

Research on strength attenuation law of concrete in freezing - thawing environment

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Abstract. By rapid freezing and thawing method, the experiments of concrete have been 300 freeze-thaw cycles specimens in the water. The cubic compression strength value under different freeze-thaw cycles was measured. By analyzing the test results, the water-binder ratio of the concrete under freeze-thaw environments, fly ash and air entraining agent is selected dosage recommendations. The exponential attenuation prediction model and life prediction model of compression strength of concrete under freezing-thawing cycles considering the factors of water-binder ratio, fly ash content and air-entraining agent dosage were established. The model provides the basis for predicting the durability life of concrete under freezing-thawing environment. It also provides experimental basis and references for further research on concrete structures with antifreeze requirements.

1. Introduction

Concrete freeze-thaw damage is one of the main causes of concrete structures aging diseases and seriously affect the long-term use and safe operation, which to make these buildings continue to play their role, every year to spend huge amounts of maintenance costs. The existing experimental data on the properties of concrete after freeze-thaw cycles are mostly based on the mass damage and the relative dynamic elastic modulus as the standard, for concrete antifreeze safety design level. However, in practical applications, we are most concerned about the mechanical properties of concrete. For example the loss of strength is directly related to the service performance and safety of buildings. China's current standard GB/T50082-2009^[4] and DL / T5151-2001^[5], the provisions of the antifreeze grade concrete did not consider the strength index. Domestic and foreign research on the mechanical properties of concrete under the action of freeze-thaw cycles is limited, and the methods of freeze-thaw cycles are not the same. As for the life prediction model of freeze-thaw damage to concrete, few are available.^[3]

Therefore, it is necessary to carry out the experimental study on the effect of freeze-thaw cycles on the concrete strength and establish the prediction model of the life-span of the frozen-thawed environment based on the intensity. This is of theoretical significance not only for the analysis of concrete structure, coastal and offshore concrete structures in the north, but also for practical application and economic benefits.

On the basis of theoretical research on the basis of experimental data, considering the concrete water cement ratio, fly ash content, freeze-thaw cycle of concrete compressive strength index Attenuation Prediction Model of air entraining agent content and other factors, in order to freeze-thaw of life of concrete pre environment test provides the basis, but also provide a reference for the durability of concrete and durability design.



2. Experimental

2.1. Specimen design

A Chinese standard 42.5R Portland Cement by cement Factory of QingLing in Shanxi province, fitness modulus of 3.4% (80 μ m standard test sieve) ; Class II fly ash in Weihe Power Plant, fitness modulus of 18% (45 μ m standard test sieve) ; Medium sand of Fine aggregates in Xi'an ba River; The coarse aggregate is limestone broken stone with diameter of 5~20 in Chengyangkou Town, Shaanxi Province; Air-entraining agent Tongji University, using natural wild plant soap as the main raw material developed SJ-3-type high-efficiency air-entraining agent; the tap water was adopted as mix water. The mixture proportion of specimen is given in Table 2.

Table 1. Standard specimen mix proportion of A2 per square meter.

Water-binder ratio	cement /kg	Fly ash /kg	sand /kg	stone /kg	water /kg
0.45	280	120	637	1183	180

Table 2. Concrete mix proportion of different indicators

Number	Air content	Water-binder ratio	Fly ash content	Air-entraining agent content
A1	3.7%	0.35		
A2	4.4%	0.45	30%	
A3	4.5%	0.55		
A4	4.5%		0	0.03%
A5	4.5%		10%	
A6	3.5%	0.45	50%	
A7	1.8%		30%	0.02%
A8	3.5%			0.025%

2.2. Test methods

Air content was measured before forming the specimen . Determination of air content using CA-3-type concrete air content analyzer. This test uses GBJ82-85^[4] frost resistance test "fast freezing method". The specimen is placed in the freeze-thaw box immersed in water at a temperature of 15 ~ 20 °C for 4 days, each freeze-thaw cycle should be completed within 2h ~ 4h, from 6 °C to -15 °C time not less than the freezing time 1/2, while the time from a 15 ° C to 6 ° C is not less than 1/2 of the entire melting time, and the sample center temperature is controlled at (-17 \pm 2) ° C and (8 \pm 2) ° C.

The concrete specimens were respectively subjected to 300 freeze-thaw cycles, wherein the mass loss and the value of dynamic modulus were measured after every 25 freeze-thaw cycles, specimens of 100mm \times 100mm \times 400mm prisms; Mechanical tests were performed after 50 freeze-thaw cycles, specimens of 100mm \times 100mm \times 100mm cubes. Test, the specimen on the loading plate of the test machine, the physical center of the specimen axis and then load the standard static loading rate, each working condition at least three specimens tested. When the discrete is found to be large, increase the number of specimens in order to complete the data accuracy.

2.3. Result

After freeze-thaw cycles of concrete specimens in water, the degree of surface flaking increases with the number of freeze-thaw cycles. In the uniaxial compression test of concrete after freeze-thaw cycle, with the increase of the number of freeze-thaw cycles, the cracking sound of concrete is more obvious.

Especially A6 specimens with the content of fly ash up to 50%, the cracking sound is more severe than the other parts. Different freeze-thaw cycles of concrete compressive strength test results in Table 4.

Table 4. Concrete freeze-thaw times the number of compressive strength test results (MPa)

Number	50 times	100 times	150 times	200 times	250 times	300 times
A1	60.9	59.2	56.3	52.7	49.9	45.7
A2	49.1	48.3	42.7	41.2	39.6	35.8
A3	31.9	31.5	27.7	27	25.8	23.1
A4	48.9	45.5	42.4	41.1	40.9	38
A5	51.9	51.3	48.7	42.1	39	37.6
A6	43.2	39.6	34.1	25.6	— ^a	—
A7	46.8	39.9	23.8	—	—	—
A8	48.1	47.7	41.1	38.2	36.9	32.6

^a "-" indicates that the specimen has been damaged

3. Establishment of Concrete Compressive Strength Attenuation Model in Freezing - thawing Environment

3.1. Propose the mode

According to the experimental data in this paper, the compressive strength of concrete with the frequency of freeze-thaw cycles roughly consistent with the exponential distribution of the law, Concrete attenuation is caused by the breakdown of its own structure, Natural law should be done with the original law of attenuation, approximately in line with Newton's law of material cooling. Considered raw materials, admixtures, water-binder concrete compressive strength attenuation similar. Assuming a attenuation rate of dR_t / dN , it should be proportional to the difference in compressive strength in the freeze-thaw cycle. It can be defined as follow:

$$\frac{dR_t}{dN} = -\lambda(R_t - R_0) \quad (1)$$

$$R_t = aR_0 e^{-\lambda N} \quad (2)$$

Concrete with a water-binder ratio of 0.45 as a standard specimen and based on its test results. Regression analysis was made on the results of compressive strength test in 300 freeze-thaw cycles. Its attenuation coefficient $\lambda = 0.001$, The relationship between compressive strength R_t and the number of freeze-thaw cycles N is:

$$R_t = aR_0 e^{-0.001N} \quad (3)$$

Let the parameter $\rho = R_t / R_0$. Where, a is the coefficient to be determined, λ is the attenuation coefficient, R_t , R_0 are the initial compressive strength after freeze-thaw cycle and before freeze-thaw cycle respectively, and N is the number of freeze-thaw cycles undergoing. Assume $a = k_w k_f k_a$, Where, k_w , k_f , k_a , respectively, the different water-binder ratio w , different fly ash content f and different air content under single factor such as compressive strength correction factor. The relationship between the residual compressive strength ratio ρ and the number of freeze-thaw cycles N is:

$$\rho = k_w k_f k_a e^{-0.001N} \quad (4)$$

3.2. Determination of correction factor k_w

3.2.1. Determination of correction factor water-binder ratio. According to the test results, the water-binder ratio $w = 0.35, 0.45, 0.55$, The compressive strength loss rates of different freeze-thaw cycles were respectively normalized to concrete with $w = 0.45$, At this time fly ash content of 30%, air-entraining agent content of 0.03%. The relationship between the correction coefficient and the water-binder ratio when the water-binder ratio is calculated by regression is:

$$k_w = 0.824w^{-0.1332} \quad (R^2=0.904) \quad (5)$$

3.2.2. Determination of modification coefficients of fly ash k_f . Through the normalized treatment of concrete with $f = 30\%$ for the compressive strength loss rate of different freeze-thaw cycles when the fly ash dosage $f = 0, 10\%, 30\%, 50\%$. At this point take 0.45 water glue ratio, air entraining agent content of 3 / million. The regression calculated the different fly ash dosage correction factor and the relationship between fly ash content:

$$k_f = -2.528f^2 + 1.013f + 0.956 \quad (R^2=0.868) \quad (6)$$

3.2.3. Determination of air content correction factor k_a . Through compressing the compressive strength loss rate of different air-entraining agent dosage $a = 0.02\%, 0.025\%$ and 0.03% , the compressive strength loss rates of different freeze-thaw cycles were respectively normalized with concrete at $a = 0.03\%$. At this point take 0.45 water glue ratio, fly ash content of 30%. The regression calculation of different air content correction coefficient and air content as follows:

$$k_a = 0.556 \ln a + 2.779 \quad (R^2=0.964) \quad (7)$$

where $1.8\% \leq a \leq 7\%$

3.3. Model establishment

According to the formula (3) - (7), the compressive strength index attenuation law after freeze-thaw cycles can be obtained based on the compressive strength as the evaluation index, the synthetic water / cement ratio w , the content of fly ash f and the content of air a Model, that is:

$$\rho = 0.824w^{-0.133}(-2.528f^2 + 1.013f + 0.956)(0.556 \ln a + 2.779)e^{-0.001N} \quad (8)$$

Where $\rho = R_t / R_0$, N is the number of freeze-thaw cycles, w is the water-binder ratio, f is the fly ash content, a is the air content, R_t, R_0 are the freeze-thaw cycles and the initial Compressive strength.

3.4. Model validation

In order to verify the accuracy of the model, The selection of Professor Li Jinyu et al. [9] 's existing experimental data is compared with the results obtained from the prediction model in this paper. The water-binder ratio of concrete is 0.65, the content of fly ash is 0, the air content is 6%, the initial strength is 21.9 MPa, After 225 quick freezing and thawing cycles, the specimen compressive strength was 17 MPa. Using the predicting model of the compressive strength index attenuation law in this paper, the compressive strength of the specimen after 177 MPa was obtained after 225 quick freezing and thawing cycles. The comparison result shows that the error is 4%, which shows that the model is more accurate.

4. Prediction of durability life of concrete under freezing and thawing conditions

By (8), we can deduce the number of freeze-thaw cycles N :

$$N = 1000 \left| \ln \frac{1.093w^{0.133} \rho}{(-2.528f^2 + 1.013f + 0.956)(0.556 \ln a + 2.779)} \right| \quad (9)$$

Where $\rho = R_t / R_0$, N is the number of freeze-thaw cycles, w is the water-binder ratio, f is the fly ash content, a is the air content, R_t, R_0 are the freeze-thaw cycles and the initial Compressive strength.

The main steps of predicting life expectancy of existing buildings by using the prediction model obtained in this paper are as follows:

- Known mix ratio of existing building concrete materials, such as water-binder ratio, fly ash content and air content.
- The initial strength of existing building concrete is known, and the existing strength is measured by nondestructive testing.
- Calculate the number of rapid freezing and thawing times that we used in this paper, using the prediction model of freeze-thaw cycles (9) .
- Predict the safe operation period or remaining life of the existing buildings through the contrast between indoor and outdoor of rapid freezing and thawing test method.

5. Project examples

The Ming Tombs Reservoir is located in Shisanling Township, Changping County, Beijing. Dam site is located in the East River sand tributary of Dongshan Village. Reservoir was built on January 21, 1958, completed on July 1 that year. Take the central southwest of the reservoir as an example^[10]. The standard ratio of the concrete batching on the pool: the water-binder ratio is 0.44, the content of fly ash is 0 and the air content is 6.5%. The average compressive strength of concrete for 28 days 35.4MPa (to meet the design requirements of 25MPa)^[11]. According to the test results of three concrete slabs on the southwest slope of the reservoir in 1999, the strength can meet the requirements of C25^[12]. Based on the design index of 25MPa, according to the model, it can be estimated that the concrete panel can undergo about 454 cycles of rapid freezing and thawing. Based on the experimental study of Li Jinyu et al.^[13] Beijing area suffered an average of 84 outdoor natural environment freeze-thaw cycles annually, the effect of rapid freezing and thawing test method indoor and outdoor contrast ratio of 1: 12.9, It can be concluded that the reservoir undergoes 6.5 quick freezing and thawing cycles every year, $454 / 6.5 = 69.85$, That is, the safe operation period of concrete here is about 70 years; The remaining life of the concrete slab in the upper pool in the southwest slope of the reservoir is about 20 years.

6. Conclusion

- In this paper, the freeze-thaw durability of fly ash aerated concrete is studied, and the three factors affecting the freeze-thaw durability are discussed: water cement ratio, fly ash content and air entraining agent content. Through experimental analysis, it is concluded that the most influential frost resistance is the dosage of air-entraining agent, followed by the content of fly ash.
- The concrete water-binder ratio will also affect the mechanical properties of concrete in freezing-thawing environment, the compressive strength loss rate also decreases of concrete with small water-binder ratio. Therefore, the requirements of frost resistance should be preferred to use higher strength concrete.
- The content of fly ash affects the mechanical properties of concrete in freeze-thaw environment. The fly ash with 10% -30% incorporation can reduce the compressive strength loss of concrete, and the compressive strength of concrete decreases with the addition of 50% and the rate has increased significantly. Therefore, the requirements of frost resistance of fly ash content of concrete should not exceed 30%.
- In this paper, the predicting model and life prediction model of exponential attenuation strength against compressive strength are established. Taking into account the factors of water-binder ratio, fly ash content and air-entraining agent content, the model can be used as concrete for freeze-thaw environment in life prediction. However, the model is established under the condition of raw material and water-binder ratio of 0.35-0.55. To establish a more adaptable prediction model, a large amount of experimental research is needed.

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References

- [1] Niu Ditao. Durability and Life Prediction of Concrete Structures [M]. Beijing: Science Press, 2003.
- [2] Zhang Yu, Jiang Li Xue, Zhang Weiping, *et al* Introduction to the durability of concrete structures [M]. Shanghai: Shanghai Science and Technology Press, 2003: 79-81, 226-232
- [3] Jin Zuquan. Concrete durability and life prediction under severe conditions in western China [D]. Nanjing: Southeast University, 2006.
- [4] GB/T50082-2009, *long-term Performance and Durability of Concrete Test Methods* [S]
- [5] DL / T5151-2001, *Hydraulic Concrete Test Procedures* [S].
- [6] Gokce S, Nagataki T, Saeki M Hisada. Freezing and thawing resistance of air-entrained concrete-containing recycled coarse aggregate: the role of air content in demolished concrete [J]. *Cement and Concrete Research*, 2004, **34**: 709- 806.
- [7] Tanke Feng. Effect of water-binder ratio and admixture on frost resistance of concrete [J], *Journal of Wuhan University of Technology*, 2006, (3): 59-60.
- [8] Osama. A, Mohamed, Factors Affecting Resistance of Concrete to Freezing and Thawing Damage, *Journal of Materials in Civil Engineering*, February, 2000, **12**, No. 1.
- [9] Li Jinyu, Cao Jianguo, Xu Wenyu *et al*. Research on the mechanism of freeze-thaw damage of concrete [J], *Journal of Hydraulic Engineering*, 1999, (1): 41-49.
- [10] Liu Sila, Tang Guangpu. Prediction of concrete freeze-thaw durability under field conditions [J], *Chinese Journal of Rock Mechanics and Engineering*, 2007 (12): 2412-2419.
- [11] Li Zongtai, Wang Dali. Frost resistance test of concrete roof anti-seepage panel of Shisanling Pumped Storage Power Station [J], *Hydroelectric Power*, 1999 (5): 45-47.
- [12] Peng Tao, Li Jinyu, Cao Jianguo. Quality inspection and frost resistance evaluation of upper reservoir of Shisanling Pumped Storage Station [J], *Hydroelectric Power*, 2003 (1): 65-67.
- [13] Li Jinyu. *Durability of concrete structures in freeze-thaw environment design and construction guidelines* [A]. *Chinese Society of Silicate 2003 Annual Conference Cement-based Materials Proceedings (second)* [C], 2003.