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A Technical Review of Hydro-Project Development in China

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ABSTRACT

This paper summarizes the development of hydro-projects in China, blended with an international perspective. It expounds major technical progress toward ensuring the safe construction of high dams and river harnessing, and covers the theorization of uneven non-equilibrium sediment transport, inter-basin water diversion, giant hydro-generator units, pumped storage power stations, underground caverns, ecological protection, and so on.

1. The development of hydro-projects in China and a comparison with projects abroad

China is no stranger to recurrent floods and droughts. In the two millennia prior to1949, China suffered from a total of 1092 floods and 1056 droughts. In 1920, a severe drought in North China starved more than 500 000 people to death; in 1931, the Yangtze River flood rendered a death toll of 145 000 people. Since 1949, China has built numerous dams, inter-basin water diversion projects, pumped storage power stations, and more, in a bid to ensure flood control and water supply, and to increase the proportion of non-fossil energy sources. Water disasters now cost less than 2% of China's gross domestic product (GDP).

A dam is the most important indicator of water conservancy and hydropower development. While history does not record the construction of the earliest dam, it is acknowledged that China, India, Iran, and Egypt are the pioneer countries of dam construction. Records indicate that only three dams higher than 30 m existed before *anno Domini* (AD) 1000, among which the highest was the Fushan Weir earth dam in China (48 m in height). Before 1900, there were only 31 dams higher than 30 m, among which the highest was the Gouffre d'Enfer masonry gravity-arch dam in France (60 m in height).

The worldwide drive to build water conservancy and hydropower projects began around 1900. For its part, China went through four stages with this endeavor. In the first stage, from 1900 to 1949, China possessed only 21 dams higher than 30 m, with a total storage capacity of about 2.8×10^{10} m^3 and a total installed hydropower capacity of 540 MW. Water disasters remained a mortal malady, only varying in their severity based on the quantity of rainfall causing them. Technologies to combat water hazards were meager. In the second stage, from 1949 (when the People's Republic of China was founded) to 1978 (when China's reform and opening up began), China was the most active country in the world in building reservoirs and dams. The number of dams higher than 30 m increased from 21 to 3651, the total storage capacity increased to about 2.989×10^{11} m^3, and the total installed hydropower capacity increased to about 18 670 MW. These dams were constructed mainly for the purposes of flood control and irrigation. Despite these great achievements, China still lagged behind developed countries due to a lack of technology, investment, and similar aids. The third stage, from 1978 to 2000, was marked by the completion of huge dams such as the Ertan Dam. China achieved qualitative breakthroughs in water conservancy and hydropower development, and leaped from its former position as a late and weak arrival in the field to a new position as an internationally leading country in many aspects. Many projects stood the test of the major Yangtze River flood in

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1998 and the great Wenchuan earthquake in 2008. Projects constructed during this stage were characterized by quality design, speedy construction, and stringent safety, and generally fulfilled their purposes. In the 21st century, China entered the fourth stage of indigenous innovation and pioneering development, marked by the operation of the Three Gorges Project and the South-to-North Water Diversion Project. With the successive completion of Xiaowan, Longtan, Shuibuya, Jinping I, and other projects, China rewrote world records again and again. China began to pay more attention to the safety of mega projects and super-high dams, as well as to ecological protection. From a global perspective, China has marched fully into the international market, and now occupies over half of it.

As of 2014, China has built more than 98 000 reservoirs with a total storage capacity of 8.166×10^{11} m^3, accounting for 29% of the annual runoff of all rivers and streams in China. China's effectively irrigated farmland has reached up to 6.9×10^7 hm^2, accounting for 23% of global farmland; 6539 dams over 30 m high have been completed or are under construction, accounting for 43% of all such dams worldwide; total installed hydropower capacity has exceeded 300 GW, accounting for 27% of such capacity worldwide; the total installed hydropower capacity of pumped storage power stations has reached 22 110 MW, accounting for 12% of such capacity worldwide; the length of water delivery trunk canal has exceeded 13 800 km, and the length of hydraulic tunnel is over 10 000 km. China arguably owns the largest number of reservoirs and dams, the greatest farmland irrigation area, the biggest installed hydropower capacity, and the longest water diversion route in the world. Figs. 1 and 2 and Tables 1–3 provide international comparisons [1].

China owns the most water conservancy and hydropower projects in the world, and implements the strictest water resource management policies, under which water resources bearing capacity must be factored into the planning of cities and their industrial development. Nonetheless, project construction is still necessary, considering China's large population and uneven distribution of water resources in time and space. Figs. 3 and 4 compare the correlation between the degree of water resources development and the human development index (HDI), based on the data for 100 countries. The HDI is an important index for measuring comprehensive national strength. It can be concluded that developed countries generally achieve high HDI (involving life expectancy, educational level, and per capita GDP) and correspondingly command a high level of water resources development. In 2014, when the HDI in China was 0.727, China had developed 52% of its hydropower resources and its storage capacity per capita reached 600 m^3, basically approximating the indexes of relatively developed developing countries. It is clearly demonstrated that the development of reservoirs and hydropower projects in China is in line with the national economic and social growth on the whole.

2. Technologies for guaranteeing safety of high dams

The development of rockfill dams, gravity dams, arch dams, and cemented material dams in China has been elaborated in the literature [1–5]. Safety is treated as paramount when it comes to high dams, and various new technologies have been developed.

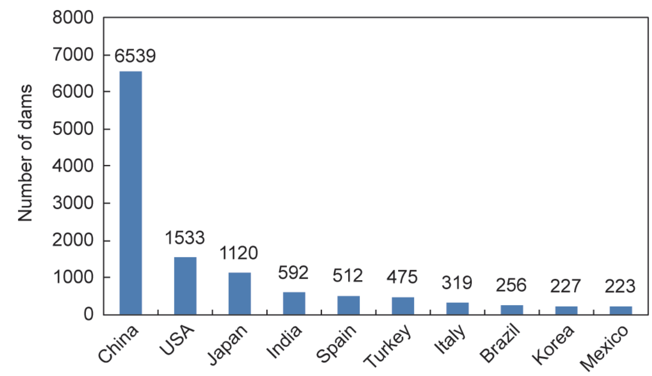

Fig. 1. Numbers of dams higher than 30 m in major countries.

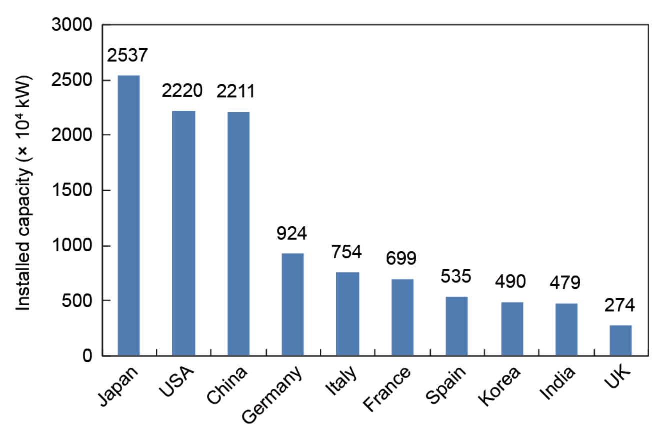

Fig. 2. Installed hydropower capacities of pumped storage stations in major countries.

Table 1
Top 10 highest dams in the world.

Rank	Dam name	Country	Dam type	Dam height (m)	Total storage capacity ($\times 10^8$ m^3)	Installed capacity (MW)	Year of completion
1	Jinping I	China	Arch dam	305.0	79.88	3 600	2014
2	Nurek	Tajikistan	Earth-rock dam	300.0	105.00	2 700	1980
3	Xiaowan	China	Arch dam	294.5	150.00	4 200	2012
4	Xiluodu	China	Arch dam	285.5	126.70	13 860	2015
5	Grande Dixence	Switzerland	Gravity dam	285.0	4.00	2 069	1962
6	Kambarata-I	Kyrgyzstan	Earth-rock dam	275.0	36.00	1 900	1996
7	Inguri	Georgia	Arch dam	271.5	11.00	1 320	1980
8	Vajont	Italy	Arch dam	262.0	1.69	—	1961
9	Nuozhadu	China	Earth-rock dam	261.5	237.03	5 850	2015
10	Chicoasén	Mexico	Earth-rock dam	261.0	16.80	2 430	1981