Research on Deterioration Model of Concrete Road in Cold Area

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Abstract: Based on the concrete damage data under the interaction of fatigue loads and freeze-thaw cycles, a concrete freeze-thaw cycle deterioration model and a fatigue damage deterioration model are established respectively. Based on the concrete fatigue damage deterioration model, a freeze-thaw influence factor is introduced, and a freeze-thaw The model of concrete degradation under fatigue and fatigue, and the relationship between freeze-thaw damage, fatigue damage and time are discussed separately, so as to study the remaining life of concrete roads.

1. Introduction

In recent years, the construction of concrete roads in China has developed very rapidly. As of the end of 2018, a statistical survey showed that the total mileage of concrete roads was about 4.486 million kilometers, and the road density was 50.48%. Most of these areas are in seasonal frozen soil areas. Every year it is subject to different degrees of freeze-thaw damage, which seriously affects the service life of concrete roads. At present, based on the research on concrete degradation under the interaction of freeze-thaw and fatigue, Song Yupu [1] carried out concrete freeze-thaw damage reliability analysis and remaining life prediction, and derived the calculation formula for concrete freeze-thaw damage failure probability; Liu Guirong[2]'s research on the fatigue life influence coefficient model under freezing and thawing was carried out. It was found that the environment and the coupling effect reduced the shear bearing capacity of the flexural members, and the deterioration formula was given. Our research group[3] conducted a test on the dynamic characteristics of concrete under fatigue loading and freeze-thaw cycles, and obtained the concrete degradation curve. Trottier et al. [4] and Lappa [5] proposed crack changes in concrete based on alternating freeze-thaw fatigue tests.

The above studies are all experimental studies on the concrete mechanism level, which laid a theoretical foundation for the research on the remaining life of concrete roads based on freeze-thaw and fatigue. However, the current design research on the service life of concrete roads is urgently needed. Therefore, this paper studies the life of concrete roads based on statistical angles, and uses the experimental data to fit the concrete degradation model based on freeze-thaw and fatigue. Finally, the mathematical model of the remaining life of concrete roads and the number of freeze-thaw and fatigue times is obtained.
2. Related experimental research

Our research group carried out fatigue test, freeze-thaw test and fatigue and freeze-thaw alternate action test on C60 concrete test block. The concrete quality mix ratio of the test piece is cement: stone: sand: water = 374: 1164: 723: 184, the concrete uses ordinary portland cement with 28d compressive strength greater than 52.5MPa, and the coarse aggregate uses basalt crushed stone. It is 20mm, the fine aggregate uses Yangtze River sand, and its fineness modulus is in the range of 2.3 ~ 2.4. The water reducing agent is the JM series of high-efficiency FDN water reducing agent of the Jiangxi Academy of Sciences. The content is 0.2%. The average compressive strength fc of the concrete was measured as 60.1 MPa.

The freeze-thaw test method was in accordance with the provisions of the "Test Methods for Long-term Performance and Durability of Common Concrete" (GBJ 82-85). The test pieces were subjected to freeze-thaw cycles 75 times. The mass loss of concrete was recorded every 25 cycles, and its wave velocity was measured with an ultrasonic detector to obtain the relative dynamic modulus of elasticity of the concrete. The fatigue test is divided into: (1) linear static loading, from zero load to the average fatigue load, the average fatigue load is 0.3fc, and the loading rate is 0.1kN / s; (2) dynamic cyclic loading, according to the loading frequency is 5Hz, the cycle A sine wave with an amplitude of 0.2 fc was used for loading, and the relative dynamic modulus of elasticity of the concrete specimen was measured every 25 thousand fatigue loads. Fatigue and freeze-thaw alternate tests are divided into: (1) Concrete fatigue loading is performed first, and the loading times are 0, 0.5, and 10,000 times, respectively, and then freeze-thaw cycles are performed, and the times are 0, 25, 50, and 75 times, respectively. Mass and relative elastic modulus of concrete. (2) The freeze-thaw cycle is performed before fatigue loading. The loading times are the same as the previous tests. The relative dynamic modulus of elasticity of concrete is shown in Table 1, Table 2, and Table 3.

| Tab.1  The relative dynamic modulus of elasticity of freeze-thaw test |
|---------|------------------|
| Freeze-thaw times (times) | Relative dynamic modulus of elasticity |
| 0       | 1.000            |
| 25      | 0.973            |
| 50      | 0.929            |
| 75      | 0.904            |

| Tab.2  The relative dynamic modulus of elasticity of fatigue test |
|---------|------------------|
| Fatigue times (10,000 times) | Relative dynamic modulus of elasticity |
| 0.00  | 1.000            |
| 0.25  | 0.895            |
| 0.50  | 0.874            |
| 0.75  | 0.861            |
| 1.00  | 0.841            |
| 1.25  | 0.804            |
| 1.50  | 0.792            |
| 1.75  | 0.788            |
| 2.00  | 0.772            |
| 2.50  | 0.784            |
| 3.00  | 0.765            |

| Tab.3 Relative dynamic modulus of elasticity of concrete under alternating action |
|------------------|------------------|
| Fatigue times  (10,000 times) | Relative dynamic modulus of elasticity |
| Freeze-thaw 0 times | Freeze-thaw 25 times | Freeze-thaw 50 times |
| 0      | 1.000            | 1.000               |
| 0.25   | 0.895            | 0.868               | 0.847               |
| 0.50   | 0.874            | 0.847               | 0.822               |
| 0.75   | 0.861            | 0.830               | 0.797               |
| 1.00   | 0.841            | 0.822               | 0.793               |
3. Test results under alternating freeze-thaw and fatigue

From the data in Table 1, using software fitting can get Figure 1:

Figure 1. The relationship between the relative dynamic modulus of elasticity of concrete and the number of freeze-thaw cycles

With a single freeze-thaw load, can get:

\[ P_t(x) = a_1 \cdot e^{b_1 \cdot x} + c_1 \cdot e^{d_1 \cdot x} \]  

In the equation, \( P_t(x) \) is the relative dynamic modulus of elasticity under freeze-thaw load, \( x \) is Freeze-thaw times, \( a_1, b_1, c_1, d_1 \) is Freeze-thaw correlation coefficient, \( a_1 = -0.007, b_1 = 0.013, c_1 = 0.998, d_1 = -1.194 \times 10^{-5} \), \( \text{SSE} = 2.034 \times 10^{-6}, R\text{-square}=0.996, \text{Adjusted R-square}=0.9994, \text{RMSE}=0.0006 \).

From the data in Table 2, using software fitting can get Figure 2:

Figure 2. The relationship between Relative dynamic modulus of elasticity of Concrete and Fatigue Times

With a single Fatigue load, can get:

\[ P_f(y) = a_2 \cdot e^{b_2 \cdot y} + c_2 \cdot e^{d_2 \cdot y} \]  

In the equation, \( P_f(y) \) is the relative dynamic modulus of elasticity under Fatigue load, \( y \) is Fatigue times, \( a_2, b_2, c_2, d_2 \) is Fatigue correlation coefficient, \( a_2 = 0.185, b_2 = -1.766, c_2 = 0.805, d_2 = -0.016 \), \( \text{SSE} = 0.0016, R\text{-square}=0.972, \text{Adjusted R-square}=0.962, \text{RMSE}=0.0136 \).

From the data in Table 3, using software fitting can get Figure 3:
Figure 3. The relation between dynamic elastic modulus and the fatigue frequency under different freezing-thawing times.

Figure 3 is an alternate test of fatigue loading and freeze-thaw cycles. The fitting curves in Figure 3 all show the characteristics of large slope in the first half, rapid decline, and gentle decline in the second half. Thus, it was proved that the fatigue load plays a leading role in the alternate action, and the freeze-thaw cycle is a secondary effect to accelerate concrete damage.

4. Degradation model of concrete under the action of freeze-thaw and fatigue

4.1 Relative dynamic modulus of elasticity (RDME)

One of the current research methods for concrete damage at home and abroad is to use the relative dynamic modulus of elasticity (RDME) to characterize the damage of concrete structures. The relative dynamic modulus of elasticity can accurately and intuitively reflect the internal damage of concrete specimens. The method uses the principle of ultrasonic speed measurement, which will not cause additional damage to the concrete specimen. The formula for calculating the relative dynamic modulus of elasticity:

$$E_r = \frac{E_n}{E_0} = \frac{V_n^2}{V_0^2}$$ (3)

In the equation, $E_r$ is the relative dynamic modulus of elasticity of the concrete subjected to freeze-thaw and fatigue, $E_0$ is the initial dynamic elastic modulus of the concrete specimen, and $E_n$ is the dynamic elastic modulus of the concrete specimen after $n$ freeze-thaw cycles or $n$ fatigue loads. $V_n$ is the ultrasonic wave velocity of the concrete specimen after $n$ freeze-thaw cycles or $n$ fatigue loads, and $V_0$ is the initial ultrasonic wave velocity of the concrete specimen.

According to China's "Standard for Long-term Performance and Durability Test Methods of General Concrete" (GBT50082-2009), the relative dynamic modulus of elasticity of concrete can be considered to be in a failed state if the relative dynamic modulus of elasticity of the concrete is reduced by more than 40%.

4.2 Freeze-Thaw Impact Factor

In Figure 3, the relative dynamic modulus of elasticity of the concrete under different freeze-thaw cycles is approximately the same. The freeze-thaw effect factor is defined as the same number of fatigue loads, and the relative dynamic elastic modulus of the concrete without freeze-thaw and freeze-thaw. The ratio of the loss of the modulus is calculated by using the data in Table 3. It is found that the loss of the relative dynamic modulus of elasticity of the concrete increases approximately as an exponential function with the increase of the times of freeze-thaw cycles. The freeze-thaw influencing factor of the test is obtained by fitting:

$$\alpha(x) = a_3 \cdot e^{b_3 \cdot x}$$ (4)

In the equation, $a_3 = 0.99$, $b_3 = -0.00075$; $R^2 = 0.9824$. 
4.3 Degradation model of concrete under freeze-thaw and fatigue

According to formula (2) and formula (4), the concrete fatigue load can be taken as the main influencing factor, and the concrete degradation model that introduces the influencing factor of freeze-thaw cycle is:

\[ P_t(x, y) = P_t(y) \times \alpha(x) = (a_2 \cdot e^{b_2 \cdot y} + c_2 \cdot e^{d_2 \cdot y}) \times (a_3 \cdot e^{b_3 \cdot x}) \]  

(5)

In the equation, \( P_t(x, y) \) is relative dynamic modulus of elasticity of concrete under freeze-thaw cycles and fatigue loads, \( x \) is Freeze-thaw times, \( y \) is Fatigue times, \( a_2 = 0.185, b_2 = -1.766, c_2 = 0.805, d_2 = -0.016, a_3 = 0.99, b_3 = -0.00075 \).

5. Conclusion

Based on the fitting results of experimental data, this paper proposes a concrete degradation model based on fatigue and the influence factor of freeze-thaw. In this model, the fatigue load is the main aspect, and the freeze-thaw effect is the secondary aspect. Influence factors to simplify the model. Because the model test data is less, it can only predict the life of C60 concrete roads. If it needs to be expanded and used, it needs to supplement the corresponding test data and fit a new model according to the ideas of this paper before it can be used.

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