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Study on Durability Optimization of Building Materials

Zhang Fu

Department of Civil and Architectural Engineering, Nanchong Professinal Technic College, Sichuan 637131, China
zhangfu28374@126.com

This paper is to explore the relevant factors that affect the durability of building materials and to further optimize the durability of it. Concrete is chosen as the main inspection materials, and studies its durability is tested by dynamic elastic modulus. After the freeze-thaw test and immersion test, the durability of concrete will be reduced to varying degrees. Factors such as the change of temperature, water condition and other external factors will affect the durability of concrete. The optimization studies of the durability of other related building materials can also be carried out by focusing on these factors.

1. Introduction

Optimizing the durability of building materials is of great importance to ensure the service life of the projects and reduce the cost of the maintenance. As the most widely used building material, concrete has a direct impact on the quality of most of the construction work and it’s still possible to improve its durability.

In this paper, the main factors influencing the durability of concrete are analyzed through dynamic modulus of elasticity and comparative experiments for different factors. Based on this, the means of enhancing the durability of related building materials are proposed.

2. Literature review

The design method of concrete mix proportion in ACI (American Certification Institute), France, Britain and China is the most typical. The method of ACI in the United States is simply based on the table in the specification and obtained through checking the table. The selection basis of each parameter is not strong, and the sensitivity to the change of material character is not strong, which is the empirical mix design method. The business rule engine method proposed by Pei and Xing considered many factors, and it was also based on the form of graph selection (Pei and Xing, 2016). The Dreux method proposed by Balona and so on was mainly based on the Paul rice formula, considering a variety of factors and taking into account the durability when choosing the water consumption (Balona et al., 2018). Wambeke and others proposed a design method based on the physical and mathematical models of the thickness of the slurry layer and the ratio of air to solid - delarred, but the calculation process and design steps are too complex to be popularized (Wambeke et al., 2018). China's coordination ratio is more focused on empirical design, mainly based on the fixed ROMI strength model proposed by Lovanh and so on. The theoretical foundation of the design method is weak, the empirical selection is the most, and the result of the calculation has large deviation. Secondly, the choice basis of sand rate and water consumption are insufficient (Lovanh et al., 2016).

On the basis of existing high performance computing practical tests, Castro et al. made some assumptions about the main mix ratio design parameters, and assuming that the volume ratio of cement paste to aggregate is 35:65 (Castro et al., 2016). The water consumption should be set according to the strength grade of concrete. Assuming the gas content, then the cement consumption is calculated according to the water consumption and the volume of cement paste. It is assumed that the volume ratio of cement and mineral misery (fly ash, ash and slag, etc.) is 75:25, and the volume of ash and fly ash or slag is 10% and 15%. The volume ratio of coarse aggregate is set to 60:400, and the miserable amount of high efficiency water reducing agent is set to 1% when compound double miserably. Because there are many assumptions in this method, the calculated mix ratio of the first plate can only play a guiding role. In order to get the correct mix ratio, a lot of experiments are needed.

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The total calculation method proposed by Zhu and others is mainly based on 4 hypotheses: the concrete composition materials (including solid, gas and liquid 3 phases) have volume addition and property; the gap of the stone is filled with dry mortar; the void of dry mortar is filled with water; dry mortar consists of cement, fine admixture, sand and air (Zhu et al., 2017; Zhang et al., 2016). The absolute volume method proposed by Mello and others suggests that the void in the concrete is filled with cement mortar, the void in the cement mortar is filled with cement slurry, and the void in the cement is filled with water (Mello et al., 2016). Secondly, after a large number of studies on high performance concrete (HPC) were carried out by Hussain and others, it is believed that the optimum volume ratio of cement paste and aggregate should be achieved to make HPC at the same time to achieve the best construction and workability and strength. The quantitative relationship between the volume of cement paste and aggregate volume in the design of the HPC mix ratio is determined (Hussain et al., 2018). Based on this, some calculation models and formulas are derived, and the single dose of each component can be obtained. This method modifies the defect that the traditional absolute volume method cannot fully calculate the dosage of each component. But the calculation method and process are complex and difficult to popularize.

The LCPC method of the Luqiao laboratory in France carried out a large number of experiments on the model material, and used the cemented slurry to carry out the rheological test. In addition, the mortar is used to carry out the mechanical test, and a database is set up to establish a number of mathematical models. Each model is the relationship between the performance of concrete and the working performance, and then according to the needs of the engineering, it is combined into the calculation model. The computer aided software are used to reduce the preparation of the coagulant, reduce the workload of the trial match, and improve the efficiency of the mix design.

On the basis of the dense coefficient method tush and the simplification of some aggregate theory, a kind of aggregate particle size is studied. The concrete aggregate is filled with dense material. Based on the study of concrete strength and rheological theory, according to the compact theory, the compactness coefficient of fine and coarse aggregate is applied to each component of concrete to determine the mix proportion of concrete. The density coefficient is related to the macroscopic properties of aggregate size, coagulation strength, workability and so on.

The PBMD method sets up a database to collect the relationship between the existing concrete performance and the mixture ratio, and obtains the satisfaction curve. According to the performance requirements of the concrete, the satisfaction curve combination is determined to calculate the match ratio. It is specifically shown in the following 3 stages and 7 steps: concrete requirement; preliminary design and standard design method; collection of data to set up satisfaction curve; satisfaction curve combination; comparison between actual results and requirements; coagulant ± mix ratio correction; determination of the final match ratio according to the requirements.

In order to change the tradition of designing concrete mix proportion according to strength, the empirical range between chloride diffusion coefficient and water glue ratio, strength and aggregate amount of cementitious material is given by list. The concrete mix ratio is calculated according to the water glue ratio of durability index, and the strength of the concrete can be tested to meet the predetermined strength requirements after testing. In fact, for the concrete structure in the corrosive environment, the strength and durability have the same important position. It is necessary to make both listed in the reference parameters of the concrete mix design.

To sum up, the above research work is mainly focused on the quantitative analysis of structural durability of concrete and the mix ratio design of the concrete in the environment of chloride erosion. The method of analyzing and designing the durability of concrete under the erosion of chlorine salt is established and applied to the durability analysis and design of practical engineering. Therefore, based on the above research status, the analytical solution and approximate solution are calculated for chloride diffusion and distribution in concrete structures under different geometric shapes. The calculation model of durability control area is set up, and the quantitative analysis method of durability of concrete structure is proposed. Combining the quantitative analysis of durability of concrete structure under the condition of chlorinated salt ring, the analysis and design method of the durability of concrete under the erosion of chlorine salt is established. It realizes the quantitative analysis and design of the durability of concrete structures and materials based on the environmental conditions, durability requirements and strength requirements of the structure.

3. The main factors affecting the durability of concrete and dynamic elastic modulus

3.1 The main factors affecting the durability of concrete

The durability of concrete and other building materials is deeply valued in engineering practice. At present, domestic and foreign engineering generally agree that as same as strength, durability is an important quality index of concrete. With the continuous emergence of new varieties of cement, extensive incorporation of new admixtures, the testing or assessments of the durability of concrete are very necessary.

The main factors affecting the durability of concrete include cyclic wet-dry environments, cold and hot changes, freeze-thaw cycles (acid, salt and organic chemical corrosion usually considered from the corrosion resistance of concrete), among which the most serious damage is freeze-thaw cycle of concrete. After freeze-thaw cycles test, according to the quality deterioration indicator J, the durability can be assessed. In this paper, the selected quality indicators include:

Compressive strength of concrete. After the freeze-thaw cycle test, due to the damage, the strength of concrete specimens decreased. Generally, its durability is expressed by the maximum number of freeze-thaw cycles when the strength declines to 75%.

Dynamic elastic modulus of concrete. Elastic modulus is a parameter reflecting the elastic properties of a material. Dynamic modulus of elasticity is one of those several types. When the internal structure of concrete changes, the dynamic modulus of elasticity correspondingly changes. Therefore, when the dynamic modulus of elasticity decrease to 60% of the original value (some set at 75%), the maximum number of freeze-thaw cycles that the concrete suffered can represent its durability.

The expansion rate of concrete. Water in concrete can be frozen at low temperatures, causing changes in volume, and so that loose structure. The more the number of freeze-thaw, the greater the expansion rate of concrete. It is generally believed that when the expansion rate of concrete reaches 1%, the concrete has been significantly damaged. The number of freeze-thaw cycles that concrete can withstand at that time indicates its durability.

3.2 Dynamic elastic modulus

The elastic modulus of a building material is the ratio of the load to the elastic strain under this load. As concrete is not a pure elastomer, an arc (Figure 1 arc OA) can be seen in the stress-strain diagram. Generally, the so-called elastic modulus is the slope of the secant of this arc within a certain load range. This is the static elastic modulus EO. As can be seen from Figure 1, the initial segment of the arc approximates a straight line, and OE is the extension of that segment, OE's slope corresponding to the abscissa is called original elastic modulus E. The dynamic elastic modulus Ed is the ratio of the stress increment to the corresponding strain increment (the slope of the straight line HH ') after the material has been "adapted" to a small period of periodic loading. This ratio does not follow load changes, and its value is equal to the original elastic modulus of E. (HH` Parallel OE).

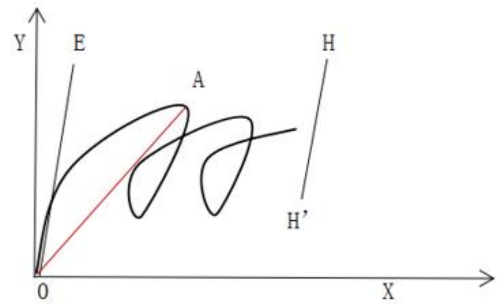

Figure 1: Arc OA

It has been confirmed that there is a relationship between the dynamic elastic modulus and the propagation velocity of vibration waves within the material: (In this formula, ϖ is the proportion of materials used in the specimen; g is the acceleration of gravity).

$$V = \sqrt{\frac{E_d}{\varpi} g}$$

It can be seen that the dynamic elastic modulus Ed is proportional to the square of the resonance frequency f. As long as the resonant frequency of the specimen being measured, the dynamic modulus of elasticity can be easily calculated. Dynamic modulus of elasticity is closely related to the structure of the material itself. Not only does it show an average of the entire bulk modulus of the specimen, but it also reflects localized damage, since localized damage can prevent the propagation of sound vibrations. This method is especially convenient

when we study the concrete's elasticity changes with its natural or structural alteration.(such as hardening, corrosion, freezing effects)
We mainly tested by means of dynamic modulus tester, which is a frequency measuring instrument. The exciter converts electrical oscillations into mechanical vibrations, and then applied it to the concrete specimen. The concrete resonance frequency can be measured through the receiver. The dynamic elastic modulus of concrete can be calculated by the resonance frequency.

3.3 Accelerated deterioration test of pre-stressed concrete pipe pile

Take the rebar to be corroded in the concrete as the anodes, stainless steel or copper as the cathode, concrete as the medium. In order to reduce the concrete resistivity, the concrete components are usually immersed in NaCl solution to keep moisture. Control current strength and the power time, accelerate the deterioration test steps: 1) put the sample in Table 1 into a pool of 4200 * 4200 * 950, as shown in Table 1.

Table1: Geometrical size and material properties of specimen

Sample number	Pipe pile type	length	diameter	thickness	strength
1#	phc	3.0m	400mm	1420	c60
2#	t-phc	3.0m	600mm	1520	c65

2) Soak the pipe pile for 10d with 5% NaCl solution; connect the lead wires in the pipe pile with the positive pole of the DC power supply and place another piece of stainless steel in the pool, then connect with the negative pole of the power supply, finally turn on the DC power supply and accelerate the corrosion test;
3) Use the same applied voltage to each pipe pile to simulate the deteriorating effect of pipe pile under the same corrosive environment; keep the voltage at a constant value of 7V and energizing time for 60d during electrification;
4) After reaching the expected time of electrification, the power should be ended, the pool of water could be drained. Place pipe pile for 10d, and after it being fully dried, the next step can be carried out. Schematic diagram of accelerated corrosion device is shown in Figure 2.

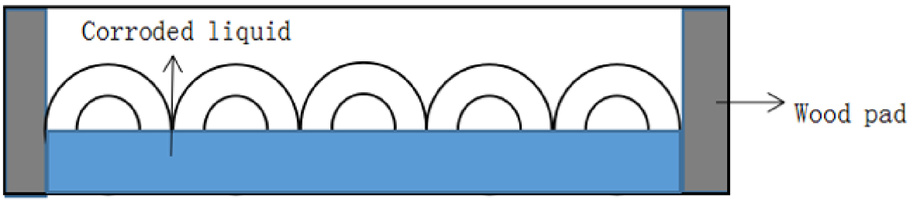

Figure 2: Schematic diagram of corrosion device

5) By analyzing the results of accelerating corrosion test and observing the appearance of the surface of the pipe pile, it can be found that: 1) Visible corrosion cracks appear in the direction of the spiral stirrups and pre-stressing tendons on the two pipe piles; 2) The corrosion of the end plate is more serious, and the original protective coating is expanded by the rust products, which cannot effectively protect the seams in the long-term corrosive environment; 3) Similar to the connection of the PHC pile, T-PHC pile hoop corrosion is also serious, and the original epoxy coating is expanded by the rust products and can't provide an effective protection in the long-term corrosive environment.

4. Pipe piles tensile strength test

Tensile strength tests on four pipe piles were carried out after the accelerated degradation test for assessing their ultimate tensile strength. This test uses tension jack as equipment and the cylinder area is 41838mm2. The loading device is shown in Figure 3.
Loading steps are as follows: 1) First, put the tube pile to be tested into the loading frame and load by jack after checking the installation; 2) Step loading; 3) Stay for 30s after each load, and check the presence or absence of cracks, the deformation of the ferrule, end plate and cracks in the joint weld, etc. Until the pipe pile is destroyed or the load is difficult to increase, the load at the time of cracking and destruction of the pipe pile should be recorded. When it is loaded by two jacks, the load on both sides and the displacement of the beam must seek to be synchronized, and the load size should be measured by the force sensor.

Figure 3: Test loading device

At the initial stage of loading, the specimens are in elastic state and the concrete works together with the pre-stressed reinforcing steel bars. As the load continues to increase, the two types of pre-stressed concrete pipe piles exhibit different tensile failure modes, and the PHC pile suddenly ruptured. The joint was cracked by the upper end. The width was 5mm and the load was continued. The end plate flange of the fixed end plate was disengaged and the pier head was pulled off. The two end plate flanges were opened. Both of 1 #, 2 # PHC pile failure cross-sections occur in the connection joints. 2) With the increase of load, T-PHC pile shows a slight circumferential crack, and as the load increases, the crack width continues to increase. Finally, the test piece makes a sound, the pressure gauge pointer falls, and the pile body of the tension end cracks. The main tendon pulls off with no abnormal joints. According to "pre-tensioning method of pre-stressed concrete pipe pile" (GB13476-2009) 4.2.1.2, steel pier head strength should be no less than 90% of the standard strength of the material, so take 0.9 times of the standard tensile strength of steel rods, also 0.9fptk of it. The American Standard ACI543R-00 stipulates that the tensile strength of concrete piles should be calculated by the load of the steel bar and multiplied by the load factor 0.9. The theoretical value and test value of the tear load and ultimate load of the specimen is shown in Table 2.

Table 2: Load value at each stage

Sample number	Tensile	cracking test	Limit test	phase data
1#	167	417	167	358
2#	251	427	251	358

The actual tensile bearing capacity of 1 # and 2 # PHC piles is 167,251kN, which is far less than their cracking load, so the failure occurs when the 1 # and 2 # pipe piles did not crack. Figure 4 compares the calculated theoretical values and experimental values of the tensile bearing capacity of the pipe pile. From Figure 4, it can be seen that the actual tensile load capacity of 1 # and 2 # PHC piles are 167,251 kN. Compared with the theoretical value of 358 kN, it decreased 53% and 30% respectively.

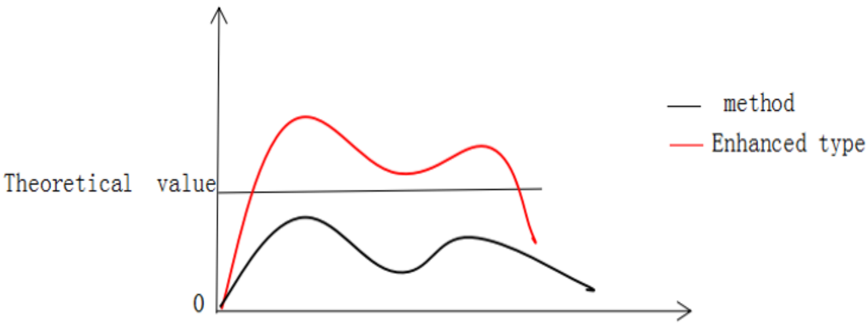

Figure 4: ensile bearing capacity

5. Conclusion

(1) Under the same corrosive environment and time, corrosive cracks caused by steel corrosion can lead to the decline of tensile crack loads of the two kinds of pipe piles.
(2) The tensile bearing capacity of two kinds of pipe piles decreases. The tensile bearing capacity of PHC pile decreases by 30% ~ 53%, and of T-PHC pile decreases by 0% ~ 6%.
(3) The axial tensile failure mode of PHC pile is converted from the pile body to the end connection, and the axial tensile failure mode of T-PHC pile is still manifested as the pile pulled off damage.
(4) T-PHC piles have better durability than PHC piles.

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