Academic Journal of Science and Technology
ISSN: 2771-3032 | Vol. 3, No. 2, 2022

Research Progress of concrete Vibratory Technology

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Abstract: Traditional vibrating equipment and technology combined with manual experience to judge the quality of concrete vibrating is highly subjective and poorly standardized. Due to under-vibration, over-vibration and leakage vibration, the concrete has defects such as holes, segregation and cracks, which lead to the pouring quality not meeting the design requirements. The research progress of vibrating technology is introduced from four aspects: parameters affecting vibrating quality, evaluation method of vibrating quality, key technologies and development trends of vibrating. The research shows that intelligent vibrating has a significant role in promoting the development of civil engineering construction, and also lays a good foundation for the development of related engineering equipment and vibrating machinery automation.

Keywords: Concrete, Vibrating quality, Influencing parameters, Intelligent vibrating.

1. Introduction

As the most basic material of civil engineering, the construction quality of concrete is directly related to the overall quality of the building structure, and the pouring vibration plays an important role in its construction quality. At present, there are many problems in the vibrating process in the industry, such as whether the vibrating is fully and completely dependent on human experience, whether there is an effective supervision method for the corresponding vibrating specifications, and the traditional vibrating construction has many drawbacks, resulting in the reduction of concrete mechanical properties, microscopic Structural defects increase, and it is difficult to make concrete vibrating effectively and compactly with artificial subjective judgment, and the vibrating effect is lost. At this stage, there is a serious lack of practical technology in the quality monitoring of concrete vibrating and pouring engineering in my country, which will affect the application and operation of the later stage of the project and also pose a threat to the life and health of users. In a wharf project in Wuhu, due to the illegal operation of one-time pouring of super-thick concrete and vibrating rods, the cantilever section collapsed when the concrete was poured and vibrated, resulting in two deaths. In a coastal railway that has been in operation, the void of the secondary lining of the tunnel accounts for 99.4% of the total number of diseases. Due to the poor vibrating of the concrete during the pouring process, voids are generated. , creating a safety hazard. To this end, it is crucial to promote the rapid development of intelligent vibrating technology in engineering applications.

2. Vibration Quality Influencing Parameters

There are many parameters affecting the vibration quality. This paper mainly studies the rheological parameters of concrete and the vibration parameters. The 309R series of standards [1-2] formulated by ACI in the United States cover the rheological and mechanical processes that occur during the consolidation of fresh concrete, and describe the principles of consolidation mechanisms of different vibrating equipment. In terms of concrete rheological parameters, Banfill research shows [3] that fresh mortar undergoes structural rupture, and the equilibrium flow curve conforms to the Bingham model. It is generally believed that the Bingham model can be used to describe the complex rheological properties of concrete [4]. The rheological properties of concrete in the vibrated state should be described by the yield stress $\tau0$ and the plastic viscosity η. Studies have shown that [5-9] have: the yield stress is the minimum stress applied to the concrete in order to make the concrete flow and deform. The smaller the yield stress, the greater the shear force, which is more beneficial to the enhancement of the fluidity of the mixture and the compactness of the concrete; the plastic viscosity reflects the internal structure of the fresh concrete to overcome the flow deformation. The stronger the logistics. In addition, Banfill also predicts the effective vibration radius of the concrete liquid-solid interface with the optimal combination of low yield stress and high plastic viscosity. As a function of the vibration and rheological properties of the concrete, the vibration radius increases with the increase of plastic viscosity. increases, the yield stress decreases accordingly.

In terms of vibrating parameters, researches on vibrating time, vibrating frequency and vibrating depth are mainly carried out. Studies have shown [10-12]: when the vibration time is too short, the concrete will appear under-vibrated state, resulting in the reduction of mechanical resistance in simple compression and the attenuation of the bonding force between the reinforcement and the concrete, the main result corresponds to the local heterogeneity within the material . On the contrary, if the vibrating time is too long, it is easy to cause the bleeding of the concrete shiny film, causing problems such as segregation and bleeding. Vibration time has an effect on concrete slump, apparent density deviation rate and air content, and the effect on air content is the most significant. Under the action of the same frequency and peak acceleration, prolonging the vibrating time causes the difference of the final spacing factor to be ignored, and the gas content loss is 0.5%~1.5%. Ma [13] pointed out that an appropriate increase in the vibrating time can effectively improve the chloride ion permeability, compressive strength and workability of concrete; the vibrating frequency is that the mechanical energy and electrical energy of the fresh concrete are converted by the vibrator respectively. For the mechanical vibration energy [14], the generated energy propagates in the form of vibration waves with a certain amplitude and frequency, so that the concrete is subjected to high-energy vibration, and the concrete is vibrated to achieve compaction. The research shows that the higher the vibrating frequency, the greater the energy, and the vibrating frequency is proportional to the energy of the vibrating rod [15]. Hu[16] studied the relationship between vibration frequency and concrete strength. For the same concrete, the higher the vibration frequency, the shorter the vibration density. Yang [17] found that high-frequency vibration is not conducive to the increase of air content of air-entrained concrete, while appropriate high-frequency vibration is beneficial to increase the air bubble retention rate and frost resistance of hardened concrete. Lei [18] found that high-frequency vibration can improve the consolidation density of concrete, and the average fatigue life is about 27% longer than that of low-frequency vibration. Tymkowicz [19] studied that the deterioration of concrete is mainly due to the excessive vibration frequency, resulting in too low air content in the hardened concrete, and the formation of ettringite or alkali-silica in the voids [20], resulting in segregation and damage to the concrete structure. one of the main reasons. Zhang [21] conducted high-frequency vibration on two different aerated concretes through freeze-thaw cycle tests, and the results showed that long-term high-frequency vibration would lead to a decrease in frost resistance. As for the vibration depth, according to GB 50666-2011 "Concrete Structure Engineering Construction Specification" [22], the vibration depth should not be less than 50mm when concrete is poured in layers. American ACI 347-04 points out that the internal vibration depth should not exceed 1.2m [23]. At present, the on-site workers plug and unplug the movable vibrator at will, and it is impossible to accurately judge whether the depth of plugging and unplugging meets the process requirements. Bian [24] studied the real-time induced voltage change generated by the Hall sensor at the vibration trigger position, and calculated the vibration distance value. Gardner [25] found that the lateral pressure exerted by the concrete will be proportional to the immersion depth of the vibrator head in the concrete, and ultra-deep vibration will lead to a significant increase in the lateral pressure of the template, jeopardizing the safety of the template.

At present, scholars at home and abroad have only analyzed the advantages and disadvantages of the construction quality of vibrating by the influence parameters such as yield stress, plastic viscosity, vibrating time, vibrating frequency and vibrating depth. The influence of different working conditions and factors of vibrating on the compaction of concrete may be further studied, and the relationship model of concrete influence parameters-construction conditions-evaluation index is established to provide a theoretical basis for the rapid development of intelligent vibration technology.

3. Vibration Quality Evaluation Method

Evaluating the construction quality of concrete vibrating by sampling hardened concrete cores has limitations such as manual experience discrimination, limited sampling, and inability to obtain sampling results in real time [26]. The evaluation is carried out through two main aspects: ① Vibration and compaction effect of concrete, such as degree of liquefaction under vibration, visual evaluation, vibration parameters, etc.; ② Post-event feedback of hardened concrete, such as pore structure, resistance value, concrete compressive strength, etc. . The evaluation of the effect of hardened concrete density is related to the pore structure and resistance value of concrete. The formation of concrete pores is mainly the evaporation of air and excess free water introduced in the concrete mixing process [27], and the pore structure greatly affects the strength development of concrete [28-31]. According to the pore size, the internal pore size of concrete can be divided into several nanometers to millimeters. Due to the vibration, the bubbles are subjected to upward buoyancy and downward viscous resistance. The combined effect of the two determines the floating movement characteristics of the bubbles, making the density and Uniformity develops in the opposite direction [32], changing the concrete pore structure, while concrete compaction and uniformity affect structural concrete durability.

The above evaluation indicators can reflect the pros and cons of the vibrating quality of concrete from pre-analysis and post-event feedback, but there is still a lack of a unified evaluation method for the impact of vibrating compaction on the quality of concrete construction. Therefore, the evaluation of the construction quality of concrete vibrating should be regarded as the key direction to rapidly promote the development of intelligent vibrating technology in the future.

4. The Key Technology of Concrete Vibrating

Different vibrating construction methods are shown in Figure 1 [2]. Today, with the gradual acceleration of the process of engineering intelligence, the intelligent automation research of existing vibrating technology in the construction industry such as civil engineering and water conservancy is slow, and it is difficult to perform in terms of performance and function. Meet the multi-threaded construction needs. The key technology of vibrating starts from the main evaluation indicators, and studies the supervision and control methods, systems, equipment, and software of the evaluation indicators, such as the visualization of the vibrating compaction effect, the performance of concrete, and the control of the degree of liquefaction under vibration. Therefore, it is necessary to develop the scientific development concept of the key construction of concrete vibrating, and strengthen the overall efficiency-creating ability of the intelligent vibrating system.

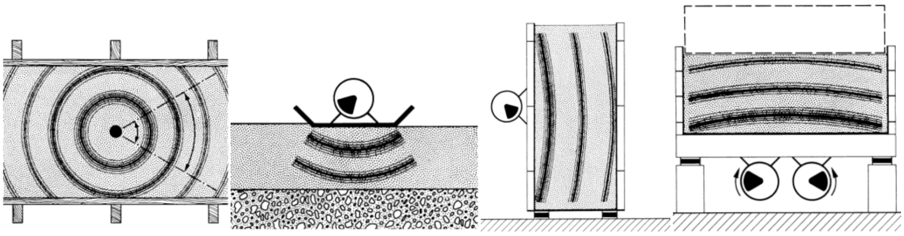


Figure 1. Schematic diagram of different vibrating methods

4.1. Vibration Supervision and Control Methods

4.1.1. Vibration Information Visualization Based on Artificial Intelligence

The visualization of the vibrating compaction effect is to observe the interior of the concrete, which can clearly observe the characteristics of the concrete composition and the model relationship during the vibrating process [33-34]. Michael [35] used a scintillation camera and radioisotope-labeled spheres to obtain real-time images of aggregate settlement of the labeled spheres in vibrating mortar or concrete using nuclear medicine techniques to study the rheological properties of vibrating concrete mixtures. Today, the vibrating construction information is more intuitively reflected through the artificial intelligence vibrating technology.

Quan [36] organizes, categorizes and analyzes vibrating quality control indicators, uses data fusion and machine learning technology to remotely monitor the progress of concrete vibrating, and displays a 3D visual view of the vibrating rod. Liu[37] chose an efficient convolution filter algorithm, and proposed a method of using a stereo camera to track and identify the position and stage of the internal vibrator in real time. Measure the position of the vibrator and calculate the depth of the vibrator, and build a user graphical interface. However, the stereo camera system requires complicated and time-consuming manual calibration in the field, which is hindered by the field lighting conditions, which greatly limits the large-scale application of this method. Zhou[38] segmented concrete pore structure images through Image-Pro plus deep learning to generate accurate and realistic pore characteristic parameters, which is an effective way to link the microstructure and concrete macroscopic. Tian[39] transmits the collected vibration data through General Packet Radio Service (GPRS) and stores it to the cloud server, the action radius and effective vibration area are determined by the experimental geometric model, and the vibration effect is displayed in the form of 3D visualization at the control site, such as shown in Figure 2. Li[40] judged the working quality of the vibrator by using the pixel value information of the picture in the concrete vibrating completion area, screened out the mapping relationship of the qualified vibrating time, the optimal distance of the interference area and other information, and automatically controlled the vibrator. distributed.

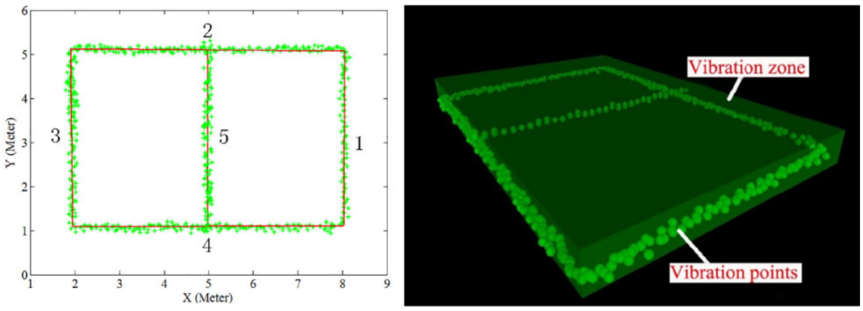


Figure 2. Two-dimensional (left) and 3D (right) images of tracking vibration points[39]

4.1.2. Refinement of Vibrating Construction Based on Intelligent Sensor Control

At present, the quality control of concrete vibrating construction is mostly invalid feedback control. By considering the characteristics of different projects, giving full play to the advantages of high-tech such as wireless sensing, Internet of Things transmission, digital monitoring, computer simulation, etc., applying innovative vibrating automation equipment, adopting corresponding quality control measures, and adjusting vibrating parameters in real time around the clock to achieve vibration Refine management and control of tamping construction to achieve the purpose of refining the vibrating management and control process. Fan [41] used the comprehensive sensing Internet of Things technology to realize the terminal intelligent control, judge the germ layer coverage time and the vibrating depth, and implement early warning on the concrete vibrating state, vibrating time and vibrating rod insertion depth, and effectively control the overall vibrating construction. In addition, liquefaction by vibration is to analyze the liquefaction area. Burlingame [42] used the temperature difference between the vibrated area and the non-vibrated area of concrete to visually determine the effective range and vibration degree of the vibrated area by using thermal imaging, but it was not possible to measure it. Vibration duration and depth.

4.1.3. Monitoring Concrete Performance Based on Resistivity Method

Currently, conductivity or resistivity [43] methods have been developed to monitor and evaluate concrete properties, with great potential for in-situ monitoring of the stability of fresh concrete during placement and vibration. Hassan [44] designed and developed a special electrode plate measuring device inside a plexiglass mold to detect the occurrence of concrete segregation by monitoring the changes in the relative resistance of different layers in real time using electrical impedance spectroscopy (EIS). Kwok [45-46] first proposed a real model for predicting the 28d compressive strength of concrete by microwave effective conductivity. The results show that the effective electrical conductivity can accurately predict the compressive strength of concrete with similar water-cement ratio. The magnitude of the slope of the strength-conductivity curve can indicate the grade of early standard concrete. Farqad [47] used the non-contact resistivity method to study the microstructure development of different grades of cement with a fixed water-cement ratio. The results show that the changing trend of the resistivity curve can be used to evaluate the strength of cement and distinguish the quality of cement, and establish a new general relationship between gel space ratio and resistivity. Jin[48] proposed to embed multi-element sensors in concrete, through resistivity probes and multiple chloride ion selective electrodes, the internal resistivity, free Cl- content of concrete pore solution at different depths and steel corrosion parameters can be monitored non-destructively in real time. It provides key durability parameters for finely assessing concrete health and predicting concrete service life.

4.1.4. Real-time Positioning of Vibrating Construction Based on Indoor and Outdoor Positioning Technology

The global positioning system (GPS) satellite positioning technology has developed from the initial static single-point positioning to real-time dynamic positioning (RTK). Research shows [49-51]: GPS combined with construction quality dynamic information (PDA) real-time acquisition technology has greatly improved the work efficiency of traditional vibrating monitoring methods, meeting the needs of real-time precise positioning of vibrating area locations, and improving vibrating trajectory. Prediction planning, remote control of vibration information requirements, and intelligent feedback provide corresponding technical support for real-time monitoring of vibration construction. Ultra wide band (UWB) integrates multi-source positioning technology, and combines with mobile communication, Internet of Things, equipment integration and other technologies to achieve high-precision positioning and tracking across multiple scenarios. By developing a portable and practical wireless device to improve the ranging error of UWB, it can display the vibrating ability of different vibrating depths in the problem vibrating area, and meet the application requirements of construction scenarios [52-54]. It has the advantages of strong time domain resolution, high ranging accuracy and low cost.

4.2. Concrete Vibration Monitoring System

Zhong [26] carried out research on intelligent vibration of high arch dam concrete on the basis of years of research on intelligent monitoring of construction quality. The key technologies of intelligent vibration mainly include four aspects: intelligent perception, intelligent analysis, monitoring and early warning, and feedback control. Based on artificial intelligence, Internet of Things, intelligent vision and other technologies, the vibrating process is refined and perceived, the quality of the vibrating construction is thoroughly and thoroughly analyzed, and the vibrating construction process is fed back and controlled to effectively improve the vibrating construction quality.

Quan [36] performed data visualization labeling by developing a digital monitoring system of UWB sensors and inclinometers. Machine learning and artificial neural networks are used to automatically process monitoring data, and analyze various parameters of vibrating to obtain real-time evaluation of vibrating quality, but the system can only be used in laboratory scale at present. Tian[50] developed a visual monitoring system for the vibrating state of concrete, which can locate the vibrating state of fresh concrete in real time and quantitatively evaluate the defects in the vibrating process. Dong [55] proposed a real-time monitoring method for the vibration quality of fresh concrete. Based on the IoT monitoring framework, infrared sensors are used to measure the vibration depth, and cameras are used to collect images of the concrete surface. On the basis of fine-tuning the ResNet-50 model, a surface image classification model is established to determine the appropriate vibration duration. In this way, target detection and high-precision classification are carried out on the image, and the presence or absence of defects in concrete vibrating is monitored in real time. The intelligent monitoring system for concrete dam vibrating construction quality developed by Shen [51] implements refined dynamic evaluation of concrete dams by training random forest models, which is of great development value for optimizing the vibrating quality of concrete dam silo surfaces and on-site real-time control.

4.3. Vibration Equipment

Compared with traditional manual vibrating, which has the disadvantages of low work efficiency and high labor intensity, mechanical vibrating is widely used in the construction of concrete structures. According to the characteristics, performance and application range of different vibrators, it is found that the vibration radius varies with the amplitude and frequency provided by each vibrator [1], see Table 1. The vibrating equipment gradually performs pouring and vibrating operations from a single vibrator that vibrates a local area to a large volume and a large warehouse surface. Mechanical equipment such as vibrating trolleys and vibrating intelligent robots came into being and were applied to actual engineering projects [56], solving a series of problems such as harsh vibrating environment, complex construction conditions, and poor stability of artificial vibrating in civil engineering construction. . The vibrating trolley [57] can realize the visual monitoring of concrete vibrating at the dam construction site by monitoring the position, inclination, insertion depth and vibrating time of multiple vibrating rods of the vibrating frame in real time. Tianjin University [58] proposed a visual real-time monitoring system and method for normal concrete vibrating quality based on vibrating trolley construction. This system includes GPS positioning, wireless network transmission and other equipment installed on the vibrating trolley, inclination angle, infrared ranging , ultrasonic ranging and other sensors, as well as database servers and monitoring clients. It is convenient for on-site construction personnel and supervisors to adjust the construction plan in time according to the situation to ensure the quality of concrete vibrating. The vibrating robot system developed by Wang [59] has a vibrating robot body structure including walking, mechanical arm, vibrating rod group, energy, perception and other modules and an on-board controller. The function of intelligent unmanned vibrator promotes the reform of the unmanned mode of vibrating machinery.

Table 1. Range of characteristics, performance, and applications of internal* vibrators, flexible shaft, and motor-in-head vibrators

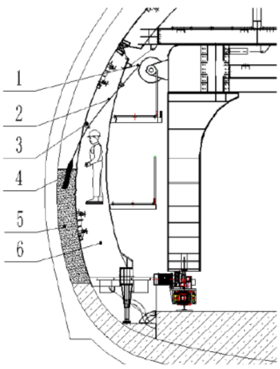
Number	Diameter of head(mm)	Recommended Frequency(Hz)	Radius of Influence(mm)	Application
1	20-40	150-250	75-150	Ultra-thin members and narrow spaces for plastic and flowing concrete
2	30-65	140-210	125-250	Plastic concrete for thin walls, sheets and along construction joints
3	50-90	130-200	175-350	Installed in groups to provide internal vibration of the pavement
4	75-150	120-180	300-500	Structural concrete for mass concrete and heavy construction
5	125-175	90-140	400-600	Mass concrete for gravity dams and bridge piers

Note: Adapted from ACI Commission Report: Guide to Concrete Strengthening 309R-05 ACI Handbook of Concrete Practice 2006 Part 2

5. Development Trend of Intelligent Vibration of Concrete

5.1. Railway Tunnel

At present, the pouring and vibrating of the inverted arch lining concrete in the construction of railway tunnels often lead to the phenomenon that the vibrating of the tunnel lining is not compact and the cores are hollow, and even cause serious disasters. Studies have shown [64-66]: In order to ensure the quality of the lining, the tunnel concrete can be vibrated inside and outside at the same time to obtain a better vibration consolidation effect, and new vibration equipment and intelligent systems have been developed to prevent the occurrence of disasters caused by concrete defects. Effectively solve the problems of limited scope of vibrating area and low construction efficiency at present. Zhang [66] developed a side wall automatic lifting plug-in vibrating system that combines a vibrating trolley with a vibrating rod, as shown in Figure 3, breaking through the shackles of a single vibrating rod construction, and the moving trajectory of the vibrating rod can be passed through the cable Guided by the guide ring to effectively improve the concrete vibrating effect.



1. Elastic roller; 2. Cable; 3. Guide ring; 4. Vibrator; 5. Concrete; 6. Trolley template

Figure 3. Structure of side wall automatic lifting plug-in vibrating system[68]

5.2. Concrete Dam

The rise of a new generation of informatization and intelligent dam building technology drives the innovative development of new theories, new technologies, and new equipment, and promotes the urgent transformation and upgrading of traditional construction models. Intelligent vibrating car can realize unmanned on-site pouring and intelligent vibrating of high-speed rail track slabs[67]. Wang [59] found that trajectory planning is the core of the vibrating robot's automatic vibrating, considering that the vibrating action can be decomposed into "insertion-vibration". The vibrating motion path can be decomposed into a spatial motion passing through a series of key point sets M{P0, P1, P2, P3}, as shown in Figure 4.Liang [68] controls the position of the two vibrating mechanisms at the height of the green layer by controlling the insertion and withdrawal of the vibrating rods by the hydraulic device, forming a closed-loop vibrating system of "monitoring-feedback-regulation", which realizes the construction of the transverse joint surface of the concrete dam pouring silo. unmanned vibrating construction.

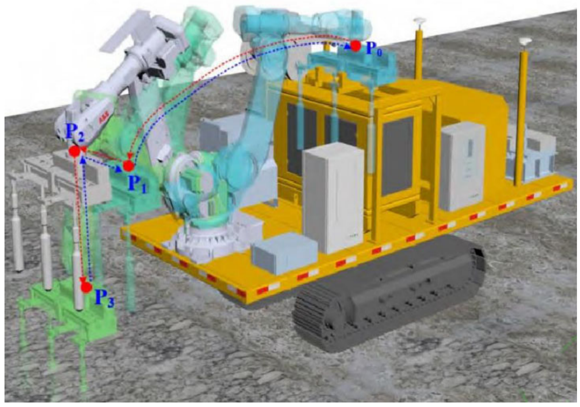


Figure 4. Trajectory planning of the vibrating robot[61]

6. Conclusion

The result of the combined action of multiple factors reflects the quality of the concrete vibrating, and both the concrete rheological parameters and the vibrating parameters have a significant influence on the vibrating quality. However, the research on the parameters and evaluation indicators affecting the vibrating quality has not been sufficient, and technologies such as digital monitoring, artificial intelligence, and Internet of Things communication have been applied to the construction of concrete vibrating. The upgrading of chemical technology should be carried out in the following aspects:

(1) Strengthen the research on the effect of the influencing parameters on the quality of concrete vibrating, and carry out deeper research on the evaluation of concrete vibrating quality.

(2) Research the vibrating monitoring system that can adapt to different application fields and combine the characteristics of the project itself, conduct centralized management and real-time discrimination of the quality of concrete vibrating, and optimize the precise management and control ability of concrete vibrating.

(3) The vibrating intelligent system lags behind in software development, operation and promotion, etc. The system software should be able to respond to the vibrating construction quality in real time and effectively, and the hardware should be simple to use, reliable in performance, and cost-controllable to promote vibrating. The system is moving towards globalization of commercial promotion, intuitive visualization of information, and automatic and intelligent construction.

(4) Deepen the research on the vibration mechanism, improve the vibration construction specifications according to different vibration conditions, and establish a vibration construction standardization system.

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