STUDY ON CEMENTED-ROCKFILL DAM

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Abstract: In order to solve the great deformation of rockfill which may lead to concrete face and watertight seal structure of peripheral joints destroyed in CFRD, the new material named cemented-rockfill which has greater deformation modulus and higher compressive strength was discussed. Cemented-rockfill is a kind of material made by adding little cement and water to the rockfill or sand-gravel without mixing or just simple mixing, continuously constructed by thin-layer roller compacted method. The cemented-rockfill material has an advantage over rockfill in greater deformation modulus, that can improve the material property, and eliminate the probability of great deformation in rockfill dam. At the same time, the new material retain the construction method as the CFRD, so it has its great advantage. Based on the results of tests, the engineering properties of the cemented-rockfill material are analyzed, including the constitutive law, strength properties, seepage properties, thermodynamics properties etc. The analysis results show that the cemented-rockfill material has many good properties for the dam material, it has advantages both in technology and economy. Then, take the material property into consideration, the construction method and construction technology of cemented-rockfill were discussed. At last, the new types of dam based on this technology, named face cemented-rockfill dam (FCRD) and cemented-rockfill mixing dam (CRMD), are investigated. In FCRD, an impervious membrane for water tightness was placed on the upstream slope, concrete faced is most widely used for rockfill dams before, at present, the two-graded compacted RCC tending to dominant in FCRD; and the spillway can be placed on the dam body because of the greater deformation modulus and higher shear strength of cemented-rockfill. In CRMD, the cemented-rockfill is arranged on the main rockfill zone, and the rockfill is arranged on the secondary rockfill zone. It is less project quantity and more safety compared to CFRD.

Key words: cemented-rockfill; cemented-rockfill dam; material property; new types of dam

1 Introduction

The improvement of construction methods and innovation of materials can promote the dam construction technologies. With these technical renovations, CFRD and RCCD and some other new dam structures have greatly improved the dam construction[1].
The concrete face rockfill dam (CFRD) has been developed and sprung up in recent years because it has obvious advantages\[2][3\]. As the great deformation of rockfill which may lead to concrete face and watertight seal structure of peripheral joints destroyed in high CFRD, the height of CFRD has been limited. Generally, there are many factors which influence the deformation of CFRD, where properties of construction materials is a fundamental factor.

To solve this problem, Guo Chengqian\[4\] introduced the concept of modified rockfill in 1993, which referred to add some cement in the rockfill and then compact it, this can greatly improve its deformation modulus and compressive strength, or even close to soft rock or low grade RCC. Tests show that modified rockfill has great deformation modulus, and can decrease the dam deformation efficiently. The modified rockfill meliorate the property of dam rockfill, eliminate the possibility to cause compressive strain, and keep the rockfill dam construction characterize. Guo Chengqian broached a plan to build the dam with modified rockfill entirely, but did not go further.

Modified rockfill is also called Cemented-Rockfill, which is a material between concrete and rockfill, has been studied abroad.

The first ideas related to the cement-soil were envisioned by Raphael\[5\], whose basic idea was the design of an intermediate type of dam between gravity and earthfill dam, using a material between concrete and soil. Later, Londe \[6\] developed and introduced worldly the concept of Hardfill.

Since 1990's, Japanese engineers have done a lot of work to develop Hardfill technology which called CSG dam\[7][8\] and has its own specific characters. CSG is a material made by adding little cement to rock-like material such as riverbed gravel or excavation muck that can be obtained easily near dam sites, mixing it simply and rolling with vibration rollers, which can be considered as a lean RCC. CSG dam is a symmetrical trapezoid-shaped dam; The strength of CSG is relatively not stronger than concrete. On the other hand, because the stress occurred in a symmetrical trapezoid-shaped dam is small; the required strength of its material can be low. It, therefore, can to use the CSG as a construction material for the trapezoid-shaped dam.

Based on the former study, the characteristics of cemented-rockfill material and the designing and construction of cemented-rockfill dam have been studied in this paper.

2 Characteristics of cemented-rockfill

Cemented-rockfill is a material made by adding little cement to rock-like
material such as rockfill or gravel, mixing it simply and rolling with vibration rollers, which can be considered as a lean RCC. Figure 1 shows the typical stress-strain curve of Cemented-rockfill[8]. From the figure, Cemented-rockfill shows the elasto-plasticity behavior, only the elastic range of cemented-rockfill is considered in designing.

![Typical stress-strain curve of cemented-rockfill](image)

The cemented-rockfill have the following characteristics:

1. Cemented-rockfill is a kind of material which is rolled and compacted by adding little cement in rockfill (artificial mining) or gravel (nature existing). Its mechanical property is higher than rockfill but lower than concrete.

2. The dam material with some cement became cemented-rockfill after rolled but not granular material. Therefore, the dam has good anti-scouring ability and great shear and compressive resistance ability. Good anti-scouring ability is an outstanding advantage of this dam type, which can lower construction diversion standard as allow flooding across the dam during the construction period and increase safety degree as can anti-seepage and allowing flood overtopping in use period.

3. Cemented-rockfill has greater deformation modulus. Reference 6 referred that the deformation modulus of cemented-rockfill can reach 10 GPa, that is about 10 or 100 times of rockfill. Higher deformation modulus can decrease dam deformation sharply, that’s good for upstream impervious body.

4. Cemented-rockfill dam mainly to sustain impervious body and keep dam stability, and also transmit the load to the base. Therefore, there only require the dam materials have certain strength, deformation modulus and anti-scouring ability.
ability, but no anti-seepage requirement. So that can decrease cement mixing amount (compared to concrete) and relax aggregate requirement. Meantime, cracks control, interface treatment and local discretization and some other requirement can be relaxed.

(5) Lower cement usage. Londe[6] summarized foreign experiences and put forward that: while mix cement 50~60 kg/m³ in rockfill, its strength can reach to 5 MPa (90d age), that can satisfy 100-m high dam strength requirement. Lower cement mixing amount mean lower hydration heat and smaller temperature rise. Therefore, the temperature stress is much smaller than RCCD. Besides, the dam has no anti-seepage requirement; even micro cracks have little influence to the structure function. So there need not to set expansion joint and that can construct as normal rockfill dam.

(6) Lower cement usage can decrease the total cost.

(7) The loose aggregate (rockfill) requirements can simplify the preparation section and reduce the cost, produce less waste slag that can protect vegetation and shrink the scale of quarry plant and reduce transport cost.

(8) Cemented-rockfill dam construction method maintains normal rockfill dam construction features, simple and fast.

3 Experimental research

3.1 Aggregate characteristics

The technical characteristics of cemented-rockfill are that strength mixing cement with the rockfill. Cement plays a major role in cementing. Considering advantage of China's rich fly-ash resource, the indoor experiment no only study the cemented sand and gravel but also the cemented sand and gravel mix with fly-ash, and compare the technical performance of them. There have no temperature control requirements and admixture in view of the relatively small amount of cemented material. The sand and gravel is naturally graded from the river. According to screening results, it can be seen the gravel particles partial rough on the whole and fine particle content is few for the reason that the project area located in the upper reaches of the river. So its workability is poor for the concrete aggregates. The super size gravels are eliminated and the maximum grain size is less than 100mm in the experiment.

3.2 Laboratory test

Mainly work of Laboratory experiments are the volume weight after compaction and compressive strength workability test. Research results show that with the same water content, volume weight of cemented-rockfill increase with cemented material dosage; when a certain amount of plastic material, the volume weight increases with increasing water consumption firstly, as water
consumption exceeds the optimal value, compaction density decrease. Compressive strength of cemented-rockfill increases with the amount of plastic material and monotonous rise. Compressive strength after 28 days (mix the fly-ash) decreased slightly. The optimal water consumption is 90kg/m³ when the total plastic material within 60~80 kg/m³. Analyzing the results of workability, mixing aggregate separate seriously, lower cohesive property, forming difficulty when VC value is greater than 20s; increase water consumption can reduce VC value; when the same amount of cemented materials been used, VC value can be decrease by mix fly-ash, that means workability can be improved by mix fly-ash, but the volume weight and compressive strength corresponding decrease.

3.3 Field test

According to lab test results, the site roller compaction trial had been done combined with preparation work of construction. Considering the economy of construction and workability, the field tests done the two groups of cement dosage trail of 80kg/m³ and 60kg/m³ instead of 100kg/m³ and 40kg/m³ .The trail been done according to the optimal water consumption (90kg/m³).Fly-ash does not been used in the small engineering work load and far transport distance. Materials are took after mixed and eliminate the super size gravel, then made into specimen, and the compressive strength results are very close to laboratory test results.

Field tests show that the cemented-rockfill has the same characteristics as RCC, which is surface bleeding easily, construction control indicators can be expressed by VC value of the workability, its value between 10s and 15s. Digging pit shows that compaction effect from surface to the bottom is greater while the overall density less than RCC. Accounting to the results of impermeability test, the cemented-rockfill has lower impermeability capability; the permeability coefficient of cemented-rockfill is from $10^{-2}$ to $10^{-5}$cm/s, so the watertight upstream facing should be took into consideration as seepage control measure.

4 Construction Research of cemented-rockfill dam

4.1 Construction procedure

Construction procedure of the cemented-rockfill dam is illustrated in Figure 2.
Proper mixing equipment of cemented-rockfill in Japan was illustrated in figure 3.

4.2 Construction method
The gravel larger than 150mm is to be eliminated by rakes, and then be transported to stockyard by self-unload truck. It is mixed by load truck for the first time after mix into cement fly-ash, and then blunged to uniformity. The rolling thickness is 17 cm; rolling 8 times with vibration rollers.

4.3 Construction features
There is only a certain strength, deformation modulus and anti-scouring ability to the material requirement. Therefore, cracks control, interface treatment and local discretization and some other requirement can be relaxed. As there no need to make the quality of cemented-rockfill as good as RCC, simplify the construction procedure can be considered to quicken construction speed and reduce the cost. This paper proposed an assumption, to reference EVR and rockfill concrete construction procedure, cancel mixing procedure, adopt “Unload” → “Paving” → “Cement sprinkling (self-fill)” → “Roller compaction”, this method can be called “self-fill roller compaction”. Cancel mixing procedure not only can cancel
mixing plant and some other equipments, but also can quicken the construction speed, as the engineering quantity (volume) is much smaller than normal rockfill dam, so the construction period can be greatly shorted.

![Image of technological process](image)

**Figure 4. Technological process of cemented-rockfill dam construction by “self-fill and roller compaction”**

5 Structural types of cemented-rockfill dam

The possible new types of dam based on this technology are presented as follows.

5.1 Face cemented-rockfill dam (FCRD)

As shown in figure 5, in FCRD, an impervious membrane for water tightness was placed on the upstream slope, concrete face was widely used for rockfill dams in the past, at present, the two-graded compacted RCC tend to dominant in FCRD; and the spillway can be placed on the dam body because of the greater deformation modulus and higher shear strength of cemented-rockfill.

The range of slope of FCRD is from 1:0.5 to 1:0.7 generally. The concrete impervious face in the upstream acts as a impervious barrier like CFRD. The FCRD has the advantages of greater safety, shorter construction period lower construction cost.

![Image of face cemented-rockfill dam](image)

**Figure 5. Face cemented-rockfill dam**
5.2 Cemented-rockfill mixing dam (CRMD)

As shown in figure 6, in CRMD, the cemented-rockfill is arranged on the main rockfill zone, and the rockfill is arranged on the secondary rockfill zone. It is less project quantity and more safety compared to CFRD.

The range of upstream slope of CRMD is from 1:0.3 to 1:0.4 usually, and the downstream slope similar with the CFRD. The concrete impervious face in the upstream area acts as an impervious barrier like CFRD. The CRMD has the advantages of greater safety, shorter construction period lower construction cost.

![Figure 6. Cemented-rockfill mixing dam](image)

5.3 Characteristics of cemented-rockfill dam

(1) As cemented-rockfill belongs to lower medium penetrability, that can not satisfy free drainage requirement, to ensure the dam safety, there need to set vertical drainage in dam upstream area and connect to horizontal drainage in the dam bottom so that can keep dry in the downstream area.

(2) The penetrability of different area fill material should gradually increase from upstream to downstream and satisfy the hydraulic transition requirement. Generally, there need not to set filter and transition.

(3) Upstream impervious face can adopt concrete face, but not limit in concrete material. Other economical and reliable impervious materials such as asphalt concrete, geomembrane can be
considered to improve its competition. In practical application, two graded aggregate RCC should be the first priority as its convenient construction, low cost and good anti-seepage effect.

6 Conclusion

In order to improve the great deformation of rockfill which may lead to safety problems in CFRD, the new material named cemented-rockfill which has greater deformation modulus and higher compressive strength was discussed. The analysis results show that the cemented-rockfill material have many good properties for the dam material, it has many advantages both in technology and economy. Then, taking the material property into consideration, the construction method and construction technology of cemented-rockfill were discussed. At last, the possible new types of dam based on this technology, namely face cemented-rockfill dam (FCRD) and cemented-rockfill mixing dam (CRMD) are investigated. The cemented-rockfill dam has an excellent future but many problems still require a further study and a satisfactory solution.

References