

Analysis on the Application of Field Testing Technology for Cement Concrete Pavement Strength

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Abstract: As the core structure of road engineering, the strength performance of cement concrete pavement has a direct impact on the pavement bearing capacity, service life, and driving safety after later operations. This study combines the actual construction and operation needs of road engineering sites to conduct systematic research on three mainstream on-site testing technologies for concrete pavement strength. These techniques are the rebound method, ultrasonic rebound comprehensive method, and core drilling method. The purpose is to accurately grasp the physical quality of the road surface and effectively identify structural hazards. After expounding the core purpose and specification requirements of strength testing, this paper analyzes the working principle, supporting equipment, operation steps, and core technical points of the three technologies one by one. This paper also compares the parameters of the three technologies, so as to highly clarify the applicability of the technologies under different working conditions.

Keywords: Field detection; Cement concrete; Pavement strength; Rebound method; Ultrasonic-rebound method

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1. Introduction

Under the background of long-term road service, the road surface is frequently affected by multidimensional factors such as vehicle load compaction, rainwater erosion, alternating temperature and humidity changes, and construction process deviations. The road surface is prone to diseases such as cracking, hollowing, damage, and strength attenuation. This has a serious negative impact on the traffic quality and service life of the road surface. Strength, as the core indicator for evaluating the structural performance and quality status of cement concrete pavement, focuses on the systematic application analysis of three mainstream on-site testing technologies, and compares the advantages, disadvantages, and applicability of various technologies. This can effectively provide standardized and scientific technical support for on-site inspection work, and provide technical guarantees for the quality and long-term operational safety of cement concrete pavement

engineering^[1].

2. Purpose and requirements for strength testing of cement concrete pavement

2.1. Purpose of testing

On-site testing of cement concrete pavement strength is the core work of road engineering quality acceptance and later operation and maintenance control. The core purpose is to accurately determine the solid strength of pavement concrete and confirm whether it meets the design standards and relevant specifications. From the perspective of engineering construction, on-site inspection work can effectively identify potential local defects, insufficient strength, and other defects that may be reserved in multiple construction processes such as concrete pouring, vibration, and curing, achieving precise positioning of engineering quality hazards^[2]. From the perspective of road operation, under the erosion of the natural environment and long-term load, the strength of concrete pavement inevitably deteriorates slowly. Regular intensity testing will enable operating units to monitor the patterns of changes in road performance effectively. At the same time, combining strength indicators to determine the causes of pavement diseases provides data support for subsequent maintenance, repair, and reinforcement projects.

2.2. Testing requirements

The on-site testing of the strength of cement concrete pavement must strictly comply with national and industry standards such as the “Test Regulations for Cement Concrete Raw Materials in Highway Engineering” and the “Technical Regulations for Testing the Compressive Strength of Concrete by Rebound Method.” At the same time, the testing team needs to combine engineering design documents and construction standards to implement standardized and regulated operations for testing work, ensuring the accuracy, authenticity, and effectiveness of testing data. In addition, the inspection team needs to reasonably arrange the inspection points based on the scope of road construction, structural zoning, and disease distribution, strictly control the environmental conditions and operating procedures, and standardize the equipment operation procedures. The testing team ensures that the technical parameters of testing intensity, angle, and spacing are unified to prevent data deviation caused by human operation errors^[3].

3. On-site testing of cement concrete pavement strength

3.1. Strength testing of cement concrete based on rebound method

3.1.1. Technical principles and equipment

The rebound method belongs to the most widely used non-destructive testing technology in the current industry. The core principle of this technology is to estimate strength results based on the correlation between concrete surface hardness and compressive strength. The compressive strength of concrete materials is positively correlated with their surface elastic hardness. Under the action of standard spring elasticity, the rebound rod of the rebound instrument vertically impacts the flat surface of the concrete. During the impact, the surface of the concrete will undergo elastic deformation. The rebound value of the rebound rod of the equipment can directly reflect the hardness of the concrete surface^[4]. Based on a large number of experiments, a conversion curve between rebound value and concrete standard compressive strength can be established to calculate the compressive strength of the tested pavement concrete accurately. The core

equipment during the application of the rebound method includes a concrete rebound tester, a carbonation depth measuring instrument, and auxiliary tools such as sandpaper, a brush, and a record sheet.

3.1.2. Testing steps and key points

The steps for conducting strength testing of cement concrete pavement based on the rebound method mainly follow the standardized process of preliminary preparation, point layout, surface treatment, on-site testing, and data correction.

Step 1: Preliminary preparation. The testing team in this stage needs to verify the rebound instrument calibration certificate to confirm that the equipment performance is intact and meets the standards. During this process, the team can calibrate using a standard steel anvil to ensure that the calibration error is controlled within the allowable range of the specifications. On this basis, the road surface area to be measured is strictly cleaned to avoid special positions such as cracks, joints, pits, corners, etc., and the area to be measured is reasonably divided based on the area of the road section to be measured. The area of a single measurement area should be controlled at $200\text{mm} \times 200\text{mm}$, and the number of measurement areas for each pavement slab should be ≥ 10 . Step 2: Surface treatment of the survey area. In order to ensure the key step of detection accuracy, the monitoring team used sandpaper to polish the surface of the survey area and removed the floating slurry, stains, and peeling to ensure that the surface was smooth, solid, dry, and free of debris interference. Step 3: On-site bounce detection. During the operation, the team needs to place the rebound gauge perpendicular to the surface of the concrete pavement measurement area. The rebound gauge applies pressure slowly and uniformly. Read and record the rebound value after the impact rod completes the impact and rebound. Each testing area requires the rebound gauge to bounce continuously 16 times. After removing the 3 maximum and 3 minimum values, the team calculated the remaining 10 average values and used them as the effective rebound values for the measurement area. On this basis, the team used a carbonization depth measuring instrument to select 3 points for carbonization depth detection in each measurement area, and collected the average value as the final carbonization depth value of the measurement area. Step 4: Data correction. After completing the on-site testing, the monitoring team needs to use the concrete pouring process, curing age, and carbonation depth to effectively correct the original rebound data. The team then uses the standard conversion formula to calculate the estimated compressive strength of the concrete. This ensures that the test data closely matches the actual strength of the pavement structure.

3.2. Strength testing of cement concrete based on ultrasonic rebound comprehensive method

3.2.1. Technical principles and equipment

The ultrasonic rebound comprehensive method belongs to a composite non-destructive testing technology that combines ultrasonic testing and rebound testing. It can not only effectively make up for the lack of detection accuracy of the single rebound method, but also solve the defect of insufficient stability of the single ultrasonic method. The technical principle of the ultrasonic rebound comprehensive method is that the compressive strength of concrete has a stable correlation with surface hardness and internal compactness values. The rebound value can reflect the surface hardness and strength state of concrete. The application of ultrasound reflects the internal density, porosity, and overall uniformity of concrete by propagating sound velocity inside the concrete. During the period of mutual supplementation and correction of two technical

parameters, a ternary conversion relationship of “rebound value—sound velocity—compressive strength” can be established to estimate the overall compressive strength of concrete accurately. The accuracy and reliability of the test results can be improved. The ultrasonic rebound comprehensive method is equipped with testing equipment that focuses on concrete rebound testers, non-metallic ultrasonic detectors, transducers, and coupling agents. The non-metallic ultrasonic detector is the core equipment. This device has data storage, sound velocity testing, and automatic correction functions, and is highly suitable for large-scale detection in concrete pavement engineering. The coupling agent is responsible for eliminating the air gap between the transducer and the concrete surface, and improving the stability of ultrasonic propagation ^[5].

3.2.2. Testing steps and key points

The ultrasonic rebound comprehensive method testing process covers four major steps: equipment calibration, measurement area layout, rebound testing and ultrasonic testing, and data integration and conversion.

Step 1: equipment calibration. In this stage, the monitoring team needs to carry out steel anvil calibration and acoustic time calibration for the rebound tester and ultrasonic detector, respectively, to ensure that the instrument accuracy meets the standard. Step 2: Test area layout. The team strictly cleans the testing area of the road surface, polishes and flattens the surface, and removes any floating slurry and debris. The team can maintain consistency with the rebound method for the layout standards of the testing area. The team evenly distributes the testing areas, and for each testing area, the team performs rebound testing and ultrasonic testing simultaneously. This ensures the matching of the two sets of data. Step 3: Rebound testing and ultrasonic testing. Among them, the operation process of rebound detection is consistent with the single rebound method. The team records the effective rebound average and carbonization depth values of each testing area to collect surface strength parameters accurately. During the ultrasonic testing period, the team used the matching method to arrange the testing points. The team symmetrically arranged the transducers on both sides of the testing area, and then evenly applied coupling agent to ensure that the transducers and concrete surfaces were tightly adhered without displacement or hollowing. The team started the instrument and emitted ultrasonic waves. They recorded the sound time and speed values of ultrasonic waves propagating inside concrete, and repeated the testing work three times in each measurement area. After removing abnormal data, they took the average value as the effective sound speed value. During the operation, in order to ensure the synchronization and matching of the two detection data, the detection position cannot be changed after confirming the detection point position in the same measurement area. At the same time, it is necessary to strictly control the spacing and detection angle of the transducers to ensure the stability of the ultrasonic propagation path. Step 4: Data integration and conversion. After completing the rebound and ultrasonic data acquisition, the computer combines the rebound value, sound velocity value, and carbonation depth value to estimate the compressive strength of concrete using a standardized ternary conversion formula.

3.3. Strength testing of cement concrete based on core drilling method

3.3.1. Technical principles and equipment

The core drilling method is the only “semi-damaged direct detection” technology in the strength testing of cement concrete pavement. It is also a recognized precision testing technology in the industry, often used as

a calibration basis for other non-destructive testing techniques. The core principle of the core drilling method is the use of drilling equipment. The team drilled standard cylindrical core samples from the pavement concrete slab and then conducted laboratory pressure tests to complete compressive strength tests on the core samples. Then they can directly determine the actual compressive strength of concrete. This technology does not require a parameter conversion process and can directly obtain strength data based on solid core samples. It can truly and intuitively reflect the overall strength state of concrete pavement from the surface to the interior. The core testing equipment of the core drilling method includes drilling and coring machines, which can be divided into electric water-cooled and gasoline-based coring machines. The supporting equipment includes core sample trimming equipment, diamond hollow drill bits, pressure testing machines, calipers, and maintenance water tanks ^[6]. Among them, the pressure testing machine is the core equipment in the laboratory, used to determine the ultimate compressive load of the core sample accurately.

3.3.2. Testing steps and key points

The core drilling method detection process includes four steps: point layout, drilling and coring, core sample processing, and laboratory pressure test strength determination. Due to its potential to cause minor damage to the road surface, it is necessary to strictly control the operating range during the operation ^[7].

Step 1: Point layout. Based on the distribution of road surface blocks, the team evenly selects core sampling points. This process needs to avoid road joints, damage, and steel reinforcement positions, while also avoiding the core areas of road traffic and driving. During the deployment period, the number of cores taken from a single detection section should be ≥ 3 to ensure the representativeness of the data. On the basis of confirming the location, the team strictly cleaned up the work area and ensured safety protection, fixing the core-taking machine equipment to ensure its horizontal and vertical stability. Step 2: Drilling and coring operations. Taking the water-cooled drilling method as an example, the team continuously supplies water to cool the drill bit during drilling, reducing the damage caused by high-temperature drilling friction to the core structure. At the same time, they strictly control the drilling depth, determining the depth based on the design thickness of the road surface to ensure the drilling of complete core samples and avoid core sample breakage, missing corners, or delamination. Step 3: Core sample processing. After the core extraction is completed, the team promptly seals the drilled holes on the road surface. They use specialized repair mortar for backfilling and compaction to ensure the restoration of road smoothness and integrity, avoiding damage expansion and water accumulation in holes. Subsequently, they labeled the extracted core samples with numbers and transported them to the laboratory for standard maintenance. After completing the maintenance work, they polished and leveled the end face of the core sample, effectively removing burrs and concave-convex defects on the surface of the core sample. Step 4: Determination of laboratory pressure test strength. The team places qualified core samples at the center of the pressure testing machine, and then conducts compressive tests on the equipment under constant loading. During the experiment, they strictly recorded the ultimate load of the core sample and calculated the compressive strength of the concrete based on the cross-sectional area of the core sample. During the experiment, it is necessary to take the average value of multiple core samples for testing as the detection result ^[8].

4. Comparison and applicability analysis of three testing technologies

In order to accurately distinguish the application advantages, monitoring efficiency, accuracy, and other

numerical values of various technologies, and ensure that they can adapt to the testing scenarios of different projects in practice, this study conducts a horizontal comparative analysis of the core performance indicators of the three testing technologies. The specific comparison of core parameters is shown in **Table 1**:

Table 1. Comparison of core technical parameters of rebound method, ultrasonic rebound comprehensive method, and core drilling method

Detection technology	Detection accuracy	Detection efficiency	Equipment cost	Degree of road damage
Rebound Method	General: The error is between 10% and 15%.	Extremely high, this method is suitable for large-scale surveys	Low, its equipment is portable and inexpensive	There was no damage
Ultrasonic Rebound Comprehensive Method	Higher: The error is between 5% and 8%.	Medium, the efficiency of this method is slightly lower than that of the rebound method	Medium, it has complete supporting equipment	There was no damage
Core Drilling Method	Very high: The error is less than or equal to 3%.	Low, this method has a complex workflow	High, its equipment and testing costs are high	There is a slight semi-damage

As shown in **Table 1**, from the perspective of technical performance and engineering applicability, the three technologies can form a complementary detection system that can effectively adapt to different detection scenarios. The rebound method has the advantages of high efficiency, convenience, low cost, and no damage. It is suitable for large-scale surveys of newly built road surfaces, screening of old road surfaces, and regular inspection of operation and maintenance work during later operation. However, this technology can only effectively reflect the surface strength, and the data is susceptible to external interference, resulting in limited accuracy ^[9]. The ultrasonic rebound comprehensive method will combine the advantages of the rebound method and ultrasonic method technology. It can simultaneously detect the surface hardness and internal compactness of concrete. Its data stability and accuracy have been improved, and it can avoid errors caused by carbonization and surface wear. As a precise benchmark detection technology, the core drilling method produces more authoritative and reliable detection results compared to other techniques. But it will cause slight damage to the road surface and have low detection efficiency. It is suitable for arbitration testing, engineering completion acceptance, and review of various non-destructive testing technology results for quality dispute sections ^[10].

5. Conclusion

In summary, this study systematically investigates the principles, equipment, operational procedures, and core points of three mainstream on-site detection techniques: rebound method, ultrasonic rebound comprehensive method, and core drilling method. This study clarified the performance differences and applicable scenarios of different technologies through comparison. Based on the research results, it can be concluded that the three detection technologies have their own advantages and complement each other. During actual engineering applications, the monitoring team should combine the engineering scenario, detection purpose, and accuracy requirements to reasonably match the detection technology and standardize the process of detection operations. In doing so, the team fully utilizes the inherent advantages of each method, avoids technical shortcomings, and improves the quality and efficiency of pavement strength detection. The team effectively supports the quality control of cement concrete pavement construction, post-maintenance and repair, as well

as the treatment of old road section diseases.

Disclosure statement

The author declares no conflict of interest.

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