

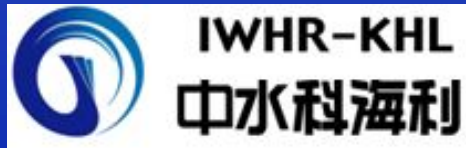
# RCC Dam and Its Main Technical Concerns



中国水利水电科学研究院  
China Institute of Water Resources and Hydropower Research



Yue Yuezhen    Chen Gaixun



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# Development of RCC In China

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- ❑ In 1978, China began to study RCC Technology in laboratory. In the next years, a series of experimental researches and field-tests had been conducted.
- ❑ 1981, carried out section test at highway of Tongjiezi hydropower station, 1983 at Xiamen airport parking apron.
- ❑ 1983, placed 20000m<sup>3</sup> high volume fly ash RCC at Shaxikou hydropower station in Fujian province, the RCC contained 68 kg/m<sup>3</sup> cement and 107 kg/m<sup>3</sup> fly ash (61%).

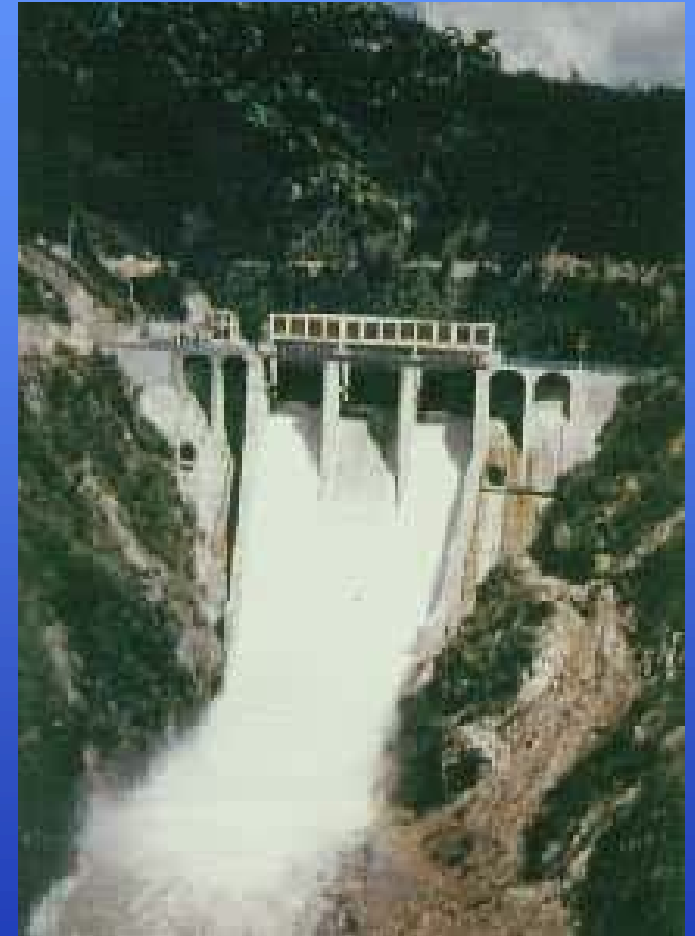




# Development of RCC In China



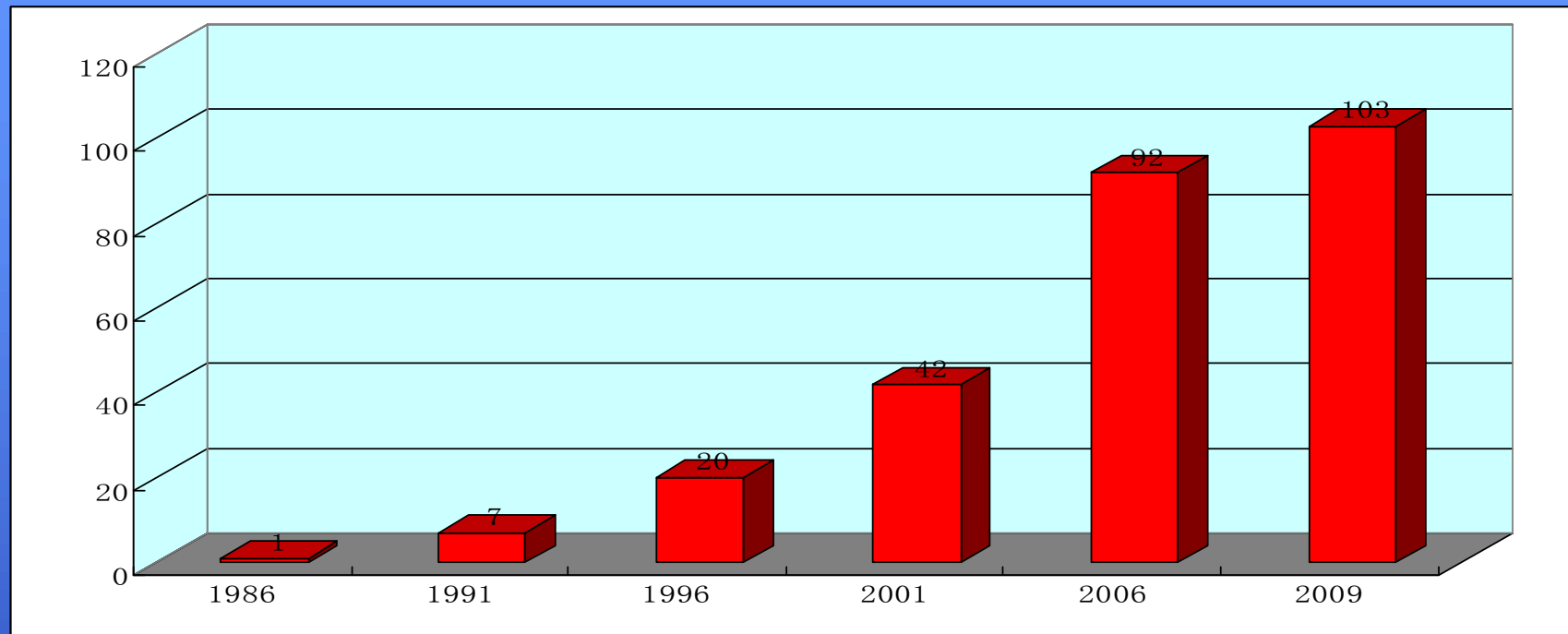
- ❑ 1985, started to build the first RCC dam, Kengkou RCC gravity dam (56.8m) in Fujian province, and completed within nearly six months in 1986.
- ❑ The success at Kengkou realized a new approach of concrete dam construction in China and established the direction and tendency of RCC dam Technology in China:
  - ❑ RCC mix with high content of fly ash, low cement content
  - ❑ Placing on large area continuously and compacting in thin layer
- ❑ Since 1986, the RCC dam Technology has achieved rapid and continual development in China.



# Development of RCC In China



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□ Up to now, China has completed more than 100 RCC dams. Among them, more than 20 dams are arch dam.

□ Another 30 RCC dams are under construction .

# The Records and Innovations

- Nowadays, China has been becoming one of the leading country in RCC dam technology around the world, not only in the number and the size of RCC Dams, but also in the records and innovations.
  - The highest RCC gravity Dam: Longtan (192/216m) and Guangzhao (200.5m)





# The Records and Innovations

- Built the highest RCC arch dam: Shapai (132m), Wanjia kouzi dam in Yunnan with the height of 157.6m under design, construction commenced in 2010.



Rised 57.5m without intermission

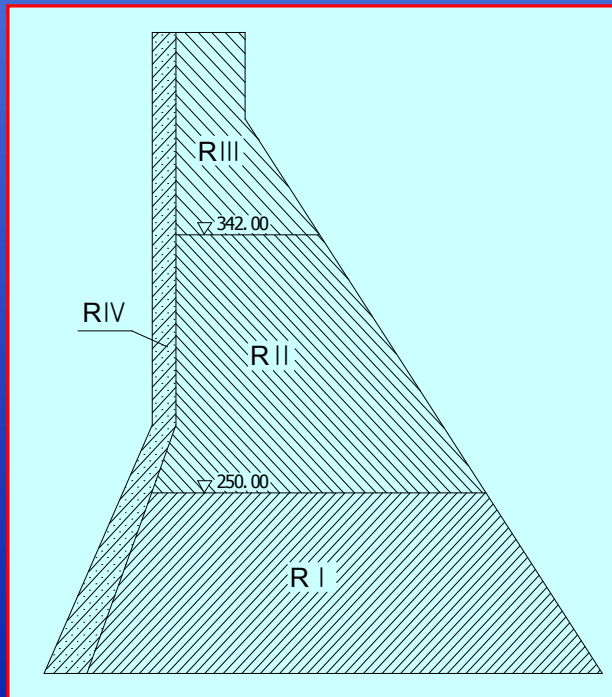
- New records of RCC placement ( $1100000 \text{ m}^3$ ) RCC placed in 4 months at the third stage of the TGP Cofferdam (90 m) the peak production rates  $476000 \text{ m}^3/\text{month}$ ,  $21000 \text{ m}^3/\text{day}$ , and  $1265 \text{ m}^3/\text{hour}$ .



# The Records and Innovations



- ❑ Grout-enriched vibrated concrete (GEVC)
- ❑ All RCC dam using the combination of GEVC and RCC with 40mm NMSA for anti-seepage

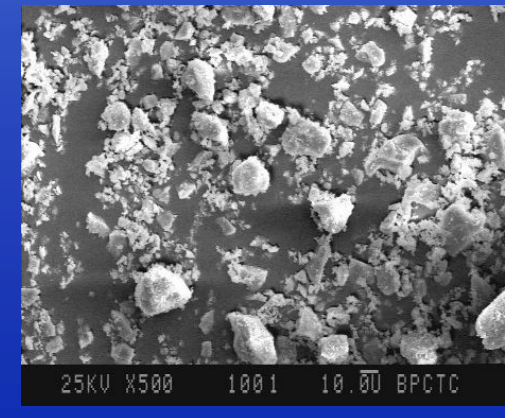
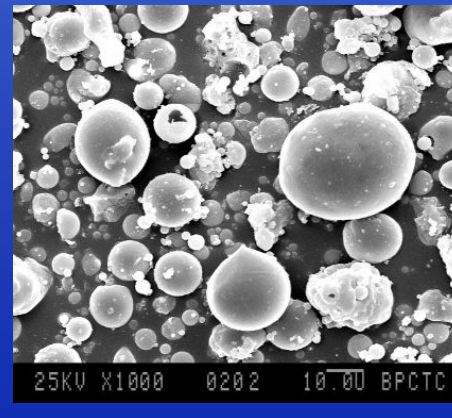
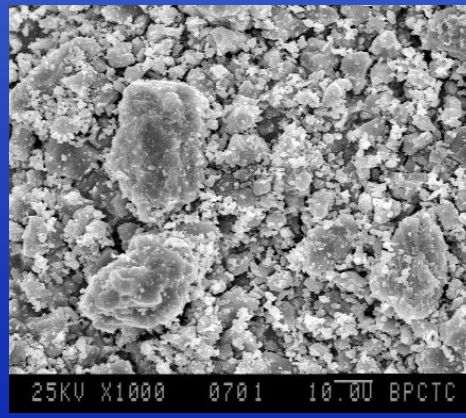
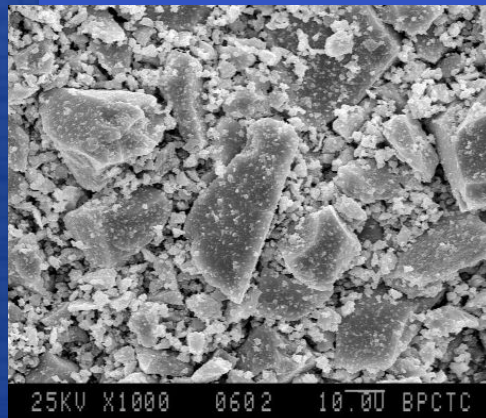


- ❑ Proportioning RCC mix for harsh environment :
  - ❑ Cold weather
  - ❑ Hot weather
  - ❑ Arid climate



# The Records and Innovations

- ❑ New types of SCM in the area lacking fly ash
  - ❑ Granulated slag : ferromanganese slag (锰铁矿渣) , phosphorous slag (磷矿渣) ,etc
  - ❑ Tuff
  - ❑ Pozzolana
  - ❑ Limestone powder, etc
  - ❑ Combination of the two (blended SCM)



# The Records and Innovations

- ❑ Chemical admixtures for RCC
  - ❑ WRRRA and WRHRA admixture
  - ❑ WRHA and anti-freezing admixture
  - ❑ Air entraining admixture
- ❑ It has been well established that many technical and economical advantages can be achieved by using admixtures in RCC mix. The main benefits :
  - ❑ Decreasing unit water content and cementitious content of RCC, thus resulting in a low temperature rise in RCC body and consequently reducing undesirable thermal stresses and cracking.



# The Records and Innovations

- ❑ Improving the workability and compactibility of RCC mix by plasticizing and/or air-entraining. As a result, vibration time required to fully consolidate concrete can be reduced, and productivity of vibratory roller will be higher.
- ❑ Retarding the initial setting of RCC to keep the surface of RCC lifts plastic and alive, extending workable time of RCC mix and allowable exposure time of lift joints, contributing to prevent cold joints and enhance the bonding of lift joints.
- ❑ Considerably improving the durability of RCC by lowering water-cementitious ratio, and/or entraining air bubbles in RCC.
- ❑ Improving the quality of RCC dam and saving cost.





# The Records and Innovations

- ❑ Cooling RCC using embedded polyvinyl cooling pipe





# The Records and Innovations

- ❑ Vacuum chute :
- ❑ Transportating RCC mix along deep slope without segregation





# The Records and Innovations

## □ Trunk-style chute :



The section of chute could be rectangle or circle , size 800mm



High speed belt conveyor and tower spreader at Longtan Dam



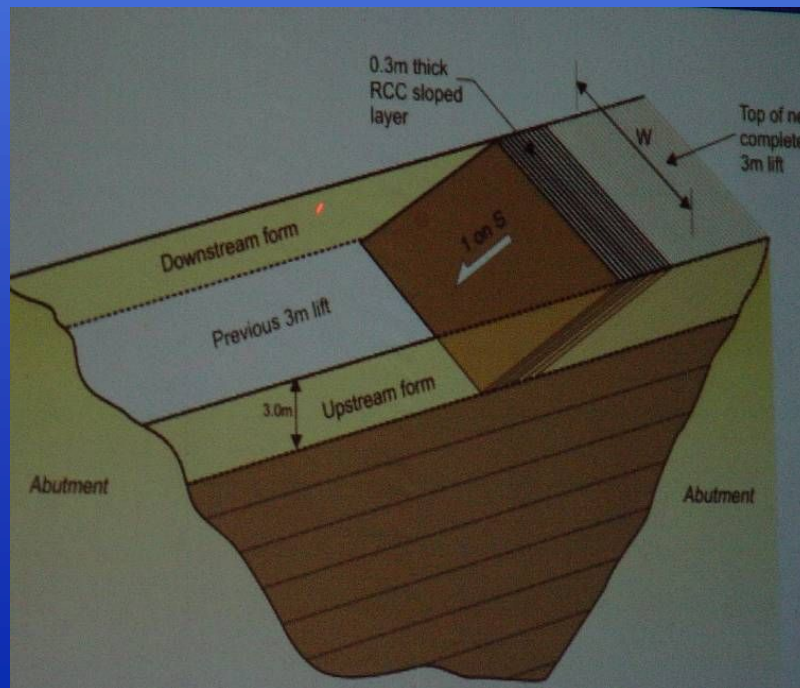


# The Records and Innovations

## ▣ Sloped layer method

Reduce placing area, decrease the requirements of the capacity of construction equipments, but raise the difficulties of compacting operation and quality control.

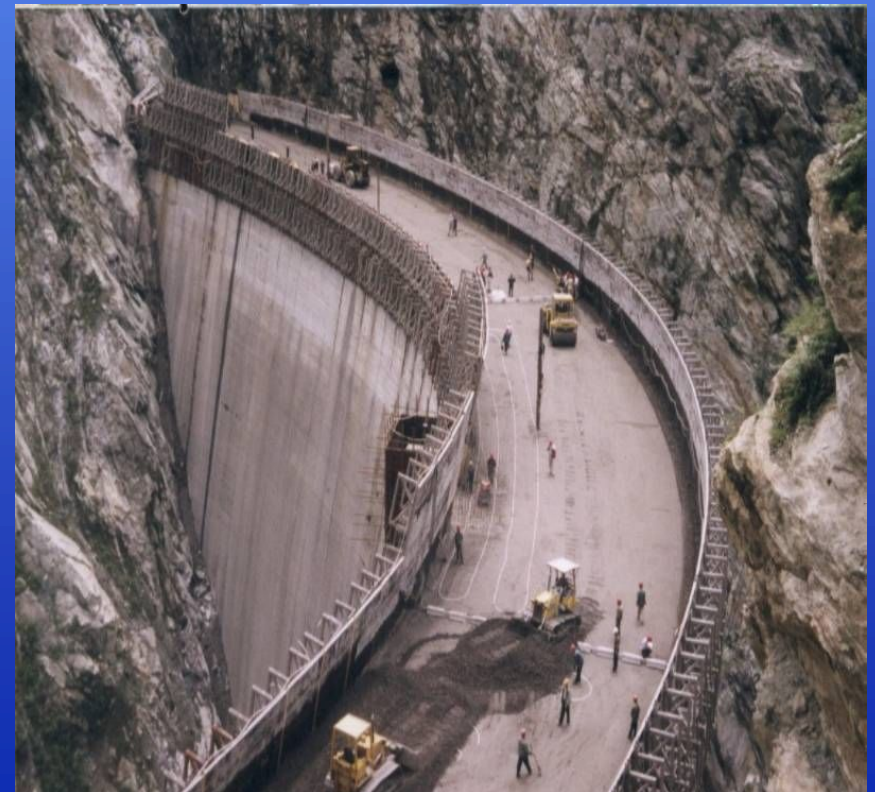
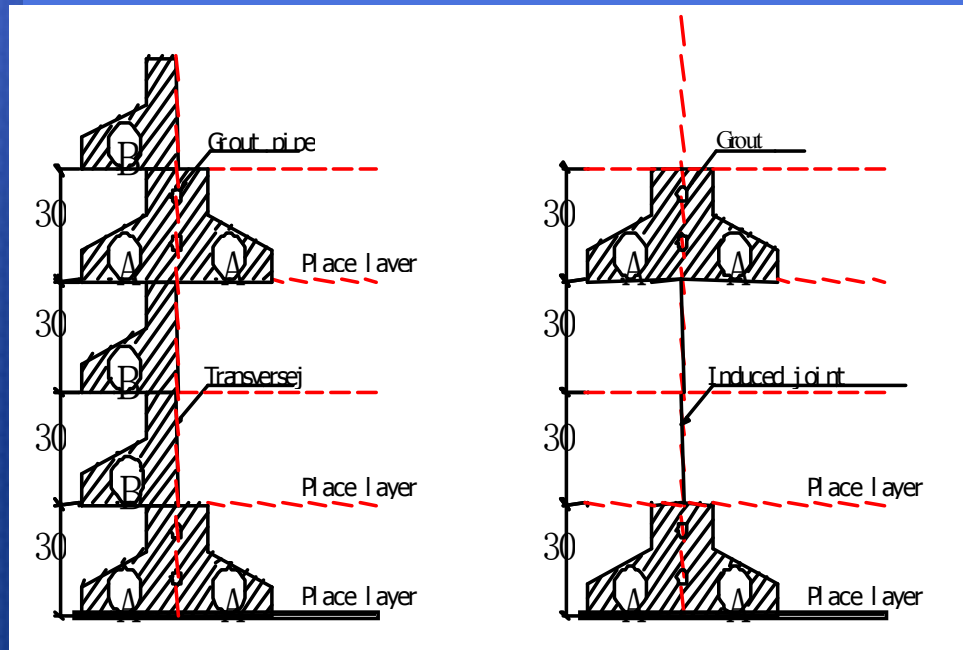
Having advantages in hot weather and raining season .



# The Records and Innovations

## □ Repeated-joint grouting

Specially developed for Shapai RCC arch dam and adopted by nearly 20 RCC arch dams in China.



# Characteristics of RCC Mix in China

- ❑ The mix proportions should be optimized to produce RCC with the following criteria:
  - ❑ Sufficient strength to withstand the loads to be imposed and stress caused by hydration heat.
  - ❑ Adequate durability to withstand satisfactorily the weather and other destructive influences to which it may be exposed
  - ❑ An appropriate range of consistency (VC time) under a given weather condition, dry enough to support the weight of the vibratory roller but wet enough to permit efficient consolidation
  - ❑ Adequate cohesion, so that segregation does not occur during transportation and spreading.





# Characteristics of RCC Mix in China

- ❑ An aggregate content as much as possible in order to achieve a relative high compacted density.
- ❑ Easy development of good bond (high bond strength and low permeability) between lifts
- ❑ Low cement content, low hydration heat and low permeability
- ❑ The experiences in China have demonstrated that the most appropriate mix proportions are the medium to high-paste content RCC mixes, which have a low cement content, a high pozzolan content and a low water-cementitious material ratio with maximum aggregate size of 80mm.



# Characteristics of RCC Mix in China

## □ Cement

P.O (32.5~42.5), MHPC42.5 (*C595Type PM/SM C150Type IV*)

## □ Mineral admixtures

- Fly ash (in absolute majority)

- Combination of the two SCMs (phosphorous slag & tuff, ferromanganese slag & limestone powder, fly ash & limestone powder)

- Pozzolana

## □ Chemical admixtures

All of RCC dam in China incorporated chemical admixtures, both water reducing admixture and air entraining admixture

- w/cm: more often in the range of 0.45~0.60

- Vp/Vm: 0.38~0.44

- Sand Ratio: 30%~39%

- Content of CM: 140~190kg/m<sup>3</sup>, dosage: 50%~65%

- Cement content: 50~100kg/m<sup>3</sup>



# Seepage Control of RCC Dam



- For low-cementitious RCC dam, the roller-compacted concrete is usually fairly permeable, particularly at the joints between the layers.
- For RCD dams, RCD dam usually has an upstream membrane to protect interior concrete. The upstream membrane usually adopts facing concrete between 2.5m and 3m thick.
- For high cementitious RCC dams, the design philosophy is that the roller-compacted interior concrete should be the watertight barrier. RCC has to be designed to bond layer to layer and to have an in-situ permeability equivalent to that of a traditional concrete dam.
- For medium cementitious RCC dams, an upstream membrane is generally adopted to protect interior RCC concrete.



# Seepage Control of RCC Dam

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- In the early stage of RCC development, most RCC dams used conventional concrete facing (usually 3m wide) on upstream zone .
- Defects always existed in the connection zone between roller-compacted concrete and conventional concrete, which are main cause for leakage
- The temperature at the contact zone of the facing concrete and RCC concrete is higher, which is unfavorable for cracking prevention.



# Seepage Control of RCC Dam



- From 1993, all RCC dams constructed in China adopted combination anti-seepage structure of GEVC and Grade 2 RCC (the maximum aggregate size of 40mm). The GEVC is close to upstream formwork with the thickness of 30~50cm. The thickness of Grade 2 RCC is 1/15~1/20 of dam height.
- In-situ tests were carried out in Jiangya RCC project to measure the permeability of GEVC and Grade 2 RCC. The results of the permeability coefficient was  $1.7 \times 10^{-10}$ ~ $3.5 \times 10^{-11}$  cm/s for GEVR and  $5.6 \times 10^{-11}$ ~ $7.0 \times 10^{-12}$  cm/s respectively.

# Seepage Control of RCC Dam



- The recovery ratio of drilling core of RCC dam is generally 98% on Mianhuatan, Jiangya, Longtan and Guangzhao dams. Break rate of core sample on layer joints is ranged in 5%~8%, in Longtan Dam; this value is only 2.5%. The length of each core sample is over 10m; the maximum length is 15.03m.



# Temperature and Crack Control



**Why to take measures for temperature control?**

**The crack resistance of RCC is lower than convention concrete**

**Crack resistance**

**Because of larger block size, the restriction region of foundation is larger**

**Restriction**

**Because of placing without longitudinal joints, cracks are easier to occur in RCC dams**

**construction**

# Temperature and Crack Control

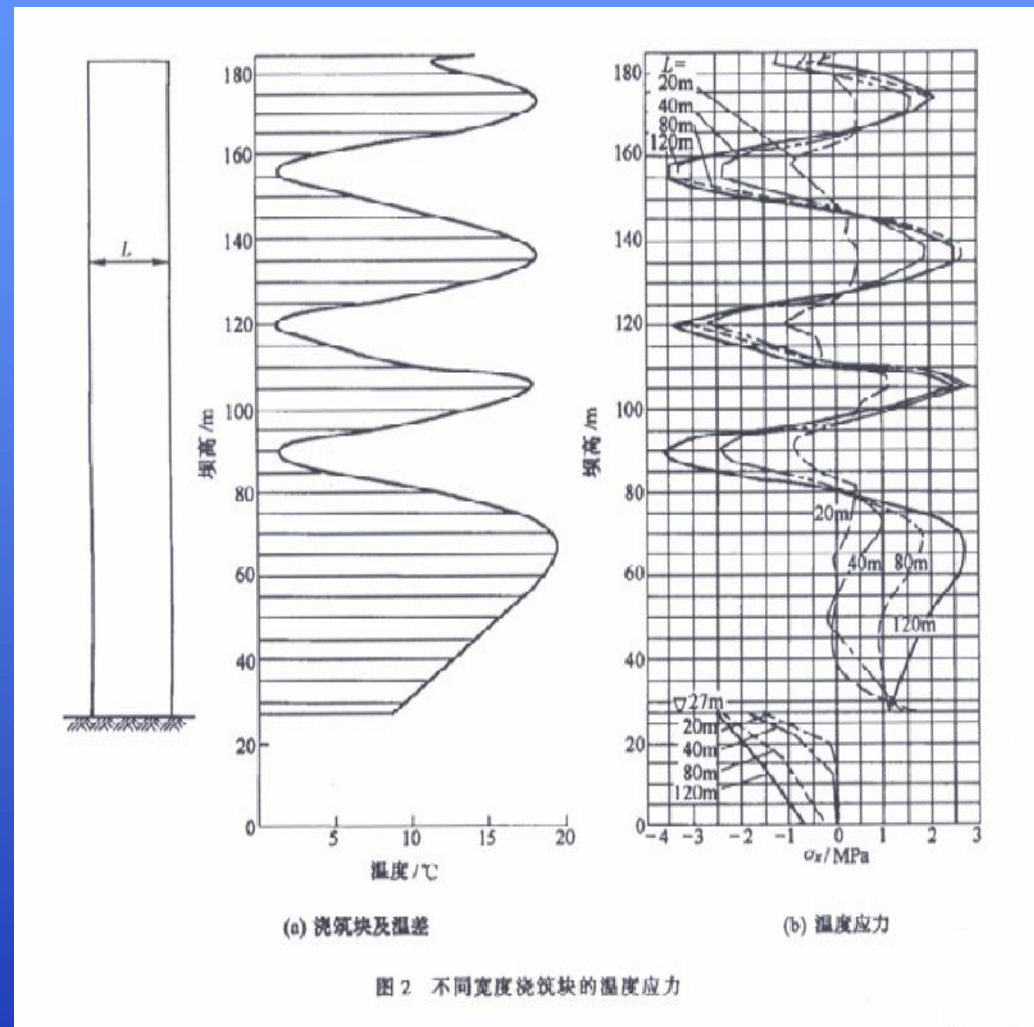
- The Characteristics of RCC Dam in Temperature and Thermal Stress
- **Effects of material properties**
- RCC has less adiabatic temperature rise than conventional concrete, and the temperature rise develops slowly at early age and gains a large temperature rise in late ages.
- crack resistance capacity of RCC is lower than that of conventional concrete.
- creep of RCC is lower than that of conventional concrete, which is unfavorable to crack control.



# Temperature and Crack Control



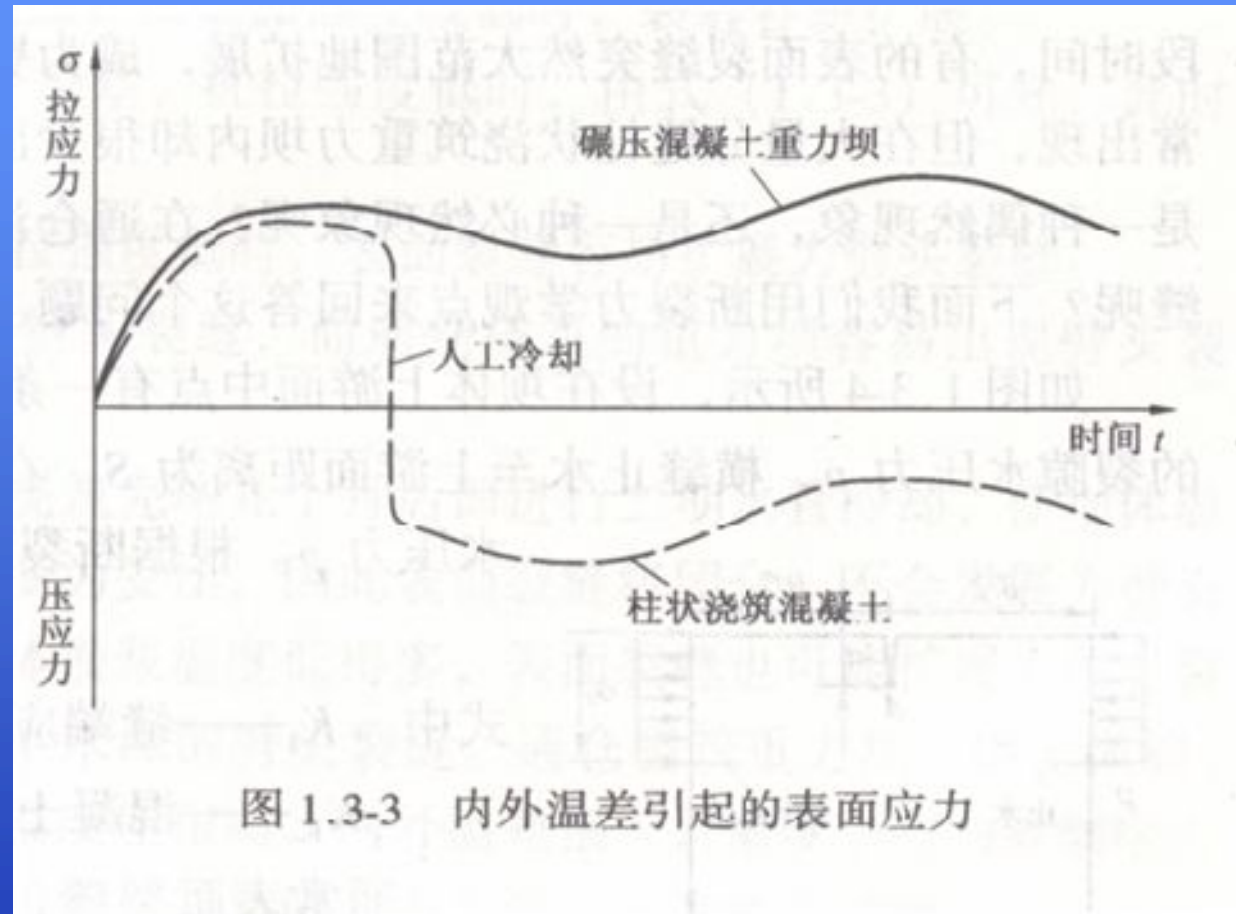
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- Thermal stresses caused by the vertical temperature variation

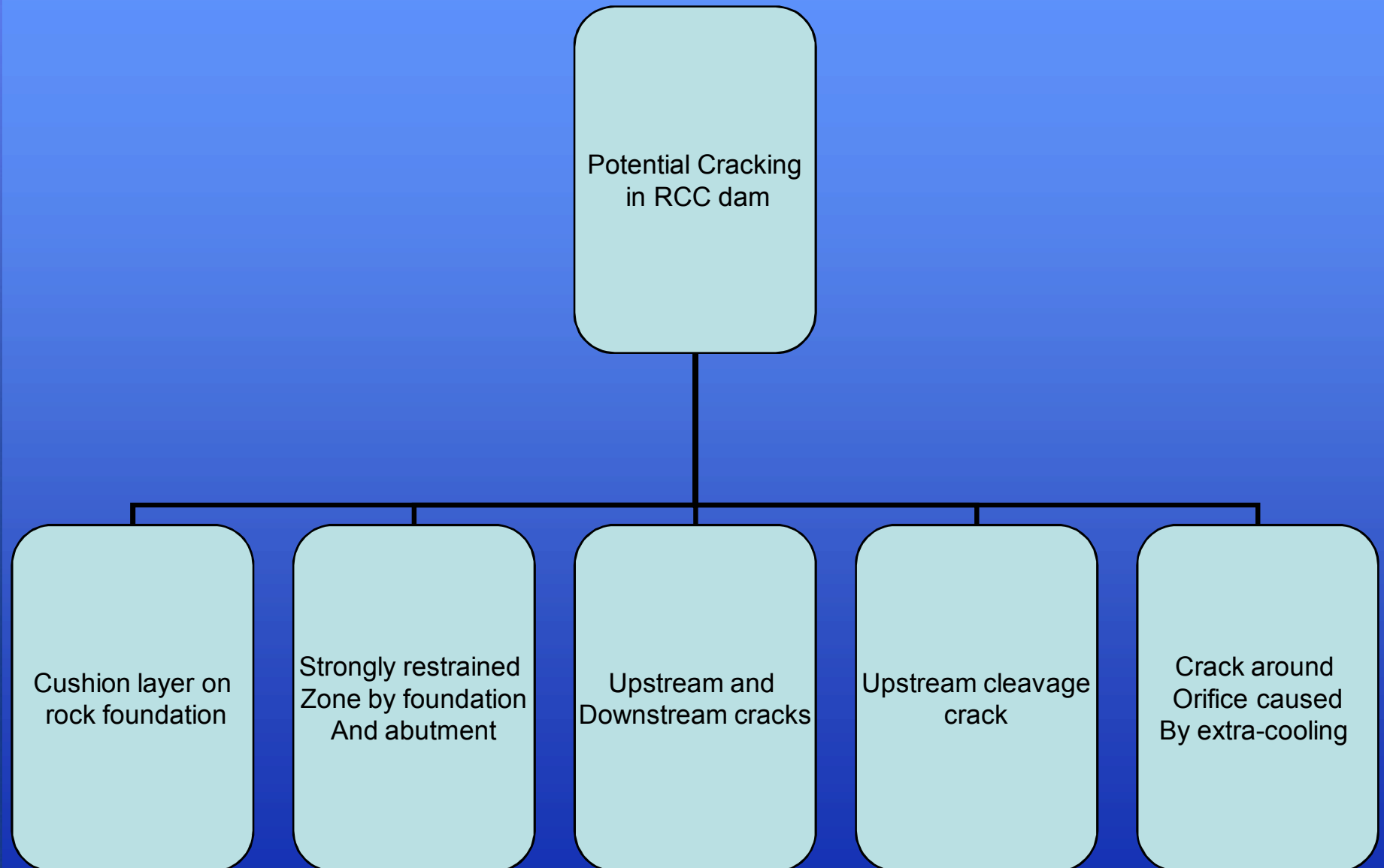


# Temperature and Crack Control



- Superficial thermal stress due to temperature difference between surface and interior of dam

# Temperature and Crack Control



# Temperature and Crack Control

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## Cushion layer on rock foundation

Generally a layer of conventional concrete with thickness 1.5~3m will be cast on the surface of rock foundation as a cushion layer of RCC dam and followed by a long period of stop to allow for foundation grouting. Many cracks appeared in the cushion layer in practical projects.



# Temperature and Crack Control

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- **Strongly restrained zone by foundation and abutment**
- For RCC gravity dam, in the zone near foundation with the height of  $0.2H$  ( $H$  is dam height), dam's volume change owing to temperature change is strongly restrained by foundation, the large tensile stress could be formed.



# Temperature and Crack Control

- **Preventing upstream and downstream cracks**
- The vertical temperature difference will cause significant horizontal tensile stress in the dam body along river flow direction. In the process of this temperature drop, the vertical temperature difference will cause at the same time vertical tensile stress at upstream and downstream surface, the tensile stress combined with the tensile stress caused by the temperature difference between the surface and interior may exceed the tensile strength of RCC. Especially for the RCC project located in cold region, the horizontal cracks are easily formed owing to the vertical temperature difference.



# Temperature and Crack Control

- **Easier occurrence of cleavage cracks in RCC dam**
- During construction period, superficial cracks may exist on the upstream surface of RCC gravity dam. Because the dam temperature drops very slowly, when the reservoir is impounded, the temperature on the upstream face is low while the temperature in the interior is still high. The stress resulted from the temperature difference between the surface and interior of the dam in combination with the splitting effect of the water pressure in the crack could lead to the extending of the cracks.





# Temperature and Crack Control

- **Extra-cooling around orifice in dam**
- For the orifice in the dam, there exists the temperature difference between interior and surface of orifice. Because RCC is constructed with longitudinal joints, the orifice is in the strongly restrained region of foundation, thus the temperature difference may cause greater tensile stress and lead to cracks.



# Temperature and Crack Control Influencing Factors

- Climatic data of dam site
- Concrete property parameters, such as elastic modulus, adiabatic temperature rise, thermal expansion coefficient, creep, tensile strength, etc
- Construction procedure, including placing season, placing temperature, speed of going up, etc
- Temperature control measures, including insulation, pipe cooling, spraying water;
- Dam block size



# Temperature and Crack Control -stimulation analysis

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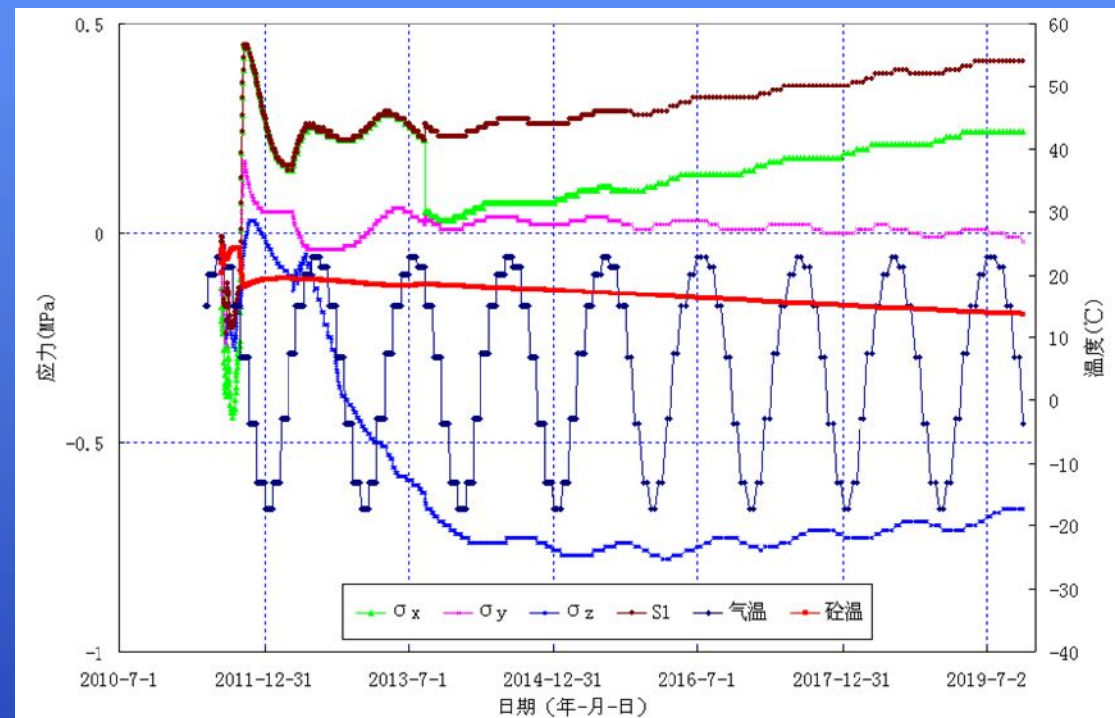
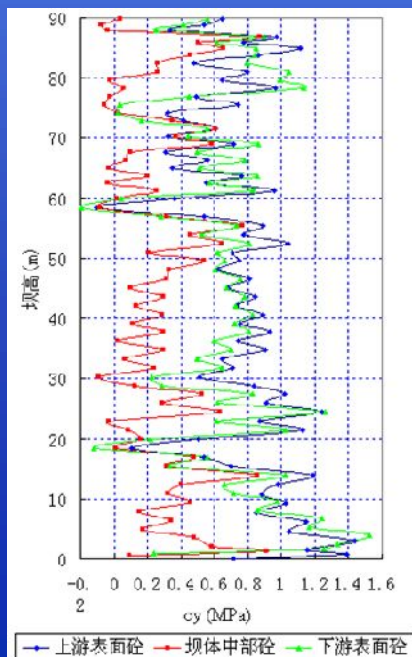
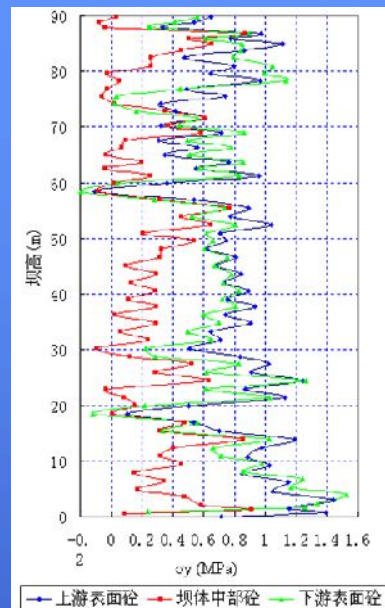
- The accurate temperature and stress field distribution can only be confirmed by stimulation analysis method. So for the final design of large- and medium-sized RCC dams, it is usual to use a finite-element analysis to evaluate the thermal stress and crack potential.
- (1) the maximum temperature and stress; (2) the zone of maximum and over standard value; (3) the time of maximum value.



# Temperature and Crack Control



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# Temperature and Crack Control

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- **Temperature Control Measures**
- controlling the placing temperature,
- adopting embedded post-cooling system to control dam's temperature distribution, the high density plastic cooling pile should be used,
- using surface insulation to control the temperature difference between the surface and interior.



# Temperature control Measures of RCC dam



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Optimizing mixing proportion of RCC

Reasonable arrangement of  
transverse joints

Surface insulation

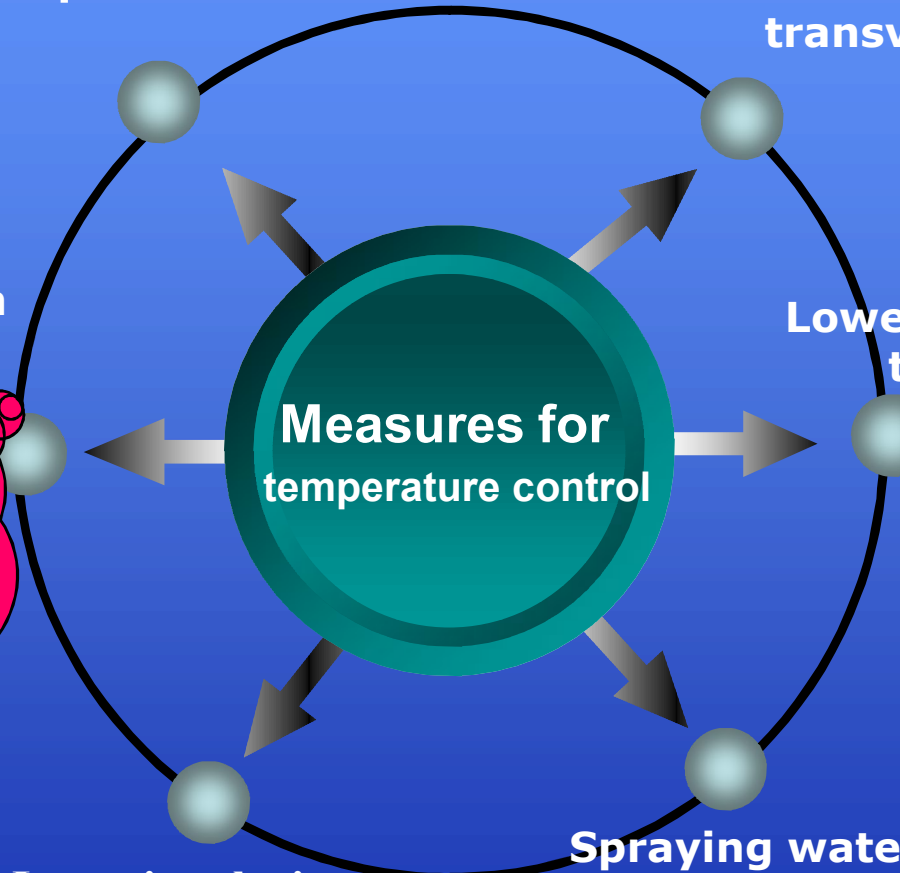
Lowering the pouring  
temperature

Measures for  
temperature control

Via the surface  
insulation  
measures, to  
decrease the  
temperature  
difference

Spraying water in working place

Lowering the inner  
Temperature via water cooling pipe





# Temperature and Crack Control



- **Joint Setting of RCC dam**
- For RCC gravity dam in warmer region, in mild region and in cold region, the spacing between transverse joints usually is 30~40m, 20~30m and 15~20m wide respectively.
- There are no transverse joints but only inducing joints in the arch dam in early stage. Practice shows that there may be severe cracks after completion without transverse joints like Puding Dam. From Shapai high RCC arch dam ( $H=132\text{m}$ ) on, all high RCC arch dam adopt the combination of transverse joints and inducing joints.

# Brief Introduction of Guanyinge RCC Dam

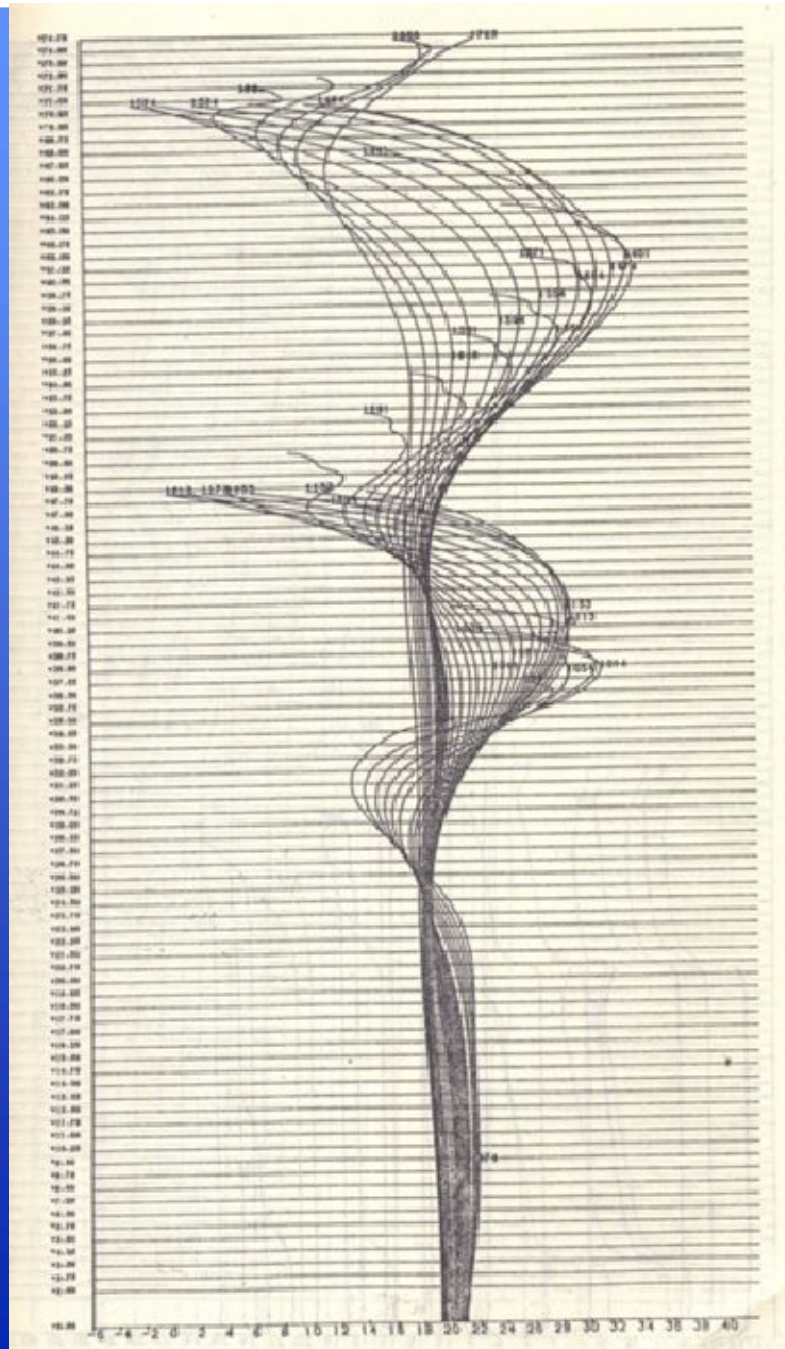


- Guanyinge RCC Dam located in Liaoning province in north China is 82m high. It is one of few RCC dams constructed by using RCD method. The annual year mean air temperature is  $6.77^{\circ}\text{C}$ . Dam construction commenced in 1990 and finished in 1995. Guanyinge RCC dam has conventional concrete facing of 3m wide with the transverse joint spacing of 15m. Because the air temperature is low in winter, so construction suspended for 5 months for each winter. In 1994, horizontal cracks were found on upstream face.

# Brief Introduction of Guanyinge RCC Dam

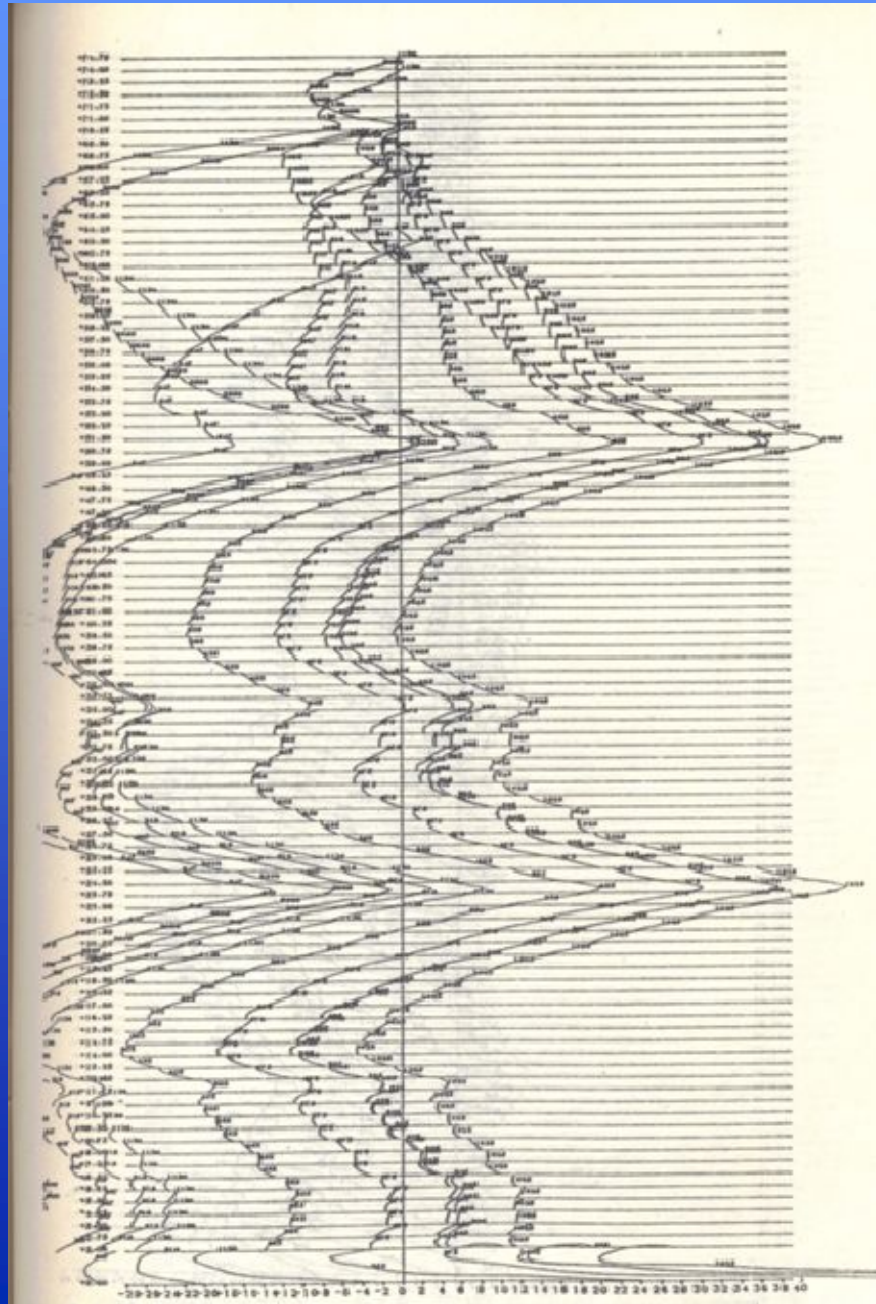


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# Brief Introduction of Guanyinge RCC Dam



# Brief Introduction of Guanyinge RCC Dam



- Reasons for cracking:
- (1) larger temperature difference exist in vertical direction owing to insufficient insulation during winter suspension.
- (2) ambient air temperature variation is about  $40^{\circ}\text{C}$ , surface insulation is not sufficient, which bring about larger temperature difference between surface and interior.

# Conclusions

- (1) After more than 20 years development of RCC technology, China has made great progress and achieved lots of innovations.
- (2) Section of RCC mixture proportion is vital for ensuring RCC quality. In combination of other techniques, RCC could be placed in cold weather, hot weather and arid climate.
- (3) The high cementitious content RCC are widely adopted and the anti-seepage structure based on high cementitious content RCC is proved to be very successful.
- (4) The temperature and crack control Of RCC dam has much difference from that of conventional concrete dam owing to different construction method. In order to achieve good crack control effects, design and construction must be carefully done.
- (5) The simulation analysis of the temperature and thermal stress of RCC dam is efficient way to evaluate dam's crack potential and safety. For high- and medium-sized RCC dam the simulation analysis of the temperature and thermal stress is recommended to be used.



# Our Practice in RCC Dam Technology

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- ❑ Since 1978, IWHR has conducted the researches on RCC dam Technology and has been playing a leading role all the while.
- ❑ Concentrating his attention on the studies of fundamental principles and key techniques, consulting service, and training of engineer.
- ❑ 1983 at Shaxikou hydropower station in Fujian province, the excellent field performance of high volume fly ash RCC mix, proposed by IWHR, set the stage for China-style RCC.



# Our Practice in RCC Dam Technology

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- ❑ Draft SDJS10-86"Testing standard of RCC in hydraulic structures"(1986), 1994 revised under designation SL48-94, 2006 revised under designation SL352-2006.
- ❑ Join the group drafting SDJS14-86"Construction specifications for hydraulic roller compacted concrete", 1994 revised under designation SL53-94, 2000 revised under designation DLT5112-2000
- ❑ During the past 30 years, IWHR took part in almost all large size RCC dams and milestone RCC projects.

# Our Practice in RCC Dam Technology

## □ Representative RCC Dam

### □ Longtan RCC gravity dam

- ◆ Raw material selecting, quality control and mixing proportion optimizing and technical consultation
- ◆ Proposing technical criteria for the quality control of raw materials, such as cement, PFA, admixture and crushed aggregates, as well as the construction mix proportion optimizing, the durability improving and treatment of lift joints.





# Our Practice in RCC Dam Technology

## □ Representative RCC Dam

### □ Shapai RCC arch dam

- ◆ Checking test of the RCC mix proportions
- ◆ Arrangement and details of transverse joint and induced joint
- ◆ Developing repeated-joint grouting technique





# Our Practice in RCC Dam Technology

- Jinghong RCC gravity dam
  - ◆ Developing a blended pozzolan composed of ground ferromanganese slag & limestone powder, solving the deficiency problem of the fly ash in the RCC construction, established the conception of using limestone powder as the mineral admixture for the RCC, and enlarged the application space of the RCC dam technology.
  - ◆ Raw material selecting, proposing technical criteria for the blended pozzolan.
  - ◆ Mixing proportion optimizing and Quality control



14.3m long RCC core extracting from Jinghong Dam





# Our Practice in RCC Dam Technology



A RCC core extracted from Longtan RCC dam (15.03m long)





# RCC Dam and Mix Proportion

China has been becoming the leading country in RCC dam technology around the world. Chinese RCC dam technologies have broken away from restrictions of climates and regions, are able to build RCC dams anywhere.

# Thanks

