

Roadbed continuous compaction quality testing and settlement difference detection "dual control" practice and methods

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Abstract. The continuous compaction quality testing technology of roadbed is disturbed by many external factors, and improving the accuracy of testing is the key link of construction quality control. With the background of a reclaimed soil roadbed project, the test method for continuous compaction quality control of roadbed was formulated, including the compaction testing test section division and the combination of rolling number of passes as well as the "dual-control" process system; the linear relationship between the VCV value and the sand filling method of compaction testing was verified; the GPS elevation data were compared with the sand filling method to determine the compaction level. 22.264, correlation coefficient $R=0.8781$; through the analysis of variance between GPS elevation data and measured elevation data, the stability of GPS automatic elevation data is determined, and the test data proves that the characterization of roadbed compaction by settlement difference value and VCV detection value has good consistency, and that "dual control" of settlement difference method and VCV value is reasonable. "is reasonable, and gives the 96 area sandwiched with gravel particles of dry stiff clay fill soil roadbed rolling reasonable total number of times for 9 times, VCV reasonable threshold value of 65.30.

Keywords: highway foundations; continuous compaction testing; differential settlement detection; dual control; practice and methodology.

1. Introduction

Roadbed continuous compaction quality control technology is widely used in railroad roadbed compaction, airport foundation compaction, long-distance highway roadbed compaction practice, its high degree of digitization, compaction test reliability, high efficiency, realize from "point detection" to "surface detection", save a lot of manpower and material resources, so by the construction field and research institutes are widely concerned[1]. It saves a lot of manpower and material resources, so it has been widely concerned by various construction fields and scientific research institutes. A large number of scholars at home and abroad have discussed the principle[2,3], evaluation method[4,5,6], construction application[7,8], factor analysis and other aspects[9,10], and corresponding specifications have been formulated at home and abroad[11,12,13]. At present, the continuous compaction quality control system generally uses a single indicator to judge the degree of good or bad compaction quality, and the variability of external factors interferes with and affects the accuracy of compaction quality detection. This paper proposes the concept of "dual control of compaction quality detection and settlement difference detection", which utilizes the compaction system to automatically calculate the settlement difference as the second control index of compaction quality, and combines the "VCV value" with the "VCV value", which is the second control index of compaction quality. This paper proposes the concept of "dual control of compaction quality detection and settlement difference detection", which utilizes the compaction system to automatically calculate the settlement difference as the second control index of compaction quality, and then combines with the "VCV value" to realize the "dual control" of compaction quality and improve the accuracy of compaction quality detection.

2. Continuous compaction quality check test

2.1 Test preparation

The soil source of the soil extraction site near the project site is dry stiff clay, in which gravel particles are interspersed. In accordance with the requirements of the Technical Specification for Highway Subgrade Construction (JTG/T 3610-2019), the natural density of the soil samples was tested to be 1.78g/cm³, the natural moisture content was 15.5%, the liquid limit was 43%, the plastic limit was 23%, and the plasticity index was 20%, and after the CBR test, the result was 8.4, which meets the requirements for roadbed fill. The range of soil source gradation is shown in Table 1.

Table 1. Range of soil source particle composition

Sieve hole size (mm)	53	31.5	19	9.5	4.75	1.18	0.6	0.075
Percentage of quality passed(%)	100	90~100	65~85	-	30~50	-	8~25	0~5

A SINOMACH (Luoyang) LSS32 vibratory roller, which left the factory in 2017, was selected for this continuous compaction test, and the basic parameters of the roller are shown in Table 2.

Table 2. Parameters of LSS32 Vibratory Roller

parameters	value	parameters	value
quality of work	22000Kg	maximum travel speed	10.5Km/h
amplification	1~2mm/weak vibration amplitude	vibrating wheel width	2130mm
vibration frequency	28Hz	vibrating wheel diameter	1600mm
excitation force	380~240kN	diesel engine power	129Kw

2.2 Test site selection and test preparation

The paving smoothness and uniformity requirements of filler in 96 area are higher, which reduces the error of compaction effect due to filler quality and paving smoothness, and the test results can better respond to the real compaction state of filler, and the data results are reliable, so this test selected a project roadbed section K55+460~K55+560 pile 96 area as the test section of compaction testing. The test section is about 100m long, 14.6m wide, and the width of single track rolling area is 2m. the test section is located in the high fill roadbed in the lake area, and the embankment fill is treated with lime. The lime was randomly sampled to test the effective calcium and magnesium content of lime, undissolved residue and other parameters, and the soil source test was carried out to obtain the maximum dry density, optimum moisture content, liquid limit, plasticity index and other important parameters of the soil samples, which were then rolled and graded in layers using the grid method and the method of controlling the unloading of materials by hanging wires to ensure the quality of the road section.

In order to better meet the reliability of the test, this test is set up a total of 3 areas of light compaction area, medium compaction area, heavy compaction area, and its rolling method is carried out according to the 3-area 6-trace flat grinding method, as shown in Fig. 1.

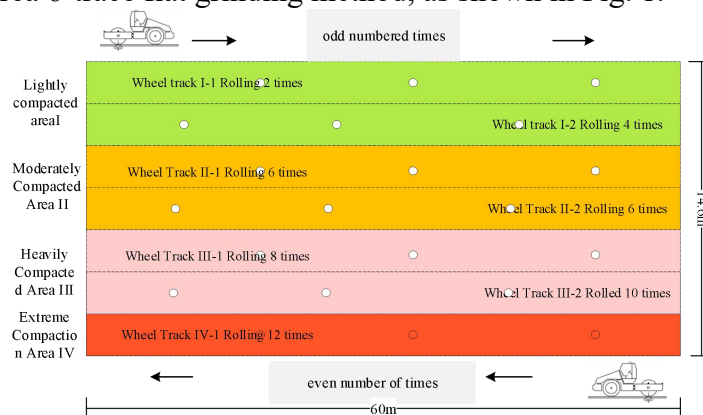


Fig. 1 Compaction test section division

2.3 Pilot program

Before the rolling test, according to the requirements of the test program, use lime to draw the edge line of the corresponding test area and measurement marking points on the site, so that the location of the weak area of rolling quality can be accurately located after the completion of rolling. The rolling is carried out strictly according to the predetermined route, starting from the starting line and ending at the termination line, and the whole process is continuous and even rolling, without braking, shifting, acceleration and deceleration in the middle of the process. In order to facilitate the subsequent data processing, it is required to complete all the rolling in one area and then carry out the rolling work in the next area, and the test process is shown in Figure 2 below. The continuous compaction control system is installed on the roller, which is in the state of movement and vibration, and its accuracy must be affected compared with the static measurement. Before rolling, a marking point is drawn with lime at the center of the wheel track every 5m, and then the elevation coordinates of each point after rolling are measured with the measuring equipment, and then the measured data are plotted into a curve, and compared with the GPS elevation curve collected by the continuous compaction control system, and the mean value and square value are calculated. Compare the measured data with the GPS elevation change curve collected by the continuous compaction control system, calculate the mean value and variance, and then judge whether the accuracy and stability meet the construction requirements. Let the roller equipped with continuous compaction control system start from the starting line position to the end of the termination line position, and the system automatically collects the VCV value and GPS elevation data. After rolling in the four compaction states of light, medium, heavy and extreme rolling, three different points are selected near each wheel track GPS elevation detection point for sand filling method to detect compaction, and a total of six wheel tracks in four rolling areas need to collect 18 sand filling compaction detection points. The continuous compaction testing process is shown in Fig. 2.



Fig. 2 Continuous compaction testing process

2.4 Data Acquisition and Processing

2.4.1 Data Acquisition and Processing of Continuous Compaction Quality Inspection System

In the process of roadbed crushing, the vibrating wheel is simultaneously subjected to the excitation force from the roller itself and the resistance force of the roadbed, and the joint action of the two causes the vibration response of the vibrating wheel. The crushing process of roadbed fill is the formation process of structure, and the soil body is compacted by the vibration compaction of the road roller. Under the known condition of the excitation force exerted by the road roller, the system conducts real-time measurement and processing of the information of the dynamic response of the vibrating wheel by means of the principle of dynamics and signal recognition analysis to get the structural resistance index related to the compaction state of the roadbed (the vibration compaction value of VCV), which is used as the parameter to evaluate the compaction state of the roadbed, thus realizing the assessment of the roadbed compaction state and the vibration response of the vibrating wheel. As a parameter for assessing the compaction state of roadbed, it can realize

the control of the compaction quality of roadbed. The schematic diagram of the excitation system for continuous compaction monitoring is shown in Fig. 3.

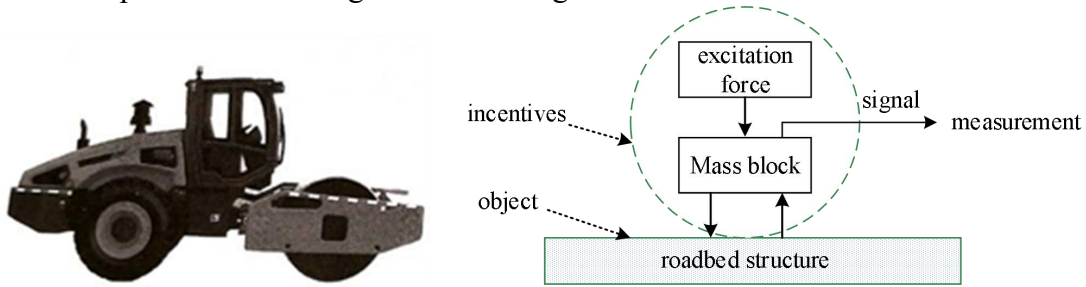


Fig. 3 Schematic diagram of the excitation system for continuous compaction monitoring

$$M\ddot{x} + F(x) = P \sin \omega t \quad (1)$$

Where: M is the vibration mass; p is the vibratory roller excitation force, $p = me\omega^2$, m , e are the eccentric mass and eccentric distance; $F(x)$ is the system resistance, i.e. the reaction force of the pressed structure on the vibrating wheel; x is the measured response value.

At the two ends of the test area, the area before the start line and after the end line belongs to the area where the roller shifts gears and changes lanes, the excitation force of the roller is reduced, the rolling is not uniform, and its compaction value cannot reflect the normal compaction state of the rolling area, and the compaction data of the area is appropriately excluded.

2.4.2 Data acquisition and processing of differential settlement measurements

On the basis of the compaction process monitoring system, the continuous compaction control system adopts the Beidou high-precision positioning technology, and carries out real-time centimetre-level high-precision positioning of the road roller by means of the vehicle-mounted mobile station, the digital transmission radio, the base station receiver, etc., so as to obtain the roller's crushing parameters (including the thickness of the paving layer, the thickness of the grinding, the number of grinding passes, and the running speed, etc.) in the course of the roadbed filling, and to realize real-time construction parameters of the roadbed filling, Realise real-time, continuous and automatic monitoring of roadbed filling construction parameters. The GPS positioning signal received by the continuous compaction control system is the RTK differential signal sent by the base station through the radio station, and its principle and positioning accuracy are the same as that of the RTK equipment used for measurement, only that the roller is in the state of movement and vibration, which may have some influence on its positioning accuracy. The static GPS-RTK positioning accuracy can reach millimetre level.

2.4.3 Sand filling compaction test

The sand filling method compaction test is carried out in accordance with the steps of the specification "Standard for Geotechnical Test Methods" (GB/T 50123-2019). Table 3 is a summary of the test combinations of different wheel tracks in the four regions.

Table 3. Test combinations for different wheel tracks

area	compact state	wheel track	Combination of milling processes			Test combinations
			number of weak oscillations	number of strong oscillations	total number of passes	
I	lightly compacted areas	I-1	1	1	2	VCV value + elevation measurement + sand filling method
		I-2	1	3	4	
II	moderately compacted areas	II-1	1	5	6	
		II-2	1	5	6	
III	heavily	III-1	1	7	8	

	compacted areas	III-2	1	9	10	
IV	Extreme compaction areas	IV-1	1	11	12	

3. Test results and analyses

The compaction system collects 1 data every 1 second, and automatically collects data such as compaction degree, speed, GPS coordinates and travelling direction through the continuous compaction control system, and the equipment extracts part of the data as shown in Fig. 4 and Fig. 5.

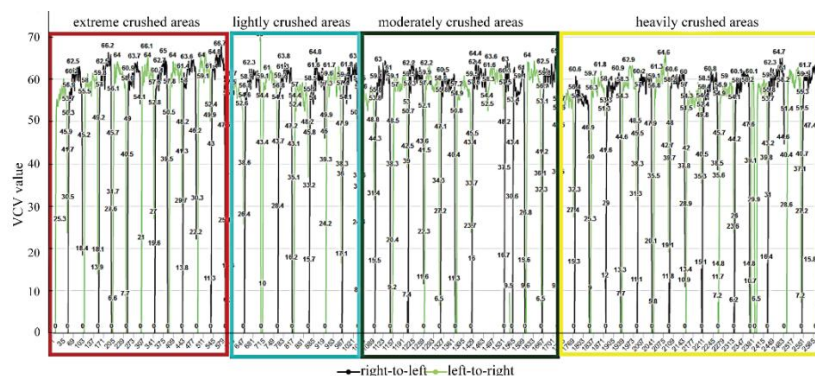


Fig. 4 Output test results of continuous compaction quality inspection system

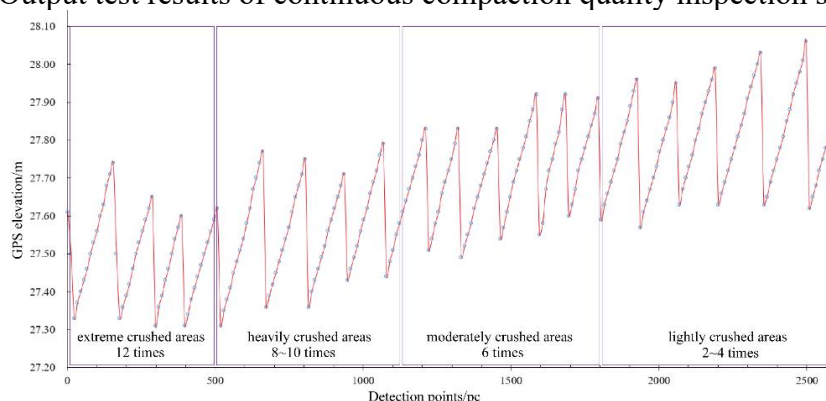


Fig. 5 Elevation change curve of continuous compaction control system

The area at both ends of the test area (before the start line and after the end line) belongs to the roller shift and lane change area, and its compaction value can not reflect the normal compaction state of the rolling area, and after the invalid data at both ends are eliminated, the compaction change curve is shown in Fig. 6.

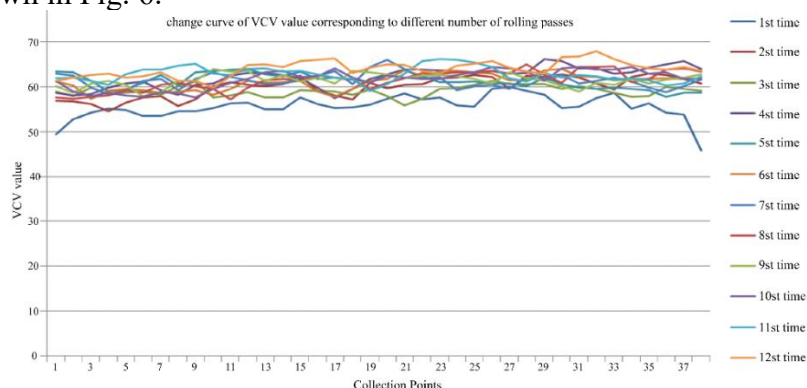


Fig. 6 Variation curve of continuous compaction VCV detection value and the number of compaction passes

3.1 VCV fitted to compaction

According to the field test, the VCV value of continuous compaction quality control index and the compaction value of sand filling method were obtained, as shown in Table 4; according to the least squares method, the correlation coefficient R was obtained from the linear fitting of the two, as shown in Fig. 7[11].

Table 4. Measured values of VCV and compaction for different numbers of rolling passes

Number of compaction passes	detection point	compaction	VCV value	Number of compaction passes	detection point	compaction	VCV value
2	1#	87.30	57.50	8	10#	96.02	66.17
	2#	87.90	59.10		11#	95.73	63.78
	3#	89.50	58.50		12#	95.80	65.89
4	4#	89.43	59.99	10	13#	95.93	66.02
	5#	93.03	60.63		14#	96.10	66.03
	6#	91.31	62.12		15#	96.23	66.30
6	7#	93.85	62.69	12	16#	97.00	66.69
	8#	94.40	62.02		17#	96.79	66.54
	9#	94.25	61.78		18#	96.53	66.23

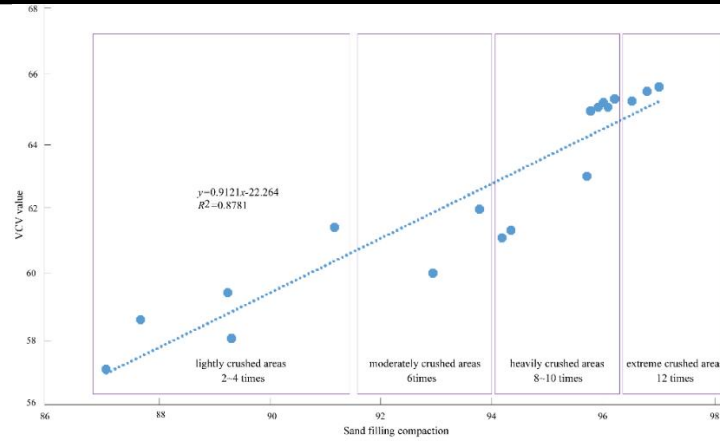


Fig. 7 VCV-compaction fitting curve

From the above linear fitting, it can be seen that the compaction value measured by sand filling method is more dispersed in the light compaction area and medium compaction area, and more intensive in the heavy compaction area and the limit compaction area, i.e., the dispersion of VCV value is larger in the compaction of 1-6 times, and the VCV value is more aggregated in the compaction of 8-12 times, etc. There is a better linear correlation between the VCV value and the compaction value detected by the traditional sand filling method; the functional relationship is as follows: $y = 0.9121x - 22.264$, $R = 0.8781$, where x denotes the compaction value detected by sand filling method, y denotes the VCV value.

Let $x = 96$, $y = 65.30$, theoretically the VCV value is greater than 65.30, that is, it can meet the compaction requirements of 96 area. According to the data in Table 4, the linear interpolation method is used to calculate the reasonable number of times of rolling n . The average value of VCV is 65.28 at 8 times of rolling.

The average value of VCV is 65.28 in 8 times of rolling, and the average value of VCV is 66.12 in 10 times of rolling, and the number of reasonable times of rolling is calculated by linear interpolation method $n = 8 + (66.12 - 65.28) / (66.12 - 65.30) = 8.02$, and the upper integer is 9 times.

3.2 VCV values and settlement difference analysis

3.2.1 Number of compaction passes and settlement difference

The GPS positioning signal received by the continuous compaction control system is the RTK differential signal sent by the base station through the radio station, and its positioning accuracy will be affected by it because the roller is in the state of movement and vibration during the compaction process. Extracting the GPS measurement data and measured data of 14 testing points in the same compaction, and analysing them through variance calculation, it can be found that the variance is 0.0855, and both of them keep better consistency, as shown in Fig. 8, which meets the requirement of measurement accuracy. The GPS elevation received by the continuous compaction control system can be used to replace the measured data for the compaction detection.

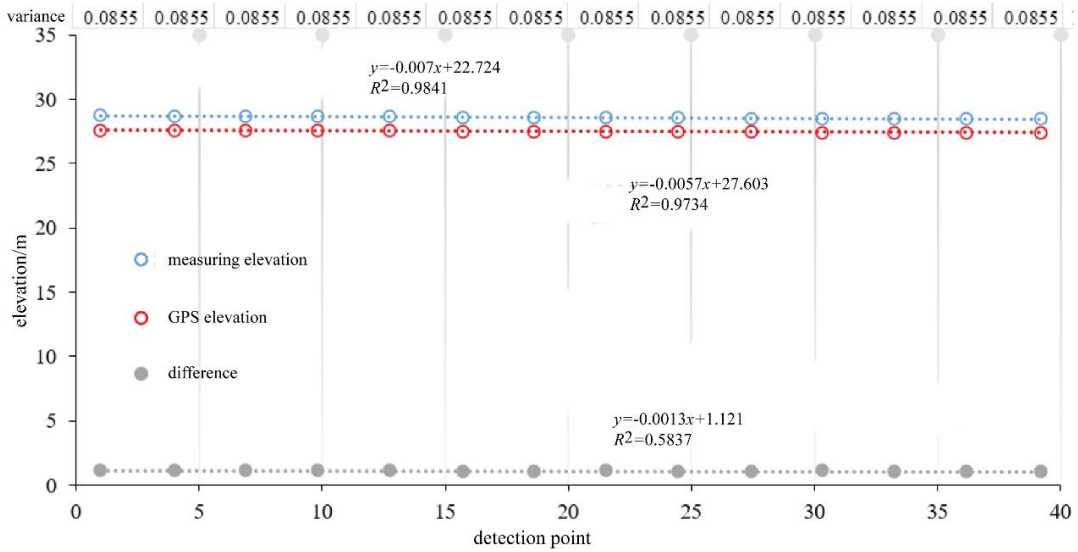


Fig. 8 Error analysis of GPS elevation and measured elevation

3.2.2 VCV detection value and settlement difference

In order to explore the settlement difference method to detect the compaction of the roadbed compaction of the number of compaction, the limit of compaction area randomly take six points for elevation measurement, and calculate the settlement difference value, the average value of the settlement difference, and the standard deviation of the settlement difference value, the results of the measurements and the calculated values are shown in Table 5.

Table 5. Mean and standard deviation of settlement differences

Number of tests	Settlement difference at each observation point (mm)						average value (mm)	standard deviation (mm)
	1#	2#	3#	4#	5#	6#		
weak vibration 1 time	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
strong vibration 1 time	27.20	21.70	13.50	18.80	19.00	12.20	18.73	1.60
Strong vibration 3 times	21.20	22.40	24.40	25.80	24.30	31.40	24.92	1.69
Strong vibration 4 time	2.34	1.89	1.10	1.98	2.34	0.99	1.77	0.02
10th time	1.70	0.80	1.50	1.50	1.70	0.80	1.33	0.01

The observation results show that when the 9th time (VCV value=65.3) its mean value is 1.77mm, standard deviation is 0.15mm, and the 10th time (VCV value=66.12) its mean value is

1.33mm, standard deviation is 0.01mm, which meets the requirement that the mean value is less than 5mm, standard deviation meets the requirement that it is less than 3mm[14], which maintains a good consistency with the VCV value, and the difference in settlement value can be As the second index of continuous compaction quality. With the increase of the number of rolling times, when the soil and stone material reaches or approaches the maximum compaction state, the settlement gradually becomes smaller and tends to be stable, and its compaction quality can be reflected indirectly through the settlement difference method[14].GPS can measure the elevation of each rolling process, and the difference between the latter and the former elevation is the settlement difference method, which is convenient for data acquisition and difference calculation, and it can be combined with the VCV value to realise "double control" of the quality of the continuous compaction of the roadbed. "Double control", the specific process method is shown in Fig. 9 below.

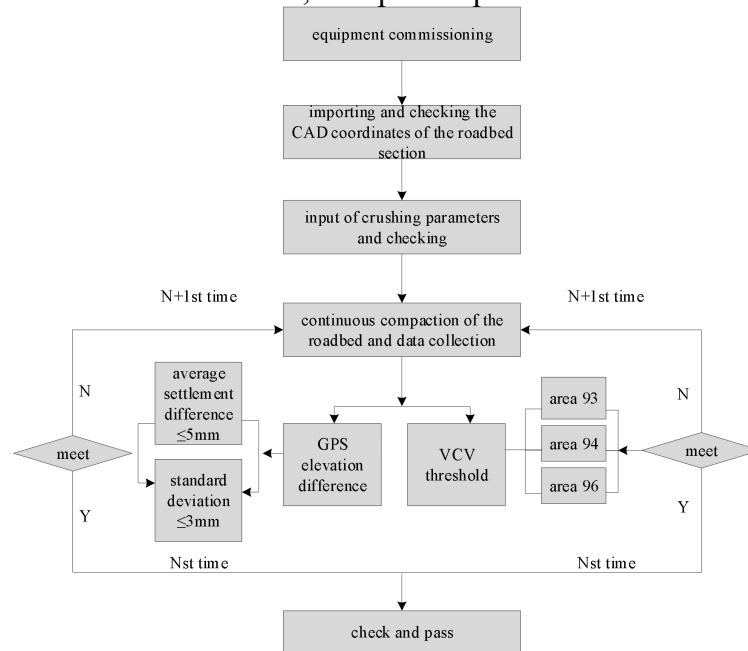


Fig. 9 Continuous compaction "dual control" testing process

4. Summary

(1)The test method for continuous compaction quality control of roadbase was formulated, including the division of compaction test section, the combination of rolling cycles and the "double control" process system;

(2)Verify the linear relationship between VCV value and compaction degree detected by sand filling method, and get the expression $y=0.9121x-22.264$, with the correlation coefficient $R=0.8781$;

(3)Through the analysis of variance between GPS elevation data and measured elevation data, the stability of GPS automatic elevation data is determined, and the test data proves that the characterisation of roadbed compaction by settlement difference value and VCV detection value has good consistency, and that the "dual control" of settlement difference method and VCV value is reasonable, and it gives the results of the 96-area sanding method. The reasonable total number of rolling times for dry stiff clay fill with gravel particles in zone 96 is 9 times, and the reasonable threshold value of VCV is 65.30.

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