



# Study on the Field Vibration Rolling Test of Cohesive Soil Filled in Reservoir

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**Abstract.** The backfill soil in the reservoir area has engineering properties such as high liquid limit, high plasticity index and high water content, so it is difficult to determine the key construction parameters. Combining the nuclear densimeter method and sand filling method, through the indoor compaction test and field compaction test, the relationship between dry density and moisture content, dry density and rolling times, compaction degree and rolling times is analyzed, and the dry density measured by different test methods is fitted and analyzed, so as to determine the construction parameters such as the paving thickness, moisture content, compaction equipment and rolling times of backfill soil. The test results show that when the loose paving thickness is 35 cm and the rolling times is 6, the soil moisture content is between 28.0% and 28.6%, and the compaction degree is 98.9% and 99.5%, which meets the requirements of reservoir filling construction. The moisture content and compactness of soil measured by nuclear densimeter method and sand filling method are close to each other. The test results have a strong correlation, and the determinable coefficient reaches 0.94, which verifies the reliability of the two test methods. The research results have important reference value and scientific significance for guiding the selection of backfill and filling construction in the reservoir area.

**Keywords:** rolling test; cohesive soil; dry density; moisture content

## 1 Introduction

In the construction of water conservancy projects, the soil with high liquid limit, high plasticity index and high water content usually has the characteristics of low gravity, poor stability and low strength. Its filling construction is a complex and challenging technical problem, which has brought many difficulties to the engineering construction. The compaction process of soil can make the soil particles rearrange and close to each other. The pores of large particles are filled with small particles, which increases the number of soil particles per unit volume and reduces the porosity, so as to improve the compactness and shear strength of soil, and reduce the compressibility and permeability of soil. Therefore, soil compaction is one of the key indicators and control indicators of construction quality detection [1]. Yin et al. [2] analyzed the relationship between dry density, rolling equipment, rolling times and porosity of virtual paving thickness

meter in combination with field rolling test, and proposed rolling parameters that meet the design requirements. Duan et al. [3] taking the upper reservoir of changlongshan pumped storage power station as an example, the rolling effect of dam filling material under different amount of water was studied through field rolling test, and the economic and reasonable construction compaction parameters were determined. Zheng et al. [4] monitored the whole process of filling material mining and processing, transportation to the dam, water addition, dam material paving, open bin rolling, sampling test, dry density detection and other links. Combined with the GPS digital monitoring system, they monitored the rolling process remotely and dynamically. The monitoring results showed that the measured dry density and porosity of dam filling met the design requirements. Zhan et al. [5] combined with the field blasting and rolling test, and found that the particle grading that meets the design requirements cannot be obtained only by blasting. Therefore, the dam zoning and filling design parameters of each area are dynamically adjusted. Pan et al. [6] determined the paving thickness, paving method, rolling machines and tools, rolling times, operation speed, water addition and other construction parameters of dam building materials through on-site rolling test for the Loess core sand gravel mixed dam. Zhan et al. [7] designed indoor impact rolling model tests of natural dam materials with different impact wheel mass and traction speed based on the law of similarity, and comprehensively tested the development and propagation law of dynamic stress, deformation characteristics, particle movement and reinforcement effect after impact rolling by macro and micro methods. Xu et al. [8] demonstrated and analyzed the rationality of rockfill blasting excavation parameters and design technical requirements of asphalt concrete core dam through on-site rolling test, and determined the economic and reasonable construction parameters that meet the design filling and compaction standards. Zhu et al. [9] used GPS monitoring system to monitor the compaction parameters of filling dam materials in real time, effectively controlled the construction parameters of dam filling and compaction process, and reduced the impact of human factors on construction quality. Liu et al. [10] established a multi-objective optimization model of compaction parameters that comprehensively considered the construction efficiency, compaction density and quality assurance of earth rock dams based on the quantitative analysis of the impact of compaction parameters on the compaction quality of earth rock dam materials through the orthogonal test of compaction, and proposed a t-distribution variation fireworks algorithm for solving the optimization model to determine the economic and reasonable compaction parameters.

According to the special engineering properties of the reservoir filling soil, in order to clarify the technical parameters such as the water content control, laying thickness, compaction equipment, rolling times and construction detection of the filling soil in the construction process, indoor compaction test and on-site rolling test were carried out for the filling soil, so as to determine the key technology of filling construction of high liquid limit, high plasticity index and high water content soil.

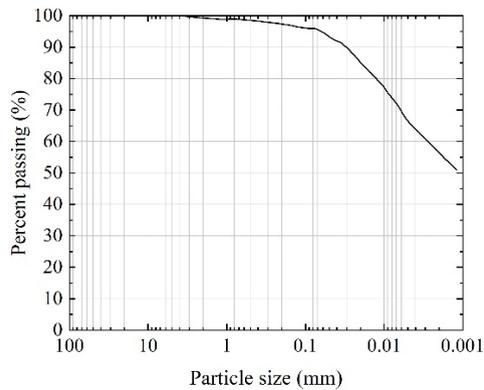
## 2 Materials and Methods

### 2.1 Test Materials

According to the filling design requirements, the backfill is high liquid limit clay, and its main physical properties are shown in Table 1. It can be seen from Table 1 that the liquid limit (WL) and plastic limit (WP) of backfill soil reach 83% and 33% respectively. Figure 1 shows the grading curve of the backfill. It can be seen from the figure that the content of particles less than 0.075 mm in the backfill accounts for 97%, the plasticity index (IP) is 50%, and the backfill is defined as clay.

**Table 1.** Physical property indicators of backfill soil.

Liquid limit $w_L(\%)$	Plastic limit $w_P(\%)$	Plasticity index $I_P(\%)$	Free swelling ratio $\delta_{ef}(\%)$	Carbonate content $\omega(\%)$
83	33	50	145	15.21



**Fig. 1.** Grading curve of backfill soil.

Figure 2 shows the monthly surface temperature curve of the project area from 1991 to 2020. It can be seen from the figure that the local climate is Mediterranean, hot and dry in summer, mild and rainy in winter. The monthly average temperature is above 13°C, and the high temperature leads to large evaporation. According to the indoor compaction test of the filling soil, the compaction curve of the backfill soil is obtained, as shown in Figure 3. The maximum dry density of backfill is 1303 kg/m<sup>3</sup>, and the optimal water content is 28.9%.

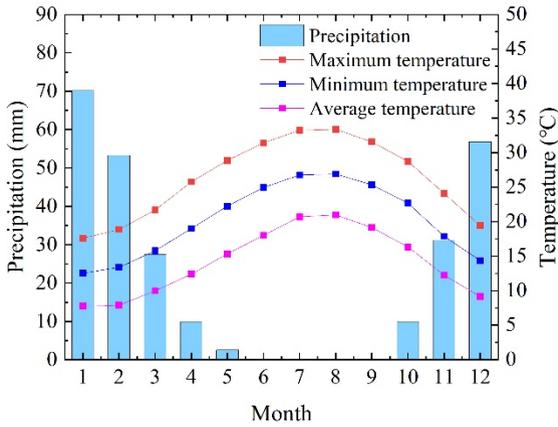


Fig. 2. Monthly surface temperature and precipitation.

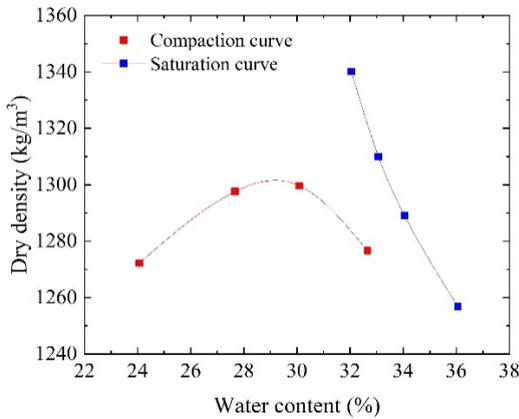


Fig. 3. Backfill soil compaction curve.

## 2.2 Test Equipment

According to the characteristics of the project, in order to ensure the smooth implementation of the construction task, the main allocation of labor force for the rolling test is shown in Table 2.

Table 2. Rolling test equipment.

Mechanical equipment	Type	Number	Notes
Hydraulic backhoe	VOLVO EC380	1	
Dump truck	VOLVO A25	2	Quarry mining and transportation

Bulldozer	VOLVOEC950F	1	
Self propelled convex vibration roller	BOMAG	2	
Total station	TS09	1	
Leveling instrument	Dna03	1	
Geotechnical experimental instruments		1	
Multi functional sprinkler truck		1	Self dumping truck modification

### 2.3 Test Method

The clay material used in the rolling test comes from the excavation scope of the upper and lower reservoir basins. The rolling test requires a total of 4000 m<sup>3</sup> of clay material. The test site is 80 m long and 30 m wide. It is divided into three test areas (area a, area B and area C). A 4 × 4 m square grid is arranged in each test area to measure the compaction settlement. Table 4 shows the rolling test scheme. The rolling parameter combination adopts the gradual convergence method, i.e. keeping other parameters unchanged, changing one of the parameters, obtaining the optimal value of the parameter through the test, and so on, and finally re checking the test with all the optimal parameters. When the test results meet the design requirements, the combination of rolling parameters will be taken as the construction parameters. Combined with the rolling equipment and construction technology, the loose paving thickness of the rolling layer is preliminarily determined as 25 cm, 25 cm, 30 cm, 30 cm, 35 cm and 35 cm, and the moisture content is controlled within the range of -3% to +2% of the optimal moisture content. The 20 t bump vibratory roller is selected as the rolling equipment. The rolling times are 4, 6 and 8, and the rolling speed is 2~3 km/h. The rolling experiment scheme is shown in Table 3.

**Table 3.** Rolling experiment scheme.

Number	Laying thickness (cm)	Water content (%)	Vibrating roller	Rolling numbers (N)	Rolling method
Foundation	Clay surface after surface stripping	Natural water content	20t convex vibration roller	8	Whole area vibration compaction
First	25	OMC-3%~ OMC+2%	20t convex vibration roller	4	Area a: vibration pressure
				6	Area b: vibration pressure
				8	Area c: vibration pressure
				4	Area a: static pressure twice, vibration pressure twice
Second	25	OMC-3%~ OMC+2%	20t convex vibration roller	6	Area a: static pressure twice, vibration pressure four times
				8	Area b: static pressure twice, vibration pressure six times
				8	Area c: static pressure twice, vibration pressure six times
Third	30	OMC-3%~	20t convex	4	Area a: vibration pressure

		OMC+2%	vibration roller	6	Area b: vibration pressure
				8	Area c: vibration pressure
				4	Area a: static pressure
					twice,vibration pressure twice
					Area b: static pressure
Fourth	30	OMC-3%~	20t convex	6	twice,vibration pressure four
		OMC+2%	vibration roller		times
				8	Area c: static pressure
					twice,vibration pressure six
					times
				4	Area a: vibration pressure
Fifth	35	OMC-3%~	20 t convex	6	Area b: vibration pressure
		OMC+2%	vibration roller	8	Area c: vibration pressure
				6	Area a: static pressure
					twice,vibration pressure twice
					Area b: static pressure
Sixth	35	OMC-3%~	20t convex	8	twice,vibration pressure four
		OMC+2%	vibration roller		times
				8	Area c: static pressure
					twice,vibration pressure six
					times

### 3 Results and Analysis

#### 3.1 Analysis of Rolling Test Results

According to the rolling test scheme in Table 4, the rolling parameter combination adopts the gradual convergence method, and finally rechecks with all the optimal parameters. In order to ensure the reliability of the test results, the moisture content and dry density of the soil after rolling are measured by nuclear densimeter and sand filling method respectively. The compaction degree is the ratio of the dry density of the field rolled clay to the maximum dry density obtained from the compaction test. Table 4 shows the test results of nuclear densimeter method and sand filling method. It can be seen from Table 4 that for the nuclear densimeter test results, when the rolling times are 6 and the soil moisture content is 28.0%, the compaction degree is the maximum, reaching 99.5%. For the test results of sand filling method, when the rolling times are 6 times and the soil moisture content is 28.1% and 28.6%, the compaction degree is the maximum, reaching 99.3%. The moisture content and compactness of the test piece measured by nuclear densimeter method and sand filling method have little difference, indicating that both methods can better test the effect of rolling test. When the number of rolling passes is 6, under the same degree of compaction, the water content detected by the sand filling method is less than that measured by the nuclear densitometer method, which may be because the sand filling method is easily affected by the environmental conditions such as the temperature of the on-site base

course, and its water content may have deviation, resulting in the smaller test results. The compaction standard of soil material is not that the more compacted the soil material is, the better the compaction is. The more compacted the soil material is, the more severe the test can be withstood by the built dam, and the more guaranteed the filling quality of the dam body. However, the over compaction of soil not only increases the compaction cost, but also produces shear failure, which can not achieve the desired technical and economic effect. To sum up, when the thickness of covering soil is 25 cm, 6 times of vibration pressure is the optimal combination of technical parameters; When the thickness of soil cover is 30 cm, the optimal combination of technical parameters is static pressure twice and vibration pressure four times; When the thickness of soil is 35 cm, 6 times of vibration pressure is the optimal combination of technical parameters.

**Table 4.** Nuclear density meter and sand filling method test records.

Number	Soil thickness (cm)	laying Roller numbers	Nuclear density meter method			Sand filling method			Settlement (cm)
			passes Roller content (%)	Water density (kg/m <sup>3</sup> )	Dry Compaction degree (%)	Water content (%)	Dry density (kg/m <sup>3</sup> )	Compaction degree (%)	
First	25	4	28.9	1285	98.6	29.0	1283	98.5	2.0
	25	6	28.5	1295	99.4	28.6	1294	99.3	5.0
	25	8	27.9	1300	99.8	28.0	1299	99.7	5.1
Average value			28.4	1293	99.3	28.5	1292	99.2	4.0
Second	25	4	29.3	1275	97.9	29.5	1270	97.5	2.3
	25	6	28.2	1290	99.0	28.3	1287	98.8	4.5
	25	8	27.8	1301	99.8	27.7	1300	98.9	5.0
Average value			28.4	1289	98.9	28.5	1286	99.4	3.9
Third	30	4	28.7	1287	98.8	28.9	1285	98.6	4.0
	30	6	28.3	1289	98.9	28.4	1288	98.8	7.0
	30	8	27.7	1299	99.7	27.9	1301	99.8	7.0
Average value			28.2	1292	99.1	28.4	1291	99.1	6.0
Fourth	30	4	28.2	1291	99.1	28.3	1289	98.9	4.5
	30	6	28.0	1296	99.5	28.1	1294	99.3	7.0
	30	8	27.8	1300	99.8	27.9	1299	99.7	7.1
Average value			28.0	1296	99.5	28.1	1294	99.3	6.2
Fifth	35	4	28.9	1286	98.7	29.0	1289	98.9	5.0
	35	6	28.3	1288	98.8	28.4	1290	99.0	7.5
	35	8	28.0	1295	99.4	28.1	1292	99.2	7.8
Average value			28.4	1290	99.0	28.5	1290	99.0	6.8
Sixth	35	4	28.7	1286	98.7	28.8	1284	98.5	5.0

35	6	28.3	1290	99.0	28.4	1287	98.8	7.3
35	8	27.9	1295	99.4	28.0	1293	99.2	7.4
Average value		28.3	1290	99.0	28.4	1288	98.8	6.6

### 3.2 Correlation Analysis of Test Results

In order to compare the difference and correlation between the nuclear densitometer method and the sand filling method to obtain the dry density of backfill, the least square method is used to analyze the correlation of the test data in Table 4. As shown in Figure 4, taking the dry density data measured by the nuclear densitometer method as the abscissa and the dry density data measured by the sand filling method at this point as the ordinate, the least square method is used for data fitting, which can well draw a straight line. It can be seen from the figure that the test data points are not discrete enough and are evenly distributed on both sides of the straight line. The determinable coefficient of the fitted straight line reaches 0.94, indicating that the two methods have a strong correlation, which verifies the reliability of the test method.

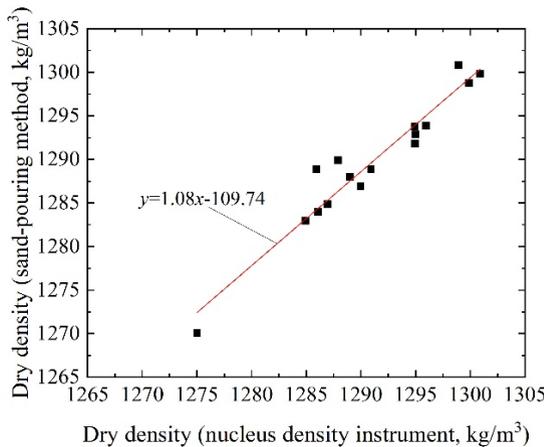
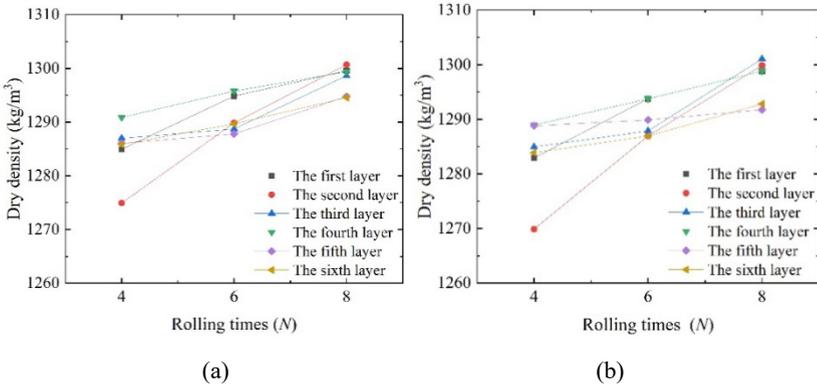


Fig. 4. Dry density fitting curves of different measurement methods.

### 3.3 Comparative Analysis of Test Results

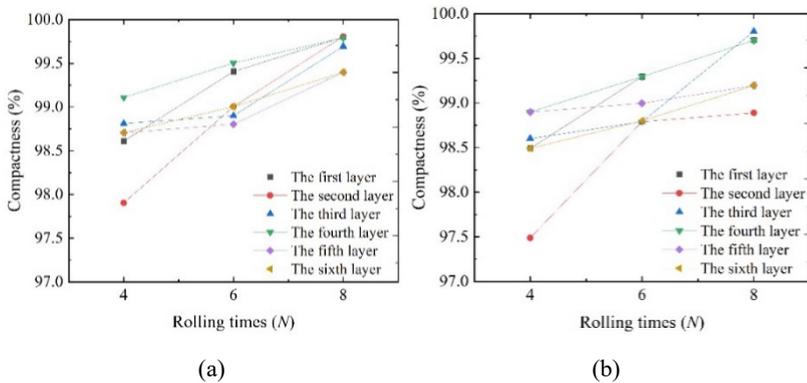
See Figure 5 for the relationship curve between the dry density of backfill soil and the number of rolling passes under the nuclear densitometer method and sand filling method. It can be seen from the figure that from the dry density of the ground material, the variation range of dry density measured by nuclear densitometer method is 1275~1301 kg/m<sup>3</sup>, and the variation range of dry density measured by sand filling method is 1270~1301 kg/m<sup>3</sup>. The dry density of backfill increases with the increase of rolling times, and reaches the maximum when rolling for 8 times. It can be seen from Table

4that when the soil is rolled for 8 times, the water content is too low, so the best rolling times for the test is 6 times.



**Fig. 5.** Relationship curve between dry density and rolling times ((a)nucleus density instrument method; (b)sand-pouring method).

See Figure 6 for the relationship curve between the dry density of backfill soil and the number of rolling passes under the nuclear densimeter method and sand filling method. It can be seen from the figure that the compactness of the rolled sample varies from 97.9% to 99.8% measured by the nuclear densimeter method and 97.5% to 99.8% measured by the sand filling method. The compaction degree increases with the increase of rolling times. When rolling for 8 times, the compaction degree of each layer of soil reaches the maximum. Considering the actual construction situation on site, the best rolling times obtained from the test is 6 times. The test results in Fig. 4 and Fig. 5 can be mutually corroborated.



**Fig. 6.** Relationship curve between compactness and rolling times((a)nucleus density instrument method; (b)sand-pouring method).

According to Section 4.2.1 of the owner's technical terms, the dry density of the filling layer after rolling during dam filling shall not be less than 95% of the standard proctor's maximum dry density, and the average dry density of three consecutive layers shall not be less than 98% of the standard proctor's maximum dry density. The indoor compaction test shows that the maximum dry density of soil is 1303 kg/m<sup>3</sup>, and the optimal water content is 28.9%. For the nuclear densimeter method, when the rolling times are 6, the soil moisture content is between 28.0% and 28.5%, and the soil compaction degree is 98.9% to 99.5%. For the sand filling method, when the rolling times are 6, the soil moisture content is between 28.1% and 28.6%, and the soil compactness is 98.8% to 99.3%, which can meet the requirements of reservoir filling construction.

## 4 Conclusions

(1) According to the indoor compaction test results, the maximum dry density of backfill material is 1303 kg/m<sup>3</sup>, and the optimal water content is 28.9%. According to AASHTO m-145-91 (2000) specification, the backfill can be named as a-7-5 high liquid limit plastic clay in combination with particle grading, liquid limit and plasticity index.

(2) The rolling test results show that when the rolling times are 6 times and the soil moisture content is between 28.0% and 28.6%, the soil compaction degree is 98.9% to 99.5%, which meets the requirements of reservoir filling construction.

(3) When the thickness of covering soil is 25 cm, 6 times of vibration pressure is the optimal combination of technical parameters; When the thickness of soil cover is 30 cm, the optimal combination of technical parameters is static pressure twice and vibration pressure four times; When the thickness of soil is 35 cm, 6 times of vibration pressure is the optimal combination of technical parameters.

(4) The moisture content and compactness of backfill soil measured by nuclear densimeter and sand filling method are basically the same. The dry density measured by the two methods is fitted by the least square method, and the determinable coefficient is 0.94, which shows that the test results of the two methods have a strong correlation, which verifies the reliability of the test method.

(5) During construction in summer and rainy season, water content control is very important to ensure the stability and engineering quality of the filling dam. When water needs to be added to the soil material, the sprinkler head can be used to sprinkle water directly or the mobile high-pressure jet gun and large tonnage sprinkler can be used to sprinkle water; When the soil is wet, the paver can be used to loosen and dry the soil until the moisture content meets the requirements before rolling.

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