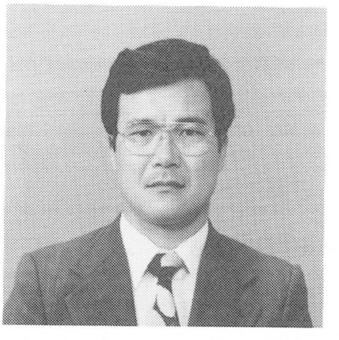
SYNOPSIS

The Concrete Committee in Japan Society of Civil Engineers (JSCE) organized the Subcommittee on Durability Design for Concrete Structures in 1988 to provide some recommendations for design in consideration of durability of concrete structures, that is, durability design.

The "proposed recommendation on durability design for concrete structures" was drawn up in 1989 by the subcommittee on the basis of the results of research works and discussed consensus of committee members.

Hajime OKAMURA, Chairman



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PROPOSED RECOMMENDATION ON DURABILITY DESIGN FOR CONCRETE STRUCTURES

CONTENTS

Proposed Recommendation on Durability Design for Concrete Structures

CHAPTER 1 GENERAL

1.1 Scope of Application

This proposed recommendation provides general standards that are to be applied when designing concrete structures for durability.

Commentary

In designing concrete structures, examination of safety and examination of-durability are both necessary in addition to examination for their suitability to the normal usage they are designed for. The examination of safety consists of confirming that the structure concerned is assured of an appropriate degree of safety against any load that is imposed on it during its construction and service period. Its practices are specified in detail in the JSCE Standard Specification for Design and construction of Concrete Structures, 1986, Part 1 [Design].

As for examination of durability, however, the JSCE Standard Specification for Concrete Structures provides no systematic specifications. Thus, the primary purpose of this recommendation is to propose general standards on durability design for concrete structures.

The term "durability design" employed here is to be understood as design methodologies in order to make new concrete structures more durable. That is, it is a notion distinctly different from the durability diagnosis or prediction of the remaining service lifetime that are done on existing concrete structures for their repair or structural improvement.

This proposed recommendation covers reinforced concrete and prestressed concrete, and intends to give basic notions of durability design that are common to them. Admittedly, however, there will arise cases in the design of actual structures where provisions of this recommendation are insufficient, or, in certain special cases, where application of standards of this recommendation is rather inappropriate.

Nevertheless, we hope that the intent of this proposal would be properly referred to even in these cases.

1.2 Definition of Terms

In this recommendation, a number of terms have been defined as follows:

Environmental index: an index calculated by the environmental condition and the required period with maintenance free of new concrete structures.

Durability index: an index calculated in the designing stage prior to actual construction works on the basis of conditions of execution, quality of materials and design details.

Durability points: points of merit that quantifies, in determining durability index, the influence of individual factors affecting the durability of structures.

Maintenance-free:a state of affairs in which a structure can be judged to be durable by a convenient means such as visual inspection or to be in need of neither repair nor structural improvement.

1.3 Notations

S_p : environmental index

S_o : value of environmental index under normal environmental conditions

$\triangle Sp$: increased increment of environmental index for severe environmental conditions

Tp : durability index

Tp(I, J): durability points

CHAPTER 2 EXAMINATION OF DURABILITY

Examination of durability for concrete structures shall be made by confirming that for each member, the durability index Tp is not less than the environmental index Sp.

$$Tp \geqq Sp. \quad (2.1)$$

Commentary

The attributes that any durability design should aspire to possess may be summarized as follows:

(1) In recognition of the pressing demands for making concrete structures truly durable, research and development is being conducted everywhere. Therefore, the design method to be adopted should be of such a framework that is suitable to incorporate new findings and results —ones which will promise improvement of durability for structures— and to assimilate them so as to contribute to general advancement of design methodology.

(2) Regardless of the design method by which a structure has been examined for safety, such as allowable stress method or limit states design method, durability design should still be applicable.

(3) The design method to be adopted should be able to evaluate the influences of the quality of concrete, the practices of construction, and the design details on the durability of structures comprehensively, as well as, quantitatively.

Eq. (2.1) is provided under a notion that each and every structural member should be examined for its durability by comparing the value of durability index Tp with environmental index Sp.
That each member is to be individually examined means that, as in the case of examination for safety, all and any cross sections that may exhibit worst durability shall be examined. Conversely, if and when the structure has passed the durability examination for all the portions checked, that structure may be judged as sufficiently durable.
This proposed recommendation presumes that the durability examination to be conducted in the designing stage for materials and construction works are taken into account in actual construction procedure. If Eq. (2.1) is found to be unsatisfied in this stage, then designs, materials, and construction methods should be modified before actual construction begins.
Durability index Tp, which will be specified in detail later in Chapter 4 and 5, is given by the sum of individual durability points. These points are, in turn, determined quantitatively for the factors which exert influences on durability of structures, and are designated for each material, design details, and construction works. In this way, any results obtained in research and development for improvement of durability of structures can be reflected in the durability index by quantitatively evaluating the influences of such a newly gained knowledge. Moreover, Eq. (2.1), when used in this manner, will remain unaffected by the method of safety examination adopted, whatever it was. Note that the quantitative evaluation of a factor for its influence on the

durability of structures is admittedly a highly difficult proposition to realize. But in this proposed recommendation, it had been done on the basis of past experiences and results of researches. We agree, therefore, that it will be improved by future research and development.
The concept shown in Eq. (2.1) is not only definitely new but also Japan's original. It may be regarded as fundamentally similar to the methodology of examination for structural safety design. That is, in examining the durability of members, the method of calculating environmental index corresponds to method of calculating member forces, the calculation of the durability index corresponds to the calculation of the capacity of members, and the method of examining durability to the method of examining structural safety. This correspondence is summarized in Table 2.1.

Table 2.1 Examination of Durability

—Comparison with Examination of Safety—

Durability	Safety
Calculation of environmental conditions	Calculation of member forces
Calculation formula for capacity of durability	Calculation formula for capacity of members
Examination of durability	Examination of safety

CHAPTER 3 ENVIRONMENTAL INDEX

3.1 General

(1) Environmental index Sp shall be determined in consideration of the environmental conditions and the required period with maintenance-free that the new structure demands.

(2) Environmental index Sp may, as a general rule, be computed by the following formula:

$$Sp = So + \Sigma(\triangle Sp), \qquad (3.1)$$

where So is the given value of environmental index in normal environmental conditions, and $\triangle Sp$ is an increased increment which is added to the environmental index according to severe environmental conditions such as salt attack or in the effects of freezing and thawing, as shown in table 3.2.

(3) The value of So for a maintenance-free period of 50 years shall, as a general rule, be 100. For particularly prolonged or shortened maintenance-free periods, however, the value of So shall be increased or decreased accordingly.

Commentary

There are cases when a structure, though still sound and durable, is demolished because its functional performance has become obsolete. Yet it is generally accepted that the so-called durable concrete structures are required to be maintenance-free for 50 years or so. For this reason, we have determined in this proposed recommendation those structures which are maintenance-free for 50 years under normal environmental condition with 95% reliability to be the standard for durable concrete structures. If we establish and accept this philosophy, the expenses for maintenance after the assumed maintenance-free period will not become too large.
Here, the term "maintenance-free" refers to such a state of affairs that the structure concerned may be judged to be durable by a convenient means of inspection, such as visual inspection, or in need of neither repair nor structural improvement. In this proposed recommendation the value of environmental index has been determined to be 100 for structures with a required maintenance-free period of 50 years in normal environmental condition. For structures that are built for a maintenace-free period of 10 to 15 years under normal environmental conditions, on the other hand, we have assumed So to be 0 or thereabout.
However, should setting of So to 100 turn out to be grossly uneconomical, or assigning a value larger than 100 become more economical as a whole, the maintenance-free period should be shortened or prolonged accordingly.

3.2 Increased Increments of Environmental Index

For structures that are subjected to severe attacks of salt or of freezing and thawing, that is, those which are under severer environmental conditions than those under normal ones, the environmental index Sp shall be determined in consideration of increased increments △Sp shown in Table 3.1. When these severe environmental conditions are superimposed, the corresponding △Sp shall be accumulated.

Table 3.1 Increased Increments of Environmental Index, Δ Sp

Environmental Conditions	Δ Sp
Severe salt attack	10 ~ 70
Severe freezing and thawing	10 ~ 40

Commentary

Unlike the cases of normal environmental conditions, the cases that involve strong effects of salts or freezing and thawing should be dealt with by increasing the environmental index in consideration of these effects.
There could be other environmental conditions that will affect the durability of concrete structures more adversely than those listed in Table 3.1, such as certain kinds of special soil and atmospheres of hot spring spas. Needless to say, such cases, whose environmental conditions are both highly severe and extraordinary, should be dealt with individually and concretely. It is for this reason that they have been excluded from the scope of this proposed recom-

mendation.
Moreover, note that each $\triangle$Sp in Table 3.1 is given, not as a definite value, but as a range. This is because unequivocal definition is difficult since the effects of salt on structure depend on locality, topology, distance from the sea shore, weather, marine meteological conditions, and the likes, and because effects of freezing and thawing differ also from one locality to another. Therefore this means that the specific value of an increased increment should be determined individually for the structure concerned in consideration of environmental conditions of the location where the structure is to be built.
For the case of severe salt attack, Japan Road Association's "Guidelines on Road Bridges for Prevention from Salt Attack and Commentary" can be a good reference. According to this book, the countermeasures are graded by the nature of locality and the distance from sea shore line. It is possible to adopt this practice to determine the increased increment: for example, when the location concerned corresponds to the Grade I area, a value of 70 is assigned to $\triangle$Sp, 40 for the Grade II area, and 10 for the Grade III area.
Likewise, for concrete structures that are subject to marine environments, such as port structures, splashes from waves and other effects of marine meteological conditions should naturally be taken into consideration: for example a value of 70 may be given to $\triangle$Sp if these conditions are severe, or 40 if they are comparatively mild.
The cases of strong freezing and thawing actions primarily apply to those cold localities where concrete has to bear damages due to freezing and thawing to a large extent. For these cases, The Cement Association of Japan's "Report of Special Committee on Durability: Map of Factors That Give Adverse Effects on Durability" could be consulted.
In this report, a frost damage day is defined as such a day when the highest temperature is not lower than 0℃ while the lowest temperature is not higher than - 5℃, and areas are graded by the annual number of the frost damage days. According to this classification, $\triangle$Sp may be set, for example, to 40 when the number of frost damage days is 60 days/year or more, 10 when it is 10 ～ 20, and 0 when it is 10 or less.
When these environmental conditions are superimposed in combination, every increased increments should be added up, even though there may be a synergistic effect.
Aside from salt attacks and freezing and thawing, there are other factors that can heavily damage the durability of structures: for example, fatigue by cyclic loading and alkali aggregate reaction. With regard to fatigue, however, quantitative prediction of the deterioration of durability is quite difficult, particularly for cases where the effects by cyclic loading are superimposed on those of environmental conditions such as concrete slabs in road bridges. In this case, the mechanism on deterioration of durability is complicated. Therefore, we have decided to put these problems aside in this present proposed recommendation, even though they are very important, in anticipation of future research works.
Evaluation of alkali aggregate reaction has been exempted from this recommendation for different reasons: not only deterioration of concrete by this phenomenon does not fall into the same category as other factors discussed earlier, but also this problem should and can well be dealt with prior to actual construction procedures.

CHAPTER 4 DURABILITY INDEX

(1) Durability index Tp shall be computed by cosidering the quality of concrete materials, the quality of concrete and reinforcement, consideration to cracks, shapes and dimensions of members, details of reinforcing bars and tendons, design drawings, concreting works, reinforcement, formworks, shoring and addi-

tional factors for prestressed concrete as well as protection of concrete.

(2) Durability index Tp may, as a general rule, be computed by the following formula:

$$Tp = 50 + \Sigma Tp(I, J), \qquad (4.1)$$

where Tp(I, J) is durability points which quantitatively represents the influences of various factors on the durability of structures. Durability points Tp(I, J) may be computed according to Table 4.1.

Table 4.1 Durability Points, Tp(I, J)

I	J	Items	Tp(I, J)
1		Concrete Materials	
	1	Cement	10 ～ 0
	2	Water absorption ratio of aggregates	8 ～ - 10
	3	Grading of aggregates	0 ～ - 5
	4	Admixtures	20 ～ - 15
2		Concrete and Reinforcement	
	1	Workability	35 ～ - 30
	2	Strength and permeability	20 ～ - 15
	3	Unit water content	10 ～ - 25
	4	Amount of chloride contents	5 ～ - 30
	5	Quality control on the supplier's plant of concrete	10 ～ - 10
	6	Anti-corrosive reinforcing bars and tendons	Modify Tp(4, 2)
3		Consideration to Cracks	
	1	Thermal cracking index	10 ～ - 20
	2	Flexural crack width	10 ～ - 20
4		Shape and Dimensions of Members, Detailing of Reinforcing Bars and Tendons, Design Drawings	
	1	Shape and dimensions of members	Considered in Tp(2, 1)
	2	Concrete cover	30 ～ - 30
	3	Clear distance and layers of reinforcing bars and tendons	15 ～ - 35
	4	Additional reinforcement	10 ～ 0
	5	Construction joints	0 ～ - 25
	6	Design drawings	0 ～ - 30
5		Concreting Works	
	1	Experience and qualification of a chief engineer in site	20 ～ - 5
	2	Acceptance of supplied concrete	5 ～ - 5
	3	Transportation, placing, and compaction	25 ～ - 45
	4	Surface finishing and curing	5 ～ - 40
	5	Construction of joints	Modify Tp(4, 5)

6		Reinforcement, Formworks and Shoring	
	1	Cutting and bending of reinforcing bars	5 ～ 0
	2	Placing of reinforcing bars	5 ～ - 20
	3	Properties of formwork	20 ～ - 15
	4	Properties of shoring	5 ～ - 5
7		Additional Factors for Prestressed Concrete	
	1	Experience and qualification of site engineers for prestressed concrete structures	0 ～ - 5
	2	Mix properties of grout	5 ～ 0
	3	Properties of concrete for anchor pockets	0 ～ - 5
	4	Quality control for injection of grout	0 ～ - 5
8		Protection of Concrete	
	1	Protection of concrete surface	20 ～ 0

Commentary

We have determined durability index Tp not only by collecting qualitative informations available today but also by evaluating quantitatively the influences of various factors which affect on the durability of concrete structures. For environmental index Sp, increased increments according to environmental conditions around the structures are provided depending on degree of salt attack and effects of freezing and thawing. On the other hand, durability index Tp is, as shown in Eq. (4.1), defined uniquely.

This is because even though the degree of intensity or the effects of individual factors on durability index Tp could be changed according to the situation, strict quantification of them is difficult. Because durability index is to be given as the total of durability points of many various factors, a structure with high durability index can be considered to be comprehensively excellent and durable. From these considerations, durability index was provided uniquely.

In determining a value of durability index, it was a difficult task to evaluate the factors that can affect durability of structures quantitatively and individually. In particular, how to quantitatively evaluate these factors in relation to construction works was most difficult because human factors are necessarily involved.

It is, however, an acknowledged pressing matter to improve durability and reliability of concrete structures. Therefore, we have decided, despite insufficient data, to determine durability points Tp(I, J) for early practical application. Further refinement through research works is earnestly desired.

Table 4.1 presents factors that can affect the durability of concrete structures in eight main different categories (I = 1 ～ 8). Each category is divided into six subcategories (J = 1 ～ 6), to each of which a quantitatively evaluated value is given. Take note that these subcategories should not be considered as completely independent, but as mutually related to each other. Nevertheless, for the sake of simplicity, they have been treated as if they were independent entities, and so provided.

Enough care has been taken so as not to double count the effect of a subcategory factor. However, few of them that were found to be impossible to separate have been provided in relation to each other.

CHAPTER 5 DURABILITY POINT

5.1 Durability Points for Concrete Materials, Tp(1, J)

Durability points for concrete materials shall be computed by quantitatively evaluating the effects of various raw materials that compose the concrete concerned, that is they are to be determined neither by subchapter 5.2 on Durability Points for Concrete and Reinforcement nor by subchapter 5.3 on Durability Points for Consideration to Cracks.
As a general rule, durability points for concrete materials may be determined as shown in Table 5.1.

Table 5.1 Durability Points for Concrete Materials, Tp(1, J)

J	K	Items and Formulas	Tp(1, J)
1		Cement	
	1	• Use of cement of small dry shrinkage or hardening shrinkage	10
		• Use of ordinary cement	0
2		Water Absorption Ratio of Aggregates	
	1	$2 \cdot (2 - A_{21}) + 4 \cdot (1 - A_{22}) \geqq -10$	8 ～ − 10
		A_{21}: water absorption ratio of fine aggregate, %	
		A_{22}: water absorption ratio of coarse aggregate, %	
3		Grading of Aggregates	
	1	• Case of falling outside of standard grading ranges	− 5
		• Ordinary case	0

4	Admixtures		
	1	• Expansive admixture properly used* • Silica fume properly used* • Drying shrinkage reducing admixture properly used*	10 or 20 10 10
	2	When freezing and thawing is severe: • Air-entraining agents or AE water reducing agents not properly used • Air-entraining agents or an AE water reducing agents properly used	 - 15 0

*These points should not be added up.

Commentary

The characteristics of concrete itself which affect durability of concrete structures are evaluated in subchapter 5.2 on Durability Points for Concrete and Reinforcement and in subchapter 5.3 on Durability Points for Consideration to Cracks. In this subchapter the factors that are not dealt with in 5.2 and 5.3 are provided.

(1) The durability points for ordinary cement has been given a value of 0. If some special cement could be developed and be in practical use with small drying shrinkage and small hardening shrinkage, the durability points for such a cement must be up to 10. By this, we hope to encourage cement manufacturers to undertake Research and Development activities.

(2) We have evaluated the quality of aggregate by its rate of water absorption. This is because when the water absorption rate is large, not only the resistance to freezing and thawing of concrete will be remarkably degraded, but also such concrete will be liable to generate surface cracking.

(3) In this proposed recommendation standard grading of aggregate refers to that grading which is provided in JSCE Standard Specifications for Design and Construction of Concrete Structures, Part 2, [Construction]. The undesirable effects arising from the use of aggregate below standard grading are in part covered by subchapter 5.2 on Durability Points for Concrete and Reinforcement. The evaluation of workability of fresh concrete requires the use of aggregate with standard grading. Considering this, this proposed recommendation imposes a penalty whenever the aggregate concerned is not within the standard grading range.

(4) Proper use of expansive admixtures is effective for improving durability for they not only can decrease drying shrinkage and hardening shrinkage of concrete, but also can introduce chemical prestress in it. When used improperly, however, they will produce undesirable effects, resulting in degraded durability.
The term "proper use" refers to such a case when not only a supervisor with sufficient experience in the use of expansive admixtures is present at the construction site, but also such admixtures are applied in accordance with JSCE Recommended Practice for Expansive Cement Concrete, 1979. In this case, a

value of 10 may be assigned when the admixture is applied to compensate drying shrinkage, or a value of 20 when the purpose is to introduce chemical prestress.
Results of past researches and actual experiences have proven the effectiveness of the proper use of silica fume and drying shrinkage reducing agents for improving durability of concrete structures. We have taken this fact as favorable. No specifications exist in JIS nor in and standard or guideline (proposal) of JSCE on the quality and usage of these admixtures. None the less, an experienced supervisor or engineer must always stay and watch the construction procedure in the site.
For situations where the action of freezing and thawing is severe, AE concrete having appropriate air content according to maximum size of coarse aggregate and to environmental conditions is generally used. That is to say, if AE concrete is not used, no freeze-thaw resistance will be ensured.
Finally, insofar as the desirable effects of admixtures such as water reducing agents, superplasticizers, and segregation resistance agents to fresh concrete, have already been evaluated in subchapter 5.2 on Durability Points for Concrete and Reinforcement, therefore durability points concerned with them are not given in this section.

5.2 Durability Points for Concrete and Reinforcement Tp(2, J)

(1) Durability points for concrete shall be determined by considering the workability of fresh concrete, strength and permeability of hardened concrete, unit water content amount of chloride contents, and quality control in the supplier's plant of concrete.

(2) Durability points for reinforcement shall be determined by considering their anti-corrosive performance.

(3) Durability points for concrete and reinforcement may, as a general rule, be determined as shown in Table 5.2.

Table 5.2 Durability Points for Concrete and Reinforcement, Tp(2, J)

J	K	Items and Formulas	Tp(2, J)
1		Workability	
	1	Flowability: $2 \cdot (B_{10}-10) + B_{11} \cdot (1-B_{10}/30)$ B_{10}: slump (cm) B_{11}: coefficient concerned with the shape and dimensions of the member that influence the easiness of pouring and filling fresh concrete (15 ～ - 15)	30 ～ - 30
	2	Segregation resistance: $5 - B_{12} \cdot B_{10}^2$ B_{12}: coefficient that takes the resistance to components segregation into account = 0.05 ～ 0, but generally 0.05	5 ～ - 25
2		Strength and Permeability	
	1	$55 - B_2$ B_2: water-cement ratio (%)	20 ～ -15

3		Unit Water Content	
	1	$0.5 \cdot (160 - B_3)$ when $B_3 \leq 160$ $1.0 \cdot (160 - B_3)$ when $B_3 > 160$ B_3: unit water content, kg/m^3	$10 \sim -25$
4		Amount of Chloride Contents	
	1	$5 - 0.5 \cdot (10 \cdot B_4)^2$ B_4: amount of total chlorine ions, kg/m^3	$5 \sim -30$
5		Quality Control on the Supplier's Plant of Concrete	
	1	• Non-JIS Mark licensed plant • JIS Mark licensed plant or equivalent	- 10 0
	2	• Equipped with automatically measuring and recording devices • Equipped with especially high performance mixers • Equipped with roofed aggregate storage yards • Case of well control for surface water content of fine aggregates	4 2 2 2
6		Anti-Corrosive Reinforcement Bars and Tendons	
	1	Modify Tp(4, 2) by putting $D_2 = B_6$ B_6: concrete cover on non-anti-corrosive reinforcements in cm, but should be taken to be 9 cm when all rebars are anti-corrosive	

Commentary

(1) We have evaluated the workability of fresh concrete for the total properties of flowability and segregation resistance.
Flowability is evaluated by slump value B_{10} which represents the properties of fresh concrete, and the coefficient of B_{11} which could be determined from the easiness of pouring and filling fresh concrete everywhere in the various shaped and sized members. For a member of simple shape and size with easiness of pouring and filling fresh concrete. The coefficient of B_{11} can be as large as 15. But for slender and complicated shapes and sizes the coefficient can be as small as - 15.
Generally, B_{11} may be computed as follows:
$B_{11} = (10 - 8/D_{11}) + (5 - D_{12}^2) + D_{13}$,
where D_{11}: minimum lateral size of the member in meter, but shall be 0.5 m for any sizes smaller than 0.5 m;
D_{12}: maximum height in meter of one lift for pouring concrete in the member but shall be $\sqrt{10}$ m for any heights greater than $\sqrt{10}$ m;
D_{13}: coefficient which accounts for the changes in sectional dimensions in the direction of height : - 5 when a section of smaller sectional area exists above the section concerned, otherwise, zero.

The segregation resistance is to be evaluated by the slump value B_{10} and the coefficient of B_{12}. The well known observation that the larger slump fresh concrete has, generally speaking, less resistance against segregation has been taken into account.

The coefficient of B_{12} has been introduced to evaluate other factors besides slump value which affects the characteristics of segregation resistance.
B_{12} may generally be set to 0.05 though proper use of segregation resistance agents can reduce this value. The use of powder materials such as cement, fly ash, blast furnace slag etc. of appropriate shapes and particle sizes can also reduce the value with proper mix-proportion.
The possibility for B_{12} to attain a value of zero has been provided in the expectation that an ideal concrete which could be poured and filled perfectly everywhere in the formworks without any consolidation procedures will be developed in the future. For a certain underwater concrete with some special admixtures, we can assume a B_{12} close to zero.
Finally, durability points for workability is to be obtained by summing up the points for flowability and segregation resistance.

(2) Durability of concrete structures depends on the strength and permeability of concrete. Strength and permeability have been assumed to be evaluated by water-cement ratio which has the biggest influence on those properties.

(3) Among the various factors that can affect hardening shrinkage and drying shrinkage, we have noted mix-proportion of concrete to be influential and evaluated the amount of unit water content.

(4) Since the unfavorable effects of chloride content in concrete increase abruptly when its amount exceeds a certain value, the evaluation formula has been given in this item.

(5) Even if the supplier's concrete butcher plant is not a JIS-mark licensed plant, or when the concrete is manufactured at a temporary plant on the construction site, these plants may be regarded as equivalent to JIS licensed plants. This is true only in the case when the specifications of JIS A 5308 and those of the Standards for Examination of Ready Mixed Concrete are satisfied by the materials, the equipments, the quality control, etc.
An automatically measuring and recording equipment is required not only to print out a weighed value automatically, but also to print it simultaneously on the delivery invoice so that purchasers are able to confirm the mix-proportion of concrete upon acceptance.
The mixing performance of a concrete mixer, which greatly affects the quality of concrete, has been mostly evaluated in the items concerned with properties of fresh concrete and hardened concrete. Since the effect on the uniformity of concrete is not considered in other sections, the performance of mixing is evaluated in this item.
Because the quality of concrete can change greatly by the amount of surface water of aggregate, fine aggregate in particular, it is very important to always maintain the amount of surface water always at a certain planned value.

(6) When epoxy resin coated reinforcing bars are used as anti-corrosive reinforcement, durability points may be augmented only in the case when they are used according to JSCE Recommendation for Design and Construction of Concrete Structures Using Epoxy-coated Reinforcing Steel Bars, 1986 and required quality can be realized. The favorable effects of epoxy-coated reinforcing bars are evaluated as a conceptional increase of concrete cover. The method of conversion to value of concrete covershall be determined according to the condition of epoxy-coated bars arrangement.
Other types of anti-corrosive reinforcements may be evaluated in a similar manner.

5.3 Durability Points for Consideration to Cracks, Tp(3, J)

Durability points for consideration to cracks shall be determined by taking both thermal cracks and flexural cracks into account.
Durability points may, as a general rule, be computed as shown in Table 5.3.

Table 5.3 Durability Points for Consideration to Cracks, Tp(3, J)

J	K	Items and Formulas	Tp(3, J)
1		Thermal Cracks	
	1	$10 \cdot (1 - 1/C_1)$ C_1: thermal cracking index	10 ~ - 20
2		Flexural Cracks	
	1	$10 \cdot (1 - 3 \cdot C_2^2)$ C_2: width of flexure crack formed by permanent load/allowable crack width	10 ~ - 20

Commentary

In some cases cracks affect highly unfavorable influences on durability of concrete structures. In this proposed recommendation, we have decided to consider mainly thermal cracks that are caused by the heat of hydration of cement and flexural cracks due to load. The two types of cracks can be quantitatively evaluated in the design stage. Moreover, whenever quantitative examination is possible, other sorts of cracks should also be dealt with in this section.

(1) Thermal cracking index is defined in JSCE Standard Specifications for Design and Construction of Concrete Structures, 1986, Part 2, [Construction] Chapter 15. It is given as the ratio of tensile strength of concrete to maximum thermal stress in tension; the greater the value, the smaller, the probability of occurrence and the width of crack.
For simplicity, thermal cracking index may be calculated by using the results of temperature distribution calculation after placing concrete. In this case thermal cracking can be obtained by $15/\triangle Ti$ when stresses due to the internal restraints are predominant where $\triangle Ti$ is the temperature difference between the interior and exterior of the member at peak temperature (℃); or $10/(0.5\triangle To)$ when stresses due to external restraint are predominant, where $\triangle To$ is the difference between the maximum average temperature of the member and its equilibrium temperature with the ambient air temperature (℃). The index calculated by such a simplified method generally gives a smaller value.
Temperature distribution calculation may be done by a simplified method assuming thermal properties of concrete such as thermal conductivity, thermal diffusivity, specific heat and the ultimate adiabatic temperature rise in consideration of mix proportion of concrete and construction conditions. When thermal analysis is conducted by personal computers, it could be recommended for convenience to use marketing programs given by Japan Concrete Institute which are based on results of Research Committee on Thermal Stresses in Mass Concrete.
In the case of prestressed concrete structures, width of thermal cracks due to heat of hydration of cement might become smaller or shut. In this case durability points for thermal cracks could be not less than zero.

However, since every thermal crack cannot always become smaller or shut, durability points for thermal cracks shall be calculated according to the conditions of each checked section of the member.

(2) The formula for computing width of flexural cracks and its allowable values are provided in JSCE Standard Specification for Design and Construction of Concrete Structures, 1986, Part 1 [Design] Chapter 7.

5.4 Durability Points for Shape and Dimensions of Member, Details of Reinforcing Bars and Tendons, and Design Drawings, Tp(4, J)

Durability points for shape and dimensions of member, details of reinforcing bars and tendons, and design drawing account for the factors which influence durability of concrete structures, such as difficulty and easiness of concrete placing, type of construction joint, and style and quality of design drawings. Durability points shall be determined by the shape and dimensions of the member, concrete cover, clear distance and piled-up number of reinforcing bars, additional reinforcement, and type of construction joint.
Durability points may, as a general rule, be determined as shown in Table 5.4.

Table 5.4 Durability Points for Shape and Dimensions of Members, Details of Reinforcing Bars and Tendons, and Design Drawings, Tp(4, J)

J	K	Items and Formulas	Tp(4, J)
1		Shape and Dimensions of Members	Considered in Tp(2, 1)
2		Concrete Cover	
	1	$30 \cdot (\sqrt{D_2} - 2)$ D_2: concrete cover, cm	30 ～ - 30
3		Piled-up Number and Clear Distance of Reinforcing Bars	
	1	$15 \cdot (1 - \sqrt{2 \cdot D_{30}}/D_{31})$ D_{30}: piled-up number of rebars D_{31}: horizontal clear distance of rebars/maximum size of coarse aggregates	15 ～ - 25
	2	$0.5 \cdot (10 - D_{32})$ D_{32}: depth to which ϕ 60 mm internal rod-typed vibrator is unable to insert, cm	0 ～ - 10
4		Additional Reinforcement	
	1	$25 \cdot D_4$ D_4: cross sectional area of additional rebars/cross sectional area of concrete, %	10 ～ 0

5		Construction Joints	
	1	• Reversed horizontal concreting joints $= -25 \cdot E_5$ • Horizontal joints $= -20 \cdot E_5$ • Vertical joints $= -10 \cdot E_5$ E_5: coefficient that takes construction methods of joints making into account, and is $0.3 \sim 1.0$	$-7 \sim -25$ $-6 \sim -20$ $-3 \sim -10$
6		Design Drawings	
	1	• Specification of concrete cover unclear • Reinforcing bars and tendons for a portion not shown in the same drawing • Presence of construction joints not clearly indicated	− 5 − 5 − 20

Commentary

(1) Since the influences of shape and dimensions of members on fillingness of concrete are considered to have a close relationship to the flowability of fresh concrete, they are evaluated with durability points for workability of concrete.

(2) The depth of carbonation and penetration of chloride contents may be considered as proportional to the square roots of time. Thinner concrete cover is very unfavorable to the prevention of deterioration of durability. Also, appropriate thicker concrete cover is highly effective in preventing degradation of durability even when cracks are present. The formula has been derived from these view points.

(3) The influences of reinforcing bars arrangement on easiness of placing concrete, that is, the influential level on easiness of pouring and filling fresh concrete and compacting it with internal rod-typed vibrators, have been given in terms of horizontal clear distance of reinforcing bars for beams and slabs, or vertical for columns and walls, and the piled-up number of reinforcing bars.
To attain durable concrete structures, those portions of concrete which are directly exposed to external environmental conditions need to be dense and non-porous with sufficient compaction. Conditions of reinforcing bars arrangement in this section are provided in order to evaluate the level how they disturb the smooth pouring and filling of concrete to surface layer of members. Therefore durability points shall be calculated considering horizontal clear distance of horizontally arranged reinforcing bars near bottom surface of members in the case of heams and slabs, and vertical clear distance of vertically arranged reinforcing bars near lower portion in a lift of placing concrete in the case of columns and walls.
In the case of prestressed concrete members, sheathes or prestressing tendons can be regarded as similar to reinforcing bars when calculating durability points. In beam and slab members, when reinforcing bars with small diameter are placed in the bottom surface of members within horizontal projected plane by a sheath, only the influences by sheath may be considered when calculating durability points.
From recent investigations on actual cases of salt attack and deterioration in concrete deck slabs of road bridges, evident lack of compaction in the bottom surface of members have been found. Many of these had such shapes and dimensions that a rod-typed vibrator could not possibly reach until the bottom

surface of the member. In order to draw designers' attention to these facts, the term relating to the depth where internal vibrator cannot be inserted is provided.

(4) To restrict the amount and the width of cracks due to drying shrinkage and temperature change of concrete within non-harmful level, additional reinforcements for exposed surface have been evaluated to be influencial.
When additional reinforcements are placed in two different directions, smaller amount of reinforcing bars must be taken in to account.

(5) Any construction joint, no matter how carefully it is made, will be a weak point in the structure compared to uniform concrete of no joints. It is for this reason that we have provided a value of zero for structures containing no joints, and given penalty for any construction joint. This means that, if introduction of any construction joints is inevitable, this poor level with negative durability points must be compensated by other excellent items in durability design procedure.
Here, the coefficient of E_5, which represents the relative merit concerned with the method for making joints may, as a general rule, be determined as follows:

- Sand blasting or jet chiseling followed by washing out with high pressure air or with high pressure water:
  $E_5 = 0.3$;
- Spraying setting retarder followed by washing with high pressure air or high pressure water:
  $E_5 = 0.5$;
- Washing with high pressure air or with high pressure water:
  $E_5 = 0.7$;
- No additional treatment: $E_5 = 1.0$.

(6) Design drawings can be said to be the only way to let people in a construction site know about the intentions of designers. As design and construction procedures have been completely separated in the present construction industry, we cannot deny the harmful effects caused by unconsciously generalized vague rules concerned with the methods of indicating design drawings and the unreasonable beliefs of designers. The items provided in this section are to clarify these harmful effects and give some penalties in that case.
According to investigation reports, that it is very important to keep enough concrete cover for durability of concrete structures. However, present design drawings do not clearly indicate whether the value given as concrete cover is for the net concrete cover or it is for the distance from the concrete surface to the rebar center; or, whether it is given with respect to the outer rebar or to the inner rebar.
Therefore, as we consider that not all designers have recognized the importance of concrete cover for durability of structures, we have provided this section in order to recommend to each designer to transmit his intention concerning with concrete cover in the design procedure by making detailed design drawing where concrete cover is clearly indicated.
Owing to recent developments in high strength concrete and reinforcing bars, cross sections of members are becoming more slender. This often means an excessive congestion of reinforcing bars, resulting sometimes in obstruction to smooth pouring and filling of fresh concrete.
One of the major causes of this trouble is that the arrangement of rebars and tendons in a given portion is indicated over several different sheets of design drawing. For large-scale prestressed concrete structures, in particular, reinforcements such as bearing supports, anchorage zone for prestressing tendons, openings, and dapped end portion are often indicated individually and separately. Because of this, we could not make a judgment for smooth pouring and filling of fresh concrete by examining only one sheet of design draw-

ings. Appropriate attention should be paid on this point.
Finally, any construction joint should be positioned where the problems on strength and durability are the least likely to occur. Moreover, since they affect the positioning of splices in reinforcement, a large penalty is imposed unless they are clearly specified in design drawings.
Durability points for construction joints should not be double counted in consideration of unclear indication in design drawings and construction method of joints.

5.5 Durability Points for Concreting Works, Tp(5, J)

Durability points for concreting works shall be determined by considering the practical conditions on the level of chief engineers who are dealing with concreteing works, acceptance of concrete, transportation, placing, compacting, surface finishing and construction method for joints.
Durability points may, as a general rule, be determined as shown in Table 5.5.

Table 5.5 Durability Points for Concreting Works, Tp(5, J)

J	K	Items and Formulas	Tp(5, J)
1		Chief Engineer-in-Attendance	
	1	• Registered consulting engineer • Chief Concrete Engineer • Concrete Engineer • First-Class Civil Engineer	4 4 2 2
	2	$E_{12} - 7$ E_{12}: number of years of experience	$-8 \sim -5$
2		Acceptance of Supplied Concrete	
	1	Supervisor from the main contractor not stationed on the acceptance place	-5
	2	Case of immediate confirmation on mix proportion of each batch by checking measuring and recording documents of concrete plant	5
3		Transportation, Placing and Compaction	
	1	Supervisor for concreting not stationed at pouring place	-5
	2	Hieght of one lift of concrete	Considered in Tp(2, 1)
	3	$2 \cdot (1.5 - E_{33})$ E_{33}: height of free fall of concrete, m	$0 \sim -5$
	4	$20 - E_{34}$ E_{34}: fastest rate of concrete pouring from a single outlet (m^3/h)	$10 \sim -10$

	5	• Compacted with form vibrators at fabricated plant • Compacted using both form vibrators and internal vibrators at construction site • Compacted in an ordinary manner using internal vibrators • No compaction with internal vibrators is conducted	10 5 0 - 25
4		Surface Finishing and Curing	
	1	• Use of film curing agents • Ordinary surface finishing • Being a beam, column, and such, no surface tamping compaction is conducted • Being a member of large surface area, no surface tamping compaction is conducted	5 0 - 5 - 10
	2	2 • (E_{42} - 5): use of ordinary cement 2 • (E_{42} - 3): use of quick hardening cement 2 • (E_{42} - 7): use of blast furnace slag cement or fly ash cement E_{42}: curing period, days	- 8 ~ 0 - 6 ~ 0 - 10 ~ 0
	3	• No special curing conducted despite of cold weather concreting • No special curing conducted despite of hot weather concreting	- 20 - 15
5		Construction of Joints	Modify Tp(4, 5)

Commentary

(1) Recently the progress of construction technology concerned with concrete structures is so remarkable that labour saving and shorter time scheduling have been made possible by the development of machines and equipment. However, the construction of concrete structures still remains an engineering matter or an art using conventional concrete in standard performance. This means that adequacy of personnel institution system and arrangement of engineers, as well as competence of each site-engineers are extremely important for realizing exact durable concrete structures.
Both the owner and the contractor have been generally making efforts at assigning especially competent engineers —competent in various senses of word— to those concrete structures which they recognize to be not only important but also complicated. That is to say, it is a common practice to assign excellent engineers in the construction of concrete structures that draw popular attention. In these cases, we may be allowed to say that structures which are excellent in quality and high in durability will be realized.
Of course, ordinary structures do not call for such especially competent engineers. But it is only true that collective competence and skillfulness of engineers are the major factors that determine the durability of the concrete structure they are building. It is for these reasons that we have decided on positively evaluating the competence of the chief engineer-in-attendance in computing durability points for concreting works.

of concrete is large, the parger possibility of unfavorable segregation in materials has been taken in account.
For compacting fresh concrete, the use of both form vibrators and internal rod-typed vibrators have been evaluated to be more effective for durability of concrete structures where the latter one is present usual compacting method.
The concrete structures such as cast-in-situ concrete piles or under water concrete structures, where consolidation procedures are quite impossible and fresh concrete is placed directly to required position, we have determined to give bigger penalty for durability points on compaction. In these cases durability points on the depth where internal rod-typed vibrators can not be inserted shall be evaluated to zero.
For the transportation of fresh concrete in construction site, there are various methods available such as concrete pump, bucket, and belt conveyer. Whichever a method has been chosen, it hardly affects on durability of concrete structures directly of itself. Rather, we have found that the speed of placing concrete from one outlet, is most influential which has close relations to the method of transportation. This means that, when the speed of pouring fresh concrete from one outlet is too fast, the atmosphere of any construction site tends to become hurryscurry, whereas unhurried placing of fresh concrete makes workers, with composure. We have positively appreciated the latter situation.
When large amount of concrete is placed over a wide area, therefore, increasing the number of outlets and decreasing the individual speed of pouring in construction planning is more effective to realize more durable concrete structures than increasing the speed of pouring from a single outlet.
We could take an approach by directly evaluating the kinds and number of compacting equipments and tools such as internal rod-typed vibrators that have been applied in construction site. Nevertheless, we have determined in this proposed recommendation that constant presence of an excellent supervisor in the site and the limitation to the speed of pouring fresh concrete are good enough for the purpose to prepare suitable conditions.

(4) For concrete structures to be durable, surface layers of any member need to be dense and non-porous. From this point of view, it is well known that the denseness and non-porousness of concrete near surface layers are strictly determined by the method of surface finishing and curing. Therefore, the importance of curing in the construction procedure has been emphasized so far. The standard method, or minimum requirements of curing methods and period are clearly provided in the JSCE Standard Specifications for Concrete Structures, 1986, [Part 2] Construction.
The evaluation of this proposed recommendation is based on this standard specification for curing concrete: to keep concrete in moist conditions for required period. Namely, when these curing conditions are satisfied, durability point is zero; whereas if these standard curing conditions cannot be achieved for any reason such as bad site conditions or confused structural dimensions, durability points shall be evaluated to be negative value.
For slab we have evaluated that the surface finishing with tamping procedure is standard. It is provided on the basis of research results that tamping procedures applied properly after placing concrete are capable of eliminating the unseen potential internal defects in surface layer of slab, and that the fatigue strength of slab subjected to cyclic loading by traffic wheel loads can be affected by initial cracks due to other factors besides externally applied loads.
Even in the case when concrete structures are required to be constructed in cold or hot weather conditions, there might be some cases when so-called special curing for cold or hot weather conditions has not been practiced. In order to evaluate excellence and poorness clearly and distinguish excellent construction procedures from poor ones, we have determined to give large negative durability points to those cases when the special curing is not practiced even when the situation demands such a special curing.

Quantitative evaluation of the competence of a chief engineer will naturally be difficult. Yet, by noting his knowledge, wisdom, ability of judgment, ability of decision making, ability of execution, personality, passion, engineering sense, etc., classifying and distinguishing one engineer among current staffs should be quite possible.
In this proposed recommendation, years of experiences and qualifications of a chief engineer are to be evaluated objectively.
Even though we cannot say that all who possess these attributes are necessarily excellent engineers, we find that most of excellent engineers can meet these attributes.
The two conditions for an excellent chief engineer are as follows:
First, he has to be in possession of comprehensive knowledge on processes of manufacturing concrete and construction procedures of structures, and be able to make an appropriate construction planning for any site conditions on the basis of his own vision of concrete structures. In short, he has to be able to recognize that concrete is alive.
Second, he must be able to halt concrete works whenever unexpected conditions arise. Namely, those chief engineers who can immediately order a stop of work and construction procedure when he faces a problem that will cause degradation of quality of concrete are exact excellent engineers.
It means that excellent engineers can and must make appropriate judgments from weather forecasts, change in the weather, and delay in the arrival truck agitator due to traffic congestion, etc.

(2) "The place of acceptance of supplied concrete" means, for general methods of construction work, the place where fresh concrete from the chute of agitator trucks is poured into the hopper of mobile concrete pump.
In this proposed recommendation we emphasize the importance of having an engineer of the contractor —the firm that is held responsible to the construction works concerned— stationed at the place of acceptance of supplied concrete. That is to say, no matter how well the testing methods and the management standards are provided, the acceptance of concrete cannot contribute to durable concrete structures, unless the site organization provides for an engineer who can judge immediately whether the newly arrived concrete should be accepted or rejected.
From this point of view, we do not deny the merits of currently general tests such as slump test, air content test, and compressive strength test as criteria for judging the quality of accepted fresh concrete. However, we believe we are not ensured what quality of fresh concrete is supplied in actual structures.
For the ideal quality assurance for acceptance in construction-site in the future, a certain methodology must be established to confirm the exact amount of individual components of fresh concrete, such as cement, aggregates, water, and admixtures, which can be evaluated beforehand on their individual characteristic of quality. With this methodology we can confirm the actual mix-proportion and mixing procedure that must determine the actual properties of fresh concrete.

(3) The constant presence of a supervisor-in-charge at the point where concrete is being placed, is very important both to prevent the production of poor level concrete and to ensure excellent level quality of concrete by making appropriate decisions and giving suitable directives to workers against sudden changes in weather conditions or breakdown of equipments and tools.
If the height of one lift is too large, unfavorable effects of bleeding must be remarkable and we will have more difficulties for smooth pouring and filling fresh concrete everywhere in the formworks. Because these effects have close relationships to flowability of concrete, it is determined to evaluate them in durability points for workability of fresh concrete. When the free fall height

5.6 Durability Points for Reinforcement, Formworks and Shoring, Tp(6, J)

Durability points for reinforcement, formworks and shoring shall be determined by considering the of materials, methods, machines and workmanship concerning with assembling of reinforcements, construction of formworks and shoring available.
Durability points may, as a general rule, be determined as shown in Table 5.6.

Table 5.6 Durability Points for Reinforcement, Formworks, and Shoring, Tp(6, J)

J	K	Items	Tp(6, J)
1		Cutting and Bending of Reinforcing Bars	
	1	When a real-size measure is used to check the shape of worked rebars	5
2		Placing of Reinforcing Bars	
	1	Type of spacer:	
		• mortar, ceramic spacer, etc.	0
		• plastic spacer	- 5
		• steel spacer	- 10
	2	Number of spacers:	
		• for horizontal bars: no more than 4 spacers/m^2	- 10
		• for vertical bars: no more than 2 spacers/m^2	- 10
	3	Binding wires	
		• use of anti-corrosive binding wires	5
		• all binding wires folded away form the surface concrete cover	5
3		Properties of Formworks	
	1	• Use of a textile formworks	10
		• Use of permanently buried pre-cast formworks	5
		• Use of formworks specifically made to the shape of members	5
	2	When the metalic parts of form-ties are left in concrete cover	- 10
	3	Type of materials for post-filling cone holes:	
		• plastics	- 5
		• mortar	0
		• non-shrinking mortar or precast cones made of mortar	5
	4	Use of anti-corrosive insert	5

4	Shoring		
	1	• Shoring that are to be used repeatedly at the fabricating plant or yard • Steel shoring not of the above mentioned • Wooden shoring	5 0 – 5

Commentary

(1) When the amount of reinforcing bars is comparatively large, the construction accuracy of cutting and bending of rebars will cause the difficulties for arranging them exactly in required position. As a result, those unfavorable situations may occur such as smaller concrete cover or narrow clear distance where internal rod-typed vibrators cannot be inserted in concreting. Therefore, the examination on shapes and dimensions of reinforcing bars and tendons with the usage of actual sized drawings is quite desirable, in this case, durability points shall be computed positively.

(2) The terms relating to assembling reinforcing bars are provided to ensure the construction accuracy mainly of concrete cover. The use of spacers in insufficient strength and stiffness will result in degrading accuracy of assembling reinforcing bars. The use of corrosive materials in concrete cover means to create weak points for durability. This is reflected on determining durability points for materials of spacers.
For the spacers of main reinforcing bars in girders or slabs when the weight of reinforcing bars is directly imposed on the spacers, four or more spacers per 1 m^2 have been considered to be sufficient. On the other hand, for the spacers of main reinforcing bars in webs, walls and columns when it does not directly act on the spacers, two or more spacers per 1 m^2 have also been considered to be sufficient with required construction accuracy.
When steel binding wires are present near surface layer of concrete members, durability and appearances are often deteriorated by their corrosion products seeping out to the surface. It is for this reason that high durability points have been given when special cares are taken for the material of binding wires or the method of binding.

(3) The use of textile formworks makes surface layer of concrete dense, few of bubbles and rich in cement paste. This is practically equivalent to somewhat refining the quality of concrete itself, and may be regarded as effective to improve durability. This effect can be account by evaluating the quality of concrete higher than it really is, but in this proposed recommendation we have determined to add the durability points positively.
This way has also applied to the permanently buried precast formworks which can be ensured to have sufficient bond and unification with placed concrete. On the other hand, however, when steel reinforcements are incorporated in the precast formworks, concrete cover to be used in examination on durability points shall be that of these bars. Moreover, the cases when special features have been added to formworks according to the configuration of members, it has been evaluated on durability points, positively.
In the case when the metallic parts of form-ties and inserts from corrosive materials are left in concrete cover, it is considered that these materials will deteriorate durability of members. Even when there are no corrosive metallic

parts remained in concrete cover, durability points for formworks have been changed according to the quality of materials used for filling up cone holes.

(4) In manufacturing factories or fabricating yards, the shoring which supports formworks is often re-used for many times. In this case, the construction accuracy concerned with a deflection of formworks can be limited to small value, therefore these kinds of shoring have been positively evaluated compared with usual shoring in the field. Wooden shorings with high that can be regarded as possessing the same or higher construction accuracy and reliability as steel shorings may be evaluated as equivalent to steel shorings.

5.7 Durability Points of Additional Factors for prestressed concrete, Tp(7, J)

The items that are particular to prestressed concrete works and are not duplicated with those for ordinary concreting works shall be evaluated for their influences in terms of durability points for additional factors for prestressed concrete.
Durability points may, as a general rule, be determined as shown in Table 5.7.

Table 5.7 Durability Points for Additional Factors for Prestressed Concrete, Tp(7, J)

J	K	Items	Tp(7, J)
1		Experience or Qualification of Chief Engineers	
	1	When no chief engineer with experiences and qualification in PC works is present	- 5
2		Mix Proportion of Grout	
	1	Use of non-bleeding type grout	5
3		Properties of Concrete for Anchor Pockets	
	1	• Use of ordinary cement concrete • Use of expansive cement concrete	- 5 0
4		Quality Control for Injection of Grout	
	1	If no check list to examine the grouting work is available on the site	- 5

Commentary

It may be generally mentioned that prestressed concrete structures are more durable than reinforced concrete structures because of using high strength concrete and designing crack control. Durability points given in this proposed recommendation are so designed that, when they are calculated for each item, these advantages of prestressed concrete structures will have been rationally evaluated.
However, proper care should be exercised on certain kinds of construction works which are particular to prestressed concrete. Because the structure is prestressed concrete structures, degrading durability of structures will occur in the end, if the construction works are conducted rather carelessly. The items here are provided to indicate these sorts of characteristics. That is to say, durability points have been determined with good construction works as standard.
Prestressed concrete structures are more sensitive than reinforced concrete structures to improper construction works to be more deteriorated in durability. The expected advantages of prestressed concrete structures can be developed whenever the construction work is well managed and carefully executed. On the contrary if it is poor, the resulting durability of structures will be rather more strictly deteriorated.

(1) This proposed recommendation has been put forward in recognition of the contribution of quality assurance on prestressing forces to improve durability of prestressed concrete structures. That is, we believe that the management of applying prestressing forces which is of a prime importance, can be taken into account adequately by evaluating the on-site availability of supervising engineers who are well experienced in prestressed concrete works.

(2) Taking into account of recent several investigation reports where prestressed concrete structures had clearly been deteriorated, we have determined to positively recommend the use of non-bleeding type grouting materials.

(3) The work for post-filling fresh concrete in anchor-pocket near anchorage zone is peculiar to prestressed concrete structures. If it is performed improperly, various kinds of defects might apparently occur when durability of structures is deteriorated. From this point of view we have provided the quality concerned with materials of post-filling fresh concrete in anchor-pocket. In the case of prestressed concrete structures when prestressing tendons, sheaths and anchorage equipments are arranged in comparatively slender members, it is important to strictly evaluate the easiness for pouring and filling fresh concrete. For this, reason durability points Tp(2,1), which are given to workability in consideration of shape and dimensions of members, and Tp(4, J), which are for shape and dimensions of members, details of reinforcement and design drawing, should be examined for every part of each member.

5.8 Durability Points for Protection of Concrete, Tp(8, J)

Durability points for protection of concrete shall be determined by considering the characteristics of the surface protection of members.
Durability points may, as a general rule, be determined as shown in Table 5.8

Table 5.8 Durability Points for Protection of Concrete, Tp(8, J)

J	K	Items	Tp(8, J)
1		Protection of Concrete	
	1	• Stone plates or tiles pasted	20
		• Epoxy resin coating of acknowledged weatherability	15
		• Plastics pasted	10
		• Finish with polymer cement or epoxy resin impregnation	5
Note: A sum of any of these points and Tp(4, 2) shall not exceed 30.			

Commentary

Any protection that has been placed on concrete surface calls for maintenance against its deterioration. For the surface protection with shorter service lifetime, it might be evaluated to have negative durability points. On the other hand, however, it could also be considered that concrete members within the surface protection are kept from external attacks until its efficiency has been totally lost. Even if the protection is not properly repaired, durability of structures must have been improved compared with the case where no such protection has ever been applied. It is for this reason that we have determined to appreciate the protection of concrete positively.

APPENDIX
EXAMPLES OF DESIGNING ON REINFORCED CONCRETE BRIDGE PIER

1. Structural Design Conditions

1) Type: reinforced concrete bridge pier

2) Environmental conditions:
- Marine splash zone, i.e., salt attacked environmental conditions. For footings, which are buried in the ground, normal environmental conditions are applied.
- To be maintenance-free for 50 years.
- Environmental index for pier:
  $Sp = So + \Sigma(\triangle Sp)) = 100 + 40 = 140.$
- Environmental index for footing:
  $Sp = 100 + 0 = 100.$

2. Materials

The concrete and reinforcing bars are assumed to be as follows on the basis of designed compressive strength $f'ck$ = 300 kgf/cm^2 (for pier) and 210 kgf/cm^2 (for footing) and in consideration of the availability of ready mixed concrete, and conditions in the construction site:

1) Concrete

	Pier	Footing
Designed compressive strength, kgf/cm^2	300	210
Cement	Blast Furnace slag cement rank B	ditto
Maximum size of coarse aggregate, mm	40	40
Slump, cm	8	8
Water-cement ratio, %	53	55
Unit water content, kg/m^3	155	160
Unit cement content, kg/m^3	292	291
Water absorption ratio, %		
Fine aggregate	1.5	1.5
Coarse aggregate	2.0	2.0

2) Reinforcing bars: JIS SD 30B, splices of gas welded

3. Cross Sectional Shapes and Dimensions

The general view of the structures is as shown in Fig. 1, where the height and block area which have been determined by considering the concrete volume per one casting, have been shown.

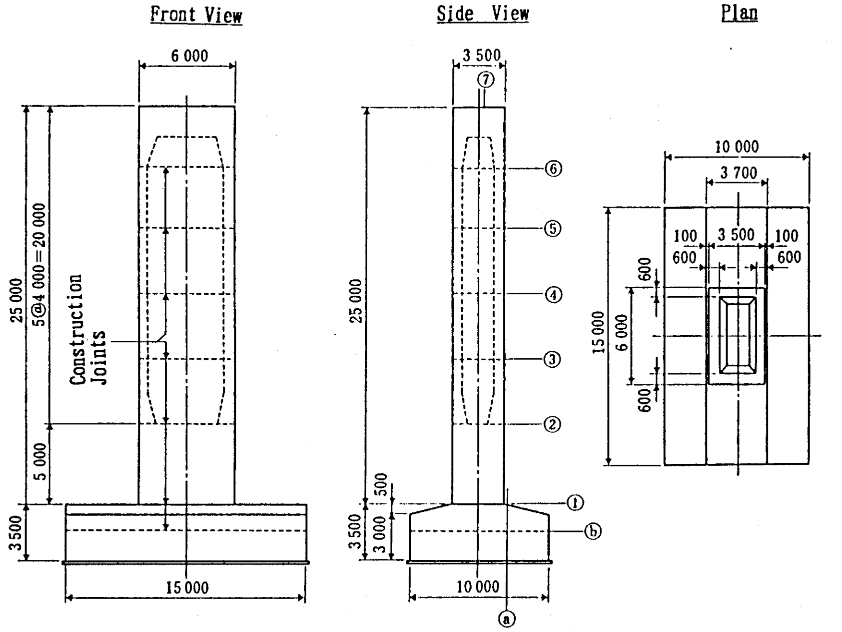


Fig. 1 General View of Structures

4. Arrangement of Reinforcing Bars

The arrangement of reinforcing bars in the structures is as shown in Fig. 2.

5. Determination of examined portions for Durability Design

The portions which are to be examined for durability design should be those sections that are orthogonal to main tensile reinforcing bars and where the value of concrete cover can be clearly seen. In other words, they are to be determined as the ones involving most complicated arrangement of reinforcing bars among those sections which are examined in conventional design for structural safety.
Moreover, the cross sections that are related to following items should be examined, on performance of durability because they have possibilities to have lower durability points.

(1) portions near construction joints;
(2) portions near the section where the shape and dimensions of

cross sections change abruptly;

(3) portions that are close to splices of reinforcing bars;

(4) portions that are deepest from concrete pouring position

(5) portions where the shape and dimensions of cross section are quite different from general portions.

In this example structure, by checking Fig. 1 and Fig 2 carefully, examined portions for durability design have been determined as follows on the basis of these rules.

1) pier: sections ① and ③

2) footing: sections ⓐ and ⓑ

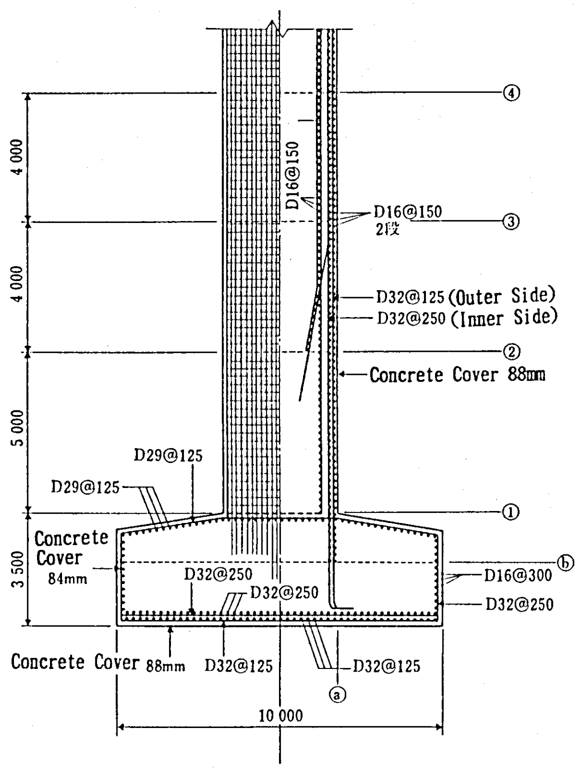
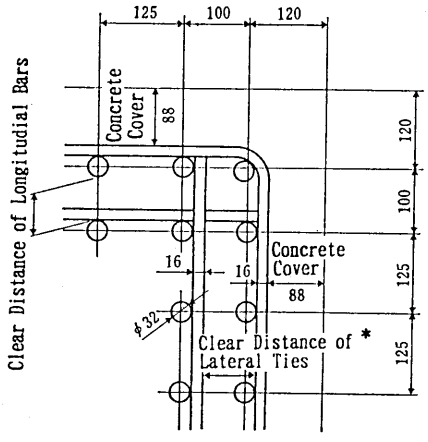


Fig. 2 Arrangement of Reinforcing Bars



* Piled-up Number of Lateral Ties are regarded as 2

Fig. 3 Details of Arrangement of Reinforcing Bars

6. Calculation of Durability Index

The results of calculating durability index for every item are shown in Table. 1.

Pier, section ①: $T_p = 50 + 36 = 86 \leqq S_p = 140$, not satisfied
Footing, section a: $T_p = 50 + 51 = 101 \geqq S_p = 100$. satisfied
Following considerations have been taken into account in calculating durability points.

(1) The quality of materials and construction works are both standard level with regard to present technical levels in Japan, and no particular consideration was taken for severe environmental conditions.

(2) Thermal cracking index was calculated in accordance with JSCE Standard Specifications for Concrete Structures, 1986, Part 2 [Construction], Chapter 15, Mass Concrete, by determining various coefficients, including such as adiabatic temperature rise, physical constants and boundary conditions, based on analytical results on thermal stresses which have been conducted with the use of commercially applied computer programs which had been developed by Research Committee on Thermal Stresses of Mass Concrete organized in Japan Concrete Institute.

(3) The crack width for pier was considered to zero, since it is always an axially compressive member, while that for footing was calculated in the consideration of total dead load.

(4) The amount of additional reinforcing bars has been taken into account to be the smaller one arranged in each direction near the surface of member.

(5) The clear distance and piled up number of reinforcing bars in vertical members are determined to be the value which has smaller durability points by examining primary reinforcements and ties respectively shown in Fig. 3.

7. Durability Design

To satisfy the requirement of durability index Tp not less then environmental index Sp at the section ① of the pier, following improvements concerned with materials, design and construction works have been taken into account.

(1) Materials
1) Increase slump value to 12 cm.(unit water content is increased)
2) Decrease water-cement ratio.(unit cement content is increased)
3) Decrease maximum size of coarse aggregate to 25 mm.
4) Others.

(2) Construction works
1) Improve the on-site chief engineers' levels.
2) Adopt reinforcement and formworks that are particularly effective to salt attacks.
3) Improve the management system for concreting works.
4) Others.

(3) Design
No changes.

The durability index at the section ① of the pier has been calculated as follows, where the required environmental index is satisfied by considering improved levels of materials, design and construction works.

$$Tp = 50 + 97 = 147 \geqq Sp = 140 \; ; \quad \text{satisfied}$$

Section ① of Pier

Blank Form for Computing Durability Points — (1)

J	K	Items	Formula	Tp(I, J)
1	1	Cement: BF-B	10 or ⓪	0
2	1	Water absorption, ratio of aggregates (%): • fine A_{21} = 1.5 • coarse A_{22} = 2.0	$2 \cdot (2 - A_{21}) + 4 \cdot (1 - A_{22})$ (≥ -10)	− 3
3	1	Grading of aggregates	⓪ or − 5	0
4	1	• Expansive admixture • Silica fume • Drying shrinkage reducing agent	10 or 20 10 10	
	2	AE agent not used	⓪ or − 15	0
			$\Sigma Tp(1, J) =$	− 3
1	1	• Minimum lateral dimensions of the member D_{11} = 3.5 , m Lift height: $\leq \sqrt{10}$ D_{12} = 5.0 , m • Change in sectional area: D_{13}(− 5 or ⓪) • Slump: B_{10} = 8 , cm	$B_{11} = (10 - 8/D_{11}) + (5 - D_{12}^2) + D_{13}$ = 3 $2 \cdot (B_{10} - 10) + B_{11} \cdot (1 - B_{10}/30)$ = − 2 ≤ 30	0
	2	Resistance to segregation of components: B_{12} = 0.05	$5 - B_{12} \cdot B_{10}^2$ = 2 ≥ -25	
2	1	Water-cement ratio: B_2 = 53 , %	$55 - B_2$ (20 ∼ − 15)	2
3	1	Unit water content B_3 = 155 , kg/m³	$0.5 \cdot (160 - B_3)$, or $1.0 \cdot (160 - B_3)$ (10 ∼ − 25)	3
4	1	Chlorine ion: B_4 = 0.03 , kg/m³	$5 - 0.5 \cdot (10 \cdot B_4)^2$ (5 ∼ − 30)	5
5	1	Non-JIS mark licensed plant	− 10	
	2	• Automatically measuring and recording • Special mixer • Roofed storage • Fine aggregate surface water content controlled	4 2 2 2	0
6	1	Concrete cover on non-anticorrosive reinforcing bars:	B_6 = , cm	Tp(4, 2)
			$\Sigma Tp(2, J) =$	14

Blank Form for Computing Durability Points — (2)

J	K	Items	Formula	Tp(I, J)
1	1	Thermal cracking index: C_1 = 1.8	$10 \cdot (1 - 1/C_1)$ (10 ∼ − 20)	4
2	1	Ratio of flexure crack width: C_2 = 0	$10 \cdot (1 - 3 \cdot C_2^2)$ (10 ∼ − 20)	10
			$\Sigma Tp(3, J)$ =	14
1	1	Shape and dimensions of member		Tp(2, 1)
2	1	Concrete Cover: D_2 = 8.8 , cm	$30 \cdot (\sqrt{D_2} - 2)$ (30 ∼ − 30)	29
3	1	• Piled-up number: D_{30} = 2 • Clear distance /maximum size of coarse aggregate D_{31} = 1.7	$15 \cdot (1 - \sqrt{(2 \cdot D_{30})}/D_{31}$ (≧ − 25)	− 3
	2	Depth to which the internal vibrator cannot reach: D_{32} = 0 , cm	$0.5 \cdot (10 - D_{32})$ (0 ∼ − 10)	0
4	1	Ratio of cross section of additional bars D_4 = 0.13 , %	$25 \cdot D_4$ (≦ 10)	3
5	1	Method of working the joints: E_5 • Sand blasting: 0.3 • Setting retardation agent: 0.5 • High pressure water: 0.7 • Left untreated: 1.0	Reverse horizontal concreting: $- 25 \cdot E_5$ Horizontal concreting: $- 20 \cdot E_5$ Vertical concreting: $- 10 \cdot E_5$	− 10
6	1	• Cover unclear • Presence of joints not designated • Reinforcing bars not shown on the same drawing	− 5 − 20 − 5	0
			$\Sigma Tp(4, J)$ =	19

Blank Form for Computing Durability Points — (3)

J	K	Items	Formula	Tp(I, J)
1	1	• Registered Engineer • Chief Concrete Eng. • Concrete Eng. • First Class Civil Engineer	4 4 2 2	
	2	Experience of work: E_{12} = 8 , years	$E_{12} - 7 = 1$ (8 ~ − 5)	5
2	1	Engineer of general contractor not stationed	− 5	
	2	Measurement printed out	5	0
3	1	Work superintendent not stationed	− 5	
	2	Height of 1 lift: E_{32} = 5 , m	Considered in Tp(2, 1)	
	3	Height of free fall: E_{33} = 2 , m	$2 \cdot (1.5 - E_{33}) = -1$ (0 ~ − 5)	
	4	Maximum placing speed E_{34} = 18 , m^3/h	$20 - E_{34} =$ 2 (10 ~ − 10)	
	5	• Form vibrator at plant • On site use of both • Internal vibrator • No tamping	10 5 0 − 25	1
4	1	• Film curing agent • No tamping	5 − 5 (beams and columns) − 10 (slabs)	
	2	• Ordinary cement • Quick hardening cement • Blast furnace cement or fly ash cement • Curing: E_{42} = 7 , days	$-8 \leq 2\,(E_{42} - 5) =$ $-6 \leq 3\,(E_{42} - 3) =$ $-10 \leq 2\,(E_{42} - 7) = 0$ (≤ 0)	0
	3	No curing	− 10 (cold time) − 5 (hot time)	
5	1	Construction of joints		Tp(4, 5)
			ΣTp(5, J) =	6

Blank Form for Computing Durability Points — (4)

J	K	Items	Formula	Tp(I, J)
1	1	Use of working measure	5	0
2	1	Type of spacer	- 5 (plastic) - 10 (steel)	
	2	Number of spacers insufficient	- 10	
	3	Binding wire anticorrosive Folded a way inside	5 5	0
3	1	• Textile formworks • Precast formworks • Specifically made formworks	10 5 5	
	2	Metalic parts of form-ties left behind	- 10	
	3	Cone hole filler: • plastic • mortar • non-shrinking mortar • precast cone	 - 5 0 5 5	- 10
	4	Anti-corrosive insert	5	
4	1	• Repeatedly used shorings • Wooden shorings	5 - 5	0
			ΣTp(6, J) =	- 10
1	1	No experiences	- 5	
2	1	Non-bleeding	5	
3	1	• Ordinary concrete • Expansive concrete	- 5 0	
4	1	No check list	- 5	
			ΣTp(7, J) =	--
1	1	• Stone plates or tiles pasted • Epoxy-resin coating • Plastics pasted • Polymer cement • Epoxy-resin impregnation	20 15 10 5 5	--
			ΣTp(8, J) =	--
			ΣTp(I, J) =	36
			Tp = 50 + ΣTp(I, J) =	86