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Durability Design Based on Serviceability Stage for Corroded Reinforced Concrete Structures

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ABSTRACT

After analyzing such factors as the structural durability failure state, environmental load and resistance, the durability limit state equation considering steel corrosion initiation, concrete cover cracking and maximum corrosion-induced damage value is established to meet its durability service life requirements under chloride environment. For three different durability limit states, the design theory of reliability, the partial factors of variables for load and resistance are introduced to reflect the target reliability requirements of structural durability, and subsequently the partial factors expression form of structural durability design is established. According to the principle of the same reliability level for partial factors design and probability design, the determination method of partial factors for resistance and the values of resistance partial factors under different durability limit states are presented.

Key words: concrete structure; limit state; partial coefficient; durability design

1.0 INTRODUCTION

Some concrete structures by the chloride salt erosion, especially some bridges, harbor , wharf , etc. often appear different degree of steel bar corrosion, concrete damage, etc. phenomenon, its durability problems are more prominent (GjØrv,2009). The durability insufficient of the concrete structures can lead to the decrease of the service function and safety reliability of the structures, and consequently cause the high charges of maintenance and repair, and safety problems. Therefore, in order to ensure the safe and reliable operation of the structures and reduce the economic loss caused by maintenance and repair, the durability design of concrete structure needs carrying out to the different extent of chloride salt erosion. Some achievements in the research on durability design method of concrete structure have been made at home and abroad. *Durable Concrete Structures, CEB Design Guide* was published in Europe in 1989, Recommendations for Durability Design of Concrete Structure was issued in Japan in 1990, in 1996 the RILEM enacted *Durability Design of Concrete Structures* report. However, these guidelines or recommendations fail to quantify the durability of the structures. With the deepening of durability research, in 2000 the EU had *the General Guidelines for Durability Design and Redesign* (Duracrete, 2000), introducing the design of service life, make the structure's durability design gradually has the concept of quantity. After that, some scholars (Fabrice *et al.,* 2009) studied the probabilistic method of the durability design of concrete structures. Based on summarizing the research results at home and abroad, from the year 2000 to 2010 *JTJ 275-2000 Corrosion Prevention Technical Specifications for Concrete Structures of Marine Harbour Engineering*, *CCES 01-2004. Guide to Durability Design and Construction of Concrete Structures*, *GB/T 50476-2008 Code for Durability Design of Concrete Structures*, *TB 10005-2010 / J 1167-2011 Code for Durability Design on Concrete Structure of Railway* were successively enacted in China. These guides or codes have played an active role in improving the durability of concrete structures. However, durability design in these guides or codes considers durability of structures still mainly from the aspects of material, structure, construction, maintenance, etc., such as specified minimum thickness of concrete cover, the maximum water-cement ratio, the minimum dosage of cement and air content and type of cement, etc. Obviously, these rules do not give a clear relationship between the durability and the service life of the structures, as well as the level of risk the owners may bear. In order to quantify the durability and reliability of structures, according to the characteristics of the performance degradation of concrete structure under chloride environment, based on analyzing the durability failure state and reliability setting level of structures, the partial coefficient of load and resistance variable is induced in this paper to reflect the target reliability index requirements of structure durability, and consequently establish a quantitative design method of concrete structure durability based on the reliability.

2.0 THE DETERIORATION PROCESS OF THE LIFE CYCLE PERFORMANCE OF STRUCTURES

The corrosion of concrete steel bar in the chloride environment is the main reason for the deterioration of structure performance. For the whole process of reinforcing bar corrosion, Tuutti (1982) proposed the two-stage model of reinforcement corrosion, which consists of corrosion-induced stage and corrosion propagation stage. The reinforcing bar did not rust, and the structural performance was not significantly changed in corrosion-induced stage. After the reinforcing bar into the corrosion propagation stage, due to the emergence and development of corrosion product, the corrosive force leads to phenomena of concrete cover cracking and spalling, and etc., the degradation of structure performance is accelerated significantly, bearing capacity and reliability index, and etc. are reduced. According to effect on the performance of structure after reinforcement corrosion, corrosion propagation stage can be further divided into three stages: steel corrosion initiation to cover corrosion-induced cracking, cover corrosion-induced cracking to cumulative damage reaching the allowable limit, and applicability not meeting the requirements to bearing capacity affected. Based on the analysis of the existing structure performance degradation mechanism and process, the durability of the structure is carried through the whole life cycle of the structure, and the influence on the structural performance is different. The durability design of concrete structures, therefore, can not only stay on the qualitative regulation on such aspects as structure material, structure, construction and maintenance, and etc., must also consider the quantitative influence of durability on the safety and applicability of structures.

3.0 DURABILITY LIMIT STATE AND TARGET RELIABILITY INDEX

3.1 Durability Limit State

The design of structural durability is based on the performance design, the core of the performance design is to meet the predetermined functional requirements of the structures and to reflect the individualized demands of the owners (Zhong and JIN,2013). According to thought of performance design and performance in the process of service, during the entire life cycle of structures, each stage of the process of degradation can be taken as basement of durability limit state, therefore, the durability limit state is a dynamic performance state, which can be defined according to the demands of users, the different durability limit state reflects the different requirements of owners or users on the performance of structures. According to the current research on the degradation process of structure performance, reinforcing bar corrosion initiation in concrete structure, cover corrosion-induced cracking and the corrosive damage reaching a certain limit are very important time nodes of entire life cycle performance of structures, are often chosen as the limit state of durability failure. These limit states in the reliability level setting, the determination of limit state function and probability design method will be in-depth studied in this paper.

3.2 Target Reliability Index

In the study of the durability design based on reliability, the reliability level setting of durability failure state, or, the determination of target reliability index , is very pivotal, which is the foundation of the durability reliability analysis of structures. Because the design codes of structures have not yet included the content of the design of the durability limit state, so the target reliable index of the durability limit state is also lacking. Considering such factors as the public psychology, the possibility of repair injury in failure condition, the degree of the importance of structure, the consequences of failure, class of durability and economic factors within service life, etc., he reliability indexes in reinforcing bar corrosion initiation, the moment of cover corrosion-induced cracking and corrosive damage (corrosion cracking width or depth of reinforcing bar corrosion) reaching values of the allowable limit are given 1.0, 1.5, 2.0 respectively in the literature (Zhong and Jin, 2013) .

4.0 DURABILITY DESIGN METHOD BASED ON PROBABILITY

4.1 Probabilistic Model of Durability Design

Durability design, the same as structural design, is based on structural performance, limit state and reliability. When designing the bearing capacity of structure, the definition of load and resistance variable is clear, which have such load variables as people, vehicles, snow, wind and mechanic, and etc., resistance variable as the material parameters, such as compressive strength of concrete and steel yield strength. Similar to the concept of design in the structural code, this definition can also be used for durability design, material variables represent resistance variables, while the variable describing environment as the load variable. Therefore, the limit state function of the structure under environmental load can be expressed as:

$$Z = R - S_{\mathrm{L}} \tag{1}$$

where, R is structural resistance; S_{L} is environmental effects.

If taking reinforcing bar corrosion initiation, cover corrosion cracking or corrosive damage (corrosion cracking width or depth of corrosion) reaching an acceptable level as "failure", the failure probability can be expressed as:

$$p_{\mathrm{f}} = p(R - S_{\mathrm{L}} < 0) < P_{\mathrm{target}} \quad (2)$$

where, p_{f} is the failure probability of structures; p_{target} is the target failure probability.

After the environmental effect, statistical parameters of structural resistance and probability distribution type are determined, the different durability limit states can be probability designed by the probability model of equation (2). However, considering the probability calculation method is too complex to use in actual engineering, therefore, with the help of the derived method of bearing capacity limit state applied to design expression, the method of partial coefficient is adopted to design the durability limit state of structures. By selecting the corresponding component coefficient, the target reliability index can be met as much as possible.

4.2 Design Method of Durability Partial Coefficient

When complex probabilistic design is converted into expression of partial coefficient design, the partial coefficients that can meet the requirements of reliable index for durable targets need determining. The partial coefficient of load in the design of limit state of bearing capacity is divided into two parts: the constant load partial coefficient and the live load partial coefficient, considering a simple combination of constant load and live load. However, for durability design under erosion environment, due to the consideration of the normal service caused by durability, the impact of environment is the most important factor, the effect of structure gravity on durability limit state is negligible, only considering the effect of environmental impact and the corresponding partial coefficient. For the partial coefficient of resistance, after the partial coefficient of the environment action is gived, the durability resistance partial coefficient γ_{D} that meets the target reliability index of durability can be determined by using the principle of equal reliability level setting, the method is as follows:

Under environmental load, the limit state equation of structures by adopting the probabilistic method is expressed as follows:

$$R - S_{\mathrm{L}} = 0 \quad (3)$$

When the partial coefficient method is adopted (only the chloride ion load is considered)，the design expression of structures can be expressed as:

$$\gamma_{\mathrm{Q}} S_{\mathrm{Lk}} = R_{\mathrm{k}} / \gamma_{\mathrm{D}} \quad (4)$$

where, S_{Lk} is the standard value effect of environmental live load; R_{k} is the resistance standard value; γ_{Q} is partial coefficients for environmental action.

By the principle of the same durability reliability level for the structures designed according to the method of partial coefficients and the probabilistic method, the partial coefficient of durability resistance is:

$$\gamma_{\mathrm{D}} = \frac{R_{\mathrm{k}}^{*}}{\gamma_{\mathrm{Q}} S_{\mathrm{Lk}}} \quad (5)$$

where, R_{k}^{*} is the resistance standard value, which is obtained based on the target reliability index according to the probability method.

5.0 THE DETERMINATION OF PARTIAL COEFFICIENTS FOR DIFFERENT DURABILITY FAILURE STATES

5.1 Reinforcing Bar Corrosion Initiation Status

Environmental Load Effects and Resistance

The main reason of reinforcing bar corrosion under chloride environment is the chloride ion diffusion and accumulation, so the chloride ion concentration (mass fraction, the same below) on the surface of structure can be taken as environmental load. Under the action of environmental load, it is assumed that the content of chloride ions in concrete mixture can be neglected, and the environmental effect can be expressed by the second diffusion law of Fick :

$$X = 2\sqrt{Dt}\,\mathrm{erf}^{-1}\left(\frac{C_{\mathrm{s}} - C(x,t)}{C_{\mathrm{s}}}\right) \quad (6)$$

where, X is the diffusion depth of chloride ions; t is exposure time; C_{s} is chloride ion concentration on the surface of concrete; D is the chloride diffusion coefficient in concrete; $C(x,t)$ is the concentration of chloride ions at t moment and x location away from the concrete surface; $\mathrm{erf}(\cdot)$ is error function.

When the chloride ions invade the steel surface and reach the critical value of the rebar corrosion, the steel bar begins to rust, the time depends on the thickness and the quality of the concrete cover, thus, the thickness and quality of the cover are regarded as the resistance of the structure to the erosion.

For a given environment, durability design is to provide the basis for the determination of concrete quality and cover thickness, that is to say, the thickness of the concrete cover is determined by quantitative design. As with bearing capacity design to determine the method of resistance, considering the requirements of structural design service life, after determining the design value of chloride ions load and material capacity parameters, when the concentration of chlorine ions $C(x, t) = C_{\mathrm{cr}}$ away from x location on the surface of concrete, the corresponding diffusion depth X_{cr} is just the minimum cover thickness required for durability design, at the moment the erosion resistance can be expressed as:

$$R_{\mathrm{p}} = X_{\mathrm{cr}} = 2\sqrt{Dt}\ \mathrm{erf}^{-1}\left(1 - \frac{C_{\mathrm{cr}}}{C_{\mathrm{s}}}\right) \qquad (7)$$

Through formula (7) to determine the minimum cover thickness (resistance) required for the reinforcing bar corrosion initiation, the surface chloride concentration in the formula is the design value of environmental load, and it should be treated as a constant. Considering the uncertainty of calculation model, resistance can be expressed as:

$$R = K_{\mathrm{P}} R_{\mathrm{p}} = K_{\mathrm{P}} X_{\mathrm{cr}} \qquad (8)$$

Thus, the statistical parameters of member resistance are:

$$\mu_{\mathrm{R}} = \mu_{K_{\mathrm{P}}} \mu_{R_{\mathrm{P}}} = \mu_{K_{\mathrm{P}}} \mu_{X\mathrm{cr}} \qquad (9)$$

$$\delta_{\mathrm{R}} = \sqrt{\delta_{K_{\mathrm{P}}}^2 + \delta_{R_{\mathrm{p}}}^2} = \sqrt{\delta_{K_{\mathrm{P}}}^2 + \delta_{X_{\mathrm{cr}}}^2} \qquad (10)$$

$$\mu_{R_{\mathrm{P}}} = R_{\mathrm{p}}[\mu_{\mathrm{D}}, \mu_{C_{\mathrm{cr}}}];$$

$$\sigma_{R_{\mathrm{P}}} = \left\{ \sum_{i}^{n} \left[\left. \frac{\partial R_{\mathrm{p}}}{\partial X_i} \right|_{\mu} \right]^2 \sigma_{X_i}^2 \right\}^{\frac{1}{2}}$$

$$\delta_{R_{\mathrm{P}}} = \frac{\sigma_{R_{\mathrm{P}}}}{\mu_{R_{\mathrm{P}}}} \quad (i = 1,2,\cdots,n);$$

where, μ_R, δ_R are the mean value and the coefficient of variation of resistance respectively; X_{cr} is the diffusion depth corresponding to the chlorine ion critical concentration; K_{P} is the random variable of the calculated model uncertainty; $\mu_{K_{\mathrm{P}}}$ 、 $\delta_{K_{\mathrm{P}}}$ are the average value and the coefficient of variation of the random variable K_{P} respectively; $\delta_{X_{\mathrm{cr}}}$ 、 $\mu_{X_{\mathrm{cr}}}$ are the average value and the coefficient of variation of X_{cr}; X_i is the random variable of R_{P}; $\left.\frac{\partial R_{\mathrm{p}}}{\partial X_i}\right|_{\mu}$ is the partial derivative at the mean value.

<u>Limit State Equation</u>

Taking chloride ions eroding onto the steel surface and start rusting as the failure criterion, the erosion depth of chloride ions is taken as the environmental load effect, while the diffusion depth at time when the rebar begins to rust is taken as structural resistance, the limit state equation and failure probability design expression is:

$$Z = R - S_{\mathrm{L}} = K_{\mathrm{p}} X_{\mathrm{cr}} - K_{\mathrm{p}} X = 0 \qquad (11)$$

$$p_{\mathrm{f}} = p(R - S_{\mathrm{L}} < 0) = p(K_{\mathrm{p}} X_{\mathrm{cr}} - K_{\mathrm{p}} X < 0) < P_{\mathrm{target}} \qquad (12)$$

<u>The Determination of the Partial Coefficient γ_{D_0} of Durability Resistance for Reinforcing Bar Corrosion Initiation</u>

The environmental erosion effect is variable, is one variable, difficult to predict accurately, multiplied by one partial coefficient to make the estimation of the erosion load more safe. Reference to the recommendations of the literature (Liu, 2007), the partial coefficient of chloride ion action (surface chloride concentration) in this paper is valued 1.2.

The structure under environment action must be able to withstand its erosion effects. Erosion resistance is related to the environmental conditions of structures, when the resistance partial coefficient of different durability failure states is given, the following 3 situations: D (Severe) , E (very serious) and F (Extreme severity) under marine chloride environment in *GB/T 50476-2008 Code for Durability Design of Concrete Structures*, are considered in this paper.

According to the literature (Zhong *et al.*, 2013). Table 1 shows the statistics parameters of chloride ion load at different environmental levels. The statistical parameters of Resistance R are calculated by the formula (9), (10), the statistical parameters of variables affecting resistance are shown in the Table 2：

Taking reinforcing bar corrosion initiation as the standard of durability service life's ending, according to the above given determination method of the partial coefficient of durability resistance, when R subject to logarithmic normal distribution and S_{L} obeying normal distribution, a MATLAB program which compiled with second-order moment method is run to obtain the corresponding resistance standard value R_{k}^* of target reliable indicator $\beta = 1.0$; and then by the formula (5) to obtain the partial coefficient γ_{D_0} of durability resistance of different environmental action levels under reinforcing bar corrosion initiation state (calculated results are listed in Table. 4 .

Table 1. Statistical parameters of chloride ion load C_{s} at different environmental levels

Grade	Environment	C_{s} /%			Distribution type
		Mean value	**Standard deviation**	**Variable coefficient**	
III-D	Atmospheric zone(mild salt fog)	0.25	0.20	0.80	Normal
III-E	Atmospheric zone(heavy salt fog)	0.35	0.25	0.71	Normal
	Splash/Tidal range zone, athermal area	0.60	0.30	0.50	
III-F	Splash/Tidal range zone, hot area	0.60	0.80	1.33	Normal

Table 2. Statistical parameters of variables affecting resistance

Random variable	Mean value	Variable coefficient	Distribution type
$D \times 10^{-8}$ / ($cm^2 \cdot s^{-1}$)[6]	0.970 (m_w / m_C = 0.4)	0.20	Normal
Splash zone	0.070	0.30	Normal
Atmospheric zone, the change area of water level	0.087	0.15	
Uncertain coefficient of calculating model	1.000	0.20	

5.2 Corrosion Cracking State of Cover

Load Effect and Resistance

The cracking of cover caused by corrosion of reinforcing bars is due to the corroded expansion force exceeding the tensile strength of concrete. The corroded expansion force of cover cracking is related to the corrosion amount (corrosion depth) of reinforcement. It is known by the Faraday Corrosion Law that the corrosion depth of rebar is proportional to the corrosion current density, and within the same time the greater the corrosion current density is, the deeper the corrosion depth of the rebar is, and consequently the greater the corroded expansion force is. As a result, analyzing the reliability of corrosion cracking failure status, the corrosion current density can be regarded as the load random variables, the effects of its cause (corrosion depth) is calculated according to the following formula(Zhong *et al.*, 2015):

$$\begin{aligned}\delta(t) &= 0.0116\int_{t_0}^{t} i_{\text{corr}}(t)\text{d}t \\ &= 0.0116\int_{t_0}^{t} 32.13\frac{(1-m_{\text{W}}/m_{\text{C}})^{-1.64}}{x}t^{-0.29}\text{d}t \\ &= 0.525\frac{(1-m_{\text{W}}/m_{\text{C}})^{-1.64}}{x}(t^{0.71}-t_0^{0.71}) \\ t_0 &< t < t_{\text{cr}} \end{aligned} \quad (13)$$

where, t_0 is the time of reinforcing bar corrosion initiation (year); t is the time after corrosion of reinforcing bar (year); t_{cr} is the time of cover corrosion cracking (year); $i_{\text{corr}}(t)$ is the corrosion cur rent density with time (μA/cm^2); x is the thickness of the concrete cover (mm).

When the corrosion depth of reinforcing bar reaches the critical corrosion depth of cover cracking, the cover cracks. As a result, the critical corrosion depth δ_{cr} of cover corrosion cracking can be regarded as structural resistance, and calculated according to the following formula(Zhong *et al.*, 2015):.

$$\delta_{\text{cr}} = k_1k_2k_3\left[0.15\left(\frac{m_{\text{W}}}{m_{\text{C}}}\right)^{1.55} f_{\text{c}}^{0.34}\left(1+\frac{2x}{d}\right)^{0.19} d^{-0.3}\right] \quad (14)$$

where, $k_1 = 1-0.07m_1-0.54m_2-2.47m_3$; m_1, m_2, m_3 are the quality fraction of fly ash, slag, silicon ash respectively; k_2 is the correction coefficient of rebar position, k_2 = 1.0 (corner area), k_2 = 1.33 (middle area); k_3 is the correction coefficient of rebar type, k_3 = 1.0 (ribbed steel bar), k_3 = 0.88 (light round bar); d is steel bar diameter; f_{c} is the compressive strength of concrete 28d.

Limit State Equation

For the corrosive cracking failure state, taking the corrosion depth caused by corrosion current density as load effect, while taking the critical corrosion depth at the moment of the cover corrosive cracking as structure resistance, the limit state equation and the failure probability can be expressed as:

$$Z = R - S(t) = \alpha_{\text{cr}}\delta_{\text{cr}} - \alpha\delta(t) = 0 \quad (15)$$

$$p_{\text{f}} = p[R - S(t) < 0] = p[\alpha_{\text{cr}}\delta_{\text{cr}} - \alpha\delta(t) < 0] \quad (16)$$

where, α_{cr} is the model uncertainty coefficient of formula (14); α is the model uncertainty coefficient of formula (13).

Determination of Durability Resistance Partial Coefficient $\gamma_{\text{D}_{\text{cr}}}$ for Corrosion Cracking State

The corrosion current density is taken as a random variable, difficult to predict accurately, need to be multiplied by a partial coefficient. In reference to the values of variable load partial coefficient in the design of structures, the partial coefficient of corrosion current density is proposed 1.4 in this paper.

Table 3 shows the statistical characteristics of the main influencing factors (Li *et al.*,1990). Among them, due to lack of related statistical data of the corrosion current density, so, for atmospheric zone (mild salt fog), atmospheric zone (heavy salt fog), splash/tidal range zone (a thermal area), splash/tidal range zone (hot area), the variation coefficients of corrosion current density are assumed 0.15, 0.20, 0.35 and 0.50 respectively in this paper.

Taking the corrosion cracking of concrete cover as the standard of the structure durability service life's ending. By adopting the same method as one determining the partial coefficient γ_{D_0} of durability resistance under reinforcing bar corrosion initiation, the partial coefficient $\gamma_{\text{D}_{\text{cr}}}$ of resistance can be obtained to meet the target reliability index $\beta = 1.5$ of durability, and the calculated results are also listed in Table 4.

5.3 The Maximum Acceptable Level of Corrosive Damage

Load Effect and Resistance

After the corrosion cracking of the concrete cover, the corrosion-induced crack provides an extremely convenient channel for the invasion of the erosive media, thus, accelerates the corrosion speed of the reinforcing bar. The structural damage caused by further corrosion of reinforcement is usually shown as increase of crack width, peeling of concrete cover and lower rigidity. All these damages affecting normal service are affected by the degree of corrosion (corrosion depth) and corrosion current density. Therefore, like failure state of cover cracking, the corrosion current density is still regarded as the load random variable, and the resulting load effect can be calculated as follows(Zhong *et al.*, 2015):

$$\delta(t)=\delta_1(t_{cr})+0.012\int_{t_{cr}}^{t}[0.368\ln t+1.131]dt$$
$$=\delta_1(t_{cr})+4.272\times10^{-3}(t\ln t-t_{cr}\ln t_{cr})+0.884\times10^{-2}(t-t_{cr})$$
$$t_{cr}<t \qquad (17)$$

where, $\delta_1(t_{cr})$ is corrosion depth of reinforcement at time of corrosion cracking, calculated from the formula（13）.

Taking the corrosion depth δ_d of reinforcement, when the surface of concrete has the maximum acceptable appearance damage, as the structural resistance, δ_d can be calculated by following formulae (18)-(19). (CECS220, 2007)

A bar with circular steel bars：

$$\delta_d=0.255+0.012\frac{x}{d}+0.84\times10^{-3}f_{cuk} \qquad (18)$$

A bar with ribbed steel bars：

$$\delta_d=0.273+0.008\frac{x}{d}+0.55\times10^{-3}f_{cuk} \qquad (19)$$

where, f_{cuk} is the standard value of compressive strength for concrete cube.

Limit State Equation

After the load effect and resistance model are given, the limit state equation and the failure probability of the corrosion-induced damage reaching the maximum acceptable degree are expressed respectively as:

$$Z=R-S(t)=\alpha_d\delta_d-\alpha\delta(t)=0 \qquad (20)$$

$$p_f=p[R-S(t)<0]=p[\alpha_d\delta_d-\alpha\delta(t)<0] \qquad (21)$$

Where, α_d is the model uncertainty coefficient for calculating δ_d; α is the model uncertainty coefficient of formula (17).

Calculation of the Partial Coefficient γ_{D_d} of Durability Resistance

Taking the corrosion depth of reinforcement, at the time when the surface of concrete appears acceptable maximum appearance damage, as the standard of structural durability service life is ending. The partial coefficient γ_{D_d} of durability resistance by the same way as the limit state of reinforcing bar corrosion initiation and cover cracking is determined. According to the durability target reliable index $\beta=2.0$, the corrosion depth of reinforcing bar reaching the maximum acceptable degree, the different levels of environmental action are considered, and then γ_{D_d} can be calculated by data of Table 3, and the results are shown in Table 4.

Table 3. Statistical parameters of main influence factors

Random variable	Coefficient of mean value	Variable coefficient	Distribution type
i_{corr}	1.05	0.15/0.20/0.35/0.50	Normal
x	0.85	0.30	
d	1.00	0.015	
f_c	0.85	0.10	
α_{cr}	1.00	0.20	
α	1.00	0.20	

Table 4. Resistance partial factors under different durability limit states

Grade	Environment	γ_{D_0}	$\gamma_{D_{cr}}$	γ_{D_d}
III-D	Atmospheric zone (mild salt fog)	1.48	1.10	1.28
III-E	Atmospheric zone (heavy salt fog)	1.57	1.17	1.36
	Splash/tidal range zone, athermal area	1.64	1.22	1.39
III-F	Splash/Tidal range zone, hot area	2.21	1.40	1.68

After load and partial coefficient of resistance under different environmental conditions and different durability limit states are given, durability of structure can be quantitatively design according to the partial coefficient design expression of equation (4) to ensure that the degradation structure within the design service life period has the qualified requirements of reliability index.

6.0 CONCLUSIONS

(1) Based on structural reliability theory, the partial coefficients of load and resistance variables are introduced to reflect the target reliability index of durability, and according to the principle of probability design and partial coefficient design with the same reliability level, the expression of partial coefficient design is established based on reliability, the determination method of resistance partial coefficient value is given.

(2) For the durable serviceability of structures, considering the effect levels of C (moderate), D (Severe), E (very serious) under marine chloride environment in *GB/T 50476-2008 Code for Durability Design of Concrete Structures*, the equation of durability limit state under the three conditions of reinforcing bar corrosion initiation, cover corrosion cracking, and the corrosion-induced damage reaching maximum limit is established, and the values of partial coefficient of durability resistance under the different environmental effect levels and the different durability limit states are given respectively in this paper.

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