficient for the dead weight and the loads applied during the construction.

[Commentary] (1) The formworks should be installed exactly and tightly in the designated positions for fear of the leakage of the mortar or the loose of the joints between the formworks during the placement of the concrete.

(2) The surface of the formworks should be finished smooth to make the surface of the concrete flat. Also, the surface of the weirs should be cleaned up before using again because the adhesion of

mortar to the weir once used is inevitable. The cleaning up, transportation and assembling of the forms should be done so carefully that the surface of the weirs may not be scratched because the scratches can promote the adhesion of the concrete.

The weir should be coated with the release agent prior to the placement in order to prevent the adhesion of the concrete to the weir and to make the removing of the forms easy. The release agent used should not have harmful affect or stain on the concrete.

(3) The holes of the bolts in the concrete for installing the formworks should be filled with mortar with the equivalent quality to that of the placed concrete.

(4) The strength of concrete depends on the type of cement, mixture proportions, temperature of the concrete and the outside temperature. The timing of the removal of the formworks after placing the concrete should be determined by taking those factors into consideration. The formworks should not be removed unless the sufficient strength of the concrete has been attained for preventing the defects such as harmful cracks. The standard compressive strength at which the formworks can be removed should be over 3.5 N/mm^2 of the concrete in the upstream and downstream faces of the dam body and more than 10 N/mm^2 of the concrete around the openings like galleries. If the temperature of the concrete is much higher than the outside temperature at the removal of the formworks, the surface of the concrete should be covered to prevent the quick cooling of the concrete resulting in the crack.

The transverse formworks may be removed before the strength concrete reaches the specified one according to the constructing schedule in the dam project by the extended layer or RCD construction method on conditions that the thickness of one lift is small, that the concrete is not subject to large load and that cares for preventing such harmful effects as crack in the hardened concrete is taken.

8.3 Transportation

(1) The equipments for transportation of dam concrete should have the required capacity of transporting and should minimize the segregation of the materials at the charge, transport and discharge of the dam concrete.

(2) The mixed dam concrete should be transported to the area of the placement promptly.

[Commentary] (1) Here, the equipments for transportation of dam concrete mean the equipments for transporting the mixed dam concrete at the batching plant to the designated area of the placement. Buckets are normally used for the transportation in the placing of concrete with longitudinal construction joints while dump trucks and belt conveyors are normally used as well as buckets in the RCD or extended layer construction method. Concrete pumps, on the other hand, are sometimes used for placing of concrete into the place of the rock surface or the training walls.

The equipments for the transportation of the dam concrete should have not only the required capacity of transporting but also be adaptable to switching the mixture proportions of the concrete and cause the segregation of the materials hardly. It is important that the number of the transshipment of the dam concrete should be minimized because it may cause the segregation of the materials.

(2) The workability of the dam concrete may be lower long after the mixing, which is

represented by the lower slump value of the conventional concrete or by the larger VC value of the RCD concrete. The mixed dam concrete, therefore, should be promptly transported to the position of the placement. The required quality of dam concrete should be ensured at the position of the placement. If the variation in the quality of the dam concrete during the transportation is expected, it is recommended that the quality should be adjusted by taking the expected variation into accounted. The slump loss especially of conventional concrete produced at a ready-mixed concrete plant may be larger due to the long-distance transportation than that produced on the construction site. In such cases, it is necessary to set up the higher slump value and air content of the mixed concrete by taking the expected reductions into accounted.

In the cases where the dam concrete is to be transported by dump trucks directly from outside the dam body in the RCD construction method or so, it is possible that dirt or other foreign bodies sticking to the tires of the dump trucks may be brought onto the dam body. Cleaning tools for the dump trucks, therefore, should be installed at the entrance to the dam body to clean up the dirty tires.

8.4 Preparation for Placement

(1) Loose rocks, detritus and other foreign bodies on the surface of the bedrock should be removed and the spring water zone should be treated properly before the dam concrete is placed.

(2) The horizontal construction joints should be cleaned up and treated before the new dam concrete is placed over the hardened concrete.

(3) The surface of the bedrock or the face of the horizontal construction joint onto which the dam concrete is to be placed should get wet firstly and then mortar should be bedded on it.

(4) The mixture proportions of the bedding mortar should be determined so that the joint between the bedrock and the dam concrete may not be the structural defect. The standard thickness of the layer of the bedding mortar should be 20 mm onto the place of the rock surface and 15 mm onto the face of the horizontal construction joint respectively.

[Commentary] (1)The joint between the dam body and the supporting bedrock should have the bond performance necessary to carry and transfer the load from the dam and the performance of waterproof necessary to control the seepage flow from the reservoir. The finishing of the surface of the bedrock such as removing loose rocks, detritus and other foreign bodies should be done carefully before the dam concrete is placed onto the bedrock so that the bond performance between the dam concrete and the bedrock may be ensured.

The spring water from the bedrock may deteriorate not only the bond performance between the dam concrete and the bedrock, but also the quality of the dam concrete due to the washout of the mortar from the concrete. Therefore, appropriate treatment for the spring water such as waterproof by caulking or removal of the spring water by pitching of pipes should be done before the dam concrete is placed into the spring water zone.

(2) The horizontal construction joint of concrete may easily be the defect against ensuring the structural safety and the waterproofing of the concrete dam. The main cause for the weak horizontal construction joint is laitance due to the bleeding from the concrete. The laitance deposited on the

face of the horizontal construction joint, therefore, should be removed with such a method as pressurized water or electrical brushes before the hardening of the dam concrete is completed. This kind of treatment is called “green cut cleanup.”

The timing of starting the green cut cleanup should be determined by taking such factors as the mixture proportion of the dam concrete, the outside temperature and the equipment for the cleanup into consideration. Earlier starting of the green cut cleanup may result in loosening the coarse aggregate particles from the concrete or excessive removal of the concrete. Later starting, on the contrary, may result in too much time required for the green cut cleanup or inadequate cleanup. It is therefore desirable that the timing of starting the green cut cleanup should be determined experimentally or by other means.

Even after the green cut cleanup is completed, the face of the horizontal construction joint may also be subject to the dirt due to the installation of the formworks, the assembling of the reinforcing bars, the installation of the buried structures in the dam body, the traveling of the construction equipments, the deposition of free lime during the curing of concrete or so. The face of the horizontal construction joint onto which the dam concrete is to be placed, therefore, should be cleaned up again by such a method as pressurized water or electrical brushes.

After a long suspension during the winter season or for other reasons, dirt or foreign bodies on the face of the horizontal construction joint needs sure removing before resuming the placing of the dam concrete. It is also desirable that the horizontal cut-off plate along the direction to the axis of the dam crestline should be installed on the upstream facing side for closing the construction joint that has wintered and that the horizontal cut-off plate should be connected with the cut-off plate closing the transverse joint specified in 8.9.2 “Horizontal Construction Joint” to ensure the water-tightness of the dam. Except in such special cases as removing the concrete subject to frost damage, chipping of the face of the construction joint should not be done for fear of loosening particles of the aggregate from the surface of the concrete.

(3) Mortar should be bedded onto the surface of the bedrock and the face of the horizontal construction joint before placing the dam concrete so that sufficient bond strength and water-tightness of the joint between the dam concrete and the bedrock and those of the construction joint may be ensured. The mortar should be bedded especially onto the surface of the bedrock so carefully as if to coat it. The surface onto which the mortar is to be bedded should get wet beforehand because the dry surface may result in unsure bond strength due to the loss of the water in the mortar. Also, the puddles on the surface onto which the mortar is to be bedded should be removed beforehand because the higher water/cementitious material ratio due to the puddles left on the surface may deteriorate the quality of the mortar.

(4) The mixture proportions of the bedding mortar should be determined so that the joint between the bedrock and the dam concrete or the horizontal construction joint may not be the structural defect. The water/cementitious material ratio of the bedding mortar, therefore, needs to be not more than that of the dam concrete to be placed.

The standard thickness of the layer of the bedding mortar should be 20 mm onto the surface of the bedrock and 15 mm onto the face of the horizontal construction joint respectively so that the bedding may be ensured. The area onto which the mortar is to be bedded at a time should be determined so that the placing of the dam concrete following the bedding of the mortar may be completed in around 30 minutes because the drying or set of the mortar may start long after the bedding.

8.5 Placement

8.5.1 General

(1) The transportation, placement and compaction of the dam concrete into the designated block of placement should be carried out continuously and promptly. The procedure for the placing of the dam concrete in the designated block should be determined so that the exposed surface area of the placed dam concrete will be minimized.

(2) Dam concrete should not be placed if it is raining and it may have a harmful influence on the quality of the dam concrete. If the placement of the dam concrete in progress is suspended unavoidably, the close side of the dam concrete should be disposed according to the treatment for the horizontal construction joint.

[Commentary] (1) Concrete used as the material for dam body should be homogeneous and contimuous. If the placement of dam concrete in progress is suspended, the close side may be the structural defect. The transportation and placing of the dam concrete, therefore, into the designated block of placement should be carried out continuously and promptly. The procedure for the placement of the dam concrete in the designated block of the placement should also be determined so that the exposed surface area of the placed dam concrete may be minimized because it is possible that the drying of the surface of the dam concrete left long should result in the lower workability which is represented by the lower slump value of concrete or by the higher VC value of RCD concrete. In addition, the placed dam concrete should be compacted as soon as possible. If the placed dam concrete is to be left unavoidably long, appropriate care should be taken in the concrete so that the compaction of the concrete may not be difficult.

It is desirable that the direction of the placement of dam concrete should be parallel to the axis of the dam crestline so that the defects due to the segregation or the close sides due to the rain fall or so may not be linked together along the direction of the stream resulting in the leakage route formed. In the upper part of the dam body, on the other hand, it is normally recommended that the direction of the placement should be parallel to the direction of the stream because it is possible that the placing performance with the direction of parallel to the axis of the dam crestline may be reduced and that the quality of the dam concrete be damaged due to the small depth of the dam body. That is why it is recommended that the direction of the placement of dam concrete should be the direction of the stream in such expected cases.

(2) If dam concrete is placed under the wet weather, the alien rainwater to the concrete may increase the water/cementitious material ratio or may cause the leakage of the mortar or so resulting in the harmful influences on the quality of the concrete. Placement of the dam concrete, therefore, should not be done under the heavy rain fall. In many cases, the placement of conventional or RCD concrete gets suspended under the hourly rain fall of more than 4 mm and 2 mm respectively.

Placement and compaction of the dam concrete in the designated block do not have to be suspended in the rain on condition that the placed dam concrete before the compaction is covered with the sheet so that the rain water may not be mixed with the concrete resulting in the spill of the mortar from the concrete. The placing should be suspended, on the other hand, under the heavy rain. The placement of the dam concrete before the limit for joint may be resumed with no treatment for the close position of the dam concrete. On the other hand, insufficient compacted close position of the concrete should be removed and be treated by the same manner as for the horizontal construction joint before the resume of the placing of the dam concrete beyond the limit for construction joint.

8.5.2 Placement of conventional concrete

(1) The discharging of dam concrete to the position of the placement should be done so that the segregation of the materials may not occur.

(2) The thickness of one layer of placing of conventional concrete at a time should be determined by taking the length and the performance of the internal vibrators used into accounted.

[Commentary] (1) Conventional concrete is used in the dam body except as the internal concrete in the RCD construction method. In the dam concrete, even the conventional concrete, segregation may occur easily than in the normal concrete because the unit cement content in RCD concrete is smaller. It is difficult to homogenize the concrete after segregation of the materials has once occurred. That is why the discharging of the dam concrete to the position of the placement should be done so carefully that the segregation of the materials may not occur.

It is desirable that the dam concrete should be discharged from the equipment for the transportation at the height of 1 meter or less above the surface of the placement. The dam concrete to be placed to the position around the forms should be discharged into the position slightly apart from the formwork and then the discharged dam concrete should be transported exactly to the position of the forms by a wheel loader or other equipments so that it may not hit the formwork directly because the direct hit by the discharged concrete may damage the formwork. Cares should be taken in the balance of the height of the placed concrete to fill the space around the internal structures so that it may not be subject to the extreme inclined pressure of the concrete.

(2) The thickness of one layer of the conventional concrete to be placed at a time should be determined by taking the length and performance of the internal vibrator used into accounted. If one lift of the dam concrete is divided into the plural number of layers for the compaction, the thickness of one layer should be determined so that the tip of the internal vibrator used may reach around 100 mm below the top of the lower layer to ensure the unity between the upper and lower layers of the concrete.

8.5.3 Placement of RCD concrete

(1) Cares should be taken in the discharging of the dam concrete into the area of the placement so that the segregation of the materials will be minimized.

(2) The RCD concrete discharged into the area of the placement should be spread with being mixed by bulldozer to homogenize the concrete. The thickness of one layer of spreading the concrete should be determined by taking the easiness of the mixing and the effect of rolling compaction of the dam concrete by the bulldozer into consideration.

[Commentary] (1) Cares should be taken in the discharge of RCD concrete into the position of placement so that the segregation of the materials may be minimized because RCD concrete has extremely stiff consistency. For example, the pile of the discharged dam concrete from the dump truck should not be high but low and long.

RCD concrete is normally placed after the conventional concrete is placed in the RCD construction method in order to prevent the segregation around the border zone between the conventional and RCD concrete as the upstream or downstream facing or the form for end side when the RCD concrete is discharged. It is also effective in maintaining the designated horizontal thickness of the conventional concrete.

(2) The segregation of RCD concrete discharged from dump trucks can be solved by the conscientious spreading by the bulldozer. That is why the RCD concrete should be spread into the thin layers by the bulldozer. The number of the layers is normally 3 for one lift with the thickness of 0.75 meter and 4 for 1 meter respectively and then the spread RCD concrete is compacted by the vibrating rollers. The thickness of one layer is normally around 27 cm so that the thickness of the compacted RCD concrete by the vibrating rollers may be around 25 cm. The edge of the lane is prone to the segregation. The segregated components should be swept together and be mixed up with the concrete for the next lane so that the uniform concrete can be obtained. Rolling compaction of the RCD concrete can also be expected as a result of the spreading of the thin layer by the bulldozer and more densely compacted dam concrete can be obtained after the compaction by the vibrating rollers. That is why the bulldozer should move and spread the RCD concrete evenly.

8.6 Compaction

8.6.1 Compaction of conventional concrete

(1) Internal vibrator having sufficient capacity of compaction should be used for the internal concrete.

(2) The conventional concrete should be compacted sufficiently so that segregation does not occur. Especially the border zone between the different mixture proportions should be compacted carefully for the structural unity.

[Commentary] (1) The maximum size of the coarse aggregate of the dam concrete is larger and the consistency is stiffer compared with the normal concrete. That is why the internal vibrator for the dam concrete should have the sufficient capacity of compaction. The back hoe having 3 to 4 internal virbrators on load is used for the compaction of the dam concrete. The hand internal vibrator is employed only for the compaction of the zone of the corner or that having reinforcing bars where the sure compaction cannot be carried out by the loaded internal vibratos.

(2) The internal vibrator, for the compaction, should be inserted vertically into the conventional concrete as the dam concrete and the concrete up to the deep zone should be compacted sufficiently. The tip of the internal vibrator should be inserted into the depth of around 10 cm of the lower layer so that the sufficient unity between the upper and lower layers of the concrete may be ensured. In addition, the dam concrete should not be put transversely for fear of the segregation.

Whether the conventional concrete has got compacted sufficiently can be confirmed by observing no more settlement of the dam concrete, no more large arising air bubble on the surface, the glossy surface with arising water and so on. The compaction of the dam concrete should not be finished until such a phenomenon can be observed. The internal vibrator should be pulled out of the dam concrete so that the hole as the trace of the vibrator may not be left.

Because the mixture proportion is different between the external and internal concrete or between the structural (e.g. around the galleries) and internal concrete, the placing or compacting of those two types of concrete cannot normally be carried out at the same time. That is why the internal vibrator should be inserted into the border zone for the unity of the two types of the concrete.

8.6.2 Compaction of RCD concrete

(1) Vibrating roller with sufficient capacity of compaction should be used for the compaction.

(2) The work sequence from the mixing to compaction should be carried out within a minimum time period. The compaction should be completed normally within 3 hours in summer or 4 hours in winter after the mixing.

(3) RCD concrete should be compacted so that the sufficient compaction density can be obtained. It should be compacted carefully especially in the border zone between the neighboring lanes or different mixture proportions for the unity.

[Commentary] (1) Vibrating roller with sufficient capacity of compaction should be used in the compaction of RCD concrete with extremely stiff consistency. The type of the vibrating roller employed should be fixed by referring to the previous construction records. If a new type of machine is to be employed or the thickness of one lift is to be increased, the capacity of compaction should be verified through the trial constructions in advance.

(2) Because RCD concrete has extremely stiff consistency, no immediate compaction after the mixing may make the sufficient compaction difficult. That is why the compaction of the dam concrete should be completed as immediately as possible after the mixing. Although it depends on the type of the materials, mixture proportion, temperature or humidity, the allowable time by which the compaction of the dam concrete was completed after the mixing has been mostly around 3 hours in summer or 4 hours in winter according to the previous records. That is why the standard allowable time was set up as described above.

(3) The number of times of the compaction by the vibrating roller should be set up according to the previous records or the result of the trial construction so that the sufficient compaction density may be obtained. Whether the RCD concrete has got compacted sufficiently can be verified by recognizing almost no more settlement of the surface of the concrete, slight appearance of the cement paste on the surface or other phenomena. The compaction of RCD concrete should be continued until such phenomena can be realized. Also, the degree of the compaction can be checked by the density of the compacted concrete measured by RI method. According to the past records, one back-and-forth motion without vibration and 5 to 6 back-and-forth motions with vibration are mostly carried out for the compaction of RCD concrete with the thickness of one lift of 0.75 meter by the vibrating roller of the 10 ton-class. As the finishing, one more back-and-forth motion without vibration is commonly carried out after the vibrating compaction of RCD concrete is completed so that the hair cracks or uncompacted aggregate particles with small diameter on the surface of the compacted RCD concrete may be solved.

Sufficient compaction cannot be expected along the track of the edge of the wheel of the vibrating roller. That is why the overlap of the neighboring compaction should be around 20 cm in width. Also, the border zone between conventional and RCD concrete with each mixture proportion, e.g. the border between external and internal concrete or between structural and internal concrete around the gallery, is difficult to be compacted sufficiently because each different compaction method is applied. Consequently, RCD concrete is easily prone to segregation. That is why the border zone of concrete between different mixture proportions should be united by the sufficient compaction in which the internal vibrator is inserted into the conventional concrete. The concrete around the form for end side or the close side in case of rain should also be compacted sufficiently with the same method as specified above.

8.7 Surface Finishing

(1) The upstream face with the storage reservoir should be finished so that the required water-tightness can be obtained.

(2) The surface of the dam concrete exposed to the open air should be finished so that the required durability can be obtained.

(3) The surfaces of the concrete in the overflow section, training channels and energy dissipator of a dam should be finished smooth without unevenness so that they will resist the abrasion due to the running water.

[Commentary] (1) It is not usual that the special cut-off structure is designed for the concrete dam because the dam concrete with sufficient compaction has high water-tightness. However, the concrete in the upstream surface with the storage reservoir should have the low water/cementitious material ratio and be compacted sufficiently so that the required water-tightness may be obtained. That is because the upstream surface with the storage reservoir is important for obtaining the water storage function of the dam similar to the cut-off plate along the transverse joint.

(2) The surface of the dam concrete exposed to the open air requires high durability. That is why it should have the low water/cementitious material ratio and be compacted sufficiently in order to maintain the required durability. On the other hand, the finishing should be moderate because excess compaction of the concrete around the edge of the form or excess finishing trowelling of the surface of the concrete may result in the poor durability due to the gathering mortar with the high water content.

(3) The surface of the concrete in the overflow section, training channel and energy dissipator of the dam should be finished smooth without unevenness. That is because those parts may be subject to damage due to the abrasion or the cavitation caused by the running water and sands. The standard allowable local gap on the surface of the concrete touching with the form should be less than 6 mm on the plane parallel to the stream, 3 mm on the plane normal to the stream, and 6 mm on the overall plane respectively with measured by the ruler of 1.5 meter in length. On the other hand, the standard allowable local gap on the surface without touching the form should be less than 6 mm with measured by the ruler of 3 meters in length. The local gap on the part exposed to the high velocity flow should be treated more carefully. The small projection on the surface should be grinded so that the gap may be less than the allowable value.

8.8 Curing

8.8.1 General

(1) The surfaces of the dam concrete after placing should be kept wet by spraying or ponding.

(2) If the surface of the concrete after placing is expected to be subjected to low temperature or sudden change in temperature, insulated curing should be carried out.

(3) The method and schedule of curing of dam concrete should be decided by taking the environmental conditions, e.g. outside temperature or humidity, the lift schedule, and so on into consideration.

[Commentary] (1) Sufficient hydration of the cement cannot be developed if the surface of the dam concrete is dried and the water is lost during or after the placing. In addition, sudden drying of the surface of the dam concrete due to the direct rays of the sun or the wind may result in the cracking of the concrete. That is why the dam concrete should be cured under the proper temperature and humidity for a certain period after the placing so that the quality such as the strength, durability and water-tightness may be obtained. The curing of the concrete after the placing should normally be followed by the important notices specified by these Specifications: Construction.

The important notices for the curing of hot weather concreting should be referred to Section 8.10, Hot Weather Concreting.

(2) Insulated curing of the dam concrete after the placing should be carried out with heat insulating sheet or mat under the low temperature because there is the possibility of the freezing of the surface. In addition, the opening such as gallery, elevator shaft and temporary diversion conduit is easily subject to sudden change in the temperature and drying due to the outside air and it may result in cracking. That is why the opening should be covered with sheet or door.

(3) The method and duration of the curing of the dam concrete should be decided by taking the environmental conditions such as outside temperature and humidity, the lift schedule and so on into consideration. The horizontal construction joint should be cured sufficiently until the concrete of the next lift is placed. The concrete is normally cured by ponding in the concrete placement method with longitudinal contraction joint. On the other hand, spraying with sprinkler is normally employed for the curing in extended layer construction or RCD method because the ponding is mostly impossible due to the operation of the construction machines and so on. The curing of the upstream and downstream facing on which the ponding is impossible is normally cured by flowing water from the top for sufficient period.

8.8.2 Protection against harmful impacts

The dam concrete should be protected against harmful impacts such as excess vibration, shocks and loads during curing.

[Commentary] The dam concrete that has not hardened sufficiently yet is prone to damage like cracking due to excess vibration, shocks and loads and so on. That is why the materials should not be put on or heavy objects should not fall to it for the protection.

In addition, the surface of the dam concrete at the young age should be protected with steel plate or rubber sheet in case the dump truck is moving around on it in extended layer construction or RCD method.

8.8.3 Surface protection during long term suspension of placement

The surface of the dam concrete should be protected by such an appropriate method that the freezing and harmful thermal cracking should be prevented in case of long term suspension of the placement.

[Commentary] Long term suspension of the placement of the dam concrete may cause a large difference in the temperature between the surface and the inside of the concrete resulting in the thermal cracking due to the internal restraining. The dam concrete also may freeze in winter in the cold district. That is why the long-term close side of the dam concrete should be protected with insulating mat, ponding water, spreading sand and so on so that the freezing or harmful cracking may be prevented.

8.9 Joint

8.9.1 General

The joints in the dam body should be designed and provided so that the unity or water-tightness will not be damaged.

[Commentary] Joint is necessary for mass concrete such as dam concrete for preventing the thermal cracking. However, the joint is prone to be the weakness for the unity or water-tightness like the cracks even if it is intentional one. That is why the treatment for the joint is necessary such as joint grouting or installation of cut-off plate.

The sticking mortar or dirt to the concrete should be surely removed along the joint on which the grouting is to be carried out. That is because the sticking object or dirt may be the obstacle for the grouting and its effect in the unity.

8.9.2 Transverse joint

(1) The transverse joint should be provided with the cut-off plate so that the leakage can be prevented.

(2) Joint grouting should be carried out along the transverse joint for the unity of the dam body in the concrete arch dam.

[Commentary] (1) Because the transverse joint is prone to be the leakage route from the storage reservoir, the original cut-off plate and a duplicate (or duplicate cut-off plates) should be installed along the transverse joint around the upstream side. Cut-off plate should be installed also along the transverse joint around the downstream side of the overflow section. Cupper, stainless steel or vinyl chloride has been used as the materials for the cut-off plates, and vinyl chloride has become the dominant recently. The treatment for the horizontal construction joint should be carried out much carefully and the placement and compaction of the concrete should be done surely so that the effect of the cut-off plate may be ensured.

In addition, the transverse joint should be provided with the joint drainage hole for watching the performance of waterproof by the cut-off plate and for the drainage of the water leaking in the transverse joint. The joint drainage hole should be installed on the down-stream side of the cut-off plate and its bottom end should lead to the side ditch inside the gallery.

(2) Three-dimensional design should be employed for the concrete arch dam in principle. That is why the joint grouting should be carried out along the transverse joint for the unity of the dam body. Shear key should also be installed on the transverse joint so that the transfer of the shearing force may be ensured along the transverse joint. The shear key should have the horizontal key by taking the direction of the shear transfer into consideration.

8.9.3 Longitudinal joint

The joint grouting should be carried out so that the unity of the dam body is ensured.

[Commentary] Because the longitudinal joint of the concrete dam may damage the structural unity of the dam body, the joint grouting should be carried out for the unity of the dam body. The shear key should also be installed on the longitudinal joint so that the transfer of the shearing force along the longitudinal joint may be ensured. The shear key should have the vertical key by taking the direction of the shear transfer into consideration.

The longitudinal joint should normally lead to the downstream facing or end inside the dam body. The edge of the longitudinal joint ending inside the dam body should normally be reinforced with both splitted pipes and steel bars or be connected with the gallery to eliminate the joint so that the upward crack may not propagate from the edge of the joint.

8.10 Hot Weather Concreting

8.10.1 General

(1) The placing of the dam concrete should be carried out appropriately as the hot weather concreting if there is the possibility of the daily mean temperature of more than 25 °C.

(2) The temperature of placement of the concrete should be decided appropriately so that the atmosphere of high temperature will not damage the dam concrete.

[Commentary] (1) The reduction in the workability or air content of the dam concrete may usually be faster at the high temperature of placement. The setting or hardening rate may also be higher and the compaction may be difficult shortly after the mixing. In addition, plastic shrinkage crack may be prone to occur on the surface of the dam concrete due to the sudden drying. While the strength development at the young age may be promoted, the long-term strength development may be reduced. That is why the treatment of the materials, mixing, placement and casting should be carried out appropriately for the hot weather concreting.

(2) Although the temperature of the placement of the dam concrete should normally be less than 25 °C, the change in its property may not be so rapid as the temperature of more than 25 °C. It is necessary to grasp the relationship between the temperature of the placement and the rate in the property of the dam concrete at each site and to take measures according to the conditions of the site.

The lower one of the concrete temperature as the hot weather concreting and the temperature of the placement obtained Chapter 4, Plan for Temperature Restriction should be the temperature of the placement.

8.10.2 Treatment of materials

The materials for the hot weather concreting should be treated so that the required workability can be obtained.

[Commentary] In case that there is the possibility of the reduction in the workability of the dam concrete resulting in the damage to the quality, the temperature of the mixed concrete should be restricted so that the quality may not be damaged.

Lower temperature of the aggregate is effective in lowering the temperature of the mixed concrete because the heat capacity and the unit content of the aggregate in the dam concrete are large. The measures for it should be, for example, roof over the aggregate bin or stockpile, heat insulating cover, shield net from the sun or sprinkle water for the aggregate bin, or sprinkle water or blowing cool wind over the coarse aggregate. The measures for lowering the temperature of the mixing water should be, for example, the usage of the water from the mountain stream or cold water from the cooling plant. The temperature of the cement should also be restricted because cement with high temperature just after the production may be delivered.

The use of retarding type of water reducing agent, AE water reducing agent or high range water reducing and air entraining agent is effective in controlling the sudden reduction of the workability of the dam concrete and the sudden increase in the setting or hardening rate. The type and dosage of the chemical admixture especially for RCD concrete should be decided so that the workability suitable for the compaction may be maintained for required period because it may take a long time to complete the compaction of the border zone of the lanes after unloading of the concrete. It also should be noted that the dosage of the retarding type of admixture should be decided through sufficient examination because its excess dosage may result in large delay of the setting.

8.10.3 Mixing and placement

(1) The temperature of the mixed concrete should be decided by taking the weather conditions and time until the compaction into consideration so that it will not cause a bad influence on the compaction work of the dam concrete.

(2) The bedrock, form or other bodies that can absorb the water from the dam concrete should be kept wet when it is placed. Also, in case there is the possibility of high temperature of the form or other bodies, appropriate measures should be taken such as spraying or installing cover.

[Commentary] (1) The temperature of the mixed concrete should be decided by taking the weather conditions and time until the compaction into consideration so that the compaction work may not receive a bad influence because the temperature of the mixed dam concrete is prone to rise before the compaction at high temperature such as during the day in summer. The mixed dam concrete should be transported and placed without delay. In case the distance between the batcher plant and the dam site is long and it may cause high rise in the temperature of the concrete, a countermeasure such as the insulation should also be taken during the transportation.

(2) The temperature of the bedrock, metal form and other bodies become high due to the direct sunshine in the hot season. The touch of the placed dam concrete with the bodies with the high temperature may have bad influences on the quality of the dam concrete such as the quick set. The moisture of the concrete may be lost quickly during placing by the dry bedrock, placed concrete or form and the workability may be reduced resulting in making the compaction difficult. That is why the position of placement should be kept wet by covering with the sheet and so on or spraying or fogging until just before the placing. Cares should be taken in the spraying or fogging so that the puddles may not remain on the position of placement.

8.10.4 Curing

Curing of the dam concrete should be started without delay after the completion of dam concrete placement so that the surface of the placed concrete is protected against the drying and the temperature rise.

[Commentary] If the surface of the dam concrete after the compaction is exposed to the direct sunshine or wind in the hot season, the moisture is prone to be lost quickly resulting in the plastic shrinkage cracking. That is why the fogging or spraying should be started without delay after the placing of the dam concrete and the surface should be protected against the drying and temperature rise by covering with curing mat, spraying or ponding after the concrete is hardened to the extent that the human footprint cannot be left.

8.11 Cold Weather Concreting

8.11.1 General

In cases that the daily mean temperature is low and the freezing of the dam concrete is expected, the appropriate countermeasures for the cold weather concreting should be taken.

[Commentary] The countermeasures for the cold weather concreting should be taken under the weather conditions of the daily mean temperature of less than 4 °C because the surface of the dam concrete may be frozen even in the day time as well as the night or early morning. The dam concrete should not normally be placed in case of the daily mean temperature of less than 0 °C because it is probable that the dam concrete should be frozen. The technologies for controlling the atmosphere of the placement of the concrete have been improved recently. For example, the dam concrete has been placed throughout the year despite of the low outside temperature by maintaining the temperature of more than 0 °C with the cover over the block of the placement. Such a new technology should be applied to the real construction after consideration of the size, the term and the cost of the construction of the dam.

The temperature of placement of the concrete should be raised in the cold weather concreting and the temperature of the placed concrete should be kept the appropriate one.

8.11.2 Treatment of materials

(1) Frozen aggregate or the aggregate with ice and snow should not be used for the mixing of the concrete as it is.

(2) The cement should not be heated in any cases but the water may be heated for raising the temperature of the concrete.

[Commentary] (1) If the frozen aggregate is used for the mixing as it is, the temperature of the mixed dam concrete may be low and the dam concrete itself may be frozen. If the aggregate with ice and snow is used for the mixing as it is, it may result not only in the lower temperature of the mixed dam concrete but in difficulty in maintaining the unit water content constant. That is why the frozen aggregate or the aggregate with ice and snow should not be used for the mixing as it is.

(2) The cement should not be heated in any cases because the cement with high temperature in contact with water may result in the quick set of the cement. On the other hand, heating water is effective in raising the temperature of the dam concrete because it is easy to heat water and its heat capacity is large. The temperature of the heated water should be controlled so that the quick set of the cement may not occur during the mixing. The water with the temperature of less than 40 °C for mixing may not normally cause the quick set of the cement.

8.11.3 Mixing and placement

(1) The order of charging heated materials into the mixer should be decided so that the quick set of the cement may not occur.

(2) Ice and snow stuck on the form, surface of placement or buried object should be removed by an appropriate method before the dam concrete is placed.

(3) The temperature of placement of the dam concrete should be the one by which the freezing of the concrete will not occur and normally be more than 5 °C .

(4) In case that it is possible that the surface of the placed dam concrete will be frozen, the concrete should not be placed or an appropriate countermeasure should be taken.

[Commentary] (1) Warm water and aggregate should be charged at first then cement be charged into the mixer normally for the cold weather concreting because the cement in contact with warm water may cause the quick set.

(2) Because ice and snow stuck on the form, surface of placement or buried object may have a bad influence such as lowering the temperature of the placed concrete or varying the water/cementitious material ratio, they should be removed before the dam concrete is placed. Covering the form with sheet is effective in preventing the sticking of ice and snow on it, or spraying the foaming agent on the outer surface of the form is effective in promoting heat-retention.

(3) The fall of the temperature may result in the freezing of the surface of the dam concrete if

the temperature of placement is low. That is why the temperature of placement of the dam concrete should be normally more than 5 °C. On the other hand, the optimum temperature of the mixed concrete should be set up because too high temperature of the dam concrete may result in cracking due to the thermal stress.

(4) In case there is the possibility of the freezing of the dam concrete, the dam concrete should not normally be placed. On the other hand, in case the placement is to be carried out unavoidably, the surface of the concrete should be covered with the insulating sheet just after the placing so that the freezing of the dam concrete may be prevented.

8.11.4 Curing

(1) The temperature of the dam concrete should be maintained during the curing, by which there is no possibility of the freezing of the dam concrete.

(2) The curing of the dam concrete should be continued until it reaches the strength by which there is no possibility of the frost damages at early age.

[Commentary] (1) The temperature of the concrete can be maintained by which there is no possibility of the freezing of the concrete by preventing the radiation from the surface of the concrete and utilizing the heat of hydration of the cement. That is why the surface of the dam concrete should be normally covered with the sheet having high insulation capacity and insulation curing be carried out by utilizing the heat of hydration of the cement for the cold weather concreting in the mass concrete like dam concrete. In case the surface area is small, the heater may be used for heating the dam concrete. In addition, the opening such as the gallery should not be exposed to the open air so that the cold air may not enter the gallery.

(2) It is not appropriate that the required resistance to the freezing and thawing of the dam concrete should be shown by the strength because the resistance depends on the air voids system such as the amount, size and distribution of the entrained air and the thermal and moisture conditions at freezing. However, it has been verified that AE concrete with proper amount entrained air can normally resists to the frost damage at early age in case the compressive strength is more than 5 N/mm^2. That is why the appropriate curing should be continued until the compressive strength of the dam concrete reaches 5 N/mm^2 by maintaining the temperature of the concrete of more than 5 °C. The temperature of the dam concrete should be kept more than 0 °C for two days even after the compressive strength reaches 5 N/mm^2 so that the rapid cooling of the dam concrete may be prevented.

CHAPTER 9 QUALITY CONTROL

9.1 General

(1) In order to meet the performance requirements for dam concrete, quality control should be performed for the quality of materials, mixture proportions, performance before hardening , strength of specimens, the quality of compaction at the construction site, etc.

(2) The method and frequency of tests for quality control should be determined in advance on the basis of such factors as the size of dam, the method and progress, and concrete manufacturing capacity.

(3) If quality control test results indicate the possibility of failure to attain the required quality of dam concrete, the cause of such failure should be estimated, and details such as materials, mixture proportions, mixing methods, placing methods or compaction methods should be changed accordingly.

[Commentary] (1) If the quality of dam concrete varies considerably, safety and water-tightness of the dam concrete may be damaged. If the specification requirements are to be met without correcting such variations, the safety factor may be larger and the dam concrete be designed uneconomically. In order to produce the dam concrete with the required quality economically, it is necessary to make quality control at a certain frequency and reflect the results in the construction process.

It is extremely difficult, however, to directly determine if the dam concrete placed in the dam body meets the quality requirements. It is therefore common practice to define quality control items that make it possible to estimate the quality of the dam concrete placed into the dam body with sufficient accuracy and to indirectly perform the quality control by the use of those items. Such quality control items include the quality of materials, mixture proportions, performance before hardening, strength of standard specimens, and state of compaction of the dam concrete at the construction site.

Usually, the dam concrete is produced at a concrete manufacturing facility set up for that purpose. In some recent projects for relatively small dams, the dam concrete produced at ready-mixed concrete plants was used. Although this specification assumes that concrete is produced at a manufacturing facility set up for that purpose, ready-mixed concrete plants may be regarded as batcher plants, and quality control should be performed in accordance with *Part 2, Standard Methods*.

(2) In quality control, test methods to be used should be determined in advance to minimize the variability of test results due to the test methods. Frequency of test cannot be standardized; it should be determined in advance in view of such factors as the size of dam, the contstruction method and progress speed, the concrete manufacturing capacity and the state of construction work. In many cases, aggregates with a particle size of 40 mm or more are used for dam concrete. Quality control tests are usually conducted on concrete specimens without wet-screened aggregates over 40 mm.

(3) If the quality control test results indicate the possibility of failure to attain the required quality of dam concrete, it is necessary to estimate the cause of such failure and change details such as materials, mixture proportions, mixing methods or compaction methods so as to attain the

required quality. It is desirable that the frequency of quality control tests should be determined appropriately in view of the variability of quality and the state of construction work so that higher quality can be achieved.

9.2 Quality Control of Materials

(1) The quality of cement and admixtures should be controlled on the basis of mill sheets obtained by tests at a plant or, if necessary, the results of extra tests conducted at the construction site.

(2) The quality of aggregates should be controlled in terms of such control items as density, absorption, fineness modulus and other necessary items.

[Commentary] (1) In order to produce the dam concrete with the required quality, the cement and admixtures need to meet the quality requirements specified at the mixture design stage.

It is common practice to control the quality of cement and admixtures on the basis of mill sheets obtained by tests at a plant. The quality of cement and admixtures that have been in storage for a long period of time, however, may have deteriorated. When such cement or admixtures are used, therefore, extra tests should be conducted at the construction site, and whether they can be used should be judged according to the results of those tests.

Table C9.2.1 shows the standard items and methods for the quality control of cement and admixtures. Necessary control items and frequency of quality control need to be determined in advance in view of such factors as the size of dam and construction methods.

Table C9.2.1 Standards for quality control of cement and admixtures

Material	Type	Item	Method	Control standard
Cement	Cement types specified in JIS	Items specified in JIS for the cement types	Verification based on mill sheets obtained by tests at a plant or the method of JIS R 5201:1997 (2002 recognized)	Conformity with JIS for the cement types
	Cement types not specified in JIS	Items specified to achieve the purpose of use	Verification based on mill sheets obtained by tests at a plant or a method conforming to JIS R 5201:1997 (2002 recognized)	Conformity with a standard specified to achieve the purpose or use
Mineral admixture	Fly ash	Quality items in JIS A 6201:1999 (2004 recognized)	Verification based on mill sheets obtained by tests at a plant or the method of JIS A 6201:1999 (2004 recognized)	Conformity with JIS A 6201:1999 (2004 recognized)
	Ground granulated blast furnace slag	Quality items in JIS A 6206 (2002 recognized)	Verification based on mill sheets obtained by tests at a plant or the method of JIS A 6206:1997 (2002 recognized)	Conformity with JIS A 6206:1997 (2002 recognized)
	Admixtures other than those mentioned above	Necessary items	Verification based on mill sheets obtained by tests at a plant or a necessary test method	Conformity with a standard specified to achieve the purpose of use
Chemical admixture	Air-entraining agents, water-reducing agents, air-entraining water-reducing agents, air-entraining high-range water-reducing agents	Quality items in JIS A 6204:2006	Verification based on mill sheets obtained by tests at a plant or the method of JIS A 6204:2006	Conformity with JIS A 6204:2006
	Chemical admixtures other than those mentioned above	Necessary items	Verification based on mill sheets obtained by tests at a plant or a necessary test method	Conformity with a standard specified to achieve the purpose of use

(2) The density and absorption of aggregates can be used as indicators of the physical properties of aggregates. The density of aggregates is also necessary for the determination of field mixture proportions. Changes in the fineness modulus of aggregates, particularly the fineness modulus of fine aggregates, greatly affect the consistency of dam concrete. The fineness modulus of fine aggregates, therefore, should be controlled so that its changes can be minimized.

Table C9.2.2 shows the standard items and methods for the quality control of fine aggregates and coarse aggregates. Necessary control items and frequency of quality control need to be determined in advance in view of such factors as the size of dam and construction methods.

Table C9.2.2 Quality control standards of fine aggregates and coarse aggregates

Material	Type	Item	Method	Control standard
Aggregate	Fine aggregate	density in saturated surface-dry condition	Method of JIS A 1109:2006	Conformity with the provisions of Section 5.4.1
		Absorption	Method of JIS A 1109:2006	Conformity with the provisions of Section 5.4.1
		Grading	Method of JIS A 1102:2006	Conformity with the provisions of Section 5.4.2
		Clay lumps	Method conforming to JIS A 1137:2005	Conformity with the provisions of Section 5.4.4
		Aggregate particles passing a 75 µm sieve	Method of JIS A 1103:2003	Conformity with the provisions of Section 5.4.4
		Chloride (chloride ion content)	Method of JSCE-C 502-2007 or JSCE-C 503-2007	Conformity with the provisions of Section 5.4.4
		Organic impurities	Method of JIS A 1105:2001	Conformity with the provisions of Section 5.4.4
		Chemical and physical soundness (alkali–silica reactivity)	Method of JIS A 1145:2001 or JIS A 1146:2001	Conformity with the provisions of Section 5.4.3
		Frost resistance	Method of JIS A 1122:2005	Conformity with the provisions of Section 5.4.3
	Coarse aggregate	density in saturated surface-dry condition	Method of JIS A 1110:2006	Conformity with the provisions of Section 5.5.1
		Absorption	Method of JIS A 1110:2006	Conformity with the provisions of Section 5.5.1
		Grading	Method of JIS A 1102:2006	Conformity with the provisions of Section 5.5.4
		Clay lumps	Method conforming to JIS A 1137:2005	Conformity with the provisions of Section 5.5.5
		percentage of soft particles	Method of JIS A 1126:2001	Conformity with the provisions of Section 5.5.5
		Abrasion loss	Method of JIS A 1121:2001	Conformity with the provisions of Section 5.5.3
		Aggregate particles passing a 75 µm sieve	Method of JIS A 1103:2003	Conformity with the provisions of Section 5.5.5
		Chemical and physical soundness (alkali–silica reactivity)	Method of JIS A 1145:2001 or JIS A 1146:2001	Conformity with the provisions of Section 5.5.2
		Frost resistance	Method of JIS A 1122:2005	Conformity with the provisions of Section 5.5.2

9.3 Quality Control of Dam Concrete

9.3.1 Control of mixture proportions

Mixture proportions for dam concrete should be controlled on the basis of material weighing records.

[Commentary] The quality of dam concrete includes the quality of fresh concrete and the quality of hardened concrete. Although the quality of fresh concrete can be checked prior to the placement of dam concrete, the quality of hardened concrete cannot be directly checked prior to the placement of dam concrete. The quality of hardened concrete, therefore, should be controlled indirectly by checking the quality and mixture proportions of the materials used with reference to past project data.

The mixture proportions of dam concrete should be controlled by checking the weighing records of the materials put into the mixers. Materials are batched according to field mixture proportions determined by modifying the specified mixture proportions. This requires correction for changes in the density of aggregates, correction for too large particles and too small particles in different classes of aggregate and correction for the surface moisture content of aggregate and so on. Because the accuracy of the correction for the surface moisture content of fine aggregate greatly affects the accuracy of mixture proportions, it is necessary to control the surface moisture content of aggregate so that the results can be reflected in the batching of materials. In the case of RCD concrete, changes in water content greatly affect workability. It is therefore common practice to install a measuring equipment for surface moisture of fine aggregate at the batcher plant and measure the surface moisture content of aggregate at each batch .

9.3.2 Quality control of fresh concrete

(1) The quality of fresh concrete should be controlled by checking consistency, unit mass, air content and other necessary control items.

(2) The placing temperature of concrete should be controlled so that the value specified according to the temperature control plan is met.

[Commentary] (1) Dam concrete should have workability suitable for works such as transportation, placement and compaction. One indicator of the workability of fresh concrete is consistency. Consistency is measured in terms of slump in the case of conventional concrete and the VC value in the case of RCD concrete. The slump of conventional concrete should be measured in accordance with JIS A 1101, "Method of test for slump of concrete," and the VC value of RCD concrete must be measured in accordance with JSCE F 507, "Method of test for consistency of RCD concrete."

Quality control tests of fresh concrete are necessary for checking not only the placing performance of dam concrete but also the quality of hardened concrete. Quality control items for this testing include unit mass and air content. The unit mass is used to check if the mixture proportions of concrete are the same as the required mixture proportions. The air content is used to evaluate the freezing–thawing resistance of concrete. The unit mass is measured in accordance with JIS A 1116, "Method of test for unit mass and air content of fresh concrete by mass method" or an equivalent method. The air content is measured in accordance with JIS A 1128, "Method of test for air content of fresh concrete by pressure method," JIS A 1116, "Method of test for unit mass and air content of fresh concrete by mass method," or JIS A 1118, "Method of test for air content of fresh concrete by volumetric method." When comparing the quality of fresh concrete containing wet-screened aggregates used for these tests with the quality of fresh concrete containing full-size aggregates, it is necessary to take the effect of wet screening into consideration.

The frequency of quality control of fresh concrete varies with the progress speed of the dam and the amount of placement of the concrete at a time, but the quality control tests are usually conducted every two hours.

(2) The placing temperature of concrete should be controlled so that the values specified in the plan for temperature restriction, and hot weather concrete and cold weather concrete can be met. Methods for lowering the placing temperature include placing concrete at night, using cold water, and cooling aggregates with cold water or cool wind. It is a standard requirement to measure the placing temperature of concrete in a quality control test of fresh concrete. A commonly used method for raising the placing temperature is to use heated water. If the placing temperature is controlled, concrete temperature changes during transportation because of the difference from ambient temperature. If transportation time is long as when a ready-mixed concrete plant is used, it is

necessary to identify the amount of change in temperature during transportation.

9.3.3　Quality control of hardened concrete

The quality of hardened concrete should be controlled by checking compressive strength and other necessary items. It is a standard requirement to check compressive strength at an age of 91 days.

[Commentary] Concrete strength includes compressive strength, tensile strength and shear strength. These strengths are strongly correlated. Usually, therefore, the quality of hardened concrete is controlled through test for compressive strength. Compressive strength is measured in accordance with JIS A 1108, "Method of test for compressive strength of concrete."

Basically, tests for compressive strength are conducted at an age of 91 days when the specified strength is determined. In order to evaluate the quality of concrete at an early age, however, it is desirable that strength should be controlled by using measured values at ages of 7 days and 28 days in addition to 91 days. In this case, it is necessary to determine the relationship between the compressive strengths at an age of 91 days and at an earlier age in advance.

Compressive strength used for concrete quality identifications should be the average of compressive strengths of three or more specimens in the same batch. The concrete quality identifications based on compressive strength are often made in accordance with JIS Z 9003, "Single Sampling Inspection Plans Having Desired Operation Characteristics by Variables (Standard Deviation Known)" and JIS Z 9004, "Single Sampling Inspection Plans Having Desired Operation Characteristics by Variables (Standard Deviation Unknown)."

9.3.4　Control of compaction of RCD concrete

The compaction of RCD concrete should be controlled so that the required compaction density can be attained.

[Commentary] The compressive strength of RCD concrete is dependent on not only the water/cementitious material ratio but also compaction density because RCD concrete has extremely stiff consistency. In the case of a gravity concrete dam, the unit mass of dam concrete used as a dam body material greatly affects its stability. The compaction of RCD concrete, therefore, should be controlled so that the required compaction density can be attained.

Methods of controlling the state of compaction of RCD concrete include a method based on the number of rolling compaction of vibratory rollers, a method by Radio Isotope density test, and a method based on the measuring of settlement during compaction. In the method based on the number of rolling compaction of vibratory rollers, the relationship between the number of rolling compaction and the compaction density of RCD concrete is determined experimentally or otherwise in advance, and the state of compaction is controlled by checking the number of rolling compaction. In the Radio Isotope density test, the state of compaction is controlled by measuring the compaction density of the concrete by the use of the radiation source rod of the Radio Isotope density gauge inserted into compacted RCD concrete. In the method based on the measuring of settlement during compaction, the elevation of the lift surface is measured by leveling before and after compaction. The relationship between settlement and the compaction density of RCD concrete is determined experimentally or otherwise in advance, and the state of compaction is controlled by checking the amount of settlement. Of these methods, the control method based on the number of rolling compaction is widely used.

Decisions as to the compaction control of RCD concrete should be made appropriately, in view of such factors as the size of dam and the progress speed on the basis of past project data or trial construction results.

CHAPTER 10 INSPECTION

10.1 General

(1) A rational and economical inspection plan should be prepared, and inspections that are necessary at each stage of construction should be conducted so as to determine if dam concrete meets the performance requirements.

(2) Inspection items and inspection methods should be determined, in view of the maintenance management plan, so that inspection results can be used as the initial inspection records during service life.

[Commentary] (1) The term "inspection" refers to the act by the Owner of checking if the quality of dam concrete produced and placed by the Contractor meets a predetermined criterion for judgment. Inspection can be broadly classified into two types, namely, inspection conducted at an intermediate stage of construction and inspection conducted upon completion of construction. In this chapter, the inspection of dam concrete includes inspection conducted by the Owner's supervisor during construction.

Fig. C10.1.1 shows the relationship between the inspection and quality control conducted by the Owner and the Contractor each.

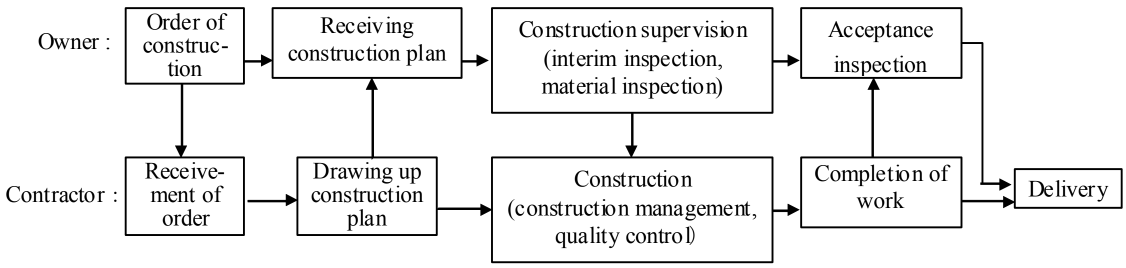


Fig. C10.1.1 Flow of inspection in a construction project

(2) In an ordinary concrete dam construction project, as part of construction supervision over quality control and construction management, the Owner's supervisor or other personnel inspect the state of construction work or materials at the construction stage. Usually, the inspection items for these inspections and inspection methods are the same as those described in Chapter 9, Quality Control. The frequency of inspection should be determined appropriately taking into consideration such factors as the size of dam, construction methods and the progress speed.

Important inspection items include defects such as cracks, the dimensions of working form and appearance with the addition of the items related to materials, properties and construction. Because inspection results are used as initial data at the maintenance stage, it is necessary to determine inspection items and inspection methods, giving careful consideration to the maintenance management plan. Inspection results concerning materials, properties and construction-related items constitute important data necessary for maintenance. Recording methods, therefore, need to be determined carefully so that the inspection results can be stored as part of a database.

10.2 Inspection Method

Inspection should be conducted by a method that makes it possible to verify that the placed dam concrete meets the performance requirements.

[Commentary] Inspection should include not only the observation and examination of materials, the performance of fresh concrete, the state of compaction and the performance of hardened concrete and the inspection on the basis of construction records but also the inspection of the appearance and working form of the placed dam concrete. Reliable waterproof is an important function for dam and yet cut-off plates and construction joints cannot be directly inspected in many cases because of invisibility of them. In such cases, inspection is made by, for example, conducting inspections at appropriate points in time during construction or checking quality control records such as photographs. It may also be necessary to conduct special nondestructive tests or core sampling. When conducting an inspection, it is necessary to select a reliable and objective inspection method, taking maintenance management plans and operation plans into consideration.

Whether the dam concrete meets the functional requirements for a concrete dam is finally verified through trial ponding.

10.3 Judgment

Performance indicators (inspection items) and their tolerances for the performance of dam concrete should be specified for the inspection, and the inspected items should be deemed to have passed the inspection if their measured values are within tolerance.

[Commentary] Inspection items are usually specified on the basis of the performance requirements for dam concrete. In the case of dam concrete, allowable limit of characteristic values for materials and properties and construction-related permissible value for judgment during construction are determined prior to construction, and these values can be used as criterion values for inspection. The inspected items are deemed to have passed the inspection if their measured values meet those criterion values.

10.4 Treatments

(1) If an inspected result has been rejected, appropriate treatments should be taken.

(2) The causes of reject, the parts of the dam for which treatments have been taken, and the methods of treatment should be recorded.

[Commentary] (1) If an inspected result has been rejected, the effect of the measured values on the performance of the dam should be evaluated quantitatively, and appropriate treatments should be taken. In the event of reject, it is necessary to estimate the effect of the part of defect on the functionality of the dam during its service life. This requires identifying the cause of reject and the extent of the problem, evaluating the effect of the measured values on the functionality of the dam, and finally considering whether it can be tolerated. If it is considered intolerable, treatments and corrections need to be taken in the form of monitoring, repair or reconstruction.

(2) Treatments that are taken when measured values do not fall within the allowable range

permitted by the specifications for inspection provide important maintenance-related information. The information, therefore, on the parts of defect of the dam, causes, basis of judgment and the methods of treatment should be recorded.

CHAPTER 11 MAINTENANCE

11.1 General

For the maintenance of dam concrete, an appropriate maintenance management plan should be prepared, taking into consideration the characteristics of each dam and the environmental conditions at the dam site. Dam concrete should be maintained in accordance with the plan so that the structural performance requirements for the concrete dam can be met.

[Commentary] This chapter deals only with the maintenance of dam concrete used for the dam body. The maintenance, therefore, of concrete dams as structures and appurtenance facilities should be performed separately in accordance with appropriate criteria. The maintenance of reinforced concrete used as structural concrete or for other applications should be performed in accordance with these Specifications, Maintenance.

As mentioned in these Specifications, Maintenance, the maintenance of a structure is the act of maintaining the performance of the structure during its service life within an allowable range, and it consists of three tasks: "check," which involves inspection, the estimation of deterioration mechanisms, prediction of deterioration , evaluation of structural performance, and judgment as to the necessity of actions; "remedial measures," which is taken on according to checks as the need arises; and "recording" of checks and actions taken. In order to perform these tasks appropriately in connection with dam concrete, an appropriate maintenance management plan based on a solid understanding of the characteristics of the dam concerned and the environmental conditions at the dam site should be drawn up.

Part 2, Maintenance by Deterioration Mechanism, of these Specifications, Maintenance deals with eight deterioration mechanisms, namely, carbonation, chloride induced deterioration, frost damage, chemical attack, alkali–silica reaction, fatigue of slab, fatigue of beam member and abrasion. Deterioration mechanisms peculiar to dam concrete are frost damage, which is expected because a dam is constructed in a mountainous, relatively cold region, and abrasion caused by water and sediment moving along the overflow surfaces of dams. In the case of an ordinary concrete structure, cracking of shrinkage due to temperature are classed as initial defects. Since, however, dam concrete is considerably massive, cracking may result from long-term temperature changes. Thermal shrinkage, therefore, can be classified as a deterioration mechanism peculiar to dam concrete. In cases where other deterioration mechanisms are involved, these Specifications, Maintenance should be followed.

11.2 Check of Dam Concrete

In cases where there is a possibility of degradation in the performance of dam concrete caused by frost damage, abrasion or cracking of shrinkage due to long-term temperature, it is necessary to conduct inspection, estimate the deterioration mechanism, predict deterioration, evaluate performance and judge the necessity of corrective actions appropriately in accordance with the maintenance management plan.

[Commentary] The state of dam concrete should be evaluated appropriately in order to identify the present state of dam concrete deterioration resulting from frost damage, abrasion or cracking of shrinkage due to temperature, estimate the deterioration mechanism, and judge the necessity of corrective actions. Evaluation methods and the time of evaluation should be determined in accordance with these Specifications, Maintenance or in view of the structure of the dam body and the environmental conditions at the dam site.

Because the deterioration of dam concrete usually occurs progressively from the surface, the possibility of a rapid decline in structural safety should be low. Visual observation, therefore, is the primary means of determining the present state of deterioration.

11.3 Remedial Measures

If it has been judged that remedial measures are necessary, appropriate remedial measures should be taken so that the performance requirements can be met in view of the state of deterioration of dam concrete.

[Commentary] If it has been judged that remedial measures need to be taken, repair or reinforcement measures must be taken appropriately so that the performance requirements for dam concrete can be met.

11.4 Recording

Records of maintenance should be kept during the service life of dam concrete.

[Commentary] The state of deterioration of dam concrete and the repair and reinforcement measures taken in connection with such deterioration should be recorded, and the records should be kept.