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A method for durability evaluation of concrete for freeze-thaw by graphical-benchmark

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Abstract. According to the evaluation of concrete in durability under the condition of freeze-thaw, the typical damage phenomena and its detection method is investigated. It has the theoretical analysis on mechanism of concrete failure due to freezing and throwing, and develops the relativity of influence factors adopting laboratory tests. Intuitive icons of graphical-benchmarks for evaluating the durability of concrete is supplied, and the method can be used to predict the durability life of concrete in freezing and thawing environment.

Key words. Durability, concrete, graphical-benchmark, freeze-thaw.

1. Introduction

Concrete is a hydrophilic material, and the character of water absorption means the swelling of capillary water in micro pore of concrete after freeze makes deterioration of elastic modulus, compression strength and tensile strength of concrete seriously, which is the material deterioration of concrete in Freeze - thaw environment. At the present time, existing theory of freeze-thaw damage generally includes the hydrostatic classical theory, osmotic pressure theory, ice prism theory and so on. Wei jun introduced a damage model that can describe the durability degradation the process of concrete [1]. Bazant proposed a predictive theoretical mathematical model of concrete on frost resistance [2]. Xiao Qianhui built a prediction model of freezing and thawing cycles of concrete [3] . Since the model involves some different physical processes in the freeze-thaw cycle of concrete, which has to rely on the finite element method and test to confirm the parameter range. Powers proposed the

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expansion and compression of concrete infiltration pressure theory, and the hydrostatic pressure theory is the most representative. Degradation mode that taking into account mineral admixture, freeze-thaw cycles, water-cement ratio, gas content and flash content is put forward by China scholars, which is more comprehensive consideration [4–6]. Research Institute of Highway of the Ministry of Communications gives the model of freeze-thaw cycle considering load stress based on the analysis of the existing test results. Based on full study of current research, most of the models for freeze-thaw of concrete are fitted by parameters resulting in poor operability and veracity [7, 8]. Aiming at the existing problems mentioned above, this paper puts forward a set of evaluation system of concrete antifreeze durability based on the apparent damage characteristics, which can be used in on-site testing [9].

2. Mechanism of graphical-benchmark

The method of graphical-benchmark takes graphic icons of freeze-thaw cycles as standard figures, and the parameter is the damage situation of the concrete. Specifically, the process is that ranged from intact to concrete peel, then the coarse aggregate exposes atmospheric environment, and final fracture of concrete.

During this process, the number of freeze-thaw cycles corresponding to changes is recorded. Then it calculated the corresponding relation between freeze–thaw state and natural conditions according to equivalence relation between laboratory test and natural habitat, thus, the life of freeze-thaw for concrete can be obtained.

3. Project of test

3.1. Test specimen of concrete

The size of test specimen A is 100 mm × 100 mm × 100 mm, which is used to test the compressive strength of concrete, and specimen B is 100 mm × 100 mm × 400 mm, which is used to establishment the graphical control system. It must be said that specimen B should also test the dynamic elastic modulus loss and mass loss corresponding cyclic number. The concrete of three different strengths, namely C30, C40 and C50 with the water-cement ratios of 0.45, 0.39 and 0.31 are manufactured respectively to increase comparability of results.

3.2. Specimen production and maintenance

Specimen of concrete are cured under the condition of constant temperature and humidity conditions (25 °C, 60% RH) by sealed curing 24 hours, then demolished of the template and after curing for 24 days in the chamber, then the specimen is immersed for 4 days in water of 20 ± 2 °C, and the specimens begin to freeze-thaw test in 28 day. It is shown in Figure 1.

Fig. 1. Specimen of concrete

3.3. Concrete freeze-thaw test

The freeze-thaw test of concrete is analyzed by using quick frost method. The upper and lower limits of freeze - thaw temperature are 6 °C and −18 °C. A freeze-thaw cycle is about 3 h, and measure elastic modulus once every 25 cycles. When there is specimen has been completed the specimen, the same size specimen should be placed in the original specimen position to make the temperature field of specimen stable when it is frozen in the cold liquid.

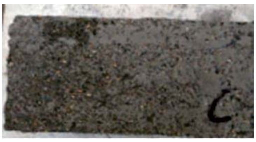
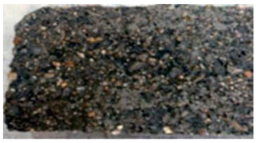
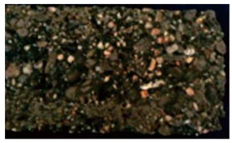
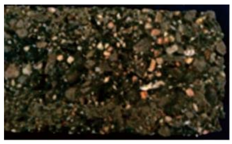
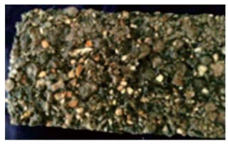
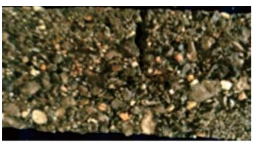
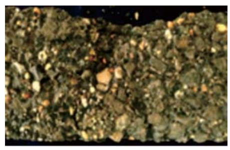
4. Graphic-benchmarking method

4.1. Graphic control system to establish

According to the results of laboratory tests in concrete freeze-thaw, The number of different freeze-thaw cycles corresponding to the concrete damage conditions shown in Table 1.

It can be seen from the Table 1 that the freeze-thaw damage process of concrete can be roughly divided into four stages, that is, 0–150 times on concrete freeze-thaw cycle is the first stage that the concrete surface mortar begins to fall off. 175–250 times is the second stage. At this stage, the mortar corroded heavily, and the flakes begin to fall off locally, but the coarse aggregate still keeps its effect. The third stage of 275 $\sim$ 400 times that concrete surface integrity has been completely destroyed, coarse exposed a wide range of materials. Taking 400 times as the fourth stage that concrete began to appear into a block falling phenomenon, the central location of the crack further expanded until the final concrete specimen fracture.

Table 1. Different freeze-thaw cycles corresponding to the concrete damage status

		
25 times	50 times	75 times
		
100 times	125 times	150 times
		
175 times	200 times	225 times
		
250 times	275 times	300 times
		
350 times	400 times	450 times
		
	500 times	

4.2. Years of estimated useful life in durability

Two of the condition picture record as $N_{0.3}$, $N_{0.2}$ that similar damage to the actual freeze-thaw photos are chosen as freeze-thaw cycles of graphic benchmark. The average value of N_0 is taken as the number of freeze-thaw cycles.

The annual nominal number of freeze-thaw cycles for concrete is:

$$\Delta N = N_0/t_0. \tag{1}$$

Where ΔN denotes the number of freeze-thaw annual cycles, times; N_0 — the number of freeze-thaw cycles that have gone through; t_0 denotes the service life of the structural, a.

The remaining life of durability for existing structural can be calculated as following [10]:

$$t_e = (N_{\text{lim}} - N_0)/\Delta N. \tag{2}$$

Where t_e denotes the remaining life, a; N_{lim} denotes the annual nominal number of freeze-thaw cycles in different grade concrete, C30, C40 and C50 are taken as 300 times, 400 times and 475 times.

When the service life is less than and have not yet suffered obvious freeze-thaw, the durability of freeze-thaw is:

$$t_e = \frac{N_{\text{lim}} k}{n}. \tag{3}$$

Where k denotes the ratio that takes into account number of freeze-thaw cycles with the actual condition and laboratory; n denotes the number of annual nominal freeze-thaw cycles structure. It is recommended that follow the order as follow :

1) The advised value of k is 10 to 15, and it should be taken as a smaller value in severe conditions, or it takes the larger one.

2) The advised value of n is recommended to be carried out according to actual situations. If no clear documentary evidence is available, it can refer to: 120 times/year in Northeast China, 84 times/year in North China, 118 times/year in Northwest China, 18 times/year in central China, 18 $\sim$ 84 times/year in east China, and South China is 0.

5. Frost resistance durability of bridge

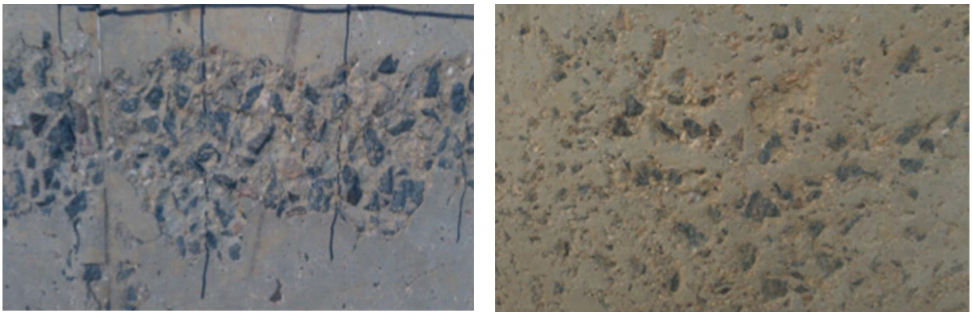
It takes a real bridge as an example. The application result of pier appeared the freeze-thaw damage, Figures 2 represent the typical freeze-thaw damage conditions of pier.

Area 1:

As the damage condition in Figure 2a, the coarse aggregate has appeared in some locations. The average height of damage is not consistent with the laboratory. After conversion according to the area, the height of damage are 150mm. The damaged part of test surface is:

$$n = \frac{150}{400} = 37.5\%.$$

Comparing with the laboratory freeze-thaw, the area of spalling is 40% , The number of cycles is roughly equivalent to the damage state is 200 times for laboratory, which is shown as Figure 3.



(a) (b)

Fig. 2. freeze-thaw damage of pier

Fig. 3. 200 freeze-thaw cycles picture of damage in laboratory

Time of freeze-thaw for the bridge is about 19 years. the annual average number of laboratory freeze-thaw cycles in the region is

$$\overline{N} = \frac{N}{t_0} = \frac{200}{19} = 10.52.$$

According to the rapid freeze-thaw test in laboratory, it can be seen that the maximum number of freeze-thaw cycles is about 300 times, that is, the ultimate life is

$$t_{\max} = \frac{300}{10.52} = 28.5 \text{ years.}$$

Area 2:

Comparing with the laboratory freeze-thaw, the area of spalling is 20%, The number of cycles is roughly equivalent to the damage state is 100 times for laboratory, which is shown as Figure 4.

The annual average number of laboratory freeze-thaw cycles for area 2 is

$$\overline{N} = \frac{N}{t_0} = \frac{100}{19} = 5.26.$$

According to the rapid freeze-thaw test in laboratory, it can be seen that the

Fig. 4. 100 freeze-thaw cycles picture of damage in laboratory

maximum number of freeze-thaw cycles is about 300 times, that is, the ultimate life is

$$t_{\max} = \frac{300}{5.26} = 57.0 \text{ years.}$$

Calculate the residual life of freeze-durability in two different situations is :

$$t_1 = 28.5 - 19 = 9.5 \text{ years}, t_2 = 57.0{-}19 = 38.0 \text{ years.}$$

Based on the principle of presumption of freeze-thaw durability of concrete, the minimum of the calculated value is taken as the estimated value of the remaining life, it means the remaining freeze-thaw durability of the bridge is 9.5 years.

6. Conclusions

(1) The graphic-benchmarking is established by the apparent damage test of concrete in freezing-thawing environment.

(2) It proposed a method to evaluate the freeze-thaw durability life based on the comparison of graph benchmark.

(3) This is a nondestructive testing method, which can be used for nondestructive testing and assessment of concrete materials in freezing and thawing environment.

References

[1] Wei J., Wu X. H., Zhao X. L.: *A model for concrete durability degradation in freeze thawing cyeles.* Acta Mechanical Solida Sinica *16* (2003), No. 4, 353–358.

[2] Bazant Z. P.: *Mathematical model for freeze-thaw durability of concrete.* Journal of the American Ceramic Society *71* (1988), No. 9, 776–783.

[3] Xiao Q. H., Niu D. T., Zhu W. P.: *Strength degradation model and durability service life prediction of concrete in freezing-thawing circumstance.* Building Structure *41* (2011), No. S2, 203–207.

[4] *General Guidelines for Durability Design and Redesign.* The European Union-Brite Euram III, Doeument BE95-1347/R15, February (2000).

[5] Fagerlund G.: *The significance of critical degree of saturation at freezing of pore and brittle materials*. In: Scholer C F, Durability of concrete. Detroit: American Concrete Institute (1975).

[6] Loand K. E.: *Continuous damage model for Load response estimation of Concrete*. Cement and Concrete Research (1980), No. 10, 382–492

[7] Cho T.: *Prediction of cyclic freeze–thaw damage in concrete structures based on response surface method*. Construction and Building Material (2007), No. 21, 2031–2040.

[8] Osama A. M.: *Factors affecting resistance of concrete to freeing and thawing damage*. Journal of Materials in Civil Engineering *12* (2000), No. 1.

[9] Golce S., Nagataki T., Saeki M. H.: *Freezing and thawing resistance of air-entrained concrete incorporating recycled coarse aggregate: the role of air content in demolished concrete*. Cement and Concrete Research *34* (2004), 709–806.

[10] GB/T 50082-2009.: *Standard for test methods of long-term performance and durability of ordinary concrete*. China (2010).

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