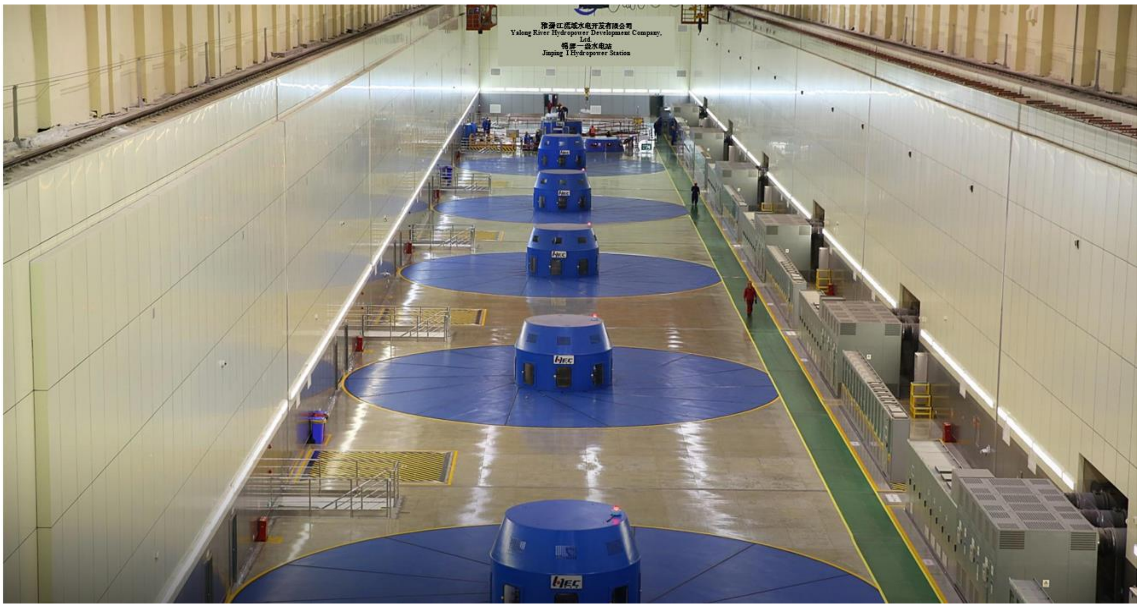
F.1 General Information of Project

Name of project			Jinping I Hydropower Station Project
Location			Liangshan Yi Autonomous Prefecture, Sichuan, China
Main purpose			Power generation and flood prevention for the middle and lower reaches of the Yangtze River
Reservoir Capacity (10^8m^3)			77.6
Installed Capacity (MW)			3600
Company involved	Owner		Yalong River Hydropower Development Company, Ltd.
	Designer		POWERCHINA Chengdu Engineering Corporation Ltd.
	Dam project contractor		Sinohydro Bureau 7 Co., Ltd., China Gezhouba Group No.2 Engineering Company Limited, Sinohydro Bureau 14 Co., Ltd., China Gezhouba Group Road & Bridge Co., Ltd. (formerly known as China Gezhouba Group No. 5 Engineering Company Limited), Sinohydro Bureau 4 Co., Ltd.
	Consultant		China Water Resources and Hydropower Construction Engineering Consulting Co., Ltd., CWRC Engineering Construction Supervision Center (Hubei), China Northwest Water Conservancy & Hydropower Engineering Consulting Co., Ltd., Sichuan Ertan Construction Consulting Co., Ltd., Hunan Jianghai Technology Development Co., Ltd.
	Manufactures and assembly firms		Harbin Electric Corporation, Dongfang Electric Corporation, Sinohydro Bureau 14 Co., Ltd., Sinohydro Bureau 3 Co., Ltd., Sinohydro Bureau 3 Co., Ltd.
Concrete Dam	Type		□Gravity Dam ☑Arch Dam
	Height(m)		305
	Crest width(m)		16
	Crest length(m)		552.23
	Crest elevation (m)		1885
	Concrete Placing Volume (10^4m^3)		558
	Design Flood (m^3/s)		13600
	Water Release Structure	Type	(Dam body) 4 crest outlets + 5 low level outlets + 2 emptying bottom outlets + (dam toe) plunge pool and 1 flood discharge tunnel on the right bank connecting the pressurized section with the unpressurized section
		Discharge(m^3/s)	12,708m^3/s ~ 13,918m^3/s (discharge of the flood discharge tunnel: 3,229m^3/s ~ 3,320m^3/s)
		Energy Dissipation type	(Dam body) collision-free in the air + energy dissipation through plunge pool and flow deflecting by dovetailed flip bucket at the outlet of flood discharge tunnel
Hydropower Station	Type		Underground powerhouse
	Length (m)		276.99

	Width (m)_	25.6
	Height (m)	68.80
	Installed Capacity (MW)	3600
	Annual Power Generation (TWh)	16.62
Construction	Project Started Date	November 12, 2005
	Water Storage Date	November 30, 2012
	Project Finished Date	April 22, 2016
	The maximum concrete placing volume per day (m^3/d)	6779.9
	The maximum concrete placing volume per month (m^3/m)	176031
Operation	Normal Storage Water Level (m)	1880.00
	The first time to Normal High Water Level	August 24, 2014
	The Maximum Water Level after Commissioning (m)	1880.00
	Dam Crest Displacement at Normal Storage Water Level Most Recently (mm)	29.07
	Leakage (total/dam, L/s)	31.21 (leakage of drainage gallery at dam foundation), zero-leakage at dam body.

Photos of project



雅砻江流域水电开发有限公司
Yalong River Hydropower Development Company, Ltd.
锦屏一级水电站
Jinping I Hydropower Station

F.2 Innovative technologies

1. Overview of the project

Standing as a 305m-high double curvature concrete arch dam, Jinping I Dam is the highest dam in the world recognized by Guinness World Record. Jinping I Hydropower Station resides on the Yalong River, in Liangshan Yi Autonomous Prefecture, Sichuan, and tops all other cascade hydropower stations in the lower reach of Yalong River. Costing a total of RMB 40.1 billion, it has a total installed capacity of 3,600MW and a multi-year average annual power generation of 16.62 billion kWh. Since it was put into operation, it has significantly improved the ratio of clean energy in China's energy structure, assisted in the poverty alleviation of the west part of China, and helped the flood control of the Yangtze River.

Jinping I Reservoir has a normal storage water level of 1,880m and a dead water level of 1,800m. Under the normal storage water level, the storage capacity is 7.76 billion m^3 and the regulation capacity is 4.91 billion m^3. Therefore, it is an annual regulation reservoir. The dam has a crest elevation of 1,885m and a minimum foundation surface elevation of 1,580m. Its crown cantilever has a crest thickness of 16m and a base thickness of 63m. The maximum central angle is 93.12º. For the top arch, its center line has an arc length of 552.23m; its thickness-to-height ratio is 0.207; its arc-to-height ratio is 1.811. The dam body has used 5.58 million m^3 of concrete.

The dam body has 4 crest outlets (outlet size: 11m×12m), 5 low level outlets (outlet size: 5×6m), and 2 emptying bottom outlets (outlet dimension: 5×6m). A plunge pool is arranged at the dam toe to dissipate the energy. The plunge pool uses the composite trapezoidal section and has a horizontal width of 45m (base board) and a maximum width of 112m.

Large in scale, Jinping I Hydropower Station is located in a region featuring remote mountains, deep valleys, and complicated engineering geological conditions, which had created various technical difficulties. During construction, we have encountered and solved a series of key technical issues, e.g. stability and treatment of high and steep slopes under complex geological conditions; treatment of dam foundation under complex geological conditions; integrated safety of the ultra-high arch dam; high-performance concrete and its raw materials for the ultra-high arch dam; temperature control, anti-cracking, and high-strength and fast construction for the ultra-high arch dam; influences of flood discharge and energy dissipation and atomization in the narrow river valley featuring ultra-high water head and large discharge; deformation control of surrounding rocks for the underground powerhouse and underground caverns in an ultra-low strength-stress ratio; construction layout for the ultra-high arch dam in the valley surrounded by high mountains. These complicated technical difficulties made the construction extremely challenging. According to Academician Lu Youmei, a winner of the Engineering Achievement Award of World Federation of Engineering Organizations (WFEO), Three Gorges Project is the "most sizable" project and Jinping Project is the "most difficult" project. Through nearly 25 years' hard work, we have solved these technical difficulties and obtained abundant and innovative achievements. In 2018, Jinping I Hydropower Station won the Award for Outstanding Project of the Year of International Federation of Consulting Engineers (FIDIC). In 2015, the project team of Jinping Hydropower Station won the Award for

Engineering Construction Excellence of the World Federation of Engineering Organizations (WFEO). As Academician Pan Jiazheng (an internationally well-known hydropower expert) said, "from the perspective of the hydropower development in China, Jinping Project has set a new milestone for China's constructions of high arch dams, especially 300m high arch dams."

2. Major technological innovations used in the project

(I) Analysis of the complicated geological environment for dam construction

The deep unloading phenomenon developing on the left bank of the dam site is a unique geological phenomenon in Jinping Project. After a section of relatively integrated rock mass in the shallow unloading belt of the bank slope, a series of open fractures or fissure loose belts (different in scale but collectively referred to as "deep unloading") are revealed. The maximum horizontal depth of the deep unloading fissure development ranges from 150m to 300m.

Through systematic researches, the formation mechanism of the deep unloading on the left bank has been found. The pivotal areas of the project have characteristics such as, valley surrounded by high mountains, high ground stress, and deep unloading, thus, we have proposed an innovative multi-source data-based geology modeling technology, which is oriented to the engineering geology for hydropower projects. We have used it to solve the technical difficulty in the survey and analysis of Jinping I Project under complex geological and topographical conditions. We have taken an evasive approach and properly selected the location of dam axis. By this means, the part lying below 1800m of the left dam abutment of the arch dam has relatively less development of deep fissures, hence avoiding the impact of deep fissures on the left bank in the lower reach. Prof. Nicholas Barton, the developer of Q-system of rock mass characterization, said in his visit to Jinping Project, " a proper approach has been used for engineering geological classification of dam foundation rock mass in this project." By this means, we have finally made a breakthrough in ultra-high arch dam constructions in the deep unloading development area.

(II) Slope reinforcement design for complicated, high, and steel slopes

The side slope excavated for the dam abutment on the left bank of the arch dam is 530m high. It is a reverse slope featuring complicated geological structures. It is composed of sandy slate (upper part) and marble (lower part), with the development of f_5, f_8, $f_{42\text{-}9}$, and other faults that may affect the slope stability. For the dam abutment on the left bank, the sandy slate has obvious toppling deformation in the elevation of 2000m and above, and the sandstone has serious relaxation cracking in the elevation of below 2000m. Besides, the deformed and fractured rock mass is formed by $f_{42\text{-}9}$ fault and the tension fissure in the dam head on the left bank, which forms a large potential sliding mass and severely affects the safety and stability of side slopes in this project.

We have conducted systematic geological investigations and rock-soil tests, fully revealed the spatial layout of the left bank fault, joint fissure, and other structural planes, and accurately acquired the physico-mechanical properties and parameters of the rock mass and structural planes. With the help of digital analysis methods, we have finally determined the integrated reinforcement scheme for slopes of the dam abutment, i.e. "shear-resisting holes in the deep stratum, large-tonnage long anchor cables in the middle stratum, and anchorage, 3D water drainage, and slope seepage control in the shallow and surface system".

Specific and differentiated treatment measures have been taken for different parts of the slope, to ensure stability in the 500m-level complicated, high, and steep slopes. These technological achievements have been promoted and applied in large-scale projects such as Lianghekou Hydropower Station.

(III) Dam foundation reinforcement for highly asymmetrical ultra-high arch dams

For the load-bearing mass on the left bank of the arch dam, the middle and upper parts of rock mass are fractured sandy slate and have the development of f_5, f_8, and f_2 faults, interlaminar extruded and disturbed belt, later intruded lamprophyre vein (X), and deep unloading rock mass with a depth of 300m, while the lower part of rock mass is composed of marble. The left bank dam foundation is soft in the upper part and hard in the lower part. The right bank dam foundation is steep in the upper part and mild in the lower part. It is mainly composed of marble (greenschist on the bottom), featuring hard in the upper part and soft in the lower part. The comprehensive modulus of deformation is just 1.3~5.4GPa in the upper part of dam foundation on the left bank, but above 20GPa in the dam foundation on the right bank, i.e. approximately 10 times difference. As these two banks have the most-asymmetrical geological conditions at the 300m-level ultra-high dam site, the shape selection of arch dam, dam body load-bearing status, anti-sliding stability and deformation stability of arch abutment, and seepage control of the foundation are severely influenced.

To improve the deformation symmetry of the arch dam, we have carried out the simulation analysis and geological model test and put forward an innovative multi-direction load-bearing reinforcement structure for the load-bearing mass under complicated geological conditions, which has a larger load-bearing range, a bigger load transmission depth, and better deformation resistance. We have adopted the 560,000 m^3 large cushion abutment to expand the load-bearing range, improved the deformation resistance of the fractured rock mass in the middle and upper parts of the left bank dam foundation, and taken comprehensive treatment measures, including the concrete replacement for shafts and load transmission adits, high-pressure consolidation grouting, and 3D water drainage. Besides, we have dispersed the arch thrust and improved the general rigidity and deformation resistance of the load-bearing mass. After treatment, the comprehensive modulus of deformation in the upper part of the dam foundation on the left bank has increased by 2.3~9.7 times, and the distortion and deformation of the arch dam (the maximum deformation is severely inclined to the left bank) have been significantly improved. This has laid a foundation for the successful construction of Jinping I arch dam. In addition, these technological achievements have been promoted and applied in many hydropower projects, such as Mengdigou and Yebatan projects.

(IV) Structural design of ultra-high arch dam under complicated geological conditions

It is easy to find normal cracks on the downstream face of the ultra-high arch dams which have been built, and these cracks may affect the overall resistance capability of the structure. For this issue, we have studied and found that it is difficult to avoid the combination of high pressure and low tensile stress in the middle and lower parts that are close to the foundation of the arch dam in the downstream face, hence under the effect of this combination, the remarkable decrease in the concrete anti-cracking capacity is the immanent cause for normal cracks. Taking into account the form of arch dam foundation surface and the foundation treatment design, on the basis of the optimized design of the arch dam shape, we have developed an optimization technique of improving the load-bearing condition by adding the dam toe structure, which has enhanced the overall anti-cracking capacity of the arch dam. The fiber-reinforced concrete is used in the foundation and orifices of the dam monolith on the steep slope, to improve the concrete anti-cracking capacity at the dam foundation and orifices. Load-resisting mass lateral anchor cables are arranged at the downstream of dam toe on the left and right banks, to the extent of about 1.5 times the thickness of the arch end, to reduce the lateral deformation of the load-resisting mass. By using the aforementioned arch dam structure anti-cracking technique and anti-cracking reinforcement measures, we have mitigated the cracking risk of the arch dam and enhanced the anti-deformation capacity of the dam foundation. Besides, the related technological achievements have been incorporated by *Design Specification for Concrete Arch Dams*, providing valid guidance for further constructions of high arch dams in the future.

(V) The world's first flood discharge and energy dissipation ultra-high arch dam with zero collision between the crest outlet and low level outlet on the dam body

Jinping I Hydropower Station features a high water head (flood discharge fall head of dam body: 222.6m), large discharge (total discharge of dam body: 10,607m^3/s), and narrow valley in the dam site area (water width in the dry season: 60~80m). Besides, the overall stability of side slopes in the flood discharge atomization area on the left bank is mainly controlled by the rainfall from flood discharge atomization at the dam body. As a result, Jinping I Hydropower Station faces unprecedented challenges in flood discharge and energy dissipation, as it needs to increase the energy dissipation efficiency of water release structure on the dam body, reduce the flood discharge atomization strength and range when crest outlets and low level outlets on the dam body are used together for flood discharge, and handle the problems of corrosion inhibition, anti-cavitation, and outlet energy dissipation of the flood discharge tunnel under an ultra-high flow rate.

High concrete arch dams such as Ertan Dam usually uses the dam body-type flood discharge and energy dissipation of "nappe collision during water discharge and energy dissipation through the plunge pool", in which water flows from upper and lower outlets collide with each other in the air and generate a large amount of water mist that may cause serious flood discharge atomization. To alleviate the influence of flood discharge atomization on the overall stability of side slopes, we have adopted a research method integrating both hydraulic model test and theoretical numerical analysis. Through numerous tests and analytic demonstrations, we have finally selected the rectangular wide-tail pier overlapping slope (crest outlet) + indiffusible outlet (low level outlet), which can fulfill the requirement of a high arch dam for flood discharge and energy dissipation. By this means, we have formed the collision-free flood discharge and energy dissipation technique, which has significantly reduced the rainfall intensity in the atomized rainfall area and the splashed rainfall area. The related technological achievement has been promoted and applied in the high arch dam in a valley surrounded by high mountains, e.g. Mengdigou Hydropower Station.

(VI) The first ultra-high arch dam using alkali-reactive aggregate over the whole dam

About 5.58 million m^3 of concrete has been used for Jinping I Dam. There is no natural aggregate near the dam site. Within 50km of the dam site, only sandstone aggregate can meet the strength requirement of the ultra-high arch dam. However, the sandstone aggregate is an alkali-silica reactive aggregate. Previously, AAR has occurred in over 100 hydropower stations across the world, making people have to saw off or dismantle the station regularly. For the ultra-high arch dam, no alkali-reactive aggregate concrete has been used before.

We have applied numerous test methods, e.g. accelerated mortar bar method, accelerated prism method, concrete prism method, and full-grade concrete prism method (simulation of actual working conditions), and verified the influence rule of difference factors (aggregate combination, fly ash quality and mixing amount, total alkali content in the concrete, and curing temperature) on the alkali-active swelling ratio of sandstone aggregate. In light of the systematic research and full-grade test verification based on mechanical, deformation, and thermal performance of the dam concrete, we have proposed an aggregate combination (sandstone coarse aggregate + marble fine aggregate) scheme. By using high fly ash content (35%), we have exceeded the fly ash content limit (30%) for the concrete used in the high arch dam. We have formulated the control method and control indicators for the total alkali content in the concrete (for Grade 4 concrete of the arch dam, the total alkali content is controlled within 1.5kg/m^3). By this means, we have effectively inhibited the alkali reactivity of sandstone aggregate, significantly reduced the water consumption and binder consumption in the concrete, and enhanced the volume stability and anti-cracking durability of the concrete. Besides, we have obtained a kind of high-performance concrete with high strength, moderate elasticity modulus, large limiting extended value, and low contractility. This concrete has laid a foundation for the excellent construction of Jinping I arch dam, and its technology has been promoted and applied in large hydropower projects (e.g. Lianghekou Hydropower Station) and the "Belt and Road" harbor project in Brunei.

(VII) The first ultra-high arch dam using the layer concreting thickness of 4.5m

Jinping I dam site is located in a deep and narrow river valley. The dam body only has 26 dam monoliths, many of which are orifice dam monoliths. During the dam concreting, optional dam monoliths are limited, making it hard to meet the requirement for overall equilibrium rise during dam construction. Besides, it is unable to meet the flood season requirement of the project. Since we have already made full use of common measures (e.g. increasing the construction resources, shortening the roll-over duration, and optimizing the cable crane arrangement) to improve the arch dam construction efficiency, during the construction of Jinping I arch dam, we have to overcome the limit for layer concreting thickness (3m) in the specification and increase the layer concreting thickness.

We have invented a method to pour conventional concrete in a large volume and large thickness and determined the temperature control method for pouring concrete monolithically in thick layers (i.e. strict standard for the maximum temperature and temperature difference, equilibrium in time and space of the temperature gradient, thin-thick layer regulation for three major height differences, and high-standard quality control during the whole process) during the dam concrete construction period. By this means, we have increased the layer concreting thickness from 1.5m~3m (as stipulated in the specification) to 4.5m and above, thus overcoming the limit for layer concreting thickness that has been followed in the specification. In addition, we have developed the self-adaptive intelligent cut-through temperature control system and complete equipment, which have been used for intelligent and accurate control of concrete temperature during the thick-layer concreting process at the dam. Subsequently, we have obtained the packaged technology of thick-layer concreting and temperature control anti-cracking, which ensured the concrete placing quality (5.63 million m^3 of concrete) for the arch dam without any temperature crack. By using this technological achievement, we have found a solution to achieve safe and effective construction of the ultra-high arch dam in the deep and narrow valley. It cost us only 50 months to complete the concrete placing of Jinping I arch dam. We have achieved the best construction efficiency in the worst construction environment and drafted the *Specifications for Concrete Dam Thick Lift Construction* (T/CHINCOLD 001-2020). The thick lift construction technology has been promoted and applied in many high arch dams, including Wudongde, Yangfanggou, and Yebatan dams.

(VIII) The world's first large underground cavern group project under the high ground stress environment and in a low strength-to-stress ratio

In the location where Jinping I underground powerhouse project resides, the ground stress of surrounding rocks is 35.7MPa, but the strength of surrounding rocks ranges from 60 to 75MPa, leading to a strength-to-stress ratio of only 1.5~3.0 for surrounding rocks, which is the smallest ratio in similar projects. During the excavation of the underground powerhouse, the surrounding rocks have a variety of problems, including 16m deep unloading, strong collapse, and great deformation. For complicated conditions (extremely low strength-to-stress ratio and fault intersection) existing in the large powerhouse cavern group, we have put forward a deformation control technology that features shallow/surface wall fixing, deformation coordination, and overall load-bearing. One year after excavation, the deformation of surrounding rocks for the underground powerhouse is reduced completely, which has guaranteed the safe and stable unit operation. Later, this technology has been promoted and applied in other hydropower station projects, such as Houziyan Project.

(IX) Developing the key technology for expanding the construction site for a large hydropower project in the valley surrounded by high mountains

Located in high mountains and steep slopes, the project site has encountered problems such as site restriction and frequent geological hazards, which made it hard to arrange large construction facilities that are necessary for the construction of a large hydropower project. We have put forward an innovative time-space expansion technology, which includes the underground space, engineering construction platform, and artificial slag-filling platform. Besides, we have adopted diversified 3D material transportation technology, such as slag transportation through slopes + foundation pit mucking, vertical shaft + tunnel, and long-range conveyer belt through the mountain and river. By this means, we have saved 620,000 m^2 of land. This technology has been promoted and applied in hydropower station projects such as Mengdigou project.

(X) Creating a multi-layer scientific research and consultation system that embodies the wisdom of global hydropower engineers

For prominent problems and leading-edge basic theories faced by the project during construction, the project developer has launched independent scientific researches by enterprises and established the Yalong River Joint Fund with the National Natural Science Foundation of China, to absorb and incorporate social technological resources into the basic researches and improve the high dam construction technology in the world.

Besides, top consulting entities, such as China International Engineering Consulting Corporation, has been engaged in the review of critical technological schemes for the project; China Consulting (Group)

Corporation has been incorporated as a permanent consulting entity on the project site, to provide consulting services in terms of technology and quality problems on the site. Leading experts from the Chinese Academy of Engineering, e.g. Academician Tan Jingyi, Academician Ma Hongqi, and Academician Zhang Chaoran, have been organized to establish the " Special Board of Consultants for Jinping Hydropower Project", to provide annual inspections and consulting services in terms of project quality and critical/key technical issues. An expert from MWH Company (USA) has been hired as the Quality Director of the Project, who has participated in the Project Owner's quality supervision and management in the whole process; A2Z Company (Norway) has been employed to provide consulting services in terms of constructions and temporary works of Jinping I Hydropower Station. The multi-layer consulting system has embodied the wisdom of global hydropower engineers and significantly ensured the smooth progress of the Project. Besides, these construction and management experiences have been promoted and applied in the construction of Lianghekou Hydropower Station.

3. Performance of the project

(I) Construction process

For the project, the river closure was carried out on December 4, 2006; two units (the first batch) were put into operation on August 30, 2013; all units were put into operation on July 2014; water impounding to the normal storage water level of 1,880m was achieved on August 24, 2014 for the first time.

(II) Reservoir impounding

The impounding of Jinping I Hydropower Station Project was started on November 30, 2012. It went through 4 stages and finally reached the normal storage water level of 1,880m on August 24, 2014. Targets for all 4 stages were completed smoothly at one time.

(1) Stage 1: It started on November 30, 2012, as soon as the diversion tunnel closed the gate. On December 7, 2012, the water level reached 1,706.70m. Average impounding rate: 8.3m/day.

(2) Stage 2: It started on June 15, 2013. On July 19, 2013, the water level reached 1,800.47m. Average impounding rate: 2.6m/day.

(3) Stage 3: It started on August 26, 2013. On October 14, 2013, the water level reached 1,839.48m. Average impounding rate: 0.8m/day.

(4) Stage 4: It started on July 3, 2014. On August 24, 2014, the water level reached 1,880m - the normal storage water level. Average impounding rate: 0.8m/day.

(III) Achievements of operational monitoring for the project

Monitoring values of the arch dam are conforming to laws of mechanics and have water level correlation, time-based convergence, and spatial coordination. An elastic working state is found from the arch dam. The maximum radial displacement of the arch dam is 43.19mm; the maximum compressive stress is 7.25MPa; the maximum tensile stress is 1.03MPa; after curtain grouting, the maximum reduction factor of uplift pressure at the dam foundation is 0.22; after water drainage, the maximum reduction factor of uplift pressure is 0.04. All values are less than the design control values. Furthermore, the dam foundation has stable seepage, which is decreasing year by year. According to the project safety monitoring and hydraulics prototype observation for the water release structure, the dam body, dam foundation, and load-bearing mass of Jinping I arch dam can work normally; overall stability of slopes in the pivotal area is achieved; the water release structure is operating in line with the design expectation. The project passed the completion acceptance for pivotal projects on April 22, 2016. Excellent in quality, this project is the fastest project that has passed the completion acceptance for pivotal projects among 300m-level ultra-high arch dams.

(IV) Project acceptance

The project was commenced in November 2005. By July 12, 2014, all units had been put into operation. All 6 units have been started up successfully at one time, passed the 72-hour test run, accomplished the target of "safe and stable operation for 100 days after startup for operation". Excellent in quality, the project has passed the safety appraisal and impounding acceptance by China's related authorities, and passed the completion acceptance for pivotal projects in April 2016. Up to now, it has been operating steadily for 7 years. This project has won China's highest award for scientific innovation in the field of civil engineering - "Tien-yow Jeme Civil Engineering Prize", and the highest project quality honor - "National Quality Engineering Award (Gold)".

4. Technical achievements ever achieved

(I) Effect of technical demonstration

This project has provided a variety of technological and theoretical supports for the high arch dam construction under complicated geological and topography conditions, e.g. complicated/high/steep slope reinforcement, complicated load-bearing mass treatment, structural design for the ultra-high arch dam under complicated geological conditions, flood discharge and energy dissipation and mist reduction in a narrow valley with ultra-high water head, preparation of high-performance concrete with sandstone alkali-reactive aggregate, intelligent temperature control, anti-cracking, and effective thick lift construction of concrete for the arch dam, deformation control of large underground cavern group under a low strength-to-stress ratio, and expansion of construction site for the large hydropower station in the valley surrounded by high mountains. Through this project, our high arch dam construction and technology level have been enhanced. These achievements have been incorporated by industrial and technical standards, offering extensive guidance. As the only high arch dam above 300m that has been built in the world, Jinping I dam has provided a good construction demonstration for other high concrete arch dams in the world. Its related technologies have been incorporated by *Handbook of Hydraulic Structure Design* (national key book) and other specifications, as they are of great application values and social benefits. This project offers important reference to both construction technology development of existing arch dams and the design/construction of future ultra-high arch dams.

(II) Economic benefit

Numerous advanced technologies have been studied and applied in the construction of the ultra-high arch dam for Jinping I Hydropower Station. The 305m ultra-high arch dam has been built successfully and has been operating safely and stably. Since the hydropower station was put into operation for power generation, the generator units have been running stably. By May 2021, the new sales revenue reached about RMB 38 billion.

(III) Awards

Jinping I Hydropower Station has won the 2018 Outstanding Project Award of the International Federation of Consulting Engineers (FIDIC), 2018~2019 National Quality Project Award, 2017 Tien-yow Jeme Civil Engineering Prize, special prize for 2016~2017 National Investment Project, and prize for 2019 National Civilization Project for Soil and Water Conservation. Besides, the project team of Jinping Hydropower Station won the Award for Engineering Construction Excellence of the World Federation of Engineering Organizations (WFEO) in 2015.

5. Environmental and social aspects and local contributions of the project

(I) Benefits of ecological environment

Based on the concept of "Green Jinping, Ecological Jinping, and Scientific Jinping", we have performed the ecological and environment-friendly design for Jinping I Hydropower Station, which is centered on environmental protection and saving energy, land, water, and materials. The technological achievements have won the first prize for Soil and Water Conservation and Landscape Design for Production and Construction Projects and the first prize of 2019 Evaluation of Green Construction and Design for Engineering Construction Projects. This project has won the award of 2018 National Civilization Project for Soil and Water Conservation.

(1) Improving the energy structure and reducing greenhouse gas emissions

Every year, Jinping I Hydropower Station replaces 16.62 billion kWh of thermal power and saves 5.484 million tons of standard coal for the power system, which means that this project can reduce 46,000 tons of sulfur dioxide, and 14.48 million tons of carbon dioxide. In a word, it effectively reduces harmful gas emissions and plays a vital role in promoting energy conservation and emission reduction and optimizing China's energy structure.

(2) Increasing the groundwater discharge temperature by intaking water from different layers and improving the living environment for aquatic organisms

During construction, fishes and other aquatic organisms living in the downstream may be severely affected due to the water level change of 80m in the reservoir and the water temperature in the reservoir. For this issue, we have adopted the layered water intaking technology by using stoplog and built the independent bank-tower intake, which can achieve layered water intaking ecologically and environmentally. Through the ecological water intaking in seven layers, this intake could restore the natural water temperature of the river channel and effectively protect the living environment of aquatic organisms.

(3) Saving water through technological innovation and protecting ecological harmony by vegetation measures

The advanced cylindrical valve technology is used in the units. This technology helps reduce the shutdown frequency and water leakage of the units and saves 87.6 million tons of water every year. The efficient energy-saving and zero-discharge treatment technologies are adopted during construction. They help save 28 million tons of water. Domestic wastewater is recycled and reused through reclaimed water. This technology helps save about 240,000 tons of water every year. By planting trees and shrubs, 3D vegetation nets, and grass seeds, we have achieved the ecological restoration of forest and grassland covering an area of 221 hectares. The flat ratio of disturbed land reaches 99.33%.

(4) Remarkable effect of soil and water conservation

We have innovated our construction management and adopted the construction layout featuring "closure in advance and slag collection and mucking through foundation pits". By this means, we have successfully solved the problem of water and soil loss, which is unavoidable if excavated materials from the dam abutment are discharged into the river in the V-shaped valley in the dam area. The control ratio of water and soil loss is 1.13, indicating that all targets for soil and water conservation have been realized.

(5) Promoting fish breeding and protecting the Yangtze River

We have built fish breeding stations along the river's basin for fish fry release. We have spent a budget of RMB 160 million to build the Jinping-Guandi Fish Breeding and Release Station, which was completed and put into operation in 2011. Its design release quantity is about 1.5 million ~ 2 million per year. With the largest cost estimate for fish breeding station in China, it has the largest release scale and the leading technique. Currently, the artificial domestication and propagation techniques for 6 short-term released fishes (*Schizothorax wangchiachii*, *Schizothorax dolichonema*, *Schizothorax kozlovi*, *Schizothorax chongi*, *Leptobotia elongata*, and *Percocypris pingi*) have been successfully mastered. Technically mature propagation and breeding processes have been formed. Breakthroughs have been obtained in the artificial domestication and propagation techniques of the middle/long-term released fishes (e.g. *Gymnocypris potanini* and *Anabarilius liui*). Phased progress has also been obtained in terms of artificial domestication and propagation of *Euchiloglanis davidi*. Up to December 2020, we have continuously released for 11 years. A total of nearly 11 million qualified fish fries have been released. Since the independent operation in 2014, the average annual release quantity has exceeded 1 million (2.05 million in 2018), which has strongly supported the protection of the whole Yangtze River.

(II) Social aspects and contributions to local development

(1) Actively undertaking social responsibility and constantly supporting the development of the great Liangshan Mountain area

Up to May 2021, a total of RMB 7.672 billion of tax has been paid to Liangshan Yi Autonomous Prefecture. Besides, we helped to build the Laogou Reservoir (capacity: 21.22 million m^3) and its related trunk canal (27.5km), which have provided local residents with irrigation water and improved their domestic water. We also made donations to the local "Hope Primary School" and carried out student assistance activities every year.

(2) Controlling the Yangtze River flood by its high dam and big reservoir.

In the flood season every year, this project can assist people in the Yangtze River flood control. With its help, people have effectively handled different flood peaks. Besides, it has minimized the disaster loss and reduced sediment accumulation in the Three Georges Reservoir of the Yangtze River. In the dry season, Jinping I Reservoir can regulate the river. On average, the discharge of the downstream river has increased by $374m^3/s$, which improves the silt discharge capacity of the river and enhances the water conditions (e.g.

water temperature and water quality of the water body).

(3) Promoting the international forefront and basic scientific researches

Through Jinping Mountain Tunnel, the site access road for Jinping I Hydropower Station, we have built China Jinping Underground Laboratory, the largest underground laboratory, with the world's hugest overburden of 2400m and the best overall conditions. This laboratory facilitates the basic scientific researches, including the international forefront physical science research, deep-ground medical science, and deep-ground rock mass mechanics.

In response to these critical technological difficulties, we have collaborated with the National Natural Science Foundation of China and established the Yalong River Joint Fund (two phases). With the help of technologies, we have solved a series of technical difficulties during the construction of the 300m-level ultra-high arch dam and promoted technological advances in the field of international high concrete dam construction.

(III) Providing high-quality electricity and contributing to national development

Jinping I Hydropower Station constantly supplies clean electricity to the Sichuan and Chongqing region and Eastern China. It has generated a total of over 130 billion kWh and provided high-quality electricity for the production, living, and economic development of Eastern China and the Sichuan and Chongqing region. In addition to its gigantic power generation benefits in the dry season, it also has remarkable cascade compensation benefits. Every year, it increases the electricity generation by 6 billion kWh for cascade hydropower stations in the downstream of Yalong River. Furthermore, it increases the electricity generation by 3.77 billion kWh for Xiluodu (Jinsha River), Xiangjiaba, the Three Gorges, and Gezhouba hydropower stations.