Last Phase of China's Three Gorges Dam Construction is Underway: Environmental Case Study

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Abstract

China's Three Gorges Dam (TGD) provides excellent educational opportunities for environmental engineering educators as they discuss its various aspects with their students and engage them in analyzing its multi-faceted impact. Many individuals and agencies around the world are collecting data to help study the short- and long- term ecological and environmental effects of building the Three Gorges Dam. Other far-reaching effects of the project on areas such as energy, industry, business, culture, society and transportation are now starting to become a tangible reality rather than speculations. Time will show to what extent the fears and concerns that many are having were justified.

Summary

The largest project in the world, China's Three Gorges Dam (TGD) – 1.44 miles (2.31 km) long and 620 ft (185 ms) high – is well into its third and final phase. Since Sunday, June 1, 2003, waters of the Yangtze River – third longest river in the world after the Nile and the Amazon – have been flowing through water diversion holes at the bottom of TGD in the portions completed during Phase I (1993-1997) and Phase II (1997-2003) of the project.

The gigantic concrete gravity dam officially began to store water in the 400 mile (640 km) long ribbon-like reservoir upstream of it, as the sluice gates of the dam started to be closed on schedule. Water level has been rising 4-6 ft (1.2-1.8 ms) each day, reaching 135 meters (433 feet) on June 10, 2003 and submerging numerous cities, towns, villages, arable lands, natural resources, and habitat of countless species.

At a special session convened in Beijing in September 2003 (www.threegorgesprobe.org, October 16, 2003), the Three Gorges Project Construction Committee (TGPCC) decided to raise the water level in the reservoir an additional four meters from the current level of 135 meters by October 30, 2003. The project's policy-making body also decided at the meeting to fill the reservoir to 156 meters above sea level in 2005 -- one year earlier than planned. News of these unexpected revisions to the long-established project timetable has been released in stages. Reasons given were to address navigation problems that have occurred downstream the TGD and to boost power generation.

Hundreds of thousands of people have been and are being moved to make way for the reservoir upstream the giant TGD. Filling this reservoir marks a major step toward completing the world's largest water-conservation, hydroelectric power generation project, scheduled for 2009, making its overall construction duration almost 17 years.

The five-story ship lock is now operational in both directions and a limited number of the turbines are already generating hydroelectric power. Chinese officials, however, admitted that there are about 80 cracks in the dam – size and location of which not specifically identified – which could cause leaks if not fixed. However, these cracks –they added— would not threaten the structural integrity or the performance of the project.

Numerous cracks in the dam, up to 10 meters long, were discovered in October, 1999, (www.threegorgesprobe.org, May 30, 2003), but only revealed in March 2002 by the popular South Wind Window (Nanfang chuang) magazine, a sister publication of the Guangzhou Daily (Guangzhou Ribao). After visiting the dam, reporter Zhao Shilong wrote that he had seen cracks stretching from top to bottom of the huge concrete structure. After the problem was brought into light, Lu Youmei, general manager of the Three Gorges Project Development Corp., acknowledged in Three Gorges Project Daily (Sanxia gongcheng bao) that cracks had appeared on the whole upstream face of the 483-meter-long spillway section, and that they extended from 1 meter to 1.25 meters into the dam.

Meanwhile, security officials are reported (www.threegorgesprobe.org , November 27, 2003) to be taking steps to counter the possibility of a terrorist attack on the Three Gorges Dam involving the large boats that are now able to navigate that section of the Yangtze.

Introduction:

Some of the most sophisticated of the 20th/21st century technologies were applied to complete Phase I (1994-1997) and Phase II (1997-2003) of the largest dam in the world, The Three Gorges Dam of China. Phase III (2003-2009) is currently in full swing, while the completed parts are operational. The Three Gorges Dam Project (TGDP) is the world's largest dam -- nearly 4 times larger than Hoover Dam, with a height of 620 feet (200 yards or 185 meters) and a length of approximately 1.44 miles (2.31 km). The TGDP is composed of the dam, two power plants and the navigation facilities. The dam is composed of three sections: the spillway dam, the intake dam, and the non-overflow dam. The permanent navigation structures include a ship lock and a ship lift.

TGDP Location:

The Three Gorges area is one of the world's most famous scenic sites around Qutang, Wuxian and Xiling gorges. TGDP is located almost 750 miles (1200 km) south of Beijing, and 650 miles (1000 km) west of Shanghai, China. More specifically, TGDP is constructed in Sandouping Village, Yichang County, Hubei Province, within the Xiling Gorge, about 25 miles (40 km) upstream from the existing Gezhouba Project located at Yichang City.

TGDP Site:

The site for TGDP was selected at Sandouping, along the Yangtze River, after studying about 15 other sites. It has many advantages. The crystalline rock, intact granite with 100 MPa of compressive strength forms a good foundation bed for the dam. In addition, there are no major disadvantageous geologic structures in the vicinity of about 9 miles (15 km) around the dam site, while the regional seismic activities are small in intensity, low in frequency. However, (www.threegorgesprobe.org , December 2, 2003) two civil engineering professors at Wuhan University believe that earthquakes in the Three Gorges reservoir area are a real cause for concern, and call for more resources to be put into investigating the region's seismic problems.

At the construction site of TGDP, the river valley is relatively open and broad, with the hills on both sides of the river fairly flat, providing for a good-size lake right at the upstream of the dam. Also, the existence of the small islet of Zhongbaodao near the right hand side bank of the Yangtze River was favorable for the river diversion project.

TGDP Main Hydraulic Structures

1. The Dam

The 60-story high dam is a concrete gravity type that is composed of three sections: the spillway dam, the intake-dam, and the non-overflow dam. The total length of the dam axis is 1.44 miles (2.31 km), with the crest elevation at 632 ft (189 m) and a maximum height of 620 ft (185 m).

The spillway dam, located in the middle of the river course, is 0.3 mile (483 m) long in total, where there are 23 bottom outlets and 22 surface sluice gates. The dimensions of the bottom outlets are 23 x 30 ft (7 x 9 m), with the elevation of the inlets at 300 ft (90 m). The net width of the surface sluice gates is 27 ft (8 m), with its sill elevation at 525 ft (158 m).

On both sides of the spillway dam section, there are the intake-dam and non-overflow dam sections. With a maximum discharge capacity of 102,500 m^3/s (at the pool level 600 ft - 180.4m), the project is able to discharge the possible maximum flood (PMF).

2. Power Stations

Two powerhouses are placed at the toe of the dam, one to the left and another to the right. The total length of the powerhouse on the left is 0.4 mile (0.65 km), with 14 sets of hydro turbine generator units installed. The total length of the powerhouse on the right is 0.37 mile (0.6 km), with 12 hydro turbine generator units installed.

Those 26 sets of hydro turbine generator units (Francis type - 700 MW each), totaling 18,200 MW of installed capacity will produce 847 TW.h of electricity output annually. There are 15 transmission lines; with 500 kV AC lines to Central China and Chongqing City and about 500 kV DC lines to East China.

Meanwhile, enough room has been preserved on the right bank, for a future underground powerhouse with extra 6 hydro turbine generator units totaling 4,200 MW of installed capacity. The intakes of these units are being constructed simultaneously with the project.

3. Navigation Facilities

The permanent navigation structures consist of the permanent ship lock and a ship lift. The ship-lock's design capacity of annual one-way navigation is 50 million tons. It is designed as a double-way, five-step flight locks carved from granite on the river's left bank and lined with concrete; each lock chamber is dimensioned at 930 x 113 x 17 ft (280 x 34 x 5 m) -- length x width x minimum water depth -- capable of lifting 10,000 tons of barge fleet 285 feet, making it the largest such system in the world.

Construction of the Three Gorges ship lift—which will also be the largest in the world both in terms of height and hoisting capacity—is scheduled to start in 2005 and be completed in 2009 (www.threegorgesprobe.org , November 7, 2003). The ship lift is designed as a one stage vertical hoisting type with a ship container sized 400 x 60 x 11.7 ft (120 x 18 x 3.5 m), capable of carrying one 3,000 ton passenger or cargo boat each time.

After almost half a century of study, a decision on the design of the ship lift has been made. The Three Gorges Project Construction Committee approved a rack and piston hoisting system of a type that has been in use for decades in large ship lifts abroad, particularly in Germany. The mechanism will be able to lift vessels weighing up to 3,000 tons, raising them to the higher water level on the upstream side of the dam much more quickly than the five-stage ship lock that went into operation in June 2003. According to the Three Gorges Project Corp., it will take a vessel half an hour to be hoisted by the ship lift, but 2.5 hours to get through the five-step flight ship lock. (In reality, passengers have found that the trip through the five locks takes about four hours.)

However, because of its sheer size, the Three Gorges ship lift is considered a challenge to design, manufacture and install. The Survey and Design Institute of the Changjiang Water Resources Commission (CWRC) is responsible for the overall design of the structure, including the hoisting mechanism. Some key components will be imported and foreign companies will be invited to submit designs for the ship-container part of the structure.

It should be mentioned also that one temporary ship lock was designed and constructed for use during the construction period with an effective chamber size of 800 x 80 x 13.3 ft (240 x 24 x 4 m). After it served its purpose, it will now become a silt-flushing structure.

TGDP Reservoir:

TGDP is the largest water conservancy project ever built in the world. The TGDP is blocking the Yangtze River to impound a narrow, ribbon-like reservoir. This ribbon- or river-like (rather than a lake-like reservoir), will have a total length of over 400 miles (600 km) -- longer than Lake Superior -- and an average width of 0.7 miles (1.10 km) -- less than twice the width of the natural river channel.

The surface area of the reservoir will reach 1,084 km^2, and the land area to be inundated will be 632 km^2 -- almost twice the original water surface area. With the normal pool level (NPL) at 570 feet above sea level (190 yards or 175 meters), the total storage capacity of the reservoir is 39.3 billion m^3. The average annual runoff is 451 billion m^3 and 526 million tons of annual sediment discharge.

TGDP Construction Phases

When completed, the total duration of construction TGDP will be 17 years, divided into three phases:

- 1993-1997: 1^{st} phase construction, including preparation period, dominated by massive earthmoving, and spanned five years. Its completion was signaled by the damming of the Yangtze River on November 8, and the opening of the diversion channel.
- 1998-2003: 2^{nd} phase construction, running 6 years and was completed on schedule and the first generating unit in the left-bank power plant went on line and the permanent ship lock began operation.
- 2003-2009: 3^{rd} phase (final) construction, planned to be completed in six years, marked by the completion of all 26 electricity-producing turbo-generators.

TGDP Quantities of Construction Work

The main work estimated quantities to be done in the construction for principal structures and diversion works are as follows:

- Earth-and-rock excavation — 102.83 million m^3
- Earth-and-rock embankment — 31.98 million m^3
- Concrete placing — 27. 94 million m^3
- Re-bar — 463.0 x 10^3 tons
- Metal works — 256.5 x 10^3 tons
- Installation of hydro turbine generator — 26 sets (18,200 MW)

A breakdown of the quantities pertaining to each structure is as follows:

Classification of Structures	Dam	Powerhouses	Navigation facilities	Diversion works	Total
Excavation (10^6 M^3)	10.38	19.58	55.84	17.03	102.83
Embankment (10^6 M^3)	NA	3.03	7.86	21.09	31.98
Concrete (10^6 M^3)	16.00	3.45	5.35	3.14	27.94
Re-Bar (Ton)	172000	124000	165000	2000	463000
Metal Works (Ton)	71600	77200	98100	9600	256500
Installation of Unit (MW)	NA	18,200	NA	NA	18,200

More Technical Information on TGDP:

The second of the three construction phases of the TGDP is now complete. TGDP's biggest challenge was perhaps keeping to an aggressively ambitious schedule while constructing—according to the highest technical specifications and foreign inspection—the permanent 5-story ship lock, the dam's spillway, and left intake structure, which houses 14 giant turbines. The schedule called for the first two turbine generators to be producing power—and critical revenue—by 2002, followed by the remainder of the bank in 2003. This needed breaking every known record for concrete construction.

To meet deadlines, over 25,000 workers poured concrete at a pace of about 520,000 cubic yards [400,000 cubic meters] per month. This required an extensive and complex system for transporting enormous quantities of concrete from the mixing plants to the dam. The equipment, from U.S. supplier Rotec Industries, consisted of about five miles of fast, movable, and rotating conveyors.

Two aggregate excavating and processing systems were constructed and were able to supply coarse and fine size aggregates for concrete mixing. With the addition of two other concrete batching plant systems, the concrete production rate reached 2,380 m^3 per hour, which satisfied the capability of 550 thousand m^3 per month concrete placing. Because concrete generates considerable amount of heat as it sets, large volumes can become exceedingly hot, damaging the material's structural strength. Hence, curing of concrete was essential to keep it at a temperature of about 45^o F (7^o C) as it hardened.

Each batching plant has its own cooling system that guaranteed that temperature for cooling concrete, particularly in summer.

As the dam progressed to its eventual height of 620 feet, six tower cranes specially fitted with jacking systems raised the conveyors. In addition to their lifting capacity, the tower cranes had swinging telescopic conveyors that are designed to pour concrete at the impressive rate of more than 600 cubic yards per hour. A mobile crane delivered concrete from a large hauler to construct the dam's left wall.

The construction pit for erecting the main dam was dug to a depth of 260 feet, allowing the foundation work to begin. Numerous holes (with a total length of more than 60 miles) were drilled into the ground and filled with pressurized grout. This "grout curtain" would help protect the main dam from uplift by preventing water from seeping underneath the structure. (For the same purpose, 870,000 square feet of concrete walls were sunk below the transverse cofferdams.)

The double-way, five-step flight ship-lock was carved in granite on the river's left bank and lined with concrete. To carve space for the multiple chambers of the lock, workers had to blast with precision more than 75 million cubic yards of hard rock.

To facilitate transporting thousands of workers to the construction site, the government built a four-lane highway from Yichang, the nearest city of significant size. By any standard, the $110-million road, which cuts through the mountains that frame Xiling, was itself a considerable undertaking: 40 percent of its total length of 17 miles consists of bridges and tunnels, including a twin bore that is more than two miles long. Additionally, a 2,950-foot suspension bridge, the longest in China outside of Hong Kong, was built at Sandouping for access to the project's right bank.

TGDP Cost:

In 1990, the cost of the project was estimated at US$12-billion (Y90.09-billion). A more recent estimate is $27-billion (Y223-billion). Nearly half the project's cost is being applied to the resettlement of hundreds of villages and towns along the river's edge.

TGDP Controversy:

The construction of the largest dam in history at China's Three Gorges is already in its 11^{th} year, and is expected to be completed by 2009 with a cost of over $27-billion. TGDP, perhaps more than any other project in history, has attracted the attention of many individuals and groups in China as well as worldwide and created much controversy.

TGDP Advantages:

1. **Flood Control:** TGDP is claimed to reduce the severity of flooding by 90%.
2. **Power Generation:** Through its 26 turbines at full capacity, TGDP will generate 18,200 MW annually, making it the biggest hydropower producer in the world.

This would provide 15% of China's electricity -- mostly in the Yangtze River Basin area. That output is equivalent to aprox. 50 million tons of coal or that of 18 nuclear power plants, producing “clean” 84 billion kilow.hrs output per yr.

3. **Navigation Improvement:** TGDP will allow the passage of 10,000-ton ships to Chongqing instead of the limited 5000-ton ships, increasing the annual one-way navigation capacity from present 10 million tons to 50 million tons, and decreasing the navigation cost by 35-37%.
4. **Other:** The project is expected to promote the development of fishery in the reservoir, as well as tourism and recreational activities. To a certain extent, it should improve the water quality of the middle and lower reaches of the river during the dry season, and create favorable conditions for the south-to-north water transfer.

TGDP Disadvantages:

1. The reservoir will flood 13 cities, 140 towns, 1,352 villages, and 657 factories.
2. Construction will force the resettlement of almost two million people.
3. The reservoir will flood approximately 75,000 acres of the best agricultural and cultivated farmland in the region.
4. 108 sites of cultural and historical importance will be lost.
5. 80 species of fish, Yangtze dolphin, finless porpoise, Chinese sturgeon, and giant panda will be endangered.
6. Silt accumulating upstream (perhaps even affecting Chongqing, at the reservoir’s opposite end) which could eventually threaten the dam’s stability.
7. Navigation benefits are exaggerated because heavy sediment buildup in the reservoir is likely to continue to hinder navigation.
8. Flood control benefits are overstated: the reservoirs could at best store only a fraction of the floodwaters entering the Yangtze during a peak-flow year.
9. Dam construction will divert funds from more beneficial, less risky projects.
10. Possible disaster area – military/terrorist attacks target.

Educational Opportunities

The School of Technology at Eastern Illinois University (EIU) is a firm believer in the importance of hands-on education. To study the TGDP, (EIU) students literally went all the way from Charleston, Illinois to the project’s site in Sandouping, China to see with their own eyes and research that project. This was achieved when the author offered a study abroad course in China for which students received credit.

While in China, students met many of the officials working on the design and the construction of the TGDP. They also met with environmental engineers and discussed the various aspects of environmental and ecological effects of the project. Discussing the different aspects of the project with Chinese students and professors in different Chinese universities proved very informing and effective.

Writing a research report on the project was a part of the course requirements. Upon their return from China, students also presented their findings in classes, seminars and focus groups. Information was also discussed through videos taped, and photos shot during the course as well as those that were available in the market. Students' led seminars, panel discussions, and workshops that discussed literature available in print as well as On-line proved to be very stimulating. Meanwhile, inviting experts on the TGDP as guest speakers to classes and holding focused seminars, workshops, and panel discussions created effective educational opportunities.

Forming students' research groups to monitor the progress of the project, track facts, collect data, and analyze the information would engage students in an educationally rich activity. This commotion would add to students' sense of history and geography, besides, of course, the technical, political, economical, and sociological aspects of the project. Publishing the results of such research in professional literature and presenting them in national and international professional conferences is an integral part of the educational/ learning process and also being powerful ways for disseminating information.

Other educational opportunities include comparisons held between the TGDP and other similar projects worldwide that would put the project in perspective. Also, building small-scale replicas, or computer generated models of the TGDP or parts thereof present a great opportunity for both building the models themselves and then experimenting with them.

Conclusion

China's massive Three Gorges Dam project provides excellent educational opportunities for environmental engineering educators as they discuss it with their students and engage them in analyzing its multi-faceted impact. Many individuals and agencies around the world are collecting data to help study the short- and long- term ecological and environmental effects of building the Three Gorges Dam. Other far-reaching effects of the project on areas such as energy, industry, business, culture, and transportation are now starting to become a tangible reality rather than speculations. Time will show to what extent the fears and concerns that many are having were justified.

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