COYNE ET BELLIER
Ingénieurs Conseils

ELECTROCONSULT

IPA
Energy + Water Economics

TECHNO-ECONOMIC ASSESSMENT STUDY
FOR ROGUN HYDROELECTRIC CONSTRUCTION PROJECT

OSHPC BARKI TOJIK

Phase II Report: Project Definition Options

Dam Safety

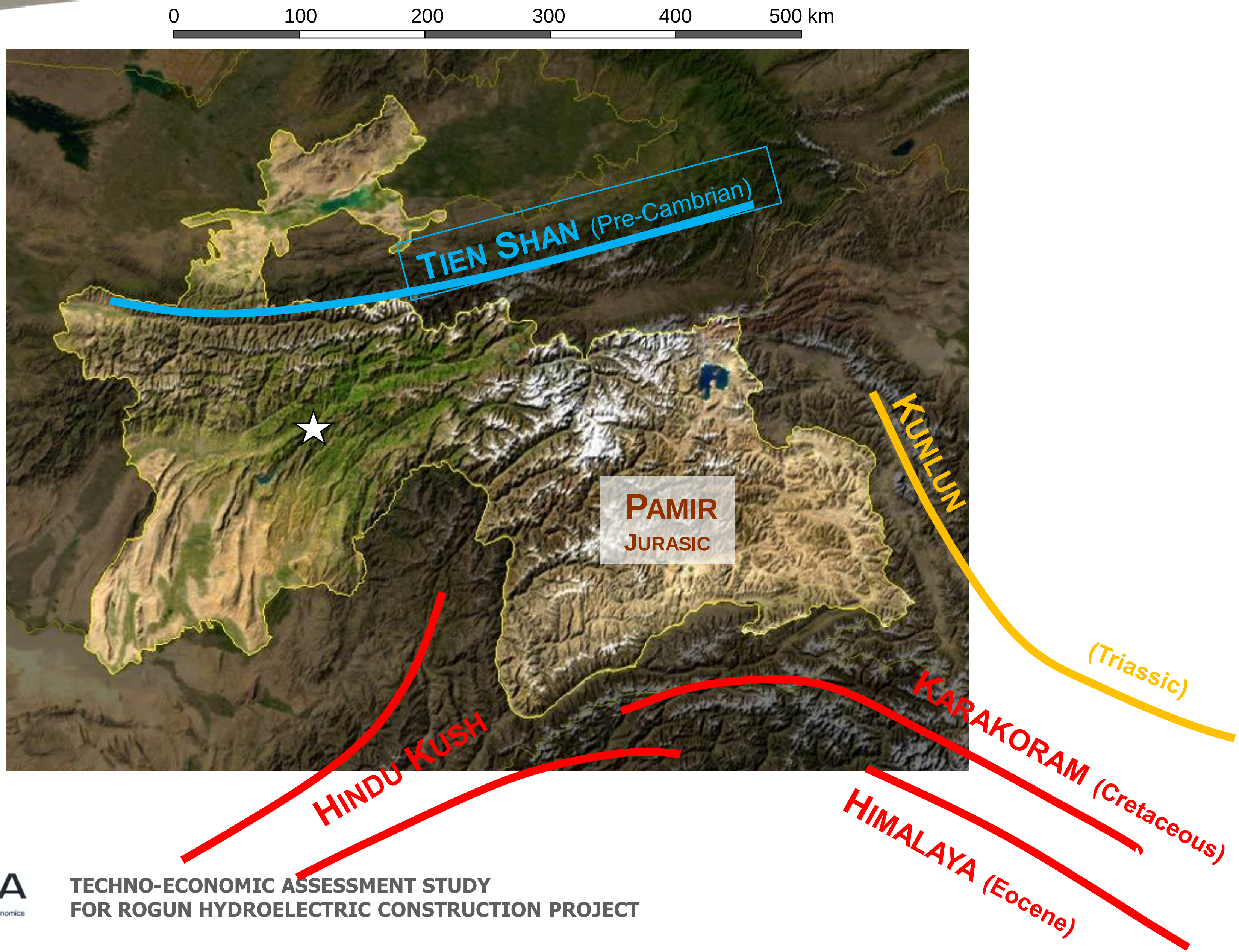
Part 1: Basic data & Dam Design

DAM Safety

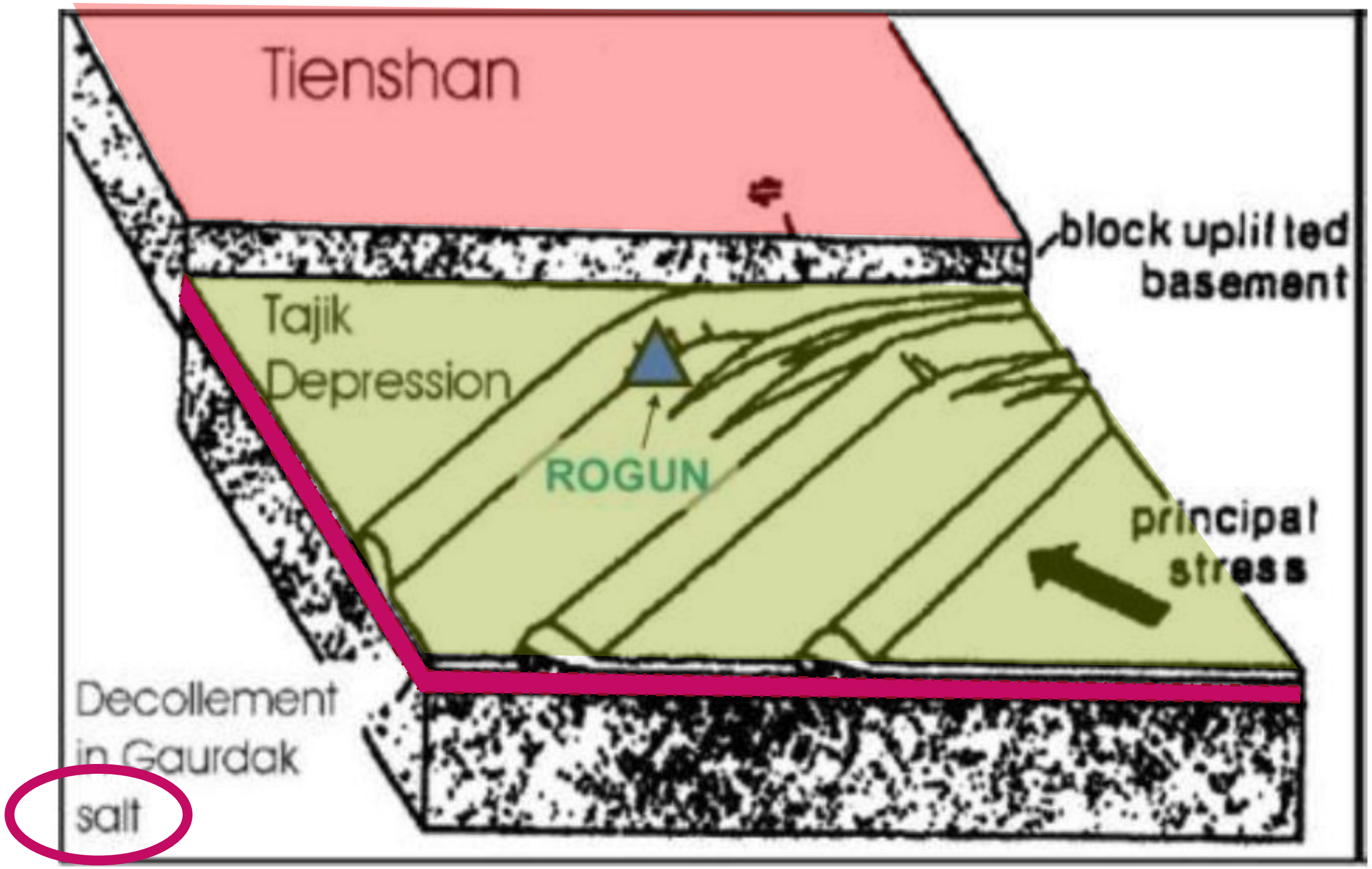
- Geology / Geotechnics ……:
- Tectonics / Seismicity …………:
- **DAM Design**
- - Dam Location
- - Type of Dam
- - Dam Stability *Part 1*

- Hydrology ………………………………: *Part 2*
- **DAM Protection**
- - Flood Evacuation Organs

Site geology



Site geology



Schematic regional setting near the zone of contact between the Tajik Depression and Tien-Shan

Site geology - Faults

Regional thrust faults within the Tajik Depression unit

- IONAKSH fault, GULIZINDAN fault
- Rooted in the Jurassic salt layer, salt wedges extruded in the hanging wall
- Oriented NE-SW, steep dip SE, SE bloc thrusts over NW bloc
- Fault zone acts as hydraulic barrier in the upstream – downstream direction, except for the residual cap above the salt wedges
- IONAKSH fault – medium-high permeability measured in BH-DZ1 in the atypical zone, at elevation 1450 (150 m above the FSL)

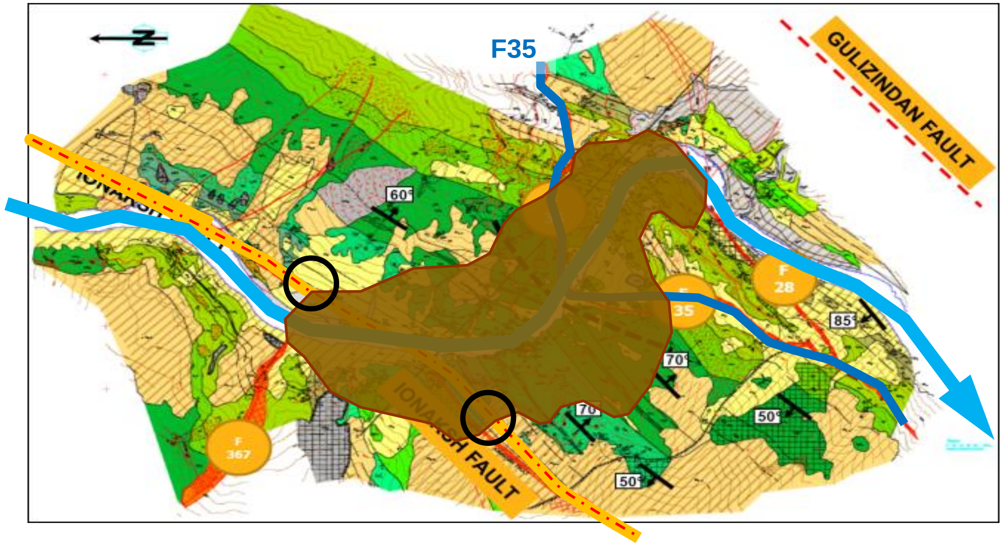
Site geology - Faults

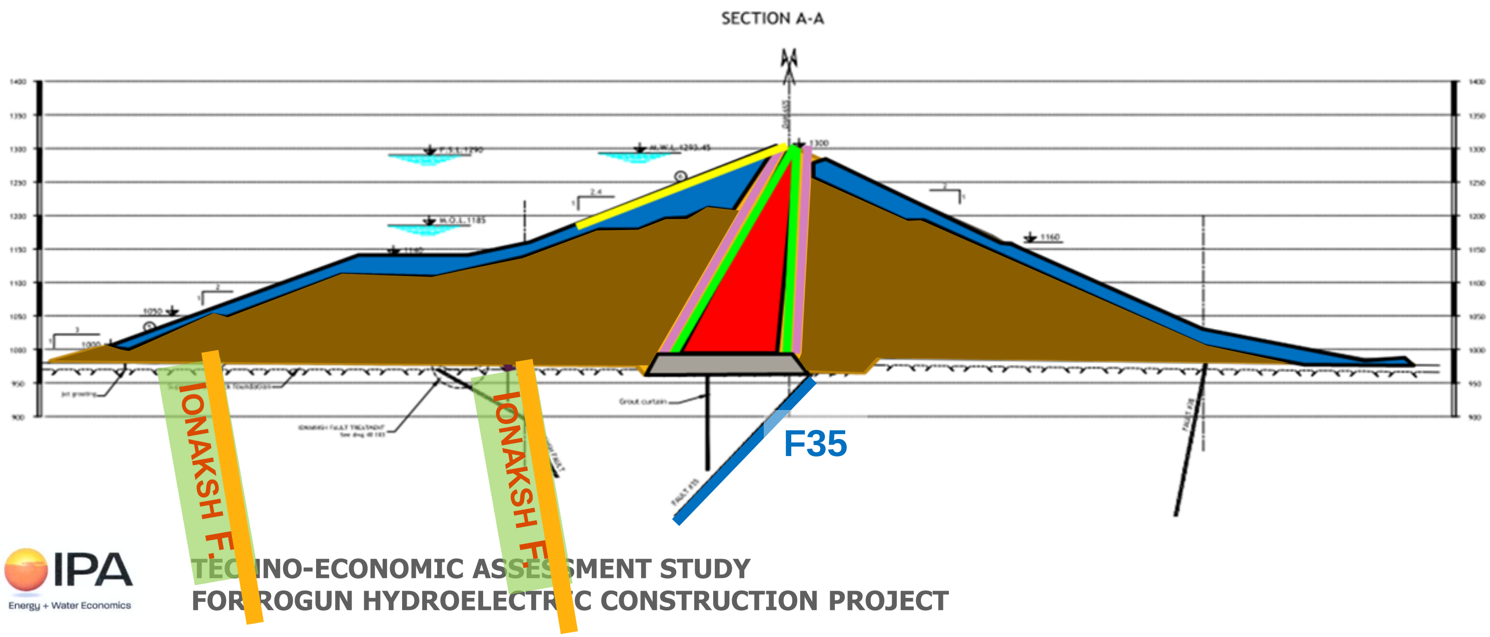
Local faults

- Antithetic faults: dip opposite to the main thrusts
  - Fault no.35, Fault no.70
  - The main discontinuity system (S4) has similar attitude
  - Faults and discontinuities cross the dam foundation and the tunnels
  - The PH cavern is tackled by the zone of influence of F no.35 and is crossed by S4 discontinuities
- Other faults
  - Fault no.28, near parallel with bedding, steep dip, in the area of the outlets and downstream pool
  - Fault no.367, near perpendicular to the bedding strike, steep dip, upstream, cut by Ionaksh fault. Tackles the upstream cofferdam.

Site geology - Faults : *Dam location?*

- Regional thrust faults
  - IONAKHSH, GUILZIDAN
- Local faults
  - Antithetic: Fault n° 35 and Fault n° 70
  - Other faults: Fault n°28, Fault n°367





Seismic hazard Assessment

The DSHA, Deterministic Seismic Hazard Assessment:

The seismic hazard assessment was carried out in several steps:

Determination of the magnitudes and distances of the MCE (Maximum Credible Earthquake) likely to occur on each identified active fault or/and seismogenic sources that can affect the dam;

Estimate of the PGA (Peak Ground Acceleration) at the site, induced by each reference earthquake on each identified active fault; and

Estimate of the expected ground motions at the site.

Estimate of Maximum Credible Earthquake (MCE)

Seismogenic source	MHE Depth, width, distances to the site, Mw	MHE + 0.5 Depth, width, distances to the site, Mw
Guissar Fault	Mw=7.4 Focal depth = 10 km Down-dip rupture width=26 km Joyner-Boore distance = 5 km Rupture distance = 5 km	Mw=7.9 Focal depth = 10 km Down-dip rupture width=42 km Joyner-Boore distance = 5 km Rupture distance = 5 km
Vakhsh Fault	Mw=6.4 Focal depth=10 km Down-dip rupture width=10 km Joyner-Boore distance = 2.3 km Rupture distance = 6.2 km	Mw=6.9 Focal depth=10 km Down-dip rupture width=16 km Joyner-Boore distance = 1 km Rupture distance = 3.4 km
Ionaksh and Gulizindan ramps	Mw=5.9 Focal depth=5 km Down-dip rupture width=6 km Joyner-Boore distance = 0 km Rupture distance = 2.4 km	Mw=6.4 Focal depth=5 km Down-dip rupture width=9 km Joyner-Boore distance = 0 km Rupture distance = 1.1 km

Distances, depth and magnitudes proposed for the largest expected earthquakes on each critical seismogenic source

10 PROPOSED SEISMIC MONITORING

In the context of Rogun, two kinds of seismic instrumentation are required:

- **a strong-motion network** (accelerometers) to survey the seismic behavior of the dam under strong earthquakes. For this purpose, accelerometers need to be located in the free field away from the dam, in the dam abutments and in the dam body.

- **a microseismic network** around the dam and in the reservoir region, which could record the background seismicity prior to the start of dam construction (at least two years before is generally the time period recommended) and the seismicity during construction, the first filling of the reservoir and the subsequent years of reservoir operation. Instruments should be digital seismic stations with velocity sensors. The number of instruments and geographic distribution depend on the desired threshold magnitude, the size of the reservoir and the regional seismic network already in place. Six to eight stations seems to be a minimum. A distribution of one station every 5 km is required if the network is to detect events as low as M~1.0.

It is recommended to implement this seismic monitoring as soon as possible in order to estimate the background (base-line) seismicity prior to the dam construction.

PSHA developed afterwards.

Dam stability – Results of dynamic analysis

Some typical results

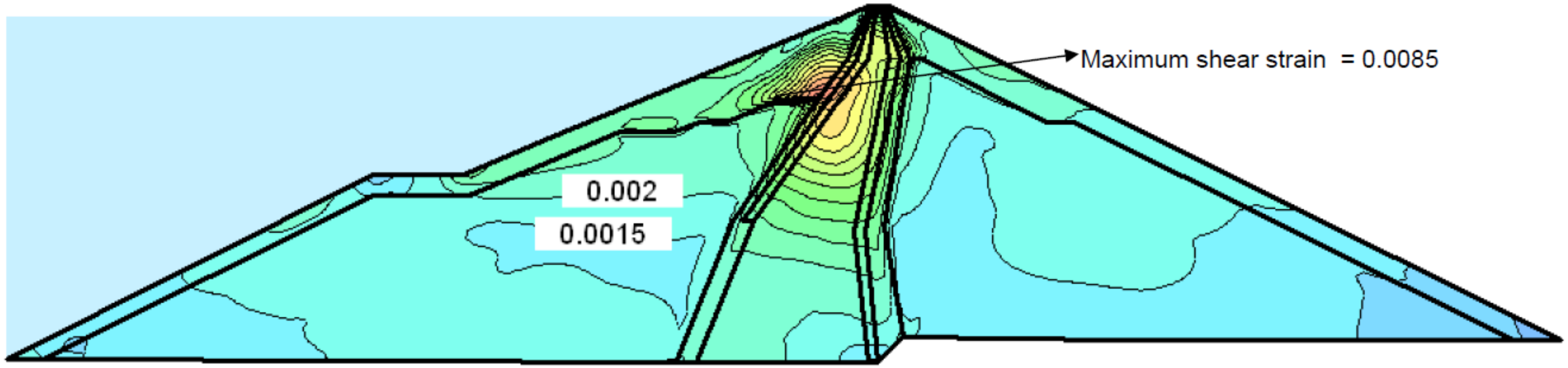


Figure 6.10 : Maximum Shear strain - Section 2-1

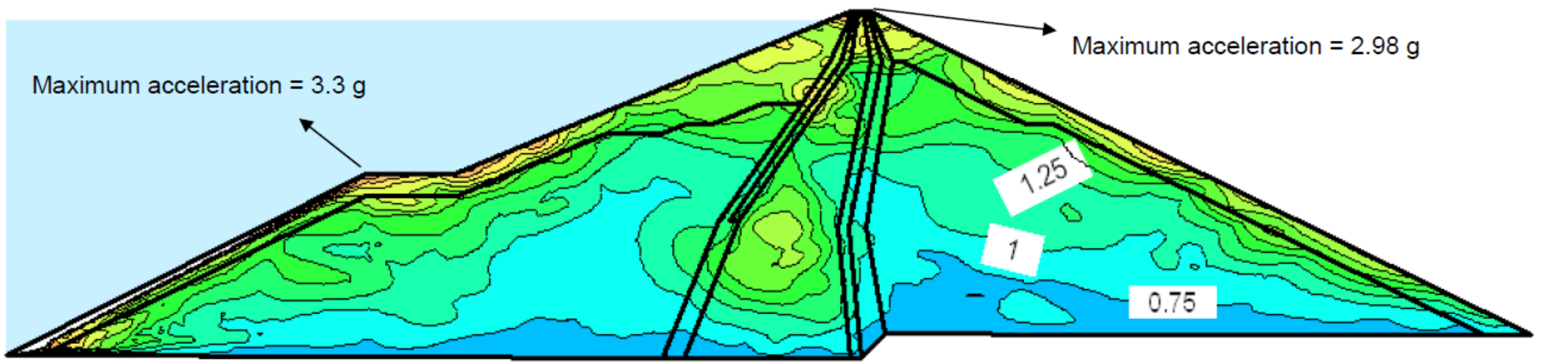


Figure 6.11 : Maximum horizontal acceleration - Section 2-1

Dam stability - conclusions

Dam stability: conclusions:

The Rogun dam stability is governed by the seismic load case.

Dam slopes have been found to be sufficient to ensure the dam stability.

Large horizontal displacements call for widening (d ≥ 10 m) filter and transition sections in order to ensure function continuity even in the case of the MCE.

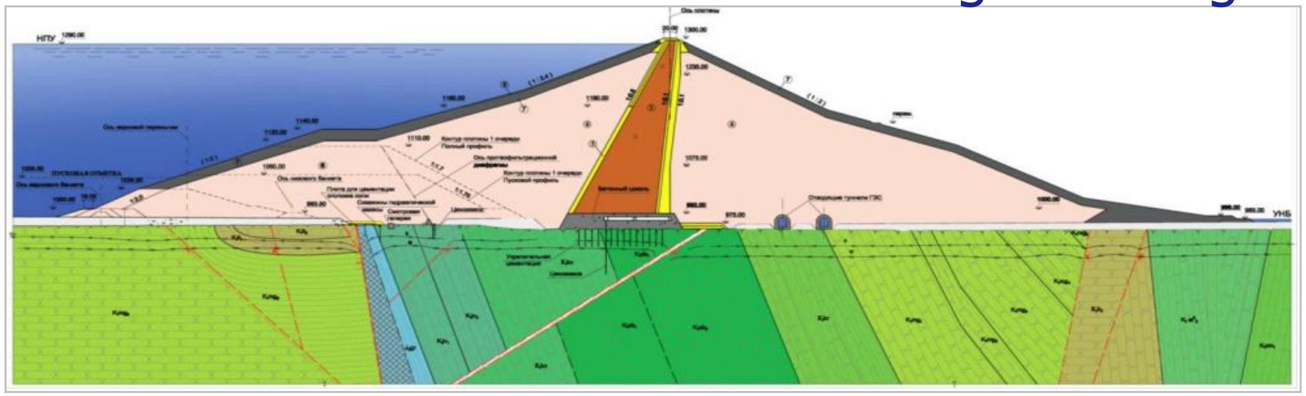
Freeboard should be enough to accommodate maximum settlement (s ≈ 1.5 % for MCE).

Special care should be given to the upper 50m of the dam, by placing there rock fill that has a higher friction angle than alluvium.

Further studies for design optimization:
3D geometry: S-shaped valley and steep banks: arch effects and stress reorientation.
Elasto-plastic, non-linear material: permanent displacements and excess pore pressure.

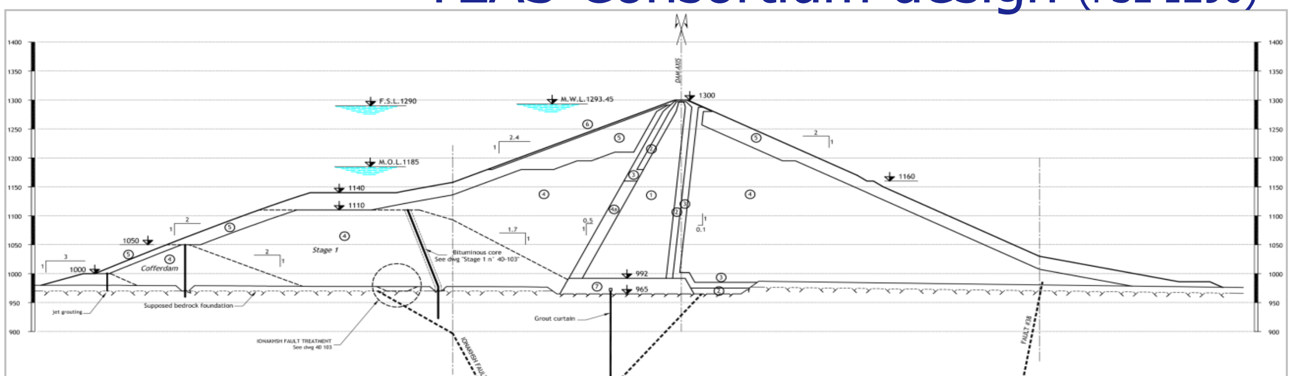
Dam cross section

Original Design



71.4 Mm^3

TEAS-Consortium design (FSL 1290)



73.6 Mm^3

- Cofferdam crest heightened.
- Water tightening arrangements for PC+CD+S1 improved.
- More frictional material in critical areas.
- Filter widths enlarged.

Slope stability – General considerations

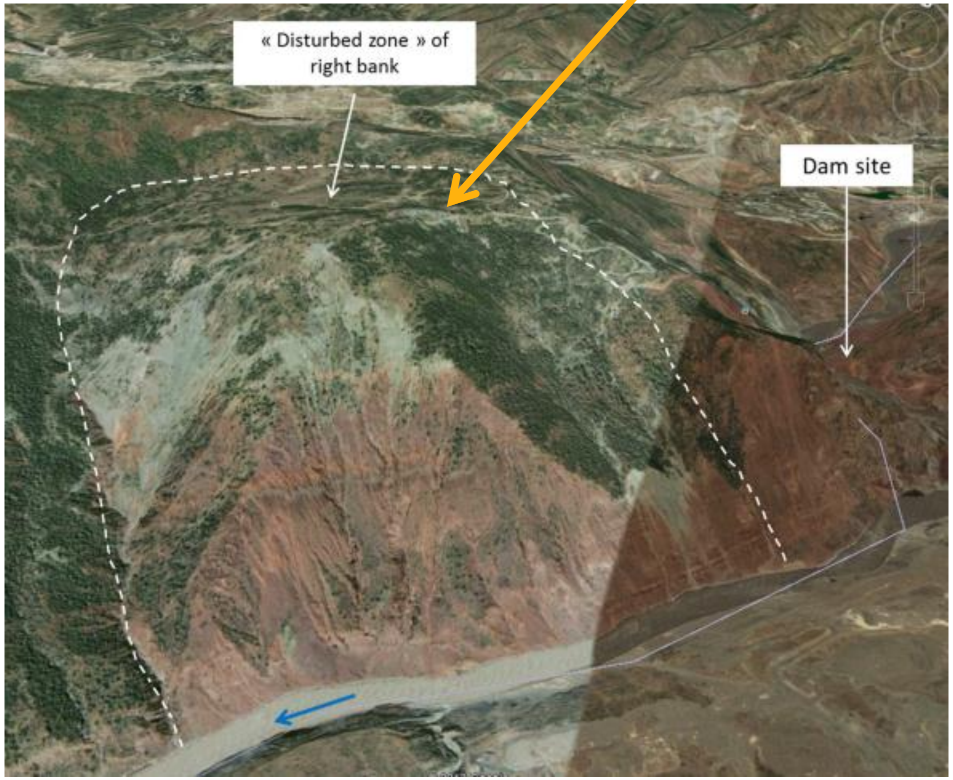
- Rock falls
  - Frequent occurrence, mainly a threat to safety of workers
  - Recommended: cleaning, rock bolts, wire meshes and monitoring
- Landslides involving Quaternary deposits
  - Well identified since the early stages
  - Standard mitigation measures are recommended to prevent their development (drainage, reshaping the slopes, retention structures)
- Landslides controlled by structural discontinuities
  - Left Bank
  - Downstream Right Bank

Right Bank Disturbed Zone

Right Bank Disturbed Zone

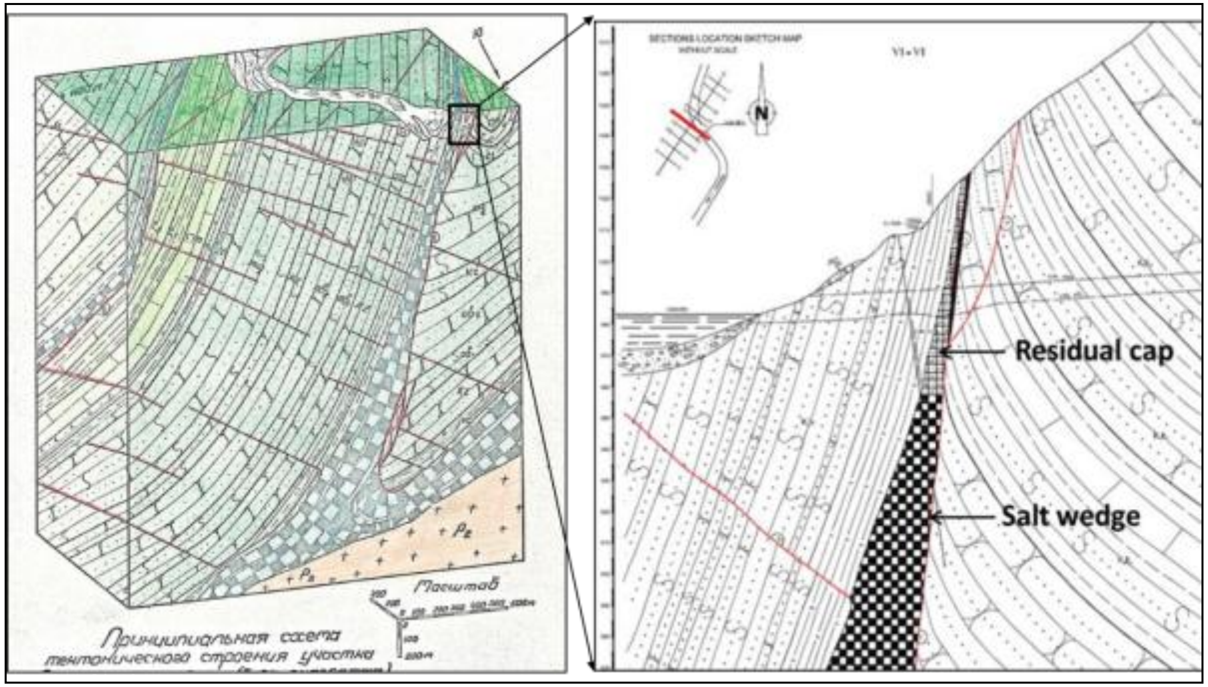
"DISTURBED ZONE" OF RIGHT BANK

- Atypical morphology of the upper right bank
  - Large flat plateau exhibiting karstic features
  - Former investigations did not extend to this zone (apart from some seismic survey in 2005)
  - Interpreted as the result of old landslides according to previous studies (up to 900Mm³!)
- Reveals to be of tectonic origin (see Geological Report)



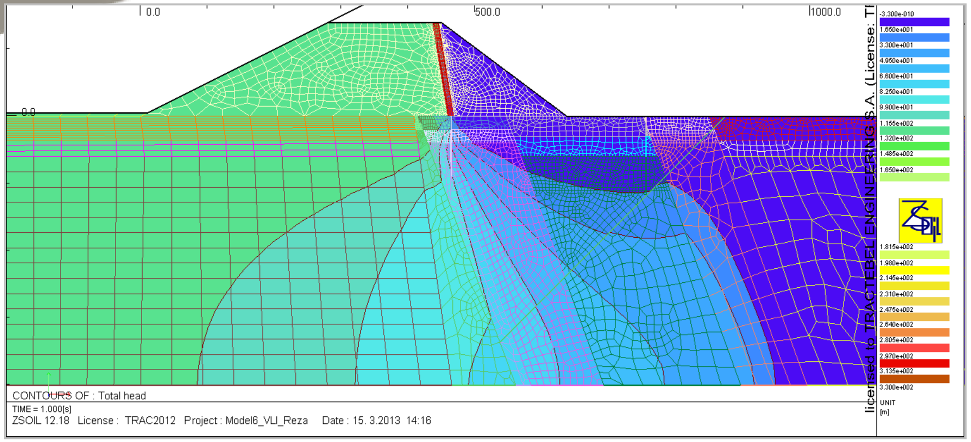
Salt Wedge

Site geology – Salt wedge

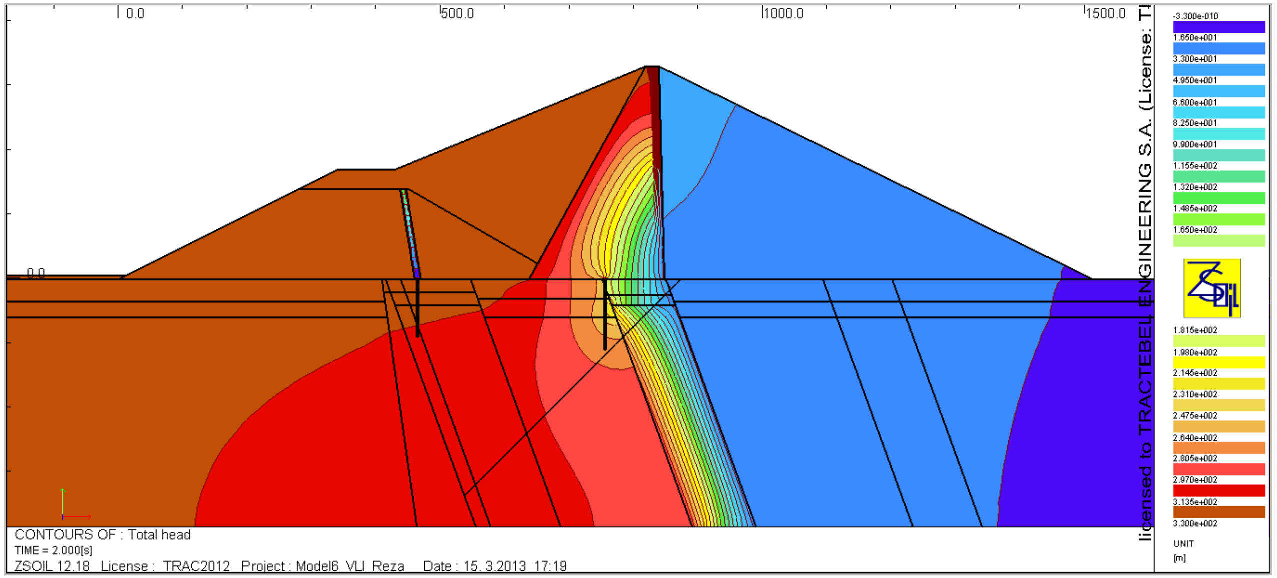


- Top of salt wedge 952-970 masl, close to the GWL
- Thickness increasing 15 m / 100 m depth
- Base of the salt layer at Rogun HPP site ~2000 m below the river level
- The salt wedge is watertight, but the residual cap is locally permeable
- Extrusion rate of salt wedge is estimated at 2.5 cm/year

Seepage modelling: results



Same graphical scale.
Same scale of equipotentials



Salt wedge: conclusions

- **Remedial measures** are needed to manage the potential dam safety and sustainability risks of the salt wedge
- Measures should include both **grouting** of the cap rock and **hydraulic barrier**.
- Adequate **monitoring** to detect any loss of efficiency and ensure timely maintenance
- These two measures are **sufficient** to ensure that the salt wedge dissolution does not endanger the integrity and function of the dam
- The **costs** of these measures have been estimated and appropriately included in the economic analysis of the proposed project

Dam safety

- **Basic Data**:

  compilation .... ✓

  extension (measurement campaigns) .... ✓

  improved interpretation .... ✓

- **DAM Design :**

  static & dynamic behaviour checked .... ✓

- **Neighbouring structures:**

  LB landslides .... ✓

  D/S RB "landslide" .... ✓

  Salt Wedge .... ✓

  Reservoir leakage .... ✓

Thank you !