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Study of the key technologies of application of tuff powder concrete at the Daigo hydropower station in Tibet

Songtao Peng [a,b], Xiang Li [c], Zhenyu Wu [a,*], Jiankang Chen [a], Xiang Lu [a]

[a] State Laboratory of Hydraulic and Mountain River Engineering, College of Water Resources & Hydropower, Sichuan University, Chengdu, Sichuan 610065, China
[b] China Huadian Corporation Tibet Energy Co., Ltd. Grand Branch of Daigo Hydropower, Sangri County 856200, China
[c] Changjiang River Scientffic Research Institute of Changjiang Water Resources Commission, Wuhan, Hubei 430010, China

HIGHLIGHTS

- The performances of tuff concrete should satisfy the requirements of Daigo hydropower station.
- The application of tuff can save the cost and reduce the control difficulty of schedule.
- Usage of tuff was investigated comprehensively in the research.
- The results have guiding significance for districts with rich tuff.

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ABSTRACT

High-mix fly ash (FA) is often used in roller compacted concrete (RCC) to ensure construction quality and reduce project cost. However, cost and difficulty of schedule control will increase if FA is transferred from other areas because the resource is relatively scarce in Tibet of China. Based on the richness of tuff resources at the Daigo hydropower station in Tibet, studying the feasibility of concrete application with tuff powder as the admixture is necessary because of the low cost and small impact on schedule. Research compared the performance indicators of RCC of tuff concrete (concrete mixed with only tuff powder), FA concrete (concrete mixed with only FA) and concrete mixed with FA and tuff. The results showed the tuff concrete increased the earlier compressive strength, earlier tensile strength and the drying shrinkage ratio and reduced the impermeability and frost resistance in freeze-thaw cycles. The tuff concrete performed well against cracks and deformation in comparison with the FA concrete and can meet the design requirements of the Daigo hydropower station. The results provide data for the selection of concrete mixtures for the Daigo hydropower stations.

1. Introduction

Since the 21st century, the climate problem has gradually gained the world's attention. Studies show that the emissions of greenhouse gases are a very important factor leading to global climate change. Limiting greenhouse gases will bring new opportunities for the development of renewable energy, including hydropower [1]. The global theoretical reserves of water resources are approximately 43.6 trillion KWh, and Asia's water is at the top of the five continents, especially China and India [2]. China's hydropower installed capacity reaches 400 million kilowatts, which is equivalent to reducing the consumption of more than 400 million tons of standard coal per year, the emissions of more than 10.6 tons of carbon dioxide per year and the emissions of more than 6.66 million tons of sulphur dioxide; thus, China's hydropower plays a considerable role in clean energy [3,4].

The economic and social development of Western China is relatively backward, while there are abundant water resources. In the 12 western provinces, the water resources account for approximately 79.3% of the total, especially the provinces of Sichuan, Yunnan and Tibet. The developed hydropower is only approximately 20% in Western China; it shows relatively high potential and a broad prospect. The increasing numbers of high concrete dams put into construction and operation in most of the western regions are in highland areas, where the terrain and climate conditions are complex and demand higher requirements in the quality of concrete. Even though the use of roller compacted concrete (RCC) dams as a method of dam construction started late in China, the

* Corresponding author.
E-mail addresses: 18202862072@163.com (S. Peng), 1039968669@qq.com (X. Li), scuwzy@qq.com (Z. Wu), 267278319@qq.com (J. Chen), scu-lx@qq.com (X. Lu).

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construction of dam technology has been rapidly developed since the Kengkou RCC gravity dam was built in Fujian Province of China in 1986. Compared with the other two major dam types for large-scale water conservancy and hydropower project construction, the development trend of RCC dams is better [5–7]. The technology of high RCC dams in China has the characteristics of low cement content and high mixed fly ash (FA). However, FA resources are relatively scarce in Southwestern China, so FA must be transported by rail from distant provinces with secondary transport, which has a great influence on the cost and time limit due to some uncontrollable factors [8–10].

Some reactions and performance of volcanic ash have been studied in relevant engineering areas with abundant volcanic ash resource at home and abroad. Studies ranging from the change of strength and reactive effect to durability properties have been reported [9,11–15]. There are some interesting works undertaken on volcanic ash concrete, such as H. Tchakoute Kouamo [16] et al. researched the acceleration of the volcanic ash reaction by adding metakaolin. Kozo Onoue [17] et al. concluded that compared with ordinary concrete, lightweight concrete, whose coarse aggregate is volcanic ash, at an impact speed of 1.5 m/s and 4.5 m/s, can reduce the maximum impact load by 28% and 41%. K.M.A. Hossain [18] et al. verified that the pore structure of the refinement led to higher performance of volcanic ash concrete based on studying the performance of volcanic ash concrete, and Mohammed Seddik Meddah [19] discovered that the strength development and durability of concrete mixed with natural volcanic ash is more advanced than that mixed with shale powder.

The Daigo hydropower station lies in Tibet of China. It is an RCC gravity dam and demands a large amount of mineral admixtures. The FA resources are relatively scarce and need to be transported from central provinces, which will increase the cost of engineering and project duration. In view of the available volcanic ash resources around the power station, the performances of concrete by solely adding FA, solely adding tuff powder and compounding FA and tuff powder are researched, which can provide some support for the admixture choice of Daigo hydropower station.

2. Significance of the present research

The Daigo RCC gravity dam is located in the Tibet Autonomous Region of China. The dam site is above sea level approximately 3500 m and also has the plateau climate characteristics, such as large daily temperature difference, low air pressure and strong solar radiation. The maximum daily temperature difference is up to 25 °C, and the annual number of freeze-thaw cycles is more than 100 days. In view of the lack of high quality admixture resources in the vicinity of the project, such as FA, slag powder, and the richness of tuff resources within 100 km of the dam site, there is great potential for concrete application with tuff powder, and study of the feasibility is necessary.

2.1. Low cost

The total concrete of the Daigo hydropower station is approximately 3.32 million m^3, with the admixture of 23 million tons. Choosing FA as admixture means that it will be transferred by the Qinghai-Tibet railway and secondary transit of road transport from the nearest factory in Qinghai province, Ningxia province and other places. There are two tuff origins near the dam site: LuoCun tuff and WoKa tuff. The LuoCun tuff is approximately 25 km away from the dam, and the WoKa tuff is approximately 30 km away from the dam, as shown in Fig. 1. Judging from the distance, LuoCun and WoKa are both not far from the dam site. The LuoCun tuff is near and less difficult to mine. If 100 thousand tons of FA, transported from Ningxia province, are replaced by the LuoCun tuff powder, the project investment could save approximately 95 million yuan in transportation costs, as shown in Table 1.

2.2. Small impact of the schedule

Railway transportation is a better way to transport FA from Qinghai and Ningxia provinces. However, the Qinghai-Tibet Railway lies in the plateau area, which is cold, hypoxic, sparsely populated and extremely lacking in emergency rescue manpower, materials and equipment. There are steep slopes, tall bridges, long and dangerous roads [10]. Due to the influence of regional climate change, external uncertain interference events, equipment quality and maintenance quality, practitioners technical level and the mental state and many other factors, transportation accidents cannot be avoided, which cannot guarantee that rail transport can occur on time. In fact, the stable supply of mineral admixture is the key link in engineering construction, so the influence of time limit is unpredictable. Because there are further requirements of the construction schedule in the plateau area, it is very important to study the performance of concrete mixed with tuff powder.

3. Experimental outline

3.1. Materials

3.1.1. Cement

The selection of cement is 42.5 medium heat Portland cement (HPC). The chemical composition is shown in Table 2, which meets the ASTM C150/C150M-2012 [20].

3.1.2. Admixture

There are two kinds of mineral admixture used in the experiment, FA and tuff powder in LuoCun, the chemical compositions of which are reported in Table 3, with reference to ASTM C618-05 [21].

3.1.3. Aggregates

The aggregate of the test was artificial aggregate, which was made by a gravel plant with processing, crushing, and screening. The gradation curve of the fine aggregate with reference to ASTM C33/C33M-13 [22] is presented in Fig. 2. The apparent density, ruggedness and water absorption of aggregates are also presented in Table 4.

3.1.4. Additive

A highly efficient water reducing agent and an air-entraining agent were adopted in this test, which fulfil the ASTM C688-14 [23]. The basic information is shown in Table 5.

3.2. Mixture proportion

The mixture proportions of concretes are shown in Table 6. In the table, "T-1, T-2 and T-3" is a mixture for three-graded roller compacted concrete (3-RCC) in which the mass proportion of S, M and S is 30:40:30; "T-4, T-5 and T-6" is a mixture for two-graded roller compacted concrete (2-RCC), in which the mass proportion of S and M is 50:50. A forced action mixer was used to mix the concrete. First, all of the materials except the water were put into the mixer. After 30 s of dry mixing, water containing a water reducing agent and an air-entraining agent was poured into the mixer, followed by 2-min of mixing. The vibrating compacted values (VC) and the air content were measured immediately after the completion of mixing.