Techno-Economic Assessment Study
Rogun HPP

Phases 0 & 1 Considerations and Assessment Status Update

Riparian Consultations and Information Sharing

17 /18/20 October 2013

Engineering and Dam Safety Panel of Experts

Presenters: R.Gill (Chair), L.Spasic-Gril, Prof. P.Marinos

Engineering and Dam Safety Considerations by Panel of Experts

Subject	EDS PoE
Assessment Commentary	Roger Gill (Chair)
Salt Wedge & Cavern	Prof. Paul Marinos
Diversion Tunnels, Other Underground Structures & Construction Materials	Ljiljana Spasic-Gril
Early Generation Equipment	Roger Gill (for John Gummer)

ASSESSMENT PROCESS COMMENTARY

- The Engineering and Dam Safety PoE can report that the Consultant's assessment studies to date have been subjected to an intense level of technical scrutiny by both the PoE and the Word Bank.

- The Consultant has been responsive to constructive input and the PoE is comfortable that issues raised have been dealt with appropriately to date.

- The PoE is currently focused on considering the finalization of the critical sediment management studies and awaits the next steps in the economic and financing studies.

POE Assessment of Study Status

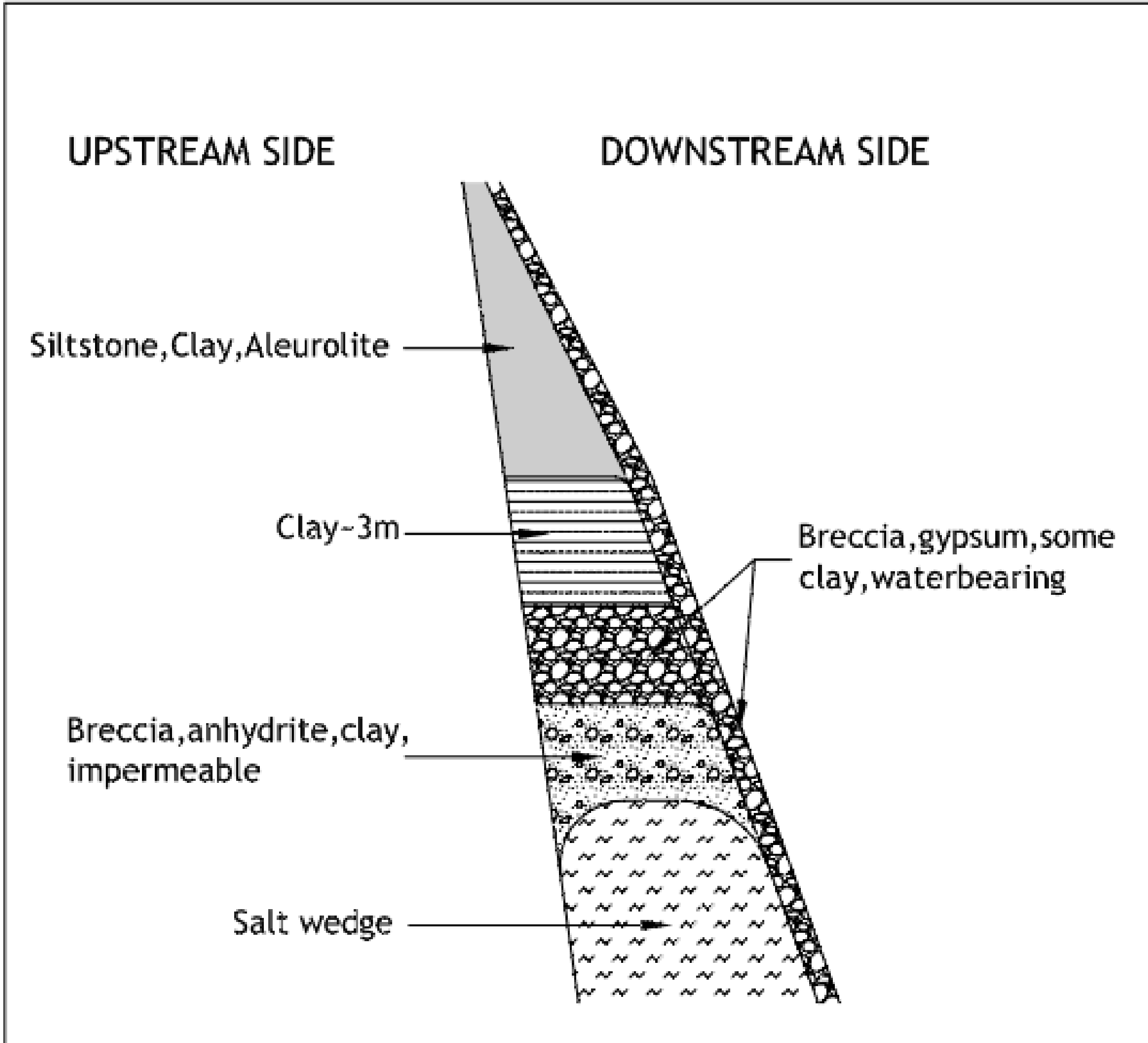
Activities in progress	Remarks
Engineering design criteria	Issued October 2012 and discussed in 2012 Consultations
Phase 0 Geotechnical Investigations of the Salt Wedge	Summary published: PoE to present comments October 2013
Phase 1 Existing Works – Cavern, Diversion Tunnels and Existing Equipment	Summary published: PoE to present comments October 2013
Phase 2: Techno-Economic Assessment Components	
•Geology	Completed and reviewed in February 2013 Consultations
•Hydrology	Completed and reviewed in February 2013 Consultations
•Seismicity	Studies nearing satisfactory completion
•Sediment management	Significant Issue: remains under consideration.
•Reservoir operation simulation study	Ongoing: Flow downstream of Nurek to be held within historical flow levels
•Safety against high floods	Ongoing: Rogun reservoir operation to increase hydrological safety of downstream dams.
•Economic and financial assessment	Ongoing: Data input in progress including finalizing cost estimate

SALT WEDGE IN THE DAM FOUNDATION AND RESERVOIR

Prof. Paul Marinos

The Issue:

A salt wedge exists under the upstream part of the dam axis along the creeping Ionakhsh fault which, if not addressed effectively to prevent dissolution by the potential hydraulic gradient, could impact the feasibility of the project.


UPSTREAM SIDE
DOWNSTREAM SIDE
Siltstone,Clay,Aleurolite
Clay–3m
Breccia,gypsum,some clay,waterbearing
Breccia,anhydrite,clay, impermeable
Salt wedge

The data and analysis:

- The structural geometry and the hydrogeological setting is well understood, including the importance of a clay cap under which the salt is compact and intact.
- A leaching and rising process of the salt wedge is accepted and the analysis performed by the TEAS Consultant is considered acceptable.
- Two models exist – one developed by the Consultant and one previously by HPI. They are not significantly different which is reassuring for the conclusions and mitigation measures proposed.
  - The differences are due to the values of the parameters used, those by HPI are based on several assumptions
  - While additional data from the recent long term pumping test is valuable, the Consultant's model also requires assumptions to be made.

The data and analysis (continued):

- The PoE considers that the values chosen as input parameters to the model are reasonable given the uncertainties.

- Two decisive inputs are based on assumptions:
  - The salt rise rate and the coating by the clayey cap.
  - Only a parametric analysis can address these uncertainties and we endorse the way this issue was treated and the factor of safety of 3 that was used.
  - Our opinion after considering the geological conditions on the abutments is that the salt rise is probably less than the base line of 2.5cm/year.

The data and analysis (continued):

- Different scenarios for various wedge rising rates have been considered for the Stage 1 and Main dams, taking into consideration the period of exposure of each situation.
  - A scenario with the most hostile assumptions has a very low possibility of occurrence.

- Appropriate mitigation measures and early recognition of any problem is necessary to address such a scenario before it develops.

- The positive rise of the salt is reasonably considered to be absorbed by the shell of the dam.

Protection/Mitigation:

- The principle of applying equilibrium of hydraulic heads on both sides of the salt wedge to eliminate the hydraulic gradient, the main motor of leaching, is absolutely correct. This can theoretically address the problem.

- The grout curtain over the impermeable section of the wedge (clay cap and compact salt) forms an additional passive protection. A significant part of this curtain is already constructed.

- Both the hydraulic curtain and the grouting have to be implemented. One will cover any possible deficiency of the other. And such deficiencies may occur even if more accurate data were available

Protection/Mitigation (continued):

- An absolutely conservative design and tough operating procedures for these curtains must be applied with close supervision.
- The PoE agrees that a 3^{rd} level of protection using a brine curtain should not be deployed due to clogging of injection holes and the enormous quantities of salt required.

Monitoring :

- The PoE supports the Consultant’s proposal for specially designed monitoring arrangements to continuously check the effectiveness of the mitigation measures including:
  - piezometers,
  - water conductivity assessing potential dissolution,
  - displacements, deformations measured through inclinometers in the salt wedge and its environment,
  - microgravity methods to assess the rise of salt or cavity formation,
  - sonar inspection of the dam face after impoundment for abnormal deformation.

- The existing model should be calibrated with data from the monitoring and be used as a predictive tool during the operation of the dam.

Restoration in case of a reduction in effectiveness:

- Of equal importance is the provision of restoration options in case there is a reduction in the effectiveness of the curtains. This will require the provision for:
  - regrouting or reinstallation of the hydraulic barrier from the crest of the Stage 1 dam
  - appropriate measures on the Main dam such as directional drill holes from the banks.

SALT WEDGE – CONCLUSION

- The PoE endorses the conclusion of the consultant on the feasibility of the project vis-a-vis the adverse condition imposed by the evaporitic intrusion at the dam foundation.
  - This conclusions goes with the condition that a sophisticated monitoring system is installed and operates uninterruptedly; and remediation capability is ready for any works exhibiting diminished effectiveness.

POWERHOUSE CAVERN

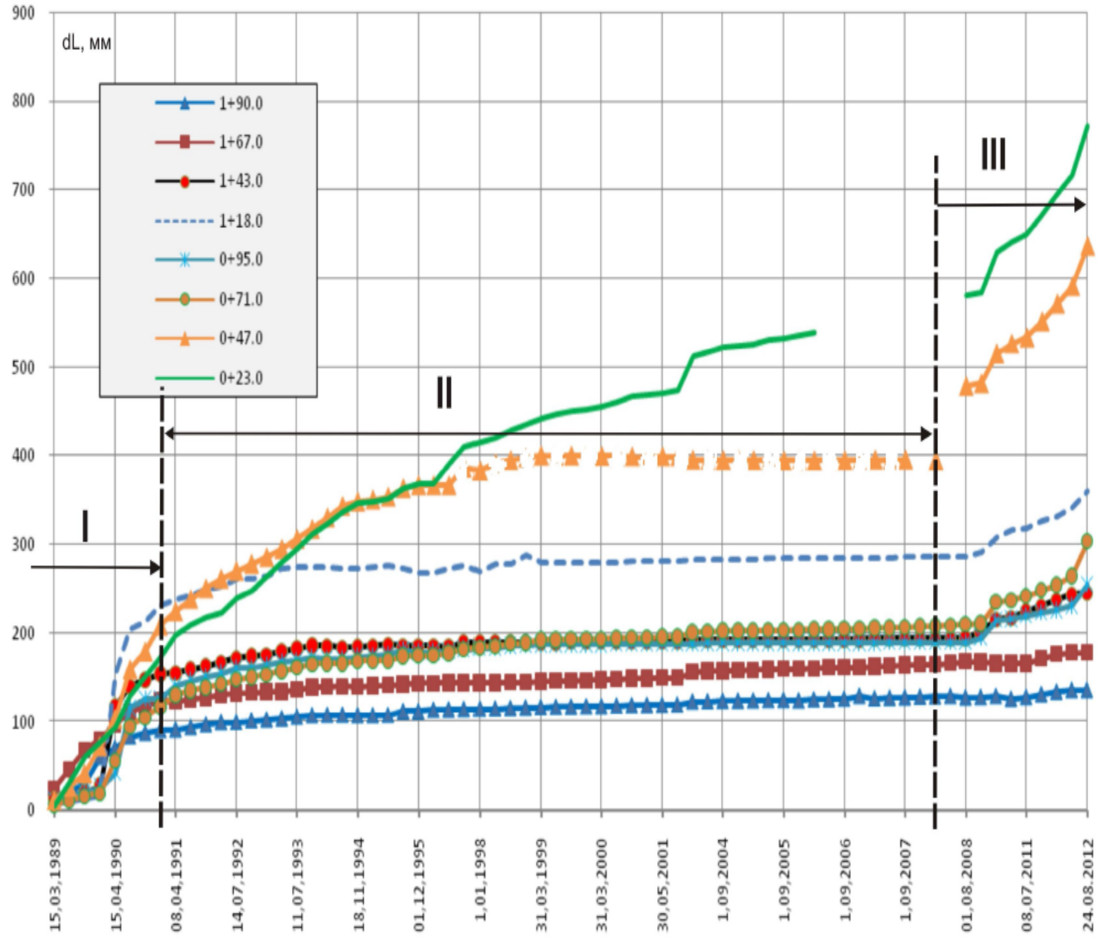
Prof. Paul Marinos

The Issue:

- The machine cavern is located in sandstone and siltstone, the latter mainly occurring in the area of Units 5 and 6. It is approximately 21m wide, 69m high and 220m long. A significant amount of excavation has been already conducted (more than 30m in height)
- Time dependent deformations have been exhibited since the late 80's and questions were raised about an increasing creep behavior and the possibility of compromised stability mainly in the siltstone section.
- An independent site inspection and evaluation of conditions and convergence measurements was undertaken by the PoE in April 2013, in conjunction with a sampling campaign by the Consultant.

The state of deformations:

- Significant wall convergence has been recorded amounting to 600mm in the siltstone sections up to the middle of 2008 and about 750mm up to August 2102.



The convergence as presented in the graph of HPI report 2012.

Note: the scale of time is irregular and the gradient of convergence is actually lower.

The convergence should correspond to the closure of the opening of the cavern and not to the convergence of its wall.

The causes:

- The PoE suggested, after the inspection in April 2013, the possibility of progressive distress of the rock mass in association with the ageing of the strengthening measures applied since the late 80s, to be the reason of the time dependent deformation and not a gradual deterioration of the petrographic quality due to softening of the siltstone. Such a state could be addressed efficiently by additional support in the sidewalls.

- The PoE concurred with undertaking numerical modelling with all new data from measurements and laboratory test results by both HPI (3D model) and the TEAS Consultant (2D model) to resolve the feasibility of implementation of Units 5 & 6 in the siltstone zone.

Distressing of the siltstones after excavation, under the concrete struts

Cores of siltstone behind the concrete lining at +999.

This area correspond in the upper part of the cavern, excavated 20 years earlier.
No change of the nature of the rock can be recognized.

Recommendations of the Consultant:

The report of the Consultant recommends that cavern stabilisation measures for Units 5 & 6 are implemented prior to any further excavation in the caverns. The stabilisation measures will include:

a) Installation of 35m long rock anchors on both sidewalls and in both caverns, above the current excavation level, starting from the crown downwards to reduce/limit the rate of movement, and

b) Reinforcement and stabilisation of the highly de-stressed rock mass in the “pillar area” between the two caverns. This will be achieved by installation of the Multiple Packer Sleeved Pipe (MPSP) that will reinforce the rock mass, as well as be used for consolidation grouting.

PoE Comments and Conclusions

The EDS PoE believes that with the implementation of the proposed stabilization works the stability of the caverns can feasibly be secured.

However, the PoE has made additional recommendations to:

a) Continue with the monitoring of the caverns' displacements;

b) Update the numerical model to take into account the new displacement measures and the additional results of the laboratory testing;

c) Define the extent of the proposed stabilisation works in the "pillar area".

d) Identify other feasible strengthening measures to the "pillar area" and allow adequate contingency funds in the cost estimate .

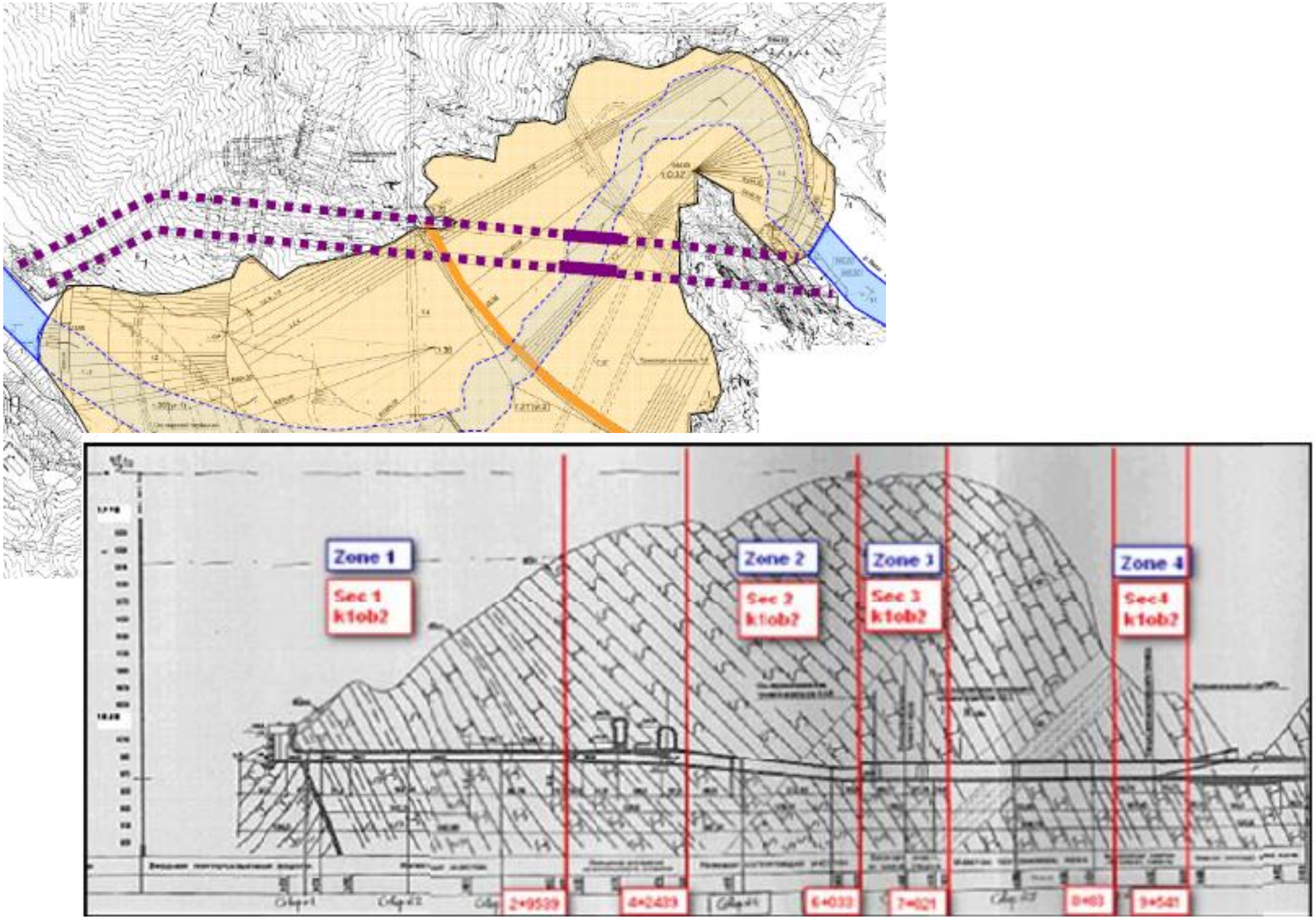
e) In the view of the PoE strutting of the caverns, as excavation goes, is another solution that may also be implemented along with the new anchors

f) Prior to detail design, undertake the in-situ testing of rock anchors, including creep pull-out tests on anchors and anchor heads and in-situ trial testing of the rock mass grouting. These activities should be included in the cost estimate of the stabilisation works.

DIVERSION TUNNELS

Ljiljana Spasic-Gril

Diversion Tunnels DT1 &DT2



Diversion Tunnels DT1 &DT2

TEAS Consultant has undertaken:

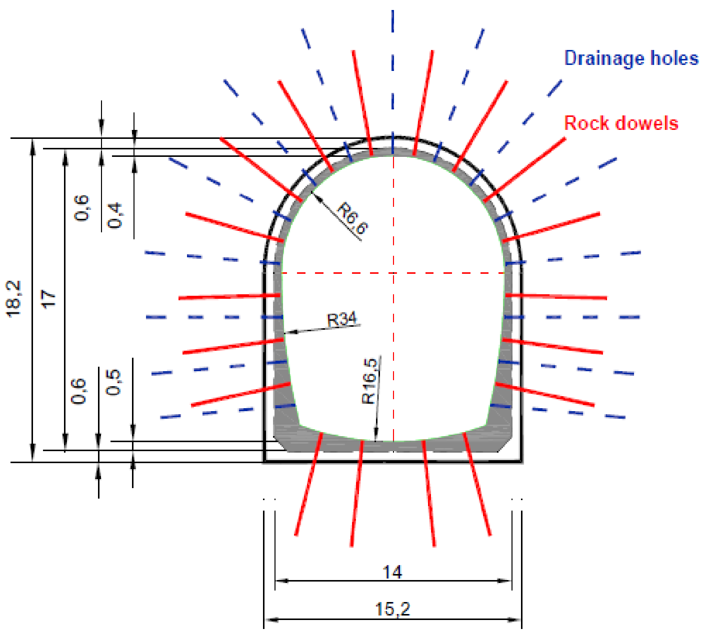
- Tunnel inspection;
- Testing (strength of the concrete lining & permeability of the rock);
- Assessment of the tunnel loading (rock, water & seismic loading) in accordance with international standards and compared with the original design.

Diversion Tunnels DT1 &DT2

TEAS Consultant's findings:

- DT1 & DT2 do not fulfill the technical requirements in respect to safety and serviceability required by the presently internationally recognized design criteria and standards;
- The tunnels need substantial remedial works;
- Special consideration will need to be given to the areas where the faults F70 & F35 are crossed.

Diversion Tunnels DT1 &DT2- recommended remedial works



- Install drainage systems through the tunnels linings or drainage galleries;
- Strengthen the structure by adding additional reinforced concrete lining and fully grouted rock dowels;
- Install high strength rock bolts to stabilize the tunnel invert in some stretches;
- Additional grouting along the stretches where high rock mass permeability was measured;
- Install special measures where tunnels cross faults F70 & F35 which will enable relative movements of the tunnel segments.

Diversion Tunnels DT1 &DT2

PoE agrees with:

- *Assessments undertaken;*
- *Methodology applied;*
- *Remedial works proposed, which have been applied to all alternatives*.

OTHER UNDERGROUND STRUCTURES

Ljiljana Spasic-Gril

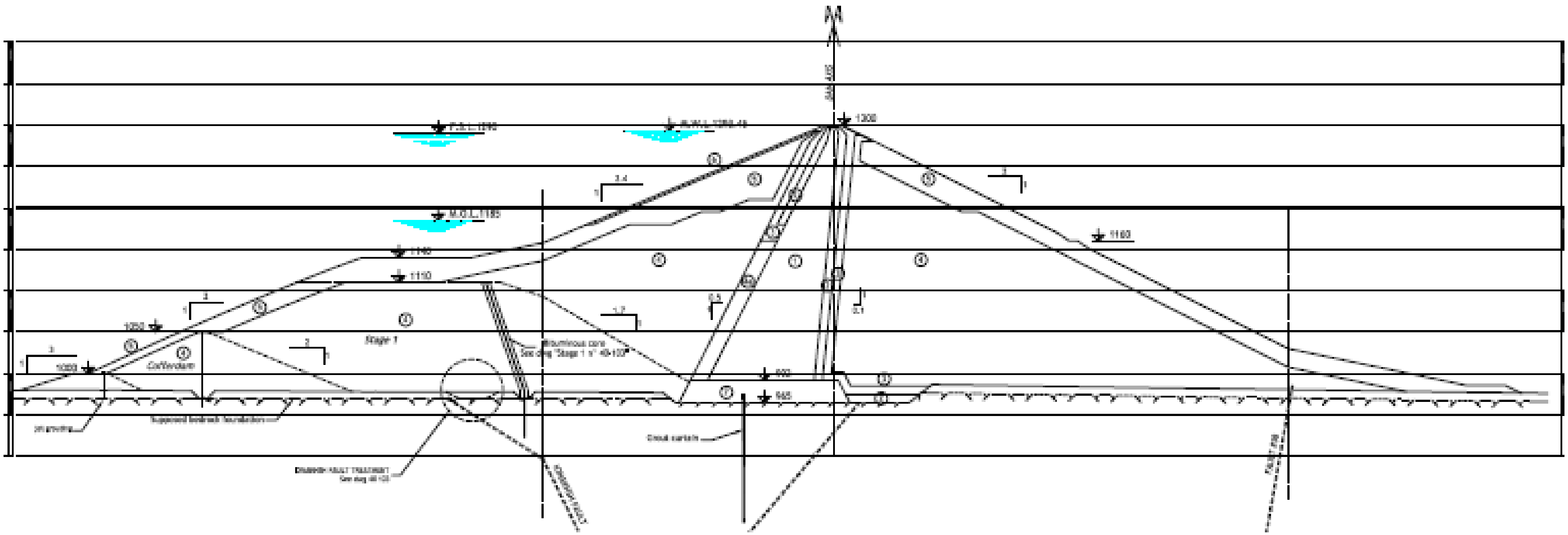
Other Underground Structures

- Several other underground structures, mainly permanent and temporary transportation tunnels, were inspected in detail by the Consultant in order to record all defects and recommend possible remedial measures;
- No evidence of structural instability was noted;
- However, some defects were noted (honeycombing etc). While these deficiencies will need to be addressed, in general they do not impair the safety condition of the works;
- *EDS PoE agrees with the recommendations.*

CONSTRUCTION MATERIALS

Ljiljana Spasic-Gril

Dam- Typical Cross Section



Construction Materials – quantities for 1300m alternative

	Dam part	**Quantity**
	[-]	***[m^3]***
1	Core	6 992 490
2 - 3	Fine filters	5 621 610
	Coarse filters	
4	Shoulders materials	43 063 864
5	Rock fill / Rock shell	17 365 059
6	Rip rap	554 675
7	Concrete slab under the core	354 405
Total	*(excluding concrete slab)*	**73 597 698**

Construction Materials – quantities for 1265m alternative

Alternative 1 265 m	**Dam part**	**Quantity**
	[-]	***[m³]***
1	Core	5 130 207
2 - 3	Fine filters	3 383 714
	Coarse filters	
4	Shoulders materials	33 182 921
5	Rock fill / Rock shell	12 475 052
6	Rip rap	368 629
7	Concrete slab under the core	329 782
Total	*(excluding concrete slab)*	**54 540 523**

Construction Materials – quantities for 1230m alternative

Alternative 1 230 m	Dam part	Quantity
	[-]	*[m^3]*
1	Core	3 714 728
2 - 3	Fine filters	3 366 184
	Coarse filters	
4	Shoulders materials	18 924 605
5	Rock fill / Rock shell	9 352 361
6	Rip rap	302 589
7	Concrete slab under the core	308 811
Total	*(excluding concrete slab)*	**35 660 467**

Construction Materials

Four quarries/borrow areas are considered suitable for provision of construction materials:

- Borrow Area 15 (BA15): material for alluvium shoulders, filters and concrete aggregate;
- Stockpiles from Lyabidora borrow area to be used for transition and filters (primary source);
- Borrow Area 17 (BA17): dam core;
- Quarry 26 (Q26) : rock shell and rip rap.

Construction materials: Findings

- The volumes of material needed for the dam are available in quarries / borrow areas and associated storages;
- BA 17: core material – will need to be improved (add fine material from different source (BA21) to improve watertightness; remove particles >200mm; also will need to reduce moisture content). These additional measures have been taken into account in the cost estimate;
- BA 15: Specific care to be given to timely extraction of the material as this borrow area will be flooded at the early stages of the construction.

Transport of Embankment Material

- Cofferdam: use trucks/dumpers;
- Main Dam: use a conveyor system (partly in open air and partly in tunnels);
- Consultant recommends that a brand new conveyor system be designed and installed because:
  - the existing equipment cannot be economically refurbished;
  - the technology of the conveyors has improved since the Rogun conveyor system was designed more than 30 years ago. The performance of both the electro-mechanical parts and belts have improved significantly.

EARLY GENERATION EQUIPMENT

Roger Gill

(based on John Gummer report)

<u>Existing M&E Equipment:</u>

- The PoE, though John Gummer, assessed the condition of the electrical and mechanical equipment that has already been acquired and is in storage.

PoE comments are that:

- The powerhouse is functionally well designed and no major changes to equipment are warranted. Attention is drawn to the measures required to avoid oil pollution of the waterways.
- The units are well designed for the era in which they were manufactured and do not require major modification. However it is recommended that the final design of the permanent runners (which have yet to be manufactured) be reviewed using modern CFD methods, with the objective of improving efficiency and performance.
- An assessment on the propensity for silt damage to the turbine hydraulic channels should be conducted.

PoE comments on Existing M&E Equipment (continued):

- The staged development as foreseen in the original scheme is both safe and expedient. The only problems foreseen being loss of generation during modification of the turbines and generators. It is recommended that the option of variable speed generators for Units 6 and 5 be investigated as this has the possibility of giving considerable economic benefits as a result of continuous generation and improvements in turbine efficiency during long term generation.

Conclusions – Phase 1 Key Issues

After extensive review and site inspections the EDS PoE considers that:

- stability of the powerhouse caverns can be feasibly secured with the implementation of proposed stabilization works ;
- remedial works proposed for Diversion Tunnels DT1 & DT2 are necessary and appropriate;
- some defects in other underground structures will need to be addressed, but in general they do not impair the safety condition of the works;
- the volumes of material needed for the dam are available on site, but core material will need to be improved by adding fine material from a different source to improve watertightness;
- existing equipment for units 5 & 6 are well designed for the era in which they were manufactured and do not require major modification.