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THE APPLICATION OF RCC IN SOUTH AFRICA

by

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Introduction

Introduction

- RCC application at Willow Creek Dam (USA, 1975) and Tarbela Dam (Pakistan, 1974-86) made South African aware of RCC and its potential
- First experiments with RCC at Kwena Dam in 1978
- First 3 dams under construction in 1986:
  - South Africa: Zaaihoek Dam and De Mistkraal Weir
  - Leboa Government: Flag Boshielo Dam (formerly Arabie Dam)
- Success with initial dams paved way for further RCC dams
- Today there are 27 dams in South Africa where RCC has been used
- It is the purpose of this talk to show how RCC design and construction techniques were developed for dams in South Africa and how its use has since been extended

Historical development of DWAF design standards for RCC dams

First trials at Kwena Dam (1978)

Main goals:

- Establishing workable RCC and bedding layer mixes
  - Three stone sizes
  - Use of cement replacements such as MGBFS
- Establishing most suitable plant for RCC placing and compaction
- Testing of hexagonal precast concrete panels as permanent formwork
  - Disadvantages found greater than advantages
  - Not used again for any dam to date
- Experience gained with RCC provided confidence to design and construct first "**all RCC**" dams, viz. Zaaihoek Dam & DE Mistkraal Weir.

Kwena Dam
Precast hexagonal panels
BOMAG

RCC and bedding layer mix specifications

Initial RCC mix proportions

Material	Zaaihoek	De Mistkraal	Flag Boshielo
Cement	30% OPC & 70% MGBFS Total = 120 kg/m^3	30% OPC & 70% PFA Total = 116 kg/m^3	OPC - -
Stone (mm)	9.5-19, 19-38, 38-76	9.5-19, 19-38, 38-76	4.75-76 (open graded)
Sand	Pit sand & Crusher sand	Pit sand & Crusher sand	Pit sand & Crusher sand

Initial facing concrete mix proportions

Cement type:	50% OPC and 50% MGBFS or PFA
Cement content:	230 to 260 kg/m^3
Stone sizes:	9.5 – 19 mm, 19 – 38 mm, 38 – 76 mm
Sand:	Blend of pit and crusher sands

Initial bedding layer mix proportions

NB: Bedding layers applied in thickness of 75 mm

Mix: Same as for facing concrete but with +38 mm stone removed

Problems experienced:

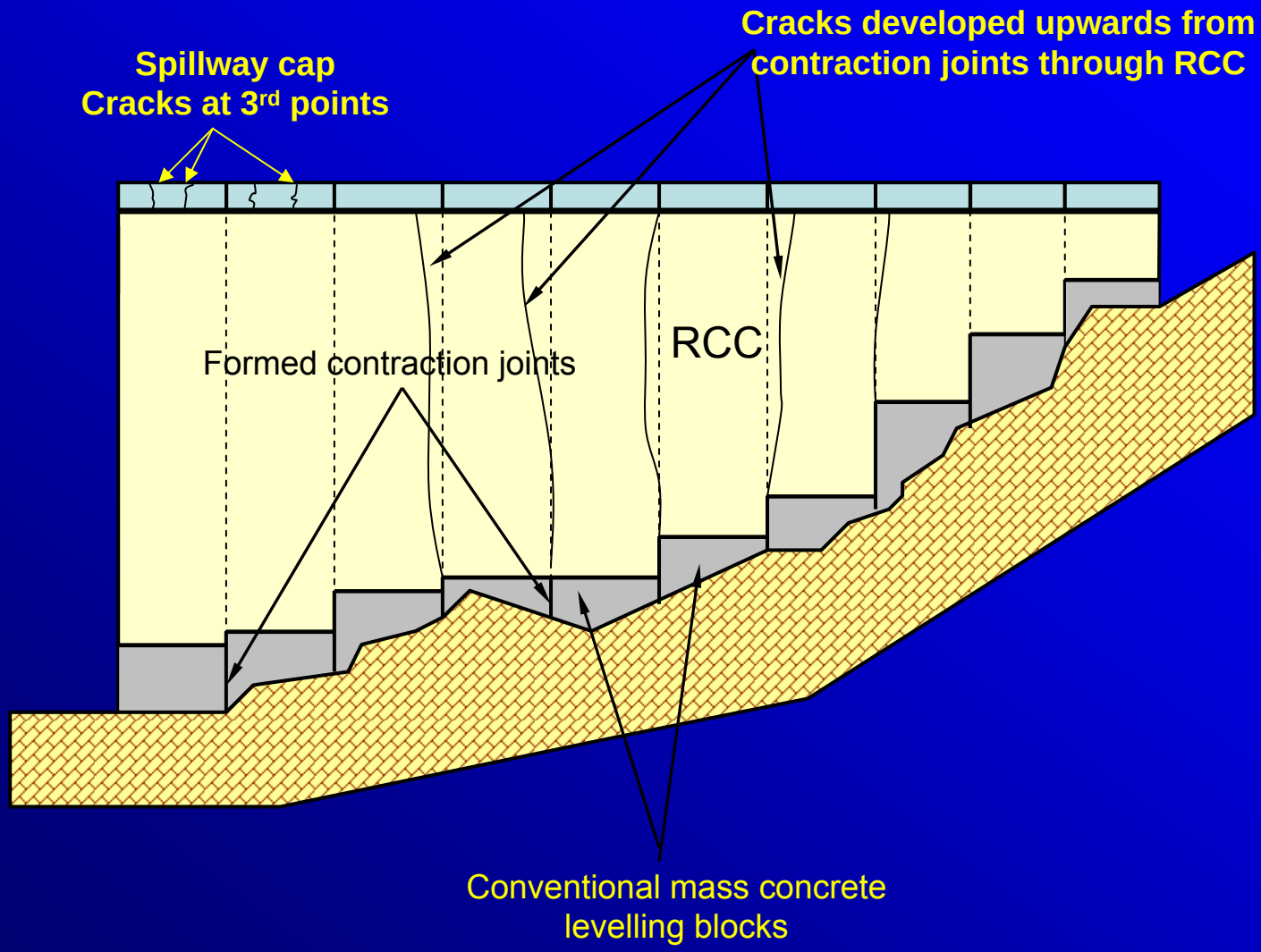
- 38 – 76 mm stone too big and caused segregation
- 75 mm thick bedding layers caused pumping of RCC layer above

Changes made for future dams:

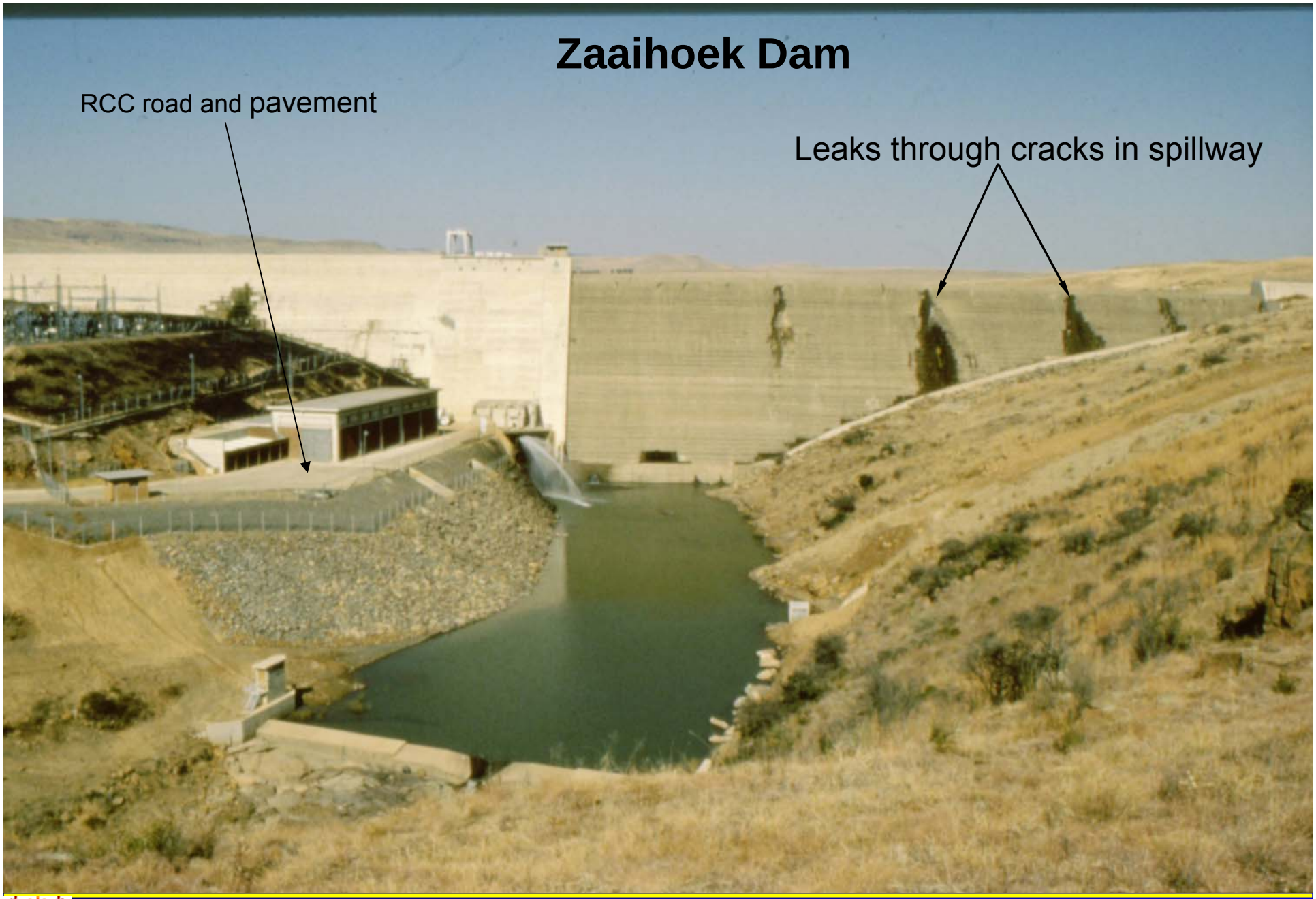
- Max. stone size for RCC and facing concrete limited to 53 mm
- Total cementitious material content for RCC increased to 150 to 200 kg/m^3
- Bedding layer thickness reduced from 75 mm to:
  - 25 mm for class 20/19 (MPa/stone size) concrete
  - 10 mm for mortar

Crack control

Zaaihoek Dam crack development



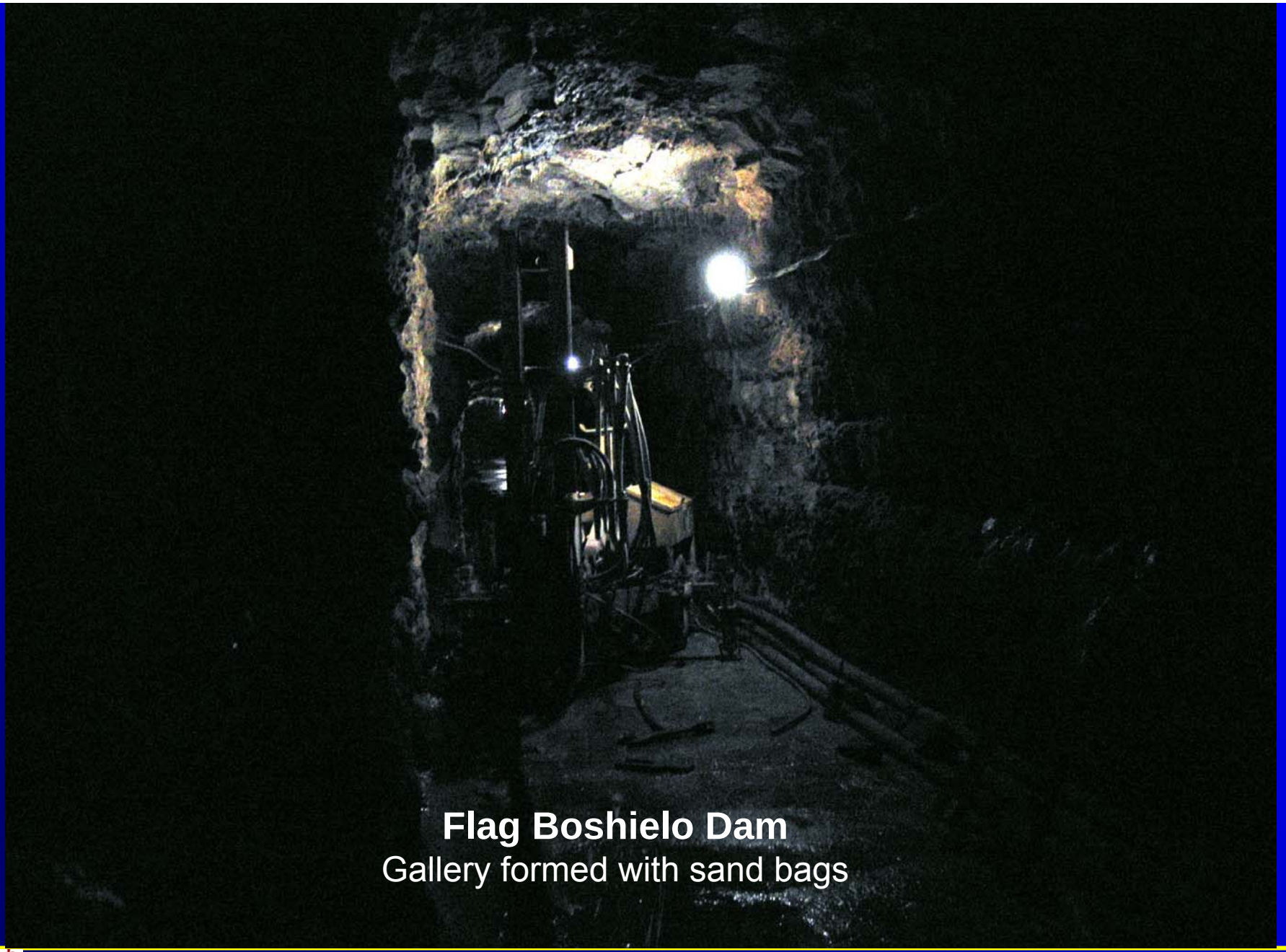
Zaaihoek Dam



Galleries

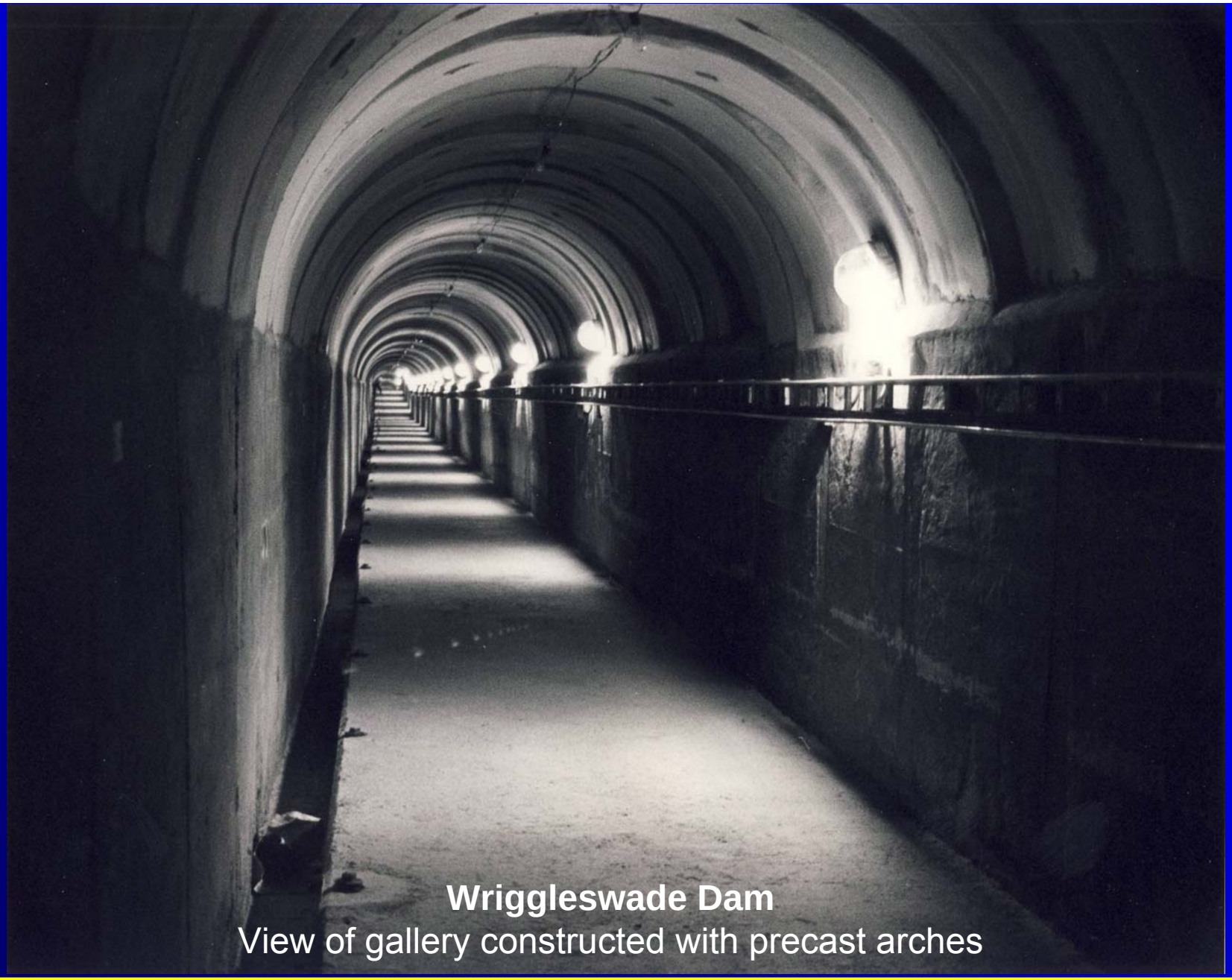
Zaaihoek Dam

- Gallery in spillway formed with crushed stone and timber planks
- Results very unsatisfactory:
  - Stone removal a very slow and costly process
  - Gallery wall and roof finish very poor
  - Gallery lights gave a poor illumination
  - Gallery upstream wall sometimes too close to upstream face of dam
- Rest of dam's gallery formed with formwork
- Results very good:
  - Distance to upstream face of dam controlled
  - Wall and roof finish very good
  - Good illumination obtained from gallery lights
  - Sloping galleries easily constructed
- Decision: Future galleries all to be constructed with formwork and precast arches



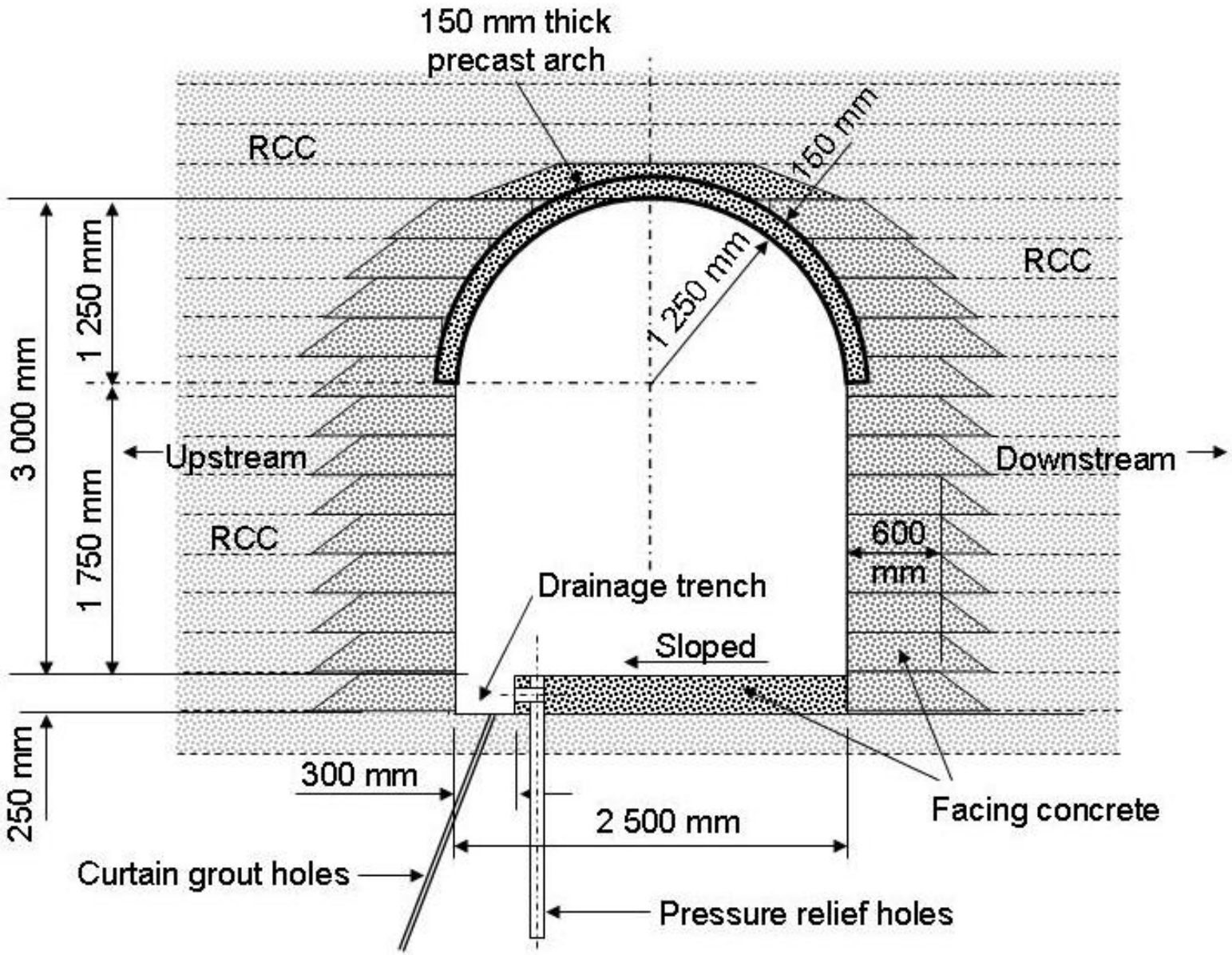
Flag Boshielo Dam

Gallery formed with sand bags



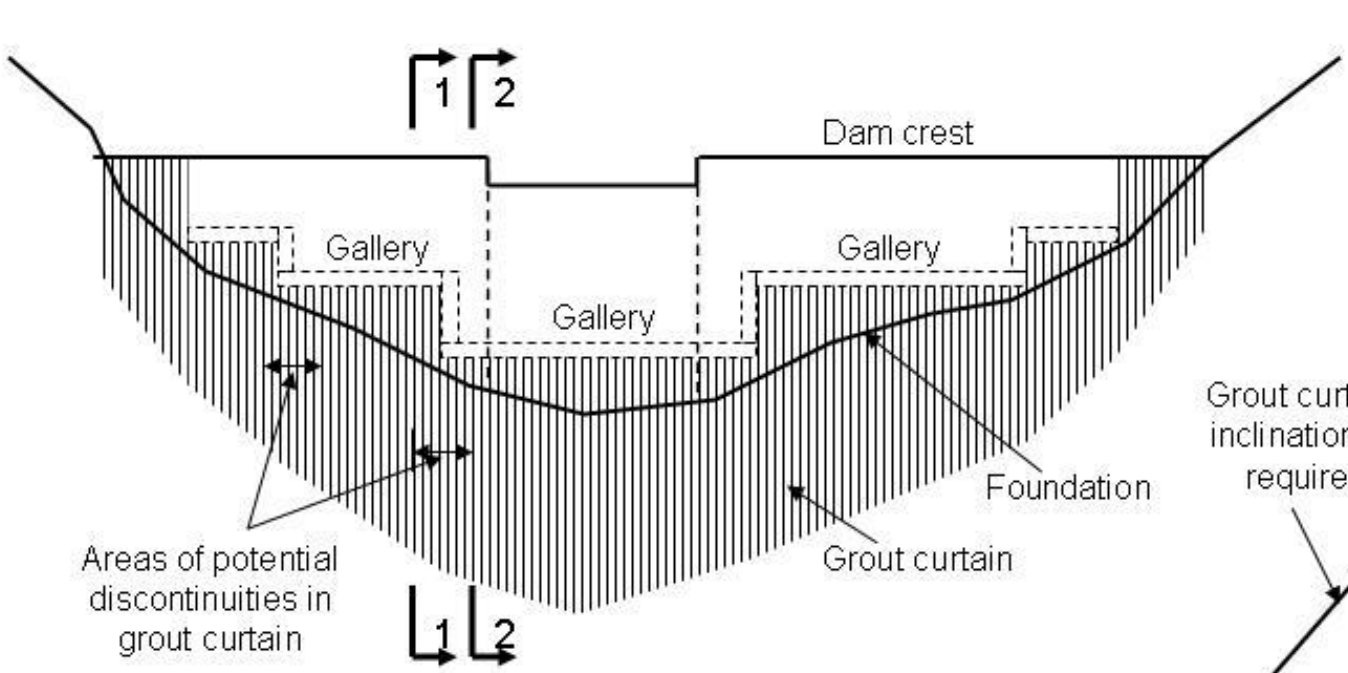
Wriggleswade Dam

View of gallery constructed with precast arches

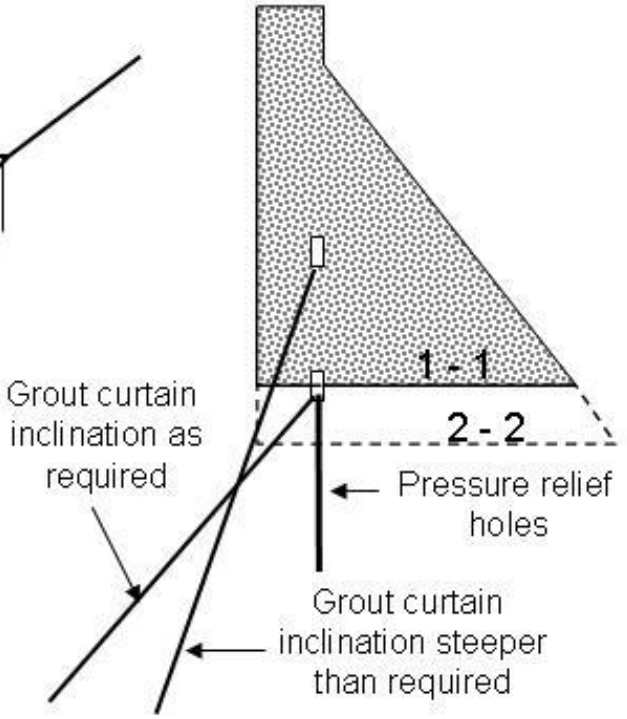

150 mm thick
precast arch
RCC
150 mm
RCC
1 250 mm
1 250 mm
3 000 mm
1 750 mm
Upstream
Downstream
RCC
600
mm
Drainage trench
Sloped
250 mm
300 mm
2 500 mm
Facing concrete
Curtain grout holes
Pressure relief holes

Problems with horizontal galleries

- Anomalies with grout curtain
- Not quickly accessible for drilling and grouting

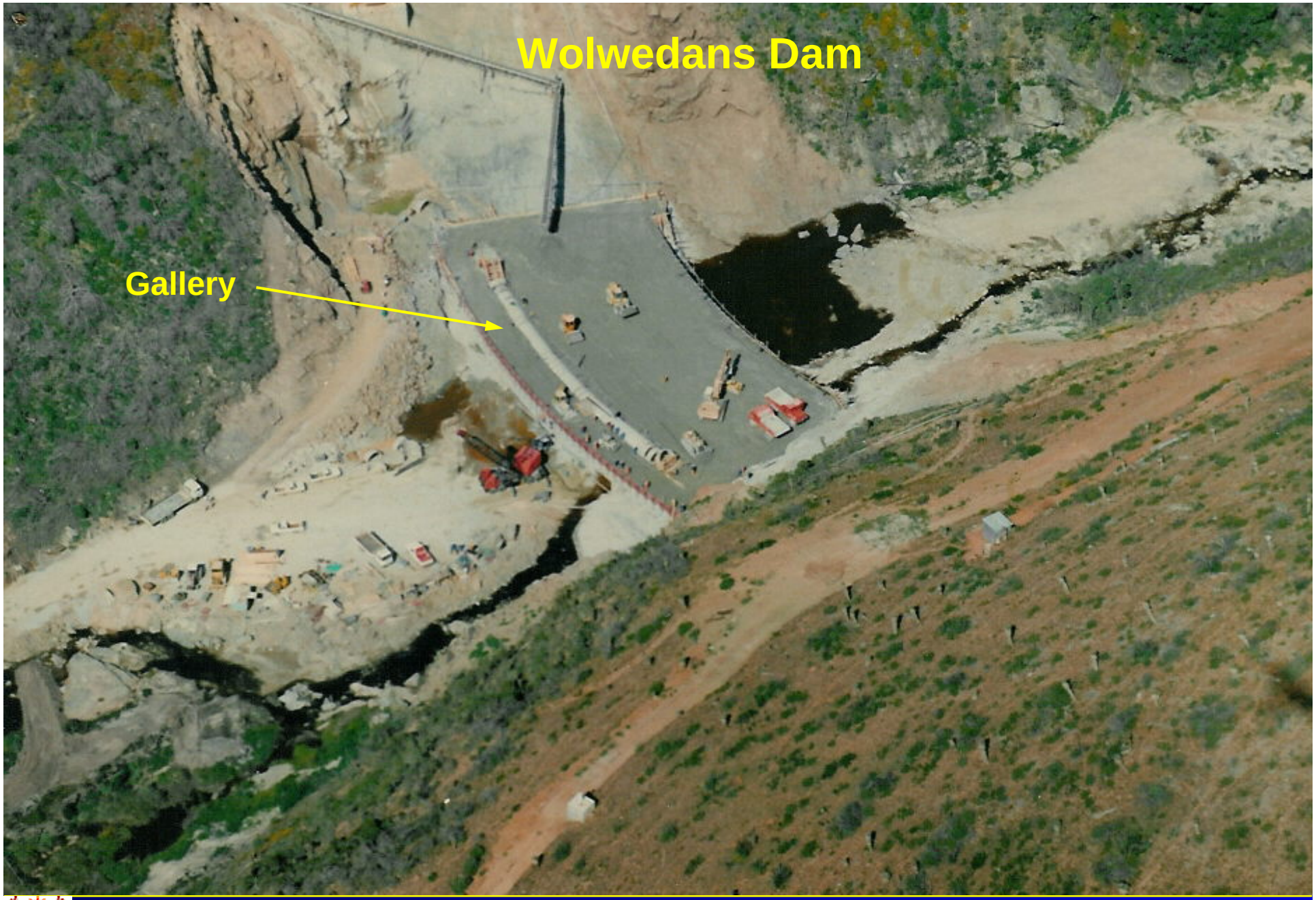


UPSTREAM ELEVATION OF DAM



SECTIONS 1 – 1 & 2 - 2

Wolwedans Dam

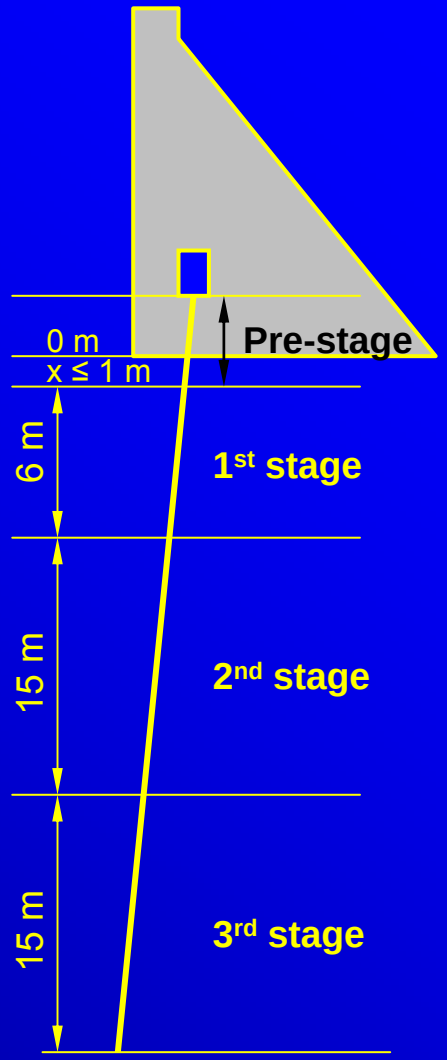


Wolwedans Dam
Gallery
Gallery

Foundation grouting

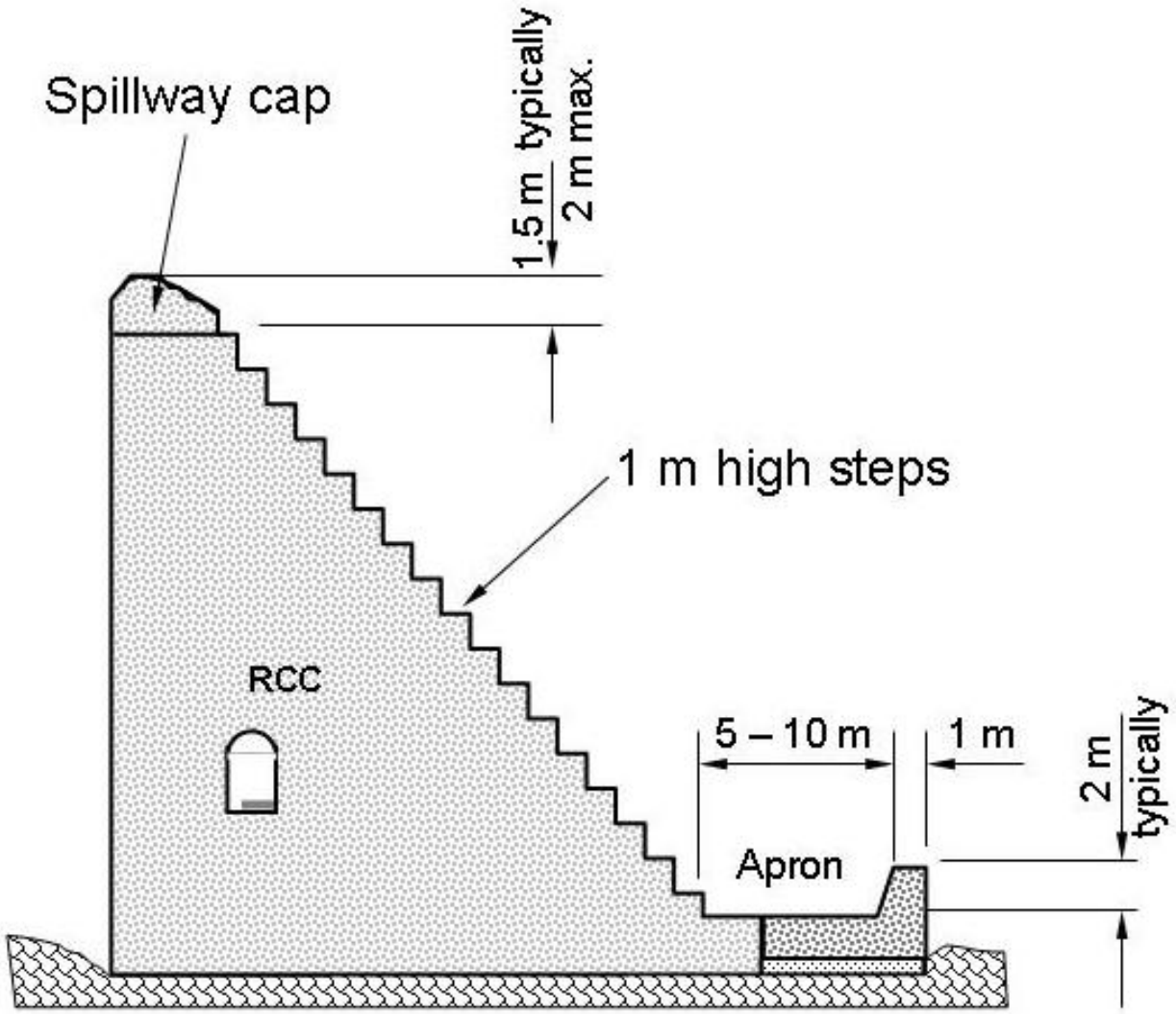
Zaaihoek Dam:

- Dam has very tight and solid dolerite foundations
- Downstage grouting done from drainage gallery
- High Lugeon values and grout takes with 1st stage
- Low Lugeon values and grout takes with 2nd and 3rd stages
- Elsewhere in dam high Lugeon values in RCC
- Problem not the rock, but the RCC above rock
- Solution: "Pre-stage grouting"



Spillways

- Almost all large dams provided with 1 m high steps:
  - Ease of construction
  - Energy dissipation
  - Ease of inspecting and working on downstream face
- 1 m high steps correspond to 4 x 250 mm compacted RCC layers
- Steps formed with facing concrete with 28-day strength of 20 MPa
- Spillways hydraulically modeled to check behaviour - De Mistkraal
- Special ogee spillway caps developed for steep sloped gravity dams
- Downstream apron varies from 5 to 10 m in length – saving of concrete
- Small weirs – steps usually correspond to RCC layer thickness
- To date all stepped spillways are still in very good condition

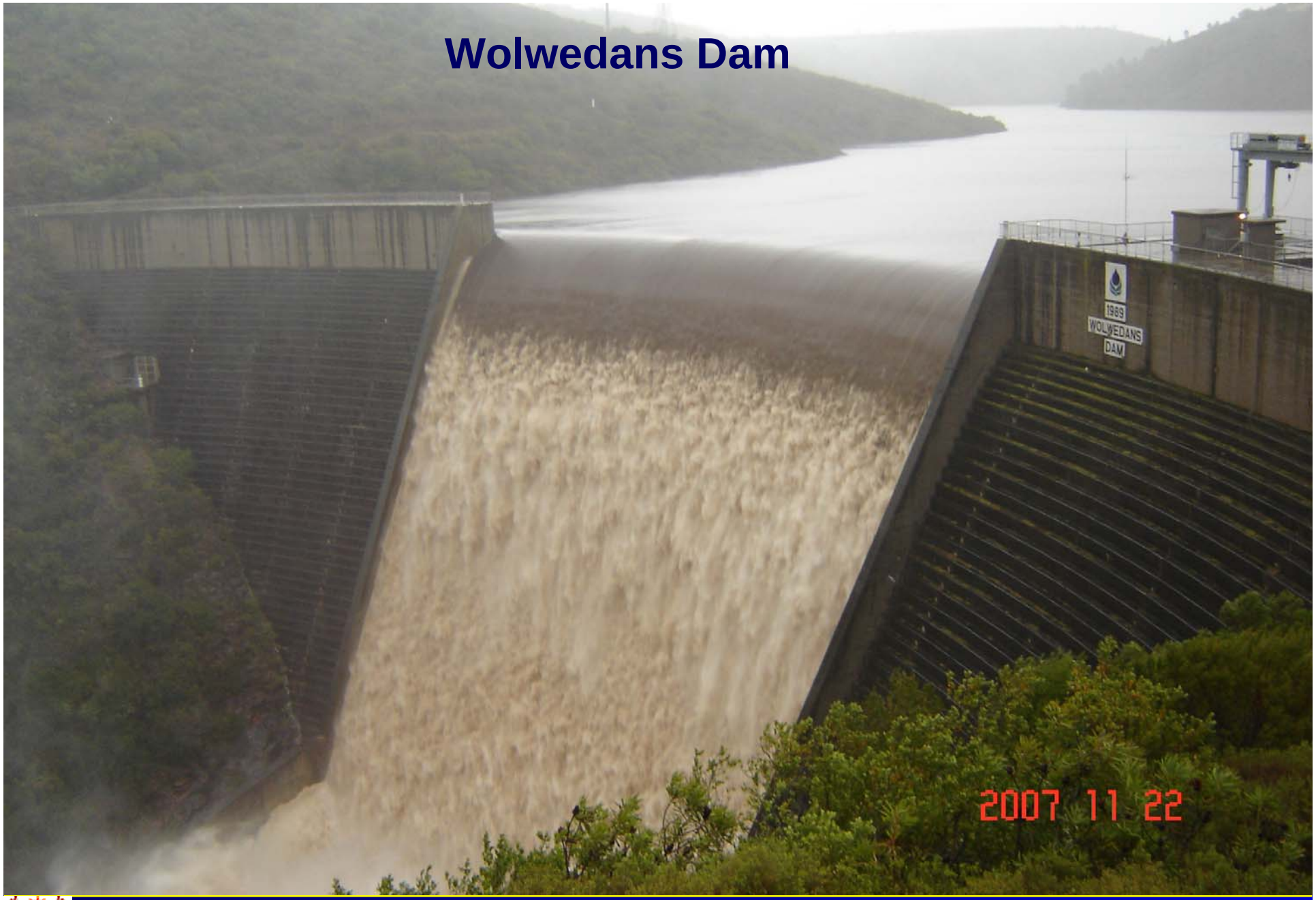


TYPICAL SPILLWAY ARRANGEMENT

Wriggleswade Dam

Wolwedans Dam

Wolwedans Dam

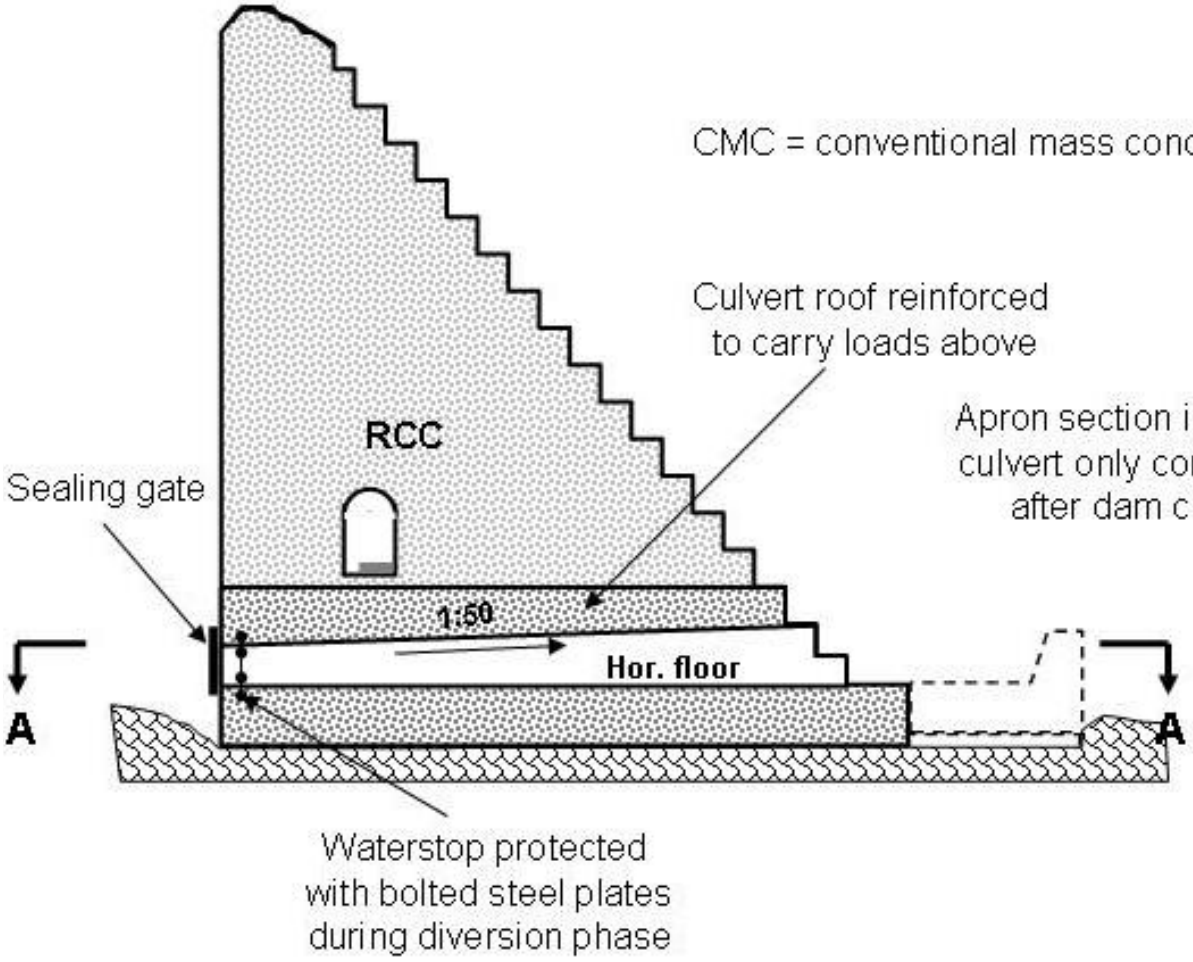


River diversion

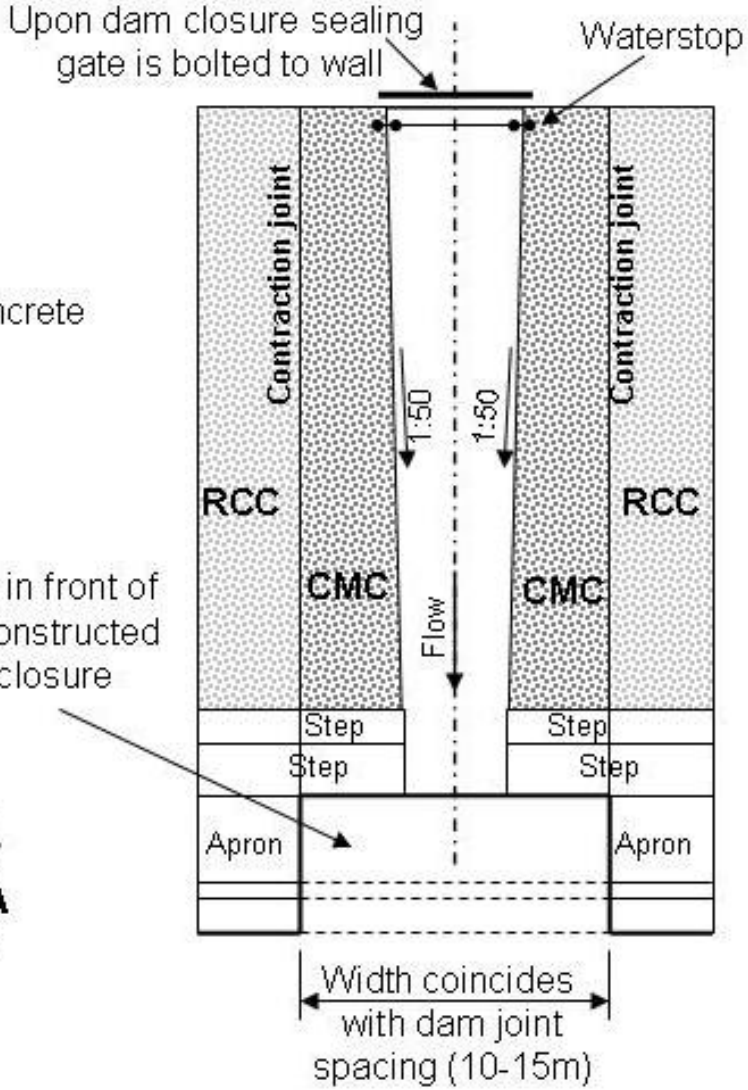
- Flow of South African rivers generally seasonal
  - Wet season: High low flows with occasional major floods
  - Dry season: Low flows generally low – some rivers dry up
- River diversion usually constructed during end wet season / start dry season
  - Very low embankment coffer dams built to isolate diversion structure
  - Small rivers: Pipe through dam wall may suffice
  - Large rivers: One or more fair size culverts constructed in mass concrete
- RCC placed across river during dry season to a safe height above river bed
- Major floods allowed to pass over RCC as no damages are incurred
- As wall rises, the discharge capacity of the culverts increase and risk reduces
- Culvert finally sealed with self-compacting flow-concrete injected from downstream end of culvert

Note:

1. Culvert roof and walls provided with facilities for cavity grouting.
2. Dam closure achieved with self-compacting flow-concrete pumped into culvert from downstream end.



SECTION THROUGH DAM AND DIVERSION CULVERT



SECTION A-A

Interesting applications of RCC in South Africa

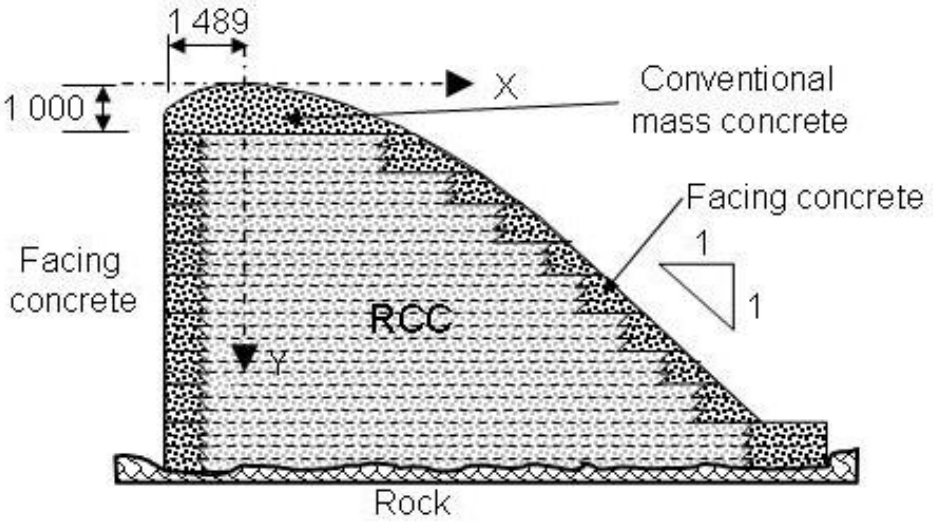
Weirs (H <15 m)

- Several RCC weirs have been constructed in South Africa during 1986 to 1996
  - By DWAF (e.g. Sabie, Crocodile, Olifantspoort & Neusberg)
  - By private owners (e.g. Groenvlei, Zaaiplaas, Elandsvlei, Waterkloof & Paxton)

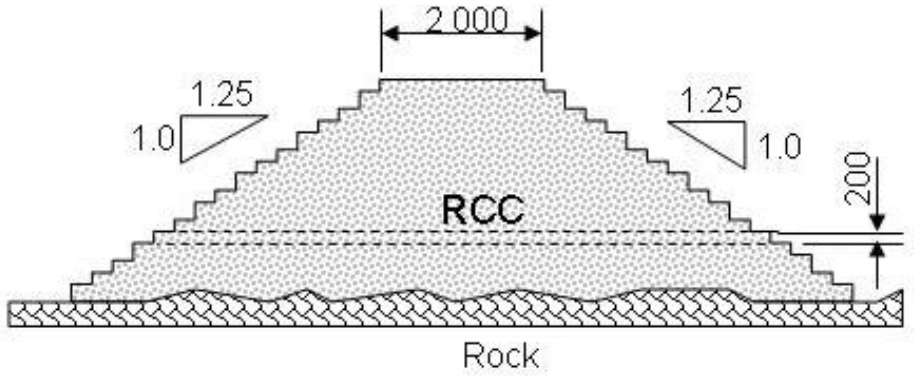
- Private weirs:
  - Small plant (e.g. plate compactors, wheel barrows, small mixers, etc.
  - Aggregates usually local material and not necessarily of high quality
  - Considerably labour intensive
  - Mostly conventional design

- DWAF weirs:
  - Small and large plant used depending on size of weir
  - High quality material generally used
  - Less labour intensive
  - Different design approaches taken (e.g. trapezoidal cross-sections, flat ogee, etc)

Weirs (heights <15 m) *(continued)*



NEUSBERG WEIR: CROSS-SECTION



CROCODILE WEIR: CROSS-SECTION

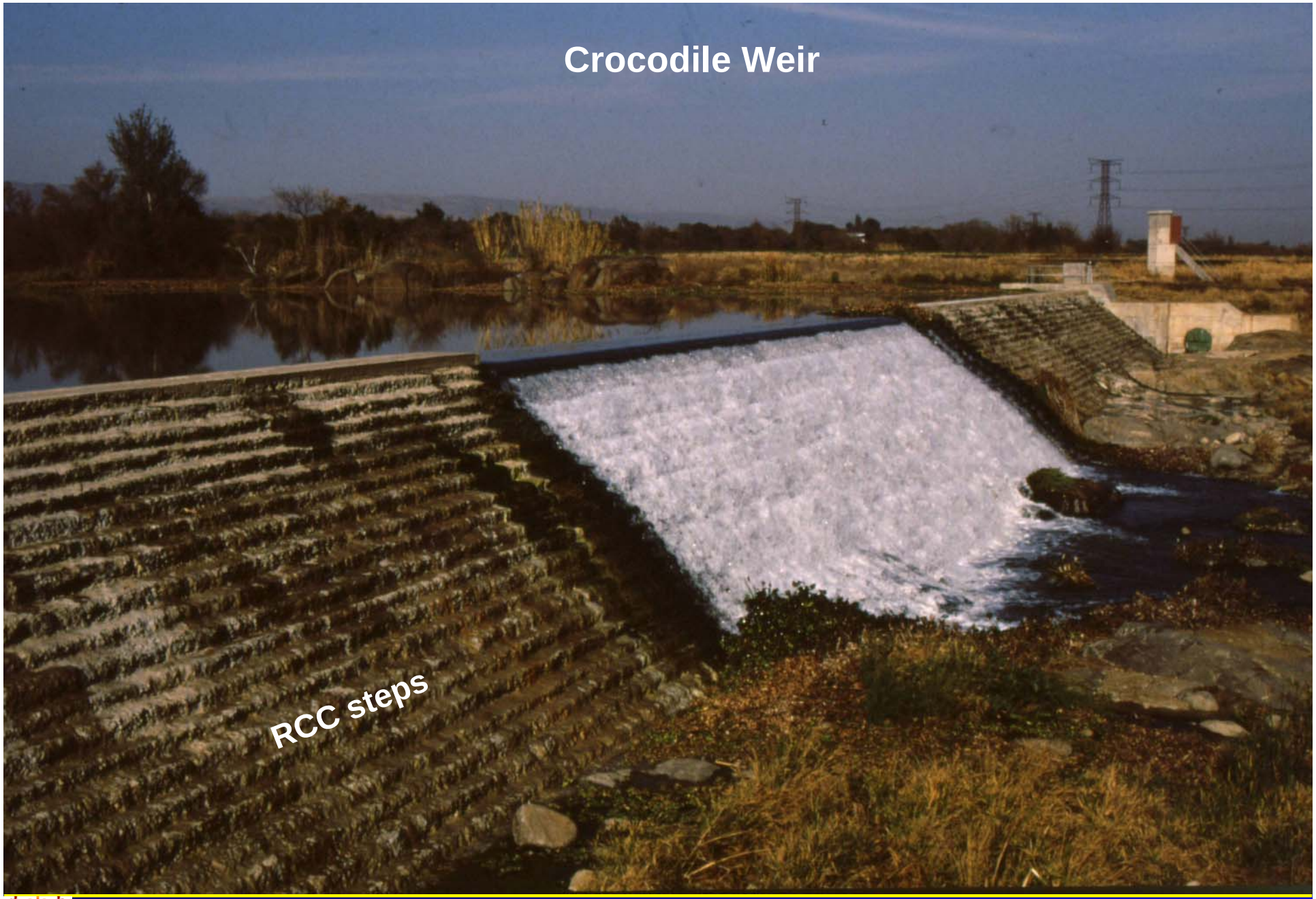
Neusberg Weir

River:	Orange
Length:	960 m
Max. height:	14 m
Average height:	5 m
Spillway notches:	3
Diversion culverts:	4

Crocodile Weir

River:	Crocodile (West)
Length:	155 m
Max. height:	7 m
Average height:	6 m
Spillway notches:	1
Diversion pipe:	1

Crocodile Weir



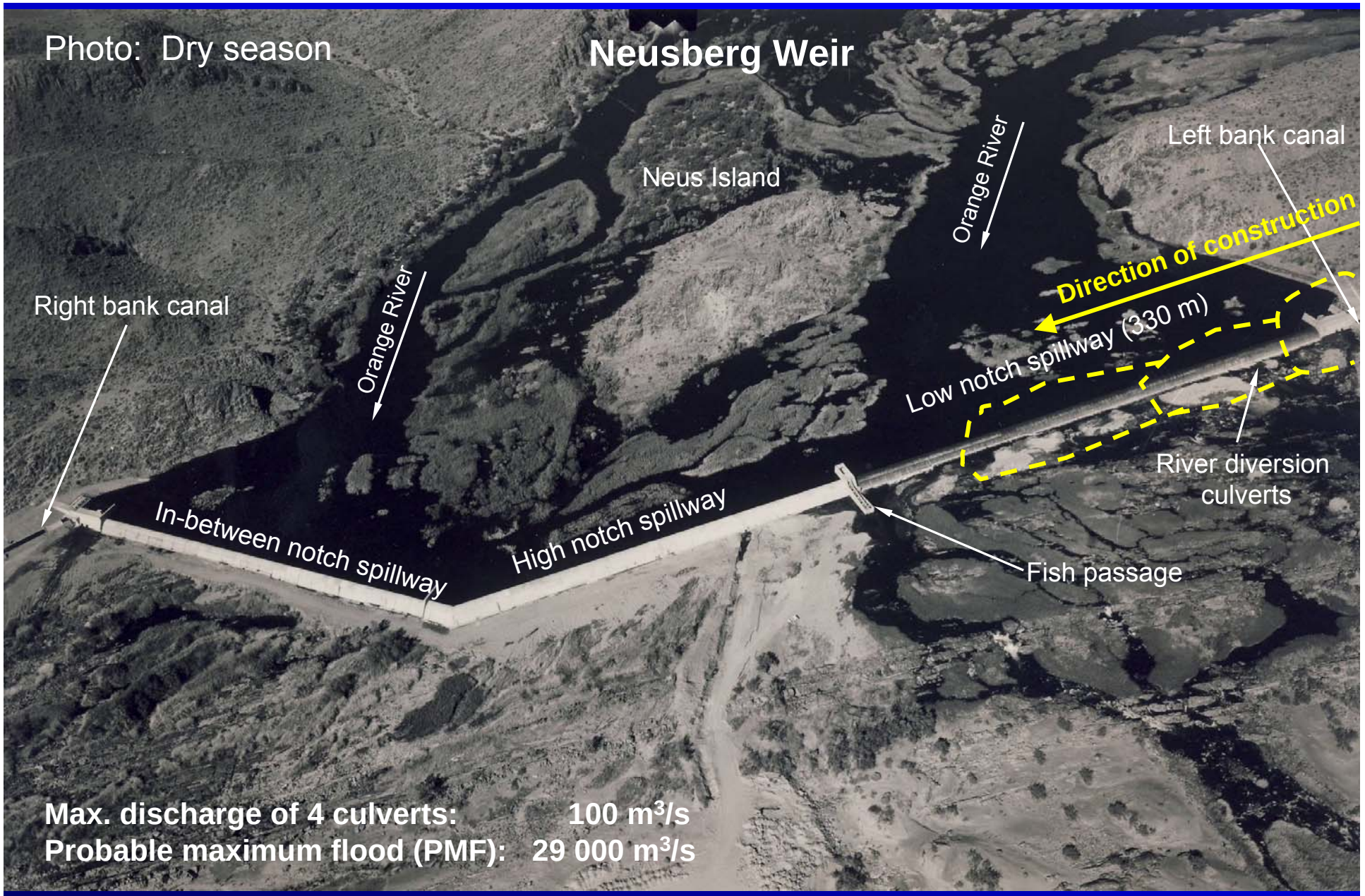


Photo: Dry season
Neusberg Weir
Neus Island
Orange River
Left bank canal
Direction of construction
Low notch spillway (330 m)
Right bank canal
Orange River
River diversion culverts
In-between notch spillway
High notch spillway
Fish passage
Max. discharge of 4 culverts: 100 m³/s
Probable maximum flood (PMF): 29 000 m³/s

Flood attenuation dams

To date two flood attenuation dams have been constructed in South Africa:

- **Qedusizi Dam**: A dam to protect the town of Ladysmith, Kwazulu-Natal Province, from frequent floods of the Klip River which runs through the town
- **Botterkloof Dam**: A dam to prevent bank erosion of the Ash River caused by varied tunnel discharges from the Muela Power Station in Lesotho
- Both dams have been provided with uncontrolled outlets within the dam wall.

Qedusizi Dam (*"End of suffering"*)

- The town of Ladysmith is frequently flooded by the Klip River that runs through town
- The river can only accommodate a discharge of 450 m^3/s before it bursts its banks
- Flooding of the town results in loss of life and incurs great economic losses for the town and its people
- The Qedusizi Dam has been proposed to protect the town against all floods up the 1:100 year flood
- The dam site is ideal (large basin) and only 2 km upstream of the town
- A composite dam with 315 m long central spillway and earth embankment flanks have been proposed
- The dam has been provided with two 3.2 m high x 5 m wide uncontrolled bottom outlets situated in the river section

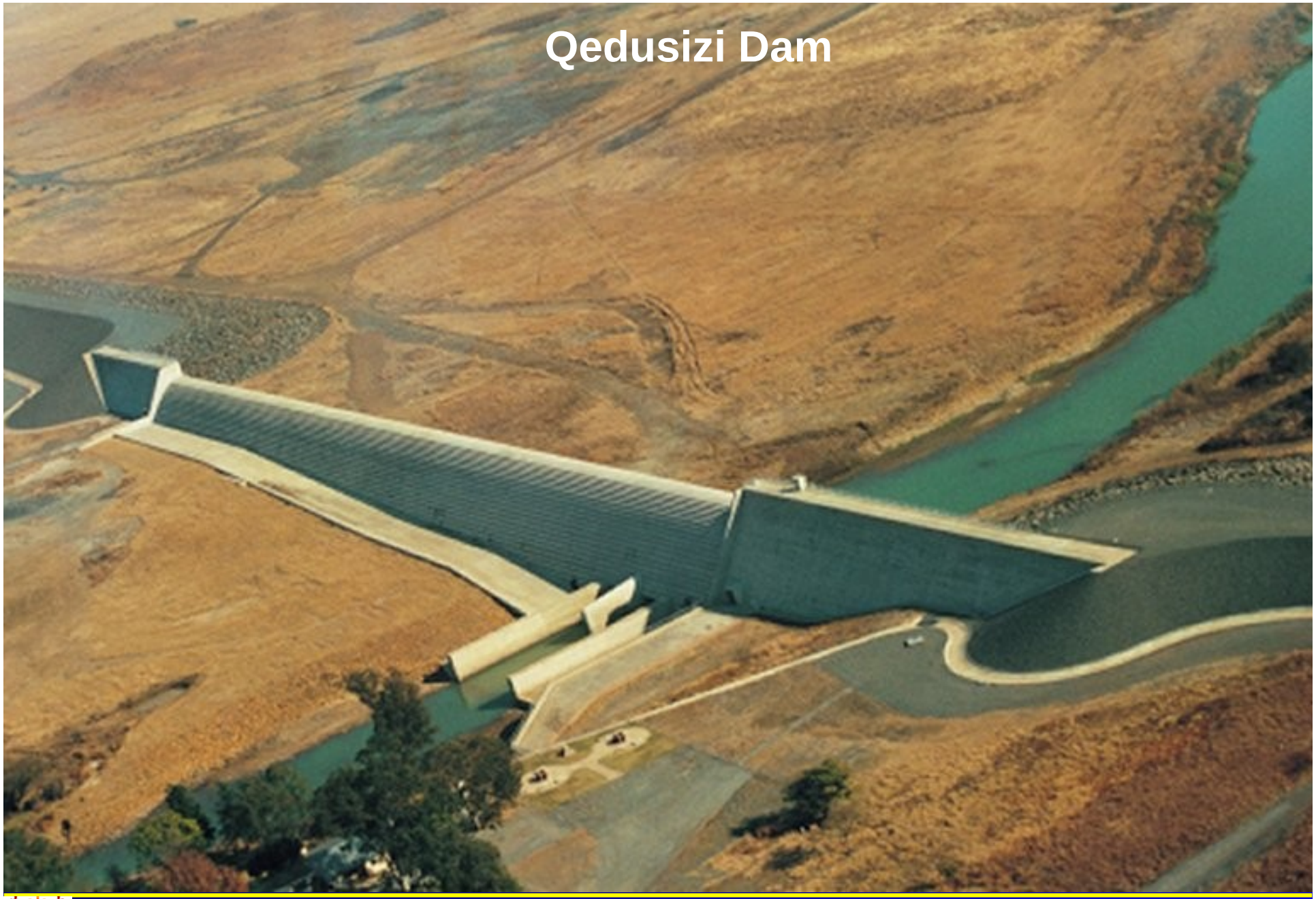
Qedusizi Dam *(continued)*

- With the water level in the dam at spillway crest level, the bottom outlets can discharge 386 m^3/s and ensure that the 1:100 year flood does not overtop the spillway
- Together with a further discharge of 64 m^3/s from an incremental catchment downstream of the dam, the flow of the Klip River is maintained to the allowable maximum of 450 m^3/s
- The max. height of the dam is 32 m and the max. height of the spillway 28 m
- The 315 m long spillway is stepped with 1 m high steps
- Both the spillway and the cut-off walls extending into the embankments have been constructed with RCC because of the speed of construction RCC offered
- The battered cut-off walls have smooth surfaces to allow good compaction of soil against it
- Both the spillway and cut-off walls have been provided with a single gallery

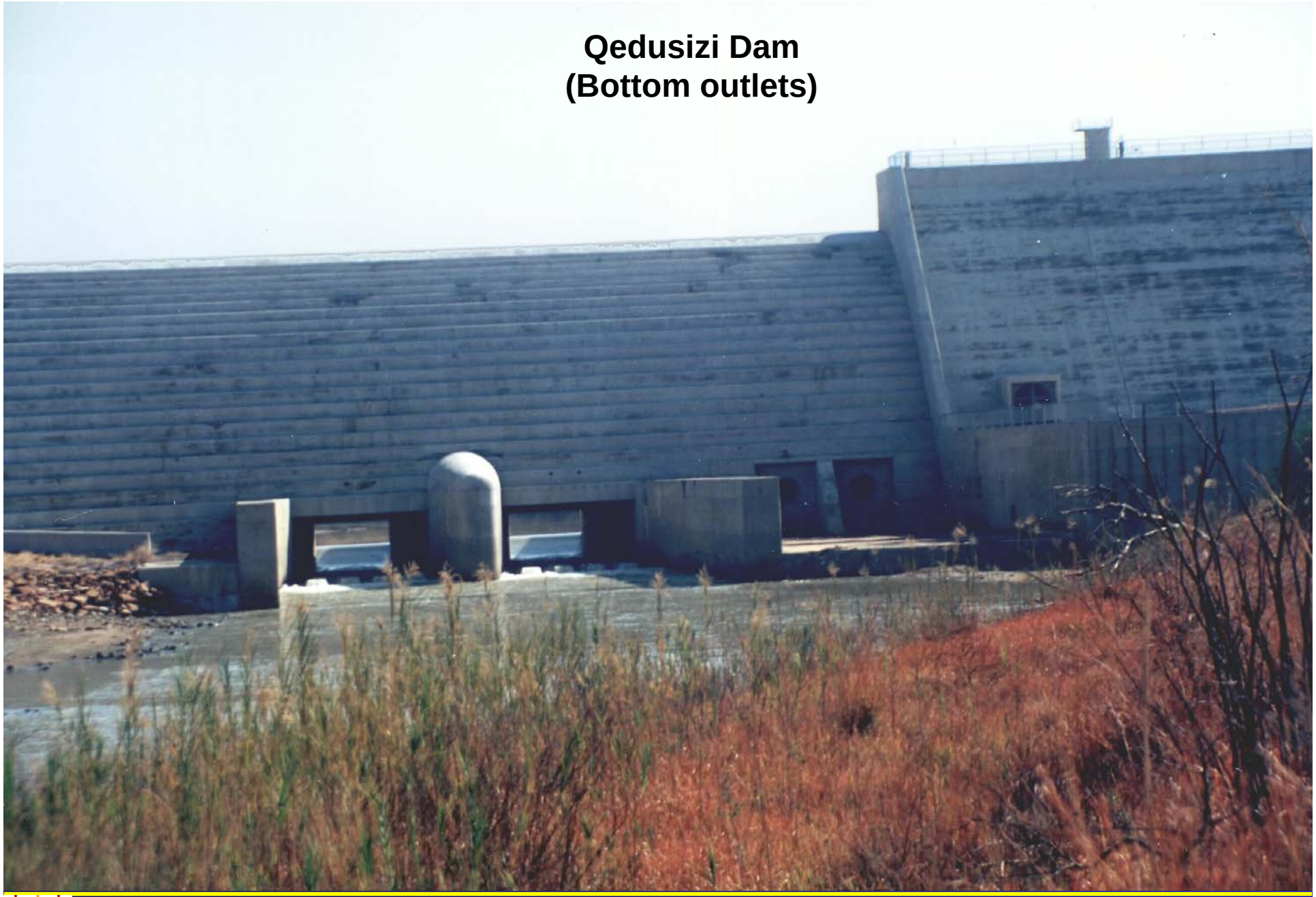
Qedusizi Dam *(continued)*

- The dam has been designed so that it can one day be converted into a storage dam
- The bottom outlets have designed such that water enters it at critical velocity
  - This improves the initial discharge capacity, and
  - Ensures that sediment of smaller floods are pulled through efficiently
- The total volume of concrete is 156 000 m^3 of which 78 000 m^3 is RCC
- The dam has already served its purpose on several occasions since its completion in 1998

Qedusizi Dam



Qedusizi Dam
(Bottom outlets)



De Mistkraal Weir

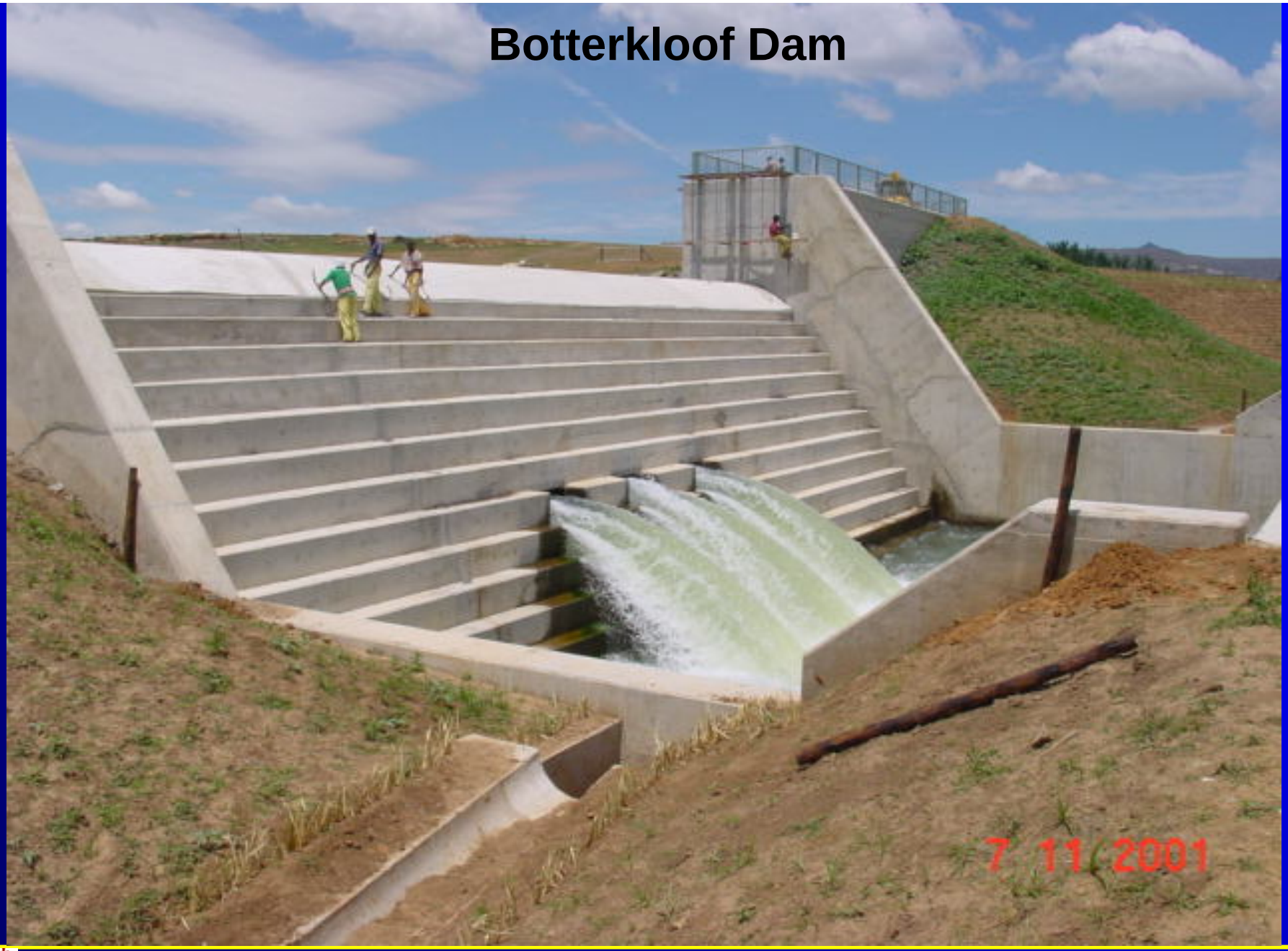
Botterkloof Dam

- The Botterkloof Dam is situated on Ash River, near Clarence, in the Free State Province of South Africa
- It has been built about 1.5 km downstream of the LHWP Northern Supply Tunnel outfall
- The purpose of the dam is to:
  - Stabilize irregular tunnel discharges emanating from the Muela Hydropower Station in Lesotho which causes severe bank erosion of the Ash River and silts up the municipal dam of the town of Bethlehem
  - To dissipate excess energy caused by sudden drop of the river bed
- The composite dam has a 30 m long central RCC spillway with earth embankment flanks
- The 20m long cut-off walls extending into the embankments are also constructed with RCC

Botterkloof Dam *(continued)*

- The spillway is 12.5 m high and the cutt-off walls 16 m
- The spillway is stepped – steps 600 mm high
- Spillway provided with three 1.2 x 1.2 m high culverts 6.5 m below spillway crest
- RCC used for speed of construction because of short tunnel off-period
- Total volume of concrete used is 22 000 m^3 of which 6 200 m^3 is RCC and facing concrete

Botterkloof Dam



Trough spillways for embankment dams

Inyaka Dam

- **Inyaka Dam** is the only dam in South Africa that has a trough spillway constructed with RCC
- The Inyaka Dam is situated on the Marite River, a tributary of the Sabie, near Bushbuck Ridge in the Mpumalanga Province of South Africa
- The dam supplies water to a rural and semi-rural population of 650 000 people, contributes to the environmental flow requirements of the Sabie River and supplies a small amount of water for irrigation
- The central trough spillway was required because founding rock could only be found at shallow depths within the river section of the dam
- The trough spillway has an overall length of 263.1 m of which:
  - The upstream 58 m is a horseshoe-shaped spillway (spillway length 138 m)
  - Followed by a 141.1 m long sloping spillway chute
  - A 64 m long stilling basin

Inyaka Dam *(continued)*

- The dam has a max. height of 53 m and an overall length of 600 m of which 48.5 m is the width of the trough spillway at full supply level.

- The spillway is capable of discharging:
  - 2 850 m^3/s when utilising its 4.6 m freeboard
  - 3 500 m^3/s when the water level is at the top of the 1 m high parapet wall on the crest of the dam wall - only 300 m^3/s less than Q_{PMF} = 3 800 m^3/s

- The trough spillway contains two longitudinal conduits:

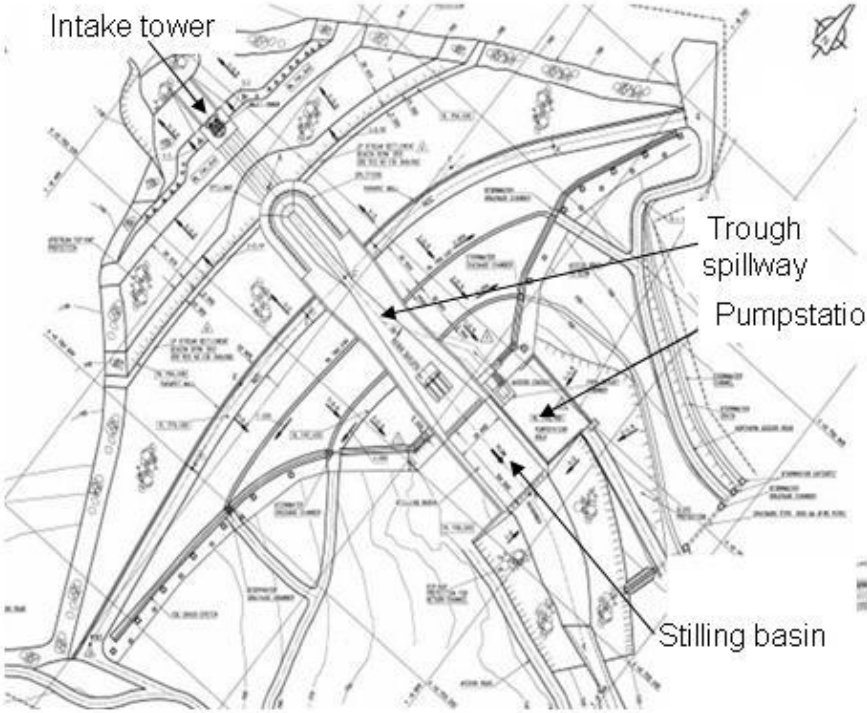
  - A semi-circular river diversion conduit of 12 m dia. in the lower part which is connected to the base of the intake tower 44 m upstream of the spillway, and

  - A semi-circular upper conduit housing the outlet pipes of the dam and also linked to the intake tower - height 4 m and intrados 3.125 m

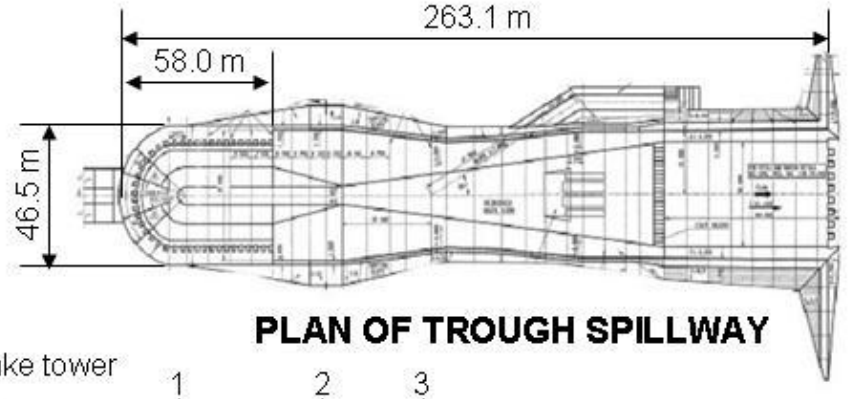
- Diversion capacity of lower conduit was 650 m^3/s – biggest flood experienced during construction was 500 m^3/s

Inyaka Dam *(continued)*

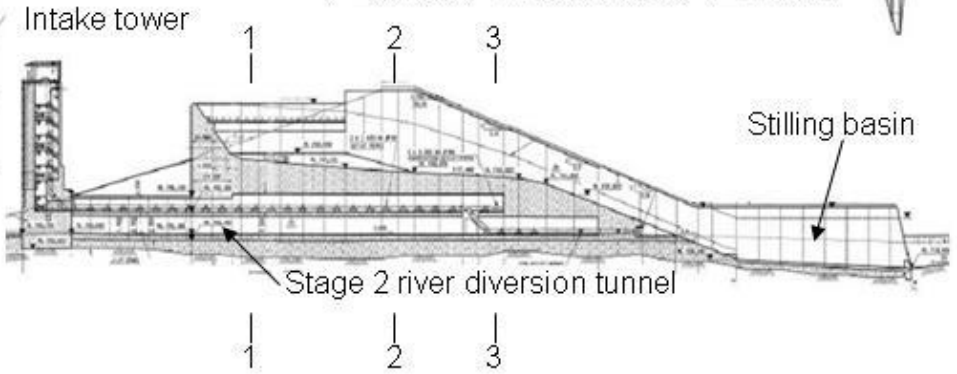
- The use of RCC for the trough spillway not for speed of construction but rather for avoiding the construction of very expensive contraction joints
  - RCC construction made use of crack induced joints that are cheaper than formed contraction joints
- RCC placing rates achieved during construction:
  - Open areas at foundation level: 60 m^3/hr
  - Congested areas at higher levels: 20 m^3/hr
- Mortar used as bedding layer – when applied thicker than 10 mm it resulted in in pumping and rolling of the RCC layer above
- Total concrete volume 408 300 m^3 of which 183 600 m^3 was RCC
- RCC mix: 180 kg/m^3 cementitious material (33:67 OPC:PFA), 90 kg/m^3 water, 774 kg/m^3 sand, 1 434 kg/m^3 stone (4.75-19, 19-38, 38-53)
- 28-day strength: 15 MPa; 90-day core strength: 35 MPa, 1-year cores: 40 MPa



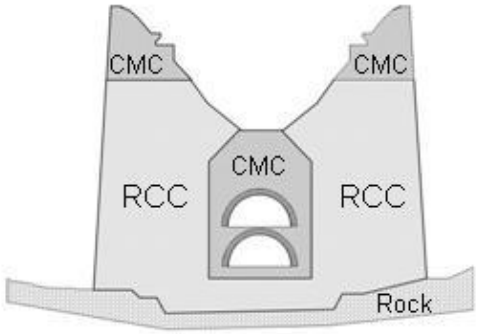
PLAN VIEW OF INYAKA DAM



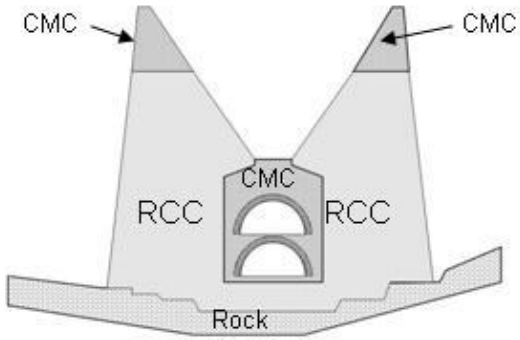
PLAN OF TROUGH SPILLWAY



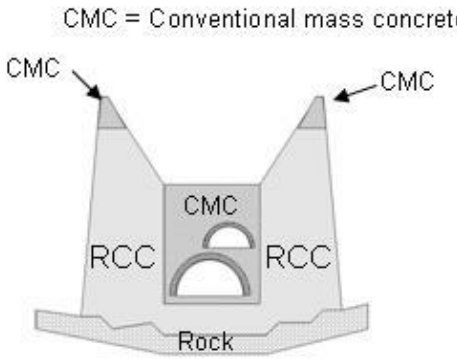
SECTION THROUGH SPILLWAY



SECTION 1-1



SECTION 2-2



SECTION 3-3

Inyaka Dam

Inyaka Dam looking downstream

Arch gravity dams

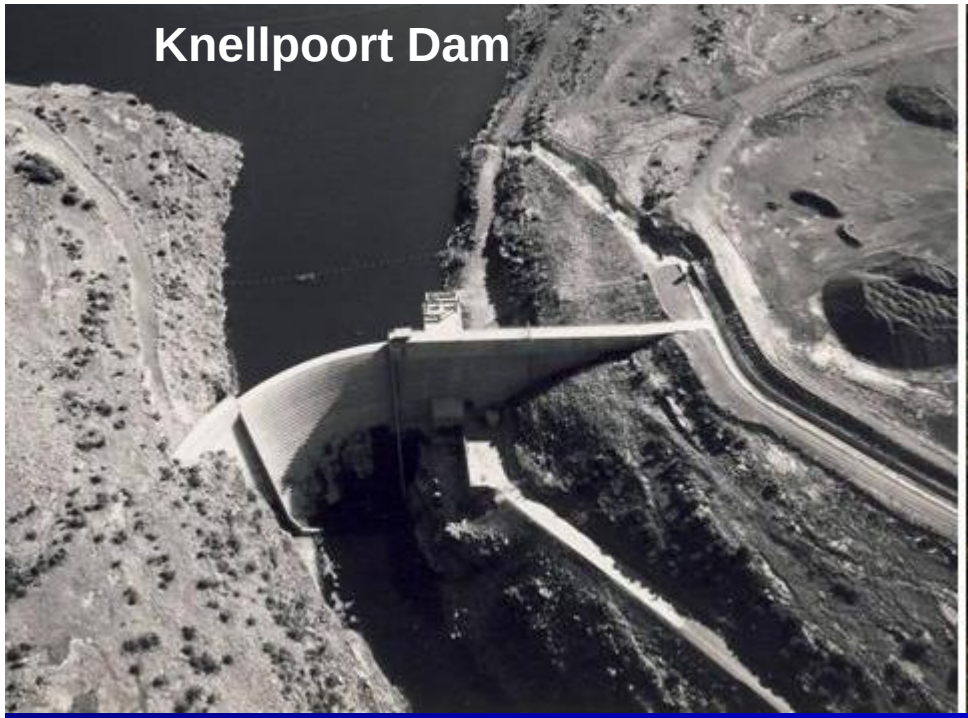
- The idea of extending the use of RCC to arch dams was already conceived by engineers of DWAF in **1986** during the construction of the Zaaihoek Dam and De Mistkraal Weir
- The opportunity to design and construct RCC arch dams arose in **1987** when dams were proposed in the gorges of the Rietspruit and the Great Brak River.
- Both sites were ideal for the construction of RCC arch/gravity dams
- Under the inspired leadership of the late Frank Hollingworth the designs for **Knellpoort Dam** (Rietspruit) and **Wolwedans Dam** (Great Brak River) took off in early 1988

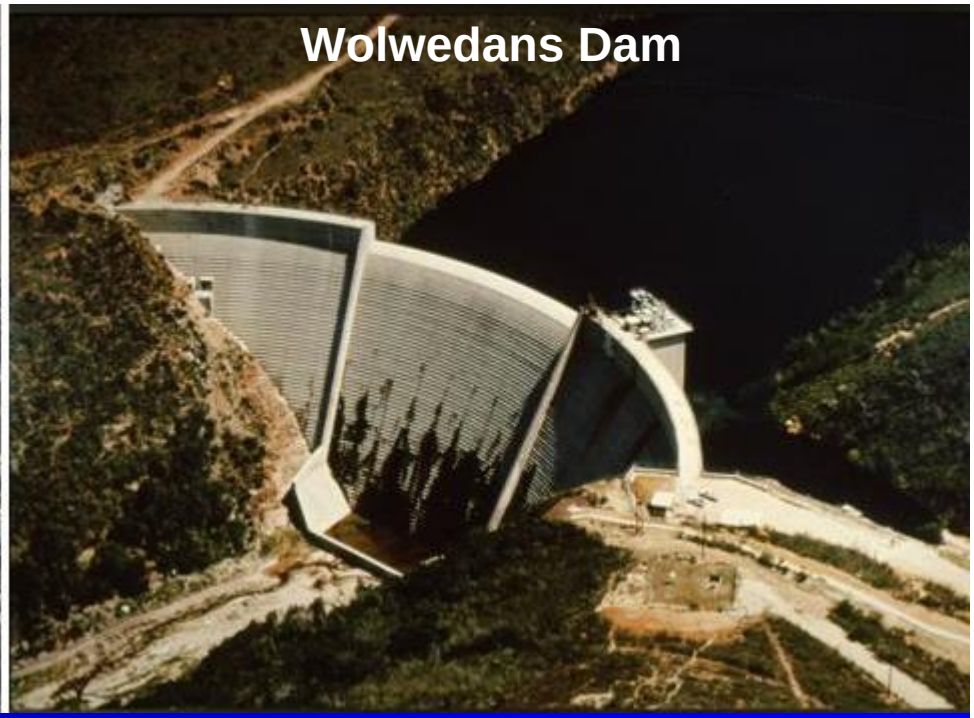
Knellpoort Dam

- Knellpoort Dam is situated on the Rietspruit, a tributary of the Caledon River, near Wepener in the Free State Province of South Africa
- The site is close to the RSA/Lesotho border in an area where the winters are very cold with early morning temperatures often reaching -5 to -10 ^{o}C
- The dam's storage is used to supply the city of Bloemfontein, the provincial capital with urban domestic and urban industrial water.
- The 50 m high dam is an asymmetric arch with a straight gravity left flank
- Details:
  - Extrados: 80 m
  - Upstream face: Vertical
  - Downstream face: 0.60:1 (H:V)
  - Crest length: 200 m
  - Crest width: 5 m
  - Total concrete volume: 59 000 m^3
  - Total RCC volume: 45 000 m^3
  - RCC cementitious content: 203 kg/m^3 (30:70 OPC:PFA)
  - Compressive strength: 17.2 MPa at 28-days

Wolwedans Dam

- Wolwedans Dam is situated on the Great Brak River near George in the Southern Cape Province of South Africa
- The area has a Mediterranean climate but experiences short hot spells in summer during berg wind conditions when ambient temperatures often reach 38 ^{o}C
- The dam's storage is used to supply urban domestic water to the city of Mossel Bay and industrial water to the Mossgas gas-fuel plant close to Mossel Bay
- The 70 m high dam is a near symmetric arch
- Details:
  - Extrados: 135 m
  - Upstream face: Vertical
  - Downstream face: 0.50:1 (H:V)
  - Crest length: 270 m
  - Crest width: 5 m
  - Total concrete volume: 203 000 m^3
  - Total RCC volume: 127 000 m^3
  - RCC cementitious content: 194 kg/m^3 (30:70 OPC:PFA)
  - Compressive strength: 16.1 MPa at 28-days; 32.7 MPa 1 to 2-year cores





- Both dams structurally analyzed with the same finite element (FEM) program
- Analyses indicated low stress levels under all assumed loading conditions
- Major concern was how cracks would develop under extreme temperature drops
- The practical solution was to induce crack joints where required and grout them when required
- The question was how one would know when to grout – answer: instrumentation

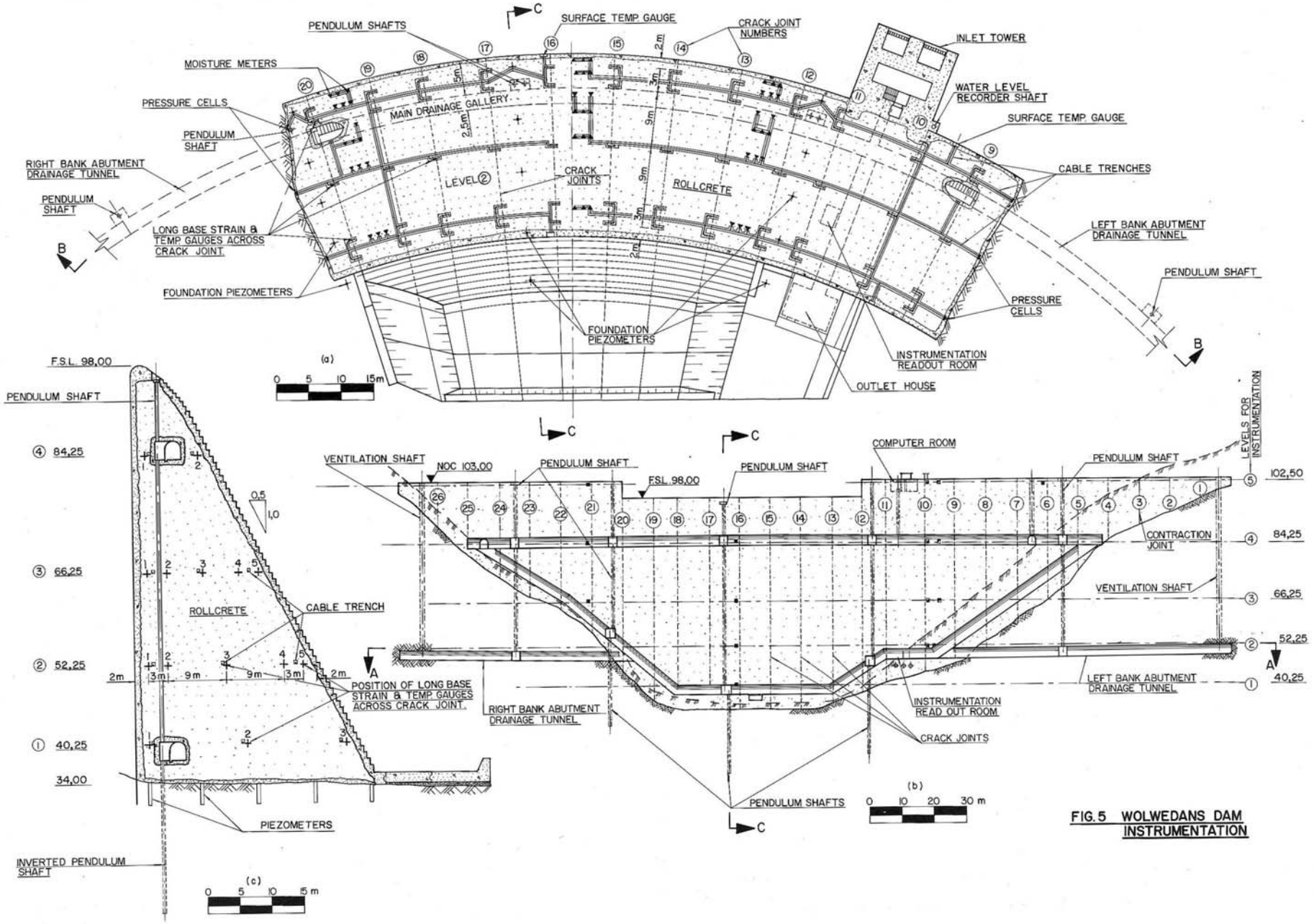
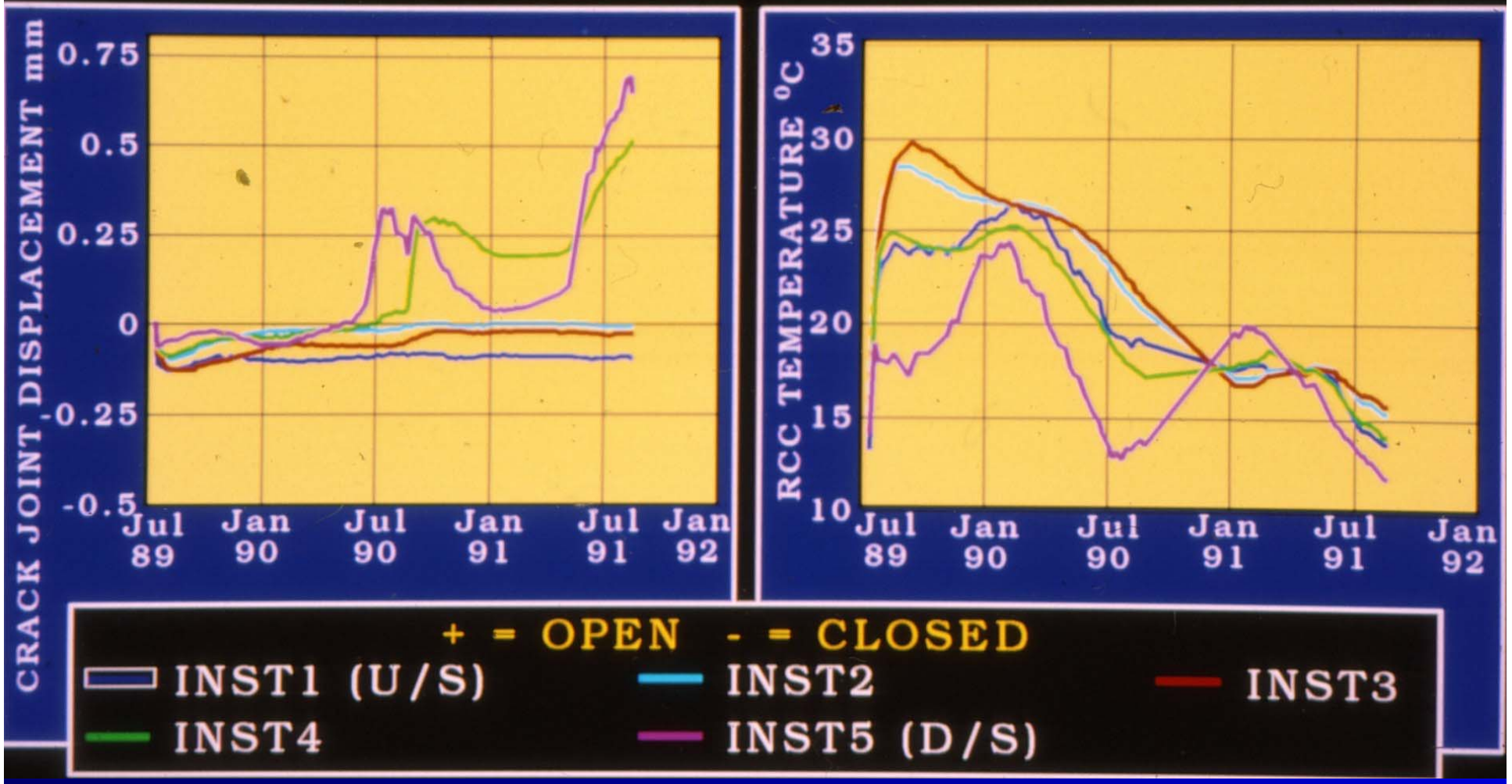


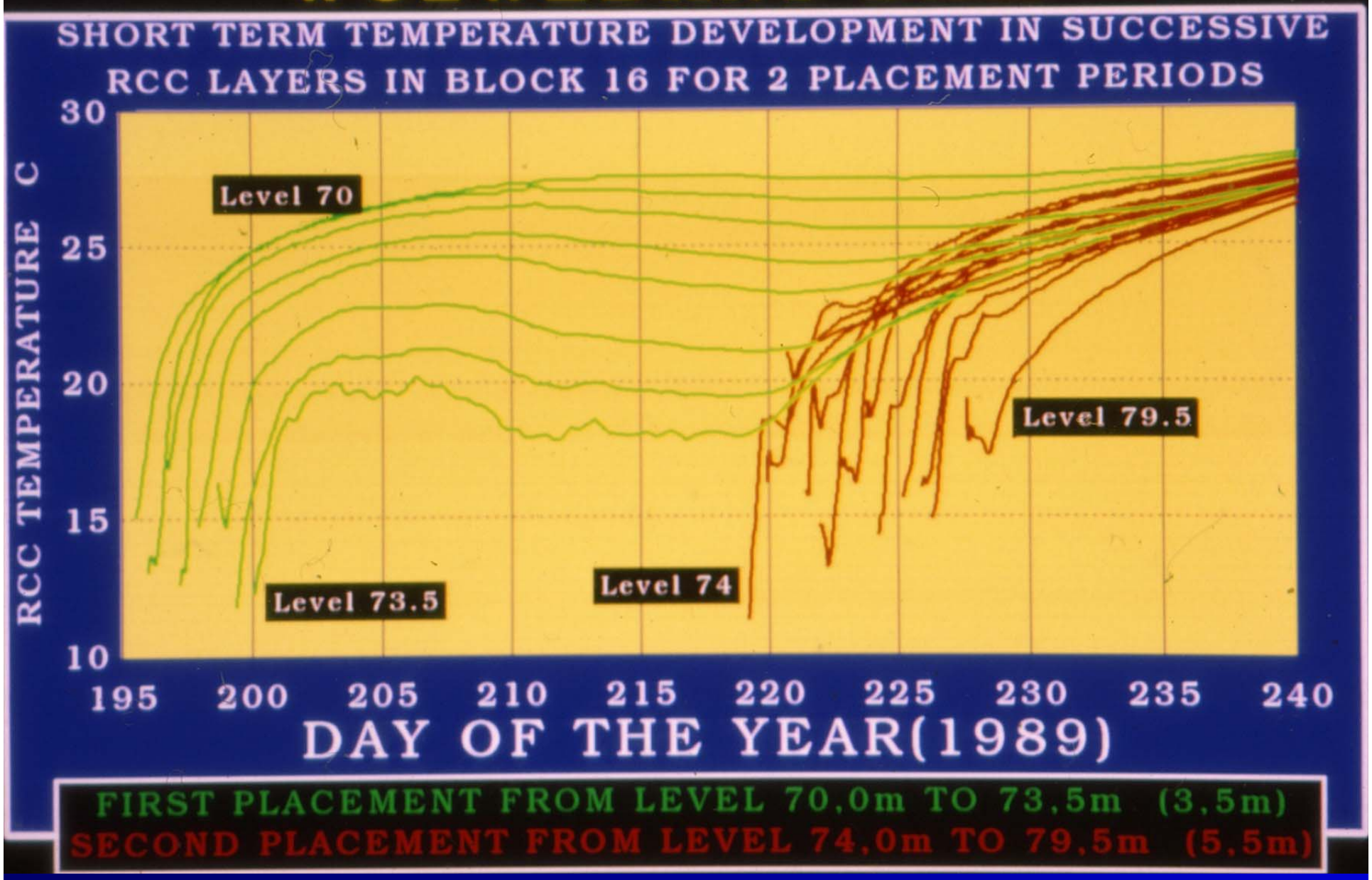
FIG. 5 WOLWEDANS DAM INSTRUMENTATION

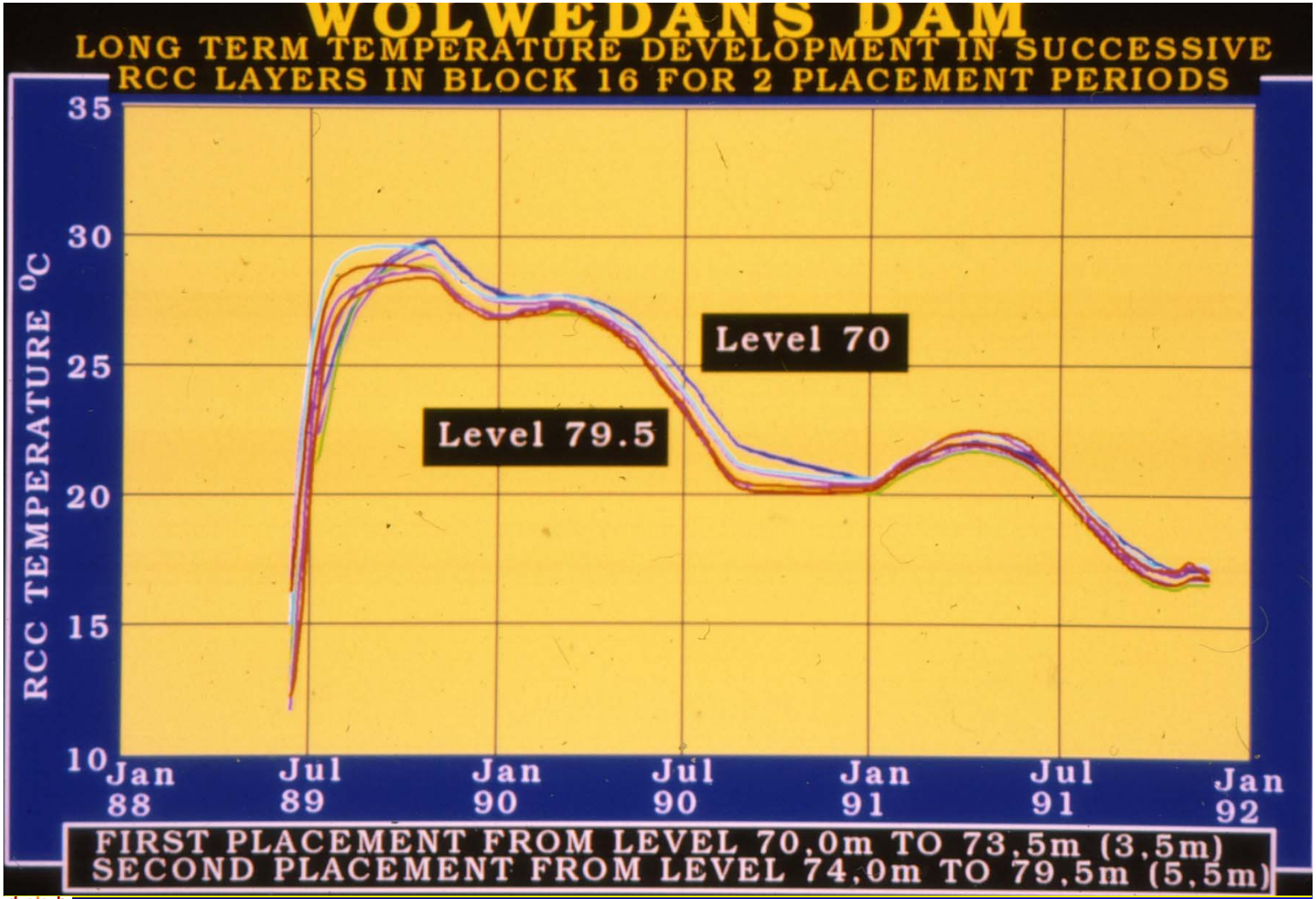
WOLWEDANS DAM

CRACK JOINT 11 AT LEVEL 66,25 m



WOLWEDANS DAM




WOLWEDANS DAM
LONG TERM TEMPERATURE DEVELOPMENT IN SUCCESSIVE RCC LAYERS IN BLOCK 16 FOR 2 PLACEMENT PERIODS
RCC TEMPERATURE °C
35
30
25
20
15
10
Level 70
Level 79.5
Jan 88
Jul 89
Jan 90
Jul 90
Jan 91
Jul 91
Jan 92
FIRST PLACEMENT FROM LEVEL 70,0m TO 73,5m (3,5m)
SECOND PLACEMENT FROM LEVEL 74,0m TO 79,5m (5,5m)

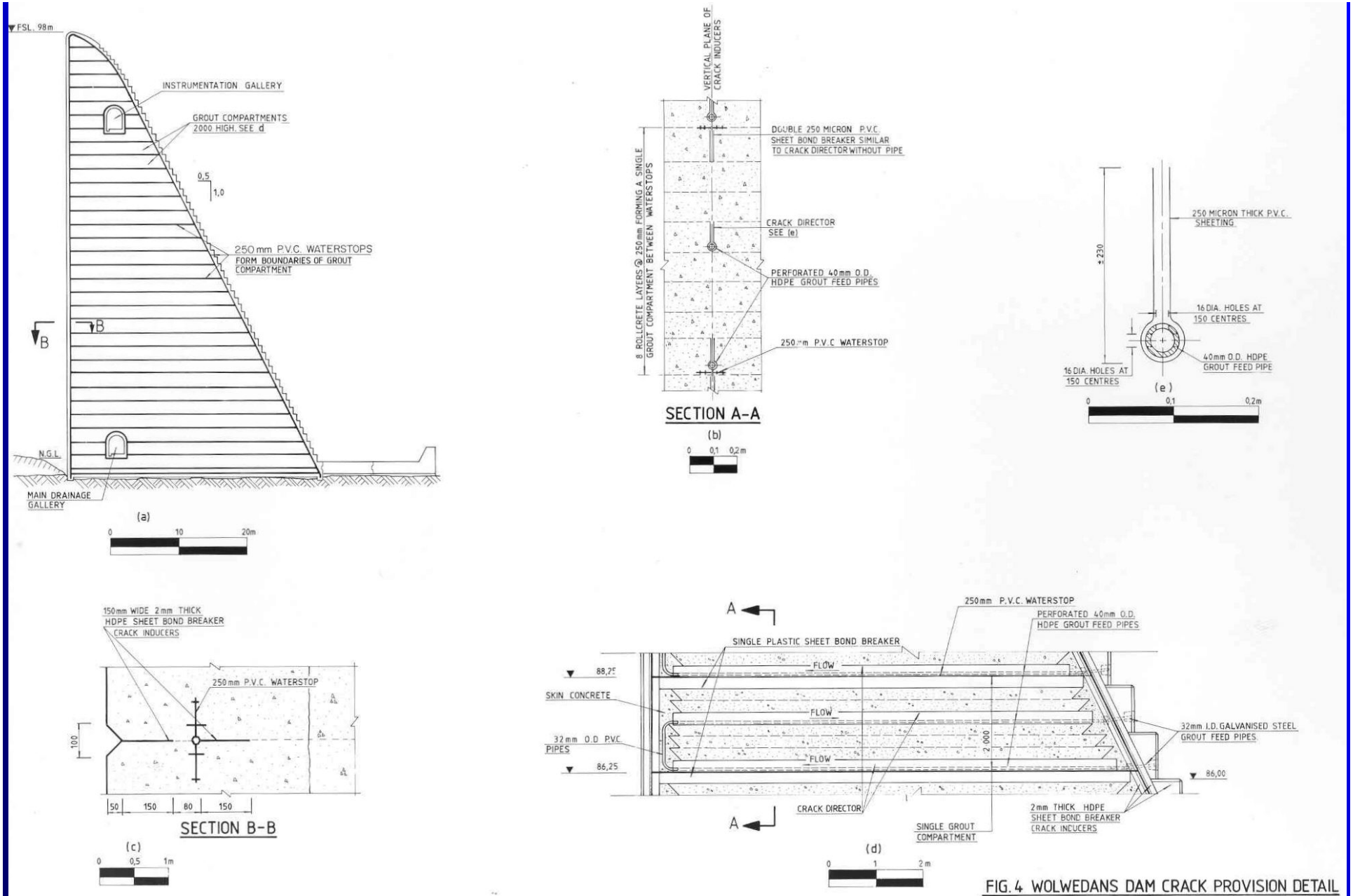
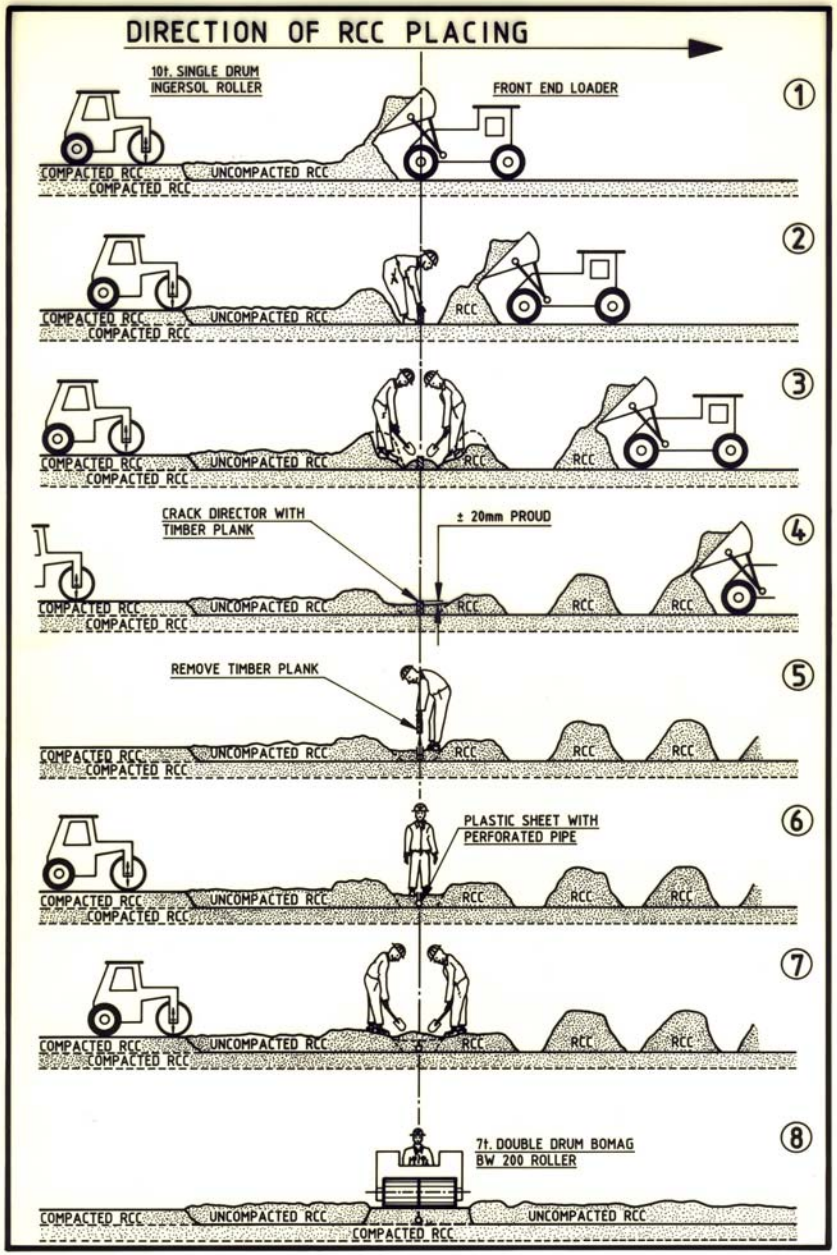


FIG. 4 WOLWEDANS DAM CRACK PROVISION DETAIL



Wolwedans Dam

Diagram showing the sequence in which crack inducers with grout pipes were installed

"The Application of RCC In South Africa"

Johann Geringer, Department of Water Affairs and Forestry, South Africa

50th Brazilian Concrete Congress: RCC Symposium, Salvador, Brazil, 5-8 September 2008

Where are RCC arches now?

A double curvature RCC arch dam in China with a height of 120 m

Placing RCC along slopes

- Construction of 34 m high Wriggleswade Dam started in 1987
- The dam is a 757 m long straight RCC gravity dam
- The dam is founded on siltstone with a tendency to flake when exposed to the atmosphere
- It was crucial to cover the foundation with concrete as quickly as possible after every portion of the dam's excavation was finished
- Contractor proposed that RCC be placed on slope rather than in horizontal layers – Client agreed to proposal
- The result was that RCC was placed along slopes as steep as 5:1 (H:V)
- The dam has behaved very well despite the manner in which RCC was placed

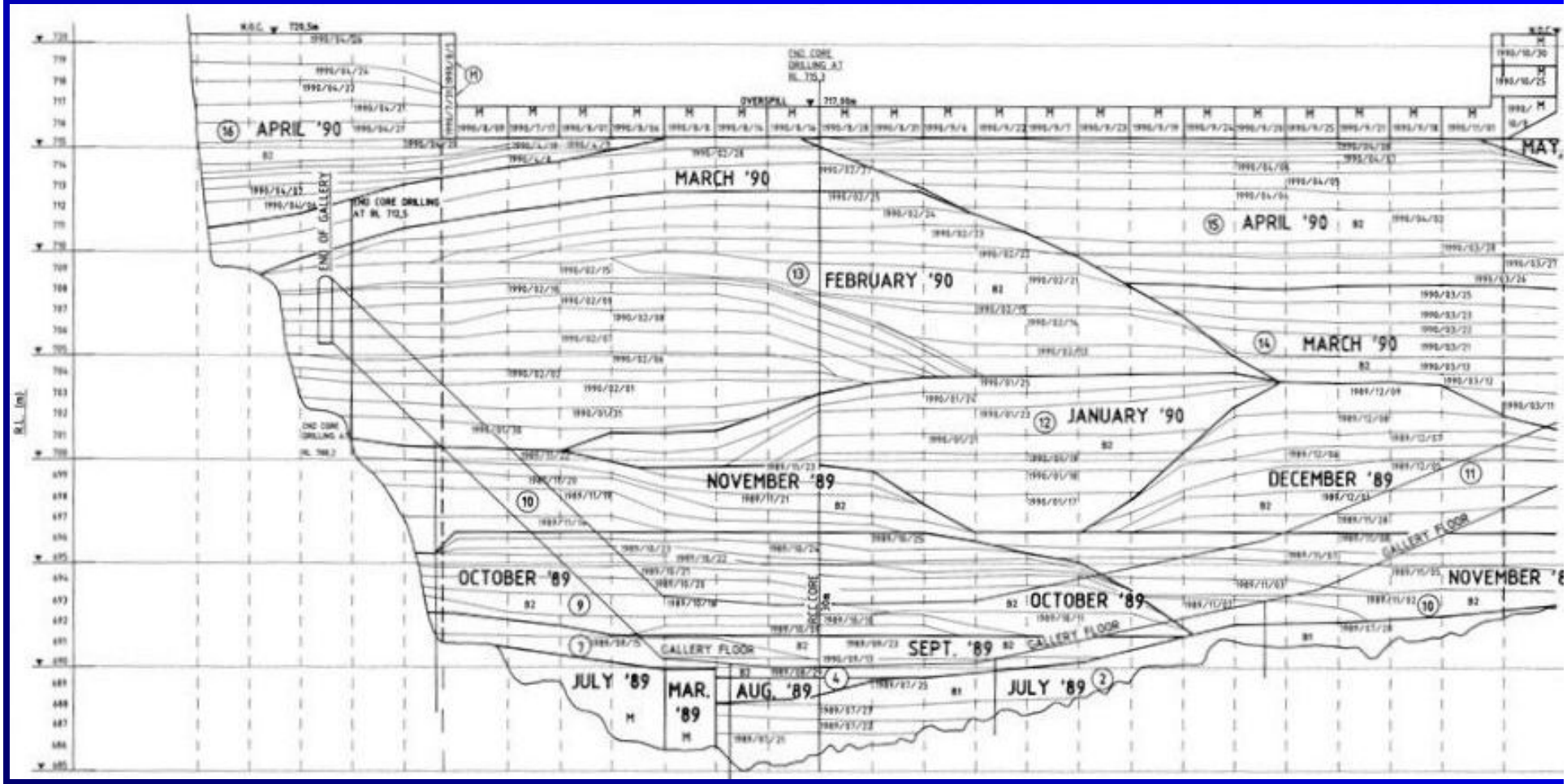
Placing RCC along slopes *(continued)*

The sloped placing had several positive results:

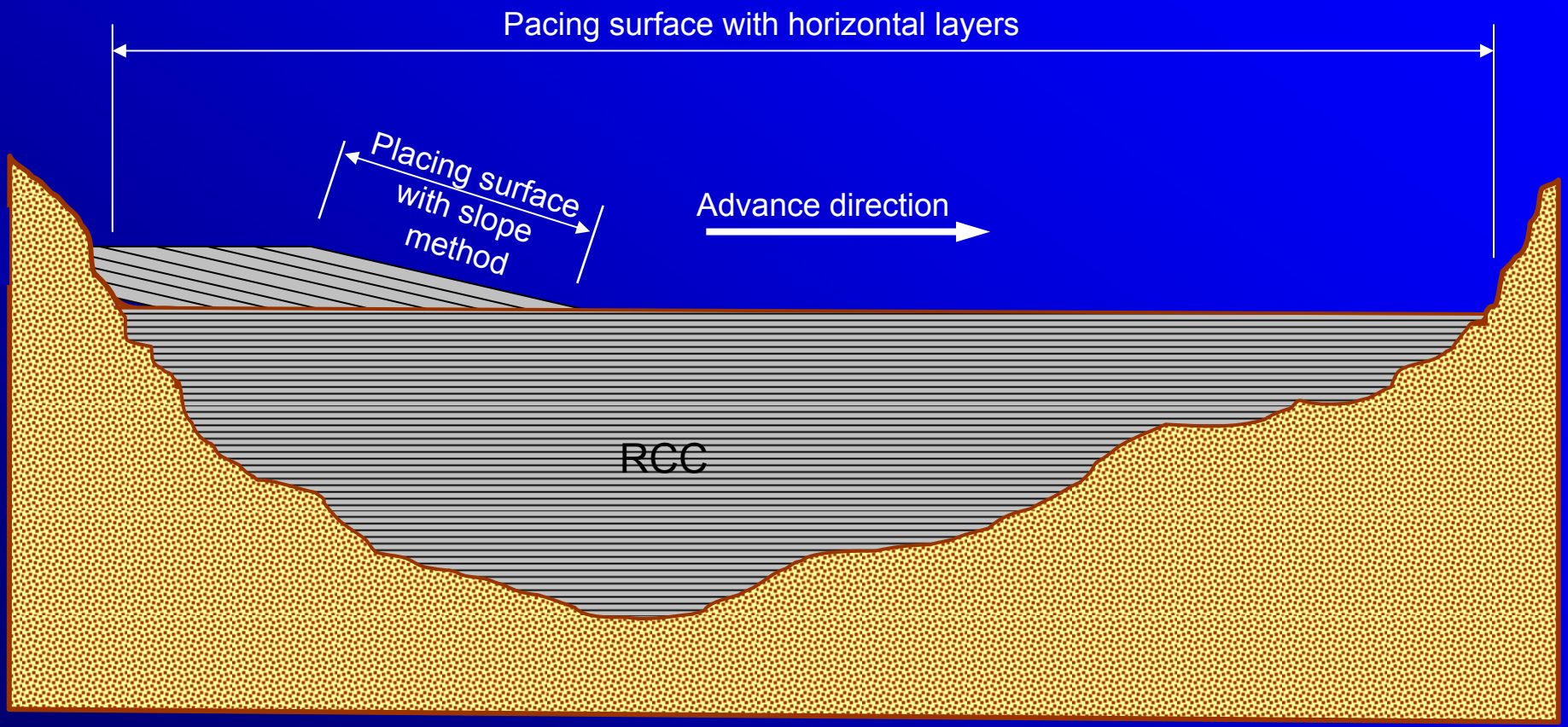
- It allowed optimum utilisation of plant capacity and man power
- It reduced the area of a freshly placed RCC layer and therefore minimized exposure time before being covered by new RCC layer
- The mildly sloped RCC surfaces created made access to other parts of the wall very easy
- It eliminated the need to construct expensive contraction joints which would be necessary with horizontal RCC placing
- There was an overall financial benefit from all the saving accrued
- It paved the way for the “sloped method” currently employed elsewhere in the world

Wriggleswade Dam

Record of RCC placing below the dam's spillway



SLOPING PLACEMENT OF RCC



Raising of existing dams

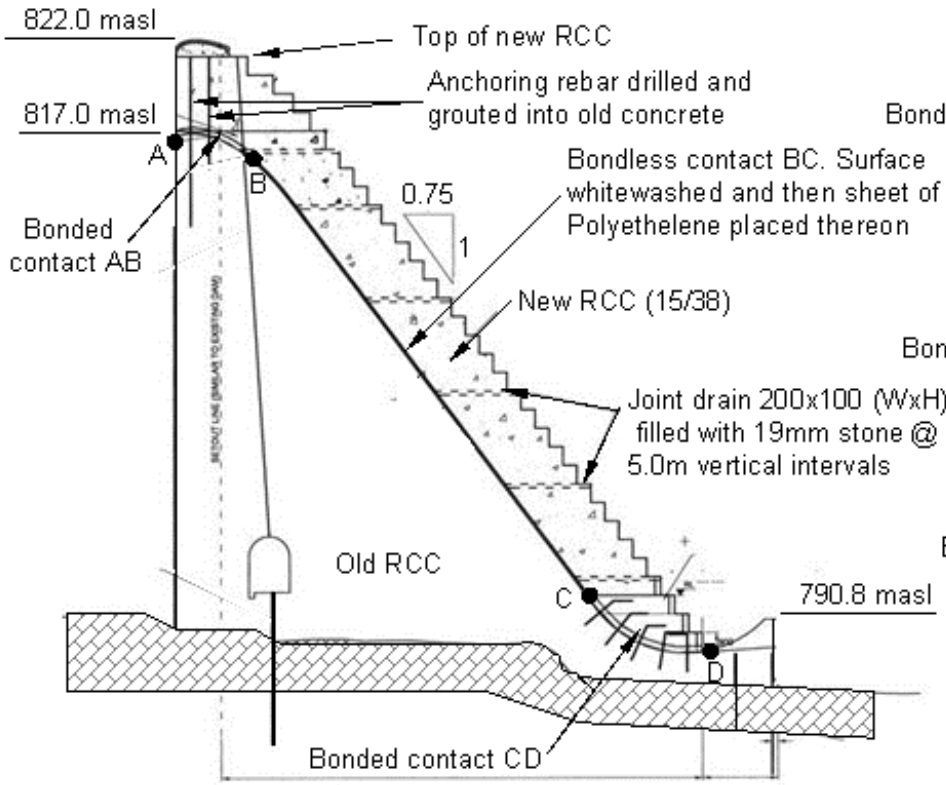
Flag Boshielo Dam

- Flag Boshielo Dam, formerly known as Arabie Dam, is the first RCC dam in South Africa that has been raised with RCC
- The dam was raised by 5 m to increase its storage from 100 to 180 million m^3 for increased demands of particularly the mining and domestic sectors of the area
- The original Flag Boshielo is a composite dam with a smooth faced RCC spillway, an earth embankment left flank and a stepped faced RCC gravity right flank
- Originally the dam was to be raised with crest gates but other dam safety related issues decided to retain an uncontrolled spillway for the dam
- The flood levels of the raised dam had to be limited as too high flood levels would have had serious environmental impacts in the dam basin
- To increase the spillway capacity of the dam, while maintaining the current spillway length, a break section was provided on a saddle at the end of the left flank

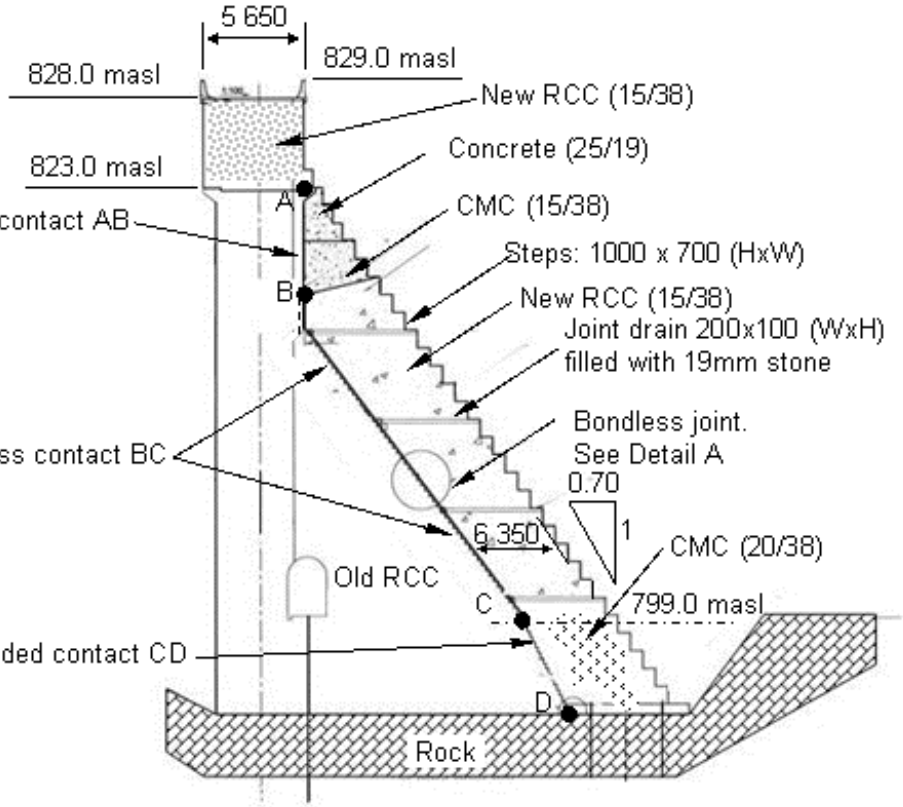
Flag Boshielo Dam *(continued)*

Principle philosophy followed:

- New concrete should have time to settle and shrink to prevent secondary stresses induced in wall thickening concrete
- New concrete should be de-bonded from old concrete so that it is free to move
- Old surfaces of dam:
  - Smooth faces: To be white washed and provided with plastic sheet
  - Stepped faces: Steps to backfilled with low strength concrete, then treated in same way as smooth face
- RCC to be used for wall thickening because of:
  - It could be more rapidly placed than conventional concrete
  - Would develop less heat than conventional concrete and shrink faster
- Downstream face of wall thickenings will be stepped because:
  - It suited the RCC construction method
  - The stepped spillway would have energy dissipation advantages

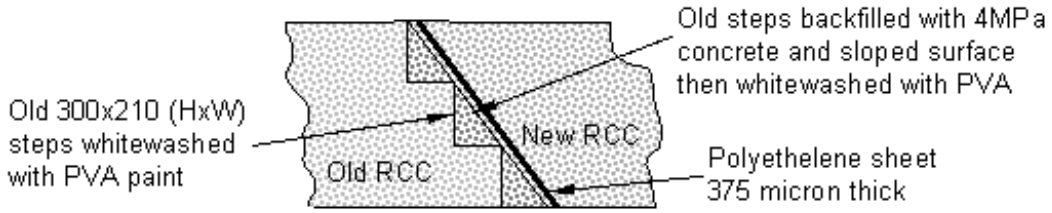


SECTION THROUGH SPILLWAY



SECTION THROUGH RIGHT BANK NOC

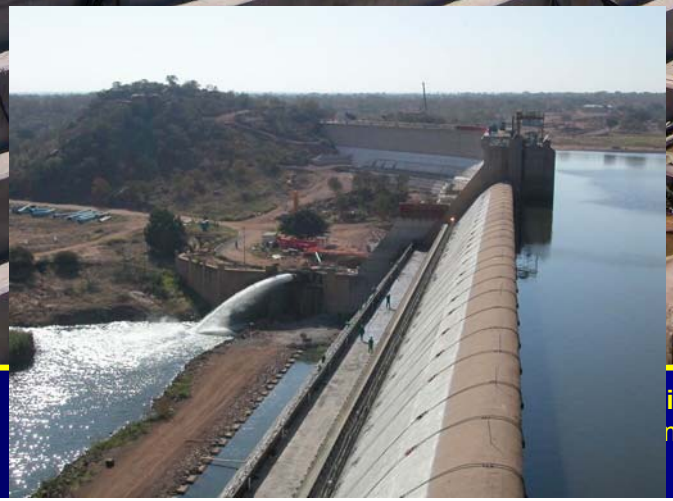
FLAG BOSHIELO DAM RAISING DETAILS



DETAIL A: BONDLESS JOINT

Flag Boshielo Dam Raising

Flag Boshielo Dam Raising



Flag Boshielo Dam Raising

Flag Boshielo Dam Raising

Flag Boshielo Dam Raising

Dams currently under construction or due for construction

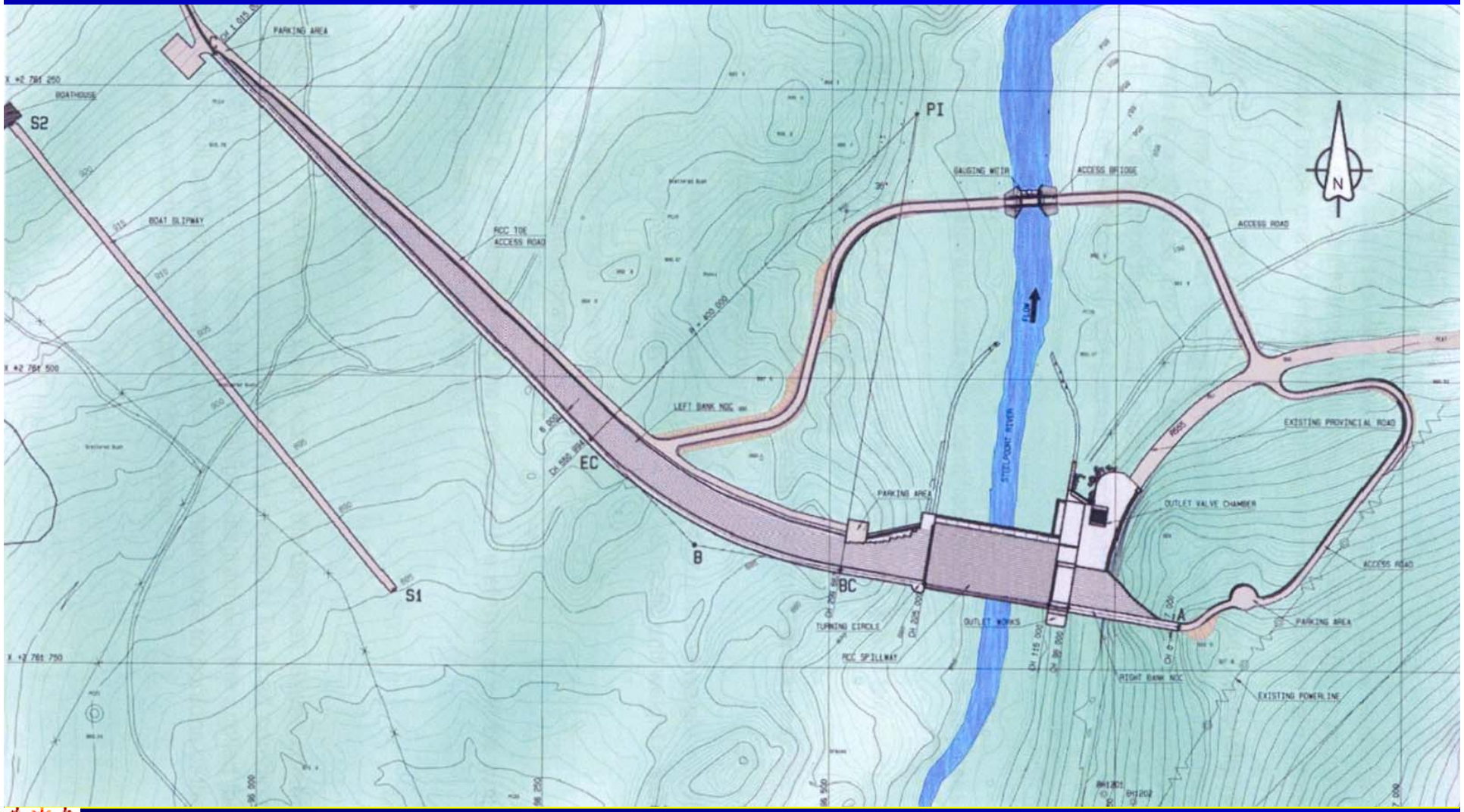
De Hoop Dam is currently the only RCC dam under construction in South Africa

- At 81 m the highest South African RCC dam to date
- Longest RCC gravity dam to date – crest length 1 015 m
- Downstream face has slope of 0.80:1 (H:V)
- Length of uncontrolled stepped spillway 100 m
- Expected completion date 2012

Spring Grove Dam will be a composite dam with a central RCC spillway and

- Maximum height 40 m
- Total length of RCC about 120 m
- Expected completion date 2011

De Hoop Dam
Currently under construction



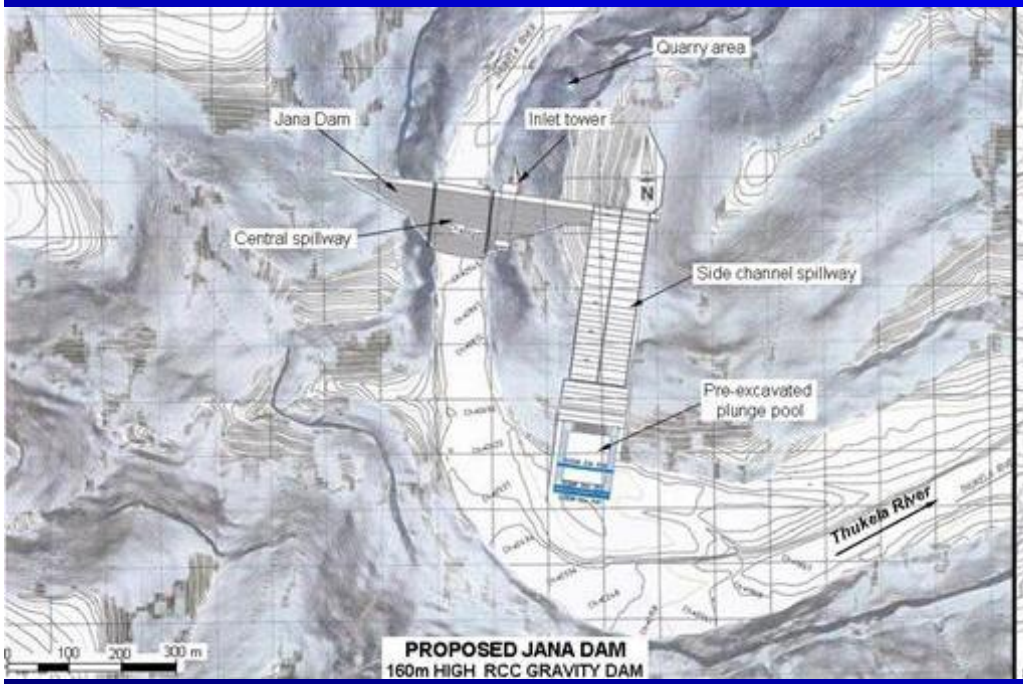
Future dams considered

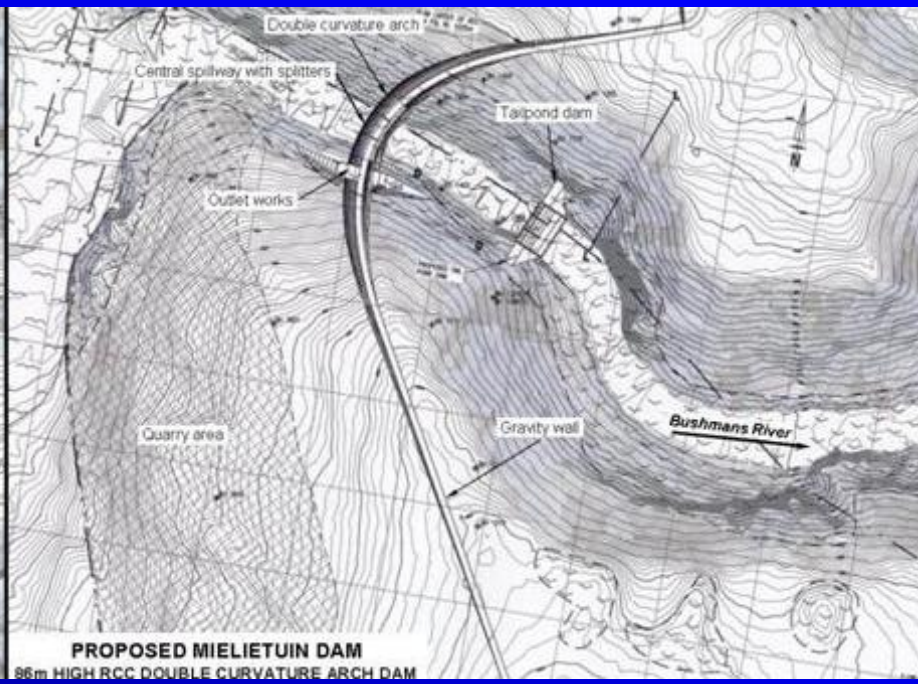
A number of new dams are currently being planned in South Africa

The **Thukela Water Project (TWP)** is however the most significant one and a decision on the project is expected soon as it is in competition with Phase-2 of the Lesotho Highlands Water Project

The TWP will have two dams:

- Jana Dam: A 160 m high RCC gravity dam
- Mielietuin Dam: An 85 m double curvature RCC arch with a gravity flank


Quarry area
Jana Dam
Inlet tower
N
Central spillway
Side channel spillway
Pre-excavated
plunge pool
Thukela River
0
100
200
300 m
PROPOSED JANA DAM
160m HIGH RCC GRAVITY DAM


Double curvature arch
Central spillway with splitters
Tailpond dam
N
Outlet works
Quarry area
Gravity wall
Bushmans River
PROPOSED MIELIETUIN DAM
96m HIGH RCC DOUBLE CURVATURE ARCH DAM

Conclusion

- RCC dams in South Africa have good track records
- This give designers the confidence to exploit the RCC method even further
- As has been demonstrated RCC has already been apllied in various ways and it should be anticipated that more uses will soon see the light
- RCC has been used for dams, roads, pavements, culvert structures, etc.
  What is next??

The End

Thank you for your attention