STANADARD SPECIFICATION FOR CONCRETE STRUCTURES –2001 "MAINTENANCE"

JSCE Working Group on Standard Specification for Concrete Structures –2001 "Maintenance"

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PREFACE

As the number of deteriorated concrete structures increases in Japan, the demand for the maintenance works for concrete structures are gradually increasing. However, no standard method and guideline for the maintenance work is yet established in JSCE. Based on this background, "JSCE Committee on Concrete" organized a subcommittee on maintenance of concrete structures in October 1995, which was chaired by Prof. Seki of Waseda University, and published "Recommendations for Maintenance of Concrete Structures (draft)". Hereafter it is referred to as "Recommendations". However, after the publication of "Recommendations", the necessity of maintenance has further increased. In addition, new findings have been accumulated with the progress in concrete technology. In 1999, a working group (WG) on "Standard Specification for Maintenance of Concrete Structures" was newly organized, which was chaired by Prof. Toyoaki Miyagawa of Kyoto University, aiming to establish the first JSCE Standard Specification on Concrete Structures' Maintenance. Based on "Recommendations" proposed by the former subcommittee, and through one years' activity, this newly organized WG proposed the "Standard Specification for Concrete Structures –2001 "Maintenance"", as the first JSCE specification on concrete structures' maintenance. It is composed of two parts, "Part1: Maintenance Fundamental" and "Part 2: Standard Maintenance Method". With the completion of this specification, a series of Standard Specification becomes to cover all areas of concrete structures' life cycle, from "Design", "Construction", to "Maintenance".

This Concrete Library presents the English version of "Standard Specification for Concrete Structures –2001 "Maintenance"". At first, the outline incorporating "the basic idea of maintenance" and "the background of formulation of this specification" is summarized. Then, main contents of this specification are introduced. I hope that many research engineers and field engineers will take into account this specification, not only in Japan but also all over the world, and apply this specification to all maintenance fields of concrete technology.

Here, I wish to express our deep gratitude to the Committee on ISO Affairs in Civil Engineering, the Japan Society of Civil Engineers, for the grants in translation and publication. Without the support, this English version could not be completed. Finally, I wish to express my gratitude to all WG members for their sincere efforts to the committee activities.

Toyoaki MIYAGAWA
Chairman of the Working Group on Standard Specification for Concrete Structures –2001 "Maintenance"
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OUTLINE

1. Basic Idea of Maintenance

A concrete structure is strongly expected to retain the required levels of its functions for the required period of service life. In engineering discussions, "a function" is difficult to be dealt with quantitatively, it can be translated into that "the performances of the structure shall be retained above the required levels with adequate reliability during the structure's designed service life". This means that an adequate maintenance work is inevitable for every concrete structure. In order to perform the rational maintenance, it is necessary to seize the time-dependent changes of performances of the structure during their service life. However, such changes, in most cases, cannot be strictly analyzed at the current engineering levels. Therefore, they are mostly verified by considering a limit state of the structure in consideration of the durability under the expected deterioration mechanism, by using the deterioration model.

The level of maintenance is closely related to the levels of the design and the construction execution. This means, for example, that when no maintenance is carried out, design and construction execution shall be carried out to provide sufficient margins of performances to the structure. On the other hand, when frequent maintenance is carried out, the margins of performances can be set to be rather small. Therefore, it can be said that performances of a concrete structure can be clearly specified only with a service life scenario incorporating their maintenance strategy.

2. Background of Formulation

In consideration of the importance of maintenance, "JSCE Concrete Committee" organized a subcommittee on maintenance of concrete structures, to publish "Recommendations for Maintenance of Concrete Structures (draft)," which is a groundbreaking code of maintenance for concrete structures, in October 1995, hereafter referred to as "Recommendations". However, after the publication of "Recommendations", the necessity of maintenance has been increasing. And also, new findings have been accumulated based on the progress in concrete technology. Incorporating these sets of technological knowledge with additional investigations' results, "Standard Specification for Concrete Structures –2001 "Maintenance"" is completed. With the completion of this specification, a series of Standard Specification becomes to cover the all areas of concrete structures' life cycle, from "Design", "Construction", to "Maintenance".

3. Outline of "Standard Specification for Concrete Structures –2001 "Maintenance""

This specification was formulated based on "Recommendations", and was systematized as a series of "The Standard Specifications" with "Design" and "Construction". This "Maintenance" is also formulated with no confliction with international standards, such as ISO. The basic policies of the formulation are as follows;
(1) The maintenance consists of "**initial inspection**", "**deterioration prediction**", "**inspection**", "**assessment**", "**judgement**", "**remedial measures**", and "**record**".
(2) To clarify the role of maintenance in the flow from planning to the end of service life of concrete structures. Maintenance shall be taken into consideration in the total stage of planning of the structure, because the level of maintenance affects the design and construction execution.
(3) The description is "performance based style", in accordance with the international trend of codes. **Figure 1** shows hierarchical structure of this specification. The fundamental theory is the performance assessment and judgement, both at the time of inspection and the end of the expected service life.
(4) This specification consists of the two parts: "Maintenance Fundamental" describing the basic concept

and the flow of maintenance, and "Standard Maintenance Method" describing the specific procedures adopted for different deterioration mechanisms.
(5) Categories of maintenance are defined, with considering engineers' activities.

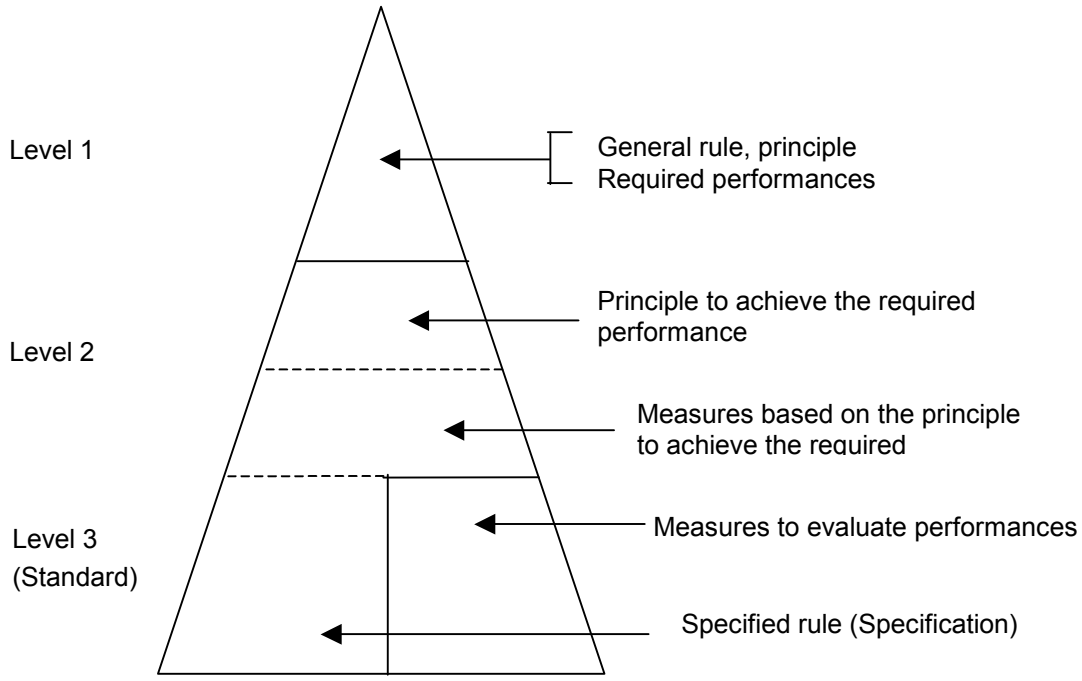

Figure 1 Hierarchical Structure of Performance Specifications

4. Outline of "Part 1: Maintenance Fundamental"

In this specification, "**initial defect**", "**damage**", and "**deterioration**" are clearly distinguished. An initial defect is defined as placing-induced defect, such as cracking, honeycombs, cold joints, sand streaking, etc. A damage is defined as defects occurred in a short period and not developing over subsequent time, such as cracking and scaling due to earthquakes, impact loading, etc. Deterioration is defined as defects that develop over long time. This specification deals with "deterioration," which causes performance degradation in parts/members of structures.

Figure 2 shows a general maintenance flow. As a first step, it is necessary to collect information on the structure by initial inspection. For a newly constructed structure, "**the maintenance category**" is confirmed in the design procedure and "initial inspection" shall be carried out at the start of their service life. On the other hand, for existing structures, the first inspection is defined as "initial inspection" to collect information on the structure. Based on the information obtained in the initial inspection, at first the maintenance category shall be determined, and subsequent maintenance shall be carried out by reasonably combining "deterioration prediction", "inspection", "assessment/judgement", "remedial measures", and "record".

Maintenance includes totally the following steps, "**initial inspection**" "**deterioration prediction**", "**inspection** (**routine inspection**, **regular inspection**, **detailed inspection**, and **extraordinary inspection**)", "**performance assessment/judgement**", "**investigation**" and "**remedial measures**", and

"**record"**. Off course, the combination of these steps differs to the different maintenance category, considering the importance of the structure, hazards to the third parties, and environmental conditions. In the case that the identifying the deterioration mechanism is impossible, remedial measures shall be determined by so-called the engineering judgement.

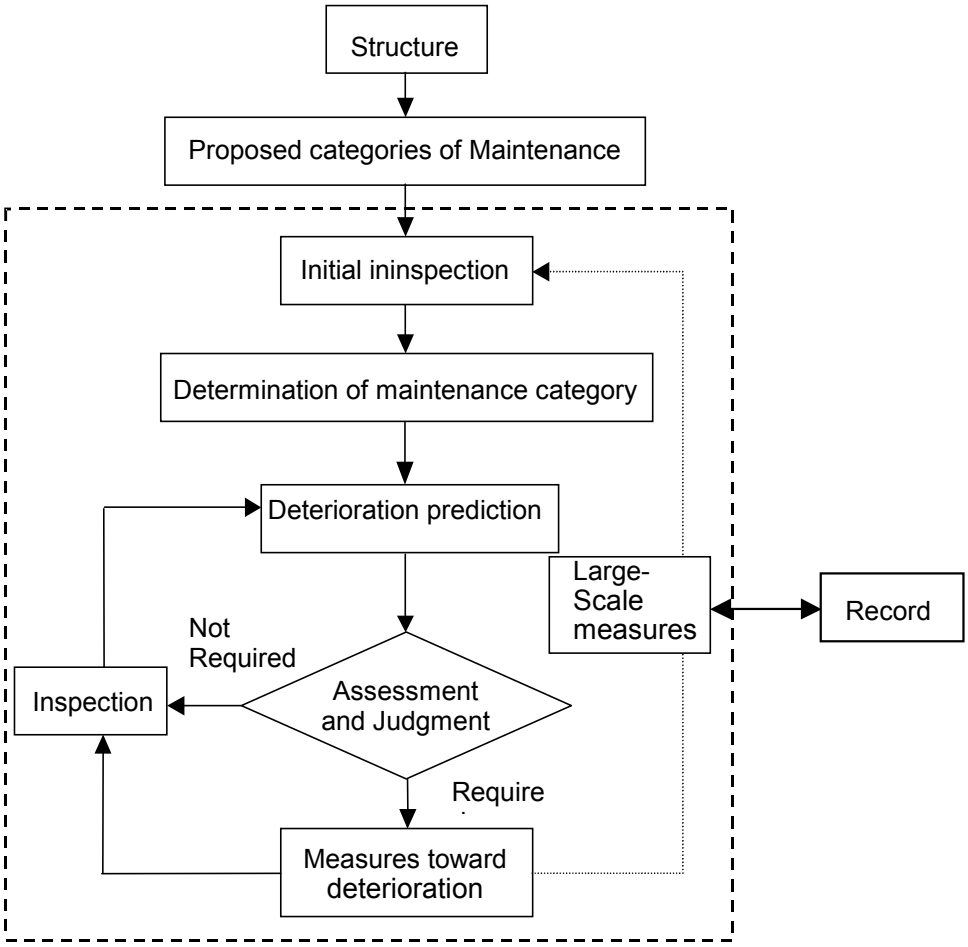

Figure 2 General Maintenance Procedure

5. Outline of "Part2: Standard Maintenance Method"

5.1 Constitution

"Part2: Standard Maintenance Method" describes the standard methods of "deterioration prediction", "inspection", "assessment", "judgement", "remedial measures", and "record", when the deterioration mechanism has become clear or highly probable. "Part 1: Maintenance Fundamental" and "Part 2: Standard Maintenance Method" shall be closely related in the maintenance procedure. "Part2: The Standard Maintenance Method" deals with seven types of deterioration mechanisms, carbonation-induced deterioration (Chapter 13), chloride induced deterioration (Chapter 14)," frost attack (Chapter 15), chemical attack (Chapter 16), alkali aggregate reaction (Chapter 17), fatigue of RC slab (Chapter 18), and fatigue of RC beam (Chapter 19)."

5.2 Scope

The scopes of the seven Standard Maintenance Methods are summarized as follows:

"Chapter 13: Standard Maintenance Method for Carbonation Induced Deterioration" covers the performance losses of structures due to reductions in pH values of pore solutions in concrete induced by CO_2 penetration into concrete from the atmosphere and the resulting reinforcement corrosion.

"Chapter 14: Standard Maintenance Method for Chloride Induced Deterioration" covers reinforcement corrosion induced by chloride ions supplied externally from the environment, such as seawater and de-icing salts, or internally from concrete production. It also covers the performance losses of structures due to the progress of reinforcement corrosion.

"Chapter 15: Standard Maintenance Method for Frost Attack" covers the performance losses of structures due to concrete deterioration by freezing expansion of moisture in concrete and the resulting in the reinforcement corrosion.

"Chapter 16: Standard Maintenance Method for Chemical Attack" covers the performance losses of structures due to deterioration of concrete and reinforcement corrosion induced by acids (sulfates), especially found in sewage-related facilities, chemical plants, in hot spring area, and in special kinds of soils.

"Chapter 17: Standard Maintenance Method for Alkali Aggregate Reaction" covers the performance losses of structures due to the concrete expansion, concrete cracking and reinforcement corrosion. This chapter deals with alkali-silica reaction (ASR) mainly occurred in Japan.

"Chapter 18: Standard Maintenance Method for Fatigue of RC Slab of Road Bridge" primarily covers reinforced concrete slabs of road bridges, and their performance losses due to concrete cracking caused by widely varied wheel loads.

"Chapter 19: Standard Maintenance Method for Fatigue of RC Beam of Railway Bridge" primarily covers reinforced concrete beams of railway bridges, and their performance losses due to the steel reinforcement cracking caused by repeated loading.

STANDARD SPECIFICATION FOR CONCRETE STRUCTURES –2001 "MAINTENANCE"

Part 1: Maintenance Fundamental

Chapter 1. General

1.1 Scope

(1) This Standard Specification for Concrete Structures -2001 "Maintenance" covers maintenance of concrete structures.
(2) **Part 1: "Maintenance Fundamental"** provides the principles of maintenance of concrete structures.
(3) **Part 2: "Standard Maintenance Methods"** provides standard methods of maintenance of concrete structures for each deterioration mechanism.

1.2 Definitions

Terms as used in this Specification are defined as follows:
Maintenance: All of the technical actions taken to maintain the performance of a structure above the required level throughout its service period.
Preventive maintenance (category A): Maintenance of a structure proactively carried out to prevent its performance degradation; also referred to as preventive preservation.
Corrective maintenance (category B): Maintenance of a structure reactively carried out according to the degree of performance degradation; also referred to as corrective preservation.
Observational maintenance (category C): Maintenance of a structure primarily dependent on visual inspection without such direct action as repair and strengthening.
Indirect-inspection maintenance (category D): Maintenance of a structure by indirect inspection, e.g., of the ground under structures nearby without direct inspection of the structure.
Service period: A period during which a structure is in service.
Planned service period: A period during which a structure is intended to be in service.
Service life: A period after which a structure and/or its members are no longer achieves the required functions due to performance degradation and become unusable.
Design service life: A period specified in the design of a structure during which the structure and its members are required to fully achieve the intended functions.
Remaining design service life: A period from the time of a given inspection of a structure to the end of its design service life.
Functions of a structure or its member: Roles played by a structure or its member according to the purpose or requirements.
Performance of a structure or its member: Capabilities exhibited by a structure or its member according to the purpose or requirements.
Durability: Resisting ability of a structure to gradual degradation of its performance and functions over time.
Performance over time: Performance of a structure to retain the required performance throughout its service period.
Safety performance: Performance of a structure to eliminate life hazards due to its fracture.
Serviceability performance: Performance of a structure in regard to its serviceability and functionality.
Hazards to third parties: Hazards of damage and/or injury caused by concrete fragments falling from a deteriorated structure.

Inspection: A generic term for actions taken to grasp the current state of a structure.
Repair: Maintenance measures to restore or improve the durability of a structure and reduce hazards to third parties.
Strengthening: Measures to restore or improve the mechanical performance of a structure, such as load-bearing capacity and rigidity.
Serviceability restoration: Measures to restore the serviceability of a structure.
Functionality improvement: Measures to improve the functionality of a structure.
Appearance improvement: Measures to improve or enhance the aesthetic appearance of a structure as well as the landscape surrounding of the structure.

Chapter 2. Required Performance for Concrete Structures

2.1 Principle

In the maintenance, performances required for the structure shall be clearly defined.

2.2 General

(1) Performances required for general structures include "**safety performance**", "**serviceability performance**", "**performance related to hazards to third parties**", "**aesthetic appearance and landscape**", and "**performance over time**".
(2) Load-bearing performance, which generally includes seismic performance, is be referred to as safety performance.
(3) Performance related to serviceability or functionality is referred to as serviceability performance.
(4) Performance over time related to each of the four performances, i.e., safety performance, serviceability performance, performance related to hazards to third parties, and aesthetic appearance/landscape, is referred to as performance over time.

Chapter 3. Principle of Maintenance Procedure

3.1 Principles

(1) Structures shall be maintained according to a designated maintenance category by formulating a maintenance program to retain the performance within the specified tolerances throughout their service life. And maintenance system includes adequate "**initial inspection**", "**deterioration prediction**", "**inspection**", "**assessment/judgement**", "**remedial measures**", and "**record**".
(2) In the maintenance of structure, in addition to the assessment and judgement at inspection, assessment and judgement shall be made based on the deterioration prediction throughout the service life.
(3) In the assessment and judgement, required performance for the structure or its related segments/members shall be defined, and the design service life shall be made clear.
(4) Adequate deterioration prediction, and assessment/judgement shall be carried out in consideration of the maintenance category and the state of deterioration.
(5) The results of design, construction methods, initial inspection, deterioration prediction, inspection, assessment/judgement, and remedial measures shall be recorded.

3.2 Maintenance procedure

Structures shall be maintained by reasonably combining some of initial inspection, deterioration prediction, inspection, assessment/judgement, remedial measures and record.

[Commentary]
Figure C3.2.1 shows a standard procedure of maintenance on a structure.

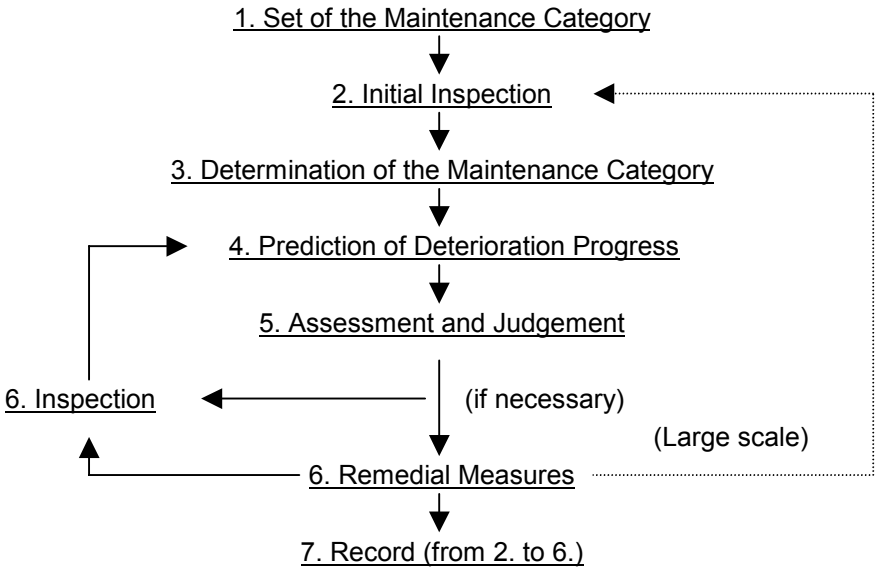

Figure C3.2.1 Standard procedure of maintenance on a structure

3.3 Maintenance categories and descriptions

Structures shall be adequately maintained according to the maintenance category designated in consideration of the importance of the structure/members, hazards to third parties, life span, and environmental conditions.

[Commentary]
In this Specification, four categories of maintenance were selected as levels of maintenance work.

A: Preventive maintenance (maintenance based on preventive preservation)
B: Corrective maintenance (maintenance based on corrective preservation)
C: Observational maintenance (maintenance primarily by visual observation)
D: Indirect-inspection maintenance (maintenance without inspection)

3.4 Inspection

(1) Inspection shall be carried out by suitable methods to discover deterioration, damage, or initial defects and to maintain the performance of the structure above the required level. In the case of any initial defect or damage, immediate measures shall be taken.
(2) Inspection shall be carried out at a suitable frequency depending on the maintenance category of the structure.

(3) Inspection includes "**initial inspection**", "**routine inspection**", "**regular inspection**", "**detailed inspection**" and "**extraordinary inspection**". The suitable inspection shall be carried out based on the importance of the structure and the results of deterioration prediction.

[Commentary]
The details of each inspection are described in **Chapters 5, 6, 7, 8** and **9**.

3.5 Classification and identification of deterioration mechanisms

(1) According to the defects emerged on the structure, deterioration mechanism shall be made clear.
(2) Deterioration factors shall be adequately pointed out and classified into "extrinsic factors" including environmental and usage conditions and "intrinsic factors" including design and construction conditions.
(3) The deterioration mechanism shall be adequately identified on the deterioration phenomena and deterioration factors.
(4) As for complex deterioration with multiple deterioration mechanisms, the mechanisms of the deterioration shall be adequately identified.

[Commentary]
Major deterioration mechanisms are roughly classified into those induced by environmental actions, such as carbonation induced deterioration, chloride induced deterioration, frost attack, chemical attack, and alkali aggregate reaction, and those induced by loading conditions, such as fatigue. The details of the identification of deterioration mechanisms are described in **Chapter 4**.

3.6 Deterioration prediction

(1) In order to carry out an adequate maintenance of a structure, deterioration prediction shall be carried out for segments/members of the structure.
(2) The relationship between the performance and the degree of deterioration of each segment/member shall be recognized to elucidate how deterioration affects each performance, especially performance degradation.
(3) Deterioration prediction shall be made by using an adequate model, fabricated by identification and classification of the deterioration mechanisms and deterioration factors.
(4) The accuracy of deterioration prediction should be determined based on the accuracy of the deterioration model, and the importance of the structure.

3.7 Assessment and judgement

(1) The performance of a structure should be assessed, considering the progress of deterioration, relevant deterioration mechanism, based on the results of inspection. The assessment should be made for both the time of inspection and the end of planned service period.
(2) The judgement on the performance degradation of a structure should include the determination on whether remedial measures are necessary or not. Judgement for emergency measures should be made if necessary.
(3) Assessments and judgements should be based on initial inspection and inspections.
(4) Assessment and judgement should be primarily based on visual observation and detailed investigations or surveys.

[Commentary]
The test and survey methods are described in **Chapter 10**.

3.8 Remedial measures

When the structure is judged that remedy is necessary, adequate remedial measures shall be taken in consideration of the maintenance category, the remaining life span, and the execution difficulty of measures.

[Commentary]
Remedial measures include "**intensified inspection**", "**repair**", "**strengthening**", "**appearance improvement**", "**utility restoration**", "**functionality improvement**", "**usage restriction**", and "**demolishing/removal**". The details of remedial measures are described in **Chapter 11**.

3.9 Records

Records shall be taken and restored by an adequate method.

[Commentary]
The details of record are described in **Chapter 12**.

Chapter 4. Identification of Deterioration Mechanism

4.1 Principles

(1) Deterioration mechanism shall be identified through an adequate procedure.
(2) Deterioration mechanism expected for newly constructed structure should be identified by the design record, used materials, construction condition, and the environmental and usage conditions.
(3) Deterioration mechanism of an existing structure should be identified in consideration of the environmental and usage conditions, and the characteristics of the defects.
(4) In the case that deterioration mechanism cannot be identified from the environmental and usage conditions, or characteristics of the defects, it should be identified by using the deterioration indexes.

[Commentary]
The basic procedure of identifying the deterioration mechanism is expressed as follows;
(a) Checking the type, size, and location of the defects by careful observation.
(b) Checking the extrinsic factors, that is, the environmental and usage conditions of the structure.
(c) Checking the deterioration indexes for assessing the progress and degree of deterioration.

Table C4.1.1 Deterioration mechanism related to deterioration factors, indexes, and phenomenal characteristics of deterioration

Deterioration mechanism	Deterioration factor	Characteristics of defects	Deterioration index
Carbonation	Carbon dioxide	Cracking in the direction of bar axis Peeling of concrete	Carbonation depth, Corroded area or volume of steel bars

Chloride induced deterioration	Chloride ions	Cracking in the direction of bar axis Rust exudation	Chloride ion content, Corroded area or volume of steel bars
Frost attack	Freezing and thawing action	Fine cracks, Scaling, Pop-outs, Deformation	Depth of frost deterioration Corroded area or volume of steel bars
Chemical attack	Acid materials Sulfate ions	Discoloration, Peeling of concrete	Intrusion depth of deterioration factors, Carbonation depth, Corroded area or volume of steel bars
Alkali-aggregate reaction	Reactive aggregate	Expansive cracking in restraining directions Map cracking White colored gel Discoloration	Expansion (cracking)
Fatigue of RC slab	Traffic of large vehicles (over designed load)	Lattice (Raft) cracking, Corner disintegration, Free lime	Crack density Deflection
Fatigue of RC beam	Repeated loads	Cracking and rupture of tensile steel	Accumulated damage, Crack length of steel bars

4.2 Method of Identifying Deterioration Mechanism

(1) The identification of deterioration mechanism after initial inspection should be made based on extrinsic factors of deterioration and characteristics of the defects.
(2) After detailed investigation and survey, it shall be judged whether the detected defects are caused by deterioration or not. Next, the deterioration mechanism shall be found out by using the deterioration indexes.

[Commentary]
Table C4.2.1 gives the deterioration mechanism inferred from environmental and usage conditions.

Table C4.2.1 Deterioration mechanism inferred from environmental and usage conditions

Extrinsic factor		Deterioration mechanism inferred
Environmental condition	Coastal area	Chloride induced deterioration
	Cold climate	Frost attack, Chloride induced deterioration
	Spa area	Chemical attack
Usage condition	Repeated wetting and drying	Alkali aggregate reaction, Chloride induced deterioration, Frost attack
	Use of deicing salt	Chloride induced deterioration Alkali aggregate reaction
	Repeated loading	Fatigue
	Carbon dioxide	Carbonation
	Acid water	Chemical attack

Chapter 5. Initial Inspection

5.1 Principles

(1) Initial inspection of a structure should be carried out prior to putting it into service for newly constructed structures. For existing structures, it should be carried out during its service, or after large scale remedial measures.

(2) Initial inspection should be carried out to detect the initial defects, defects, damage, or deterioration, as well as to identify the deterioration mechanism and the deterioration stage.
(3) The results of initial inspection shall be recorded.

5.2 Inspection methods

(1) Initial inspection should be carried out for the entire structure.
(2) Initial inspection should consist of visual observation and hammer tapping, as well as a review of documents on the design, construction, previous maintenance.

[Commentary]
Simple methods, such as visual observation and hammer tapping, are main parts of initial inspection. Design documents and construction records are also required to be investigated. It is also recommended that easy non-destructive tests be applied. Individual inspection methods are described in **Chapter 10**.

5.3 Estimation of deterioration mechanism and deterioration prediction

(1) Deterioration mechanisms should be identified from the results of initial inspection.
(2) Deterioration prediction should be made in regard to possible deterioration mechanisms, by using an appropriate deterioration model.

[Commentary]
Identification of deterioration mechanism is essential for prediction of deterioration stage. At the time of initial inspection, it is necessary to infer possible deterioration mechanism to predict the deterioration stage for subsequent maintenance. The possible deterioration mechanism should be estimated by considering the presence of deterioration factors as external factors such as a chloride-related environment, cold climate, hot spring area, urban area, and so on. Internal factors should also be considered, such as the materials, design, and construction, based on the design and construction records, to infer possible deterioration mechanism. Inference of deterioration mechanisms should be in accordance with **Chapter 4.**

5.4 Assessment and judgement

(1) Assessment and judgement of a structure should be made based on the presence/absence of initial defects, damage, and deterioration of the structure, members/parts of the structure.
(2) Immediate measures shall be taken if deterioration, damage, or initial defect is hazardous to third parties.
(3) Assessment and judgement should be made for the whole time of service life based on deterioration prediction.
(4) Detailed inspection should be made if necessary.
(5) Adequate measures shall be taken if necessary.

Chapter 6. Routine Inspection

6.1 Principles

(1) Routine inspection should be carried out to detect deterioration, damage, or initial defects, and to grasp the degree of such defects.

(2) The results of routine inspection shall be recorded.

[Commentary]
Routine inspection is carried out by simple methods, such as visual observation, hammer tapping, to grasp the location, and state of occurrence of deterioration. Recording should be in accordance with **Chapter 12**.

6.2 Inspection methods

(1) The inspection items, frequency, and the parts of the structure to be inspected should be adequately determined. When determining these matters, the maintenance categories, importance of the structure, and results of deterioration prediction should be taken into consideration.
(2) The methods of routine inspection should primarily include visual inspection, sometimes by using photographs, videos, and binoculars. When some defects are found, inspection by hammer becomes important and effective.

[Commentary]
The inspection items include (i) cracking, (ii) delamination, peeling, spalling, and scaling, (iii) steel exposure and corrosion, (iv) exudation of rust and efflorescence, (v) water leakage, (vi) abnormal displacement/deformation, (vii) abnormal supporting condition, (viii) abnormal sound/vibration, (ix) discoloration, and so on. The parts of the structure to be inspected during routine inspection should be those inspectable during routine patrol, but it is advisable that routine inspection should cover the parts as large as possible. The frequency of inspection should be adequately determined in consideration of the workforce and/or budget, as well as the importance of the structure, hazards to third parties, and results of deterioration prediction. The methods of routine inspection include visual inspection by visual observation, photographs, videos, and binoculars, inspection by hammer tapping. Individual methods are described in **Chapter 10**.

6.3 Assessment and judgement

(1) When deterioration, damage, or initial defect is recognized during routine inspection, the cause and the degree of the defects shall be assessed.
(2) Immediate measures shall be taken, if deterioration, damage, or initial defect is hazardous to third parties.
(3) Detailed inspection should be carried out, if necessary.
(4) Initial defects and damage recognized during routine inspection shall be treated with adequate measures.

[Commentary]
Routine inspection primarily includes visual inspection of the structure, its members, and parts of the structure. The degrees of deterioration, damage, and initial defects should be assessed. Grading is useful as a simple method of assessment. The grading of defects on concrete surfaces may be established based on (i) pattern, number, length, and width of cracks, (ii) area of delamination, peeling, and spalling of cover concrete and area of the range of abnormal hammer tapping sound, (iii) area of scaling and degradation area, (iv) presence and degrees of exudation of rust and efflorescence, and water leakage. It is advisable to assess the degrees of these defects by designating them to several grades. Judgement criteria should also be established beforehand to relate the grade of the defects to, e.g., one of the following states; (i) acceptable,

(ii) impossible to judge whether acceptable or not, (iii) unacceptable. When establishing the criteria, the relationship between the grades and states (i) to (iii) should be adequately evaluated in consideration of the service conditions and required performance of the structure.

Chapter 7. Regular inspection

7.1 Principles

(1) Regular inspection should be carried out to detect or grasp the degree of deterioration, damage, and initial defects at parts of the structure covered by routine inspection, as well as details of the structure where such defects are difficult to be recognized in routine inspection.
(2) The results of regular inspection shall be adequately recorded.

[Commentary]
Regular inspection is carried out primarily by simple methods, such as visual observation and hammer tapping, with the aim of locating and defining deterioration, damage, and initial defects of an entire structure including its members and parts of the structure where such defects are difficult to be recognized in the routine inspection. An engineer having enough knowledge on the design, construction, and maintenance of concrete structures should carry out regular inspection. Regular inspection, which provides time series data of the structure, is useful for grasping the progress of deterioration and confirming the validity of deterioration prediction. For this reason, it is important to maintain accurate records, such as the inspection date and name of inspector, as well as detailed drawings of defects. Records should be in accordance with **Chapter 12**.

7.2 Inspection methods

(1) The items and frequency of regular inspection, and the parts of the structure to be inspected, should be adequately determined. These should be determined in consideration of the maintenance categories, importance of the structure, past maintenance records, and results of deterioration prediction.
(2) The methods of regular inspection should be primarily visual inspection and inspection by hammer tapping, with non-destructive survey and core drilling. The inspection methods should be determined in consideration of the maintenance categories, importance of the structure, past maintenance records, and results of deterioration prediction.

[Commentary]
The inspection items are similar to those of routine inspection. Non-destructive survey and core drilling should be included in regular inspection, if necessary. As a method of close inspection, scaffold can be used in the regular inspection. It is advisable to measure the width and the length of cracks and the range of delamination using simple scales, to quantitatively grasp the defects on concrete surfaces.
The scope of inspection should be the entire structure. Careful inspection should be carried out for the parts of the structure where defects are difficult to be detected during routine inspection. The frequency of regular inspection, which is normally every few years, should be adequately determined, in consideration of the results of deterioration prediction, importance and types of the structure, design service life, remaining service life, environmental conditions, maintenance category, existing maintenance records, and cost efficiency. Individual methods are described in **Chapter 10**.

7.3 Assessment and judgement

(1) When deterioration, damage, or initial defect is recognized during regular inspection, the cause, and the degree shall be assessed.
(2) Immediate measures shall be taken when any deterioration, damage, or initial defect is hazardous to third parties.
(3) Based on the results of above-mentioned (1), detailed inspection should be carried out, if necessary.
(4) Initial defects and damage recognized during regular inspection shall be treated with adequate measures.

Chapter 8. Detailed inspection

8.1 Principles

(1) Detailed inspection should be carried out when judged necessary during initial inspection, routine inspection, regular inspection, or extraordinary inspection.
(2) Detailed inspection should be carried out to understand in detail the condition of the structure and state of deterioration process.
(3) The results of detailed inspection shall be adequately recorded.

[Commentary]
Detailed inspection should be carried out to grasp in detail the condition of the structure. Understanding in detail the state of deterioration occurring in the structure is necessary for identifying the deterioration mechanism, doing deterioration prediction, assessment and judgement of the performance of the structure, and determining remedial measures.

8.2 Inspection methods

(1) Detailed inspection should be carried out for parts of the structure which requests detailed data.
(2) The items and methods relevant to the purpose of detailed inspection should be adequately selected in consideration of deterioration mechanism, the results of initial, routine, regular, and extraordinary inspections, as well as deterioration prediction.

[Commentary]
Detailed inspection is carried out to (i) specify that the defects is deterioration, damage, or initial defects, (ii) identify the deterioration mechanism, (iii) grasp the deterioration stage and condition of damage and initial defects, and (iv) collect the data for the prediction of deterioration. It is advisable to collect quantitative data on the deterioration of concrete and corrosion of reinforcing steel, while grasping apparent damage condition. The inspection items, which can specify defects as deterioration, damage, or initial defects, should be selected. It is generally necessary to drill cores near the defects and grasp the bar arrangement (cover depth and bar spacing) and reinforcement corrosion by non-destructive tests or chipping. Observation of concrete samples and its analysis reveal the carbonation depth, chloride ions penetration or chemical agents intrusion, depth of frost deterioration, presence/absence of alkali aggregate reaction products, and so on, while clarify the deterioration mechanisms.

It should be noted that in detailed inspection, the inspection items and methods should be selected to collect detailed actual data necessary for the deterioration prediction model of the relevant deterioration

mechanism. It is necessary that inspection items be selected in consideration of the relationship between deterioration mechanisms and inspection items. When performances important for assessment and judgement are specified, inspection items closely related to the structures' performances should be selected and carried out. In the case where the environmental conditions strongly affect the progress of deterioration, detailed inspection should include, for example, airborne salts, CO_2 concentration, water supply, number of freezing and thawing cycles, and external forces of deterioration, such as the intensity and number of traffic load cycles.

8.3 Deterioration prediction

Deterioration prediction based on the results of detailed inspection should be performed using an adequate model incorporating the relevant deterioration mechanism. Data necessary for the prediction should be obtained from inspection.

8.4 Assessment and judgement

(1) The causes of deterioration, damage, and/or initial defects occurring in the structure shall be identified. Deterioration mechanism shall also be identified.
(2) From the results of detailed inspection, assessment and judgement should be made on the safety performance, serviceability performance, performance related to hazards to third parties, and aesthetic appearance/landscape of the structure.
(3) Using the deterioration prediction model, assessment and judgement should be made on the safety performance, utility performance, performance related to hazards to third parties, and aesthetic appearance/landscape of the structure for the planned life span. Moreover, performance over time of the structure should be assessed and judged.
(4) Remedial measures shall be taken if necessary.

[Commentary]
Reduction in load-bearing capacity is generally brought about by reduction of the effective area of concrete due to frost deterioration or chemical erosion, reduction of the cross-sectional area of reinforcement and changes in the bond properties due to corrosion. When evaluating the load-bearing capacity, it is advisable to set the effective section of the concrete and the cross-sectional area of the reinforcement based on the measured actual data in detailed inspection. The load-bearing performance is judged "decreased" when the load-bearing capacity calculated based on the inspection results becomes lower than the sectional force calculated with the required safety factor. For safety performances other than load-bearing capacity, such as stability and ductility, assessment and judgement should be carried out based on a concept similar to that of load- bearing capacity. It is preferable to use equations specified in design standards.
In regard to the serviceability performance, the required performance can be verified directly by the indexes obtained from inspection, such as deflection, vibration properties, inclination, water leakage, and so on. Hazards to third parties are assessed and judged as the risk of delamination, cold joints, etc. of concrete that can cause injury of people and/or property by falling concrete fragments. Aesthetic appearance and landscape are assessed and judged from the aspect of the possibility of cracking, scaling, rust exudation, water leakage marks, which damage the aesthetic appearance and landscape at the surrounding of the structure. Assessment and judgement of this performance may often be difficult. It should be carried out in consideration of the deterioration condition, as well as the maintenance category, importance/location, and remaining life span of the structure, cost efficiency of remedial measures, etc.

The above-mentioned performance-based assessment/judgement is preferable as a method of assessment and judgement based on detailed inspection. However, sometimes it is very difficult to carry out the performance-based assessment/judgement. In that case, assessment/judgement based on highly practical grading method may be also employed instead of the above-mentioned performance-based assessment and judgement. The commonly used grading of apparent defects related to the progress of deterioration, are "**initiation**", "**propagation**", "**acceleration**", and "**deterioration stages**". From the results of detailed inspection, the degree of deterioration of the structure should be assessed using this grading. The judgement should be carried out considering the performance requirements, maintenance category, importance of the structures, remaining service life and type of performances of the structure, as well as the economic efficiency of remedial measures. Selection of measures and specific methods are described in **Chapter 11**.

Chapter 9. Extraordinary Inspection

9.1 Principles

(1) Extraordinary inspection should be carried out when the structure is subjected to an accidental action such as an earthquake, typhoon or other natural disaster, fire, collision of vehicles or boats, etc.
(2) Extraordinary inspection should be carried out to grasp the condition of the structure, and to assess/judge the necessity of remedial measures.
(3) Extraordinary inspection should include an inspection carried out for similar type structures that have a risk to cause similar accident after defects of a structure caused an accident. It is specially called "**emergency inspection**".
(4) The results of extraordinary inspection shall be adequately recorded.

9.2 Inspection method

(1) When the structure is subjected to a natural disaster or accident, extraordinary inspection shall be carried out as soon as possible.
(2) The range to be inspected should be the member or the parts of the structure with damage due to the disaster or accident.
(3) Extraordinary inspection should be carried out by visual observation and hammer tapping test.

9.3 Assessment and judgement

(1) When collapse of the structure due to natural disaster or accident has a risk of hazards to third parties, appropriate emergency measures shall be taken as quickly as possible. Appropriate measures shall be also taken immediately when defects are detected, such as delamination of cover concrete, leading to hazards to third parties.
(2) When damage or defects are recognized, detailed inspection shall be carried out, while taking appropriate measures.

9.4 Emergency inspection

(1) Emergency inspection should be carried out on the similar structures when defects in a structure caused an accident.
(2) Emergency inspection should be carried out to detect the similar defects occurred in the structure that caused the accident, and assess/judge the necessity of remedial measures.

(3) The range to be inspected should be members or parts of the structure having a similar risk of defects that caused the accident.

Chapter 10. Techniques of Testing and Surveying

10.1 Scope

(1) Adequate methods of testing and surveying should be selected for " Initial inspection", "Routine inspection", "Regular inspection", "Detailed inspection", and "Extraordinary inspection" in consideration of the state of the structure, needed information and deterioration mechanism.
(2) The methods described in this chapter should be employed as standard methods for test and survey.
(3) The results of testing and surveying should be adequately recorded and restored.

10.2 Visual observation and hammer (tapping) test

(1) The surface condition of concrete should be visually observed.
(2) For quantitative assessment of concrete surface defect, a simple measuring apparatus should be used.
(3) Subsurface defects inside concrete, such as voids, should be found by hammer (tapping) test.

[Commentary]
As a first step of inspection on structure, the surface condition of concrete should be visually observed. Observation items are as follows: (i) Color change or stain of concrete surface, (ii) cracking of concrete, (iii) scaling of concrete, (iv) delamination of concrete, (v) spalling of concrete, and (vi) exposure, corrosion and rupture of steel reinforcement inside concrete.

10.3 Testing with non-destructive apparatus

10.3.1 General

(1) When sufficient information cannot be obtained only from visual observation or hammer (tapping) test, non-destructive testing method should be effectively conducted.
(2) Suitable non-destructive apparatus should be selected, in consideration of the purpose, scope, and required accuracy of testing.

10.3.2 Method with optical fiber scope

The method with an optical fiber scope should be used to observe the inside of concrete through a narrow space, such as concrete cracking.

10.3.3 Method with rebound hammer

The method with rebound hammer should be used to assess the concrete strength by measuring the subsurface hardness of concrete.

10.3.4 Electric and magnetic method

(1) Electric and magnetic method includes the method utilizing the high electrical conductivity and magnetism of steel bars or the method utilizing the dielectricity of concrete.
(2) Electric and magnetic method provides the following information;
    (i) Location, diameter and cover depth (thickness) of reinforcing steel bars in concrete.
    (ii) Moisture content of concrete.

10.3.5 Methods using elastic waves propagating through concrete

(1) The characteristics of elastic waves propagating through concrete should be measured to obtain information inside concrete. The methods include " Ultrasonic method", "Impact Elastic Wave Method", and "Acoustic Emission (AE) Method".
(2) The methods using elastic waves provide the following information;
   (i) Compressive strength of concrete.
   (ii) Cracking of concrete.
   (iii) Spalling of concrete.
   (iv) Voids in concrete.
   (v) Loading history of the structure.

10.3.6 Methods using electromagnetic waves

(1) In this method, electromagnetic waves transmitting through or reflecting off concrete should be used to obtain information inside concrete. These are classified into "X-ray method", "Radar method", and "Infrared method", according to the type of electromagnetic waves used.
(2) The methods using electromagnetic waves primarily provide the following information;
   (i) Locations, diameters and cover depth (thickness) of steel reinforcement in concrete.
   (ii) Voids in concrete.
   (iii) Cracking in concrete.
   (iv) Spalling of concrete.

10.3.7 Electrochemical methods

(1) Electrochemical methods include "Half-cell potential", "Polarization resistance", and "Polarization curve", which are the methods based on an electrochemical characteristics of corrosion on steel reinforcement.
(2) Electrochemical methods primarily provide the following information;
   (i) Corrosion tendency of steel reinforcement in concrete.
   (ii) Corrosion rate on steel reinforcement in concrete.
(3) Measurement of specific resistance of concrete itself, which is included in electric methods, will also provide information of corrosion tendency of the reinforcement.

10.4 Partial and small-scale destructive tests

(1) In this method, a small part of the structure is destroyed to investigate the physical properties and state of deterioration of concrete.
(2) Partial and small-scale destructive tests primarily include core drilling and concrete surface chipping.

[Commentary]

The following measurement should be conducted by using core specimens and/or chipping of concrete cover; (i) Crack depth measurement by core specimen, (ii) loading test of cores specimen, (iii) carbonation depth measurement of concrete, (iv) chemical analysis of concrete, (v) chloride content in concrete, (vi) mix proportion analysis, (vii) free expansion and residual expansion test, (viii) air/water permeability test of concrete, (ix) pore size distribution test, (x) void distribution test, (xi) corrosion survey of steel bars , and (xii) tensile strength of steel bars taken out from concrete.

10.5 Direct assessment of the structural behaviors of existing structures

(1) Strain, deformation, acceleration, should be measured relating to the mechanical performance of the existing structure.
(2) Through the direct assessment of mechanical performance of existing structures, the following information should be obtained;
   (i) Rigidity of the member's cross-section.
   (ii) Natural frequency and damping coefficient.

[Commentary]
In order to assess the mechanical performance of superstructure of existing bridge directly, the following test items are conceivable: (i) Static and dynamic loading tests, and (ii) vibratory loading tests.

10.6 Assessment of environmental action

10.6.1 General
Information for identifying the causes of deterioration and for predicting the future progress of the deterioration should be obtained by assessing the environmental conditions of the structure.

10.6.2 Environmental actions related to carbonation induced deterioration
Assessment of environmental action related to the carbonation of concrete and carbonation induced steel corrosion should be regarded to climatic conditions, such as air temperature, relative humidity, frequency of rainfall, and solar radiation, etc.

10.6.3 Environmental actions related to chloride induced deterioration
(1) Assessment of environmental actions related to the penetration and diffusion of chloride ions in concrete should be regarded to the following items.
   (i) Effects of seawater and air-borne salts.
   (ii) Effects of deicing salts.
   (iii) Climatic conditions, such as air temperature, relative humidity, amount of rainfall, and solar radiation, etc.
(2) Assessment of environmental actions related to the steel corrosion by chloride induced deterioration should be regarded to climatic conditions, such as air temperature, relative humidity, frequency of rainfall, and solar radiation, etc.

10.6.4 Environmental actions related to frost attack
Assessment of environmental actions related to the frost attack should be regarded to climatic conditions, such as lowest air temperature, solar radiation, and number of freezing and thawing cycles etc., and water supply conditions to the concrete surface.

10.6.5 Environmental actions related to chemical attack
Assessment of environmental actions related to chemical attack should be regarded to the type of contact solution to the concrete surface and air temperature.

10.6.6 Environmental actions related to alkali aggregate reaction (ASR)
Assessment of environmental actions related to ASR should be regarded to the following items;
   (i) Climatic conditions, such as air temperature, relative humidity, and solar radiation, etc.

(ii) Exposure condition of concrete surface to rainwater.
(iii) Water supply conditions from the ground.
(iv) Alkalis supply conditions to the concrete.

10.6.7 Environmental actions related to deterioration due to fatigue

Assessment of environmental actions related to deterioration due to fatigue of concrete slabs should be regarded to the following items.

(i) Loading conditions.
(ii) Actual conditions, such as rainwater permeation into concrete, use of deicing salts, etc.

10.7 Performance test on repairing materials

Adequate test methods for concrete repairing materials should be selected, in consideration of the purpose of the tests.

Chapter 11. Remedial Measures Toward Deterioration

11.1 Principles

(1) When a structure is assessed and judged as having a risk of performance degradation, adequate remedial measures shall be selected in consideration of the maintenance category, remaining life span, and difficulty of maintenance.
(2) To execute the selected remedial measures, an adequate plan for the measures shall be formulated for the relevant deterioration mechanism and degree of deterioration of the structure.
(3) When planning remedial measures including the selection of methods and materials, target performance levels shall be set.
(4) When the deterioration mechanism is clearly known, adequate measures shall be selected for the relevant degree of deterioration, in accordance with the Part II of this Specification.
(5) When the structure has a risk of hazards to third parties, appropriate remedial measures shall be taken promptly.

[Commentary]

Table C11.1.1 classifies remedial measures based on the target performance level of the structure.

Table C11.1.1 Remedial measures classified by target performance level

Performance	Target level		
	Performance between as-built and current performances	Same level as as-built performance	Performance higher than as-built performance
Durability	Repair	Repair/ Strengthening	Repair/ Strengthening
Safety		Strengthening	Strengthening
Serviceability		Utility restoration/ Strengthening	Functionality improvement/ Strengthening
Performance related to hazards to third parties	Repair	Repair	
Aesthetic appearance/landscape		Appearance improvement	Appearance improvement

11.2 Types of remedial measures

Remedial measures shall be appropriately selected among **"extensive inspection**", "**repair**", "**strengthening**", "**appearance improvement**", "**utility restoration**", "**functionality improvement**", "**usage restriction**", and "**demolition/removal**".

11.2.1 Extensive inspection

Extensive inspection means increment of the frequency and items of inspection from those of original plan. The extension level of the frequency and items shall be determined based on the results of assessment and judgement, and the remaining life span.

11.2.2 Repair

Repairing methods and materials shall be selected in consideration of the deterioration mechanism and post-repair maintenance. A repair plan shall be formulated based on the target levels of performances.

11.2.3 Strengthening

Strengthening methods and materials shall be selected in consideration of the deterioration mechanism and post-strengthening maintenance. A strengthening plan shall be formulated based on the target levels of performances.

11.2.4 Appearance improvement

Appearance improvement means the improvement of the landscape by, for example, coating the structure or placing concrete overlay. An appearance improvement plan and execution plan shall be formulated in consideration of the landscape of the area, function and remaining life span of the structure.

11.2.5 Utility restoration

Utility restoration shall be based on the determined target level, and an execution plan shall be formulated accordingly.

11.2.6 Functionality improvement

Functionality improvement shall be based on the determined target level, and an execution plan shall be formulated accordingly.

11.2.7 Usage restriction

Usage restriction means for example, the traffic load limitation, etc. The degree and method of the usage restriction shall be determined based on the assessment/judgement. The usage restriction shall be implemented after carrying out detailed inspection.

11.2.8 Demolition/removal

Demolition/removal plan shall be formulated by selecting a method suitable for the structure in consideration of the environmental conditions, safety, post-demolition treatment, execution period and cost efficiency.

11.3 Repair

11.3.1 Principles

(1) Repair is adopted as measures to eliminate hazards to third parties and to restore or improve the

performance over time.

(2) The state of deterioration of the structure shall be well investigated before repairing.

(3) A repair plan shall be formulated, and repair shall be executed based on the repair plan. Adequate control and inspection shall be carried out during and after repairing.

(4) In repairing, it is necessary to eliminate the deterioration factors. In the case that the deterioration factors cannot be eliminated, it is necessary to inhibit the progress of deterioration.

(5) When the deterioration mechanism is clearly known, repair shall be carried out in accordance with the Part II of this specification.

11.3.2 Repair plan

(1) A repair method suitable for the relevant deterioration mechanism shall be selected based on the results of preliminary surveying.

(2) In a repair plan, an adequate repair level shall be set in consideration of the maintenance category, importance of the structure, remaining life span, cost efficiency, and post-repair maintenance.

(3) An appropriate repair design and execution plan shall be formulated.

[Commentary]

Table C11.3.2.1 summarizes the example of repair policies, compositions of repair works and factors to be considered when establishing the repair level.

Table C11.3.2.1 Deterioration mechanisms and repair plan

Deterioration mechanism	Repair policies	Composition of repair works	Factors to be considered in establishing the repair level
Carbonation induced deterioration	-Removal of carbonated concrete -Infiltration restraint of CO_2 and water after repair	-Patching -Surface protection -Re-alkalization	-Removal level of carbonated concrete -Corrosion protection of steel reinforcement -Patching material -Surface protection material and thickness -Alkalinity of concrete
Chloride induced deterioration	-Removal of infiltrated Cl^- -Infiltration restraint of Cl^-, water and oxygen after repair	-Patching -Surface protection -Desalination	-Removal of infiltrated portions of concrete -Corrosion protection of steel reinforcement -Patching material -Surface protection material and thickness -Removal level of infiltrated Cl^-
	-Potential control of steel reinforcement	-Anodic material -Power supply of cathodic protection	-Quality of anodic material -Polarization level
Frost attack	-Removal of deteriorated concrete -Infiltration restraint of water after repair -Improvement of freeze-and-thaw resistance of concrete	-Patching -Injection into crack -Surface protection	-Freeze-and-thaw resistance of patching material -Injection material and execution method -Surface protection material and thickness

Chemical attack	-Removal of deteriorated concrete -Infiltration restraint of deterioration inducing chemicals	-Patching -Surface protection	-Patching material -Surface protection material and thickness -Achievement level of removal of deteriorated concrete
Alkali aggregate reaction	-Restraint of water supply -Release of internal water -Restraint of alkali supply -Restraint of crack progress (mostly strengthening is required)	-Injection into crack -Surface protection	-Injection material and execution method -Surface protection material and thickness

11.4 Strengthening

11.4.1 Principles

(1) Strengthening is adopted for maintenance measures to restore or improve the mechanical performances, such as load-bearing capacity and rigidity.
(2) The state of deterioration of the structures shall be surveyed before strengthening.
(3) A strengthening plan shall be formulated, and strengthening shall be executed based on the strengthening plan. Adequate control and inspection shall be carried out during and after execution.
(4) Strengthening design shall include verification whether the structure will achieve the required level after strengthening.

11.4.2 Strengthening plan

(1) In a strengthening plan, an adequate strengthening level shall be set in consideration of the maintenance category, importance of the structure, and remaining life span.
(2) A strengthening method shall be selected based on the results of inspection, assessment/judgement. The selected method should provide the specified strengthening level, on the structural conditions, execution conditions, performance over time, and maintenance after strengthening.
(3) In the strengthening plan, the strengthening design, and the execution plan shall be formulated.

Table C11.4.2.1 Available strengthening methods

Strengthening methods	Interchange of concrete members	Interchange
	Increase in concrete section	Overlay
		Concrete jacketing
	Addition of members	Girder addition
	Addition of supports	Supporting
	Addition of reinforcement	Steel plate bonding
		FRP bonding
		Steel plate jacketing
		FRP jacketing
	Introduction of prestress	Prestressing

Chapter 12. Records

12.1 Principles

The results of design, execution, initial inspection, deterioration prediction, inspection, assessment and judgement, and remedial measures shall be recorded and stored.

12.2 Period of storing records

(1) In principle, records of maintenance should be stored as long as the structure is in service.
(2) Records of maintenance should be stored even after the end of the service period of the structure even after the end of the service period of the structure as a reference data for maintenance of other structures.

12.3 Recording formula

Records shall be kept in appropriate and regulated formula that enables their contents to be easily referred.

12.4 Recording items

(1) Items to be recorded should be basic data of the structure, environment, maintenance category, results of initial inspection, methods and results of deterioration prediction, inspection plan and results, results of assessment/judgement, and photographs. The names of the maintenance manager and inspectors shall be recorded, and design drawings and specifications shall also be stored.
(2) When remedial measures such as repairs and strengthening are taken, the methods and execution records shall be recorded together with the names of design managers, execution managers, and execution control managers.

[Commentary]
Table 12.4.1 gives recommended items to be recorded.

Table 12.4.1 Typical recording items

	Recording items	
Primary items	Personnel	Maintenance manager, Inspector, Recorder
	Basic data of structure	Environment, Maintenance category, Existing records
Inspection	Type of inspection	Initial, Routine, Regular, Detailed, and Extraordinary inspection
	Time	Date/Time of inspection
	Location	Object structure, Members to be inspected, Detailed locations of inspection
	Items	Items of inspection
	Methods	Method for each inspection item (in detail if unspecified)
	Results	Results of each inspection item, Various test results
Prediction of deterioration	Prediction method	Prediction model used or equations and their parameters
	Results	Outputs of prediction in initiation, propagation, acceleration, and deterioration stages
Assessment & judgement	Method of assessment/ judgement	Method of calculating performances of structure, Criterions of assessment
	Deterioration grading	Grading results, such as initiation, propagation, acceleration, and deterioration stages
	Results	Results of assessment/judgement for each segment/member or structure
Remedial measures	Personnel	Design manager, Execution manager, Execution control manager
	Methods Execution record	Execution plan and drawings for remedial measures Time, Completion drawings, Execution report, History of remedial measures

Part 2: Standard Maintenance Method

Chapter 13. Standard Maintenance Method for Carbonation Induced Deterioration

13.1 General

(1) This Standard Maintenance Method provides standard methods of deterioration prediction, inspection, assessment, judgement, remedial measures and record carried out for maintenance or formulation of a maintenance plan of structures in which carbonation induced performance degradation has occurred or structures with a high risk of carbonation induced performance degradation. Items common to all deterioration mechanisms should be in accordance with the Part I.
(2) This Standard Maintenance Method covers maintenance activities, carried out to discover carbonation induced steel reinforcement corrosion and concomitant concrete deterioration at an early stage, and to retain the performance of the entire structure.
(3) This Standard Maintenance Method is primarily applied to structures designated to maintenance category B.

13.2 Method of deterioration prediction

13.2.1 General

(1) Prediction of carbonation-induced deterioration should comprise a prediction of the duration of "initiation stage", "propagation stage", "acceleration stage" and "deterioration stage".
(2) Prediction of deterioration should be based on the results of inspection. Where no inspection results are available, prediction should be made by appropriately assessing the qualities of concrete and the environmental conditions to which the structure is exposed with an adequate safety factor.

13.2.2 Prediction of carbonation progress

(1) Prediction of carbonation progress shall be made with adequate consideration to the qualities of concrete and the effects of the environmental conditions to which the structure is exposed.
(2) Prediction of carbonation progress should be made by using either of the following methods:
  (i) Square root relationship between time and carbonation depth.
  (ii) Accelerating test.

13.2.3 Prediction of progress of steel corrosion

(1) Prediction of the progress of steel corrosion shall be made with adequate consideration to the qualities of concrete and effects of the environmental conditions to which the structure is exposed.
(2) The onset of steel corrosion should basically be judged by uncarbonated cover depth.
(3) Prediction of the progress of steel corrosion before the onset of corrosion cracking should be made by either of the following methods:
  (i) Method based on the corrosion amount obtained from the inspection results.
  (ii) Method utilizing the uncarbonated cover depth.
(4) Prediction of the onset of corrosion cracking should be made by either of the following methods:
  (i) Judgement from the amount of corrosion.
  (ii) Method using a mechanical model.
(5) The corrosion rate of reinforcing steel after the onset of corrosion cracking should be predicted with adequate consideration to the effect of cracking on the mass transfer, for example, water and oxygen.

13.2.4 Correction of prediction

When the state of deterioration obtained from inspection has a gap from the previous prediction, the cause should be investigated, and the deterioration prediction should be corrected. The subsequent maintenance plan should be changed if necessary.

13.3 Methods of inspection

13.3.1 General

For a structure suffering or expected to suffer carbonation induced deterioration, the items, methods and time of inspection shall be selected so that appropriate assessment of the state of degradation, prediction of deterioration progress, judgement for the necessity of remedial measures and determination of such measures can be performed, while considering the maintenance category of the structure.

[Commentary]

Table C13.3.1.1 gives a standard for inspection items for each stage of deterioration.

Table C13.3.1.1 Standard inspection items

	Initiation stage	Propagation stage	Acceleration stage	Deterioration stage
Defective appearance	OO	OO	OO	OO
Carbonation depth	OO	O	*	*
Chloride ion content	*	*	*	*
Steel corrosion	O	OO	OO	OO
Concrete strength	*	*	O	OO
Load-bearing capacity	*	*	O	O
Bar alignment	OO	O	*	*
Deterioration environmental action	*	*	*	*
Monitoring	*	*	*	*

OO: Mandatory items, O: Desirable items, *: Items to be adopted if necessary

13.3.2 Initial inspection

Initial inspection items should be adequately selected for new structures, existing structures and structures after remedial measures, respectively.

[Commentary]

Items particularly important in the initial inspection of structures involving the risk of carbonation induced deterioration include the followings; (i) water-cement ratio (or water-binder ratio), (ii) presence/absence of a mineral admixture and its type and content (if applicable), (iii) concrete cover thickness, (iv) environmental conditions and (v) initial defects.

13.3.3 Routine inspection

Routine inspection should basically comprise inspection of defects on concrete surfaces, such as cracking, peeling/spalling, rust exudation, free lime and discoloration, as well as water leakage and deterioration of appearance, such as displacement/deformation.

13.3.4 Regular inspection

In regular inspection, appearance investigation should be carried out in more detail than the routine inspection. Monitoring should be performed if required.

13.3.5 Detailed inspection

(1) In detailed inspection, degree of defects on concrete surfaces, such as width and length of corrosion cracks, and qualities of cover concrete should be tested in regard to the entire structure or portions with significant deterioration, while collecting quantitative data on the carbonation depth and steel corrosion.
(2) Investigation shall be made on the deformability of the structure or its members and the strain of concrete and reinforcement by appropriate methods such as loading tests.
(3) If it is necessary, investigation shall be conducted on the environmental conditions, such as temperature and humidity, and deterioration external forces, such as carbon dioxide concentration and loads acting on the structure.

[Commentary]

The grade of the appearance of structures involving carbonation induced performance degradation is given in Table C13.3.5.1

Table C13.3.5.1 Grade of appearance and deterioration of structures

Grade of appearance	State of deterioration
Grade I-1 (Initiation stage)	No apparent defects. Uncarbonated cover depth is greater than the threshold value.
Grade I-2 (Propagation stage)	No apparent defects. Uncarbonated cover depth is less than the threshold value. Corrosion occurs.
Grade II-1 (Former acceleration stage)	Corrosion cracking occurs.
Grade II-2 (Latter acceleration stage)	Many corrosion cracks occur. Rust exudation and partial peeling/spalling are observed. Corrosion amount increases.
Grade III (Deterioration stage)	Many corrosion cracks occur. Crack widths are large. Rust exudation and peeling/spalling are observed.

13.4 Assessment and judgement

(1) Assessment and judgement of the results of initial inspection, routine inspection, regular inspection and extraordinary inspection should be in accordance with the Part I. Assessment and judgement of the results of detailed inspection should be in accordance with the following items of this section, (2), (3) and (4).
(2) Since performance degradation of a structure due to carbonation is induced by corrosion of steel reinforcement, affected performances should be assessed with sufficient care as to which stage the structure is in, initiation, propagation, acceleration or deterioration stages.
(3) It is desirable that the assessment of various performances of a structure shall be made for the time of inspection and for the end of the designed service life by quantitative methods. However, where quantitative method is not available, the semi-quantitative grading method should be used.
(4) Judgement shall be made in consideration of the degree of performance degradation, importance of the structure and maintenance category.

[Commentary]

The performance degradation is assessed semi-quantitatively by referring to Table C13.4.1.

Table C13.4.1 Appearance grades of structures related to typical performance degradation

Appearance grade	Safety Performance	Serviceability Performance	Hazards to third parties Aesthetic appearance/landscape
Grade I-1 (Initiation stage)			
Grade I-2 (Propagation stage)			
Grade II-1 (Former acceleration stage)			
Grade II-2 (Latter acceleration stage)		Reduction in rigidity (increase in deformation/ generation of oscillation) - Losses in steel cross-sectional area - Reduction in bond strength between steel and concrete - Losses in concrete cross-sectional area due to delamination/peeling	Deterioration in aesthetic appearance - Cracking - Rust exudation - Reinforcement exposure Hazards to third parties - Peeling/spalling
Grade III (Deterioration stage)	Reduction in load-bearing capacity/ductility - Losses in steel cross-sectional area - Losses in concrete cross-sectional area due to delamination/peeling		

13.5 Remedial measures

13.5.1 Selection of remedial measures

When remedy is judged to be necessary, measures that satisfy the performance requirements shall be selected. When it is difficult to select measures based on performance verification, they may be selected based on the appearance grading of the structure.

[Commentary]

When remedial measures are judged to be necessary, the measures should be selected among followings; (i) extensive inspection, (ii) repair, (iii) strengthening, (iv) appearance improvement, (v) utility restoration, (vi) functionality improvement, (vii) usage restriction and (viii) demolition/removal. As for the standard relationship between assessment/judgement results and remedial measures, the Part I should be referred to. When judgement based on quantitative assessment is difficult, judgement should be based on the grade of deterioration of the structure. It is advisable to follow Table C13.5.1.1 as a standard.

Table C13.5.1.1 Appearance grades of structures and remedial measures

	I-1 (Initiation stage)	I-2 (Propagation stage)	II-1 (Former acceleration stage)	II-2 (Latter acceleration stage)	III (Deterioration stage)
Extensive inspection	O	O	OO	OO	
Repair	(O)	O	OO	OO	O
Strengthening				OO	OO
Appearance improvement			OO	OO	O
Utility restoration				OO	OO
Functionality improvement				O	OO
Usage restriction				O	OO
Demolition/removal					OO

OO: Recommended standard measures, O: possible measures, (O): preventive measures

13.5.2 Repair and strengthening

Methods and materials for repair and strengthening shall be selected to achieve the specified effects in consideration of the performance degradation.

[Commentary]

The measures given in Table C13.5.2.1 should be taken as a standard.

Table C13.5.2.1 Appearance deterioration grades of structures and standard methods

Appearance grade of structure	Standard methods
I-1 (Initiation stage)	(Surface coating)*
I-2 (Propagation stage)	Surface coating, (re-alkalization)
II-1 (Former acceleration stage)	Surface coating, (cathodic protection), (re-alkalization)
II-2 (Latter acceleration stage)	Surface coating, patching, (cathodic protection)
III (Deterioration stage)	Adhesion of steel plate/fiber-reinforced polymer (FRP), Out cables, Concrete lining, Increasing thickness

*: Preventive methods

13.6 Records

Items peculiar to carbonation should be recorded.

Chapter 14. Standard Maintenance Method for Chloride Induced Deterioration

14.1 General

(1) This Standard Maintenance Method provides standard methods of deterioration prediction, inspection, assessment, judgement, remedial measures and recording carried out for maintenance or formulation of a maintenance plan of structures in which chloride induced performance degradation has occurred or structures with a high risk of chloride induced performance degradation. Items common to all deterioration mechanisms should be in accordance with the Part I.

(2) This Standard Maintenance Method covers maintenance activities carried out to discover chloride induced steel reinforcement corrosion and concomitant concrete deterioration at an early stage and retain the performance of the entire structure.

(3) This Standard Maintenance Method primarily is applied to structures designated to maintenance category B.

14.2 Method of deterioration prediction

14.2.1 General

(1) Prediction of chloride-induced deterioration should basically comprise prediction of the duration of the initiation stage, propagation stage, acceleration stage and deterioration stage and diffusion of chloride ions and progress of reinforcement corrosion.

(2) Prediction of deterioration should be based on the results of inspection. Where no inspection results is available, prediction should be made by appropriately assessing the qualities of concrete and environmental conditions where the structure is exposed to, and by incorporating an adequate safety factor.

[Commentary]

The factors determining each stage and its duration are presented in Table C14.2.1.1

Table C14.2.1.1 Definitions of deterioration stages

Deterioration process	Definition	Major factors determining duration
Initiation stage	Up to the time when the chloride ions content at the cover depth reaches the threshold value* for steel corrosion.	Diffusion of chloride ions. Content of initially included chloride ions.
Propagation stage	From the beginning of steel corrosion to the onset of corrosion cracking	Corrosion rate of reinforcing steel.
Acceleration stage	Period during which corrosion is accelerated by corrosion cracking	Corrosion rate of reinforcing steel with cracking in concrete.
Deterioration stage	Period in which the load-bearing capacity is significantly reduced by the increase in corrosion	

* The value is 1.2 kg/m^3 according to Standard Specification for Concrete Structures –1999 "Construction".

14.2.2 Prediction of chloride ion diffusion

(1) Prediction of chloride ion diffusion shall be made with adequate consideration of the quality of concrete and the effects of the environmental conditions to which the structure is exposed.

(2) Prediction of chloride ion diffusion should be made by one of the following methods;

(i) Method using the solution of the diffusion equation under appropriate boundary conditions.

(ii) Acceleration test.

(iii) Numerical analysis taking account of the reaction of chloride ions and their transfer across the boundaries between concrete and the environment.

[Commentary]

The transfer of chloride ions in concrete is based on the diffusion theory, therefore, the prediction of chloride ion diffusion can be made by using the diffusion equation, which is known as Fick's second law, under appropriate boundary conditions.

$$C(x,t) = C_0\left(1 - erf\frac{x}{2\sqrt{D \cdot t}}\right) \qquad \text{(Solution 14.2.2.1)}$$

where C(x, t) = chloride ion content at the depth of x (cm) and at time t (years) (kg/m^3)

C_0 = chloride ion content on the concrete surface (kg/m^3)

D = apparent diffusion coefficient of chloride ions (cm^2/year)

erf = error function

Chloride ion contents incorporated from mixing materials may be considered by assuming C(x,0) given in the equation (solution 14.2.2.2) to be the initial chloride ion content.

$$C(x,t) = C_0\left(1 - erf\frac{x}{2\sqrt{D \cdot t}}\right) + C(x,0) \qquad \text{(Solution 14.2.2.2)}$$

where C(x,0) = content of initially included chloride ions (kg/m^3)

14.2.3 Prediction of progress of steel corrosion

(1) Prediction of the progress of steel corrosion shall be made with adequate consideration of the qualities of concrete and effects of the environmental conditions to which the structure is exposed.

(2) The onset of steel corrosion should be judged by the chloride ion content at the cover depth.

(3) Prediction of the progress of steel corrosion before the onset of corrosion cracking may be made by either of the following methods;

(i) Method based on the corrosion amount obtained from the inspection results.
(ii) Method that incorporates corrosion rate.

(4) Prediction of the onset of corrosion cracking may be made by either of the following methods:
(i) Judgement from the amount of corrosion.
(ii) Method using a mechanical model.

(5) The corrosion rate of reinforcing steel after the onset of corrosion cracking should be predicted with adequate consideration of the effect of cracking on mass transfer through cracks.

14.2.4 Correction of prediction

When the state of deterioration obtained from inspection results differs from the previous prediction, the cause should be investigated, and the deterioration prediction shall be corrected. The subsequent maintenance plan should be changed if necessary.

14.3 Methods of inspection

14.3.1 General

For a structure suffering or expected to suffer from chloride induced performance degradation, the items, methods and time of inspection shall be selected so that appropriate assessment of the state of degradation, prediction of deterioration progress, judgement for the necessity of remedial measures and determination of such measures can be performed, while considering the maintenance category of the structure.

[Commentary]

Table C14.3.1.1 gives standard inspection items for each deterioration stage.

Table C14.3.1.1 Standard inspection items

	Initiation	Propagation	Acceleration	Deterioration
Defective appearance	OO	OO	OO	OO
Chloride ion content	OO	OO	OO	O
Carbonation depth	OO	OO	O	*
Steel corrosion	O	OO	OO	OO
Concrete strength	*	*	O	OO
Load-bearing capacity	*	*	O	O
Bar alignment	OO	O	*	*
Deterioration external force	OO	O	*	*
Monitoring	*	*	*	*

OO: Mandatory items, O: desirable items, *: items to be adopted as required

14.3.2 Initial inspection

For initial inspection, inspection items should be adequately selected for new structures, existing structures and structures after remedial measures.

[Commentary]

Items particularly important in the initial inspection of structures involving the risk of chloride induced deterioration are followings: (i) water-cement ratio (or water-binder ratio), (ii) type of cement, (iii) presence/absence of a mineral admixture and its type and content, (iv) content of initially included chloride ions, (v) concrete cover depth, (vi) environmental conditions and (vii) initial defects.

14.3.3 Routine inspection

Routine inspection should comprise inspection of defects on concrete surfaces, such as cracking, peeling/spalling, rust exudation, free lime and discoloration, as well as water leakage and deterioration of appearance, such as displacement/deformation.

14.3.4 Regular inspection

In regular inspection, appearance investigation should be carried out more in detail than the routine inspection. Monitoring should be performed if necessary.

14.3.5 Detailed inspection

(1) In detailed inspection, defects on concrete surfaces, such as width and length of corrosion cracks, and qualities of cover concrete should be grasped in regard to the entire structure or portions with significant deterioration, while collecting quantitative data on the chloride content in concrete and steel corrosion.
(2) Investigation shall be carried out on the deformability of the structure or its members and strain of concrete and reinforcement by appropriate methods such as loading tests.
(3) If it is necessary, investigation shall be conducted on the environmental conditions, such as temperature and humidity, and external forces causing deterioration, such as amount of air-borne salt and loads acting on the structure.

[Commentary]

The grades of the appearance of structures involving chloride induced performance degradation are given in Table C14.3.5.1

Table C14.3.5.1 Grades of appearance and deterioration of structures

Grade of appearance of structures	State of deterioration
Grade I-1 (Initiation stage)	No apparent damage. Below the threshold chloride ion content for corrosion onset.
Grade I-2 (Propagation stage)	No apparent damage. Above the threshold chloride ion content for corrosion onset. Corrosion occurs.
Grade II-1 (Former acceleration stage)	Corrosion cracking occurs. Rust exudation is observed.
Grade II-2 (Latter acceleration stage)	Many corrosion cracks occur. Rust exudation and partial peeling/spalling are observed. Corrosion amount increases.
Grade III (Deterioration stage)	Many corrosion cracks occur. Crack widths are large. Rust exudation and peeling/spalling are observed. Displacement/deflection is large.

14.4 Assessment and judgement

(1) Assessment and judgement of the results of initial inspection, routine inspection, regular inspection and emergency inspection should be in accordance with the Part I. Assessment and judgement of the results of detailed inspection should be in accordance with the following items of this section (2), (3) and (4).
(2) Since performance degradation of a structure due to chloride induced deterioration is induced by corrosion of steel reinforcement, affected performances should be assessed with sufficient care as to which stage the structure is in; initiation, propagation, acceleration and deterioration stages.
(3) It is recommended to make assessment of various performances of a structure at the time of inspection and at the end of the designed service life by quantitative methods. However, where quantitative method is inapplicable, the semi-quantitative grading method may be used.

(4) Judgement shall be made in consideration of the degree of performance degradation due to chloride-induced deterioration, importance of the structure and maintenance category.

[Commentary]
Relationship between the grade of defects of the appearance and the performance degradation is presented in Table C14.4.1.

Table C14.4.1 Appearance grade of structures related to typical performance degradation

<table>
<tr><th>Appearance grade</th><th>Safety performance</th><th>Serviceability performance</th><th>Hazards to third parties
Aesthetic appearance/ landscape</th></tr>
<tr><td>Grade I-1 (Initiation stage)</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Grade I-2 (Propagation stage)</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Grade II-1 (Former acceleration stage)</td><td>-</td><td>-</td><td rowspan="3">Deterioration in aesthetic appearance
- Cracking
- Rust exudation
- Reinforcement exposure

Hazards to third parties
- Peeling/spalling</td></tr>
<tr><td>Grade II-2 (Latter acceleration stage)</td><td>-</td><td rowspan="2">Reduction in rigidity (increase in deformation/generation of oscillation)
- Losses in steel cross-sectional area
- Reduction in bond strength between steel and concrete
- Losses in concrete cross-sectional area due to delamination/peeling</td></tr>
<tr><td>Grade III (Deterioration stage)</td><td>Reduction in load-bearing capacity/ductility
- Losses in steel cross-sectional area and rupture
- Losses in concrete cross-sectional area due to delamination/peeling</td></tr>
</table>

14.5 Remedial measures

14.5.1 Selection of remedial measures

When remedy is judged to be necessary for chloride induced performance degradation of a structure, remedial measures that satisfy the performance requirements should be selected. When it is difficult to select measures based on performance verification, they may be selected based on appearance grading of the structure.

[Commentary]
Remedial measures vary depending on the type and importance of the structure, rate of deterioration progress and maintenance category. The criteria given in Table C14.5.1.1 are advisable as a standard.

Table C14.5.1.1 Appearance grades of structures and remedial measures

Appearance grade of structure	Grade I-1 (Initiation stage)	Grade I-2 (Propagation stage)	Grade II-1 (Former acceleration stage)	Grade II-2 (Latter acceleration stage)	Grade III (Deterioration stage)
Extensive inspection	O	O	OO	OO	
Repair	(O)	O	OO	OO	O
Strengthening				OO	OO
Appearance improvement			OO	OO	O
Utility restoration				OO	OO
Functionality improvement				O	OO
Usage restriction				O	OO
Demolition/removal					OO

OO: Standard measures, O: possible measures, (O): preventive measures

14.5.2 Repair and strengthening

Methods and materials for repair and strengthening shall be selected to achieve the specified effect in consideration of the performance degradation due to chloride induced deterioration.

[Commentary]

Repair and strengthening of structures deteriorated by chloride-induced deterioration are classified into the methods given in Table C14.5.2.1 according to the expected effects.

Table C14.5.2.1 Expected effects and methods of repair and strengthening

Expected effect	Method
Reduce supply of steel-corroding factors	Surface coating
Eliminate steel-corroding factors	Patching, Electrochemical desalination
Suppress progress of steel corrosion	Surface coating, Cathodic protection, Patching, Rust-preventing coating
Improve load-bearing capacity	FRP adhesion, Patching, Out cables, Concrete lining, Thickness increasing

In selecting a suitable method, Table C 14.5.2.1 as well as the current state of performance degradation should be considered. As a standard, measures given in Table C14.5.2.2 should be taken.

Table C14.5.2.2 Appearance deterioration grades of structures related to standard methods

Appearance grade of structure	Standard method
Grade I-1 (Initiation stage)	(Surface coating)*
Grade I-2 (Propagation stage)	Surface coating, Cathodic protection, Electrochemical desalination
Grade II-1 (Former acceleration stage)	Surface coating, Patching, Cathodic protection, Electrochemical desalination
Grade II-2 (Latter acceleration stage)	Patching
Grade III (Deterioration stage)	Adhesion of FRP, Patching, Out cables, Concrete lining, Increasing thickness

*: Preventive methods

14.6 Records

Items special to chloride-induced deterioration should be recorded.

Chapter 15. Standard Maintenance Method for Frost Attack

15.1 General

(1) This standard maintenance method provides standard methods of deterioration prediction, inspection, assessment, judgement, remedial measures and record carried out for maintenance or formulation of a maintenance plan of structures in which performance degradation due to frost attack has occurred or structures with a high risk of performance degradation due to frost attack. Items common to all deterioration mechanisms should be in accordance with the Part I.
(2) This maintenance standard covers maintenance activities those are carried out to discover frost attack at an early stage and retain the performance of the entire structure.
(3) This standard maintenance method is primarily applied to structures designated to the maintenance category B.

15.2 Method of deterioration prediction

15.2.1 General

(1) Prediction of frost attack should comprise prediction of the duration of the initiation stage, propagation stage, acceleration stage and deterioration stage.
(2) For the prediction of the duration of each stage, it is effective to estimate the possibility of frost attack and deterioration depth from concrete surface.

[Commentary]
Table C15.2.1.1 presents a model (concept) of the relationship between the depth of frost attack and the performance degradation of a structure and the factors determining each stage and its duration.

Table C15.2.1.1 Definitions and factors determining duration of deterioration stages

Deterioration stage	Definition	Major factors determining duration
Initiation stage	Concrete is subjected to freezing and thawing but deterioration is not apparent	Risk of frost attack, number of freezing and thawing cycles
Propagation stage	Surface deterioration of concrete progresses, however, reinforcement corrosion does not occur	Depth of frost deterioration (number of freezing and thawing cycles, freezing water content)
Acceleration stage	Concrete deterioration and reinforcement corrosion increase	Depth of frost deterioration, rate of reinforcement corrosion
Deterioration stage	Concrete deterioration exceeds the cover depth and reduction in the load-bearing capacity becomes significant	Rate of reinforcement corrosion

15.2.2 Prediction of frost attack

Frost attack of a structure can be predicted based on the environment in which the structure is in use, quality of aggregate and frost resistance of concrete.

[Commentary]
A representative phenomenon of frost attack derived from aggregate is pop-out. Water present in aggregate freezes, causing the aggregate to expand, thereby consequently surface mortar layer delaminates. Water absorption of less than 3% and weight loss of less than 12% by "aggregate soundness test" are generally proposed as the critical values for physical properties of aggregate to achieve enough frost resistance. For concrete, freezing and thawing test of the concrete is used for frost resistance evaluation. Concrete is judged to have high frost resistance when its relative dynamic modulus of elasticity is larger than 80% and its length change is less than 200 μm after 300 cycles.

15.2.3 Prediction of frost deterioration depth
Prediction of the frost deterioration depth should be made from the depth of frost deterioration and its rate of progress obtained from inspection.

15.3 Methods of inspection

15.3.1 General
For a structure suffering or expected to suffer from performance degradation due to frost attack, investigation shall be made focusing on the environmental conditions, such as lowest temperature, and depth of frost deterioration of concrete by visual observation, etc.

[Commentary]
Table C15.3.1.1 gives standard inspection items for each deterioration stage.

Table C15.3.1.1 Standard inspection items

Appearance grade of structure	Initiation stage	Propagation stage	Acceleration stage	Deterioration stage
Defective appearance	OO	OO	OO	OO
Chloride ion content	O	O	O	OO
Carbonation depth	*	*	OO	OO
Steel corrosion	*	*	O	OO
Concrete strength	*	*	*	*
Load-bearing capacity	*	*	*	*
Bar alignment	*	O	O	*
Deterioration external force	OO	OO	OO	OO
Monitoring	*	*	*	*

OO: Mandatory items, O: desirable items, *: items to be adopted as required

15.3.2 Initial inspection
For initial inspection, inspection items should be adequately selected for new structures, existing structures and structures after large scale remedial measures.

[Commentary]
Initial inspection is conducted not only for new structures, but also at the beginning of maintenance for structures with performance degradation due to frost attack and structures after remedial measures. It is therefore important to select items with which the progress of deterioration can be grasped. Items particularly important in the initial inspection of structures having the risk of frost deterioration include the followings; (i) Quality of aggregate (water absorption, soundness loss), (ii) water to cement ratio (or water to binder ratio), (iii) air content (air void spacing factor), (iv) concrete cover thickness, (v) water saturation

of concrete (water content), (vi) environmental conditions (lowest temperature, number of freezing and thawing cycles) and (vii) initial defects.

15.3.3 Routine inspection

Routine inspection should comprise inspection of defects on concrete surfaces, such as micro cracks, scaling and pop-out, and water supplying (wetting of concrete).

[Commentary]

It is necessary to inspect changes in the surface condition of concrete, such as pop-out, micro cracks and scaling, which are common to frost attack. Even if no deterioration is found on concrete surface, concrete is expected to deteriorate where wetting of concrete exists by water supplying. It is therefore desirable to check the water supply conditions during inspection.

15.3.4 Regular inspection

Regular inspection is carried out to obtain information that is difficult to obtain during routine inspection. Appearance investigation should be carried out more in detail than the routine inspection, such as appearance-related properties and water supplying.

[Commentary]

The major purpose of regular inspection is to obtain information that is difficult to grasp during routine inspection. Therefore, portions of structure where deterioration was recognized during routine inspection should be investigated more in detail.

15.3.5 Detailed inspection

For detailed inspection, it is effective to confirm the environmental conditions to which the structure is exposed, such as lowest temperature and number of freezing and thawing cycles, as well as to measure the depth of frost deterioration by using drilled core specimens.

[Commentary]

Inspection items should be selected according to the purpose of inspection.

(i) Environmental conditions

The degree and form of frost deterioration generally vary depending on the lowest temperature, number of freezing and thawing cycles and degree of water supply that the structure is subjected to.

(ii) Depth of frost deterioration

The depth of frost deterioration should be assessed by the scaling depth and depth of deterioration due to micro cracks. The depth of scaling should be measured on the surface of the structure. The depth of deterioration due to micro cracks should be measured by using the drilled core specimens taken from where frost attack is confirmed and judged from the distributions of ultrasonic velocity and pore size along the depth.

(iii) Reinforcement corrosion

Reinforcement corrosion directly affects the performance of a structure, therefore, it is necessary to expose the reinforcement for directly investigating the presence/absence of corrosion, location and area of corrosion (if possible), weight and depth of pitting corrosion.

(iv) Appearance of the structure

Defects on the appearance of a structure caused by frost attack can be valuable information for performance assessment. It is therefore necessary to inspect the portion having the defects and the degree of the defects as quantitatively as possible. The relationship between the appearance grade and the state of deterioration is

as presented in Table C15.3.5.1.

Table C15.3.5.1 Grades of appearance and deterioration of structures

Grade of appearance of structures	State of deterioration
Grade I (Initiation stage)	Subjected to freezing thaw action but no performance degradation. Initial soundness is retained.
Grade II (Propagation stage)	Small depth of frost deterioration. Little change in rigidity with no reinforcement corrosion, but aesthetic appearance is affected.
Grade III (Acceleration stage)	Large depth of frost deterioration. Hazards to third parties such as spalling occur with reinforcement corrosion.
Grade IV (Deterioration stage)	Depth of frost deterioration is greater than the cover depth. Significant reinforcement corrosion with adverse effects on utility performance and safety performance.

15.4 Assessment and judgement

(1) Assessment and judgement of the results of initial inspection, routine inspection, regular inspection and extraordinary inspection should be in accordance with the Part I. Assessment and judgement of the results of detailed inspection should be in accordance with the following items of this section, (2) and (3).

(2) Performance degradation of a structure due to frost attack is induced by reduction in cross-sectional area of concrete and corrosion of steel reinforcement, therefore, affected performances should be assessed with sufficient care as to which stage the structure is in; the initiation, propagation, acceleration or deterioration stage.

(3) It is desirable that assessment of various performances of a structure shall be made by quantitative methods for the time of inspection and for the end of the planned life span. However, if quantitative methods are inapplicable, the grading method may be applied.

[Commentary]

The deterioration process is related to typical performance degradation as presented in Table 15.4.1. It is therefore practical to assess the performance degradation of the structure semi-quantitatively at the time of inspection referring to Table C15.4.1 by grading its appearance.

Table C15.4.1 Appearance grades of structures related to typical performance degradation

Appearance grade of structure	Safety performance	Serviceability performance	Hazard to third parties Aesthetic appearance/landscape
I (Initiation)			
II (Propagation)			Degradation of aesthetic appearance - Scaling - Pop-out - Cracking Hazards to third parties - Peeling - Spalling
III (Acceleration)			
IV (Deterioration)	Degradation of load-bearing capacity - Losses in concrete cross-sectional area - Steel corrosion	Displacement/deformation - Losses in concrete cross-sectional area - Steel corrosion	

15.5 Remedial measures

15.5.1 Selection of remedial measures

When remedy is judged to be necessary for performance degradation caused by frost attack of a structure, remedial measures that satisfy the performance requirements shall be selected. When it is difficult to select measures based on performance verification, they should be selected based on appearance grading of the structure.

[Commentary]

When judgement based on quantitative assessment is difficult, grading of the deterioration of the structure should be used as a standard. Remedial measures vary depending on the type and importance of the structure, rate of deterioration progress and maintenance category. The criteria given in Table C15.5.1.1 are advisable as a standard.

Table C15.5.1.1 Appearance grades of structures and remedial measures

Appearance grade of structure	Grade I (Initiation stage)	Grade II (Propagation stage)	Grade III (Former acceleration stage)	Grade IV (Deterioration stage)
Extensive inspection		O	O	O
Repair	(O)	O	OO	OO
Strengthening			O	OO
Appearance improvement		OO	OO	O
Utility restoration			O	O
Functionality improvement				O
Usage restriction			O	O
Demolition/removal				OO

OO: Standard measures, O: possible measures, (O): preventive measures

15.5.2 Repair and strengthening

Methods and materials for repair and strengthening shall be selected to satisfy the specified effect in consideration of frost-induced performance degradation.

[Commentary]

The purposes of repair and strengthening include suppression of water supply, which is the primary cause of frost attack, removal of deteriorated portions and increase in the load-bearing capacity. Methods for fulfilling these purposes include those given in Table C15.5.2.1. Also, the method to be selected is depending on the degree of deterioration as given in Table C15.5.2.2. Measures for an earlier stage of deterioration are much simple in most cases. Judgement should therefore be made based on the maintenance plan.

Table C15.5.2.1 Expected effects and methods of repair/strengthening

Expected effect	Method
Reduce water supply	Surface coating, Grouting into cracks
Remove deteriorated portions	Patching, Grouting into cracks
Improve load-bearing capacity	Increasing thickness, Concrete replacement, Concrete lining

Table C15.5.2.2 Appearance deterioration grades of structures related to standard methods

Appearance grade	Standard method
I (Initiation stage)	(Surface coating)*
II (Propagation stage)	Surface coating
III (Acceleration stage)	Surface coating, Grouting into cracks, patching
IV (Deterioration stage)	Grouting into cracks, Increasing thickness, Concrete replacement, Concrete lining,

*: Preventive methods

15.6 Records

Items peculiar to frost attack should be recorded.

Chapter 16. Standard Maintenance Method for Chemical Attack

16.1 General

(1) This Standard Maintenance Method provides standard methods of deterioration prediction, inspection, assessment, judgement, remedial measures and recording carried out for maintenance or formulation of a maintenance plan of structures in which performance degradation due to chemical attack has occurred or structures with a high risk of performance degradation due to chemical attack. Items common to all deteriorating mechanisms should be in accordance with the Part I.
(2) This Standard Maintenance Method covers maintenance activities carried out to discover concrete deterioration and steel reinforcement corrosion due to chemical attack at an early stage and retain the performance of the entire structure.
(3) This Standard Maintenance Method is primarily applied to structures designated to maintenance category B.

16.2 Method of deterioration prediction

16.2.1 General

(1) Prediction of deterioration due to chemical attack should comprise prediction of the duration of the initiation stage, propagation stage, acceleration stage and deterioration stage, and cover the progress of protective coating deterioration, concrete deterioration and reinforcement corrosion.
(2) Prediction of deterioration should be based on the results of inspection. If no inspection result is available, prediction should be made by assessing the quality of protective coating, concrete and the environmental conditions to which the structure is exposed, with an adequate safety factor.

[Commentary]
For a structure facing a risk of chemical attack, the factors determining the deterioration stages and periods are presented in TableC16.2.1.1. When structures without a protective coating such are subjected to acid attack, the initiation stage can be extremely short and immediately followed by the propagation stage.

Table C16.2.1.1 Definitions of deterioration stages

Deterioration stage	Definition	Major factors determining duration
Initiation stage	Up to the time when concrete deterioration starts	Rate of permeation of deterioration factors into protective coating
Propagation stage	Up to the time when concrete deterioration depth reaches the reinforcement level	Rate of permeation of deterioration factors into concrete
Acceleration stage	Period during reinforcement corrosion progresses	Corrosion rate of reinforcing steel
Deterioration stage	Period during the load-bearing capacity is significantly reduced by the losses in the cross-sectional area of concrete and reinforcing steel	Corrosion rate of reinforcing steel

16.2.2 Prediction of progress of chemical attack

(1) Prediction of the progress of chemical attack shall be made with adequate consideration of the qualities of the protective coating and concrete and the effects of the environmental conditions to which the structure is exposed.

(2) Prediction of the progress of chemical attack should be made by either of the following methods;

(i) Use of simulation testing.

(ii) The rule of square root of time.

16.2.3 Prediction of progress of steel corrosion

(1) Prediction of the progress of steel corrosion shall be made with adequate consideration of the effects of substances causing chemical attack.

(2) Onset of steel corrosion should be judged by the uncarbonated concrete cover depth.

(3) Prediction of the progress of steel corrosion should be made by either of the following methods;

(i) Method based on the corrosion amount obtained from the inspection.

(ii) Use of simulation testing.

16.2.4 Correction of prediction

When the state of deterioration obtained from inspection differs from the previous prediction, the cause should be investigated, and the deterioration prediction shall be corrected. The subsequent maintenance plan should be changed if necessary.

16.3 Methods of inspection

16.3.1 General

For a structure suffering or expected to suffer from performance degradation due to chemical attack, the items, methods and time of inspection shall be selected so that assessment of the state of performance degradation, prediction of deterioration progress, judgement for the necessity of remedial measures and determination of such measures can be adequately performed, with considering the maintenance category of the structure.

[Commentary]

Table C16.3.1.1 gives a standard for inspection items for each deterioration stage.

Table C16.3.1.1 Standard inspection items

Deterioration stage	Initiation	Propagation	Acceleration	Deterioration
Defective appearance	OO	OO	OO	OO
Permeation depth of deterioration factors	OO	OO	O	*
Carbonation depth	*	OO	O	*
Steel corrosion	*	O	OO	OO
Concrete strength	O	OO	OO	O
Load bearing capacity	*	*	O	OO
Bar alignment	*	OO	O	*
Deterioration external force	OO	OO	OO	OO
Monitoring	*	*	*	*

OO: Mandatory items, O: desirable items, *: items to be adopted as required

16.3.2 Initial inspection

For initial inspection, inspection items should be adequately selected for new structures, existing structures and structures after remedial measures.

[Commentary]

Items particularly important in the initial inspection of structures involving the risk of chemical attack include the followings; (i) Environmental conditions, (ii) Presence/absence of protective coating for concrete and its type, (iii) Water-cement ratio (or water-binder ratio), (iv) Presence/absence of a mineral admixture and its type and content, (v) Cover depth and (vi) Initial defects.

16.3.3 Routine inspection

Routine inspection should include an inspection of defects on the surfaces of protective coating, such as quality change, cracking, peeling and spalling. It should includes on the surfaces of concrete, such as quality change, cracking, peeling, spalling, rust exudation and free lime, and other deterioration of appearance, such as water leakage and displacement/deformation, as well as abnormal smell.

16.3.4 Regular inspection

In regular inspection, appearance investigation should be carried out in more detail than the routine inspection. Monitoring shall be performed if necessary.

16.3.5 Detailed inspection

(1) In detailed inspection, defects on the surfaces of protective coating (width and length of cracks and areas of peeling/spalling) and surfaces of concrete (width and length of cracks and depth of cross-sectional loss), qualities of concrete cores and concrete cover for reinforcement should be grasped in detail. These should be examined with regard to the entire structure or portions, by collecting quantitative data on the penetration depth of deterioration factors, carbonation depth and steel corrosion.

(2) Investigation shall be conducted on the deformability of the structure or its members and strain of protective coating, concrete and/or reinforcement by appropriate methods such as loading tests.

(3) If it is necessary, investigation shall be conducted on the environmental conditions, such as temperature, humidity and concentrations of deterioration factors, deterioration external forces and loads acting on the structure.

[Commentary]

The appearance grades of structures with degraded performances due to chemical attack are given in Table

C16.3.5.1.

Table C16.3.5.1 Grades of appearance and state of deterioration of structures

Grade of appearance	State of deterioration
Grade I (Former initiation stage)	No apparent defects.
Grade II-1 (Latter initiation stage)	Defects are observed on protective coating.
Grade II-2 (Propagation stage)	Defects are observed on concrete surfaces. Deterioration factors do not penetrate to the reinforcement level yet.
Grade III-1 (Former acceleration stage)	Significant cross-sectional losses of concrete. Deterioration factors penetrate to the reinforcement. Reinforcement corrosion is observed.
Grade III-2 (Latter acceleration stage)	Significant cross-sectional losses of concrete. Reinforcement corrosion increases.
Grade IV (Deterioration stage)	Significant reinforcement corrosion. Large displacement/deflection.

16.4 Assessment and judgement

(1) Assessment and judgement of the results of initial inspection, routine inspection, regular inspection and extraordinary inspection should be in accordance with the Part I. Assessment and judgement of the results of detailed inspection should be in accordance with the following items of this section, (2), (3) and (4).
(2) Performance degradation of a structure due to chemical attack is induced by cross-sectional losses of concrete and corrosion of steel reinforcement, affected performances should be assessed with sufficient care as to which stage the structure is in; the initiation, propagation, acceleration or deterioration stage.
(3) It is desirable that performance assessment is made for the time of inspection and for the end of the planned life span by quantitative methods. If quantitative methods are inapplicable, the semi-quantitative grading method may be used.
(4) Judgement shall be made in consideration of the degree of performance degradation due to chemical attack, importance of the structure and maintenance category.

[Commentary]
Performance degradation of the structure may be semi-quantitatively assessed referring to Table C16.4.1 based on the grading of defects of the appearance according to Table C16.3.5.1.

Table C16.4.1 Appearance grades of structures related to typical performance degradation

Appearance grade	Safety performance	Serviceability performance	Hazards to third parties Aesthetic appearance/ landscape
Grade I-1 (Former initiation)	-	-	-
Grade II-1 (Latter initiation)	-	-	Deterioration in aesthetic appearance - Peeling/spalling of protective coating

Grade II-2 (Propagation)	Reduction in load-bearing capacity - Losses in concrete cross-sectional area	Reduction in rigidity (increase in deformation/generation of oscillation) - Reduction in bond strength between steel and concrete	Deterioration in aesthetic appearance - Quality changes/cracking of concrete Hazards to third parties -Peeling -Spalling
Grade III-1 (Former acceleration)		Reduction in rigidity (increase in deformation/generation of oscillation) -Losses in concrete cross-sectional area -Losses in steel cross-sectional area	Deterioration in aesthetic appearance - Quality changes/cracking of concrete - Reinforcement exposure - Rust exudation
Grade III-2 (Latter acceleration)	Reduction in load-bearing capacity/ductility - Losses in steel cross-sectional area		
Grade IV (Deterioration)			

16.5 Remedial measures

16.5.1 Selection of remedial measures

When remedy is judged to be necessary for performance degradation of a structure due to chemical attack, remedial measures that satisfy the performance requirements shall be selected. If it is difficult to select measures based on performance verification, they may be selected based on appearance grading of the structure.

[Commentary]

If judgement based on quantitative assessment is difficult, judgement should be made based on the grading of deterioration of the structure. Remedial measures vary depending on the type and importance of the structure, rate of deterioration progress and maintenance category. The criteria given in Table C16.5.1.1 are advisable as a standard.

Table C16.5.1 Appearance grades of structures and remedial measures

Appearance grade of structure	I (Former initiation)	II-1 (Latter initiation)	II-2 (Acceleration)	III-1 (Former acceleration)	III-2 (Latter acceleration)	IV (Deterioration)
Extensive inspection	O	O	OO	OO	OO	
Repair	(O)	OO	OO	OO	OO	O
Strengthening			O	OO	OO	OO
Appearance improvement		OO	OO	OO	OO	O
Utility restoration			O	OO	OO	OO
Functionality improvement			O	O	OO	OO
Usage restriction					O	OO
Demolition/ removal						OO

OO: Standard measures, O: possible measures, (O): preventive measures

16.5.2 Repair and strengthening

Methods and materials for repair and strengthening shall be selected to achieve the specified effect in

consideration of performance degradation due to chemical attack.

[Commentary]
Repair and strengthening of structures deteriorated by chemical attack are classified into the methods given in Table C16.5.2.1 according to the expected effects.

Table C16.5.2.1 Expected effects and methods of repair/strengthening

Expected effect	Method
Suppress progress of chemical attack	Surface coating (resin lining, sheet lining), FRP adhesion
Suppress progress of steel corrosion	Surface coating, Patching, Rust-preventing coating
Improve load-bearing capacity	FRP adhesion, Thickness increasing, Concrete lining

In selecting the methods, Table C 16.5.2.1 as well as the current state of performance degradation should be considered. As a standard, measures given in Table C16.5.2.2 should be taken.

Table C16.5.2.2 Appearance deterioration grades of structures related to standard methods

Appearance grade of structure	Standard method
I (Former initiation)	(Surface coating)*
II-1 (Latter initiation)	Surface coating
II-2 (Propagation)	Impregnation, Patching, Surface coating
III-1 (Former acceleration)	Patching, Surface coating
III-2 (Latter acceleration)	Patching, Surface coating, Thickness increasing
IV (Deterioration)	FRP adhesion, Patching, Surface coating, Thickness increasing, Concrete lining

*: Preventive methods

16.6 Records

Items special to chemical attack should be recorded.

Chapter 17. Standard Maintenance Method for Alkali Aggregate Reaction

17.1 General

(1) This Standard Maintenance Method provides standard methods of deterioration prediction, inspection, assessment, judgement, remedial measures and recording carried out for maintenance or formulation of a maintenance plan for structures in which performance degradation due to alkali aggregate reaction (ASR) has occurred or structures with a high risk of performance degradation due to ASR. Items common to all deterioration mechanisms should be in accordance with the Part I.
(2) This Standard Maintenance Method covers maintenance activities carried out to discover ASR-induced expansion and concomitant concrete deterioration at an early stage and retain the performance of the entire structure.
(3) This Standard Maintenance Method is primarily applied to structures designated to maintenance category B.

17.2 Method of deterioration prediction

17.2.1 General

(1) Prediction of the progress of deterioration of ASR affected structures should be performed using the expansion of concrete and subsequent crack propagation as indexes.

(2) Prediction of deterioration should be based on the results of inspection. If no inspection result is available, prediction should be made by assessing the alkali-silica reactivity of aggregate, quality of concrete and environmental conditions to which the structure is exposed, with an adequate safety factor.

[Commentary]

The grade of the ASR affected deterioration progress of structure is defined as follows;

Grade I: ASR progresses but expansion is not yet apparent (initiation stage).

Grade II: Concrete expansion progresses continuously with steady supply of water and alkali, causing cracking (propagation stage).

Grade III: Expansion due to ASR becomes significant with the almost maximum expansion rate, while crack propagates (acceleration stage).

Grade IV: Crack density increases and steel corrosion progresses, while the load-bearing capacity of members is decreased by the strength loss of concrete and damage of reinforcing steel (deterioration stage).

Table C17.2.1.1 Definitions of deterioration stages due to ASR

Deterioration process	Definition	Major factors determining duration
Initiation stage	ASR progresses but expansion is not yet apparent.	Rate of ASR gel formation (Type and content of reactive components, alkali content)
Propagation stage	Expansion continuously progresses with steady supply of water and alkali, causing cracking.	Rate of water-absorbing expansion of ASR gel (Supply of water and alkali)
Acceleration stage	Expansion due to ASR becomes significant with the almost maximum expansion rate, while cracking propagates.	Rate of water-absorbing expansion of ASR gel (Supply of water and alkali)
Deterioration stage	-Crack density increases and steel corrosion progresses -Load-bearing capacity of members is affected by the strength loss of concrete and damage of reinforcing steel.	Rate of water-absorbing expansion of ASR gel (Supply of water and alkali) Corrosion rate of steel Rate of increase in tensile stress of reinforcement

17.2.2 Prediction of ASR progress

(1) Prediction of the ASR progress shall be made with adequate consideration to the alkali-silica reactivity of aggregate, mixture proportions of concrete and effects of environmental conditions to which the structure is exposed.

(2) Prediction of ASR affected deterioration should be made from the results of inspection of the structure or accelerated curing tests of drilled cores, by using the amounts of expansion of concrete and subsequent cracking as indexes.

17.3 Methods of inspection

17.3.1 General

For a structure suffering or expected to suffer ASR affected performance degradation, the items, methods

and time of inspection shall be selected so that appropriate assessment of the state of degradation, prediction of the progress of deterioration, judgement for the necessity of remedial measures and determination of such measures can be performed, with considering the maintenance category of the structure.

17.3.2 Initial inspection

For initial inspection, items to be inspected should be adequately selected for new structures, existing structures and structures after large scaled remedial measures.

17.3.3 Routine inspection

Routine inspection should comprise inspection of defects on concrete surfaces, such as cracking, discoloration, gel exudation, rust exudation and peeling/spalling, as well as deterioration of appearance, such as displacement/deformation, dislocation and faulting of the structure.

17.3.4 Regular inspection

In regular inspection, appearance investigation should be carried out in more detail than the routine inspection. Monitoring should be performed to grasp the crack propagation and expansion behavior of the structure.

17.3.5 Detailed inspection

(1) In detailed inspection, alkali silica reactivity of aggregate and ASR resistance of concrete should be assessed. Also, data should be collected from the entire scope of inspection or representative points of the structure in regard to defects on concrete surfaces, such as cracking, discoloration and gel exudation, on qualities of concrete by strength measurement of drilled cores and estimated residual expansion by accelerated curing tests on drilled cores.
(2) The alkali-silica reactivity of aggregate is judged by the chemical method and the mortar bar method, specified in Appendix 7 and 8, in JIS A 5308: Ready-mixed concrete.
(3) The ASR resistance of concrete is judged by the extent of cracking and expansion of concrete specimens made of concrete proportioned and produced under the same conditions as that used for the structure and subjected to an accelerated curing test.
(4) The residual expansion of concrete is judged by the expansion of drilled cores of the structure and subjected to an accelerated curing test.
(5) The load-bearing capacity and rigidity of the structure shall be examined by methods such as loading test.

[Commentary]

The grades of the appearance of structures involving ASR affected performance degradation are as given in Table C17.3.5.1.

Table C17.3.5.1 Grades of appearance and deterioration of structures

Grade of appearance	State of deterioration
Grade I (Initiation stage)	ASR occurs, but no apparent defects.
Grade II (Propagation stage)	Cracking occurs due to ASR-induced expansion. Discoloration and gel exudation are observed.
Grade III (Acceleration stage)	Cracking due to ASR propagates. Number, width and density of cracks increase.

Grade IV (Deterioration stage)	Many cracks due to ASR occur. Horizontal and vertical drifts of the structure are observed. Partial peeling/spalling occurs. Steel corrosion progresses with rust exudation and large displacement/deformation.

17.4 Assessment and judgement

(1) Assessment and judgement of the results of initial inspection, routine inspection and regular inspection should be in accordance with the Part I. Assessment and judgement of the results of detailed inspection should be in accordance with the following items of this section, (2), (3) and (4).
(2) Performance degradation of a structure due to ASR is induced by expansion and subsequent cracking of concrete, therefore, performances should be assessed with sufficient care as to which stage the structure is in; the initiation, propagation, acceleration or deterioration stage.
(3) Assessment of the performances of the structure should be made by the grading method.
(4) Judgement shall be made in consideration of the degree of performance degradation due to ASR, importance of the structure and maintenance category.

[Commentary]
The progress of ASR-induced deterioration is related to the safety performance, serviceability performance and hazard to third parties of the structure as given in Table C17.4.1.

Table C17.4.1 Appearance grades of structures related to typical performance degradation

<table>
<tr><td rowspan="2">Appearance grade</td><td colspan="3">Typical performance degradation</td></tr>
<tr><td>Safety performance</td><td>Serviceability performance</td><td>Hazard to third parties</td></tr>
<tr><td>Grade I
(Initiation)</td><td></td><td></td><td></td></tr>
<tr><td>Grade II
(Propagation)</td><td>-</td><td rowspan="3">Reduction in water tightness
- Cracking
Onset of Corrosion of reinforcing steel
- Cracking
Displacement/deformation of structure
- Deflection
- Dislocation
- Faulting</td><td rowspan="3">Deterioration in aesthetic appearance
- Cracking
- Discoloration
- Gel exudation

Hazards to third parties
- Peeling/spalling</td></tr>
<tr><td>Grade III
(Acceleration)</td><td rowspan="2">Reduction in ductility
- Reinforcement corrosion
Reduction in load-bearing capacity
Precise verification of load-bearing capacity
Simple verification
Losses in concrete strength,
Losses in bond strength between concrete and steel,
Yielding and rupture of rebar</td></tr>
<tr><td>Grade IV
(Deterioration)</td></tr>
</table>

17.5 Remedial measures

17.5.1 Selection of remedial measures
When remedy is judged to be necessary for ASR affected performance degradation of a structure, remedial measures that satisfy the performance requirements shall be selected. When it is difficult to select measures based on performance verification, they may be selected based on appearance grading of the structure.

[Commentary]
Remedial measures vary depending on the type and importance of the structure, rate of deterioration progress and maintenance category. The criteria given in Table C17.5.1.1 are advisable as a standard.

Table C17.5.1.1 Deterioration grades of structures and remedial measures

Deterioration grade of structure	I (Initiation)	II (Propagation)	III (Acceleration)	IV (Deterioration)
Extensive inspection	O	O	OO	OO
Repair	(O)	OO	OO	O
Strengthening			O	OO
Appearance improvement			O	OO
Utility restoration				OO
Functionality improvement		OO	OO	O
Usage restriction		O	O	OO
Demolition/removal		O	O	OO

OO: Recommended standard measures, O: Possible measures, (O): Preventive measures

17.5.2 Repair and strengthening

Methods and materials for repair and strengthening shall be selected to achieve the specified effect in consideration of the performance degradation due to ASR.

[Commentary]

Repair and strengthening of structures deteriorated by ASR are classified as given in Table C17.5.2.1 according to the expected effects.

Table C17.5.2.1 Expected effects and methods of repair/strengthening

Expected effect	Method
Suppress progress of ASR	Surface coating (coating, impregnation), Grouting into cracks
Confine expansion due to ASR	Applying prestress, Lining with steel plates, PC, FRP
Remove deteriorated portions	Patching
Improve load-bearing capacity	Adhesion of steel plates/FRP, Applying prestress, Increasing thickness, Lining with steel plates/PC/FRP, Out cables

17.6 Records

Items special to ASR should be recorded.

Chapter 18. Standard Maintenance Method for Fatigue of RC Slab of Road Bridge

18.1 General

(1) This standard maintenance method provides standard methods of deterioration prediction, inspection, assessment, judgement, remedial measures and recording carried out for maintenance or formulation of a maintenance plan of reinforced concrete slabs in which performance degradation due to fatigue has occurred or reinforced concrete slabs with a high risk of performance degradation due to fatigue. Items common to all deterioration mechanisms should be in accordance with the Part I.

(2) This maintenance standard covers maintenance activities carried out to discover deterioration/damage of reinforced concrete slabs due to fatigue at an early stage and retain the performance of entire structure.

(3) This maintenance standard is primarily applied to RC slabs designated to maintenance category B.

18.2 Method of deterioration prediction

18.2.1 General

(1) Prediction of fatigue of reinforced concrete slabs should basically comprise prediction of the duration of the four stages of the deterioration process, initiation stage, propagation stage, acceleration stage and deterioration stage, by utilizing the inspection results, such as changes on the bottom surface of the slab.

(2) Prediction of deterioration should be based on the results of inspection. Where no inspection results are available, prediction should be made by incorporating an adequate safety factor in consideration of factors affecting the progress of deterioration.

[Commentary]

Table C18.2.1.1 presents the process of performance degradation of slabs due to fatigue and factors affecting the progress of deterioration

.

Table C18.2.1.1 Definitions of deterioration stages of reinforced concrete slabs

Deterioration process	Definition	Major factors determining duration
Initiation stage (Grade I)	A few cracks can be recognized in one direction along longitudinal bars due to drying shrinkage or loading. Depending on the restraining conditions of the main beams, transverse cracks also develop due to drying shrinkage and temperature changes in the main beam.	Applied design standard Slab thickness Transverse reinforcement content Slab span Execution Drying shrinkage Service conditions Traffic, Tonnage of vehicles Wheel paths
Propagation stage (Grade II)	As the bending cracks in the axial directions develop, transverse cracks also begin to develop, forming map cracking. Despite the increase in the apparent crack density, the continuity of the reinforced concrete slab is retained.	
Acceleration stage (Grade III)	Cracks are interconnected into fine networks, and they begin to open and close with rubbing motions. When cracks ravel, the resistance of the integrated concrete cross section is no longer expected. The load-bearing capacity of the reinforced concrete slab abruptly decreases.	In addition to the above, Environmental conditions Effect of seepage water Remedial measures taken Slab waterproofing Repair/strengthening
Deterioration stage (Grade IV)	The continuity of the slab is lost when penetrating cracks occur in the slab cross sections. The slab begins to resist the wheel loads as a group of beams divided by penetrating cracks. The ultimate load-bearing capacity of the members is affected by the intervals of penetrating cracks, concrete strength and reinforcement content.	All of the above

18.2.2 Correction of prediction

When the state of deterioration obtained from inspection results differs from the previous prediction, the cause should be investigated, and the deterioration prediction shall be corrected. The subsequent maintenance plan should be changed if necessary.

18.3 Methods of inspection

18.3.1 General

For a reinforced concrete slab suffering or expected to suffer performance degradation due to fatigue, the

items, methods and time of inspection shall be selected so that appropriate assessment of the state of degradation, prediction of deterioration progress, judgement for the necessity of remedial measures and determination of such measures can be performed, while considering the maintenance category of the slab.

[Commentary]

For slabs, the inspection items for all of the initial inspection, routine inspection and regular inspection primarily include visual observation of apparent defects. Table C18.3.1.1 gives a standard inspection items to assess and judge the fatigue of slabs.

Table C18.3.1.1 Standard inspection items for each deterioration stage

Inspection item	Initiation	Propagation	Acceleration	Deterioration
Defective appearance	OO	OO	OO	OO
Defects on road surfaces	*	O	O	OO
Cracking behavior	*	*	O	OO
Cross-sectional values	O	O	O	O
Load-bearing capacity	O	O	O	O
Traffic properties	O	O	O	O
Monitoring	*	*	*	*

OO: Mandatory items, O: desirable items, *: items to be adopted as required

18.3.2 Initial inspection

For initial inspection of reinforced concrete slabs, inspection items and methods shall be adequately selected for new slabs, existing slabs and slabs after remedial measures.

18.3.3 Routine inspection

Routine inspection should basically comprise inspection of defects on concrete surfaces, such as cracking, peeling/spalling, rust exudation, free lime and discoloration. The locations, time of occurrence and outline of deterioration should basically be grasped through observation of defects of appearance.

18.3.4 Regular inspection

In regular inspection, visual inspection should be carried out more in detail than the routine inspection. Monitoring should be performed if necessary.

18.3.5 Detailed inspection

(1) In detailed inspection, the slab displacement and qualities of materials such as concrete should be confirmed at significantly deteriorated portions, while collecting quantitative data for judging the necessity of repair/strengthening and investigating the methods of repair/strengthening.
(2) Methods suitable for the purpose of inspection should be selected for detailed inspection.

18.4 Assessment and judgement

(1) Assessment and judgement of the results of initial inspection, routine inspection, regular inspection and extraordinary inspection should be in accordance with the Part I. Assessment and judgement of the results of detailed inspection should be in accordance with the following items of this section, (2), (3) and (4).
(2) Performances of reinforced concrete slab affected by fatigue should be assessed with sufficient care as to which stage the slab is in; the initiation, propagation, acceleration or deterioration stage.
(3) Assessment of various performances of a reinforced concrete slab during inspection and for the end of

its planned life span should be made by the method of grading.

(4) Judgement shall be made in consideration of the degree of performance degradation caused by fatigue, the importance of the structure and maintenance category.

[Commentary]

The appearance grade of a slab is related to typical performance degradation as given in Table C18.4.1.

Table C18.4.1 Appearance grade of structures related to typical performance degradation

Appearance grade	Safety performance	Serviceability performance	Hazards to third parties Aesthetic appearance/ landscape
Grade I (Initiation)	-	-	-
Grade II (Propagation)	-	-	-
Grade III (Acceleration)	Reduction in shear rigidity - Crack raveling	-	Deterioration in aesthetic appearance - Cracking - Free lime - Settling of concrete surfaces Hazards to third parties - Peeling/spalling
Grade IV (Deterioration)	Reduction in load-bearing capacity - Penetrating cracking - Rainwater permeation - Reinforcement corrosion	Damage to road surfaces by fatigue - Cracking/settling of road surfaces	

18.5 Remedial measures

18.5.1 Selection of remedial measures

When it is judged that remedy is necessary, remedial measures that satisfy the performance requirements should be selected. When it is difficult to select measures based on performance degradation, remedial measures may be selected based on appearance grading of the slab subjected to fatigue.

[Commentary]

Table C18.5.1.1 gives a typical selection of remedial measures for each grade of deterioration of a slab due to fatigue.

Table C18.5.1.1 Appearance grade of structures and remedial measures

Deterioration grade of structure	I (Initiation)	II (Propagation)	III (Acceleration)	IV (Deterioration)
Extensive inspection	O	OO	OO	O
Repair	(O)	OO	O	O
Strengthening		(O)	OO	OO
Appearance improvement			O	O
Utility restoration				O
Functionality improvement	(O)	(O)	(O)	O
Usage restriction				O
Demolition/removal				O

OO: Recommended standard measures, O: Possible measures, (O): Preventive measures

18.5.2 Repair and strengthening

Methods and materials for repair and strengthening of a reinforced concrete slab shall be selected to achieve the specified effect.

[Commentary]

Methods and materials for repair and strengthening are classified as given in Table C18.5.2.1 according to the expected effects. When selecting the methods and materials, the grade of deterioration of the slab should be taken into consideration. Standard methods are given in Table C18.5.2.2.

Table C18.5.2.1 Expected effects and methods of repair/strengthening

Expected effect	Method
Reduce hazards to third parties and improve aesthetic appearance/landscape	Surface treatment (coating)
Improve fatigue durability by eliminating the effect of water	Application of slab waterproofing
Improve fatigue durability by suppressing crack opening	FRP adhesion, Application of prestress
Restore section stiffness by applying members on the extreme tension fiber	Adhesion of steel plate to slab bottom, Increasing thickness of reinforced concrete, Application of additional beams
Improve fatigue durability by increasing the shear stiffness of the section on the compression side	Increasing thickness of slab top surface of slab

Table C18.5.2.2 Appearance deterioration grades of structures related to standard methods

Appearance grade of structure	Standard methods
I (Initiation)	Slab waterproofing
II (Propagation)	Slab waterproofing, Steel plate/FRP adhesion, Top thickness increasing, Bottom thickness increasing, Additional beams
III (Acceleration with an effect of seepage water)	Slab waterproofing, Steel plate adhesion, Top thickness increasing, Additional beams
III (Acceleration without an effect of seepage water)	Slab waterproofing, Steel plate adhesion, Top thickness increasing, Bottom thickness increasing, Additional beams
IV (Deterioration)	Usage restriction, Replacement

18.6 Records

Items special to fatigue of reinforced concrete slab should be recorded.

Chapter 19. Standard Maintenance Method for Fatigue of RC Beam of Railway Bridge

19.1 General

(1) This standard maintenance method provides standard methods of deterioration prediction, inspection, assessment, judgement, remedial measures and recording carried out for maintenance or formulation of a maintenance plan of reinforced concrete beams in which performance degradation due to fatigue has occurred or reinforced concrete beams with a high risk of performance degradation due to fatigue. Items common to all deterioration mechanisms should be in accordance with the Part I.

(2) This maintenance standard covers maintenance activities in general that are carried out to discover deterioration/damage of reinforced concrete beams due to fatigue at an early stage and retain the performance of the entire structure.

(3) This maintenance standard is primarily applied to RC beams designated to maintenance category B.

19.2 Method of deterioration prediction

19.2.1 General

(1) Prediction of fatigue of beams should basically comprise prediction of the duration of the initiation stage, propagation stage, acceleration stage and deterioration stage.

(2) Prediction of fatigue of beams should be based on the results of inspection. Where no inspection results are available, prediction should be made by appropriately assessing the design conditions and service conditions and incorporating an adequate safety factor.

[Commentary]

The crack propagation law based on fracture mechanics is available as a crack propagation model for reinforcing steel, by which crack propagation can be divided into four stages. The "initiation stage" is a stage up to the occurrence of the initial crack, which is detectable from the relationship between the fatigue crack width and the number of cycles under constant cyclic stress. Then comes the "propagation stage," during which fatigue cracks propagate relatively steadily. In the next "acceleration stage," cleavage is found on the fracture surfaces and fracture occurs. Steel bars in the beams then begin to fracture, reducing the load-bearing capacity of the beams in the "deterioration period."

19.2.2 Prediction of fatigue progress

(1) Prediction of fatigue progress shall be made by considering the effects of design conditions and service conditions.

(2) Prediction of fatigue progress may be performed using the crack propagation law or linear cumulative damage law of reinforcing steel.

[Commentary]

The crack propagation law can be used as a method of predicting the progress of beam fatigue. This law uses an index of the fatigue crack width of reinforcing steel, which is the major factor of fatigue fracture of beams. The linear cumulative damage law can also be used as a simple method of progress prediction.

(i) Crack propagation law

According to the crack propagation law, the relationship between the rate of fatigue crack growth of reinforcing steel (da/dN) and the stress σ is expressed as follows:

$$\frac{da}{dN} = C \cdot \Delta K^{m} \qquad \text{(C19.2.2.1)}$$

where a = crack width, N = number of cycles, C = coefficient,

ΔK = stress intensity factor ($= \Delta\sigma\sqrt{\pi a}$), m = coefficient,

Δσ = stress range

By integrating the above equation and solving it in regard to the critical crack width a_f, the following equation is obtained:

$$a_f = \sqrt[\frac{m}{2}-1]{\left[\frac{1}{a_i^{\frac{m}{2}-1}} - N \cdot C \cdot \left(F \cdot \Delta\sigma \cdot \sqrt{\pi}\right)^{m} \cdot \left(\frac{m}{2}-1\right)\right]^{-1}} \qquad \text{(C19.2.2.2)}$$

where F = correction factor for location and shape of crack

The fatigue crack width of reinforcing steel can be predicted using this equation.

(ii) Linear cumulative damage law

The degree of cumulative fatigue damage as shown in Eq.(C19.2.2.3) can be used as a simple method of predicting the progress of fatigue while being aware of the deterioration process.

$$M = \sum_i \frac{n_i}{N_i} \qquad \text{(C19.2.2.3)}$$

where M = degree of cumulative fatigue damage
n_i = number of cycles of acting stress range S_{ri}
N_i = fatigue life under acting stress range S_{ri}

19.2.3 Correction of prediction

When the state of deterioration obtained from inspection results differs from the previous prediction, the cause should be investigated, and the deterioration prediction shall be corrected. The subsequent maintenance plan should be changed if necessary.

19.3 Methods of inspection

19.3.1 General

For beams suffering or expected to suffer fatigue-induced performance degradation, the items, methods and time of inspection shall be selected so that appropriate assessment of the state of degradation, prediction of deterioration progress, judgement for the necessity of remedial measures and determination of such measures can be performed, while considering the maintenance category of the beams.

[Commentary]

Table C19.3.1.1 gives the standard inspection items for assessment/judgement the fatigue deterioration of beams and predicting the progress of deterioration.

Table C19.3.1.1 Standard inspection items for each deterioration stage

Inspection item	Initiation	Propagation	Acceleration	Deterioration
Design conditions	OO	O	*	*
Service conditions (loading action, frequency)	OO	OO	OO	OO
State of cracking	OO	OO	OO	OO
Crack opening amplitude	O	OO	OO	OO
Beam deflection	O	OO	OO	OO
Reinforcement stress range	*	O	OO	OO
Fatigue crack detection	*	O	OO	OO
Concrete strain	*	*	O	O

OO: Mandatory items, O: desirable items, *: items to be adopted as required

19.3.2 Initial inspection

For initial inspection of beams, inspection items shall be adequately selected for new structures, existing structures and structures after remedial measures, respectively.

[Commentary]

Table C19.3.2.1 gives the standard inspection items for initial inspection of fatigue of beams.

Table C19.3.2.1 Standard inspection items for initial inspection

Inspection item	Inspection method	Necessity
Service conditions (loading conditions, frequency)	Design drawings/specifications or monitoring	OO
State of cracking	Visual observation	OO
Crack opening amplitude	Measurement using crack gauges	*
Beam deflection	Measurement using displacement gauges	*
Stress of reinforcing steel	Measurement using strain gauges	*

OO: Mandatory items, O: desirable items, *: items to be adopted as required

19.3.3 Routine inspection

Routine inspection should comprise the inspection of defects on concrete surfaces, such as cracking.

19.3.4 Regular inspection

In regular inspection, visual inspection should be carried out more in detail than the routine inspection. Monitoring should be performed if necessary.

19.3.5 Detailed inspection

(1) In detailed inspection, the state of cracking should be grasped in detail by visual inspection in regard to the entire beams or portions adversely affected by fatigue. Measurement should be made for the steel stress and beam deflection and for fatigue crack detection on steel surfaces, in order to collect quantitative data necessary for predicting deterioration due to fatigue.
(2) Investigation should be made on the deflection of the structure or beams and strain of concrete and reinforcing steel by using a controllable loading apparatus, if necessary.
(3) Quantitative data on the service conditions should be collected.

[Commentary]

Table C19.3.5.1 gives standard items for detailed inspection of beam fatigue.

Table C19.3.5.1 Standard items for detailed inspection

Inspection item	Inspection method	Necessity
Service conditions (loading conditions, frequency)	Design drawings/specifications or monitoring	OO
State of cracking	Visual observation	OO
Crack opening amplitude	Measurement using crack gauges	OO
Beam deflection	Measurement using displacement gauges	OO
Stress of reinforcing steel	Measurement using strain gauges	OO
Fatigue crack detection	Magnaflux method, Fluorescent penetrant method, Eddy current method, Ultrasonic method, Radiation method	OO
Reinforcing steel arrangement	Electromagnetic reflection, Electromagnetic induction	O
Concrete qualities	Core drilling, Scleroscope, Ultrasonic propagation rate method	O

OO: Mandatory items, O: desirable items, *: items to be adopted as required

19.4 Assessment and judgement

(1) Assessment and judgement of the results of initial inspection, routine inspection, regular inspection and extraordinary inspection should be in accordance with the Part I. Assessment and judgement of the results of detailed inspection should be in accordance with the following items of this section (2), (3) and (4).
(2) Performance degradation of a structure due to fatigue is induced by fatigue damage of reinforcing steel,

affected performances should be assessed with sufficient care as to which stage the beams are in; the initiation, propagation, acceleration or deterioration stages.

(3) It is desirable that assessment of various performances of beams during inspection and for the end of the planned life span be made by quantitative methods. However, where quantitative methods are inapplicable, the semi-quantitative grading method may be applied.

(4) Judgement shall be made in consideration of the degree of performance degradation due to fatigue, importance of the structure and maintenance category.

19.5 Remedial measures

19.5.1 Selection of remedial measures

When it is judged that remedy is necessary for performance degradation of beams due to fatigue, remedial measures that satisfy the performance requirements should be selected. If this is difficult, remedial measures may be selected based on appearance grading of beams.

[Commentary]

When it is judged that remedial measures are necessary, measures should be selected among followings; (i) extensive inspection, (ii) repair, (iii) usage restriction, (iv) strengthening, (v) demolishion/removal, (vi) appearance improvement, (vii) functionality improvement, and (viii) utility restoration.

19.5.2 Repair and strengthening

Methods and materials for repair and strengthening shall be selected to achieve the specified effect in consideration of the performance degradation due to fatigue.

[Commentary]

Table C19.5.2.1 gives the types of repair and strengthening of beams deteriorated by fatigue classified by the expected effect.

Table C19.5.2.1 Expected effects and methods of repair/strengthening

Expected effect	Method
Restore safety performance (Improve load-bearing capacity)	Strengthening with out cables, Adhesion of steel plates, Adhesion of continuous fiber sheet, Additional beam placement
Restore utility performance (improve rigidity)	Adhesion of steel plates, Additional beams
Eliminate hazards to third parties	Adhesion of continuous fiber sheet

19.6 Records

Items special to fatigue should be recorded.