OSHPC BARKI TOJIK

TECHNO-ECONOMIC ASSESSMENT STUDY FOR ROGUN HYDROELECTRIC CONSTRUCTION PROJECT

PHASE I

ASSESSMENT OF THE EXISTING ROGUN HPP WORKS

SUMMARY

September 2013

Report No. P.002378 RP 39 rev. C

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Ingénieurs Conseils

ELECTROCONSULT

IPA
Energy + Water Economics

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1 PROJECT BACKGROUND AND SCOPE OF ASSESSMENT

The proposed Rogun Hydropower Project (Rogun HPP) is located on the Vakhsh River, approximately 110 km north-east of Dushanbe and about 80 km upstream of the existing Nurek dam.

Studies began in 1965 and Rogun project activities began in 1976; a significant volume of construction was developed, mostly underground works and surface facilities, until the activities were suspended following the dissolution of the Soviet Union.

Subsequently, additional studies were carried out until, in 2011, Barki Tojik appointed the Consortium Coyne et Bellier / Electroconsult / IPA to conduct a Techno-Economic Assessment of Rogun HPP, which includes examining the adequacy of the selected site for the development of the proposed project, under World Bank funding and oversight.

According to the Hydroproject Institute of Moscow (HPI) design update of 2010, the project includes a 335 m high earthfill dam with a total volume of 71.4 Mm^3. The power generation facilities include six independent power waterways, an underground powerhouse in which 6 generating units (600 MW each) would be housed, the transformers cavern, six bus duct galleries, two cable galleries and the outdoor switchyard. The protection against floods, according to the original HPI design, was to be provided by a system of tunnels in both banks of the valley, i.e. three diversion tunnels, the third level operation tunnel and the remote tunnel spillway.

In consideration of the fact that most of the works were carried out 30 years ago and the construction activities were then stopped, as well as due to some problems that occurred in the intervening period, a thorough assessment of their present conditions was required. This is the scope of Phase I of the Techno-Economic Assessment Study.

The task includes evaluating the conditions of the existing facilities for accommodations, plants, and equipment for construction, infrastructures and any existing work carried out for the project implementation. Analyses were conducted to determine the usefulness of the existing facilities for the potential future development of the proposed project, as well as their adequacy to be permanently incorporated into the overall final layout. When deemed necessary, this Phase I Report makes recommendations for bringing the works to the required standards of safety and quality. The valuation of the constructed structures, given the remedial measures eventually required, is also provided, as per internationally-recognized methodology.

This summary presents the Consultant's assessment of the adequacy of the existing Rogun HPP works. This assessment has been reviewed by the Government of Tajikistan, the Panels of Experts and the World Bank technical team. It will be finalized after comments received from riparian counterparts and civil society stakeholders are reviewed and appropriately taken into account.

2 ASSESSMENT OF THE CONDITIONS OF THE OPEN AIR WORKS

2.1 Access Roads and Transportation Tunnels

2.1.1 Access Roads

Having good condition of access roads is a key factor in the success of the project, in terms of both budget and deadlines. Around 86 km of surface roads have already been built on site.

The access road linking the main Public Road from Dushanbe to Rogun City and Rogun Dam Site is a 10 km asphalt paved road. This road provides critical access for the workers and the transport of materials/equipment.

There is also an extensive network of hauling roads which have to be enlarged with a minimum width of 12 m to 15 m plus shoulders and drainage.

Existing accesses need to be rehabilitated, especially between each quarry, construction site, and the dam.

2.1.2 Transportation Tunnels

There are two types of transportation tunnels on site:

- Permanent tunnels: designed for giving access to the underground structures for transport of equipment and materials during the construction phase, and for access to the plants and auxiliaries for maintenance during the operation phase.

- Temporary tunnels: providing access to the structures only during the construction phase.

For the project as a whole, around 60 km of tunnels have been planned. About 27 km have already been excavated and lined, including 6.5 km of transport tunnels. An additional 4.5 km of transport tunnels have yet to be excavated or completed.

The present condition of the tunnels had been assessed during site inspections. Some damages or deficiencies were observed (on concrete lining, open joints, ventilation, and drainage). These issues would hinder the traffic and consequently the progress of the works, and will need to be rectified, as further explained in Sections 3 and 4 hereafter.

Temporary Transportation Tunnels

Tunnel n°	Position	Length [m]	Width of the road [m]	Description
T3	Right bank	1530	[12.8 ; 13.50]	The main access tunnel to the riverbed during the construction period.
T37	Right bank	635	6.7	Extension of the tunnel T3.
T37A	Right bank	174	7.7	Extension of the tunnel T3.
T37'	Left bank	174	7.7	Extension of the tunnel T37 through the bridge n°1.
T5A	Right bank	194	6.7	Branches of the tunnel T3.
T7	Right bank	185	10	
T7A	Right bank	100	12.5	
T22	Left bank	515	[10.4 ; 11.5]	Access to the Stage 1 dam crest. Not yet completed.
T10A	Left bank	Not yet built, dimensions to be specified according to the traffic		Used for the transport of materials. It is not yet excavated.
Conveyor Tunnel	Left bank	2100	7.56	Can be used to install a belt conveyor system or to transport materials by trucks.

Permanent Transportation Tunnels

Tunnel n°	Position	Length [m]	Width of the road [m]	Description
T2	Left bank	690	10.3	Access to the gate chamber, to the saline gallery and to the Dam body.
T3'	Right bank	537	[10.1; 13.4]	Extension of the tunnel T3. Permanent access to the dam grouting galleries.
T4	Left bank	1385	[7;8]	Access to the Powerhouse. Mostly lined.
T6	Left bank	110	8.90	Access to the Transformers Cavern.
T8	Left bank	280	11.3	Main access to Diversion Gate Chambers. Connected with the tunnel T4.
T10	Left bank	Not yet built, dimensions will be specified according to the traffic		Used for the transport of materials and access to the left bank. It is not yet excavated.
T18	Left bank	Construction has started		Access to the penstock chamber.

Other tunnels are indicated in the HPI report as yet to be excavated and lined, in addition to the above tunnels. The routes of these tunnels have been updated by the Consultant in the TEAS.

Tunnel n°	Description
T39 –T41	Connecting the upstream and the downstream of the dam at the elevation around 1300.
T23	Short branch of tunnel T39 giving the access to the Crest road.
T43	Giving the access to the gate chamber of the Vortex tunnel.
T-CT3	Giving the access to the gate chamber tunnel CT3.

The planning and the design of the surface and underground accesses to the main underground structures and appurtenant structures have to be reviewed according to the updated Programme of the Works.

The access roads and/or transport tunnels for delivering materials to the dam body as the placement works progress have not yet been planned for the full construction of the dam. This is a key issue to be resolved at the detailed design stage.

2.2 Quarries

Quarries will supply the materials for the underground and above-ground concrete works and for the construction of the embankment dam.

To this end, sources of materials have been identified on the Right Bank and on the Left Bank both upstream and downstream of the dam.

The quarries are listed in the table below.

Name	Intended use
Right bank	
BA15 A	Concrete works
BA21	Fine materials for the core
Left bank	
BA15	Dam body: Alluvium shell materials, concrete works
Lyabidora	Transition layers of dam
BA17	Loam materials of the core
Q26 A and B	Rockfill shell materials

The quarries have all been visited and the following observations were made:

- No activity has been observed.
- The machines were not in operation so it was not possible to check their production capacity and performance.

The following tables summarize the available amounts of material to be placed in the highest dam alternative, as well as the processing required to meet the technical specifications. A list of subjects requiring further studies is also given.

Source (Quarry/Borrow area)	Total intitial quantities	Extracted quantities	Quantities to discard	Stockpiled quantities	Remaining quantities	Suitable quantities for dam (alluvium shoulders, core, rock shell, rip rap)	Needed quantities for dam	Suitable quantities for concrete aggregates
	[Mm^3]	[Mm^3]	[Mm^3]	[Mm^3]	[Mm^3]	[Mm^3]	[Mm^3]	[Mm^3]
BA 15	75.6	26.6	3.1	22.1	49	64.7	Alluvium shoulders : 39.6	Suitable for concrete aggregate after processing
Lyabidora	6.6	4.0	1.6	4.0	1.0	5.0	Transitions : 4.9	-
BA 17	17	2.5		2.5	14.5	17.0	Core : 7.3	-
Q 26 A and B	5.2 18	0.8	1.2 1.1	0.8	22.4	23.2	Rock shell : 17.8 / Rip rap : 1.5	-

Table 2-1: Conclusions summary on construction materials 1/2

Source (Quarry/Borrow area)	Processing / Treatment to bring to specifications	Issues to be addressed in Phase II
Borrow area 15	Remove materials > 700 mm which represents about 2-3% (for alluvium shoulders)	Specific exploitation methods / phasing are to be defined to avoid flooding issues.
Lyabidora	Remove boulders > 100 mm which represents about 13 - 16 % (for transitions)	Additional tests are to be done to check out the high mica and powdered clay content.
Borrow area 17	Reduce moisture content to 10-12 %. Remove materials > 200mm. Increase fine content (*)	Processes for: fine content increase, particles >200 mm removals, moisture reduction, are to be defined and tested accurately. (*)
Q 26 A and B	Physical and mechanical properties are to be tested and defined precisely.	-

Table 2-2: Conclusions summary on construction materials 2/2 – According to HPI recommendations

(*) As noted above, the material of borrow area 17 cannot be used for placement directly in the dam core, due to its insufficient content in clayey-silty particles (finer than 80 µm). Special processing is to be designed accordingly.

The Phase II Report on construction materials will confirm or modify the conclusions presented in this report on construction materials.

2.3 Production of Conventional Vibrated Concrete (CVC)

2.3.1 Organization of CVC Production

<u>Original concept (from the late 1980s):</u>

For the production of aggregates and concrete, there was a central plant for processing aggregates upstream of a central mixing plant that supplied concrete to the entire project site.

<u>HPI concept (2009 report):</u>

The concept of the production of aggregates and concrete changed. Instead of concentrating the production of aggregates and concrete in one place, the production was split in two sites (No. 1 and No. 2).

In the HPI report, there is an analysis of the demand of aggregates according to the further use of the processed materials as well as a tentative programme of the consumption of these materials. There is as well a tentative programme of the demand of concrete.

2.3.2 Assessment of the CVC Production

There are at present:

- 9 smaller batching and aggregate plants spread all over the site instead of 3 batching plants and aggregates plants as anticipated in the HPI report. Some of the plants are located in areas that will be flooded when the level of the reservoir rises.
- A dry mix shotcrete plant and a salt grout plant are installed.
- A concrete laboratory is located in the works shop area.

2.3.3 Conclusion

- The aggregates plants consist of very old equipment, which will be subject to frequent breakdowns, and will consequently limit the production of the batching plants.
- The equipment can be used for works which are not on the critical path.
- The concrete production facilities need to be significantly upgraded.

2.4 Transport of Embankment Materials Conveyor Belt System

The HPI report proposes two alternatives for the transport of shell materials, because the conveyor system might not be available in due time as the tunnel is still to be excavated and the conveyor system is not yet available:

- For cofferdam: the report proposes to use trucks/dumpers;
- For the Main Dam: the transport is supposed to be made with the conveyor system.

2.4.1 Design of the Conveyor System

The 1986 concept of the conveyor belt system consists of 4.3 km in open air and 2.1 km in a tunnel. It was 2 m wide and could transport shell materials with a maximum size of 400 mm.

In 2009, HPI issued a revised solution considering:

- One surface branch of around 0.5 km running from the stockpile LG2 to feed the conveyor system with pebbles and fine materials.
- An underground branch of around 700 m running from the conveyor to a delivery point at Elevation 1075, located above the Stage 1 of the dam body.

2.4.2 Assessment of the Conveyor System

- The crushing plant was abandoned years ago.
- Some stretches of the belt conveyor have been buried and some remains of the steel frame cannot be reused.
- The existing lining of the tunnel must be checked and 1.1 km has not been excavated yet.
- The roads running along the surface part of the belt conveyor have to be rehabilitated.

2.4.3 Conclusions

It is recommended 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 performances of both the electro-mechanical parts and the belts have improved significantly.

2.5 Construction Sites

The construction sites are identified in the table below (Steel assembly plan and Spiral cases pre assembly plant are assimilated as such).

Name	Description
Construction site No1	The major site installation area divided in areas: A: Prefabrication of concrete products, batching plants and aggregates plants. B, C, D: Workshops, warehouses, parking yard of equipment E: Steel structures, equipment, machineries… F: Offices
Construction site No2	Batching plant No1, Shotcrete plant, Aggregates Plant No1
Construction site No3	Site installation of a subcontractor
Construction site No4	Scheduled to accommodate the assembling and testing plant of the 600 MW transformers for the Power House/Transformers Chamber
Construction site No5	Aimed to house the assembling and testing plant of the 600 MW Transformers
Steel Assembly Plant	Steel lining and reinforcement cages for the salt gallery are prepared in this Plant
Spiral Cases Pre Assembly Plant	Draft Tubes and Spiral Cases were anticipated in the early 1990's to be pre-assembled in this plant

2.6 Equipment on Site

During the 1980s, equipment was supplied or transferred from the Nurek Dam Project for the site installations and the beginning of the works, or supplied for site installation and permanent works in the Powerhouse Units 5 and 6.

The equipment available on site of the current Main Contractor RogunGESstoy is recent, looks in good condition, and is suitable for the works to be conducted during the pre-Contract[1] period. However, this equipment is more oriented to civil works and earthworks than to tunneling works.

1 A possible implementation plan being developed for the Rogun HPP, as required by the ToRs, foresees a pre-Contract phase, primarily covering (a) rehabilitation of existing works and site facilities, and (b) preparatory activities for the main construction contract.

Concerning the equipment of the Subcontractors, it has been observed that the equipment is generally not up-to-date. As for the Main Contractor, the equipment available on site is more oriented to civil works and earthworks and geotechnical works than to tunneling works.

In order to complete the project on time and economically, the reliability and the performances of the construction equipment allocated to the works is of prime importance. Then the old existing equipment could be used for the pre-Contract stage and works that are not critical (or will not become critical during a project implementation stage).

2.7 General Site Installations

The general site installations are listed in the table below.

Camps for Civil Works (CW), E&M and Hydraulic Steel Structures (HSS)	Assessment
Labour Camps	The workers will be hired from Rogun Town and the villages in the vicinity. Therefore the need to construct labour camps is anticipated to be limited.
Staff Camps	The refurbishment of apartments/buildings in Rogun will be required; some work has already been undertaken.
Camp facilities (Restaurant, Clinic/First Aid, Hotel/Guest House)	Camp facilities (Restaurant, Clinic/First Aid, Hotel/Guest House) are built and in operation. Until 2012, up to 8500 employees were serviced by them. In Rogun and Obi Garm, infrastructures exist to accommodate labour force, including shops, mini-markets, canteens, schools, modern equipped hospitals, first aid units, and sanatorium. However, some of these existing camps facilities have to be improved. Moreover, the capacity of these infrastructures is not sufficient for the completion of the entire works.
Camp plants/utilities	Camp plants/utilities (water treatment, fresh water supply network, supply of electricity, etc.) mostly exist and at present are in operation. But an effective drainage system does not exist. 220kV transmission line is delivering electricity to Rogun city and the site. Waste water treatment plants (BIO 4200 and BIO 700) are installed.
Camp Telecommunications	Mobile telephone and internet are available on site.
Site Installations for Civil Works	**Assessment**
Laboratories (Concrete laboratory, Soil laboratory)	Building a new concrete laboratory at construction site n°2 is necessary. Soil laboratory must be installed close to the dam or core treatment.
Supply of Compressed Air	Smaller electrical compressors close to the demand of compressed air to be installed.
Cement Debagging Plant	The number and the capacity of the debagging silos have to be increased and located close to the concerned batching plant.
Batching and Aggregates Plants	The aggregates and concrete production facilities have to be upgraded.
Grouting Plant	Shall be equipped with turbo mixers and shall be installed as close as possible to the injection area.
Preparation of the Core Materials (mixture between BA17 and BA11)	Place and mean of transport will be determined.
Preparation of the Shell Materials	The >400mm (5%) have to be removed from the raw materials

	before transport to the dam site
Warehouses and Workshops	The location and the arrangement are usually left to the initiative and the organization of the Contractors and Subcontractors.
Site Installations for HSS and E&M	**Assessment**
Construction Site n°1, Zone E	Adequate for pre-assembling of the HSS parts during the early stages of the Project.
Left bank, close to LG1	Adequate for assembling of draft tubes and spiral cases during the early stage of the Project.
Construction Site n°4, 5	Adequate for assembling and testing of transformers.
Construction Site n°2	Adequate for pre-assembling of the HSS parts, when Site n°1 Zone E will be inundated.

3 FIELD ASSESSMENT OF THE UNDERGROUND WORKS AND ELECTROMECHANICAL EQUIPMENT

3.1 Present Status of the Underground Works

Extensive underground works have been performed at the Rogun project site during the period 1982-1990. Some of these structures suffered from the flood-related events that took place in 1993 (overtopping of the upstream cofferdam in May and mud-flow from the Obi-Shur River in June), resulting in extensive sediment inflow and flooding. Significant repair works were conducted in recent years to rehabilitate the affected structures.

The Consultant conducted various site visits, collecting documentation and performing inspections of the works, with the aim to identify the most critical locations for further study.

Lugeon and concrete strength tests were carried out in the presence of the Consultants, who collected data relevant to the status of the most important underground structures.

3.1.1 Powerhouse Cavern

The Powerhouse Cavern, located in a sedimentary complex constituted by sandstone and siltstone, is approximately 21 m wide, 69 m high and 220 m long. Large amounts of excavation works have been already conducted, in particular in the area of Units 5 and 6, where the elevation of the spiral case was reached, and considerable quantities of excavation supports were installed in the past.

Significant walls deformations have been recorded, amounting to almost 600 mm in the siltstone portion up to August 2008 and reaching a total of about 738 mm up to August 2012. The increase from 600 to 738 mm was due to the deepening of the excavations in the area around Units 5 & 6.

Cracks and damages are affecting the lining concrete structures at various locations on the cavern sidewalls and neighboring structures as a consequence of this convergence process (i.e. the inward movement of the cavern walls), as well as other less significant problems.

Based on the results of a pull-out tests campaign which indicated the ineffectiveness of the anchors installed in the past, rehabilitation works have been planned, including the replacement of the original supporting system with a system composed of multi-wire tendons, columns to support crane beams and transversal struts.

3.1.2 Transformers Cavern

The Transformers Cavern, located in the same geological environment of the powerhouse, is approximately 19 m wide, 42 m high and 212 m long. Currently, most of the excavation works have been completed.

In contrast with the case of the powerhouse cavern, there is no evidence of global instability, nor of damages requiring rehabilitation works.

3.1.3 Diversion Tunnels

The two Diversion Tunnels have been totally excavated and almost completely lined, with the exception of the river-crossing culverts near the downstream end.

The construction of the tunnels started in the 1980s and major collapses occurred during the first period of operation in both of them.

Extensive remedial works have been carried out to stabilize the collapses and construct a new heavily reinforced concrete lining that is 1.8 m thick. Steel lining has been installed in the reaches that are more susceptible to erosion by sediments.

At present there is no visual evidence of local or global instability problems and only minor finishing defects have been detected. The structural adequacy of these tunnels for the anticipated loads is assessed in Section 4.

In the reach of the tunnels where Fault 35 is crossed, a reinforced concrete lining 1.8 m thick divided into rings 3 m long was adopted. This permits relative displacements between these elements in case creeping occurs in correspondence with the shear zone.

3.1.4 Other Underground Structures

Other underground structures were also inspected in detail in order to record all defects and recommend possible remedial measures.

In general no evidence of structural instability was noted. The most common defects related to lining surface rough finishing, the presence of honeycombs in the concrete, reinforcement bars exposed and oxidizing, and uncontrolled water inflows. However, while these deficiencies will need to be addressed, in general they do not impair the safety conditions of the works.

The most serious problems recorded were in some transportation tunnels, in which portions of concrete lining were missing at the contact between the sidewalls and the invert; such a situation requires implementing proper remedial works to bring the structures to the required safety and serviceability conditions.

In order to check the actual strength of the concrete lining, compression tests on specimens obtained through drillings were performed in various tunnels, and the effectiveness of the grouting treatments was checked through a Lugeon tests campaign.

3.1.5 Concrete Compression Tests

The scope of the tests on specimens drilled from the existing structures was to determine the concrete compressive strength. This information was taken into account for the structural verifications of tunnels and caverns. These tests were conducted on the lining of the existing Caverns (powerhouse and gate chambers), Diversion Tunnels, Stage 1 Headrace Tunnel and transportation tunnels T-4 and T-3.

The results of the tests show concrete compression strength figures usually in excess of 25 MPa: this value was assumed as reference for the structural verifications (see Section 4).

3.1.6 Lugeon Tests

Lugeon tests were performed in the second portion of the holes drilled for core recovery in the Diversion Tunnels and in the Stage 1 Headrace Tunnel.

Based on the analysis of the results, it is deemed necessary to perform additional consolidation grouting treatment especially from chainage 5+20 to chainage 8+70 of both Diversion Tunnels, in particular in the reaches of the tunnels crossing Fault n° 70, where Lugeon values up to 60-70 were recorded.

Also, additional grouting is envisaged in the stretch of the Stage 1 Headrace Tunnel between chainage 1+60 and 2+60.

3.2 Electromechanical Equipment

As verified during the inspections, most of the equipment required for the Stage 1 Project configuration has been already installed or is available in the Country.

With regard to the power generating equipment, a considerable part of the first two units was already supplied and is stored in Tajikistan. The two turbines are almost complete but only one generator was supplied.

Considering that the units have been stored for 20 years, their conservation state is generally good and they are considered suitable to be installed in the plant, even though considerable completion and modification works may be required.

Also some other components of the remaining units were already supplied. However, it is the recommendation of the Consultant that only the components corresponding to the first two units should be installed. This will avoid imposing to a new supplier the use of equipment designed and manufactured by other companies, for which guarantees may not be provided.

4 STRUCTURAL ASSESSMENT OF THE UNDERGROUND STRUCTURES

Within the frame of the TEAS for the Rogun HPP, the Consultant had to perform the technical assessment of the already constructed underground works, including recommendation of appropriate measures to correct unsafe conditions and to bring the existing works to specifications. The bases for the assessment are constituted by the calculations of typical sections of various tunnels, as well as the Hydrogeological and Geomechanical Models, provided by the designer HPI.

4.1 Assessment of Tunnels

4.1.1 Structural Verifications

The technical assessment of the tunnels was performed in two phases: first, by verifying the structures' resistance with respect to the combined normal action and bending moment as well as shear action and second by conducting a detailed stress analysis of one section of the Diversion Tunnel N°. 1, aimed at verifying whether the proposed remedial measures were suitable to provide the required conditions of safety and serviceability.

The verifications were carried out on the most representative structures, implementing for the 39 cases analyzed 2D frame models, solved with finite element method, and following the loads combination coefficients adopted by the Designer, the Russian Standards and those recommended in Eurocode EC2, according to the Ultimate Limit State method.

The following aspects were noted with respect to the loads considered by the designer:

- The **rock loading** was based on the Protodyakonov formulation and no rock–structure interaction pressure was considered in addition to the dead-weight of the loosened rock mass, with underestimation of the long term loads acting on the tunnels lining.
- The maximum value of 100 kPa of **water load** adopted by the designer implies an excellent performance and a good maintenance of all drainage systems; such a performance may not be realized in actual operation.
- The methodology used by the designer for implementing the effect of the **earthquake load** in the calculations is no longer acceptable according to the modern procedures, which would yield stresses that are much more significant than those obtained through the former methodology.
- Furthermore, in several cases the designer adopted a coefficient of reduction of 50% for the vertical rock load and for the load induced by water. In some cases water load is totally absent.

The verifications that were undertaken using the same loads considered in the original design (which are considered not conservative) and with the load combination coefficients in accordance with the Ultimate Limit State method, led to the conclusion that the tunnels' permanent supporting systems need to be strengthened.

The geometric lining features and reinforcement schemes described in the detailed design drawings do not leave any possible safety margin in terms of bearing capability, even against small variations or underestimations of only one of the parameters taken into consideration in the study. This makes it impossible to meet the structural verification requirements whenever more stringent loading conditions are adopted and evaluated.

In several cases, the reinforcement is very close to, or even lower than, the minimum steel area required for shrinkage and temperature-effects control.

A uniform external water pressure of 200 kPa was adopted by the Consultant. The analyses showed that this water load, even without any other load, resulted in overstressing the concrete lining where the thickness was 60 cm (e.g. in the tailrace tunnels stretch starting from the draft tubes collectors and further downstream along most of their development, from ch. 6+033 to ch. 7+021, where the thickness of the lining is 60 cm).

Therefore, the Consultants deem the tunnel structures inadequate in their present condition for their intended purposes. **They do not fulfill the technical requirements in respect to safety and serviceability required by the presently internationally recognized design criteria and Standards, and the tunnels permanent supporting systems need to be strengthened.**

4.1.2 General Recommendations

Based on these considerations, it is deemed necessary to proceed with the implementation of measures adequate to improve the structural stability of the tunnel structures that were not found in line with design criteria and standards internationally recognized for projects of the importance and magnitude of Rogun HPP.

The possible interventions can be aimed at controlling the loads acting upon the structures (drainage systems constituted by drillholes through the tunnels linings or drainage galleries) or at strengthening the structures through additional supports (bolts or anchors more effective than those presently installed, or additional reinforced concrete lining).

Because the efficiency of the drainage system may vary with time, it is necessary to ensure its long term serviceability, through regular maintenance and a monitoring program.

These interventions can be combined as necessary to achieve the required degree of safety in respect to the expected loads.

In any case, further analyses will need to be carried out in a subsequent detailed design phase to develop appropriate strengthening measures for different tunnel structures. For the purpose of this study, plausible estimates have been made of the extent of rehabilitation measures required for the various tunnels and of the related costs.

It is worth mentioning that the Client has carried out a field investigation campaign aimed at mapping the extent of the distressed zone in the rock-mass surrounding the tunnels, in order to integrate the description of the failure zone around the tunnels linings. For the detailed design phase, it will be necessary to define the rock mass characteristics, the seismic loads, the water pressure (not less than 200 kPa for all stretches upstream from Fault 35 and 100 kPa for stretches downstream from the same) and other appropriate load conditions for each section to be analyzed.

The outcomes of the investigations can be used, concurrently with the information and findings already available, to validate the data frameworks necessary to perform the detailed design (Phase III) of the strengthening measures, taking into account the actual conditions of the rock surrounding the structures.

4.1.3 Stress Analysis of the Proposed Stabilization Measures

In order to verify the adequacy of the possible stabilization measures, the most critical section of the diversion tunnels, adopted along most of the free-flow stretches downstream from the junction with the draft tubes collectors, was analyzed in detail. This analysis took into account the most recent information regarding the excavation and primary support stage.

Two dimensional FEM analyses were conducted, modeling the unreinforced primary lining and simulating the effects of a plausible excavation process on the supporting system, with the intent to study:

- the rock mass and primary concrete lining response, with the aim to determine the extent of the failure zone to which long term rock mass parameters have been applied in a subsequent analysis step.
- the structural behavior of the existing reinforced final lining, verifying its bearing capability when it is acted upon by the external water pressure load, the seismic load and the load induced by the rock-structure interaction. Under the complex of these loading conditions, the existing reinforced lining stability cannot be achieved. This requires an integrative support stabilization set of measures.
- the response of the proposed additional rock support and stabilization measures that have been finally verified.

The analyses confirmed that, through the proposed set of stabilization measures, it is possible to definitively increase the bearing capability of the supporting system complex and ensure that the tunnel structure meets the required criteria of safety and serviceability.

4.1.4 Specific Recommendations

Based on the analyses carried out, which show that the proposed remedial measures can effectively upgrade the tunnels' safety conditions, these remedial measures have been proposed for the majority of the permanent tunnels, mainly with the purpose of providing an economical evaluation for the study of the dam alternatives.

As far as the Diversion Tunnels are concerned, the proposed interventions mostly include the implementation of a pattern of fully grouted dowels, additional reinforced concrete lining with a horseshoe shape, and a drainage drillings pattern.

In some stretches, the adoption of high strength rock bolts to stabilize the tunnel invert was envisaged. Also, drainage drillings all around the gates structure area are proposed, aimed at limiting the water external pressure. Two grouting and drainage galleries, one at each external side of the two tunnels, are also proposed.

The same set of interventions is also proposed for the permanent tunnels, but for the cables galleries and various drainage / grouting galleries, only reinforced shotcrete lining is proposed rather than concrete lining.

Special measures shall be implemented in the tunnels stretches crossing fault 35, consisting of casting a new thick lining that is heavily reinforced, provided with transversal joints, that allows for relative movements between the “rings” in case a creeping effect occurs at the fault section.

As for the various gates chambers, it is recommended to check the proper attributes of the drainage system, performing maintenance or improvements where required.

Following the results of the Lugeon tests carried out in the Diversion Tunnels and in Stage 1 Headrace Tunnel, additional grouting is envisaged along those stretches where high rock mass permeability was detected.

Finally, repairs of the areas of local damages and incomplete concrete lining with new reinforced concrete or shotcrete are recommended for the main transportation tunnels; along with their development, a safety steel mesh bolted to the existing concrete is to be placed. Whenever necessary, lattice girders would be adopted to assure the tunnel section stability, embedded in a new concrete lining or shotcrete.

4.2 Assessment of the Powerhouse and Transformers Hall

During the Consultants’ analysis, particular attention was paid to the assessment of the powerhouse cavern, in which significant walls deformations have occurred over the years.

In respect to the powerhouse complex stability, the designer had showed that no stable configuration could be achieved during excavation of units 5 and 6 when accounting for the decrease of the rock mass parameters due to the excavation process.

During 2012, the designer developed a new 3D Finite Element Model of the complex Powerhouse – Transformers Cavern, to back-analyze the cavern deformational response as observed in the period 1989-2007, based on the available convergence measurements.

The model developed by HPI is deemed too complex for analyzing the performances of the underground structures and to become a tool for providing a reliable and quick assessment during the future construction process.

Therefore, in order to carry out an independent assessment, it became necessary to prepare and analyze a 2D model that implemented reliable constitutive laws suitably representing both the elastic-plastic and the time-dependent behaviors of the rock mass.

The analyses aimed to assess the actual stability conditions of the caverns complex as well as a preliminary set of measures to be implemented to achieve its adequate performance, with particular reference to the portion excavated within the siltstone rock mass.

The available determinations (natural in-situ stress, main features of the structural rock-mass set up, etc.) have been taken into account in the model, and the starting set of strength and deformability parameters has been critically derived from the database on rock properties and the numerical analyses previously carried out.

The need for an exhaustive re-determination of the same quantities, relevant to the siltstone rock, for use in future detailed design modeling studies, has been recognized and a special sampling campaign and laboratory testing program is being carried out.

The actual excavation sequence carried out since September 1986 to date, as well as the rock support system set up and concrete struts installation with time, have been carefully modeled.

The process of the rock parameters degradation has been obtained through the back analysis procedure, based on the actual deformation response versus time observed in the powerhouse cavern. Once the computed deformations have been found to match the recorded values, the entire excavation and support application sequence until the completion of the caverns was simulated, investigating the behavior of the rock, the existing supports and further interventions envisaged.

The development of failure zones and shear bands in the rock mass, in particular in the pillar between the two caverns, have denoted the inadequacy of the stabilization measures adopted so far; the extent of the failure zones is greater than the length of the installed rock anchors.

The strains and deformations distribution shows the critical stability conditions of the cavern complex. This requires additional reinforcement and stabilization measures before any further deepening of the excavation in the powerhouse cavern can be undertaken safely.

The proposed stabilization measures include rock anchors 35 m long on both sidewalls and stabilization/strengthening of the rock mass of the pillar between the Powerhouse and Transformers caverns in the Units 5 and 6 zone, to be achieved by installing steel piles with properly spaced valves to allow for consolidation grouting (Multiple Packer Sleeved Pipe system). **The analyses confirmed that, through the proposed set of stabilization measures, it is possible to improve the stability conditions in the caverns with the aim to achieve, once the detailed intervention design will be completed, the full compliance of the work with the required criteria of safety and serviceability.** The proposed stabilization measures will need to be optimized by more detailed studies in subsequent phases of the project.

The provision of a suitable monitoring system of the convergence occurring in underground excavation is a mandatory condition to be fulfilled before any further excavation deepening. This is also an essential component of the interactive observational design approach.

5 COST ESTIMATE OF THE EXISTING WORKS

Among the tasks to be carried out as part of the Phase I study, the Consultant was required to prepare a detailed estimate of the investment made in the Project (sunk cost at current price level) on the basis of an agreed methodology. This has been done. The cost estimate information is considered confidential and thus will not be shared publicly.

6 CONCLUSIONS

Based on the site inspections and the various analyses performed, it is concluded that, with the implementation of the proposed stabilization measures for the underground works, the existing works and electromechanical equipment can be used for the potential future development of the proposed project.