Study on Compaction Characteristics and Construction Control Index of Gravel Materials in a Core Wall Dam

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Abstract: Gravel materials are widely used in dam engineering in western China due to their excellent engineering characteristics such as high compaction density, high shear strength and strong water permeability. The compaction standard of gravel materials is evaluated by the relative density index. Therefore, after a reasonable compaction standard is determined, the next most critical link is the control of construction filling quality. Based on the results of field rolling tests, this paper analyzes the basic influence laws of gravel content, paving thickness, rolling times and water content on the compaction dry density and relative density of gravel materials, and studies the basic compaction characteristics of gravel materials, and determines the construction compaction parameters based on satisfying the design compaction standard. By controlling the gradation, rolling parameters and water content of dam construction gravel materials, the filling quality of dam construction can meet the design compaction standard, so as to ensure the safety and stability of dams.

1. Introduction

As a cohesionless coarse-grained material, gravel has a series of excellent engineering characteristics, such as strong water permeability, high shear strength, large compaction density and small subsidence deformation. Generally, there are enough reserves near the dam site, so gravel materials are more and more widely used in the main filling of the dam. Therefore, the quality control of gravel filling is particularly important [1-2]. In the vast areas of China, especially in Xinjiang, natural gravel materials are widely distributed in riverbeds and Gobi deserts, and the reserves are very rich [3]. In the rapid development of local material dam construction, it is an important principle to design gravel dams according to local conditions and local materials. Compared with rock blasting (or excavation) rockfill materials, natural gravel materials have low mining, transportation and construction costs, which can greatly save construction funds. They are good materials for high-face dams and have broad application prospects [4]. The compactness of the soil has an important influence on its deformation characteristics, strength characteristics, permeability characteristics and seismic dynamic characteristics [5]. The main engineering problem faced by high-face dams is the deformation control of the dam body. R J MRRASL and T Mogami et al. [6-8] have done corresponding research on the strength index and stress-strain law of rockfill materials, and believe that gravel filling materials have great advantages in controlling dam deformation. Generally speaking, the higher the compactness of
soil, the more favorable the engineering characteristics are to the structural safety and stability of geotechnical structures. Especially for the dam body deformation, which is a safe control condition of high-face dams, the dam body deformation characteristics can be better controlled by controlling the filling compactness of the dam body.

In engineering, the relative density index is generally used to control compaction quality, which can reflect the compactness of coarse-grained materials better than the compaction degree [9]. When the dam compaction standard is determined, the goal of filling quality control in dam construction has been determined, and the practical engineering problems have become to adopt economical and reasonable rolling methods and parameters to roll the dam materials in order to meet the dam design compaction standard. On the one hand, the rolling test studies the rolling parameters of dam filling; on the other hand, because the gradation and compaction parameters play a key role in the compaction density of gravel materials, the rolling test also plays the role of checking design gradation and loading gradation to check the material source quality. With the remarkable improvement of the working range and performance of construction machinery in recent years, it has become possible to reach the rolling standard that was previously considered impossible, and there are more rolling methods to choose, such as the type of rolling machine, the number of rolling times, the way of moving, the thickness of paving and the water content of dam materials. Different rolling methods have different effects on the economic benefits of engineering. Moreover, the engineering characteristics of different soil materials are significantly different, so it is difficult to widely apply the experience of certain or more projects, and it is necessary to carry out special research. In a word, for the determination of gravel materials compaction mode and parameters in a particular project, it is necessary to consider the double influence of dam filling standard and economic benefit, and to ensure dam filling quality and safety.

2. Test program and process

In this paper, the field rolling test was carried out on the gravel material of a water conservancy project in Xinjiang, and the specific test program and process is as follows:

1. Site preparation: Select a large area near the material source, which has a solid foundation and relatively flat surface. Use a bulldozer or loader to level the site, and then use a vibration flat roller to compact to ensure that the height difference of the whole field does not exceed 20cm, and the local height difference does not exceed 5cm, and the surface settlement of the field is less than 2mm after rolling twice.

2. Material source selection: In order to ensure the overall representativeness of the selected material yard and the test material, according to the results of the previous material yard exploration, the soil material screening test is carried out on the typical soil material of the selected material yard to determine that the gradation curve of the soil material in the material field is within the design envelope line, and the material source meets the test requirements.

3. Loading and paving: The loading of the test rolling layer is generally carried out by the advancing method. The loading and unloading of the test material are completed by dump trucks, and the gravel material is paved and leveled by bulldozers and loaders. After leveling, the thickness of uncompacted paving need to keep 5~10cm more than that of the planned paving after rolling. During the paving process, the paving thickness of the test soil material is controlled by the bubble level and the benchmark. After the thickness and flatness of the soil layer meet the requirements, the test area is statically rolled twice with a vibrating roller, and then marked with a white lime line as the boundary of the different test areas and various marks.

4. Sprinkling water and rolling: Sprinkle water quantitatively and evenly in the sprinkling test area, and then roll it immediately according to the predetermined rolling plan. The rolling adopts the strong vibration rolling mode, and the speed of the rolling vehicle is controlled at 2~3km/h, and the traveling method adopts the forward and backward staggered distance method. One back and forth of the same rolling strip is counted as rolling twice. When the next rolling strip is rolled, it needs to overlap with the previous rolling strip, and the rolling overlap width is controlled at about 20cm. During the change of forward direction and strip conversion, the rolling vehicle begins to vibrate at least 2m from the
outer side line of the test site to ensure the full compaction of the test area.

(5) Pit detection: Four points are selected in each working condition area to excavate test pits, and all the excavated test materials are weighed. After the excavation is completed, the irrigation method is used to measure the volume of test pits. The excavated test material is subjected to particle screening and water content sampling inspection on site. The dry density and gravel content of each test pit are sorted out and calculated by the test results, and then converted into relative density by the formula to evaluate whether each rolling parameter combination meets the design compaction standard.

(6) Proof test: According to the above-mentioned comprehensive rolling test results, select 2 to 3 working conditions that meet the design compaction standards for proof tests, repeating the above test process to ensure the pass rate of the rolling test pit.

The technical roadmap of field rolling tests is shown in figure 1.

3. Results and analysis

3.1. The effect of gravel content on compaction characteristics
Combining with the results of the digging test of the roller compaction test, it can be seen that the gradation has an important effect on the compaction characteristics of gravel materials. The compaction effect of different gravel contents is obviously different. The gravel materials with good gradation have better compaction effects and are easy to be compacted. It can be seen from figure 2 that when the gravel content of test pits increases from 69% to 76%, the overall average compacted dry density value gradually increases; when the gravel content continues to increase, the overall average compacted dry density value of test pits begins to decrease. It can be preliminarily considered that the optimal gravel content for the gravel material of this material yard is about 76%. Therefore, under the condition of deviating from the optimal gradation, the relative density of soil after compaction will be much lower than that of the optimal gradation even if it meets the design requirements. For such dam materials, although it is acceptable from the point of view of compaction, the relatively low absolute dry density will inevitably make the stress deformation characteristics and

![Figure 2. The relationship between the gravel content and the dry density of gravel materials.](image)

strength characteristics low. This is also a problem that should be considered in the design of dam
materials gradation control envelope. Therefore, controlling the gradation of dam materials has an important effect on ensuring the compaction quality of dam filling.

3.2. The influence of paving thickness on compaction characteristics

Figure 3 shows the relationship between the paving thickness and the compacted dry density and relative density of gravel materials. According to Figure 3, it can be seen that the compacted dry density and relative density of gravel materials decrease as a whole with the increase of the paving thickness regardless of whether water is added or not. This is mainly because the compaction effect of the vibration roller decreases with the increase of the depth of the material layer. The larger the paving thickness is, the worse the compaction effect on the bottom is, which leads to the decrease of the overall dry density and relative density. However, under some conditions, the dry density of the 80cm paving thickness is larger than that of the 60cm paving thickness. This is because the better gradation of some test pits in the 80cm paving thickness area. On the whole, the difference of dry density and relative density between 60cm and 80cm is less than that of 80cm and 100cm, so the paving thickness is not smaller or larger, but the appropriate thickness should be determined by considering all factors. If the paving thickness is too small, although the compacted dry density is easy to meet the filling standard, it is unfavorable to the economic cost and construction period. If the paving thickness is too large, it is not easy to make the dry density reach the compaction standard, and the safety and stability of dams cannot be guaranteed.

![Figure 3](image)

3.3. The influence of rolling times on compaction characteristics

It can be seen from Figure 4 that with the increase of rolling times, the relative density of gravel materials increases. For the same paving thickness, when rolling times increase from 6 to 8, the relative density of compaction has a significant increase. Especially when the paving thickness is 80cm and 100cm, the relative density increases greatly, close to 10%. When rolling times increase from 8 to 10, from 10 to 12, the increase of relative density is greatly reduced, only about 3%, indicating that as rolling times increase, the relative density of gravel materials tends to stabilize. This is mainly due to the fact that there are a large number of voids in the gravel materials. When rolling times are small, the skeleton voids formed by the coarse particles are not completely filled by the fine particles. As rolling times increase, the voids of gravel materials are filled more and more densely, and the relative density will also tend to be stable. Similarly, if rolling times are too small, it is not easy to compact dam materials and meet the compaction standard. If rolling times are too large, although it can absolutely ensure that the filling quality of dam materials meets the requirements of the compaction standard, it is not economical. Therefore, in the actual project, the appropriate rolling times must be selected not only to ensure that the filling quality of dam materials reaches the compaction standard, but also to consider the construction period and economic feasibility.
3.4. The influence of water content on compaction characteristics

According to figure 3 and figure 4, it can be seen that the water content has a significant impact on the filling and compaction of gravel materials. The dry density and relative density of water compaction under the same paving thickness and rolling times are much larger than those without water. The main reasons are as follows: the natural average water content of gravel materials is 1~3%, and there is the water molecular attraction between particles of gravel materials in this range. When the particles are rearranged under the vibration load, the attraction between water molecules need be overcome, so the compaction effect is the worst. When the added water reaches 15% of the volume ratio, the water content of gravel materials tends to be saturated, and the attraction between water molecules disappears, and the particles are completely covered by water molecules, which can make the particles more lubricated and easier to be compressed when they are rearranged.

4. Research on the quality control of gravel materials filling

4.1. Determination of construction rolling parameters

According to the design compaction standard ($Dr \geq 0.85$), the relative density index pass rate of the comprehensive rolling tests of multi-condition combination at the first stage is shown in table 1. The following conclusions can be drawn from table 1: (1) When the paving thickness is 60cm, not all the relative density index of the test pits without water in the four different rolling times is up to the standard, and when the water content reaches 15%, the relative density index of all the test pits in the four different rolling times meet the design standard. (2) When the paving thickness is 80cm, not all the relative density index of the test pits without water in the four different rolling times is up to the standard. In the case of adding water, one test pit in the 6 rolling times fails to meet the standard, and all test pits in the other three different rolling times meet the standard. (3) When the paving thickness is 100cm, the relative density index of all pits can meet the standard only when water is added and rolling times reach more than 10. In other conditions, some test pits fail to reach the standard.

After the preliminary judgment in the first stage, it is believed that the relative density of all test pits under the conditions of paving thickness of 80cm, adding water 15%, rolling 8 times and paving thickness of 80cm, no water added, rolling 10 times can meet the design compaction standard. Therefore, in actual construction and filling, the first recommended rolling parameters are: paving thickness of 80cm, adding water 15%, and rolling 8 times. If the actual construction does not have the condition of adding water during large-scale filling, the rolling parameters that can be used are: paving thickness of 80cm, no water added, and rolling 10 times.

60cm (0) stands for the paving thickness of 60cm, sprinkling water rate of 0. Dr(A) stands for the average relative density. QN/QR stands for the qualified number/qualified rate.
Table 1. Rolling test pits compaction standard qualification rate table.

| working condition | 60cm (0) | 60cm (15%) | 80cm (0) | 80cm (15%) | 100cm (0) | 100cm (15%) |
|-------------------|----------|------------|----------|------------|-----------|-------------|
| 6 times           | 0.829    | 1/25%      | 0.898    | 4/100%     | 0.784     | 1/25%       |
| 8 times           | 0.843    | 2/50%      | 0.934    | 4/100%     | 0.836     | 1/25%       |
| 10 times          | 0.854    | 2/50%      | 0.943    | 4/100%     | 0.869     | 3/75%       |
| 12 times          | 0.914    | 3/75%      | 0.953    | 4/100%     | 0.891     | 3/75%       |

Table 2. Qualification rate table of proof test pits compaction standard.

| pits number       | 1       | 2       | 3       | 4       | 5       | 6 |
|-------------------|---------|---------|---------|---------|---------|---|
| 80cm, 15%         | qualified or not | qualified | qualified | qualified | qualified | qualified |
| 80cm, 15%         | qualified | qualified | qualified | qualified | qualified | qualified |

4.2. Dam materials gradation control

According to the results of the above rolling test, it can be seen that the gravel materials with good gradation have a better compaction effect and can be compacted easily. Therefore, it is important to control the gradation of the loading dam materials to ensure the quality of the dam rolling compaction. On loading materials in the stockyard, pay attention to avoid loading over-diameter particles, and try to ensure the uniformity of dam materials loading, and avoid the separation of coarse and fine particles. When the material source is found to be poorly graded, it should be stripped in time, and loading on the dam is prohibited. The dam materials that have been filled on the dam should be guaranteed to be uniformly discharged and spread to avoid the separation of coarse and fine materials.

4.3. Rolling parameters control

According to the rolling construction parameters determined in the first-stage comprehensive rolling test and the second-stage proof rolling test, the paving thickness should be strictly controlled during construction, and the thickness of uncompacted paving should not exceed 90cm, and the rolling times should be guaranteed.

As far as the water content is concerned, in actual engineering, we generally encounter three kinds of materials with different water contents: (1) The first type is dry materials. The source site is located on the high terraces on both sides of the river channel, at a certain height from the water surface line of the existing river channel, and the internal groundwater level is low. The material source is basically in a dry state, and the water content generally ranges from 0 to 1%. (2) The second type is dry and wet materials. The source site is near the existing river channel, and the difference between the altitude and the water surface line of the river channel is not large. The groundwater level partly passes through the material layer, and the water content is often near the compaction valley point, and the general range is 2~5%. (3) The third type is saturated materials. The height of the source site is basically the same as the existing river channel, and part of the materials are soaked in water, and the water content is saturated or supersaturated.

Many dam material source sites are located on non-existing river beds (all levels of terraces), and their gravel materials are often in a relatively dry state because they are not affected by river water. The compaction effect of gravel materials in the dry state is better, and the construction efficiency is higher, especially in winter. For gravel materials with a large water content close to saturation, it is also easy to be compacted in the actual engineering, and the compaction effect is better than that of dry and wet materials, so it can be directly rolled on the dam. For gravel materials with super-saturated water content whose material source is below the water level, appropriate drainage measures can be taken during transportation to reduce the water content of the loading dam material, which can reduce
the drainage volume of the dam body during the dam construction. For some projects, the gravel materials for dam construction are mainly taken from the current river bed. Due to the influence of seasonal floods and groundwater, the natural water content of the soil materials in the yard varies greatly, such as the Altash concrete face dam. The water content of the gravel materials in this type is in a range that is not easy to compact. If the gravel materials are mined and dried to reach a dry state, this construction method is obviously inappropriate in terms of the economic cost and construction period. Therefore, in order to eliminate the uneven water state of dam materials and ensure the compaction quality of dam materials, it is necessary to sprinkle water on the dam materials when the water state of the material yard cannot be accurately determined and distinguished.

5. Conclusions
Main conclusions are drawn as follows:
(1) The on-site rolling test process mainly includes the following steps: site preparation-material source selection-site leveling-loading and paving-sprinkling and rolling-digging inspection-proof test-sorting out data.
(2) The gravel content has an important influence on the compaction effect of gravel materials. As the gravel content increases, the dry density and relative density increase. When the gravel content reaches about 76%, the dry density and relative density both reach the maximum. As the gravel content continues to increase, the dry density and relative density begin to decrease. The paving thickness and rolling times also have an important influence on the compaction effect of gravel materials. As the paving thickness decreases and the rolling times increase, the dry density and relative density increase, but the amplitude of the increase becomes smaller. Similarly, the water content also has a significant impact on the compaction effect of gravel materials. The dry density and relative density under the condition of adding water are obviously much larger than that under the condition of not adding water.
(3) According to the results of the first stage comprehensive rolling test and the second stage proof rolling test, it can be suggested that the rolling parameters of the site construction of this project should be as follows: paving thickness of 80cm, adding water 15% and rolling 8 times. When the site construction does not have the condition of adding water, the rolling parameters can be adopted as follows: paving thickness of 80cm, no water added, rolling 10 times.
(4) The filling quality of gravel dams is mainly controlled from two aspects: on the one hand, the gradation control of the loading dam materials, mainly to avoid oversize particles and bad gradation materials; on the other hand, the control of construction rolling parameters, including the paving thickness, the rolling times, adding water content and so on.

Acknowledgments
This study is funded by National Key R&D Program of China (2017YFC0404905 and 2016YFC0401601).

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