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# PROPOSED SPECIFICATION OF DURABILITY DESIGN FOR CONCRETE STRUCTURES

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JSCE Research Working Group on Durability Design for Concrete Structures under Subcommittee on Standard Specification for Design and Construction of Concrete Structures

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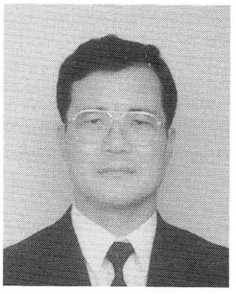

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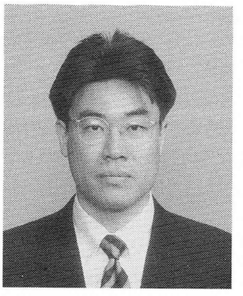

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**SYNOPSIS:** The Proposed Specification of Durability Design for Concrete Structures provides durability design that is upgraded on the basis of the Proposed Recommendation on Durability Design for Concrete Structures published in 1989. The durability of reinforced and prestressed concrete structures is examined comprehensively using various factors with respect to design principle, concrete materials and construction works. The examination is made quantitatively by a comparison between the Durability Index and the Environmental Index, which are respectively determined with durability-related factors and environmental conditions encountered by a concrete structure concerned.

**Keywords:** durability design, reinforced concrete structures, prestressed concrete structures, the Durability Index, the Environmental Index

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# PREFACE

The Concrete Committee in Japan Society of Civil Engineers (JSCE) organized Subcommittee on Durability Design for Concrete Structures in 1988 and published the Proposed Recommendation on Durability Design for Concrete Structures in 1989. The publication had been referred and contributed to the construction of durable concrete structures under severe environmental conditions ever since. However, it was also true that there were some questions and comments for the application of the durability design. Therefore, in 1992 the Concrete Committee reorganized a working group for the purpose of upgrading the durability design under Subcommittee on Standard Specification for Design and Construction of Concrete Structures in JSCE.

The Proposed Specification of Durability Design for Concrete Structures follows the framework of a previous methodology on durability design for reinforced and prestressed concrete structures. However, the determination of the Durability Index and the Environmental Index is subjected to several changes to fit actual practice. The Proposed Specification of Durability Design for Concrete Structures will prove to be an useful guideline for the construction of durable concrete structures under severe environmental conditions.

# CHAPTER 1 GENERAL

## 1.1 Scope

This proposed specification provides the methodology and procedure of durability design for concrete structures and is intended to be used to make concrete structures highly durable under severe environmental conditions.

**[Commentary]**

Concrete structures have been designed so as to have suitability in their normal usages and the appropriate degree of safety to any loads applied under construction and during service periods. To examine and confirm the suitability and safety considerations the JSCE Standard Specification for Design and Construction of Concrete Structures has been provided and used. A similar examination should be taken to ensure the satisfactory degree of the durability of concrete structures. This is based on the fact that the use of concrete structures has been increased in diverse marine and industrial environments. However, the current JSCE Standard Specification for Design and Construction of Concrete Structures provides no systematic approach for examining the durability of concrete structures. Therefore, it is necessary to establish and implement durability design at an equal stage to other structural designs. Primary purpose of this proposed specification is to specify the methodology and procedure of durability design which will be applied to meet a particular demand to make concrete structures highly durable for an intended service life under severe environmental conditions of chloride ingress and freezing and thawing action.

The application of durability design in this proposed specification is limited to newly constructed concrete structures that need to have satisfactory durability under severe environmental conditions. In addition, this proposed specification should not be used to predict the time of repair and re-strength requirements and remaining service periods for existing concrete structures.

This proposed specification will be used primarily for reinforced concrete and prestressed concrete structures in which common basic notions in durability design for both types of concrete are given. Admittedly, when applied for actual concrete structures with their own uniqueness, there will arise cases where provisions of this proposed specification are insufficient and need to be modified appropriate to each special case. It is hoped that the intent of this proposed specification would be properly understood and referred to even for these cases.

## 1.2 Definition of Terms

Terms used in this proposed specification are defined as follows:

| | | |
|---|---|---|
| Environmental Index | – | calculated on the basis of environmental conditions and required periods until the implementation of any maintenance activities for newly constructed structures |
| Durability Index | – | calculated on the basis of design details, the quality of materials and conditions of construction works, which is done in a design stage and during construction planning prior to the execution of actual construction works |
| Durability Point | – | calculated by adding respective points given for individual factors affecting the durability of concrete structures in relation to design details, the quality of materials and conditions of construction works |
| Maintenance-free | – | state of affairs in which concrete structures can be judged to be durable by such convenient means as a visual inspection |

and hence in need of neither repair nor structural improvement.

### 1.3 Notations

| | | |
|---|---|---|
| $S_p$ | – | the Environmental Index |
| $S_o$ | – | a given value defined for moderate environmental conditions in the Environmental Index |
| $\Delta S_p$ | – | the increment of the Environmental Index determined according to environmental conditions |
| $T_p$ | – | the Durability Index |
| $T_p(I,J)$ | – | the Durability Point |

## CHAPTER 2 EXAMINATION OF DURABILITY

The durability of concrete structures is, as a general rule, examined if following relationship is satisfied or not where the Durability Index, $T_p$ is not less than the Environmental Index, $S_p$.

$$T_p \geqq S_p \tag{2.1}$$

**[Commentary]**

Durability design is intended to accommodate following aspects:

(1) In the recognition of pressing demand for making concrete structures truly durable, research and development are being conducted everywhere. Therefore, durability design be adapted should be in such a framework that can treat new findings and results from up–dated research to be incorporated in so as to contribute to the advance of design methodology.

(2) Durability design should be applicable with any structural design methods such as allowable stress design or limit state design.

(3) Durability design should comprehensively treat factors on design details, quality of concrete and construction methods and evaluate the durability of concrete structures objectively.

The Durability Index, $T_p$ is given by the sum of individual Durability Points, $T_p(I,J)$ for selected factors in relation to design principle, the quality of concrete and construction works. These factors are introduced in details in CHAPTER 4 and 5. According to the degree to which the durability of concrete structures is affected these factors were weighed and quantitatively evaluated for the Durability Point, $T_p(I,J)$. This was done on the basis of past experience and results obtained by a number of researches done to date. However, this is admittedly a highly difficult proposition to realize.

In this proposed specification Eq.(2.1) will be used to examine individual structural members of a particular concrete structure that may be in danger for its durability. However, the examination of durability can be omitted for members which are apparently more durable than others in the same concrete structure. In this way, the concrete structure may be judged to be sufficiently durable, if particular portions subjected to the examination show all higher $T_p$ than $S_p$.

The concept of this durability design that is summarized in Eq.(2.1) is not only definitely new but also Japan's original. It may be regarded as an essentially similar concept to that of structural design for suitability and safety. In examining the durability of a particular member with Eq.(2.1), the method of calculating the Environmental Index, $S_p$ corresponds to the method of calculating a member force in structural design for safety. Similarly, the calculation of the Durability Index, $T_p$ corresponds to the calculation of a capacity of the member. This correspondence is summarized in Table 2.1.

**Table 2.1 Examination of Durability – Comparison with Examination of Safety**

| Durability | Safety |
|---|---|
| Calculation of the Environmental Index, $S_p$ | Calculation of member forces |
| Calculation formula for the Durability Index, $T_p$ | Calculation formula for the capacity of members |
| Examination of durability | Examination of safety |

Durability design may be carried out at two stages. The first stage for the examination to be carried out is when structural design is done. In this designing stage factors in relation to materials and construction works are to be assumed for the calculation of $T_p$. The second stage will be when Eq.(2.1) is found to be unsatisfied in the first stage and durability design is repeated prior to the execution of actual construction works according to construction planning. In this stage, design details, quality of materials and conditions of construction works are necessary to improve to ahcieve satisfactory $T_p$.

## CHAPTER 3 ENVIRONMENTAL INDEX

### 3.1 General

(1) The Environmental Index, $S_p$ varies with environmental conditions to which newly constructed concrete structures are exposed and with maintenance-free periods required.

(2) The Environmental Index, $S_p$ is, as a general rule, calculated with following formula:

$$S_p = S_o + \Sigma(\Delta S_p) \tag{3.1}$$

where $S_o$ is a given value for a given maintenance-free period under moderate environmental conditions, and $\Delta S_p$ is an increment which varies with the aggressiveness of chloride ingress or freezing and thawing action. Details are provided in the next section 3.2 for $\Delta S_p$.

(3) The value of $S_o$ is defined to be equal to 100 for a maintenance-free period of 50 years. However, for particularly prolonged or shortened maintenance-free periods, the value of $S_o$ will be increased or decreased respectively.

**[Commentary]**

It is normally accepted that so-called durable concrete structures are required the maintenance-free period of 50 years or so. For this reason, it is defined in this proposed specification that with a reliability of 95 percent, concrete structures with a standard level of durability under moderate environmental conditions will serve for 50 years without any maintenance activities. The value of $S_o$ is specified to be 100 for a maintenance-free period of 50 years under moderate environmental conditions. However, there may be some cases where to set $S_o$ equal to 100 turns out to be grossly uneconomical under given conditions while the value larger than 100 becomes more economical under similar conditions. Accordingly, maintenance-free periods may be decreased or increased for these cases. This proposed specification suggests that $S_o$ be zero for maintenance-free periods of 10 to 15 years while appropriate $S_o$ may be 150 for a maintenance-free period of 100 years under moderate environmental conditions.

## 3.2 Increment of Environmental Index

(1) The Environmental Index, $S_p$ should be carefully determined with an increment of the Environment Index, $\Delta S_p$ which is shown in Table 3.1 where maintenance-free period is assumed to be 50 years. Environmental conditions to be considered in this proposed specification are limited to chloride ingress and freezing and thawing action. To increase or decrease maintenance-free periods for each particular environment, the increment of the Environmental Index, $\Delta S_p$ is increased or decreased respectively within ranges shown in Table 3.1.

(2) For environmental conditions where chloride ingress and freezing and thawing action occur simultaneously, each increment of the Environmental Index, $\Delta S_p$ is added together ($\Sigma\,\Delta S_p$).

**Table 3.1 Increment of the Environmental Index, $\Delta S_p$**

| Environmental conditions | $\Delta S_p$ |
|---|---|
| Chloride ingress | 10 ~ 70 |
| Freezing and thawing action | 10 ~ 50 |

**[Commentary]**

Durability design in this proposed specification takes into account the effect of environmental conditions on the durability of concrete structures where chloride ingress or freezing and thawing action or two actions combined is respectively included. Practically this is done by the increment of the Environmental Index, $\Delta S_p$. There can be present other environmental conditions that affect the durability of concrete structures more adversely than those listed in Table 3.1. These environments may exist in certain kinds of special soils or in an environment of hot springs. For such cases where environmental effects are considered to be significantly higher and unique, the durability of concrete structures needs to be examined separately. Therefore, these particular environmental conditions have been excluded from the scope of this proposed specification. The increment of the Environmental Index, $\Delta S_p$ in Table 3.1 is not given as a definite value, but it ranges from 10 to 70 for chloride ingress and from 10 to 50 for freezing and thawing actions. This is because the effect of chloride ingress or freezing and thawing action on concrete durability is hardly defined as a single function. The degree to which chloride ingress affects the durability of concrete structures is different dependent upon locality, topology, distance from the sea shore, weather, marine meteorological conditions and so on. In addition, the action of freezing and thawing is controlled by such local conditions as the maximum and minimum temperature in a day and the degree of humidity. In this way, the Increment of the Environmental Index, $\Delta S_p$ should be determined within the ranges given for respective cases in a careful consideration of local characteristics where concrete structures are to be constructed.

In order to specify the increment of the Environmental Index, $\Delta S_p$ for environments of chloride ingress in more objective manners the Guideline on Road Bridges for Prevention from Salt

Attack and Commentary issued by the Japan Road Association is recommended to refer. In this guideline book, various countermeasures are specified to combat chloride ingress. They are conveniently ranked in the Grade I to Grade III on the basis of the nature of locality and distance from sea shore lines. Therefore, the specific value of increment of the Environmental Index, $\Delta S_p$ for case with chloride ingress will be obtained according to the Grades. For instance, for environments of chloride ingress that are defined in the Grade I, the increment of the Environmental index, $\Delta S_p$ may be 70 when maintenance-free period is a 50 years. Similarly, it may be 40 for the Grade II and 10 for the Grade III. In addition, for marine concrete structures the effect of sea water spray and meteorological conditions unique to marine environments should be taken into account for the determination of the increment of the Environmental Index, $\Delta S_p$. It may be equal to 70 in case where these conditions appear to be extremely severe and may be equal to 40 for comparatively mild conditions. Moreover, $\Delta S_p$ should be determined properly for concrete structures subjected to freezing and thawing actions with deicing agents. The type and amount of the agent used should be reflected to determine $\Delta S_p$, especially for concrete structures without any protection nor countermeasures to the attack of chemical agents.

The increment of the Environmental Index, $\Delta S_p$ for concrete structures subjected to the action of freezing and thawing is determined based on following simplified equation:

$$N_d = (F_t + F \text{ x } u) \text{ x } C \qquad (3.2)$$

where $N_d$ is the calculated number of freezing and thawing cycles, $F_t$ is the total number of days of freezing and thawing action per year determined on the basis of atmospheric temperature, $F$ is the total number of days of freezing determined on the basis of atmospheric temperature, $u$ is the rate of thawing due to sunlight and $C$ is the coefficient of frost damage reduced due to moisture effects. Using Eq.(3.2) $N_d$ is calculated for a particular environment of freezing and thawing actions and then the increment of the Environmental Index, $\Delta S_p$ is determined according to $N_d$: $\Delta S_p$ is equal to 50 for $N_d$ larger than 100, equal to 40 for 90 ~ 100, equal to 30 for 80 ~ 90, equal to 20 for 70 ~ 80, equal to 10 for 40 ~ 70, and equal to 0 for $N_d$ less than 40. The rate of thawing due to sunlight, $u$ and the coefficient of frost damage reduced due to moisture effects, $C$ are calculated in following manners.

**Table 3.2 The Rate of Thawing Due To Sunlight, *u* (%) Varied with Daylight Hours and Temperatures (Selected Cities)**

| Min. Temp. in a day (℃) | Max. Temp. in a day (℃) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ~ -10.1 | | | | | -10.0 ~ -5.1 | | | | | -5.0 ~ -1.0 | | | | |
| | Selected Cities[#1] | | | | | | | | | | | | | | |
| | KC | AS | SP | AB | OB | KC | AS | SP | AB | OB | KC | AS | SP | AB | OB |
| -1.0 ~ -5.0 | | | | | | | | | | | 100 | 50 | 50 | 65 | 75 |
| -5.1 ~-10.0 | | | | | | 20 | 30 | 30 | 60 | 70 | 45 | 55 | 75 | 70 | 80 |
| -10.1 ~-15.0 | 0 | 10 | 10 | 20 | 30 | 15 | 20 | 30 | 45 | 80 | 50 | 45 | 75 | 80 | 80 |
| -15.1 ~-20.0 | 0 | 0 | 0 | 10 | 20 | 15 | 15 | 20 | 60 | 60 | 60 | 45 | 45 | 85 | 85 |
| -20.1 ~-25.0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 20 | 35 | 50 | 35 | 50 | 60 | 70 | 75 |
| -25.1 ~ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 25 | 0 | 10 | 20 | 30 | 40 |

Selected Cities[#1] (Daylight Hours in a month) -
KC : Kutchan (~ 75.0), AS : Asahikawa (75.1 ~ 105.0), SP : Sapporo (105.1 ~ 135.0),
AB : Abashiri (135.1 ~ 165.0), OB : Obihiro (165.1 ~)

The rate of thawing due to sunlight, $u$ varies with such meteorological data as the maximum and minimum temperature and the daylight hours in a day and the value is listed in Table 3.2 for limited areas in Japan. The rate of thawing due to sunlight, $u$ for other regions may be given using values in Table 3.1 where the daylight hours are similar to those listed. The coefficient of frost damage reduced due to moisture effect, $C$ reflects the effect of moisture state of concrete surface due to the melting of snow or rain on frost damage. The procedure to determine the coefficient of reduced frost damage due to moisture effect, $C$ is shown in Fig. 3.1 where the effect of moisture state resulting from the melting of snow on frost damage is assumed to be twice as severe as that for rain. In this procedure another coefficient indicating moisture state in cold regions, $C_0$ is calculated and then the coefficient of frost damage reduced due to the moisture effects, $C$ is determined on the basis of a list given in Table 3.3. The calculated number of freezing and thawing cycles, $N_d$ that is determined according to above procedures, is listed in Table 3.4 for limited areas in Japan.

**Table 3.3 Coefficients of Frost Damage Reduced Due to Moisture Effect, $C$ Varied With Coefficients Indicating Moisture State in Cold Regions, $C_0$**

| $C_0$ | 0~50 | 51~100 | 101~150 | 151~200 | 201~250 | 251~300 | 301 ~ |
|---|---|---|---|---|---|---|---|
| $C$ | 0.30 | 0.50 | 0.70 | 0.80 | 0.90 | 0.95 | 1.00 |

**Table 3.4 Number of Freezing and Thawing Cycles, $N_d$ for Selected Cities**

| Cities | $F_t$ (Days) | $F$ (Days) | NT[#1](Days) | NF[#2](Days) | FT[#3](℃) | $C_0$ | $N_d$ |
|---|---|---|---|---|---|---|---|
| Asahikawa | 77 | 71 | 25 | 102 | ~ -30 | 285 | 96 |
| Sapporo | 87 | 45 | 29 | 116 | ~ -20 | 295 | 114 |
| Obihiro | 103 | 52 | 39 | 142 | ~ -30 | 212 | 128 |
| Kushiro | 103 | 40 | 32 | 135 | ~ -25 | 140 | 95 |
| Hakodate | 88 | 35 | 23 | 111 | ~ -20 | 168 | 89 |
| Morioka | 100 | 14 | 10 | 110 | ~ -20 | 161 | 88 |
| Sendai | 79 | 2 | 1 | 80 | ~ -15 | 98 | 40 |
| Nikko | 97 | 41 | 33 | 130 | ~ -20 | 174 | 104 |
| Tokyo | 18 | 0 | - | 18 | ~ -5 | 88 | 9 |
| Nagano | 98 | 5 | 3 | 101 | ~ -15 | 136 | 71 |
| Karuizawa | 124 | 19 | 15 | 139 | ~ -20 | 133 | 97 |
| Matsumoto | 114 | 3 | 2 | 116 | ~ -20 | 113 | 81 |
| Fukui | 38 | 0 | - | 38 | ~ -10 | 406 | 38 |
| Okayama | 63 | 0 | - | 63 | ~ -10 | 53 | 32 |

NT[#1] : the number of thawing days due to sunlight, NF[#2] : the number of freezing and thawing days, FT[#3] : the range of minimum temperatures in a freezing day

For environments with combined effects of chloride ingress and freezing and thawing action, the increment of the Environmental Index, $\Delta S_p$ is determined simply by adding each $\Delta S_p$. External factors that adversely affect the durability of concrete structures include fatigue due to the action of cyclic loads and alkali-aggregate reaction. However, the fatigue effect is excluded from the determination of the Environmental Index, $S_p$ in this proposed specification. This is because it involves complex mechanisms in degrading concrete durability, especially for concrete bridge deck where other environmental effects apparently exist. Therefore, quantitative evaluation is considered to be impossible at present. This will be taken into account with progressive researches on this particular subject in the future. In addition, the effect of alkali–aggregate reaction is also disregarded since adequate precautions can be taken on this matter during the selection of aggregates prior to mixture.

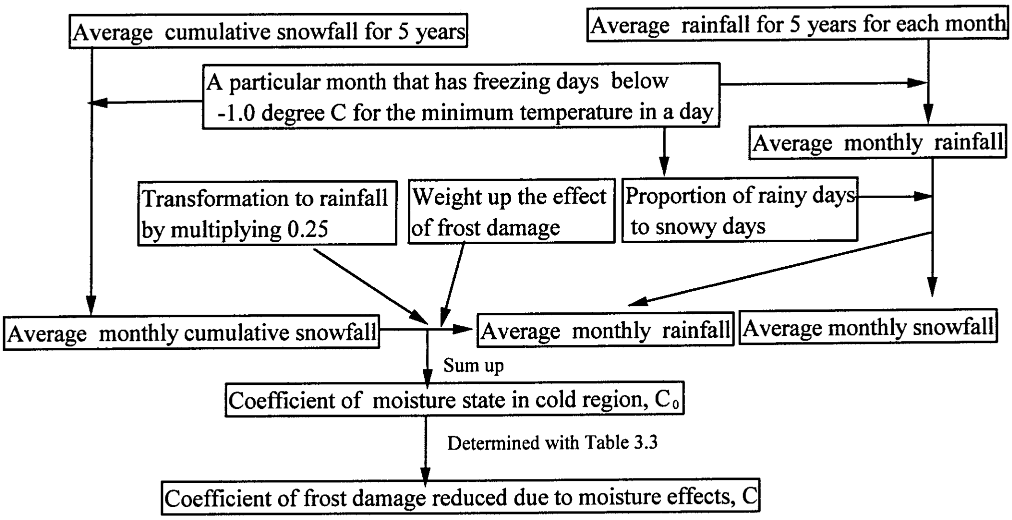


**Fig.3.1 Flow to Determine Coefficient of Moisture State in Cold Region, $C_0$**

## CHAPTER 4 DURABILITY INDEX

1. Since numerous internal and external factors control the durability of concrete structures, the Durability Index, $T_p$ should be determined in a comprehensive manner including all of these relevant factors. However, because of limited understanding it appears to be difficult to quantify each factor to calculate the Durability Index, $T_p$. Therefore, only primary factors in relation to design procedures, construction methods and materials for concrete structures are used for the calculation. These factors are divided into following eight groups ($I$=1~8); (1) design procedures, the shape and dimension of a member, types of reinforcement, reinforcement arrangements and other details and design drawings, (2) consideration of cracks, (3) specially designed formworks and the protection of concrete surface, (4) the quality of concreting materials, (5) the quality of concretes, (6) concreting works, (7) re–bar works, formworks and falseworks and (8) additional works for prestressed concrete. Each group is further subdivided in various categories ($J$) to account for the Durability Point, $T_p(I,J)$.

2. The Durability Index, $T_p$ is, as a general rule, calculated as follows:

$$T_p = 30 + \Sigma T_p(I, J) \tag{4.1}$$

where $T_p(I, J)$ is the Durability Point which represents given points calculated in respective groups noted above ($I$=1~8). The Durability Point is calculated by adding points assigned to respective categories ($J$) in respective groups ($I$). Although the Durability Point is fully explained in the next chapter, the summery of the Durability Point, $T_p(I, J)$ is introduced in Table 4.1.

**Table 4.1 The Durability Point, $T_p(I, J)$**

| $I$ | $J$ | Factors | $T_p(I, J)$ |
|---|---|---|---|
| 1 | | [Design Procedure, Shape and Dimension of a Member, Types of Reinforcement, Reinforcement Arrangement and Other Details and Design Drawing] | |
| | 1 | Chief engineer for design | 6 ~ -2 |
| | 2 | Shape and dimension of a member | considered in $T_p(5,1)$ |
| | 3 | Concrete cover | 30 ~ -30 |
| | 4 | Anti-corrosive reinforcement | considered in $T_p(1,3)$ |
| | 5 | Clear distance and the piled-up number of reinforcements | 15 ~ -35 |
| | 6 | Additional reinforcement | 10 ~ 0 |
| | 7 | Construction joint | 0 ~ -25 |
| | 8 | Design drawing | 0 ~ -35 |
| 2 | | [Consideration of Cracks] | |
| | 1 | Thermal crack | 10 ~ -20 |
| | 2 | Flexural crack | 30 ~ 0 |
| 3 | | [Specially Designed Formwork and Protection of Concrete Surface] | |
| | 1 | Specially designed formwork | 10 ~ 0 |
| | 2 | Protection of concrete surface | 20 ~ 0 |
| 4 | | [Quality of Concreting Materials] | |
| | 1 | Cement | 10 ~ 0 |
| | 2 | Water absorption of aggregate | 8 ~ -10 |
| | 3 | Particle size distribution of aggregate | 0 ~ -5 |
| | 4 | Admixture | 10 ~ -15 |
| 5 | | [Concrete] | |
| | 1 | Placing of fresh concrete | 35 ~ -30 |
| | 2 | Strength and permeability | 20 ~ -15 |
| | 3 | Unit water content | 10 ~ -25 |
| | 4 | Amount of chloride ions | 5 ~ -30 |
| | 5 | Quality control in the supplier's plant of concrete | 18 ~ -10 |
| 6 | | [Concreting Work] | |
| | 1 | Chief engineer for construction at site | 25 ~ -10 |

| | | | |
|---|---|---|---|
| | 2 | Acceptance of supplied concrete | 5 ~ -5 |
| | 3 | Transportation, placement and compaction | 20 ~ -45 |
| | 4 | Surface finishing and curing | 8 ~ -45 |
| | 5 | Construction of joints | considered in $T_p(1,7)$ |
| 7 | | [Rebar Work, Formwork and Falsework] | |
| | 1 | Cutting and bending of reinforcing bars | 5 ~ 0 |
| | 2 | Placing of reinforcing bars | 10 ~ -20 |
| | 3 | Formwork | 10 ~ -15 |
| | 4 | Shoring | 5 ~ -5 |
| 8 | | [Additional Works for Prestressed Concrete] | |
| | 1 | Chief engineer for prestressing works | 4 ~ -5 |
| | 2 | Mix proportion of grout | 5 ~ 0 |
| | 3 | Quality of concrete for anchor pockets | 0 ~ -5 |
| | 4 | Quality control for the injection of grout | 0 ~ -5 |

**[Commentary]**

On the basis of a large amount of knowledge and information regarding concrete durability obtained to date various factors ($J$) have been selected in each group ($I$) to account for the Durability Point, $T_p(I, J)$. These factors were weighed and then given some points. If a factor concerned has a significant effect on the durability of concrete structures then a higher or positive point is given within the range. The overall distribution and balance of points were carefully examined in determining the maximum and the range of respective points. Needless to say, however, to quantify the effects on the durability of concrete structures cannot be made without a number of difficulties. Especially, effects of design procedures and construction works have been the most difficult to be quantified since they include factors associated with the quality of designers and workmen. It is admitted that there has been little data to quantify them in an objective manner. However, to include human factors is essential as they are related closely to making concrete structures highly durable. With increased knowledge on this subject the points given to the human factors will be modified to more appropriate values.

Each effect should not be considered completely independent but as mutually related to each other and hence it may be inappropriate to quantify individually. However, for the sake of simplicity, they have been treated as if they were independent entities and so provided. Great care has been taken so as not to double count factors concerned. A note to indicate similar effects, e.g. considered in $T_p(5,1)$, is provided in Table 4.1 for some factors that were found to be impossible to separate one from the other. In order to examine overall distribution and balance of the points among selected factors in relation to design, materials, construction and additional works for prestressed concrete, which are normally categorized for convenience, the range of the total points are respectively summerized in Table 4.2.

The Durability Index, $T_p$ is calculated uniquely using Eq.(4.1) regardless of environmental conditions. Although it is an ideal to count environmental effects for the calculation of the Durability Index, $T_p$, these effects are included in the Environmental Index, $S_p$. Therefore, it is presumably acknowledged that concrete structures that meet Eq.(2.1) in this proposed specification will satisfactorily perform well under severe environmental conditions.

Any factors which are considered to be important but excluded from this proposed specification must be treated on the basis of the JSCE Standard Specification for Design and Construction of Concrete Structures.

**Table 4.2 Overall Distribution and Balance of the Total Points of Selected Factors**

| | |
|---|---|
| Design | 131 ~ − 147 |
| Materials | 116 ~ − 140 |
| Construction | 88 ~ − 145 |
| Additional Works for Prestressed Concrete | 9 ~ − 15 |
| Total points | 344 ~ − 447 |

## CHAPTER 5 DURABILITY POINT

### 5.1 Durability Point for Design Prosedure, Shape and Dimension of Member, Types of Reinforcement, Reinforcement Arrangement and Other Details and Design Drawing, $T_p(1,J)$

The determination of the Durability Point, $T_p(1, J)$ is associated with the experience and qualification of chief engineers in charge of design, the shape and dimension of a member, concrete cover, anti-corrosive reinforcement, the clear distance and piled-up number of reinforcements, additional reinforcement, construction joints and design drawings. The Durability Point, $T_p(1, J)$ is calculated with given items and formulas shown in Table 5.1.

**Table 5.1 The Durability Point for Design Prosedure, Shape and Dimension of Member, Type of Reinforcement, Reinforcement Arrangement and Other Details and Design Drawing, $T_p(1, J)$**

| $J$ | $K$ | Items and Formulas ($K$) in Each Factor ($J$) | $T_p(1, J)$ |
|---|---|---|---|
| 1 | | [Chief Engineer for Design] | |
| | 1 | • Registered consulting engineer | 2 |
| | 2 | • $A_{12} - 7$<br>$A_{12}$ : the number of years of experience | 4 ~ −2 |
| 2 | | [Shape and Dimension of Member] | considered in $T_p(5,1)$ |
| 3 | | [Concrete Cover] | |
| | 1 | • $\{30(A_3 - 5)\}/4$<br>$A_3$ : concrete cover (cm) | 30 ~ −30 |
| 4 | | [Anti-Corrosive Reinforcement] | |
| | 1 | • Calculate with an equation in $T_p(1,3)$ by replacing $A_3$ with $A_4$<br>$A_4$ : concrete cover defined for non-anti-corrosive reinforcements in cm, but may be equal to 9 cm when all rebars are anti-corrosive | |
| 5 | | [Clear Distance and Piled-Up Number of Reinforcement] | |
| | 1 | • $15(1 - \sqrt{2A_{50}}/A_{51})$<br>$A_{50}$ : the piled-up number of reinforcement<br>$A_{51}$ : the horizontal clear distance of reinforcements / the maximum size of coarse aggregates | 15 ~ −25 |

| | | | |
|---|---|---|---|
| | 2 | • $0.5(10 - A_{52})$<br>$A_{52}$ : the maximum depth to which an internal-rod-typed vibrator with $\phi$60 mm can reach (cm) | 0 ~ -10 |
| 6 | | [Additional Reinforcement] | |
| | 1 | • $25A_6$<br>$A_6$ : the cross sectional area of additional reinforcements / the cross sectional area of concrete member (%) | 10 ~ 0 |
| 7 | | [Construction Joints] | |
| | 1 | • Reversed horizontal construction joints : $-25A_7$<br>• Horizontal joints : $-20A_7$<br>• Vertical joints : $-10A_7$<br>$A_7$ : coefficients varied with treatment methods, 0.3 ~ 1.0 | -7 ~ -25<br>-6 ~ -20<br>-3 ~ -10 |
| 8 | | [Design Drawing] | |
| | 1 | • Concrete cover is not clearly specified<br>• Reinforcements and tendons in a particular portion are not depicted in the same drawing<br>• Construction joints are not clearly indicated | -5<br>-5<br><br>-25 |

**[Commentary]**

1. ($J$=1) In order to properly execute durability design engineers in charge of it, especially chief engineers responsible for final decision play an important role. Therefore, the period of the experience of design and qualifications that chief engineers hold are used to evaluate human factors objectively.

2. ($J$=2) The shape and dimension of a member have a marked effect on compactability of fresh concrete that is related closely to flowability and the resistance of segragation of the concrete. Therefore, the Durability Point for the shape and dimension of a member, $T_p(1,2)$ is counted in the Durability Point for compactibility of fresh concrete, $T_p(5,1)$.

3. ($J$=3) The depth of carbonation and chloride penetration in concrete cover appears to be in proportional to the square root of time while it is reported that the damage of concrete surface due to the action of freezing and thawing progresses in proportional to the square of time. Therefore, the thickness of concrete cover is necessary to be large enough to maintain the durability of concrete structures. This can be true even for the case with cracks present in the concrete cover. The developement of equation for calculating the Durability Point, $T_p(1,3)$ is based on above appreciation.

For precast concretes and other factory products, the equation defined for the Durability Point, $T_p(1,3)$ may be replaced with $(A_3 - 4)$ for $(A_3 - 5)$. This is due to the fact that reinforcements are normally arranged in proper position with accuracy for factory-made products. In addition, sufficiant compaction and curing are also practiced.

4. ($J$=4) The use of reinforcement coated with epoxy resin as an anti-corrosive reinforcement has a beneficial effect and hence is considered in the Durability Point, $T_p(1,3)$. In this case it is treated as "a conceptional increase in concrete cover" and the thickness may be increased up to 90 mm regardless of actual concrete cover. However, application of the reinforcements must be in strict accordance with the JSCE Reccomendation for Design and Construction of Concrete Structures Using Epoxy-Coated Reinforcing Steel Bars published in 1986.

Similarily, the Durability Point may be increased for the use of continuous fiber reinforced plastic bars and other types of anti-corrosive reinforcements.

5.($J$=5) The clear distance and piled-up number of reinforcements have effects on the placing of concrete. When a full of reinforcements is packed in a given mould the flow of fresh concrete is obstructed and some portions in the mould may remain insufficiently filled with the concrete. Furthermore, the arrangement of reinforcements has a marked influence on compaction of fresh concrete using internal rod–typed vibrators. For the compaction with the internal vibrators to be executed adequately there needs to be a spacious room without obstruction of reinforcements. Especially, the horizontal clear distance of horizontally arranged reinforcements in the vicinity of the bottom surface of a member is influential for beam and slab members while the vertical clear distance of vertically arranged reinforcements near lower portion in the single lift of concrete placement is influential for columns and walls. Also the piled–up number of these reinforcements has an effect for each case. Therefore, these effects are regarded to determine the Durability Point, $T_p(1,5)$.

For a prestressed concrete member, sheaths or prestressing tendons can be regarded as reinforcing bars to calculate the Durability Point. Furthermore, an additional bar with small diameter, which is placed in the vicinity of the bottom surface of a beam and slab member and is located within a horizontal projected plane by the sheath, may be neglected for the calculation of the Durability Point.

Recent investigation on the deterioration of bridge decks due to chloride ingress in particular reveals the evident lack of compaction in the vicinity of the bottom surface of the slab members. Many of these have such shapes and dimensions that rod–typed vibrators hardly reach the bottom portion in the members. Therefore, it is neccesary to provide the depth that internal–rod–type vibrators cannot reach. Note that the Durability Point may be zero in the case where self–placing concrete is used, which is introduced in Commentary 2. in section 5.5.

6.($J$=6) An additional reinforcement will be used to restrict the number and width of cracks that occur due primarily to drying shrinkage and temperature gradient. Therefore, it is preferable to the durability of concrete structures. When additional reinforcements are arranged in two differnt directions the Durability Point is counted for whichever has a smaller diamter.

7.($J$=7) Any construction joints, no matter how they are carefully jointed, can reduce the capacity of concrete structures in structural and durability terms when compared with uniform concrete members without construction joints. It is for this reason that the Durability Point is zero for uniform concrete members while it is largely reduced for concrete members containing any construction joints. Since a reduction in the Durability Point is significant, if the introduction of construction joints is inevitable from standpoints of construction proceduers, some beneficial effects must be added to increase overall Durability Point in this group.

The coefficient $A_7$ in the calculation of the Durability Point varies with treatment methods used for construction joints and is defined as follows.

(1) Sand blasting or jet chiseling followed by washing out with high pressure air or high pressure water : $A_7$ = 0.3

(2) Spaying setting retarder followed by washing out with high pressure air or high pressure water : $A_7$ = 0.5

(3) Washing out with high pressure air or high pressure water : $A_7$ = 0.7

(4) No additional treatment : $A_7$ = 1.0

8.($J$=8) It is not exaggerated to say that a design drawing is an only way to let construction engineers and workers know about the intension of design engineers. This is because of the fact that design procedures have been currently conducted by completely different engineers or groups from those who work in construction sites. Under this circumstance, design principle is hardly transmitted correctly unless the design drawing is clearly depicted. It is also true that a vague rule that has been unconsciously generalized and become an unreasonable belief among design engineers exist. Therefore, in order to avoid it and make design drawings comprehensible the drawing of concrete cover, reinforcements and construction joints should be clearly indicated.

A number of design drawings rarely insist clearly whether the thickness of concrete cover is a distance between concrete surface and reinforcement surface or between concrete surface and the center of reinforcement or whether it is for outer or inner reinforcements. Admittedly, it may be true that few design engineers recognize a direct impact of concrete cover on the durability of concrete structures. This proposed specification recommends that an additional design drawing be provided to direct concrete cover.

Recent uses of high strength concrete and high strength reinforcing steel have enabled the cross sectional area of a concrete member to become small. This has often led to the concern that reinforcements will be packed in a relatively smaller portion that acts as the blockage of the flow of fresh concrete. One of major causes in this problem is attributed to the fact that a design drawing for the arrangement of reinforcements and tendons in a particular portion is depicted over several separate sheets. For a large-scale prestressed concrete structure in particular, reinforcements positioned in bearing supports, anchorage zone for prestressing tendons, openings, and so on are often drawn individually for each purpose in separate sheets. Because of this, one design drawing does not allow to account for the smooth placing and filling of fresh concrete. Therefore, appropriate attention should be provided.

Any construction joints and splices should be positioned where strength and durability of concrete structures are hardly affected. In most cases where design drawings contain no indication of construction joints, enough care for the treatments must be neglected. Therefore, a large penalty is given unless construction joints are clearly specified in design drawings. In addition, construction joints are not indicated in design drawings at design stage for some reasons. For this case it is essential to discuss the position of construction joints and their treatments with designers during construction plannings to make sure if they are properly treated.

## 5.2 The Durability Point for Consideration to Cracks, $T_p(2, J)$

The Durability Point, $T_p(2, J)$ is determined for thermal cracks and flexural cracks and is calculated with given formulas shown in Table 5.2.

**Table 5.2 The Durability Point for Consideration to Cracks, $T_p(2, J)$**

| *J* | *K* | Formulas (*K*) for Factors (*J*) | $T_p(2, J)$ |
|---|---|---|---|
| 1 | | [Thermal Crack] | |
| | 1 | • $20(1 - 1/B_1)$<br>$B_1$ : Thermal Crack Index | 10 ~ -20 |
| 2 | | [Flexural Crack] | |
| | 2 | • $5(B_2^2 - 7B_2 + 6)$,<br>$B_2$ : the width of flexural crack formed due to permanent loads / allowable crack width | 30 ~ 0 |

**[Commentary]**

Cracks are normally considered to have an unfavourable influence on the durability of concrete structures. Therefore, the development and propagation of any cracks should be reduced as much as possible. The Durability Point in this group is determined for thermal cracks that occurs because of heat evolution due to the hydration of cement particles and flexural cracks. The development of these cracks can be predicted using a given formula or sophisticated design tools.

1. ($J$=1) The equation shown in Table 5.2 is developed with the Thermal Cracking Index that is defined in the JSCE Standard Specifications for Design and Construction of Concrete Structures [Construction], 1986. The Thermal Cracking Index is expressed as a ratio of the tensile strength of concrete to the maximum thermal stress in tension: a larger value indicates the smaller probability of the occurrence of thermal cracks and the smaller width of the cracks. The Thermal Cracking Index is also determined in a simplified manner using temperature distribution in a concrete member after placement. The Thermal Cracking Index is obtained with a formula of $15/\Delta T_i$ where $\Delta T_i$ is the maximum temperature difference between concrete surface and the interior of concrete (℃). For thermal stress to occur due to external restraints the Thermal Cracking Index is calculated with $10/(0.5\Delta T_0)$, where $\Delta T_0$ is the difference between the maximum average temperature of concrete and its equilibrium temperature in an ambient air temperature (℃). It is noted that the Thermal Cracking Index calculated with the simplified method gives normally a smaller value. In addition, for calculating temperature distribution within concrete, thermal properties of the concrete are, for convenience, assumed for a given mixture proportion, materials and construction conditions. These properties include thermal conductivity, thermal diffusivity, specific heat and the ultimate adiabatic temperature rise. Furthermore, thermal analysis can be conveniently conducted with personal computers in which it is recommended to use a commercial program developed by the Research Committee on Thermal Stresses in Mass Concrete in the Japan Concrete Institute.
For prestressed concrete structures, prestress developed in the concrete tends to reduce the width of thermal cracks or close crack openings. Then, the Durability Point for thermal cracks may not be less than zero. However, since this is not always the case, the Durability Point for thermal cracks will be calculated for each section of a member under examination.

2. ($J$=2) In order to determine the coefficient, $B_2$ in the equation developed for the Durability Point for flexural cracks, the JSCE Standard Specification for Design and Construction of Concrete Structures [Design] is referred. It provides a formula to calculate the width of flexural cracks and allowable values for given environmental conditions.

## 5.3 The Durability Point for Specially Designed Formworks and Protection of Concrete Surface, $T_p(3, J)$

The Durability Point, $T_p(3, J)$ for specially designed formworks and the protection of concrete surface is determined for the quality and types of formworks and protection methods adopted. It is calculated with given items ($K$) shown in Table 5.3.

**Table 5.3 The Durability Point for Specially Designed Formwork and Protection of Concrete Surface, $T_p(3, J)$**

| $J$ | $K$ | Items ($K$) for Each Factor ($J$) | $T_p(3, J)$ |
|---|---|---|---|
| 1 | | [Specially Designed Formwork] | |
| | 1 | · Textile formwork<br>· Permanently buried precast formwork<br>· Formwork specially designed to fit in the configuration of a particular member | 5 or 10<br>5<br>5 |
| 2 | | [Protection of Concrete Surface] | |
| | 1 | · Stone plate or tile pasted<br>· Epoxy resin coating of acknowledged weatherability<br>· Plastic pasted<br>· Finish with polymer cement or epoxy resin impregnation | 20<br>15<br>10<br>5 |
| | | Note: Do not add any of these points and $T_p(1,3)$ above 40. | |
| | | Note: Do not add $T_p(3,1)$ and $T_p(3,2)$ for $T_p(3, J)$. | |

**[Commentary]**

1. ($J$=1) The use of textile formworks will make the surface layer of concrete dense, few of air bubbles and rich in cement paste. This results in the enhancement of the quality of concrete and hence its durability. For a textile formwork that meets required performance according to the Japan Institute of Construction Engineering, the Durability Point may be equal to 10. The Durability Point for the use of a permanently buried precast formwork is equal to 5 in a limited case where sufficient bond and unity with in-situ placed concrete are ensured. When a steel reinforcing bar without surface coating is arranged within a precast formwork, the depth of concrete cover is given as it is to calculate the Durability Point for concrete cover, $T_p(1,3)$. The use of a specially designed formwork with any features to fit in the configuration of a given member is appreciated and positively evaluated for the Durability Point.

2. ($J$=2) Maintenance will be necessary even for surface protection in the course of a service life depending on the quality of the protection materials. However, concrete members protected with surface protection are free of external attacks and hence remain to be sound until the performance of the surface protection becomes no longer ineffective. Then, surface protection is thought to make concrete structures durable for longer service periods as compared with the case where no protection of concrete surface is provided. This may be true even if repair works for the deteriorated portion of surface protection will never be carried out. For this regard, the Durability Point is determined according to types of surface protection employed.

## 5.4 The Durability Point for Concrete Materials, $T_p(4, J)$

The Durability Point for concrete materials, $T_p(4, J)$ is determined for various types of cements, aggregates and admixtures, which are related to but little accounted for not only in the Durability Point for consideration to cracks, $T_p(2, J)$ but also in the Durability Point for concrete $T_p(5, J)$. The Durability Point for concrete materials is calculated with given items and formulas shown in Table 5.4.

**Table 5.4 The Durability Point for Concrete Materials, $T_p(4, J)$**

| $J$ | $K$ | Items and Formulas ($K$) for Each Factor ($J$) | $T_p(4, J)$ |
|---|---|---|---|
| 1 | | [Cement] | |
| | 1 | • Cement that reduces drying shrinkage and autogenous shrinkage<br>• Ordinary cement | 10<br>0 |
| 2 | | [Moisture Absorption of Aggregate] | |
| | 1 | • $2(2 - D_{21}) + 4(1-D_{22}) \geqq -10$<br>$D_{21}$ : moisture absorption ratio of fine aggregate (%)<br>$D_{22}$ : moisture absorption ratio of coarse aggregate (%) | 8 ~ -10 |
| 3 | | [Particle Size Distribution] | |
| | 1 | • Within a standard range<br>• Deviating from the standard | 0<br>-5 |
| 4 | | [Admixture] | |
| | 1 | Properly used:<br>• expansive admixture<br>• silica fume<br>• drying-shrinkage-reducing agent | 10 or $T_p(2,2)$<br>10<br>10 |
| | | Note : Do not add these points | |

| | | | |
|---|---|---|---|
| | 2 | When freezing and thawing action is severe, air-entraining agent or AE water reducer or superplasticizer is:<br>• not used<br>• used | <br><br>−15<br>0 |

**[Commentary]**

1. ($J$=1) The use of special types of cement manufactured for a purpose of the reduction of drying shrinkage or autogenous shrinkage should be appreciated as compared to ordinary portland cement. This may be appreciated, especially with regard to the reduction of crack developments in concrete and hence may be counted positively in the Durability Point for consideration to cracks, $T_p(2, J)$. Although these types of cement are yet commercially available the Durability Point is given 10 for their uses. Therefore, it is anticipated to encourage for cement manufactures to be in active for research and development on the manufacture of these cements.

2. ($J$=2) Moisture absorption of aggregates is used to determine the quality of fine and coarse aggregates. This is because aggregates of higher moisture absorptions have a negative effect on the performance of concrete structures under the action of freezing and thawing. Also cracks tend to occur on the surface of concrete containing aggregates with higher absorption rates.

3. ($J$=3) A standard for the particle size distribution of aggregates is provided in the JSCE Standard Specifications for Design and Construction of Concrete Structures [Construction]. The use of aggregate whose particle size distribution meets the standard is a prerequisite to evaluate workability of concrete in the Durability Point, $T_p(5,1)$.

4. ($J$=4, $K$=1) Expansive admixtures can help to reduce drying shrinkage and autogenous shrinkage of concrete due to chemical prestress and prestrain induced in the concrete and reinforcement, respectively. However, since improper use of expansive admixtures will result in undesirable effects the JSCE Recommended Practice for Expansive Cement Concrete must be referred. Also supervisors with sufficient experience in the use of expansive admixtures is necessary to be present at construction sites. When expansive admixtures are used for a purpose of counteracting the shrinkage of concrete the Durability Point is given 10. When the use of expansive admixtures is for the introduction of chemical prestress and chemical prestrain in a reinforced concrete member, its favorable effect is accounted for the calculation of the width of flexural cracks in the Durability Point for Consideration to Cracks. $T_p(2,2)$. In this case, the width of flexural cracks is calculated according to the JSCE Recommended Practice for Expansive Cement Concrete where $\varepsilon'_{cs}$ is given zero.

Concrete containing silica fume will have dense microstructure and hence is believed to perform well under severe environments. The JSCE Proposed Recommended Practice for Concrete with Silica Fume must be referred for its use.

The effectiveness of drying-shrinkage-reducing agents has been proven so as to improve the durability of concrete structures. However, this agent must be used with experienced supervisors at construction site since there are no specification directed on the quality and usage of drying-shrinkage-reducing agents in the Japanese Industrial Standards nor in the JSCE Standard nor Recommendation at present.

5. ($J$=4, $K$=2) Air entrained concrete is normally used under environments with severe freezing and thawing actions. Therefore, in order to introduce adequate amount of air content in concrete subjected to freezing and thawing actions, which depends on the maximum size of coarse aggregate, air entraining admixtures should be used. Favorable effects of such admixtures as water reducing agents, high range water reducers, superplasticizers and segregation resistance agents, especially on the properties of fresh concrete are counted in $T_p(5,1)$.

## 5.5 The Durability Points for Concrete, $T_p(5, J)$

The Durability Point for concrete $T_p(5, J)$ is determined for the compactability of fresh concrete, the strength and permeability of hardened concrete, unit water content, the amount of chlorides content and quality control in supplier's plants of concrete. The Durability Point for concrete is calculated with given items and formulas shown in Table 5.5.

**Table 5.5 The Durability Point for Concrete, $T_p(5, J)$**

| $J$ | $K$ | Items and Formulas ($K$) in Each Factor ($J$) | $T_p(5, J)$ |
|---|---|---|---|
| 1 | | [Compactability] | 35 ~ −30 |
| | 1 | • Flowability : $2(E_{10} - 10) + E_{11}(1 - E_{10}/30)$<br>$E_{10}$ : Slump (cm)<br>$E_{11}$ : Coefficients varying with the shape and dimension of a member (15 ~ −15) | 30 ~ −30 |
| | 2 | • Segregation resistance : $5 - E_{12}(E_{10})^2$<br>$E_{12}$ : Coefficients (0.06 ~ 0), normally equal to 0.06 | 5 ~ −25 |
| 2 | | [Strength and Permeability] | |
| | 1 | • $55 - E_2$<br>$E_2$ : water to cement ratios (%) | 20 ~ −15 |
| 3 | | [Unit Water Content] | |
| | 1 | • $0.5(160 - E_3) : E_3 \leqq 160$<br>• $1.0(160 - E_3) : E_3 > 160$<br>$E_3$ : unit water content (kg/m$^3$) | 10 ~ −25 |
| 4 | | [Chlorides Content] | |
| | 1 | • $5 - 0.5(10E_4)^2$<br>$E_4$ : total chloride content (kg/m$^3$) | 5 ~ −30 |
| 5 | | [Quality Control on the Supplier's Plant of Concrete] | |
| | 1 | • Non-JIS-Mark-licensed plant<br>• JIS-Mark-licensed plant | −10<br>0 |
| | 2 | • Equipped with automatically measuring and recording devices<br>• Equipped with significantly high performance mixers<br>• Equipped with roofed aggregate storage yard<br>• Control of the surface moisture content of fine aggregate:<br>its accuracy ±0.5 %<br>its accuracy ±1.0 %<br>• Controlled consistency with torque | 4<br>2<br>2<br><br>4<br>2<br>4 |

**[Commentary]**

1. ($J$=1, $K$=1) The compactability of fresh concrete is evaluated with flowability and segregation resistance. The flowability of fresh concrete is quantified using the equation with two coefficients relevant to slump, $E_{10}$ and the shape and dimension of a member, $E_{11}$. The equation allows the flowability of fresh concrete to be more controlled by the shape and dimension of a member as slump becomes lower. $E_{11}$ is equal to 15 for the most suitable shape and dimension in terms of the compactability of fresh concrete while it is given −15 for the worst case. For other cases $E_{11}$ is calculated as follows:

$$E_{11} = (10 - 8/A_{21}) + (5 - F_{32}^2) + A_{22} \tag{5.5}$$

where $A_{21}$: the minimum of lateral dimension of a member (m) (equal to 0.5 m for any dimensions less than 0.5 m)
$F_{32}$: the maximum height of single lift for placing concrete (m) (equal to $\sqrt{10}$ m for any heights larger than $\sqrt{10}$ m)
$A_{22}$: coefficients determined with the dimension of a cross section in the direction of height (equal to −5 for the case where the section of smaller sectional area is present above a particular section concerned, otherwise equal to zero)

2. ($J$=1, $K$=2) The segregation resistance of fresh concrete is quantified with slump, $E_{10}$ and a given coefficient, $E_{12}$ that accounts for any factors relevant to segregation other than slump. The segregation resistance calculated with the equation is reduced as slump increases. $E_{12}$ is normally equal to 0.06 but can be reduced, for instance when segregation resistance agents are properly used. In addition, $E_{12}$ is assumed to be close to zero for underwater concrete with some special admixtures.

Self–placing concrete of significantly higher workability has been achieved without causing segregation. The manufacture of high performance concrete of this kind becomes possible only when enough care has been taken with regard to mixture proportions including grain shapes and sizes and particle size distribution of such powders as cement, fly ash and blast furnace slag, and the application of a large amount of superplasticizer and segregation resistance agents, if needed. For the self–placing concrete, the Durability Point for the flowability may be given a full mark and also the coefficient, $E_{12}$ necessary to calculate the Durability Point for the segregation resistance may be equal to zero.

3. ($J$=2) Of great importance is the strength and permeability of concrete with regard to the durability of concrete structures. These characteristics may be appropriately evaluated with a water to cement ratio.

4. ($J$=3) Among several factors affecting hardening shrinkage and drying shrinkage of concrete, unit water content in a mixture proportion is especially highlighted and therefore included for the determination of the Durability Point for Concrete.

5. ($J$=4) Chlorides in fresh concrete can cause the corrosion of reinforcing steel only when the content exceeds a certain amount. This accounts for the development of the equation to calculate the Durability Point for the amount of chlorides in fresh concrete.

6. ($J$=5, $K$=1) Quality control exercised in concrete manufacturing plants should be included in the determination of the Durability Point for Concrete. Adequately controlled quality of concrete could be obtained in concrete butcher plants that hold a license by the JIS (Japanese Industrial Standards) as compared with plants without the JIS license. In addition, a temporary plant to produce concrete at a construction site may be considered to be comparable to concrete butcher plants with the JIS license if materials and equipments used and the quality control meet the JIS A 5308 and the Standards for Examination of Ready Mixed Concrete.

7. ($J$=5, $K$=2) Automatically measuring and recording devices allow to print out correctly the weighed value of each concrete materials as well as delivery invoice that will be useful for purchasers to confirm the mixture proportion of ordered concrete before accepting it.

The mixing efficiency of a concrete mixer can control the quality of fresh and hardened concrete. This section focuses on the uniformity of concrete agitated in a mixer, which is one of key factors for the production of high quality concrete.

The quality of concrete is, to a great degree, controlled by the surface moisture of aggregates, especially that of fine aggregates. Therefore, the amount of the surface moisture of fine aggregates is needed to be accurately controlled.

## 5.6 The Durability Point for Concreting Works, $T_p(6, J)$

The Durability Point for Concreting Works is determined with the experience and qualification of chief engineers available at construction site, procedures in the acceptance of supplied concrete, methods of concreting works for transportation, placing, compaction, surface finishing and curing and construction methods for joints. The Durability Point is calculated with items and formulas given in Table 5.6.

**Table 5.6 The Durability Point for Concreting Works, $T_p(6, J)$**

| $J$ | $K$ | Items and Formulas ($K$) for Each Factor ($J$) | $T_p(6, J)$ |
|---|---|---|---|
| 1 | | [Chief Engineer at Construction Site] | |
| | 1 | • $A^+$<br>• A<br>• B<br>• C | 25<br>15<br>5<br>-10 |
| 2 | | [Acceptance of Supplied Concrete] | |
| | 1 | • Supervisor from the main constructor is not stationed at the acceptance place of supplied concrete | -5 |
| | 2 | • Mix proportion of each batch is immediately confirmed by checking a record sheet from the concrete plant | 5 |
| 3 | | [Transportation, Placing and Compaction] | |
| | 1 | • Supervisor for concreting works is not stationed at the place of concreting | -5 |
| | 2 | • Height of the single lift of fresh concrete | considered in $T_p(5,1)$ |
| | 3 | • $2(1.5 - F_{33})$<br>$F_{33}$ : height in which fresh concrete freely falls (m) | 0 ~ -5 |
| | 4 | • $20 - F_{34}$<br>$F_{34}$ : The maximum speed of concrete discharged from a single outlet ($m^3/h$) | 10 ~ -10 |
| | 5 | • Compacted with form vibrators at the fabrication plant<br>• Compacted with not only form vibrators but also internal vibrators at the construction site<br>• Compacted with internal vibrators in an ordinary manner<br>• No compaction | 10<br>5<br>0<br>-25 |
| 4 | | [Surface Finishing and Curing] | |
| | 1 | • Use of a film curing agent<br>• Ordinary surface finishing<br>• No surface tamping for beam and column members<br>• No surface tamping for a member of large surface area | 5<br>0<br>-5<br>-15 |
| | 2 | • For ordinary portland cement<br>$2(F_{42} - 5) : F_{42} \leqq 5$, $(F_{42} - 5) : F_{42} > 5$<br>• For high early strength portland cement<br>$3(F_{42} - 3) : F_{42} \leqq 3$, $1.5(F_{42} - 3) : F_{42} > 3$<br>• For blast-furnace slag cement or fly ash cement<br>$2(F_{42} - 7) : F_{42} \leqq 7$, $(F_{42} - 7) : F_{42} > 7$<br>$F_{42}$ : curing periods (days) | 3 ~ -8<br>3 ~ -6<br>3 ~ -10 |

| | | | |
|---|---|---|---|
| | 3 | • No special curing for cold weather concreting<br>• No special curing for hot weather concreting | −20<br>−15 |
| 5 | | [Construction Joints] | considered in $T_p(1,7)$ |

**[Commentary]**

1. ($J$=1) Recent advances in construction technology for concrete structures have enabled a remarkable reduction in the number of construction workers and in construction periods. Advanced technology is owing primarily to the development of innovative construction machines and equipments. However, in ordinary constructions using conventional concretes of standard level of current performance criteria, engineering matters still remain of dominant factors controlling the durability of concrete structures overall. This includes the institution of personnel system, the arrangement of a right engineer at a right place and the competence of each site-engineer involved.

Most owners and contractors have been willing to assign a challenging project to competent engineers who have a full of experience, knowledge, skills and other excellence. Consequently, the construction of concrete structures has been successfully conducted, which have high quality and are hence highly durable. On the other hands, for a customary construction where excellent engineers are not always called for the project, the collective competence and skillfulness of respective engineers is a major factor to increase the durability of concrete structures. In the Durability Point, $T_p(6,1)$, the quality of chief engineers at a construction site is ranked according to the number of years of site experience and types of qualifications that will permit objective evaluation of human factors for chief engineers.

The quantitative evaluation of the capability of a chief engineer will be difficult to be made. However, an excellent and reliable engineer will always have accumulated knowledge and wisdom, determination, the ability of judgement and execution, good personality, passion, overall engineering senses and so on, which may be used to distinguish one engineer from others. In this section, the Durability Point for chief engineers at a site is determined with four technical ranks, e.i. $A^+$, A, B and C, respectively. To rank a particular enginner, Table 5.6.1 may be used in which technical points are provided for his or her qualification and years of experience. For a technical rank of A or B, the total of the technical points calculated ranges from 11 to 20, or from 2 to 10, respectively. A chief engineer who is ranked at C has no qualification specified in Table 5.6.1. A technical rank of $A^+$ is provided for a limited number of engineers who are acknowledged to be excellent and leading engineers in a large construction company in Japan.

It is not necessarily true that all engineers who have a number of qualifications and lengthy experience are excellent engineers, but at least an excellent engineer will hold a certain qualification and experience. Most of excellent engineers can meet following attributes. First of all, he or she is in possession of comprehensive knowledge on the process of manufacturing concrete and construction procedures of concrete structures and can make an appropriate construction planning for any site conditions on the basis of his or her own vision of the concrete structures. Secondly, he or she has strong determination to be able to suspend concreting works whenever unexpected conditions arise, which otherwise are most likely to cause the degradation of the quality of concrete. An excellent engineer can judge if a successive construction work is suspended or cancelled according to weather forecast and traffic congestion that will delay the arrival of truck agitators.

2. ($J$=2, $K$=1) Whether supplied concrete is accepted or rejected because of unsatisfactory performance criteria is normally judged at a construction site where fresh concrete is discharged from the chute of an agitator truck into the hopper of mobile concrete pump. It should be emphasized that an engineer from a particular contractor who has responsibility to construction works must be stationed at the place of the acceptance of supplied concrete. In addition, they

**Table 5.6.1 Determination of Technical Point for Chief Engineer at Construction Site**

| | Technical points |
|---|---|
| Registered consulting engineer specializing in concrete technology | 4 |
| Chief concrete engineer | 4 |
| Concrete engineer | 2 |
| First-class civil engineer | 2 |
| $F_{12}$ − 7 ($F_{12}$ : the number of years of experience) | 8 ~ -5 |

Note : Do not add technical points of the Chief concrete engineer and the Concrete engineer

should be given authority to make an immediate decision if the concrete is accepted or not through properly conducted site tests. This is definitely important to contribute to making concrete structures durable.

3.($J$=2, $K$=2) Currently accepted tests that are carried out to investigate the quality of newly arrived fresh concrete at a construction site include a slump test, an air content test and a compressive strength test. Although the credibility of these tests is highly acknowledged, actual constituents used for mixing the concrete remains unknown. Therefore, in addition to these tests, a certain methodology must be established to allow to check the quality and amount of cement, aggregate, water and admixture used, mixture proportion and mixing procedure upon acceptance. With knowledge of individual materials used it can be possible to some degrees to confirm the performance of concrete. Therefore, it is strongly recommended that either acceptance or rejection be made with the confirmation of a record sheet that provides written information on materials used for mixture in details.

4. ($J$=3, $K$=1) In the course of placing concrete the constant presence of a supervisor in charge of the concreting work at a placing cite is crucial. He or she can not only prevent the placement of concrete of lower quality but also ensure an excellent job through appropriate decision and directives to workers with the sudden change of weather conditions or the breakdown of equipments and tools.

5. ($J$=3, $K$=2) During placing concrete the larger height of a single lift will result in more unfavorable effects such as bleeding and inadequate filling of concrete within a given formwork. The reduction of the Durability Point for this effect is taken into consideration in $T_p(5,1)$.

6. ($J$=3, $K$=3) Noticeable segregation of concrete may occur if the height of freely falling concrete is larger during discharging from the nose of a hopper or bucket.

7. ($J$=3, $K$=4) The speed of placing concrete should be determined with conditions of construction sites. The convey of fresh concrete is done with various methods using concrete pumps, buckets or belt conveyers. Whichever is used, it hardly affects directly the durability of concrete structures. However, the speed of placing concrete from a single outlet in each method is increased the atmosphere of casting site becomes busy that may bring about unfavorable effects on successive concreting works. On the other hand, suitable conditions will be provided with adequately lower speed. In this way, the latter condition is positively appreciated and favorable for a durable concrete as a whole. When large amount of concrete is placed over a wide area it is recommended to increase the number of outlets to decrease the speed of placing concrete from individual outlets in each concreting method. As a result this will be an effective to make the comfortable placement of concrete without causing major troubles at construction sites.

8. ($J$=3, $K$=5) The use of a form vibrator as well as an internal rod-typed vibrator will be more effective in compacting fresh concrete than the use of an internal rod-typed vibrator alone. The latter accounts for a general compaction method employed at an ordinary construction site.

For cast–in–situ concrete piles or submerged concrete that is directly placed under water, consolidation procedure is normally difficult to be effective. Then, the Durability Point is greatly reduced. In these cases, the depth that an internal rod–typed vibrator can reach is considered to be zero in the Durability Point, $T_p(1,5)$.

In this section, $T_p(6,3)$, the Durability Points for $K$=3,4 and 5 are given full marks, respectively when self–placing concrete with higher workability is used. Upon the use of the high performance concrete, formworks must be strengthen enough to tolerate the pressure of the concrete, which is assumed to be equivalent to liquid pressure at each depth.

9. ($J$=4, $K$=1) For making concrete structures sufficiently durable, the surface layer of a concrete member needs to be dense and non–porous. To do so, the method of surface finishing and curing becomes important. Appropriate methods of the surface finishing and curing are provided in the JSCE Standard Specifications for Concrete Structures [Construction]. In a standard method of surface finishing for a concrete slab member tamping procedure is appreciated. Experimental results show that a proper tamping after placing concrete can reduce potential internal defects in the vicinity of the surface layer of concrete. Also, the fatigue strength of concrete subjected to cyclic loadings due to traffic wheel load is adversely affected because of internal cracks present within the surface layer of a slab member. These cracks are often considered to present in a slab concrete when no tamping is conducted. Therefore, the effect of tamping is appreciated for the surface finishing of concrete.

10. ($J$=4, $K$=2) Appropriate temperatures and curing periods during which wet condition is maintained must be selected in accordance with the Specification. When curing methods hardly meet the standard due primarily to a given condition at a construction site the Durability Point is negatively evaluated.

11. ($J$=4, $K$=3) For concrete structures under cold or hot climates curing methods must be properly planned. However, it is admitted that special curing methods required for these concretes are seldom implemented. Therefore, the Durability Point is negatively evaluated for the case where no special curing method is employed for a particular climatic condition.

12. ($J$=5) The construction and treatment of construction joints are normally planned in a design stage. Therefore, the Durability Point is counted in $T_p(1,7)$ where the treatment method of joints is taken into account depending on their types and positions in a concrete member.

## 5.7 The Durability Points for Reinforcement, Formworks and Shoring, $T_p(7, J)$

The Durability Point for Reinforcement, Formworks and Shoring is determined with materials, devices and technologies employed for assembling reinforcements and for constructing formworks and shoring. The Durability Point, $T_p(7, J)$ is calculated with items given in Table 5.7.

**Table 5.7 The Durability Point for Reinforcement, Formwork and Shoring, $T_p(7, J)$**

| $J$ | $K$ | Items ($K$) for Each Factor ($J$) | $T_p(7, J)$ |
|---|---|---|---|
| 1 | | [Cutting and Bending of Reinforcing Bar] | |
| | 1 | • When a real–size measure is used to confirm the shape and dimension of a reinforcing bar | 5 |
| 2 | | [Assembly of Reinforcing Bar] | |
| | 1 | Types of spacer:<br>• mortar or ceramic spacer, etc.<br>• plastic spacer<br>• steel spacer | <br>0<br>–5<br>–10 |

| | | | |
|---|---|---|---|
| | 2 | The number of spacer:<br>• no more than 4 spacers/$m^2$ for horizontal bars<br>• no more than 2 spacers/$m^2$ for vertical bars | <br>−10<br>−10 |
| | 3 | Binding wire:<br>• use of an anti-corrosive binding wire<br>• all binding wires folded away from concrete surface | <br>5<br>5 |
| 3 | | [Properties of Formwork] | |
| | 1 | • When the metallic part of a form-tie is left in concrete cover | −10 |
| | 2 | Types of post-filling materials for cone holes:<br>• plastic<br>• mortar<br>• non-shrinking mortar or precast cone made of mortar | <br>−5<br>0<br>5 |
| | 3 | • Use of an anti-corrosive insert | 5 |
| 4 | | [Shoring] | |
| | 1 | • Shoring that is to be used repeatedly at the fabrication plant or yard<br>• Steel shoring not included above<br>• Wooden shoring | 5<br>0<br>−5 |

**[Commentary]**

1. ($J$=1) When a large amount of reinforcing rebars is used in a particular position of a concrete member, arranging and positioning them may be poorly conducted. Also the lack of accuracy in cutting and bending reinforcing rebars is often found. Consequently, the thickness of concrete cover and clear distance are inadequate compared with intended ones. Therefore, it is favorable that the shape and dimension of reinforcements to be cut and bent will be actually measured with some special devices including actual size rulers.

2. ($J$=2, $K$=1) It is necessary to increase construction precision as much as possible to keep the intended thickness of concrete cover. Spacers should have strength and stiffness enough to maintain construction accuracy in assembling reinforcing rebars in a given formwork. In addition, to use spacers made of corrosive materials within concrete cover may reduce the durability of concrete structures.

3. ($J$=2, $K$=2) The number of spacers used should be specified to assemble reinforcing rebars within a given formwork. The weight of main reinforcing rebars is loaded directly on spacers, especially for a girder and a slab member. In this case, it will be appropriate that the total number of spacers should be four or more per one square meter. On the other hand, the number will be reduced to two or more for a web, wall and column member as the direct loading of the weight of main reinforcements on spacers is normally avoided.

4. ($J$=2, $K$=3) Steel-made binding wires which present in the near surface layer of concrete are often corroded that may result in the deterioration of the concrete member. Therefore, the use of a binding wire made of anti-corrosion materials is favorable.

5. ($J$=3) The metallic part of a form-tied device and an insert made of corrosive materials are often left in concrete cover, which may be corroded and the durability of concrete members may be affected. In addition, the quality of materials used for filling up a cone hole is important from durability points of view.

6. ($J$=4) In a manufacturing factory and fabrication yard, a shoring that supports formworks is often re-used. This practice can help to reduce the deflection of formworks as compared with

ordinary practices in fields. Therefore, the re-use of shoring is positively evaluated. The strength and stiffness of a wooden shoring are normally lower than those of a steel-made shoring. However, the use of wooden shorings of higher or equivalent stiffness than that of steel-made shorings will result in the acceptable level of construction accuracy similar to the case with steel-made shorings.

## 5.8 The Durability Point for Additional Factors for Prestressed Concrete, $T_p(8, J)$

The Durability Point, $T_p(8, J)$ is determined for additional factors which are particular to prestressed concrete works and are not duplicated in ordinary concrete works. The Durability Point is calculated with items and formulas given in Table 5.8.

**Table 5.8 The Durability Point for Additional Factors for Prestressed Concrete, $T_p(8, J)$**

| $J$ | $K$ | Items ($K$) for Each Factor ($J$) | $T_p(8, J)$ |
|---|---|---|---|
| 1 | | [Chief Engineer for PC Works] | |
| | 1 | • No chief engineer of experience and qualification for PC works is present<br>• Concrete engineer for PC works is present | –5<br>4 |
| 2 | | [Quality of Grouting Materials] | |
| | 1 | • Non-bleeding type grout | 5 |
| 3 | | [Quality of Concrete for Anchor Pocket] | |
| | 1 | • Use of ordinary concrete<br>• Use of expansive concrete | –5<br>0 |
| 4 | | [Quality Control for Injection of Grout] | |
| | 1 | • If no check list to examine grouting works is available at site | –5 |

**[Commentary]**

Generally speaking, prestressed concrete structures are more durable than reinforced concrete structures primarily because the concrete has higher strength and is designed to control cracks. However, the construction procedure of prestressed concrete structures has more influences on the durability of the structures as compared with that for reinforced concrete structures. Therefore, a properly planned construction methodology and good workmanship will be essential for prestressed concrete structures to perform well.

1. ($J$=1) An experienced and qualified engineer should be present during the construction of prestressed concrete structures in order primarily to control prestressing force. Therefore, a supervisor who is well experienced in prestressed concrete works should be available on site.

2. ($J$=2) Recently several investigations have reported the significance of grouting materials on the durability of prestressed concrete structures. Among various factors concerned, the use of non-bleeding type grounting materials will be effective with regard to the durability.

3. ($J$=3) One of peculiar works for prestressed concrete structures is to fill fresh concrete into anchor-pockets near anchorage zone. The treatment technology should be carefully planned and implemented, especially the quality of post-filling concrete will be important.

For prestressed concrete great care must be taken for placing and filling concrete with $T_p(1, J)$ and $T_p(5, J)$ since fresh concrete is normally placed in congested space of a slender member.