

# Construction and Impact Analysis of the Three Gorges Dam

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**Abstract.** The Yangtze River occupies an important position in China's development strategy. Due to the intensification of human activities and its natural characteristics, the Yangtze River floods frequently, so the construction of the Three Gorges Dam plays a key role in flood control. The stability of the Three Gorges Dam(TGD) and its impact on the environment of the Yangtze River Basin have attracted much attention. The paper aims to analyze the construction system of the TGD, its key technologies, and its environmental impacts on the middle and lower reaches of the Yangtze River, to provide a theoretical basis for maintaining the safety of the dam and the sustainable development of the Yangtze River Basin. The results found that the TGD is a concrete-type gravity dam, which consists of a flood relief dam, a powerhouse and navigation facilities. Its flood discharge and energy dissipation, cofferdam and navigation construction technologies are at the forefront of the world. Studies have shown that the completion of the dam has increased the magnitude of climate fluctuations, the level of pollution of water sources, and made the river channel change, but it has certain economic benefits for the society. At the same time, with the advancement of science and technology, 3S and other technologies can be used to strengthen the monitoring of the stability of the TGD. The results of this paper provide a theoretical basis for the construction status of the TGD and the sustainable development of the Yangtze River Basin.

**Keywords:** TGD; Construction; Key Technology; Impact.

## 1. Introduction

As the longest river in China, the Yangtze River has an important economic and strategic position. With socio-economic development and intensified human activities, the environment of the Yangtze River basin has been affected by frequent floods; therefore, effective flood control measures, such as the establishment of flood control facilities in the middle and lower reaches of the Yangtze River and the enhancement of water resource management, are needed to cope with the flooding problem.

To solve the flooding problem of the Yangtze River, experts proposed the construction of the Three Gorges Project (TGP). The Three Gorges Dam (TGD), as an important part of the TGP, has continuously caused many scholars to participate in the discussion from before to after the construction, analyzing the changes in precipitation, Chinese sturgeon spawning, and summer runoff of the Yangtze River to argue the pros and cons of the impacts of the TGD on the natural and human environment [1-3]. However, due to the early construction time of the TGD and the influence of various factors such as geology, cracks have appeared, posing a certain threat to the safety and stability of the dam; in addition, from the data of various studies, it can be found that before and after the construction of the dam, the environment of the upstream, middle and downstream of the Yangtze River has undergone certain changes, which proves the impacts of the construction of the TGD. Therefore, it is of great significance to research the construction and impact analysis of the TGD to maintain the ecological sustainable development of the Yangtze River basin and to protect human life and health.

Against the above background, this paper summarises the research results on the construction and impact of the TGD in recent years. It mainly summarises the construction system and key technologies of the TGD, and takes the middle and lower reaches of the Yangtze River as the study area to describe the impacts of the dam's construction on the natural and human environment. On this basis, the paper makes suggestions for maintaining the safety of the dam and refining its construction

to minimise the adverse impacts and furthermore makes an outlook for the sustainable development of the Yangtze River Basin.

## 2. Construction System of the TGD

### 2.1. Necessity of the TGD

Under the trend of global warming, extreme weather and climate events are occurring frequently, with great impacts on our economy and society. The Yangtze River Economic Belt, one of the most powerful and influential regions in the country, is facing a growing flood crisis due to urbanisation and its special natural conditions. With the rapid development of socio-economic and regional integration, the exposure of the affected areas and the social vulnerability of the region are also increasing, and flooding has become the primary factor restricting the economic development and life and health of the Yangtze River Basin [4]. For that reason, the construction of the TGD plays a key role in flood control.

It has been proved that the construction of the TGD has improved the flood control capacity for floods of less than one in 100 years and reduced the disaster losses caused by frequent floods, but some scholars still believe that the maintenance cost of the TGD is too high and the environmental damage to the Yangtze River basin is serious [5, 6]. It was found that the construction of the TGD has little impact on shipping, and it can also generate electricity and store water, which has very great economic benefits, while the ecological impact of the TGD needs to be further explored [7].

### 2.2. Structure of the TGD

The TGD is made up of the main dam, powerhouses and navigation structures (Fig. 1). The dam has a total length of 3035 meters and a height of 185 meters. There are 14 units on the left bank and 12 units on the right bank of the hydroelectric power plant, with a total of 26 generating units. The front row consists of small turbine generators with a capacity of 700,000 kilowatts, and the general installed capacity is 1820 kilowatts. The annual power generation is 84.7 billion kilowatt-hours.

The TGD was planned to be completed in three phases over 17 years. The preparatory work began in 1993, followed by the closure of the river channel in 1997. In 2003, the first batch of turbines and permanent ship locks were put into operation, with the entire project scheduled for completion in 2009. During the years from 1999 to 2001, new world records were continuously set for annual concrete pouring. In 2002, the left bank dam reached a height of 185 meters and a two-way five-step ship lock was completed, successfully closing off the diversion channel. A significant milestone was achieved in 2003 when major goals such as reservoir filling, improvement of navigation conditions, and power generation were accomplished within the TGD project. Throughout its construction period, sufficient funding was available for the project which helped maintain perfect control over costs during the initial design stages [8].

The TGD is a concrete gravity dam, known for its high level of safety and excellent earthquake resistance capacity. Concrete for the TGD is not only strong but also resistant to seepage, freezing, cracking, impact and abrasion, carbonation and erosion [9].



**Fig 1.** The structure of the TGD (unit: m) [9].

### **3. Key Technologies for Construction of the TGD**

In June 1994, at the Global Super Engineering Conference held in Barcelona, the second largest city in Spain, and chaired by the US Development Council (WDC), the TGP was listed as one of the global super engineering projects. The TGP ranks among the world's leading engineering projects in terms of scale, science and technology, and comprehensive utilization benefits. The success of TGD relies on the mastery of several key engineering techniques, which are discussed in more detail below.

#### **3.1. Flood discharge and energy dissipation technology**

The flood relief structure of the TGD is characterised by large flood discharge, high head, large discharge, etc. It is calibrated according to the 10% increase of the 10,000-year flood and the flood flow of 124,300m<sup>3</sup>/s. Due to the large installed capacity, the number of required installation units, so the flood control dam section should be as short as possible. The final dam flood relief facilities use deep holes and table holes arranged in between and the flood relief dam section arranged 23 deep holes, 22 table holes and 22 inflow bottom holes. Table holes and deep holes are separated by a long partition wall along the dam surface, and the bottom holes of the diversion are chosen to be pressurised long tubes, which realises a staggered three-layer layout of large discharge holes [10, 11]. Such layout not only meets the multi-objective operational requirements such as river closure in the third stage, flood discharge in the power generation period, water retention in the cofferdam, drainage and sand removal in the operation period, and lowering of the water level when necessary; it also greatly shortens the length of the spillway dam section, reduces the excavation of the two abutments, and saves the project investment.

#### **3.2. Key technology of Concrete cofferdam technology**

"Three-phase diversion" refers to the project of blocking the open channel and building three-phase upstream and downstream earth-rock cofferdams to ensure the normal passage of the river and construction safety during the construction period [12]. TGP construction diversion using "three-phase diversion, nullah navigation" program, has built a period of earth-rock cofferdams and crushed concrete longitudinal cofferdams, the second phase of the upstream and downstream earth-rock cofferdams, the third phase of the upstream and downstream earth-rock cofferdams, the third phase of the crushed concrete cofferdams, a total of five, the success of the use of the foundation of the earth-rock cofferdams of the new silt and sand treatment, shaped concrete seepage walls, vibroporous high spray, conventional high spray, integrated drilling and spraying and self-consolidating mortar integrated seepage control technology [10].

The integrated and innovative cofferdam blasting and demolition technology was adopted, the concept of integrated design for construction and demolition was put forward, and the demolition program of pre-positioning a centralized chamber (hole) in the cofferdam was adopted for the first time, thus realizing the underwater directional dumping of the cofferdam. At the same time, ultrasonic fish-driving technology was successfully used, effectively avoiding the impact of blasting on aquatic organisms and the environment.

#### **3.3.3 Key technology of five-step ship lock**

TGD double line five-stage continuous ship lock is the world's largest and most technically complex inland waterway lock, the maximum head of 113m, the effective size of the lock chamber of each lock stage is 280\*34\*5m, the annual single throughput capacity of 50 million t. The site is selected on the left bank of the dam, the upper and lower reaches of which are connected by a pilot channel to the main channel of the Yangtze River, with a total length of 6,442m, of which the section of the main building is 1,607m long, which is the most concentrated area of high slopes, with the maximum slope height of 170m, and the continuous slope height of more than 120m ranges up to 460m [13].

Compared to traditional gravity ship lock structures, the five-step lock innovatively adopts the "fully lined ship lock" design, which achieves higher load-carrying capacity and construction efficiency through high strength tension-shear structural bolts [14]. At the same time, the lock adopts a large aspect ratio and high center of gravity giant herringbone gate (single gate weighing 855 t), including giant gate body whole packing suspension technology, graded loading, top lifting combination, balanced equal load lifting technology, hydraulic lifting digital closed-loop synchronous control technology. The three sides of the five-step lock are in the strong constraint zone (the lock chamber floor and the two sides are old concrete), which were buried underwater immediately after the completion of the project, and equipped with concrete temperature-controlled anti-cracking construction technology.

## 4. Impact analysis of the TGD

### 4.1. Impact of the TGD on the natural environment

Studies have shown that both the natural and human environment of the Yangtze River basin have changed to some extent after the construction of the TGD, with a dual trend towards better and worse. This paper takes the middle and lower reaches of the Yangtze River as the study area to analyse the comprehensive impact of the TGD (Fig.2).

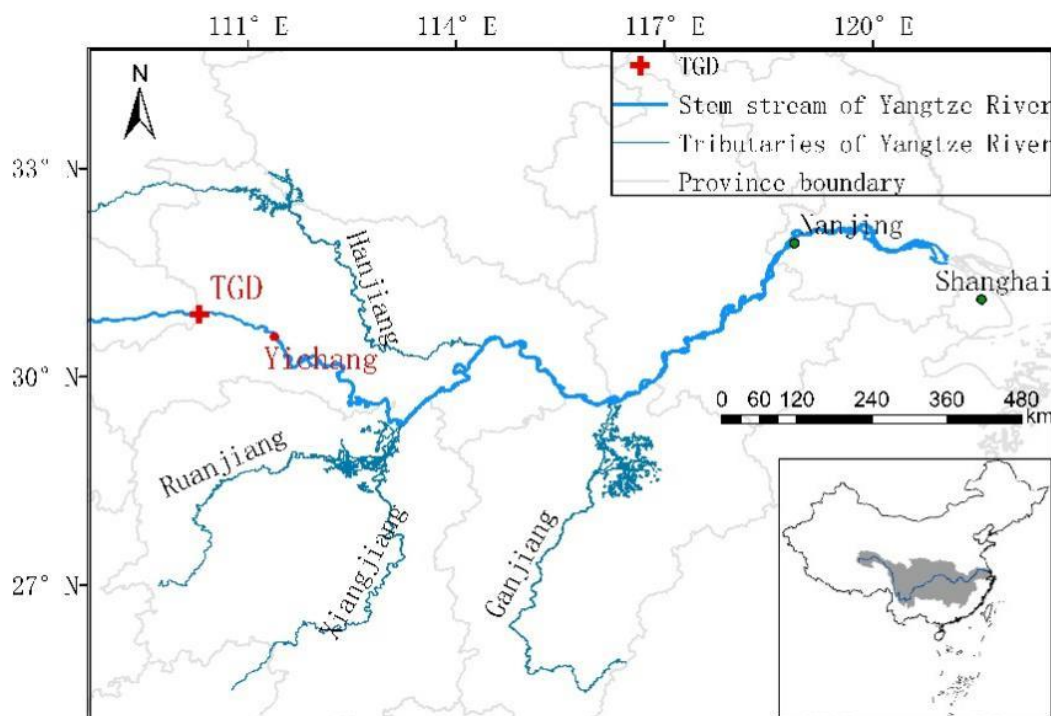


Fig 2. The middle and lower reaches of Yangtze River [15].

#### 4.1.1. Impact on climate

Zeng et al. found that the climate fluctuation in the reservoir area was greater after the dam was built, but the climate change was mainly influenced by changes in the surrounding environment. The dry island effect caused by urban expansion and the reduction of vegetation transpiration made the humidity in the reservoir area decrease, but the relative humidity increased due to water storage in the reservoir. In general, the humidification effect was greater than the dehumidification effect [15]. There are some fluctuations in the average annual precipitation in the Three Gorges Reservoir (TGR) area, but the magnitude is not obvious. Warming occurs in the southern part of the lower reaches of the Yangtze River, while cooling occurs in the northern part of the river, and the precipitation sequences are roughly the same before and after.

#### 4.1.2. Impact on Water Sources

Water pollution in the TGR area and the entire Yangtze River basin after the construction of the TGD seriously threatens the water quality situation in the TGR area and the Yangtze River basin. Li et al. found that the sources of sewage are mainly divided into three categories, namely industrial wastewater, domestic wastewater, and wastewater from the shipping industry, among which the pollution control efficiency of the TGR area industrial parks is low due to the relatively small scale and dispersal of pollution [16]. Meanwhile,  $F^-$ , T-Hard,  $N_3^-$ -N, TN and Se affected the contents of nutrients, inorganic pollutants, metal-like elements, and water mineralisation, respectively, which in turn affected the water quality. They also show seasonal differences, with the waning period from February to May and the flood season from July to August [17].

The annual runoff has not changed much, and has slightly decreased, but there is a redistribution of the process within the year, and the dam maintains the stability of the runoff of the Yangtze River by "cutting the peaks and filling the valleys". There is a close connection between water bodies. The number of days above the warning level of Poyang Lake decreased, but the number of days below the ecological level increased significantly. In terms of time, the impact of winter is greater than that of summer, which makes the water level lower and the drought more serious. At the same time, it also changed the lake area. Yuan used remote sensing technology to monitor and pointed out that the surface area of Dongting Lake showed a decreasing trend between 2000 and 2010 [18]. The TGD's recharge to the dry season is beneficial to alleviate the salty tide intrusion at the mouth of the Yangtze River.

#### 4.1.3. Impact on sediment

Since its operation in 2003, the TGD has intercepted nearly two-thirds of the upstream sediment, and the downstream riverbed has now shifted from deposition to erosion, leading to erosion and dam failure [19]. Chen et al. analysed the state of marine sedimentation before and after the construction of the TGD using  $^{210}\text{Pb}$  isotope analysis of the sedimentation state of the sea before and after the construction of the TGD found that the sedimentation rate of the underwater delta and the inner shelf decreased significantly after 2006 [20].

The water-sand characteristics are the most fundamental dynamic factors in the evolution of the river system, directly influencing the adjustment of the river channel. Regarding the water-sand relationship, a positive correlation is observed during various periods. However, the construction of the TGR has altered the water-sand characteristics of the river section, leading to the fining of bed sediments in the reservoir area and the coarsening of bed sediments downstream due to the scouring effect of clear water. This imbalance in river scouring has resulted in issues such as increased flow velocity in the sandy-pebble section below the dam, erosion of continental banks, and channel migration in the sandy section.

#### 4.1.4. Impact on organisms

Climate and soil have an important influence on the vegetation in the middle and lower reaches of the Yangtze River basin, and the vegetation change increased significantly in the area south of the Yangtze River, while the two lakes region showed a decreasing trend. The phytoplankton diversity index in the tributaries of the Yangtze River decreased significantly after the storage of 156 m of water in the TGR, but the composition did not change [21].

Dam construction has had an impact on the biodiversity of freshwater fishes. After the construction of the dam, the original river habitat was drastically changed, resulting in the loss of the original habitat and the emergence of new habitats for fish, and the results showed that the highest proportion of fish inhabited and spawned in the backwater bays formed after the dam [22]. In addition, changes in hydrological rhythms and a significant reduction in the area of spawning grounds caused a decline in Chinese sturgeon populations, and human activities and the Three Gorges Project explain the endangerment of Chinese sturgeon species.

#### 4.1.5. Impact on natural disasters

The TGP investigation indicates that the dam is located on a remarkably stable and solid massif without any active faults in its vicinity. Furthermore, historical records spanning over two millennia do not show any occurrence of major earthquakes at or near the dam site [23]. However, Chen and Talwani pointed out that the presence of active faults may trigger moderate reservoir-induced earthquakes although the TGD is built on stable granite [24]. Therefore, the stability situation of the TGD remains to be further investigated.

The massive power of the TGD to intercept water has begun to erode the steep banks of the Yangtze River, which, together with frequent fluctuations in water level, has triggered a series of landslide disasters and has also led to the destruction of the geological structure of the area near the dam [25]. The TGR area is surrounded by high and steep rock bodies, which will pose a huge threat to navigation channels and coastal towns if they collapse. For example, on 8 October 2017, about 7,000 m<sup>3</sup> of rock mass collapsed at Phoenix Hill, nearly half of which went into the Daning River. Yin et al. found that the risk of landslides can be controlled by altering the storage level of the TGD [26].

The TGD plays a key role in the flood control system of the Yangtze River, and mainly plays the role of flood control by stopping floods, cutting peaks and staggering peaks. As of July 2020, the TGR has accumulated more than 50 floods, and the total amount of floods intercepted has exceeded 150 billion m<sup>3</sup> [27]. In the defence of the Yangtze River basin mega-flood in 2020, the TGR combined with the upstream and midstream reservoirs to impound a total flood volume of about 30 billion m<sup>3</sup> [28].

#### 4.2. Impact of the TGD on the human environment

The Three Gorges Project is the largest comprehensive water conservancy project in the world. Wang calculates that the total output value of the TGR area increased by 4.43 times during the construction period from 1993 to 2008. A model prediction shows that for every 1% increase in the construction capital of the Three Gorges Project, the economy of the reservoir area grows by about 0.2%, which proves that the construction of the TGD has a driving effect on the economy [29]. The flood control, power generation and shipping after the completion of the project also contributed to the economic growth [27].

After the construction of the TGD, there are 6 lakes and 10 islands formed in the TGR area and 5 lakes and 4 islands formed on the tributaries. There are more than 70 new and enhanced tourist attractions with development value. The traditional cultures of Ba-Shu, Ba-Chu and Qin-Long have been preserved, forming a tourism economic circle of the TGD that integrates hydropower projects and landscape scenery, including landscapes such as the TGD, Tianjingxia Ground Fissure and Jianzhi Upright Man Site. Kan et al. found through statistics that in 2009, the total number of tourists received in the TGR area was 5.8 million person-times, which was 3.2 times that of 2000. Meanwhile, the average annual growth rate of tourism income in the Three Gorges area in the first decade of the 21st century was 27.3%, driving regional employment and economic development [30].

The construction of the TGD has changed the original social system of the surrounding residents. The resettlement project not only involves the settlement of 1.3 million migrants but also affects the relocation of factories and enterprises and the protection of cultural relics. The relocation of migrants will bring about problems of social integration, such as potential safety hazards, public services, population quality, social interaction, and cultural differences. At the same time, due to the early planning of the Three Gorges migrants, issues such as gender equality and care for vulnerable groups were not fully considered, causing certain social impacts.

### 5. Conclusions

This paper examines the architectural design, core technologies, and impacts of the TGD. The findings indicate that: 1) The TGD is a concrete gravity dam known for its high strength and resistance to erosion. It comprises spillway dams, power stations, and navigation facilities, generating an annual

output of 84.7 billion kilowatt-hours. 2) The construction techniques employed in the TGD are at the forefront globally. Notably, its spillway structure boasts a significant flood discharge capacity. To preserve the ecological environment, innovative methods such as controlled blasting for cofferdam removal and ultrasonic fish deterrent systems were utilized. Regarding navigation structures, the two-way five-step ship lock features a "fully lined ship lock" design, minimizing rock excavation. 3) The debate surrounding the construction of the TGD primarily centers on its environmental and social impacts. Analysis of the middle and lower reaches of the Yangtze River reveals that the dam's influence is multifaceted. Positive outcomes encompass mitigating saltwater intrusion, enhancing flood control, stimulating employment, and boosting economic development. Conversely, the dam has also led to adverse effects, including water contamination, riverbed alteration, decreased biodiversity, and the socio-economic challenges associated with population relocation.

The research results on the stability of the TGD are inconsistent and need to be further explored in depth. With the development of science and technology, the deformation of the dam can also be monitored in the future using 3S technology and InSAR technology. The findings of this paper are conducive to the TGD to refine its construction and provide a reliable theoretical basis for the ecological sustainable development of the Yangtze River Basin.

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