Electronic Supplementary Materials

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Thermal anti-cracking safety control for concrete dams

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Table S1 Main parameters of low- and medium-heat Portland cement concrete (GB/T 200; Li et al., 2017)

No.	Mineral and chemical composition	Low-heat Portland cement			Characteristics of hydraulic concrete	Medium-heat Portland cement	
		Enterprise standards of CTG[a)]	Chinese national standards (GB/T 200)	American national standards		Enterprise standards of CTG (CTG·PC·XILD01)	Chinese National Standards (GB/T 200)
1	Tricalcium silicate C_3S (%)	(30%~40%)	--	--		≤55	≤55
2	Dicalcium silicate C_2S (%)	≥40 (40% ~ 50%)	≥40	≥40		--	--
3	Tricalcium aluminate C_3A (%)	≤4.0 (3%)	≤6.0	≤7.0	Limit the early heat release	≤4.0	≤6.0
4	Tetracalcium ferric aluminate C_4AF (%)	≥15 (15%~19%)	--	--	Improve bending strength and abrasion resistance	≥15	--
5	Free calcium oxide f-CaO (%)	≤0.8	≤1.0	--		≤1.0	≤1.0
6	Magnesium oxide MgO (%)	4.0~5.0	≤5.0	≤6.0	Compensation for shrinkage deformation caused by temperature drop	4.2~5.0 (Actual control 4.5±0.3)	≤5.0
7	specific surface area (m^2/kg)	250~340	≥250	≥280	Limit the early heat release	≤320	≥250
8	Alkali content Na_2Oeq (%)	≤0.55	≤0.60	≤0.60		≤0.55	≤0.60
9	28d compressive strength (MPa)	47±3.5	≥42.5	≥17.0	Guarantee strength stability	49±3.5	≥42.5
10	28d flexural strength (MPa)	≥7.0	≥6.5	--		≥7.5	≥6.5
11	Heat of hydration (kJ/kg), 3 d	≤220	≤230	--	Control the value and rate of early heat release	≤241	≤251
	7 d	≤250	≤260	≤250		≤283	≤293
	28 d	≤300	≤310	≤290		Actual 334	--

Note: CTG: China Three Gorges Corporation

Table S2 Anti-cracking safety control scheme and effect for cascade hydropower stations in lower reaches of Jinsha River

Engineering	The anti-cracking safety control scheme				Application effectiveness	
	Concrete materials	Progress control	Temperature control	Digital management	Field test	Site survey
Xiluodu (Concrete arch dam, height 285.5 m, installed capacity 13860 MW)	Hydraulic medium heat Portland cement with high internal magnesium oxide + concrete mixed with PVA fiber in the strongly constrained region and block surface with long interval + efficient admixture + concrete mixed with first-class fly ash.	Coupling simulation analysis of progress, temperature, and working behaviour, optimization of interval based on anti-cracking safety, intelligent control of the concrete pouring process, and dam shape control.	Innovation and application of intelligent cooling control system; Pre-cooling concrete; Timely insulation in different regions; The full dam is treated as a constraint area for thermal anti-cracking control; Spatio-temporal temperature coordinated control.	Development and application of basic modules intelligent construction management platform.	Max temperature compliance rate≥90% Temperature variation compliance rate≥96%	No thermal cracks were found in the main structure of the dam. The world's longest normal concrete core sample was taken out from the Baihetan Dam, with a length of 36.74 m
Wudongde (Concrete arch dam, height 270 m, installed capacity 10200 MW)	Hydraulic low-heat Portland cement + efficient admixture + concrete mixed with first-class fly ash.		Upgrade and full application of intelligent cooling control system; Development of intelligent spray, curing, thermal insulation, etc; Temperature control strategy of small gradient, slow cooling, and accurate control; Spatio-temporal evolution process control of dam temperature.	Upgrade and full application of intelligent construction management platform.	Max temperature compliance rate≥99% Temperature variation compliance rate≥98%	
Baihetan (Concrete arch dam, height 289m, installed capacity 16000 MW)					Max temperature compliance rate≥97% Temperature variation compliance rate≥98%	

Section S1

The Xiluodu double curvature arch dam is 285.5-m high (Fig. S1). The construction officially commenced at the end of December 2005. During the construction process, it was discovered that the geological conditions of the riverbed would affect the construction period by 9.5 months. To reduce the progress delay, quality, and safety risks caused, actions were taken, including deepening the design of the dam foundation structure, reasonable image control for tiding over the flood, optimization and adjustment of the progress control standards for continuity and proportionality, and comprehensive application of the temperature control measures of the intelligent cooling control system. On the premise of no concrete thermal cracks and the structural safety of the dam, the goal of reservoir impoundment and commissioning was achieved in 2013, laying a solid foundation for the long-term safe and stable operation of the hydropower station.

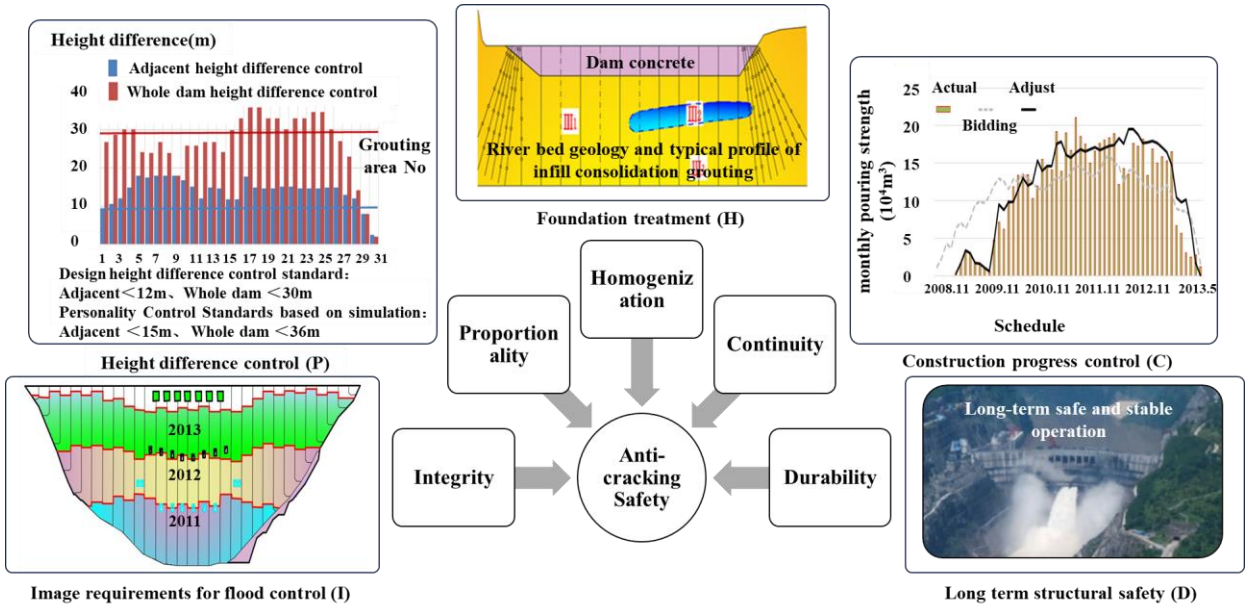

Fig. S1 Key characteristics of Xiluodu concrete arch dam during dam construction