Effects of Plateau Climate Environment on Concrete Performance

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Abstract. Transportation construction on the Qinghai-Tibet Plateau has always attracted much attention, and the completion of the Qinghai-Tibet Plateau Railway, one of the four major projects in the new century, is bound to accelerate the economic development of the plateau region and the completion of more infrastructure. Therefore, concrete materials are widely used in the construction of the plateau region, and the long-term performance of its materials and structures in this environment is worthy of attention. The plateau climate has three main characteristics: large temperature difference, low air pressure, and low humidity, which makes the concrete withstand different degrees of damage from preparation to use, thereby reducing the overall carrying capacity and safety of the building structure, reducing its service life, and increasing the risk of building erosion by the environment. This paper mainly summarizes and analyzes the factors affecting the performance of concrete in the plateau environment, that is, temperature, humidity and air pressure, and on this basis, explores their comprehensive influence. The comprehensive study shows that temperature could cause a freeze-thaw cycle of concrete, resulting in continuous accumulation of internal damage of concrete; Low temperature could cause water migration in concrete, easily causing concrete shrinkage and carbonization; Low air pressure could reduce the shrinkage and durability of concrete structures. Based on a series of theoretical studies, this paper further discusses the relevant solutions applicable to various practical engineering problems.

Keywords: Concrete; Climate; Qinghai-Tibet Plateau.

1. Introduction

The Qinghai-Tibet Plateau is an inland plateau in Asia, which is often called the "roof of the world" and "the third pole". It is rich in mineral resources. Therefore, the infrastructure construction of the plateau has attracted the attention of various countries for decades. However, the plateau terrain and permafrost are widely spread, the ecosystem is fragile, geological disasters occur frequently, and the coping technology is relatively insufficient, which has long restricted the construction of transportation facilities in this region [1].

At present, in practical engineering, compared with other building materials, concrete has outstanding advantages, such as a wide source of raw materials, excellent performance, and low cost. This makes concrete in the field of construction has been extremely widely used, and has become one of the world's most important building materials.

In recent years, the development of economic and transportation construction on the Qinghai-Tibet Plateau has promoted the rapid completion of various projects, and the study of the performance and optimization of concrete structures in extreme environments has become increasingly important. The service environment of concrete buildings is more complex, and the environmental conditions and climate characteristics are different, and the influence mechanism and degree of influence on the mechanical properties and durability of concrete are also different. Therefore, the three characteristics of the plateau environment: large temperature difference, low air pressure, and low humidity, all have a great impact on the physical mechanics and chemical properties of concrete and then affect the engineering properties and service life of concrete.

In the plateau environment, the performance of concrete from preparation is affected by the surrounding environment. Low air pressure and large temperature differences may lead to densification problems such as high porosity, cracks and holes in the concrete structure after final hardening [2], and from the surface to the inside, the water inside the structure quickly migrates to

the outside, resulting in the rapid water loss of the whole concrete. At the same time, the alternating phenomenon of positive and negative temperature in the plateau frequently occurs in the year, which reduces the service life of concrete structures and affects the stability of building structures. In addition, the ambient air pressure in the plateau area is much lower than that in the plain area, and the low air pressure accelerates the evaporation of water in the concrete, which affects the durability and microstructure of the concrete structure such as the permeability resistance, water absorption, and frost resistance, and further reduce the service time of the concrete. Therefore, the analysis of the factors that affect the structural properties of concrete in the plateau environment is an important prerequisite for obtaining relevant solutions.

This paper summarizes and analyzes the mechanism and law of the influence of temperature, humidity and air pressure on the structural performance of concrete, expounds on their constitutive relationship, and explores from the perspective of the mathematical model to further analyze the comprehensive influence of the three on concrete. Finally, the problems and solutions encountered in the actual project are discussed and analyzed, and the prospects and difficulties of the future construction of the Qinghai-Tibet Plateau project are summarized.

2. Influence factors

The three major characteristics of a plateau environment are large temperature difference, low air pressure and low humidity. In order to study the comprehensive impact of these three factors on the performance of concrete structures, 40℃, 60% and 0.76kPa are generally taken as the critical values for the division of large temperature difference, low humidity and low air pressure. This chapter discusses the influence of three factors on the performance of concrete.

2.1. Low temperature

The climate environment in the plateau region is different from that in other regions, with low average temperature and more frequency of alternating positive and negative temperatures in a year, and the difference in temperature between day and night is much larger than that in normal areas, so the freeze-thaw cycle often occurs in concrete, which is one of the main reasons for the low service life of concrete infrastructure in the plateau region. The frost resistance of concrete refers to its resistance to the internal frost heave cracking of concrete under the alternating environment of positive and negative temperature, which is one of the important indexes to evaluate the durability of concrete. In addition, the temperature directly affects the hydration reaction process of cement [3], which makes concrete have certain structural defects when it is initially formed. Therefore, some scholars believe that temperature is the dominant factor affecting the development of concrete structures and performance.

Given the influence mechanism of temperature on concrete preparation, many scholars analyze the performance of concrete by changing the material used for concrete preparation. Zou [4] used mPCMs and other qualities to replace sand, thereby preparing mPCMs with different dosages, and measured the temperature control effect, mass loss rate, dynamic elastic modulus loss rate, strength loss rate and other parameters of different dosages of PCM under freeze-thaw environment. The results show that with the increase of freeze-thaw times, the quality loss of concrete first appears negative and then increases continuously. The dynamic elastic modulus decrease continuously and the porosity continue to increase.

In addition to the initial effects, low temperatures can also affect the durability of concrete during its later service. Ge [5] studied the change law of the mass loss rate, relative dynamic elastic modulus and durability coefficient of concrete under different preparation and curing environments through the rapid freeze-thaw cycle test of concrete, and concluded that the mass loss rate of several groups of concrete gradually increased with the increase of the number of freeze-thaw cycles. Through this research experiment, it can be concluded that the greater the number of freeze-thaw cycles, the greater the overall quality loss rate. This result shows that with the increase of the number of freeze-thaw

cycles, the damage inside the concrete continues to accumulate, thus destroying the concrete internal construct.

2.2. Low humidity

The decrease of internal humidity is one of the important reasons for concrete shrinkage [6]. The climatic conditions of low humidity and low pressure in the plateau area accelerate the water loss on the surface of the concrete, resulting in the rapid migration of internal water from the surface to the inside, and eventually the rapid water loss of the concrete as a whole. Therefore, studying the mechanism of water migration is also an important way to study the influence of humidity.

Aiming at the problem of water loss in concrete structures, many scholars have established a theoretical model to analyze the law of water migration and predict the shrinkage of concrete. Bazant and Najjar (1972) established a nonlinear diffusion equation to describe the water transport mechanism of concrete. Through further research, other scholars concluded that water migration exists in concrete at any stage, and causes humidity changes of internal components and affects their performance, especially for concrete structures with high durability requirements during service. Saeed (2019) further found on the basis of this rule that the water diffusion coefficient is an important parameter in the humidity migration model, which depends on pore water content, porosity and internal humidity field.

Water migration causes changes in the internal humidity of concrete. Through the parameter inversion experiment of the above model, it can be concluded that the influence of humidity on the stress of the statically indefinite beam is more obvious than that of the simply-supported beam. Therefore, in the construction of the plateau, the concrete structures of all kinds of Bridges have greater shrinkage due to low humidity. Further loss of water carbonization may be caused.

In many concrete shrinkage prediction models, humidity affects coefficient kRH [7-8] and has been added as an important parameter in the process of model establishment. The humidity influence coefficient of the more widely used shrinkage model is summarized:

Model ACI-2009:

$$k_{RH} = \begin{cases} 1 & RH \le O.4 \\ 1.4 - 1.2RH & 0.4 \le RH \le 0.8 \\ 3.0 - 3.0RH & 0.8 \le RH \le 1.0 \end{cases} \quad (1)$$

Model B3:

$$k_{RH} = \begin{cases} 1 - RH^3 & RH \le O.98 \\ 12.74 - 12.94RH & 0.98 \le RH \le 1 \\ 3.0 - 3.0RH & RH = 1.0 \end{cases} \quad (2)$$

Model GL-2000:

$$k_{RH} = 1 - 1.18RH^4 \qquad RH \ge 0.2 \quad (3)$$

Model CEB-FIP MC2010:

$$k_{RH} = \begin{cases} -1.15 \times (1 - RH^3) & 0.4 \le RH \le O.99 \\ 0.25 & RH > 0.99 \end{cases} \quad (4)$$

Where RH - the ambient humidity value.

In addition, through comparative study, it is found that the influence of humidity on concrete is different with different ages. At an early age, the environmental humidity mainly affects the surface part of the specimen. However, with the growth of age, the influence depth of environmental humidity increases, and the internal humidity gradually changes, so the shrinkage rate under different environmental humidity conditions in the post-age is significantly different.

2.3. Infrabar

It can be seen from formula (1-4) that the effect of air pressure on shrinkage rate is not considered in the existing concrete shrinkage prediction model. Some scholars [6] did further research on this basis and obtained the barometric influence coefficient of concrete shrinkage under different relative humidity conditions kp, which can be used as a supplement to the environmental coefficient in the concrete shrinkage model in the form of product, as shown in equation (5):

$$k_P = \begin{cases} -0.426P + 1.424 & RH = 20\% \\ -0.796P + 1.778 & RH = 60\% \end{cases} \quad (5)$$

Where k_P—the influence coefficient of air pressure on concrete shrinkage. P—Atmospheric pressure value.

The shrinkage performance of concrete is affected by ambient humidity, ambient air pressure and curing age. The dimensions of these three influencing factors are different, and the magnitude difference is obvious. Based on the above formula, the comparative experiment shows that, for the shrinkage performance of concrete, each influencing factor is ranked according to the degree of influence: ambient humidity < curing age < ambient air pressure. It can be seen that the influence of ambient air pressure on the shrinkage of concrete is obviously greater than that of humidity.

Ambient air pressure also affects the durability of concrete structures. Durability refers to the ability of concrete to resist the effects of environmental damage and to ensure its long-term performance and visual integrity [9]. The decrease in durability leads to the insufficient bearing capacity of the structure, which makes the building structure fail. Some scholars have tested the macro-durability, morphology and pore structure of concrete under different pressure conditions, and reached a conclusion: low-pressure conditions accelerate the water loss in concrete, but also improve the water absorption rate of concrete; At the same time, low-pressure accelerates the loss of water in concrete and increase the surface peeling quality of concrete in the process of salt-freezing cycle.

Based on this, some scholars compare the compressive strength of concrete under low pressure and normal pressure value, and also deal with the influence of air pressure on concrete structure. The experiment shows that the compressive strength of concrete under the standard curing environment of low pressure is relatively high, and it can be further concluded that the strength of concrete prepared in the plateau environment is higher than that in the plain environment.

2.4. The comprehensive influence of plateau climate

The combined effect of low humidity and low pressure in the plateau area could accelerate the evaporation of water on the surface of the concrete, increase the difference in internal and external humidity, and accelerate the migration of internal water to the surface, thus aggravating the reduction of internal humidity of the concrete. Under such conditions, the hydration reaction of the cement is affected, and the compactness and mechanical properties of the concrete may also be reduced. Some scholars carried out variable experiments on low-humidity and low-pressure environment simulation boxes and observed the changes of concrete specimens by strictly controlling temperature and air pressure. The test results show that low humidity and low pressure increase the shrinkage of concrete, and the influence of pressure is greater than that of ambient humidity.

In addition, the plateau area "temperature drop", "heavy rain" and "cloud cover" these three common drastic weather. Some scholars take the concrete column as a typical analysis component [4] and calculate the stress on the surface and inside of the concrete column for stress analysis by simulating different drastic weather conditions in the plateau region. The experimental results show that the surface tensile stress of concrete column is the largest in "heavy rain" weather, followed by "sudden cooling" weather, and the least in "cloud cover" weather. In addition to the "cloud cover" weather does not exceed the tensile limit value of concrete, "temperature drop" and "rain" weather surface cracking risk is greater. Therefore, under the climate of drastic change in the plateau, rain causes uneven stress distribution in the internal structure of concrete, resulting in tension cracking.

3. Solutions

Through the research and experiments of domestic and foreign scholars, we can conclude that temperature, humidity and air pressure could cause different degrees of damage to concrete structures. All three could change the structure of concrete from the inside, and further cause the durability of concrete from the macro level. At present, the effects of temperature, humidity and air pressure on concrete structures have been well ascertained. According to the research results, some scholars have put forward relevant measures.

At the macro level, low air pressure has a great influence on the strength and shrinkage of concrete, and its microcosmic manifestation is that the porosity of concrete structure increases with the decrease of air pressure. Based on this, some scholars have explored and found that under the condition of low pressure, the change of microstructure and porosity in concrete could lead to the difference in ultrasonic wave velocity in concrete. Therefore, aiming at different filling processes, a method was proposed to evaluate the filling compactness of CFST by measuring ultrasonic wave velocity [10].

Scaling component method. During the construction of the real bridge, a scaled concrete-filled steel tube model with the same perfusion process was prepared and an ultrasonic wave velocity test was carried out to obtain the ultrasonic wave velocity vm of the scaled concrete-filled steel tube model, and its compactness index could be calculated by equation (Eq. 6a).

Numerical simulation analysis. Under the conditions of known air pressure and concrete strength, the ultrasonic wave velocity of the dense solid is calculated according to equation (Eq. 6) and set in the numerical model, and then a reasonable porosity can be set to conduct numerical simulation analysis and obtain the density index.

Empirical formula method. Under the conditions of known air pressure and concrete strength, the compactness index can be calculated by equation (Eq. 6b) based on the empirical equation (Eq. 7).

Among them, the scaled component method is closer to the actual situation, and the numerical simulation analysis method can be used to explore the effect of vs, pores and specific defects on the ultrasonic wave velocity of CFST, and the empirical formula method is the most convenient and quick (Eq. 8). In practice, appropriate methods can be selected for compactness evaluation according to different known conditions and real working conditions.

$$\alpha=\begin{cases}\dfrac{d}{d'}\cdot\dfrac{\frac{D'}{v_m}-\frac{2b'}{v_g}}{\frac{D}{UPV_T}-\frac{2b}{v_g}} & \text{(a)}\\[2ex] \dfrac{d}{\gamma\cdot\left(\frac{D}{UPV_T}-\frac{2b}{v_g}\right)} & \text{(b)}\end{cases} \tag{6}$$

$$\mathrm{UPV}=27.80\lambda\ (\mathrm{fcu}-29.14)+4422 \tag{7}$$

$$\mathrm{vs}=\frac{UPV-2853}{0.852(1.17-0.17\lambda}+2898 \tag{8}$$

At the same time, in order to increase the frost resistance of concrete, some scholars have found that the concrete performance can be changed by adding dosage to the concrete material. According to the experiments of Zou [4], the dynamic elastic modulus of PCM gradually increases with the increase of the dosage of mPCMs (5℃), which indicates that mPCMs (5℃) can effectively strengthen the freezing resistance of concrete, while mPCMs at other degrees of Celsius cannot achieve the ideal effect. This provides excellent technical support for practical projects.

4. Conclusion

According to the influence of the climatic characteristics of the Qinghai-Tibet Plateau on the performance of concrete structures, this paper studies and analyzes the low temperature, low humidity and low pressure respectively, and summarizes as follows.

Temperature could cause the freeze-thaw cycle of concrete, and with the increase of the number of freeze-thaw cycles, the damage inside the concrete continues to accumulate, which damages the internal microstructure of concrete from preparation to later service. Low humidity could cause water migration in concrete, which is easy to cause shrinkage and carbonization of concrete. For concrete of different ages, humidity has different reaction results. Based on this, the prediction model of concrete water loss shrinkage was established in related studies, and the influence coefficient of humidity km was proposed as an important parameter of the water loss model. Low air pressure can reduce the shrinkage and durability of concrete structures. Research shows that low air pressure can also cause water loss in concrete, so based on the water loss model, some scholars put forward a pressure contraction model to predict the shrinkage of concrete. Low air pressure and low humidity increase the loss of water inside the concrete structure, resulting in the shrinkage and carbonization of concrete. According to the comparative test, the effect of air pressure on the concrete structure is greater under the same conditions.

The sudden change of plateau climate, such as "temperature sudden change", "heavy rain" and "cloud cover", causes the internal structure of concrete to be stressed unevenly, resulting in the cracking of concrete on the macro performance. Based on theoretical research, some scholars have further discussed the use of ultrasonic waves to detect the compactness of concrete in practical engineering and put forward three methods: the method of scaling members, the method of numerical simulation and the method of empirical formula, which have played an important role in practical engineering. Further, some scholars proposed to change the performance of concrete structures by changing concrete materials, in which the addition of mPCMs has a significant improvement on concrete structures. This provides a theoretical basis for practical engineering.

References

[1] Wen Jun. Analysis of the environmental background conditions for the development of transportation in the Qinghai Tibet Plateau[J]. China Tibetology, 1999, 12(4): 30-48.

[2] Chen Zheng, Chen Ben, Pang Zichao, Wu Changjie. Study on ultrasonic nondestructive testing of concrete structure compactness in Tibetan Plateau environment[J]. Engineering Mechanics, 2023,40(06):1-8.

[3] CEB-FIP. CEB-FIP Model Code 2010 [S]. Mumbai, India, 2010: 21-51.

[4] Zou Y R. Study on frost resistance and damage constitutive relationship of concrete with different phase change temperature gradients [D]. Xiking School, 2023. DOI: 10.27831 /, dc nki. Gxjxy. 2022.000188.

[5] Ge X. Study on the influence of Plateau climate conditions on concrete properties and cracking mechanism [D]. Harbin Industrial University, 2020. DOI: 10.27061 /, dc nki. Ghgdu. 2019.000058.

[6] Wu Haijun, Chen Airong. Research on Durability Design Method of Bridge Structure [J]. China Journal of Highway and Transportation, 2004, 3(7): 57-65.

[7] Bazant Z. P., Panula L. Practical prediction of time-dependent deformation of concrete [J]. Materials and Structures, 1978(9): 307-328.

[8] ACI Committee. Prediction of Creep, Shrinkage and Temperature Effects in the Concrete Structures [J]. American Concrete Institute, 1997:193-300.

[9] Chen Zheng, Chen Ben, Zheng Jiilian et al. Evaluation method of core concrete compactness of concrete-filled steel tube under low pressure in Qinghai-Tibet Plateau [J]. Journal of Civil Engineering, 2021, (8): 1-13. DOI: 10.15951 / j.t. MGCXB. 2021.08.002.

[10] Double DD, Hellawell A, Perry SJ, et al. The hydration of Portland cement[J]. Proceedings of the Royal Society of London A Mathematical and Physical Sciences, 1978, 359(1699): 435-451.