Conventional Roller Compaction Method

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As an empirical control method, the conventional compaction has the characteristics of manual driving, construction site supervision, manual recording, and sampling point detection. Currently, conventional compaction methods can be divided into four types: sampling point detection, prediction and simulation analysis, construction site supervision, and influencing factor analysis. In actual engineering, conventional compaction methods mainly rely on the manual control of compaction parameters (such as the number of compaction times, compaction trajectory, vibration frequency, lift thickness, and driving speed) during construction, as well as the sampling point detection (such as compactness or dry density) of specified locations after construction to ensure compaction quality of earthwork.

compaction | Conventional Compaction Method | Sampling Point Detection | Prediction and Simulation Analysis | Construction Site Supervision | Influencing Factor Analysis

1. Conventional Compaction Method

As an empirical control method, the conventional compaction has the characteristics of manual driving, construction site supervision, manual recording, and sampling point detection [1][2][3][4]. Currently, conventional compaction methods can be divided into four types: sampling point detection, prediction and simulation analysis, construction site supervision, and influencing factor analysis [4][5][6][7][8][9]. In actual engineering, conventional compaction methods mainly rely on the manual control of compaction parameters (such as the number of compaction times, compaction trajectory, vibration frequency, lift thickness, and driving speed) during construction, as well as the sampling point detection (such as compactness or dry density) of specified locations after construction [1][5][10][11] to ensure compaction quality of earthwork. Sampling point detection methods are diverse and widely used, and most of the methods have been written into specifications and standards [5][6][7][8][9]. Prediction and simulation analysis methods can provide a certain qualitative or quantitative description of soil-roller and soil compaction [12][13]. In a certain process or part of the construction project, the supervisor will spend all or part of the time on the construction site to track and supervise the rolling construction activities, which is the construction site supervision. In term of influencing factor analysis, it is the primary problem to be solved in constructing a compaction quality assessment model.

2. Sampling Point Detection

Conventionally, the compaction quality of filling materials suitable for earthwork is evaluated through spot detection of the density, moisture content, strength, and modulus at some discrete points [1][11]; for instance, the sand cone method [14], electromagnetic soil density gauge method [15], direct heating method [16], nuclear method [17], and water-filling method [18] are currently used for detecting the density. As moisture content go, the methods mainly include the nuclear method [17], sand cone method [14], and direct heating method [16]. The dynamic cone penetrometer (DCP) method [19] and Clegg impact soil test (CIST) method [20] are used to detect strength. In terms of modulus, the lightweight deflectometer (LWD) method [21], soil stiffness gauge (SSG) method [22], and plate loading test (PLT) method [23] are detection methods in common use. Take the sand cone method as an example—it is a commonly used test method in the subgrade, and suitable for in situ determination of the density and moisture content of fine-grained soil, sand soil, and gravel soil [14][24]. Up to now, the sampling point detection methods have been widely used in roads, railways, airports, dams, and embankment. These methods have high detection accuracy and have become the benchmark method for other methods. However, there are the following main problems that need to be further resolved: (1) the compaction status of the entire working area cannot be effectively reflected; (2) most methods are destructive, which greatly disturbs the compaction area; (3) low efficiency and high cost severely restrict the construction schedule, reduce construction efficiency, and project economics; (4) partial methods have high requirements for operators and operation accuracy; (5) the compaction quality of the entire working area cannot be recorded in real time, and data traceability is extremely deficient.

3. Prediction and Simulation Analysis

In terms of prediction methods, researchers have achieved certain research results. Since the soil–roller interaction exhibits complex properties such as elastic-plasticity and non-linearity, and the stress distribution of the soil profile is extremely uneven, it is difficult to describe the compaction state of soil qualitatively or quantitatively. In the research of many scholars, it is mentioned that when an average ground pressure is given when the wheels have more load, the deeper places tent to produce tighter compaction [25][26][27]. For soil compaction, there are also some documents mentioning that tire parameters and wheel loads have significant meaning [28][29]. Klos and Waszczyszyn [30] used neural networks to predict the compaction characteristics of coarse-grained soils. Patel and Mani [12] conducted an on-site survey on sandy loam to determine the compaction of the subsoil under different ranges of wheel loads, multiple passes through the bulk density foundation, and multiple penetration resistance indicators. Through experiments, Raper and Reeves [31] evaluated the different between soil bulk density and cone index (CI, soil hardness) obtained under various conditions such as topsoil plowing, subsoil deep plowing, and fixed track tillage. Çarman [32] utilized the Mamdani fuzzy logic method to study the compaction of clay loam under conditions of pneumatic tires with different travel speeds, different wheel loads and inflation pressures, and believed that artificial neural network research is necessary for the further development of the system. Bayat et al. [33] compared the three methods of ANN, linear regression, and non-linear regression, used to predict penetration resistance, and demonstrated that ANN has the advantage of higher accuracy for multiple linear regression methods. Taghavifar et al. [34] proposed an optimization algorithm of hybrid artificial neural network and empire competition algorithm for predicting soil compaction, which has good qualitative and quantitative analysis accuracy. Cosanti et al. [35] proposed an innovative method to evaluate the compactness of river embankments.

A lot of progress has also been made in simulation analysis. Li and Schindler [36] used the finite element method (FEM) to analyze soil compaction and tire fluidity, developed two finite element tire models based on the real geometry of Bridgestone tires, and analyzed the influence of axle load and tire pressure on soil compaction. Based on the viscoelasticity of the soil, Zolotarevskaya [37] deduced the regression equation as a function of its density, moisture content, and linear compaction speed, and performed mathematical simulations and calculations on the compaction of the soil under dynamic load conditions. Shoaib and Kari [38] used the discrete element method (DEM) to perform a nonlinear elastoplastic shock wave simulation for high-speed compaction. Ghanbari and Hamidi [39] conducted a simulation analysis on the rapid impact compaction process of loose sand. Xia [40] established an FEM that can simulate the compaction process of the soil and predict the spatial density. Simulation analysis based on this model shows that the proposed large-deformation FEM can flexibly predict the compaction density of the soil. Shangguan et al. [41] presented the application of ANN-based pattern recognition to extract the density information of asphalt pavement from simulated GPR signals.

In general, the prediction methods are mainly based on ANN, linear regression, and non-linear regression to predict the compaction characteristics and compaction situation of soil. Some scholars also used CCC/RICM/IC technology to predict the compaction of the filling materials and interpolated the compactness of the entire work area. The simulation analysis methods typically utilize FEM and DEM to carry out mathematical simulation and calculation analysis on the compaction characteristics of soil under dynamic load conditions. Although the prediction and simulation analysis can provide a certain qualitative or quantitative description of soil–roller interaction as well as soil compaction, it is not time-sensitive, and cannot effectively control and manage compaction quality in real time.

4. Construction Site Supervision

Construction site supervision is usually used to judge whether the compaction quality during construction meets the design requirements [5][6][7][8][9][42]. Supervisors implement project supervision by means of site supervision, witness, site inspection, and parallel test [43][44][45]. The purpose of construction site supervision is to urge the contractor to strictly follow the relevant national laws and regulations, contractual agreements, design documents, and construction specifications to carry out the project construction, to ensure that the non-conforming problems in the construction of the project can be corrected and resolved in time, thereby ensuring achievement of supervision goals. Site supervision is to ensure that the key procedures or key operations meet the requirements of the specification. It embodies the process control, but it is by no means a “single station” for the supervision. Witness is a supervision activity that supervisors can see with their own eyes and can testify, and its essence is the control of key points by the supervisors. Site inspection is the most common and largest supervision method, which focuses on understanding the situation and discovering problems. Parallel test is an activity carried out by the supervisors to conform whether the performance of the project inspection item is qualified, and its essence is the re-examination of the construction quality. Site supervision, witness, site inspection, and parallel test are the four most basic methods of construction site supervision, which is a systematic method structure. For QC/QA of earthwork, construction site supervision is an important and indispensable link.

5. Influencing Factor Analysis

There are many factors in the construction of earthwork that affect its compaction effect. For the sake of ensuring the strong stability and strength of the earthwork, it is necessary to identify and analyze the main factors affecting the compaction effect, and then take targeted control measures to obtain a better compaction effect. Zhang [46] discussed several problems in QC/QA of earth–rock dam, and found that the type of soil, moisture content, and compaction energy have a greater impact on the compaction effect of the soil during construction. Guo [47] analyzed the influence of various factors such as compaction machinery, driving speed, moisture content, strength of the underlying layer, and rolling mode on the compactness of the pavement. Based on the surface vibration compaction method, Guo [48] carried out an indoor compaction test for natural gravel and found that the main factors affecting its compaction effect were the rock content, gradation, and vibration parameters. By monitoring the compaction parameters such as driving speed, the number of compaction times, lift thickness, and the state of the exciting force, Liu et al. [49] evaluated the factors that affect the compaction effect of earth–rock dam. For the soil–rock mixture, Tokiharu et al. [50] used the method of compaction test to study the change of the maximum dry density of the material with the maximum particle size, and the results showed that the two have a linear correlation. In the light of rockfill materials and soil–rock mixtures, Sitharam and Nimbkar [51] carried out research on the effects of different gradations and volume strains on the properties of granular materials. Liu and She [52] carried out compaction tests for different types of soil–rock mixtures, which showed that the compactness of soil–rock mixtures is closely related to compaction energy and compaction methods.

Summarizing the above research, the factors that affect the compaction effect of earthwork can be divided into internal factors and external factors. Specifically, the internal factors mainly include material properties, material type, and the strength of the foundation or underlying layer; the external factors mainly consist of compaction energy, compaction parameters, rolling machinery, compaction mode, and compaction strategy. Under the same compaction energy, the properties or types of materials determining the compaction characteristics of the filling materials are not the same. When other conditions are roughly the same, the main influence on the compaction effect is the moisture content of the materials. If the strength of the underlying layer or foundation is insufficient, the compaction effect of the filling layer will be half the effort. The compaction energy directly affects the compaction quality and construction efficiency of the earthwork, and the appropriate compaction energy will greatly improve the construction efficiency and economy. Other influencing factors attributable to internal or external factors have a greater or lesser effect on QC/QA of earthwork. Regardless of internal or external factors, it is indispensable to analyze the influencing factors related to QC/QA of earthwork.

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