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Comparative Study On the Concrete Crack Regulations Based On Durability

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Abstract: The division of the ambient environment effects of concrete structures home and abroad are compared, then the crack limit values based on durability are analyzed , the factors considered in each standard are pointed out, and then control measures of non-load cracks are summarized. the differences and similarities between standards are given , so that the engineering staffs can understand and apply the design specification flexibly.

Keywords: Concrete structure; Durability; Crack limit values; Control measures

1. Introduction

Based on the domestic and foreign concrete structural durability problems in recent years, foreign scholars put forward “the Five Times Law of Structural Durability ”. this terrible expansion effect makes governments spend a lot of money and efforts on the maintenance and reinforcement of concrete structures . and then people pay more and more attention to the durability of structures. China is a developing country that has limited financial and natural resources . therefore , we have to take a broad and long-term view, and allocate funds rationally, and use resources effectively. In another words, there are very important tasks for our country that enhance the research of the durability of concrete structure, improve the quality of design, and extend the life of structure, and then meet the functional requirements of structure in the design service life . Cracking is one of the common phenomena of concrete structures. When the structure is in the Carbonation and Chloride environment, cracks make CO_2、O_2、H_2O、Cl^- more easily enter into the interior of concrete, and then reinforcing bars corrosion occurs, the effective force area is reduced, even the protective layer of concrete falls off. SO_4^- and other chemical substances in the environment are also more likely to cause the corrosion of concrete, effect the durability and the carrying capacity of concrete structures directly. Therefore , according to the ambient environment effects of structures, some standards limit the maximum allowable crack width under loads, and then combine with a series of construction measures to ensure the corresponding durability and bearing capacity of structures in service. However, because of the differences of environmental conditions, the quality of concrete, and the consideration factors, and so on, each Standards have different rules and regulations about the cracks width. Thus, throughout the comparative analysis, figuring out the influence factors of cracks are important to determine the limit value of crack width reasonably, prevent the generation of cracks, and improve the durability of concrete structures . Moreover, the cracks caused by non-loads can be controlled by s series of construction measures.

2. Classification of the Environmental Conditions and Exposure Classes

Each codes have parallel classifications about the exposure classes, but due to the different climatic conditions and consideration factors of each country, there are still some differences when it is divided . As shown in Table 1:

According to the mechanism of structural damage, the environment is divided into 5 types, and some construction measures are combined to improve the durability of concrete structure in ”Code for the Durability Design of Concrete Structures” (GB/T 50476-2008).

“Rules for the Durability Design of Concrete Structures in Highway Engineering” (JTG/T B07-01-2013) divide the environmental category in according with the structural damage mechanism. it is similar to the ”Code for the Durability Design of Concrete Structures” (GB/T 50476-2008). However, the Salt crystallization environment and the Abrasive environment are list separately in the highway engineering. And the former reached the most serious level (F). this situation is related to the complex environmental changes along the project .

“Eurocode 2:Design of concrete structures ” (BS EN 1992−1−1:2004) also divide the environmental category in according with the structural damage mechanism. as the weather conditions in China and Europe are similar, so the design provision of structural durability and the classification of environmental categories are also similar. but the limit values of two codes, and the order of severity of the division are not the same. In the area of sea water erosion, because the Domestic code takes into account the lack of oxygen in the sea water, the correspond-

ing level of exposure environment is reduced. While the European norms, taking into account the difficulties in the maintenance of bridge piers and other factors, increase the corresponding level of action.

ACI 201.2R-08 "Guide to Durable Concrete " does not have a systematic exposition of the environment in accordance with the environmental damage mechanism of concrete structure . As can be seen from the code, it considers the influence of environmental conditions and materials on the durability of structures.

Table 1. Classification of the environmental conditions and exposure classes

Exposure condition	Code for the Durability Design of Concrete Structures	Rules for the Durability Design of Concrete Structures in Highway Engineering	Eurocode 2:Design of concrete structures	Guide to Durable Concrete
General environment (carbonation)	I-A I-B I-C	I-A I-B I-C	XC1 XC2 XC3 XC4	Fresh concrete Freezing andthawing of concrete Alkali-aggregate reaction Chemical attack Abrasive environment Corrosion of other materials
Freeze/Thaw attack	II-C II-D II-E	II-C II-D II-E	XF1 XF2 XF3 XF4	
Chlorides from sea water	III-C III-D III-E III-F	III-C III-D III-E III-F	XS1 XS2 XS3	
Deicing agent	IV-C IV-D IV-E	IV-C IV-D IV-E	XD1 XD2 XD3	
Salt crystallization	—	V-E V-F	—	
Chemical attack	V-C V-D V-E	VI-C VI-D VI-E	XA1 XA2 XA3	
Abrasive environment	—	VII-C VII-D	—	
No risk of corrosion	—	—	X0	
Note: A - slight; B - mild; C - moderate; D - serious; E - very serious; F - extremely serious				

3. Limit Value and Analysis of Crack Width in Each Code

The emergency of cracks will affect the structural durability and appearance directly. Thus , in order to ensure the durability of the structure during the service life, each code put forward their corresponding limit value of the crack width.

3.1.The Analysis of the Limit Value of Crack Width of Each Code

1) In"Code for the Durability Design of Concrete Structures", the maximum width of reinforced concrete member under load can not exceed the requirements of Table 2:

Table 2. Allowance value of crack width/mm

Exposure Class	Reinforced concrete member	Bonded pre-stressed concrete member
A	0.40	0.20
B	0.30	0.20 (0.15)
C	0.20	0.10
D	0.20	regard as two class of cracksor part of the prestressed component
E, F	0.15	regard as a class of cracks or a fully prestressed component

Note : The width in bracket is suitable for the pre-tension member with steel wires or strand. The calculation of the surface crack width of the concrete members that have self waterproof requirement should not be more than 0.20 mm.

This code refers to the crack width of transverse cracks caused by load, not including the cracks caused by non load, such as temperature. the limit value of crack width considers two factors, which are environmental action grade and force characteristic of the component. At the same time, the influence of the thickness of concrete protection layer on the calculated value of crack width is neglected.

2) In"Eurocode 2:Design of concrete structures – Part 1–1: General rules and rules for buildings" (BS EN 1992−1−1:2004), the maximum width of the concrete member can not exceed the requirements of Table 3:

Exposure Class	Reinforced members and prestressed members with unbonded tendons	Prestressed members with bonded tendons
	Quasi – permanent load combination	Frequent load combination
X0 , XC1	0.4	0.2
XC2 , XC3 , XC4	0.3	0.2
XD1 ,XD2 , XS1 , XS2 , XS3		Decompression

Note 1 : For X0, XC1 exposure classes, crack width has no influence on durability and this limit is set to guarantee acceptable appearance. In the absence of appearance conditions, this limit may be relaxed.
Note 2 : For these exposure classes, in addition, decompression should be checked under the quasi – permanent combination of loads.

This code also considers the effects of the environmental action grade and stress characteristic of components on the limit value of crack width calculation. The stress characteristics are divided into prestressed and non- prestressed . At the same time, it also considers the effect of load combination, and states the limit value of crack width under the live load, which is not taken into consideration in the several previous norms, and it is significant for the durability assessment of concrete structure. This is also worthy of domestic norms for reference.

In "Rules for the Durability Design of Concrete Structures in Highway Engineerin " (JTG/T B07−01−2013), The limit values of structural crack width can not exceed the following requirements :

Under different conditions, the maximum crack width values of bridge of reinforced concrete and partially pre-stressed B class member should not exceed the requirements of Table 4:

Table 4. Allowance value of surface crack calculating width /mm

Exposure condition	Environmental Action Grades	Limit of Maximum Crack Width	
		Reinforced concrete member	partially pre-stressed B class member
General environment (carbonation)	I-A I-B I-C	0.20	0.10
Freeze/Thaw attack	II-C	0.20	0.10
	II-D II-E	0.15	—
Chlorides from sea water	III-C	0.20	0.10
	III-D III-E III-F	0.15	—
Deicing agent	IV-C IV-D	0.20	0.10
	IV-E	0.15	—
Salt crystallization environment	V-E V-F	0.15	—
Chemical attack	VI-C	0.20	0.10
	VI-D VI-E	0.15	—
Abrasive environment	VII-C	0.20	0.10
	VII-D	0.15	—

Being similar to ”Code for the Durability Design of Concrete Structures” (GB/T 50476-2008), this code also considers the effects of the environmental class designations, environmental action grades and stress characteristic of components on the limit value of crack width calculation. However, because of the complex environment along the highway engineering and the coupling effect of excessive live – load on the concrete structure, the specific crack width limits are more strict than the former.

Under different circumstances, the crack width of reinforced concrete in tunnel support structure should not exceed the requirement of Table 5:

Table 5. Allowance value of surface crack calculating width /mm

Exposure condition	Environmental action grades	Limit of maximum crack width
General environment (carbonation)	I-A I-B	0.20
	I-C	0.15
Freeze/Thaw attack	II-C	0.20
	II-D II-E	0.15
Chlorides from sea water	III-C	0.20
	III-D III-E III-F	0.15
Deicing agent	IV-C IV-D	0.20
	IV-E	0.15
Salt crystallization environment	V-E	0.15
	V-F	0.10
Chemical attack	VI-C	0.20
	VI-D	0.15
	VI-E	0.10

The specification stipulates the structure crack width of the tunnel and bridge separately. and it has a great relationship with the structural form, the environmental condition and the load acting on the structure. Reinforced concrete members in the tunnel support structure should be calculated according to the basic combination of the load.

4) In the “Control of Cracking in Concrete Structures” (ACI 224R–01), the limit values of structural crack width can not exceed the requirements of the Table 6:

For structures, the code does not describe the environment action and the environmental action grades systematically, as same as the other codes . and for the reasonable crack width value of the structure under the action of the load, it is not only considering the effect of environmental conditions, but also considering the structure characteristics, for example, the structure with a protective coating, waterproof, and so on can control the development of the crack width. which is not considered specifically in the other codes. This is also worthy of domestic norms for reference.

Table 6. Guide to reasonable crack widths, reinforced concrete under service loads

Exposure condition	Crack width	
	in.	mm
Dry air or protective membrane	0.016	0.41
Humidity , moist air , soil	0.012	0.30
Deicing chemicals	0.007	0.18
Seawater and seawater spray, wetting and drying	0.006	0.15
Water – retaining structures	0.004	0.10

It should be expected that a portion of the cracks in the structure will exceed these values. with time, a signification portion can exceed these values. these are general guidelines for design to be used in conjunction with sound engineering judgment. Exclusing non - pressure pipes .

4. Comparative Analysis

The standards basically has to consider the effects of the environmental action grade, environmental categories, and stress characteristics of members and stress state of members on the durability of concrete structures. The division is basically close to.

The studying on the effects of structural characteristics on the corresponding limit value of the crack width and even the durability of concrete structures is relatively little. the consideration of the influence factors are inadequate. We should comprehensively consider the factors that affect the durability of the concrete structures and

ensure the durability and bearing capacity of the structure during the normal use. Comparative analysis of influence factors is shown as Table 7.

Table 3 Comparative analysis of influence factors

Influence Factors	Code for the Durability Design of Concrete Structures	Rules for the Durability Design of Concrete Structures in Highway Engineering	Eurocode 2:Design of concrete structures	Guide to Durable Concrete
Environmental action grades	√	√	√	×
Environment Category	×	√	×	√
Stress Characteristics of Members	√	√	√	×
Stress State of Members	×	√	√	×
Structural Characteristics	×	×	×	√

5. Crack Control Measures

For cracks induced by the non - loads, such as temperature shrinkage cracks, plastic shrinkage cracks, autogenous shrinkage cracks, and so on, all codes are basically in accordance with the following measures to control the development of cracks. and the cracks induced by loads need the Stress checking calculation.

5.1. Ordinary reinforced concrete

1) The Use of Materials

For the post casting parts of the bridge, such as the closure sections, the laminated pouring positions and so on, the expansion agent or the addition of fiber material can be used properly to control the produce or development of the cracks .

We can use the compensate dry shrinkage concrete to reduce or eliminate dry shrinkage cracks of concrete structures.

The latex and epoxy resin can be used to fill the surface cracks of concrete structures.

When the plain concrete structure is used in the lining of the tunnel, the fiber and other materials can be added in the concrete to improve the crack resistance.

The coarse aggregate with good appearance and the cement varieties with smaller dry shrinkage can be used to reduce the development trend of cracks.

Materials quantities, including total water content, and amount of polymer, should be closely monitored and recorded.

2) Optimization of mixture ratio

Adjusting the ratio of concrete reasonably, controlling the water cement ratio, and reducing sand percentage.

3) Construction maintenance

Reducing the mold temperature is very important to control the crack of concrete. in winter construction, when the concrete out of mold, the temperature should not be less than 10 degrees Celsius, the mold temperature should not be less than 5 degrees Celsius. In summer, the temperature of the template and the steel bar before the concrete into the mold and the local temperature should not be more than 40 degrees Celsius.

The temperature difference between the newly poured concrete and the adjacent hardened concrete or rock and soil medium is not greater than 15 degrees Celsius. Preventing shrinkage of two kinds of concrete is not synchronized, which will cause the cracks.

After stripping, thermal insulation and moisture conservation of newly exposed concrete surface should be carried out in time.

During the curing of concrete, it should regularly measure concrete temperature, concrete surface temperature and environmental temperature, relative humidity and other parameters, and adjust the curing system timely according to the changes of concrete temperature and ambient environment, and than strictly control the temperature difference between inside and outside of concrete.

Chaimo, the strength of concrete should meet the standard requirements. The temperature of concrete can not be too high, so as not to contact the air cooling too fast and cracking, and it can not be poured cold water conservation at this time. when the wind or temperature changed rapidly , before the concrete internal cooling and when the internal temperature reaches the maximum, it can not stripping.

4) Reasonable Construction Measures

The minimum reinforcement ratio and arrangement mode of the Surface distribution reinforcement of the concrete structure should meet the requirements of the relevant codes. In order to prevent the surface cracks induced by concrete shrinkage, temperature and other factors.

In the design of the bridge, the accessibility of the rubber bearing in the maintenance and the operating space for the replacement of the bearing should be considered .

For the components of the bridge, such as the guard rail and the sidewalk, it is advisable to set the transverse cutting or through joints along the longitudinal section .

It can use moderate and appropriate positioning steel to reduce the width and the quantity of cracks and decrease the invisible cracks .

The use of joints is an effective method of preventing the formation of unsightly cracking .

The thickness of concrete protective layer of structure should meet the requirements.

5) All equipment used for mixing, placing, and finishing should be designed for the type of overlay being used and should be accurately calibrated and in good working order. Both the contractor and inspecting personnel should be trained in the proper construction techniques of the particular overlay system .

5.2. Prestressed concrete

1) Anti-crack Design

Each codes consider the crack resistance design of prestressed concrete bridge structure from the overall and local aspects.

In the general anti crack design of long span prestressed concrete bridges, the stress of the section and the principal tensile stress should be carried out. At the same time, it is advisable to make the bridge reach a reasonable bridge state by optimizing the prestress distribution .

In the local crack resistance design of long span prestressed concrete bridge, the stress disturbed area (section strain distribution are not conforming to plane cross-section assumption) can do the crack resistance and reinforcement design by the solid finite element analysis method .

2) Construction Maintenance

At the time of the initial tension and final tension of the post-tension prestressed tendons, the strength grade, age and the elastic modulus of concrete shall comply with the provisions .

Prestressed concrete channel grouting should be carried out within 48h after the completion of tension, and it should ensure that the temperature of the pipeline slurry keep more than 5℃ within 72h after the end of the beam grouting in cold season .

3) Other construction measures, construction personnel requirements, construction maintenance and so on are all the same as the ordinary reinforced concrete structure.

From the above summary, it can be concluded that the crack can be controlled through the optimization of concrete materials and mixture ratio, careful construction and maintenance, reasonable structural measures to achieve. At the same time, the technical level of construction personnel must meet the requirements, to avoid the cracks caused by human action. the load cracks also need to check the section tensile stress and principal tensile stress .

6. Conclusion

Through the above comparative analysis, we can draw the following conclusions :

At present , the domestic and international standards are basically considering the types and effects of environment of the structure for the durability of concrete structures. The division is basically close to , But due to the influence of geographical environment, structure factors , the regulation of crack width limit values are not the same provisions .

At present, when the domestic norm determines the limit value of the structural crack width, the environmental effect and the influence of the mechanical characteristics of the structure are taken into account, On the basis of this, it should further consider the effects of the stress states of structure, structure characteristics and load action on the crack limits of structure .And then Combined with some structural measures, to further ensure the durability and the bearing capacity of the structure .

These specifications are basically refers to the structure under the transverse cracks caused by the load. and not including the cracks caused by temperature and other non loads, The cracks caused by temperature and dry shrinkage can also cause a great impact on the durability of concrete structure ,which can not neglected.

The crack caused by non load is a part of the concrete structure which can not be ignored, it will also cause a serious influence. Therefore, it can control the production and development of this kind of crack by means of construction, design and so on.

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