Engineering and Dam Safety Panel of Experts for Rogun Hydropower Project

Final Report

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Date: 28 August 2014

Executive Summary

This report presents the stance of the Engineering and Dam Safety Panel of Experts (EDS PoE or PoE) with respect to recommendations of the Techno-Economic Assessment Studies (TEAS) for the Rogun Hydropower Project (HPP) and highlights the distinctive issues from the PoE's perspective. It should be read in conjunction with the Phase 0, Phase 1, and Phase II summary reports prepared by the TEAS Consultant.

The primary outcome requested of the PoE's work is to ensure international standards of design, risk evaluation and impact assessment are met. The PoE has a strong team with capabilities covering geology, hydrology, seismology, dam safety, sedimentation, electro-mechanical elements, economics and hydropower policy. Over the period from April 2011 until July 2014 the PoE has been involved in field missions, independent site investigations, design review meetings and desk studies, and has participated in riparian consultations.

The creation of a clear set of design criteria, based on international standards and guidelines, to guide all phases of the TEAS work was a key early recommendation of the PoE in May 2011.

The studies have been comprehensive, rigorous and subject to intense scrutiny from both the PoE and the World Bank team.

The PoE believes the studies have resulted in a robust understanding of the site geology and geotechnics and considers the geological conditions of the dam site are appropriate for an earthfill dam. As well, suitable construction materials are available at the site in sufficient quantities for the largest proposed earthfill dam.

The PoE accepts the TEAS Consultant's analysis of the leaching and rising of the salt wedge in the Ionakhsh fault that crosses the footprint of the dam. The measures proposed to mitigate leaching and cavity formation are supported, as they have been designed with a high geotechnical factor of safety. A robust monitoring system must be fully operational during the lifetime of the dam to enable the measures proposed for remedial action to be implemented if necessary.

The PoE considers that seismic risks are adequately addressed at this feasibility stage. A Deterministic Seismic Hazard Assessment (DSHA) has predicted that a Maximum Credible Earthquake (MCE) occurring along the Vakhsh Fault with a magnitude Mw of 6.9 (maximum historical magnitude plus 0.5) is likely to produce the most severe peak ground acceleration (PGA) at the Rogun dam site. This PGA has been estimated to be 0.71g. The Ionakhsh fault is likely to generate seismic displacements in the order of 1.3m to 2m.

Reservoir triggered seismicity (RTS) and its impact on the project are suitably addressed at this feasibility stage. The DSHA study demonstrates that the RTS is likely to produce earthquake magnitudes smaller than the historically observed maximum magnitude earthquake.

The PoE recognises the validity of the hydrologic data used and the results obtained in terms of the 1:10,000 years flood and PMF.

The PoE endorses the results of the assessment of Rogun operating performances, which show that a substantial increase of electrical power production can be met on the assumption of no changes from the current downstream flow release pattern, thus honouring regional water sharing agreements.

The PoE recognises that ensuring the project can safely accommodate an end of life scenario with a sediment filled reservoir is an appropriate and significant change from previous designs. However, more work is required to define the sediment management regime during the operating life of the project and this is a priority task for the detailed design stage.

Significant work has already been undertaken to excavate tunnels as well as the power house cavern. The PoE notes that:

- substantial remedial works are needed to upgrade the two existing diversion tunnels (DT1 and DT2);
- remedial work is necessary to satisfactorily stabilise the power house cavern and the "pillar" zone between the power house cavern and the transformer hall;
- it is essential that the proposed modifications to the HPI design of DT3 are implemented before DT3 is completed and commissioned.

The PoE considers that the stability of the caverns could feasibly be secured with the implementation of stabilisation works. The PoE recommends to:

- continue with the monitoring of the cavern's displacements;
- undertake in-situ testing of proposed rock anchors prior to detailed design.

The PoE agrees with the selection of an impervious core embankment dam type and the improvements to the cross section recommended by the TEAS Consultant.

The PoE endorses the proposed approach to management of construction floods, noting that construction should proceed continuously once the river is diverted to limit the project's exposure to embankment overtopping risk.

Due to the very challenging nature of the project and its tight scheduling, the TEAS Consultant has recommended that all efforts are made to carefully select, through international tender, experienced and highly qualified contractors for the Main Contract of Works. This international tendering approach is strongly supported by the PoE.

The EDS PoE considers that the TEAS program for the Rogun HPP over the past three years has:

- addressed all the feasibility level issues of the project with a sufficient degree of technical due diligence;
- proposed dam alternatives where international quality standards have been incorporated into the feasibility-level designs;
- undertaken a comprehensive assessment of the economic viability of the various dam height alternatives using a regional power market model for a fully interconnected Central Asian Power System;
- considered the technical risks of the project and recommended a suitable suite of mitigating actions to effectively address them.

Notwithstanding the above, the EDS PoE notes that there are still matters to be addressed at the detailed design stage of the project, most notably to:

- determine the optimum installed capacity configuration;
- establish effective arrangements for sediment management during the operation stage of the project;
- confirm the stabilisation measures for the powerhouse cavern.

It is the POE's view that the outcome of these detailed assessments will not affect the feasibility of the project.

The PoE reiterates the importance, from a dam safety perspective, of making all endeavours to ensure that the dam construction can be completed in a continuous process once river diversion has commenced. In particular, the PoE recommends that full financing of those aspects of the works related to dam placing, flood evacuation tunnels and associated gate arrangements be secured prior to commencing river diversion.

From a techno-economic perspective the EDS PoE endorses the TEAS Consultant's recommendation for the further detailed consideration of the FSL 1290 masl dam alternative since:

- key dam safety issues can be acceptably addressed;
- from a sedimentation perspective it provides the longest project life;
- it addresses the exposure of Nurek to sediment build up in the medium term;
- it improves the extreme flood safety of the Vakhsh cascade as a whole enabling it to withstand the PMF;
- it is the most economic option by a clear margin and its positive economic performance is robust to a wide range of scenarios.

We also reiterate that the optimum level of installed capacity is yet to be confirmed.

This endorsement is made with the requirement that ALL the recommendations made by the TEAS Consultant during the assessment process need to be followed during the next stages of the project (as listed in the published TEAS Phase II Summary report and its Appendix A: *"Summary of main recommendations of investigations, tests and studies to be performed early in the next stages of the Project"*).

In addition, the EDS PoE notes that a decision to proceed with a particular development alternative does not rest solely on techno-economic considerations. The recommendations of the Environmental and Social Impact Assessment need to be considered in conjunction with the technical considerations to ensure that, as a minimum, international good practice is adopted for all aspects of a proposed Rogun development.

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List of Abbreviations

bcm – billion cubic meters
BT – Barki Tojik
CAPS – Central Asian Power System
CSO – Civil Society Organisation
DSHA – Deterministic Seismic Hazard Assessment
EDS – Engineering and Dam Safety
E&M – Electrical and Mechanical
EPP – Emergency Preparedness Plan
ESIA – Environmental and Social Impact Assessment
FSL – Full Supply Level
GLOF – Glacial Lake Outflow Flood
GoT – Government of Tajikistan
GSI – Geological Strength Index
hm^3 – cubic hectometer (equivalent to million cubic meters)
HPP – Hydropower Project
HPI – HydroProjekt Institute, Moscow
ICB – International Competitive Bidding
ICWC – Interstate Commission for Water Coordination
IFAS – International Fund for Aral Sea
JSC – Joint Stock Company
NGO – Non-Governmental Organisation
MCE – Maximum Credible Earthquake
MPSP – Multiple Packer Sleeved Pipe
masl – meters above sea level
OBE – Operating Basis Earthquake
O&MP – Operation and Maintenance Plan
PGA – Peak ground Acceleration
PoE – Panel of Experts
PMF – Probable Maximum Flood
PSHA – Probabilistic Seismic Hazard Assessment
RJSC – Rogun Joint Stock Company
TEAS – Techno-Economic Assessment Studies
ToR – Terms of Reference
RTS – Reservoir Triggered Seismicity
UNRCCA – United Nations Regional Centre for Preventive Diplomacy for Central Asia
VC – videoconference
WB – World Bank

1. Introduction

1.1 Background to the Rogun project

The proposed Rogun Hydropower Project (HPP) is located about 110km East-North East of Dushanbe, the capital of Tajikistan. The Rogun Dam is located on the Vakhsh River, a right tributary of the Amu Darya River. The selected dam site is in a narrow S-shaped gorge with steep flanks, some 6.5 km from the Rogun town.

Initial studies on the Rogun HPP began in 1963 and were completed in 1978 and then revised in 1981 when Nurek dam was put into operation. Nurek dam, a 300m high embankment with an overground power station, is also located on the Vakhsh River, some 75km downstream of the site of the Rogun HPP. The original studies for the Rogun HPP were undertaken by the Tashkent Hydroprojekt Institute, formerly known as Sredazgigidroproject, which was responsible for the design and construction of dams in the Central Asian Region. This institute was a branch of the Moscow Hydroprojekt Institute (HPI).

The original design for the Rogun HPP comprised: a 335m high embankment dam with a clay core and a crest at elevation 1300 masl; caverns for the power house and transformer units; diversion tunnels; tunnel spillways; and several kilometres of access tunnels. The installed capacity was proposed to be 6x600 MW (totalling 3,600 MW) with an annual power generation of 13,300 GWh.

Construction of the preparatory works started in 1976, whereas the dam construction started in 1982 and continued until 1991 when construction stopped due to the collapse of Soviet Union and the Tajik civil war. By 1991 most of the site preparation works and about 70% of the permanent underground works (access tunnels, penstocks, diversion and outlet tunnels, chambers for turbines/generators and transformers) had been completed.

In May 1993, after a partial collapse of both diversion tunnels, the cofferdam was overtopped and washed out by a flood.

In 2000, HPI was commissioned to prepare a feasibility study for the construction of the original Stage 1 Rogun HPP. In 2005/2006 a modified feasibility study was prepared by Lahmeyer International (commissioned by RussAl, which at one time had been a potential investor). This modified approach was not adopted by the Government of Tajikistan (GoT) and further design was undertaken in 2008/2009 by HPI.

1.2 Techno–Economic Assessment Studies (TEAS) and Environmental and Social Impact Assessment (ESIA)

In 2007, the Government of Tajikistan requested the World Bank to assist with the Techno-Economic Assessment Study and Environmental and Social Impact Assessment Study for the proposed Rogun HPP.

The World Bank role includes:

(a) overseeing Consultant assessment studies;
(b) funding and managing independent and international Panels of Experts;
(c) facilitating a structured consultation process with all the riparian countries.

The assessment studies are grouped into Techno–Economic Studies (TEAS) and a Social and Environmental Impact Assessment (ESIA). In 2011 GoT selected international consultants to undertake the studies:

- TEAS - consortium composed of Coyne et Bellier (France)/Electroconsult (Italy)/IPA(UK)
- ESIA - Poyry (Switzerland).

The Terms of Reference (ToR) for TEAS include *"an assessment of all the previous work done to date on the Rogun HPP and an assessment of the entire Vakhsh River development master plan. In respect of Rogun HPP the TEAS would evaluate different options for dam type, dam height, construction phasing, reservoir operations, as well as issues of dam safety. Importantly, TEAS would analyse and recommend the possible trade-offs between techno-economic issues and the safeguards issues of dam safety, environmental, social, resettlement and impacts on other riparian states"*.

The current TEAS work has been grouped into three inter-related study Phases:

- Phase 0 (Zero): Geological and Geotechnical Investigation of the Salt Wedge in the Dam Foundation and Reservoir;
- Phase I: Assessment of the Existing Rogun HPP Works;
- Phase II: Rogun HPP Project Definition Options.

Phase II includes recommending a preferred option to be taken forward for further consideration. Work could continue after Phase II leading to the development of a Bankable Feasibility Report.

The ToR for the ESIA require "*the work to be conducted in parallel with the TEAS and comply with the WB and other International Funding Institutions requirements, and be guided by the policies of the World Bank, in addition to those of Tajikistan"*.

1.3 Engineering and Dam Safety Panel of Experts

For the TEAS and ESIA assessment studies described in Section 1.2 above, the WB has established two independent Panels of Experts (PoEs): Engineering and Dam Safety Panel of Experts (EDS PoE) and an Environmental and Social Issues Panel of Experts (ES PoE).

The role of the EDS Panel, who are constituted, coordinated and funded by the WB, is to:

- ensure due diligence and international quality standards;
- provide independent advice and guidance to support objectivity and credibility in the assessment process;
- share technical expertise and knowledge.

The primary outcome of the EDS PoE's work is to:

- ensure international standards of design, risk evaluation and impact assessment are met;
- assure a level of confidence amongst the international community in the quality and integrity of the assessment process and findings.

Complete ToR for the EDS PoE are available at:
http://web.worldbank.org/WBSITE/EXTERNAL/COUNTRIES/ECAEXT/0,,contentMDK:22908545~pagePK:146736~piPK:226340~theSitePK:258599,00.html

The EDS PoE was commissioned in April 2011 and comprises the following members:

Roger Gill (RG) (Chair)	Hydropower Policy and Operations Expert
Ljiljana Spasic-Gril (LSG)	Dam Engineering/Dam Safety/Seismic Engineering Expert
Prof. Dr. Paul Marinos (PM)	Engineering Geology/Rock Mechanics Expert
Prof. Dr. Ezio Todini (ET)	Hydrology Expert (Dr Peter Adamson until October 2012)
Dr. Gregory Morris (GM)	Sedimentation Expert
John Gummer (JG)	Hydromechanical and Electromechanical Equipment Expert

Prof. Dr. Ezio Todini is also a member of the ESIA PoE; he provides continuity between the two PoEs for the work related to the reservoir operation and assessment of downstream impacts.

In addition, in May 2013, comment was sought from Prof. Dr. Julian Bommer (JB), a seismology expert, on the Preliminary Seismic Hazard Assessment for the Rogun Site.

Over a period from April 2011 till July 2014, the EDS PoE has been involved in the following activities:

- field missions and design review meetings in Tajikistan (see Table 1 below);
- design review meetings in Paris and Washington DC (see Table 2 below);
- home base report reviews (see Section 2 below), and
- participation in riparian consultations and contribution to consultation reports (see Table 3 below).

Table 1: Field missions and review meetings in Tajikistan attended by EDS PoE

Mission Date	**Mission Place**	**EDS PoE member attending**	
		In person	**Via VC or Audio**
9-16 May 2011	Tajikistan	RG, LSG	
1-8 August 2011	Tajikistan	RG, LSG, PM, PA	
September 2012	Tajikistan (site visit – independent geological reconnaissance)	PM	
9-14 November 2012	Tajikistan	RG, LSG	
13-21 February 2013	Tajikistan	RG, LSG, PM	
28 March -4 April 2013	Tajikistan (independent inspection of existing E&M equipment)	JG	
4-6 April 2013	Tajikistan (site visit – power house cavern: additional geological investigation)	PM	
16-19 December 2013	Tajikistan (1st PSHA meeting)		LSG
12-14 May 2014	Tajikistan (3rd PSHA meeting)		LSG

Table 2: Design Review Meetings in Paris and Washington DC attended by EDS PoE

Mission Date	**Mission Place**	**EDS PoE member attending**	
		In person	**Via VC or Audio**
17-21 December 2012	Washington	RG, LSG	PM, ET
21-28 May 2013	Paris	RG, LSG, PM, ET, GM (part time)	
12-21 August 2013	Washington	RG, LSG, ET (part time)	PM
1-4 October 2013	Paris	RG, ET, LSG (part time)	
18-27 November 2013	Washington	RG (part time),	LSG
10-17 February 2014	Washington	RG	
10-11 March 2014	Paris (2nd PSHA meeting)	LSG	
23-30 April 2014	Washington	RG	LSG

Table 3: Riparian Consultations attended by EDS PoE

Riparian Information Sharing & consultation meetings Date and venue		Reports discussed/ presentations by EDS PoE	EDS PoE member attending	
			In person	Via VC or Audio
1	17-19 May 2011, Almaty, Kazakhstan	Inception report	RG, LSG	
2	6-7 November 2012, Almaty, Kazakhstan	Design Criteria report, RP06; Geology (overview), Hydrology (overview)	RG, LSG, PM	
3	11- 12 February 2013, Almaty, Kazakhstan	Hydrology Report, RP07 Geological Investigation in the Right Bank 2012, RP29 Reservoir Simulation Studies (overview) Seismicity (overview)	LSG, PM, ET	
4	17-18 &20th October 2013, Dushanbe, Tajikistan	Phase 0 Summary Report, RP38 Phase I Summary Report, RP39	RG, LSG	PM
5	14-17 July 2014 Almaty, Kazakhstan	Phase II Summary Report, RP58	RG, LSG, ET	

Reports on the Riparian Consultations including input from the EDS PoE are available on the WB web site at: http://www.worldbank.org/en/region/eca/brief/rogun-assessment-studies

2. EDS PoE's Key Considerations in the TEAS Assessment

Bearing in mind that the original designs of the Rogun HPP were undertaken in the 1970s and by 1991 about 70% of the underground works had been constructed to the original designs: the EDS PoE's approach has been to ensure that both the existing works review and the new TEAS assessments are carried out in compliance with current international best practice, standards and guidelines for the design of a very high dam with a large reservoir volume. Some of the relevant standards include:

- WB Dam Safety Operational Procedure OP 4.37;
- Various International Commission on Large Dams (ICOLD) guidelines, namely: ICOLD Bulletin 59; Bulletin 82; Bulletin 95; Bulletin 120; Bulletin 148, etc;
- United States Bureau of Reclamation Standards for Design of Dams

The other key element of the PoE's approach was to ensure that a set of design criteria were in place, based on the above international standards and guidelines, which would be used to guide the studies.

Throughout the studies the PoE has closely reviewed and tested the TEAS Consultant's work and provided advice and guidance as issues were uncovered and recommendations made.

This report presents the stance of the EDS PoE with respect to the TEAS recommendations and it highlights the distinctive issues in the assessment studies from the PoE's perspective. It should be read in conjunction with the Phase 0, Phase 1, and Phase II Summary reports prepared by the TEAS Consultant. The PoE's key considerations are covered under the areas of:

- Definition of design criteria;
- Geological assessment;
- Site specific seismicity and seismic design;
- Hydrology;
- Sedimentation;
- Phase 0, Phase I and Phase II assessment studies.

2.1 Design Criteria

The creation of a clear set of design criteria, based on international standards and guidelines, as a basis for all phases of the TEAS work, was a key early recommendation of the EDS PoE in May 2011.

Of critical importance was the decision to design the project to handle the Probable Maximum Flood (PMF), which had not been the case for the 2009 design of HPI that had used a maximum flood discharge capability of 1:10,000.

Flood protection during the construction phase is to be designed using a probabilistic approach; the accepted probability is to be adapted to construction planning (time of exposure) and the gravity of potential consequences in the case of flood occurrence. It was recognised that in order to manage hydrologic risk over the relatively long construction period it will be essential that construction of the dam continues without significant interruption.

The project is to be designed to handle the Maximum Credible Earthquake (MCE), which is the largest reasonably conceivable earthquake that appears possible under the presently known or presumed tectonic framework. It is also a requirement to assess the maximum possible fault displacements, associated with the MCE, for the faults that cross the footprint of the dam and various underground structures and ensure that appropriate measures are implemented to mitigate the faults' movements.

Due to the high sediment load carried by the Vakhsh River (in the order of 100 hm^3 per annum) the design criteria recognised that the TEAS studies must address the long-term sedimentation implications to demonstrate that dam safety can always be assured.

As the studies progressed it was decided that the design criteria should also specify that the Rogun reservoir should aim to attenuate the PMF to provide flood protection for the large Nurek dam and the balance of dams in the downstream cascade. Nurek dam flood discharge capacity is currently limited to floods with a return period of up to 1:10,000.

The EDS PoE has endorsed the adopted Design Criteria that were disclosed and discussed during the 2nd Riparian consultation in November 2012 and updated in 2014:
http://web.worldbank.org/WBSITE/EXTERNAL/COUNTRIES/ECAEXT/0,,contentMDK:23291624~pagePK:146736~piPK:146830~theSitePK:258599,00.html

2.2 Geological Assessment

A critical aspect of the Rogun site was to ensure that a robust understanding existed of the local geology and geotechnics. Since the site has been partially developed for a long period of time extensive geological data existed dating back to 1978. The PoE's Prof. Dr. Paul Marinos worked in conjunction with the TEAS Consultant to clarify the geological setting. Where necessary Prof. Marinos undertook site inspections to verify the Consultant's conclusions. He was closely involved in setting a program of additional investigations which included assessing the right bank downstream of the dam, where it was initially postulated that a major landslide may exist. Prof. Marinos was also directly involved in assessing the stability of the underground power station cavern that had demonstrated significant convergence creep. The PoE's assessment of the implications of the salt wedge in the foundation of the dam and reservoir is discussed at section 2.6.

The PoE considers that the geological–tectonic context that defines the conditions of the area where the dam site is located is well documented by the TEAS Consultant. This knowledge allows a clear understanding of the causes of the deformed structures of the dam site geology, the activity of faults and the ductile intrusions of evaporitic rocks along them, such as the salt wedge. It also provides an understanding of the seismic regime, which is deeply dependent on the tectonic creep that releases part of the potential seismic energy. The state of in-situ stresses is governed by the active compressional tectonics across the broad area. Additional in-situ stress measurements will be needed at the detailed design stage.

For the site of the dam the lithological nature, sequence and development in space of the formations are well understood. The geometrical arrangement of the beds and their dip is favorable for the stability of the abutment and for an embankment dam. The structural block of rock mass where the dam is located is creeping along its delimiting faults at a rate of millimeter scale per annum. The uplift is not homogeneous and probably minor internal faults could provoke differential deformations. These deformations can be accommodated by an embankment dam, but must be considered in the design of the underground works.

In association with the bedding and minor faults, major persisting joints can provoke rockslides. Although these slides could not generate large scale instability, they may affect the stability of areas such as the portals of tunnels. In the PoE's understanding this is not a major issue of threat and usual mitigation measures can prevent local instability. Similar cases of landslides are described in the broader area, but it is considered that their size or location do not affect the feasibility of the project.

The PoE considers the geological conditions of the dam site as appropriate for the foundation of an earthfill dam. The understanding of the PoE is that there is no doubt that globally the rock mass is of low permeability, but an analytical spatial distribution of permeabilities is needed for the final design of the grout curtain. Based on the information of the new boreholes in the right abutment, beyond the dam axis, it seems that an underground hydraulic barrier is developed inside the abutment. An extension of the grout curtain inside the abutments has to be anticipated, but is not expected to be abnormally long. The PoE underlines the need for a grout curtain at both abutments, and a drainage pattern downstream of it, to secure the stability of the disturbed zones that exist there.

The downstream right valley side atypical area was initially interpreted (at the early feasibility stage in 1978) to be the result of a large scale slope instability, considered now mostly stabilized. The data from the recent additional investigation (defined in conjunction with the PoE) and their interpretation by the TEAS Consultant were presented in a special report released for the 3rd riparian consultations in February 2013. The PoE also separately assessed this very important case regarding the possible presence of an old landslide that could affect the feasibility of the project. The conclusion is that this disturbed area is the result of a large scale tectonic deformation and the setting does not present a risk for global instability.

The upstream border of the atypical area towards the dam is characterized by a sharp bend which has disturbed the rock mass. The PoE has considered this zone because it corresponds to the exit areas of appurtenant structures of the project. The PoE agrees that a detailed assessment and an appropriate design of the structures crossing this area must be undertaken in the detailed design phase.

The PoE agrees with the evaluation of the TEAS Consultant of the favourable watertightness of the reservoir as a whole. The PoE considers that the Gulizindan fault crossing to the left side of the dam site should present lower permeability conditions than those anticipated by the TEAS Consultant.

Regarding the geotechnics of the dam area, the TEAS Consultant concludes that the geotechnical conditions of Rogun dam site, although presenting some particularly acute difficulties, should not compromise the feasibility of the project provided that adequate mitigation measures are effectively implemented. The PoE endorses this assessment.

The PoE endorses and stresses the need to resume measurement of the creep of the known active and other faults with a new monitoring system. The TEAS Consultant has determined measures to apply at the crossing of the main and secondary faults in tunnels and the PoE endorses those proposals at this assessment stage. For the co-seismic displacements that are likely to occur, the

PoE advocates trying to locate exactly the possible location where co-seismic fault movement may occur.

The PoE endorses the description and appraisal of the geological and geotechnical conditions in the areas of modifications proposed by the TEAS Consultant: the gate chambers of the 3rd diversion tunnel, the mid-level outlets and the surface spillway. In particular the cuts for the surface spillway are not exposed to translational or other large scale structural failures. The engineering geology in the spillway excavation will be a rock mass quality issue and the slopes have to be designed taking into account the rock mass properties and failure criteria.

An overview of the geology, including the right bank downstream zone, was presented during both the 2nd and 3rd riparian consultations in November 2012 and February 2013.

In summary, the PoE confirms there is a robust understanding of the site geology and geotechnics and considers the geological conditions of the dam site are appropriate for an earthfill dam.

2.3 Site Specific Seismicity and Seismic Design

The proposed Rogun dam site and reservoir are located within the Tajik Depression, which is a part of the active deformation zone resulting from the Cenozoic collision between the Indian and Eurasian tectonic plates. Crustal shortening between the Pamir and the Tien Shan mountain ranges is an important consequence of this India-Eurasia convergence.

Both the Pamir and the Tien Shan mountain ranges are marked by significant seismic activity that has impact on the Rogun HPP. The seismic activity at the Rogun HPP site is associated with the following faults:

- Deep, crustal faults: Guissar and Vakhsh;
- Regional, internal faults of the Tajik Depression: Ionakhsh and Gulizindan;
- Local, secondary faults: most important are No.35 and No.70.

The Guissar and Vakhsh faults have an epicentral distance from the site of 7-8km and about 4km respectively and have a maximum historic earthquake magnitude of 7.4 and 6.4 respectively. The Ionakhsh and Gulizindan faults, as well as faults No 35 and No 70, cross the footprint of the dam. In addition to the estimation of design accelerations, an estimation of seismic displacements that could be generated by the faults is therefore extremely important for the seismic assessment of the dam and associated structures. This displacement aspect of the project design has not been adequately addressed in previous designs.

A Deterministic Seismic Hazard Assessment (DSHA) has been undertaken by the TEAS Consultant to estimate possible maximum ground accelerations and fault movements that could be developed during an MCE at the Rogun site. This report has been integrated in the Phase II Report.

The DSHA has predicted that an MCE occurring along the Vakhsh Fault with a magnitude Mw of 6.9 (maximum historical magnitude plus 0.5) and at the shortest distance to the dam site (rupture distance around 4km) is likely to produce the most severe peak ground acceleration (PGA) at Rogun. This PGA has been estimated to be 0.71g.

As for the seismic displacements along the faults that cross the footprint of the dam, the Ionakhsh fault is likely to generate seismic displacements in the order of 1.3m to 2m. The displacements that could be generated along the secondary faults, No 35 and No 70, are likely to be an order of magnitude lower, in the order of 10cm to 20cm.

Reservoir triggered seismicity (RTS) and its impact on the project are suitably addressed at this project phase. The DSHA study demonstrates that the RTS is likely to produce earthquake magnitudes smaller than the historically observed maximum magnitude. This is largely supported by observations of the RTS made prior to and during the first 10 years of operation of Nurek reservoir.

The DSHA report has recommended that:

- a Probabilistic Seismic Hazard Assessment (PSHA) also be undertaken for the detailed design phase to define ground motion levels for different return periods of earthquakes[1];
- seismic monitoring is implemented as soon as possible in order to estimate the background (baseline) seismicity prior to commencement of dam construction, and then continue monitoring during and after construction.

An overview on the selection and derivation of the seismic design parameters was presented during the 3rd riparian consultation in February 2013.

The PoE accepts the seismic parameters defined by the DSHA, as well as the recommendations made by the TEAS Consultant for further work, and considers that the seismic risks are adequately addressed at this feasibility stage.

2.4 Hydrology – Design for PMF and Cascade Implications

2.4.1 Data

The PoE endorses the use made by the TEAS Consultant of the full set of available monthly inflows to Rogun, ranging from 1932 to 2008 (used together with general data on sedimentation evaluated in the Nurek reservoir) to assess the hydropower and water resource potential benefits of the Rogun project as part of the Vakhsh cascade of reservoirs.

A flood study was carried out in order to estimate both the 1:10,000 years flood and the PMF. The analysis was based on recorded daily and instantaneous peak discharges, daily temperatures and monthly / seasonal temperatures. The statistical analysis was carried out based on Vakhsh 111 station-years record leading respectively to 5,690 m^3/s and 5,970 m^3/s for the daily and instantaneous 1:10,000 years flood peak.

Due to the peculiarity of the floods in the Vakhsh, essentially generated by snow-melt, the Consultant derived an original approach for flood estimation based on the correlation between the degree-day approach and the observed floods in the river. The result of the maximization process lead respectively to 7,770 m^3/s and 8,160 m^3/s for the daily and instantaneous PMF values. The results can be considered as conservative since the values chosen were the highest values resulting from the maximization process.

The hydrologic assessment for the project was disclosed during the 3rd riparian consultations in February 2013.

The PoE recognises the validity of the data used and the results obtained in terms of the 1:10,000 years flood and PMF.

2.4.2 Value of flood mitigation

The flood routing that will be provided by Rogun dam for FSL 1255 or FSL 1290 and proposed flood management will essentially reduce the inflowing PMF to an outflow peak equivalent to the 1:10,000 years flood peak used in the design of all the downstream reservoirs and structures. Taking into account that today the downstream cascade can only accommodate up to a 1:10,000

[1] Although not part of the Phase II study, an independent PSHA has been carried out for the project for use in the detailed design stage. Using the design parameters obtained from the PSHA a preliminary analysis has shown that the dam response and displacements are within the limits obtained from the analysis performed with the DSHA design parameters.

years flood, the construction of Rogun (for FSL 1255 or FSL 1290) will increase the safety of the downstream cascade without the need, for the time being, of extensive construction works to upgrade the flood resistance capability of the downstream structures. This increased safety will last for several decades until the sediment deposition in Rogun reduces its design performance.

For FSL 1220 it was not possible to attenuate the PMF to a peak outflow discharge at the 1:10,000 level. Consequently, for this dam height alternative, the TEAS Consultant recommends, as a minimum, that the Nurek Dam would require a surface spillway added to ensure its protection from a PMF in the cascade.

The safety of the cascade can also be enhanced by the installation of a monitoring and flood forecasting system allowing for rational real-time reservoir operational management. The use of the monitoring and flood forecasting system will also increase downstream inhabitants' flood preparedness.

2.4.3 Water resource management benefits from inclusion of Rogun in Vakhsh cascade

The Rogun reservoir will be part of the Vakhsh hydropower cascade. Therefore, a computer simulation of cascade operations was conducted to establish whether the cascade with Rogun can be managed in a way that would ensure efficient energy generation from the whole cascade while fully respecting downstream water requirements and Tajikistan's commitments under Central Asian water sharing agreements. Key assumptions are that:

- current transfer of summer water to winter at Nurek is 4.2 bcm, representing full utilisation of Nurek's regulating capacity, and it is assumed that this will not be exceeded in the combined operation of Rogun and Nurek. Operation of the Rogun reservoir will thus not entail any changes in the seasonal flow pattern downstream of Nurek;
- Tajikistan currently does not use its full share of water allocated under the regional water sharing agreements for the Amu Darya basin, of which the average unutilized allocation of water on the Vakhsh River, over the period 1992 to 2010, is 1.2 bcm. It is assumed that in future the full share will be utilised.

The simulation model used the full set of monthly inflows to Rogun ranging from 1932 to 2008 and addressed the Rogun reservoir-filling period, the normal operation of the cascade and the impact of 50 years of sedimentation. The simulations show that it will be possible for the Rogun and Nurek hydropower plants and the Vakhsh cascade to be operated for efficient energy production while honouring current regional water sharing agreements without transferring more than the present 4.2 bcm between summer and winter flow. Moreover it was also shown that the reservoir could be filled making exclusive use of the difference between the Tajik full-allocated share and the current Tajik yearly water consumption.

Additional benefits could be gained from the operation of the Rogun/Vakhsh cascade in exceptionally dry years provided that a number of joint regional agreements and commitments are made, such as:

a. operating the cascade by respecting ICWC water allocation;
b. limiting water retention in Rogun in especially dry years during the filling phase;
c. establishing an operating rule for managing Rogun and the Vakhsh cascade in exceptionally dry years;
d. setting in place a transparent monitoring/forecasting and management system.

Accordingly, the PoE endorses the results of the assessment of Rogun performances, which show that a substantial increase of electrical power production can be met on the assumption of no changes from the current downstream flow release pattern, thus honouring regional water sharing agreements.

2.5 Sedimentation

The PoE recognised at the outset of the studies that sediment management would be a significant factor in the design of Rogun and the selection of alternatives. In previous design considerations it had been assumed that sediment inflows would be managed by constructing additional dams upstream of Rogun. However, due to the uncertainties that this created for the safety of the project, the design criteria were adjusted to ensure that the Rogun design considered the full project life implications of sediment inflows on the conservative assumption that no further dams were constructed upstream.

The limited data available on sediment quantities, particle distribution and characteristics in the Vakhsh River has been a constraint on the TEAS studies. The result has been a conservative assumption of a 100 hm^3 per annum sediment load in the river (but this could in reality range down towards 60 hm^3 per annum). This assumption is acceptable for this feasibility study, but will require further detailed assessment during the design and operation phase, as proposed by the TEAS Consultant.

High level considerations of the sediment management options were studied with the conclusion that "it will not be possible to control the sediment transport in the Vakhsh river; at best one could delay and/or limit its impact on the Rogun project and propose an end of life solution, ensuring sediment balance when the dam will be abandoned."

The PoE supports the TEAS Consultant's view that "the main objectives of sediment management are first to ensure the safety of the dam at all times, and second, to guarantee the operation of the powerhouse for as long as possible."

The resultant project life estimates range from at least 115 years for the highest dam alternative (1290 masl) to at least 45 years for the lowest alternative (1220 masl).

Previous designs had exclusively utilised tunnel spillways for both construction and long term flood protection. The PoE supports the alternative approach to include a surface spillway to provide long term dam safety. For construction cost efficiency the surface spillway can be built in stages over the life of the project and in its final form will enable the full bypass of the river and its sediment load, thereby protecting the dam. The end of project life stage would involve removing the surface spillway gates and allowing eventual degradation of the spillway and gradual erosion through the rock by natural processes, which would be a "guided erosion" process. From a conceptual standpoint this is a reasonable alternative, and in the opinion of the PoE the rock on the right abutment will provide sufficient resistance so that it would "fail slowly" to avoid the sudden downstream release of large volumes of sediment. The PoE commends the approach taken in these studies to consider the end of life scenario and incorporate appropriate dam safety measures into the project design. The PoE considers this to be best practice in hydropower project planning.

The PoE engaged closely with the TEAS Consultants in their considerations of mechanisms to extend the life of the project. An innovative multilevel intake structure is proposed to enable the power plant to continue to operate as deposited sediment levels rise well above the sill of the power intake tunnels. For the 1290 masl alternative sediment could reach the intake level in 60 years (and in around 23 years for the 1220 masl alternative), so considering ways to extend the project life was vitally important. Further design work is required to confirm and optimise the intake arrangement with particular attention on gate arrangements to matters such as: corrosion risk; sealing; practicalities of operation including trashrack clearing.

As sediment is progressively deposited there will be a turbidity current layer of very fine suspended particles overlaying the bed load deposited in the base of the reservoir. Data currently available from Nurek reservoir suggest that the majority of the sediment enters that reservoir in the form of turbidity currents that can transport fine sediment to the dam prior to settling out. This process is also expected to occur at Rogun, and these sediments will eventually pass though the turbines.

Two options exist to address this turbidity current phenomenon:

1. Use the multilevel intake extending above the power tunnel to withdraw water from progressively higher elevations as sedimentation advances, delaying the passage of fine material though the powerhouse and its potentially erosive impact on the turbines;

OR

2. Use a multilevel intake extending below the power tunnel to aspire the turbidity currents containing very fine sediments through the power house earlier. This option could delay the arrival of the delta deposit containing highly abrasive sands to the area of the power intake and extend project life by reducing sedimentation.

Option 1 has been adopted as a conservative approach for this TEAS feasibility assessment recognising the risk of potentially damaging erosion implications for the turbines due to sediment inflows.

The PoE notes that the possibility of extending the multilevel intake below the intake sill in option 2 is a relatively low-cost measure that could provide valuable opportunity insurance, even if it were not used, since it would not be possible to readily retrofit such an arrangement to the project after commissioning. This is a matter for further consideration during the detailed design process, noting again the issues associated with gate design mentioned above.

It is noted that when fine suspended sediment does eventually pass through the station a closed cooling system for the E&M equipment will most likely be needed to avoid clogging of cooling water filters.

The fine sediment suspended in turbidity currents is currently thought to be very fine clay and clayey silt, however exact grain sizes and hardness are not known. As a result the PoE, on balance, considers that further detailed study is required before final implementation of options 1 or 2 can be determined. A key concern raised in particular by Mr Gummer is of the erosive impact on the turbines and associated components of very large machines that are not readily maintainable if significant damage is inflicted and he does not support passing fine sediment through the turbines. The TEAS Consultants have noted these concerns in their report and it is now a matter for cautious detailed design. Detailed information on the composition of the Vakhsh river sediments transported by turbidity currents must now be obtained by sampling the reservoir deposits and turbid water in the Nurek reservoir.

In summary, the PoE recognises that ensuring the project can safely accommodate an end of life scenario with a sediment filled reservoir is an appropriate and significant change from previous designs. However, more work is required to define the sediment management regime during the operating life of the project and this is a priority task for the detailed design phase.

2.6 Phase 0: Geological and Geotechnical Investigation of the Salt Wedge in the Dam Foundation and Reservoir

The Consultant's geological and geotechnical investigation of the salt wedge in the foundation and reservoir was assessed very closely by the PoE due to the significant implications posed to long term dam safety.

The TEAS Consultant's work is comprehensive and the hydrogeological conditions are now well understood where the salt, constrained only in the Ionakhsh fault, is assumed to be rising in the order of 2.5 cm/year and is overlain by a clayey cap. The PoE accepts the principles and analysis by the TEAS Consultant of the mechanism and process of leaching and rising of the salt wedge. Given the uncertainties of a number of parameters, an elaborate parametric analysis is included in the TEAS work. Differences from the results of the previous HPI model are not due to the principles used, but to the values of the parameters, and as a consequence the results are more conservative. In addition, two decisive inputs are substantially based on assumptions: the salt rise rate and the clayey cap. In the PoE's perception the rise is of a lower rate, probably less than 2.5 cm/year and the clay protecting cap over the salt wedge seems to be more significant.

The PoE agrees that feasible mitigation measures could be implemented to address the extremely adverse conditions imposed by the presence of this evaporitic diapir at the dam foundation. The installation of both a hydraulic curtain and undertaking grouting have to be considered together. One will cover possible deficiencies of the other. And such deficiencies may occur even if more accurate data were available and fewer assumptions were made in the modeling. The PoE notes that a conservative factor of safety from 3 to 5 was used in the analysis.

These mitigation measures require the implementation of a sophisticated monitoring system operating uninterruptedly, along with contingency measures to ensure that future remedial work can restore the full functionality of the works if issues arise. The proposal is to ensure that re-grouting of the grout curtain can be achieved when the dam is operational to cover the risk that the curtain might be damaged by the salt extrusion. The same applies for the efficiency of the hydraulic curtain.

These three items: protective measures; monitoring; and restoration in case issues arise with the original measures are now detailed design issues.

The geological and geotechnical investigation of the salt wedge and associated comments by the PoE were disclosed at the 4th riparian consultations in October 2013.

In summary, the PoE accepts the TEAS Consultant's analysis of the leaching and rising of the salt wedge in the Ionakhsh fault. The proposed mitigation measures are also supported as they have been designed with a high geotechnical factor of safety. A robust monitoring system must be fully operational during the lifetime of the dam to enable the measures proposed for remedial action to be implemented if necessary.

2.7 Phase I: Assessment of Existing Works at Rogun HPP

The objectives of the Phase I studies are to determine the usefulness of the existing works for the potential future development of the proposed project, as well as their adequacy to be permanently incorporated into the final project layout.

The Phase I assessment addressed existing works:

- underground - such as the caverns for the power house and transformers, diversion tunnels DT1 and DT2 and several other underground structures;
- overground - such as access roads, quarries, transportation of material, construction sites, existing electro–mechanical equipment and general site installation.

The Phase I report was disclosed in September 2013 and was discussed during the 3rd Riparian Consultations.

In general the PoE notes that:

- **substantial remedial works are needed to upgrade the two existing diversion tunnels (DT1 and DT2) and this has been included in the cost estimates;**
- **remedial work is necessary to satisfactorily stabilise the power house cavern and the "pillar" zone between the power house cavern and the transformer hall;**
- **existing electrical equipment for Units 5 & 6 has been assessed as suitable for use as planned;**
- **suitable construction materials are available at the site.**

Diversion Tunnels DT1 and DT2

The TEAS Consultant found that:

- in their current condition DT1 & DT2 do not fulfil the technical requirements in respect to safety and serviceability as required by 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 No. 35 and No. 70 are crossed.

Recommended remedial works include:

- installation of drainage systems through the tunnels' linings or drainage galleries;
- strengthening of the structures by adding additional reinforced concrete lining and fully grouted rock dowels;
- installation of high strength rock bolts to stabilize the tunnel invert in some stretches;
- additional grouting along the stretches where high rock mass permeability was measured;
- installation of special measures where tunnels cross faults No. 70 & No. 35 to cater for relative movements of the tunnel segments.

For DT1 and DT2 the PoE agrees with the: assessments undertaken; methodology applied; and remedial works proposed. The same remedial measures will be required for each dam height alternative.

Power House and Transformer Caverns

The caverns are located in a rock mass dominated by sandstone, deep inside the left abutment, but with siltstone present where Units 5 and 6 are located. Monitoring of convergence in the power house cavern showed weakness in the behaviour of the siltstone rock mass impacting on the stability of the zone allocated to generation Units 5 and 6. Investigation and testing was performed with the close participation of the PoE. The stability of the caverns is described in detail in the Phase I report. The PoE supports the conclusion that the progressing deformation is due to a de-stressing of the rock mass in association with the ageing of the existing rock anchors.

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

- installation of rock anchors around both caverns, above the current excavation level;
- reinforcement and stabilisation of the highly de-stressed rock mass in the "pillar area" between the two caverns. This will be achieved using the Multiple Packer Sleeved Pipe (MPSP) system.

The PoE considers that the stability of the caverns could feasibly be secured with the implementation of the above stabilisation works. The PoE recommends to:

- **continue with the monitoring of the caverns' displacements;**
- **update the numerical model to take into account the displacements and all new testing data;**
- **define the extent of the proposed stabilisation works in the "pillar area" and, along with the MPSP system, identify other feasible strengthening measures to the "pillar area" including examining the possibility of applying struts;**
- **allow adequate contingency funds in the cost estimate to cover the range of strengthening measures that might be deployed;**
- **undertake in-situ testing of rock anchors prior to detail design, including creep pull-out tests on anchors and anchor heads and in-situ trial testing of the rock mass grouting using the MPSP system.**

Other Underground Structures

The TEAS Consultant assessed several other underground structures, mainly permanent and temporary transportation tunnels. In those cases:

- no evidence of structural instability was noted;
- defects were noted which are related to the lining surface finish, presence of honeycomb in the concrete, reinforcement bars exposed and uncontrolled water inflows. While these deficiencies will need to be addressed, in general they do not impair the safety condition of the works.

Construction Materials

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

These are:

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

The volumes of material needed for even the highest dam alternative are available in quarries / borrow areas and associated storages. The following matters are recommended for further study during the detailed design phase:

- 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);
- BA 15: need to develop a detailed programme for the material extraction from this borrow area as it will be flooded at the early stages of construction.

Transport of embankment materials will be as follows:

- Cofferdam: by trucks/dumpers;
- Main Dam: by a conveyor system (partly in open air and partly in tunnels);

The TEAS Consultant recommends that a brand new conveyor system be designed and installed because the existing equipment cannot be economically refurbished.

The PoE supports the conclusions and recommendations of the construction materials assessment.

Existing Electro-Mechanical Equipment

The PoE through John Gummer, undertook a detailed review of the existing equipment and concluded that the:

- existing units 5 & 6 are well designed for the era in which they were manufactured and do not require major modification. It is recommended that the 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;
- propensity for silt damage to the turbine hydraulic channels should be studied;
- overall scheme and in particular the powerhouse is well designed and no major changes to equipment are warranted. Attention is drawn to the measures required to avoid oil pollution of the waterways;
- staged development as foreseen in the original scheme is both safe and expedient.

2.8 Phase II: Project Definition Options

2.8.1 Definition of Alternatives

As required by the TEAS ToR, the Consultant studied three full supply level (FSL) alternatives and three installed capacities for each FSL - a total of nine alternatives. These alternatives are summarized in Table 4 below.

Table 4: Phase II alternatives

	FSL = 1220 masl	FSL = 1255 masl	FSL = 1290 masl
High installed capacity	2 800 MW	3 200 MW	3 600 MW
Medium installed capacity	2 400 MW	2 800 MW	3 200 MW
Low installed capacity	2 000 MW	2 400 MW	2800 MW

For all the alternatives the Consultant has considered the same dam site, dam axis and type of dam (See Section 2.8.2 below). Also, it has been assumed that the existing underground power house cavern will be used in all alternatives.

2.8.2 Selection of Dam Site and Type

Dam Axis

The layout of the dam at the Rogun site is constrained by a number of factors:

- Location of existing diversion tunnels' intake portal: the upstream dam toe has to be set downstream of these intakes;
- The Ionakhsh Fault: watertight component of the main dam or Stage 1 dam should not cross the Ionakhsh Fault, and should be set downstream from it. This requirement is a conclusion of the Phase 0 study. Its objective is to limit the pore pressure gradients and salt dissolution across the Ionakhsh Fault;
- Fault No. 35: the main dam core should not cross this fault in order to avoid differential movement and shearing within the core in case of a seismic movement along the fault;
- The Obishure stream is a limiting factor downstream as it is close to the downstream tunnel portals.

The dam axis selected by the original HPI design met all the above criteria and the Consultant has not modified the axis of the dam. This axis has been kept for the three dam alternatives. **The PoE agrees with this selection of the dam axis.**

Selection of Dam Type

The TEAS Consultant has considered several types of dams:

- Impervious core embankment dam;
- Concrete arch dam;
- Concrete Face Rockfill dam (CFRD);
- Gravity Roller Compacted Concrete (RCC) dam;
- RCC arch gravity dam;
- RCC arch dam.

An impervious core embankment dam has been selected as the preferred dam type based on the topography, access, available materials, presence of active faults (Ionakhsh, Gulizindan and No35), presence of salt in the Ionakhsh fault, high seismicity and requirements for a regular reservoir impoundment during construction. This type of dam was also adopted in the original Rogun HPP design. The upstream and downstream slopes are kept as shown in the HPI design. However, the TEAS Consultant has made some modifications to the cross section (widening of a rockfill layer of a minimum thickness of 20 m on both upstream and downstream sides, widening of coarse and fine filters to 10m) that especially improve seismic performance of the dam.

Total volume of material required for the different alternatives is as follows:

- FSL 1290 masl – 73.6 hm^3
- FSL 1255 masl – 54.5 hm^3
- FSL 1220 masl – 35.0 hm^3

The PoE agrees with both the selection of an impervious core embankment dam type and the improvements to the cross section recommended by the TEAS Consultant.

2.8.3 River Diversion and Management of Construction Floods

General Requirements

Rogun dam construction will have several construction stages: pre-cofferdam, cofferdam, Stage 1 dam and the Main dam. The river diversion arrangements and management of construction floods during all construction stages are essential for dam safety; these are constrained by several parameters:

- river hydrology and the construction schedule;
- site topography;
- condition of the existing diversion tunnels DT1 & DT2 (see Section 2.7);
- co-seismic displacement along the Ionakhsh Fault (see Section 2.3);
- early impounding of the reservoir and early energy generation during Stage 1;
- maximum allowable head in diversion tunnels (120m allowed in normal operation condition, 150m is allowed in extreme events like high floods and earthquakes).

Structures for managing construction floods

Taking into account the above constraints, several diversion structures have been considered for different dam construction stages. They include:

- rehabilitated existing diversion tunnels DT1 and DT2;
- third Diversion Tunnel, DT3;
- mid-level outlet 1 and 2 (MLO1 and MLO2);
- high level tunnels 1, 2 and 3 (HL1, HL2 and HL3).

During Cofferdam & Stage 1:

During these stages both DT1 and DT2 (once repaired) and a modified DT3 (located on the Right Bank of the river as foreseen in the HPI design) are used for diversion during construction in all dam alternatives.

Originally, the HPI design did not envisage DT3 to be constructed for the river diversion stage. However, during the course of the TEAS assessment it was recognised that DT3 was needed to complement the discharge capacity of the existing diversion tunnels DT1 and DT2.

The location of DT3 has been substantially confirmed by the TEAS Consultant. Since the adopted tunnel route will cross both the Ionakhsh fault and fault No. 35, modifications have been proposed to the HPI tunnel design to deal with possible large displacements during a seismic event. The modifications consist of a thick, highly reinforced concrete lining divided into short stretches (rings) along the reach of the shear zones. In case differential movements occur this arrangement will allow displacement of the ring, but the tunnel cavity will remain unaffected. Further adjustments of the HPI design of DT3 have been proposed to accommodate some hydraulic requirements and repair of the tunnel lining and gates.

It should be noted that, in 2011, RJSC commissioned the construction of DT3 in accordance with the HPI design. By July 2012, when the excavation works were suspended at the request of the WB, pending completion of the TEAS and ESIA assessments, some 400 m of tunnel was partially excavated.

The PoE notes that it is essential that the proposed modifications to the HPI design of DT3 are implemented before DT3 is completed and commissioned.

During the main dam construction

Construction floods during these construction stages are handled by:

- mid-level outlets 1 and 2 (MLO1 and MLO2);
- high level tunnels 1, 2 and 3 (HL1, HL2 and HL3).

The mid-level and high level tunnels needed for each alternative are as follows:

- FSL 1290: MOL1 & MOL2, HL1 &HL2
- FSL 1255: MOL1, HL1, HL2 &HL3
- FSL 1220: ML1, HL1

In summary, the PoE endorses the proposed approach to management of construction floods noting that construction should proceed continuously once the river is diverted to limit the exposure to overtopping risk.

2.8.4 Management of Extreme Floods

Several spillway alternatives and flood management strategies were analysed for the three alternative dam sizes, taking into account the capability to limit extreme floods downstream of Rogun to the 1:10,000 years flood peak value used for the design of the downstream cascade. Effective solutions were found for both the FSL 1255 and FSL 1290 alternatives. For the FSL 1220 alternative the reservoir volume is insufficient to enable the required level of PMF attenuation and additional facilities for augmenting the flood-handling capacity of the cascade are needed - An additional surface spillway is recommended for Nurek for the FSL 1220 case.

In particular, a solution with 2 high level tunnels and one mid level outlet (necessary for construction) complemented by 1 surface spillway (essential to face potential unavailability of gates and tunnels) was found to provide an acceptable protection of Rogun FSL 1290 against the PMF.

The PoE endorses the results and recommendations on the Extreme Flood management, and stresses the need for the installation of a flood monitoring and flood forecasting system to be set in place prior to the commencement of construction works.

Flood forecasting is particularly relevant even from commencement because of the higher probability of failure accepted during the construction phase: 5% in the first 2 years of cofferdam construction, 1% in the following 4.5 years of Stage 1 and 0.5% in the following 8 years of main dam construction for the FSL 1290 dam.

2.9 Implementation Studies

The TEAS Consultant developed a detailed construction schedule for each dam height alternative based on a careful assessment of the construction methods that can be practically utilised at the site. Particular emphasis was placed on assessing the rates of dam fill placement that could be achieved. Given the very large volumes of material in all the dam alternatives the placement rate has a material impact on the project's overall duration. A crucial point to note is that the proposed programs of work are based on utilising brand new equipment capable of high rates of production and with sufficient number on site.

The TEAS Consultant performed a rigorous cost estimating task for the highest dam alternative, from which the cost estimate for the two lower dam alternatives was derived. Each element of the works had a contingency allowance added. The average contingency allowance is 11%, which is considered appropriate for a project where a large part of the underground works is already excavated and as a consequence the geological risk during construction is well understood. An expert engaged by the World Bank independently checked the estimating methodology and outcomes. Notwithstanding this rigorous cost estimating approach, during the economic analysis a scenario of estimated cost plus a further 20% was assessed to verify the project's economic viability.

For the effective execution of the works the assumption was made to establish two contract packages:

1. General Preparation Works package prior to river diversion.
2. Main Contract of Works from river diversion to completion.

Due to the very challenging nature of the project and its tight scheduling, the TEAS Consultant has recommended that all efforts are made to carefully select, through international tender, experienced and highly qualified contractors for the Main Contract of Works. **This international tendering approach is strongly supported by the PoE.**

The PoE recommends that due to the importance of this high dam that highly qualified and experienced designers and owner's engineers are engaged.

To ensure that quality standards are maintained the PoE also recommends that external expert oversight is put in place to monitor the design and construction activities.

There are a significant number of recommendations made by the TEAS Consultant as a result of the TEAS studies and they are listed in the published TEAS Summary report at *"Appendix A: Summary of main recommendations of investigations, tests and studies to be performed early in the next stages of the Project"*.

The PoE's support for the project is contingent on ALL the TEAS recommendations (Appendix A of the published TEAS Summary report) being incorporated into the final design.

2.10 Economic and Financial Analysis

Regional least–cost generation expansion plans were developed for nine possible Rogun design options, as noted in Table 4, along with an option excluding Rogun. The TEAS Consultant utilised an ambitious and quite complex modelling approach that required the development of a regional power market model for a fully interconnected Central Asian Power System (CAPS) comprising Tajikistan, Kyrgyzstan, Uzbekistan, Kazakhstan, Turkmenistan, Pakistan and Afghanistan. The model quantified the total system costs for CAPS so that the least cost option for Tajikistan could be established. Stand-alone economic analyses were undertaken for the nine Rogun design options using the results of the least-cost analysis.

The PoE can report that due to the complexity of the modelling, the underpinning assumptions were extremely thoroughly tested, in particular through rigorous critique by the World Bank, and that the study duration was extended until the model was considered to be appropriately portraying the current and projected situation in the region.

The project cost estimate used as input for the economic analyses includes the environmental and social costs in addition to the basic engineering costs for each of the alternatives. The environmental costs were developed by the ESIA Consultant and include the direct costs of resettlement plus the loss of agricultural production, which vary for each dam height alternative.

Extensive sensitivity analysis was vital to test the robustness of each Rogun alternative's contribution to the least cost plan as well as its economic viability. This analysis covered electricity demand variation, capital cost variation, thermal fuel cost variation, varied regional interconnectivity. The economic and least cost planning results show a clear preference for the FSL 1290 dam alternative. This alternative was further tested for scenarios with gas imports to Tajikistan, schedule delays, hydrologic variation, sales price variation, and delay in sales of exports from Rogun. At a 10% discount rate the highest dam option proved particularly robust to a wide range of scenario sensitivities. As an example, given the challenge of cost forecasting for large hydro projects, the FSL 1290 project provides a positive economic return (10% discount rate) even for project cost overruns of 31%, in addition to the inherent 11% contingency allowance.

It is important to recognise that once Rogun 1290 reaches full production it can meet the winter energy needs of Tajikistan for a period of around 12 years until demand in Tajikistan has grown sufficiently to require additional energy from other sources.

The Rogun project economics are underpinned by export sales of summer electricity surpluses and Pakistan is a very likely export market. The export and regional exchange of power will require the appropriate development of supporting regional transmission interconnectors and the PoE notes that this will require significant regional co-operation if the benefits of Rogun are to be fully realised.

Installed Capacity

While the FSL 1290 option with an installed capacity of 3200 MW exhibited the highest benefits from a least cost planning and economic NPV perspective, the TEAS Consultant recognised that additional analysis is required to establish the optimal installed generation capacity.

The PoE strongly supports the need for such further analysis. A total installed capacity of 3200MW implies six 533.3 MW units. However, the value of six 600MW units should be considered from the perspective of system regulation and recovery, redundancy for plant maintenance and peaking capability in the longer term. As well a decision to restrict the two existing 600 MW units to 533.3 MW requires both economic and technical justification.

Financing and Dam Safety

It is not the role of the EDS PoE to comment specifically on the finance issues for the Rogun project. However, a key dam safety issue overlaps with the financing task from the PoE's perspective. As noted in section 2.8.3 the construction flood protection for the project assumes that once river diversion occurs the dam fill will be placed continuously through to completion. Dam safety would therefore be compromised if there were to be a significant multi-year hiatus for any reason during fill placement. As one means of mitigating that risk, it is essential that full financing for the Main Works Contract elements related to dam placing, flood evacuation tunnels and associated gate arrangements is secured prior to the commencement of river diversion.

Summary

The PoE endorses the recommendation of the FSL 1290 dam alternative from an economic perspective and strongly supports the need for further analysis to determine the preferred level of installed generation capacity.

2.11 Risk Assessment

The TEAS Consultant has undertaken a formal risk analysis to recognise the set of technical risk issues associated with the project. Each risk has a defined set of mitigation measures that are designed to reduce the residual risk to acceptable levels. The PoE was involved in parts of the risk assessment discussions and has reviewed the residual risk matrix.

Six risks remain classified as "Moderate" pending the implementation of the proposed suite of mitigation measures. The sources of the six remaining risks relate to sedimentation, seismicity, Ionakhsh fault with salt in-filling, locally poor quality of rock, creeping of faults and the risk that the hydraulic head is too high on gates in hydro-tunnels. It is anticipated that once the mitigation measures are implemented these risks will reduce to acceptable levels. However, care will be needed during the detailed design and construction stages to ensure this occurs.

The environmental and social risks have been considered under the ESIA task. The EDS PoE recognises that the ESIA conclusions need to be considered in conjunction with the technical considerations to ensure that, as a minimum, international good practice is adopted for all aspects of a proposed Rogun development.

The EDS PoE considers that a thorough techno-economic risk assessment has been performed and that with effective implementation of the proposed mitigation measures the level of technical residual risk can be expected to reduce to acceptable levels.

3. Issues for Detailed Design and Implementation Phase

The TEAS Consultant has presented the core elements of a feasibility-level design, based on international design standards, that satisfactorily meets the objectives of the Rogun project.

However, the PoE's support for the project is contingent upon ALL the design concepts recommended during the TEAS assessment being followed during the detailed design stage of the project (as listed in the published TEAS Phase II Summary report and its Appendix A: *"Summary of main recommendations of investigations, tests and studies to be performed early in the next stages of the Project"*).

In addition, it is recognised that quite a number of issues must be pursued and clarified at the detailed design and construction stages of the project. While these are included in full in the recommendations of the TEAS Consultant, the POE notes the following items of particular importance.

Detailed design

- The PoE endorses the further investigations proposed by the TEAS Consultant which focus on the:
  - details of the rock mass quality and piezometric condition of the abutments;
  - upstream border of the atypical zone downstream of the right side of the dam;
  - creeping trend of the active faults;
  - state of in-situ stresses;
  - quality of the rock mass in the underground works;
  - study and monitoring of the potentially unstable zones around the dam and in reservoir;
  - geotechnical characteristics of the construction materials;
  - grout curtain design, at depth under the dam and laterally, where a few additional boreholes would be necessary to confirm the final design;
  - full on-site testing of the proposed strengthening measures prior to development of detailed design of the remedial measures to DT1, DT2 and the Power House and Transformer Hall caverns.

Emergency Preparedness Plan

- A standard dam break analysis and associated inundation maps must be included in the development of an Emergency Preparedness Plan to be drafted prior to the commencement of reservoir impoundment.

Construction

It will be necessary to:

- undertake extensive monitoring and update of the numerical model for the caverns during further excavation to the final elevations;
- ensure that funding is confirmed as a minimum for the civil and hydro-mechanical works from diversion to dam completion. The design of facilities to manage floods during the construction phase assumes that construction of the project continues without any significant hiatus. If lack of funding or other event causes a substantial delay in the completion of the civil/mechanical works then the filling rate and operation of the reservoir will need to be reviewed to maintain adequate flood management capability;
- ensure quality supervision to international standards.

Operation

- Reservoir operation levels never to go above the core crest within the dam;
- Downstream discharges must always be in line with the stipulated operating regime.

In summary, the PoE's support for the project is contingent upon ALL the recommendations made by the TEAS Consultant during the assessment process being followed during the next stages of the project.

4. EDS PoE Involvement in Riparian Information Sharing and Consultation Meetings

EDS PoE representatives have so far attended five riparian consultation meetings as shown in Table 3 above and are comfortable that the consultation process enabled the full suite of technical issues to be disclosed and discussed.

Representatives of riparian governments and NGOs attended the meetings and the comments made during the sessions have been reported in the consultation summaries that are in the public domain on the WB web site.

The PoE considers the process to be transparent and notes that all the representatives from riparian countries have been given an opportunity to comment on the documents produced, and that comments received have been appropriately considered in the TEAS Consultant's work. The key issues that have been raised have centred on the safety of the dam and the downstream water releases during construction and operation. Extensive sets of answers have been prepared in response to all the questions raised and these are available on the WB web site.

5. Concluding Statement

The Engineering and Dam Safety Panel of Experts considers that the Techno-Economic Assessment Study for the Rogun HPP over the past three years has:

- addressed all the feasibility level issues of the project with a sufficient degree of technical due diligence;
- proposed dam alternatives where international quality standards have been incorporated into the feasibility-level designs;
- undertaken a comprehensive assessment of the economic viability of the various dam height alternatives using a regional power market model for a fully interconnected regional power system;
- considered the technical risks of the project and recommended a suitable suite of mitigating actions to effectively address them.

Notwithstanding the above, the EDS PoE notes that there are still matters to be addressed at the detailed design stage of the project, most notably to:

- determine the optimum installed capacity configuration;
- optimise arrangements for sediment management during the operation stage of the project;
- confirm the stabilisation measures for the powerhouse cavern.

It is the POE's view that the outcome of these detailed assessments will not affect the feasibility of the project.

The PoE reiterates the importance, from a dam safety perspective, of making all endeavours to ensure that dam construction can be completed in a continuous process once river diversion has commenced. In particular, the PoE recommends that full financing of those aspects of the works related to dam placing, flood evacuation tunnels and associated gate arrangements be secured prior to commencing river diversion.

From a techno-economic perspective the EDS PoE endorses the TEAS Consultant's recommendation for the further detailed consideration of the FSL 1290 masl dam alternative since:

- key dam safety issues can be acceptably addressed;
- from a sedimentation perspective it provides the longest project life;
- it addresses the exposure of Nurek to sediment build up in the medium term;
- it improves the extreme flood safety of the Vakhsh cascade as a whole enabling it to withstand the PMF;
- it is the most economic option by a clear margin and its economic performance is robust to a wide range of scenarios.

This endorsement is made with the requirement that ALL the recommendations made by the TEAS Consultant during the assessment process need to be followed during the next stages of the project (as listed in the published TEAS Phase II Summary report and its Appendix A: *"Summary of main recommendations of investigations, tests and studies to be performed early in the next stages of the Project"*).

In addition, the EDS PoE notes that a decision to proceed with a particular development alternative does not rest solely on techno-economic considerations. The recommendations of the Environmental and Social Impact Assessment need to be considered in conjunction with the technical considerations to ensure that, as a minimum, international good practice is adopted for all aspects of a proposed Rogun development.