Management and Construction of the Three Gorges Project

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Abstract: The owner-responsibility system is conducted for implementation of the Three Gorges Project (TGP). For the construction management of the project, the contracting system, the contract administration system, and the construction supervision system are executed for the project management. Contractors for civil projects are determined through bidding and contracting. The permanent equipment and construction materials are purchased through bidding. Some of large-sized construction machines and mechanical and electrical equipment are procured by the international competitive bids. Qualified engineers from qualified engineering bodies, scientific research organizations, and construction companies are selected for the construction supervision. This paper covers the construction of the TGP in some detail, particularly the main dam structure, diversion work, the construction program, and management, project cost, and financing.

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Introduction

The Three Gorges Project (TGP) is the key project in developing and harnessing the Yangtze River, with huge comprehensive benefits of flood control, power generation, and navigation improvement. It is the largest water conservancy project ever built in China, and also in the world. With the normal pool level at 175 m, the total storage capacity of the reservoir is 39.3 billion m^3.

The project consists mainly of the dam, powerhouses, and navigation structures. The dam is of a concrete gravity type with a total length of 2,309.49 m at dam axis, a dam crest of 185 m, and maximum dam height of 181 m. The power station is a dam-behind type with two powerhouses, the left one and the right one, housing 14 and 12 generating units, respectively with unit installed capacity of 700 MW, totaling 18,200 MW. On the right bank, room is preserved for six generating units to be expanded in the later stage. The navigation structures, located on the left bank, consist of the continuous double-line five-step shiplock and the single-line single-step vertical shiplift.

The TGP was planned to be completed in 17 years in three phases. The preparatory work started in 1993, the river closure was achieved in 1997, the first group of units and the permanent shiplocks were in service in 2003, and the overall project is scheduled to be completed by 2009. From 1999 to 2001, new world records were created in succession in terms of yearly concrete placement. The dam rose to el.185 m on the left bank in 2002, the double-way and five-step shiplock was completed, and the diversion channel was closed successfully in the same year. Milestone results were achieved in the TGP in 2003, smoothly realizing the three major targets such as reservoir impoundment, navigation improvement, and power generation. Since the commencement of the construction, sufficient funds for the project have been in place and the project cost was perfectly controlled within the approved budget in the preliminary design, the project construction has progressed smoothly in accordance with the master schedule, and the construction quality has satisfied the designed requirements (Zhang 2003).

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Construction Planning and Scheduling

Quantities of Construction Work

The major quantity bills for the principal structures and diversion works are as follows:

- Earth-and-rock excavation 1.0283×10^8 m^3;
- Earth-and-rock fill 3.198×10^7 m^3;
- Concrete 2.794×10^7 m^3;
- Reinforcing steel 4.63×10^8 kg;
- Metal works 2.565×10^8 kg; and
- Installation of hydro turbine generating units 26 sets (18,200 MW).

Work quantities broken down into detail according to structures are listed in Table 1.

River Diversion

Three-phase diversion scheme was adopted for the project construction (Dai and Zhang 2002).

In the first construction stage, the subriver on the right side of the Zhongbao islet is enclosed, by taking advantage of the islet to build the phase I earth and rock cofferdam. At the same time, the open diversion channel is excavated and the longitudinal roller

Table 1. Quantity Breakdown of Construction Work of TGP

Structures	Earth-and-rock excavation (10^6 m^3)	Earth-and-rock fill (10^6 m^3)	Concrete (10^6 m^3)	Reinforcing steel (10^6 kg)	Metal works (10^6 kg)	Installation of generating units (sets/MW)
Dam	10.38	—	16.00	172	71.6	—
Powerhouses	19.58	3.03	3.45	124	77.2	26/18,200
Navigation facilities	55.84	7.86	5.35	165	98.1	—
Diversion works	17.03	21.09	3.14	2	9.6	—
Total	102.83	31.98	27.94	463	256.5	26/18,200

compacted concrete (RCC) cofferdam is constructed in the construction pit. Meanwhile, the construction of the temporary shiplock on the left bank of the river is constructed. In this construction phase, the river flow and navigation went through the main river course.

In the second construction stage, the construction is started with building the transverse cofferdams, so as to form, together with the completed RCC longitudinal cofferdam, into the phase II construction pit. The construction of the spillway, intake dam, and power plant on the left bank has begun. Simultaneously, the permanent shiplock and shiplift are constructed on the left bank. In this stage, the river flow is diverted through the open diversion channel, and barge fleets and passenger boats pass through either the open channel or the temporary shiplock.

In the third construction stage, the upstream phase III RCC cofferdam is built in the open channel, and the impoundment of the reservoir is up to the elevation of 135 m. The left bank power station and permanent shiplock is put into operation. In the meantime, the phase III cofferdams together with the longitudinal cofferdam, form the phase III construction pit for the construction of the right bank dam and power plant. During this period, the river flow is discharged through the outlets in the spillway dam, while the boats pass through the permanent shiplock.

Scheduling

The total duration of construction was divided into three construction stages.

1. Stage I, from 1993 to 1997, is for the construction preparation and the phase I works, which is marked with the river closure;
2. Stage II, from 1998 to 2003, is for phase II works, which marked the generation of electrical power by the first batch of generating units and the operation for ship traffic of the permanent shiplock; and
3. Stage III, from 2004 to 2009, is for phase III works, which is marked with the operation of all generating units and completion of the project.

Basic Management Frameworks for Construction

The State Council Three Gorges Project Construction Commission (TGPCC) is the top decision-making authority for the Three Gorges Project. The TGPCC established the Administrative Office and the Resettlement Development Bureau responsible for the routine work of TGPCC and resettlement, respectively.

China Yangtze Three Gorges Project Development Corporation (CTGPC), authorized to be established by the State Council, is the owner of the TGP. CTGPC is responsible for the overall construction of TGP and its management of operation and maintenance after the completion of the project, and is also responsible for the financing and reimbursement of investment including the fund for resettlement.

As determined by the State Council, the principles of the socialist market-oriented economy and the common international practice are adopted in TGP's construction. That is, the bidding management, contract management, and construction supervision system centering on the project's legal entity responsibility are carried out for the project construction and management.

The headquarters of CTGPC is located in Yichang City. There are several departments and subsidiaries under the CTGPC such as planning, financing, scientific management, Gezhouba power plant, etc. In the dam site, the project construction department has been established which is in charge of the overall coordination and management of the construction. Under this department, the subproject departments take the responsibility for management of individual construction items.

The Resettlement Bureau under TGPCC was established, which is responsible for setup of resettlement policies, resettlement planning, supervision on resettlement progress, and quality and coordination of the issues arising from the resettlement execution. The local governments of Chongqing and Hubei Province are in charge of the resettlement practice specifically including resettlement, industry relocation, and household rebuilding.

Project Management

Design Management

The design of TGP is undertaken by the Yangtze Water Resources Commission under the Ministry of Water Resources. The technical design is reviewed and approved by the Technical Committee of the CTGPC by means of panels of experts. The bidding design is reviewed and approved by the CTGPC. The detailed construction drawing design is reviewed and approved by the Construction Department under CTGPC in conjunction with various supervision units. Expert comments and ideas are widely called for by CTGPC on the key technical issues arising from the project to encourage innovation, give full play to collective wisdom, and avoid incorrect decisions.

Bidding and Contracting Mechanism

The overall project is divided into subprojects and packages or work breakdown structures based on their specific features and the projected progress schedule. These subprojects and packages are in turn awarded to qualified contractors by process of public bids.

Contractors for civil projects are selected through bidding and contracting. The permanent equipment and construction materials

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are purchased through bidding. Some of the large-sized construction machines and mechanical and electrical equipment are procured by international competitive bids (BS).

The project items are implemented by bidding in phases on an item-by-item basis, managed item by item, and integrated by summarization.

Open bidding, fair competition, equitable evaluation, and collective decision are carried out during bidding activities. The bidding activities for the project items are integrally organized and the bidding procedures are strictly controlled. The Three Gorges International Bidding Co. Ltd is responsible as the bidding agent for the construction, and evaluation experts are invited as stipulated by the bidding law to perform the evaluation independently.

Construction Supervision

The supervision of TGP is managed by the Construction Department under the CTGPC. The former is responsible for the coordination and integration of various construction supervision units. The construction supervisors are invited by CTGPC from qualified supervision agencies to supervise the construction by the contractors. At present, five major supervision companies and 972 supervisors including some international supervisors are working at the site for the supervision of a variety of contracts.

Quality Assurance System

To ensure the quality control of the construction, a series of criteria and standards which meet both design requirements and national standards have been established. The required organizations such as the test center for concrete and raw materials, the measuring center, the safety monitoring center, the test center for metal works, and the meteorological and hydrologic forecasting center have been set up to constitute the quality assurance system.

Based on the existing national standards, ministerial standards and the special requirements for the TGP design as well as the project construction characteristics, CTGPC, organized the preparation of the *Quality evaluation standards for the China Yangtze Three Gorges Project*. Over 90 quality control standards have been written in volumes and implemented to date (Dai 2003, Dai and Zhang 2003).

1. Setup of quality management agencies and responsibility systems. Responsibility systems have been established for different links from raw materials, machining, and manufacture, storage, and transport to the construction. The CTGPC organizes the involved parties to set up a Three Gorges Project Quality Management Committee, responsible for organization, coordination, supervision, and guidance.
2. Setup of quality accident treatment procedures, quality system of rewards and penalties, and the quality evaluation system of individual items. 135,107 individual items have been evaluated from the commencement of the project in 1993 until the end of 2002. The quality of the project under construction is good in general.
3. Setup of quality inspection and step-by-step control systems. The factory inspection of raw materials is performed by qualified agencies entrusted by the CTGPC in accordance with the stipulated standards and the system of factory certificate of qualification is carried out. The process of making the steel structures and the generating unit equipment involved are inspected in factories by qualified domestic and foreign manufacture supervision agencies entrusted by CTGPC, regularly reporting to the CTGPC about the quality. Arrival inspection, customs inspection, and site tests are carried out for the transportation process. The Material Test Center, Measurement Center, Safety Monitoring Center, and Metal Structure Test Center under CTGPC perform their own responsibilities according to relevant regulations.

The Three Gorges Project Construction Committee under the State Council (TGPCC) established a special panel of experts for the TGP quality inspection, responsible for the regular authoritative inspection and evaluation of the construction quality of TGP.

This quality supervision system has served as a guaranteed role to the timely alleviation of quality risks, improvement of engineering quality, and construction of a first-rate project.

Control of Construction Progress

Before mobilization of the project implementation, 70 years had been spent on the feasibility study, planning, and engineering of Three Gorges Project. In early 1993, the preparatory work and the construction of Phase-1 diversion works started. On December 14, 1994, the former Premier Lipeng announced the official commencement of the project at the construction site.

Since the commencement of the construction, sufficient funds for the project have been in place and the project cost was perfectly controlled within the approved budget in the preliminary design, the project construction has progressed smoothly in accordance with the master schedule, and the construction quality has satisfied the designed requirements.

CTGPC made a master schedule according to the objectives of the three phases. Based on this, the control of progress of each item was prepared and the bidding progress therefore was formulated. Adjustment was timely, made up of the component progress through contract management during the construction to ensure the achievement of the objectives of the control of progress on the critical path.

In the last decade, the preset progress objectives have fundamentally been achieved in various items, thus ensuring the goal of the master schedule. The successful river closure on November 8, 1997 completed the task of Phase 1 construction. The blasting of Phase 2 upstream and downstream cofferdam was successfully performed on May 1 and July 1, 2002, respectively, as scheduled and passed the stage inspection organized by the State. The master schedule has been effectively controlled. Various critical junctions have been successfully passed and it is expected that the whole project will be completed in 2009 as planned.

Project Cost and Financing

Project Cost

How much money this great project needs has been a puzzle and of public concern. The design process of projects in China goes as follows: feasibility study, preliminary design, technical design and bidding design. Based on the preliminary design approved by the Government in 1993, the total cost for the Three Gorges Project in static terms will be 90.09 billion Chinese Yuan (based on May 1993 value), 40 billion of which will be for resettlement. However, the duration of the project is some 17 years, during which the inflation index and interest rate will vary. It was predicted in 1993 that another 74.9 billion Chinese Yuan would be needed to compensate for price escalation during the construction

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period. In accordance with the integrated financing scheme for the project, a total amount of 38.9 billion will be reimbursed for the interest repayment of loans.

Financing and Fund Sources

The fund was established by the Central Government by levying 0.004–0.007 RMB per kilowatt hour from the national power consumption and this fund serves as the national capital to be poured into CTGPC. Presently, the fund amounts to some 4–4.5 billion Yuan yearly. During the 17 years of construction, the fund will total 80–90 billion.

1. Power revenues from existing Gezhouba Power plant. The existing Gezhouba Power plant, with the total installed capacity of 2,710 MW and an annual power output of 15 TW h, is the subsidiary of CTGPC. The power revenues will be used for the construction of TGP. This source will reach 8–9 billion in the 17 year construction period.
2. Power revenues from Three Gorges Project itself. The first group of the generating units of Three Gorges Project was to be in service by 2003. The power revenues from the project during 2003–2009, expected to be 35–40 billion, will be also used for the construction of the project.
3. Bond issuing. Six billion Yuan of corporate bonds has already been issued for the project. It is planned that bonds be issued every year during the construction period and the funds from this source will total 15 billion Yuan.
4. Short-term and long-term loans (domestic). Short-term and long-term loans from domestic banks are used for filling the gap in funds of the project.
5. Export credits and syndicated loans (international). Export credits and syndicated loans are required for the procurement of the imported equipment. So far, $1.1 billion United States equivalent to 9.1 billion RMB has been introduced to the construction of the project.

The above-mentioned fund sources are expected to be sufficient for the financial requirements of the Three Gorges Project.

Project Cost Control

The cost estimate approved by the State for TGP was made on the price level at the end of May 1993. The construction duration of TGP is 17 years. For this purpose, investment control measures were taken as follows:

1. Static control. The investment is controlled within an estimate budget approved by the State. The project investment is controlled by a static budget to optimize the project management and reduce the cost and various resettlement-related expenses.
2. Dynamic control. During a 17-year construction period of the project, the price indexes change every year and the bank interest floats, so costs must be adjusted every year in light of the comparison of the price indexes of that year with those of 1993. The future fund demand is predicted every year to carry out the dynamic management. Payment is made by means of dynamic price difference and financing cost reduced through various financing measures.
3. Cost escalation. Price difference adjustment has been performed for most of the contracts and compensation made to contractors once a year. Intermediaries are entrusted by CTGPC to analyze the price of construction materials, equipment, various commodities, and labor nationwide so that the rate of price escalation influencing TGP was proposed and submitted to the Three Gorges Project Construction Committee under the State Council and then examined and decided by TGPCC in conjunction with the State Planning Commission and the experts of the intermediaries. The rate is examined and decided every year for the previous year, which will be the basis for CTGPC to compensate the contractors according to the difference of the bidding price and the quotation of that year.
4. Budget control. Based on the preliminary budget approved by the State, the implementation budgets of the owner were prepared and adjusted according to the technical design and then the control prices in the implementation of the contracts of individual items were prepared according to the bidding contract prices of the items. Analyses are performed of the implementation and control of the annual budget to achieve both the item and the overall budget controls. The practice indicates that the fiscal control by CTGPC is good.

Resettlement and Relocation

Influence of Reservoir Inundation

The reservoir forming the Three Gorges Project is a valley-like reservoir, which is 650 km long with the tail-water back to Chongqing, 500–1,000 m wide (660 m on average) and covers 1,084 km^2. The inundation covers 20 counties and cities and affects a population of 840,000 based on a 1994 survey. The inundated farmlands cover 17,200 ha. Relocatees will be resettled over 17 years on a year by year basis and therefore the final number of relocatees is estimated to be 1.13 million because of population growth.

Resettlement Cost

The cost of resettlement will be 40 billion Chinese currency (based on May 1994 value), accounting for some 44% of the total project costs of 90 billion Yuan. Taking into consideration price escalation during the project construction period, the final cost for resettlement is estimated to be approximately 59.7 billion excluding the loan-borne interest repayment that will be directly paid to banks by CTGPC.

Resettlement Policy

The Chinese Government attaches great importance to the resettlement aspect of the project. Concerning the fact that the reservoir area is a relatively poor, underdeveloped, and barren region with a dense but low income population, the funds allocated for the resettlement will help this region overcome its poverty and finally achieve prosperity. The Government established a series of resettlement policies to implement the development-oriented resettlement, hoping that as many relocatees as possible can be moved from mountainous areas to the plain. Additionally, the economy of the reservoir areas will be restructured, where lagging industries will be closed and old towns will be rebuilt. With the sponsors and help from enterprises in developed regions, investments will be poured into the reservoir areas to rebuild and restructure industries there and improve communications as well as power supply. In the past 10 years, 300,000 people have been resettled with their standard of living upgraded. This has been a great success of the resettlement policy.

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Impacts on Ecology and Environment

Impacts of Three Gorges Project on ecology and the environment have been attracting worldwide attention. The environment impact assessment had been done during the planning and the verification. It is concluded that the project will create both positive and negative impacts on ecological environment but that the positive will prevail over the negative. The environmental benefits created by the project lie in the middle and lower reaches of the river and the negative impacts will be produced in the reservoir areas. But most of the negative impacts can be mitigated or eliminated by countermeasures.

The environmental benefits are mainly as follows: Upgrading the flood-preventing ability of the middle and lower reaches of the river and significantly mitigating the flood-caused environmental deterioration in the Dongting Lake area and Jianghan Plain regions. The enormous power produced by the project will replace the annual burning of coal of 50 million t, avoiding emission of waste gas, the discard of wastewater, and the discard of waste residue so as to improve the weather conditions of the reservoir areas and the water quality of the middle and lower reaches of the river in dry seasons.

Negative impacts on the environment arise from the inundation. Due to the rise of water level and submerging of rapids, the natural landscape in the Three Gorges river section will slightly change. Some cultural relics and underground ancient graves will be submerged by the reservoir. Measures are being taken to reserve or relocate those relics. After completion of the existing Gezhouba Project and Three Gorges Dam, migration passage for rare aquatic life, the Chinese surgeon, for example, was blocked. Further efforts will be made to strengthen the successful artificial spawning and breeding of those species.

There is special emphasis placed on the environmental issue caused by the resettlement. The careful plan has been worked out and is being well performed. After formation of the reservoir, the river in the reservoir regions will flow more gently, pollution on the cities and towns along the river may be increased, and therefore the drainage of sewage from the cities must be perfectly controlled.

International Cooperation

The construction of Three Gorges Project attracted worldwide attention and also promoted the relationship and cooperation between Chinese engineering fields and their international counterparts. Since 1993, over 7,000 engineers from 32 countries and areas visited the construction site, attending technical seminars with the Three Gorges Company. The international procurement for 14 generating units of the left-bank powerhouse and the construction machines was completed and the contracts were awarded. During the construction of the project, outstanding engineers and experts worldwide were invited by the company for technical consultation and construction supervision on the project construction and project management.

Conclusions

China is a developing country with a vast territory. A large number of its rivers, seas, and lakes are still under the semiprimitive state. Due to the long-term development of the geologic era and impacts of mankind's activities, the ecosystem of the Yangtze basin is becoming unbalanced and the environment is deteriorating. Therefore, human beings must fully understand Nature while they are developing and harnessing the rivers, applying the scientific principles and the concept of sustainable development.

Mobilization and implementation of Three Gorges Project was the result of decisive decision-making from the Chinese Government on the basis of the above-mentioned ideas and concepts.

The construction of the Three Gorges Project is going smoothly and all the construction packages and the resettlement are being carried out in accordance with the master schedule. Although we have another 5 years to go to finish the project and more challenges await us, we are confident of achieving our targets and goals. Now, the great project can be seen on the land, witnessed in the air, or contour-profiled even from satellite. The benefits from the project are being realized and its objectives gained.

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