COYNE ET BELLIER
Ingénieurs Conseils

ELC ELECTROCONSULT

IPA
Energy + Water Economics

TECHNO-ECONOMIC ASSESSMENT STUDY
FOR ROGUN HYDROELECTRIC CONSTRUCTION PROJECT

OSHPC BARKI TOJIK

PHASE 1 Report (Summary)

Assessment of the Existing Rogun HPP Works

- Objectives of study
  - TEAS Terms of Reference: "The Consultant shall carry out **an assessment of the existing works** at Rogun HPP to establish the adequacy of the selected site for the development of the Project"
  - This is of importance as it can affect: costs, site safety, dam safety and scheduling.
- Structure of the presentation
  - Open air works:
    - Roads and transportation tunnels,
    - Quarries, Conventional Vibrated Concrete (CVC), Conveyor Belt,
    - Construction Site, Equipment on site, General Site Condition.
  - Underground works:
    - Transportation tunnels, Drainage tunnels, Cable tunnels, Diversion tunnels
    - Powerhouse cavern and transformer hall
    - Electromechanical items
  - Conclusions

- PHASE 1 REPORT – 002378 RP. 39 Rev. C – Executive Summary

Open air works – Access roads and Transportation tunnels

– Roads

- Around **86 km** of roads have already been cut on site
- **Rehabilitation/Maintenance** of these roads are necessary to complete the future works
- Minimum width required for transport of equipment and material: **12 m to 15 m.**

– Transportation tunnels

- **Permanent** and **Temporary** tunnels
- **60 km** of tunnels planned. **27 km** have already been cut and lined.
- **Maintenance** and **remedial measures** are necessary (cf. slides on Underground Structures)

→ Accesses are a key issue to complete such a project

Open air works – Quarries/Borrow area

– Quarries should supply the materials for the underground and above ground concrete works and for the construction of the embankment Dam.

Source (Quarry/Borrow area)	Intended use	Processing / Treatment to bring to specifications
Borrow area 15	Dam body, Alluvium shell materials, concrete works	Remove materials > 700 mm which represents about 2-3% (for alluvium shoulders)
Lyabidora	Transition layers	Remove boulders > 100 mm which represents about 13 - 16 % (for transitions)
Borrow area 17	Loam material of the core	Reduce moisture content to 10-12 %. Remove materials > 200mm. Increase fine content
Q 26 A and B	Rockfill shell material	Physical and mechanical properties are to be tested and defined precisely.

Open air works – Conventional Vibrated Concrete (CVC)

– The aggregates plants consist in **very old machineries**, subject to many breakdowns, and consequently limit the batching plant.

– The equipment can be used for works which are **not on the critical path.**

– **A complete review of the plants** has to be realized, based on the demand of concrete.

Open air works – Conveyor Belt System

- The 1986 concept of Conveyor belt system consists in **4.3 km in open air and 2.1 km in a tunnel** (2 m width and can transport shell materials with a maximum size of 400 mm).
- The **crushing plant** is abandoned since long.
- **Some stretches** of the belt conveyor have been buried, some remains of steel frame cannot be reused.
- The **existing lining of the tunnel** must be checked, and **1.1 km of tunnel remains to be cut**.
- The roads running along the surface part of **the belt conveyor should be rehabilitated**.
- If the belt conveyor system is considered:
  - The remains of the existing equipment **cannot be economically refurbished**
  - The technology of the conveyors has improved since the Conveyor System has been designed **more than 30 years ago**. The performances of both the electro mechanical parts and **the belts have improved**.

Open air works – Construction site

- 5 construction sites
- Steel Assembly Plan + Spiral Cases Pre Assembly Plant

Open air works – Equipment on site

- Source of Equipment on site:
  - **Nurek Dam Project (1980's)**: for the very beginning of the works
  - **Supplied**: for site installation and permanent works in Powerhouse U5 and U6.
- Equipment condition:
  - Equipment of the **main Contracto**r RogunGESstoy: recent and in good condition (more oriented earthworks, not tunnelling works)
  - Equipment of **Subcontractors**: generally not recent.
- For future works:
  - **Reliability and performance** allocated is of prime importance
  - Old Equipment can be used for **pre-contract period**, not for works on critical path

Open air works – General Site Installation

– Labour Camps:

- The workers will be hired from **Rogun Town** and the villages in the vicinity
- The need to construct labour camps is anticipated to be limited.

– Camps/Facilities

- Restaurant, Clinic/First Aid, Hotel/Guest House are built and **in operation**
- Until August 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.
- **Rehabilitation** of some existing infrastructures is necessary
- Moreover the capacity of these infrastructures is **not sufficient for the completion of the entire works.**

– Camp plants/Utilities

- According to Client: Water Treatment, Fresh water supply network, Drainage systems, Supply of electricity) **mostly exist and at present are under exploitation**
- **Waste water treatment plants** (BIO 4200 and BIO 700) are installed
- No drainage system is apparent following the Consultant visit.

Findings: Open Air Works

Topic	Assessment
Access roads and Transportation tunnels	**Rehabilitation/maintenance** needed **Key issue** to complete such a project
Quarries	**Processing and testing** necessary to meet specifications
Conventional Vibrated Concrete (CVC)	**A complete review** of the plants has to be realized, based on the demand of concrete
Conveyor belt	The remains of the existing equipment cannot be economically refurbished **New belts** are necessary
Construction sites	**5 construction sites** identified
Equipment on site	Old equipment: adequate for **pre-contract** period only
General site	Labour Camps: construction **anticipated** to be limited Camps/Facilities: **Rehabilitation and expansion** required

PHASE 1 REPORT – 002378 RP. 39 Rev. C – Executive Summary

Underground Facilities - Approach

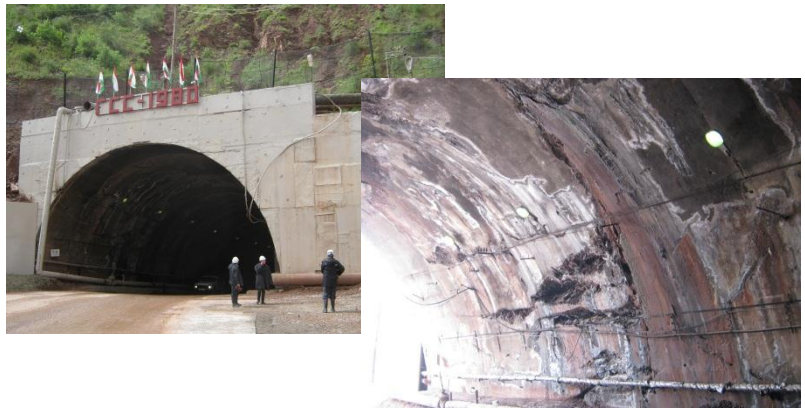
- Base Data of the Assessment
  - Inspections on Site
  - Field Investigations
  - Structural Analyses
- Calculation Models for Tunnels and for Powerhouse – Transformer Hall Complex
  - Implementation of 2D Models for Diversion Tunnels
  - Critical analysis of the 3D Model performed by Hydro Project Moscow
  - Implementation of a 2D Model for the PH and TH Caverns simulating the excavation process
  - Proposal of Strengthening Measures both for Tunnels and Powerhouse – Transformer Hall caverns
- International standards used as references
  - Eurocode: EC2, EC3, EC8
  - Russian Standards: **used for comparison of the load combination coefficients only**
- Costing
  - Estimation of the costs related with the proposed remedial measures is included in the Phase II Economic Analysis.

Inspections on Site

– Performed from June 2011 to June 2013

- Site Inspections carried out in:
  - Transportation Tunnels T3, T3', T37, T4, T2, T8, T6
  - Diversion Tunnels
  - Cables Tunnels
  - Hydraulic Curtain Galleries Left Bank, Right Bank, Joint Left – Right
  - Main Access Adits
  - Powerhouse
  - Transformer Hall
- Results summarized in:
  - Records of detected damages
  - Collection of images and photos taken during the inspections

Annex 06 of RP. 39



Adit to P3

Adit to P3

Id Datum 1619 Chainage From: 0 Chainage To: 50 date 08/06/2011

Damages:

This is the connection between the Drainage gallery to the P3 tunnel. Along this stretch the tunnel have to be lined, only temporary suuports heve been placed. The adit is 5m large and 10m hight. Rock bolts with pattern 3 x 3 m are installed.

Inspections on Site

– Performed from June 2011 to June 2013

- Records of detected damages in terms of surface %
  - For a set of tunnels a specific damages survey was carried out
  - Different classes of damages were selected
  - Tunnels were divided into stretches of fixed length and for each stretch the occurrence of each damage was shown in term of percentage of the tunnel surface of that stretch

Annex 08 of RP. 39

DAMAGES SURVEY LIST

LEGEND :

D1 : No Connection between Sidewll and Invert
D2 : Lining deterioration (honey comb) and damages
D3 : Lining weakening due to physical and chemical processes
D4 : Water Seepages
D5 : Steel bars exposed for Concrete cover damages

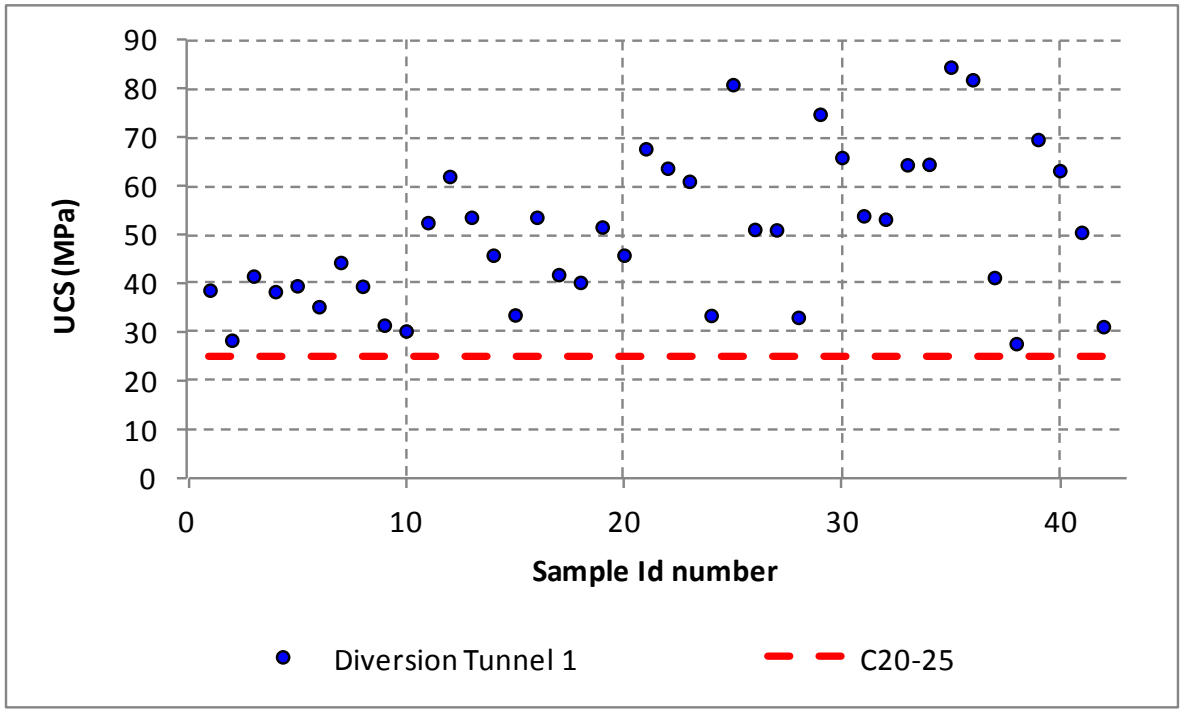
NAME	FROM Chainage	TO Chainage	D1 %	D2 %	D3 %	D4 n°	D5 %
Stage 1 Power Tunnel	1+50	1+70	0	0	0	0	0
Stage 1 Power Tunnel	1+70	1+90	0	0	0	0	0
Stage 1 Power Tunnel	1+90	2+10	0	0	0	0	0
Stage 1 Power Tunnel	2+10	2+30	0	0	0	0	0
Stage 1 Power Tunnel	2+30	2+50	0	5	0	0	0

Field Investigations

Annex 07 part. A of RP. 39

– Uniaxial compression tests on concrete samples

- Performed on:
  - Diversion Tunnels 1 and 2
  - Temporary Headrace tunnel
  - Transportation tunnels T3 and T4
  - Powerhouse



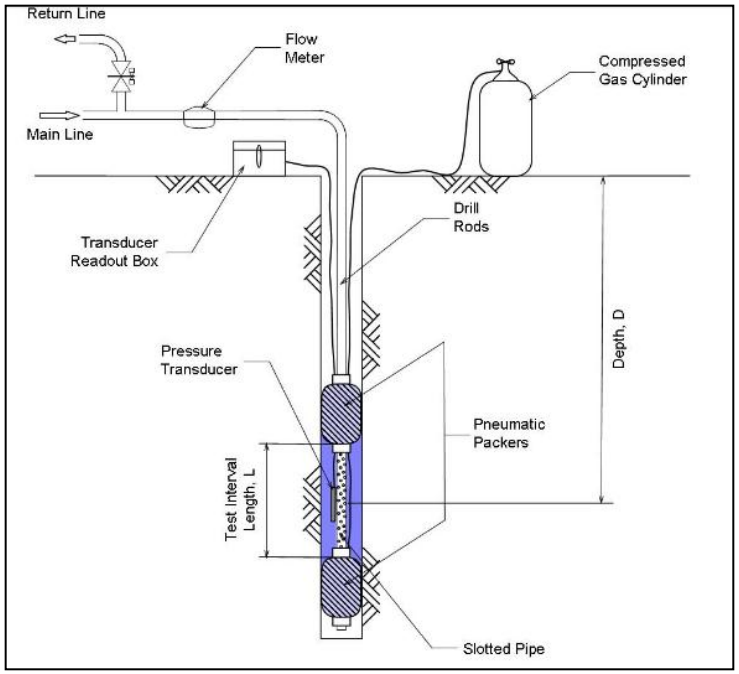
Coring

Laboratory Testing on samples

Field Investigations : Lugeon Tests

– LUGEON TEST CONCEPT AND PROCEDURE

- **Reference:** Maurice Lugeon (1933)
- **Scope:**
  - Estimating hydraulic conductivity in Rock masses (parameter that identifies the tendency of water to seep into a porous substratum) and indirectly estimating also the effectiveness of the grouting treatments performed in the past.
- **Steps:**
  - Water at constant pressure is injected into the rock mass through a slotted pipe bounded by pneumatic packers
  - Prior to the beginning of the test a maximum test pressure (P_{max}) is defined.
  - The test is conducted in five stages, with a particular water pressure magnitude associated with each stage. A single stage consists of keeping a constant water pressure at the test interval for 10 minutes by pumping as much water as required. The first stage is held at a low water pressure, increasing the pressure in each subsequent stage until PMAX is reached. Once PMAX is reached, pressures are decreased following the same pressure stages used on the way up, thus describing a "pressure loop".
  - During the execution of each stage, both water pressure (P) and flow rate (q) values are recorded every minute. Subsequently, average values for P and q are then used to compute the hydraulic conductivity for each stage.

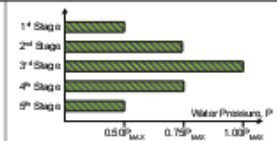
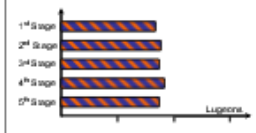
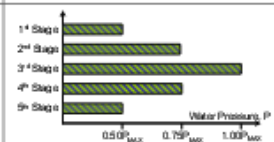
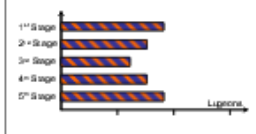
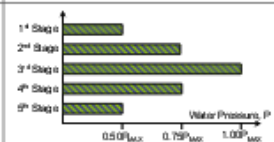
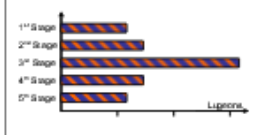
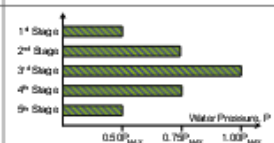
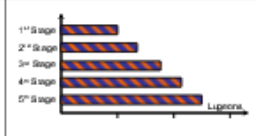
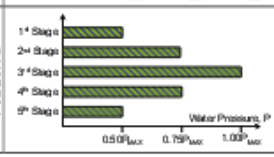
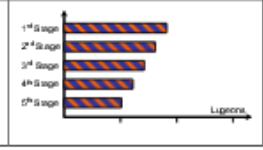


$$\text{Lugeon Value} = \alpha \times \frac{q}{L} \times \frac{P_0}{P}$$

Field Investigations

– RESULT INTERPRETATIONS:

- Interpretation practice: Houlsby (1976)
  - The current Lugeon interpretation practice is mainly derived from the work performed by Houlsby (1976).
  - Houlsby proposed that representative hydraulic conductivity values should be selected based on the behavior observed in the Lugeon values computed for the different pressure stages.
- Behaviour classification
  - Laminar Flow
  - Turbulent Flow
  - Dilatation
  - Wash-out
  - Void Filling

BEHAVIOR	PRESSURE STAGES	LUGEON PATTERN	DESCRIPTION	REPRESENTATIVE LUGEON VALUE
LAMINAR			All Lugeon values about equal regardless of the water pressure	Average of Lugeon values for all stages
TURBULENT			Lugeon values decrease as the water pressures increase. The minimum Lugeon value is observed at the stage with the maximum water pressure	Lugeon value corresponding to the highest water pressure (3^{d} stage)
DILATION			Lugeon values vary proportionally to the water pressures. The maximum Lugeon value is observed at the stage with the maximum water pressure	Lowest Lugeon value recorded, corresponding either to low or medium water pressures (1st, 2nd, 4th, 5th stage)
WASH-OUT			Lugeon values increase as the test proceeds. Discontinuities' infillings are progressively washed-out by the water	Highest Lugeon value recorded (5th stage)
VOID FILLING			Lugeon values decrease as the test proceeds. Either non-persistent discontinuities are progressively being filled or swelling is taking place	Final Lugeon value (5th stage)

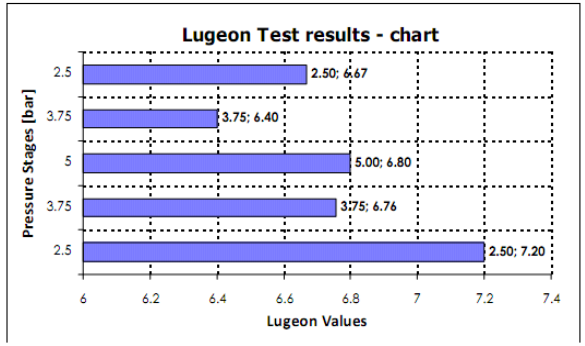
Annex 07 part. B of RP. 39

Field Investigations

– LUGEON TESTS

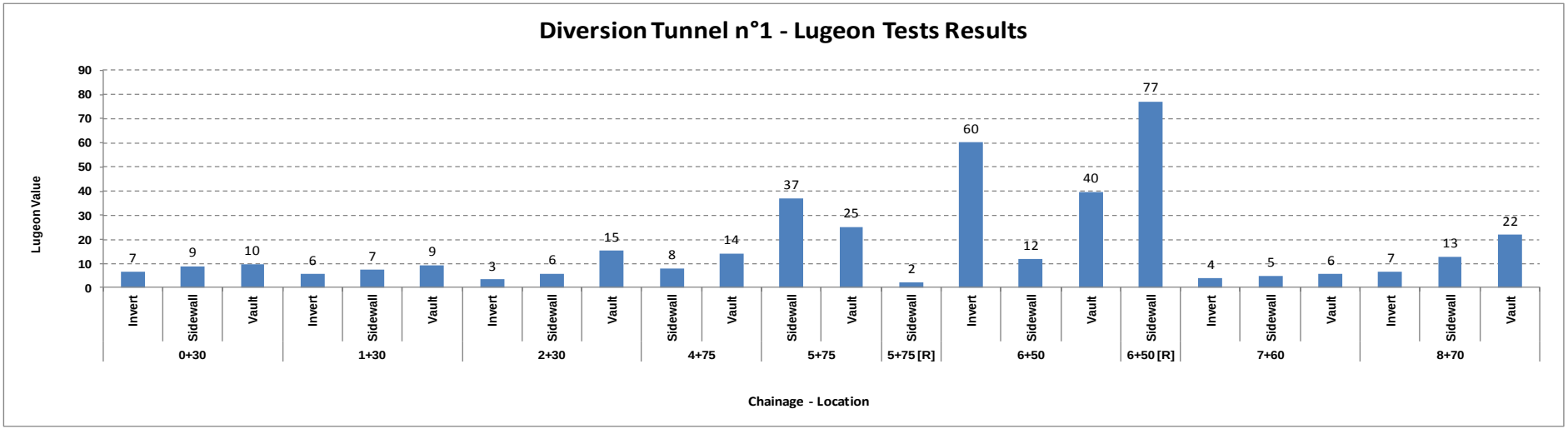
- Performed on:
  - Diversion Tunnels 1 and 2 for different chainages in 3 positions
  - Temporary Headrace tunnel

1	Diversion Tunnel n1 - ch. 0+30 - [Invert]	Lugeon 0-10 min



Lugeon Test results - Table

l/min 0-5 min	l/min 5-10 min	l/min 0-10 min	liter 0 min	liter 5 min	liter 10 min	Pressure [bar]	Lugeon value
695	2.8	2.6	2.7	681	708	2.50	7.20
736	4	3.6	3.8	716	754	3.75	6.76
786	5.2	5	5.1	760	811	5.00	6.80
835	3.6	3.6	3.6	817	853	3.75	6.40
874	2.6	2.4	2.5	861	886	2.50	6.67



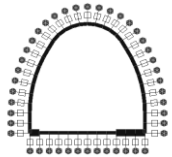
Structural Analyses

Annex 09 of RP. 39

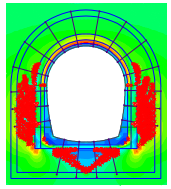
– IMPLEMENTATION OF 2D MODELS FOR TUNNELS

– For the Assessment

- 2D Frame Beam Models:
  - Tunnels
  - Rock Load Approach
  - 39 Model – 6 load combinations each



– For the proposed **Remedial Measures**



- 2D Beam Models with Rock - Structure interaction approach:
  - Diversion Tunnels 1 and 2
  - Detailed models on the tunnel section in the worst conditions

N°	FRAME	N°	FRAME
1	DG1-DG2_01_F2	17	T4_1_F2
2	DG1-DG2_02_F2	18	T4_2_F2
3	DG3-DG4_01_F2	19	T4_3_F2
4	DG3-DG4_02_F2	20	T4_5_F2
5	DT123_02_F2	21	T4_6_F2
6	DT123_2_DITCH_F2	22	T8_1_F2
7	DT123_3_F2		
8	DT123_5_F2		
9	T2_1_F2		
10	T2_1P_F2		
11	T3_1_F2		
12	T3_1_FIXED_F2		
13	T3_2_F2		
14	T3P_5_F35_F2		
15	T3P_6_F2		
16	T3P_6_FIXED_F2		

N°	FRAME
29	DIV_SEC_01_K1_B170_INV_F2
30	DIV_SEC_01_K1_B170_F2
31	DIV_SEC_01_K1_B350_F2
32	DIV_SEC_01_K1_ROOF_F2
33	DIV_SEC_01_K3_B170_F2
34	DIV_SEC_01_K3_B170_INV_F2
35	DIV_SEC_01_K3_B350_F2
36	DIV_SEC_01_K3_ROOF_F2
37	DIV_SEC_02_el_link_F2
38	DIV_SEC_02_no_link_F2
39	DIV_SEC_03_F2

– For the estimation of the Remedial Measures

- On the basis of the critical analyses made on the Diversion Tunnels, at a feasibility level, the proposed remedial measures have been extended to the majority of the permanent tunnels and the correspondent costs included in the Phase II Economic Analysis.

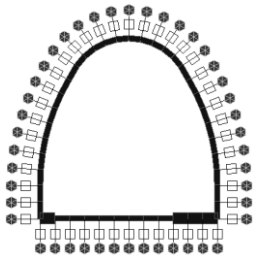
Structural Analyses : ASSESSMENT

– IMPLEMENTATION OF 2D FRAME MODELS – ROCK LOAD APPROACH

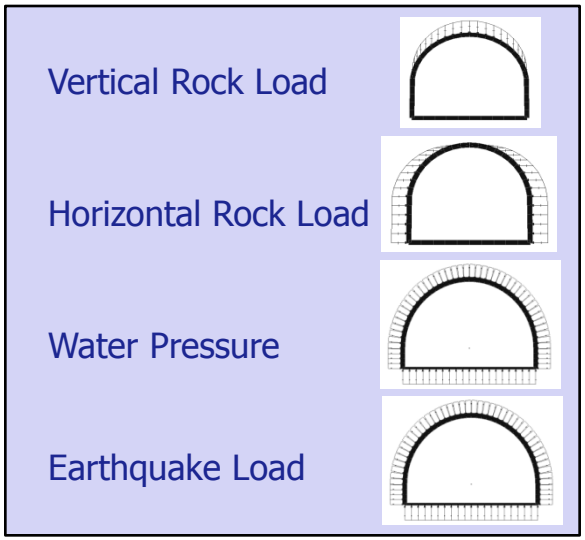
Annex 09 of RP. 39

- 2D Beam Models implementation steps:
  - Frame geometry definition (including boundary conditions);
  - Material properties;
  - Load conditions (rock load approach);
  - Sectional verifications for combined compressive and bending stresses;
  - Sectional verifications for shear stresses.

- **Total: 39 Models implemented**

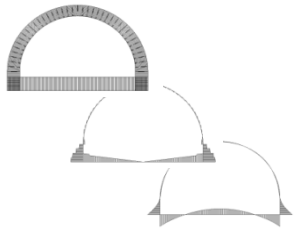


$$k = \frac{E}{R_{eq}} * \frac{1}{(1+\nu)}$$

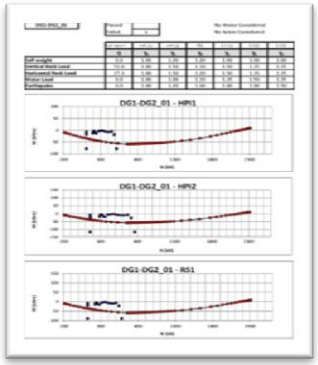


Sectional Verifications

Internal Forces



Sectional verifications

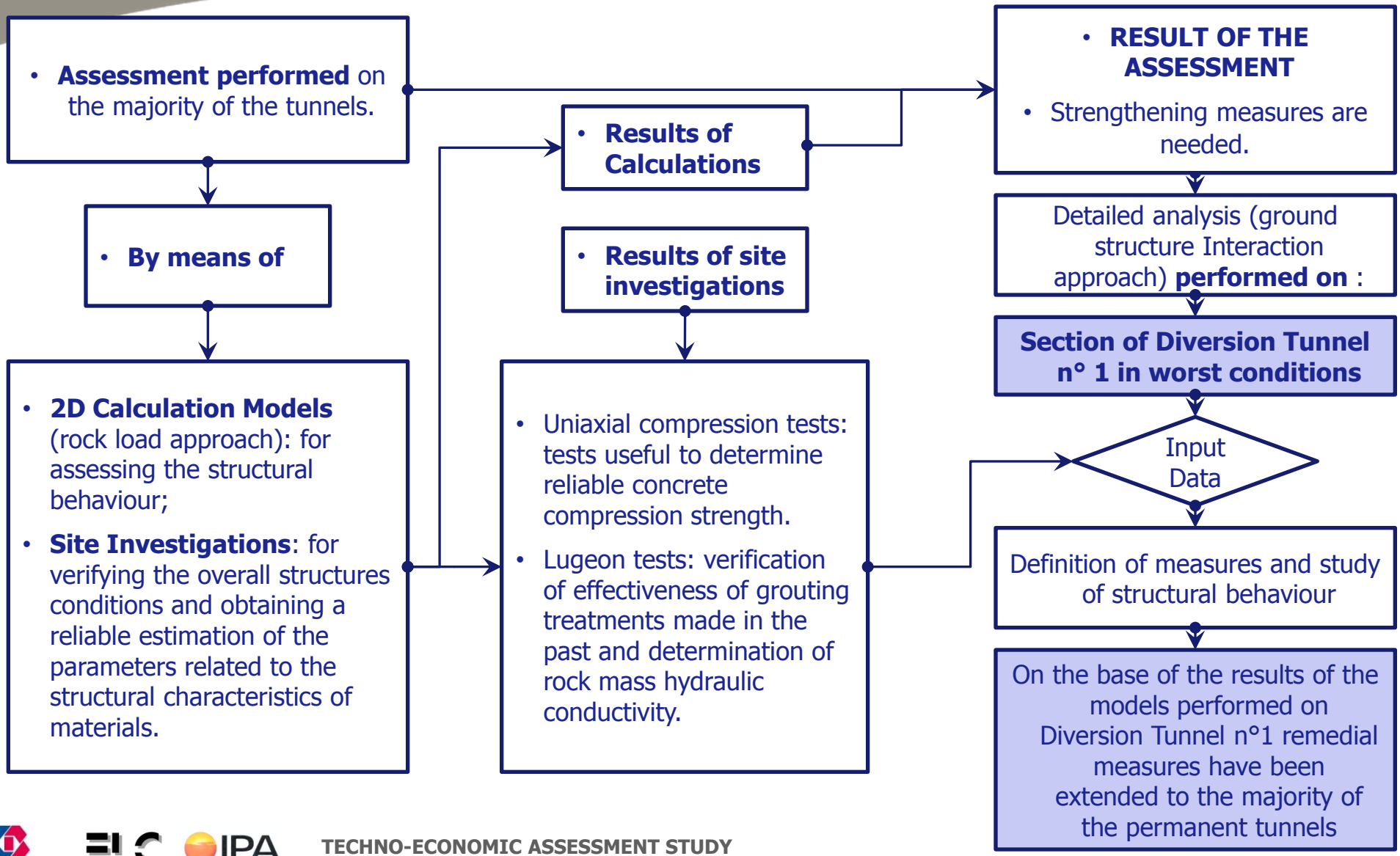


Load Combinations

			HPI1	HPI2	RS1	EU1	EU2	EU3
			γa	γa	γa	γa	γa	γa
Self Weight			1.00	1.20	1.20	1.00	1.00	1.00
Vertical Rock Load			1.00	1.50	1.10	1.50	1.35	1.35
Horizontal Rock Load			1.00	1.50	1.20	1.50	1.35	1.35
Water Load			1.00	1.00	1.10	1.35	1.50	1.35
Earthquake			1.00	1.20	1.00	1.00	1.00	1.50

Comparison of different Standard Codes in evidenced at this step.

FROM ASSESSMENT TO REMEDIAL MEASURES



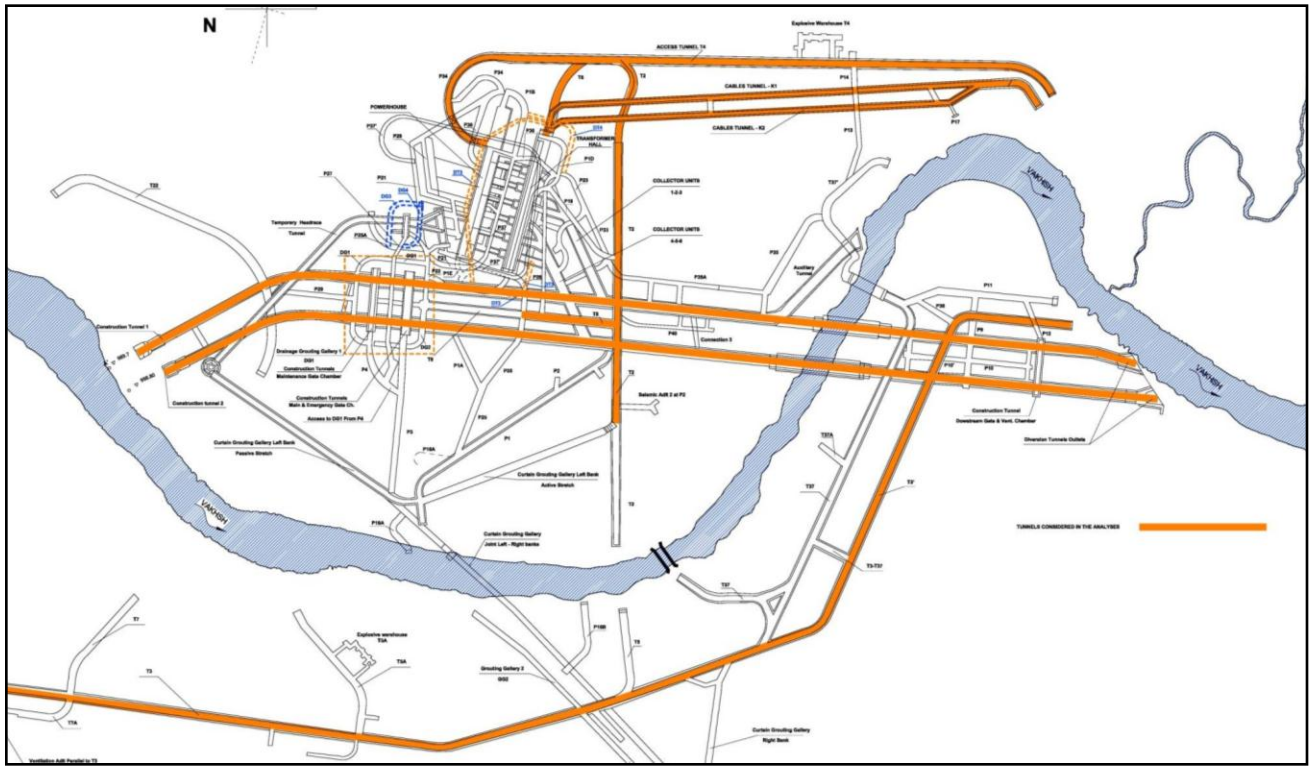
STRUCTURES FOR WHICH REMEDIAL MEASURES ARE NECESSARY

Mayor Remedial Works

- Diversion Tunnels 1 & 2
- PH-TH Caverns
- Powerhouse Access Tunnel T-4
- Permanent Access Tunnel T-3'

Minor Remedial Works

- Cables Galleries
- Powerhouse Drainage Galleries
- Temporary Access Tunnels T-3, T-37 and T-37'
- Stage 1 Headrace Tunnel



– Estimation of the costs for Remedial Measures

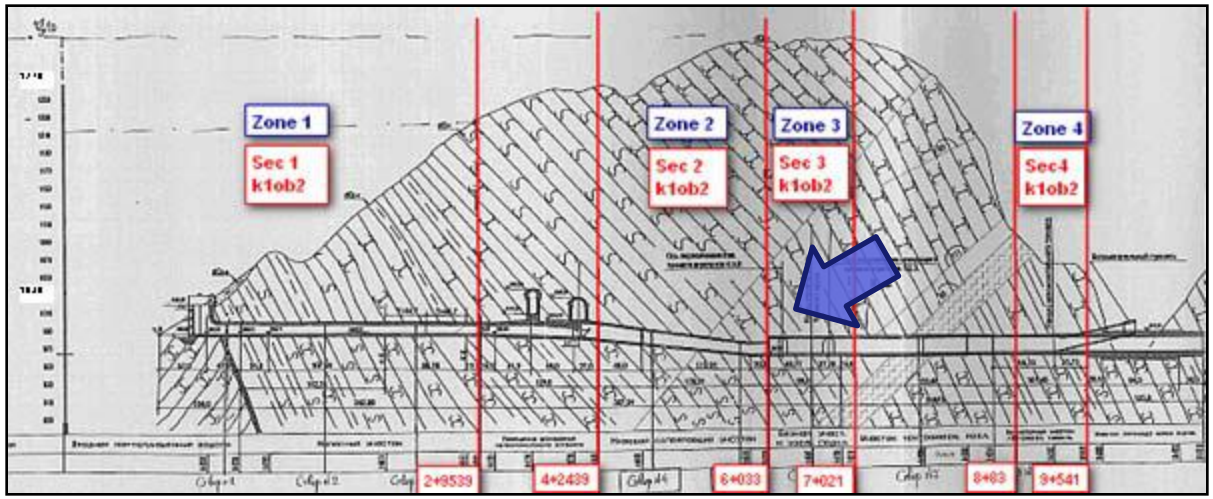
- Total cost of the remedial measures is about 1.5 % of the Total Costs

Annex 10 of RP. 39

Remedial Measures for Diversion Tunnel section in worst condition

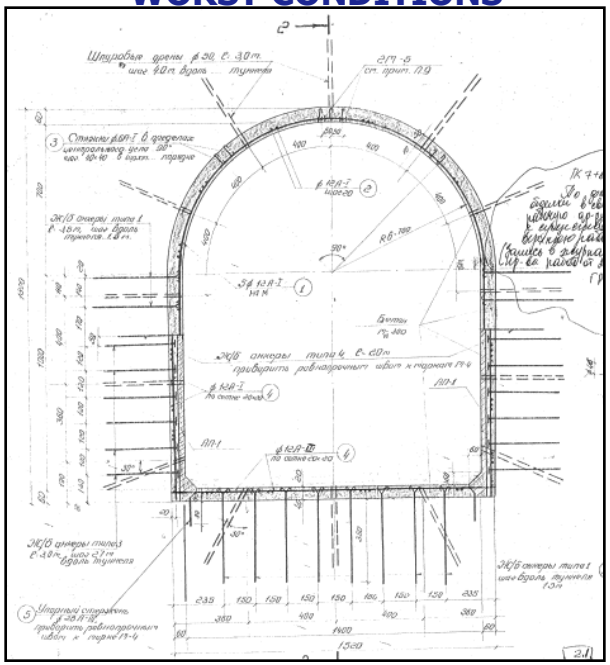
– Implementation of 2D Model : Ground – Structure Interaction

- 2D Model: Ground – Structure Interaction:
  - **Determination of the section in the worst condition for Diversion Tunnel**
  - Determination of plastic zone development around the tunnel lining
  - Definition of present lining behavior simulating the excavation phases and lining installation phases
  - Study of the behavior of the proposed stabilization measures



Section in zone 3

SECTION IN THE WORST CONDITIONS



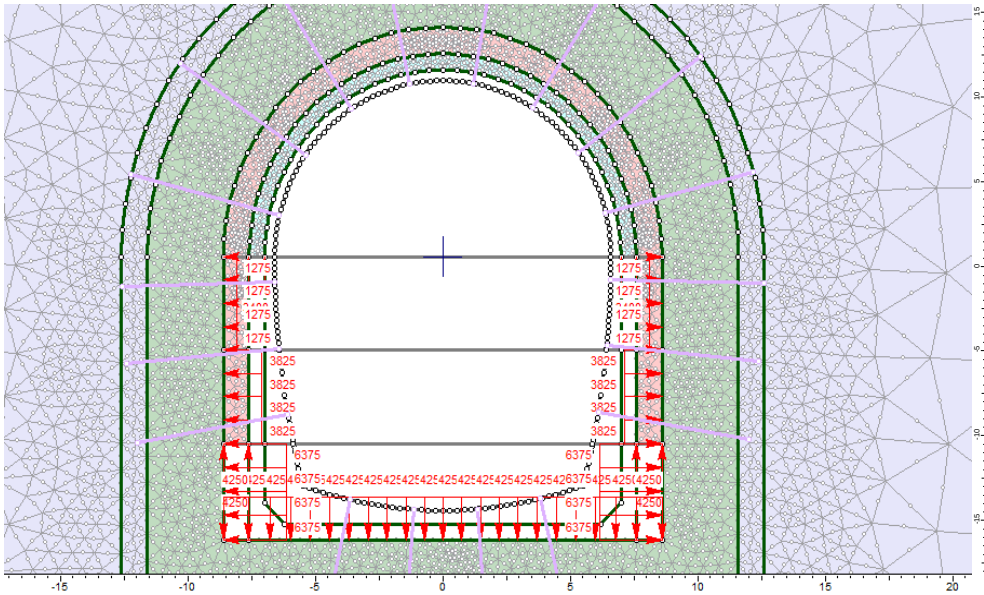
Remedial Measures for diversion tunnels

– Implementation of 2D Model : Ground – Structure Interaction

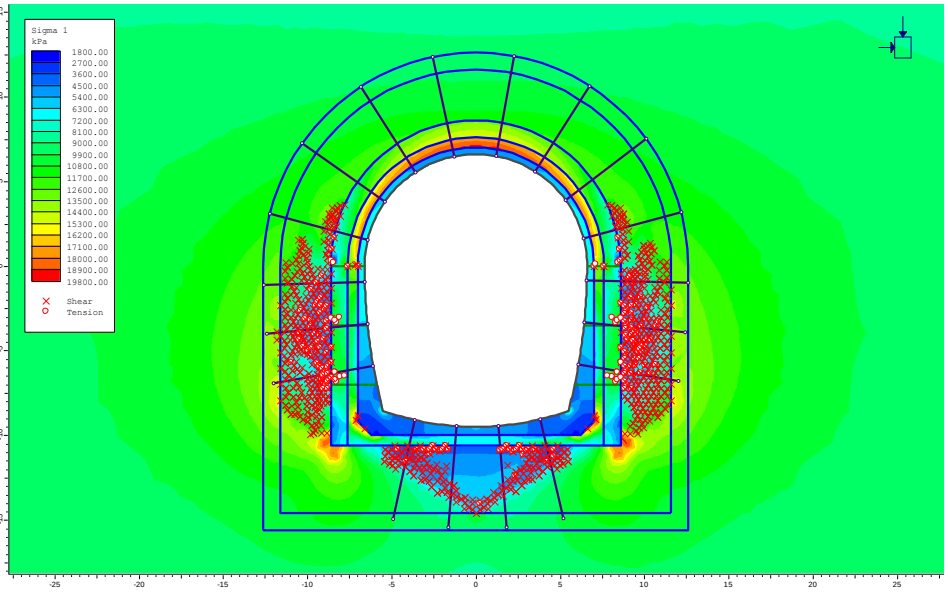
Annex 11 of RP. 39

- 2D Model : Ground – Structure Interaction:
  - Determination of the section in the worst condition
  - Determination of plastic zone development around the tunnel lining
  - **Definition of present lining behavior simulating the excavation phases and lining installation phases**
  - **Study of the behavior of the proposed stabilization measures**

Simulation of excavation phases and original lining installation



Simulation of proposed remedial measures for the section analyzed

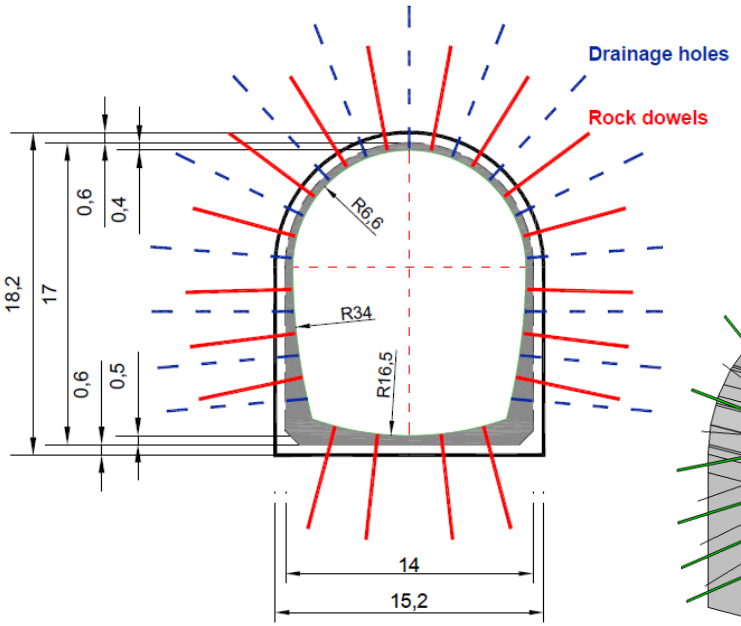


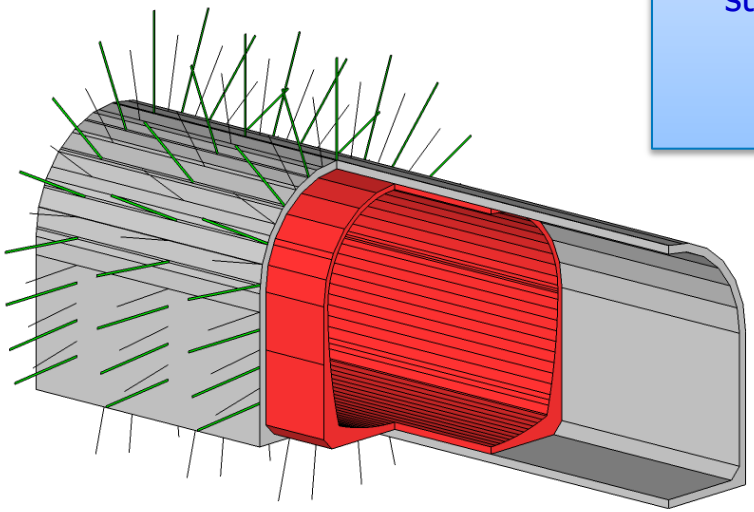
Annex 11 of RP. 39

Proposed Remedial Measures For Diversion Tunnels

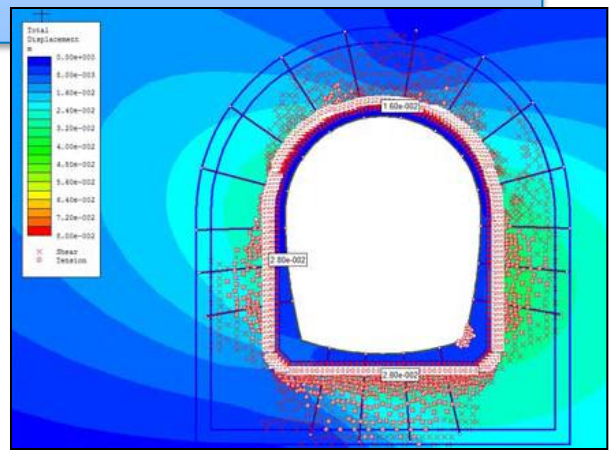
– Implementation of 2D Model: Ground – Structure Interaction approach

- Model with ground – structure interaction approach has been used for verifying the behaviour of the suggested remedial measures





- Drainage holes 8 m long
- Dowels 6 m long
- Additional concrete lining with steel lattice girders

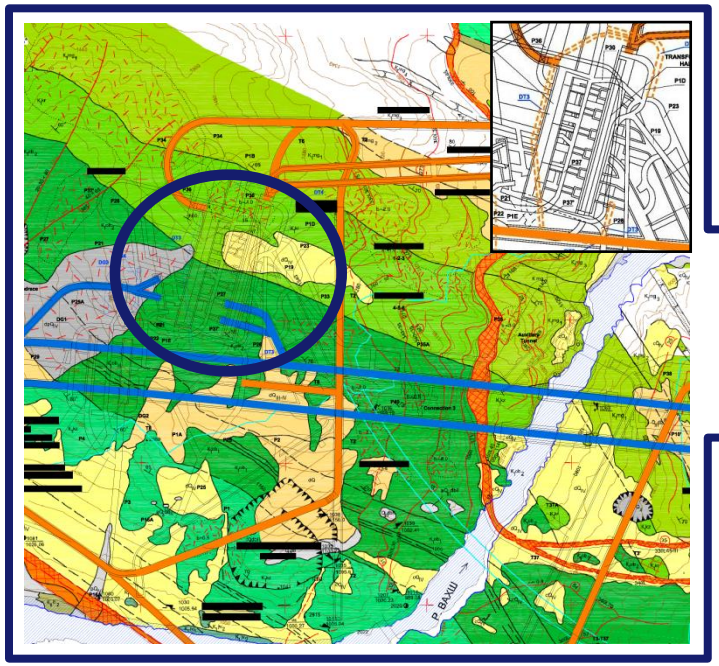


Findings: Tunnels

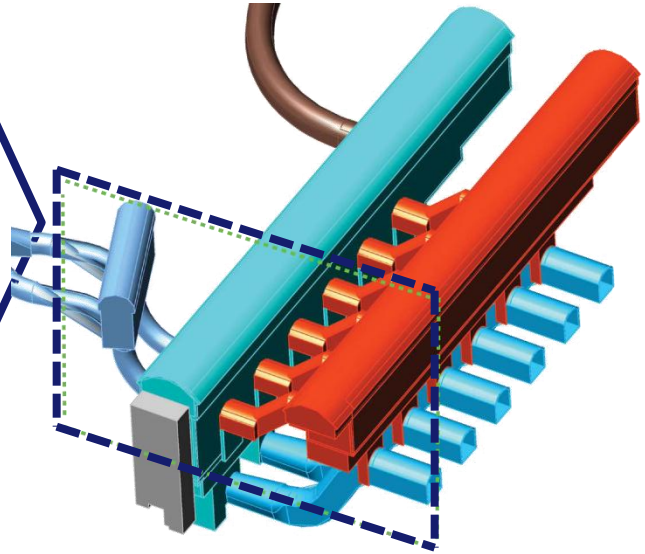
Topic	Assessment	Recommendations
Transportation Tunnels	They **do not fulfill** the technical requirements in respect to safety and serviceability foreseen by the presently internationally recognized design criteria and Standards, and the tunnels permanent supporting systems need to be strengthened.	• Strengthtening Measures are Needed • Further analyses will need to be carried out in a **subsequent detailed design phase** to identify 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.
Drainage Tunnels		
Diversion Tunnels		

Powerhouse – Transformer Hall

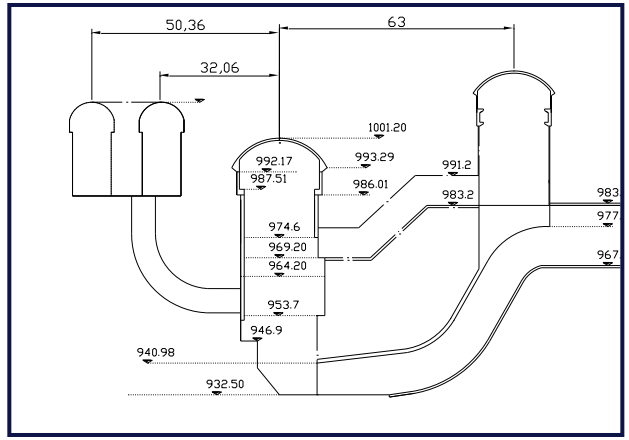
– IMPLEMENTATION OF A NEW 2D MODEL



Selection of Cross Section

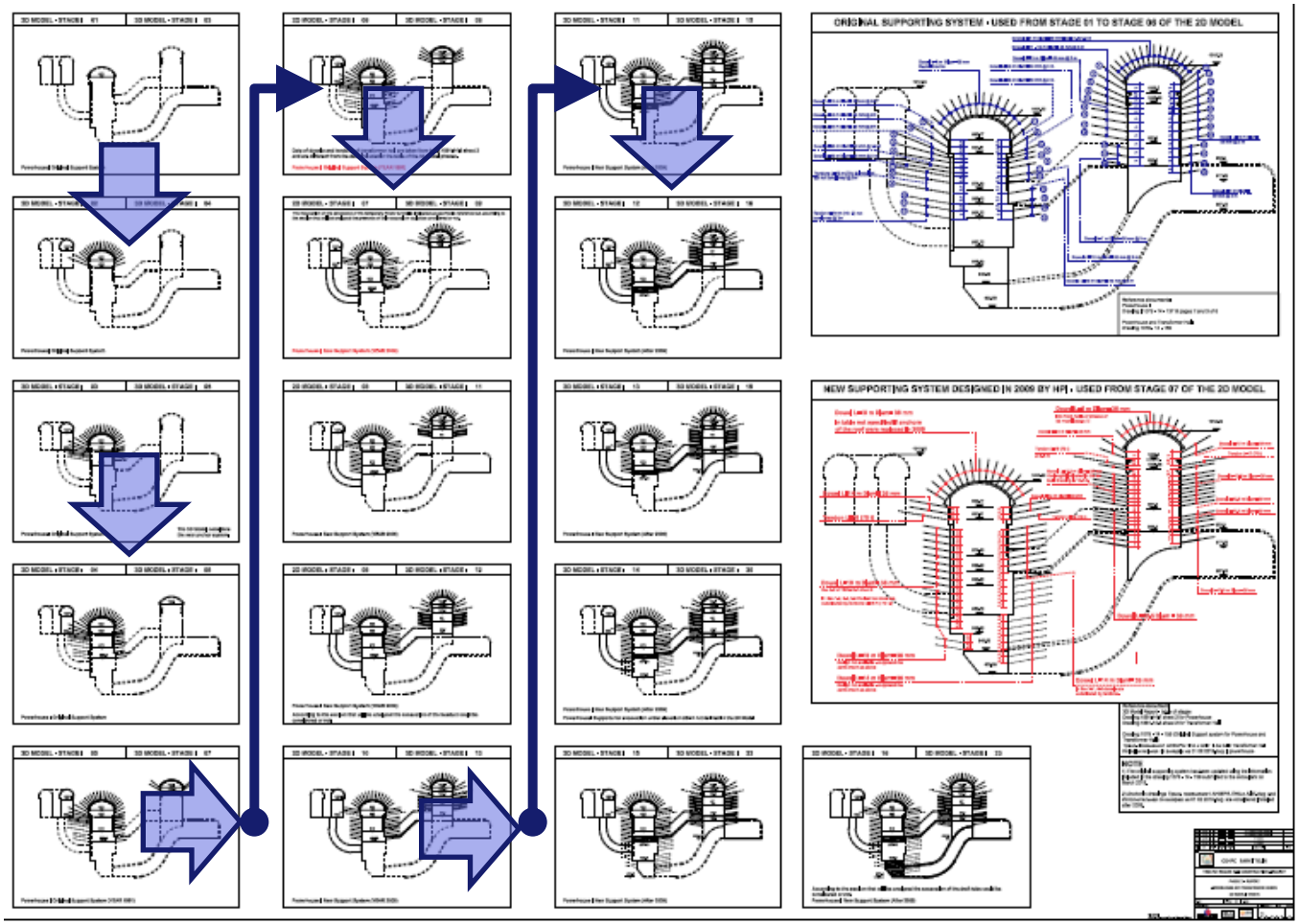


2D Model with consideration of excavation phases and supporting system installation phase



Powerhouse – Transformer Hall

– IMPLEMENTATION OF A NEW 2D MODEL

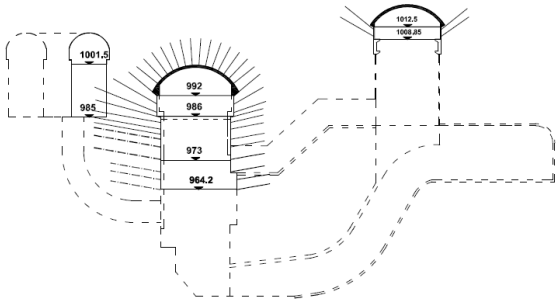


Implementation of detailed 2D Model simulating the excavation phases and the supporting system installed in the past.

Powerhouse – Transformer Hall

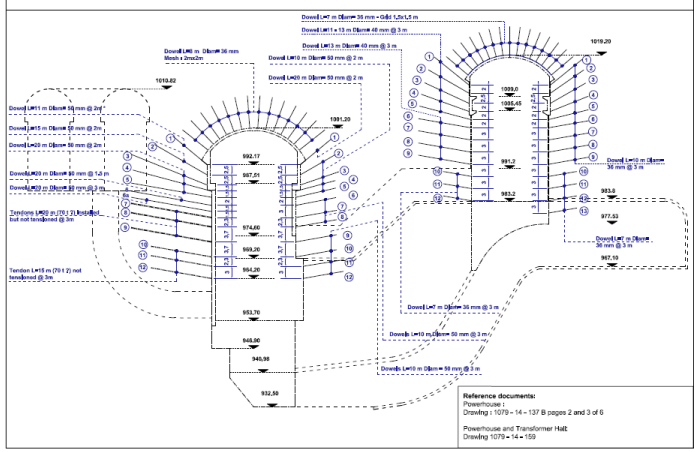
– IMPLEMENTATION OF NEW 2D MODEL – New Supporting System (After 2009)

2D MODEL - STAGE : 05 | **3D MODEL - STAGE : 07**



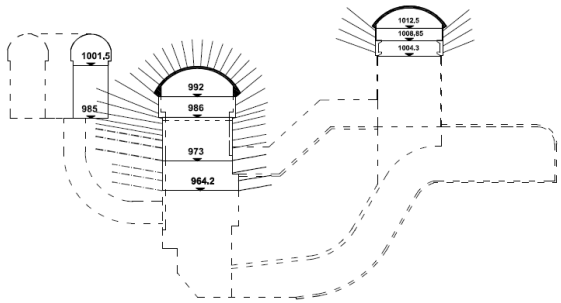
Powerhouse : Original Support System (YEAR 1991)

ORIGINAL SUPPORTING SYSTEM - USED FROM STAGE 01 TO STAGE 06 OF THE 2D MODEL



From Original to New Supporting System

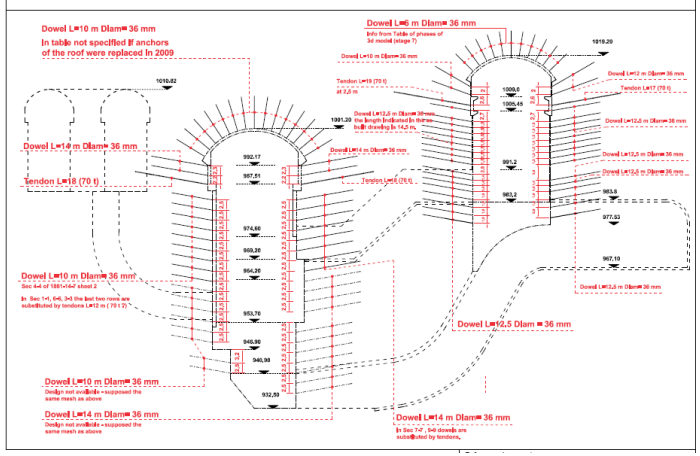
2D MODEL - STAGE : 06 | **3D MODEL - STAGE : 08**



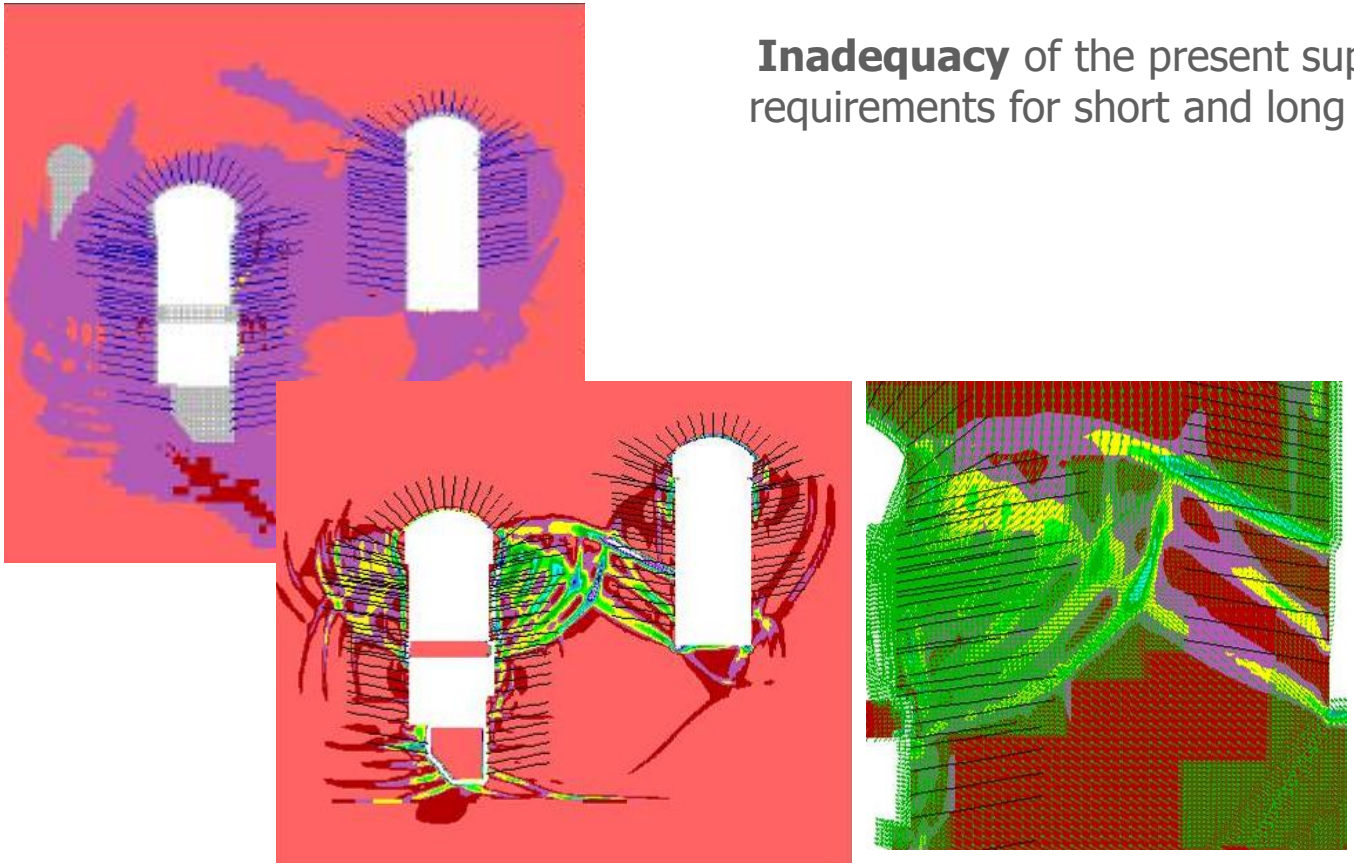
Data of dowels and tendons of transformer hall are taken from table 1861-14-6 sheet 2 and are different from the data included in the table of the 3d model phases.

Powerhouse : Original Support System (YEAR 1991)

NEW SUPPORTING SYSTEM DESIGNED IN 2009 BY HPI - USED FROM STAGE 07 OF THE 2D MODEL



Results of the Powerhouse – Transformer Hall 2D Model
Present Situation



Inadequacy of the present supports to fulfil the safety requirements for short and long term excavation stability

Implementation of

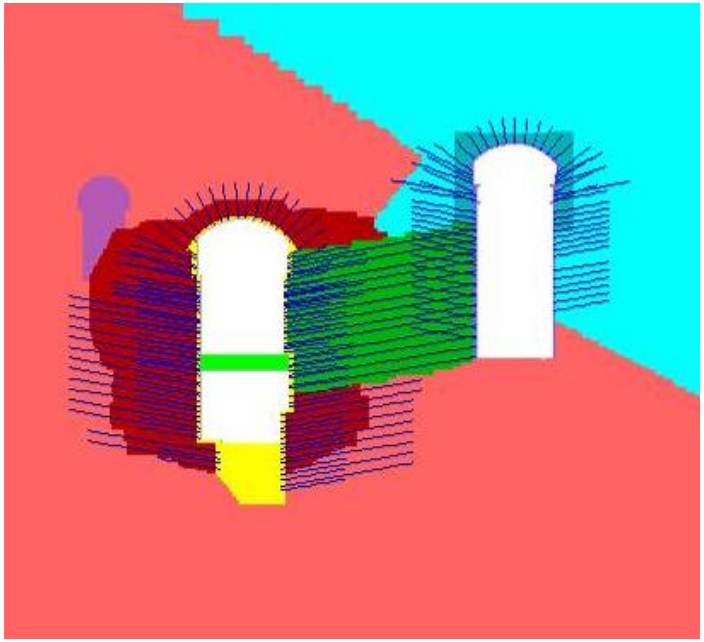
ADDITIONAL SUPPORTING SYSTEM

IS

MANDATORY

Results of the Powerhouse – Transformer Hall 2D Model

Identification of possible remedial measures and preliminary evaluation of their behaviour



- **Installation of additional tendons**
- **Multiple Packer Sleeved Pipe System in the pillar between PH and TH**
- **Installation of a suitable Monitoring System**

• The modelling studies performed show that with these **reinforcement and stabilization measures**, a **more favorable distribution** in the state of stress in the pillar between the two caverns is achieved.

• **A decrease** in the computed increment of convergence value with respect to the value predicted with the reinforcement as in the present design is also noted.

Findings: Powerhouse and Transformer Hall

Topic	Assessment	Recommendations
Powerhouse and Transformer Hall Complex	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.	•Strengthtening Measures are Needed •**Monitoring System implementation is mandatory** •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 interventions detailed design will be completed**, the full compliance of the work with the required criteria of safety and serviceability.

ELECTROMECHANICAL ITEMS

INSPECTIONS ON SITE:
During the mission a visual inspection of the existing turbine and generator components stored in **Ilyak** and **Rogun** was carried out.
Scope of the inspection was that to check the conservation state of the available components and their identification mark.

- Power Generating Equipment
- Turbine Components
- Hydraulic Steel Structures

For each stored component the conditions have been assessed listing the maintenance and the refurbishment works necessary for restoring suitable working conditions

ELECTROMECHANICAL ITEMS

Examples of Tables included in the Phase 1 Report

Main Item	Available	
	Unit 1	Unit 2
Spiral case and stay ring (both available for three units plus some additional part of stay ring)	Yes	Yes
Draft tube cone (available for all the six units)	Yes	Yes
Draft tube elbow (not clear if available for three or six units)	Yes	Yes
Head cover	Yes	Yes
Bottom cover	Yes	Yes
Runner	Yes	Yes
Guide vanes and servomotors	Yes	Yes
Ring gate and servomotors	Yes	Yes
Turbine Shaft	Yes	Yes
Turbine guide bearing		
Turbine shaft seal		
Cone supporting thrust bearing		
Governor		
Stator		
Rotor		
Excitation system and voltage regulator (to be		
Generator shaft		
Generator guide bearing and upper bracket		
Generator lower bracket		
Generator thrust bearing (pads and other el missing)		
Main transformer		
Cooling systems		
Other minor auxiliaries		

Examples of Tables listing the components available on Site and the relevant refurbishment works necessary for restoring suitable operative conditions.

N.	Part	Q'ty	Place	Repairs
Turbine				
1	Lining of draft tube elbow M1-M10	1	Rogun Quarry 15 (RQ 15)	anticorrosion
2	Lining of draft tube cone M2-M6	1	Ilyak	anticorrosion
3	Turbine stay ring M4-M9	1	Ilyak	anticorrosion
4	Spiral case M24-M46	1	Ilyak	anticorrosion
5	Accessories M3;M7;M10;M14;M15;M48;M50-M52			Revision, finishing, anticorrosion
6	Turbine shaft M70	1	Ilyak	Technical inspection
7	Runner M 69 (weight 78 t) (carbon steel)	1	Ilyak	revision
8	Turbine head cover M18 –M21	1	Ilyak	anticorrosion
9	Guide vanes M27 –M50	1	Ilyak	anticorrosion

ELECTROMECHANICAL ITEMS and HYDRAULIC STEEL STRUCTURES

Findings

Topic	Assessment	Recommendations
• **Power Generating Equipment** • **Turbine Components** • **Hydraulic Steel Structures**	Inspections on Site have been performed recording the present conditions of the available electromechanical equipment and Hydraulic Steel Structures already installed or stored on Site but not installed yet.	• **Tables listing the necessary remedial works have been included in the main Phase 1 Report.** • **Costs for rehabilitation works have been included in the Economic Analysis of Phase II Report.**

Conclusion

– Underground Structures

- Existing works range in quality from:
- **adequate** (e.g. Diversion Tunnels and Headrace tunnel Gates Caverns …); to
- **requiring minor remedial works** (e.g. transportation tunnels, drainage galleries …); or
- **requiring mandatory and sophisticated remedial actions** (e.g., permanent transportation tunnels, Diversion tunnels and Powerhouse –Transformer hall Caverns).
- Remedial action is most urgent for the **Diversion tunnels** and **Powerhouse/Transformer hall** because:
- **For Diversion Tunnels**: they are the first structures foreseen to be in operation and they will be used as tailrace tunnels in final configuration.
- **For PH-TH Complex**: the degree of deformation observed, also confirmed by 2D Calculation Model Performed, indicates inadequate safety conditions for Short Term and Long Term Excavation Stability.
- **These remedial actions for tunnels** are technically feasible and design criteria have been provided for specializing in a final design stage the proposed remedial measures that are expected to bring works to international standards;
- The results of the 2D Model of the PH-TH Caverns confirms that, with the proposed stabilization measures, it is possible to improve the stability conditions of the system. The Study performed **represents a sound reference in order to develop the final detail design** of the Stabilization works for making the structures compliant with the present internationally recognized standards safety requirements;
- Costs of upgrades and remedial works have been estimated and will be included in the economic analysis. Additional costs are about 1.5 % of total costs.

THANKS FOR THE ATTENTION.