Experimental research on cyclic impact load of concrete during curing period

Chen Chen¹, Liu Xiaoyi², Yu Jianxin³*, Liu Pan⁴, Guo Min⁵

¹School of Civil Engineering, Henan Polytechnic University Jiaozuo, P.R. China
²China National Chemical Engineering Heavy-Mechanized Corporation Ltd Beijing, P.R. China
³School of Civil Engineering, College of Safety Science and Engineering, Henan Polytechnic University Jiaozuo, P.R. China
⁴China National Chemical Engineering Heavy-Mechanized Corporation Ltd, Beijing, P.R. China
⁵The Second Construction Company Ltd of China Construction Second Bureau, Zhengzhou, Henan 450000, P.R. China

*Corresponding author: jianxinyu@hpu.edu.cn

Abstract. In order to study the influence of cyclic impact load on the compressive strength of concrete during the curing period, we used a self-made drop-weight impact test device to conduct a daily impact test on C40 concrete specimens with a curing period of 28 days. At the same time, the longitudinal wave velocity test of the test block before and after the impact was carried out, and the 28-day uniaxial compressive strength of the concrete test block was finally measured. The results show that the cyclic impact load during the curing period will cause internal damage to the concrete, and the uniaxial compressive strength is significantly reduced; the acoustic wave test results show that the damage of the concrete under the impact energy of 11.76kJ, 5.88kJ, 7.84kJ, and 8.82kJ is 0.035, 0.022, 0.031, 0.031. The uniaxial compressive strength values after 28 days decreased by 11.93, 4.68, 7.6, 10.23 MPa. There is a positive correlation between impact load, damage and reduction in compressive strength.

1. Introduction

Concrete is currently the most widely used material in civil engineering structures. In the long-term use process, in addition to being subjected to constant loads and live loads, it may also encounter accidental loads such as collisions and impacts. When the impact energy is large, it will cause the structure to collapse and fail, but in many cases, the impact energy is small, which is not enough to cause the structure to completely collapse. But it will cause a certain amount of damage inside the concrete structure, reducing its bearing capacity and dynamic characteristics change.

Researchers at home and abroad have studied the basic mechanical properties of concrete under dynamic load, such as elastic modulus, compressive strength, tensile strength and peak strain, and analyzed the difference with static. Li Xiangyun⁶ obtained the failure mode and strain response of concrete short columns wrapped with different layers of carbon fiber through the drop weight test, and obtained the relationship between the maximum impact force of the drop weight and the static bearing capacity of the short column. Krauthammer⁷ used a drop-weight testing machine to conduct axial
impact tests on high-strength concrete and ordinary concrete columns of different sizes. And used ABAQUS to simulate that the size effect of reinforced concrete members under dynamic loads is different from that under static loads. Li Xibing\[3\] used the SHPB impact compression test and found that: under the impact condition of 75% of the critical incident energy, the first impact helps to improve the compressive strength of concrete. But if the number of impacts increases, the compressive strength of concrete will deteriorate. Ding Guobo\[4\] obtained through the SHPB impact experiment: EPS concrete with curing ages of 36h and 28d, with the increase of strain rate, the impact compression strength also increases; EPS concrete with curing ages of 12h, 24h increases with the strain rate. Increase, the impact compression strength change is not obvious. Liu Lian\[5\] used an improved drop-weight impact test device to perform a low-speed impact test on a C30 concrete cylinder, and found that the concrete failure form under impact load is the same as under static load. Meng Yi\[6\] carried out an axial impact test on concrete cylindrical specimens in the strain rate range of 100~101/s and found that the average strength of concrete has a parabolic relationship with the impact velocity. Tian Yubin\[7\] conducted an axial compression test on the impacted concrete prism specimens, and found that the compressive strength of the impacted concrete specimens was reduced, and the failure form caused significant brittle failure due to damage. Hu Shisheng\[8\] used the modified rod diameter to be a straight cone variable cross-section large-size compression rod to perform impact compression experiments on concrete materials to obtain the damage-type linear viscoelastic constitutive relationship of concrete materials. Zhang Ruikun\[9\] used MTS hydraulic servo pseudo-dynamic loading experiment to obtain the dynamic response and failure mode of reinforced concrete frame columns under impact load. He Longfei\[10\] passed the drop hammer impact test of the concrete specimen and the axial compression test of the concrete specimen after the impact. And used the finite element software ANSYS/LS-DYNA to simulate the drop hammer impact test to obtain the concrete damage Constitutive model. Hao Yinghong\[11\] used an automatic impact ball press to study the dynamic impact damage behavior of rubber concrete, and used laser confocal scanning microscope (LSCM) and scanning electron microscope (SEM) to analyze its impact damage morphology and mechanism characteristics. Liu Jichao\[12\] carried out dynamic compression tests on plain concrete specimens of six sizes, and obtained the stress wave change diagram during the SHPB test by analyzing and processing the test data, and the strain rate-time change of plain concrete specimens Curve, stress-strain relationship, peak stress-strain rate relationship, etc. The influence of inertia effect and friction effect on the dynamic strength of plain concrete specimens is analyzed. Liu Canliang\[13\] took the concrete-filled steel tube as the research object and mainly studied its dynamic characteristics under multiple continuous impacts through SHPB experiment and finite element numerical simulation. Liu Juanhong\[14\] used single or multiple stress waves to act on C70 ordinary high-strength concrete (NHSC), C70 steel fiber concrete (SFRC) and NSC-RPC, and analyzed the energy difference of concrete test blocks under different impact speeds. The damage characteristics of the test block are measured by ultrasonic velocity, and the correlation between impact velocity, energy and damage value is obtained by data fitting method.

In summary, the existing results mainly focus on the study of the mechanical properties of cured concrete under dynamic action, but there are still few studies on the mechanical properties of concrete under the action of cyclic impact load during the curing period. In this paper, during the curing period of concrete components, the drop hammer impact experiment under different impact energy is carried out to analyze the change of sound velocity and compressive strength of concrete after impact.

2. Drop hammer impact test during concrete curing

The test cement is CA50-A600 aluminate cement produced by Zhengzhou Jianai Special Aluminate Cement Co., Ltd. It uses polycarboxylic acid series high-performance water-reducing agent with a water reduction rate of over 25% and a solid content of 25%. The test sand is ordinary machine-made sand with two particle size ranges, 0-0.6mm and 0.6mm-1.2mm, and tap water is used.
Table.1 Concrete mix ratio

| Cement | Fine sand (0~0.6mm) | Coarse sand (0.6mm~1.2mm) | Water | Water reducing agent |
|--------|---------------------|---------------------------|-------|----------------------|
| 50     | 80                  | 4                         | 17    | 6                    |

unit: kg

According to the mix ratio of the construction site, the pouring size is 100 mm × 100 mm × 100 mm, and 15 concrete cube specimens with strength C40, each of which is a set of molds, and there are 5 sets in total, marked as 0-1, 0-2, 0-3, 1-1, 1-2, 1-3, 2-1, 2-2, 2-3, 3-1, 3-2, 3-3, 4-1, 4-2, 4-3. After curing for 1 day, the concrete was demoulded, and then the impact test was carried out. The test adopted the method of changing the weight and drop height of the hammer to achieve impacts of different energy and different speeds. (The weight of the large hammer is 2kg and the weight of the medium hammer is 1.5kg.) Impact load is applied to the concrete specimen. The schematic diagram of the drop hammer impact loading device is shown in Figure 1.

Figure.1 Drop hammer impact loading device

Load the impact energy on each group of concrete specimens according to the impact load loading method listed in Table 2, and calculate the impact load energy of each group of specimens subjected to hammer impact by the law of conservation of energy. Put the height h of the hammer drop and the mass m of the hammer into the formula $E=m \times g \times h$ and the results are shown in Table 2.

Table.2 Impact load energy of concrete specimen

| Specimen | Impact load loading method | Impact load energy (kJ) |
|----------|---------------------------|------------------------|
| 0-1, 0-2, 0-3 | No impact                | 0                      |
| 1-1, 1-2, 1-3 | Large hammer load impact at 60cm from the concrete surface | 11.76                  |
| 2-1, 2-2, 2-3 | Medium hammer load impact at 40cm from the concrete surface | 5.88                   |
| 3-1, 3-2, 3-3 | Medium hammer load impact at 60cm from the concrete surface | 7.84                   |
| 4-1, 4-2, 4-3 | Large hammer load impact at 40cm from the concrete surface | 8.82                   |

3. Ultrasonic testing during concrete curing

3.1. Concrete ultrasonic testing method

The interior of well-placed non-damaged concrete is generally dense, and the ultrasonic wave speed is mainly related to the type of aggregate, density, elastic modulus, and Poisson's ratio of the concrete. After damage, due to the generation and expansion of internal cracks, sound waves will undergo scattering, diffraction, reflection and other phenomena during the process of passing through the concrete, making the propagation path of sound waves longer and increasing energy attenuation. These information can be reflected by acoustic parameters, so the degree of concrete damage can be estimated by analyzing the acoustic parameters of ultrasonic waves.

After the drop hammer impact load was carried out during the 28-day curing period, the specimen was collected using a sonic velocimeter to collect the acoustic parameters of the ultrasonic in the
specimen. The instrument can be used for digital detection of non-metallic materials such as concrete, rock, ceramics, and plastics. The main functions include: concrete strength detection, defect detection (including internal cavity and uncompact area detection, crack depth detection, concrete bonding surface quality detection, surface damage detection, etc.), concrete foundation pile integrity detection, material physics and mechanics Performance testing, etc.

The specific test steps are as follows: First, set the sampling period and emission voltage parameters of the ultrasonic detector. Due to the small size of the specimen, the sampling period can be selected as 0.2μs and the emission voltage as 125V. The instrument should be zeroed again. This test uses a standard rod for zeroing. Before the test, you need to mark the location of the test point, and then apply a layer of butter as a couplant on the test point. Pay attention to the uniform thickness when applying, and the application range should be slightly larger than the size of the transducer for good coupling. In the process of testing, it is necessary to maintain uniform force when the transducer and the couplant are in contact, and to minimize the error in the measurement data caused by human operation.

3.2. Analysis of specific results of ultrasonic testing

In non-damaged concrete, ultrasonic waves basically travel along a straight path. But in damaged concrete, when ultrasonic waves encounter defects such as cracks and holes, reflections, refraction and other phenomena will occur, and the propagation path will become complicated, which will affect the propagation speed of sound waves in the concrete specimen. Therefore, this test uses the above method to measure the sonic wave speed of a total of 15 concrete samples in 5 groups, and process the measured wave speed test results, and the obtained wave speed change curve is shown in Figure 2.

![Figure 2](image-url)

**Figure 2** Variation of wave velocity of each group of concrete specimens

From the graph, it can be found that the wave speed of each group of concrete specimens during 1-2d is small and has no big change, while the wave speed of 3-7d has a larger increase. After 7d, the wave speed will fluctuate relatively up and down and remain around 5000m/s. Compared with the first group without impact load, the ultrasonic wave speed obviously slowed down to a certain extent at the age of 28 days, so it is more stable to use sound speed as the criterion for concrete damage. In order to quantitatively describe the damage degree of concrete specimens subjected to multiple impacts during the curing period, the undamaged variable of ultrasonic wave velocity is used according to the formula in the basic principles of damage mechanics, expressed as: \( D_v = 1 - v^2 / v_0^2 \). In the formula, \( D_v \) is the damage factor of ultrasonic velocity; \( v_0 \) is the ultrasonic velocity of concrete specimens without impact; \( v \) is the ultrasonic velocity of concrete specimens impacted by the drop hammer. The calculation results are shown in Table 3.
Table 3  Impact load energy of concrete specimen

| Specimen   | Damage value |
|------------|--------------|
| 1-1, 1-2, 1-3 | 0.035        |
| 2-1, 2-2, 2-3 | 0.022        |
| 3-1, 3-2, 3-3 | 0.031        |
| 4-1, 4-2, 4-3 | 0.031        |

According to the damage value of each group of concrete specimens after impact obtained in Table 3, it can be concluded that the damage value of each group is not much different. Therefore, the compressive strength of the concrete specimens will be tested in the next step, and the damage of the concrete specimens will be further detected.

4. Study on the compressive properties of concrete after impact

In order to study the mechanical properties of damaged concrete, an electro-hydraulic servo universal testing machine (Figure 3) was used to perform axial compression tests on concrete specimens to obtain their stress-strain curves. Before the formal loading of the concrete specimens, preloading is required to eliminate the gaps in various parts of the specimens. During the compression test, when the concrete specimen was about to fail, the five groups of specimens showed the same situation, and the sound of concrete cracking and peeling on the outer surface could be heard. When the ultimate load is reached, the specimen suddenly breaks, producing a sharp cracking sound.

![Concrete compression test system](Figure.3)

Test results and analysis: Figure 4 is a photo of the failure of the concrete specimen without impact in this test. It can be seen from the figure that the main form of failure of the specimen is shear failure. Under the action of axial pressure, there are oblique cracks in the concrete specimen, and the cracks are finer and more numerous, and gradually extend with the increase of the axial pressure until they penetrate the specimen.

Figure 5 to Figure 8 show the damage pattern of multiple-times impact concrete. The concrete specimens after multiple-times impacts will have vertical cracks during the impact process. During the axial compression test, the original cracks will continue to extend and develop until they penetrate the specimens. Compared with unimpacted concrete, the corners, edges and surface concrete fall off during the axial compression process.

![Specimen 0-1, 0-2, 0-3 unimpacted concrete failure form after axial compression](Figure.4)
Combining the pictures of the five groups of specimens before and after the failure, it can be inferred that due to the daily impact load of the specimens during the curing phase, a certain amount of damage has occurred inside. Even if it is impossible to intuitively find obvious changes in the appearance of the specimen, the difference in the shape after the axial pressure is broken can reveal that there is internal damage. It is preliminarily inferred that under the action of multiple impact loads during the curing period of the concrete specimens, the internal cracks of the concrete have begun to occur and develop. After the compression test, the number and width of concrete cracks in concrete specimens subjected to multiple impacts are greater than those of unimpacted concrete. In addition, this test uses high-strength concrete, and the ductility drop of concrete is relatively lower than that of low-strength concrete. In the compression test, the concrete has no obvious warning before it fails, and this type of damage is brittle failure. When the high-strength concrete is subjected to multiple impacts, there is no obvious damage to the structure from the appearance. In fact, certain damage has occurred inside the structure. The structure after multiple impacts needs to prevent brittle failure.

In order to more intuitively show the changes of concrete material properties after multiple impacts, the peak load and compressive strength of different groups of concrete are recorded in the table 4.
Table 4  compressive strength of each group

| Specimen | Peak load (kN) | Peak strength (MPa) | Average strength (MPa) |
|----------|----------------|---------------------|------------------------|
| 0-1      | 542.20         | 51.51               |                        |
| 0-2      | 481.81         | 45.77               | 49.39                  |
| 0-3      | 535.72         | 50.89               |                        |
| 1-1      | 470.20         | 44.67               |                        |
| 1-2      | 243.77         | 23.16               | 37.56                  |
| 1-3      | 472.12         | 44.84               |                        |
| 2-1      | 559.51         | 53.15               |                        |
| 2-2      | 371.19         | 35.26               | 44.71                  |
| 2-3      | 481.11         | 45.71               |                        |
| 3-1      | 494.10         | 46.94               |                        |
| 3-2      | 492.16         | 46.76               | 41.79                  |
| 3-3      | 333.34         | 31.67               |                        |
| 4-1      | 412.47         | 39.18               |                        |
| 4-2      | 462.73         | 43.96               | 39.16                  |
| 4-3      | 361.71         | 34.36               |                        |

Figure 9  Average compressive strength of each group of concrete

Compressive strength is the performance of the maximum pressure per unit area that the test piece can withstand under the action of axial pressure from a macro perspective until it fails. The internal damage of the specimen after repeated impact loads during the curing period will also be fed back to the compressive strength of the specimen to a certain extent. According to the data in the table, the compressive strength of concrete specimens without falling weight impact is greater than that of other concrete specimens with falling weight impact. Compared with the compressive strength of the first group, the compressive strength of the second group of concrete specimens was reduced by 11.93 MPa after the daily impact load of 11.76 kJ during the 28-day curing period. Compared with the compressive strength of the first group, the compressive strength of the third group of concrete specimens after being loaded with an impact load of 5.88 kJ per day during the 28-day curing period is 4.68 MPa. The compressive strength of the fourth group of concrete specimens after being loaded with an impact load of 7.84 kJ per day during the 28-day curing period is 7.6 MPa lower than that of the first group. Compared with the compressive strength of the first group, the compressive strength of the fifth group of concrete specimens after being loaded with an impact load of 8.82 kJ per day during 28 days of curing was reduced by 10.23 MPa. It can be concluded that the magnitude of the load loaded on the concrete specimen
subjected to impact load during the curing period determines the degree of reduction in its compressive strength relative to the compressive strength of concrete without impact. From the comparison of the compressive strength data of these concrete specimens, it can be further found that the specimens have undergone certain internal damage after repeated drop hammer impacts during the curing period.

5. conclusions
A drop-weight impact test device was used to perform multiple impact tests on the concrete during the curing period, and an ultrasonic tester was used to determine the internal damage and the compressive strength of each concrete specimen. After analyzing and sorting out the test data and results, the following conclusions were obtained.

1) Comparing the ultrasonic measurement results of each group of concrete at the age of 28 days, it can be concluded that the wave speed of the concrete specimens loaded by the falling weight impact is slowed down to a certain extent. According to the ultrasonic defined damage formula, the damage values of the four groups of concrete are calculated as 0.035 and 0.022, 0.031, 0.031.

2) The 28-day-old concrete was subjected to an axial compression test to determine its compressive strength. And it was found that the compressive strength of concrete specimens subjected to multiple drop hammer impacts during the curing period was affected to a certain extent. And there is a positive correlation between the change of concrete compressive strength and the damage value calculated by the change of ultrasonic wave velocity.

Acknowledgments
This work was supported by a grant from National Natural Science Foundation of China (NO.51674100, NO.51704097, NO.51778215) and Key Science and Technology Program of Henan Province (212102310598). The authors would like to thank the authors of the literature for their excellent work and providing references for this paper, and thank the reviewers for critically reviewing the manuscript.

References
[1] Li Xiangyun Research on the impact resistance of short carbon fiber-confined concrete columns [D]. Hunan University, 2011.
[2] Krauthammer T, Elfahal M M, Lim J, et al. Size effect for high-strength concrete cylinders subjected to axial impact[J]. International journal of impact engineering, 2003, 28(9):1001-1016.
[3] Li Xibing, Wang Shiming, Gong Fengqiang, Ma Haipeng, Zhong Fangping. Experimental study on multiple impact damage characteristics of concrete at different ages[J]. Chinese Journal of Rock Mechanics and Engineering, 2012, 31(12):2465-2472.
[4] Ding Guobo, Xu Jinyu, Hu Zebin, Xi Feng, Bai Erlei. The mechanical properties of early-strength EPS concrete under impact load[J]. Vibration and Shock, 2011, 30(03):269-273.
[5] Liu Lian, Huo Jingyi, Liu Yanzhi, Wang Haitao, Tan Qinghua. Experimental study on dynamic mechanical properties of ordinary concrete under falling hammer impact[J]. Journal of Railway Science and Engineering, 2018, 15(06):1415-1423.
[6] Meng Yi, Yi Weijian. Research on the dynamic effects of concrete cylindrical specimens under low-velocity impact[J]. Vibration and Shock, 2011, 30(03):205-210.
[7] Tian Yubin, Huang Tao, Liu Jia, Jin Ruoxi, Zhang Chunwei. Experimental research on the damage performance of concrete subjected to impact[J]. Journal of Building Structures, 2014, 35(S1):58-6.
[8] Hu Shisheng, Wang Daorong. Dynamic constitutive relationship of concrete materials under impact load[J]. Explosion and Shock, 2002, 03(02):242-246.
[9] Zhang Ruikun. Dynamic response analysis of reinforced concrete columns under lateral impact[D]. Hebei University of Technology, 2010.
[10] He Longfei. Study on the mechanical properties and constitutive relationship of impact-damaged concrete[D]. Changsha University of Science and Technology, 2018.
[11] Hao Yinghong, Fan Lei, Han Yan, Li Hui, Tian Xule, Hao Qingli. Research on the damage of
rubber concrete under impact load[J]. Vibration and Shock, 2019, 38(17): 73-80.

[12] Liu Jichao. Refined research on impact dynamics performance of plain concrete[D]. Guangzhou University, 2014.

[13] Liu Canliang. Research on dynamic characteristics of concrete filled steel tube under multiple continuous impacts[D]. Anhui University of Science and Technology, 2018.

[14] Liu Juanhong, Zhou Yucheng, Yang Haitao, Fu Shifeng, Gu Yu. Energy and damage characteristics of shaft lining concrete under impact load[J]. Journal of China Coal Society, 2019, 44(10): 2983-2989.

[15] CECS21-2000. Technical specification for ultrasonic detection of concrete defects[S]. Beijing, China Engineering Construction Standardization Association, 2000.