Discussion for transitional material’s compaction construction technique of faced rockfill dam of one hydro-junction project

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Abstract: The transitional material zone was between the cushion material zone and the sandy gravel zone in the Faced Rockfill Dam of one Hydro-junction Project, which was from the C3 material yard with the diameter of less than 150.00 mm. By the in situ compaction tests of transitional material, its construction technique and parameters were obtained. Study showed that: its relative density was satisfied with the designed requirement (no less than 0.90) when it was compacted 8 times by the 26.0t self-propelled vibration roller at the speed of 2.0km/h on the conditions including the 20.0cm layout layer and the 5.0% water sprinkled content. Then there were series of compaction tests under the low temperature in winter. The study results was guided for the compaction construction of transitional material in the dam and was as the reference as the similar engineering.

1. Introduction

From upstream to downstream, the filling zone of Faced Rockfill Dam of one Hydro-junction Project was the upstream coverage zone (1B), the upstream blanket zone (1A), the concrete slab, the cushion material zone (2A), the special material cushion zone (2B), the transitional material zone (3A), the sandy gravel zone (3B), the blasted material zone (3C), the horizontal drainage zone (3D), respectively. For the transitional material zone, it was between the cushion material zone and the sandy gravel zone with the 4.0m width at horizontal direction. For the transitional material it was from the C3 material yard with the diameter of less than 150.00mm with gradation continuity and that the transitional material relative density was no less than 0.90 was its compaction requirement[1].

In modern times, the divided zones of faced rock dam including the transitional material zone, which was used as the transition function between the cushion material zone and the main rockfill zone, was aimed to make sure the necessary transition of compressibility and permeability from upstream to downstream in order to prevent the seepage damage of dam body caused by the loss of fine materials in cushion under the action of seepage flow. Meanwhile it was also as the transition & coordination function for the deformation both of the cushion zone and the main rockfill zone and their seepage control function[2-4]. During the Symposium on Concrete Faced Rockfill Dam held in Detroit, USA in 1985, the different transitional materials were discussed[5]. At present, the study of concrete faced rockfill dam focused on its engineering properties, such as seepage deformation property[6-9] and construction technologies of compaction[10-11]. For the Faced Rockfill Dam of one Hydro-junction
Project, its compacted materials’ technology focused on the blasted material and the sandy gravels\cite{12-13}. To ensure the compacted quality of transitional material can meet the designed requirement (relative density was no less than 0.9) after compaction and ensure the local safety and overall stability, by the in situ compaction tests of transitional material, its construction technique and parameters were obtained. Then there were series of compaction tests under the low temperature in Winter. The study results was guided for the compaction construction of transitional material in the dam and was as the reference as the similar engineering.

2. Test plan
Combined the relevant engineering experiences with the actual situation of transition material source in one Hydro-junction Project, the paving thickness of transitional material which was the sandy gravel in situ tests was 40.0cm, the added water was 5.0% (volume ratio), the rolling machine was 26.0t self-propelled vibration flat rolling with the rolling speed of 2.0km/h. The sandy gravel filling zone at upstream direction in the dam filling zone was chosen as the compaction tests site of transitional material. Before the site was used it was leveled and sprinkled. Then its height difference was adjusted within no more than 20.0cm and its local fluctuation difference was within no more than 5.0cm, as the basic layer, its elevation was measured. After the in situ compaction tests, it was paved and the subsequent compaction construction was carried out. The transitional material with 40.0cm thickness was unloaded by the step-back method, then it was leveled by tractor, after the static compaction once its thickness was measured to ensure the error range of no more than 10.0% and sprinkled. Once the above preparation was completed, the forward and backward method with lapped joint width about between 10.0 ~ 20.0cm was adopted in the compaction test with the speed of about 2.0 km/h. When the compaction times was 4, 6, 8 and 10, respectively, the physical indexed including density, water content, average settlement and gradation etc. were gathered and analyzed to obtain the optimal compaction construction parameters which was verified by the proof tests. At last, there were series of compaction tests under the low temperature in winter to obtain the construction technique and parameters.

2.1. physical properties of transitional materials
The transitional material was mainly from C3 material yard that was located between river bed, floodplain and grade I terrace of one Hydro Project and about 1.5 ~ 7.8km long from the dam site, which included three sub-yard: C3-1, C3-2, C3-3 with total reserves of about 25.2 million cubic meters. In the C3 yard, those whose diameter was less than 150.00mm were as the transitional material. Its characteristic particle size was shown in table 1.

| No. | characteristic particle size (mm) | Cu | Cv |
|-----|----------------------------------|----|----|
|     | d10 | d15 | d30 | d60 | d85 | 133.5 | 18.1 |
| T1  | up  | 0.42 | 1.52 | 20.68 | 56.14 | 104.47 | 133.5 | 18.1 |
|     | lower | 0.13 | 0.19 | 2.40 | 31.70 | 80.31 | 249.6 | 1.4 |
|     | average | 0.18 | 0.34 | 7.62 | 42.56 | 94.87 | 236.4 | 7.6 |
|     | up  | 0.09 | 0.11 | 0.19 | 0.56 | 2.09 | 6.2 | 0.7 |
| T1  | lower | 0.08 | 0.09 | 0.13 | 0.30 | 1.95 | 3.9 | 0.7 |
|     | average | 0.08 | 0.09 | 0.14 | 0.39 | 2.01 | 4.9 | 0.7 |

Note: T1 was the transitional material whose diameter was less than 5.00mm, up-upper envelope curve, lower-lower envelope curve, average-average envelope curve, Cu-Non-uniformity coefficient, Cv-Curvature coefficient.

The maximum & minimum density of transitional material was from the in situ relative density test of its natural gradations, in which five different gravel contents, such as the upper envelope gradation, the upper average line gradation, the lower average line gradation and the lower envelope gradation, were considered. The test results of maximum & minimum density was shown in figure 1 according to the different gravel contents including 6.0%, 69.7%, 73.5%, 77.2%, 81.0%. From the figure 1, it was shown that when the gravel content was from the 66.0% to the 81.0%, the maximum density of
transitional material was between 2.34g/cm$^3$~2.44g/cm$^3$, and its minimum density was between 1.93g/cm$^3$~2.07g/cm$^3$. When the gravel content was 73.5%, the maximum and minimum dry densities of transition materials reached the maximum value of 2.44 g/cm$^3$, 2.07 g/cm$^3$, respectively.

![Figure 1 relationship between maximum& minimum dry density of different content of sandy gravel](image)

2.2. compaction mechanism
The compaction mechanism was the 26.0t self-propelled vibration flat rolling, its quality was 26.0t with the vibration wheel width of 2.17m, the vibration frequency was 27/31Hz with the amplitude of 2.05/1.03mm and its exciting force was 416/275kN.

3. Results analysis

3.1. average settlement
The average settlement, average settlement rate and settlement velocity rate of transitional material was shown in table 2 when the compaction times was 2, 4, 6, 8, 10, respectively on the conditions both of the 26.0t self-propelled vibration flat rolling and the 40.0cm paving thickness. Table 2 showed that the average settlement of transitional material increased until the compaction times increased to 8 times on the condition both of 26.0t self-propelled vibration flat rolling and the 40.0cm paving thickness, then there was no further increasing tendency. The similar tendencies were the average settlement rate and the settlement velocity rate.

| compaction times (times) | 2 | 4 | 6 | 8 | 10 |
|--------------------------|---|---|---|---|----|
| average settlement (mm)  | 20| 26| 28| 30| 30 |
| average settlement rate (%) | 5.01| 6.39| 7.08| 7.38| 7.38 |
| settlement velocity rate (mm/times) | / | 3.00| 1.00| 1.00| 0.00 |

| compaction times (times) | 4 | 6 | 8 | 10 |
|--------------------------|---|---|---|----|
| average water content(%) | 2.5| 2.1| 2.5| 2.6 |
| relative density | 0.78| 0.86| 0.92| 0.96 |

3.2. relative density
The relative density of transitional material was shown in table 3 when the compaction times was 2, 4, 6, 8, 10, respectively on the conditions both of the 26.0t self-propelled vibration flat rolling and the 40.0cm paving thickness.
paving thickness. Table 3 showed that on the condition both of 26.0t self-propelled vibration flat rolling and the 40.0cm paving thickness, the relative density of transitional material increased with the increasing of compaction times. When the compaction times was 8, its relative density was 0.92 that was satisfied with the designed requirement.

3.3. average water content

The average water content of transitional material was shown in table 3 when the compaction times was 2, 4, 6, 8, 10, respectively on the conditions both of the 26.0t self-propelled vibration flat rolling and the 40.0cm paving thickness. Table 3 showed that on the condition both of 26.0t self-propelled vibration flat rolling and the 40.0cm paving thickness, there was no obvious change of average water content, about 2.5%, with the increasing of compaction times, because its change was influenced by the following factors including the content of fine material, the moisture content of fine material and the surface of coarse particle in particle gradation.

3.4. particle gradation

On the condition both of 26.0t self-propelled vibration flat rolling and the 40.0cm paving thickness, there was no obvious change of the particle gradation of the transitional material with the different compaction times, which was within the lower and upper envelope curves, particularly for the particles with the diameter both of less than 5.0mm & 0.075mm, their particles were no obvious changed.

From the above analysis, it showed that on the condition both of the 40.0cm paving thickness and the 5.0% water sprinkled content (volume ratio), the relative density of transitional material was satisfied with the designed requirement once the following construction parameters were adopted: (1) the transitional material was unloaded by the step-back method, (2) the forward and backward method was adopted to compaction, (3) the lapped joint width was about between 10.0 ~ 20.0cm, (4) it was compacted 8 times by the 26.0t self-propelled vibration roller at the speed of 2.0km/h.

4. No-watering compaction construction technique under the low temperature in winter condition

In one, it was cold with lower temperature (about -10°C~ -12°C, the lowest in history was -19°C) in the winter, the construction site was located at the narrowest part of the river, both of its sides were the high and steep mountain, which indicated it is strong winds in the wind gap during the winter. If the transitional materials was paved after it was sprinkled, its surface was very possible to freeze, as a results the construction quality couldn’t be satisfied with the designed requirement. Therefore there were a series tests of no-watering compaction construction on the condition of low temperature in winter, the gravel material, extracted from above the waterline of C3 quarry, was paved and compacted with the natural water content, it was the compaction technique with the natural water content compared with the compaction technique with the designed water content.

During the compaction technique with the natural water content, the construction technique parameters were the same with the above tests except that the gravel material, which was extracted from above the waterline of C3 quarry with the particle diameter’s size of less than 150.00mm, was the natural water content and no watering, then the indexes including density, water content, gradation, etc., were obtained when the compaction times was 10, 12, 14, respectively, finally its optimal compaction construction parameters was obtained by analyzing results data.

The average water content and relative density of transitional material was shown in table 4 when the compaction times was 10, 12 and 14, respectively on the conditions both of the 26.0t self-propelled vibration flat rolling and the 40.0cm paving thickness.

| Table 4 relative density & average water content with different compaction times |
|-------------------------------|----|----|----|
| compaction times (times) | 10 | 12 | 14 |
| average water content (%)  | 1.0 | 1.0 | 1.0 |
| relative density           | 0.83 | 0.88 | 0.93 |
Table 4 showed that on the one hand, on the condition both of 26.0t self-propelled vibration flat rolling and the 40.0cm paving thickness, the relative density of transitional material increased evenly with the increasing of compaction times. When the compaction times was 14, its relative density was 0.93 that was satisfied with the designed requirement. On the other hand, there was no change of the average water content during the same condition.

It also showed that when the compaction times was 2, 4, 6, 8, 10, respectively on the conditions both of the 26.0t self-propelled vibration flat rolling and the 40.0cm paving thickness, (1) the particle content of transitional material with the diameter of less than 5.0mm was 24.5%, 25.5% and 24.1%, respectively, (2) the particle content of one with the diameter of less than 0.075mm was 2.6%, 2.5% and 2.6%, respectively. The above analysis showed that there was no obvious change for the particle content of transitional material with the diameter both of less than 5.0mm & 0.075mm.

From the above analysis, when it was constructed at the low temperature in winter, on the following conditions of 26.0t self-propelled vibration flat rolling, the 40.0cm paving thickness and the natural water content, the relative density of transitional material was satisfied with the designed requirement once the following construction parameters were adopted: (1) the transitional material was unloaded by the step-back method, (2) the forward and backward method was adopted to compaction, (3) the lapped joint width was about between 10.0 ~ 20.0cm, (4) it was compacted 14 times by the 26.0t self-propelled vibration roller at the speed of 2.0km/h.

5. Verification tests
Based on the construction technique and related parameters from the above in-situ test study, there was the verification tests. On the same construction technique and parameters, indexes including relative density, water content, gradation, etc. of the compacted transitional material were tested, then the permeability tests were carried out to study its permeability.

5.1. Watering compaction construction technique
On the conditions both of the 40.0cm paving thickness and the 5.0% added water (volume ratio), the transitional water content was 2.5%, its relative density was 0.92 when the following construction technique was adopted: the transitional material with 40.0cm thickness was unloaded and compacted by the step-back method with the 26.0t self-propelled vibration flat rolling at the speed of 2.0km/h, then it was compacted 8 times by the forward and backward method with the lapped joint width about between 10.0 ~ 20.0cm. The permeability test in situ test showed that its permeability coefficient was $2.67 \times 10^{-3}$ cm/s, the grain test showed that there was no obvious change for the particle content of transitional material with the diameter both of less than 5.0mm & 0.075mm, the non-uniformity coefficient ($C_u$) was 272, the curvature coefficient ($C_c$) was 8.0.

5.2. No-watering compaction construction technique
On the conditions both of the 40.0cm paving thickness and the natural water content, the transitional water content was 1.0%, its relative density was 0.92 when the following construction technique was adopted: the transitional material with 40.0cm thickness was unloaded and compacted by the step-back method with the 26.0t self-propelled vibration flat rolling at the speed of 2.0km/h, then it was compacted 14 times by the forward and backward method with the lapped joint width about between 10.0 ~ 20.0cm. The permeability test in situ test showed that its permeability coefficient was $2.67 \times 10^{-3}$ cm/s, the grain test showed that there was no obvious change for the particle content of transitional material with the diameter both of less than 5.0mm & 0.075mm, the non-uniformity coefficient ($C_u$) was 305, the curvature coefficient ($C_c$) was 9.2.
6. Conclusion

6.1. Compaction construction technique & parameters
Watering compaction construction technique, its relative density could satisfy with the designed requirement with the following conditions: the transitional material with 40.0cm thickness is unloaded and compacted by the step-back method with the 26.0t self-propelled vibration flat rolling at the speed of 2.0km/h, the lapped joint width is about between 10.0 – 20.0cm, when the paving thickness is 40.0cm and the added water (volume ratio) is 5.0%.

No-watering compaction construction technique, its relative density could satisfy with the designed requirement with the following conditions: the transitional material with 40.0cm thickness is unloaded and compacted 14 times by the step-back method with the 26.0t self-propelled vibration flat rolling at the speed of 2.0km/h, the lapped joint width is about between 10.0 – 20.0cm, when the paving thickness is 40.0cm with the natural water content.

6.2. Suggestions
It was the one dam site that there was the high evaporation and the wind gap meanwhile the absorption capacity of sandy gravel was poor, when the watering compaction construction technique was adopted, it should be compacted in time after watering to avoid the water evaporation and loss that influenced the compaction quality. when the no-watering compaction construction technique was adopted, the transitional material from the above water line of C3 material yard should be paved and compacted quickly after it was transported to the construction site to avoid that the moisture was completely air dried and the rolling effect was influenced.

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