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Study on wave velocity characteristics and compressive strength of concrete under different water pressure

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Abstract: *In order to study the internal damage and static compressive strength of concrete under different water pressures, the wave velocity test and compressive test were carried out by NN-4B non-metallic ultrasonic testing analyzer and electro-hydraulic servo testing machine. The test results show that the high water pressure of concrete has an adverse impact on the development of its internal structure, and with the increase of high water pressure level, the slower the longitudinal wave passes through the specimen, the more serious the damage and deterioration of concrete, and the compressive strength decreases gradually with the increase of water pressure.*

Keywords: *concrete, water pressure, wave velocity, compressive strength*

1. Introduction

With the rapid development of social economy, concrete is more and more widely used in water environment, such as pier, dam and other concrete buildings. However, concrete is a multiphase composite material, which has defects such as micro pores and micro cracks. A certain hydraulic gradient will be generated in the water environment to form a seepage field. Under the action of seepage pore water pressure, the pore water will produce hydraulic splitting effect, so as to accelerate the expansion and penetration of concrete micro cracks, damage the whole concrete and shorten the service life of the structure.

Most scholars mainly focus on the influence of concrete internal humidity on concrete mechanical properties, and there is little research on the influence of high water pressure environment at present. Wang [0] carried out dynamic bi-directional compression tests on cubes under dry and saturated conditions. The results show that the compressive strength of dry and saturated concrete increases with the increase of strain rate and static compressive strength of saturated concrete is lower than that of dry concrete while the dynamic strength of saturated concrete is higher than dry concrete. Li[2] studied the influence of water content on the compressive strength of concrete under natural and standard curing through tests. The tests found that the influence on the compressive strength of concrete is not obvious when the water content is lower than 1%. With the further increase of water content, the compressive strength of concrete gradually decreases, and the reduction speed of the compressive strength of specimens under natural curing is faster than that under standard curing. Chen[3] studied the influence of internal pores and pore water of concrete on its mechanical properties in wet environment by using micromechanical analysis method, divided the pores in concrete into active pores and inactive pores, and considered that only active pores can be filled with water. Wang[4] carried out a series of studies on mechanical properties of concrete in wet environment by means of micro-mechanical analysis method. According to crack growth rules of wet concrete during test loading, it was shown that pore water in wet environment can reduce friction resistance which prevents crack growth and aggravate damage to concrete. Gorzelanczyk[5] studied the destruction process of concrete in different humidity environments by acoustic method and established the relationship between water content and peak stress of concrete. The test shows that the peak stress of saturated concrete is lower than that of dry concrete, while the critical stress is almost the same. Ranjith[6] found that when concrete is completely wetted, its strength is related to the loading rate, which is significantly lower than that of dry specimens at the same loading rate.

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In conclusion, with the increase of moisture in concrete, the strength of concrete will gradually decrease, but the research on mechanical properties of concrete under pressurized water environment is insufficient. In this paper, static compression tests of concrete under different water pressures (0, 1, 5 and 10 MPa) and different action times (1d, 7d and 14d) are carried out to provide theoretical basis for rational design and safe use of concrete structures in service under pressurized water environment.

2. Test Overview

2.1 Test equipment

The test equipment consists of three parts: Model NN-4B non-metallic ultrasonic testing analyzer, pressurizing equipment simulating water environment and electro-hydraulic servo tester, as shown in Fig. 1, Fig. 2 and Fig. 3.

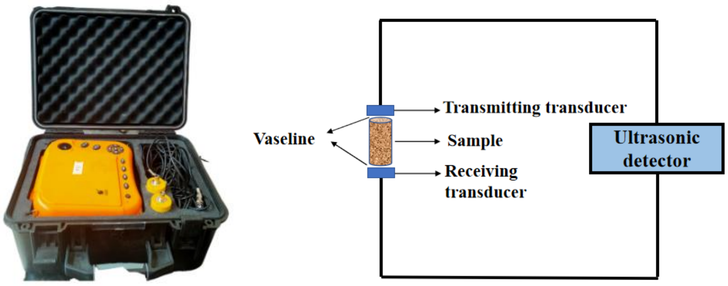

Fig. 1 Model NN-4B non-metallic ultrasonic testing analyzer

Fig 2 Pressure tank

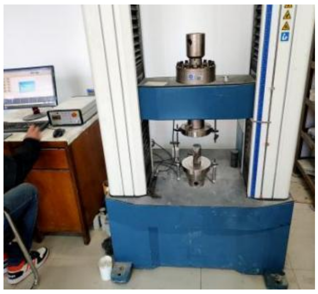

Fig 3 Electro-hydraulic Servo Tester

2.2 Sample preparation

According to the relevant stipulations and requirements of the *Code for Design of Mix Ratio of Common Concrete* (JGJ55-2011), the concrete mix ratio was calculated. According to the mix ratio (kg/m^3), it was cement: stone: sand: water: NF-F=350:1190:667:195:70 and cast into 150mm.×150mm×150 mm cubic standard specimen. The cement used in the test is conch brand P.O42.5 II ordinary portl and cement. The aggregate was basalt gravel with particle size of 5-15mm, and the fine aggregate was river sand with hard texture, good quality and fineness modulus of 2.31.

After 240 days, the concrete specimen was processed into a Φ50mm ×h 100mm cylinder through multiple processes such as coringed, cut ,polished and so on.In which The unevenness of the upper and lower end faces of the core sample shall not exceed 0.05mm, and the deviation between the height and the diameter of the upper and lower ends shall not exceed 0.3mm.Finally, the processed specimen was placed in the pressure tank for high water pressure treatment, and the next operation can be carried out after the expected time was reached.

3. Analysis of test results

3.1 Wave velocity test result analysis

First the height of the specimen is measured after the action of water pressure and the average value of three measurements is taken; Start the ultrasonic tester and set the parameters; The transducers of the

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ultrasonic detector are placed on both ends of the specimens which have been coated with Vaseline evenly; The transducers and the specimens should be placed vertically and centrally during the test; Constant pressure resulting from the gravity of the transducer can be used to ensure tight coupling and effectively avoid errors caused by unequal application of force. Adjust the measuring point on waveform to the initial point of waveform and read the time value of ultrasonic sound [7].Formulas are used to calculate the longitudinal wave velocity and velocity decrease of concrete specimens under different water pressures. The results are shown in Table 1.

$$C=\frac{h}{t_s}\times 10^3$$

$$A=1-\frac{C}{C_0}$$

Formula: C —— Longitudinal wave velocity of the specimen, m/s;

h —— The height of the specimen, mm;

t_s —— Time value of ultrasonic sound, μs;

A —— Velocity drop, %;

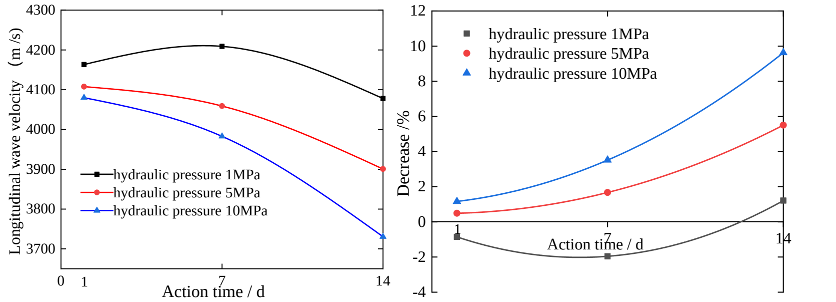
C_0 —— Sample velocity under saturated condition (benchmark group), m/s;

C —— Corresponding velocity under different water pressure and different time,m/s;

Table 1 Sample velocity at high water pressure

Group	Sample height h /mm	Time value of wave and sound/μs	Average velocity C(m/s)	Amplitude reduction A/%
Benchmark group	99.90	24.2	4128.1	0
1MPa / 1d	99.92	24.0	4163.3	-0.853
1MPa / 7d	99.75	23.7	4208.9	-1.957
1MPa / 14d	99.91	24.5	4078.0	1.212
5MPa / 1d	99.82	24.3	4107.8	0.4918
5MPa / 7d	99.95	24.6	4059.0	1.674
5MPa / 14d	99.86	25.6	3900.8	5.506
10MPa / 1d	99.96	24.5	4080.0	1.165
10MPa / 7d	99.97	25.1	3982.9	3.517
10MPa / 14d	99.98	26.8	3730.6	9.627

In order to further reflect the influence of different high water pressure levels and action time on the average wave velocity of concrete, the variation curves of concrete wave velocity under the duration of different high water pressure levels are drawn.



(a)Average longitudinal wave velocity (b) Amplitude of wave velocity drop

Fig. 4 Curve of wave velocity and action time under different water pressure

As can be seen from Fig. 4 (a), the longitudinal wave velocity of concrete sample increases first and then decreases with the increase of water pressure action time when the applied water pressure is 1MPa.In which the average wave velocity after 7 days of water pressure action is 4208.9m/s, which increases by 45m/s compared with that after 1 day of water pressure action. But decreases by 130.9m/s compared with that after 14 days of water pressure action. It shows that the damage and deterioration degree of concrete internal structure is not obvious when the water pressure level is low and the action

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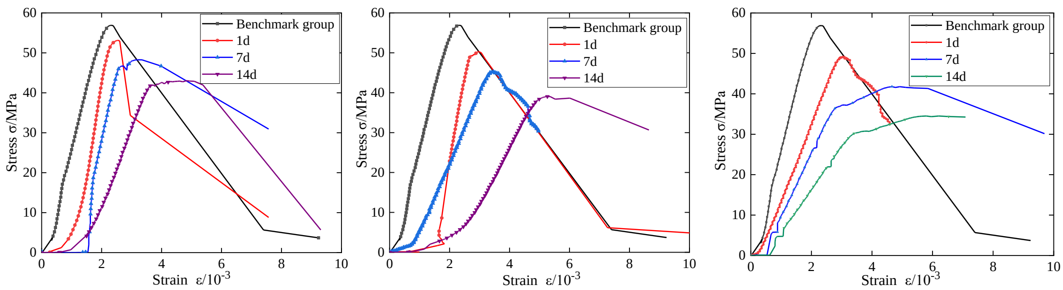
time is short. However with the extension of water pressure duration, the damage and deterioration of concrete internal structure is more obvious; When the water pressure of 5MPa and 10MPa is applied, the average wave velocity of concrete samples shows a downward trend with the continuous increase of water pressure action time, and the downward slope gradually increases. Compared with the action time of 1d, the longitudinal wave velocity of 5MPa water pressure treated samples decreases by 48.8m/s and 207.8m/s with the increase of action time, With the increase of action time, the longitudinal wave velocity of 10MPa high water pressure treated specimen decreases by 97.1m/s and 349.4m/s, which shows that the high water pressure of concrete has an adverse impact on the development of its internal structure, and with the increase of high water pressure level, the slower the longitudinal wave passes through the specimen, that is, the more serious the damage and deterioration of concrete.

Figure 4 (b) shows the fitting curve of the relative decline of concrete samples with the increase of water pressure action time under different water pressure levels. Under the water pressure of 1MPa, the average wave velocity drop of concrete sample first decreases and then increases with the increase of action time. The decline is negative at 1d and 7d, the reason is that water pressure of 1MPa is small, and a certain hydraulic gradient is formed between the inner and outer surfaces of concrete sample, so that the pressure water makes the inner part have seepage movement under the saturated state and the internal pores are expanded. Thus, the ultrasonic signal is filled with water again, the ultrasonic signal is filled more in the concrete and the propagation time in the water becomes shorter, resulting in the increase of the average longitudinal wave velocity in the early stage. The internal pores of the sample are broken by the water pressure and develop into micro cracks with the extension of the action time of the water pressure. The ultrasonic signal is scattered or reflected through the micro crack interface, and the time to reach receiving transducer becomes longer. Therefore, the average wave velocity of longitudinal wave decreases in the later stage, indicating that increase of wave velocity in the earlier stage is related to the change of water content in concrete[8-9]. However, the average wave velocity decrease of concrete samples under 5MPa and 10MPa high water pressure gradually increases with the increase of water pressure action time, and the longitudinal wave velocity decrease rate and amplitude of concrete samples damaged by 10MPa water pressure are significantly higher than those of concrete samples damaged by 5MPa water pressure. For example, after 14d of water pressure 5MPa, the longitudinal wave velocity decrease of concrete is close to 5.5%, After being subjected to water pressure of 10MPa for 14 days, the decrease of longitudinal wave velocity of concrete is 9.63%, which is 1.75 times higher than that of 5MPa water pressure, indicating that the greater the water pressure level, the greater the microcrack propagation rate of internal structure of concrete, the lower the compactness, and the greater the decrease of longitudinal wave velocity.

3.2 Stress-strain curve

The static compressive stress-strain curves of concrete samples under different water pressures are obtained through experiments. In order to compare and analyze the effects of water pressure grade and water pressure duration on concrete, each coordinate system is unified.



(a)1MPa (b)5MPa (c)10MPa

Fig. 5 Stress-strain curve

It can be seen from Fig. 5 (a), (b) and (c) that the curve change trend of concrete under different water pressure and action time is basically the same. The curve after water pressure (1MPa, 5MPa and 10MPa) treatment is generally lower than the stress-strain curve of concrete in the reference group. With the increase of water pressure action time, the pre peak stress slows down with the increase of strain and the post peak stress drop slows down, this shows that the concrete is deteriorating continuously in the water pressure environment. The main reason is that the water pressure damages the micro pore structure of the concrete sample, weakens the strength of the concrete matrix material, reduces the brittleness and enhances the ductility.

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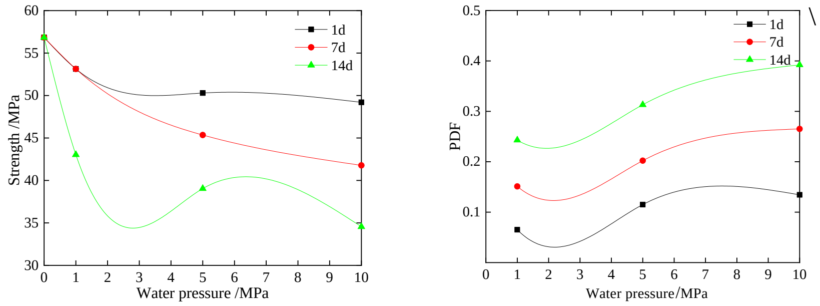
3.3 Analysis of compressive strength results

In order to further express the influence law of water pressure on concrete strength, (pressure decay factor, PDF) is introduced. The pressure decay factor PDF of concrete strength is defined as the difference between the compressive strength value of concrete strength under each water pressure and the water pressure of 0MPa divided by the strength under water pressure of 0 MPa. Fig. 6 shows the variation law of uniaxial compressive strength of concrete samples under different water pressures. Fig. 6 (a) shows the variation curve of concrete compressive strength with the increase of water pressure and Fig. 6 (b) shows the variation of pressure attenuation factor PDF with water pressure.



(a) (b)

Fig. 6 Relationship between strength and PDF and water pressure curve

Figure 6 (a) can be seen that the applied water pressure has an obvious impact on the compressive strength of concrete. With the increase of water pressure, the compressive strength of concrete decreases accordingly. When the same water pressure action time is 1d, the applied water pressure increases from 1MPa to 10MPa, and the strength decreases from 53.13mpa to 43.03mpa, with a decrease of 19%. When the water pressure action time is 14d, the concrete strength with the applied water pressure of 1MPa decreases by 14.65mpa, with a decrease of 29.8%.Compared with 10MPa, the decline rate of compressive strength is accelerated at this time, it shows that the existence of external water pressure weakens the role between concrete particles. The higher the water pressure, the faster the development of internal fine cracks, which shows the reduction of concrete material strength from the macro [10]. It can be seen from figure (b) that the pressure attenuation factor of strength increases nonlinearly with the increase of water pressure. The greater the water pressure is, the faster the growth rate of the pressure decay factor (PDF) of the strength is. When the same water pressure action time is 1d, the pressure decay factor (PDF) of the strength is 0.065, 0.115 and 0.134 respectively with the increase of water pressure; When the same water pressure action time is 14d, the applied water pressure increases from 1MPa to 10MPa, and the pressure attenuation factor PDF of strength increases by 0.07 and 0.149 from 0.243. This shows that the existence of high water pressure has an adverse impact on the load-bearing effect of concrete and the development of its later mechanical properties. With the increase of the applied load level, the damage deterioration is the more serious, which is more obvious in the aspect of uniaxial compressive strength.

4. Conclusion

In this paper, the pressure head is applied to the outside of the concrete specimen for a certain time to form a certain seepage movement process inside the concrete. The influence of water pressure on the wave velocity characteristics and compressive strength of concrete is studied by changing the water pressure and time. The main conclusions are as follows:

1) Through the wave velocity test, it is found that when the water pressure level is low and the action time is short, the damage and deterioration degree of the internal structure of concrete is not obvious; When the water pressure of 5MPa and 10MPa is applied, the average wave velocity of concrete samples shows a downward trend and the decreasing range is larger and larger with the continuous increase of the action time of water pressure.

2) Through the compression test, it is found that the strength of concrete decreases under the action of water pressure, and the greater the decrease of strength with the increase of water pressure, although this phenomenon is more obvious with the extension of the action time of water pressure.

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