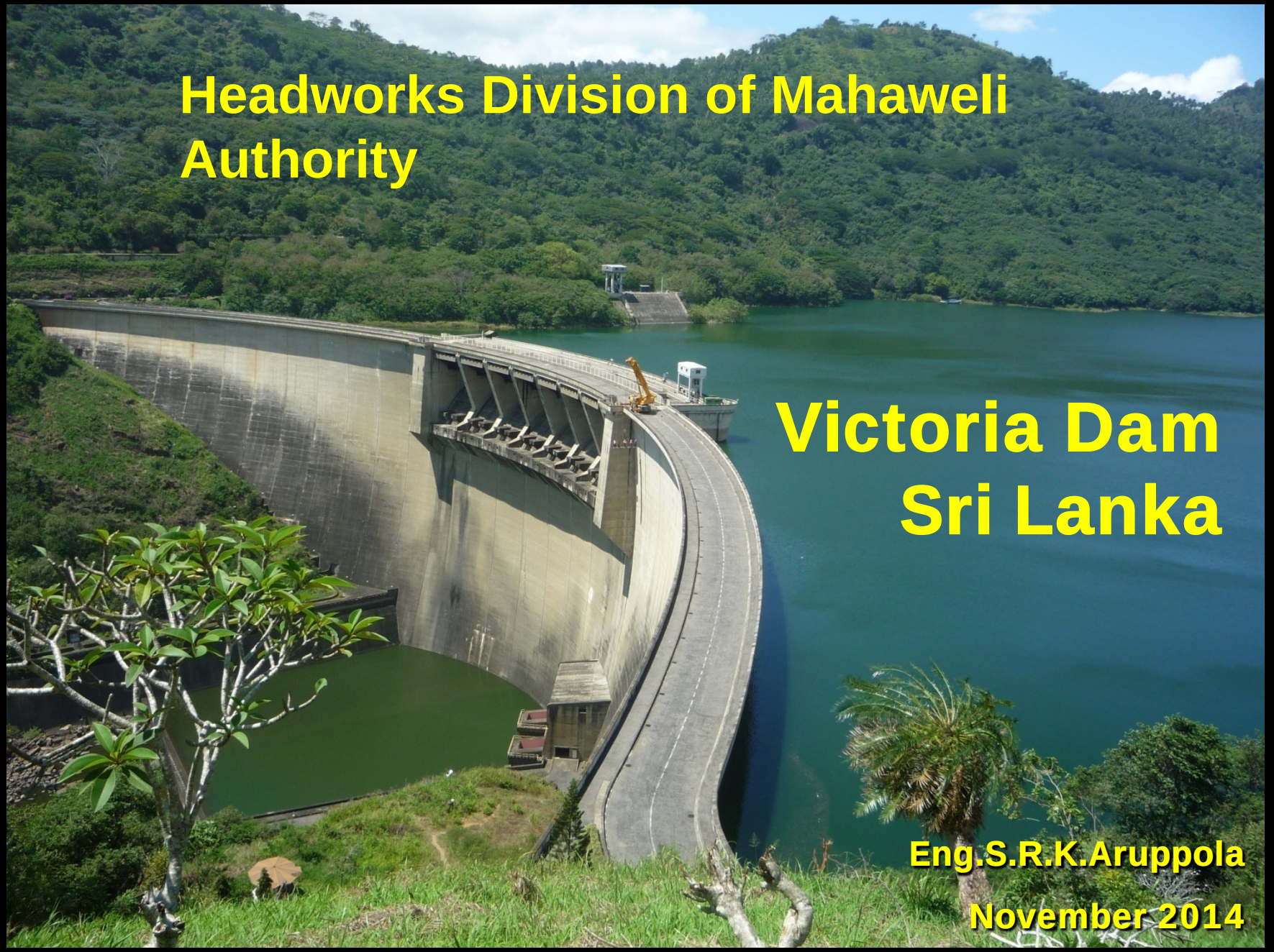
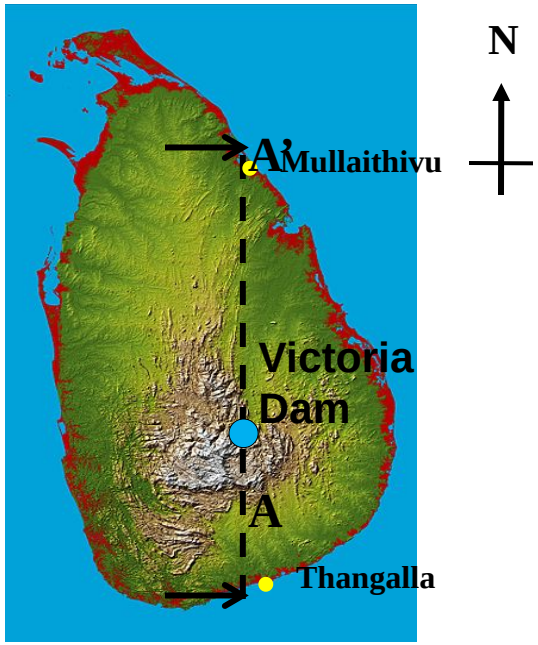
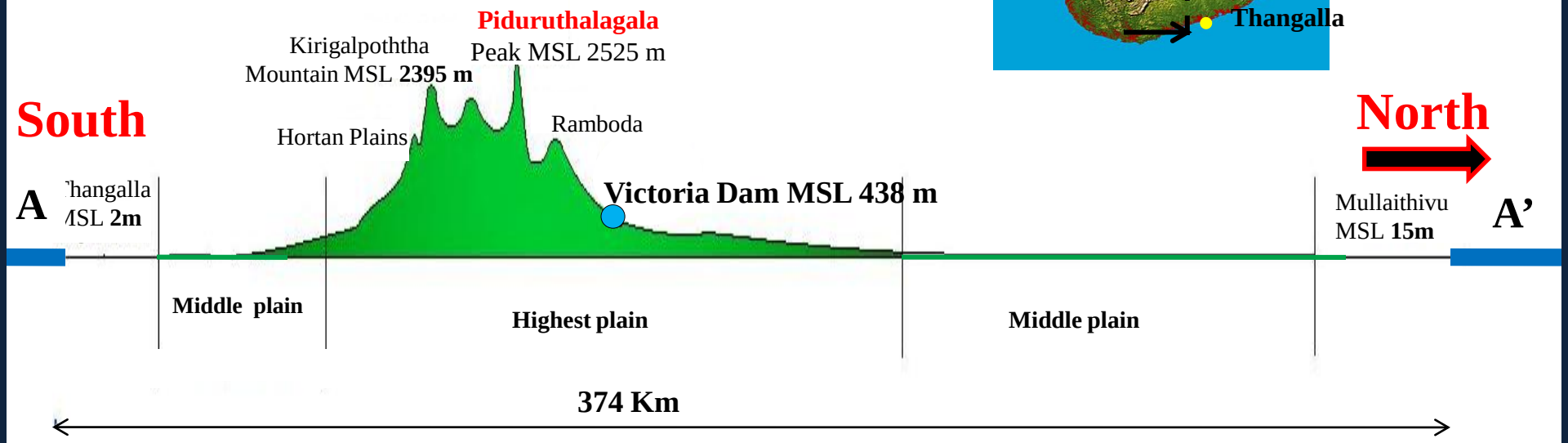

Headworks Division of Mahaweli Authority
Victoria Dam
Sri Lanka
Eng.S.R.K.Aruppola
November 2014


Sri Lanka
Kyrgyzstan
Tajikistan
Afghanistan
Pakistan
Faisalabad
Lahore
Mahendranagar
New Delhi
Jaipur
Nepalganj
Nepal
Bhutan
Birganj
Biratnagar
Mir Pur Mathelo
Karachi
Ahmedabad
India
Surat
Mumbai
Pune
Hyderabad
Vishakhapatnam
Hubli
Bengaluru
Chennai
Arabian Sea
Laccadive Sea
Sri Lanka
Bay of Bengal
Andaman Sea
Gulf of Thailand
Malaysia
Kuala
Bangladesh
Khulna
Chittagong
Myanmar (Burma)
Yangon
Thailand
Laos
Cambodia
Vietnam
Ha Noi
Phnom Penh
Lhasa
拉萨
Xining
西宁
Lanzhou
兰州
Yinchuan
银川
Hohhot
呼和浩特
Shijiazhuang
石家庄
Beijing
北京
Tianjin
天津
Taiyuan
太原
Jinan
济南
Xi'an
西安
中国
China
Chengdu
成都
Zhengzhou
郑州
Wuhan
武汉
Hefei
合肥
Shanghai
上海
Hangzhou
杭州
Chongqing
重庆
Changsha
长沙
Fuzhou
福州
Kunming
昆明
Nanning
南宁
Guangzhou
广州
Haikou
海口
Shenyang
沈阳
North Korea
Seoul
서울
South Korea
Daejeon
대전
Busan
부산
Gwangju
광주
Fukuoka
福岡
East China Sea
Naha
那覇
台湾
Taiwan
香港
Hong Kong
Macau
South China Sea
Philippine Sea
Luzon
Manila
Catanduanes Island
Philippines
Busuanga
Panay
Palawan
Negros
Leyte Island
Sulu Sea
Mindanao
Basilan Island
Celebes Sea
©2011 Google - Map data ©2011 Europa Technologies, Geocentre Consulting, SK M&C, Tele Atlas, ZENRIN


Mahawei River
(Starts at 2524 m, msl)
331 km long
Annual flow to sea :11,000 MCM
Victoria Dam
FSL: 438 m, msl
Area 65,610 km²
Population 20.3 million
SRI LANKA
INDIA
TAMIL NĀDU
Bay of Bengal
Gulf of Mannar
INDIAN OCEAN
Point Pedro
Jaffna
Chavakachcheri
Kambam
Madurai
Paramagudi
Sivakāsi
Rāmanāthapuram
Talaimannar
Mannar
Surandai
Tuticorin
Tirunelveli
Trivandrum
Nāgercoil
Vavuniya
Horowupotana
Trincomalee
Galewela
Hettipola
Naranmmala
Negombo
Gampola
Sri Jayawardenepura
Nuwara Eliya
Wadduwa
Beruwala
Ratnapura
Pitigala
Embilipitiya
Galle
Matara
Batticaloa
Paddiruppu
Weragantota
Akkaraipattu
Bibile
Badulla
Pottuvil
Bandarawela
Beliatta

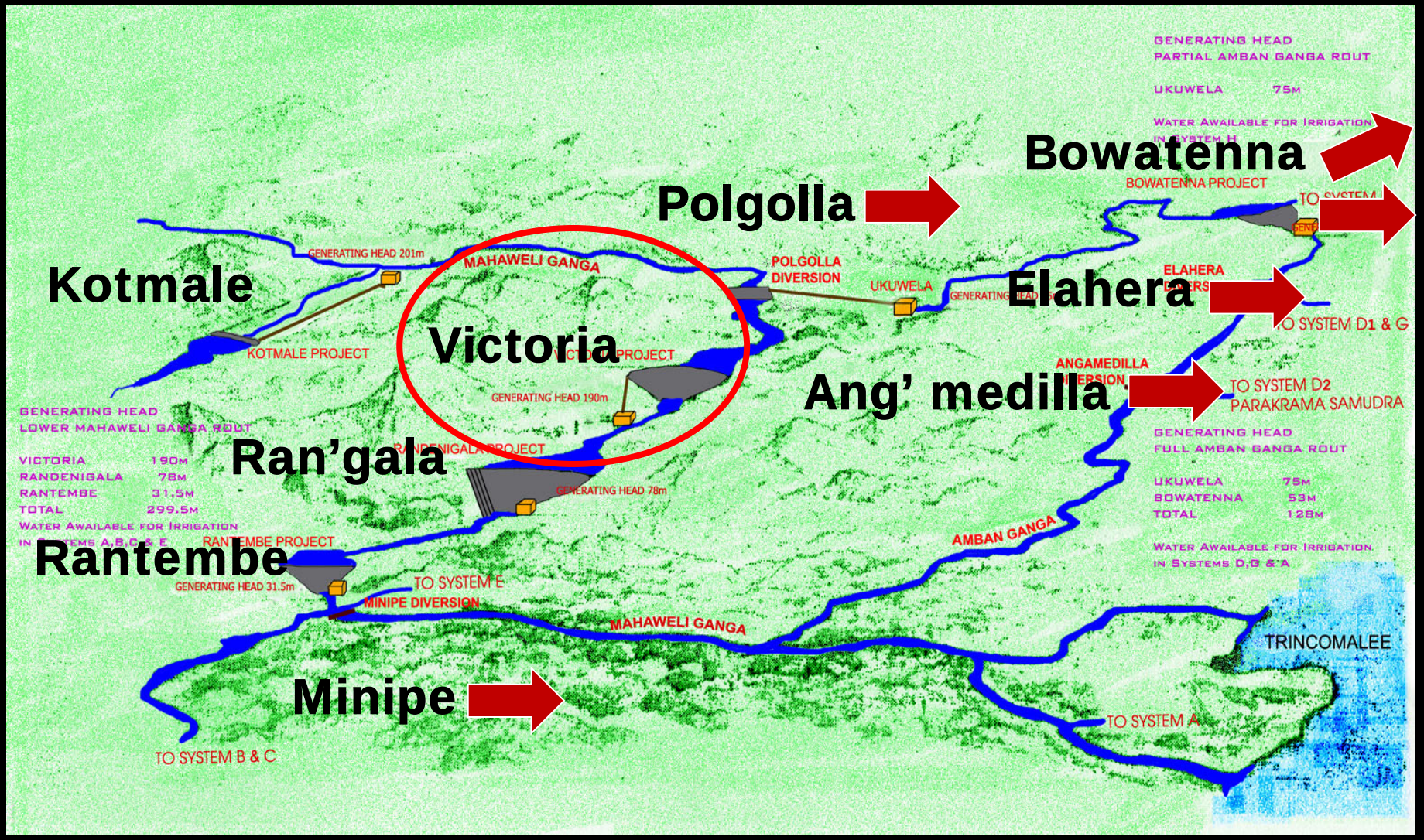
Diagrammatic Section Across Sri Lanka Showing Victoria Dam





Section A- A'

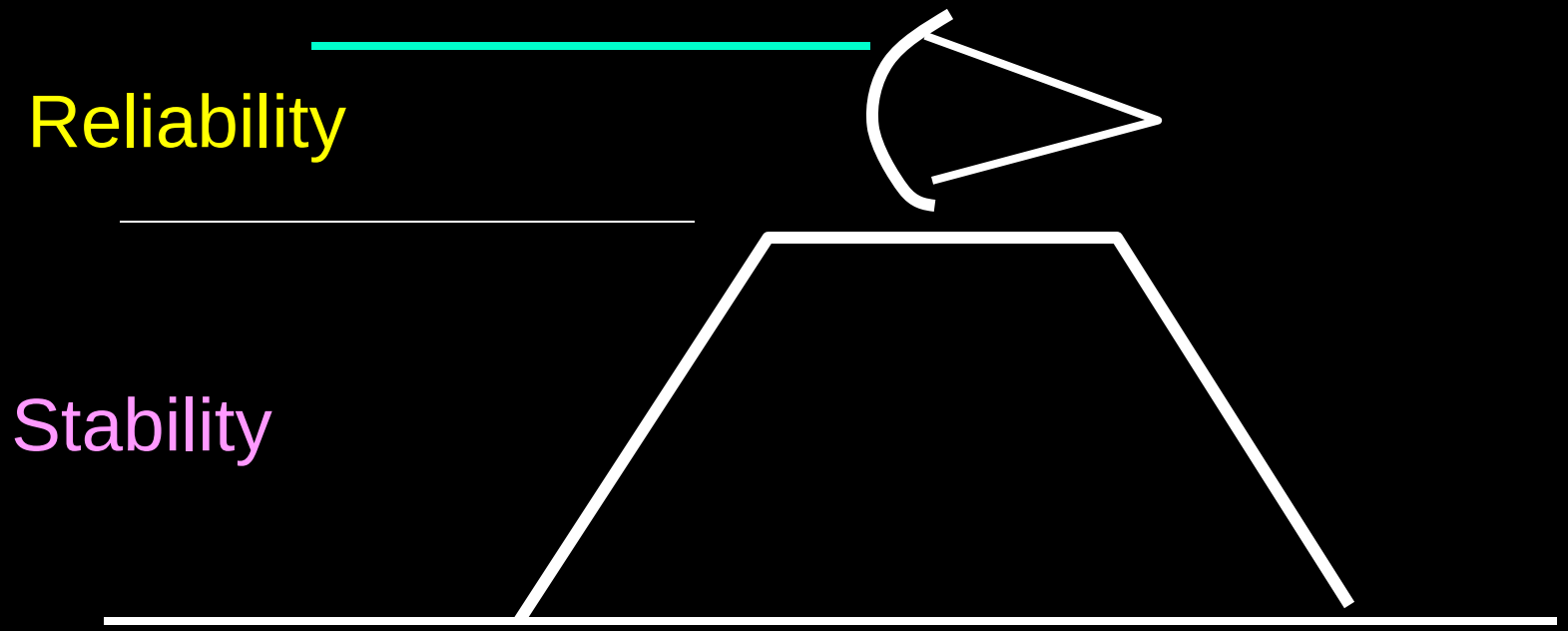
MAHAWELI SYSTEM



What is HAO&M…?

Headwork
Administration
Operation
&
Maintenance

Safety of Dam depends



Chapters

Part 1

General Information

Part 2

Instrumentation

Part 3

Observations 1~6 & Conclusion

Chapters

Part 1

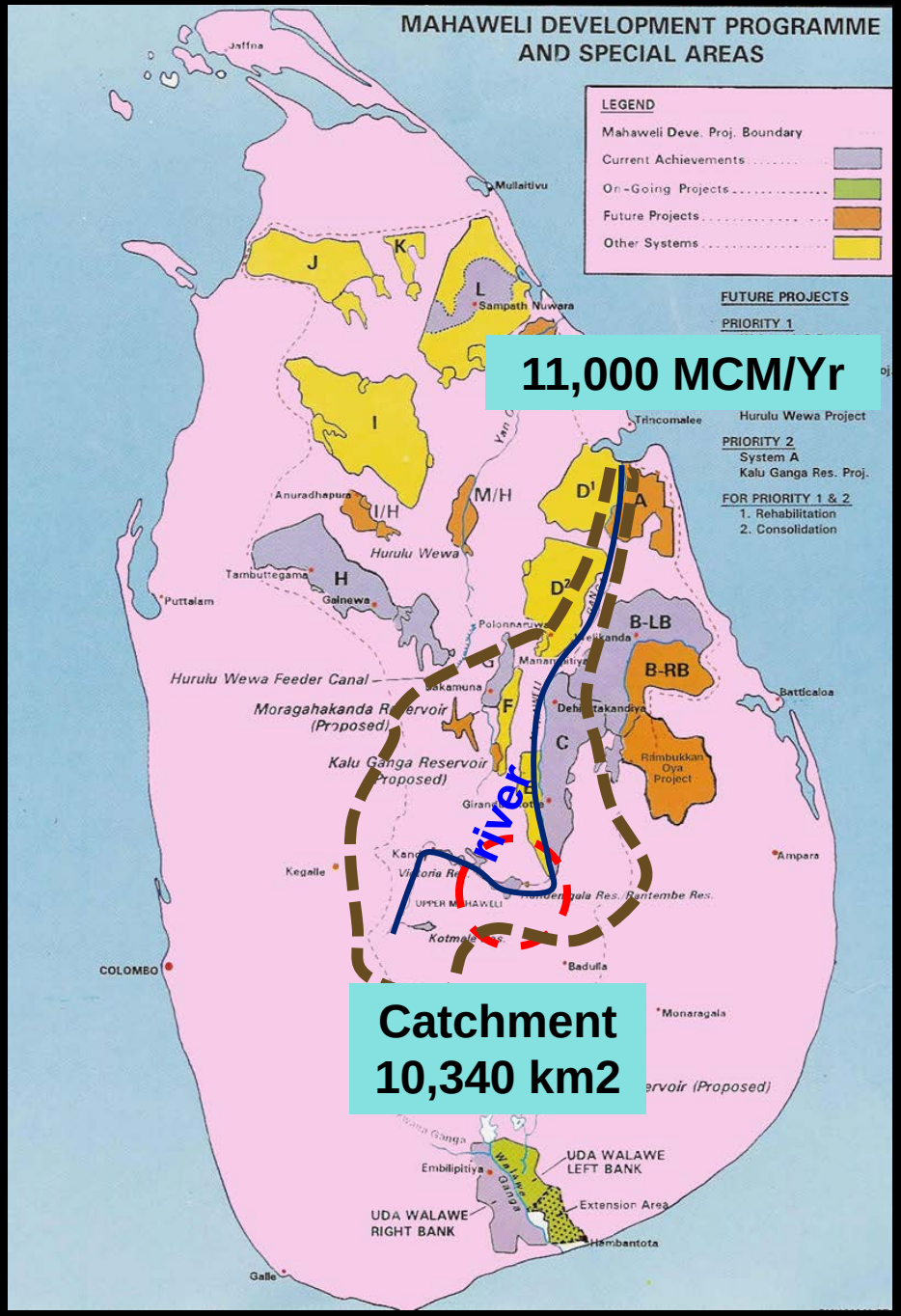
General Information

Part 2

Instrumentation

Part 3

Observations 1~6 & Conclusion



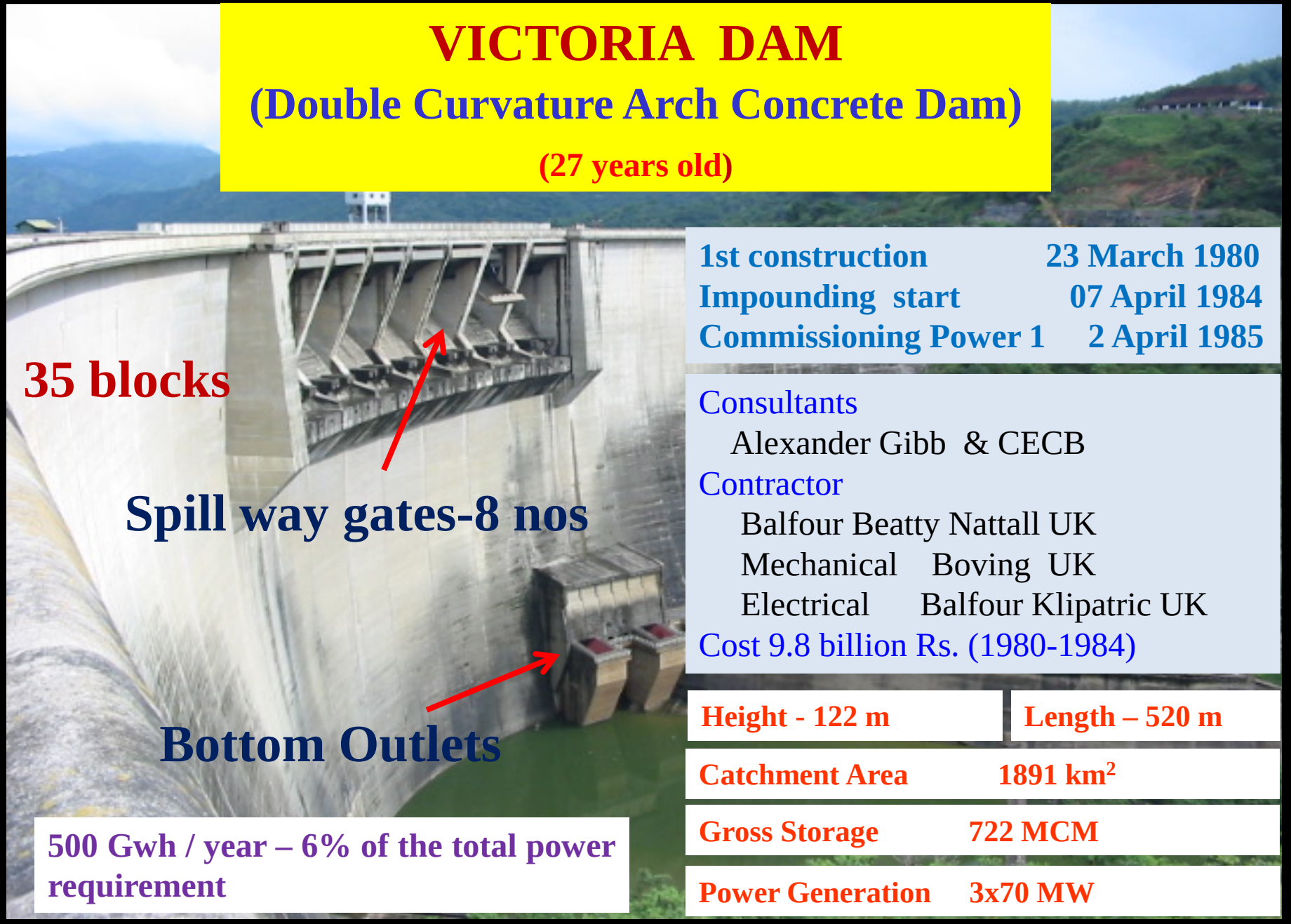
System	Project	Irrigable Area (ha)	Institute
H	Dambulu Oya	2,225	MASL
	Kandalama	4,500	MASL
	Kalawewa RB	13,965	MASL
	Kalawewa Yoda Ela	4,720	MASL
	Kalawewa LB	6,000	MASL
	Rajanganaya	7,123	ID
I/H	Nachchaduwa	2,540	ID
	Nuwara wewa	970	ID
	Tisa wewa	520	ID
M/H	Hurulu wewa	4,210	ID
	Hurulu wewa canal	2,250	MASL
G	Elahera	5,400	MASL
D	Girithale	3,075	ID
	Minneriya	8,900	ID
	Kawdulla	5,060	ID
	Kantale	6,782	ID
	Parakrama Samudra	10,420	ID
E	Hasalaka	7,750	ID
C	Sorabora	810	ID
	Mapakada	550	ID
	Dambarawa	610	ID
	Ulhitiya/Ratkinda	21,700	MASL
B	Maduruoya	16,500	MASL
	Wakaneri	3,500	ID
A	Alleya	7,050	ID
Walawa	Walawa RB	12,300	MASL
	Walawa LB	6,110	MASL
	Liyangastota	6,800	ID
	Kaltota	940	ID
Total		**173,280**	

MASL - Mahaweli Authority of Sri Lanka ID - Department of Irrigation

VICTORIA DAM

(Double Curvature Arch Concrete Dam)

(27 years old)



1st construction	23 March 1980
Impounding start	07 April 1984
Commissioning Power 1	2 April 1985

Consultants

Alexander Gibb & CECB

Contractor

Balfour Beatty Nattall UK

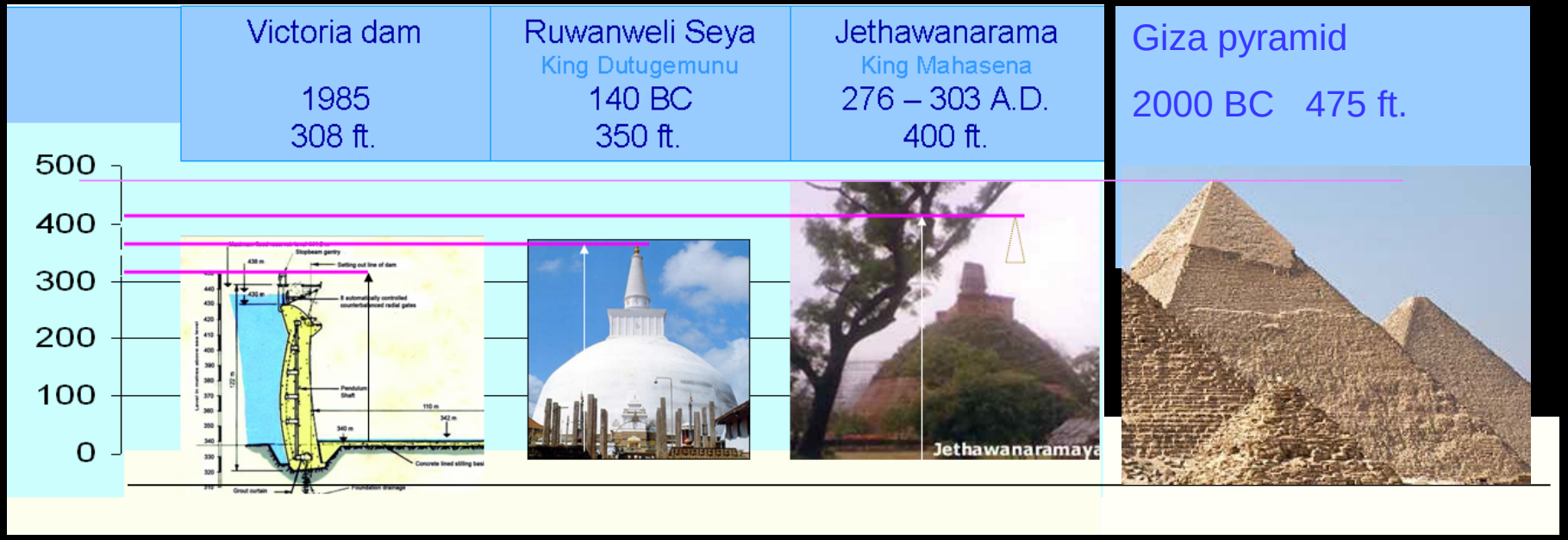
Mechanical Boving UK

Electrical Balfour Klipatric UK

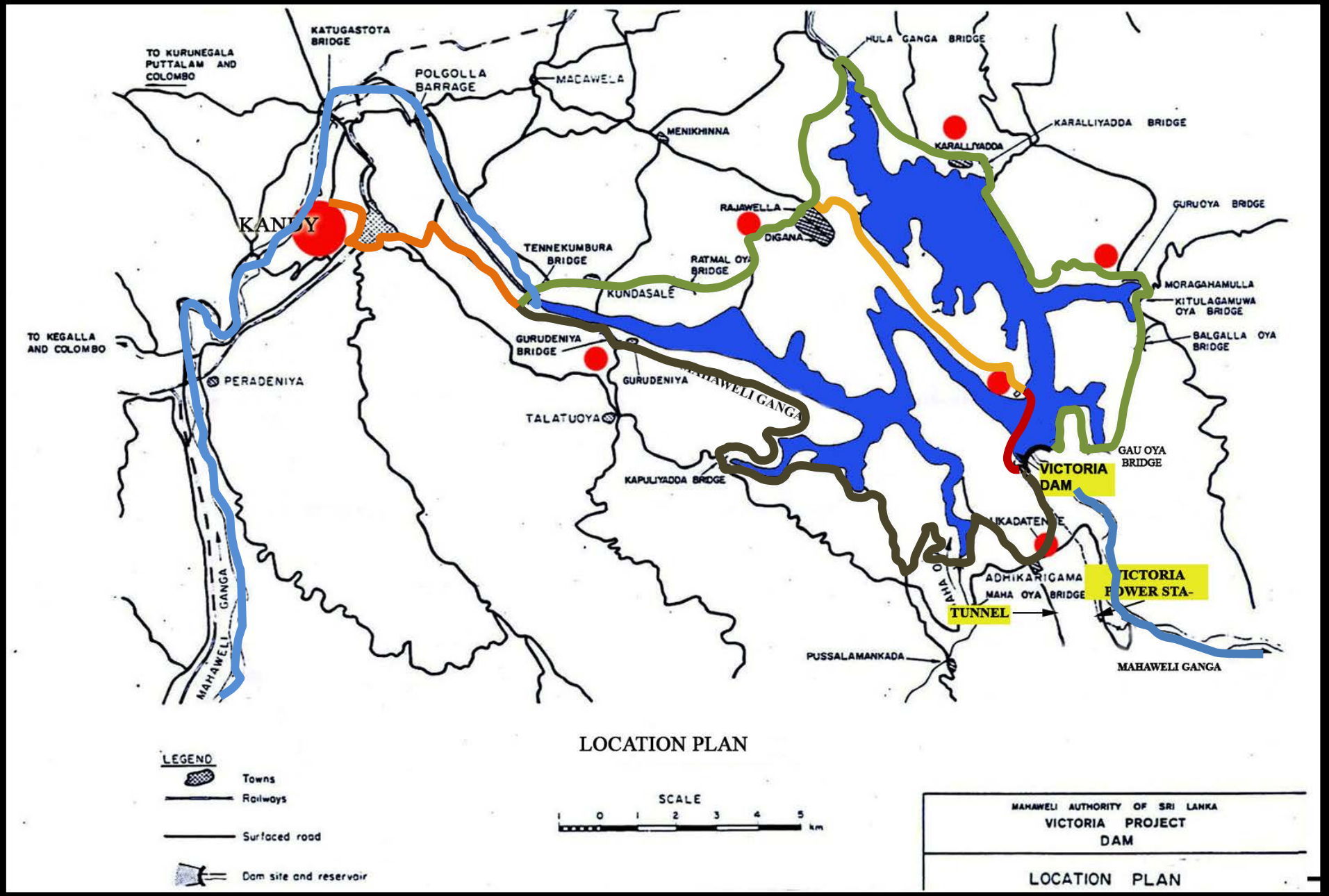
Cost 9.8 billion Rs. (1980-1984)

Height - 122 m	Length – 520 m
Catchment Area	1891 km^2
Gross Storage	722 MCM
Power Generation	3x70 MW

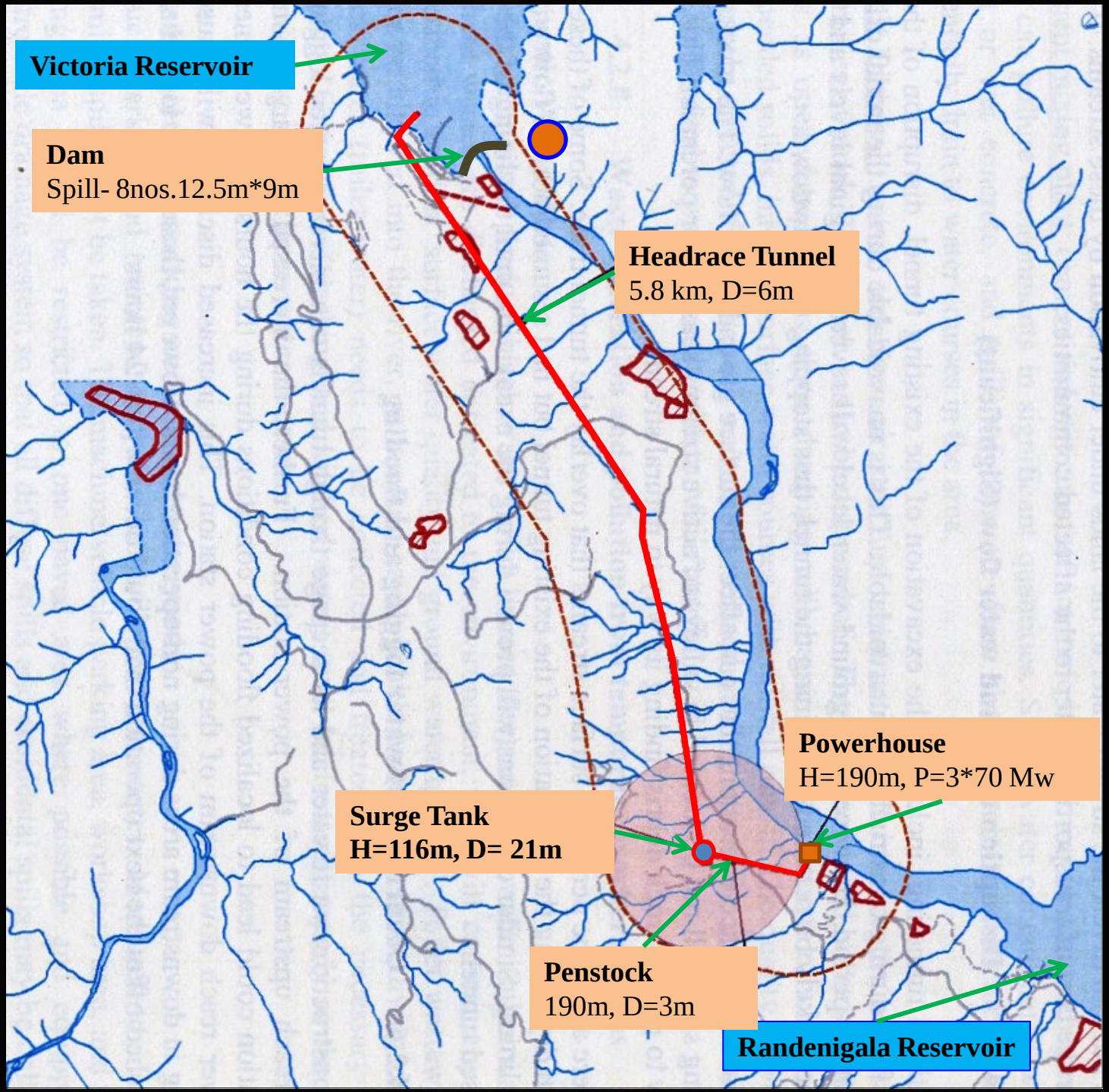
500 Gwh / year – 6% of the total power requirement



Heights of ancient and modern structures compared



LOCATION PLAN

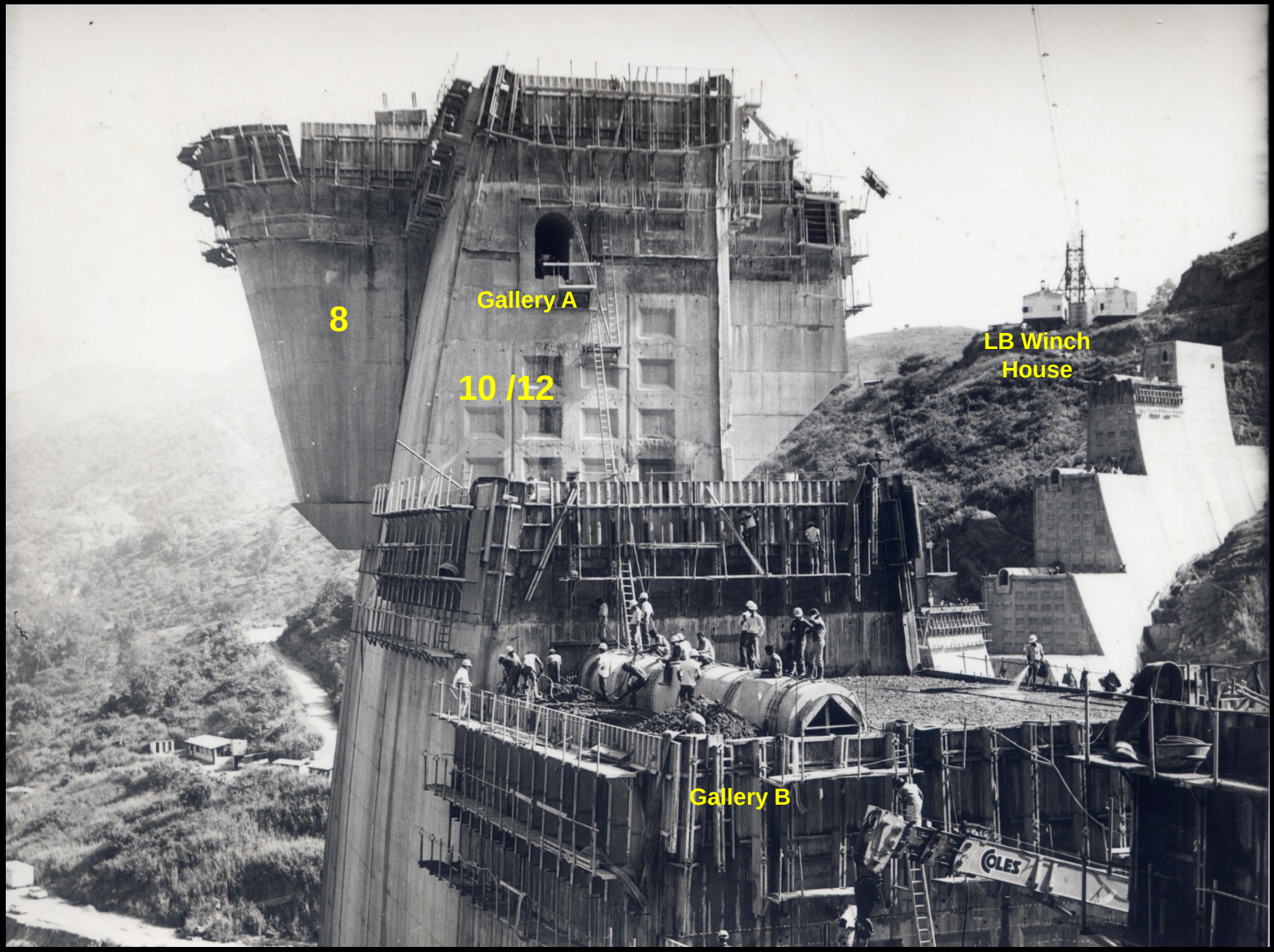

Victoria Reservoir
Dam
Spill- 8nos.12.5m*9m
Headrace Tunnel
5.8 km, D=6m
Powerhouse
H=190m, P=3*70 Mw
Surge Tank
H=116m, D= 21m
Penstock
190m, D=3m
Randenigala Reservoir

View from Left bank

Victoria Spilling (Recently in Jan/2011)

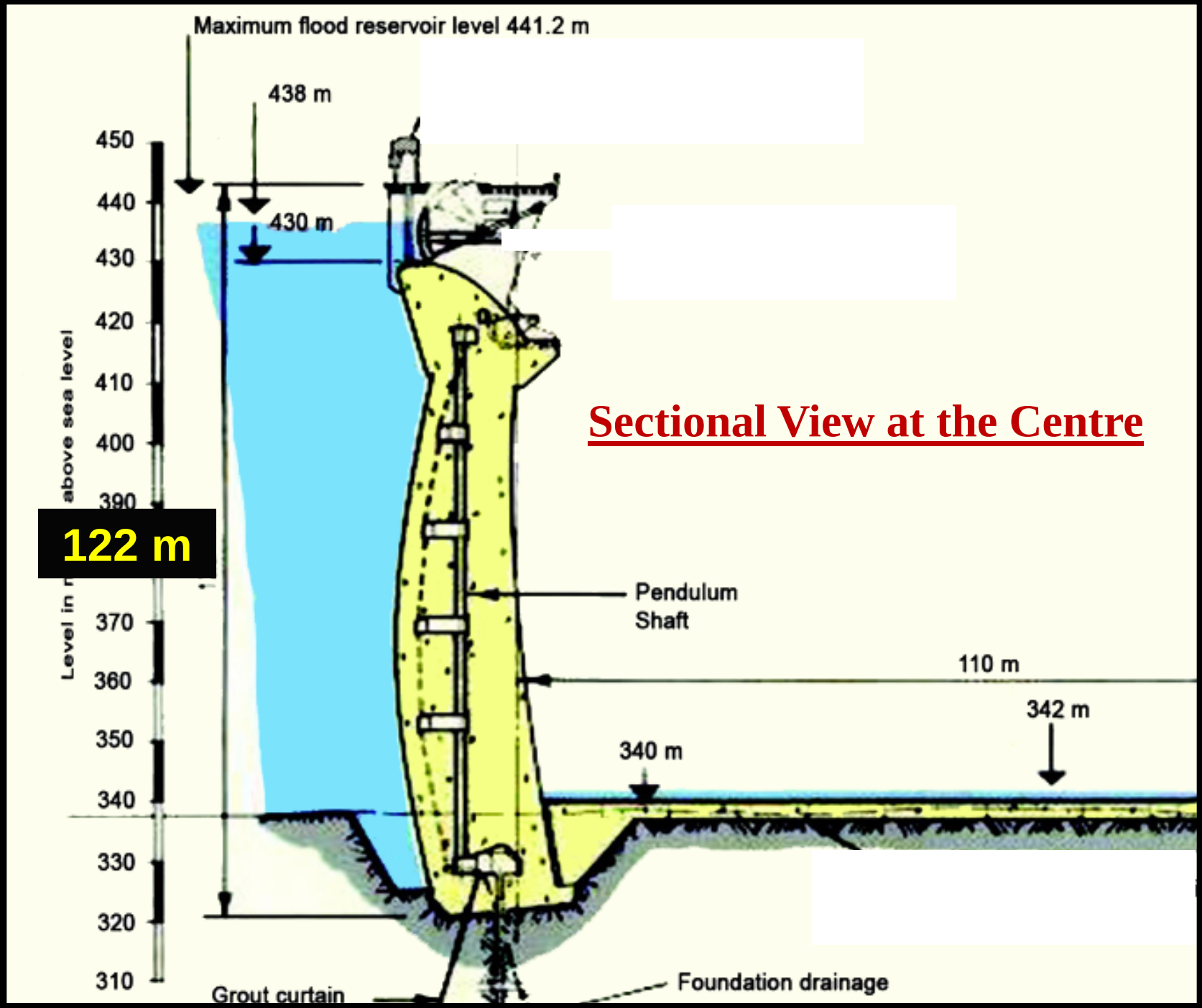
Downstream View

Dam Under Construction

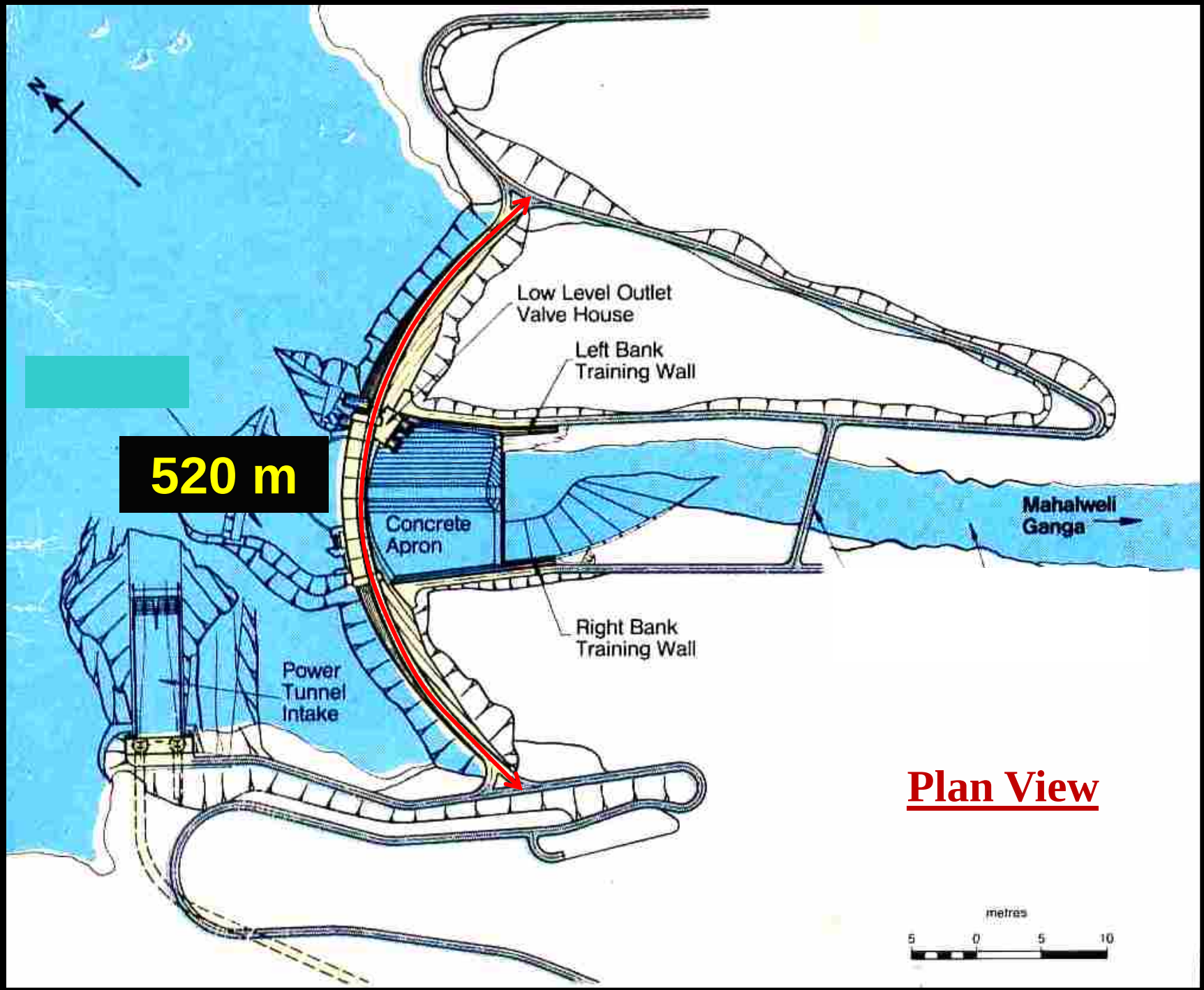


Taken on 31-Jan-1983(from RB)

Power Station



Sectional View at the Centre


N
520 m
Low Level Outlet
Valve House
Left Bank
Training Wall
Concrete
Apron
Mahaiwell
Ganga
Right Bank
Training Wall
Power
Tunnel
Intake
metres
5
0
5
10

Plan View

Dam Concrete

- **Concrete volume :480,000 m^3**
- **Low Heat Low Alkali Cement**

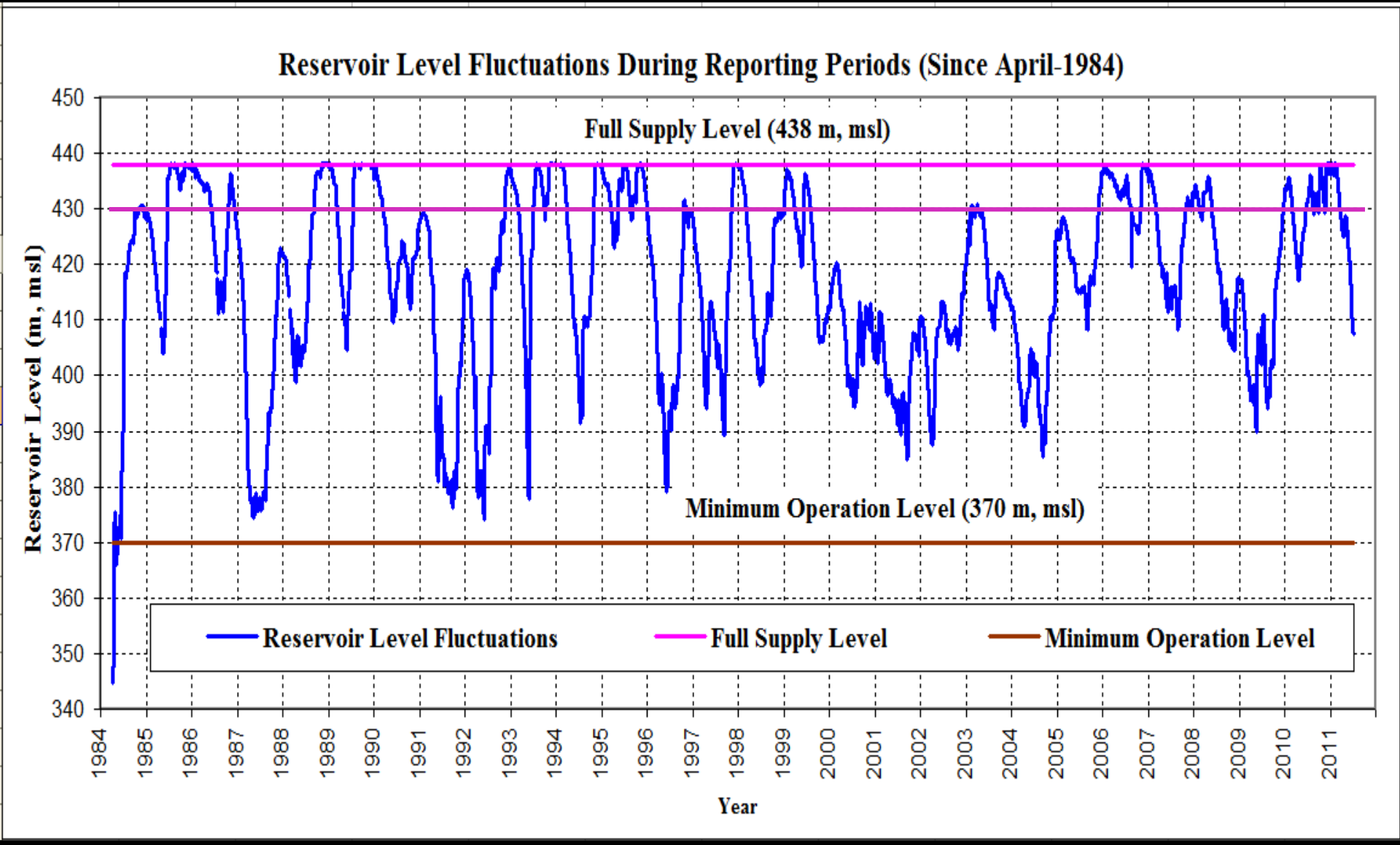
  Na_2O equivalent 0.65 %

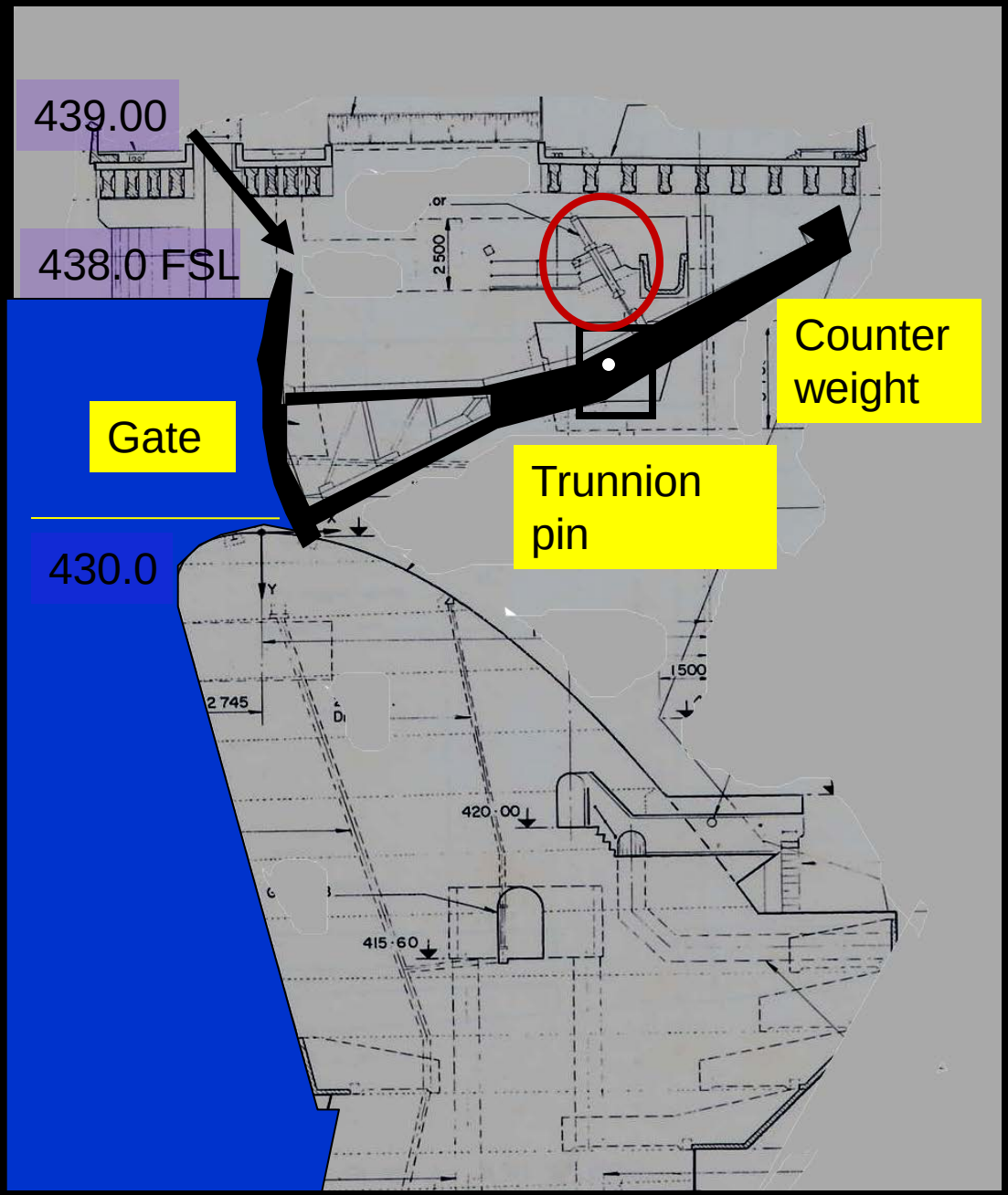
  Alkali content per m^3 ~ 1.15 kg
- **Cement content of the dam concrete**

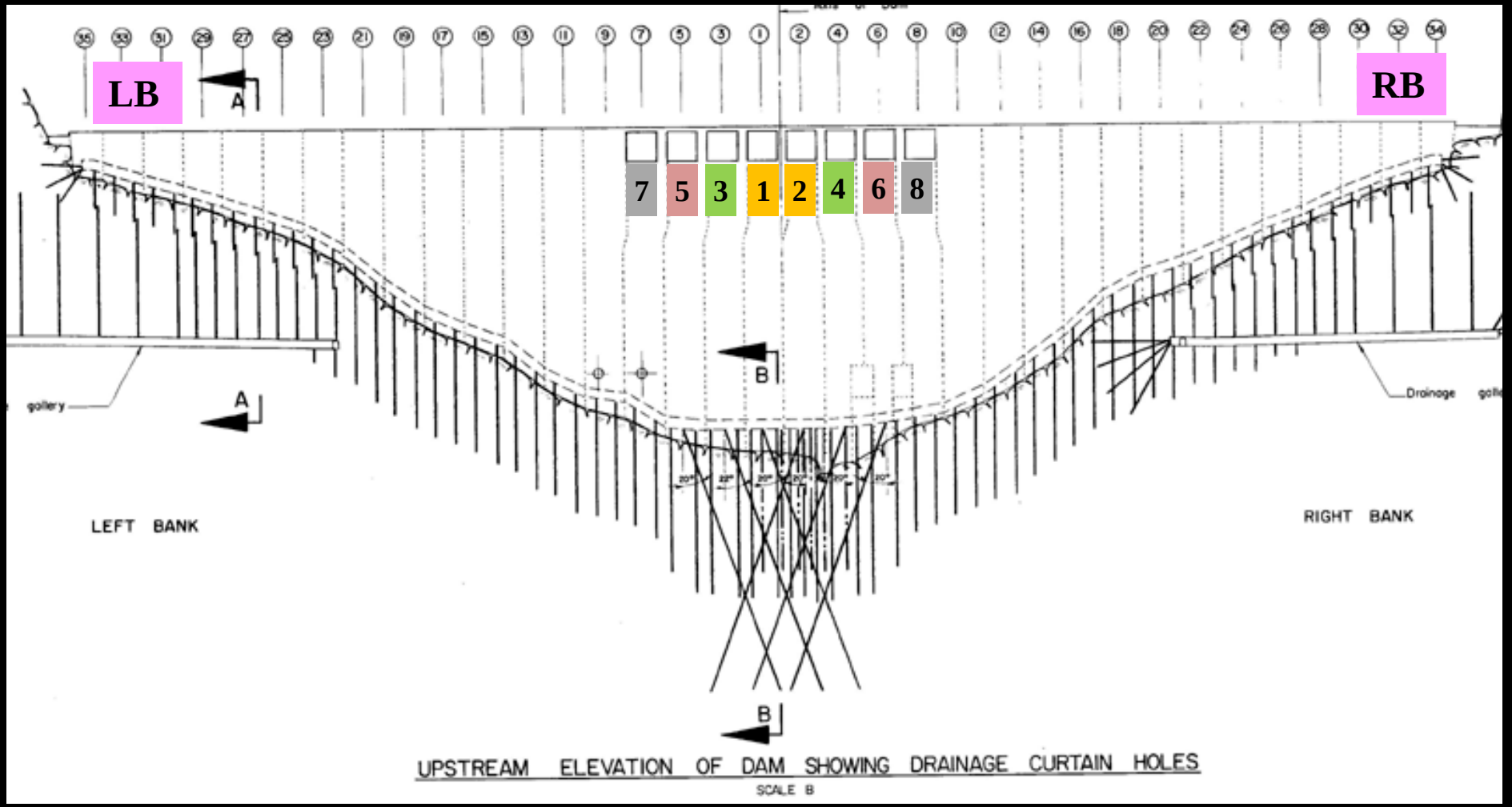
  230 ± 10 kg/m^3
- **150 mm (max) graded aggregate**
- **Upstream face**

  chemically impregnated
- **Concrete temperature controlled at 22 ^0C**

Reservoir Level Fluctuations in Victoria Reservoir for last 27 years (Since April-1984)



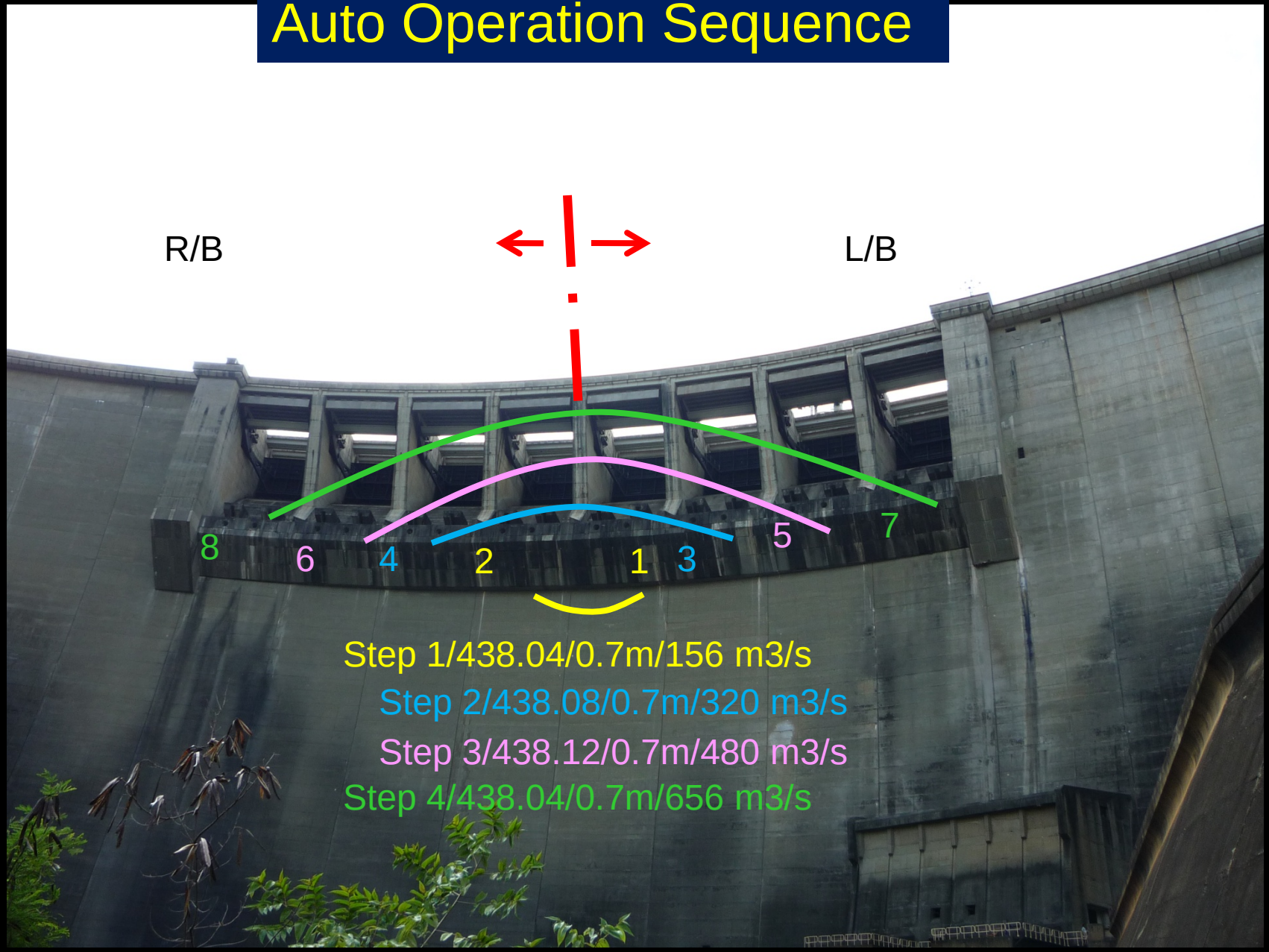

439.00
438.0 FSL
Gate
Counter weight
Trunnion pin
430.0
2500
2745
1500
420·00
415·60



Upstream View

Numbering of Blocks & Drainage Curtain

Auto Operation Sequence



Downstream View

Chapters

Part 1

General Information

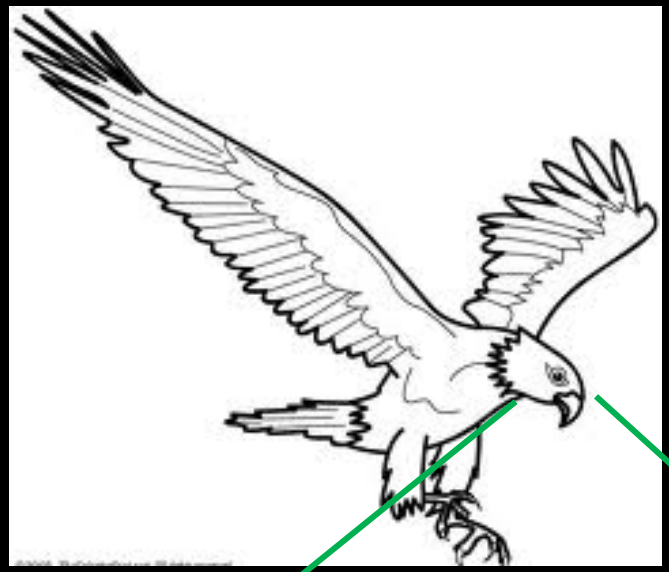
Part 2

Instrumentation

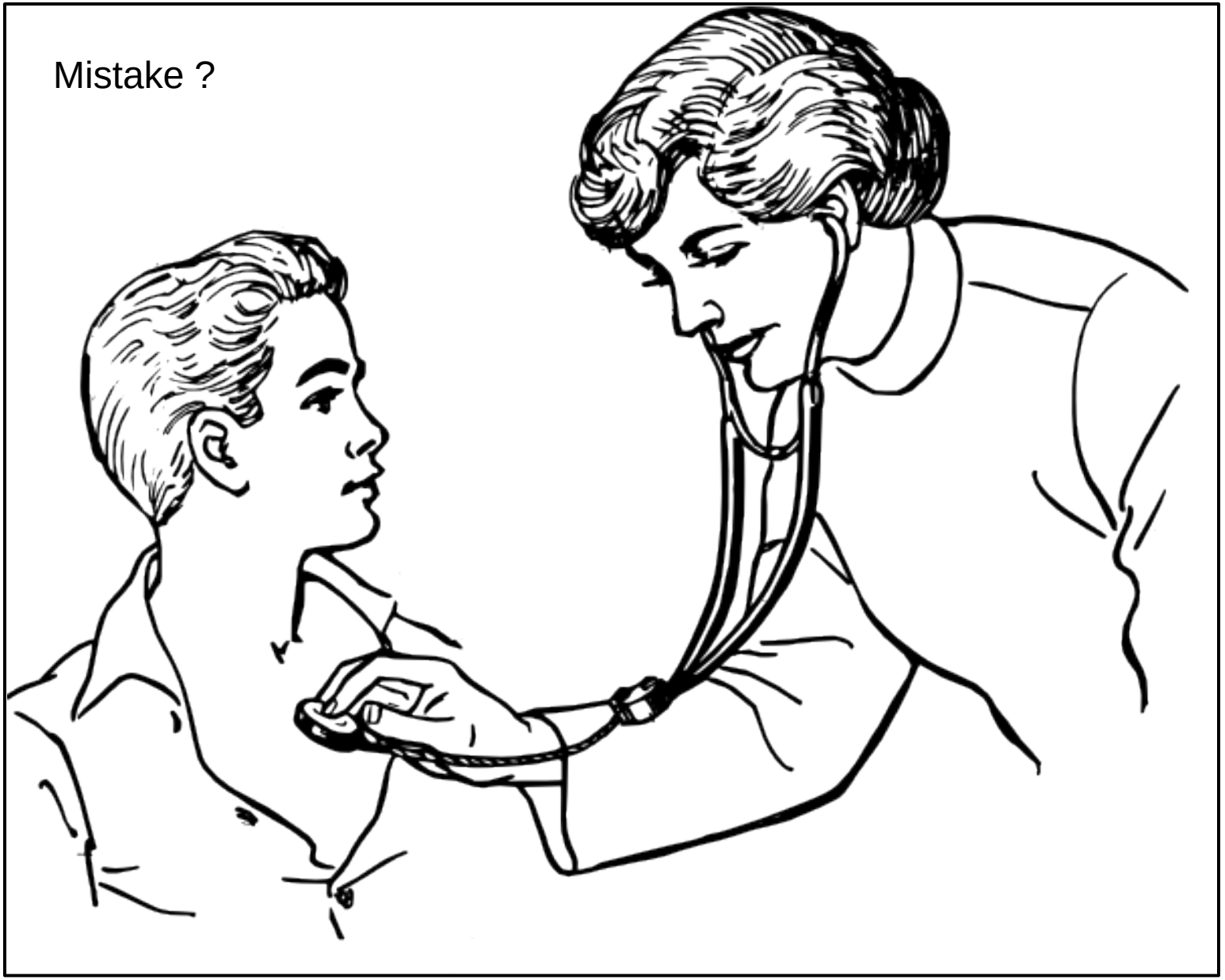
Part 3

Observations 1~6 & Conclusion

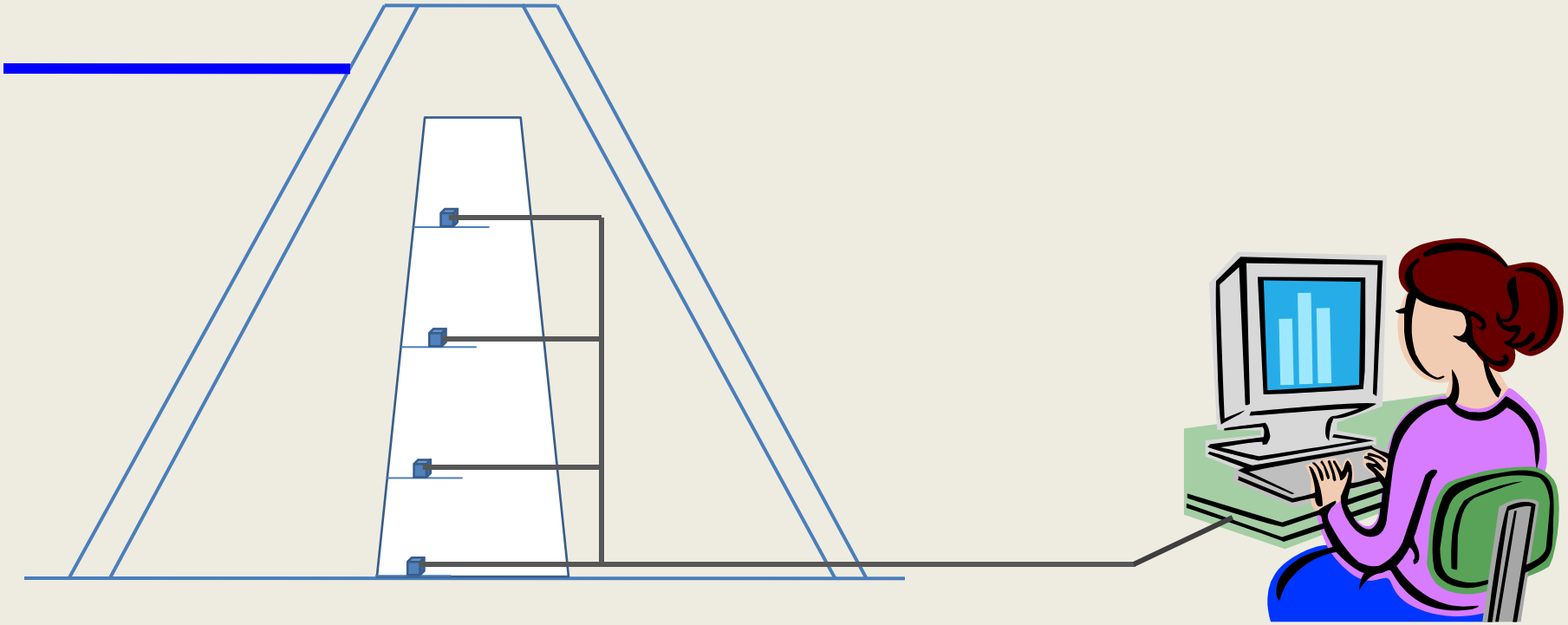
Looking the whole dam as an eagle eye



Mistake ?



Mistake ?



Dam Instrumentation

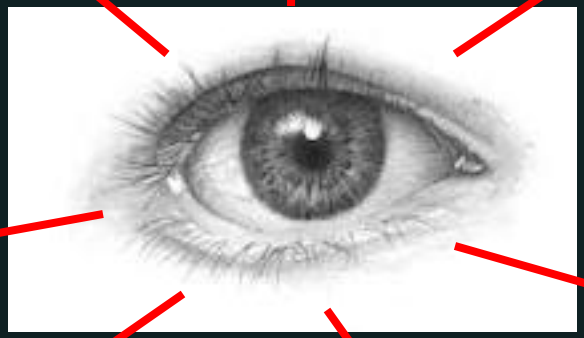
Observant Eye linked to an Intelligent Brain

Dam Instruments

Survey Targets

Piezometers

Extensometers



Drain holes

Strain gauges

Pendulum

Levelling studs

Interpretation

Long term trends

Identifying the patterns

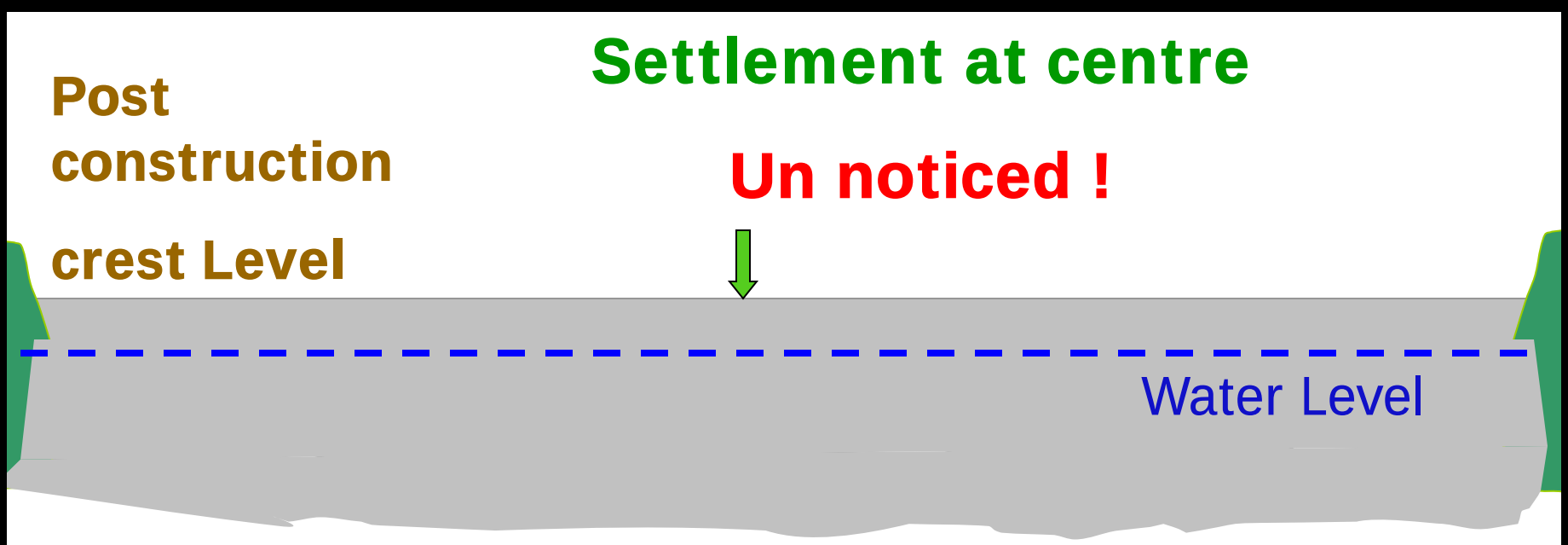
Accuracy

Calibrations

Precision

Least count

- **Observer reliability**
- **Commitment**
- **Working Principle of Instruments**



Overtopping due to Settlement of Long Embankment Dam

Settlements

Instruments in Victoria

…topics to be discussed

Pendulums

Clinometers

Extensometers

Piezometers / Drain holes

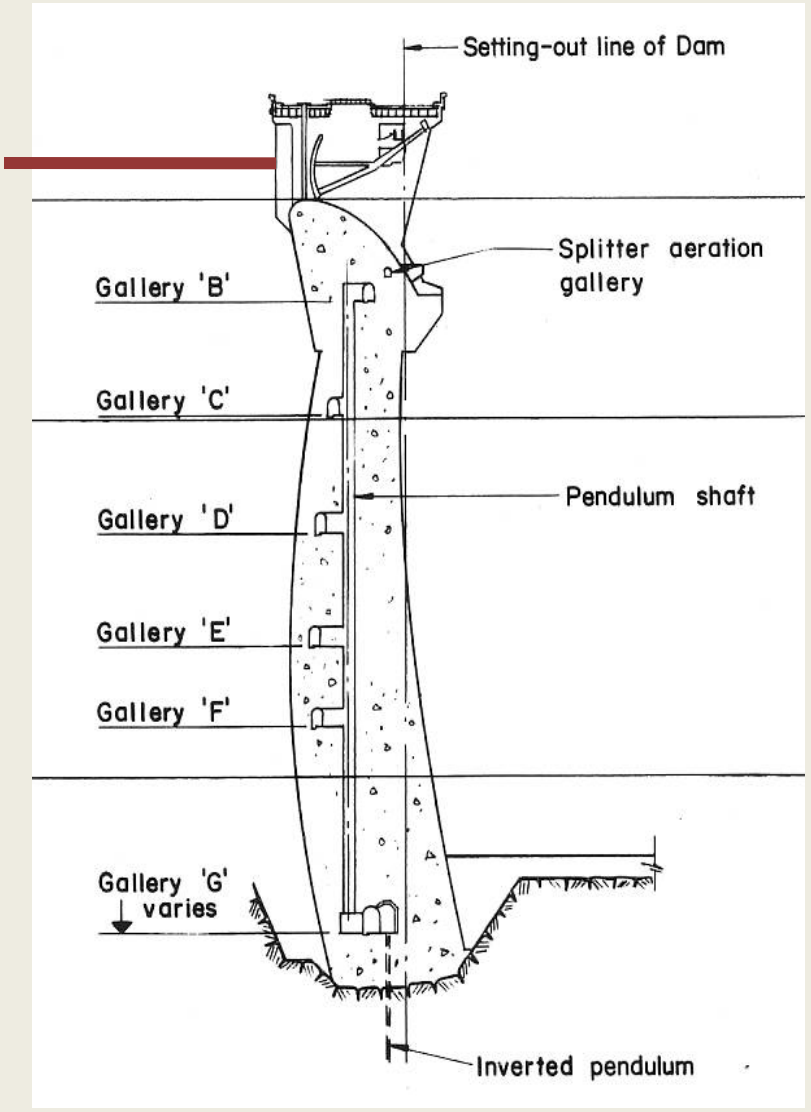
Survey Targets

Strain Gauges

Dam Instrumentation

- **Dam Deflections**
  - 7 Normal Pendulums , 1mm(2 week)
  - 24 Crest Precise Levelling 0.1mm (annually)
  - 48 Survey Face Targets , 0.5 sec(annually)
- **Foundation Deflections**
  - 7 Inverted Pendulums (0.01mm)
  - 10 VW Clinometers (5) (2 week)
  - 3-Point Extensometer (2 week)
- **Concrete Strains**
  - 269 VW Strain meters (50) (2 week)
  - 66 VW Thermometers (19) (2 week)
- **Foundation Hydrogeology**
  - 21 Piezometers 1water m (4) (weekly)
  - Drainage Flows 5 ml, 0.01s (weekly)

*out of order



Instruments in Victoria

Pendulums

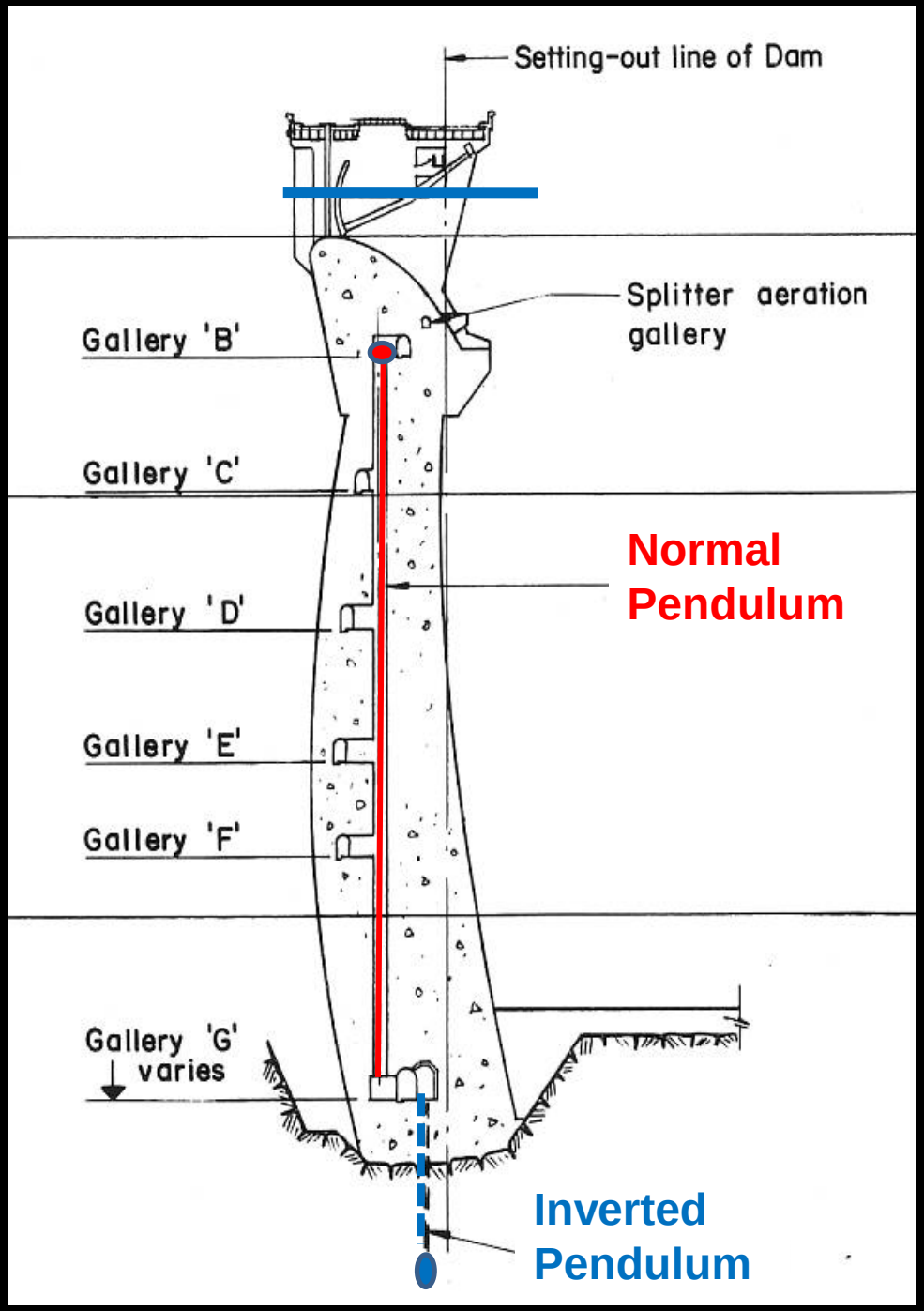
Clinometers

Extensometers

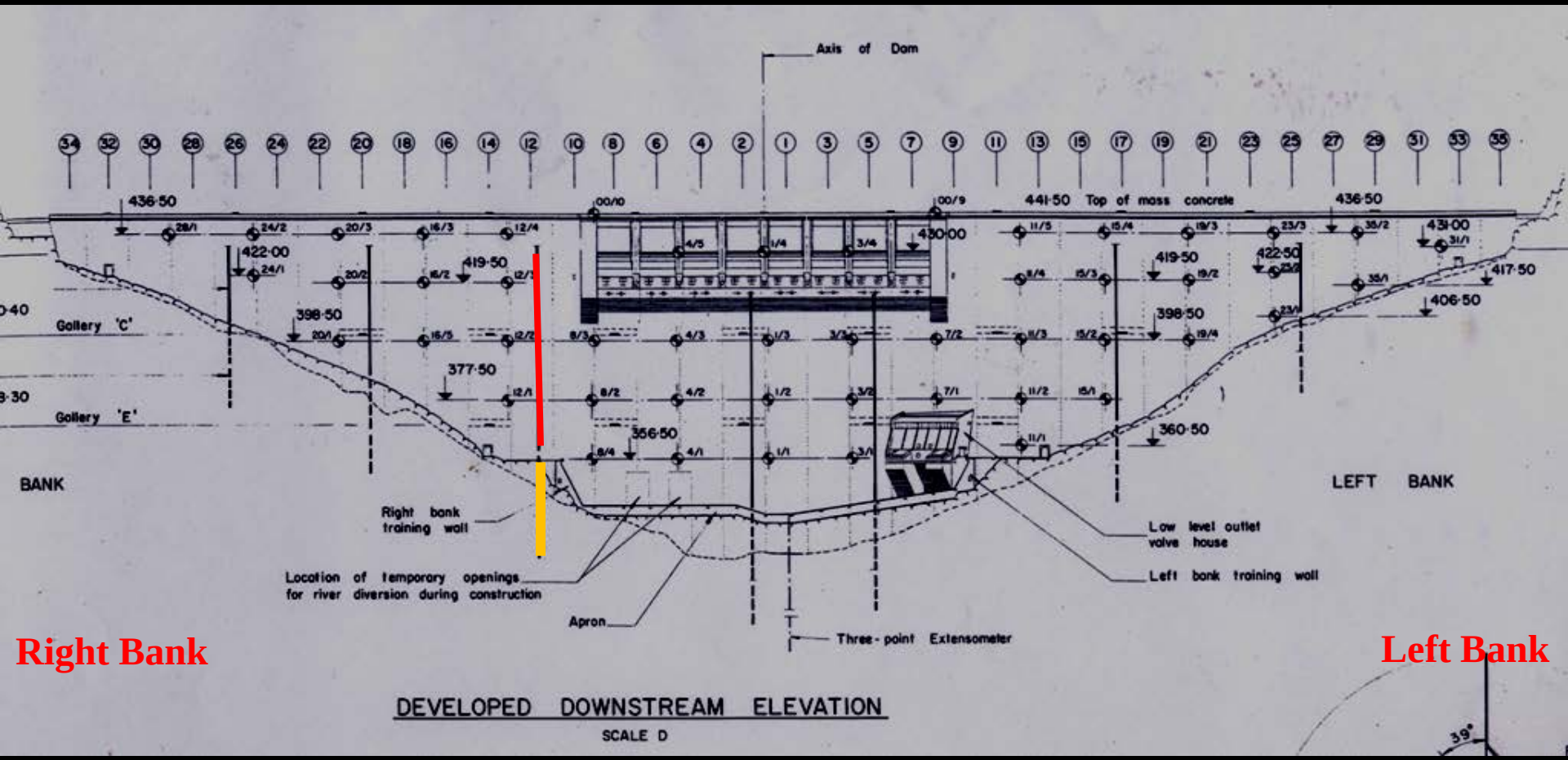
Piezometers / Drain holes

Survey Targets

Strain Gauges


Setting-out line of Dam
Splitter aeration gallery
Gallery 'B'
Gallery 'C'
Normal Pendulum
Gallery 'D'
Gallery 'E'
Gallery 'F'
Gallery 'G' varies
Inverted Pendulum

Pendulum locations



Normal and Inverted

Normal Pendulums

Inverted Pendulums

Instruments in Victoria

Pendulums

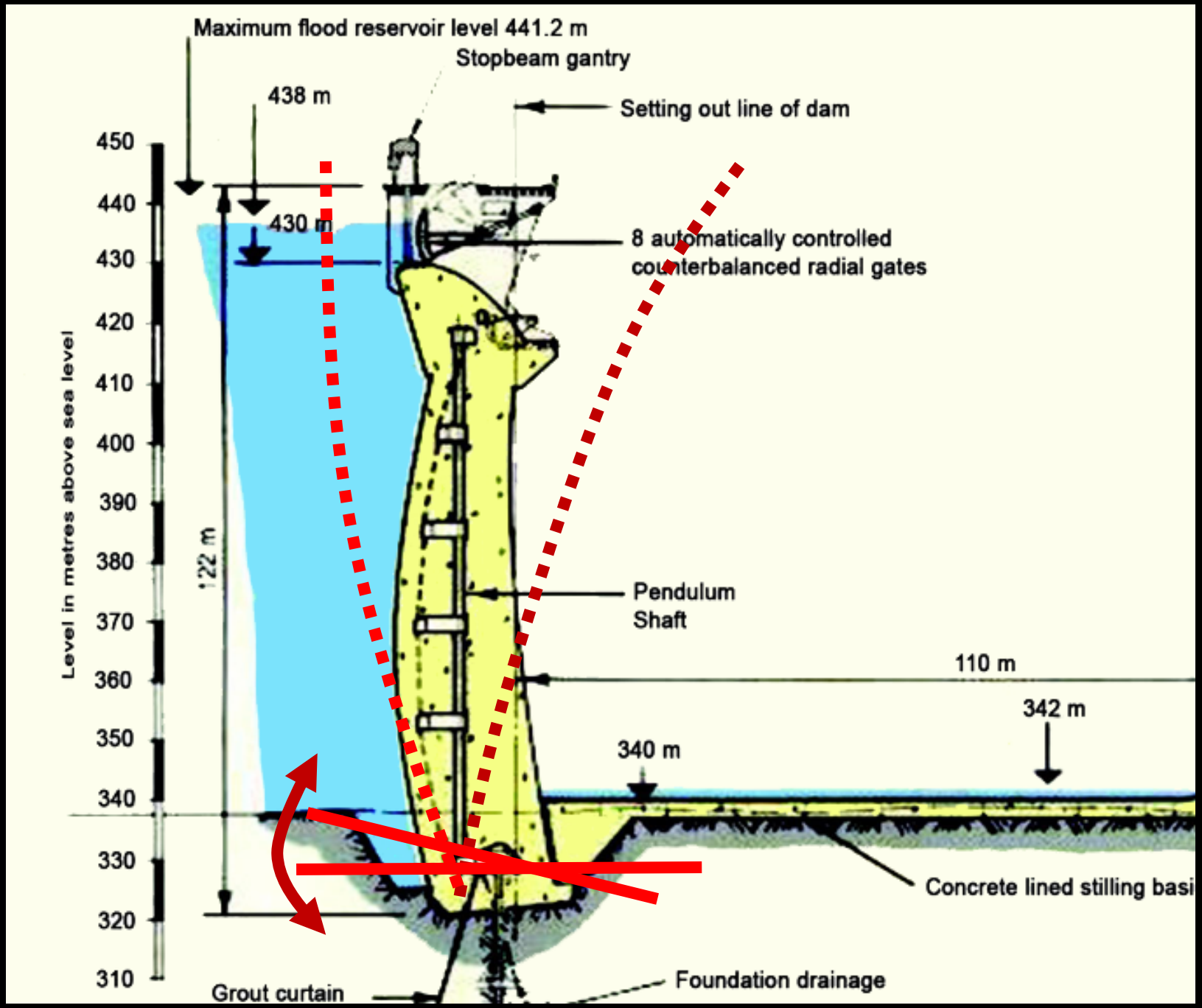
Clinometers

Extensometers

Piezometers / Drain holes

Survey Targets

Strain Gauges


Maximum flood reservoir level 441.2 m
Stopbeam gantry
438 m
Setting out line of dam
450
440
430
420
410
400
390
380
370
360
350
340
330
320
310
430 m
8 automatically controlled
counterbalanced radial gates
Level in metres above sea level
122 m
Pendulum
Shaft
110 m
342 m
340 m
Concrete lined stilling basi
Grout curtain
Foundation drainage

VW Clinometers

Instruments in Victoria

Pendulums

Clinometers

Extensometers

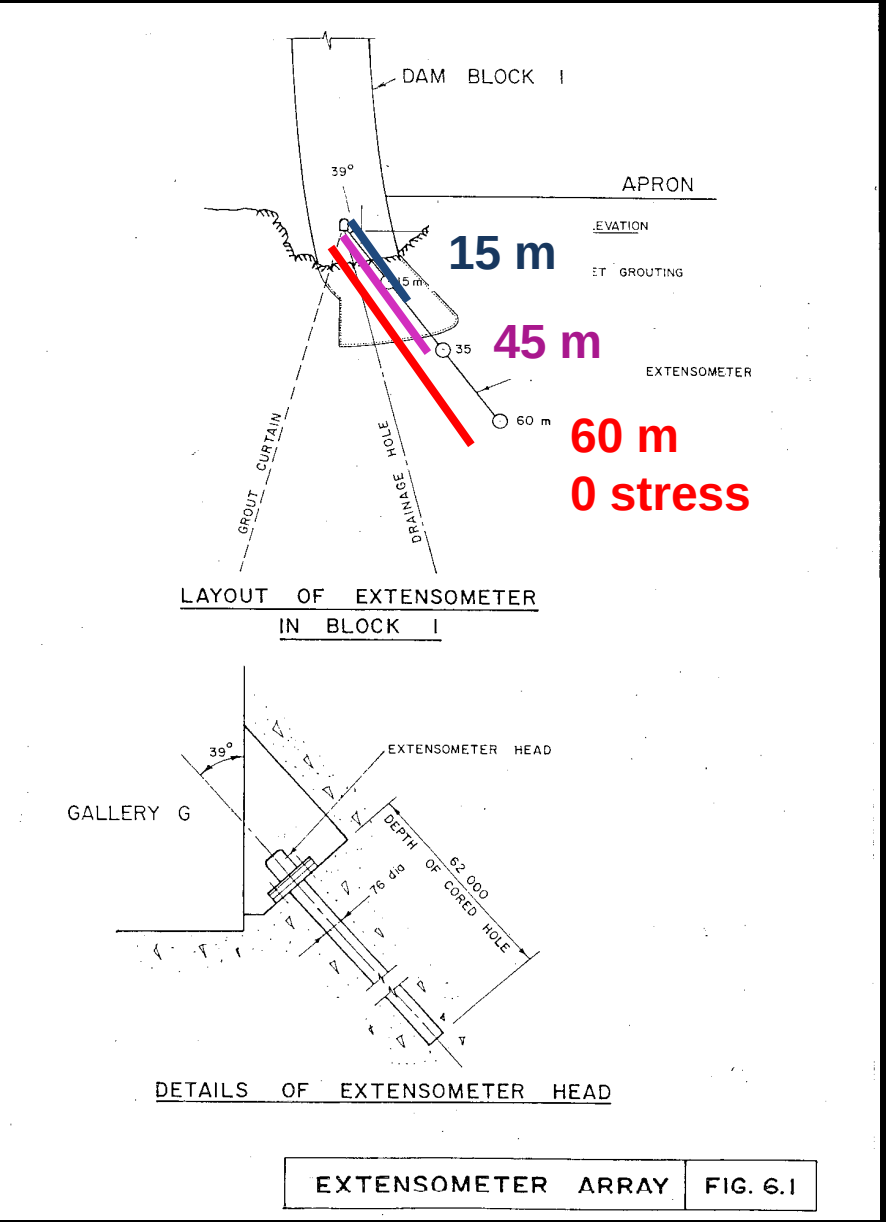
Piezometers / Drain holes

Survey Targets

Strain Gauges

Extensometer:

Detail of Installation



- In 76mm Ø hole drilled from gallery ‘G’

3-Point Extensometer

Instruments in Victoria

Pendulums

Clinometers

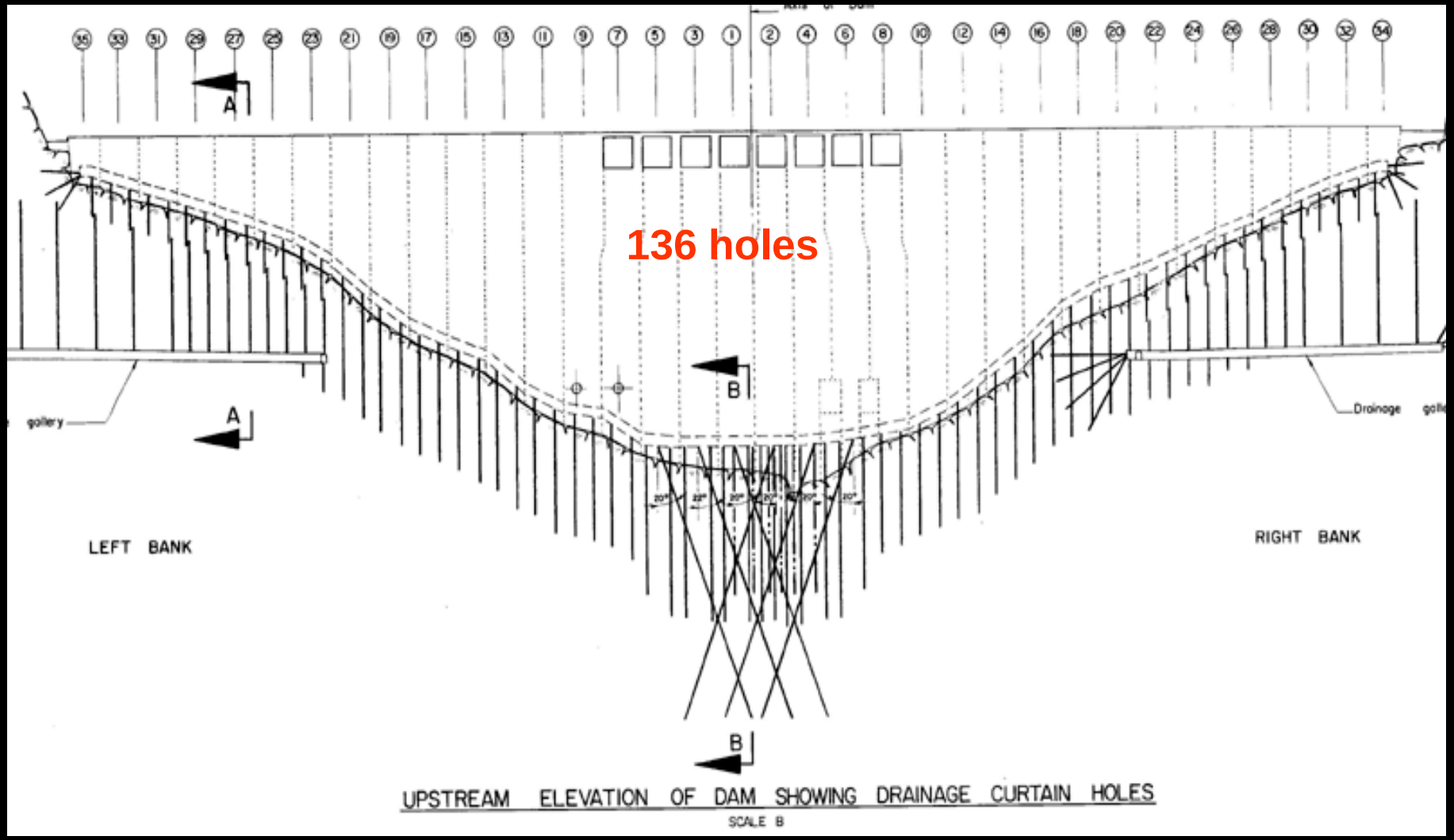
Extensometers

Piezometers / Drain holes

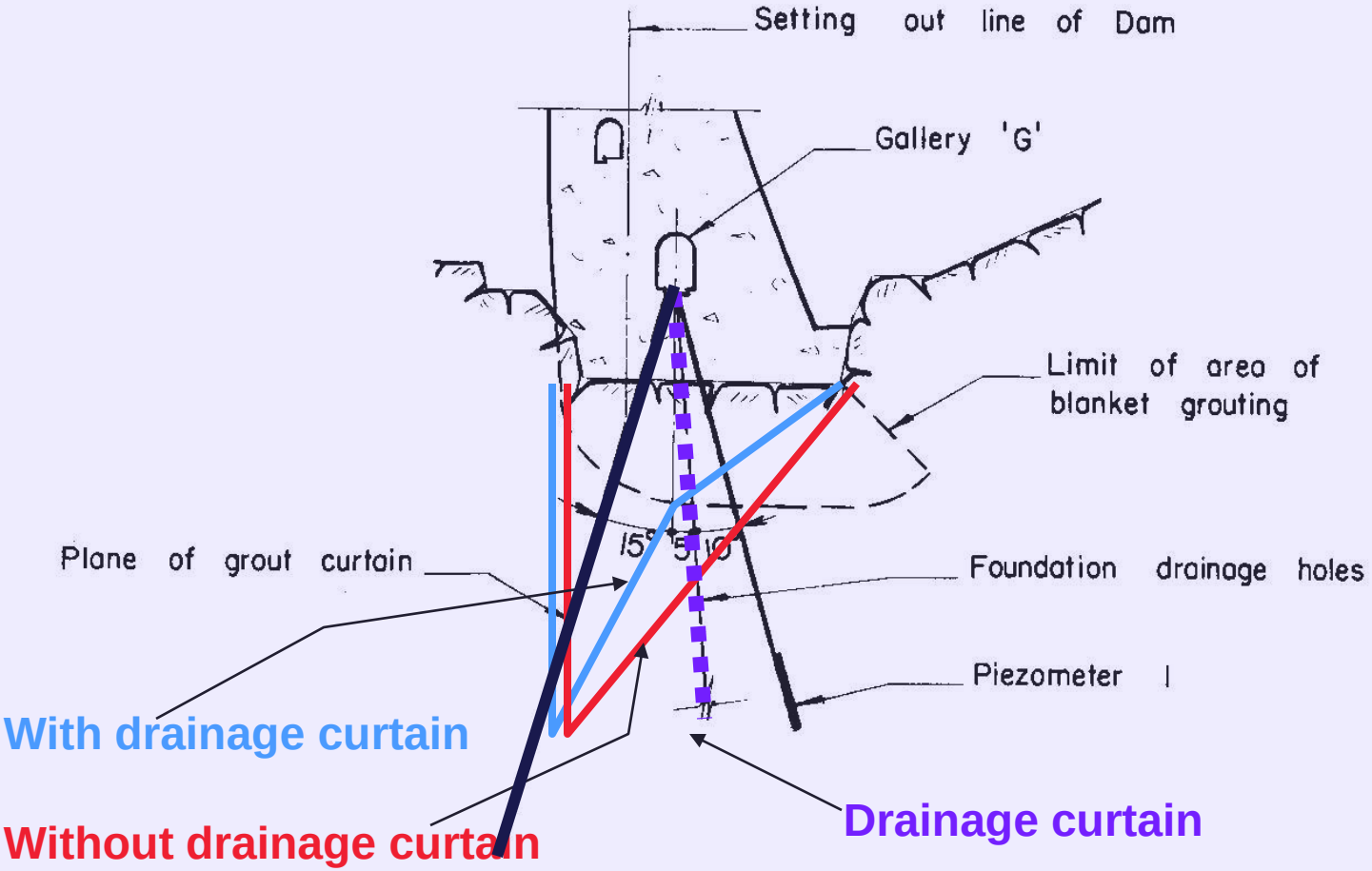
Survey Targets

Strain Gauges

Drainage Holes



De-choking of Drainage Holes



SECTION B-B

SCALE A

η=60%

Expected drainage efficiency is 60%

Piezometers

Drain Holes

Instruments in Victoria

Pendulums

Clinometers

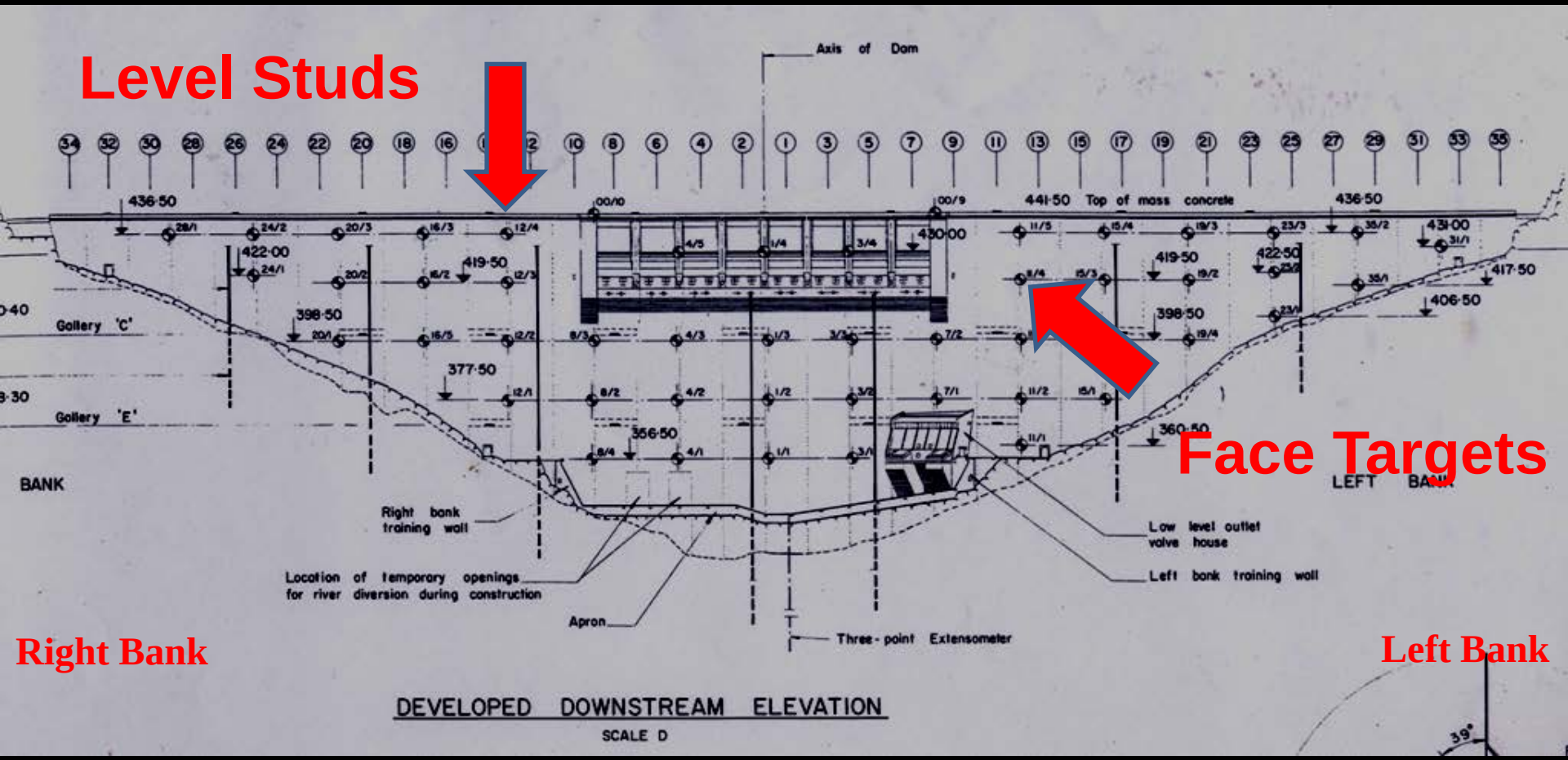
Extensometers

Piezometers / Drain holes

Survey Targets

Strain Gauges

Behaviour of Face Survey Targets



Locations of Face Survey Target on the Dam face

Dam Monitoring Survey

Geodetic Survey

Kern heavy-duty centering adapter

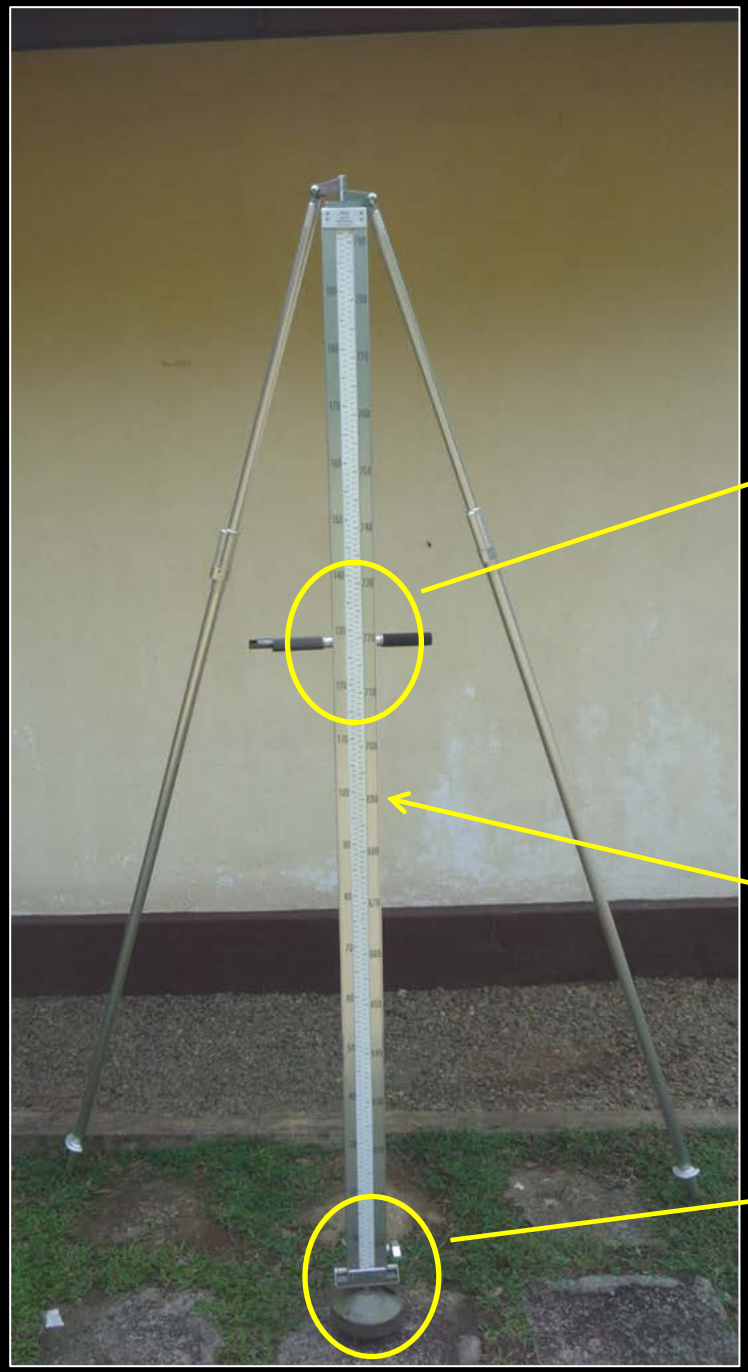
Theodolite (Kern AARAU –DKM3)

Target Plate


11 1
Survey Target Point No 11-1

Dam Monitoring Survey

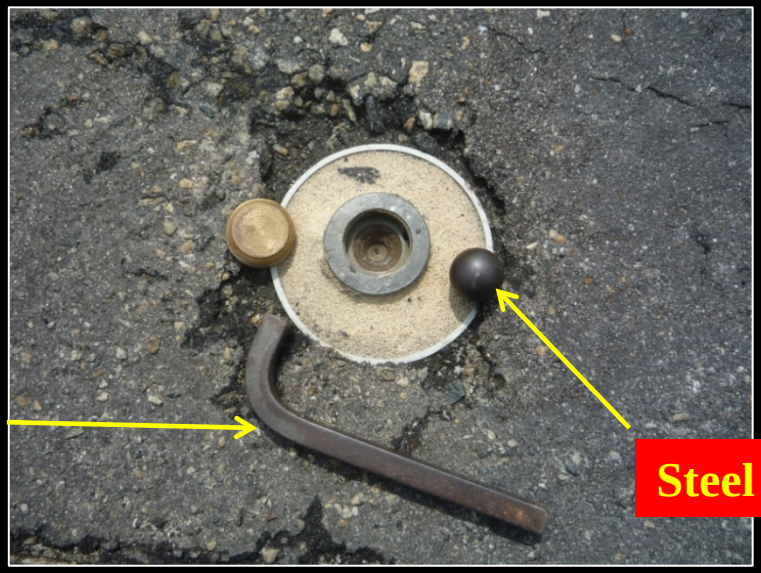
Precise Leveling



Foot Plate

Leveling Staff

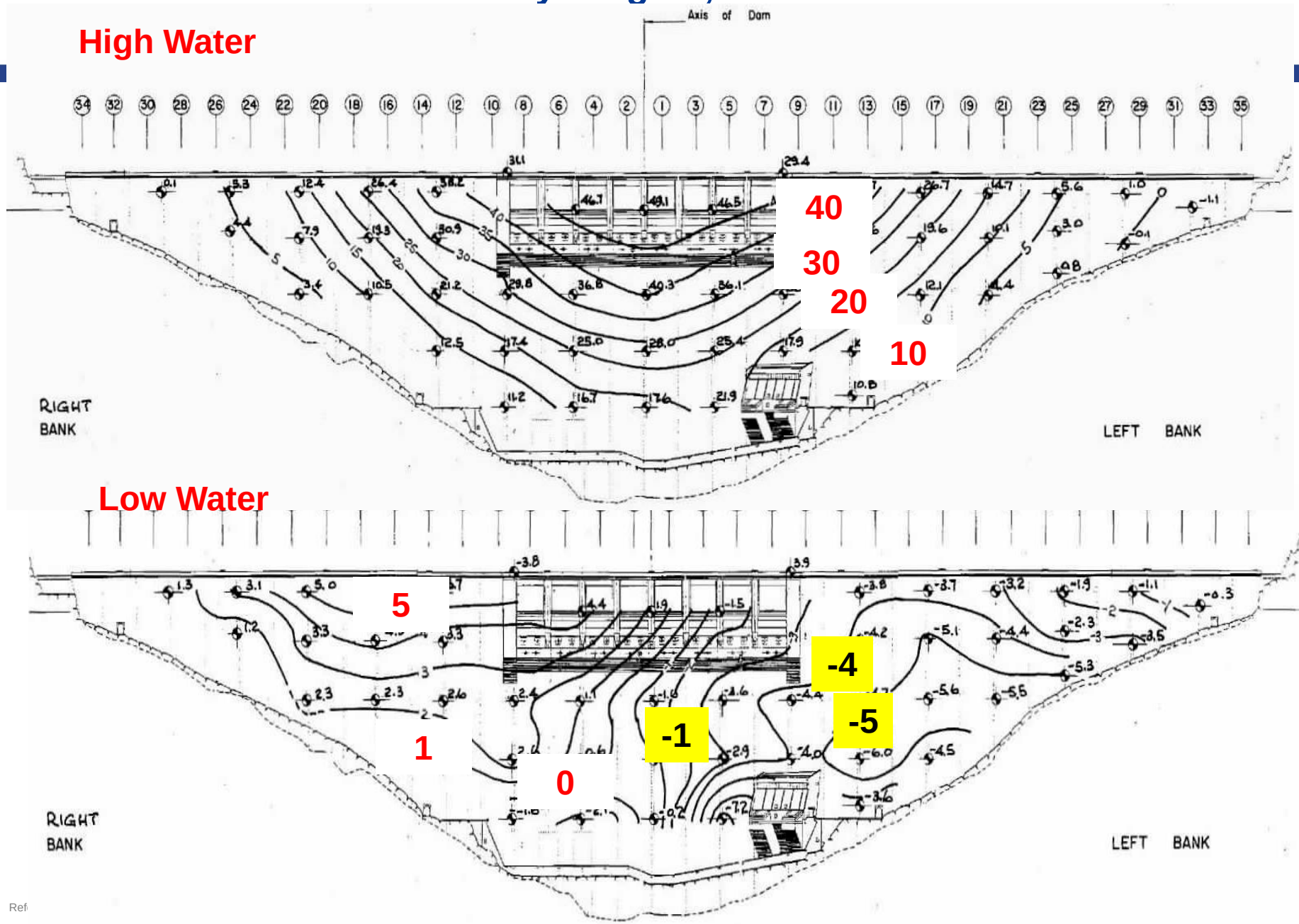
Level Stud on the Dam crest



Wrench

Steel Ball

Face Survey Targets, 2000 Dec



Instruments in Victoria

Pendulums

Clinometers

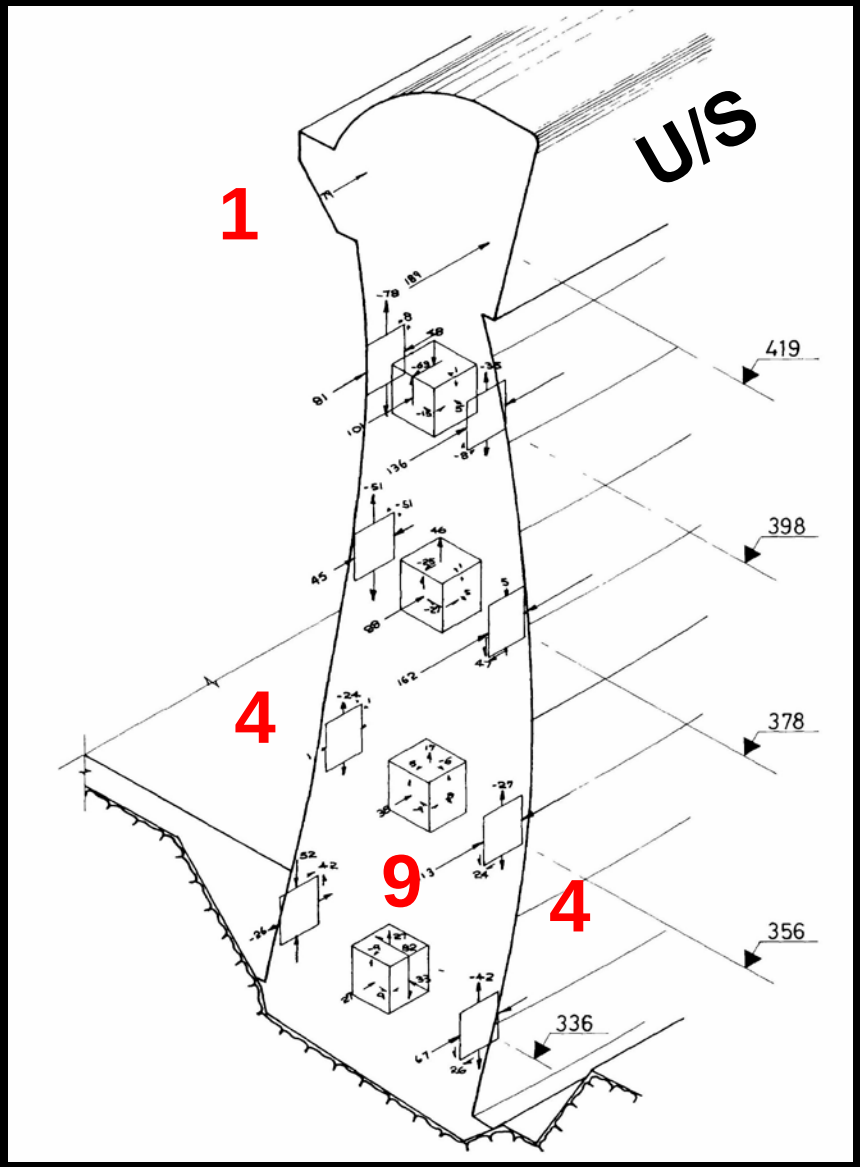
Extensometers

Piezometers / Drain holes

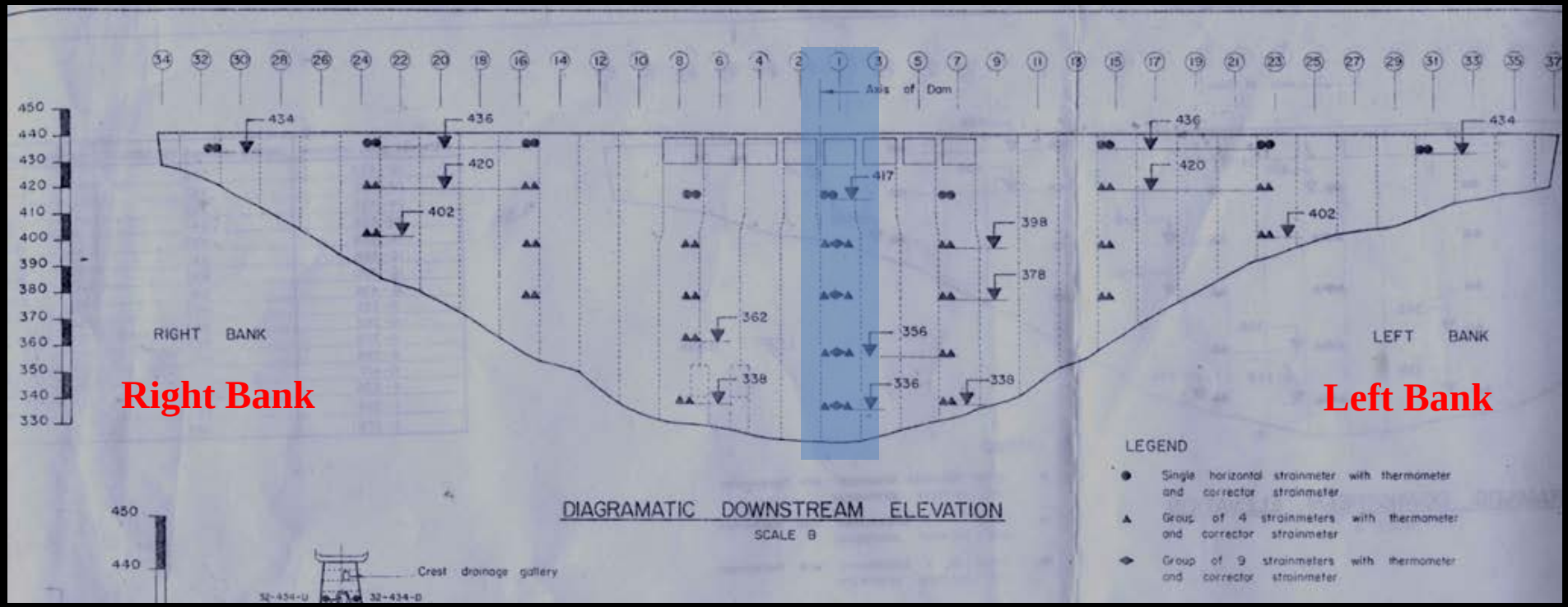
Survey Targets

Strain Gauges

Vibrating Wire Strain Gauges



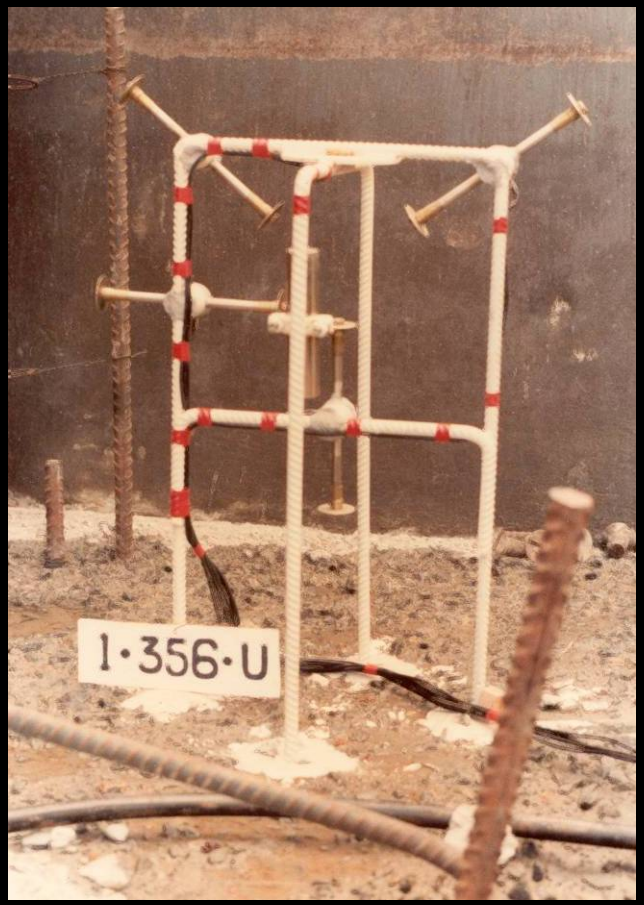
Strain Gauge Locations of the Victoria Dam

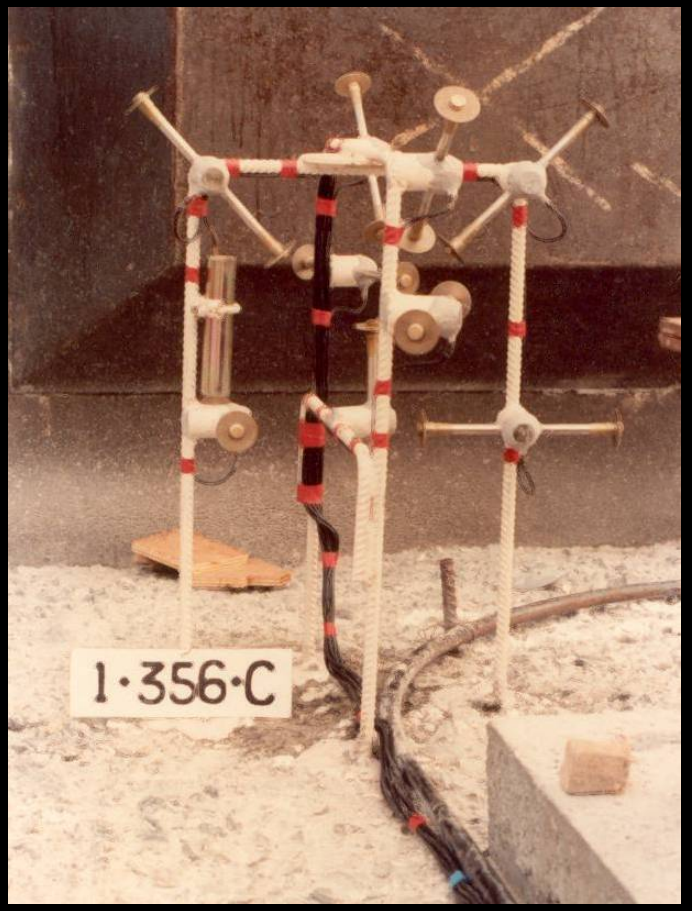


LEGEND

- ● Single horizontal strainmeter with thermometer and corrector strainmeter
- ▲ Group of 4 strainmeter with thermometer and corrector strainmeter
- ◆ Group of 9 strainmeter with thermometer and corrector strainmeter

Vibrating Wire Strain Gauges

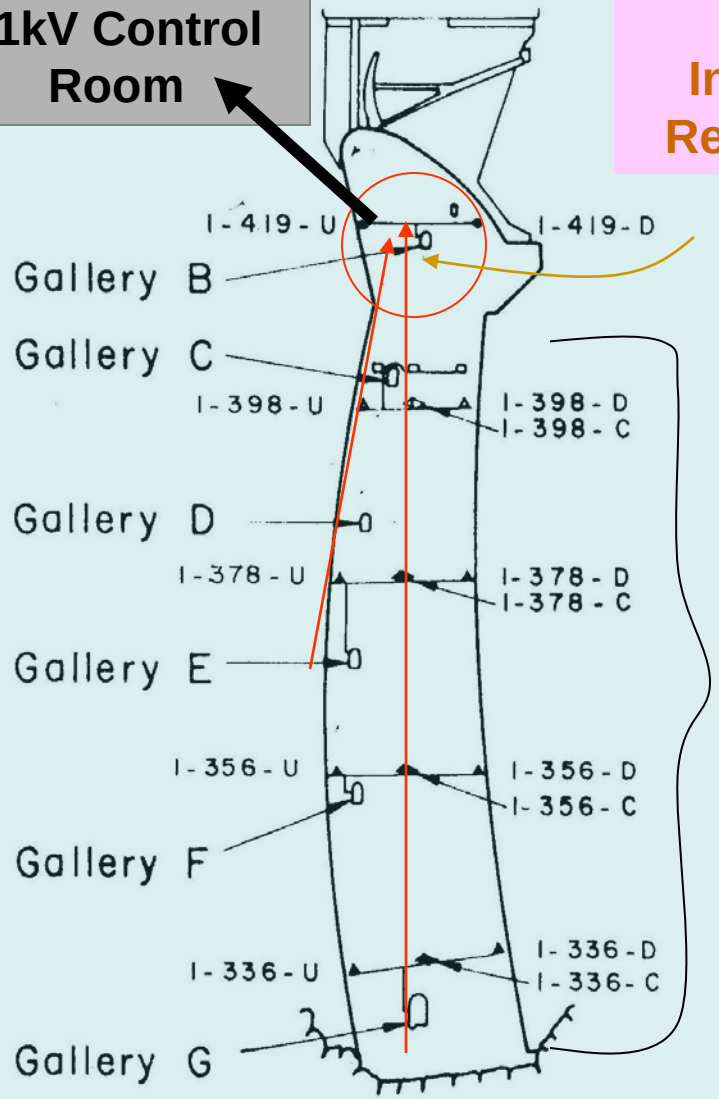




11kV Control Room

Central Instrumentation Reading Chamber

Victoria Data Logger



BLOCK I

TYPICAL SECTION THROUGH DAM

Vibrating Wire instruments	
230	Strainmeters
66	Corrector Strainmeters
66	Thermometers
10	Clinometers


Victoria Data Logger
Data logger system in the Central Instrumentation Reading Chamber
Manual Rack
Aotomatic Logger

Chapters

Part 1

General Information

Part 2

Instrumentation

Part 3

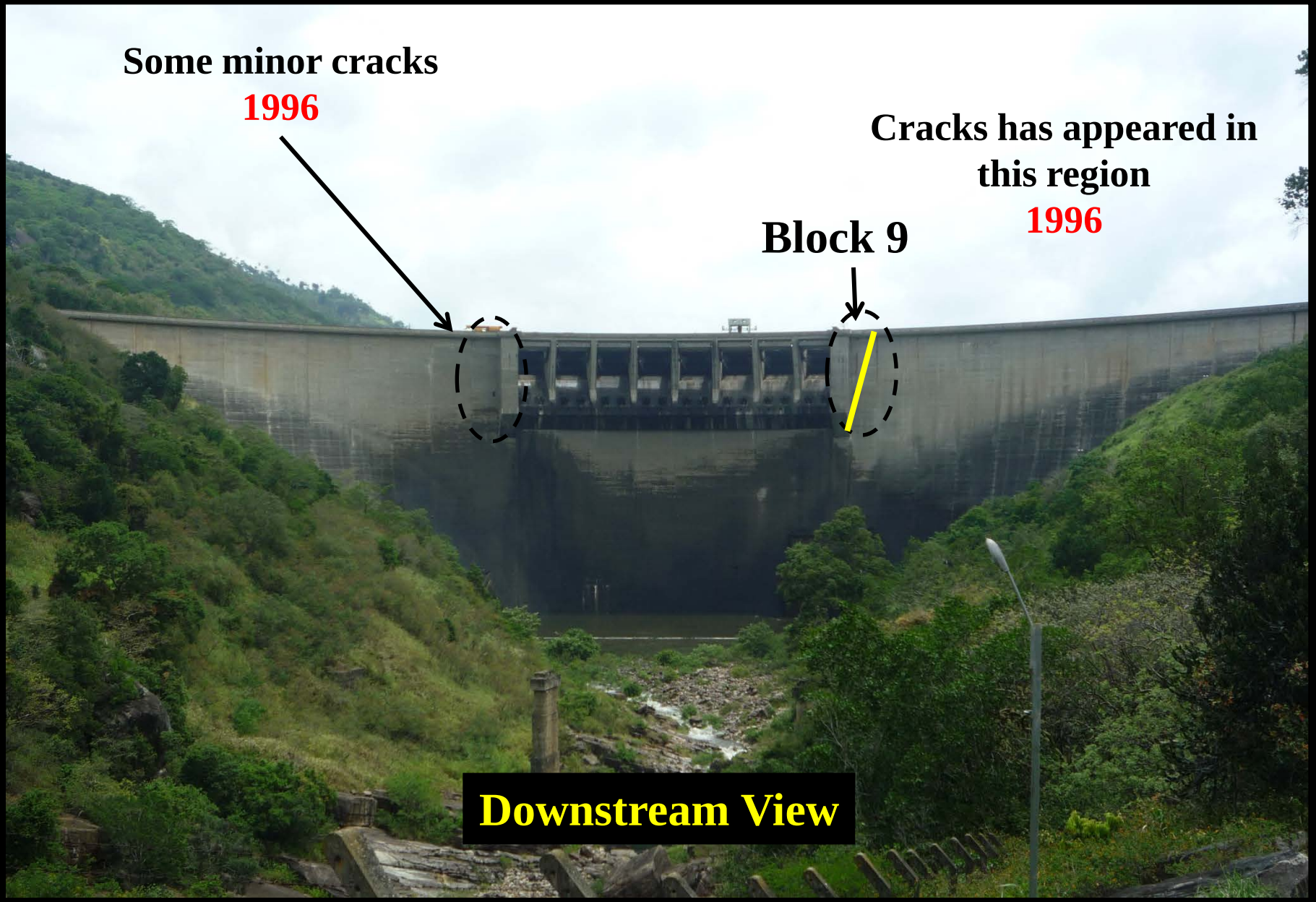
Observations 1~6 & Conclusion

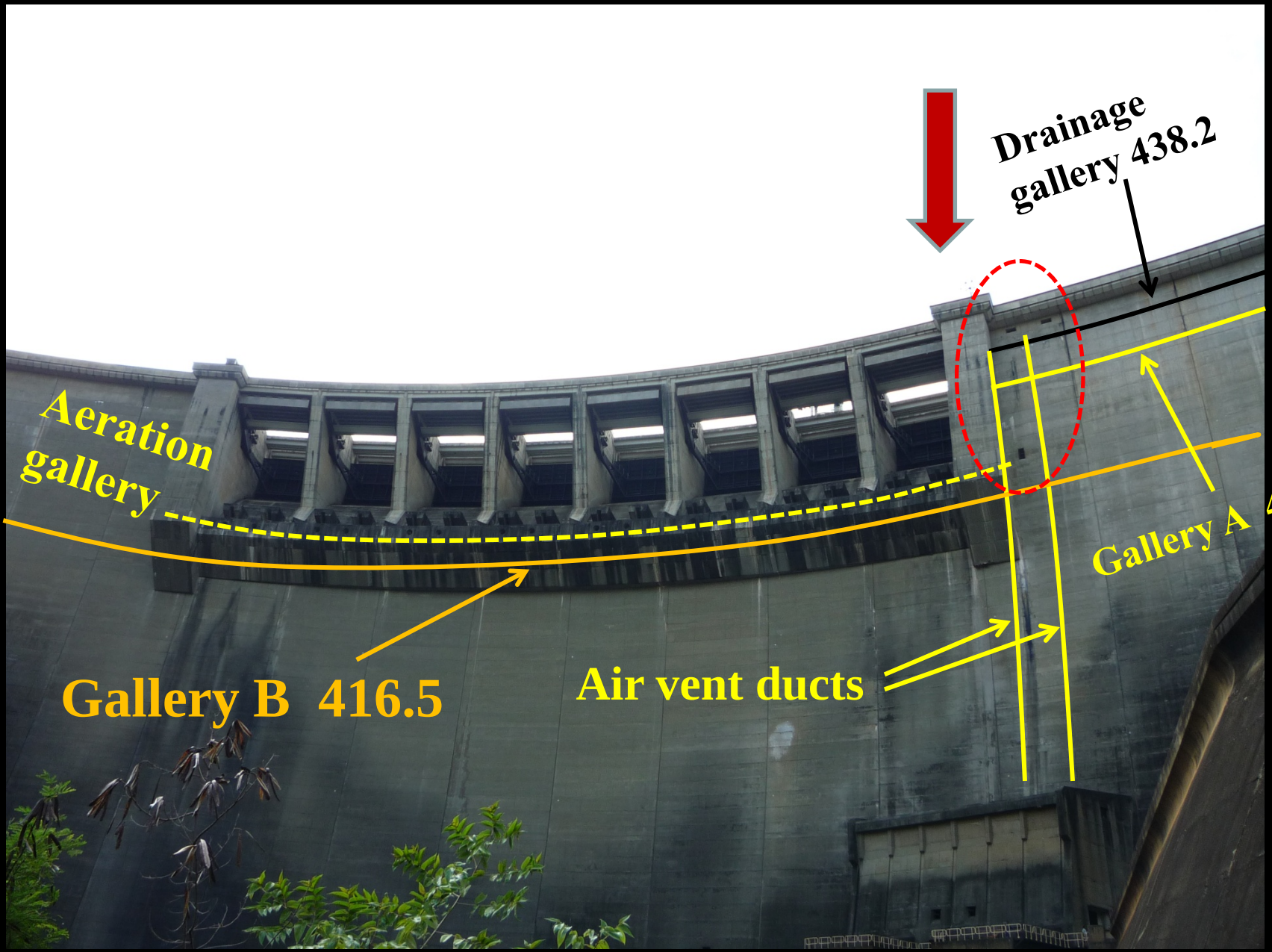
Long term trend

Observation 1 of 6

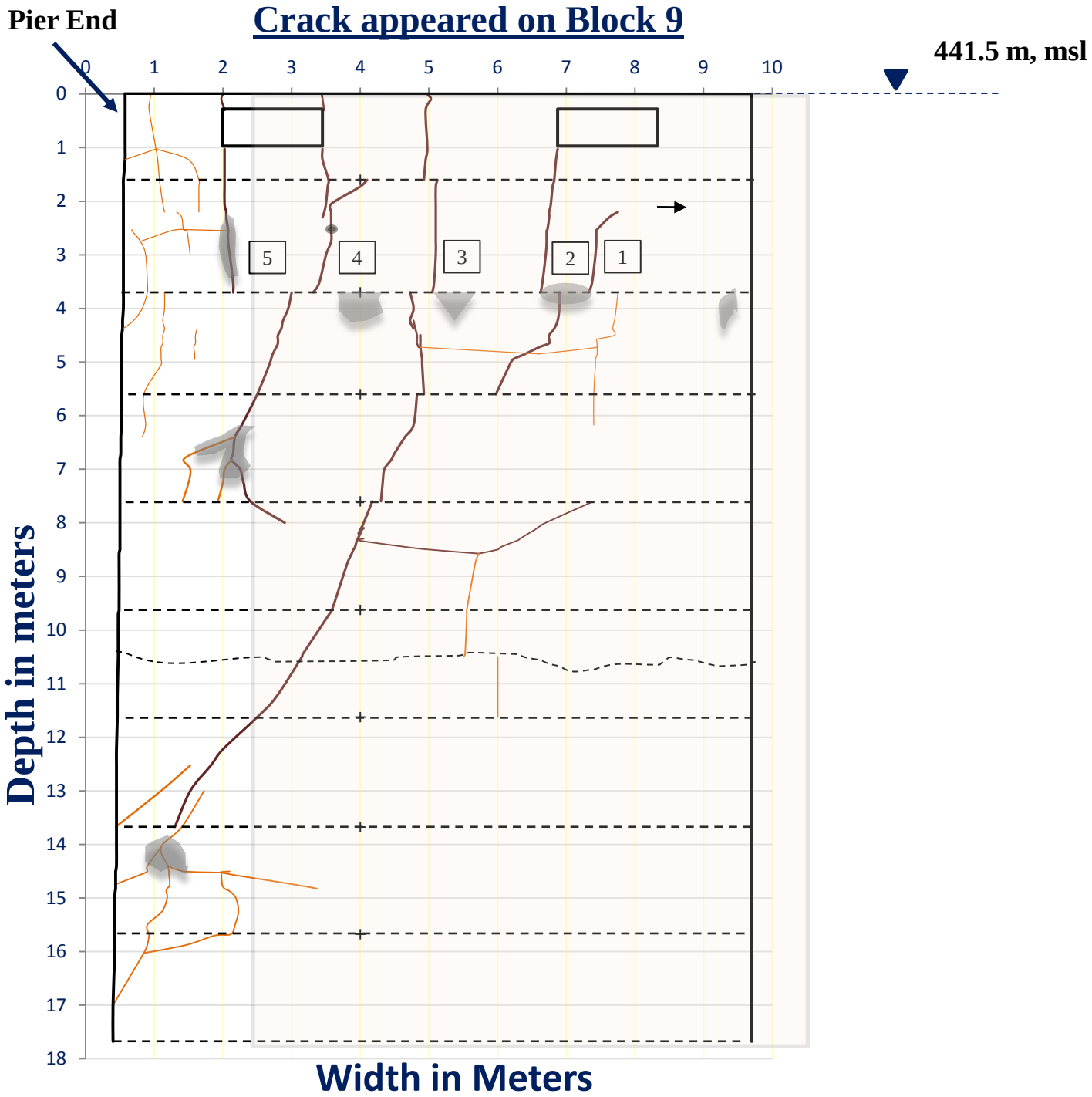
Cracks in Dam

Crack Monitoring

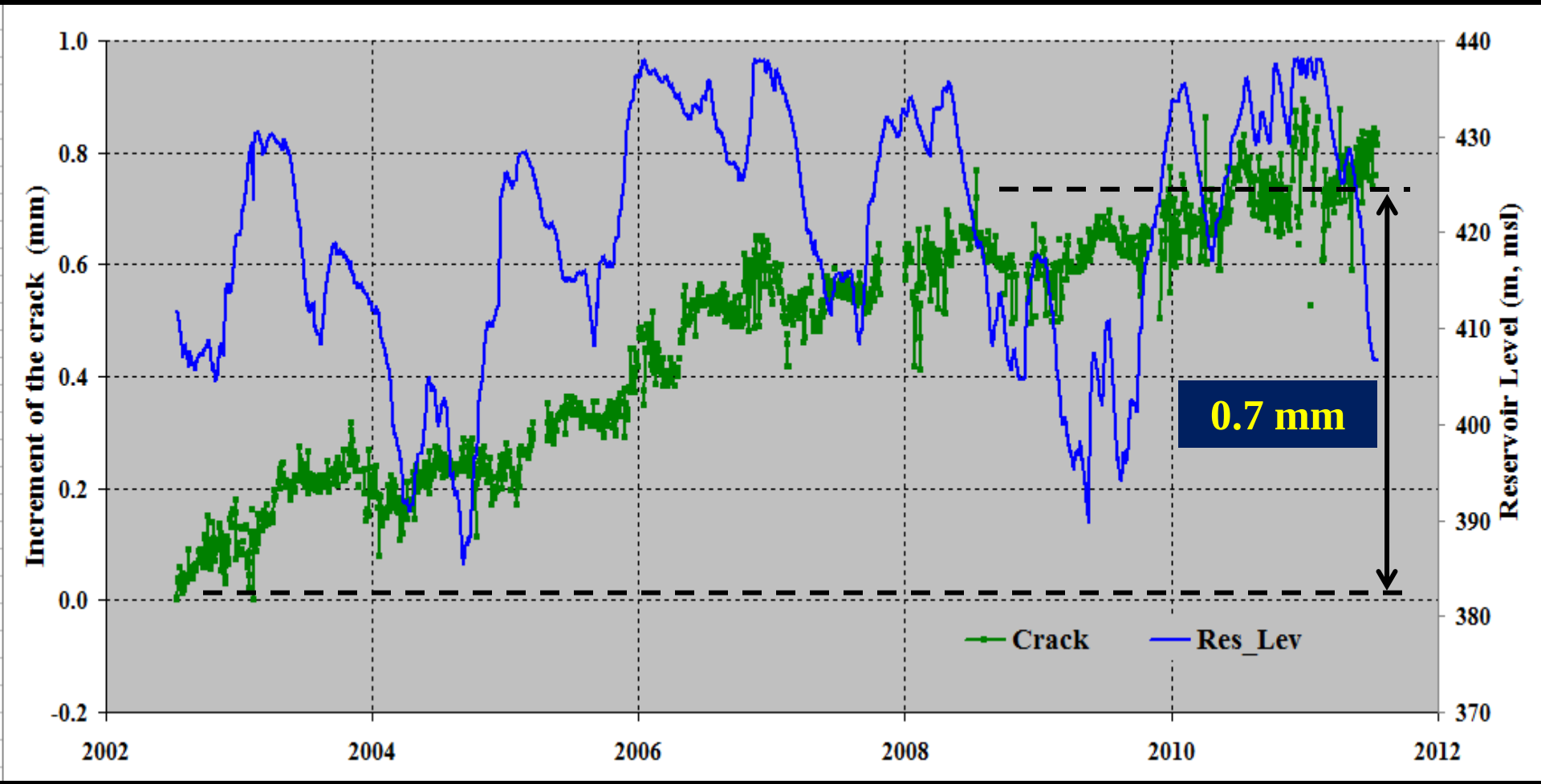



Drainage gallery 438.2
Aeration gallery
Gallery A 432.5
Gallery B 416.5
Air vent ducts


Crack Monitoring Sensor
View form the Crest: All Cracks appeared on this region
(Block 9 Downstream Face)

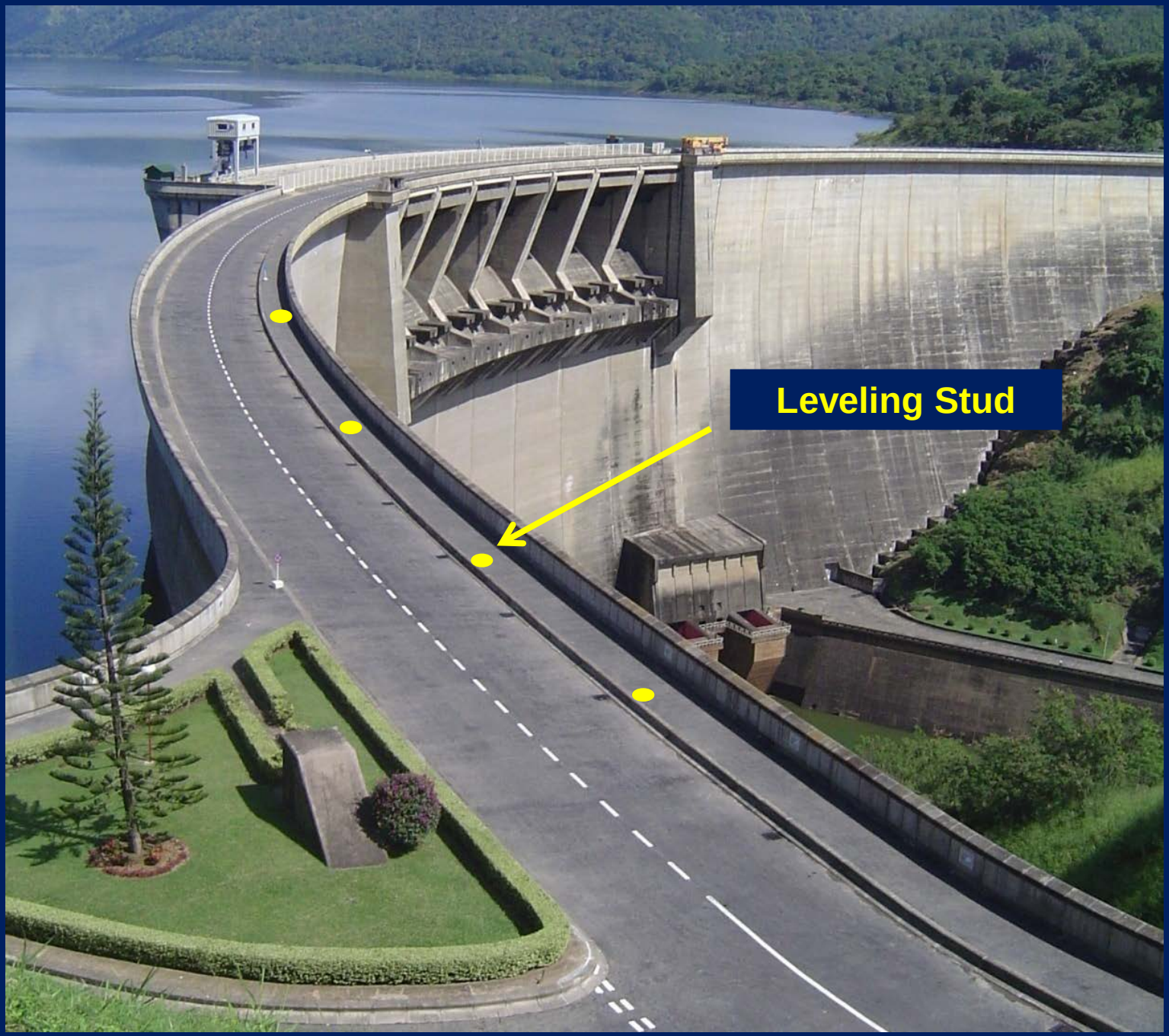

Pier End
Crack appeared on Block 9
441.5 m, msl
0 1 2 3 4 5 6 7 8 9 10
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
5
4
3
2
1
Depth in meters
Width in Meters

Increasing of main crack (Block 9) with time (Identified in 1996 and monitored since 2002)

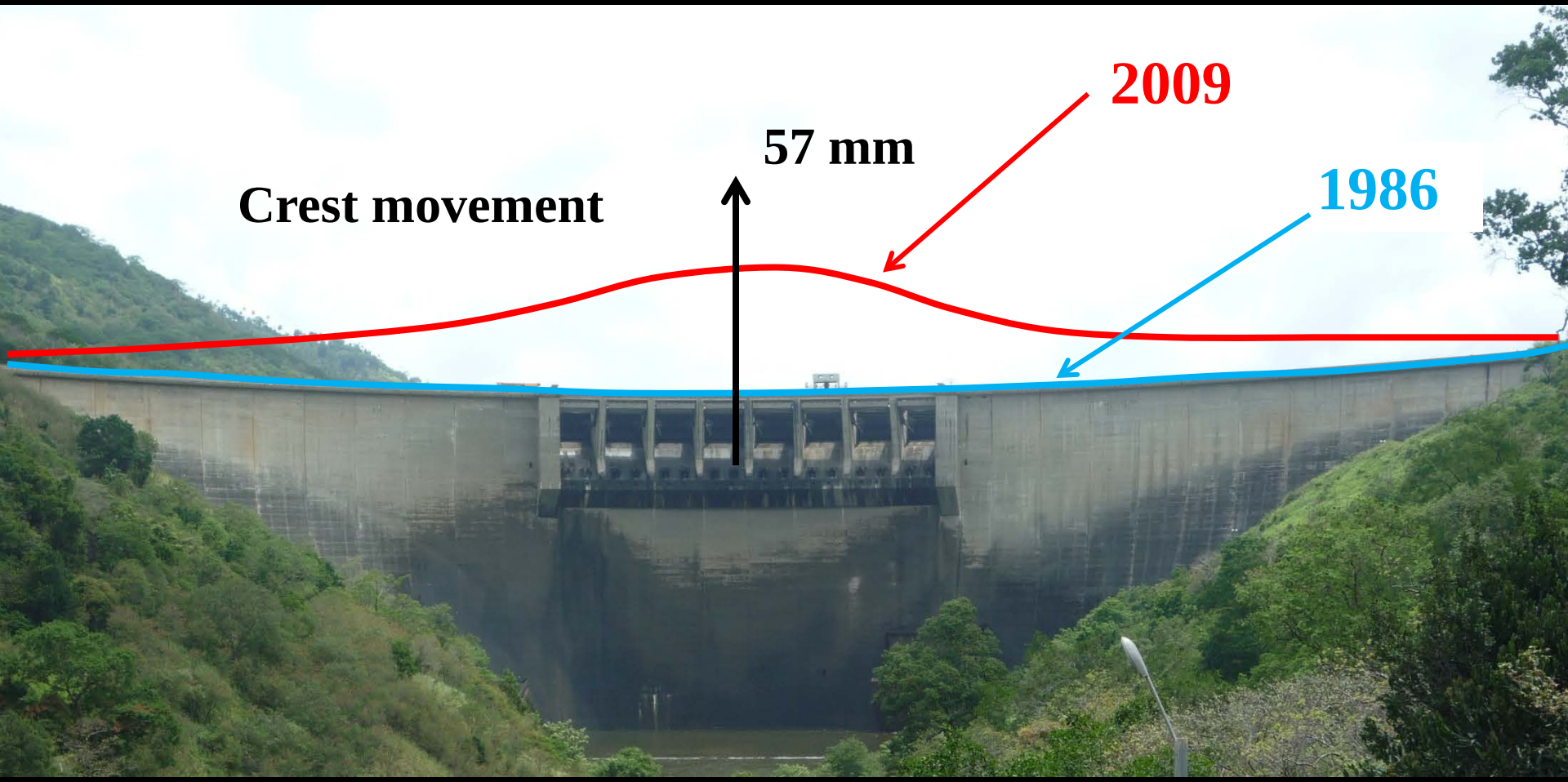


Observation 2 of 6

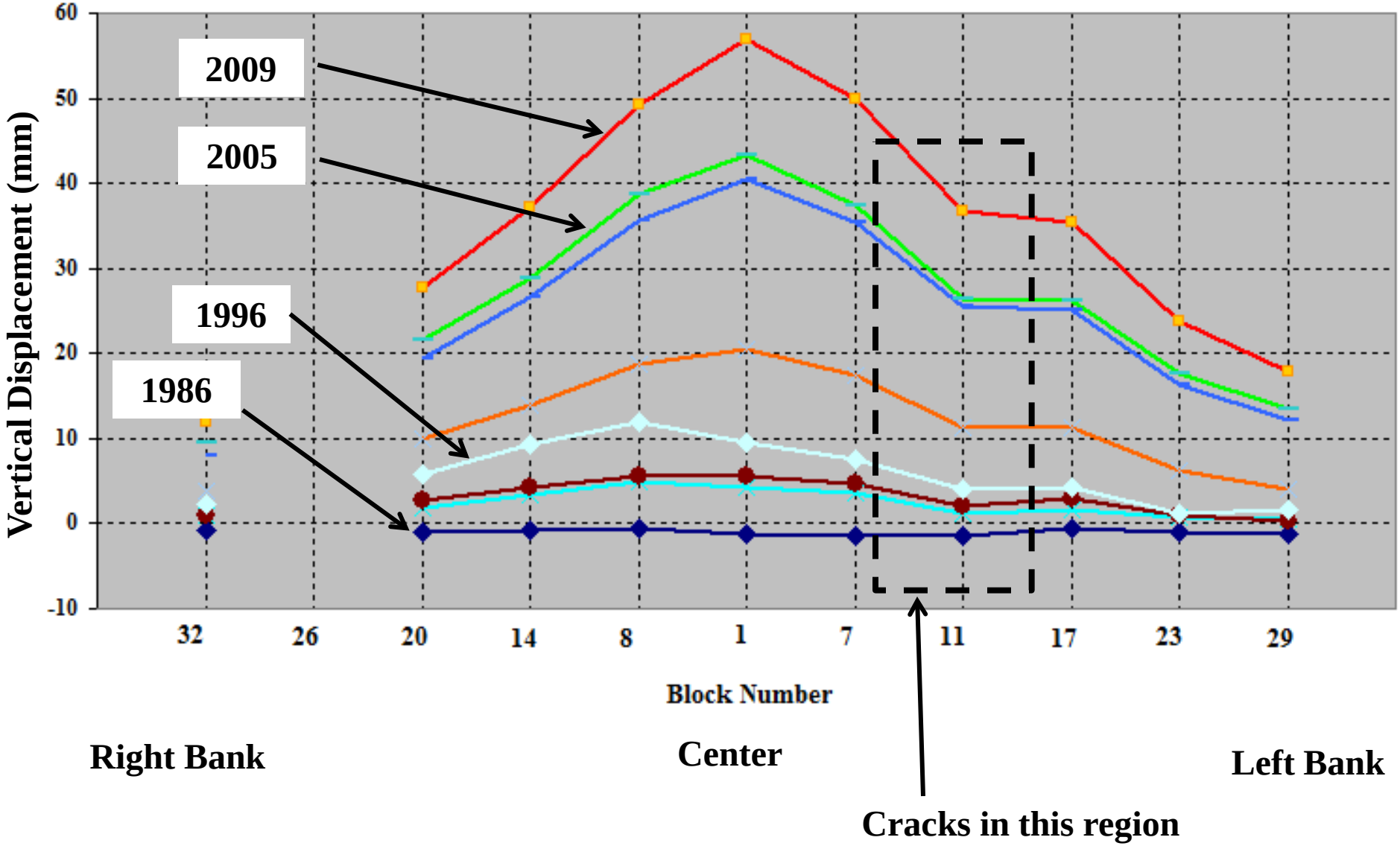
Precise Leveling
Dam Crest


Leveling Stud

Precise leveling Survey Results



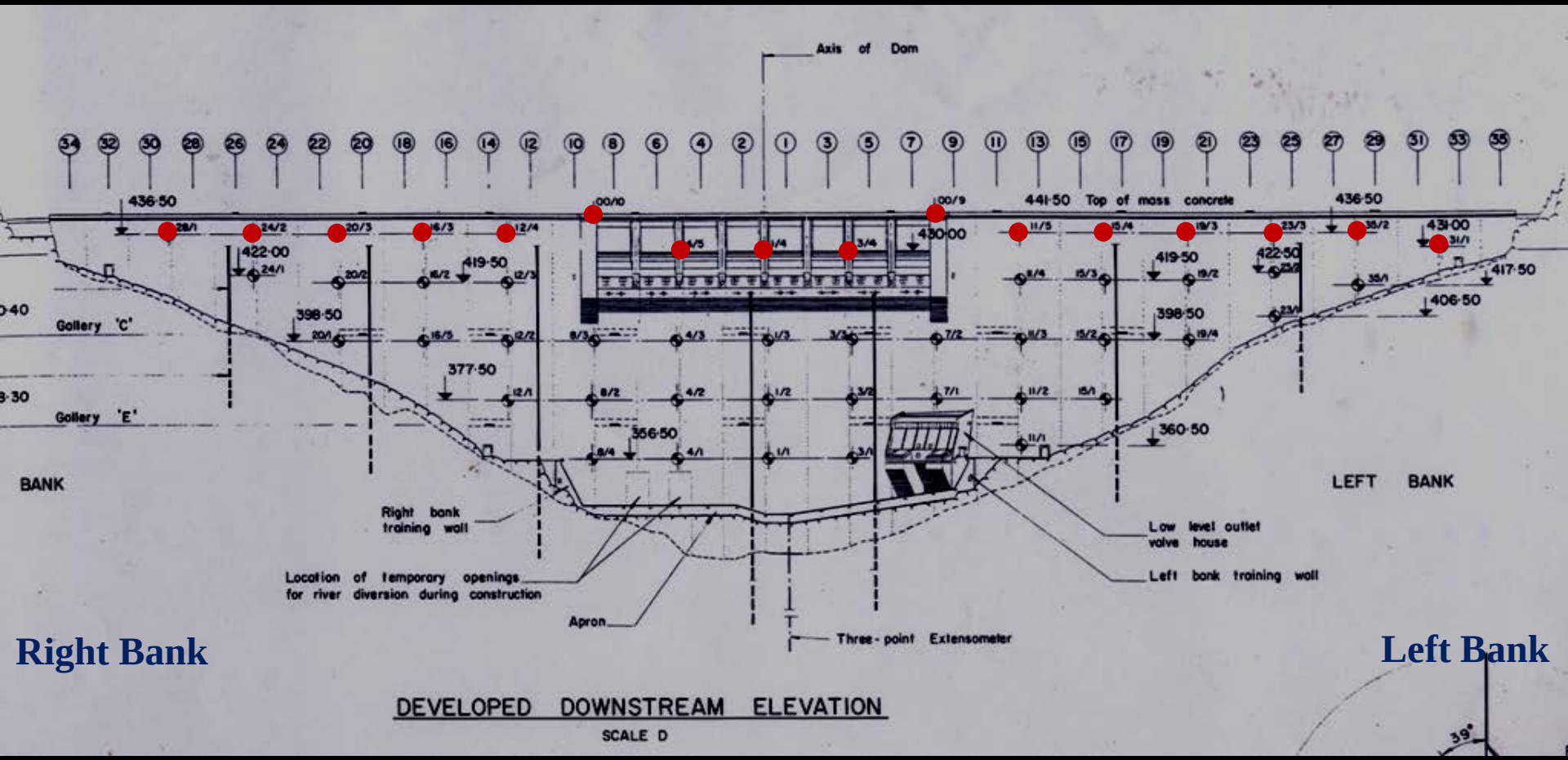
Crest displacement profile across the dam
(Precise leveling Survey Results)

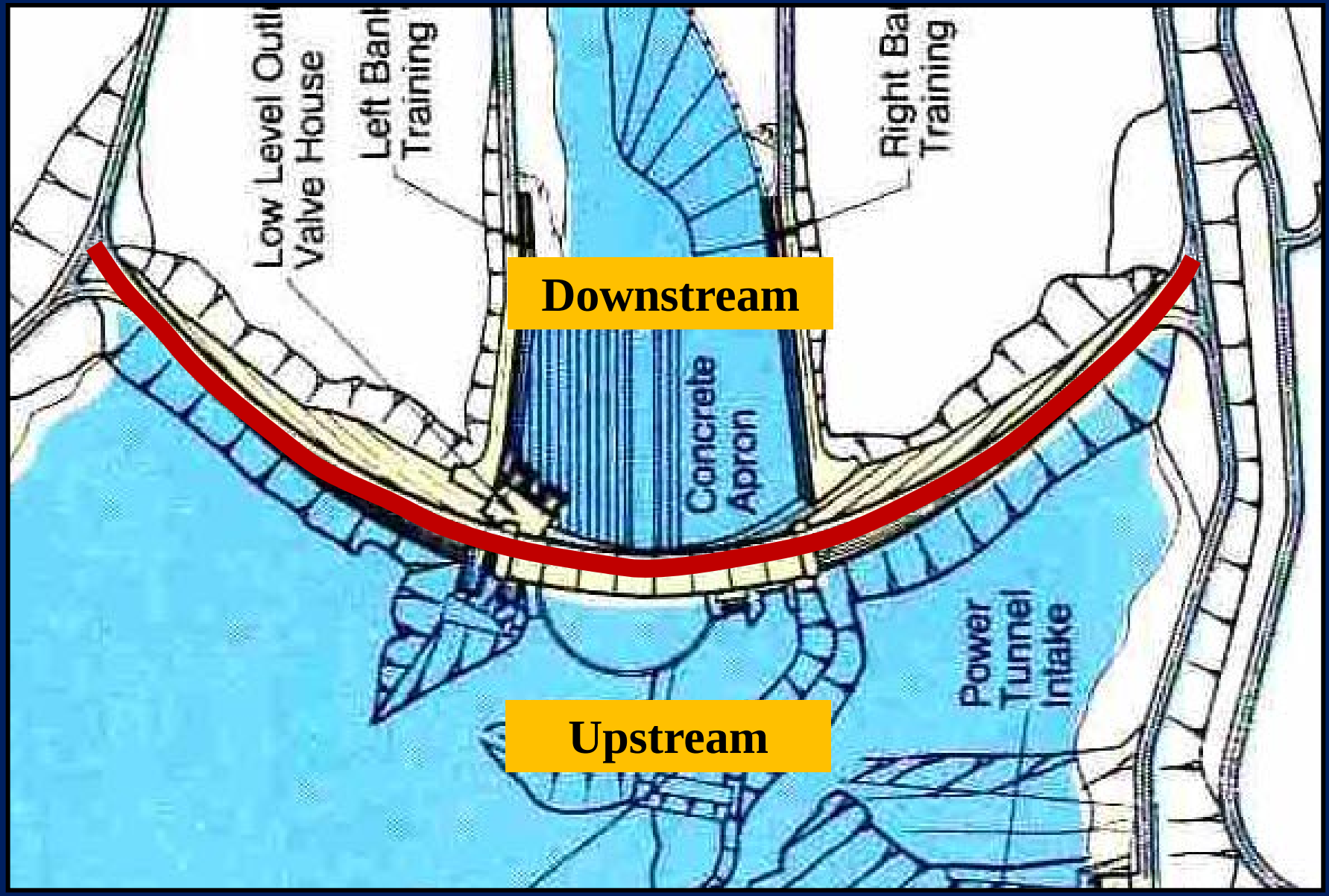


Observation 3 of 6

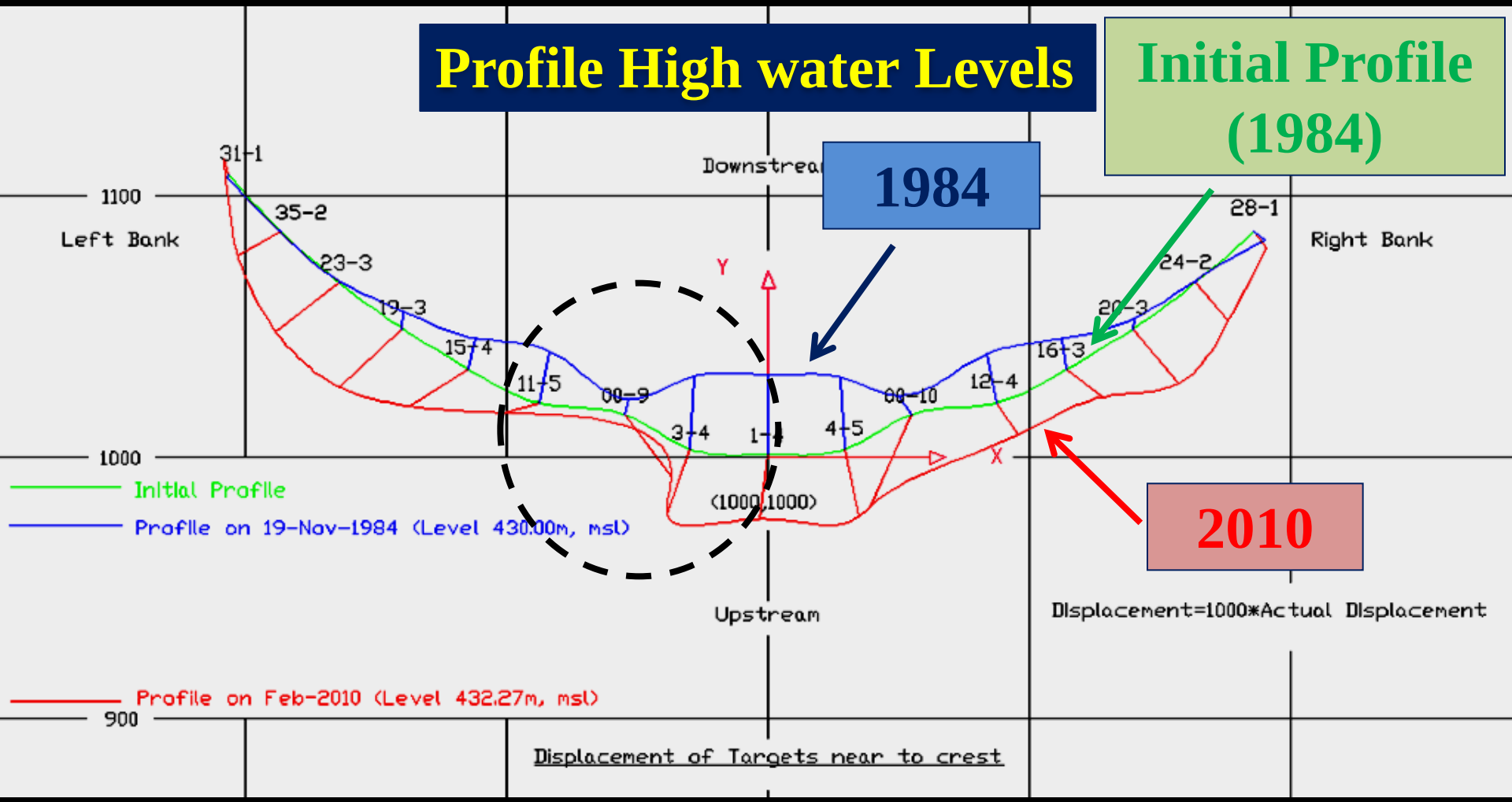
Crest Profile of the Dam in plan
(face survey targets)

Selected Face Survey Targets




Low Level Outl
Valve House
Left Ban
Training
Right Ba
Training
Downstream
Concrete
Apron
Power
Tunnel
Intake
Upstream

Changing the Crest Profile of the Dam for High water levels
(Survey Targets close to dam crest)

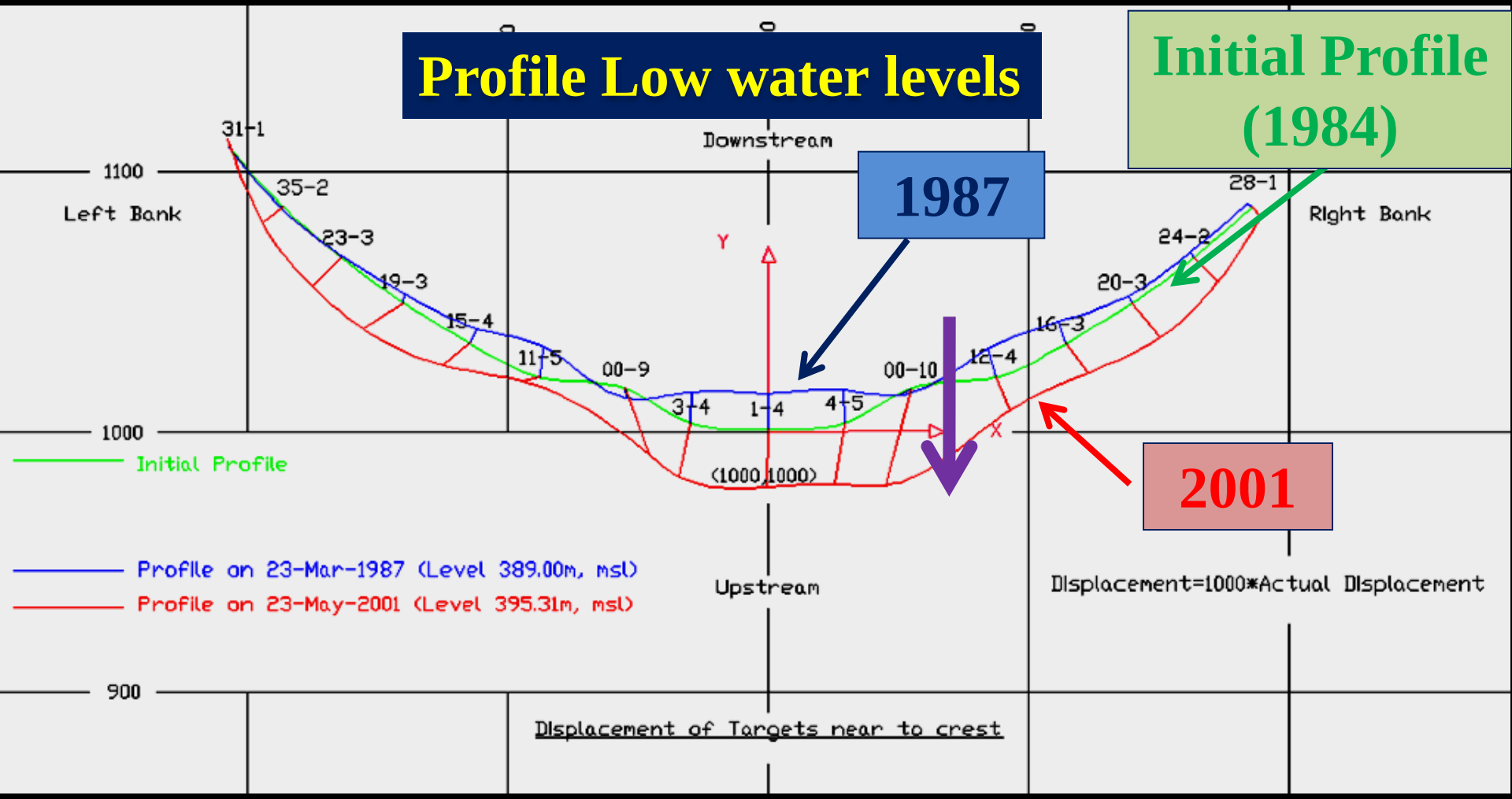


Initial Profile

Profile on 19-Nov-1984 (Water level 430.00 m, msl)

Profile on Feb-2010 (Water level 432.27 m, msl)

Crest Profile of the Dam in plan for low water levels
(Survey Targets close to dam crest)



Initial Profile

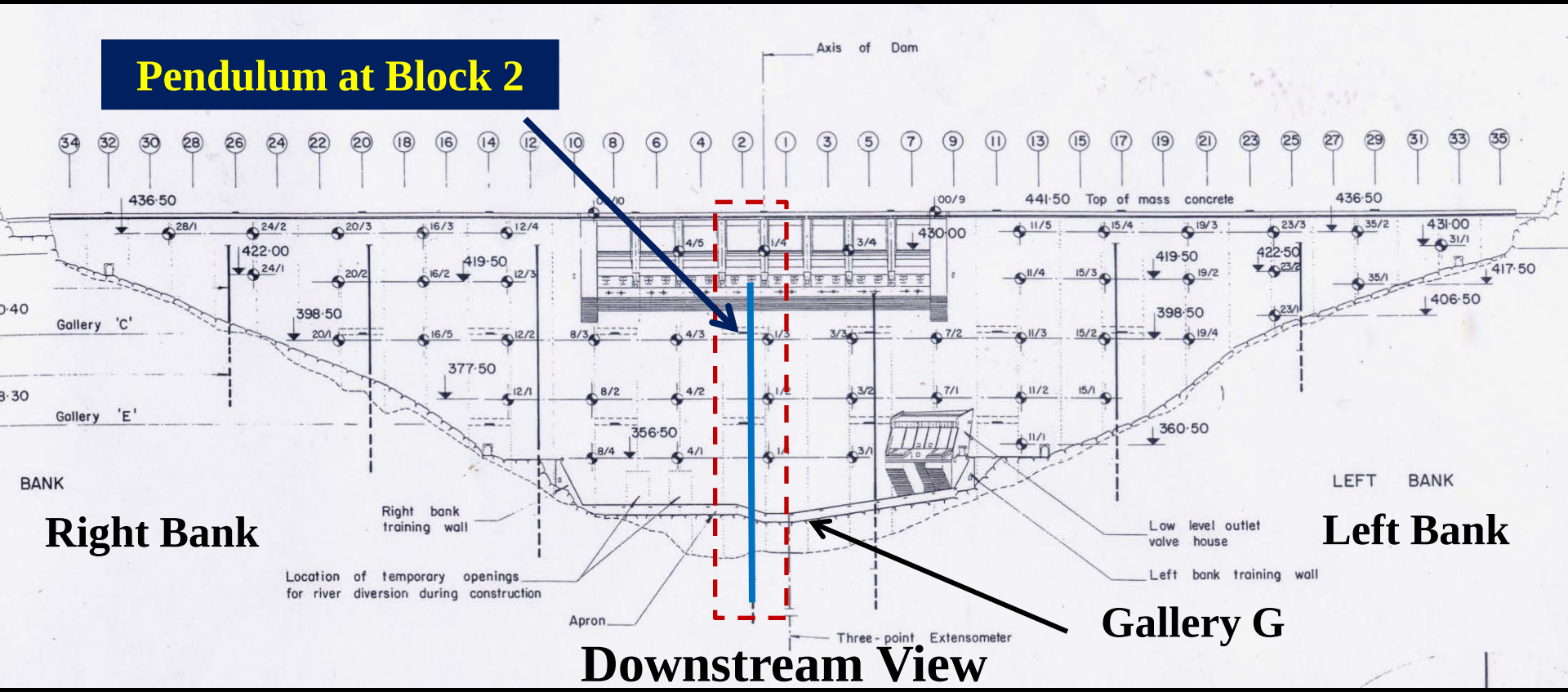
Profile on 23-Mar-1987 (Water level 389.00 m, msl)

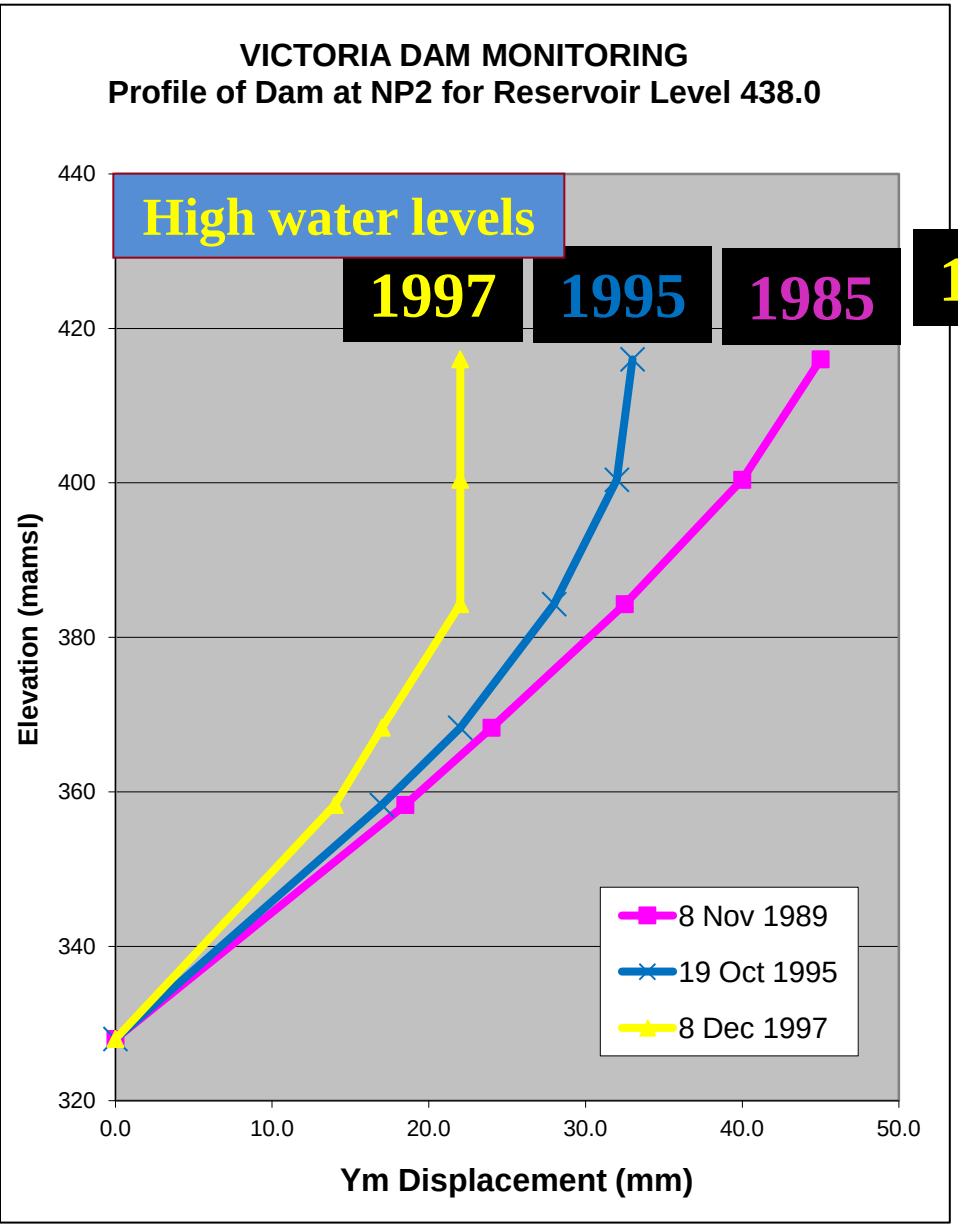
Profile on 23-May-2001 (Water level 395.31 m, msl)

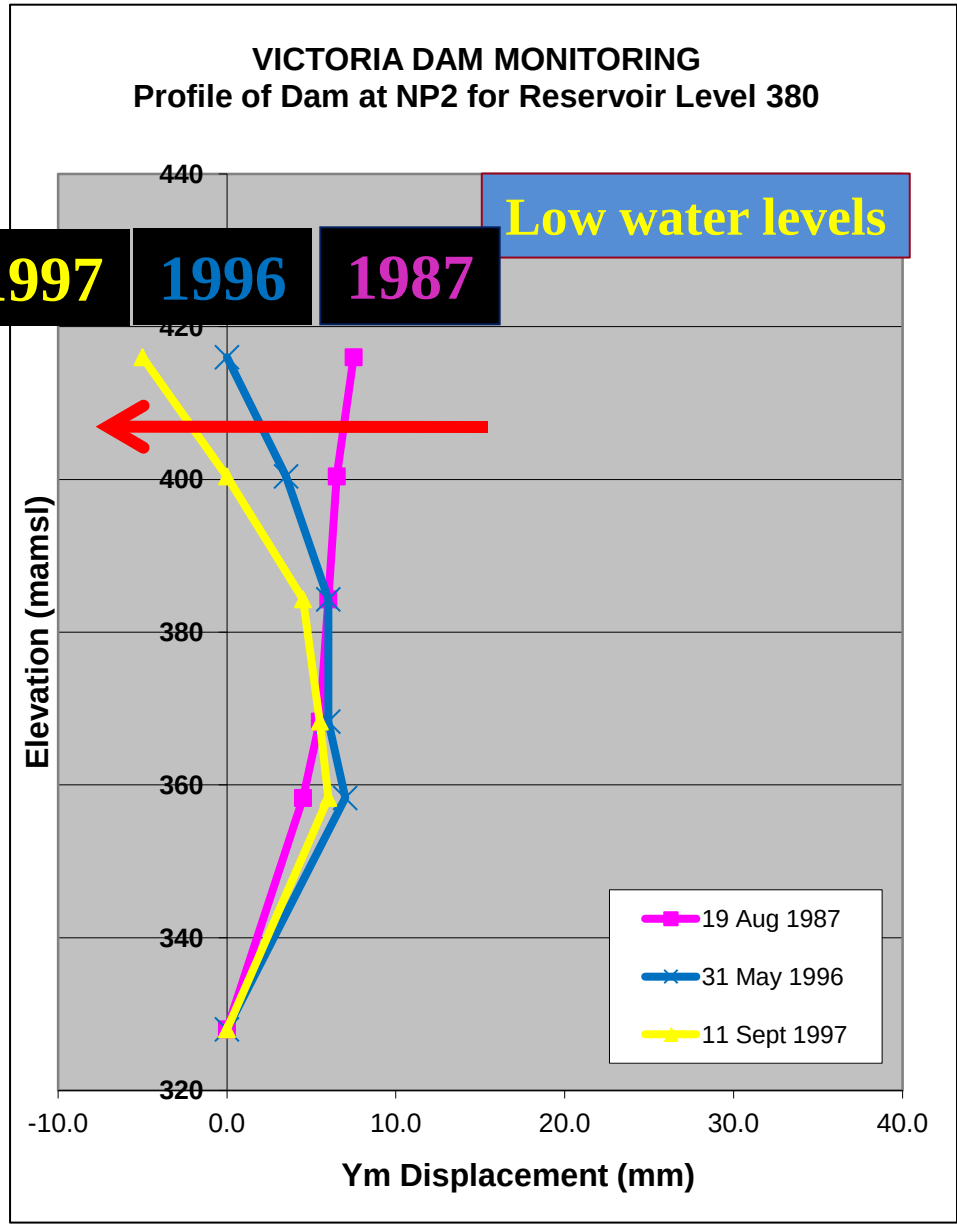
Observation 4 of 6

Pendulum Readings

Pendulum Behaviour – NP2

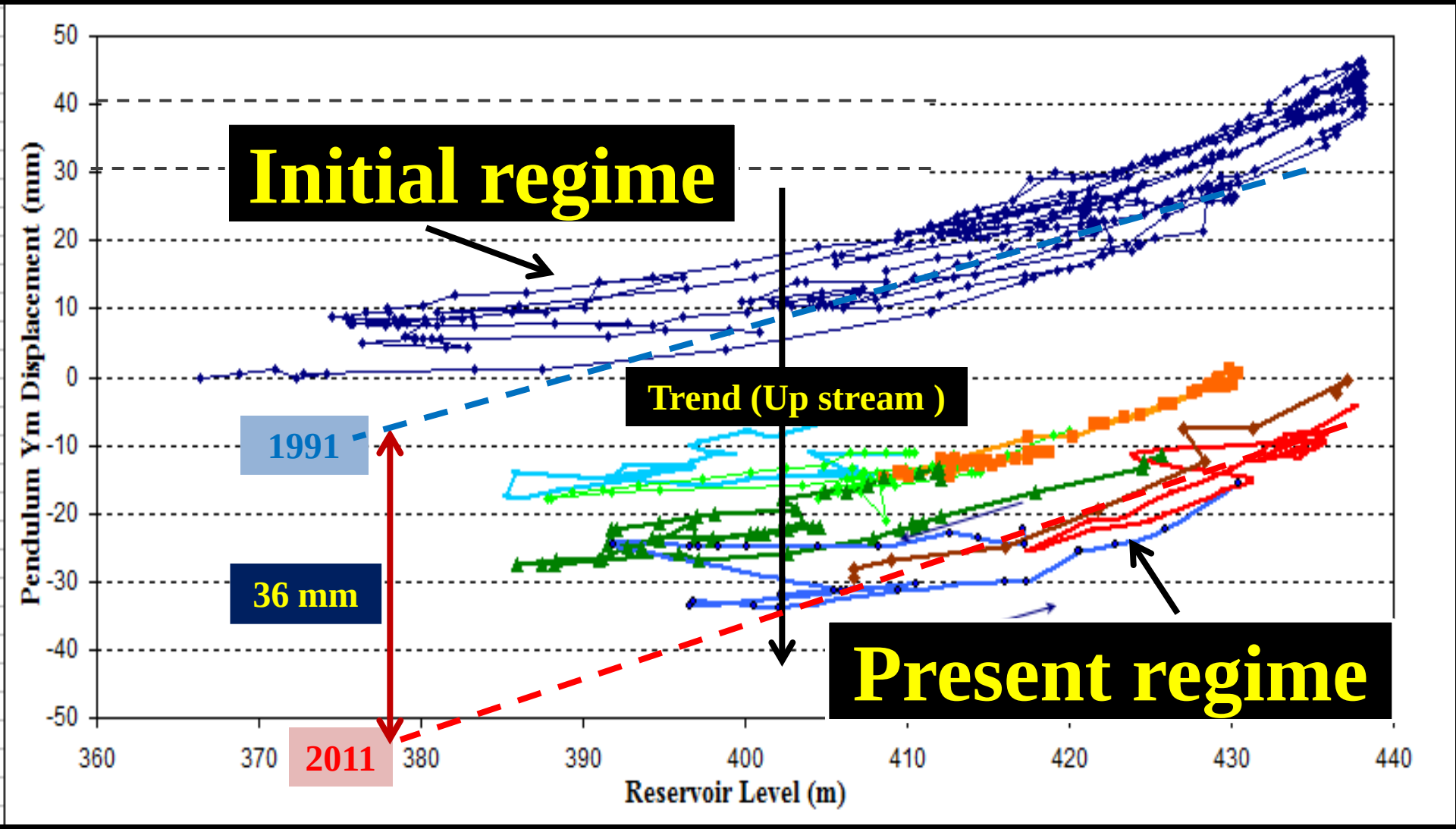






Source: GIBB Report on Inspection of Victoria Dam and Hydropower Scheme Volume 1, Dam and Reservoir, December 2000

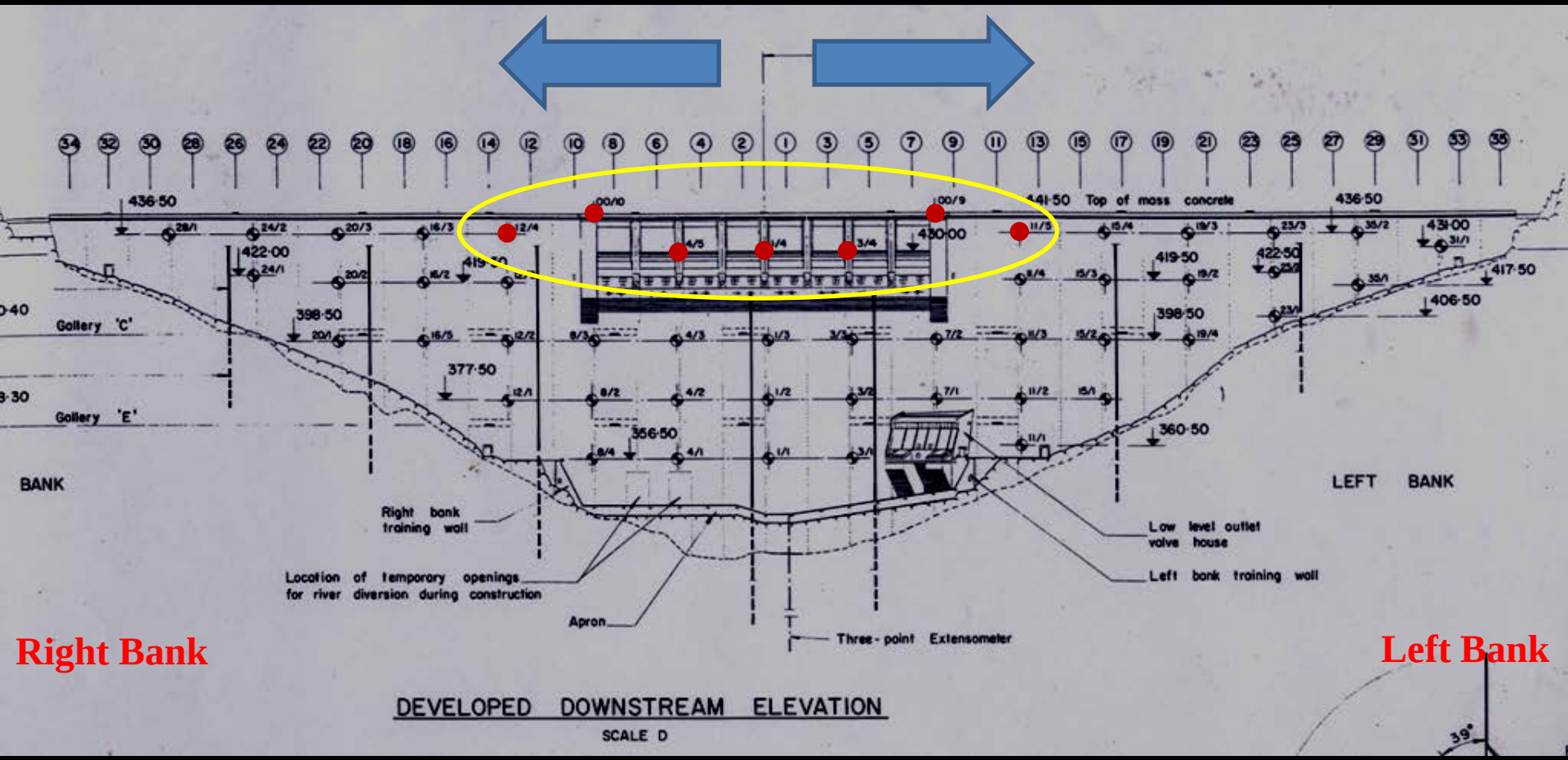
Normal Pendulum Hysteresis Plots



Observation 5 of 6

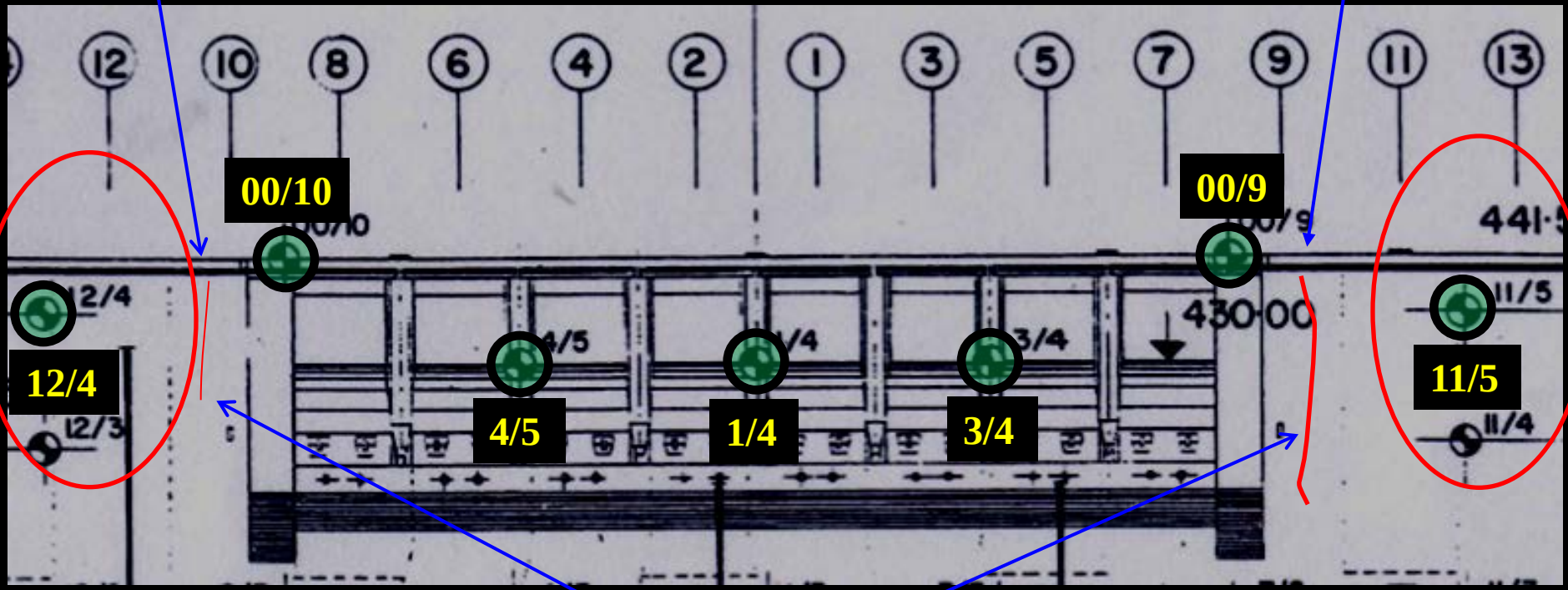
Face Survey Targets
(around spillway section)

Face Survey Targets around spillway section



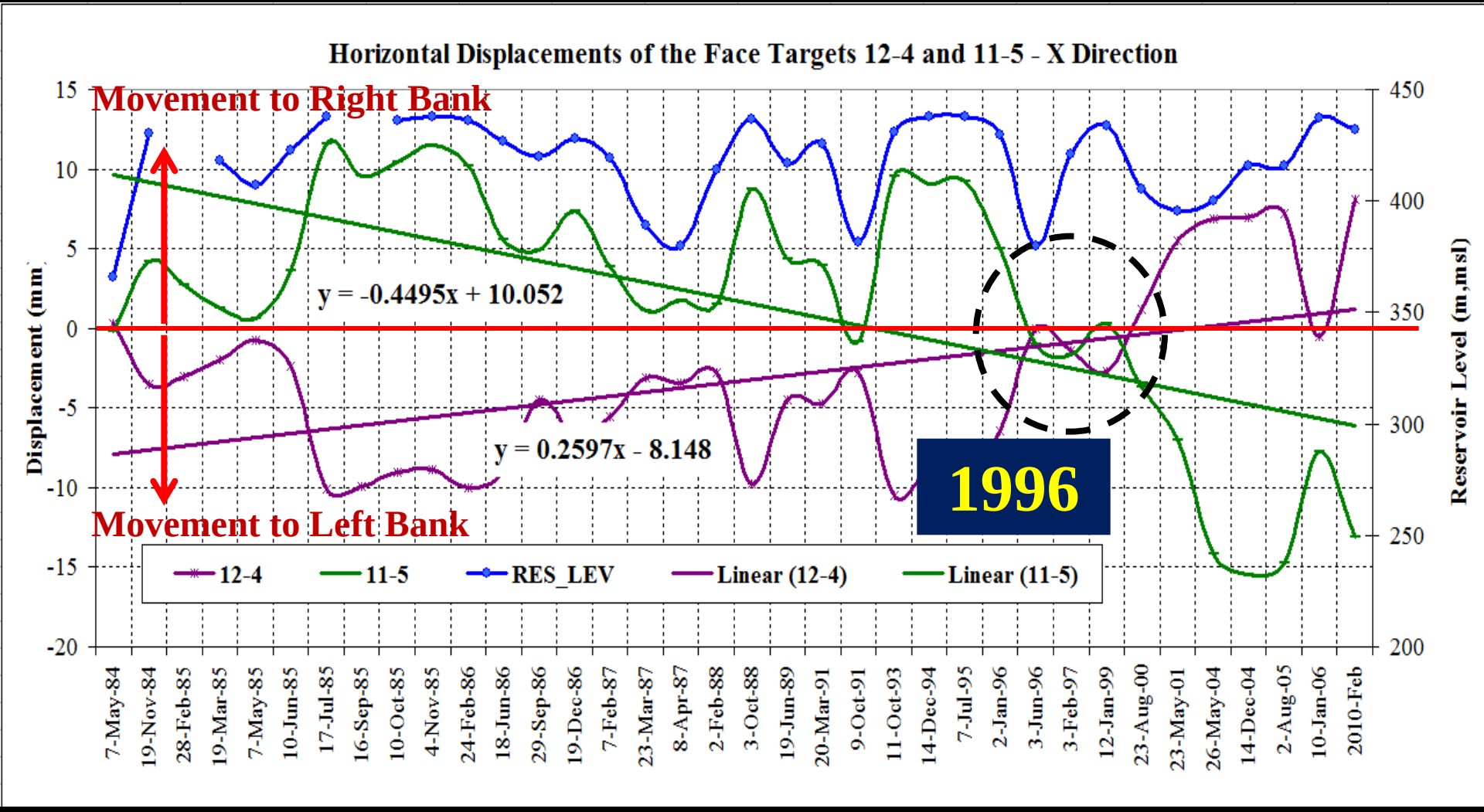
LB – RB movements

Face Survey Targets around Spillway Section

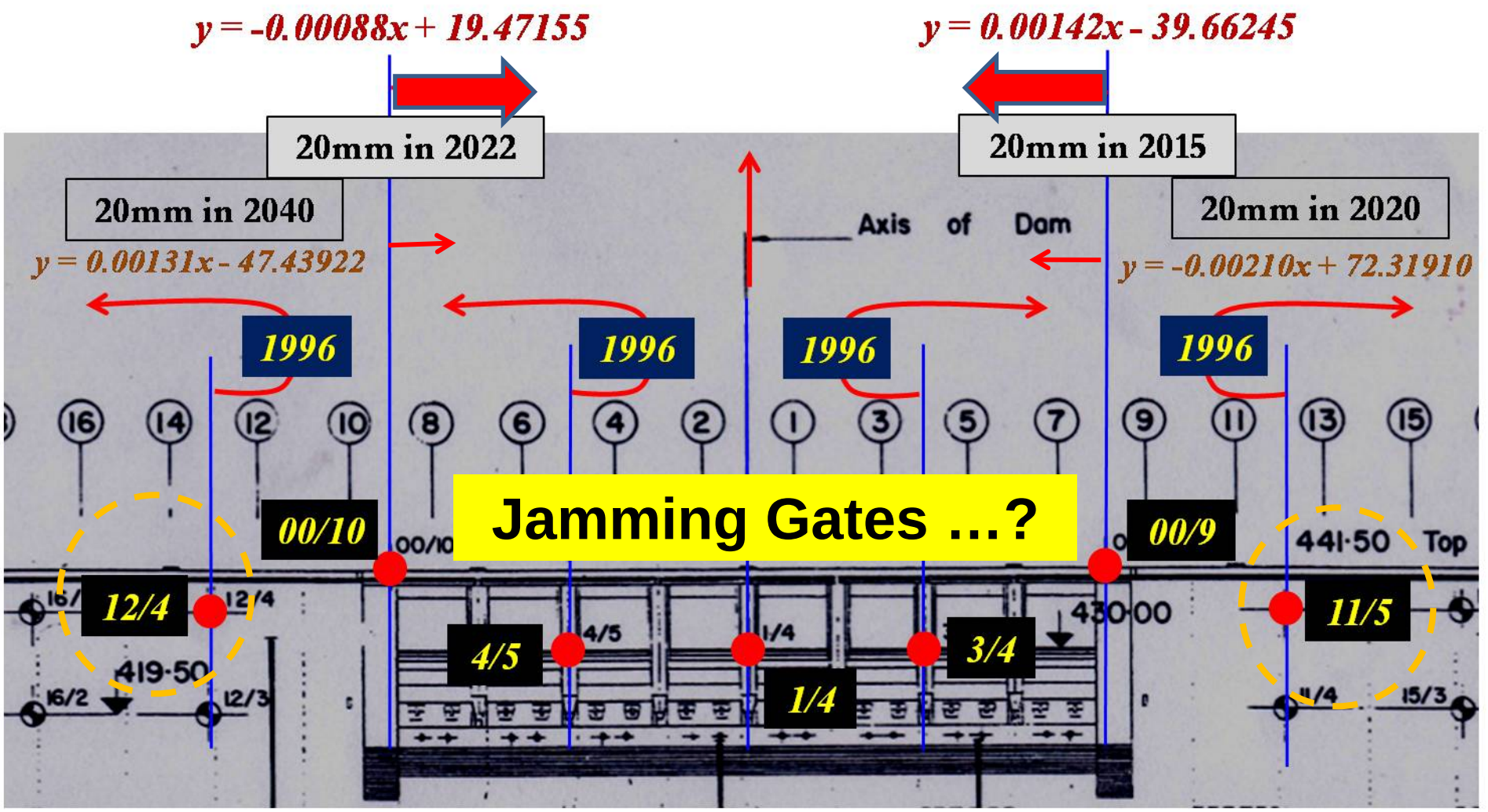


Downstream View

Historical Behaviour of Face Target 12-4 and 11-5 Horizontal Displacements in X direction



Movement of Selected targets
Horizontal Displacements in X direction

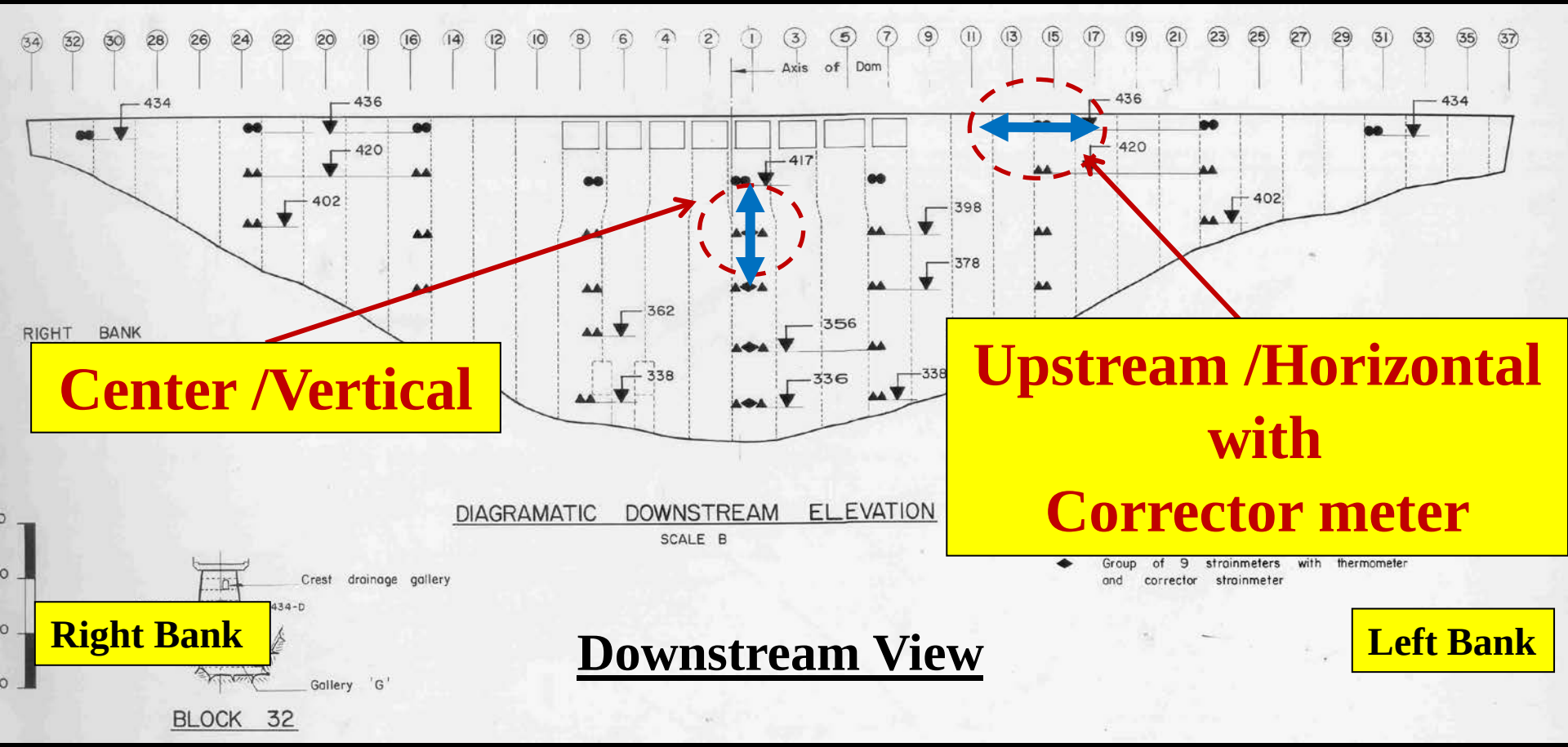


Downstream View

Observation 6 of 6

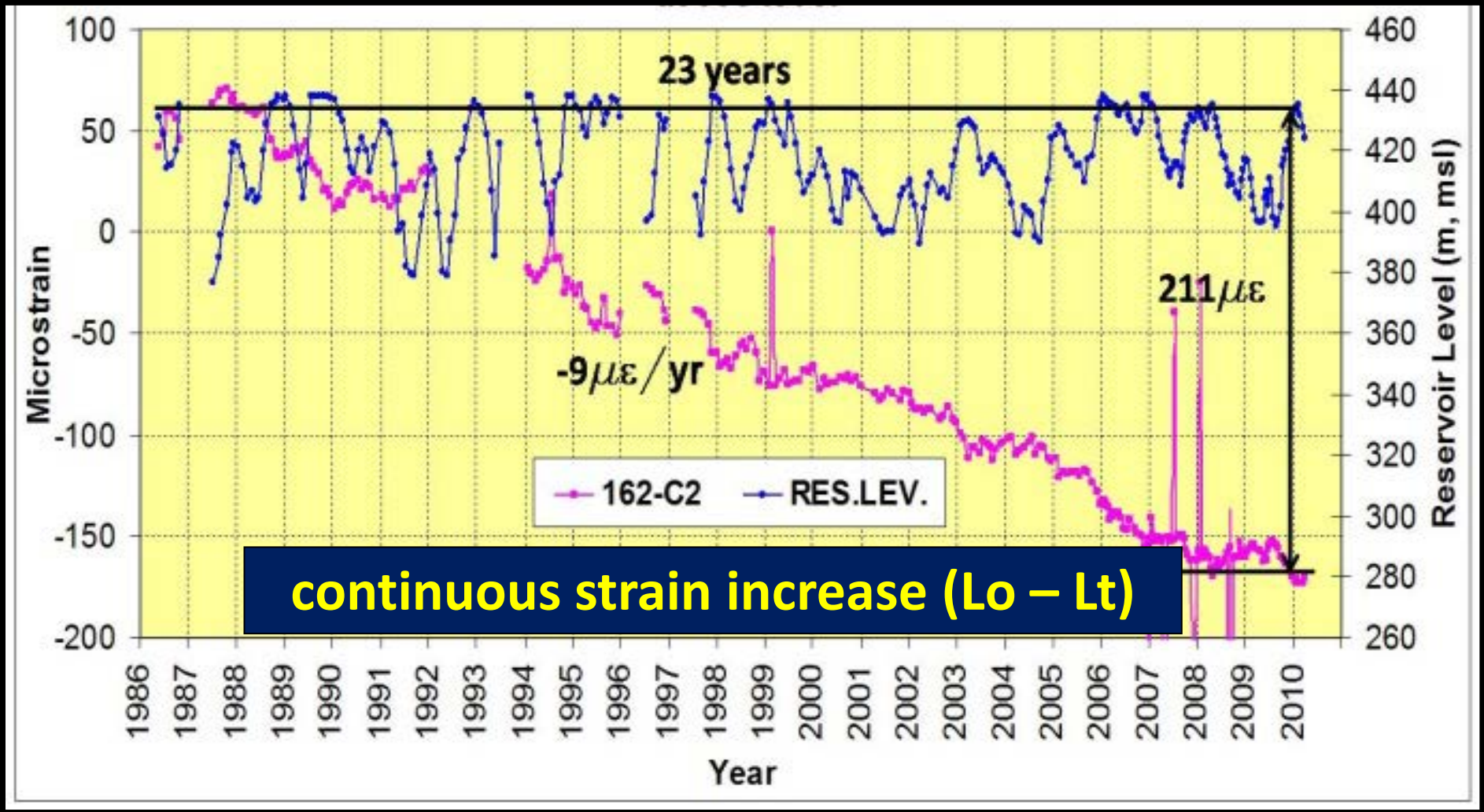
Strain Gauge
(long term trend)

Strain Gauge readings



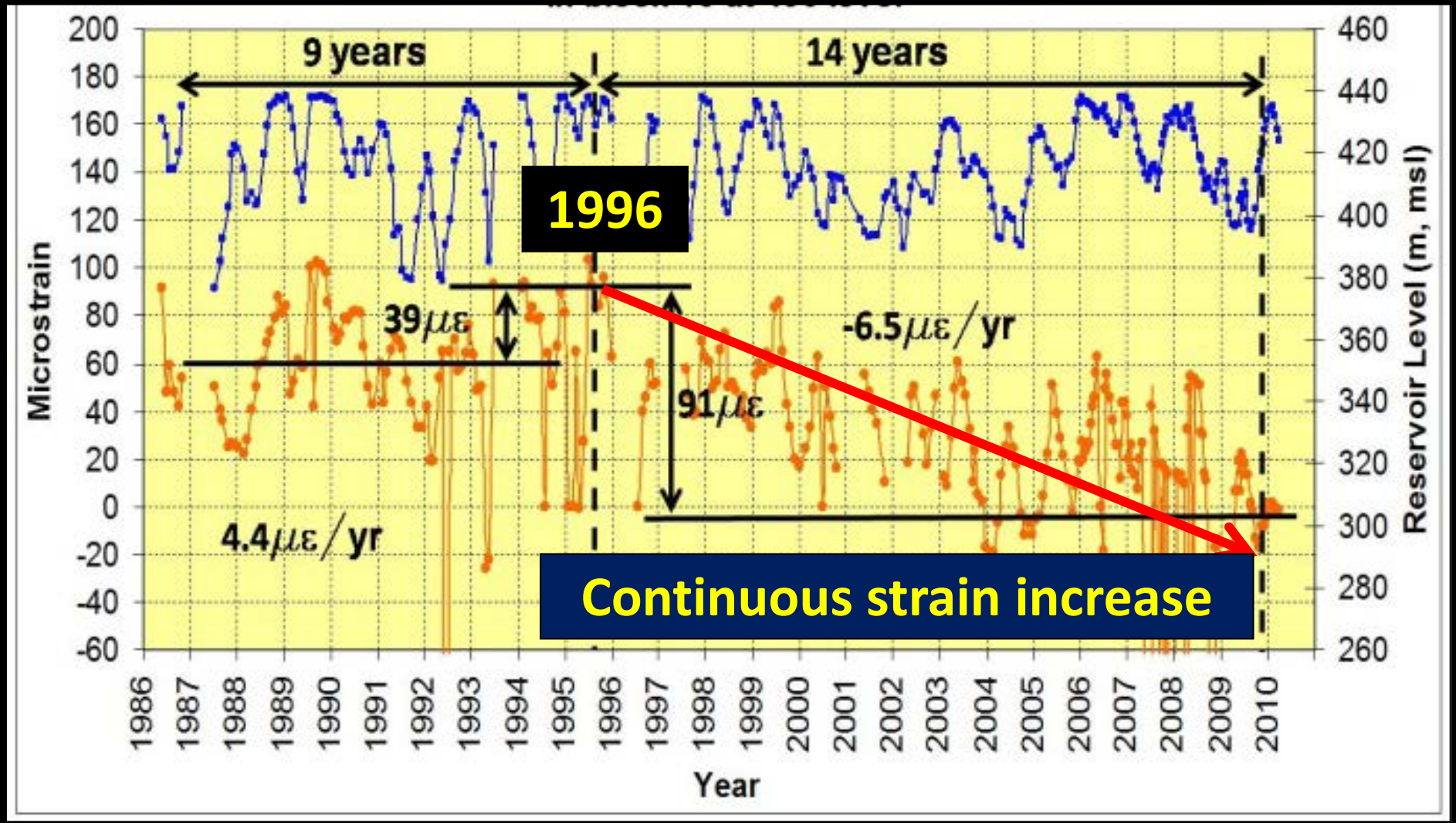
Downstream View

Vertical Strainmeter

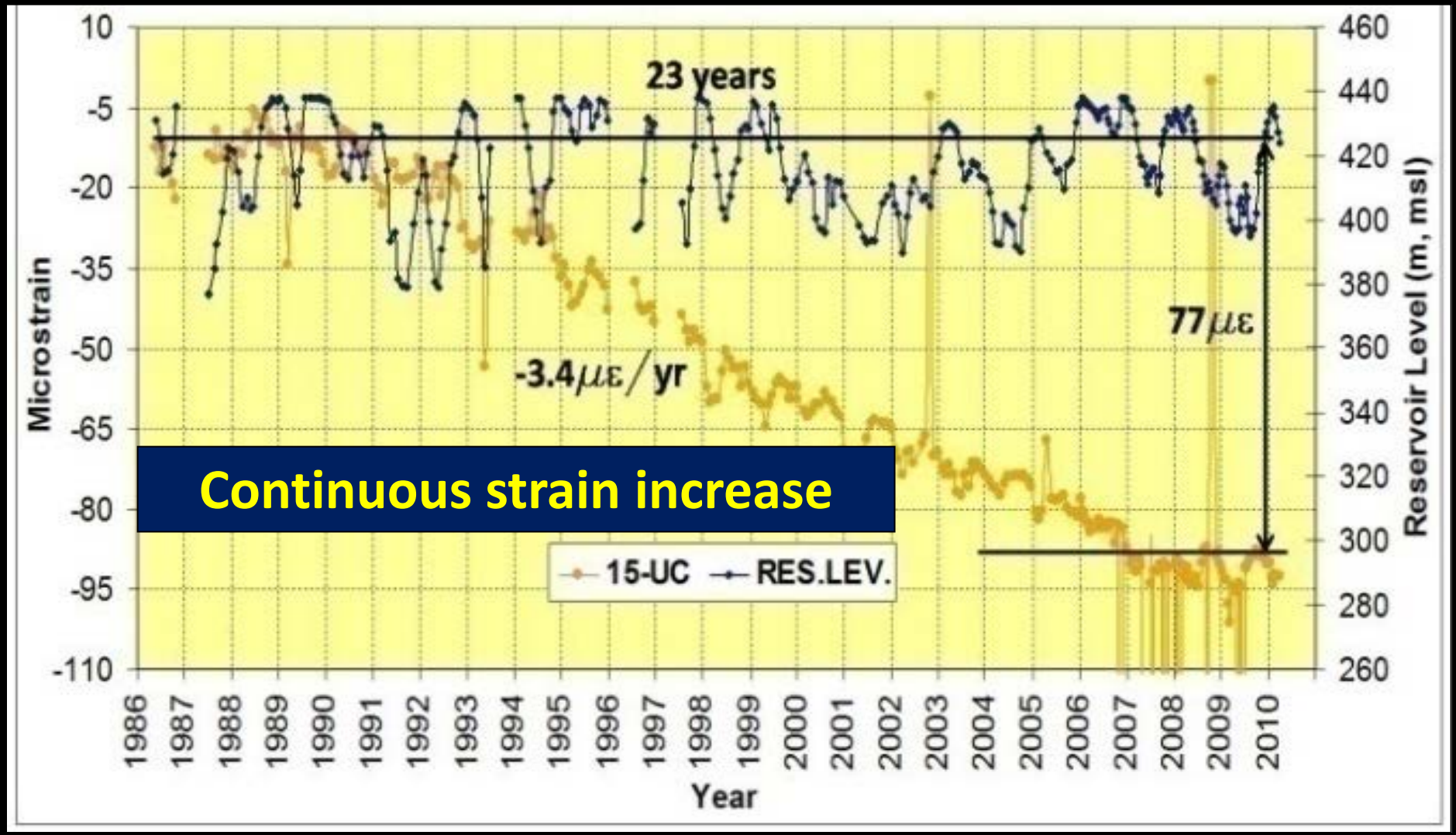


If E = 26 GPa, e= 211*10-6, then Stress= 5.5 N/mm2

Horizontal Strainmeter



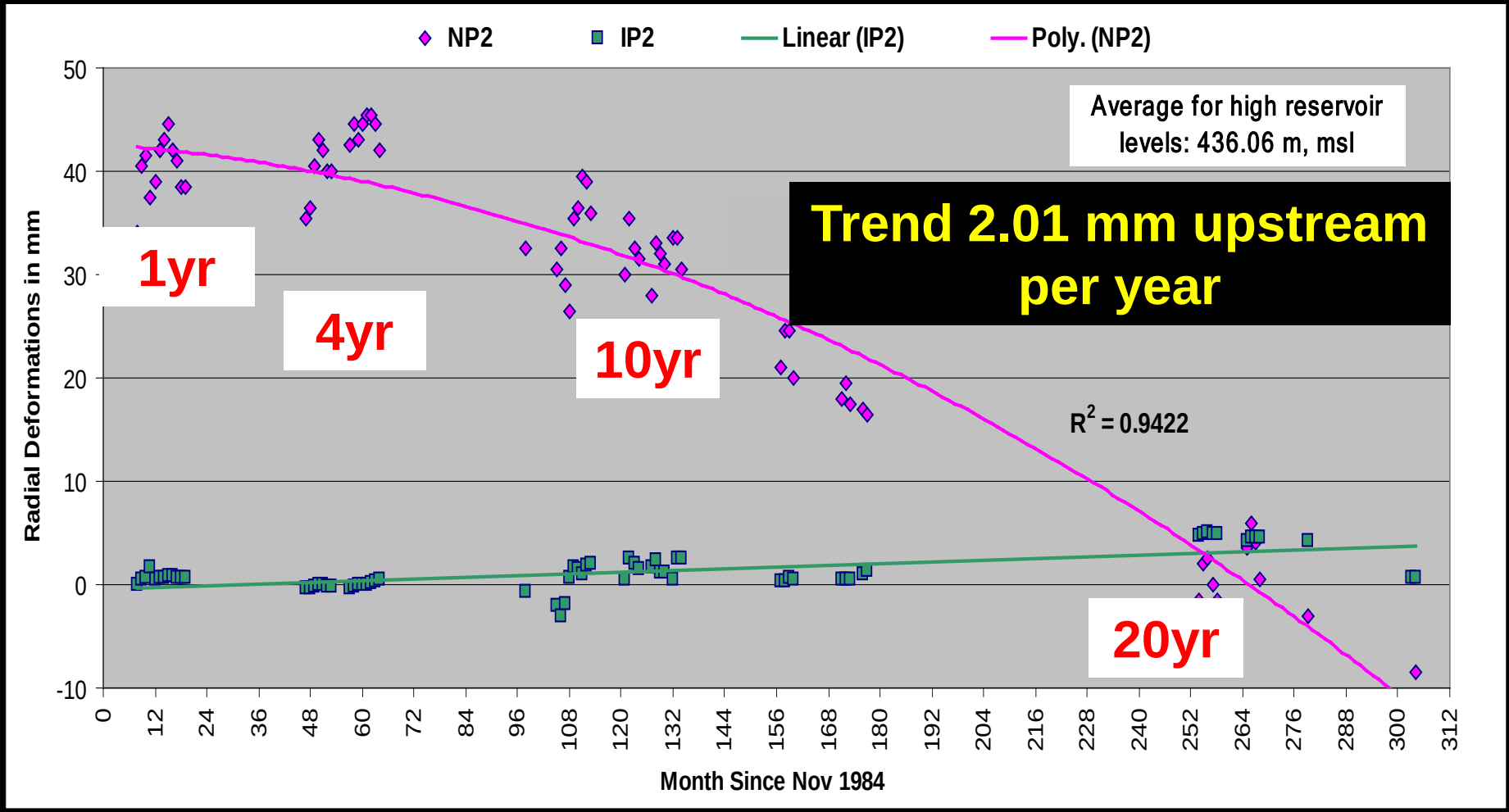
Corrector Meter (stress free con block)



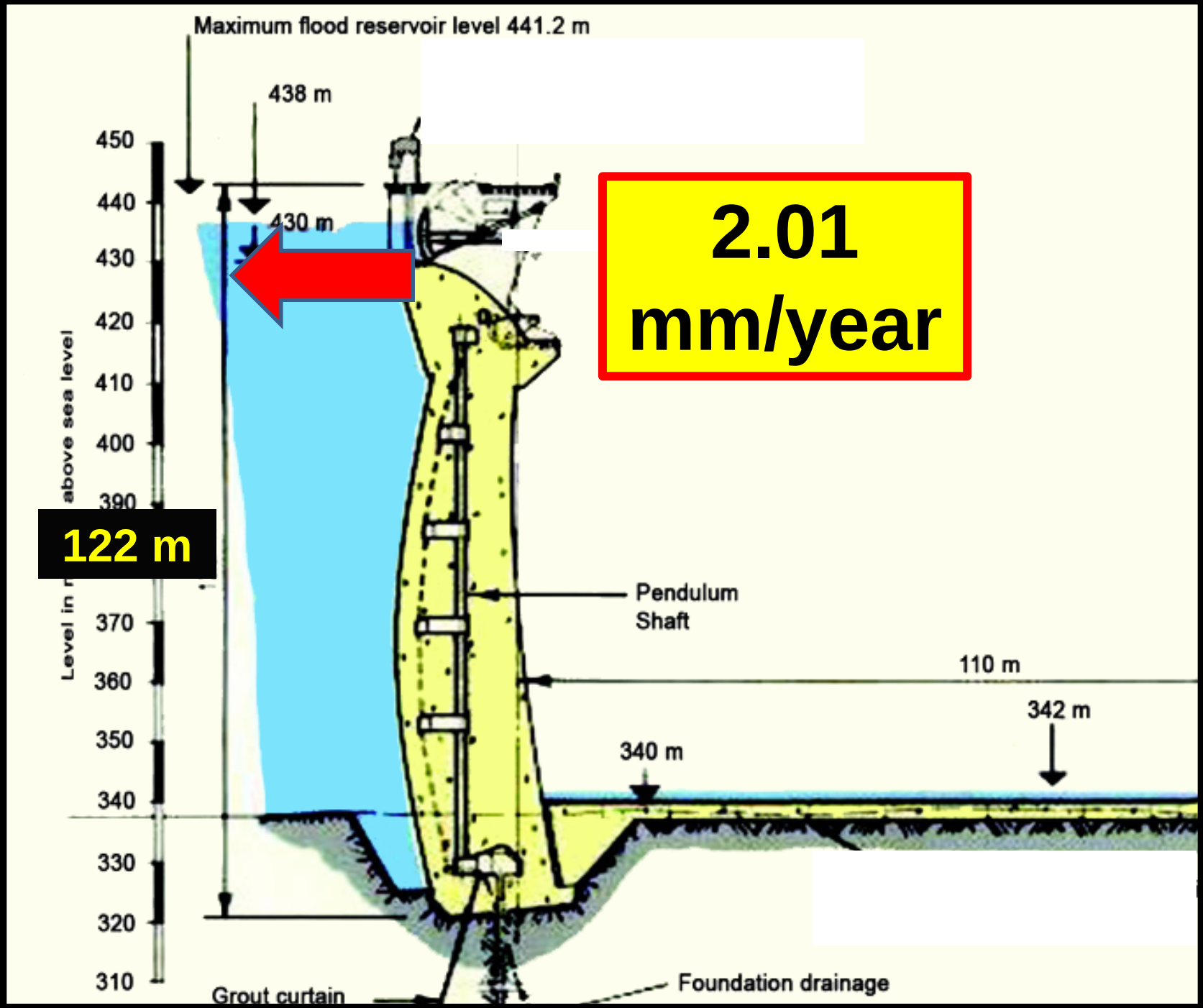
Conclusion

Dam Irreversible Deformation

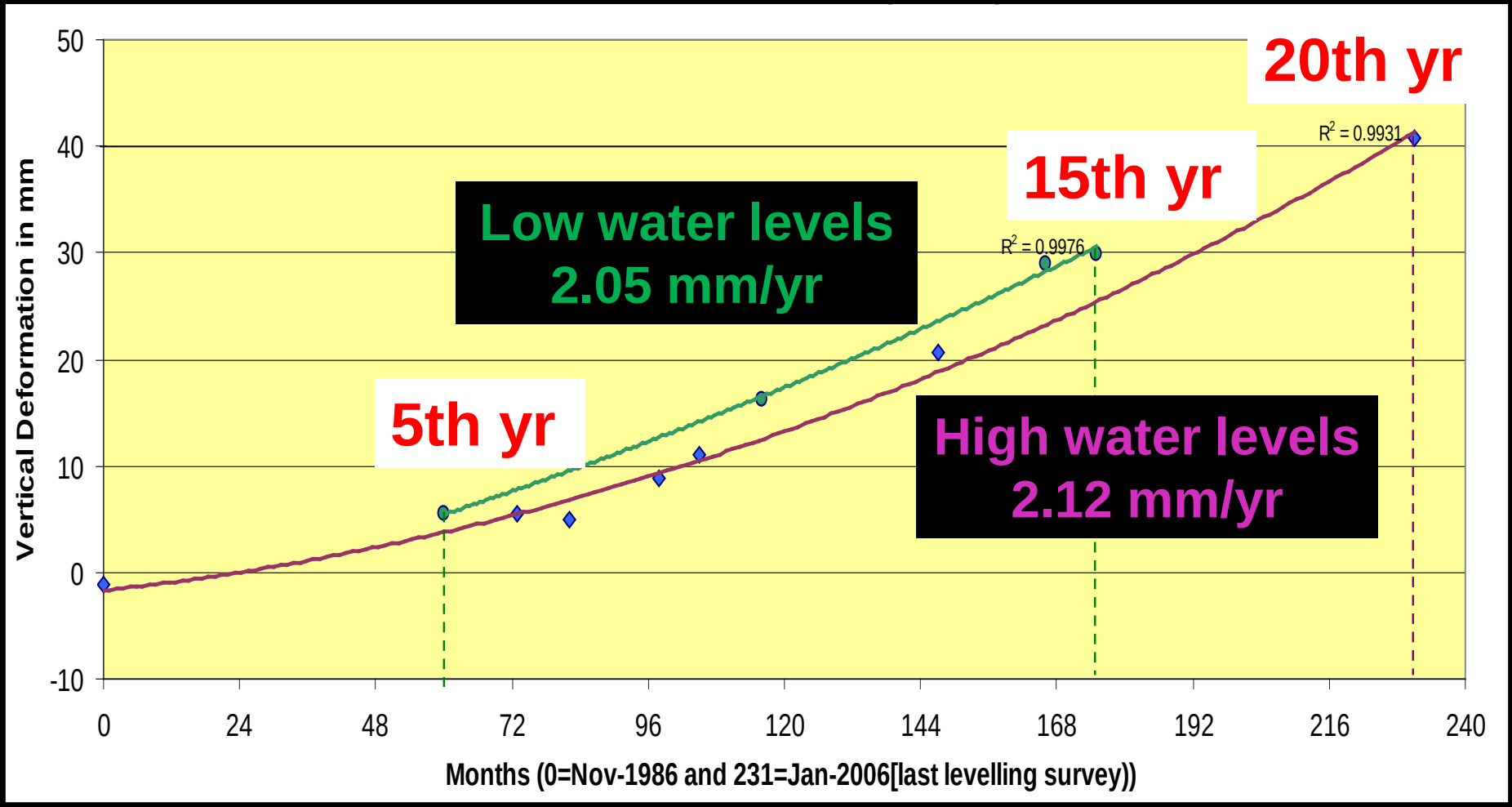
Pendulum readings at Block 2



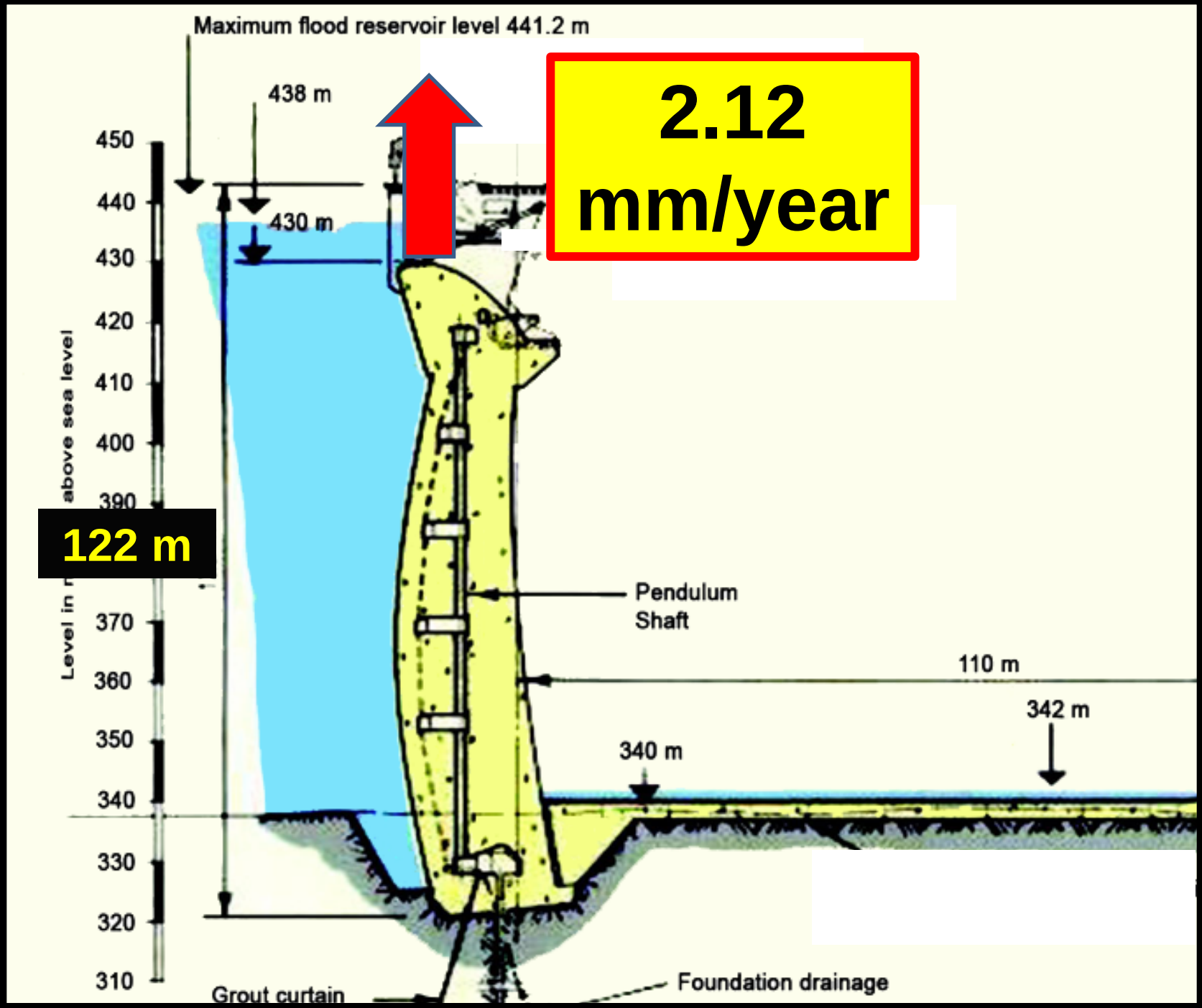
Reference: Poyry Energy AG, Comprehensive Surveillance Report-Victoria Dam, Dam Safety and Water Resources Planning Project, October 2010


Maximum flood reservoir level 441.2 m
438 m
430 m
450
440
430
420
410
400
390
370
360
350
340
330
320
310
above sea level
Level in r
122 m
2.01
mm/year
Pendulum
Shaft
110 m
342 m
340 m
Grout curtain
Foundation drainage

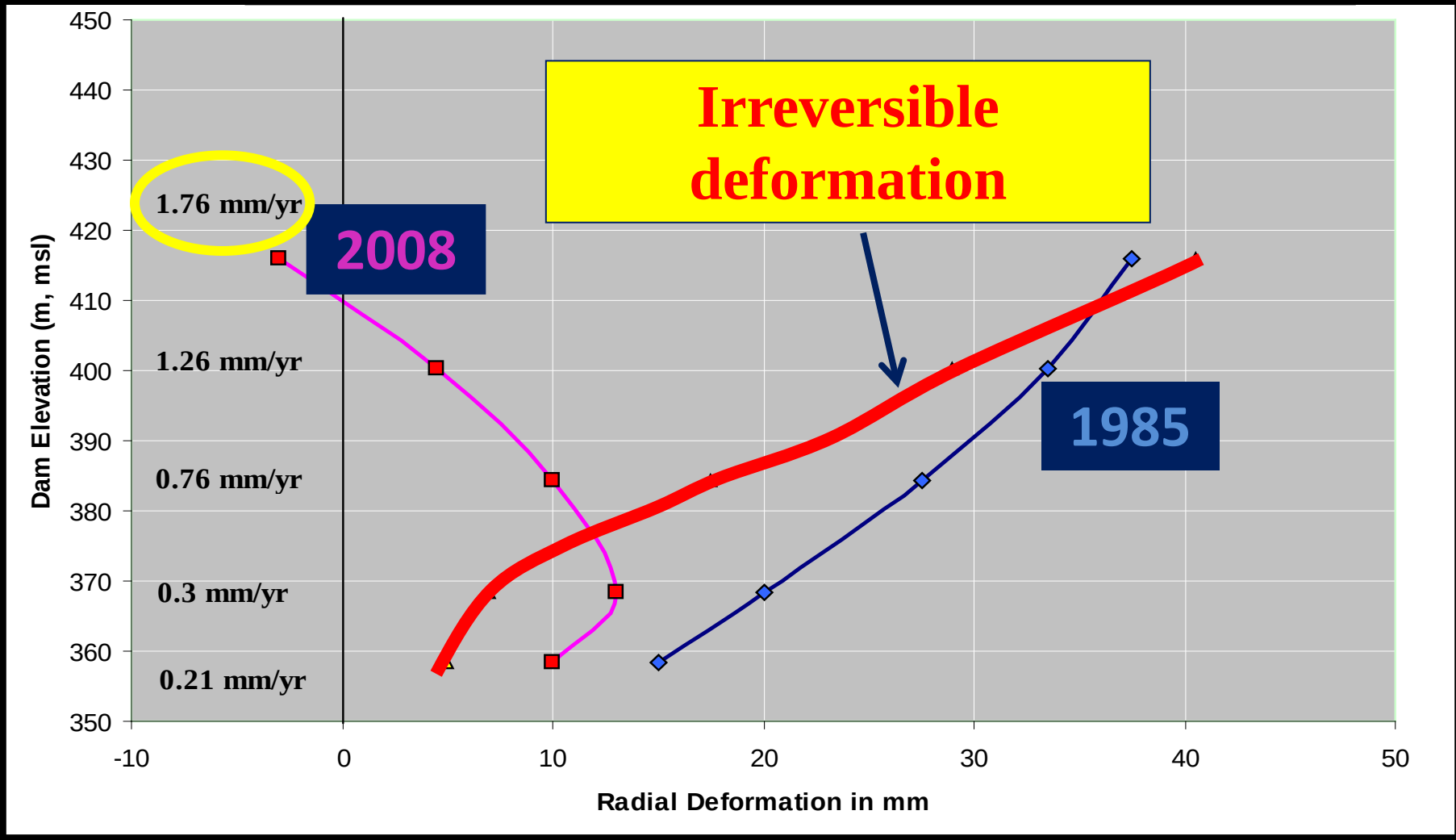
Precise level readings



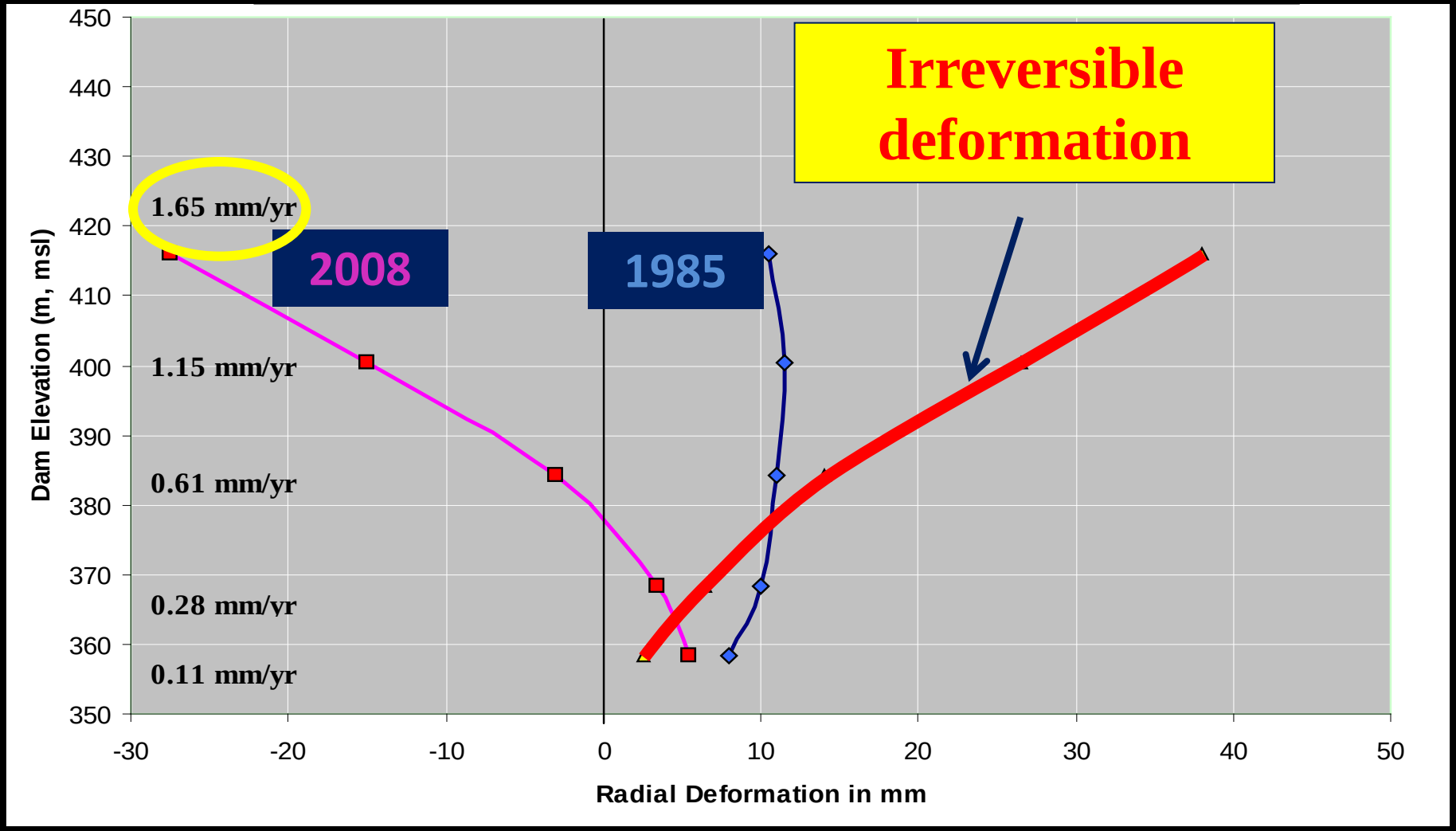
Reference: Poyry Energy AG, Comprehensive Surveillance Report-Victoria Dam, Dam Safety and Water Resources Planning Project, October 2010


Maximum flood reservoir level 441.2 m
438 m
430 m
2.12
mm/year
122 m
450
440
430
420
410
400
390
370
360
350
340
330
320
310
above sea level
Pendulum
Shaft
110 m
342 m
340 m
Grout curtain
Foundation drainage

Irreversible deformations (high water levels)



Irreversible deformations (low water levels)



Finally

Dam has shown

- Trend of upstream movement
- Trend of vertical rising

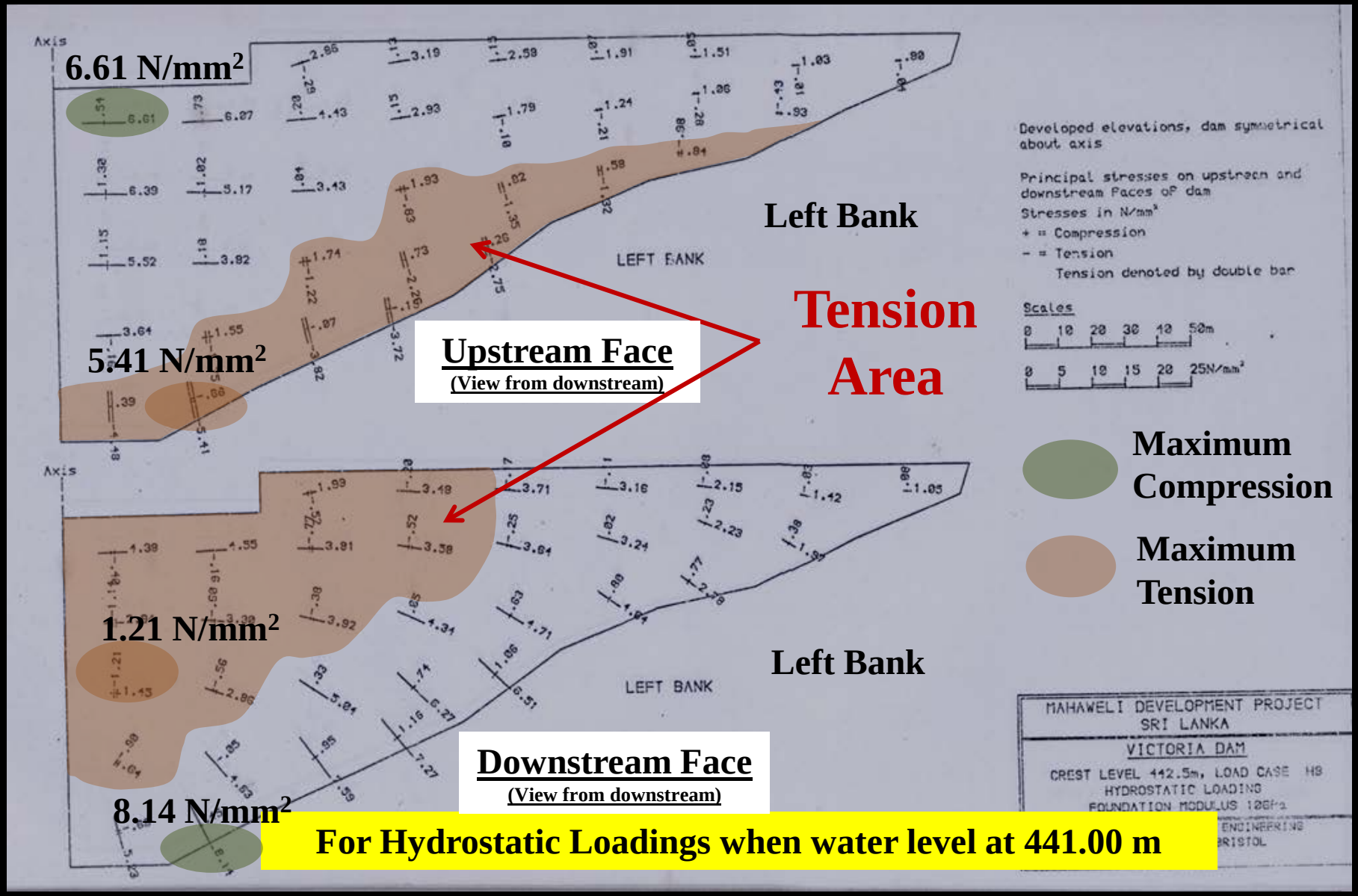
Need

- Understanding the behavior with available data
- Back analysis

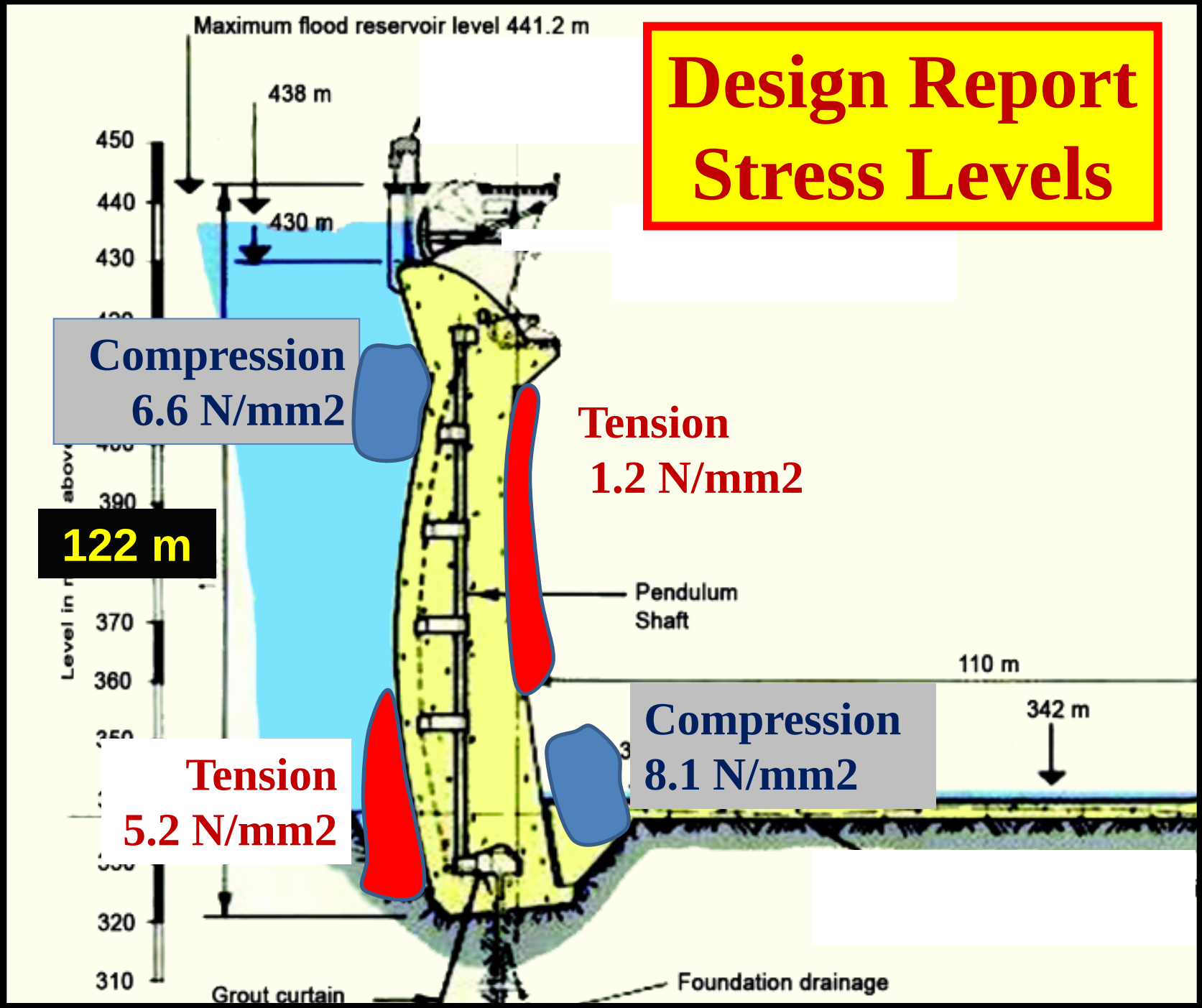
Two approaches

- Numerical Study-FEA
- Experimental Investigations
  - Possibility of AAR (ASR)
  - Lab test /core samples

Finite Element Studies of Victoria Dam
(University of Bristol, October 1980)



For Hydrostatic Loadings when water level at 441.00 m



Design Report Stress Levels

Dams and Public Safety

Concepts and Hypotheses will often be more important than calculations which may be worth little, if founded on the wrong assumptions…

Designers should be encouraged to use the most advance techniques but at the same time they must be cautioned **not to forget Elementary Forces**

Uncertainty

- We cannot say, as a matter of principle, the present in all its details….
- Need large number of measurements to predict the end effects (FoS)

FOS → $\frac{\text{Material Strength}}{\text{Load Conditions}}$

Scholar Views

I have no special talents but I am passionately curious

I know that I don’t know


Thank You