HYDROPOWER ENGINEERING TECHNICAL STANDARDS IN CHINA

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1. INTRODUCTION

Since the founding of People's Republic of China in 1949, the development of hydropower in China started from scratch and it has made great achievements. The overall installed capacity has increased from 160MW to 365GW in the end of 2019, and totally 98,000 dams of various types have been constructed. The quantity of dams, the total volume of reservoirand the total installed capacity of hydropower projects rank the first in the world. China has also established a series of hydropower station and dam projects representing the world's highest standard. Among 96 completed or under-construction ultra-high dams over 200 meters in the world, 34 are in China. Among the 20 ultra-high dams over 250 meters in the world, 8 are in China. The 22.4GW Three Gorges in China is the world's biggest hydropower station. For the concrete gravity dam, there are a number of high dams over 200 meter have been constructed, including Three Gorges(181m), Xiangjiaba(160m), Huangdeng(203m), Guangzhao(200.5m), and Longtan(192m). For the concrete arch dam, Jinping I Hydropower Station (305m), Xiaowan (294.5m), Xiluodu (285.5m), and the under-construction Baihetan (289m) are the world's top 4 highest. Shuibuya Hydropower Project (233m) is the highest congcrete faced rockfill dam around the world. Regarding the earth core rockfill dam, the Nuozhadu dam (261.5m) is the third highest and the Shuangjiangkou dam (314m) under-construction is the highest.

The safety of dams in China has stood the trail of practice. In May 12, 2008, the Wenchuan M8.0 earthquake in Sichuan, China was the most devastating earthquake since 1949, causing tens of thousands of deaths. However, although there are more than one hundred dams located in in the seismic regions, there was no dam failure, including four high dams over hundred meters, which were Zipingpu, Shuiniujia, Bikou and Shapai. The Zipingpu CFRD (165m) suffered strong earthquake with the intensity close to 10 degrees, locating 17km to the earthquake epicenter. Though suffered from damages to different extent, the four high dams remained safe in general, causing no subsequent disaster.The post-earthquake investigation report indicated that dam projects designed and constructed in accordance with Chinese regulations and technical standards have sufficient aseismatic safety. According to statistics, the annual dam break probability in China has been reduced to 5.0×10^{-5}, which is significantly lower than the international average. All the accidents happened related to small earth-rock fill dam projects that were built in the early years and had defects in design and construction. The large and medium-sized dam projects which were completed in the past three decades have never experienced major safety accidents such as dam breaks.

The rapid development of dam construction and the well-guaranteed project safety are supported by the sound industry management and technical standard systems.The establishment of China's hydropower engineering technical standards is initially based on the introduction and study of the former Soviet Union standards. Then through the accumulation of engineering construction experience, it has gradually developed its own standards systems by considering China's national conditions and practical experience, and learning from other countries'experiences since the 1970s.Since the reform and opening up in the 1980s, the ability of hydropower engineering construction and technical level have improved rapidly in China. The hydropower engineering technical standards have also been continuously supplemented and improved. It now covers the full life cycles including river planning, survey and design, construction, operation management, and demolition (or Decommissioning), also covers engineering, environmental protection, immigration and other professional fields. In recent years, as an important force to promote the development of hydropower in the world, China's hydropower engineering technical standards have gradually been integrated into the world's hydropower development and construction.

2. STANDARDIZATION MANAGEMENT OF HYDROPOWER INDUSTRY IN CHINA

China's standardization work implements a management system of "unified management and division of work" and the standardization work is directly managed by the government. The Ministry of Housing and Urban-Rural Development of the People's Republic of China undertakes the management of engineering construction standards. The National Energy Administration of the People's Republic of China (NEA) is responsible for standardization management in the energy sector, and NEA selects 15 units with technical strength as standardization management agencies to undertake the standardization management of oil, natural gas and shale gas, coal, electricity, hydropower, nuclear power, new energy and other sub-sectors in the industry. Each agency is in charge of several Technical Committees(hereinafter referred to as the TC) in the corresponding sub-industry. The TCs are responsible for the drafting and review of technical standards. NEA has specially formulated the "Administrative Measures forEnergy Standardization", which regulates the management of the TCs and the formulation and revision of standards. Each TC is composed of personnel in design, construction, operation, research and management with high technical level and rich experience.

China Renewable Energy Engineering Institute (CREEI) is one of the fifteen standardization management agencies in energy industry authorized by NEA. CREEI is specifically responsible for the daily administration of six TCs- Hydropower Investigation and Design(TC15), Hydropower Planning, Resettlement and Environmental Protection(TC16), Hydropower Electrical Design(TC17), Hydropower Engineering Economics(TC18), Hydropower Steel Structures and Hoists,(TC19). Hydropower Hydraulic Machinery(TC20). Other TCs in the hydropower industry include four standardization technical committees, such as hydropower construction, hydro-generators and electrical equipment, hydropower station automation, and dam safety monitoring, which are managed by other standardization management agencies. The scope of duties of the Committees in the hydropower industry is listed in Table 1.

Table 1 : Technical Committee and Its Duties

No.	Name of TC	Main business areas of TC
1	NEA/TC15 Technical Committee on Hydropower Investigation and Design	Survey and design standards for hydropower
2	NEA/TC16 Technical Committee on Hydropower Planning, Resettlement and Environmental Protection	Standards for Hydropower planning, environmental protection, reservoir resettlement
3	NEA/TC17 Technical Committee on Hydropower Electrical Design	Standards for the electrical design of hydropower
4	NEA/TC18 Technical Committee on Hydropower Engineering Economics	Standardsfor the technical economyassessment of hydropower projects
5	NEA/TC21 Technical Committee on Hydropower Steel Structures and Hoists	Standards for metal structure equipment and hoisting devicesin hydropower projects
6	NEA/TC20 Technical Committee on Hydropower Hydraulic Machinery	Standard for hydraulic machinery
7	Technical Committee for Standardization of Hydropower Construction	Standards for construction and organization, building materials, construction technology, quality and safety, equipment, management, etc.
8	Technical Committee for Standardization of Hydrogenerators and Electrical Equipment	Standards for technical conditions, operation and installation of hydro-generators
9	Technical Committee for Standardization of Hydropower Station Automation	Standards for technical conditions, operation and testing of automation equipment
10	Technical Committee for Standardization of Dam Safety Monitoring	Technical standards for safety monitoringin hydropower projects

3. CURRENT STATUS OF HYDROPOWER ENGINEERING TECHNICAL STANDARDS IN CHINA

At present, there are 489 effective standards in technical standard system for China's hydropower projects, with another 206 under development.

3.1 Standardsfor Engineering Investigation and Civil Design

There are 100 engineering investigation and civil design standards, which are divided into three categories: engineering investigation, hydro-structure design, and construction design.

The engineering survey part contains a total of 31 standards. It mainly includes technical standards in investigation, geology, geotechnical engineering, survey, exploration, geophysical exploration, geotechnical testing, hydrogeological testing, geotechnical and water monitoring. Key standards are*Specifications forGeological Investigation of Hydropower Engineering, Specifications for Investigation of Natural Building Materials for Hydropower Engineering, Specifications for Scalar Observation of Hydropower Engineering, Specifications for Geophysical Exploration for Hydropower Engineering, Rules for Engineering Rock Mass*, etc.

The hydraulic-structure design section contains a total of 51 standards. It mainly includes technical standards in hydraulic-structure buildings, slope engineering, hydraulic model tests, projects grade division, projects safety, and risk management. The main standards include*Classification and Design Safety Standards for Hydropower Complex,* *Design Specifications for Loads of Hydraulic Structures, Design Specifications for Hydraulic Concrete Structures, Code for Seismic Design of Hydraulic Structures for Hydropower Projects, Gravity of Concrete Code for Design of Dams, Code for Design of Concrete Arch Dams, Code for Design of Roller Compacted Embankment Dam, Code for Design of Concrete Faced Rockfill Dams, Code for Design of Spillway, Code for Design of Slopes of Hydropower and Hydraulic Engineering, Hydropower Code for Design of Engineering Workshops*, etc.

The construction design section contains a total of 18 standards. It mainly includestechnical standards in terms of construction diversion, material source, construction method, construction factory facilities, construction transportation, construction layout, construction progress and so on. Key standards are *Code forDesign of Hydropower Engineering Construction Organization, Code for Design of Hydropower Engineering Construction Diversion and Closure, Code for Design of Hydropower Engineering Concrete Production System, Code for Design of Aggregate Processing System for Hydropower Engineering*.

3.2 Standards for Planning, Resettlement and Environmental Protection

There are 42 standards for the management of NEA/TC16, which are divided into three categories: engineering planning, reservoir resettlement, and environmental protection.

The project planning section contains a total of 15 standards. It mainly includes technical standards in meteorology, terrestrial hydrology, sediment, hydrological forecasting, hydropower planning, economic evaluation, and reservoir operation and dispatching. Key standards are *Specifications for the Preparation of River Hydropower Planning, Code for Hydrological Calculation of Hydropower Engineering, Code for Calculation of Hydropower Engineering Design Floods, Code for Calculation of Possible Maximum Floods for Hydropower Projects, Code for Design of Sediments for Hydropower Projects* and so on.

The reservoir resettlement section contains 12 standards. It mainly includes technical standards in terms of physical index investigation, resettlement planning design and implementation, independent resettlement assessment, and post-evaluation. Key standards areSpecifications for *Planning and Design of Land Acquisition and Resettlement for Hydropower Engineering Construction, Specifications for Defining the Scope of Land Requisition for Hydropower Engineering Construction, Specifications for Survey of Physical Indicators for Land Requisition for Hydropower Engineering Construction, Design Specifications for Reservoir Bottom Cleaning of Hydropower Projects*, etc.

The environmental protection section contains a total of 15 standards. It mainly includes technical standards on environmental impact assessment of hydropower projects, environmental protection design and implementation, soil and water conservation schemes, and design and implementation of soil and water conservation. The key specifications that have been promulgated and implemented are *Environmental Impact Assessment Specifications for River Hydropower Planning, Environmental Impact Assessment Specifications for Hydropower Projects, Environmental Protection Design Specifications for Hydropower Projects, Specifications for Calculation of Ecological Flows of Hydropower Projects, Specifications for The Design of Fishes Multiplication and Release Stations, Specifications for The Design of Fish-Passing Facilities in Hydropower Projects, Design Specifications for The Layered Water Intake of Hydropower Stations* and so on.

3.3 Standardsfor Electrical Design

There are 26 standards managed by NEA/TC17, which falls into two major categories: primary and secondary. The formerincludes 10 standards, includingtechnical standards for electromechanical integration, units and appurtenant facilities, electrical systems and equipment, whereas the later contains 16 standards, includingtechnical standards for the control and protection of communication systems and equipment.

3.4 Standards for Steel Structureand Hoisting Devices

NEA/TC21 manages 29 standards all together, including technical standards for steel penstocks, steel gates (trash rack included) and hoists, selection and design of navigation devices and other steel structure equipment, covering technical requirements, installation, commissioning, operation and maintenance. Key specifications includeTechnical Requirements for Steel Gates in Hydropower Projects and General Technical Requirementsfor Fixed WinchHoist in Hydropower Projects.

3.5 Standardsfor NEA/TC20

The 8 standards managed by the NEA/TC20 mainly includes *technical standards for public auxiliary systems and equipment of hydropower stations.* The main standards include *Fundamental Technical Requirements for Hydraulic Turbines, Fundamental Technical Requirements for Francis Pump Turbine,Fundamental Technical Requirements forHydro Generators, andFundamental Technical Specifications for Generator-Motors*.

3.6 Standards forTechnical and Economy

There are 19 standards managed by NEA/TC18. It mainly includes the technical standards in hydropower projects, coveringthe pricing of engineering quantity, regulations on project cost, quota standardsand contract templates.

3.7 Standards for Hydropower ProjectConstruction

The154 standards managed by Technical Committee for Standardization of Hydropower Construction can be divided into five categories: construction management, civil engineering construction, equipment installation and commissioning, construction equipment and facilities, and quality inspection and evaluation.

There are 43 standards for construction management, including technical standards for construction management, river diversion and closure, on-site access, construction safety, operation safety and emergency safety.

There are 67 standards forcivil engineering, including equipment calibration methods, technology and material standards for earth-rock works,foundation treatment andgrouting, concrete works, impervious measures for hydraulic engineering buildings, concrete and asphalt concrete used in hydraulic engineering projects,sand, gravel and additives.

There are 23 standards forthe installation and commissioning of mechanical and electrical equipment, includinginstallation and commissioningstandards for turbines, units and appurtenant facilities, electrical systems and equipment and public auxiliary systems.

There are 7standards forfacilities ofconstruction factories, including all kinds of equipment and implementation standards for hydropower project construction.

There are 14 standards forquality inspection and evaluation, including the standards for civil engineering and installation and commissioning of mechanical and electrical equipment.

3.8 Others

There are 45 standards for hydro-generators and electrical equipment, mainly including the technical requirements, operation and installation standards for hydro-generators.

There are 14 standards for the automation of hydropower station, mainly including technical requirements, operation and test standards for the automation equipment of hydropower station.

There are 53 standards for dam-related safety monitoring, mainly including technical standards for the following aspects: concrete dam, earth-rock fill dam, other hydro engineering buildings, monitoring of slope deformation that poses safety threats, stress monitoring, seepage monitoring, arrangement and embedding of monitoring instruments, monitoring system automation and analysis and feedback of monitoring data.

4. COMPARISON BETWEEN DIFFERENT STANDARDS

In the process of improving the system of technical standards for hydropower projects, China has continuously summarized its practical experience and, on the other hand, has been conducting comparative studies with international technical standards, actively absorbing advanced concepts and successful practices abroad. Entrusted by the National Energy Administration of China (NEA), CREEI organized a comparative study between China's hydropower technical standards and international hydropower technical standards, and proposed the similarities and differences between China's and major international hydropower technical standards. The following text mainly focuses on the comparison and analysis results of design flood standards, design seismic standards, safety control standards for major dam types, andenvironmental protectionstandards, etc.

4.1 Flood Standards

China's hydropower projects are divided into 5 ranks according to the gross reservoir capacity, installed capacity of power stations, irrigation area and scale of downstream protection cities. The dam grades are determined according to the rank of hydropower projects. Different flood standards are stipulated depending on dams of different grades and different types (earth-rock fill dam or concrete dam). Two levels of flood standards are used: design flood and check flood, most of which adopt frequency flood design. The highest flood standard adopted for earth-rock fill dams is 10,000-year flood or PMF, while the highest standard for concrete dams is 5,000-year flood. Requirements of hydrological data series are very high for hydropower projects design in China, and relevant specifications are specially formulated to unify flood calculation methods. See Table 2 for comparison of specific design flood standards between China and other countries in the world.

Table 2 : Design Flood Standards for Dams and Reservoirs in Some Countries and ICOLD Bulletins

No	State or institution	The highest flood design standard: Flood recurrence period (year) or other	Applicable Conditions of Highest Design Standard	Classification
1	ICOLD	PMF or 5000-10000-year flood	Serious consequences of dam failure	3 levels according to the dam disaster level
2	China	PMF or 10000-year flood	Grade 1earth-rock fill dam	5 levels according to the dam grade
		5000-year flood	Grade 1 concrete dam	
3	US	PMF	Serious consequences of dam failure	3 levels each for large and small dams depends on consequences of dam failure
4	Canada			

5	Soviet Union	10000-year flood	Serious consequences of Grade I&II earthfill dam	4 levels according to project scale
6	Japan	120%×max(measured maximum flood, 200-year flood, maximum flood at dam site inferred from measured)	Rock-fill dam	2 levels according to the dam grade
7	UK	PMF	Severe casualty caused by dam failure	4 levels according to the consequences of dam failure
8	France	10000-year flood	Important dam	3 levels according to project importance
9	Germany	1000-year flood	Unusual applicable standards	3 levels according to reservoir capacity
10	Australia	PMF-10000-year flood	Serious consequences of dam failure	3 levels according to failure risk
11	Brazil	PMF	Serious consequences of dam failure	According to the consequences of the dam failure, 3 levels each for large and small dams
12	India	PMF	Large/medium dam, or small dam with serious consequences of dam failure	2 levels according to storage capacity and consequences of dam failure

4.2 Seismic Fortification Criterion

Chinese technical standard adopts MDE (Maximum Design Earthquake) or SEE (Safety Evaluation Earthquake) earthquake for dam seismic design. Local damages are allowed under MDE, but normal operation can still be achieved after restoration. Meanwhile, by strengthening the structural details of seismic design in structural design, the performance of the dam with 'no damage under small earthquake' could be achieved. Dams of different grades and different types are treated differently. For dams that may cause serious secondary disasters after the failure, 10,000-year earthquake or the MCE (Maximum Credible Earthquake) is used to check that no dam failure occurs under the earthquake.

The basic principles of dam seismic fortification in China are basically consistent with the international prevailing standards. The seismic fortification standards and requirements in China is relatively high and strict, and this is determined based on the actual investigation of earthquake damage, engineering practice and scientific research achievement in China.

Table 3 : Seismic Fortification Standards in Some Countries and ICOLD Bulletins

State or institution	**Seismic Fortification standards and Performance Target**				
	OBE	**SEE**			
ICOLD	145-year (local loss)	MCE or MDE (Requirement: no dam break)			
China	Not Control	Dam of Grade 2 or below		Dam of Grade 1	
		About 500-year		5000-year, 10000-year or MCE	
US	150-year (no damage)	MCE (important project, no dam break) 1000-year (normal project, controllable damage)			
Japan	100-year (linear-elastic)	MCE (Restorable)			
New Zealand	150-year (no damage)	10000-year or MCE (no dam break)			
Italy	1/2PGA of 500-year	MCE (important project) 2500-year (class III project)			
UK	Not Control	Class I (project)	Class II	Class III	Class IV
		1000-year	3000-year	10000-year	30000-year
Austria	Not Control	MCE			
Canada	Not Control	Medium Dam	High Dam	Extreme High Dam	Ultra High Dam
		1000-year	2500-year	5000-year	10000-year
Switzerland	Not Control	Low Dam	Medium Dam (H>25m)	High Dam (H>40m)	
		1000-year	5000-year	10000-year	

4.3 The safety control standards for dam

CREEI carried out comparative analysis on the design standards of the main dam types, such as concrete gravity dam, concrete arch dam, rolled and earth-rock fill dam, between the Chinese standards and the standards of US Bureauof Reclamation (USBR), US Army Corps of Engineers(USACE). This thesis briefly describes the similarities and differences in safety control standards of the abovementioned dam types.

(1) According to Chinese arch dam design standards, the load and work condition, arch dam stress analysis methods and arch abutment stability calculation methods are basically the same with internationalstandards,only slight differences in the safety control standards. The Chinese standard has a compressive stress safety factor of 4.4, a tensile stress safety factor of 1.8.The tensile stress is lower than 1.2 MPa (arch-beam trial-load method) and 1.5 MPa (finite element equivalent stress method). The safety factor of anti-sliding stability is 3.6, when the rigid body limit equilibrium method is used to analyze the stability of the arch base.

As for the safety factor of compressive stress control of the US standards, the figure is 3.62 according to USBR and 4.82 for USACE, and the maximum compressive stress is lower than 10-15 MPa, allowing tensile stress lower than 1 MPa. The Anti-sliding stability safety factor is 4.0.

With the completion and operation of a series of 300m ultra high arch dams, China has gained rich experience in ultra high arch dams. The safety control standards and corresponding design analysis methods of the high arch dams have also been included in the design standards, showing the latest technological progress of concrete arch dams.

(2) The main design standards for concrete gravity dams in China and rther countriesall use stress and stability analysis as safety criteria for the design of the dam body section, and adopt the material mechanics method and rigid body limit equilibrium method as the basic calculation methods, considering basically the same loads in the analysis. As for the anti-sliding stability control standards, the Chinese standard stipulates that the safety factor should be not less than 3.0, 2.5, and 2.3 in the case of basic combination of loads, check floods and earthquakes conditions respectively. The USBR manual requires not less than 3.0, 2.0, and 1.0 in the normal load, extraordinary load, and extreme load combination. The requirement is no less than 2.0, 1.7, and 1.3 respectively according to the US Engineer Corps Manual. The figure is slightly higher in Chinese standard compared with other standards. For stress safety standards, Chinese standard requires 4.0 for compressive stress safety factor, which is also at a higher level and the same with USBR. For tensile stress control, Chinese standards stipulates that vertical tensile stresses shall not occur under any conditions except earthquakes at the upstream surface of the dam heel and dam body. This requirement is basically the same with other international standards. The US standards, however, allows small amount of tensile stress.

(3) The safety control of the Chinese design standard for rolled earth-rock fill dam focuses on of the anti-sliding stability, seepage stability, and deformation stability of the dam body. The focus is generally consistent with the design concepts of foreign technical standards.The requirements for anti-sliding stability calculation theory, strength parameters, and anti-sliding stability safety factor are basically the same.Only the seismic conditions are slightly different, as the Chinese standard requireslightly higher anti-seismic safety factor.Under normal operating conditions, both Chinese and American standards require that the dam slope safety factor of high earth-rock dams is no less than 1.5. Under earthquake conditions, Chinese standard requires the dam slope safety factor to be not less than 1.1 ~ 1.2 and USAEC requires not less than 1.0.

Earth-rock dam stress and deformation calculation theory and method are basically the same. The Chinese standards pays more attention to deformation control of ultra-high rolled rock fill dams. There are plentiful achievements in material tests, constitutive models and other theories for high embankment dams, which have been incorporated into technical standards.

4.4 Technical Standards for Environmental Protection

With the development of economy and society, China pays more and more attention to environmental protection. In the past 20 years, China has made great progress in hydropower development and environmental protection technology, with relatively complete technical standards system formed in the fields of water environment, aquatic ecology, terrestrial ecology, soil and water conservation, and environmental protection during construction. For fish breeding and release, stratified water intake, fish passing facilities and other specific environmental protection area, a series of innovative environmentally-friendly engineering and environmental protection technologies have been developed and successfully applied in practice. In terms of environmental impact assessment, environmental protection measures and design of hydropower development, the Chinese standard is as comprehensive, systematic, and updated as other the internationally accepted standards. For example, China demands strict environmental impact assessments in the hydropower development, fish facilities such as fish ways, fish lifts or trapping and transporting crossing dams are needed, fish restock and fish habitat protection are popularly adopted, stratified water intakes for thermally stratified reservoirs is required to get warmer water, and ecological flow usually should not less than 10% of the annualaverage runoff. These are basically the same as the requirements of internationally-accepted standards.

5. CONCLUSION

Through the systematic comparative research, the hydropower engineering Technical standards of China are basically consistent with the major international standards in terms of design concepts, calculation and analysis methods, and safety control standards. Some of the safety control requirements of Chinese standards are even stricter.

Chinese standards have been gradually accepted and used in the world. A number of hydropower projects adopting Chinese standards have been constructed worldwide. However, Chinese standards are still not widely adopted in the world, as they are relevantly young and great in number and specific in the classification. The language and culture background also restrict its adoption in the world to some extent. To facilitate the adoption of Chinese standards worldwide, the National Energy Administration of China required that the English version has to be compiled and published on the website for all standards in their development and revision.

We hope to share Chinese hydropower engineering Technical standards with the world and make progress together with the world hydropower industry. We wish the Chinese standards will be a precious part of the cultural and ethnologicaltreasure of the whole mankind and contribute to the world hydropower development and the“building of a community of shared future for mankind”.