MAINTENANCE OF CONCRETE STRUCTURES AND ITS FUTURE STRATEGY
-- BASED ON NEWEST CONCEPTS OF THE MAINTENANCE PART IN THE JSCE STANDARD SPECIFICATIONS FOR CONCRETE STRUCTURES --

Koji TAKEWAKA[1] and Yuichi KANEKO[2]

SUMMARY

The JSCE Standard Specifications for Concrete Structures–2001 "Maintenance" was firstly issued in January 2001. After the lapse of about five years, the first edition is now on the way to revising for updating and introducing the newest concepts for maintenance of concrete structures. This paper outlines the contents of the maintenance part of the JSCE Standard Specifications, as well as the newest concepts discussed for the revision of this specification.

***Keywords**: The JSCE Standard Specifications for Concrete Structures–2001 "Maintenance"; maintenance of concrete structures; performance verification; inspection and assessment; maintenance planning; remedial measures.*

INTRODUCTION

In Japan, there is an immense stock of infrastructure built in the latter half of the 20th century. For considering the "composition of a sustainable society" for the 21st century, efficiently and effectively maintaining these existing structures is indispensable. In particular, the innumerable structures built in the era of rapid economic growth, which have had the improper performance, will all exceed the age of fifty years old in the next 10 to 20 years. This means that an extremely large number of structures might need to be repaired and/or strengthened during the next several decades.

In this background, Concrete Committee in Japan Society of Civil Engineers (here-in-after called as "JSCE") organized a subcommittee on maintenance of concrete structures, and "Recommendations for Maintenance of Concrete Structures (draft)", which is a

[1] *Professor, Department of Ocean Civil Engineering, Kagoshima University, JAPAN 890-0065, e-mail: takewaka@oce.kagoshima-u.ac.jp, Chairman of JSCE Working Group on Standard Specification for Concrete Structures "Maintenance"*

[2] *Engineer, Thermal & Nuclear Power Civil Engineering Dept., Tokyo Electric Power Services Co., Ltd., JAPAN 110-0015, e-mail: ekaneko@tepsco.co.jp, Secretary of JSCE Working Group on Standard Specification for Concrete Structures "Maintenance"*

groundbreaking code of maintenance for concrete structures, was published in October 1995. However, after the publication of “Recommendations”, the necessity of maintenance has been increased. And also, new technological findings have been accumulated based on the progress in concrete technology. Incorporating these sets of technological knowledge with additional investigations’ results, the principle of maintenance procedure of concrete structures was developed. Then, the first edition of the “Standard Specifications for Concrete Structures –2001 “Maintenance”” (here-in-after called as “Maintenance part of the JSCE Specifications”, “Maintenance part” or merely called as “Specifications”) was issued in January 2001.

With the completion of this specification, a series of the JSCE Standard Specifications for Concrete Structures becomes to cover all areas of concrete structures’ life cycle, from “Design” and “Construction”, through “Maintenance”, to demolition. The Maintenance part of the JSCE Specifications rules a principle of maintenance procedure of all kinds of concrete structure, and also indicates the specialized procedures applied to the structures suffering “Carbonation induced deterioration”, “Chloride induced deterioration”, “Frost attack”, “Chemical attack”, “Alkali aggregate reaction” , “Fatigue” and etc.

After the lapse of about five years since the first edition of the Maintenance part was issued, a revising work of this specification started last year in JSCE for updating and publishing the second edition until the end of 2007. And now, the newest concepts for maintenance of concrete structures are being discussed.

This paper presents a brief introduction of the “Maintenance part of the JSCE Specifications”, by describing the basic concept of maintenance of concrete structures adopted in the first edition, background of formulation, and also outlines the newest concepts for the maintenance of concrete structures discussed for the revised version.

BASIC CONCEPT OF MAINTENANCE

A concrete structure is expected to retain the required levels of its functions during the intended service life. In the engineering sense, however, it is difficult to understand the function as quantitative parameters, so that instead of the function, performance is usually used for evaluating the structural condition. Therefore, the first sentence in this paragraph can be translated into that “A concrete structure shall retain structural performance over the required levels with adequate reliability during the design service life.” Consequently, in order to keep the performance always above its required level, the adequate maintenance should be indispensable for most concrete structures.

The level of maintenance applied to a concrete structure is closely related to the levels of the design and the construction works of the structure. This means, for example, when maintenance free condition is required for the structure, the sufficient safety margins on the degradation of performance should be provided to the structure at the design and the construction stages. On the other hand, when frequent maintenance action is considered to be carried out, such the margins of performance may be set to be rather small. In other words, performance of a concrete structure can be clearly controlled by maintenance activities according to a service life scenario incorporating the maintenance strategy. This means that the performance-based strategy, which is also the basic concept of the JSCE Standard Specifications, should be considered on the structure through its service life including not

only the design and construction stages but also the maintenance stage after construction.

OUTLINE OF FIRST EDITION OF "MAINTENANCE PART OF THE JSCE SPCIFICATIONS"

Overview

The "Maintenance part" is systematized as a series of "The JSCE Standard Specifications" with "Design part", "Seismic Design part" and "Construction part", and is also formulated coming into not conflict with international standards such as ISO. The basic policies of the formulation are as follows;

(1) The maintenance procedure consists of initial inspection, deterioration prediction, inspection**,** evaluation, judgment, remedial measures, and recording.

(2) To clarify the role of maintenance in the structure's life from planning/design to the end of service life, maintenance shall be taken into consideration at the planning stage of the newly constructed structure, because the design concept and the construction method can be changed depending on the level of maintenance.

(3) Performance based concept is introduced in accordance with the international trend of codes. Figure 1 shows hierarchical structure of the Maintenance part. Basically, all of required performance on the target structure is checked in each inspection stage, and based on the inspection results, the structure's conditions not only at the time of inspection but also at the end of the intended service life should be evaluated and judged.

(4) The Maintenance part consists of two sub-parts, that is, "Sub-part 1: Maintenance Fundamental" describing the basic concept and the flow of maintenance, and "Sub-part 2: Standards for Maintenance" describing the specific procedures adopted for each deterioration mechanisms.

(5) Categories of maintenance are defined, with considering engineers' activities.

The contents of the Maintenance part is shown in Table 1.

Outline of "Sub-part 1: Maintenance Fundamental"

(1) Scope

In the Maintenance Part, "initial defect", "instantaneous damage", and "deterioration" are clearly distinguished and defined as follows, respectively;

Initial defect: placing-induced defects, such as cracking, honeycombs, cold joints, sand streaking, etc.

Instantaneous damage: damage occurring in a short period and not developing over subsequent time, such as cracking and/or scaling due to earthquakes, impact loading, etc.

Deterioration: the process that adversely affects the performance of a structure over time due to defects and damages occurred by naturally occurring chemical, physical or biological actions, repeated actions such as those causing fatigues, normal or severe environmental influences, and wear due to use, abuse, and others.

Here, the initial defect basically should be repaired at construction stage, therefore, it is not included the scope of this specification. The instantaneous damage does not change much in their degree with time after they arise. Therefore, in general, they may be treated promptly as emergency treatment. On the other hand, since the rate of performance degradation of structure due to deterioration would change apparently with time, the deterioration mechanism should be identified as much as possible, and appropriate actions concerning the prediction of deterioration and evaluation/judgment of performance degradations should be carried out. Therefore, the deterioration should be mainly dealt with as the target for the maintenance activities.

(2) Maintenance Category

Basis of maintenance on concrete structure is that the structure is adequately maintained such that its performance is always above the required level during its service life. However, since concrete is used in different structures such as buildings, dams, bridges, etc., which perform under different environmental conditions, it is not possible to lay down identical performance criterion for all structures. Therefore, in the Maintenance part of the JSCE Specifications, the maintenance action is classified into four different categories specified as follows;

Category A: Preventive maintenance -- the maintenance to prevent the appearance of visible deterioration on the structure during the service life.

Category B: Corrective maintenance -- the maintenance in which, appropriate counter measures should be taken after degradation appearance of the structures has appeared.

Category C: Observational maintenance -- the maintenance carried out primarily on the basis of visual inspection without any direct measure and permits certain deterioration of the structure.

Category D: Non-inspection maintenance -- the maintenance applied to the structure in which the direct inspection is difficult or practically impossible to be carried out, such as under ground structures.

Critical structures such as dams and nuclear power plants having a long service life or structures situated in very harsh environment may be classified into the higher maintenance category. Similarly, criteria for classifying structures into other maintenance categories need to be developed. It should be pointed out that certain structures in which any maintenance action is very difficult to carry out may be categorized separately.

(3) Maintenance Strategy

For fulfilling the rational and reliable maintenance activities in order to keep the performance

of structure always above its required level, it is necessary to evaluate the time-dependent degradation process of the performance of structure during the life, with adequate reliability. However, since the performance degradation cannot be always strictly analyzed based on the current engineering level. It should be verified indirectly considering a future deterioration condition expected by using the deterioration evaluate model. Here, it is needless to say that the periodic inspection results are indispensable for evaluating the performance of structure. The overall processes mentioned above are surely carried out on the basis of the “maintenance strategy”. Namely, the maintenance strategy comprehensively encompasses “inspections”, “estimation of deterioration levels and rates”, “evaluation of performance of structure”, “remedial actions”, and “recording”. 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. Figure 2 shows maintenance procedure specified in the first edition of the Maintenance Part of the JSCE Specifications.

(4) Inspection

Occurrence of deterioration and/or change in its performance of a structure should be detected through inspection. Obviously if undesirable signs of deterioration can be detected in the early stage of deterioration, suitable timely remedial action can be taken. Actual locations for inspection, items recorded and tools used should be carefully selected so that the desired information can be obtained accurately. In the Maintenance part of the JSCE Specifications, on the basis of the methods used and frequency and timing of inspection, inspection is classified into six categories as “initial inspection”, “routine inspection”, “regular inspection”, “detailed inspection”, “extraordinary inspection”, and “monitoring”. A series of main inspection categories is shown in Figure 3.

The initial inspection is carried out before the structure is put into operation after completion of construction or of repair/strengthening work. The objective of the initial inspection is essentially to compile the work records, to record any deviations from the design/drawings, to establish the initial state of the structure, and to prepare documents which can serve as basis for further maintenance action. Therefore, in a certain case in the absence of previously collected data, any inspection may be deemed to be the initial inspection.

While the structure is in service, routine and regular inspections need to be carried out to determine whether detailed inspection is required or not. The routine inspection is carried out on a routine basis without making any specific effort, at certain intervals such as daily, weekly or monthly. Regular inspection can be carried out using appropriate tools at regular intervals, such as once in a year or in several years. The exact tools to be used and the frequency of such inspections should be decided on the basis of such factors as likely mechanism of deterioration, environmental conditions, importance of the structure and classification of the maintenance action.

Detailed inspection is carried out to obtain detailed and specific information regarding the deterioration and/or performance of the structure. The Maintenance part specifies the case when the detailed inspection is required as follows;

- Some signs of deterioration or a change in the performance level are observed during a routine and/or regular inspection.

- It is difficult to obtain reliable and accurate information during a routine and/or regular

inspection.

- It is determined that the structural integrity of the structure has been adversely affected by the extent of deterioration.

- More detailed information is required before deciding the necessity and scope for undertaking a major repair, rehabilitation, or strengthening work.

In addition to the above-mentioned inspections, extraordinary inspection may also be carried out to assess the extent of damage and need for remedial action, after the structure has been subjected to an accidental load, such as earthquake, storm, flood, fire, and collision with a vehicle or ship.

Furthermore, whereas inspection could provide data at a particular point on time, need to monitor deterioration and/or performance of critical structures, through continuous recording of appropriate data, should not be lost sight of. In such cases, appropriate sensors and recording devices should be fixed to the structure, so that relevant data can be collected at any time and appropriate action can be taken before the deterioration becomes detrimental to the appearance and performance of the structure.

(5) Deterioration prediction, evaluation of performance and decision making

Figure 4 shows a procedure to predict the degradation level of the performance of structure. At first, the present level and rate of deterioration of the structure should be determined on the basis of the inspection results, design and construction records, environmental conditions and the likely mechanism and characteristics of deterioration that are identified from the exposure condition, and any other sign of deterioration. Since the inspection may provide the desired information about the instantaneous value of deterioration index, appropriate models are needed to be able to estimate the deterioration rate. These models should take into account several factors such as likely mechanism and observed characteristics of deterioration with using the information available from construction records and previous inspection.

The performance level of structure is, then, evaluated based on the estimated level and rate of deterioration mentioned above, and compared with the threshold level. Depending not only on a minimum required performance level, but also on importance and maintenance classification of the structures, the intended remaining service life and other considerations, a final decision has to be done as follows:

- On the stages of routine and regular inspections, the decision should be taken as to whether a detailed inspection is called for.

- On the stages of detailed and/or extraordinary inspection, the decision should be taken as to whether any remedial action is called for.

(6) Remedial Action

Suitable remedial action on a deteriorated structure shall be selected on the basis of the inspection results which include the deterioration mechanism, degraded performance, importance of the structure, maintenance level and the threshold levels of structural performance, and/or material properties. The methods and materials used for the remedial

actions shall be correctly chosen based on the deterioration mechanism, remaining service life, importance, and conservation value of the structure, and user satisfaction.

Among the types of remedial action shown in Figure 5, repair and strengthening are regarded as the main techniques of remedial action, of which preparation, execution, and methods and materials are described in the specification. Repair of a structure prevents or slows down its further deterioration and reduce the possibility of damage to its users or third parties. Strengthening of a structure restores or improves its structural properties including load-carrying capacity, to a level which is equal to or higher than that of the original design.

Outline of "Sub-part 2: Standards of Maintenance"

"Sub-part 2: Standards for Maintenance" describes the standard methods of "deterioration prediction", "inspection", "evaluation and judgment", "remedial actions", and "recording", when the deterioration mechanism has become clear or highly probable. The standardized maintenance methods specified in the current Maintenance part deals with seven types of deterioration mechanisms shown as follows;

(1) Standard method for carbonation induced deterioration (in Chapter 13): methods mentioned in this chapter cover the performance degradation of structures due to reductions in pH values of pore solutions in concrete induced by carbon dioxide penetration into concrete from the atmosphere and the resulting reinforcement corrosion.

(2) Standard method for chloride induced deterioration (in Chapter 14): methods mentioned in this chapter cover reinforcement corrosion induced by chloride ions, supplied externally from saline atmosphere or influence of de-icing agents, or internally contained from concrete materials, such as cement, sea sand, admixture. It also covers the performance losses of structures or parts/members due to the progress of reinforcement corrosion.

(3) Standard method for frost attack (in Chapter 15): methods mentioned in this chapter cover the performance losses of structures due to concrete deterioration by numerous repetitions of freezing and thawing action for concrete. In the structures suffering from frost attack, scaling, micro cracks and pop-out usually appear on the concrete surface.

(4) Standard method for chemical attack (in Chapter 16): methods mentioned in this chapter cover the performance losses of structures due to deterioration of concrete and reinforcement corrosion induced by acids or sulfates, especially found in sewage-related facilities, chemical plants, in hot spring area, or in special kinds of soils.

(5) Standard method for alkali aggregate reaction (in Chapter 17): methods mentioned in this chapter cover the performance losses of structures due to the concrete expansion by alkali silica reaction (ASR), which occurs cement with aggregate in concrete, mainly occurred in Japan. As the results of this expansion, the defect, such as cracks, peeling of cover concrete and damage of reinforcement is occurred in the structures.

(6) Standard method for fatigue of RC slab of road bridge (in Chapter 18): methods mentioned in this chapter primarily cover reinforced concrete slabs of road bridges, and their performance losses due to concrete cracking caused by widely varied wheel actions.

(7) Standard method for fatigue of RC beam of railway bridge (in Chapter 19): methods

mentioned in this chapter primarily cover reinforced concrete beams of railway bridges, and their performance losses due to the steel reinforcement cracking caused by repeated train actions.

In the current Maintenance part, for every deterioration mechanisms, the deterioration process is divided into four periods, these are, initiation period, propagation period, acceleration period and deterioration period, to predict the degree of deterioration and the time-dependent performance degradation of the structures or parts/members. Figure 6 shows a conceptual pattern of the deterioration process and degrading process of performance of structure. To predict each period in the deterioration process, methods indicated in Table 2 are to be adopted.

Most of structures to be built in the future will also be maintained in a manner of the maintenance category B, while most of existing structures also may be maintained in this manner. Therefore, the maintenance methods described in this sub-part are specified primarily for the structures maintained in a manner according to the maintenance category B. However, where special consideration is required for structures in different maintenance categories, such as “maintenance category A”, instructions are given accordingly. Details of the standard maintenance methods employed in the following maintenance activities are described for each deterioration mechanism, respectively;

- The method of deterioration prediction based upon four stages of deterioration progress, that is to say, initiation, propagation, acceleration and deterioration stage.
- The method of inspection for initial, routine, periodic and detailed inspection.
- The method of performance evaluation based on the results of deterioration prediction and inspection, and the method of judgment for necessity of remedial measures.
- The method for the selection of repairing/strengthening method, and the method of repair/strengthening.
- The method of records.

OUTLINE OF WORKS FOR REVISING THE “MAINTENANCE PART”

Following considerations for revising the Maintenance Part of the Standard Specifications are being discussed.

Discussion about asset management and life-cycle cost management

The current Maintenance Part of the JSCE Specifications mainly describes engineering aspects of maintenance, such as identification of deterioration mechanism, prediction of deterioration, evaluation and judgment of the results of several inspections or prediction of deterioration, remedial measures, and so on. However, for establishing the maintenance strategy more rationally, not only the engineering aspects but also social and economical ones should be required. From this view point, the newest concepts of the asset management and the life-cycle cost management are expected to be very effective for the maintenance strategy.

In the ongoing revision work, therefore, the method how the both concepts can be introduced in the Maintenance Part is being discussed.

The asset management concept introduced in the maintenance planning is expected to be useful for the project contractor to judge the maintenance priority of each structure among a lot of structures owned by the same agency/corporation. As for the concept of the life cycle cost management, application of this concept for the selection of remedial measure is discussed. When the remaining service life of a structure is long, it is relatively difficult to select a correct method and materials of repair/strengthening to meet sufficiently the performance requirement considering the limits of an available budget. In such cases, the solution of taking retrofit measures repeatedly later is used, and on this assumption, the project contractor can select a correct method and use appropriate materials easily and economically. Figure 7 shows an example to compare the life cycle costs of different repair methods.

Discussion about maintenance planning

Importance of "maintenance planning" should be described more clearly in the second edition of the Maintenance Part. A concrete structure shall retain the required levels of its performance for the intended service life with adequate reliability by providing necessary maintenance activities. For accomplishing it, an adequate maintenance plan, in which the performance of the concrete structure shall be clearly specified on the basis of a service life scenario incorporating maintenance strategy, should be preliminarily made.

For achieving proper maintenance of newly constructed structures, the maintenance plan should be formulated at the design stage, so that structural type and material used can be chosen to make the maintainability of structure, which assures easy maintenance during its design service life. On the other hand, the appropriate maintenance plan for existing structures should be formulated before starting the maintenance actions. An idea of the procedure for establishing the maintenance plan is as shown in Figure 8.

Discussion about classification of inspection

In the current Maintenance Part, "inspection" is defined as "a generic term for actions taken to understand the current state of a structure", and includes "initial inspection", "routine inspection", "regular inspection", "detailed inspection" and "extraordinary inspection". However, the range of interpretation on the "meaning of inspection" is too wide to classify it in the simple manner. On the other hand, in some international standards, not only "inspection" but also "investigation" and "assessment", which are not in the Maintenance Part, are defined. For an example, the definitions in ISO 13822 "Bases for design of structures – Assessment of existing structures" are shown as follows;

- Inspection : on-site non-destructive examination to establish the present condition of the structure

- Investigation: collection and evaluation of information through inspection, document search, load testing and other testing

- Assessment : set of activities performed in order to verify the reliability of an existing structure for future use

Considering the definitions in the international standards, the framework of inspections defined in the current Maintenance Part would be better to be rearranged. Fig.9 and Fig.10 show examples of the examination.

Discussion about the maintenance for damage due to earthquake and other disasters

In the Maintenance Part, initial defect, instantaneous damage, and deterioration are clearly distinguished, and the deterioration is mainly dealt with as the target for the maintenance activities. On the other hand, as mentioned the above, the initial defects and the instantaneous damage do not change much in their degree with time, so that they may be treated promptly as emergency treatment. However, when the damage such as due to earthquake happens with a fatal problem on the performance of concrete structure, appropriate maintenance works concerning inspection, evaluation of performance and selecting remedial measure shall be carried out. The maintenance activities for such the damage should also be prescribed in the Maintenance Part, appropriately.

Discussion for revising "Sub-part 2: Standards of Maintenance"

Revise of the Sub-part 2 of the Maintenance part should be done according to the revise of the Sub-part 1. Therefore, detailed idea for revise of the Sub-part 2 do not discussed yet. However, seven types of the deterioration conditions adopting in this sub-part for standardizing the maintenance of concrete structures are not enough to include the all of hazardous conditions with which concrete structures are faced. At least, the followings should be added considering its importance for the maintenance on the actual concrete structures;

- "Standard Maintenance Method for Abrasion"
- "Standard Maintenance Method for Complex Deterioration Mechanism"

In addition, the description of techniques of testing and surveying for inspection, and the basic concepts for upgrading of structures affected by the action of earthquake, also should be included in the sub-part.

Tentative draft contents of the second version of the Maintenance part of the JSCE Specifications discussed in the revising works is shown in Table 3

CONCLUDING REMARKS

"Standard Specifications for Concrete Structures-2001 "Maintenance"" was published in January 2001. This specification is, in a sense, "the code for code writers", that means in order to apply this specification to the actual maintenance works, every organization who own and control the structures should make own maintenance code applied to the each specified structure, based on the concept of this specification. It is supposed that it will take several years until this specification will prevail the most area of actual maintenance work of widely ranged concrete structures. Also, this 2001 version is only the first edition; the committee work is now still kept continued to prepare the second edition, it will be issued in 2007 based on the discussion for revise above mentioned.

REFERENCES

Japan Society of Civil Engineers, “Guideline (Draft) for Maintenance of Concrete Structures”, JSCE Concrete Library No.81, 1995. (in Japanese)

Japan Society of Civil Engineers, “Standard Specifications for Concrete Structures-2001 “Maintenance””, 2001. (in Japanese)

Japan Society of Civil Engineers, “Standard Specifications for Concrete Structures-2001 “Maintenance””, JSCE Guidelines for Concrete No.4, 2003.(in English)

Japan Society of Civil Engineers, “Maintenance Manuals (Series 1) and Reference Material based on The JSCE Standard Specifications for Concrete Structures “Maintenance””, JSCE Concrete Engineering Series No.57, 2003. (in Japanese)

International Standard ISO 13822, “Based for Design of Structures－ Assessment of Existing Structures”, 2003.

Japan Society of Civil Engineers, “Example of Maintenance Activities Based on JSCE Specifications for Concrete Structures”, JSCE Concrete Library No.116, 2005. (in Japanese)

Table 1 Contents of the current Maintenance part of the JSCE Specifications

"Sub-part 1: Maintenance Fundamental"

Chapter 1. General
- 1.1 Scope
- 1.2 Definitions

Chapter 2. Required Performance for Concrete Structures
- 2.1 Principle
- 2.2 General

Chapter 3. Basic Principled for Maintenance
- 3.1 Principles
- 3.2 Maintenance procedure
- 3.3 Maintenance categories and descriptions
- 3.4 Inspection
- 3.5 Classification and identification of mechanisms of deterioration
- 3.6 Prediction of deterioration
- 3.7 Evaluation and judgment
- 3.8 Remedial measures
- 3.9 Records

Chapter 4. Identification of Deteriorating Mechanism
- 4.1 Principles
- 4.2 Method of Identifying Deteriorating Mechanism

Chapter 5. Initial Inspection
- 5.1 Principles
- 5.2 Methods of inspection
- 5.3 Estimation of deteriorating mechanism and prediction of deterioration
- 5.4 Evaluation and judgment

Chapter 6. Routine Inspection
- 6.1 Principles
- 6.2 Inspection methods
- 6.3 Evaluation and judgment

Chapter 7. Periodic inspection
- 7.1 Principles
- 7.2 Inspection methods
- 7.3 Evaluation and judgment

Chapter 8. Detailed inspection
- 8.1 Principles
- 8.2 Inspection methods
- 8.3 Prediction of deterioration
- 8.4 Evaluation and judgment

Chapter 9. Extraordinary Inspection
- 9.1 Principles
- 9.2 Inspection methods
- 9.3 Evaluation and judgment
- 9.4 Emergency inspection

Chapter 10. Techniques of Testing and Surveying
- 10.1 Principles
- 10.2 Visual observation and hammer (tapping) test
- 10.3 Testing with non-destructive apparatus
- 10.4 Partial and small-scale destructive tests
- 10.5 Direct evaluation of the structural behaviors of existing structures
- 10.6 Evaluation of environmental action
- 10.7 Performance test on repairing materials

Chapter 11. Remedial Measures
- 11.1 Principles
- 11.2 Types of remedial measures
- 11.3 Repair
- 11.4 Strengthening

Chapter 12. Records
- 12.1 Principle
- 12.2 Period of storing records
- 12.3 Method of preservation of records
- 12.4 Items to be recorded

"Sub-part 2: Standards for Maintenance"

Chapter 13. Standard Maintenance Method for Carbonation Induced Deterioration
- 13.1 General
- 13.2 Method of deterioration prediction
- 13.3 Methods of inspection
- 13.4 Evaluation and judgment
- 13.5 Remedial measures
- 13.6 Records

Chapter 14. Standard Maintenance Method for Chloride Induced Deterioration
- 14.1 General
- 14.2 Method of deterioration prediction
- 14.3 Methods of inspection
- 14.4 Evaluation and judgment
- 14.5 Remedial measures
- 14.6 Records

Chapter 15. Standard Maintenance Method for Frost Attack
- 15.1 General
- 15.2 Method of deterioration prediction
- 15.3 Methods of inspection
- 15.4 Evaluation and judgment
- 15.5 Remedial measures
- 15.6 Records

Chapter 16. Standard Maintenance Method for Chemical Attack
- 16.1 General
- 16.2 Method of deterioration prediction
- 16.3 Methods of inspection
- 16.4 Evaluation and judgment
- 16.5 Remedial measures
- 16.6 Records

Chapter 17. Standard Maintenance Method for Alkali Aggregate Reaction
- 17.1 General
- 17.2 Method of deterioration prediction
- 17.3 Methods of inspection
- 17.4 Evaluation and judgment
- 17.5 Remedial measures
- 17.6 Records

Chapter 18. Standard Maintenance Method for Fatigue of RC Slab of Road Bridge
- 18.1 General
- 18.2 Method of deterioration prediction
- 18.3 Methods of inspection
- 18.4 Evaluation and judgment
- 18.5 Remedial measures
- 18.6 Records

Chapter 19. Standard Maintenance Method for Fatigue of RC Beam of Railway Bridge
- 19.1 General
- 19.2 Method of deterioration prediction
- 19.3 Methods of inspection
- 19.4 Evaluation and judgment
- 19.5 Remedial measures
- 19.6 Records

Table 2 Outline of methods of deterioration prediction

Mechanism	Methods of deterioration prediction	
Carbonation induced deterioration	Prediction of carbonation depth	Prediction of reinforcement corrosion
Chloride induced deterioration	Prediction of chloride concentration in concrete	Prediction of reinforcement corrosion
Frost attack	Evaluation on probability of frost attack	Prediction of deterioration depth induced by frost attack
Chemical attack	Prediction of erosion depth induced by chemical attack	Prediction of reinforcement corrosion
Alkali aggregate reaction	Evaluation on probability of reaction	Prediction of reaction process
Fatigue of RC slab of road bridge	Prediction of crack patterns from present crack formation obtained by inspections	
Fatigue of RC beam of railway bridge	Prediction of propagating crack in reinforcing bars (Linear cumulative damage rule)	

Table 3 Draft contents of second version of "Maintenance Part of the JSCE Specifications"

"Sub-part 1: Maintenance" (draft)

Chapter 1. General
- 1.1 Principles and Scope
- 1.2 Definitions

Chapter 2. Required Performance for Concrete Structures/Members
- 2.1 Principles
- 2.2 General

Chapter 3. Methods of Maintenance
- 3.1 Principles
- 3.2 Maintenance procedure and maintenance planning
- 3.3 Maintenance categories and descriptions
- 3.4 Inspection
- 3.5 Classification and identification of mechanisms of deterioration
- 3.6 Prediction of deterioration
- 3.7 Evaluation and judgment
- 3.8 Remedial measures
- 3.9 Records

Chapter 4. Inspection
- 4.1 Principles
- 4.2 Method of inspection
- 4.3 Method of investigation
- 4.4 Identification of deterioration mechanism and prediction of deterioration

Chapter 5. Prediction of Deterioration, Evaluation of Performance and Judgment of necessity of Remedial Measures
- 5.1 Principles
- 5.2 Methods of prediction of deterioration
- 5.3 Methods of evaluation of performance
- 5.4 Judgment of necessity of remedial measures

Chapter 6. Remedial Measures for
- 6.1 Principles
- 6.2 Types of remedial measures and selection
- 6.3 Repair and upgrading
- 6.4 Maintenance after the completion of remedial measures

Chapter 7. Records
- 7.1 Principles
- 7.2 Period of storing records
- 7.3 Method of preservation of records
- 7.4 Items to be recorded

"Sub-part 2: Standards for Maintenance" (draft)

Chapter 8. Standard Maintenance Method for Carbonation Induced Deterioration

Chapter 9. Standard Maintenance Method for Chloride Induced Deterioration

Chapter 10. Standard Maintenance Method for Frost Attack

Chapter 11. Standard Maintenance Method for Chemical Attack

Chapter 12. Standard Maintenance Method for Alkali Aggregate Reaction

Chapter 13. Standard Maintenance Method for Fatigue of RC Slab of Road Bridge

Chapter 14. Standard Maintenance Method for Fatigue of RC Beam of Railway Bridge

Chapter 15. Standard Maintenance Method for Abrasion

Chapter 16. Standard Maintenance Method for Damage, Other Deterioration Mechanisms and Complex Deterioration Mechanism

Chapter 17. Techniques of Testing and Surveying

Chapter 18. Basic Concepts for Upgrading of Structures for the Action of Earthquake

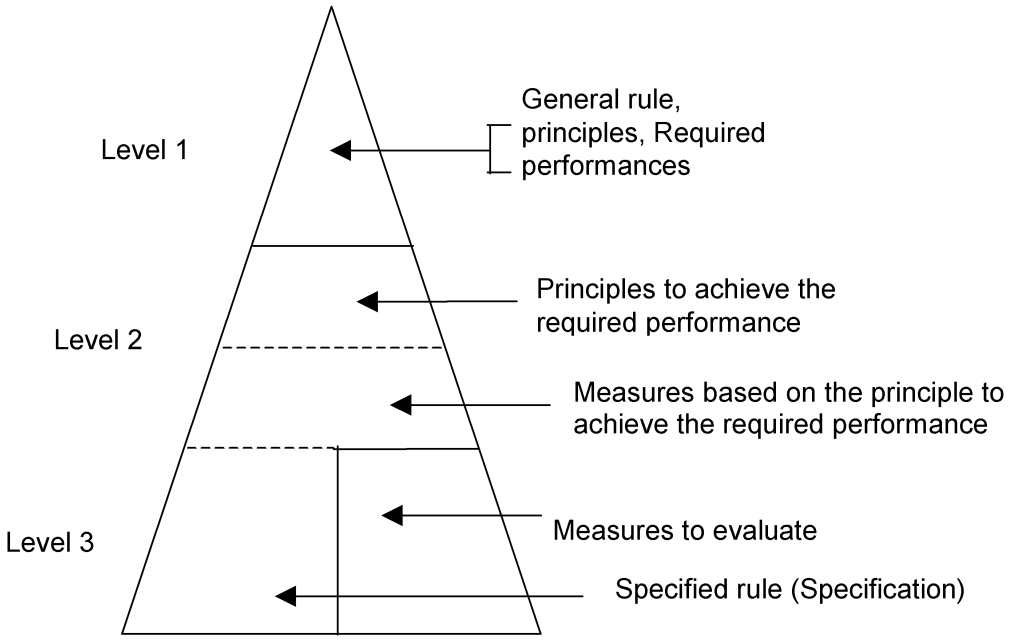

Figure 1 Hierarchical structure of performance specifications

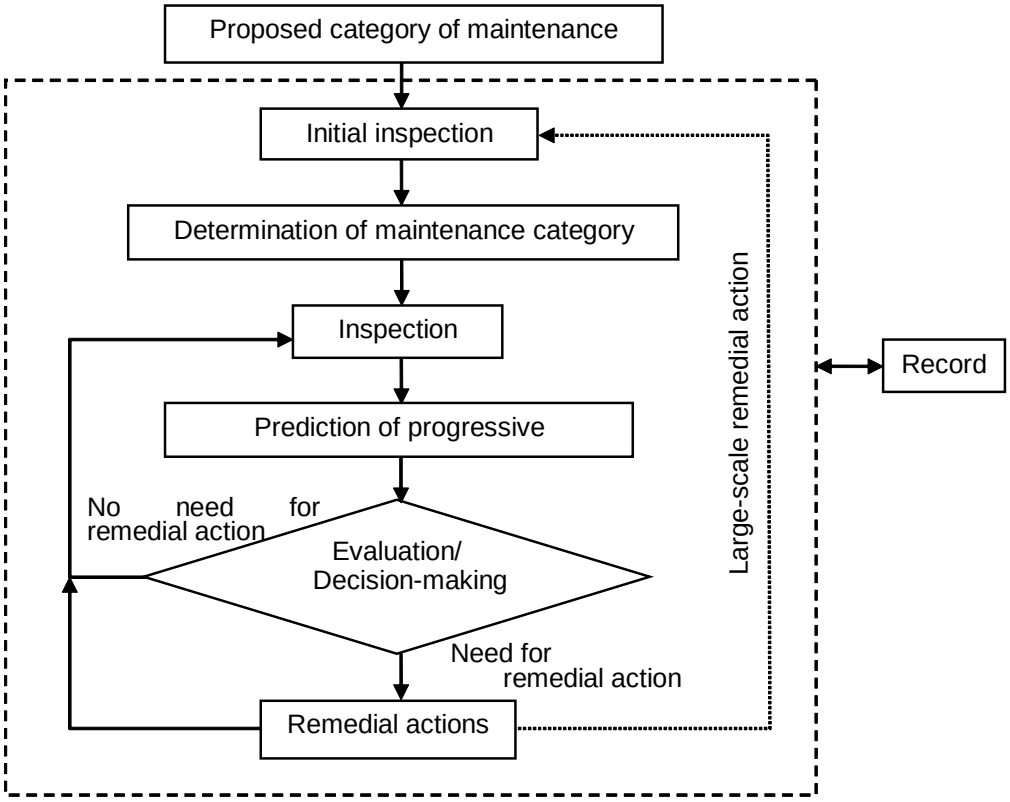

Figure 2 General maintenance procedure in the first edition of the Maintenance part

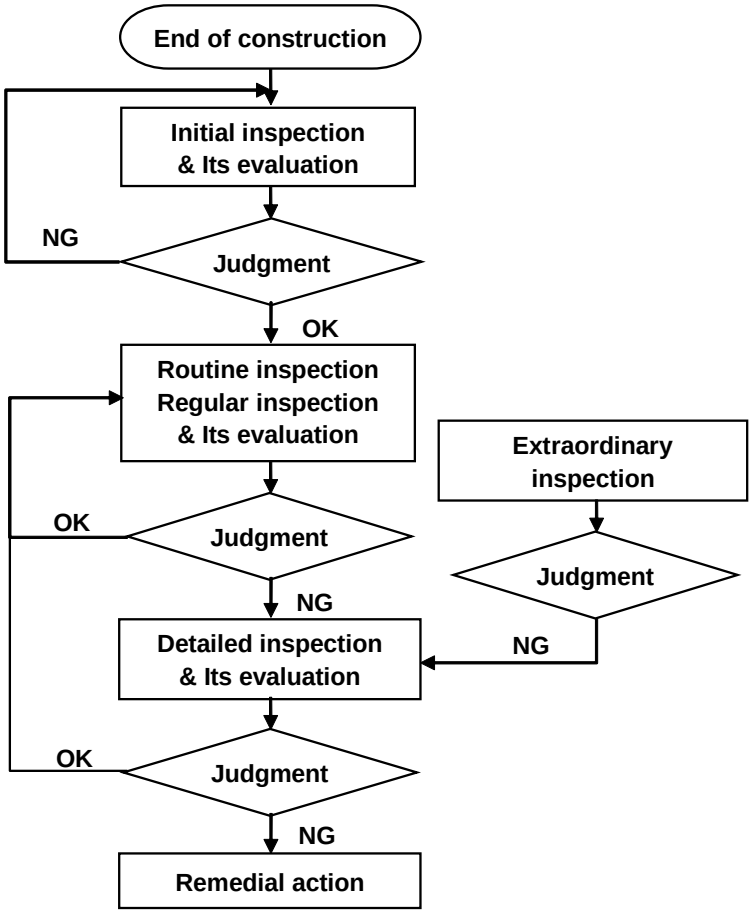

Figure 3 Series of main inspection categorized in the first edition of the Maintenance part

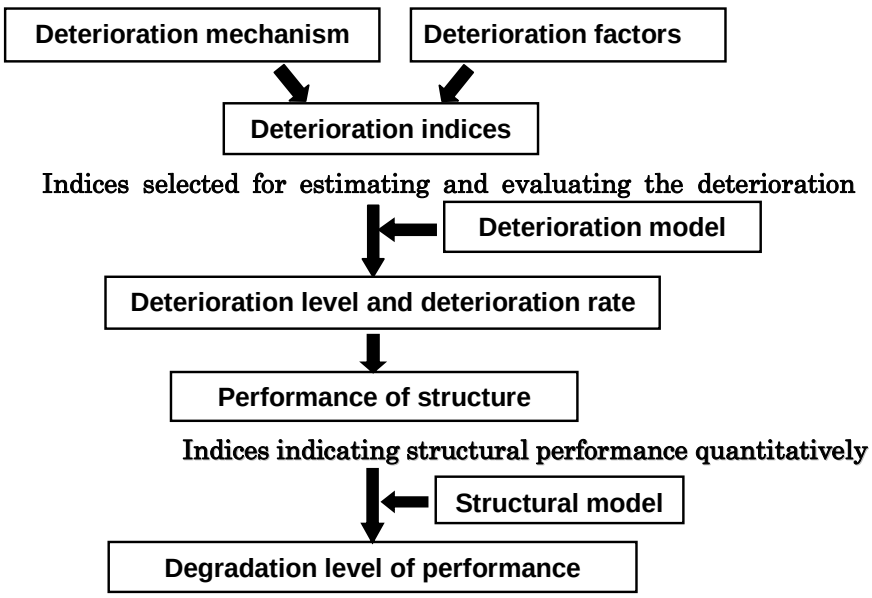

Figure 4 Procedure to predict the degradation level of the performance of structure

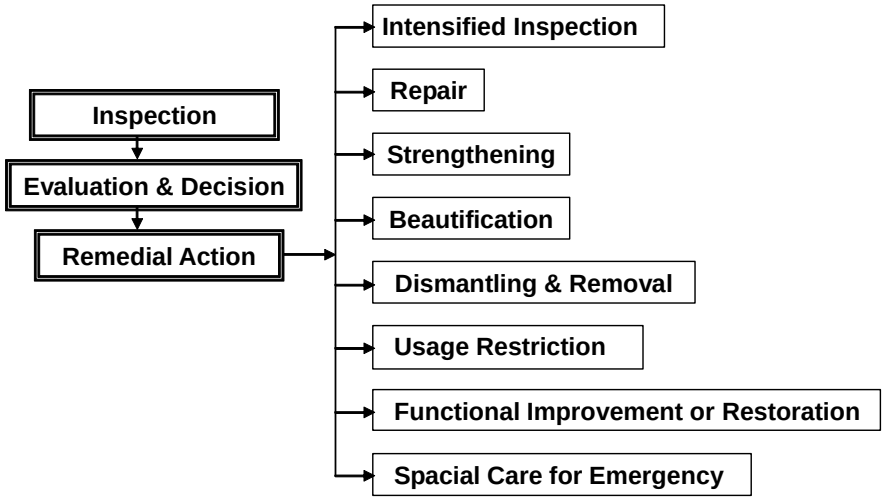

Figure 5 Type of remedial action

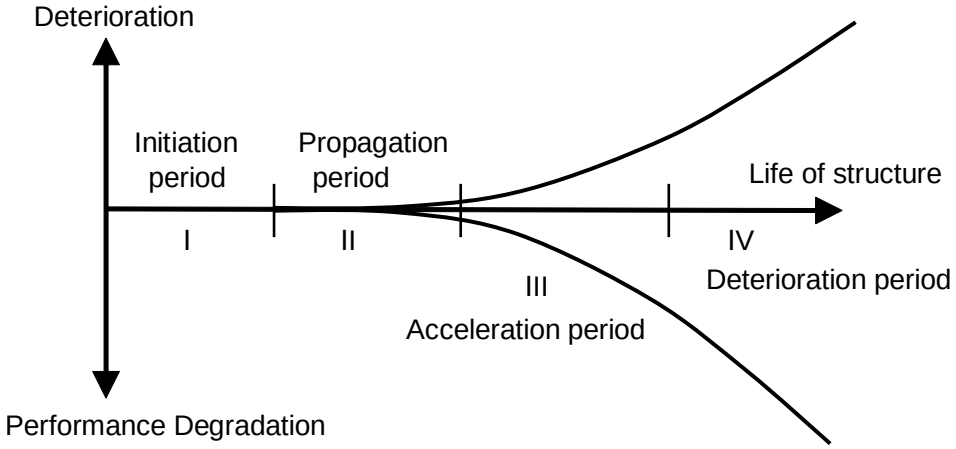

Figure 6 Conceptual illustration of deterioration and performance degradation

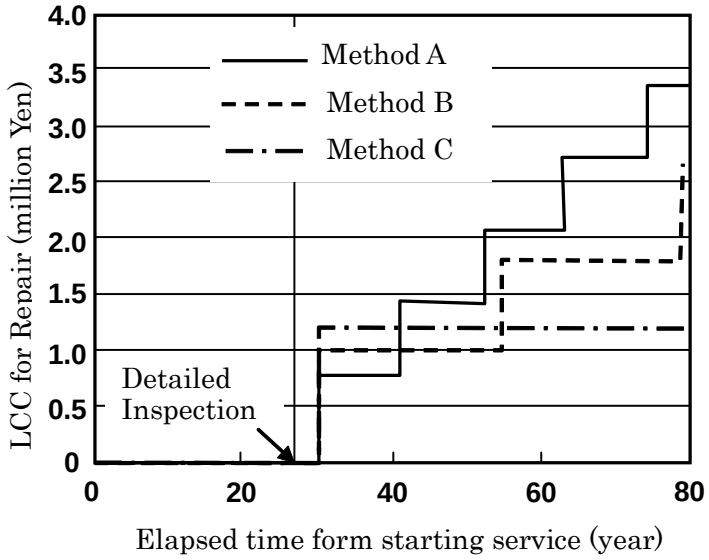

Figure 7 Example of life cycle cost evaluation for repair methods

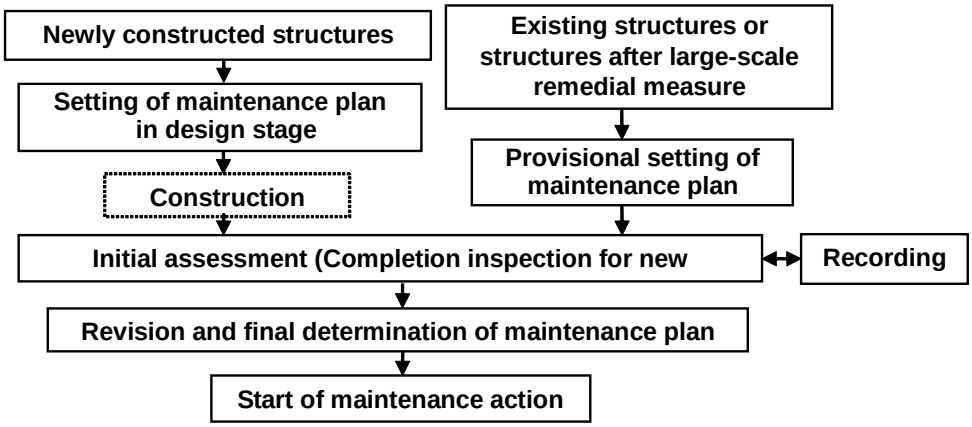

Figure 8 An idea of the procedure for establishing the maintenance plan

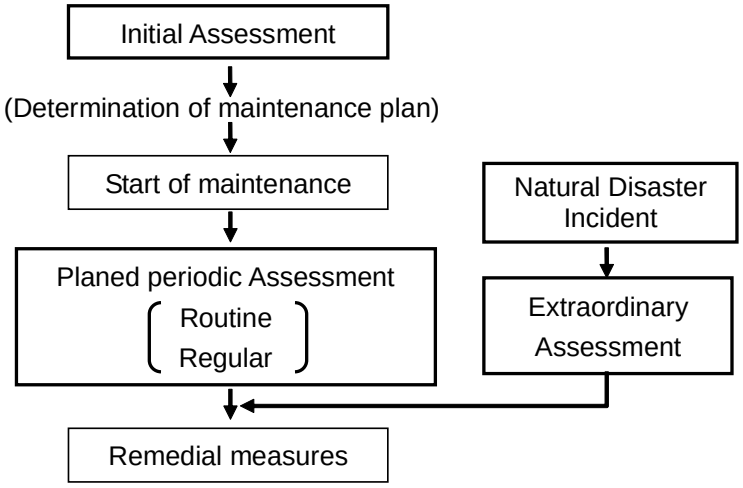

Figure 9 A new idea for framework of inspection

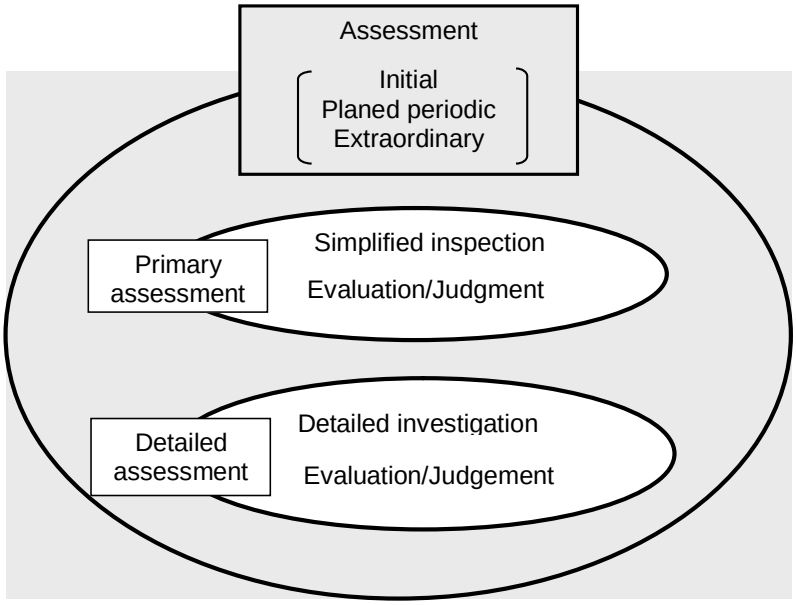

Figure 10 Definition of assessment as new concept in the Maintenance part