COYNE ET BELLIER Ingénieurs Conseils — ELECTROCONSULT — IPA Energy + Water Economics

**TECHNO-ECONOMIC ASSESSMENT STUDY**
**FOR ROGUN HYDROELECTRIC CONSTRUCTION PROJECT**

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# Phase II Report: Project Definition Options

## Risk Analysis

# Risk Analysis

- Objectives of study
  - Summarizes and qualifies the main topics that may affect the project technical feasibility, attractiveness and sustainability.
  - Detects weaknesses and proposes mitigation measures.
- Methodology
  - Identification of the main risks
  - Evaluation of the level of risk (Likelihood*Cost of consequences)
  - Management of the risks with mitigation measures
  - Re-evaluation of the level of risk (Likelihood*Cost of Consequences) after mitigation measures.

# Methodology

- Identification of CAUSES
  - 3 main families
    - Natural
    - Technical
    - Economico-Financial
  - 2 levels of detail per Family

| LEVEL 1 | LEVEL 2 | LEVEL 3 |
|---|---|---|
| Natural | Hydrology | Water availability<br>Sediments<br>Construction floods<br>Rare floods<br>GLOFs |
| | Geology / Geotechnics / Geomechanics | Salt dissolution in dam foundation<br>Salt intrusion in RB<br>RB-DS important instability<br>Long-term creeping of faults<br>Mudflows from Obishur R. and other streams<br>Leakage from reservoir<br>Co-sismic displacements<br>Reservoir rim slope instability<br>Dam material: inappropriate survey, inadequate material<br>Structures-Caverns: rock excavation<br>Co-sismic displacements<br>Dam excavation: slope instabilities |
| | Tectonics-Seismicity | Earthquakes |
| | Weather | Temperature<br>Rain<br>Snow<br>Ice |
| Technical | Design | Evaluation of natural conditions<br>Design studies<br>Maximum head in tunnels |
| | Construction | Diversion/Tailrace tunnels: construction quality<br>Construction experience and technics. Equipment<br>Construction schedule<br>Contractual issues |
| | Fabrication | Fabrication technics, materials, schedule<br>Contractual issues |
| | Maintenance & Operation | Maintenance: Experience of personnel. Schedule and planning<br>Operation: Experience of personnel. Schedule and planning<br>Monitoring programs |
| | Decommissioning | Opportunity - Procedures |
| Economico-Financial | Market prices | Materials and equipment: Present and future conditions. Availability. Inflation. |
| | Energy demand | Mid- and long term changes in demand |
| | Funding | Availability of funds. Rates. Insurances. |

# Methodology

| Access | | Reservoir system | | | | Construction site | | | Dam system | | | | Power & Energy system | | | | | | | | | | | Flood management system | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Permanent access | Construction access | Gulizidan fault area | Karstic structures | Rogun city | Reservoir rim | Site plants | Site equipments | Workers accomodations | Main dam | Stage 1 dam | Cofferdam | Pre-cofferdam | Energy production | EM: Transmission lines | EM: Switchyard | EM: Cable galleries | EM: Transformers | EM: Generator | EM: Turbines | CW: Tailrace tunnels | CW: Power house & TH | CW: Headrace tunnels | CW: Intakes | Surface spillway | High level Tunnels 1, (2), (3) | Mid Level tunnels 1,(2) | Diversion Tunnels 1,2,3 |

- Identification of Impacts
  - 6 systems of project components
    - Dam system
    - Construction site
    - Reservoir system
    - Access
    - Flood management system
    - Power & Energy System

# Methodology

- Risk estimation table
  - Level of risk = Likelihood *Cost of consequences
  - Risk is expressed in M.$

| | | CONSEQUENCE (Amount in M.USD) | | | | |
|---|---|---|---|---|---|---|
| LIKELIHOOD | | Insignificant | Minor | Moderate | Major | Extreme |
| | | 1 | 10 | 100 | 1 000 | |
| Almost certain | 1 :1 | | | | | |
| Likely | 9 :10 | | | | | |
| Moderate | 1 :10 | | | | | |
| Unlikely | 1 :100 | | | | | |
| Rare | 1 :1 000 | | | | | |
| Extremely rare | 1 :10 000 | | | | | |

10 %

80 %

10 %

# Methodology

- 26 Risk sheets
  - General information (1)
  - Identification (2)
  - Description (before mitigation measures) (3)
  - Mitigation measures (4)
  - Residual risk (after mitigation measures) (5)

**(1) GENERAL INFORMATION**

Rogun HPP — TEAS Consortium - Phase II - Risk assessment — 7/8/2013

OSHPC BARKI TOJIK — COYNE ET BELLIER Ingénieurs Conseils — ELC ELECTROCONSULT — IPA Energy + Water Economics

| Sheet n° | 7 |
|---|---|
| Risk ID | Salt dissolution in dam foundation |
| | Dam system / Flood management system |

| Risk evaluation | |
|---|---|
| Before mitigation | After mitigation |

**(2) IDENTIFICATION**

| CAUSE | |
|---|---|
| Level 1 | Natural |
| Level 2 | Geological / Geotechnical / Geomechanical |
| Level 3 | Salt dissolution in dam foundation |

| IMPACT | | |
|---|---|---|
| | SYSTEM (S) | COMPONENT (S) |
| 1. | Dam system | Main dam |
| 2 | Power & Energy system | Intake |
| 3. | Flood management system | Diversion Tunnels 1,2,3 |
| 4. | Flood management system | Mid Level tunnels 1,(2) |
| | Flood management system | High level Tunnels 1, (2), (3) |

**(3) DESCRIPTION (before mitigation)**

| CAUSE (S) | Likelihood | IMPACT (S) | Evaluation |
|---|---|---|---|
| 1. Leaching of salt wedge within Ionakhsh fault. | Almost certain | 1. Deformation of foundation and dam body. | Catastrophic |
| 2. Leaching of salt within the left bank. | Moderate | 2. Creeping or sliding of power intake foundations. | Major |
| 3. Leaching of salt within the left bank. | Moderate | 3. Damages to portals of diversion tunnels 1, 2. Damage to diversion tunnel 3. | Major |
| 4. Leaching of salt within the left bank. | Moderate | 4. Potential damage to mid-level outlet or high-level outlets. | Catastrophic |

Risk — ADOPTED

Comments (cause):
a. Excessive leaching of the salt wedge of Ionakhsh Fault: the top of the salt wedge get lower.
b. Salt elevation and arrangement within the right bank is not known, possible dissolution after impounding of such salt is deemed not impossible.

Comments (impact):
a. If the rate of leaching is larger than expected, the deformation of the stage 1 dam body and foundation may lead, in the extreme case, to overtopping. In case of the main dam, it may affect watertightness components of the dam (clay core), and may finally lead to overtopping.
b. Dissolution of the salt wedge at the foot of the slope, which constitutes the intake foundation may lead to unacceptable creeping even sliding of the intake foundation (major consequences, since flood management still assumed to be in working conditions).
c.Rapid leaching of salt may lead to unacceptable settlements of portal foundations, and collapse due to scouring.
d. Damages to the mid-level outlet and other tunnels may lead to deformation of tunnel lining, having catastrophic consequences if unnnoticed and leading to tunnel collapse after scouring by water under high velocity.

**(4) MITIGATION MEASURES**

Recommended mitigation measures (cause):
1 -2-3-4. Implementation of hydraulic barrier
/ Grouting of the top area of the salt wedge (<1 LU)
/ Monitoring of salt wedge rising rate
/ General monitoring (salt content, gravimetry, deformations, etc.)
/ Grouting of Gulizindan Fault end and right bank investigation.

Recommended mitigation measures (impact):
1 -2-3-4. Reduction of gradient above top of salt wedge
/ Reduction of water circulation above the top of salt wedge
/ Calibration of leaching model for better assessment of leaching
/ Survey of eventual leaching progression
/ Check potential leakages through right bank or Gulizindan Fault.

Comments (cause):
a. Hydraulic barrier downstream the top of the salt wedge is to be provided, with pressure being that of the reservoir to balance the gradient.
b. The grouting of the top area of the salt wedge shall be efficiently performed and actually reach less than 1 LU in hydraulic conductivity
c. Monitoring of the rising rate of the salt wedge is to performed, as an essential input data for modelling of the leaching process.
d. General monitoring as per Phase 0 report RP38 is to be implemented (measurements of settlements, salinity of water, investigation of the possible evolution in voids by microgravimetry, etc.)
e. Detailed geological investigations to check the exact elevation of salt within the dowsntream right bank are to be performed.

Comments (impact):
a. Both hydraulic barriers and grouting of the top area of the salt wedge are judged necessary from the modelling of salt leaching, at least for stage 1 dam.
b. The rising rate of the salt wedge within the Ionakhsh Fault is a key input parameter for salt leaching modelling and needs to be verified as soon as possible.
c. All other monitoring listed in RP38 report aims at following the progress of the potential dissolution of the salt wedge, by measuring settlements, water salinity variations and regular microgravimetric investigations.
d. Investigations of the right bank should allow to know if specific mitigation measures are still required.

**(5) RESIDUAL RISK (after mitigation)**

| CAUSE (S) | Likelihood | IMPACT (S) | Evaluation |
|---|---|---|---|
| 1. Leaching of salt wedge within Ionakhsh fault. | Moderate | 1. Deformation of foundation and dam body (stage 1, main dam). | Moderate |
| 2. Leaching of salt within the right bank. | Unlikely | 2. Creeping or sliding of power intake foundations. | Moderate |
| 3. Leaching of salt within the right bank. | Unlikely | 3. Damages to portals of diversion tunnels 1, 2 . Damage to tunnel 3. | Moderate |
| 4. Leaching of salt within the right bank. | Unlikely | 4. Potential damage to mid-level outlet or high-level outlets. | Moderate |

Risk — ADOPTED

Comments (cause):
a. The likelihood of reduction of efficiency of the hydraulic barrier will straightly depend upon its correct desing and implementation during construction. It makes reference to excessive leaching.
b. The loss of efficiency at long term of the grouting is unavoidable, due to the progressive creepinf of the Ionakhsh Fault, and may be completely inefficient in case of co-sismic movement along this fault.
c. Monitoring devices shall be selected and installed with care, in order to guarantee long-term service, within salty water.

Comments (impact):
a. The hydraulic barrier is mostly necessary for the stage 1 dam.
b. It is verified that loss of efficiency of grouting down to 0.1LU does not have any impact, according to salt leaching model; like hydraulic barrier, it is not really necessary for the main dam.
c. Having the monitoring means failing to work, especially for stage 1 dam results in that any leaching will occur unnoticed, and damages can appear suddenly; risk is major for the stage 1 dam.
d. It is supposed for the residual risk that dedicated investigations were carried out, such as the conditions of right bank are better known than today.

# Evaluation of Risk before and after mitigation measures

- Mitigations measures proposed by TEAS permit to decrease level of risk;
- **No Major or Extreme risk remains after mitigation measures.**
- A few cases have been expressly left at the level of Moderate (even if they could have been ranked at a lower level) in order to keep them as reminders of required further studies or actions.

**BEFORE MITIGATION**

| LIKELIHOOD | | CONSEQUENCE (Amount in M.USD) Insignificant | Minor | Moderate | Major | Extreme |
|---|---|---|---|---|---|---|
| | | 1 | 10 | 100 | 1 000 | |
| Almost certain | 1 :1 | | | 6, 14 | 4B, 11 | 4A, 7, 17 |
| Likely | 9 :10 | | | 10A, 13, 21 | 16 | 2, 18, 20 |
| Moderate | 1 :10 | | | 5 | 15C, 19 | 8A, 12, 15B |
| Unlikely | 1 :100 | | | | | 1, 3, 8B, 10B |
| Rare | 1 :1 000 | | 15A | | | 9 |
| Extremely rare | 1 :10 000 | | | | | |

**AFTER MITIGATION**

| LIKELIHOOD | | CONSEQUENCE (Amount in M.USD) Insignificant | Minor | Moderate | Major | Extreme |
|---|---|---|---|---|---|---|
| | | 1 | 10 | 100 | 1 000 | |
| Almost certain | 1 :1 | | 4B | 4A, 11 | | |
| Likely | 9 :10 | | 13, 14 | 7, 17 | | |
| Moderate | 1 :10 | | 6, 10A, 12 | 15C, 16, 18 | 15B | |
| Unlikely | 1 :100 | | 21 | 5 | 8B, 19 | 20 |
| Rare | 1 :1 000 | 9, 15A | | | | 1, 2, 3, 8A, 10B |
| Extremely rare | 1 :10 000 | | | | | |

–Only 6 risks remain “moderate”:

- Sediments (4A)
- Active fault with salt-in filling (7)
- Locally poor quality of rock (17)
- High hydraulic head upon gates in hydro-tunnels (20)
- Creep in Faults (11)
- Seismicity (15B)

| | BEFORE MITIGATION | AFTER MITIGATION |
|---|---|---|
| | 6 | 0 |
| | 6 | 0 |
| | 11 | 6 |
| | 2 | 17 |
| | 1 | 3 |
| Total | 26 | 26 |

Table 85: Risk Distribution by Severity Level
Before and After Mitigation Measures

| Group | Risk | Before (Extreme / Major / Moderate / Minor) | After (Extreme / Major / Moderate / Minor) | Cause | Effect |
|---|---|---|---|---|---|
| A | 4A | Extreme | Moderate | Sediments | Flood Management |
| A | 7 | Extreme | Moderate | Salt Wedge | Dam Safety |
| A | 17 | Extreme | Moderate | Rock Quality | Cavern Safety |
| A | 20 | Extreme | Moderate | Design Head | Flood Management |
| A | 11 | Major | Moderate | Creep in Faults | Flood Management |
| A | 15B | Major | Moderate | Seism.Displ. | Flood Management |
| B | 18 | Extreme | Minor | Construction DTs | Flood Management |
| B | 2 | Extreme | Minor | Floods | Dam Safety |
| B | 4B | Major | Minor | Sediments | Power and Energy |
| B | 12 | Major | Minor | Mudflows | Flood Management |
| B | 16 | Major | Minor | Dam Materials | Dam Safety |
| B | 8A | Major | Minor | Reserrvoir Rim | Dam Safety |
| C | 6 | Moderate | Minor | Earthquakes | Dam Safety |
| C | 14 | Moderate | Minor | Landslides | Construction Safety |
| C | 10A | Moderate | Minor | Landslides | Dam Safety |
| C | 13 | Moderate | Minor | Reservoir Leakage | Power and Energy |
| C | 21 | Moderate | Minor | Constr. Schedule | Overcosts |
| C | 15C | Moderate | Minor | Seism.Displ. | Power and Energy |
| C | 19 | Moderate | Minor | Design, Data | Overcosts, over delays |
| C | 1 | Moderate | Minor | Floods | Dam Safety |
| C | 3 | Moderate | Minor | GLOFs | Dam Safety |
| C | 8B | Moderate | Minor | Salt-Gypsum | Structural Collapses |
| C | 10B | Moderate | Minor | Landslides | Flood Management |

*Before:* 6 6 11 =23
*After :* 6 17 =23

# Sediment (Risk 4A)

- The scarce vegetation and steep river slopes facilitate the movement and transportation of **large granular material** along the river into the future reservoir.
- **In several decades** the abrasive material will reach the intake of the hydro-tunnels putting the operation of the project at risk.
- As a consequence of this **a surface spillway has been added to the project** at a high elevation in order to significantly prolong the safe useful life of the project.
- **Further investigations and studies** are to be conducted in the next project stages:
  - To improve **the knowledge** about sediments (characteristics and amount);
  - To optimize the **design for the surface spillway**;
  - To assess the schedule **when** the first part and the totality of the surface spillway will be necessary.

# Seismicity (Risk 15B)

– The Rogun Hydropower Project is located in **a complex sismo-tectonic context** where active faults have been identified with significant quaking and shearing potential.

– The dam itself is located in the tectonic block between **the Ionaksh and the Gulizindan faults**, two regional thrust faults.

– A design of a rock-fill dam with an impervious core and appropriate thickness of filters to withstand the Maximum Credible Earthquake has been developed.

– Diversion Tunnel N° 3 and the Mid-level Outlet N° 1 cross the Ionaksh fault in their upstream portions. **These tunnels** contribute to the flood management during construction.

– They have a **short period of exposure** (construction period), and appropriate mitigation measures have been envisaged:

- **Tunnels section enlargement and reinforcement** together with an additional upstream set of gates to allow for control and repair works
- At future project stages the refinement estimate of the **co-seismic displacements evaluation** is to be re-evaluated and **the technical solutions** are to be refined for execution purposes.

# Risk Analysis - Conclusion

– Large risks at the ROGUN H.P.P. have been drastically reduced thanks to a better understanding of the causes and to the implementation of well adapted design measures and other mitigation plans.

– Among the most salient risks evaluated in this phase of the studies, only six of them have been expressly left at a level of “moderate” risk. They are kept at that level as reminders for the next stage of studies of the necessity of implementing comprehensive mitigation measures.

– Five of them have **natural causes** (sediments, seismicity, active fault with salt in-filling, locally poor quality of rock) while one of them has a **design cause** (too a high hydraulic head upon gates in hydro-tunnels). These six risk cases are then to be considered as representative of the project complexity and difficulty.

– On the basis of these conclusions of the current technical risk analysis, **the Rogun Hydropower Project may then continue its development for the next step of the studies**, that is to say detailed design of the selected alternative.

– **Further analyses and investigations** must be performed in the next project stages, as recommended in detail.

THANK YOU FOR YOUR ATTENTION