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Durability Design for Concrete Structures

Durabilité dans la conception de structures en béton

Dauerhafter Entwurf von Betonbauten

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SUMMARY

The concept of durability design for concrete structures is proposed on the basis of comprehensive evaluation of materials, design detailings and construction works under a certain environmental condition. The new concept on durability index has been introduced. The methodology to calculate the index quantitatively has been provided in the proposed recommendation for durability design of concrete structures by the Committee on Concrete in the Japan Society of Civil Engineers.

RÉSUMÉ

La durabilité dans la conception de structures en béton armé repose sur une évaluation globale des matériaux, des détails constructifs et de l'exécution dans un environnement donné. Un indice de durabilité est introduit. La méthode de calcul de cet indice est proposée dans une recommandation de la société japonaise des ingénieurs civils.

ZUSAMMENFASSUNG

Der dauerhafte Entwurf von Stahlbetonbauten beruht auf einer umfassenden Evaluation der Materialien, der Entwurfsdetails und der Ausführungsmethoden für die gegebenen Umweltbedingungen. Es wird ein Dauerhaftigkeitsindex eingeführt. Die Methodik zur Berechnung dieses Indexes ist in einer Empfehlung des japanischen Bauingenieurvereins vorgeschlagen.

1. INTRODUCTION

Although many research works regarding to the durability of concrete have been performed in various fields, there has been very few attempts to treat them comprehensively to establish the design philosophy of durability.

It could be said impossible to realize durable concrete structures under taking consideration only into so-called design. It is not rational to provide requirements on the quality of materials and methods of construction works under no consideration of its relation to so-called design procedures.

The design philosophy should be regarded as important that a required durability in a certain environmental condition can be realized by various combinations of total construction procedures.

2. DEFINITION OF DURABILITY DESIGN

We, the Committee of JSCE on Durability Design of Concrete Structures, would like to define the durability design for concrete structures to design them comprehensively in considering the quality of materials, construction works and structural details to construct the structures in a certain environmental condition for required period without any maintenance and for a certain additional period with easy and economical maintenance.

Two indexes have been introduced to evaluate the total construction procedures comprehensively and the environmental conditions. One is "durability index" and the other is "environmental index".

The environmental index "Sp" is defined as an index calculated by the required period with maintenance-free in a certain environmental condition.

Durability index "Tp" is defined as an index calculated in the designing stage prior to actual construction works by the comprehensive evaluation on construction procedures such as quality of materials, design details and construction methods.

The performance of durability for new concrete structures could be examined by confirming that the durability index is not less than the of environmental index as shown in Eq.(1).

$$Tp \geqq Sp \qquad \text{.... Eq.(1)}$$

3. METHODOLOGY TO PROVIDE THE EQUATIONS FOR EVALUATION OF DURABILITY

If we intend to provide the durability design system quantitatively, we have to face the difficulties that there are tremendously many factors which affect the durability on concrete structures. One of the most difficult problems is how to evaluate the effect of site construction works, because it could be affected by the human behaviors.

A mong many kinds of the methodology to evaluate each factor quantitatively, we have adapted the methodology to assume and set up equations derived from the collected technical informations obtained by many research works and construction reports. Under the discussions within the committee the equations

have been brushed up to practically accepted levels. There are full of engineering judgements to construct each equation which shows the Japanese research and engineering level.

Some refinements on the equations should be done in the future, however, the most importance is to provide a durability design system as soon as possible even if it has some incomplete factors.

4. ENVIRONMENTAL INDEX

The procedures for providing the environmental index are as follows.

(1) A certain value of environmental index have been set up. The index is generally assumed as 100 where we intend to realize the concrete structures in moderate environmental conditions for 50 years of maintenance free with 95% confidence.

(2) The index should be increased or decreased according to the required period of maintenance free. For example, the index is to be zero when the required period is 10 to 15 years.

(3) The index should be increased according to the particularly severe environmental conditions such as chloride content atmosphere or freezing and thawing weather conditions as shown in Table. 1.

Table. 1 Increased environmental index, Δ Sp

Environmental Conditions	Δ Sp
Effect of chloride contents	10～70
Effect of freezing and thawing	10～40

After all the environmental index is generally written as shown Eq.(2).

$$Sp = So + \Delta Sp \quad \text{---} \quad \text{Eq.(2)}$$

Besides the chloride contents or freezing and thawing attacking, there are some other kinds of factors which deteriorate the durability of concrete structures, such as alkali-silica reaction and fatigue by cyclic loading.

In this stage we could not take consideration into these factors because we could not yet set up appropriate $\triangle Sp$ for them.

5. DURABILITY INDEX

The durability index could be determined by considering comprehensively quality of concrete materials, properties of fresh concrete and reinforcing

bars and tendons, design crack width, detailings such as shape and dimensions of reinforcing bars, writing method of design drawings, concretening, reinforcing, formwork and shoring and so on.

The durability index could be computed as in Eq.(3).

$$Tp = 50 + \Sigma Tp(I.J) \quad --- \quad Eq\ (3)$$

$\Sigma Tp(I.J)$ are durability points, which are evaluated quantitatively considering the factors affecting the durability of concrete structures shown in Table 2.

Table. 2 Durability point, Tp (I. J)

I	J		Tp(I. J)
1		CONCRETE MATERIALS	
	1	Cement	10～ 0
	2	Water absorption of aggregates	8～-15
	3	Grading of aggregates	0～ -5
	4	Admixtures	20～-15
2		CONCRETE AND REINFORCEMENT	
	1	Workability	35～-15
	2	Strength and permiability	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	Flexure 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～-30
	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	5～-5
8		PROTECTION OF CONCRETE	
	1	Protection of concrete surface	20～ 0

6. EXAMPLES OF EQUATIONS ON DURABILITY POINTS

In the proposed recommendation, computing methods for each durability point are provided as follows.

(1) $Tp(2.1)=Tp(2.1.1)+Tp(2.1.2)$

Workability of fresh concrete has been defined to evaluate the propertis of the flowability and segregation resistance.

The flowability is evaluated by slump value "B_{10}" and the coefficient of B_{11} which could be deternined from the easiness of pouring and filling fresh concrete everywhere in the various shaped and sized members.

Flowability : $Tp(2.1.1)=2(B_{10}-10)+B_{11}(1-B_{10}/30)$

$B_{11}=(10-8/D_{11})+(5-D_{12}^2)+D_{13}$
D_{11}:minimum lateral sige of members $\geqq$ 0.5(m)
D_{12}:maximum depth of members $\leqq$ 3.0(m)
D_{13}:coefficient regarding to the size of members.

D_{13}=-5 : if there is a smaller section the checked one.

Segregation resistance : $Tp(2.1.2)=5-B_{12}(B_{10})^2$

B_{12}:coefficient regarding to the segregation resistance, 0.05 in general.

This value can be decreased with the use of viscons agent and is to be zero for indeal high-performance concrete which could be placed everywhere in the formwork without any consolidation processes.

(2) $Tp(2.2)=55-B_2$ where B_2(%) water cement ratio

(3) $Tp(2.3)=0.5(160-B_3)$: $B_3 \leqq 160$ where B_3(kg/m³) unit water content
$1.0(160-B_3)$: $B_3 > 160$

(4) $Tp(2.4)=5-0.5(10B_4)^2$ where B_4(kg/m³) amount of chlolide content

(5) $Tp(4.2)=30(\sqrt{D_2}-2)$ where D_2(cm) concrete cover

(6) $Tp(4.3)=Tp(4.3.1)+Tp(4.3.2)$
$Tp(4.3.1)=15(1-\sqrt{2D_{30}/D_{31}})$
D_{30} : Number of piled up reinforcing bars and tendons
D_{31} : Clear distance/maximum size of coarse aggregate
$Tp(4.3.2)=0.5(10-D_{32})$
D_{32} : The depth where inner rod-typed vibrators(ϕ 60mm) could not inserted.

CONCLUDING REMARKS

The constitution of durability design system must be provided that the progress by the indivisual reasearch work could be easily adapted for the development of the total system. The proposed recommendation could be applied to any concrete structures with various kinds of structural design methods.
The spirit of comprehensive evaluation and the manner of exchanging on the basis of engineering judgements between materials, design details and construction works should be regarded as important for durability design of concrete structures.
By checking not only durability index but also enviromental index on many actual concrete structures, some items and equations should be refined in the future, nevertheless, we are sure this new durability design system could make new concrete structures to be more durable rationally and economically.

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