

Second International Symposium on Rockfill Dams

October 27 to 28, 2011

Windsor Barra da Tijuca Hotel - Rio de Janeiro - Brazil



XXVIII SNGB

National Seminar on Large Dams

October 25 to 28, 2011

Windsor Barra da Tijuca Hotel - Rio de Janeiro - Brazil



THE CONCEPT ON DEFORMATION CONTROL AND INTEGRATED DEFORMATION COORDINATION (DCIDC) OF HIGH CFRD

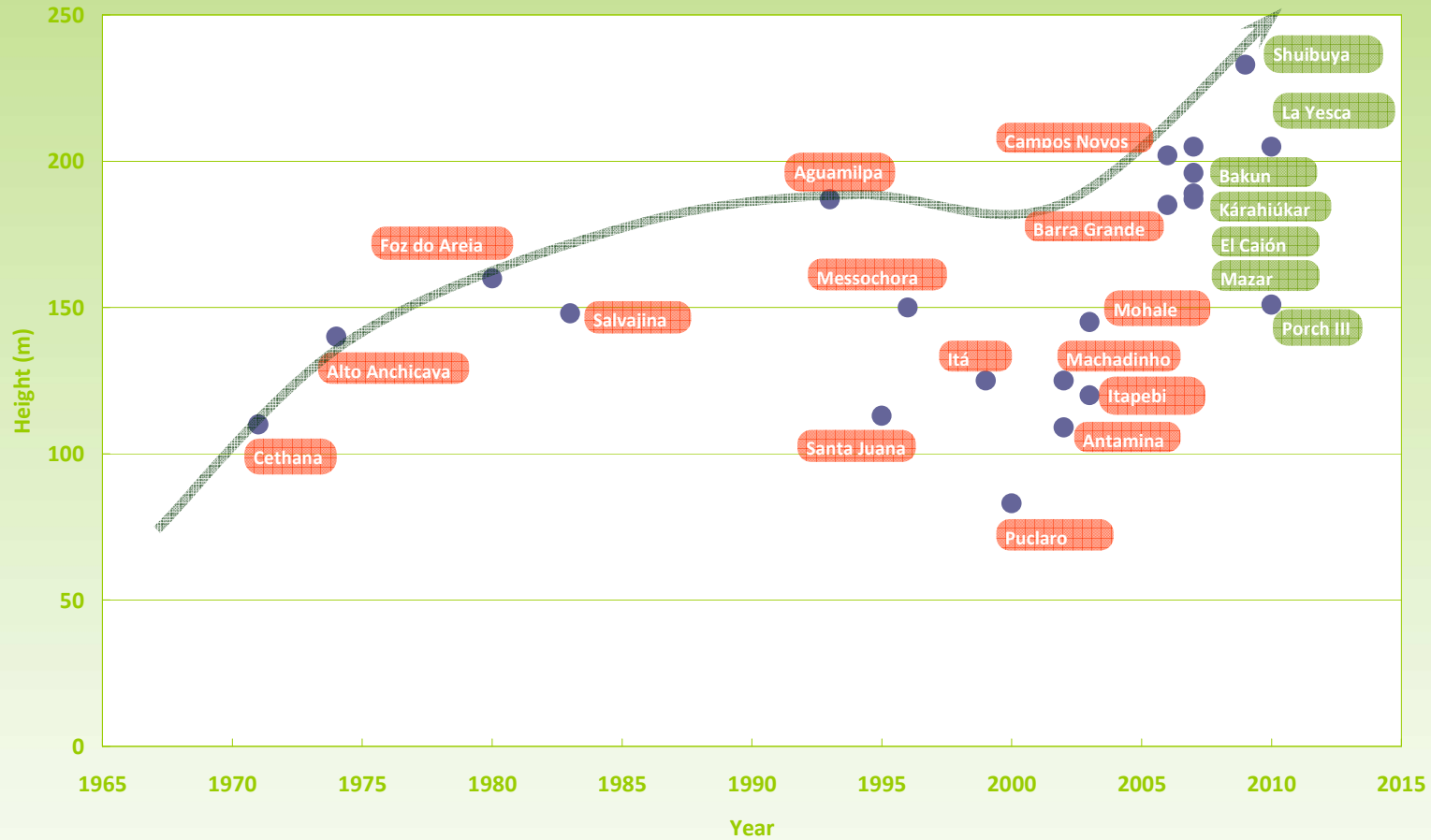
Xu Zeping

China Institute of Water Resources and Hydropower Research

Contents of presentation

- Introduction of high CFRD development
- Traditional concepts for CFRD design
- Analysis on traditional design concepts
- Deformation control and integrated deformation coordination on high CFRD
- Technologies for engineering applications

Development of high CFRD in the world



----B. Materon, 2007

CFRD construction: traditional concept

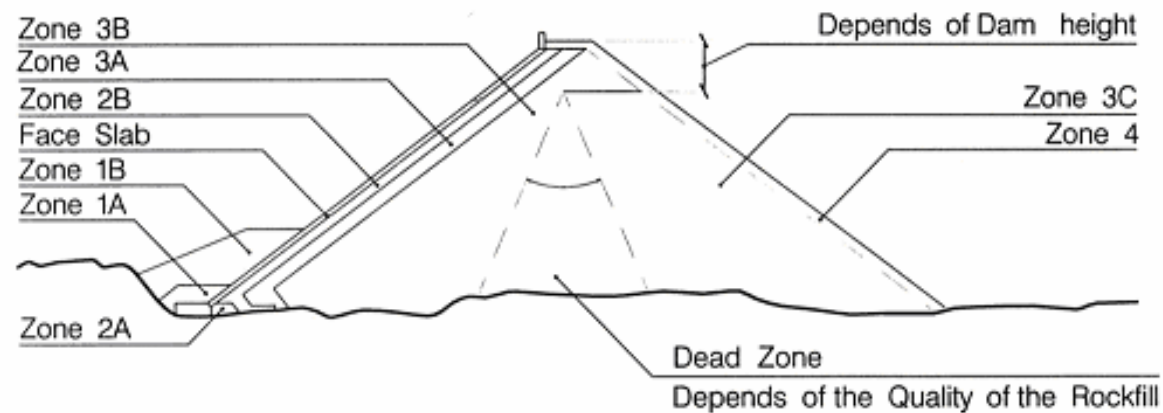


Cooke, 1998: After the construction of the first CFRD, the design of CFRD is based on previous experience, rather than theory instruction.

The CFRD is an appropriate type in the future for the very highest dams. For a 300m high CFRD constructed of most rock types, acceptable performance can be predicted, based on reasonable extrapolation of measurement on existing dams.

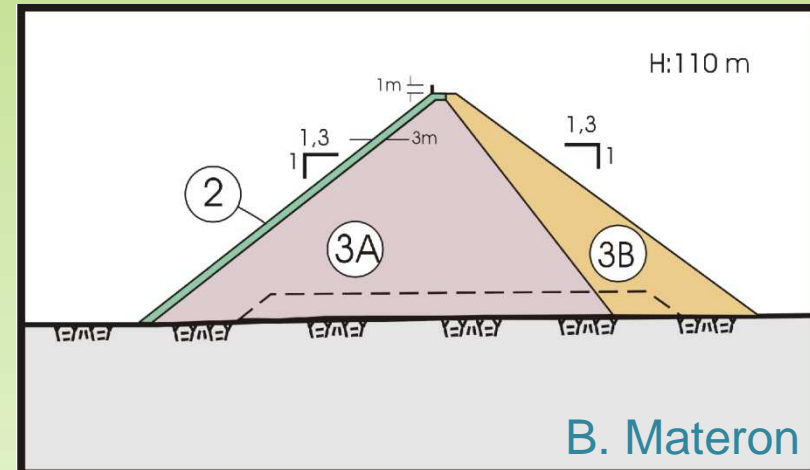
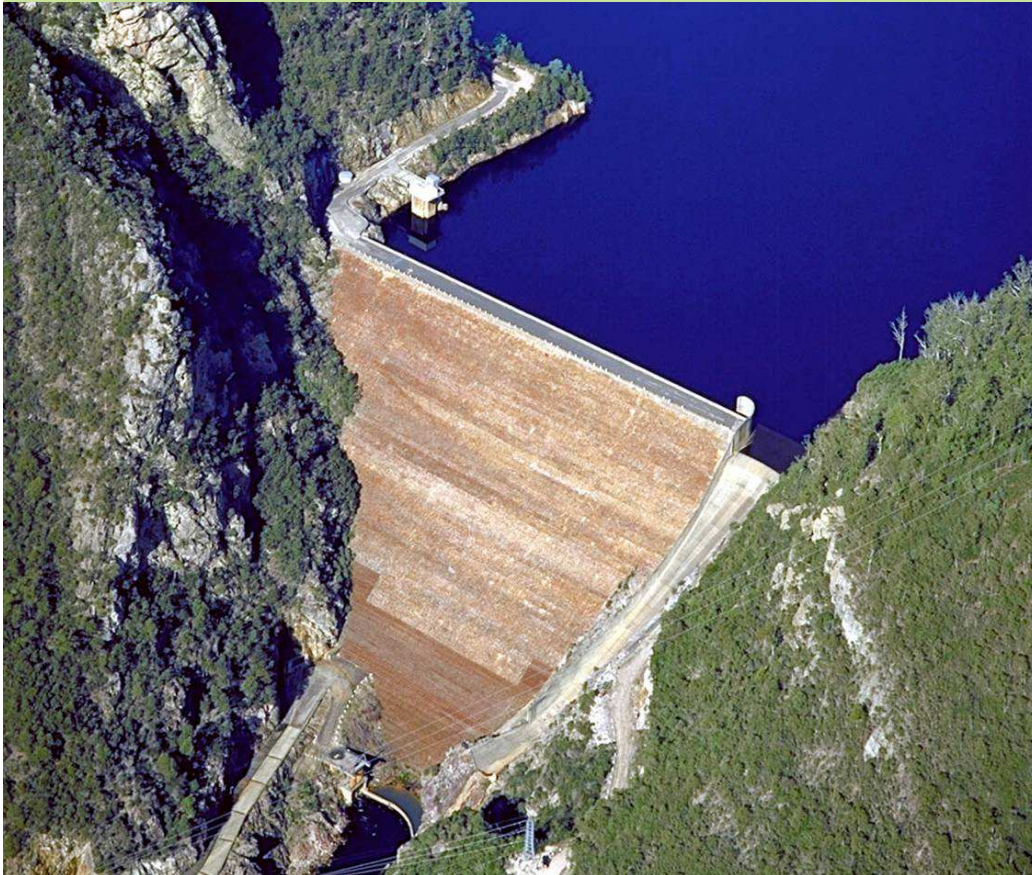
B. Cooke 2000

CFRD construction: traditional concept



- 1A COHESIONLESS SOIL
- 1B RANDOM
- 2A PROCESSED MATERIAL (\varnothing MAX. = 3 / 4")
- 2B PROCESSED MATERIAL (\varnothing MAX. = 3 - 4")
- 3A SELECTED SMALL ROCK PLACED IN SAME LAYER THICKNESS AS ZONE 2
- 3B QUARRY RUN ROCKFILL, ABOUT 0,8 m TO 1,0 m LAYERS
- 3C QUARRY RUN ROCKFILL, ABOUT 1,6 m TO 2,0 m LAYERS
- 4 DOWNSTREAM ROCKFILL

CFRD construction: traditional concept



After the construction of Cethana Dam, good performance of the following medium height CFRD has indicated the applicability of the traditional concepts and experiences.

CFRD construction: traditional concept

Rockfill deformation

- Compared with rockfill dam constructed by dumped rockfill, deformation of modern CFRD is significantly reduced by the application of layered compaction.
- Most of the rockfill deformation could be completed during its construction period. Deformation control of rockfill is not the main factor for safe operation of CFRD .

Rockfill material

- If the saturated compression strength of rock is larger than 30MPa, the rockfill is considered as a suitable material for CFRD construction.
- Although good gradation rockfill could reach to a relatively high density and modulus with proper compaction, it is unnecessary to specify the requirement of good gradation of rockfill material.

CFRD construction: traditional concept

Construction

- The normal practices for rockfill compaction is: 10 passes by 10t vibratory roller .
- It is unnecessary to add water during rockfill compaction.
- Quality control of rockfill compaction is mainly depends on compaction parameters (weight of roller, lift thickness, passes, etc.).

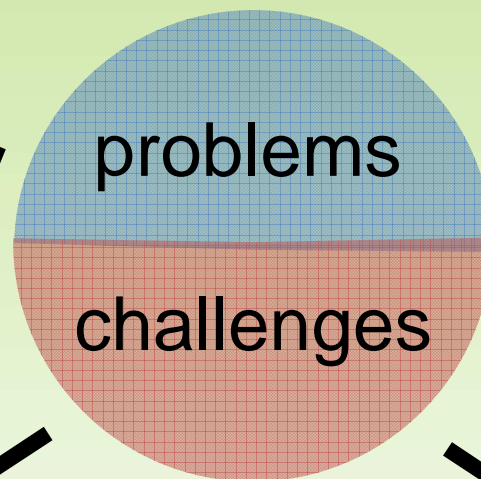
Section zoning

- From Zone 3A to 3C, the compressibility and permeability of rockfill is gradually increased.
- The deformation of zone 3C has less impact on face slab. Thus, weak rockfill can be used or the compaction requirement could be reduced.

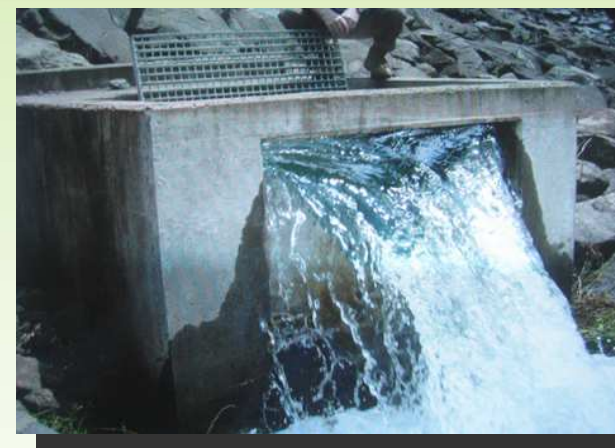
CFRD : From 100m to 200m ~ 300m



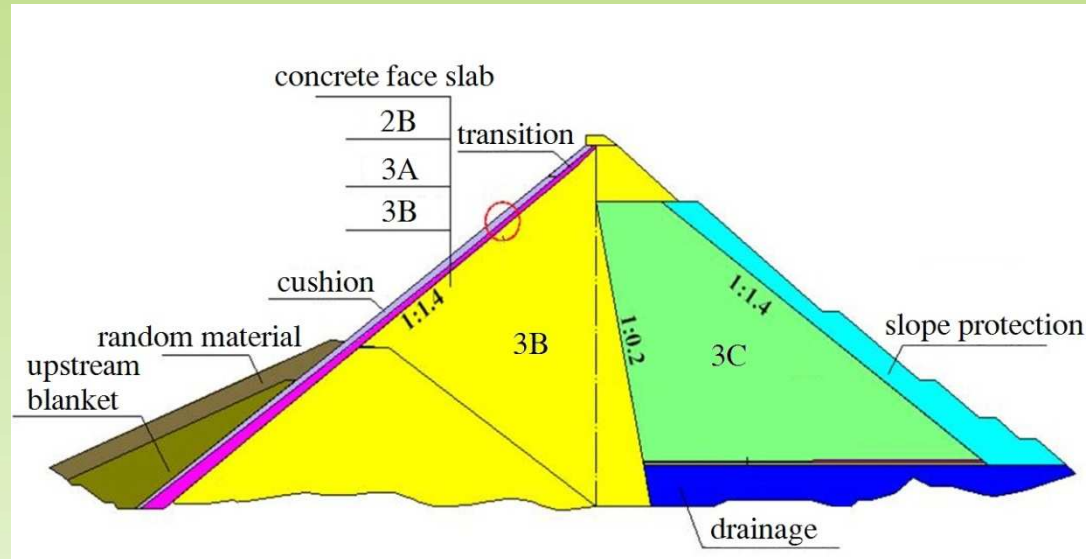
Manoel S. Freitas



Int. J. on H & D



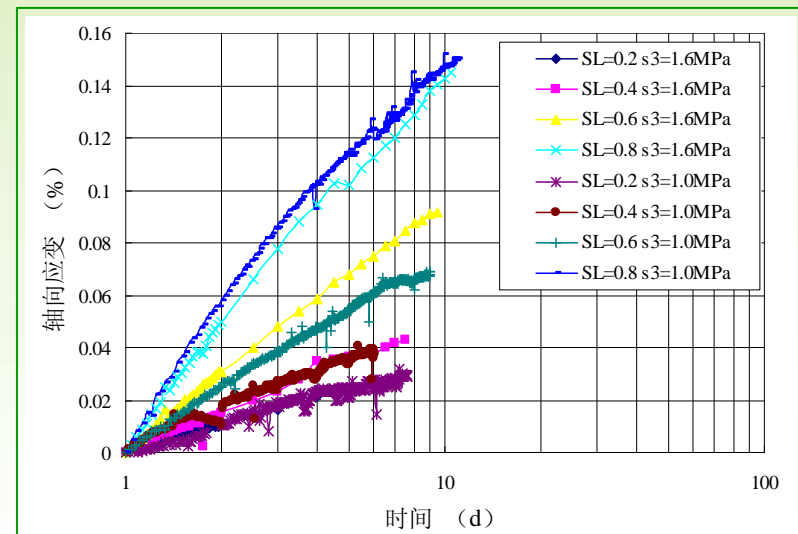
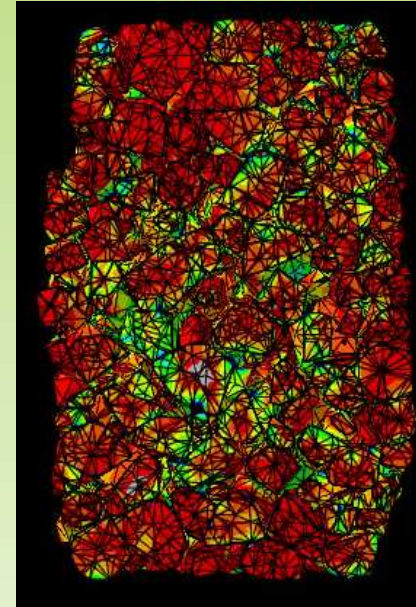
CFRD : From 100m to 200m ~ 300m



With the increasing of dam height, the stress level of rockfill will be significantly increased. The total displacements of rockfill are also increased. Thus, rockfill deformation control become the most important factor concerning the safety of high CFRD.

Deformation properties of rockfill

- As a granular material with hard particles, rockfill could reach a rather high density and have low void ratio after compaction.
- For compacted rockfill, normally, the compressive deformation can be occurred in a short period of time. Thus, for low dam, most of the rockfill settlements could be completed during construction.
- For high dam, due to the high stress level of rockfill, breakage and re-arrangement of particles will produce a significant post construction rockfill deformation.



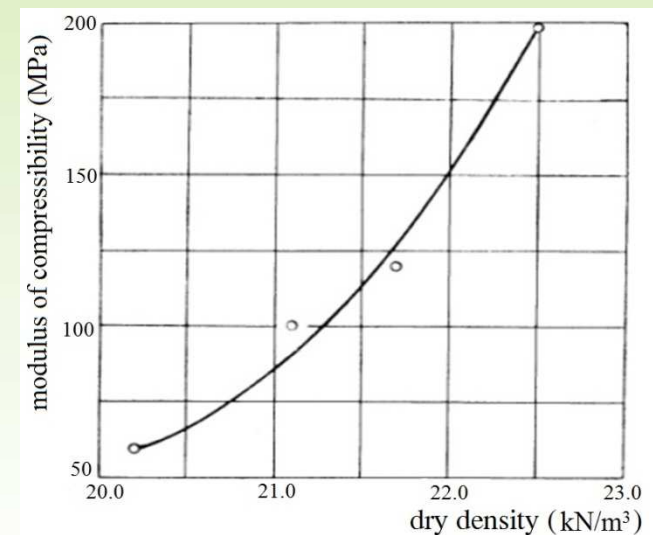
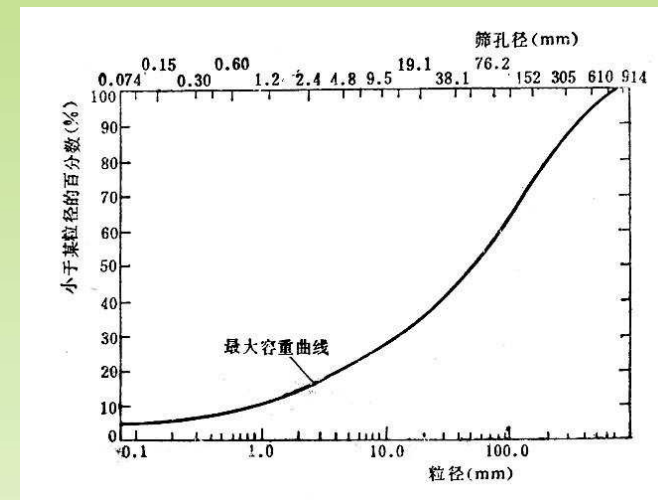
Deformation properties of rockfill

- Rockfill has the properties of wetting deformation. The mechanism of the deformation is soften and broken of the edges of rockfil particles. Furthermore, the lubricant action of water promote the movement and rearrangement of the particles. Thus, to produce additional deformations.
- Wetting deformation has close relationship with rock type and stress status.
- Rockfill wetting deformation is reduced with the increasing of density and initial water content.

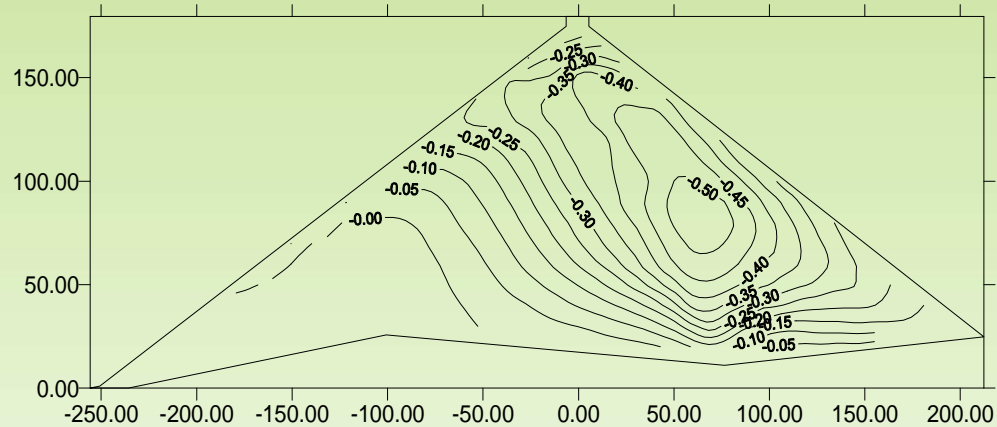


Deformation properties of rockfill

- Rockfill compressibility has close relationship with its gradation. Rockfill with good gradation could achieve low compressibility after compaction.
- Rockfill modulus of compressibility present positive correlation with its density.

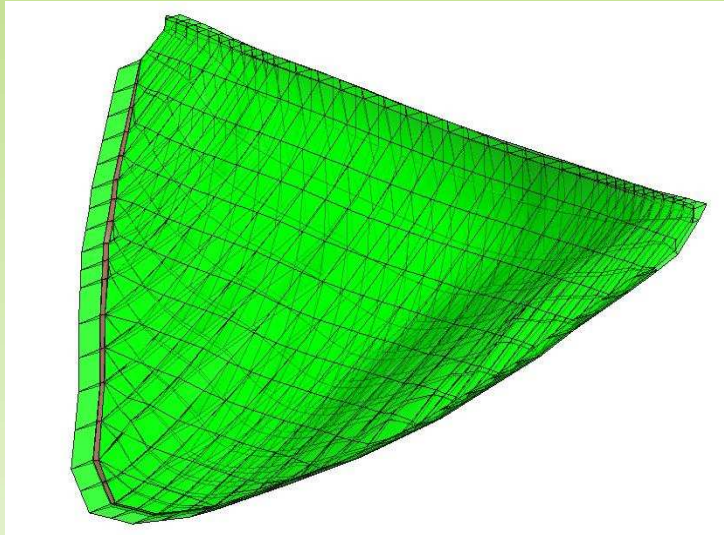


Impacts of downstream rockfill deformation



- With the increasing of dam height and upstream water load, the deformation of downstream rockfill will have important impact on the stress status of face slab.

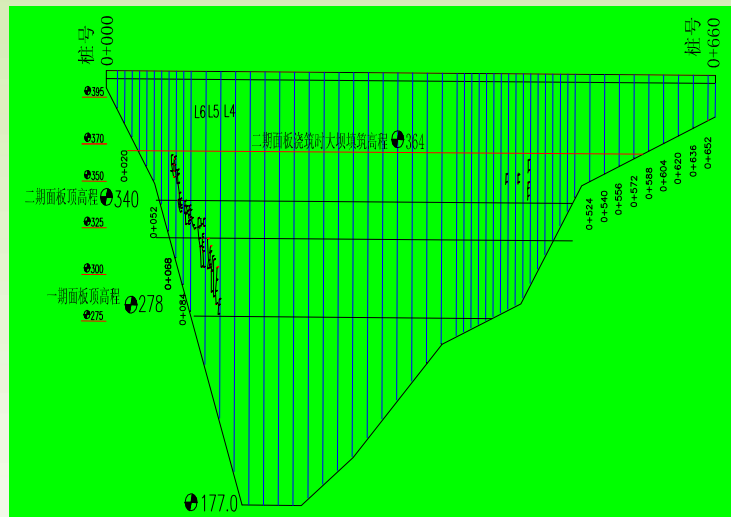
Deformation of face slab & face slab rupture



- Under the contact action between face slabs and rockfill, face slabs in the abutment area will move to river center with the load of water pressure and rockfill deformation. Face slabs in riverbed section are subject to compression stress. The stress value is directly relate with maximum rockfill settlement and horizontal displacement along river flow.

Differential displacement on the abutment

- For high dams built in V-shape valley, the differential settlement between abutment rockfill and riverbed rockfill could lead to relatively large shear stress of rockfill, thus to produce cracks parallel to abutment slope.



Deformation control and integrated deformation coordination (DCIDC)



“With the increasing of dam height, the stress and deformation properties and the operation status of CFRD will present some new features. ... By summarizing the experiences and lessons of the previous high CFRD construction, it could be noticed that the existing design criteria and conventional construction method will be adjusted for the construction of future’s 300m high CFRD.” Xu Zeping 2010

Deformation control and integrated deformation coordination (DCIDC)

Deformation control and integrated deformation coordination is the most important technologies of high CFRD construction

- Rockfill deformation govern the general operation status of CFRD
- Rockfill deformation determine the stress status of concrete face slab
- Rockfill deformation determine the displacement of joint system

Deformation control and integrated deformation coordination

- In the concept of deformation control and integrated deformation coordination, control is the base, coordination is the crux.
- The objective of deformation control and integrated deformation coordination is to achieve safety of concrete face slabs and joint system.

$$\sigma_t < \left\{ \begin{array}{c} \sigma_s \\ \sigma_a \end{array} \right\} < \sigma_c \qquad \left\{ \begin{array}{c} \max (DP_o) \\ \max (DP_s) \\ \max (DP_d) \end{array} \right\} < \left\{ \begin{array}{c} D_o \\ D_s \\ D_d \end{array} \right\}$$

Main Points on the concept of Deformation control and integrated coordination

- Rockfill deformation is directly related with rock type, gradation, compact density and dam height, factor of valley shape.

$$S=F(H,H/A^2,n,S_c,C_s)$$

- For high CFRD, rockfill materials with low compressibility, good gradation should be selected and the compact density should be strictly controlled to achieve a low deformation values.

$$n \leq n_1$$

- For high CFRD, to achieve deformation coordination of different areas though rational zoning should be highly emphasized.

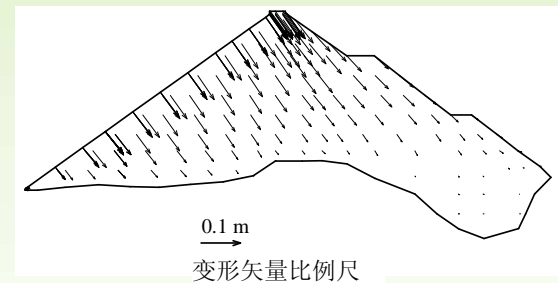
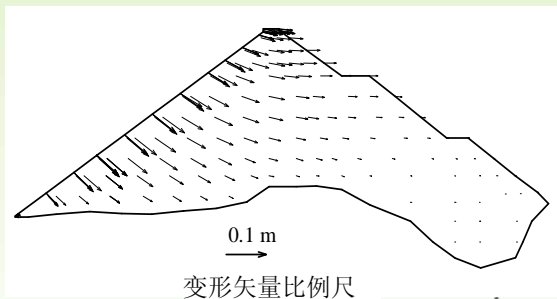
$$g \leq s_p, \quad E_u/E_d \leq r$$

- For high CFRD, the construction schedule should be well arranged to provide sufficient time for stabilization of upstream rockfill deformation.

$$T \geq t_p$$

Main Points on the integrated deformation coordination

- Coordination on deformation of upstream and downstream rockfill
- Coordination on deformation of abutment and riverbed rockfill
- Coordination on deformation of face slabs and upstream rockfill
- Coordination on deformation of upper part and lower part rockfill
- Coordination on deformation of rockfill constructed in different time



Implementation of the DCIDC concept in engineering practices

- Maximum settlement control:

$$S=dH \quad (d=0.8\% \sim 1.2\%)$$

- Compaction density control

$$n=18\% \sim 20\%$$

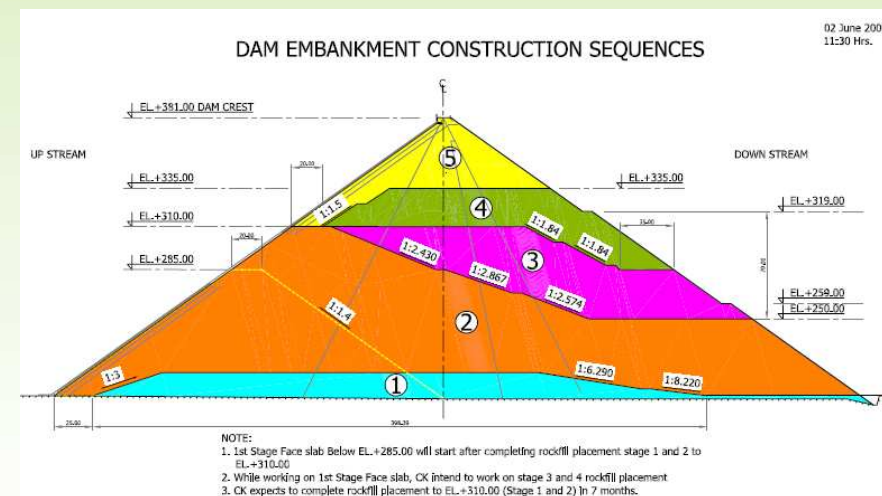
- Boundary of 3B/3C zone:

$$s_p \geq 0.5 \quad r \leq 1.5$$

- Stabilization time control:

$$t_p = 3 \sim 6 \text{ month} \quad \text{Monthly settlement} = 3 \sim 5 \text{ mm}$$

Implementation of the DCIDC concept in engineering practices



Conclude Remarks

- The concept of deformation control and integrated deformation coordination is summarized from engineering practices and theoretic analysis of many high CFRD projects.
- The concept of deformation control and integrated deformation coordination has been applied in the construction of high CFRD in China. Good results are achieved.
- From engineering practices, the concept has well reflected the key issues of high CFRD construction.
- By analysis the reasons of the problems occurred on recent high CFRD cases, it could be found that all these problems are due to the violation of the principles of the DCIDC concept.



THANK YOU FOR
YOUR ATTENTION

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