

Research on Safety and Emergency Management of Hydropower Engineering in China

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Abstract: China's hydropower has been developed rapidly, and cascade hydropower stations have been established in many basins. Once a dam fails, the induced flood could wreak havoc downstream and on both sides. Therefore in contemporary China, the safety and emergency management of hydropower engineering is very important. The main purpose of this paper is to provide reference for the sustainable and healthy development of China's hydropower station construction and management. Firstly, this paper summarizes the overall situation of China's hydropower engineering safety and emergency management from the perspective of related regulations and related authority responsibilities. Secondly, the current situation of safety and emergency management in three typical basins with different characteristics is investigated and studied. Finally, the main features of the safety and emergency management of hydropower engineering in China are analyzed and summarized. Based on these studies, it can be concluded that as a country with the largest installed capacity in the world, China has attached great importance to the safety and emergency management of hydropower projects and has formed a systematic management mechanism, which has three characteristics: (1) Comprehensive and detailed regulations and standards; (2) Broad responsibilities and significant roles of governments and their subordinate bodies; (3) Basin-based safety and emergency management.

Keywords: Hydropower Project, Safety Management, Emergency Management, Current Situation, China

1. Introduction

Hydropower development can help human beings prevent flood and drought disasters and utilize hydropower resources rationally, and plays a positive role in energy restructuring, clean electric power supply, flood control, agricultural irrigation, city water supply and improvement of navigation conditions. After a hundred years of development, China has made remarkable achievements in the hydropower sector. According to statistics, 98,460 reservoirs and dams of various types, with the total storage up to 896,700 million m³, had been completed in China by the end of 2016, allowing China to rank first in the world in terms of quantity of dam completed [1]. Among these reservoirs and dams, there are 4,610 large and medium-sized reservoirs, with the total storage of 826 billion m³. Currently, the total installed capacity of hydropower stations in China is greater than 330 GW [2]. Among which, 579 hydropower station dams have been registered and filed by National Energy Administration (NEA), with the total installed capacity of 246,343 MW and the total storage of 451,920 million m³ [3]. For hydropower stations

with the unit capacity of 6,000 kW and above, the total installed capacity is up to 298,870 MW [4]. According to *13th Five-Year Plan for Energy Development*, *13th Five-Year Plan for Electric Power Development* and *13th Five-Year Plan for Hydropower Development*, China will remain active and steady hydropower development, and advance the construction of large hydropower bases in order.

The dam of a hydropower station is a water retaining structure built on a river. As large and medium-sized hydropower stations generally feature "high dam and large reservoir", a dam break flood may cause huge damage to the lower reaches and both banks in case of an accident. Due to design and construction defects as well as improper operation management, some hydropower stations may suffer from damage to flood discharge facilities, dam overtopping, dam collapse and other accidents in case of extreme weather or sudden earthquake and geological disasters, affecting seriously the life and property safety of people living at lower reaches as well as the social public security. Along with the enhancement of composite national strength, China has paid more and more

attention to security. The *Report delivered at the 19th National Congress of the Communist Party of China* clearly points out that "overall consideration shall be given to both development and security". Safety is of great significance for the sustainable development of hydropower engineering in China. Safety and emergency management has been a major research topic in the field of hydropower engineering in China at present.

This paper is divided into three parts, to describe the research on current situations of safety and emergency management of hydropower projects in China. First, this paper summarizes current situations in two aspects, i.e. Chinese safety and emergency regulations and standards, and responsibilities of relevant Chinese agencies, to describe overall situations of safety and emergency management of hydropower projects in China, followed by investigation and research on current situations of safety and emergency management of hydropower projects in typical basins in China. Finally, this paper analyzes and summarizes main characteristics of safety and emergency management of hydropower projects in China at the current stage.

2. Overall Situations of Safety and Emergency Management of Hydropower Projects

In China, the safety and emergency management of hydropower projects is carried out mainly by relevant agencies

in accordance with relevant regulations and standards. Therefore, this section summarizes overall situations of safety and emergency management of hydropower projects in China in two aspects: relevant Chinese regulations and standards, and responsibilities of relevant Chinese agencies.

2.1. Regulations and Standards

The government of China has always paid high attention to the safety of hydropower projects. The *Regulation on the Administration of Reservoir Dam Safety*, issued by the State Council in 1991 as supporting measures, presents specific requirements for dam safety management. Meanwhile, there are the following main regulations: *Regulation for Safety Administration of Hydropower Dams in Operation* issued by the State Electricity Regulatory Commission in December 2004, Decree No. 23 of the National Development and Reform Commission — *Regulation for Safety Administration of Hydropower Dams in Operation* issued on April 1, 2015, as well as *Program for Preparation of Emergency Preparedness Plan for Flood Control and Emergency Rescue of Reservoir* issued by the State Flood Control and Drought Relief Headquarters in March 2006, and *Guidelines for Emergency Preparedness Plan of Reservoir Dam Safety Management (SL/Z720-2015)* formally issued in 2015. Refer to Table 1 for representative laws, regulations and technical standards concerning safety and emergency management of hydropower projects issued in China.

Table 1. Representative Laws, Regulations and Technical Standards concerning Safety and Emergency Management of Hydropower Projects issued in China.

S/N	Category	Description	Document No.	Date of Implementation
1	National law	<i>Law of the People's Republic of China on Work Safety</i> (2014 revision)	Order No. 13, 2014 of President of the People's Republic of China	2014.12.01
2		<i>Emergency Response Law of the People's Republic of China</i>	Order No. 69, 2007 of the President of the People's Republic of China	2007.11.01
3		<i>Law of the People's Republic of China on Precautions against Earthquake and Relief of Disaster</i> (2008 revision)	Order No. 7, 2008 of the President of the People's Republic of China	2009.05.01
4		<i>Meteorology Law of the People's Republic of China</i> (2016 revision)	Order No. 14, 2014 of the President of the People's Republic of China	2014.08.01
5		<i>Flood Control Law of the People's Republic of China</i> (2016 revision)	Order No. 88, 1997 of the President of the People's Republic of China	2016.07.02
6		<i>Electric Power Law of the People's Republic of China</i> (2015 revision)	Order No. 24, 2009 of the President of the People's Republic of China	2015.04.24
7		<i>Counter-Terrorism Law of the People's Republic of China</i>	Order No. 36, 2015 of the President of the People's Republic of China	2016.01.01
8	National administrative regulation	<i>Water Law of the People's Republic of China</i> (2016 revision)	Order No. 74, 2002 of the President of the People's Republic of China	2016.07.02
9		<i>Emergency Regulations Regarding Emergency Public Health Incidents</i>	Decree No. 376 of the State Council	2003.05.09
10		<i>Regulation on the Emergency Response to and Investigation and Handling of Electric Power Safety Accidents</i>	Decree No. 599 of the State Council	2011.09.01
11		<i>Administrative Regulations on the Work Safety of Construction Projects</i>	Decree No. 393 of the State Council	2004.02.01
12		<i>Regulation on the Administration of Reservoir Dam Safety</i> (2011 revision)	Decree No. 77 of the State Council	2011.01.08
13		<i>Regulations on the Control over Safety of Dangerous Chemicals</i> (2013 revision)	Decree No. 591 of the State Council	2011.12.01
14		<i>Flood Control Regulations</i> (2011 revision)	Decree No. 86 of the State Council	2011.01.08
15		<i>Regulation on the Prevention and Control of Geologic Disasters</i>	Decree No. 394 of the State Council	2004.03.01
16		<i>Regulation on the Administration of Earthquake Monitoring</i>	Decree No. 409 of the State Council	2004.09.01
17		<i>Regulations on Prevention of and Preparedness for meteorological Disasters</i>	Decree No. 570 of the State Council Issued on December 14, 2010 as Decree No. 36 of the State Administration of Work Safety, and revised according to Decree No. 77 of the State Administration of Work Safety issued on April 2, 2015.	2010.04.01
18	Government regulation	<i>Measures for the Supervision and Administration of "Three Simultaneities" for the Safety Devices of Construction Projects</i>		2011.02.01

S/N	Category	Description	Document No.	Date of Implementation
19	Normative government document	<i>Measures for Regulating the Work Safety of Electricity</i>	Decree No. 21 of the National Development and Reform Commission of the People's Republic of China	2015.03.01
20		<i>Measures for the Administration of Contingency Plans for Work Safety Incidents</i>	Decree No. 88 of the State Administration of Work Safety	2016.07.01
21		<i>Measures for the Administration of Reservoir Seismic Monitoring</i>	Decree No. 9 of China Earthquake Administration	2011.05.01
22		<i>Measures for the Supervision and Administration of the Construction Safety of Electric Power Projects</i>	Decree No. 28 of the National Development and Reform Commission of the People's Republic of China	2015.10.01
23		<i>Regulation for Safety Supervision and Administration of Hydropower Dams in Operation</i>	Decree No. 23 of the National Development and Reform Commission of the People's Republic of China	2015.04.01
24		Opinions of the National Development and Reform Commission and the National Energy Administration on Promoting the Reform and Development of Safe Production	FGNYG [2017] No. 1986	2017.11.17
25		Guiding Opinions of the National Energy Administration on Preventing Electrical Personnel Injury and Death Accidents	GNAQ [2013] No. 427	2013.11.14
26		Notice of the National Energy Administration on Issuing <i>Measures for the Supervision and Administration of Electric Power Safety Training</i>	GNAQ [2013] No. 475	2013.12.08
27		Notice of the National Energy Administration on Issuing <i>Twenty-five Key Requirements to Prevent Serious Accident and Failure in Electric Power Operation</i>	GNAQ [2014] No. 161	2014.04.15
28		Guiding Opinions on Strengthening the Prevention and Control of Geological Disasters in the Electric Power Industry	DJAQ [2013] No. 6	2013.01.22
29		Notice of the National Development and Reform Commission on Strengthening Earthquake Prevention and Protection of Hydropower Engineering	FGNY [2008] No. 1242	2008.07.01
30		Notice of the National Energy Administration on Issuing <i>Safety Protection Schemes such as General Plan for Safety Protection of Power Monitoring System and Evaluation Regulations</i>	GNAQ [2015] No. 36	2015.02.04
31		Notice on Strengthening Safety and Quality Assurance Measures for Major Projects	FGTZ [2009] No. 3183	2009.12.14
32		Notice of the National Energy Administration on Issuing <i>Regulations on Quality Supervision and Administration of Hydropower Projects</i> and <i>Measures for Safety Appraisal and Administration of Hydropower Projects</i>	GNXN [2013] No. 104	2013.03.08
33		Notice of the National Energy Administration on Issuing <i>Measures for Supervision and Management of Periodic Inspection of Dam Safety of Hydropower Stations</i>	GNAQ [2015] No. 145	2015.05.06
34		Notice of the National Energy Administration on Issuing <i>Measures for Registration Supervision and Management of Dam Safety of Hydropower Stations</i>	GNAQ [2015] No. 146	2015.05.06
35		Notice of the National Energy Administration on Issuing <i>Administrative Measures for Dam Safety Monitoring at Hydropower Stations</i>	GNFAQ [2017] No. 61	2017.10.18
36		Notice of the National Energy Administration on Strengthening the Prevention of Powerhouse Flooding of Hydropower Stations	GNZHAQ [2017] No. 66	2017.05.26
37		Notice of the General Office of State Administration of Work Safety on Issuing <i>Interim Measures for Evaluation of Emergency Disposal of Production Safety Accidents</i>	AJZTYJ [2014] No. 95	2014.09.22
38		Notice of the National Development and Reform Commission on Strengthening Basin Hydropower Management	FGNY [2016] No. 280	2016.02.05
39		Notice on Issuing <i>Measures for the Administration of Contingency Plans for Power Enterprises</i>	GNAQ [2014] No. 508	2014.11.27
40		Notice of the National Energy Administration on Issuing <i>Rules for Evaluation and Record of Emergency Preparedness Plan of Power Enterprises</i>	GNZAQ [2014] No. 953	2014.12.03
41		Notice of the State Council on Issuing <i>National Contingency Plan for the Relief of Natural Disasters</i>	GBH [2016] No. 25	2016.03.10
42		Notice on Deepening Evaluation on Emergency Response Capacity Building of Power Enterprises	GNZAQ [2016] No. 542	2016.09
43		Notice on Issuing <i>Program for Preparation of Emergency Preparedness Plan for Flood Control and Emergency Rescue of Reservoir</i>	BH [2006] No. 9	2006.03.13
44		Notice of the General Office of National Development and Reform Commission on Issuing <i>Classification of Major Materials for Emergency Guarantee (2015)</i>	FGBYX [2015] No. 825	2015.04.07

S/N	Category	Description	Document No.	Date of Implementation
45	Technical standard	<i>Compulsory Provisions of Engineering Construction Standards (Electric Power Engineering)</i>	2011 edition	2012.03.01
46		<i>Flood Control Standard</i>	GB 50201-2014	2015.05.01
47		<i>Code for Preparation of Safety Pre-assessment Report of Hydropower Projects</i>	NB/T 35015-2013	2013.10.01
48		<i>Classification & Design Safety Standard of Hydropower Projects</i>	DL 5180-2003	2003.06.01
49		<i>Code for Rational Service Life and Durability Design of Water Resources and Hydropower Projects</i>	SL 654-2014	2014.04.26
50		<i>Code for Seismic Design of Hydraulic Structures of Hydropower Project</i>	NB 35057-2015	2016.03.01
51		<i>Specifications for Seismic Design of Hydraulic Structures</i>	DL 5073-2000	2001.01.01
52		<i>Code for Design of Occupational Safety and Health of Water Resources and Hydropower Projects</i>	NB 35074-2015	2016.03.01
53		<i>Technical Code for Dam Break Flood Simulation of Hydropower and Water Resources Project</i>	DL/T 5360-2006	2007.05.01
54		<i>Guide of Emergency Capability Assessment for Safety Construction in Hydropower and Water Resources Projects</i>	DL/T 5314-2014	2014.08.01
55		<i>Code for Preparation of Safety Assessment Report upon Completion of Hydropower Projects</i>	NB/T 35014-2013	2013.10.01
56		<i>Occupational Safety and Health Acceptance Specification for Hydropower Projects</i>	NB/T 35025-2014	2014.11.01
57		<i>Regulation of Operation and Maintenance for Automatic System of Hydrological Collection and Transmission</i>	DL/T 1014-2006	2007.03.01
58		<i>Guide for Safety Assessment of Hydropower Dams in Operation</i>	DL/T 5313-2014	2014.08.01
59		<i>Electric Power Trade Urgently Saving Work Rules</i>	DL/T 692-2008	2008.11.01
60		<i>Guidelines for Emergency Preparedness Plan of Reservoir Dam Safety Management</i>	SL/Z 720-2015	2015.12.22
61		<i>Guidelines for Enterprises to Develop Emergency Response Plan for Work Place Accidents</i>	GB/T 29639-2013	2013.10.01
62		<i>13th Five-Year Plan for National Emergency System Building for Sudden Incidents</i>	General Office of the State Council	2017.01.12
63		<i>13th Five-Year Plan for Emergency Management for Work Safety</i>	State Administration of Work Safety	2017.09.22
64	Macro plan	<i>13th Five-Year Plan for Energy Development</i>	National Development and Reform Commission and National Energy Administration	2016.12.26
65		<i>13th Five-Year Plan for Electric Power Development</i>	National Development and Reform Commission and National Energy Administration	2017.6.5
66		<i>13th Five-Year Plan for Hydropower Development</i>	National Energy Administration	2016.11.29
67		<i>Report delivered at the 19th National Congress of the Communist Party of China</i>	Central Committee of the Communist Party of China	2017.10.18

It can be seen from Table 1 that from the perspective of safety management and measures of hydropower projects, No. 1~9, No. 16~19, No. 24~27, No. 45 and No. 67 are comprehensive safety management laws, regulations and rules and standards or cover the whole process of hydropower project, No. 46~47 and No. 62~66 involve the planning stage of hydropower project, No. 27~29 and No. 48~53 involve the design stage, No. 22, No. 31, No. 32 and No. 54~56 involve the construction and acceptance stages, No. 12, No. 13, No. 23, No. 33~36, No. 57 and No. 58 involve the operation stage; from the perspective of safety and emergency technology of hydropower project, No. 5, No. 14, No. 43, No. 46 and No. 57 involve flood control, No. 3, No. 15, No. 16, No. 21, No. 28, No. 29, No. 50 and No. 51 involve earthquake fortification and prevention of geological disasters, No. 4, No. 17 and No. 41 involve the prevention of natural meteorological disasters, No. 2, No. 9, No. 10, No. 20, No. 39~44 and No. 59~61 involve specific issues about management of contingency plans.

It is thus clear that there are available safety management methods and measures applicable to the planning, design, construction, acceptance and operation stages of hydropower projects in China, and there are corresponding regulations and

standards as support for flood control, earthquake fortification, prevention of geological and meteorological disasters and contingency plan management of hydropower projects. Moreover, "Three Simultaneities" (i.e. safety pre-assessment, safety facilities design, and safety assessment upon completion) (see No. 18 in Table 1) are also carried out for hydropower projects. All of these provide guarantee for the safety of hydropower projects. Currently, China has issued a large number of regulations and standards about safety and emergency management, basically covering the full life circle of hydropower projects.

2.2. Responsibilities of Relevant Agencies

In China, agencies involved in the safety and emergency management of hydropower projects include: national work safety supervision and administration departments, industry work safety supervision and administration departments, basin management agencies and hydropower station operation enterprises.

2.2.1. National Work Safety Supervision and Administration Departments

According to Article 8 and Article 9 of *the Law of the*

People's Republic of China on Work Safety, comprehensive work safety supervision and administration agencies in China include the State Council and work safety supervision and administration departments under the people's governments at all levels. Among these agencies, the State Administration of Work Safety is directly under the State Council. The Notice of the General Office of the State Council on Issuing the Provisions on the Main Functions, Internal Bodies and Staffing of the State Administration of Work Safety (GBF [2008] No. 91) clearly defines 17 responsibilities of the State Administration of Work Safety. Among which, main responsibilities related to the safety and emergency management of hydropower projects in basins are as follows: 1) Take responsibility for work safety supervision and administration, conduct supervision and inspection for production and operation organizations' implementation of work safety laws and regulations, their work safety conditions and their work safety management of relevant equipment, materials and personal protective equipment, conduct work safety supervision and administration for enterprises under the central government. 2) Conduct supervision and inspection for the occupational health at workplaces, issue occupational safety and health permits, and organize the investigation and treatment of occupational hazard accidents and violation of laws and rules. 3) Formulate and issue work safety regulations, standards and codes, and organize the implementation; conduct supervision and inspection for the monitoring of major hazard sources and the investigation and treatment of major potential accidents; investigate and treat production and operation organizations with unqualified work safety conditions. 4) Conduct supervision and inspection within the scope of their official duties to confirm whether the safety facilities of newly built, renovated and expanded projects are designed, constructed and put into operation with main structures of these projects simultaneously.

In March 13, 2018, the State Council performed institutional reform by incorporating the State Administration of Work Safety into the new Ministry of Emergency Management.

2.2.2. Industry Work Safety Supervision and Administration Departments

According to the *Law of the People's Republic of China on Work Safety* (hereinafter referred to as "the Law"), relevant departments under the State Council shall, within the scope of their official duties, conduct work safety supervision and administration in relevant industries and sectors as per the Law and other relevant laws and administrative regulations; relevant departments under local people's governments above the county level shall, within the scope of their official duties, conduct work safety supervision and administration in relevant industries and sectors as per the Law and other relevant laws and regulations. The work safety supervision and administration departments and the departments in charge of work safety supervision and administration in relevant industries and sectors are collectively called responsible departments of work safety supervision and administration.

As the competent authority in the energy industry, NEA is responsible for safety supervision and administration of large and medium-scale hydropower station dams which are mainly developed for power generation and respectively have an installed capacity of 50 MW and above. NEA is responsible for comprehensive supervision and administration, and assigns relevant agencies to take responsibility for the supervision and administration within the jurisdiction [5].

NEA is responsible for the safety and emergency supervision and management of cascade hydropower projects in basins. To be specific, the Electricity Safety Supervision Department and the New and Renewable Energy Department of National Energy Administration are mainly in charge of safety and emergency management. The Electricity Safety Supervision Department is mainly responsible for organizing the drafting of policies, methods and measures concerning supervision and administration of power operation safety (except for nuclear safety), construction safety of electric power projects and project quality and safety, and supervising the implementation of these policies, methods and measures; conducting power work safety supervision and administration, reliability control and power emergency management; conducting dam safety supervision and management of hydropower stations, and organizing or participating in the investigation and treatment of power work safety accidents according to laws. The New and Renewable Energy Department is mainly responsible for directing and coordinating the development of new energy, renewable energy and rural energy, organizing the drafting of development programs, plans and policies of new energy, hydroenergy, biomass energy and other renewable energy, and organize the implementation of these programs, plans and policies.

In addition, the Large Dam Safety Supervision Center is directly under NEA, take responsibility for providing technical supervision service and management guarantee for the dam operation safety of hydropower stations. Hydropower stations within the jurisdiction of NEA mostly feature "high dam and large reservoir", as well as large project scale, many technical difficulties and complex operation management. To ensure the dam operation safety of these hydropower stations, NEA has issued a series of supervision measures, mainly including safety registration of hydropower station dams, periodic safety inspection of dam, dam reinforcement, dam safety monitoring, safety appraisal, submission of dam operation safety information, and dam operation safety informatization planning. Based on the above-mentioned supervision measures, NEA has successively launched a series of normative documents, to clearly specify supervision requirements.

2.2.3. Basin Management Agencies

In China, the water administration department of the State Council has established basin management agencies for major rivers and lakes identified by the state, to exercise responsibilities in water resources supervision and management as specified by laws and administrative regulations and assigned by the water administration department of the State Council According to the Notice of the General Office of the State Council on Issuing the Provisions

on the Main Functions, Internal Bodies and Staffing of the Ministry of Water Resources (GBF [2008] No. 75) and the Notice of the Office of Central Institutional Organization Commission on Issuing Adjustment Scheme for Main Functions, Internal Bodies and Staffing of Basin Management Agencies assigned by the Ministry of Water Resources (ZYBBF [2002] No. 39), China has set up basin management agencies as per seven major basins, including: Changjiang Water Resources Commission, Yellow River Conservancy Commission, Hai River Water Resources Commission, Huai River Water Resources Commission, Pearl River Water Resources Commission, Songliao River Water Resources Commission and Taihu Basin Authority. The seven major basin management agencies are mainly responsible for the supervision and management of water resources within their jurisdiction according to laws and administrative regulations as authorized by the Ministry of Water Resources.

The specific responsibilities of all these basin management agencies are as follows [6]: 1) Ensure water resources in basins are rationally developed and utilized; 2) conduct supervision and management of water resources in basins, and take overall consideration and secure domestic, industrial and ecological water uses; 3) take charge of water resource protection; 4) take charge of flood control and drought relief in basins, and undertake day-to-day work of the Office of State Flood Control and Drought Relief Headquarters; 5) provide guidance to hydrological work in basins; 6) provide guidance to the control and development of major rivers, lakes, estuaries and coast beaches in basins; 7) take charge of the management and protection of water infrastructures, water bodies and shorelines as well as the construction and management of water projects in basins as per specified limits of authority; 8) provide guidance to and coordinate the control of soil erosion and water loss in basins; 9) provide guidance to the enforcement and execution of water laws and regulations, and investigate illegal cases violating water laws; 10) mediate and arbitrate inter-province water disputes; 11) provide direction to the development of water-energy resources in rural areas in accordance with relevant provisions, and rural electrification and approach of small hydro-power development for firewood; 12) take charge of operation or supervision and management of state-owned assets of controlled water conservancy projects, inter-province (autonomous region, municipality) water conservancy projects, and other water conservancy projects in basins under the ministry as per provisions or as authorized; 13) put forward suggestions on verification and adjustment of water supply price of water conservancy projects directly under the ministry and inter-province (autonomous region, municipality) water conservancy projects in basins as well as on-grid price of projects directly under the ministry; 14) other duties and responsibilities assigned by the Ministry of Water Resources.

2.2.4. Hydropower Station Operation Enterprises

According to Law of the People's Republic of China on Work Safety, Regulation on the Administration of Reservoir

Dam Safety and Regulation for Safety Administration of Hydropower Dams in Operation, electric power enterprises mainly have the following responsibilities concerning safety and emergency management: 1) Implement national laws, regulations and technical standards concerning dam safety; 2) establish and improve management organization systems of dam operation safety, clearly define dam safety responsibility system, set up dam operation safety management and supervision agencies, and allocate specialized personnel in charge of dam safety management; 3) formulate, implement and continuously improve rules, regulations and operation instructions concerning dam safety management; 4) establish and improve dam safety and emergency management system and working mechanism, establish joint emergency response mechanism with local governments and relevant agencies, formulate contingency plans and exercise plans concerning dam safety, and organize the implementation of these plans; 5) ensure dam safety monitoring system, flood discharge & energy dissipation and protection facilities, emergency power supply and other safety facilities are designed, constructed and put into operation with main structures of dams simultaneously; 6) properly carry out flood control of hydropower stations as per relevant national provisions, establish and improve flood control organization, flood control responsibility system and management system, prepare operation plans during flood season and contingency plans of flood control as per approved design flood control standards and reservoir operation principles, and implement these plans after submission of these plans for approval as per provisions; 7) carry out dam safety registration and periodic inspection (special inspection), reinforcement, informatization and information submission as per provisions and requirements; 8) organize routine patrol inspection and annual detailed investigation for dams, and carry out major safety inspection before, during and after flood season; 9) timely treat defects and potential hazards found during dam operation and inspection, timely organize analysis and diagnosis of abnormalities and dangerous cases during dam operation, properly perform emergency rescue and reporting in case of dam accidents of hydropower stations; 10) timely collate and analyze monitoring and inspection results, compile and analyze dam safety monitoring data per year, and monitor dam operation safety conditions; 11) collect, collate, file and manage dam project archives, operation and maintenance data and corresponding original records; 12) organize technical training for dam operation management personnel, and ensure relevant personnel work with corresponding certificates; 13) safeguard hydropower station dams within the management and protection range, to avoid interference with the normal management and operation of dams; 14) perform safety management for outsourcing organizations effectively.

The above-mentioned responsibilities of electric power enterprises in safety and emergency management fall into responsibilities in eight aspects: equipment and facilities guarantee, funding, organization and staffing, formulation of rules and regulations, education and training, safety management, accident report and emergency rescue, and others

specified by laws and regulations. Refer to Table 2 for the relation between these responsibilities and corresponding work.

Table 2. Main Contents of Responsibilities of Electric Power Enterprises in Safety and Emergency Management.

S/N	Main Responsibility	Corresponding Work
1	Equipment and facilities guarantee	5), 7), 13)
2	Funding	9), 7)
3	Organization and staffing	2), 6)
4	Formulation of rules and regulations	3), 4), 6)
5	Education and training	12)
6	Safety management	4), 6), 7), 8), 10), 11), 13)
7	Accident report and emergency rescue	4), 9)
8	Others specified by laws and regulations.	1), 7), 14)

It can be seen from the above-mentioned organization structuring and relevant responsibilities that China has

formed a multi-level safety and emergency management organization of nation→industry→basin→enterprise of hydropower stations, and responsibilities covering the following aspects related to safety and emergency management of hydropower stations are clearly defined for agencies at each level: work safety supervision and administration, work safety rules and regulations and their implementation, occupational health supervision and inspection in workplaces, risk identification, education and training, guarantee of capital and equipment, organization and staffing, contingency plans and measures for sudden incidents like natural disasters, accident report and emergency rescue. Refer to Figure 1 for China's multi-level management organization and corresponding responsibilities.

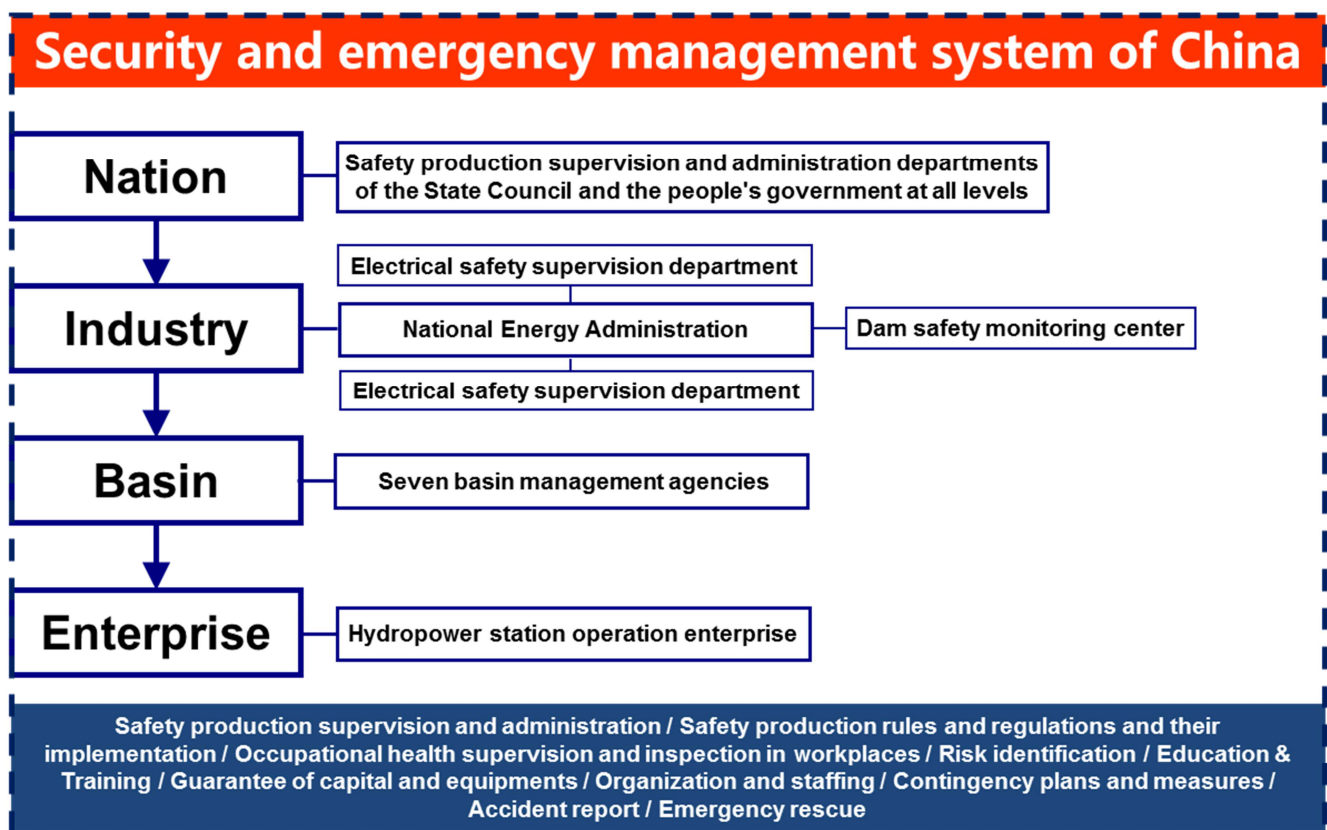


Figure 1. China's Multi-level Management Organization and Corresponding Responsibilities.

3. Analysis on Current Situations of Safety and Emergency Management of Hydropower Stations in Typical Basins

In China, hydropower resources are mainly concentrated in ten major basins: Yangtze River, Jinsha River, Yalong River, Dadu River, Wu River, Lancang River, Yellow River, Nujiang River, Hongshui River and Yarlung Zangbo River [7]. The author has conducted investigation and survey on current situations of safety and emergency management of hydropower stations in the Dadu River basin, the upper

Yellow River basin and the Lancang River basin. The investigation and survey results indicate that the safety and emergency management of hydropower stations in the Dadu River basin belongs to management in Sichuan Province, that of hydropower stations in the upper Yellow River basin belongs to inter-province management, and that of hydropower stations in the Lancang River basin belongs to international basin safety and emergency management. Refer to Figure 2 for the locations of the three basins. Current situations of safety and emergency management of hydropower stations in the three basins are summarized and analyzed below.

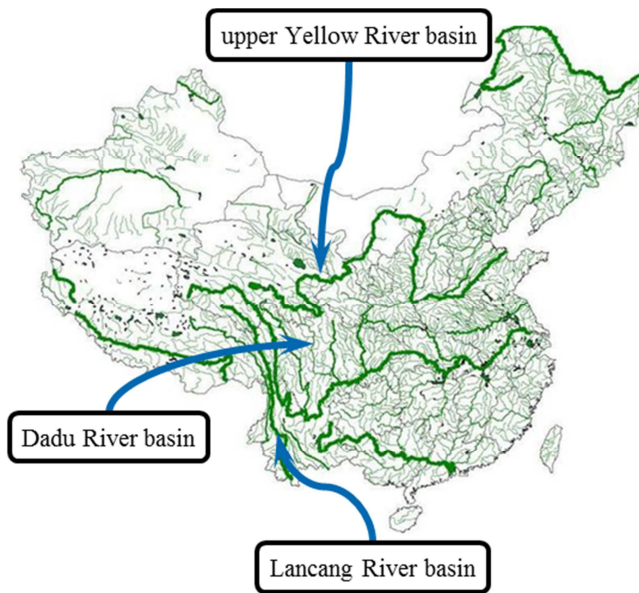


Figure 2. Location Map of Dadu River Basin, Upper Yellow River Basin and Lancang River Basin.

3.1. Dadu River Basin

The Dadu River originates from the southern foot of the Golog Mountains of Anyi Machen in Yushu Tibetan Autonomous Prefecture of Qinghai Province, with the Zumuzu River as its headwaters. The river flows through Aba County and meets the Suomo River and the Chuosijia River in Barkam County, and then the three rivers continue southwards as the Dajin Chuan. The Dajin Chuan flows through Jinchuan County and Danba County, and meets the Xiaojin Chuan in the east of Danba County and together become the Dadu River in name. The Dadu River continues flowing through Luding County and Shimian County until it turns east and flows through Hanyuan County and Ebian County, and finally empties into the Min River in the south of Leshan. The river has a total length of 1,062 km (including 852 km in Sichuan Province), and a natural drop of 4,175 m [8] (2,788 m in Sichuan Province). The Dadu River has an abundant theoretical potential of hydropower resources, with the total

installed capacity of planned cascades being 23,400 MW. Among 22 cascade reservoir and dam projects planned on the main stream of the Dadu River, there are a total of 17 earth-rockfill dams with the height greater than 100 m and the maximum dam height is up to 312 m. Meanwhile, a total of 11 hydropower stations have been completed and put into operation, and 5 are ongoing. Currently, hydropower stations completed and ongoing hydropower projects on the Dadu River are all located in Sichuan Province. With these hydropower stations completed, the flood control standards for towns distributed downstream of these hydropower stations have been improved. Meanwhile, these hydropower stations completed serve downstream city water supply and irrigation as well as economic development of reservoir area and downstream areas, creating enormous economic benefits.

Hydropower stations on the Dadu River have accident risks while yielding enormous social and economic benefits. For this reason, an emergency management organization has been set up in Sichuan Province and corresponding safety and emergency management systems have also been established for all of these hydropower stations.

3.1.1. Emergency Management Organization for Hydropower Stations in the Basin in Sichuan Province

To cope with earthquake, natural disasters, floods and other hazards, organization and command systems at all levels and their responsibilities (see Table 3 for details) have been clearly defined by *Earthquake Contingency Plan of Sichuan Province*, *Natural Disaster Relief Contingency Plan of Sichuan Province* and *Flood Control and Drought Relief Contingency Plan of Sichuan Province*. As clearly specified in the *Measures for the Safety Administration of Reservoir Dams in Sichuan* (Decree No. 223, 2008 of the People's Government of Sichuan Province), the people's governments at all levels and their flood control headquarters shall focus on the flood control and emergency rescue of Class II and III dams, and shall instruct competent departments and management agencies of reservoirs and dams to implement emergency measures for guaranteeing dam safety.

Table 3. Sichuan Provincial Emergency Organizations in charge of Treatment of Four Major Hazards (Earthquake, Geological Disasters, Flood and Dam Accident) and Corresponding Responsibilities.

Type of Sudden Incident	Emergency Organization and Command System	Responsibility
Earthquake	People's Government of Sichuan Province	Be responsible for the unified leadership of earthquake emergency response in the whole province.
	Sichuan Provincial Earthquake Relief Headquarters	Be responsible for the unified commanding, coordination and arrangement of earthquake emergency response in the whole province under the leadership of the People's Government of Sichuan Province, as well as day-to-day work of the office of Sichuan Provincial Earthquake Relief Headquarters, and emergency duty, information gathering and coordination in the period of earthquake emergency response.
Geological disaster	Sichuan Provincial Disaster Reduction Committee	Be responsible for organizing and leading the geological disaster relief work of the whole province, and coordinating extraordinarily serious and major geological disaster relief activities; contacting relevant departments and local governments to discuss about disaster evaluation and disaster relief, and coordinating the implementation of relevant supporting measures.
	Provincial Expert Board	The Expert Board of Sichuan Provincial Disaster Reduction Committee is responsible for providing policy consultation and suggestions on major decisions and important planning related to disaster mitigation and relief of the whole province, and providing advisory opinions for evaluation on major geological disasters, corresponding emergency rescue and post-disaster relief in Sichuan Province.

Type of Sudden Incident	Emergency Organization and Command System	Responsibility
Flood	Flood Control and Drought Relief Headquarters of the People's Government of Sichuan Province	Be responsible for drafting policies, regulations and systems concerning flood control and drought relief, and arranging for making flood control plans of major rivers as well as water transfer schemes for inter-city (autonomous prefecture) administrative divisions; keeping abreast of flood, drought and disaster situations of the whole province, and organizing the implementation of measures for flood control and emergency rescue as well as drought relief and disaster mitigation; regulating and controlling the water flow of water conservancy and hydropower facilities in the whole province in a unified manner; properly carrying out flood management, and organizing and properly coordinating remedial work.
	Flood control and drought relief headquarters of the local people's governments at different levels	All city-level (prefecture-level) and county-level (district-level/city-level) flood control and drought relief headquarters in the province are responsible for organizing and commanding flood control and drought relief within their own jurisdiction under the leadership of superior flood control and drought relief headquarters and the people's governments at related levels.
	Other flood control and drought relief headquarters	Management agencies and construction organizations of water conservancy projects in relevant basins shall set up corresponding specialized flood control and drought relief headquarters during flood season, to take charge of flood control and disaster relief work of the related basins and related departments. For major water conservancy and hydropower projects and large and medium-size enterprises required to undertake flood control and drought relief, corresponding flood control and drought relief headquarters shall be set up.
Sudden dam accidents	People's governments at different levels and their flood control headquarters	The people's governments at all levels and their flood control headquarters shall focus on the flood control and emergency rescue of Class II and III dams, and shall instruct competent departments and management agencies of reservoirs and dams to implement emergency measures for guaranteeing dam safety.

3.1.2. Analysis on Current Situations of Internal Safety and Emergency Management of Hydropower Stations

Relatively perfect internal emergency management systems have been established for hydropower stations completed for operation on the Dadu River [9], including:

- 1) Management systems and comprehensive contingency plans, special contingency plans and site disposal schemes have been formulated, and all of them meet the requirements for emergency management of reservoirs and dams of hydropower stations. Distribution maps of resettlement areas within the inundation zones of dam break floods, resettlement layout plans, resettlement plans and other attachments have been made available. Requirements have been clearly specified for warning and forecasting, emergency decisions, emergency response procedures, evacuation routes, shelters and emergency response measures.
- 2) According to special contingency plans, all hydropower stations have procured and stored necessary emergency rescue facilities, equipment, medicines, medical apparatus and instruments, and other materials and equipment, established site rescue equipment information database, and clearly specified the type, quantity, properties and storage position of these materials and equipment. All of these materials and equipment shall be maintained and used as per relevant provisions.
- 3) Full-time (part-time) emergency response teams have been established and shall be subjected to regular training and exercise of contingency plans.

In addition, a joint emergency response mechanism has been established between all hydropower stations and government departments at different levels, such that any Class I and II hazards can be timely and rapidly reported to provincial, city and county governments and relevant departments of Sichuan Province, and then governments at different levels can arrange for the people within their jurisdiction to give a joint emergency response.

In view of safety management, a dam safety monitoring mechanism has been established for each hydropower station, to monitor the following main items:

- a. Patrol inspection — mainly including patrol inspection for dam and dam foundation, rock mass in dam site area, near-dam reservoir banks and other parts.
- b. Monitoring of environmental variables — mainly including monitoring of upstream/downstream water level, reservoir water temperature, temperature and precipitation, carried out mainly by means of reservoir water thermometer, water gauge, staff gauge, simple meteorological station, and other instruments and equipment in front of dam.
- c. Deformation observation — mainly including observation of plane displacement, vertical displacement and tilt at such parts as dam and dam foundation, rock masses on both banks, main geological structural planes, and headrace and power generation system, carried out mainly by means of deformation control network, plumb line system, plane deformation observation point, valley width and chord line, rock displacement meter, multi-point displacement meter, leveling system, tension wire, GPS and other instruments and equipment in dam site area.
- d. Seepage monitoring — mainly including monitoring of uplift pressure, seepage pressure, seepage flow of dam foundation, groundwater table on both banks, and groundwater table on near-dam reservoir banks, and water quality analysis, carried out mainly by means of piezometer, osmometer, measuring weir, long-time observation hole of groundwater table, and other instruments and equipment.
- e. Stress-strain monitoring — It is mainly carried out for the stress-strain and temperature of dam and dam foundation as well as headrace and power generation system mainly by means of strain gauge group, zero stress-strain meter, reinforcement meter, plate strain meter, and other instruments and equipment.

- f. Vibration monitoring — mainly including earthquake monitoring and strong earthquake monitoring of structures, carried out mainly by means of seismograph.

To sum up, all hydropower stations have performed well in emergency management, since all of them have corresponding management systems and contingency plans meeting the requirements for safety and emergency management of reservoirs and dams of hydropower stations, and regularly conduct exercise. Moreover, all hydropower stations have been provided with emergency facilities and equipment as well as full-time (part-time) emergency response teams, have properly established a joint emergency response mechanism with governments at different levels, and have done a good job in dam safety monitoring.

3.1.3. Current Situations of Safety and Emergency Management of the Dadu River Basin

a. Government level

According to the *Opinions on Further Strengthening and Standardizing Hydropower Construction Management* (CFF [2016] No. 47) issued by the General Office of the People's Government of Sichuan Province in October 2016, "progress shall be made in integrated basin management" as required. The Energy Administration of Sichuan Province, as a provincial energy authority, is responsible for energy industry management and energy forecast & early warning of the whole province, issuance of energy information, tracking of energy operation and safety conditions, and participation in energy operation regulation and emergency guarantee. Currently, the Energy Administration of Sichuan Province is advancing the construction of safety and emergency management platform for cascade hydropower stations in the basin in Sichuan Province, to realize routine emergency management of the basin, and potential hazards management and emergency management of cascade hydropower stations in the basin.

b. Enterprise level

The hydropower stations on the main stream of the Dadu River, which have been completed and put into operation, are managed and operated by 5 enterprises. The development enterprise of hydropower stations on tributaries of the Dadu River is of more complex composition. Since cascade hydropower projects on the same river are developed by different employers and management organizations, challenges in overall consideration, coordination, cooperation and sharing have been presented to the basin management and emergency response.

Daduhe River-basin Hydro Power Development Co., Ltd. of CHN ENERGY (hereinafter referred to as "the company") is the owner of most hydropower stations in the basin and responsible for standard emergency management of these hydropower stations. The company's enterprise standards have stipulated unified requirements on emergency management of enterprise, requiring that all organizations shall establish an emergency response mechanism based on the principle of unified leadership, graded responsibility, territorial priority, rapid response and effective guarantee

measures. Meanwhile, the company has established full-time and part-time emergency response teams, and provided materials and equipment required by emergency response. All of these materials and equipment are subjected to regular maintenance to ensure normal operation. Moreover, the company has formulated general or special contingency plans applicable to the entire basin. According to the company's requirements, all organizations subordinated to the company shall formulate general and special contingency plans and site disposal schemes, timely revise contingency plans based on conclusions and evaluation of contingency plan management as per problems found during exercise and application of contingency plans, notify relevant departments and organizations of any revisions of contingency plans, and submit contingency plans to the company for filing. The company shall submit contingency plans to CHN ENERGY for filing.

In terms of flood control operation, Daduhe River-basin Hydro Power Development Co., Ltd. of CHN ENERGY has established a reservoir operation automation system [10]. All departments of the company can visit data of the reservoir operation automatic system through WEB, to share rain and water regimes and flood situations of the basin. As authorized by the company, the Shawan Hydropower Station, located downstream of the Tongjiezi Hydropower Station, can be accessible to real-time reservoir outflow data of the Tongjiezi Hydropower Station through WEB, and other hydropower stations in the basin can share water regimes through telephone. With short message platform and on-call system established by the company, the company's centralized control center can transmit such information as rain regimes and flood situations to the company's relevant personnel at different levels through short messages, thereby realizing information sharing. The company's centralized control center can perform joint optimal operation of cascade reservoirs, remote operation of spillway facilities and remote power generation control for hydropower stations which have been put into operation [11]. The company is responsible for flood control operation in general, while Sichuan Provincial Flood Control and Drought Relief Headquarters is responsible for flood control operation if it is required to undertake flood control of the Dadu River basin, with a corresponding report presented to the Yangtze River Flood Control and Drought Relief Headquarters for filing. If it is required to coordinate with the Three Gorges Reservoir to undertake the flood control at middle and lower reaches of the Yangtze River, the Yangtze River Flood Control and Drought Relief Headquarters is responsible for flood control operation.

3.2. Upper Yellow River Basin

Hekou Town in Togtoh County of Inner Mongolia is the boundary point between the upper and middle reaches of the Yellow River basin. The upper reaches are 3,472 km long in total, with the catchment area accounts for 51.3% of the total catchment area of the Yellow River. The upper reaches of the Yellow River are subdivided into three parts according to different channel characteristics: headwaters, valley reaches

and alluvial plain. Hydropower stations mentioned in this paper are mainly distributed on the upper reaches of the Yellow River from the Longyang Gorge in Qinghai Province to Liujia Gorge in Gansu. The main stream of the Yellow River along these reaches are 425 km long (including 105 km long reaches on which the Longyangxia Reservoir is located), and the total drop is 869 m. A total of 14 hydropower stations planned and completed are located on these reaches, with 11 hydropower stations are located in Qinghai Province and 3 in Gansu Province.

Agencies engaged in safety and emergency management of the basin include: Yellow River Flood Control and Drought Relief Headquarters, and Qinghai provincial and Gansu provincial basin emergency management agencies.

3.2.1. Yellow River Flood Control and Drought Relief Headquarters

The Yellow River Flood Control and Drought Relief Headquarters (hereinafter referred to "YRFDH") was established in 2007 upon the approval of the State Flood Control and Drought Relief Headquarters (SFDH), to extend the range of flood control of YRFDH to the upper reaches. YRFDH is composed of provincial governments of Qinghai, Gansu, Ningxia, Inner Mongolia, Shanxi, Shaanxi, Henan and Shandong, as well as Beijing, Lanzhou and Jinan Military Regions, and has an additional function in drought relief. For the river reaches directly under the jurisdiction of YRFDH, the flood control management is mainly performed by operating departments at different levels along the Yellow River. The emergency capacity building for flood control is completely based on state investment.

Currently, the flood control and drought relief management of the Yellow River basin is performed under the leadership of YRFDH through combination of regional management by local flood control and drought relief headquarters and specialized management of the Yellow River. The General Office of YRFDH is set up in the Yellow River Conservancy Commission, to take responsibility for flood control management of the Yellow River, flood control operation of major water conservancy projects and flood control command of the basin. Flood control agencies of the Yellow River at different levels are responsible for day-to-day flood control management of river reaches within their own jurisdiction.

3.2.2. Emergency Management Organization System of Qinghai Province

Relevant laws of Qinghai Province have stipulated requirements on the emergency management organization system of Qinghai Province. According to the *Earthquake Contingency Plan of Qinghai Province*, the People's Government of Qinghai Province shall be the responsibility subject of extraordinarily serious and major earthquake disasters occurring in Qinghai Province, while the prefecture-level (city-level) and county-level (city-level, district-level and administrative committee-level) people's governments shall respectively be the responsibility subjects of relatively big and ordinary earthquake disasters occurring in their own administrative divisions. According to earthquake

emergency response demands of prefecture-level (city-level) and county-level (city-level, district-level and administrative committee-level) people's governments in disaster-hit areas, the provincial government shall provide necessary coordination and support. In case of earthquake disasters, the provincial earthquake prevention and disaster mitigation leading team, which is responsible for leading and commanding earthquake prevention and disaster mitigation at ordinary times, serves as the provincial earthquake relief headquarters upon the approval of leaders of the provincial government, with the leaders of the provincial government as commanders responsible for unified leadership.

The *Natural Disaster Relief Contingency Plan of Qinghai Province* clearly specifies that the Qinghai Provincial Disaster Reduction Committee shall serve as the general emergency coordination agency for the natural disaster relief under the unified leadership of the provincial government, to take responsibility for organizing and guiding natural disaster relief of the whole province, and coordinating with China National Commission for Disaster Reduction to carry out relief activities in case of extraordinarily serious and major natural disasters. The Qinghai Provincial Disaster Reduction Committee shall, under the unified leadership of the CPC Qinghai Provincial Committee and the People's Government of Qinghai Province, carry out day-to-day work as per concrete guidance of the Qinghai Provincial Emergency Management Commission of Public Emergencies.

According to the *Flood Control Contingency Plan of Qinghai Province*, the provincial people's government shall set up provincial flood control and drought relief headquarters, and the local people's governments above county level shall also set up flood control and drought relief headquarters at corresponding levels, to take responsibility for flood control as well as flash flood emergency management and treatment within their own administration divisions. Meanwhile, relevant organizations and engineering management departments may, as required, set up flood control headquarters, to take responsibility for flood control as well as flash flood emergency management and treatment within their own jurisdiction.

3.2.3. Emergency Management Organization System of Gansu Province

Relevant laws of Gansu Province have also stipulated requirements on the emergency management organization system of Gansu Province. According to the *Earthquake Contingency Plan of Gansu Province*, in case of an earthquake, the provincial earthquake prevention and disaster mitigation leading team shall serve as the provincial earthquake relief headquarters, to lead, command and coordinate the earthquake relief work of the whole province in a unified manner. A main leader or a leader in charge of the provincial government shall act as the commander-in-chief of the headquarters. The general office of the provincial earthquake relief headquarters is set up in the Earthquake Administration of Gansu Province, to take responsibility for emergency rescue, guarantee of basic living conditions of people afflicted by natural disasters,

medical treatment, health and epidemic prevention, infrastructure support and production restoration, earthquake monitoring, prevention and treatment of secondary disasters, public security, disaster relief donation, handling of foreign affairs and Hong Kong, Macao and Taiwan-related affairs, earthquake disaster investigation and disaster loss assessment, and information issuance, publicity and reporting.

According to the *Natural Disaster Relief Contingency Plan of Gansu Province*, the Gansu Provincial Disaster Reduction Committee shall serve as the general emergency coordination agency for the natural disaster relief of the whole province, to take responsibility for coordinating and carrying out emergency response to natural disasters, emergency rescue, living arrangement of people afflicted by natural disasters, and post-disaster rehabilitation and reconstruction, as well as guiding local governments to carry out mitigation work. The vice-governor in charge shall be the director of the Gansu Provincial Disaster Reduction Committee of which the general office is set up in the Department of Gansu Provincial Civil Affairs. All members of the committee shall undertake corresponding tasks according to the assignment of responsibility.

According to the *Flood Control and Drought Relief Contingency Plan of Gansu Province*, a provincial drought relief emergency headquarters shall be established and co-located with the provincial flood control and drought relief headquarters. The vice-governor in charge shall act as the Commander-in-chief, the Deputy Secretary General of the provincial government, the Director-general of Gansu Water Conservancy Department, the Deputy Chief of Staff of Gansu Provincial Military Region and the Deputy Director-general of Gansu Water Conservancy Department as the deputy commanders. Members of the headquarters include: Gansu Provincial Military Region, Gansu General Division of Chinese People's Armed Police Force, Publicity Department of Gansu Provincial Party Committee, Gansu Water Conservancy Department, Gansu Provincial Development and Reform Commission, Gansu Economic Commission, Gansu Finance Department, Gansu Department of Civil Affairs, Gansu Department of Agriculture and Animal Husbandry, Gansu Commerce Department, Gansu Department of Public Security, Gansu Construction Department, Gansu Traffic Department, Gansu Public Health Department, Gansu Radio and Television Bureau, Gansu Poverty Alleviation Office, Gansu Provincial Meteorological Bureau, Gansu Price Bureau, Gansu Communication Administration, Gansu Supply and Marketing Cooperatives, Gansu Electric Power Company of SGCC, China Railway Lanzhou Bureau Group Co., Ltd. and other relevant departments. The provincial emergency headquarters is responsible for drought relief emergency response work of the whole province, considering and deciding major issues concerning drought relief emergency response, coordinate solutions to emergency funding required by drought relief and mitigation, supervise the implementation of responsibilities of headquarters' members, and making a unified arrangement for publicity of drought relief emergency response.

3.2.4. Current Situations of Safety and Emergency Management of the Upper Yellow River Basin from Longyang Gorge to Liujia Gorge

1) Government-level safety and emergency management of the basin

In recent years, the General Office of YRFDH has formulated the *Scheme for Joint Flood Control Operation of Longyangxia Reservoir and Liujiaxia Reservoir*. The joint flood control operation situations of Longyangxia Reservoir and Liujiaxia Reservoir in 2015 and 2016 are described below.

a. Operation scheme

- i. Longyangxia Reservoir: The flood season of the Longyangxia Reservoir is from July 1 to September 30. Considering the flood control safety of ongoing projects and the river channel downstream of the reservoir, the reservoir level is maintained at the flood control level in flood season, and can, from September 1, change to the design flood control level according to reservoir inflow and use of impounded reservoir water, and can, from September 16, change to the normal pool level.
- ii. Liujiaxia Reservoir: The flood season of the Liujiaxia Reservoir is from July 1 to September 30 during which the reservoir level is maintained at the flood control level. The reservoir level can, from September 16, change to the normal pool level according to reservoir inflow and use of impounded reservoir water.

b. Flood regulation principles

- i. General principles: In case of a flood within the range of design standard, the Longyangxia Reservoir and the Liujiaxia Reservoir are in joint operation, to jointly undertake flood control of all protected objects. With the storage below the design flood control level, the Longyangxia Reservoir operates to ensure the flood control safety of ongoing projects as well as river reaches in Qinghai, Gansu, Ningxia and Inner Mongolia. According to requirements, the outflow discharge of the Longyangxia Reservoir shall meet the requirements for flood control of protected objects along the river reaches between the Longyangxia Reservoir and the Liujiaxia Reservoir, and shall ensure the maximum water level of the Liujiaxia Reservoir will not exceed the design value in case of floods at different frequencies. Meanwhile, the outflow discharge of the Liujiaxia Reservoir shall be controlled as per the requirements for flood control of protected objects downstream of the Liujiaxia Reservoir. The outflow discharge of both the Longyangxia Reservoir and the Liujiaxia Reservoir shall not be greater than the control outflow discharge in case of floods at different frequencies, and the maximum outflow discharge of flood recession limb shall not be greater than the peak discharge shown in the flood hydrograph. In case of a flood above the design standard, relevant flood control projects shall function fully, and all necessary measures shall be taken to mitigate disaster losses.

- ii. Operation principles of the Longyangxia Reservoir: (a) The reservoir level and the reservoir inflow are considered as outflow discharge criteria; (b) if the reservoir level is lower than the flood control level, the reservoir is used for flood detention in a rational way, and then discharges water as per power generation requirements on the premise of meeting the requirements for flood control of downstream protected objects; (c) if the reservoir level is at the flood control level, both the Longyangxia Reservoir and the Liujiaxia Reservoir are simultaneously used for flood detention and discharge according to certain flood storage ratio, to meet the requirements for flood control of downstream protected objects; (d) considering that the Longyangxia Reservoir has been qualified for operation at the design flood control level, when the reservoir level is at the flood control level and lower than the design flood control level in July and August, the reservoir operation can be strengthened in real time according to reservoir inflow, inflow of the river reaches between the Longyangxia Reservoir and the Liujiaxia Reservoir as well as conditions of the downstream river channel.
- iii. Operation principles of the Liujiaxia Reservoir: (a) The natural reservoir inflow and the total flood storage of both the Longyangxia Reservoir and the Liujiaxia Reservoir are considered as outflow discharge criteria; (b) the outflow discharge of the Liujiaxia Reservoir shall meet the requirements for flood control of downstream protected objects.

2) Enterprise-level safety and emergency management of the basin

Hydropower stations which have been completed and put into operation on the main stream of the upper Yellow River reaches are managed and operated by 4 enterprises. As a result, there are also problems concerning coordination of integrated safety and emergency management of hydropower stations in the basin.

Huanghe Hydropower Development Co., Ltd. is the owner of most hydropower stations in the basin. It performs standardized emergency management for its 7 hydropower stations and has proposed unified management requirements [12]. The company has established the "water regime information inquiry and consultation system of the Yellow River" through cooperation with the Hydrology Bureau of Yellow River Conservancy Commission, to share hydrological and meteorological information of the basin as well as inflow, outflow and impoundment of reservoirs in the basin through the system [13]. Moreover, the company has also established the "specialized meteorological service network for hydropower projects on upper Yellow River reaches in Qinghai Province", to provide the following information services: daily rain regime report (daily precipitation data of each meteorological station), short-range weather forecast, 7d precipitation forecast, major weather warning, important weather information, lightning forecast, weather forecast for a period of ten days, long-term (monthly, quarterly, annual) climate forecast, and climate

forecast in flood season. In this way, unified supervision and control can be realized for water regimes and meteorological conditions in the basin.

The company's production dispatching center is responsible for unified flood regulation. All hydropower stations have their own hydrological telemetry and forecasting systems which can transmit real-time water level data to the production dispatching center for unified dispatching.

3.3. Lancang River Basin

Lancang River is one of the 14 largest hydropower bases in China and has experienced site survey and identification through several parties over the years. The upper reaches of the Lancang River in Tibet from Qamdo to Gushui are 317 km long in total and planned to be developed as per "one reservoir and seven cascades"; the upper reaches in Yunnan from Gushui to Miaowei are 447 km long and planned to be developed as per "one cascade and eight cascades" [14]. The upper reaches of the Lancang River are mainly developed for power generation, with due consideration given to tourism, environmental protection and other comprehensive benefits. Huaneng Lancang River Hydropower Co., Ltd. is responsible for unified development of the entire river reaches.

Hydropower stations in the Lancang River basin are basically under unified management of Huaneng Lancang River Hydropower Co., Ltd., facilitating safety management of the Lancang River basin. The company has formulated a group-level comprehensive contingency plan. It performs standardized emergency management for all of its hydropower stations and has proposed unified management requirements.

Huaneng Lancang River Hydropower Co., Ltd. has established a centralized control center in Kunming which is equipped with main system equipment like computer supervision and control, reservoir operation and communication equipment. As a reservoir operation center, the centralized control center has realized hydrological forecast and joint optimized operation of reservoir in the basin, and has continuously strengthened centralized reservoir operation management and cascade optimization. Currently, 180 hydrological forecast stations have been built in the basin [15], and centralized reservoir operation management has been realized through the hydrological telemetry and forecasting system of the Lancang River basin. In view of hydrological forecast capability, the centralized control center can forecast flood of the main stream for a period of about 56 h. Moreover, a large hydrological telemetry and forecasting system has been established, and its size is only next to that of the Three Gorges.

The Mekong River downstream of the Lancang River flows through Laos, Myanmar, Thailand, Cambodia and Vietnam, so there are issues about safety and emergency management of international basin. The General Office of SFDH is responsible for unified communication with the governments of the countries where the Lancang River-Mekong River basin is located. In March 2016, the Mekong Delta in the south of Vietnam was hit by the worst drought in 100 years. At the request of Socialist Republic of Vietnam, China launched an emergency water regulation scheme for cascade hydropower stations on the

Lancang River, to mitigate the severe drought in the Mekong River basin. Meanwhile, the Yunnan Provincial Flood Control and Drought Relief Headquarters established a communication and coordination team in charge of emergency water regulation for cascade hydropower stations on the Lancang River, convened special meetings and issued emergency notices to supervise and guide relevant local government and organizations to take concrete measures. In addition, China Southern Power Grid Co., Ltd., China Huaneng Group Co., Ltd. and other organizations also immediately formulated specific emergency operation schemes to guarantee smooth emergency water regulation for cascade hydropower stations on the Lancang River, realizing mutual cooperation about water resource regulation of the Lancang River - Mekong River.

4. Main Characteristics of Safety and Emergency Management of Hydropower Projects in China

Through summary of and analysis for regulations and standards and organizations related to safety and emergency management of hydropower projects in China, in combination with investigation and research on current situations of safety and emergency management of hydropower stations in typical basins in China, it is thus clear that China, as a country with the largest installed capacity in the world, has attached great importance to the safety and emergency management of hydropower projects and has formed a systematic management mechanism. To be specific, there are the following characteristics:

4.1. Comprehensive and Detailed Regulations and Standards

The comprehensiveness of regulations and standards are presented in five aspects: (1) Covering the full life circle (including planning, design, construction, acceptance and operation stages) of hydropower projects; (2) Applicable to various types of hydropower projects, like those of different grades and those with different power generation modes; (3) Covering all parts (like water retaining structures, flood discharge structures and hydraulic steel structures) of hydropower projects, as well as various types of disaster-inducing factors, like earthquake, flood and geological disasters; (4) Covering all aspects related to safety and emergency management, like monitoring, early warning and preparation of contingency plans; (5) there is a complete framework of regulations and standards, which is well arranged and extended level by level from central government to local governments and from basic principles to concrete measures.

In addition to comprehensiveness, Chinese regulations and standards about safety and emergency management of hydropower projects are also quite detailed and of high practicality, and stipulate concrete provisions on many details. For example, the *Code for Design of Occupational Safety and Health of Water Resources and Hydropower Projects* (NB 35074-2015) stipulate quite detailed provisions on setting

places and types of safety signs.

Owing to these comprehensive and detailed properties, a huge system of regulations and standards related to safety and emergency management of hydropower projects in China has been formed. It can be seen from the current situations of safety and emergency management of hydropower stations in typical basins in China that these regulations and standards can, owing to their comprehensive and detailed properties to a great extent, provide support for the management work of local governments and basin management agencies.

4.2. Broad Responsibilities and Significant Roles of Governments and Their Subordinate Bodies

China is a socialist country, where government functions can be given full play. According to 1.2 of this paper, in addition to hydropower enterprises, governments or their subordinate bodies also serve as safety and emergency management agencies of hydropower projects in China, to play their role in multi-level supervision and management, i.e. comprehensive basin supervision and management and specific local supervision and management. According to the current situations of safety and emergency management in the three typical basins (Dadu River basin, upper Yellow River basin and Lancang River basin), government departments not only shoulder responsibilities of safety supervision and management, but also play a crucial role in commanding emergency management of floods, earthquakes and other emergencies in the basin.

4.3. Basin-Based Safety and Emergency Management

According to the current situations of safety and emergency management in the three typical basins (Dadu River basin, upper Yellow River basin and Lancang River basin), the safety and emergency management of hydropower projects in intra-provincial, inter-provincial and international basins tend to be based on basin. In terms of laws and regulations, the "Notice of the National Development and Reform Commission on Strengthening Basin Hydropower Management" (FGNY [2016] No. 280), issued by the National Development and Reform Commission in February 2016, has further strengthened safety and emergency management of hydropower projects in basins. In terms of management agencies, China has set up basin management agencies in the seven major basins, to take responsibility for safety and emergency management of hydropower projects in these basins. Currently, part of river basin hydropower enterprises in China have carried out research on safety and emergency management of their own cascade hydropower projects in basins, like Qinghai Huanghe Hydropower Development Co., Ltd. responsible for development in the upper Yellow River basin, Daduhe River-basin Hydro Power Development Co., Ltd. of CHN ENERGY responsible for development in the Dadu River basin, and Huaneng Lancang River Hydropower Co., Ltd. responsible for development in the Lancang River basin. Most of these river basin hydropower enterprises have established centralized control centers responsible for unified

management of their own hydropower stations, including safety and emergency management.

The safety and emergency management of hydropower projects in basins involves many organizations, including project operators, employers, Large Dam Safety Supervision Center, National Energy Administration, basin management agencies, State Administration of Work Safety, the Ministry of Transport, the Ministry of Ecology and Environment, the Ministry of Land and Resources and the Commission of Work Safety of the State Council. Moreover, the safety and emergency management of hydropower projects on international rivers also involve cross-border issues. Therefore, the focus and key point of safety and emergency management of hydropower projects in basins are how to coordinate, organize and manage the authorities, responsibilities and benefits of all organizations as a whole, to cope with chains of frequent and compound extraordinarily serious and major disasters, thereby realizing comprehensive disaster mitigation in these basins. Currently, China has established the Ministry of Emergency Management. In this way, whole-process and all-round management for all types of disasters can be realized to a great extent, and the public security guarantee capability can be strengthened. The establishment of the Ministry of Emergency Management can promote further exploration of comprehensive emergency management mode of China, and can improve the safety and emergency management level of hydropower projects in basins.

5. Conclusions

This paper summarizes regulations and standards and organizations related to safety and emergency management of hydropower projects in China, describes the current situations of safety and emergency management of hydropower projects in China in intra-provincial, inter-provincial and international basins represented by the Dadu River basin, the upper Yellow River basin and the Lancang River basin, and further summarizes and analyzes three major characteristics of safety and emergency management of hydropower projects in China at the current stage. A safety and emergency management system of hydropower projects in China has been formed as a whole. Since China has paid more attention to public security, it can be anticipated that the safety and emergency management of hydropower projects will gradually become a key point in the development of hydropower projects in China and will, therefore, become a hot research topic in the industry. Since a large number of researches go on, there will be more perfect safety and emergency management system and mechanism of hydropower projects in China.

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