Feasibility study on construction of RCC gravity dam under special climatic conditions in Tibet

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Abstract. According to the experience in the construction of water conservancy and hydropower projects in the Mainland, RCC dam construction has two main advantages: the rapid construction speed of roller compacted concrete can realize early power generation, and the price of fly ash is much lower than that of cement, which can reduce the project cost. Tibet has special geographical environment and climatic conditions, and generally has the characteristics of "high altitude, low pressure, low temperature, large temperature difference between day and night, and dry climate". Taking the dam-building environment in central Tibet as an example, through investigation and research and analogy of similar projects, this paper analyzes the adaptability of construction of RCC gravity dams in Tibet from the aspects of geographical environment, climatic conditions, material properties, construction progress, and project cost. Adaptability to high altitudes. It provides a reference for choosing a safe, reliable, economical and reasonable dam type in the construction of water conservancy and hydropower projects. It provides reference for selecting safe, reliable, economical and reasonable dam types in water conservancy and hydropower engineering construction.

Key words: High altitude; RCC gravity dam; Alpine climate; Material properties; Adaptability.

1. Introduction

Gravity dams are widely used because of their simple shape, easy flood discharge and adaptability to various foundation conditions. However, concrete dams rely on themselves to maintain stability, so the cross-section is inevitably too large, and the material strength is not fully utilized. Conventional construction methods result in long construction periods and high cost. As a type of concrete gravity dam, roller compacted concrete gravity dam has obvious advantages over normal concrete gravity dam in construction speed and project cost. Since the 1980s, it has developed rapidly. At present, China has become the country with the most RCC gravity dams, and the height of dam construction and the development of dam construction technology are in the forefront of the world [1-2].

Tibet is a rich mine of hydropower in China. Its theoretical reserves of hydropower resources are 201 million kW, accounting for 29% of the total and ranking first in China. The technology exploitable installed capacity is 143 million kW, accounting for 24.9% of the national total, ranking second only to Sichuan Province. Among them, the installed capacity of large-scale hydropower stations in Tibet is 130 million kW, with an annual power generation of about 674 billion kW·h; the installed capacity of medium-sized hydropower stations is 11.72 million kW, with an annual power generation capacity of 62 billion kW·h; the installed capacity of small hydropower stations is 1.18 million kW, with an annual power generation of 6 billion kW·h. According to the development sequence of hydropower resources in China, the future hydropower construction will gradually be transferred to Tibet [3].

According to the experience of china's water conservancy and hydropower engineering construction, RCC dam construction has two main advantages: the rapid construction speed of roller compacted concrete can realize early power generation, and the price of fly ash is much lower than that of cement, which can reduce the project cost. In view of the special geographical environment and climatic conditions, Tibet is generally characterized by "high altitude, low atmospheric pressure, low temperature, large temperature difference between day and night, and dry climate". Whether the long-term experience accumulated in inland water conservancy and hydropower project construction is applicable to Tibet deserves further study and discussion.

Taking the dam-building environment in central Tibet as an example, the author analyzes the adaptability of RCC gravity dam in high altitude area of Tibet from geographical environment, climatic conditions, material properties, construction schedule, cost and other aspects.

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2. Engineering conditions

2.1 Traffic Conditions

(1) Highway. The existing highway network in central Tibet mainly includes G318 National Road, G109 National Road, G312 National Road, S306 Provincial Road, S101 Provincial Road, etc. The road transportation network is relatively developed. From Lhasa City, you can reach Zedang Town via G318 National Highway and S101 Provincial Highway, and then you can reach Bayi Town via S306 Provincial Highway, which is connected to the G318 National Road, and continues eastward to Chengdu (G318 National Road, namely Sichuan-Tibet Line) and Kunming (G318 National Road turns to G214 National Road and G320 National Road, namely Yunnan-Tibet Line).In addition, Xining, Lanzhou and other places can be reached from Lhasa via G109 and G312 National Highways (Qinghai-Tibet Line).

(2) Railway. At present, only the Qinghai-Tibet Railway has been opened in Tibet to the outside world. It is a single-line Class I electrified railway from Xining to Lhasa. The Lari Railway has been opened in Tibet (from Lhasa to Shigatse), and the Lalin Railway (from Lhasa to Linzhi) has also started construction. The materials and equipment can be transported by rail to road to the project site.

(3) Aviation. There is Kongga international airport on the west side of kongga County, Lhasa City, which has opened routes to many major cities in China, such as Beijing, Shanghai, Chengdu and other places.

2.2 Hydrometeorological conditions

The floods of rivers in central Tibet are mainly formed by torrential rain, and the flood and dry flows are very different. The flood season is from June to October, and the dry season is from November to May of the following year.

Central Tibet is mainly located in the climate zone of the Qinghai-Tibet Plateau. Its basic characteristics are low temperature, thin air, dry atmosphere, abnormally strong solar radiation, and complex and diverse climatic characteristics. Taking the measured data of a weather station in central Tibet from 1978 to 2009 as an example, the annual average temperature is 9.3 °C, the average temperature of the coldest month is 0.3 °C (January), and the extreme maximum and minimum temperatures are 32.5 °C and -16.6 °C, respectively.

2.3 Concrete raw material supply status

Concrete raw materials mainly include aggregates, cement and admixtures. Aggregate can be processed with excavated stone or natural sand and gravel near the project area; cement can be supplied from Gaozheng Cement Plant near Lhasa City and Huaxin Cement Plant near Shannan City. The admixture is mainly fly ash, which is not available in Tibet. Qinghai Province, which is closer to Tibet, also has less fly ash resources, while Gansu Province and Ningxia Autonomous Region have a large number of thermal power plants, such as Lanzhou Datang Xigu Power Plant, Yongdeng Liancheng Power Plant, Ningxia Ningwu Power Plant, etc., fly ash can be purchased from the above two places.

3. Adaptability to climatic conditions

The adaptability analysis to climatic conditions is firstly to collect the data of the existing and under-construction projects under similar climatic conditions, summarizes the existing engineering experience, and then analyzes the adaptability of the RCC dam construction in this area through the engineering analogy method. The climatic characteristics of similar projects are shown in Table 1.

Table 1. Similar engineering climatic conditions

project name	Average temperature over the years /°C	Average temperature of the coldest month /°C	climate characteristics	Area	Extreme temperatures /°C		maximum Dam height /m	Completion time
					max	min		
Chonghuer	2.6	-17.3	Cold	Xinjiang	36.6	-45	71	1995
Karasok [4]	2.8	-20.8	Cold	Xinjiang	40.1	-49.8	121.5	1998
Guanyinge	6.2	-14.3	Cold	Liaoning		-32.9	82	2001
Baishi	7.8	-11	Cold	Liaoning		-37	50.3	2008
Longshou	8.5	-15	Cold	Gansu	37.2	-33	80	2009
Luogu	10.9	1.5	Mild	Sichuan	33.1	-20.6	82	2009
Longkaikou	19.8	14.1	Mild	Yunnan	41.8	-2.1	119	2014
Central Tibet	9.3	0.3	Mild	Tibet	32.5	-16.6		

The average temperature of the coldest month measured by a meteorological station in central Tibet is 0.3 ℃, which is at the upper level of the projects listed in Table 1. According to the relevant provisions of China's "Code for Design Specification Hydraulic Concrete Structures" and "Design Code for Hydraulic Structures Against Ice and Freezing Action", this area belongs to a mild area[5-6]. In addition, the annual evaporation (2 084.1 mm) and relative humidity (51%) in this area are also comparable to those of similar projects (Luogu: 1805.2 mm, 70%; Longkaikou: 2778.7 mm, 51%). In summary, the RCC gravity dam can adapt to the climatic conditions of the central Tibet.

4. Adaptability of material properties

According to the relevant provisions of the "Technical Specification for Durability on Concrete of Hydraulic Engineering", the frost resistance grade of a RCC gravity dam currently in the design stage in the central Tibet area is C9020F200, and the frost resistance grade of the dam body is C9015F100 and C9020 F100[7]. The results of the RCC mix ratio test are shown in Table 2.

Table 2. Concrete mix ratio of a project in central Tibet for the RCC gravity dam

Design specifications	Sand rate/%	W/B	Water/ (kg•m^{-3})	FA/%	water-reducing admixture/%	air entraining agent /%	Volumetric weight /(kg•m^{-3})	Cement /(kg•m^{-3})	Fly ash /(kg•m^{-3})
Two-graded concrete $C_{90}20W8F200$	35	0.45	94	50	0.8	10	2370	104	104
Three-graded concrete $C_{90}15W6F100$,$C_{90}20W6F100$	30	0.5	88	60	0.8	12	2400	70	106

For RCC dams in severe cold areas in China, such as Longshou in Gansu and Kalasuke in Xinjiang, the minimum temperature is lower, and the required frost resistance grade of external RCC is F300, which is higher than the frost resistance grade of external RCC for projects in central Tibet. The frost resistance grade of the internal concrete is F50~F100, which is similar to the project in central Tibet. The mix ratio of Gansu Longshou and Xinjiang Kalasuke RCC[8] are shown in Table 3.

Table 3. RCC construction mix ratio of Longshou and Kalasuke dam

Design specifications	Sand rate/%	W/B	Water /(kg•m^{-3})	FA/%	water-reducing admixture/%	air entraining agent /%	Volumetric weight /(kg•m^{-3})	Cement /(kg•m^{-3})	Fly ash /(kg•m^{-3})
Gansu,Longshou	Two-graded concrete $C_{90}20W8F300$	32	0.43	88	0.9	45	2 400	96	109
	Three-graded concrete $C_{90}20W6F100$	30	0.48	82	0.9	7	2 400	58	113
Xinjiang,Kelasuke	Two-graded concrete $C_{180}20W10F300$	34	0.45	98	0.85	12	2 370	131	116
	Three-graded concrete $C_{90}20W8F100$	27	0.45	90	0.85	8	2 400	140	109
	Three-graded concrete $C_{180}15W4F50$	28	0.56	90	0.85	6	2 400	61	171

After analysis and comparison, the multi-year average temperature and extreme minimum temperature in central Tibet are higher than those of Longshou and Kalasuk, while the RCC dams of Gansu Longshou and Xinjiang Kalasuk have been in normal operation for many years, indicating that RCC dam construction technology is feasible in cold regions. Combined with the RCC test results of a hydropower station project in the design stage in this area, it shows that the use of RCC dam construction technology in this area is feasible, and there are no restrictive factors in material properties.

5. Adaptability of construction schedule

Central Tibet is located on the Qinghai-Tibet Plateau, with high altitude, large temperature difference between day and night, and low temperature in winter. The project construction needs to overcome unfavorable factors such as plateau hypoxia and cold winter.

RCC dams have the advantages of fast construction speed and flexible construction schedule. According to similar engineering experience, when the monthly average temperature in winter is lower than 0 °C, the construction will be stopped, and polystyrene boards, thermal insulation quilts, etc. are used for winter insulation to ensure the construction quality. Compared with normal concrete dams, under the same construction period, RCC dam can improve construction conditions, reduce the difficulty and cost of temperature control in winter construction, and ensure the construction quality. Therefore, the RCC dam in this area has good adaptability in terms of construction progress.

6. Adaptability of project cost

Based on similar engineering experience, the amount of fly ash in RCC is increased by about 60% on the basis of normal concrete. Since there is no fly ash resource in Tibet, fly ash needs to be purchased from Gansu Province or Ningxia Autonomous Region, and the transportation price is high.

According to the investigation, the ex-factory price of cement in Tibet is about 750 yuan/t, and the freight is about 1.5 yuan/t/km. The ex-factory price of fly ash in

Ningxia Autonomous Region is about 120 yuan /t, and the freight for transporting it by rail to central Tibet is about 750 yuan/t. Preliminary estimates based on the ex-factory price plus freight show that the prices of cement and fly ash arriving at the project are equivalent. The advantage of RCC dam in reducing the project cost through raw materials is not obvious, but there are no constraints on the supply of materials.

7. Conclusions

(1) It is technically feasible to use roller compacted concrete to build dams in central Tibet. The climatic conditions are better than those in Northeast China and Xinjiang. However, it still has the characteristics of high altitude, low pressure, large temperature difference between day and night, and strong sunshine. It is necessary to strengthen research on temperature control and crack prevention measures and interlayer bonding measures for roller compacted concrete, and strictly manage construction quality during the construction process.
(2) Compared with the normal concrete dam, RCC dam has the characteristics of fast construction speed and flexible construction period. It can avoid the influence of cold weather and simplify the temperature control measures in cold season, which is beneficial to ensure the construction quality of the dam body.
(3) Due to the absence of fly ash resources in Tibet, RCC dam has no obvious advantage in reducing project cost through raw materials. However, if admixtures with better mining conditions can be found near the project area to replace fly ash, such as tuff, the advantages of RCC dam in this area will be greatly improved.

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