SECOND INTERNATIONAL SYMPOSIUM ON ROCKFILL DAMS

RIO DE JANEIRO ,RJ – BRAZIL, OCTOBER 27 – 28, 2011

CFRD 07

DESIGN CRITERIA AND CONSTRUCTION FOR VERY HIGH CFRDs – CONCEPTUAL TRENDS

(TOPICS FOR DISCUSSION)

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1. Introduction

The following highest CFRDs (around 200m) were built in the last decade(several are still under construction) :

- Campos Novos (Brazil, 202m)
- Barra Grande (Brazil, 185m)
- Shuibuya (China, 233m)
- Bakun (Malaysia, 205)
- Kárahnjúkar (Iceland, 196 m)
- El Cajón (Mexico, 188m)

- Nan Ngum 2 (Laos, 182 m)
- Hongjiadu (China, 182 m)
- Sogamoso(Colombia, 190m, U.C.)
- La Yesca (Mexico, 208, U.C.)
- Jiangpinghe (China, 221m, U.C.)

(U.C. -Under construction)

All listed CFRDs are excellent examples of safety dams on operation phase and progressed construction methods .

2. Face Slab (main) current design trends

From cracking and spalling phenomenon recorded between 2003 – 2006, the following design and construction concepts were applied , so far:

- **soft joint filling (wood, or EPDM or GB materials) inserted along vertical joints → seeking to high horizontal compression at center slabs during impounding**
- **Split 15 m (standard) wide slabs in 7.5 m wide to minimizing "compression stresses" and bending efforts along vertical joints**
- **additional reinforcement (anti-spalling) to protecting against :**
  i) negative bending moments and tension cracking, and
  ii) rebars buckling along vertical joints at center parts
- **bond breaker (between slab and extruded curb) and cutting joints along the curb concrete.**

2.(a) Face Slab (main) current design trends (cont.)

- soft joint filling (wood, or EPDM or GB material) inserted along vertical joints (seeking to high horizontal compression)
  - **Compression Zones – Cases**

B. Materon, 2007

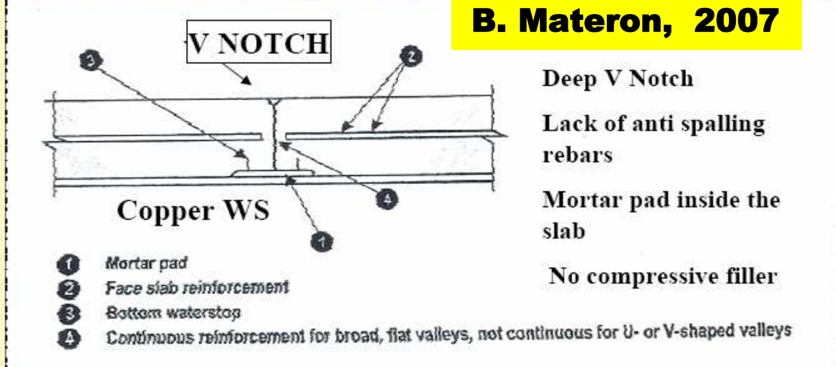


Figure 6-3, Typical Vertical Compression Joint

50 mm softwood filler thickness were Inserted along 6 center joints during 1st Face slab stage

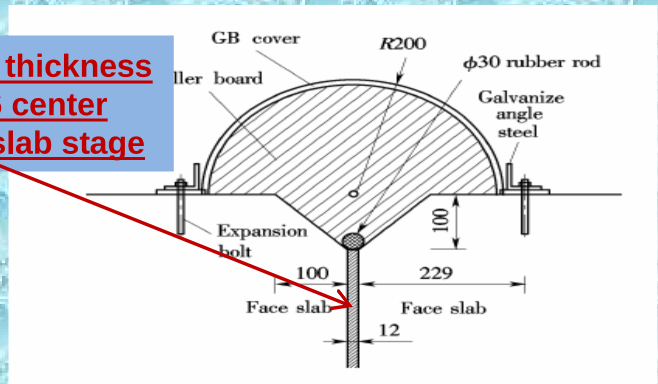
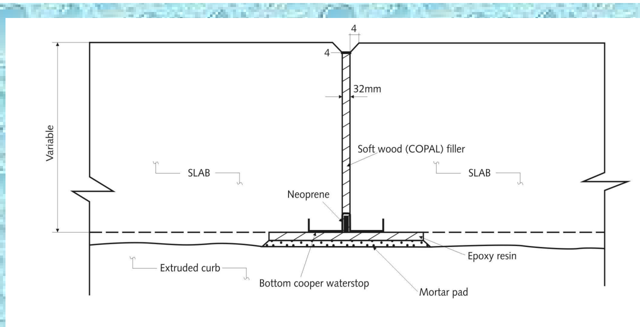


Figure 2 Compressive vertical joint surface waterstop (mm)

Bakun CFRD , slab center part

Ref. : Tan Long, O. Bandeira, H. Kong, 2008_

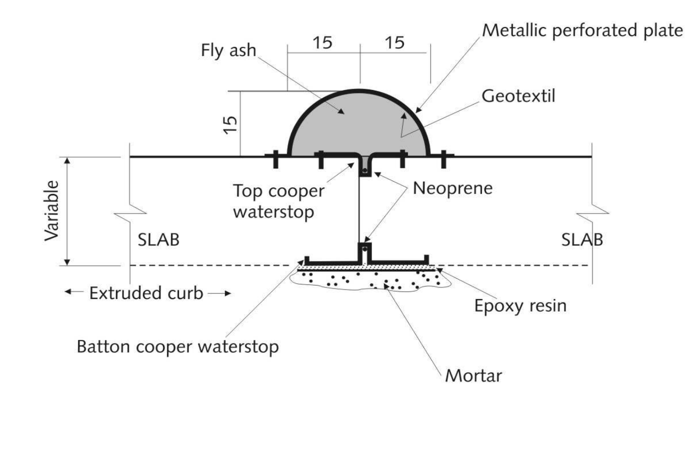


Consortium Gerencial Mazar, courtesy

Mazar CFRD, compression areas

2.(b) Face Slab (main) current design trends (Cont.)

- **Vertical joints (Flexible) in tension and shear areas at abutments**
  - **Tensile Zones – Cases**



Type 4 join (Tension zone)

Mazar CFRD

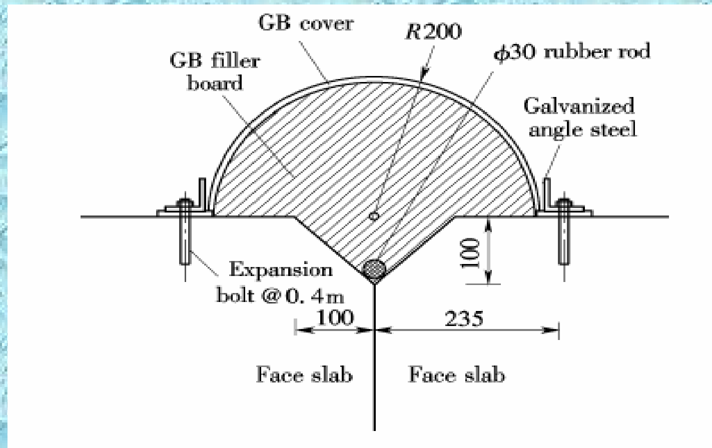


Figure 3 Tensile vertical joint surface waterstop (mm)

Bakun CFRD

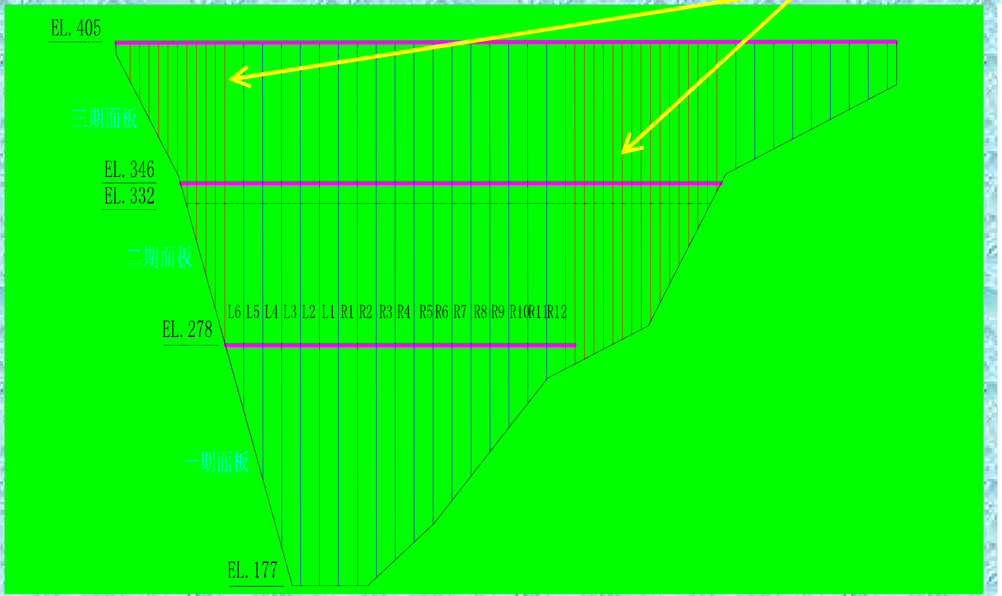
Consortium Gerencial Mazar, courtesy

Ref. : Tan Long, O. Bandeira, H. Kong, 2008_

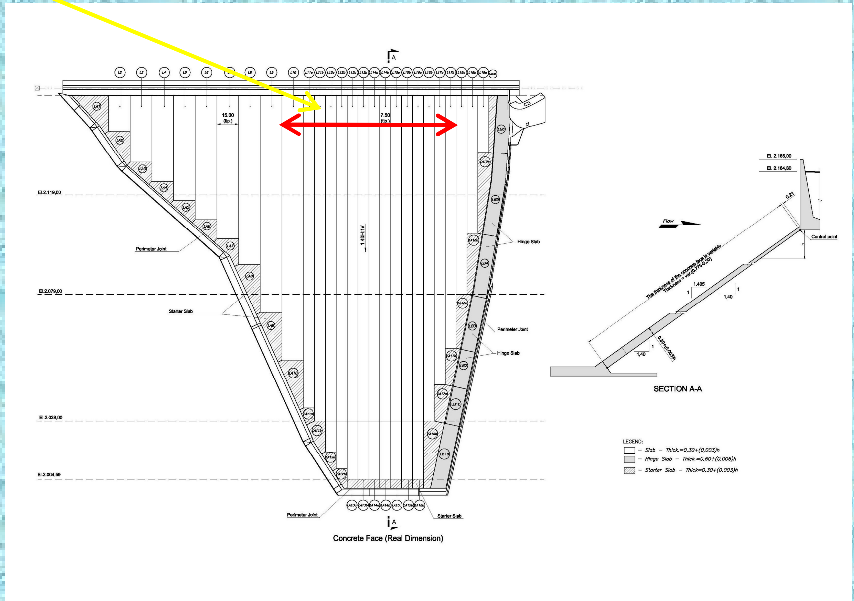
2.(c) Face Slab (main) current design trends (Cont.)

- Split 15 m wide slabs in 7.5 m to mitigate "compression stresses" along vertical joints - Cases :

7.5 m wide slabs areas



Shuibuya CFRD



Mazar CFRD

2.(d) Face Slab (main) current design trends (Cont.)

- **Split 15 m wide slabs in 7.5 m to minimizing "compression stresses" along vertical joints - Cases (cont.) ;**

Humberto Marengo, 2007

El Cajón

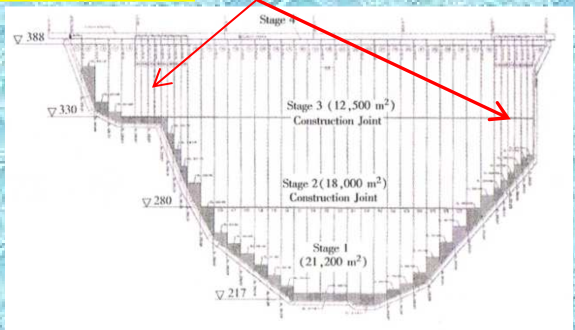
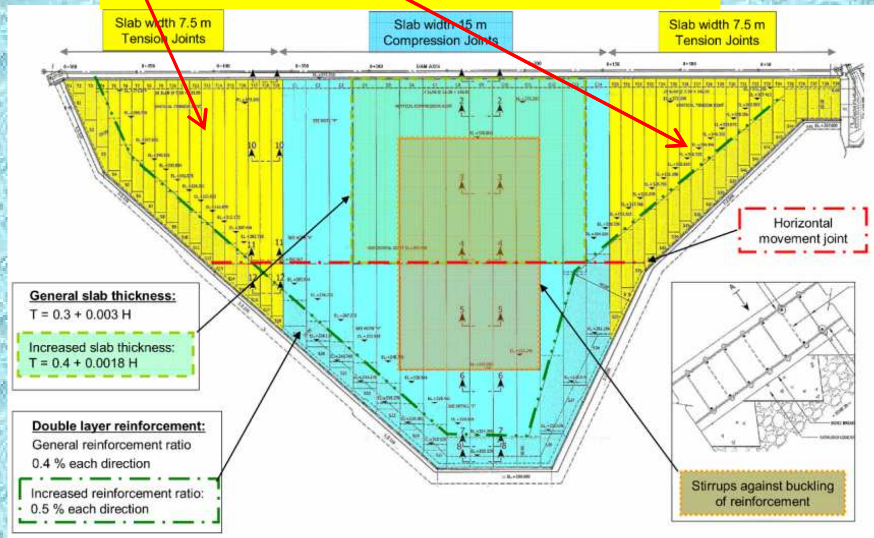


Figure 2 Slipforming stages for the concrete face

Amanda, G; Martinez, R. Chengdu, 2009)

NAM NGUM 2 CFRD 182m , Laos



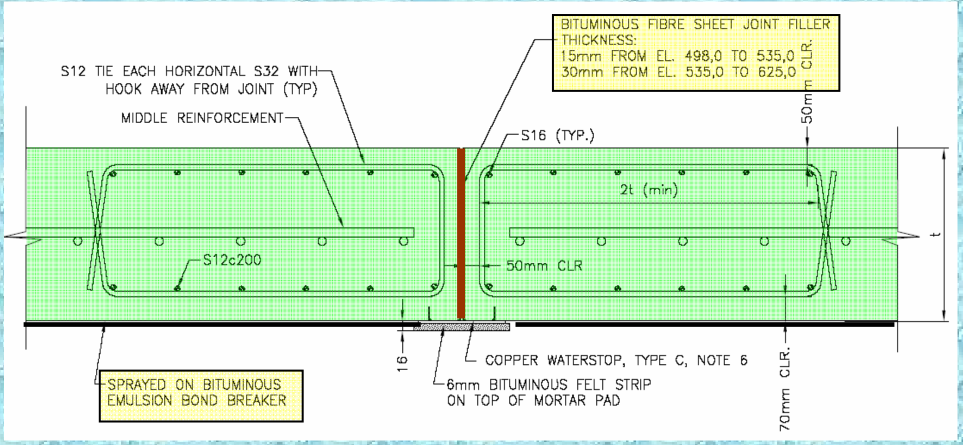
Stephen Moll, R. Straubhaar, Lisbon Feb. 2011

2.(e) Face Slab (main) current design trends (Cont.)

- additional reinforcement, aimed at to protecting

i)anti-spalling effect at slab edges,
ii)negative bending moments and tension cracking and
iii) buckling rebars along vertical joints at center parts

Cases :



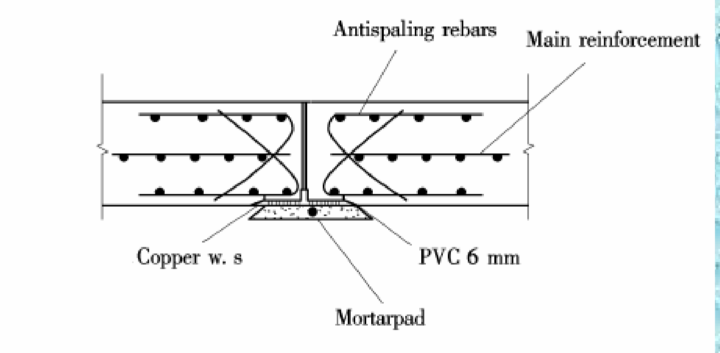


Figure 11 Foz do Areia Typical compression joint

Kárahnjúkar CFRD

Ref.: Björn STEFANSSON, J. KRÖYER Landsvirkjun, Iceland

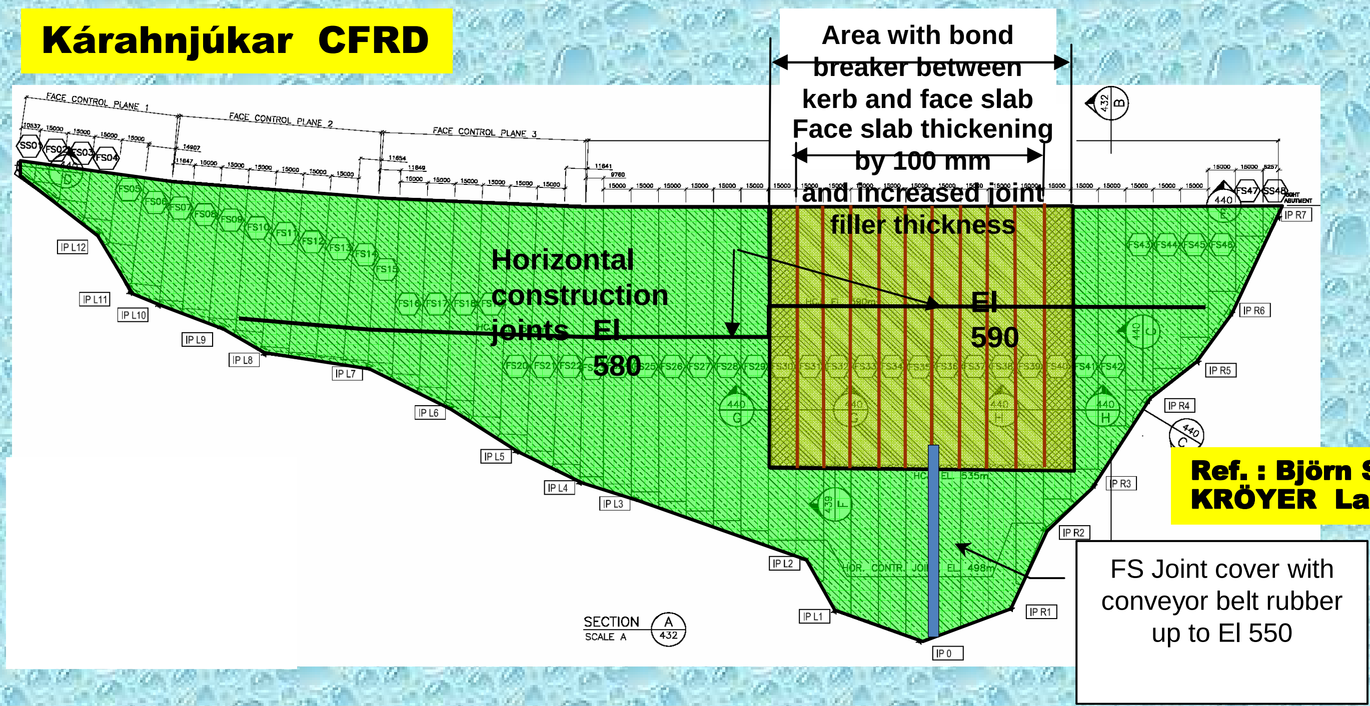
Foz do Areia (1980)
Bayardo, Materon, Chengdu 2009

2. (f)Face Slab (main) current design trends

- **bond breaker and cutting joints into the curb concrete.**

(Bond breaker between slab and curb is " a mitigation issue " and not considered essential , since is not supported by monitoring data and/or deep analytic analysis)

Kárahnjúkar CFRD



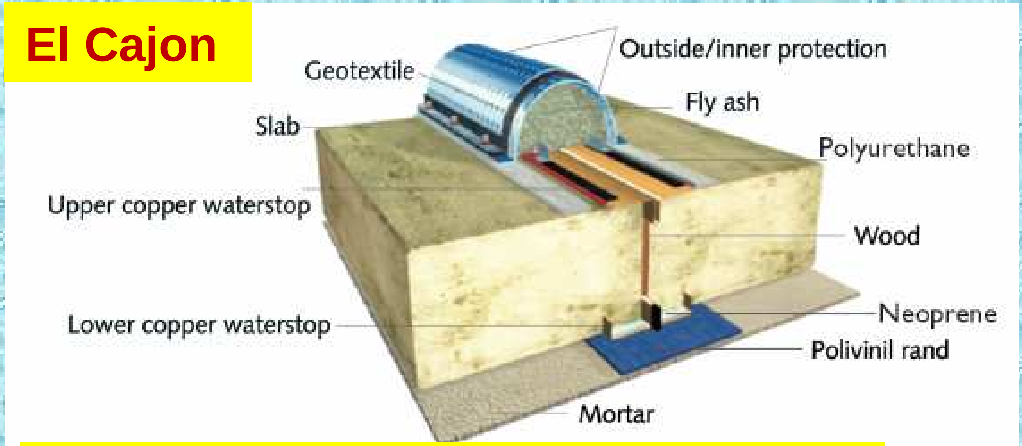
Ref. : Björn STEFANSSON, J. KRÖYER Landsvirkjun, Iceland

3. Perimeter joint current Multiple defense trends :

- corrugated flexible material at steepness abutment areas (Shuibuya, Bakun, Mazar)
- mastique or GB material or fly ash over the perimeter joint
- bottom cooper waterstop and / or top copper waterstop
- anti spalling reinforcement

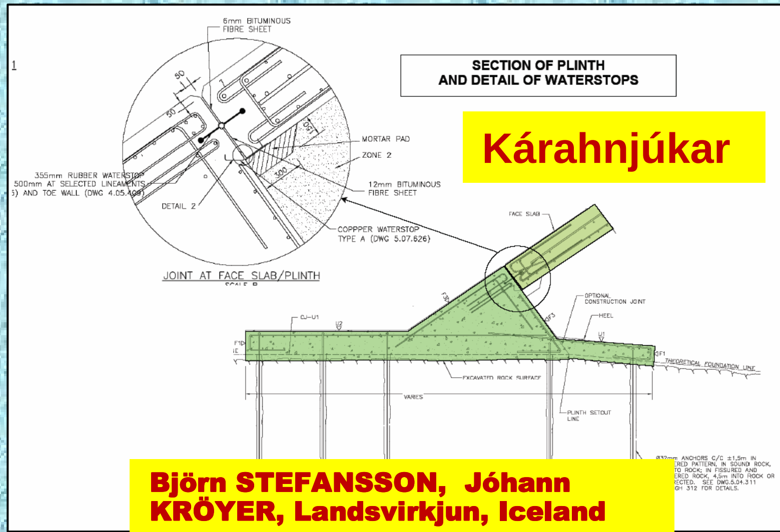
3.(a) Perimeter joint (main) current design trends – Cases:

El Cajon



Perimeter and vertical joint (tension zone – abutments Ref. Mena , Sandoval, 2007)

Kárahnjúkar

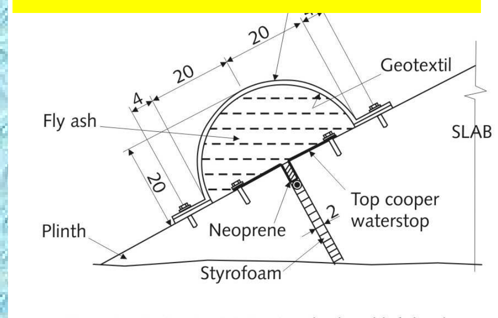


Björn STEFANSSON, Jóhann KRÖYER, Landsvirkjun, Iceland

Shuibuya and Mazar (right abut.)

A) Corrugated joint adopted in Shuibuya (China) and B) Mazar (Ecuador). Courtesy of Consortium Mazar Management.

Mazar (river bed area)



Type 1 - Perimeter joint - river bed and left bank

4. Rockfill : Current construction and design trends

- **At Zones B and C, Modulus Ev construction (>90 Mpa) for rockfill materials (gravel material achieves Ev > 150 Mpa)**

Main current specifications for rockfill high CFRDs:

- **rockfill thickness layers ranged ~ 0.50 m (Zone B and center part) and ~0.80 m(max. at Zone C)**
- **High energy compaction (15 – 25 ton) by heavy vibratory rollers**
- **improving wetting facilities 300 liters /m^3**

5. Additional current design solutions for high CFRDs:

- **During impounding, slab movements induce horizontal compression strain and significant shear tensions at abutments .**

- **3D F E M current analysis have simulated tension zones and flexion-compression and potential risks of failure at central part or abutments**

Additional design measures were adopted to mitigate and to avoid risks of slab failure at central part and at tension zones :

- **delay slab construction until rockfill settlement rate ranged 4 – 5 mm/month (Bakun, Shuibuya)**

- **Add a border slab at steep abutments (Mazar , right abutment)**

- **increase upsteam fill (zones 1A and 1B) around 50% the maximum dam height (Bakun)**

6. Design and Construction Issues for future extra high (> 250 m) CFRDs:

- **EPDM or GB are excellent synthetic materials and good alternatives as copper waterstops, in vertical joints and perimeter joint**

Advantages : → Easy manufacturing, Quality control, Easily shipping and delivery at site

and must be deeply considered to increase its application for future extra high CFRDs. → GB corrugate flexible (IWHR) is a good option for tensile zones.

- **Intense instrumentation and monitoring programs by expert engineers must be carried on to support F E M analysis and new design trends**

- **From international construction practice, slabs 15 m or 16 m wide must still be used commonly, for slipping form works.**
- **Splitting 7.5 m wide slabs in several areas (central parts, both abutments) brings more material, time and costs, and must be supported by a good F EM analysis and trust prototype monitoring data.**

- **For practical and save costs purpose, the Constructor is preferable to decide how many slab stages be implemented (two, three or only one phase), based on the construction schedule and civil works Contract bench marks, in authors' view.**

Thanks for your Attention !!!!!