Study on Compaction Construction of Special Cushion in Altas Hydro Project

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Abstract: The special cushion of the concrete face rockfill dam in Altas Hydro Project was mainly between the dam body and surrounding mountains whose compaction construction had the following characteristics: (1) the small and irregular construction site, (2) the very strict requirement of construction technology. Therefore there were series of in-situ tests to verify the designed rationality of compaction standard of special cushion materials, then the compaction construction technology and related construction parameters was advised, at last, the permeability property of special cushion materials and its compaction construction after sprinkling and soaking was discussed.

1. Introduction
The Altas Hydro Project was a large (1) type I project with the following comprehensive utilization of flood control, irrigation and power generation, etc. The total storage capacity of the reservoir was 2249 million m³, the normal storage level was 1820m, the maximum dam height was 164.8m and the installed capacity of the power station was 755MW[1].

For the concrete face rockfill dam in Altas Hydro Project, the special cushion zone was located at the lower part of the circumjacent seam, filled with the special cushion materials which was the sieved sand gravel from C3 material yard. After compaction, the requirement of relative density of special cushion zone was no less than 0.9 and the permeability coefficient was between $1 \times 10^{-2} \sim 1 \times 10^{-3}$cm/s.

The cushion zone, as the first foundation, played an important role for the concrete face rockfill dam. Because the dam security was related with the cushion’s quality that indicated that its physical property must be satisfied with the requirements both of force transmission structure and impermeability of concrete face, therefore there was the high requirement for the cushion’s compaction [2-3]. At present, there were many studies for the compaction materials of Altas hydro project including blasted material, transition zone material, cofferdam sandy gravel, etc.[4-6]. For the cushion zone-2A zone, it was the narrow construction site and many construction procedures, for the special cushion zone-2B, its construction site was more narrow and its construction technology was higher than the former, so it was necessary to carry out the in-situ test to verify the designed rationality of compaction standard of special cushion materials, then the compaction construction technology and related construction parameters was advised.
2. Test

2.1. Test plan
The influent factors of compaction test included layer, machines and its speed, compaction pass and tamping time, etc..

For layout layer, there were two thickness with 20.0cm and 40.0cm. For machines with the same speed of 2.0km/h, there were 26.0t elf-propelled vibration roller, 3.5t self-propelled vibration roller and backhoe hydraulic vibration flat. According to the different thickness and different machines, there were different compaction times, but when the compaction machine was the backhoe hydraulic vibration flat the tamping time was considered with 30s, 60s, 90s and 120s, respectively.

In different compaction tests, the in-situ test was carried out to obtain the indexes including density, water content, average settlement and gradation, etc.. On the basis of analysis the above tests data, the optimal compaction construction parameters of the special cushion material was obtained, then there were series of test such as permeability test, etc. to verify the optimal parameters.

2.2. Compaction mechanism
There were three compaction mechanisms, the 26.0t elf-propelled vibration roller, the 3.5t self-propelled vibration roller and the backhoe hydraulic vibration flat. For the 26.0t elf-propelled vibration roller, its quality was 26.0t, its vibration wheel’s width was 2.17m, its frequency was 27/31Hz, its amplitude was 2.05/1.03mm and exciting force was 416/275kN. For the 3.5t self-propelled vibration roller, its quality, vibration wheel’s width and frequency were 3.5t, 1.2m, 45Hz and 53KN, respectively. For the backhoe hydraulic vibration flat, the average ramming force was 90.0KN - 100.0KN, its working press was 130-170kg/cm³.

2.3. Physical property of special cushion material
To obtain the maximum and minimum density of special cushion material, there were series of relative density tests with the mixture of artificial sand (0~5mm) and stone (5~15mm) by 5 different ratios including 35.0%: 65.0%, 40.0%: 60.0%, 45.0%:45.0%, 50.0%:50.0% and 55.0%:45.0%. The tests’ results was shown in figure 1.

![Figure 1](image1.png)

Figure 1 Relationship between maximum/minimum density & different stone ratios of special cushion material

![Figure 2](image2.png)

Figure 2 Relationship between relative density with compaction times of special cushion material on condition of different layout layers with 26.0t elf-propelled vibration roller

Figure 1 showed that when the ratio between artificial sand (0~5mm) and stone (5~15mm) was 50.0% : 50.0%, both of the maximum density and the minimum density of special cushion material were the maximum, 2.14g/cm³ and 1.78g/cm³, respectively.

2.4. Technological process
The special cushion material was unloaded by the step-back technique. For the in-situ compaction test, the forward and backward method with lapped joint width about 10.0~20.0cm was adopted, and the speed of vibration mechanism was about 2.0~3.0km/h. When the backhole hydraulic vibration flat was
used, it was controlled by the ramping time, for the in-situ compaction test, there were 4 different ramping time, such as 30s, 60s, 90s and 120s.

3. Results analysis

3.1. Relative density
On the condition of different layout layers with the 26.0t elf-propelled vibration roller, the relationship between relative density of special cushion material with compaction times was shown in figure 2.

Figure 2 showed that the relative density of special cushion material was increased with the increasing of compaction times on the same water content when the 26.0t elf-propelled vibration roller was used. On the condition of layout layer with 20.0cm(40.0cm) its relative density reached to the point of 0.93 when the compaction time was 4(8), its relative tendency was satisfied with the designed requirement (relative density Dr≥0.9).

On the condition that the layout layer was 20.0cm in thickness with the 3.5t elf-propelled vibration roller (the backhole hydraulic vibration flat), the relationship between relative density of special cushion material with compaction times was shown in figure 3(figure 4).

![Figure 3: Relationship between relative density of special cushion material with compaction times on the condition that the layout layer was 20.0cm in thickness with the 3.5t elf-propelled vibration roller](image1)

![Figure 4: Relationship between relative density of special cushion material with compaction times on the condition of the layout layer was 20.0cm with the backhole hydraulic vibration flat](image2)

Figure 3 showed that on the condition of the 3.5t elf-propelled vibration roller, when the layout layer was 3.50cm its relative density increased with the increasing of compaction times. When the compaction times was 16, its relative density was 0.92 with the amplitude of 3.0% that was satisfied with the designed requirement. Figure 4 showed that on the condition of the backhole hydraulic vibration flat, when the layout layer with 20.0cm the relative density of special cushion material increased with the increasing of compaction time. When the ramping time was 90 seconds, its relative density was 0.92 with the amplitude of 9.0% that was satisfied with the designed requirement.

3.2. Water content
The water was sprayed on the surface of special cushion material after it was paved, the water consumption was measured by watermeters. Tests results were shown in table 1 and 2.

Table 1 and 2 showed that there were no obvious change of water content for the special cushion material on the following conditions including (1) the 26.0t elf-propelled vibration roller with different layout layers, (2) the 3.5t elf-propelled vibration roller and (3) the backhole hydraulic vibration flat. The study showed that it would have the positive compaction results for the layout gravel on the construction site after fully saturation. The more the time of gravel fully saturated, the better its compaction results[9]. But once the saturation time kept too long, time consuming was obvious and the mechanical equipment was not fully on the operation condition. Therefore the saturated time should be proper controlled after watering during the construction process and it was the one of key
problems to study the compaction results of gravel on the condition of different saturated time after watering to obtain the optimal or reasonable saturated time.

Table 1 Relationship between water content of special cushion material with compaction times on condition of different layout layers with the 26.0t elf-propelled vibration roller

| thickness(cm) | compaction(times) | 4 | 6 | 8 | 10 |
|---------------|-------------------|---|---|---|----|
| 40.0          |                   | 5.0| 5.0| 5.1| 5.2|
| 20.0          |                   | 5.0| 5.0| 5.1| /  |

Table 2 Relationship between water content of special cushion material with compaction times on condition that the layout layer was 20.0cm in thickness with the 3.5t elf-propelled vibration roller/backhole hydraulic vibration flat

| thickness(cm) | compaction time (s) |
|---------------|---------------------|
| 20.0          | 14                  |
| water content(%) | 4.4               |
| 20.0          | 30                  |
| water content(%) | 4.9               |
| 20.0          | 60                  |
| water content(%) | 4.8               |
| 20.0          | 90                  |
| water content(%) | 4.7               |
| 20.0          | 120                 |
| water content(%) | 4.7               |

3.3. Settlement

On the following conditions, (1) the 26.0t elf-propelled vibration roller, (2) layout layers were 20.0cm and 40.0cm, (2) the compaction times was 2, 4, 6, 8, 10, the relationship between average settlement of special cushion material with compaction times was shown in figure 5.

Figure 5 showed that on the condition of the 26.0t elf-propelled vibration roller with the 20.0cm and 40.0cm layout layer, the average settlement of special cushion material increased with the increasing of compaction times. When the layout layer was 20.0cm its average speed increased with no slowing down trend, when the layout layer was 40.0cm, its average speed increased with the compaction times between 0~6 and it was slower increment with the compaction times between 6~10.

From the above analysis on the condition of the 26.0t elf-propelled vibration roller, the average settlement of special cushion material was the stable tendency when it was compacted 6 times with the 40.0cm layout layer. But on the same condition, its average settlement was the increasing tendency when it was compacted 8 times with the 20.0cm layout layer. Therefore on the condition of the 26.0t elf-propelled vibration roller, the compaction results with the 40.0cm layout layer was better than the one with the 20.0cm layout layer.
3.4. Particle grain
There was the series of particle size tests of special cushion materials on the conditions including different layout layers and different compaction mechanisms. The tests results between particle size and compaction times was showed in table 3.

Table. 3 Test results of particle grain

| layout layer(cm) | compaction mechanism | compaction | particle content(%) with diameter | uniformity coefficient | curvature coefficient |
|------------------|----------------------|------------|----------------------------------|------------------------|---------------------|
|                  |                      |            | <5.000mm | <0.075mm |                     |                     |
| 40.0             | A^                  | 4/6/8/10^d | 48.6/49.8/48.4/48.5 | 1.5/1.6/1.6/1.7 | 28~29              | 1.2~1.8             |
| 20.0             | B^                  | 4/6/8^d   | 49.4/49.4/49.8 | 1.6/1.5/1.4 | 27~28              | 1.4                 |
| 20.0             | C^                  | 14/16/18/  | 49.5/49.6/49.3/49.6 | 1.3/1.5/1.6/1.8 | 28                  | 1.4~1.6             |
|                  |                      | 20^d      | 30/60/90/ | 49.5/49.5/50.3/49.4 | 1.4/1.5/1.4/1.6 | 27~29              | 1.5~1.6             |

^a 26.0t self-propelled vibration roller  
^b 3.5t self-propelled vibration roller  
^c backhole hydraulic vibration flat  
^d the measurement unit was compaction times  
^e the measurement unit was compaction seconds

It showed there were no obvious changes of particle content of special cushion material with different diameters of less than 5.0mm and 0.075mm on the different layout layers, different compactions times with different compaction mechanisms.

From the above analysis, the relative density of special cushion material could be satisfied with the design requirement after compaction once one of the following conditions was satisfied: (1) when it was fully sprayed and compacted 8 times by the 26.0t elf-propelled vibration roller with the velocity of 2.0km/h on the condition of 40.0cm layout layer, (2) when it was fully sprayed and compacted 4 times by the 26.0t elf-propelled vibration roller with the velocity of 2.0km/h on the condition of 20.0cm layout layer, (3) when it was fully sprayed and compacted 14 times by the 3.5t elf-propelled vibration roller with the velocity of 2.0km/h on the condition of 20.0cm layout layer, (4) when the ramping time was 90 seconds by the backhole hydraulic vibration flat on the condition of 20.0cm layout layer.

4. Conclusion and suggestion

4.1. Conclusion

From the above series of in-situ tests of special cushion materials according to the different conditions including layer, machines and compaction times, in which the relative density test, the water content test, the settlement test and the particle size tests etc. were included, it showed that the relative density of special cushion material could meet the designed requirement.

Table. 4 Construction parameters of special cushion material

| compaction mechanism | layer thickness (cm) | watering | speed velocity (km/h) | compaction times/ ramping time |
|----------------------|----------------------|----------|-----------------------|-------------------------------|
| 26.0t elf-propelled vibration roller | 40.0 | fully watering | 2.0 | 8 times |
|                       | 20.0 |           | 2.0 | 4 times |
| 3.5t elf-propelled vibration roller | 20.0 | fully watering | 2.0 | 16 times |
| backhole hydraulic vibration flat | 20.0 | / | 90 Seconds |
4.2. Suggestion

(1) It would have the positive compaction effect if the gravel was paved on the construction site, then the water was sprinkled and soaked into the paved gravel before it was compacted. The study showed that the longer the soaking time of gravel after sprinkling was, the better the compaction effect of it was[9]. But there were some disadvantages, for example it would be time consuming and the equipment out of operation if the soaking time of gravel was too long. Therefore the soaking time of gravel after sprinkling should be controlled properly in engineering and the compaction effect of gravel should be studied on the condition of different soaking time after sprinkling to obtain the optimum or reasonable soaking time after sprinkling to guide the construction.

(2) There were different particle gradations due to the different sources of special cushion materials in different dam engineering, as a result, the study results of compaction effect on the condition of different soaking time after sprinkling in every dam engineering was just as a reference, the cushion material, directly processed by alluvial gravel, had the characteristics of discrete, discontinuous gradation and easy separation in construction[2], therefore the permeability stability of special cushion materials should be studied seriously by the permeability test in-situ according under the different working conditions of dam to obtain its permeability stability characteristics to guide the dam filling.

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