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Overview of the Influence of Static Water Saturation on The Mechanical Properties of Concrete

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Abstract: This paper reviews a series of experimental and theoretical research results on the influence of existing pore water on the static and dynamic properties of concrete. This paper summarizes the current experimental research methods and conclusions, analyzes the influence mechanism of moisture content and loading speed on the elastic modulus and strength of concrete, and points out that the influence of pore water on concrete properties should be the result of the joint action of multiple factors.

Keywords: Concrete, hydrostatic saturation, static mechanical properties, dynamic mechanical properties.

1. Introduction

With the vigorous development of coastal, water conservancy, underground and other engineering construction, concrete structures play an increasingly important role in the water environment. Whether it's piers, dams, bridge foundations, artificial channels, new ports, or even water intakes in established reservoirs and natural lakes, these structures are inevitably submerged in water for long periods of time. In this environment, under the pressure of water, the voids inside the concrete are gradually filled with water, reaching a state of saturation. In the static state, the pore water in concrete will affect its mechanical properties [1-4]. When the water content in the concrete continues to rise, the mechanical performance of the concrete structure under the complex stress state is significantly different from that of the concrete under standard curing conditions. In an aqueous environment, concrete has to cope not only with the upper load and external pressure, but also with the pore water pressure, which makes the stress state to which it is subjected to particularly complex. In order to correctly understand the mechanical properties and dynamic characteristics of concrete structures in the water-saturated state, and ensure the structural safety of water-saturated concrete under different static and dynamic loads, scholars at home and abroad have carried out a large number of studies on the properties and mechanisms of water-saturated concrete materials.

2. Effect of Water Saturation on The Static Mechanical Properties of Concrete

2.1. Effect of water saturation on the elastic properties of concrete

After extensive experimental exploration, we have come to the conclusion that the water content of concrete is positively correlated with its elastic modulus when the porosity is consistent. This is because water is considered an incompressible liquid compared to air, so the pore water in concrete is virtually non-deforming when subjected to stress, resulting in a higher modulus of elasticity for concrete with higher water content.

Zhang et al. [5] took three different strength grades of concrete, C15, C20, and C30 as research samples, and deeply discussed the variation of the elastic modulus of concrete under six different humidity conditions. It is found that the elastic modulus of C15, C20 and C30 concrete increases with the increase of water saturation, and the elastic modulus of saturated concrete increases by 1.18, 1.19 and 1.24 times compared with dry concrete, respectively, as presented in Fig. 1. At the same time, Liu et al. [6] also experimentally verified the effects of different moisture content on the elastic modulus of concrete. It is found that with the increase of moisture content, the elastic modulus of concrete also shows an increasing trend, and the elastic modulus of fully saturated concrete is increased by 30% compared with that of fully dry concrete. There are pores and microcracks in the concrete in the dry state, and these structures play a softening effect, resulting in a relatively small elastic modulus, and the presence of free water can effectively alleviate this softening effect. In addition, Wang et al. [7] considered the influence of hydration and water viscosity on the elastic modulus of wet concrete in the later stage of cement, and analyzed the influence of water on the elastic modulus of concrete by using the Mori-Tanaka model.

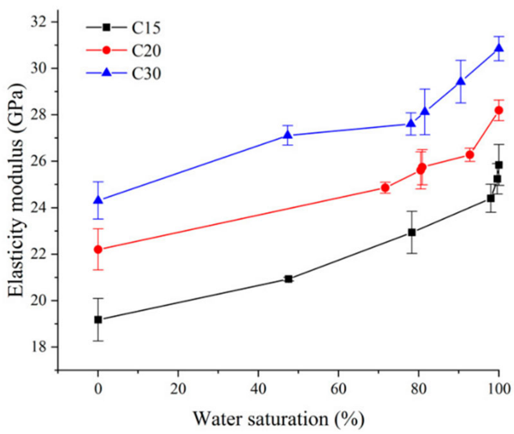

Figure 1. The elasticity modulus with different saturations (S.D. as error)

From the above research, it can be seen that due to the in-depth study of the influence of pore water on the elastic modulus of concrete, and the development of the elastic theory of isotropic composites in mesomechanics, the elastic modulus of concrete under various water content can be analyzed more accurately.

2.2. Effect of water saturation on the strength of concrete

Concrete as a typical porous dielectric material, has an intricate internal structure, including various capillaries and pores. There are various reasons for the formation of these pores, some are the bubbles left due to operational errors during the pouring process, some are the natural pores of the internal structure of the aggregate itself, and some are the gel pores inside the cement slurry and the pores formed at the contact between the aggregate and the cement slurry. When concrete is left in water for a long time, the water will gradually penetrate into these voids under the action of water pressure. Due to the influence of static action, the penetration of this moisture will inevitably lead to certain changes in the compressive properties of the concrete.

Cadoni et al. [8] first cured the concrete at a specific temperature for 90 days, then dried the concrete and completely submerged a portion of the specimen in water for a period of time. After that, they tested the compressive strength of the dried specimens and immersed them in water. The experimental data show that the compressive strength of concrete is 3.28 MPa in the dry state, and it decreases to 3.02 MPa after immersion in water, which means that the compressive strength of concrete is reduced by 7.62% due to water immersion. Song et al. [9] discussed in depth the effects of different moisture contents on the compressive strength, splitting tensile strength and stress-strain relationship of concrete. They found that the moisture content of the concrete increased rapidly at the beginning as the soaking time increased, then slowed down until it was almost saturated at 120 hours. At the same time, the compressive strength and splitting tensile strength of concrete both showed a decreasing trend with the increase of moisture content, and this effect was particularly significant. In the fully saturated state, the compressive strength and splitting tensile strength of concrete decreased by 36.35% and 32.36% respectively compared with those in the dry state. In addition, they found that lower strength grades of concrete were more sensitive to moisture content. With the increase of moisture content, the uniaxial compressive strength, splitting tensile strength and peak strain of concrete decreased, while the slope of the rising section of the stress-strain curve increased gradually, as presented in Fig. 2. Yang et al. [10] explored the variation of water content on concrete strength by soaking concrete for different times. It is concluded that with the increase of immersion time, the water content increases, showing a trend of rapid growth in the early stage and slow growth in the later stage, and the compressive strength of concrete decreases with the increase of water content, and the compressive strength of saturated concrete is only 75% compared with that in the dry state. Wang et al. [11-13] conducted uniaxial compressive tests to explore the changes in mechanical properties of saturated and dry concrete at quasi-static and medium and low loading rates. The results show that under quasi-static loading, the free water in the pores and cracks is similar to the "wedge" effect of the wedge, which accelerates the propagation of microcracks and reduces the strength of saturated concrete.

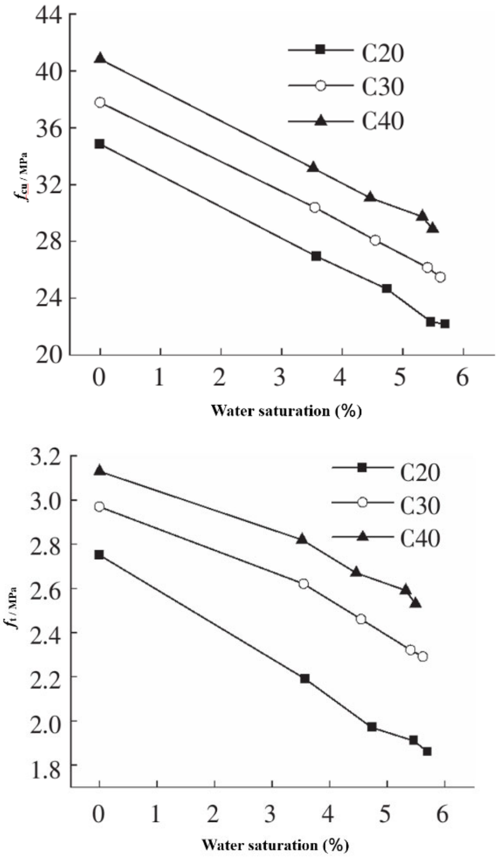

Figure 2. Compressive strength and splitting tensile strength of concrete with different moisture contents

In summary, the moisture content in concrete has a significant weakening effect on its compressive strength. Behind this phenomenon, the key lies in the interaction between moisture and the internal structure of concrete. With the increase of moisture in the concrete, the free water content in the interface transition zone also increases. This will inevitably lead to an increase in the water-cement ratio in the interface transition zone, which in turn will lead to a decrease in the force capacity of the region. Therefore, when concrete is exposed to external pressure, its compressive resistance is weakened.

2.3. Effect of water saturation on the multiaxial properties of concrete

Due to the long-term exposure of concrete structures to water and continuous operation under the action of water pressure, it is often in a complex state of multiaxial stress. Compared with the variation law of mechanical properties under uniaxial compression, the concrete under this multiaxial stress state shows a completely different variation law. Under the action of multiaxial stress, the performance of concrete is not only affected by pressure, but also by the combined action of stress in other directions, resulting in its strength, deformation and other characteristics are different from those of uniaxial compression.

Hu et al. [14, 15] performed conventional triaxial tests on concrete in natural and water saturated states, and studied the changes of peak stress, peak strain and elastic modulus of concrete under four strain rates and three confining pressures. The results show that under the same confining pressure and the same strain rate, compared with the peak stress of natural humidity concrete, the value of water-saturated concrete is small, and the elastic modulus is large, and the peak strain change of concrete under the two conditions is not obvious. The effect of confining pressure greater than strain rate on the compressive properties of wet concrete. Zhang et al. [16-19] conducted experimental studies on concrete in dry and saturated states, and the test results show that when the confining pressure increases, the compressive strength of the concrete in the two states increases significantly, indicating that the confining pressure effect is more obvious; when the confining pressure is the same, compared with the dry concrete, the compressive strength decreases, the elastic modulus increases, the peak strain decreases, and the deformation capacity becomes stronger. Finally, the strength failure criterion and constitutive relationship equation of saturated underwater concrete are established, as presented in Fig. 3. Vu et al. [19] studied the effect of saturation ratio on the properties of concrete under triaxial compressive loads, and concluded the constitutive behavior of concrete and its dependence on water saturation.

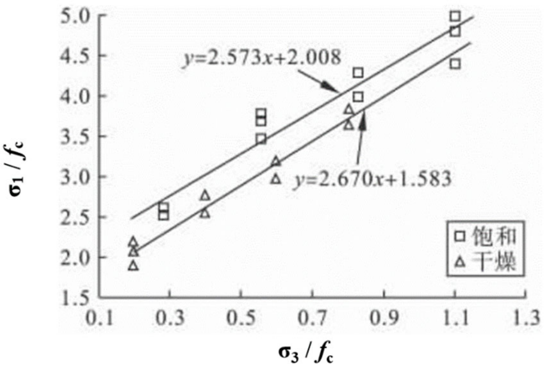

Figure 3. Linear fitting diagram of compressive strength and confining pressure

In summary, scholars at home and abroad have carried out experimental studies on the effect of free water on the properties of concrete under multiaxial loading conditions, and the compressive strength of saturated concrete under multiaxial loading conditions is significantly improved, the elastic modulus increases, the peak strain decreases, and the deformation ability becomes stronger.

3. Effect of Water Saturation on The Dynamic Mechanical Properties of Concrete

In aqueous environments, concrete-like materials are often subjected to dynamic loads such as earthquakes, shocks, and explosions. Due to factors such as the Stefen effect and pore water pressure, the pore free water in concrete exhibits a completely different mechanical response under dynamic load than under static load. At present, some scholars have carried out relevant research in this field, and are committed to in-depth exploration and understanding of the mechanical behavior of concrete under dynamic loads, in order to improve the stability and safety of concrete structures in complex environments.

Zhang et al. [20] carried out dynamic impact tests on dry and saturated concrete, and the data results proved that there is a critical strain rate between dry and saturated concrete, and the dynamic strength of wet concrete is smaller than that of dry concrete when it is less than the critical strain rate, and the opposite is greater. Forquin et al. [21, 22] found that wet concrete has a more obvious strain rate sensitivity when the strain rate is higher. Gary et al. [23] suggested that the main reason for the increasing trend of the dynamic strength of concrete is the inertia effect when the strain rate is high, and the viscous effect of water in wet concrete also has a positive effect on the dynamic strength.

In summary, under the condition of quasi-static loading, the development speed of the crack in the concrete is slow, and the free water in the crack can reach the tip of the crack, but when loading quickly, due to the rapid expansion speed of the crack, the free water in the crack is not easy to reach the tip of the crack, and the free water is not easy to be compressed, which is equivalent to filling the pores in the concrete, making the concrete more compact, and enhancing the dynamic mechanical properties of the concrete.

4. Conclusion

The influence of environmental water on the strength of concrete is a very complex problem, and a large number of experimental studies and theoretical analysis results show that: 1. At a low loading rate, the crack propagation is relatively slow, which makes the free water in the crack easily flow to the crack tip and has a splitting effect on it. This action actually promotes the propagation of cracks, which leads to a decrease in the strength of the saturated concrete. However, under the action of high strain rate, the pore water is not easy to reach the crack tip, but can inhibit the development of cracks, which has an enhanced effect on the mechanical properties of concrete. 2. Because concrete is a porous medium material, due to the long-term saturation of water, when the external water enters the concrete through the pores, because the concrete is damaged from the aggregate part and interface, the aggregate in the concrete will be softened because of the long-term action of water, and the strength of the concrete will be reduced because the softening effect has been existing with the extension of time.

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