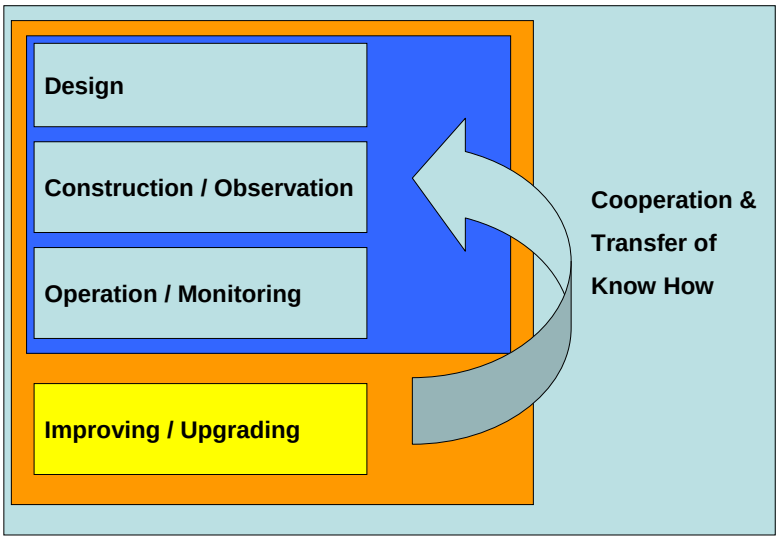
Large Dams

Design, Construction and Performance

Gerald Zenz
Graz - University of Technology

Dam Structures & Geotechnique

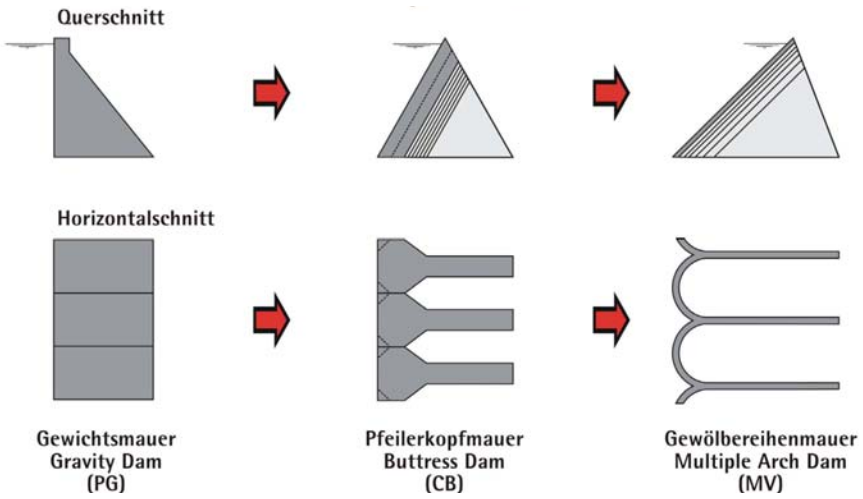


Large Dams – Design, Construction, Operation and Rehabilitation

- Gravity Dams
  - System of Load Transfer
  - Design Issues
  - Sliding Stability
- Example – HEPP Birecik – Fill and Gravity Dam Structure
- Double Curved Arch Dams
  - Bearing Behaviour
  - Design Aspects
  - Abutment Stability
- Example – Schlegeis Dam / Austria
- Example – HEPP Tzankov Kamak / Bulgaria
- Example – HEPP Ermenek / Turkey

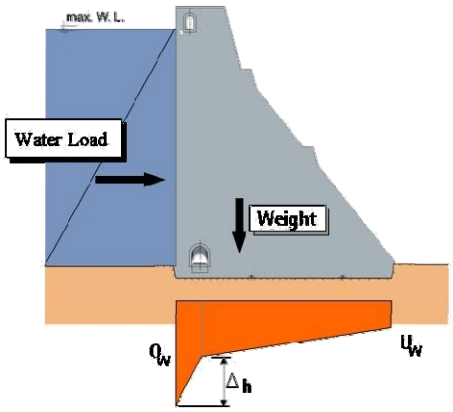
- Pumped Storage Scheme – Limberg II / Pressure Tunnel
- Rehabilitation – Bottom Outlet of Salza Dam

Gravity Type - Dam Structures



Loading Cases

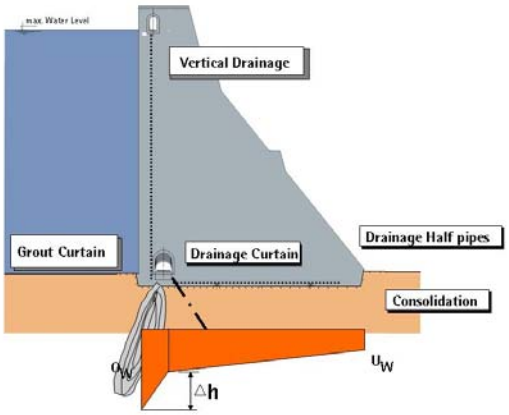
- Dead Weight
- Water Loading, Uplift
- Temperature
- Silt pressure
- Ice Loading
- Wind and Wave
- Earthquake Loading
  - Operating Earthquake OBE
  - Maximum Credible Earthquake
- Structural Alterations



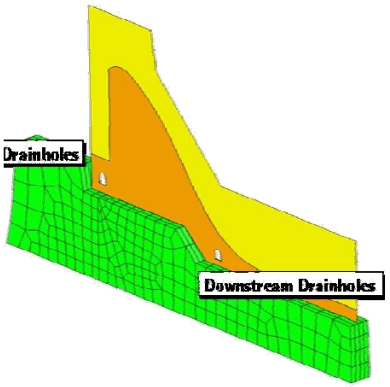
Design Control Measures

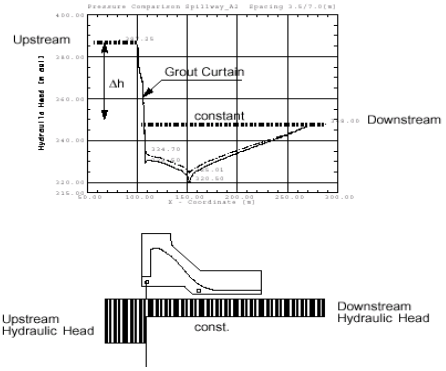
Failure Mode
Sliding in any plane in the Abutment –
-In the interface concrete to Rock
-In any possible joint
-In fault system in the Rock
-Tensile- and Compression

Usability – System Performance
-Layout
-Material Parameters
-Permeability

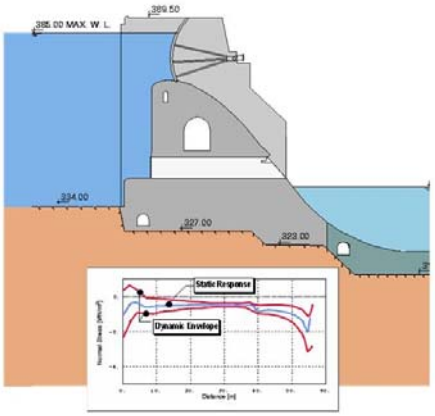


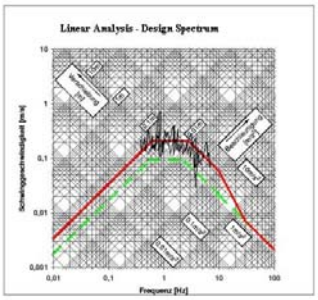
Uplift Pressure Distribution





Earthquake Loading





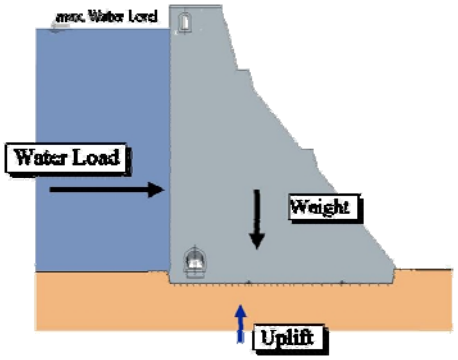
Required Safety Margin

$$\tau = \sigma_n \tan\left(\varphi_b + JRC \cdot \log_{10}\frac{JCS}{\sigma_n}\right)$$

φ_b = 29,5 °
Residual Friction Angle / Laboratory

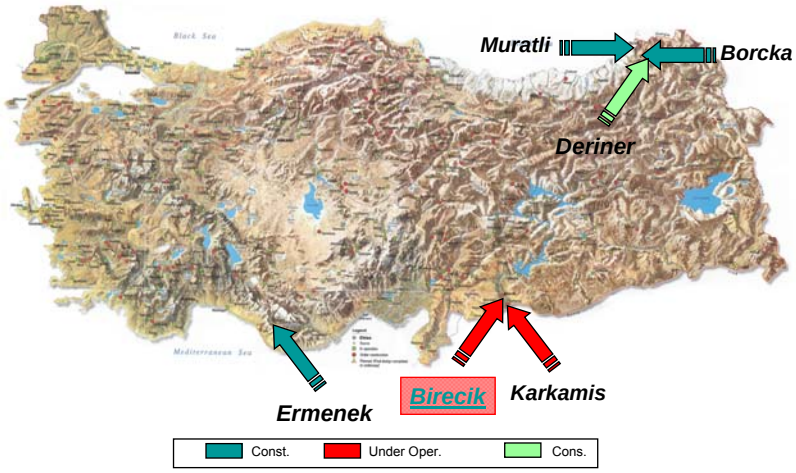
JRC = 8,3
Comparison Publication / Field

JCS = 27,2MPa
Laboratory Measurements
Correlation with Schmidt Hammer

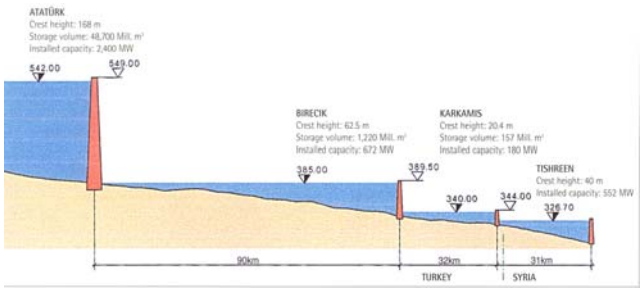


Loading Condition	Required Factor of Sliding Safety
Normal operation	1,50
Special loading (e.g. OBE)	1,30
Unusual loading conditions (e.g. MCE)	1,10

Selected Hydro Power Plants in Turkey



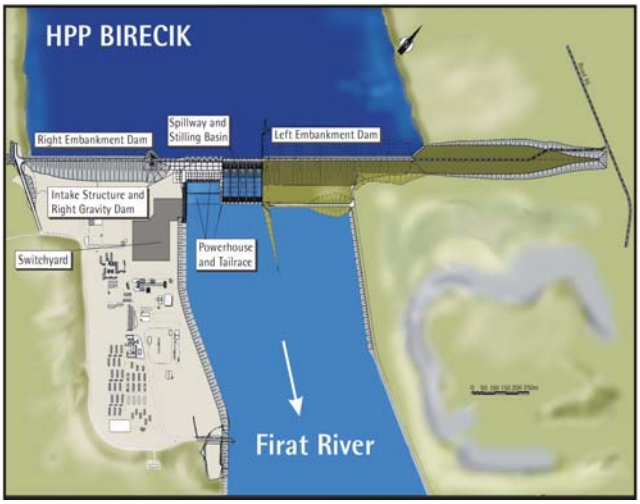
Hydro Schemes at the Euphrat



Birecik first large BOT – Project in Turkey

Start of Construction April 1996 – Construction Time 66 Month
River Diversion – June 1999
Start of Impounding – October 2000
Commercial Operation Since Oct. 2001

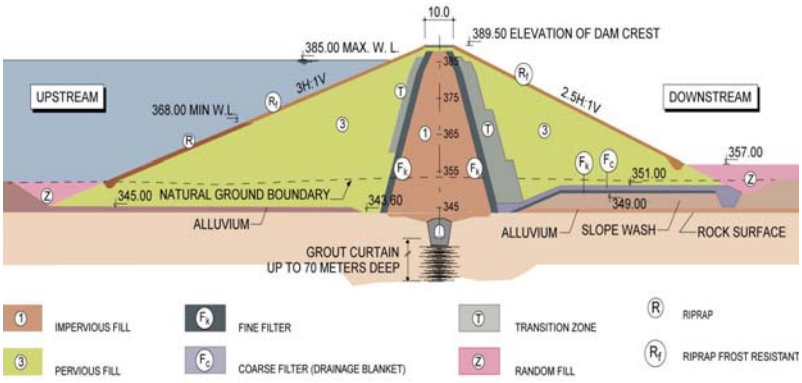
Hydro Electric Powerplant - Birecik



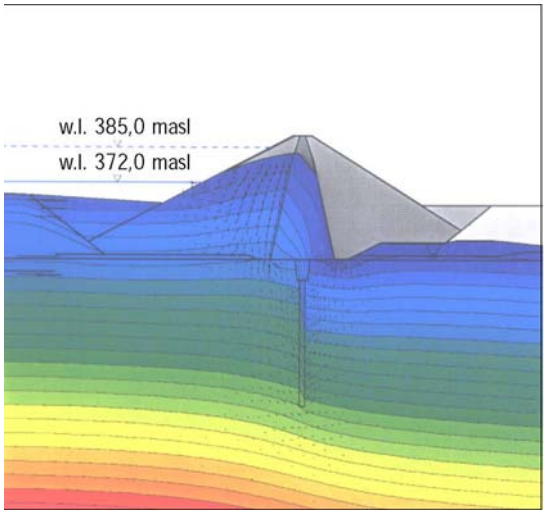
Fill Dam (2000m)
- Clay Core
- Height 62,5m

Concrete Dam (500m)
- Gravity Dam
- Intake Structure
- Power House
  6x112MW Francis
  Design Discharge
  6x317m³/s ~ 1900m³/s
- Spillway
  10 Sections 12,5m
  17500m³/sec Design Flood

Dam Cross Section



Dammquerschnitt



- Sliding Stability
- Earthquake Safety
  Soil Liquefaction
- Seepage Analysis
  Rapid Drawdown

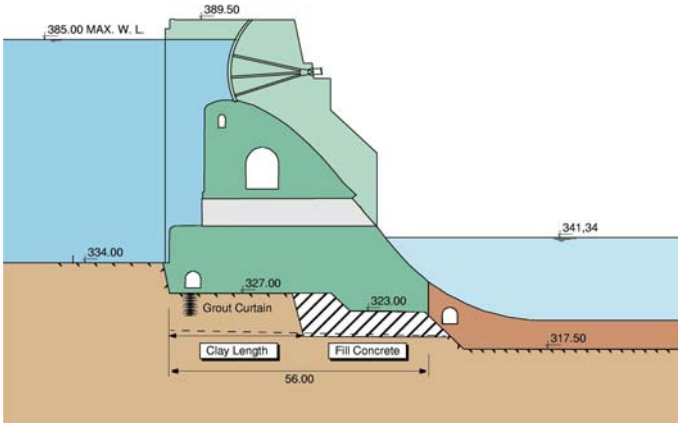
Excavation – Spillway - Intake

Geotechnical Investigations
-Site Mapping
-Drilling Campaign
-Laboratory & In Situ - Tests
-Geophysical Investigation

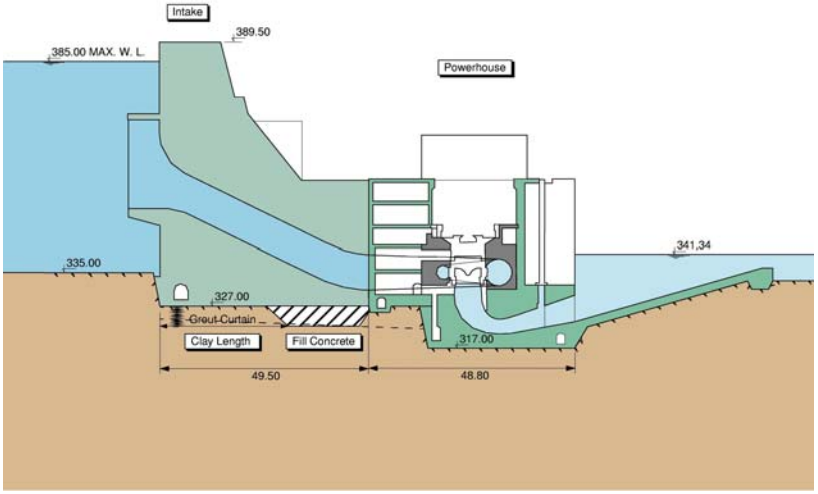
Joint System – Clay Filled

φ_{clay} = 22,4 °
Clay Friction Angle / Laboratory

Spillway - Section



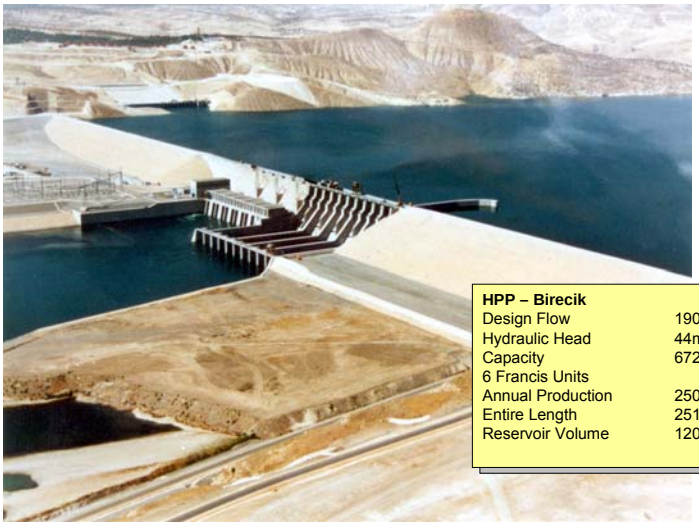
Intake Section



Additional Excavation – Spillway - Intake

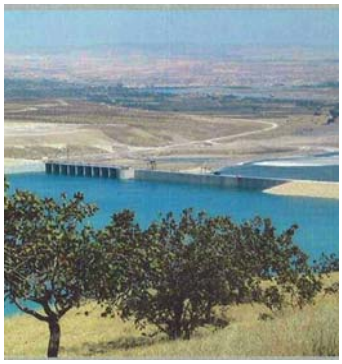
Additional Excavation

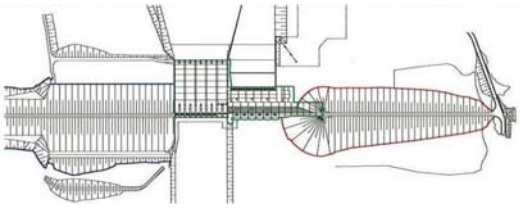
Operation - Monitoring of Performance



HPP – Birecik	
Design Flow	1900m³/s
Hydraulic Head	44m
Capacity	672MW
6 Francis Units	
Annual Production	2500GWh
Entire Length	2510m
Reservoir Volume	1200Mio m³

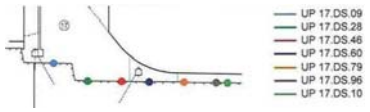
Operation – Monitoring Performance

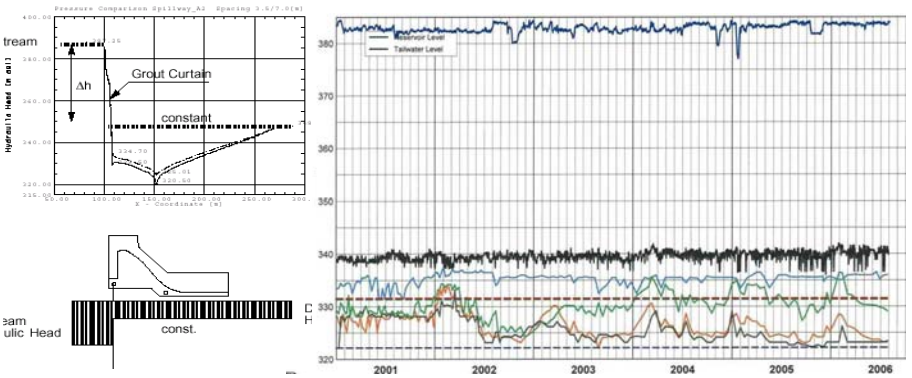




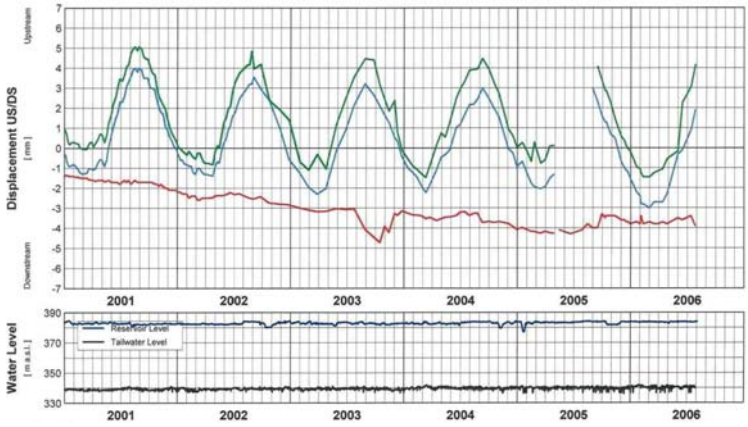
Geodetic Measurements
Seepage / Uplift
Displacements – Plump Line / Extensometers / Joint Meters
Operation – Reservoir Water Level / Downstream Water Level / Temperatures

Uplift Pressure Measurements

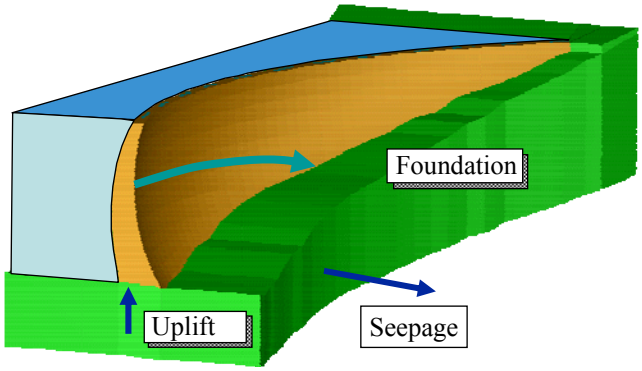




Radial Deformation Measurements - Intake



Arch Dam – Bearing Behavior

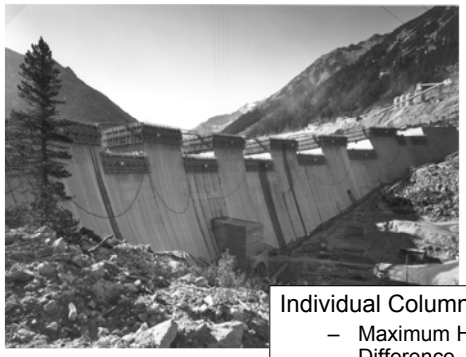


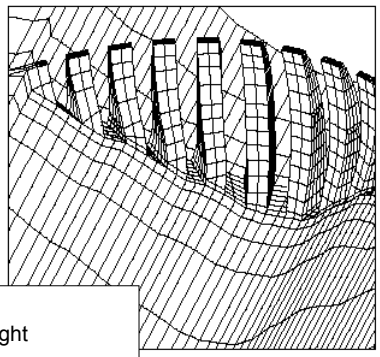
Schlegeis Dam

Crest length	725m
Height	131m
Thickness	34m / 9m
Total Concrete Volume	960000m^3

Dam Excavation

Method of Construction

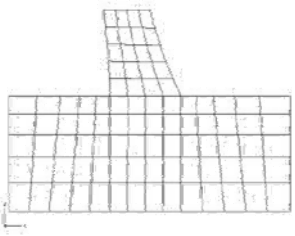


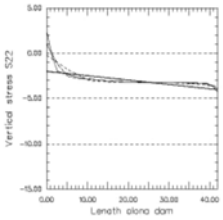


Individual Columns
- Maximum Height Difference
- Placing Temperature
- Joint Grouting

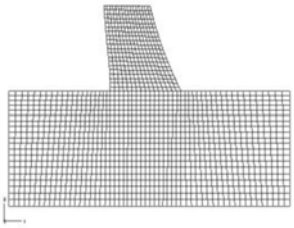
Monolithic Arch Structure
- Loading Conditions

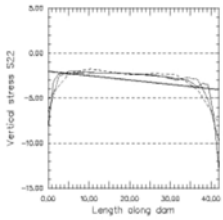
Method Dependent Results



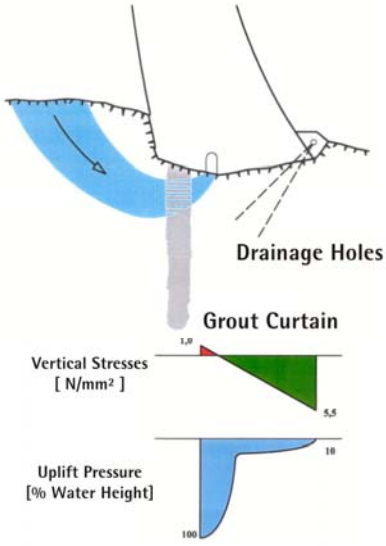


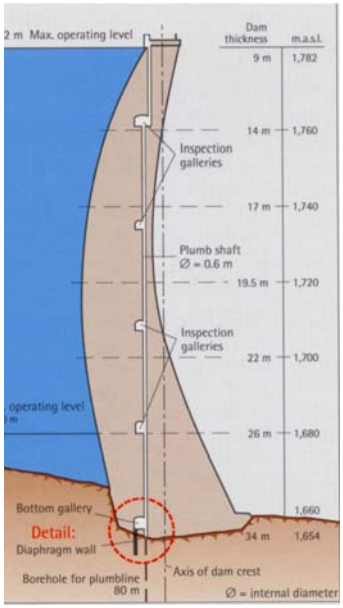
Influence – Mesh Size – Deformation Behavior



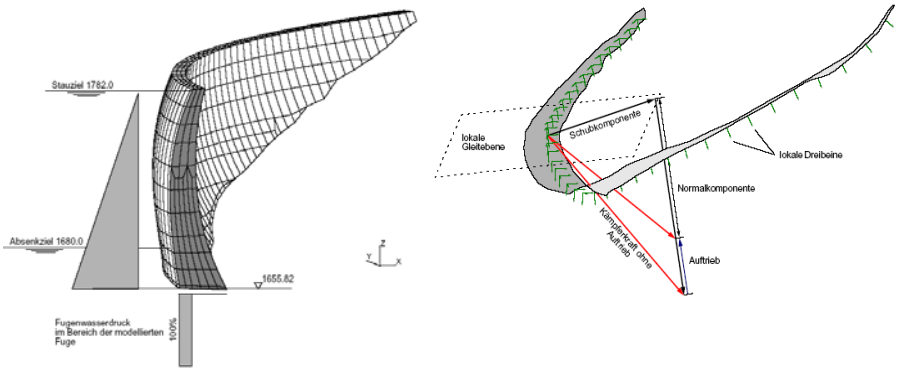


Situation at Central Cross Section

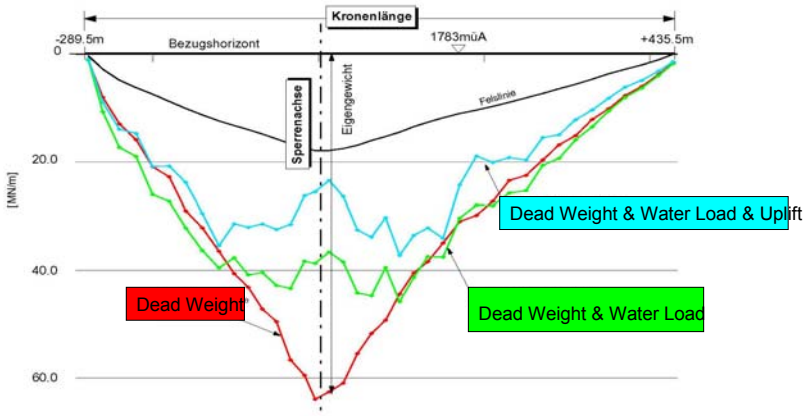




Finite Element Cross Section – Abutment Forces



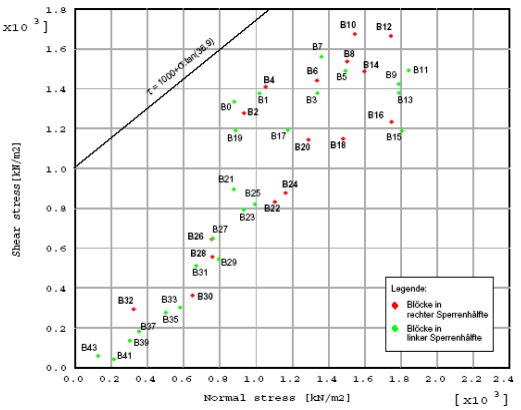
Forces Along the abutment



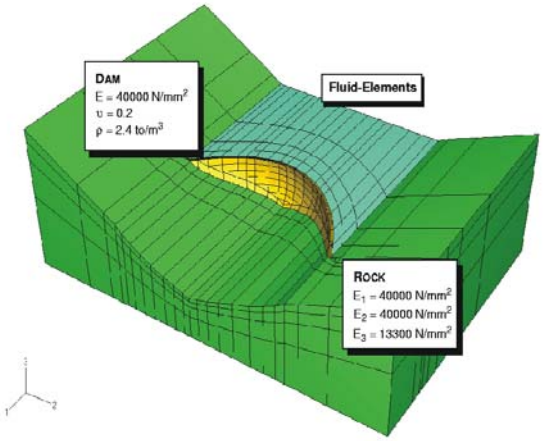
Abutment – Block Sliding Analysis

Resultant Forces
- Vertical
- Horizontal

Sliding Safety

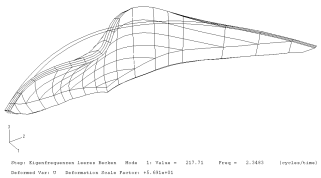


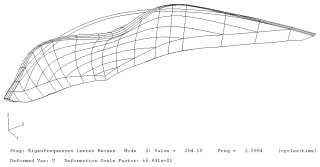
Dynamic Analyses



DYNAMIC BEHAVIOUR

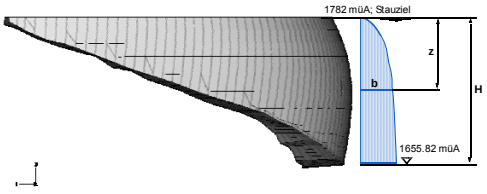
- Measured Eigenfrequencies and Mode Shapes

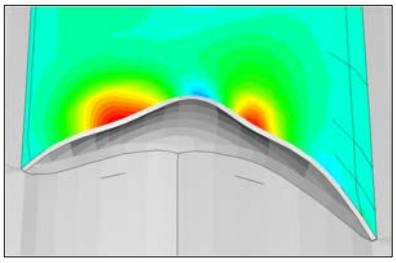




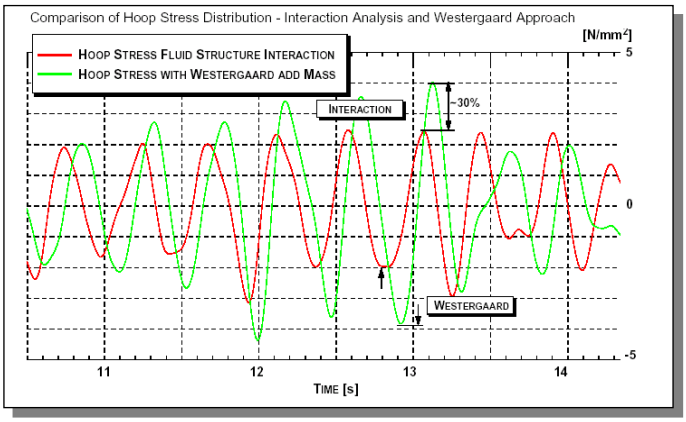
Water Level 7m below crest	
Measured	**Calculated**
1,92	1,81
2,05	1,86
2,50	2,38

Added Mass – Versus – Fluid Structure Interaction

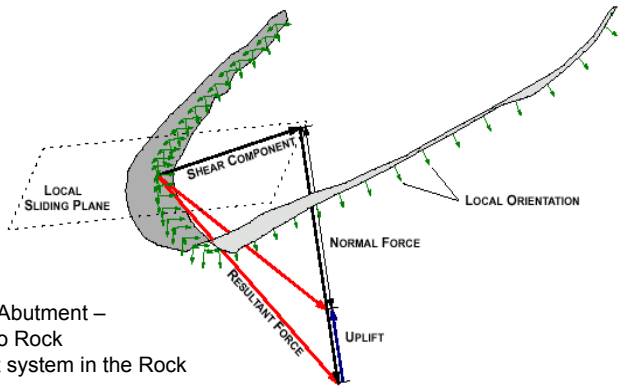




Added Mass – Versus - FSI



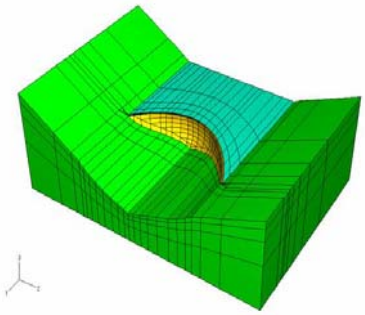
Abutment Stability

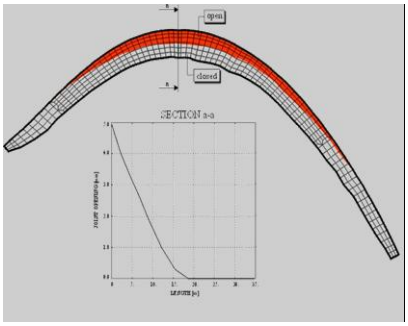


Failure Mode
Sliding in any plane in the Abutment –
-In the interface concrete to Rock
-In any possible joint / fault system in the Rock
Compression / Tension

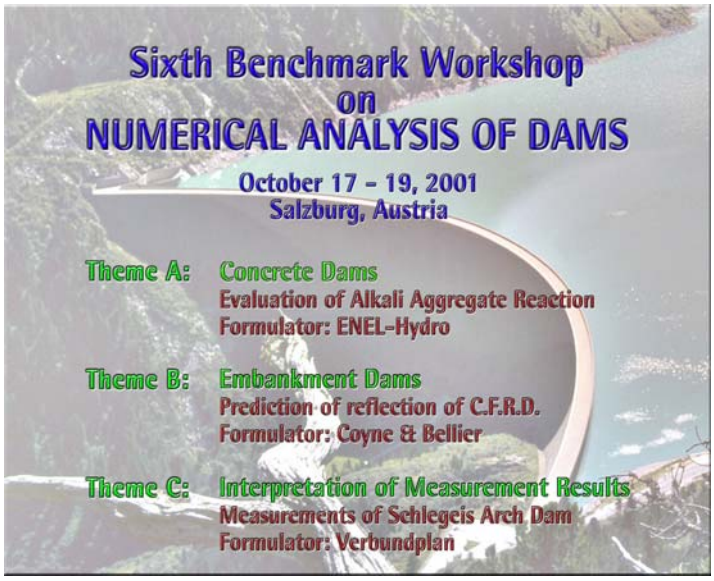
Usability – System Performance
-Layout
-Material Parameters
-Permeability / Uplift Water Pressure

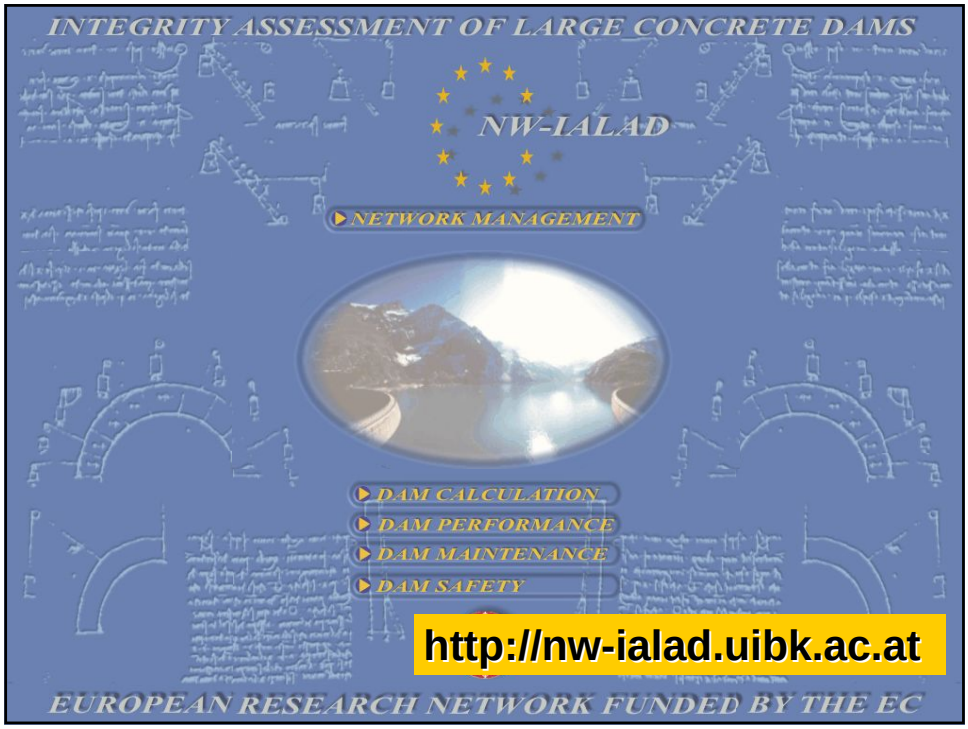
Arch Dam Behavior – ICOLD Benchmark

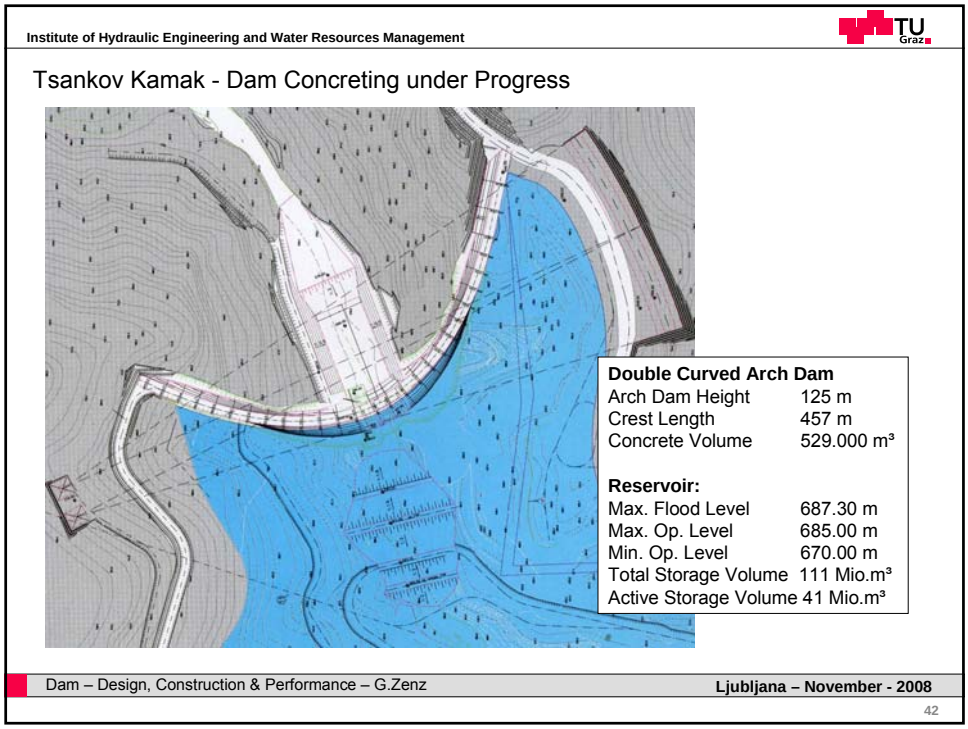


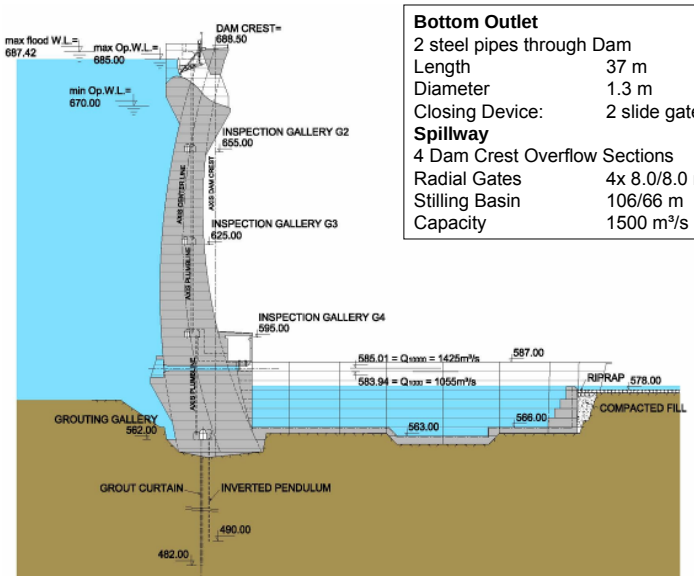


- measurements provided
- linear + nonlinear benchmark
- ICOLD – Dam Analysis




INTEGRITY ASSESSMENT OF LARGE CONCRETE DAMS
NW-IALAD
NETWORK MANAGEMENT
DAM CALCULATION
DAM PERFORMANCE
DAM MAINTENANCE
DAM SAFETY
http://nw-ialad.uibk.ac.at
EUROPEAN RESEARCH NETWORK FUNDED BY THE EC


Institute of Hydraulic Engineering and Water Resources Management
TU Graz
Tsankov Kamak - Dam Concreting under Progress
Double Curved Arch Dam
Arch Dam Height 125 m
Crest Length 457 m
Concrete Volume 529.000 m³
Reservoir:
Max. Flood Level 687.30 m
Max. Op. Level 685.00 m
Min. Op. Level 670.00 m
Total Storage Volume 111 Mio.m³
Active Storage Volume 41 Mio.m³
Dam – Design, Construction & Performance – G.Zenz
Ljubljana – November - 2008
42



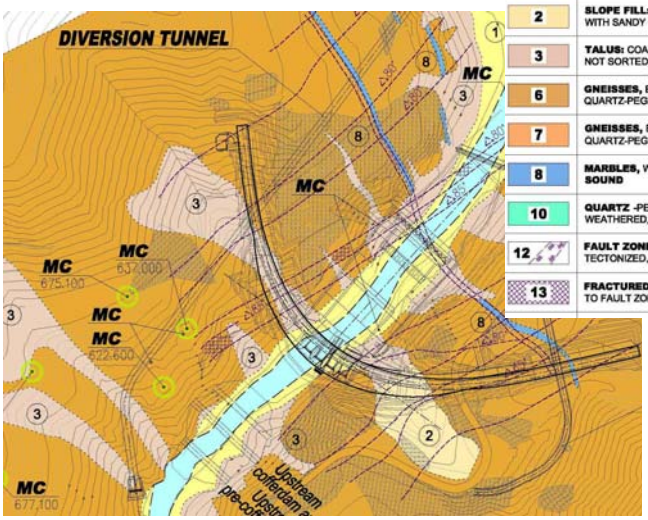
Bottom Outlet

2 steel pipes through Dam	
Length	37 m
Diameter	1.3 m
Closing Device:	2 slide gates

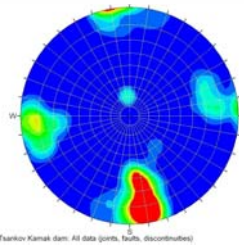
Spillway

4 Dam Crest Overflow Sections	
Radial Gates	4x 8.0/8.0 m
Stilling Basin	106/66 m
Capacity	1500 m³/s

Geotechnical Investigations



1	**RIVER ALLUVIUM:** BOULDERS AND GRAVEL WITH COARSE SANDY FILL
2	**SLOPE FILL:** ANGULAR ROCK FRAGMENTS AND BLOCKS MIXED WITH SANDY CLAY
3	**TALUS:** COARSE ANGULAR ROCK PIECES AND BLOCKS, NOT SORTED, WITHOUT FILLER
6	**GNEISSES,** BIOTITE, AMPHIBOLE-BIOTITE, MIGMATIZATED, WITH QUARTZ-PEGMATITE VEINS, **WEATHERED**
7	**GNEISSES,** BIOTITE, AMPHIBOLE-BIOTITE, MIGMATIZATED, WITH QUARTZ-PEGMATITE VEINS. **SOUND**
8	**MARBLES,** WHITE, MIDDLE SIZE GRAINED, POORLY KARSTED **SOUND**
10	**QUARTZ** -PEGMATITE, PEGMATITES, TECTONICALLY PROCESSED WEATHERED, INTENSIVELY CRACKED
12	**FAULT ZONE,** TECTONIZED, CRUSHED
13	**FRACTURED ZONE,** HEAVILY JOINTED, TRANSITION ZONE TO FAULT ZONE



Tsankov Kamak dam: All data (joints, faults, discontinuities)

Abutment Forces

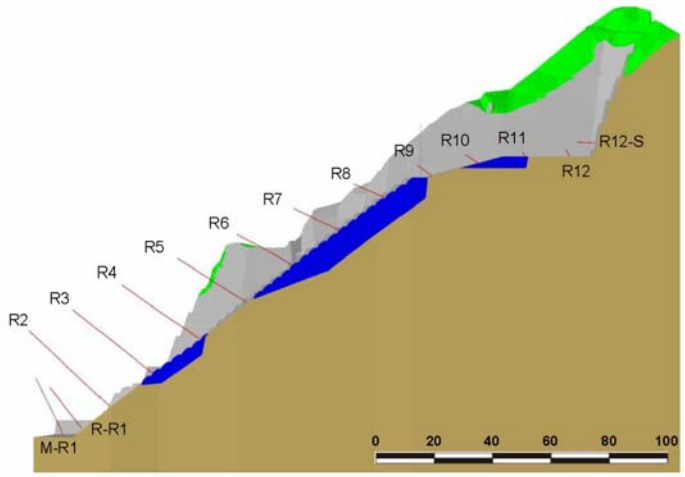


Figure 4: Section through abutment block reaction forces – G+W685+Ts

Horizontal - Geological Section

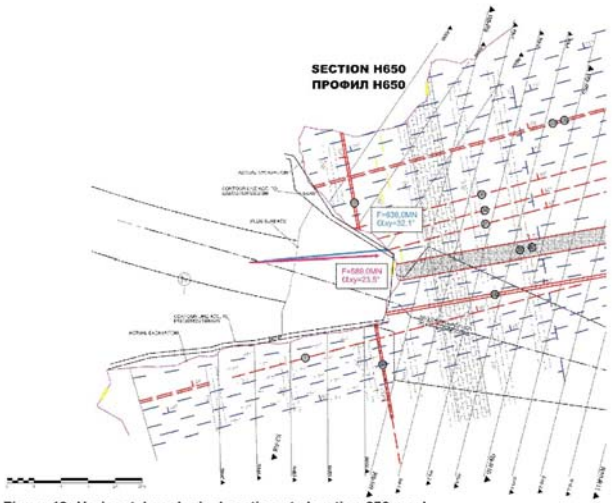
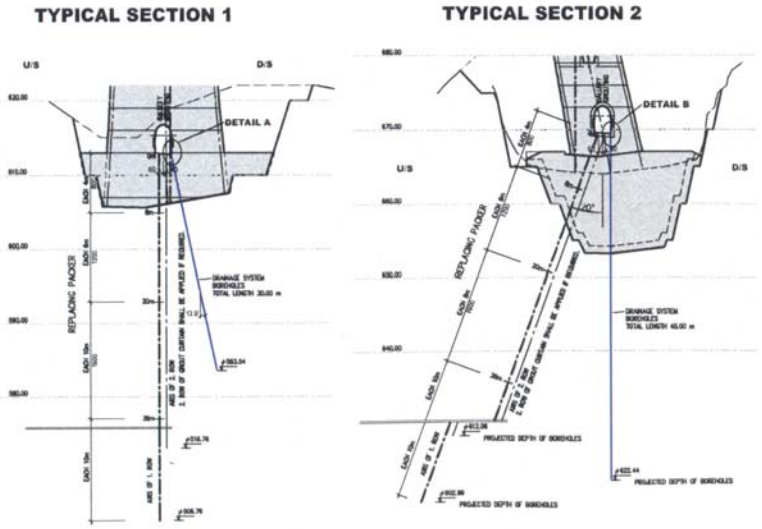
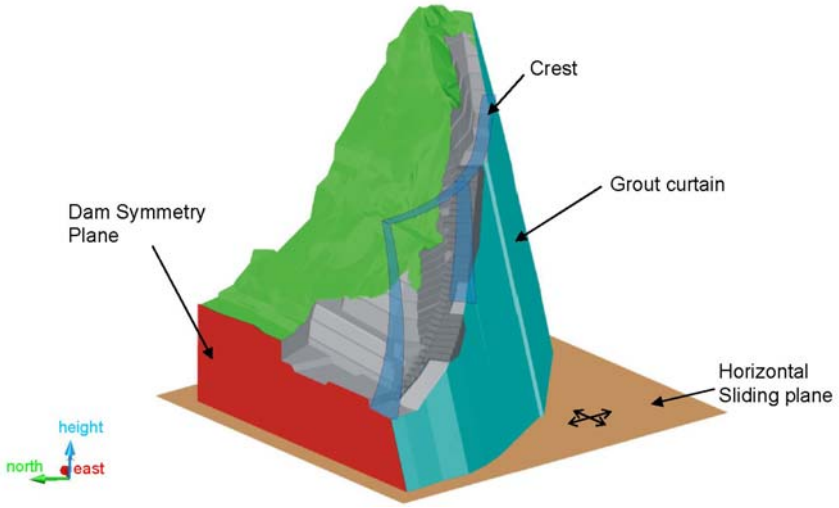


Figure 13: Horizontal geological section at elevation 650m asl.

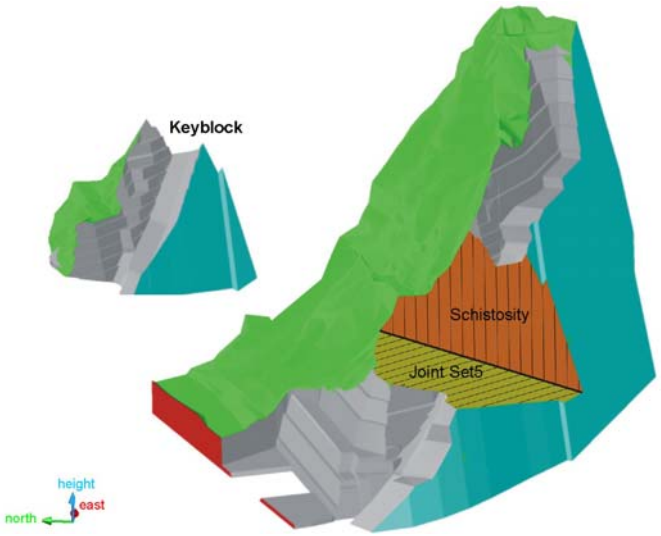
Grout- and Drainage Curtain



Model for Dam Abutment Stability Calculation

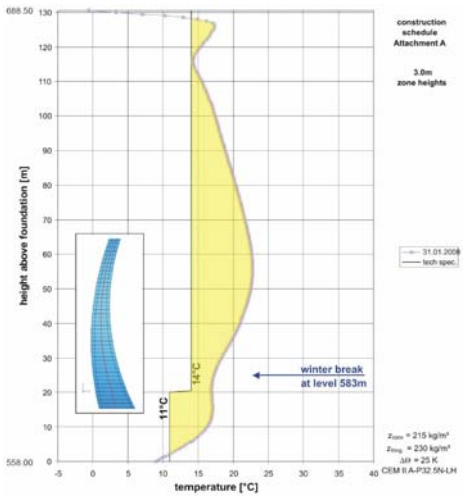


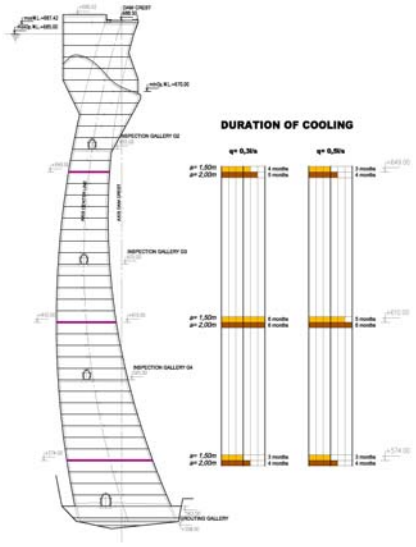
Conservative Model - Keyblock Analysis



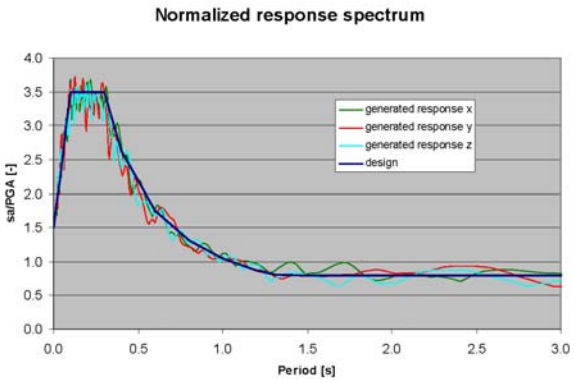
Water Pressure

Temperature Distribution – End of Construction



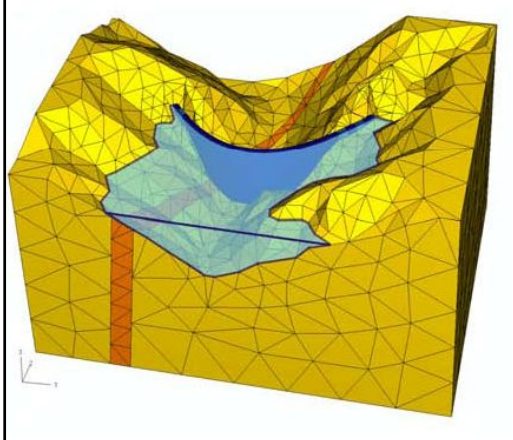


Earthquake Excitation



MCE - 0,41g for 10000year return period

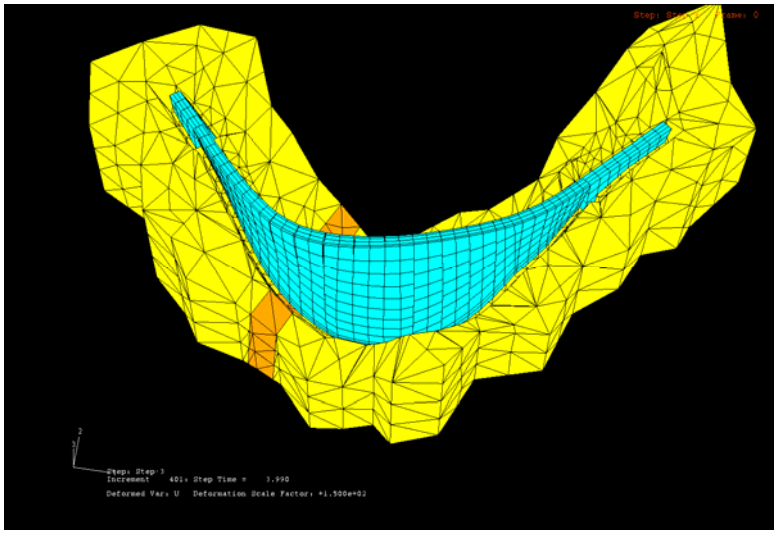
Model of Structure and Water



Nonlinear Dynamic Analysis
- Joint at the Abutment
- Block Joints
- Construction Joints

Implicit Direct Time Integration
- Massless Rock
- Reservoir Modeled
- FSI – analysis
- Acceleration time history

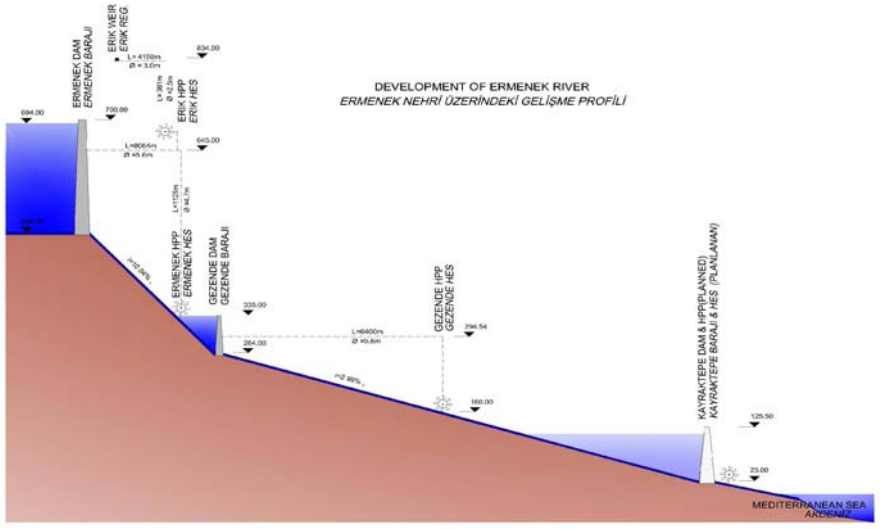
Nonlinear Dynamic Analyses

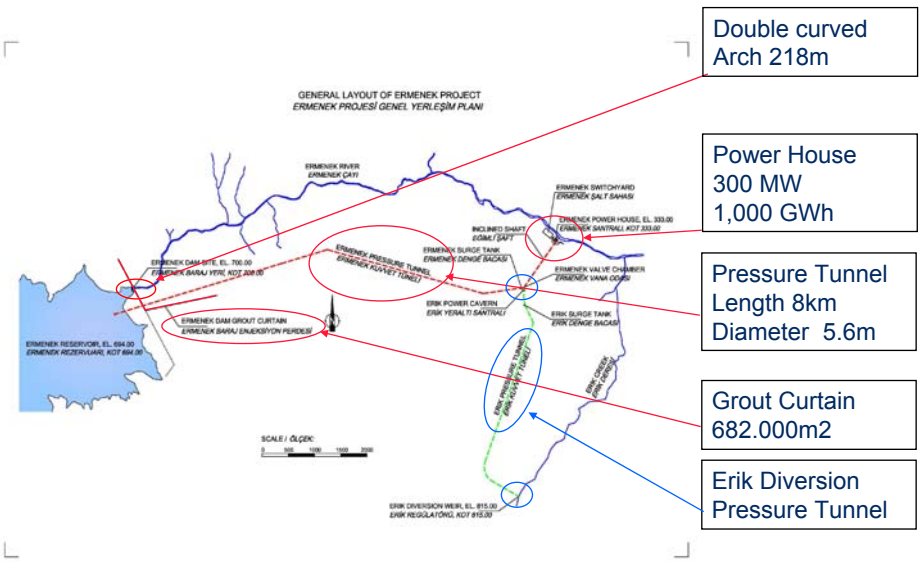


Quality Assurance
- During Execution of Construction
- Rock Abutment (Geological Monitoring)
- Concrete Production / Surface / Core
- Grouting
- Temperature Distribution

HPP Ermenek – Arch Dam Design and Construction

Reservoir Volume:	**4600 Mio m³**	**Concrete Volume:**	**289.000 m³**
Gross Height:	**361 m**	**Dam Height:**	**218 m**
Capacity:	**300 MW**	**Crest Length:**	**120 m**
Annual Production:	**1014 GWh**	**Dam Thickness:**	**Crest 7m**
Investment:	**540 Mio Eur**		**Base 25m**


DEVELOPMENT OF ERMENEK RIVER
ERMENEK NEHRİ ÜZERİNDEKİ GELİŞME PROFİLİ
ERMENEK DAM
ERMENEK BARAJI
ERIK WEIR
ERIK REG
ERIK HPP
ERIK HES
ERMENEK HPP
ERMENEK HES
GEZENDE DAM
GEZENDE BARAJI
GEZENDE HPP
GEZENDE HES
KAYRAKTEPE DAM & HPP(PLANNED)
KAYRAKTEPE BARAJI & HES (PLANLANAN)
MEDITERRANEAN SEA
AKDENİZ


GENERAL LAYOUT OF ERMENEK PROJECT
ERMENEK PROJESİ GENEL YERLEŞİM PLANI
ERMENEK RIVER
ERMENEK ÇAYI
ERMENEK SWITCHYARD
ERMENEK ŞALT SAHASI
ERMENEK POWER HOUSE, EL. 333.00
ERMENEK SANTRALİ KOT 333.00
INCLINED SHAFT
EĞİMLİ ŞAFT
ERMENEK SURGE TANK
ERMENEK DENGE BACASI
ERMENEK PRESSURE TUNNEL
ERMENEK KUVVET TÜNELİ
ERMENEK VALVE CHAMBER
ERMENEK VANA ODASI
ERMENEK DAM SITE, EL. 700.00
ERMENEK BARAJ YERİ, KOT 700.00
ERMENEK DAM GROUT CURTAIN
ERMENEK BARAJ ENJEKSİYON PERDESİ
ERIK POWER CAVERN
ERIK YERALTI SANTRALİ
ERIK SURGE TANK
ERIK DENGE BACASI
ERMENEK RESERVOIR, EL. 694.00
ERMENEK REZERVUARI, KOT 694.00
SCALE / ÖLÇEK:
ERIK DIVERSION WEIR, EL. 815.00
ERIK REGÜLATÖRÜ, KOT 815.00
Double curved Arch 218m
Power House 300 MW 1,000 GWh
Pressure Tunnel Length 8km Diameter 5.6m
Grout Curtain 682.000m2
Erik Diversion Pressure Tunnel

Pressure Tunnel

Tunnel Boring Maschine

Excav. Diameter 6,7m

Geology
- Limestone
- Karst
- Flysh
- Water intrusion

Tunnel - Durchschlag

Ausbruchsfortschritt

Max. Tagesleistung
62m/Tag

Max.Monatsleistung
1004m / Monat

Tunnel Durchschlag

8100m Gesamtlänge

Beginn
26th July 2003

Durchschlag
2nd April 2005

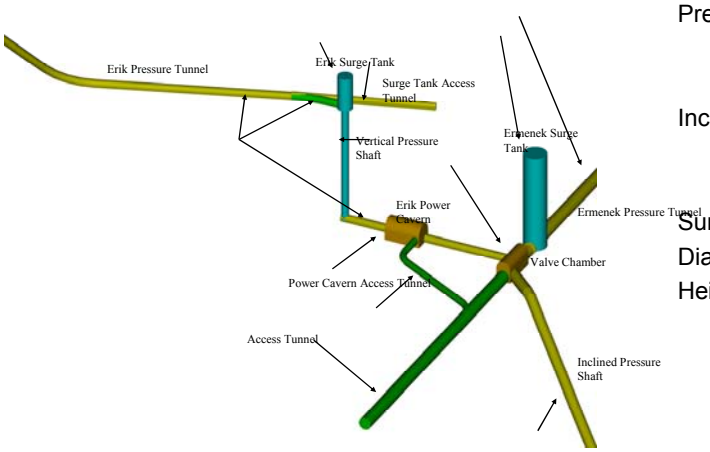
Power Station

Ermenek
NQ ~15m³/s
MQ ~43m³/s

Switcht Yard

Stability
Design – Reliefe Wells

Valve Chamber – Surge Tank



Pressure Tunnel
8,1km

Inclined Shaft
1km

Surge Tank
Diameter 10m
Height ~135m

Erik Diversion – Ermenek Surge Tank

Dam Construction Site - Downstream

Canyon

Depth 200m

Broad – 10 bis 25m

Vertical partly
Steep valley

Gorge

Ermenek - Double Curved Arch Dam

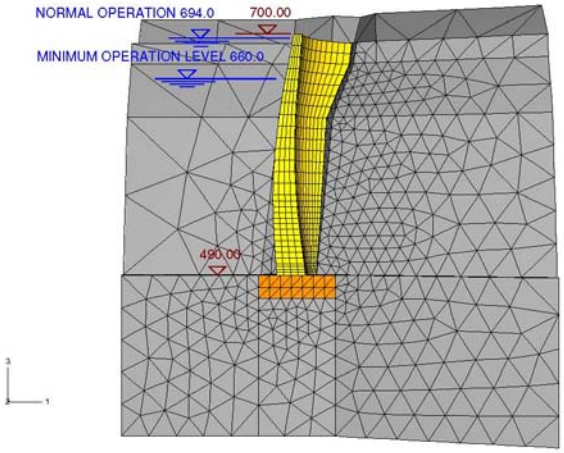
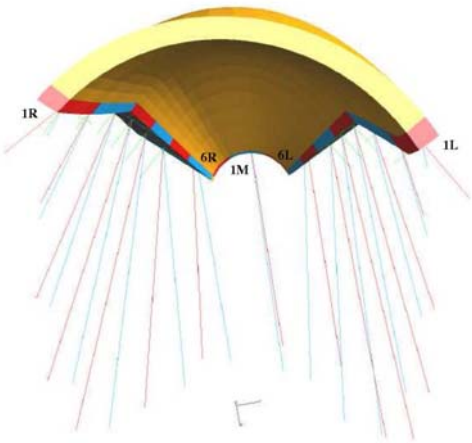


Figure 6: General cross section - elevations and water levels

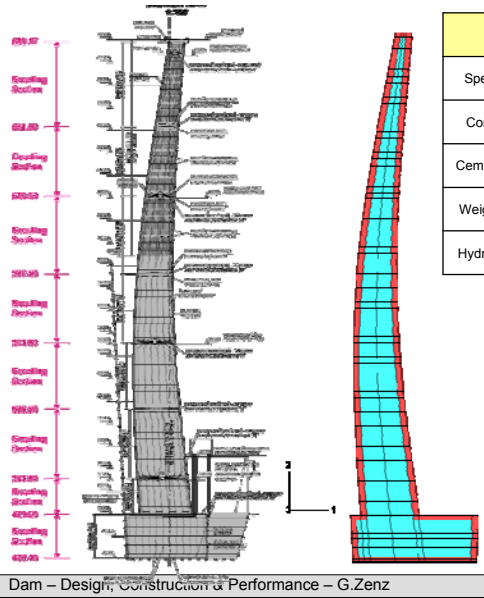
Abutment Forces – Block

Winter and Summer loading condition

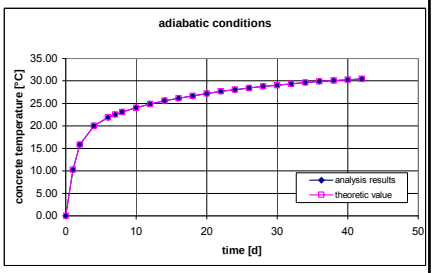
Direction and Magnitude are calculated



Hydration Heat Development



$C_{E,FA}$	
Specific heat c	0.92 kJ/(kg•K)
Conductivity k	11.2 kJ/(m•h•K) = 268.8 kJ/(m•d•K)
Cement content z	210 kg/m³
Weight density ρ	2450 kg/m³
Hydration heat H	343 kJ/kg



Calculation Parameters

Height	562	[m.a.s.l.]
F	6.60	[m²]
R	1.45	[m]
A_c	432.1	[m²]
L	216.0	[m]
K	0.00141	[1/h]
β_1	0.00657	[-]
v	0.665	[-]
C''	0.985	[-]
β	0.00105	[1/h]
B	0.000604	[1/h]

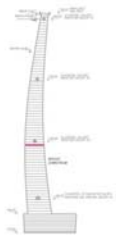


Table 16: Calculation Parameters; a = 2.0 m; q = 0.3 l/s; 562 m.a.s.l.

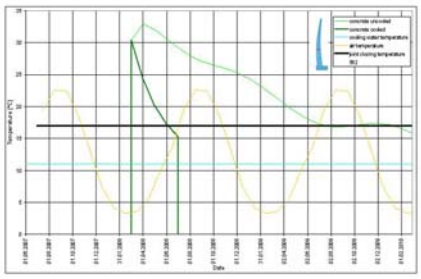
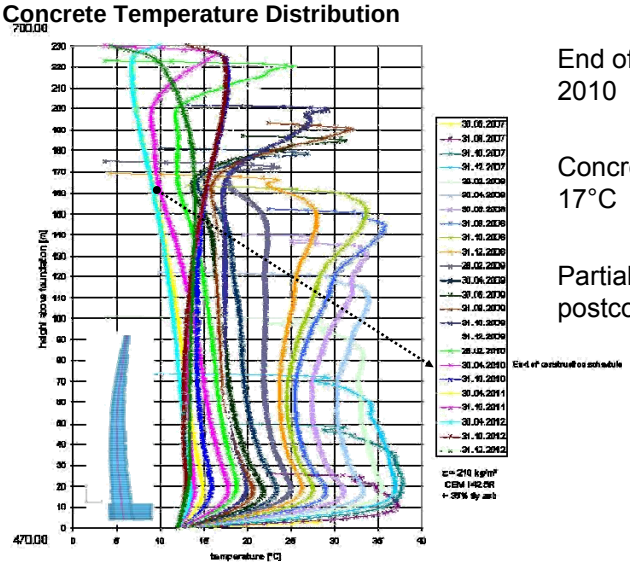


Figure 26: Temperature sequence; a = 2.0 m; q = 0.3 l/s; 562 m.a.s.l

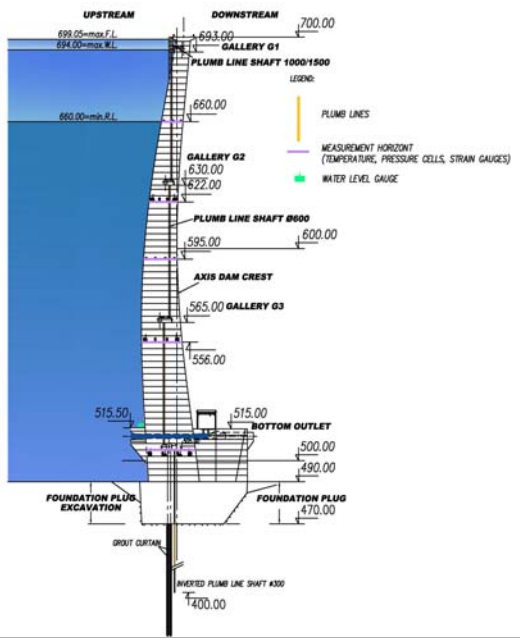
Concrete Temperature Distribution



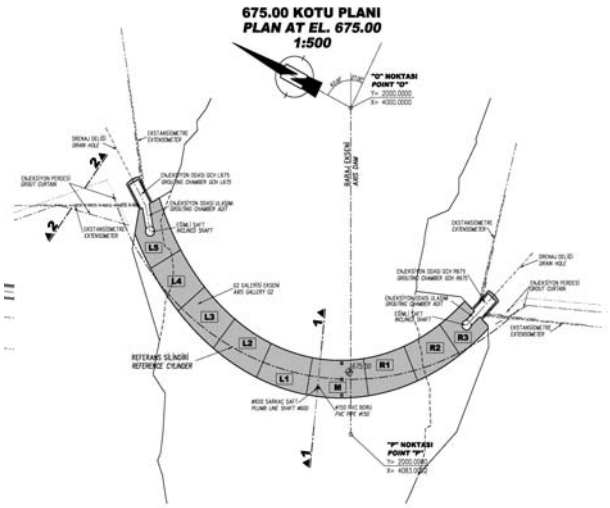
End of Construction April 2010

Concrete Temperature 17°C

Partial impounding requires postcooling

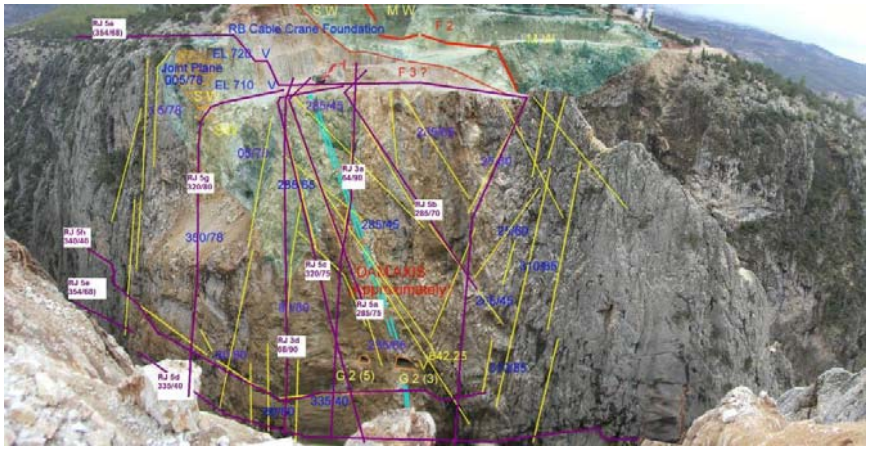


Instrumentation – Main Dam – Horizontal Cross Section

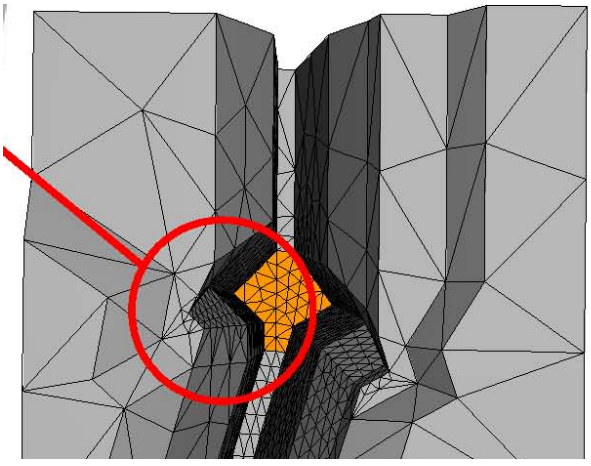


Rock Abutment – Right Bank

How a Geologist Sees the Right Bank



Detailed Investigation at Right Abutment

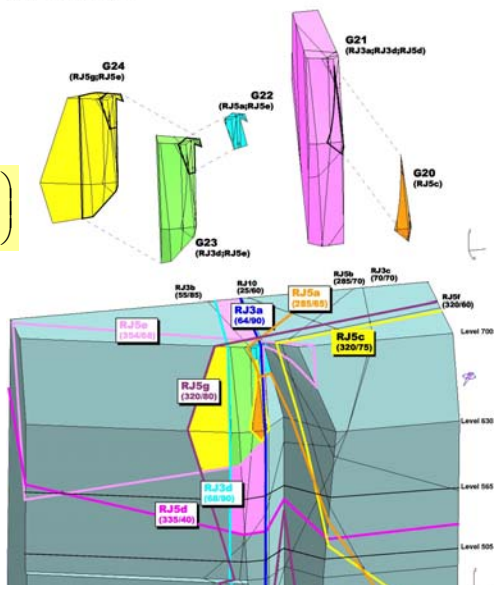


Abutment Stability

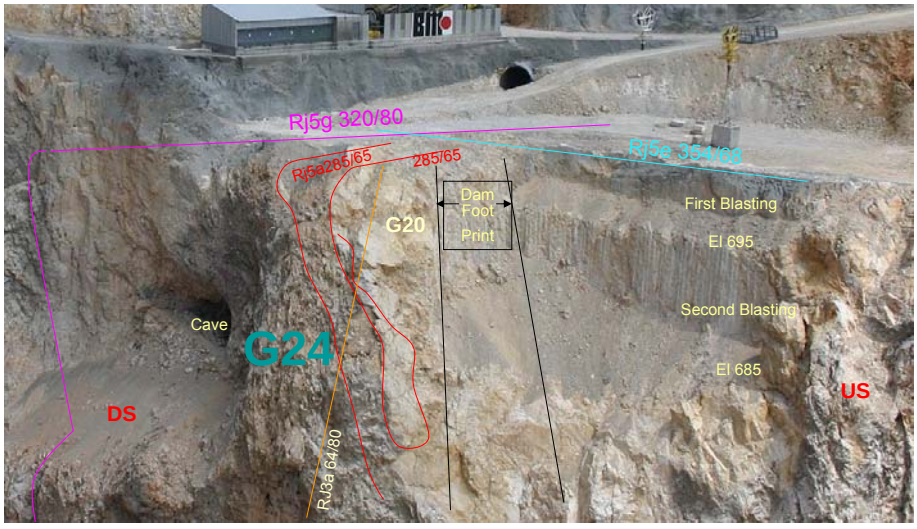
$$\tau = \sigma_n \tan\left(\varphi_b + JRC \cdot \log_{10}\frac{JCS}{\sigma_n}\right)$$

Possible Sliding Planes
RJ5e and RJ5g

RJ5g (320/80)
φ_i = 37° + f(JRC)
c_{min} = 0,2MPa



Dam Excavation Right Bank - D/S Key Blocks



D E S I G N

E X E C U T I O N

Limited Working area at the berms

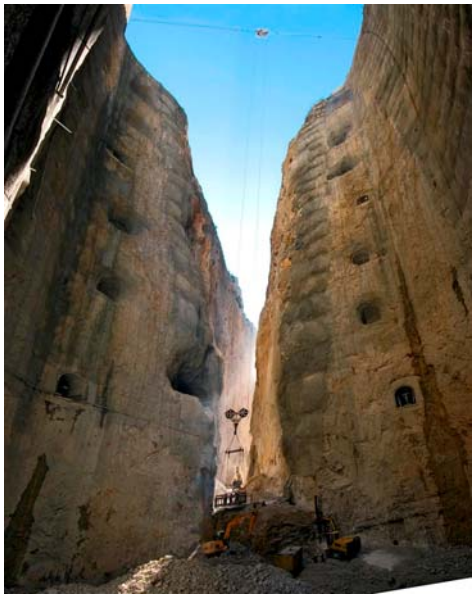
Anchor drilling from the basket

Adaptation of Appropriate Blasting

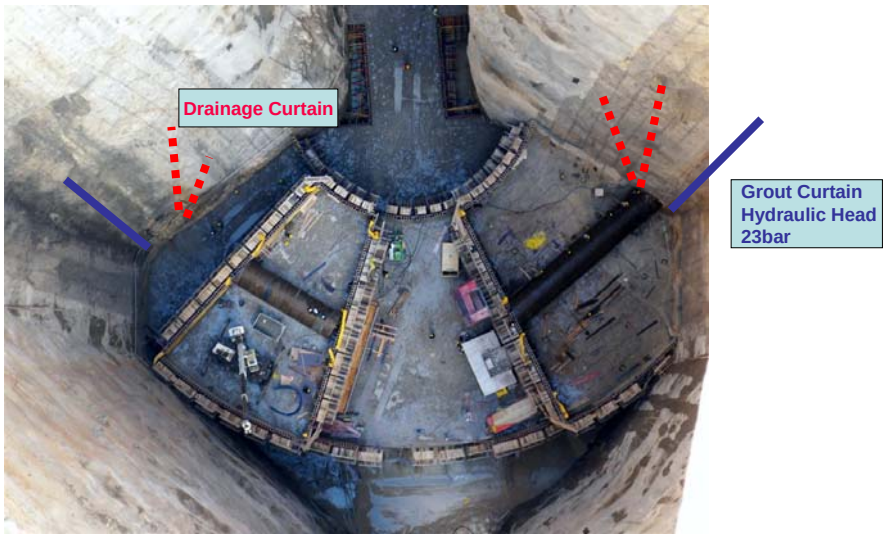
Blasting Result

Measurement During Execution

Observational Method



Dam Concreting under Progress



Status of Work

Status of Work

Elevation about 540m a.s.l

Start of Impounding – at ~610m a.s.l

Partial Impounding

Initial Large Increase in Hydraulic Head

- Grouting of Block Joints
- Temperature Distribution

2nd International Conference

LONG TERM BEHAVIOUR OF DAMS

LTBD09

12th – 13th October 2009

Graz, Austria (Europe)

First Announcement

http://www.ltbd09.tugraz.at

Topics of the Conference

- Methods of Design and Analysis of Dams
- Experimental Studies
- Dam Monitoring and Instrumentation
- Time Dependent Properties of Construction Materials for Dams and their Constitutive Modelling
- Analytical and Numerical Investigations
- Seepage under Saturated and Unsaturated Conditions
- Dam Foundation and Structure Interactions
- Seismic Aspects and Earthquake Analysis
- Safety Assessment
- Dam Maintenance
- Rehabilitation and Dam Heightening