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Pumped Storage (2014) Ltd.

ELECTRA INFRASTRUCTURE

Project:

Manara Pumped Storage Power Plant (MPSPP)

Powerhouse
Design Criteria Report

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Foreword

The current status of the design criteria displays the basics to start structural analysis calculations. Several items need a design progress to be specified, which will be updated later.

Contents

Figures and tables

1 Report Objective

This report contains the design concepts, assumptions, parameters, criteria, and methods to be employed for the machine cavern concrete structure of Manara Pumped Storage Powerplant (MPSPP). The objective of this document is to establish the basis for the structural analysis of the detail design.

All designs shall be performed according to agreed codes and standards listed below, and sound engineering practice in a consistent way. SI units will be used in computations.

1.1 Project Introduction

The Israeli Electricity Authority, established under the Electricity Sector Law, 5756-1996 (the "IEA") has decided to increase the instantaneous power available on the grid by adding PSPP's to the existing generation capacity. Ellomay Pumped Storage (2014) Limited is a private investor that is developing the Manara pumped storage plant project. The EPC has to design a PSPP that includes all equipment and civil works elements that is capable of producing:

• 156 MW for the current works, with a dedicated runner and fulfilling all regulation and this Owner's Requirements document regarding the 156 MW PSPP
• 220 MW with a dedicated runner and fulfilling all regulation and this Owner's Requirements document regarding the 220 MW PSPP

For the two capacity layouts of the plant (namely the 156 MW mode and the 220MW optional mode) initially 1 runner for 156 MW shall be provided together with detail engineering for the 220 MW runner. The manufacturing and delivering of the 220 MW runner shall be done as option after an additional order from the Owner. That is to say the 156 MW (turbine mode) runner shall be installed, and only after and subject to the allocation of additional quota, receipt of all required consents, approvals and permits, and the Owner's exercise of its option to increase the installed capacity, this runner shall be exchanged via the draft tube cone with the 220 MW runner. Both runners shall fulfil all requirements stated herein.

The project performance has to comply with IEA regulations for PSPPs, and with all relevant applicable law. It is hereby clarified that all Owner's requirements specified hereunder, shall be in addition to any applicable requirements under the Law and are not intended to derogate from any of them nor to replace them. It is the sole responsibility of the Contractor to carry out all works and services in full compliance with all applicable law and regulations.

1.2 Disclaimer

The present report is limited to the design criteria of the MPSPP powerhouse. It does not include any rock-mechanical or geotechnical design criteria. The crane beam and the shotcrete vault are also excluded from this report. Cavern rock support and crane beam are designed by Dr. Sauer and Partner (DSP).

1.3 Reference Documents

The report is based on the received documents mentioned in 1.3.1, 1.3.2 and 1.3.3.

1.3.1 Reports

No.	Document no.	Content
[R1]	MPP-DSP-TUN-TEX-GEN-REP 01008.00	Seismic Report – Tunnels/shafts and Powerhouse
[R2]	MPP-DSP-TUN-TEX-GEN-REP 01000-11	Overall DBM_RevClouds
[R3]	MPP-DSP-TUN-TEX-PWH-REP 01066.P01	PWH – DESIGN REPORT
[R4]	MPP-BAC-CIV-SCN-PWH-REP 01000.P00	Structural Analysis Report Pre-Design

1.3.2 Plans Building Design

No.	Document no.	Content
[D1]	MPP-ABT-ARC-ARC-PWH-DWG 01024	PWH - Guideline drawings 1st floor to 8th floor Section A, B, and C

1.3.3 Load Plans and E&M Requirements

No.	Document no.	Content
[L1]	MPP-BAC-CIV-SCN-PWH-DWG 01000.P00 PWH Structural Design-SH1 to Sheet SH12	Load Drawings
[L2]	MPP-VTH-ENM-TRB-PWH-DWG 01032	POWER UNIT Foundation Load Plan
[L3]	MPP-VTH-ENM-TRB-PWH-DWG 01004	LOAD PLAN Generator

1.4 Standards and Guidelines

The design criteria in this document have been developed in accordance with the current Eurocode standards. The design codes listed below are European standards (Eurocodes). Wherever there is a discrepancy between the Eurocodes and the corresponding Israeli institute standards (SI) the provisions of the Israeli standard shall apply. This design criteria further are in line with the Owners Requirements expressed in its Specifications and Design Requirements.

Guidelines or Owners Requirements may prioritize standards but may not reduce its requirements. In case of a discrepancy between guidelines and standards, the stricter requirement shall apply.

No.	Document	Content
[1]	ÖNORM EN 1990-1	Basis of structural design Edition: 2013-03-15
[2]	ÖNORM B 1990-1	Basis of structural design National specifications and national supplements Edition: 2013-01-01
[3]	ÖNORM EN 1991-1-1	Eurocode 1 – Actions on structures – Part 1-1: General actions – densities, self-weight, impost loads for buildings Edition: 2011-09-01
[4]	ÖNORM B 1991-1-1	Eurocode 1 – Actions on structures – Part 1-1: General actions – densities, self-weight, impost loads for buildings National specifications and national supplements Edition 2020-12-01

[5]	ÖNORM EN 1991-1-2	Eurocode 1 — Actions on structures — Part 1-2: General actions — Actions on structures exposed to fire Edition: 2013-01-15
[6]	ÖNORM B 1991-1-2	Eurocode 1 — Actions on structures — Part 1-2: General actions — Actions on structures exposed to fire National specifications and national supplements Edition: 2013-01-15
[7]	ÖNORM EN 1991-1-6	Eurocode 1 — Actions on structures — Part 1-6: General actions — Actions during execution Edition 2013-03-15
[8]	ÖNORM B 1991-1-6	Eurocode 1 — Actions on structures — Part 1-6: General actions — Actions during execution National specifications and national supplements Edition 2006-01-01
[9]	ÖNORM EN 1991-1-7	Eurocode 1 — Actions on structures — Part 1-7: General actions — Accidental actions Edition 2014-09-01
[10]	ÖNORM B 1991-1-7	Eurocode 1 — Actions on structures — Part 1-7: General actions — Accidental actions National specifications and national supplements Edition 2007-04-01
[11]	ÖNORM EN 1991-2	Eurocode 1: Actions on structures — Part 2: Traffic loads on bridges Edition 2012-03-01
[12]	ÖNORM B 1991-2	Eurocode 1: Actions on structures — Part 2: Traffic loads on bridges National specifications and national supplements Edition 2018-08-01
[13]	ÖNORM EN 1991-3	Eurocode 1: Actions on structures — Part 3: Actions induced by cranes and machinery Edition 2013-12-01
[14]	ÖNORM B 1991-3	Eurocode 1: Actions on structures — Part 3: Actions induced by cranes and machinery National specifications and national supplements Edition 2007-06-01
[15]	ÖNORM EN 1992-1-1	Eurocode 2: Design of concrete structures — Part 1-1: General rules and rules for buildings Edition: 2015-02-15
[16]	ÖNORM B 1992-1-1	Eurocode 2: Design of concrete structures — Part 1-1: General rules and rules for buildings National specifications and national supplements Edition: 2018-01-01

[17]	ÖNORM EN 1993-1-1	Eurocode 3: Design of steel structures — Part 1-1: General rules and rules for buildings Edition: 2014-10-15
[18]	ÖNORM B 1993-1-1	Eurocode 3: Design of steel structures — Part 1-1: General rules and rules for buildings National specifications and national supplements Edition: 2007-02-01
[19]	ÖNORM EN 1998-1	Eurocode 8: Design of structures for earthquake resistance — Part 1: General rules, seismic actions and rules for buildings Edition 2013-06-15
[21]	ÖNORM B 1998-1	Eurocode 8: Design of structures for earthquake resistance — Part 1: General rules, seismic actions and rules for buildings National specifications and national supplements Edition 2017-07-01
[22]	ÖNORM EN 1993-6	Eurocode 3 — Design of steel structures — Part 6: Crane supporting structures Edition 2010-08-15
[23]	ÖNORM B 1993-6	Eurocode 3 — Design of steel structures — Part 6: Crane supporting structures National specifications and national supplements Edition 2008-12-01
[24]	ÖNORM B 4710-1	Concrete — Part 1: Specification, production, use and verification of conformity (Rules for the implementation of ÖNORM EN 206-1 for normal and heavy concrete)
[25]	Owners General Civil Specification	RFP Document Volume 2 Section IV – General Civil Specification Rev 2.1
[26]	Owners Particular Civil Specification	MAN156TDCS01000-A-21 to MAN156TDCS010026-A-21
[27]	Israeli Standard - SI 1735	Cables for concrete stretching
[28]	Israeli Standard - SI 1225	Steel structures code
[29]	Israeli Standard - SI 4466	Steel rebar and rebar meshes for concrete
[30]	Owners Requirements	Specification International Commission on Large Dams (ICOLD)

2 Structural Description

The Manara PSP underground powerhouse has 8 levels. The generator floor and main access are on level 5, where most equipment loads during maintenance and installation phases are placed and mounted. The main portal crane lifts and moves all heavy components, restricted to specific areas on level 5 only, through slab openings down to their destinations at various other levels. Each level serves specific functions, where the main components such as the MIV, turbine, generator, draft tube gate, and others are mounted and demounted during maintenance periods.

Each slab, including the bottom slab, is formed of cast-in-situ concrete. The slabs are either placed on concrete columns or concrete walls. In addition to structural integrity, the slabs also require a certain rigidity to bear the dynamic loads of the turbines and generators.

Smoke extraction systems and safe emergency corridors are provided in the Manara PSP Powerhouse to ensure worker safety and operational integrity.

The loads of the main portal crane beam are transferred directly into the rock and do not affect the powerhouse's concrete structure. Access to prestressed anchors and main crane from PWH need to be guaranteed over full life time of the power plant.

3 Geotechnics

The geotechnical engineering is not part of the present design criteria, as mentioned in 1.2. The geotechnical analysis is contained in the following documents: [R1], [R2] and [R3].

4 Material Parameters

The material parameters are determined based on the current EUROCODES [1] and [2].

4.1 Partial safety factors for materials and products

Partial material safety factors should be obtained from [1] and [2] defined as:

$$\boldsymbol{R_d} = \frac{\boldsymbol{R_k}}{\gamma_m}$$

R_d ... Design Resistance

R_k ... Characteristic Resistance

γ_m ... Partial Safety Factor for materials and products

4.1.1 Concrete

The material safety factors for **Concrete**($\gamma_{c,s}$) according to [1] and [2] are shown in Table 1. A distinction must be made between concrete and reinforcement steel.

Table 1 Material Safety Factors for Concrete

Design situation	γ_c for concrete	γ_s for reinforcement and prestressed steel
permanent and temporary	1.50	1.15
accidental	1.20	1.00
Earthquake (MCE)	1.30	1.00
Earthquake (OBE)	1.50	1.15

4.1.2 Structural Steel

The material safety factors for **Structural Steel** ($\gamma_{m,s}$) according to [1] and [2] are shown in Table 2

Table 2 Material Safety Factors for Structural Steel

Design situation	symbol	value
Resistance of cross-section whatever the class is	γ_{M0}	1.00
Resistance of members to instability assessed by member check	γ_{M1}	1.00
Resistance of cross sections in tension of fracture	γ_{M2}	1.25

4.2 Concrete

For the structural model and its analysis, concrete according to [15] and [16] is used.

The used concrete must be separated into:

- First stage concrete
- Second stage concrete

First and second stage concrete differ in the time of execution. While first stage concrete serves as the primary structural concrete, second stage concrete is used for special in-built hydraulic steel parts.

Second stage concrete must be structurally connected to first stage concrete by reinforcement.

For the structural analysis, concrete according to Table 3 is used.

Table 3 Eurocode Standards Concrete Classes and comparison to Israeli Standards

Concrete Type according to different standards		Elasticity Modulus	Cylinder pressure strength	Cube pressure strength	Tension strength	Main Usage
Eurocode Standards [15] and [16]	Israeli Standards	E_{cm} [GPa]	f_{ck} [MPa]	$f_{ck,cube}$ [MPa]	$f_{ctk,0.05}$ [MPa]	-
C25/30	B40	31	25	30	1.8	Generally, all structural elements if not specified different
C35/45	B50	33	35	45	2.0	Prestressed building parts, generator support
C70/85*	-	41	70	85	0.32	Force-transmitting bond between concrete foundations and machines

*) Cementitious performance grout, C70/85 need to be verified by site supervisor and quality system of the contractor.

4.2.1 Concrete Material – General Notes

In case the calculation requires different concrete types, those will be added here. The requirements of standard **Error! Reference source not found.** must be considered when using and processing concrete.

4.2.2 Concrete Cover

The required concrete cover, according to [15] and [16], is used to protect the reinforcement from corrosion and ensure a bonding effect. Table 4 displays the required cover depending on the situation.

Table 4 Concrete Cover

Situation	Concrete Cover	Unit
Concrete cast directly against soil or rock	7.0	cm
Concrete directly exposed to water	5.0	cm
Walls, slabs, beams with requirements ≥ REI 180	5.0	cm
Walls, slabs, beams with requirements < REI 180	4.0	cm

If a reduction in the concrete cover is desired, this must always be carried out in coordination with the structural analysis and the fire protection plan. (REI specifies the minutes of fire resistance)

4.3 Reinforcement Steel

For the structural analysis reinforcing steel according to [29] is used. Following parameters are considered:

- Designation *B500*
- Yield strength $f_{yk} = 500$ MPa
- Design strength $f_{yd} = 434.8$ MPa
- Modulus of Elasticity (secant modulus) $E_s = 200.000$ MPa

Common diameters for reinforcement steel are shown in Table 5 . The maximum for rebar standard length will be defined as 12.0m**.** The extraordinary rebar length will be limited with 20.0m**.** Following rebar diameters are available:

Table 5 common diameters of reinforcement steel

Diameters in [mm]
8, 10, 12, 14, 16, 20, 22, 25, 28, 32, 36

4.4 Prestressing Steel

For the structural analysis prestressing steel according to [27] is used. Specification of prestressed anchors will be added based on the results of the calculation. Following parameters are considered:

- Designation *Prestressing steel strands*
- Characteristic tensile strength $f_{pk} = 1860$ MPa
- Design strength $f_{pd} = 1630$ MPa
- Modulus of Elasticity (secant modulus) $E_s = 200000$ MPa

4.5 Structural Steel

For the structural analysis reinforcing steel according to [28] is used. If structural steel will be used, the following parameters are considered:

- Steel grade *Fe360*
- Yield strength $f_y = 235$ MPa
- Ultimate strength $f_u = 360$ MPa
- Modulus of Elasticity (secant modulus) $E_s = 205000$ MPa

- Steel grade *Fe510*
- Yield strength $f_y = 355$ MPa
- Ultimate strength $f_u = 510$ MPa
- Modulus of Elasticity (secant modulus) $E_s = 205000$ MPa

5 Design Principles

This chapter describes the basics of the calculation approaches.

5.1 Classification

The MPSPP must be classified based on the potential for damage according to [1].

Explanation of the demand classes to be applied:

CC 3: hazard of many human life and/or grave economical consequence

5.2 General

The structures must be checked for:

- Stability
- Strength design
- Serviceability
- Rigidity

The analysis types to be used are listed in Table 6.

Table 6 Analysis Types

Content	Static Analysis		Dynamic Analysis	
	Methodology	Constructive Law	Methodology	Constructive Law
Reinforced Concrete	Finite Element	Linear Elastic	Response Spectrum Method	Linear Elastic

5.3 Partial safety factors

Partial safety factors according to [1] and [2] are used for:

- materials and products
- actions and combinations of actions

5.3.1 Partial safety factors for actions and combination of actions

Partial safety factors for actions and combination of actions are described in the corresponding chapter 8.1.

5.3.2 Partial safety factors for materials and products

Partial safety factors for materials and products are described in the corresponding chapter 4.1.

5.3.3 Geotechnical safety factors

The geotechnical engineering is not part of this design criteria. Please refer to the disclaimer in 1.2.

5.4 Loads

Loads must be defined in all relevant phases of the project:

- Construction Phase
- First implementation of external loads
- Loads during service time

Loads must be categorized in four groups:

- Permanent loads (G)
- Variable loads (Q)
- Accidental loads (A)
- Seismic loads (A_E)

Based on the above criteria, the load values for each group will be detailed in the drawings [L1].

5.4.1 Permanent loads

Definition according to [1]:

Action/load that is likely to act throughout a given reference period and for which the variation in magnitude with time is negligible, or for which the variation is always in the same direction (monotonic) until the action attains a certain limit value.

Examples are:

- Gravitational loads (dead loads)
- Water pressure defined between the elevation of headwater- and tail water level
- Uplift and pore pressure forces due to most critical water- / groundwater levels
- Earth pressures due to earth loads

5.4.2 Variable loads

Definition according to [1]:

Action/load for which the variation in magnitude with time is neither negligible nor monotonic.

Examples are:

- Traffic loads
- Dynamic loads (the dynamic factor should be considered acc. to E&M-supplier)
- Construction loads
- Hydraulic or hydrodynamic loads
- Temperature loads

5.4.3 Accidental loads

Definition according to [1]:
Action/load, usually of short duration but of significant magnitude, that is unlikely to occur on a given structure during the design working life.
Examples are:

- Water pressure due to maximum floods (check floods/PMF)
- Impact

5.4.4 Seismic

Definition according to [1]:
Action/loads that arises due to earthquake ground motions.
The loads are to be understood as characteristic loads and are based on valid standards, available data, and experience values from similar projects. Earthquake load will be presented in the section 5.9.

5.5 General definition and classification

The loads in the powerhouse are separated in:

- Dead Loads
- Construction Loads
- Prestressing Action
- Operation/Live Loads
  - E&M Loads Installation
  - E&M Loads Maintenance
- Accidental Loads
- Earthquake Loads

5.6 Load Case – Numbering System and Color Code

Due to the fact, that loads occur depending on the state and at different times, loads cases are classified into:

- numbers, due to the floor levels
- colors for the different types

The number of the load case presented in report [R4] must comply with the following requirements. In case of any changes, this must be updated after finalizing the report [R4].

The used color code for this design criteria is shown in Table 7.

Table 7 color codes for loads

Color	Load
Yellow	Construction Loads
Purple	Permanent Loads
Light green	Prestressing Action
Orange	Operation Loads / Live Loads
Light blue	E&M Installation Loads
Dark green	E&M Maintenance Loads
Red	Accidental Loads / Earthquake

The numbering of the load cases is shown in Table 8.

Table 8 load case numbering

Load Case	Color Code	Number	Level
Dead Load of Structure		9	-
Prestressing Action		600	Level 5
Permanent Loads		1	Level 1
Permanent Loads		2	Level 2
Permanent Loads		3	Level 3
Permanent Loads		4	Level 4
Permanent Loads		5	Level 5
Permanent Loads		6	Level 6
Permanent Loads		7	Level 7
Permanent Loads		8	Level 8
Earthquake		700 to 720	-
Live Loads (construction state)		10 to 19	Level 1
Live Loads (construction state)		20 to 29	Level 2
Live Loads (construction state)		30 to 39	Level 3
Live Loads (construction state)		40 to 49	Level 4
Live Loads (construction state)		50 to 59	Level 5
Live Loads (construction state)		60 to 69	Level 6
Live Loads (construction state)		70 to 79	Level 7
Live Loads (construction state)		80 to 89	Level 8
Live Loads (E&M installation)		110 to 119	Level 1
Live Loads (E&M installation)		120 to 129	Level 2
Live Loads (E&M installation)		130 to 139	Level 3
Live Loads (E&M installation)		140 to 149	Level 4
Live Loads (E&M installation)		150 to 159	Level 5
Live Loads (E&M installation)		160 to 169	Level 6
Live Loads (E&M installation)		170 to 179	Level 7
Live Loads (E&M installation)		180 to 189	Level 8
Live Loads (operating state)		210 to 219	Level 1
Live Loads (operating state)		220 to 229	Level 2

Live Loads (operating state)		230 to 239	Level 3
Live Loads (operating state)		240 to 249	Level 4
Live Loads (operating state)		250 to 259	Level 5
Live Loads (operating state)		260 to 269	Level 6
Live Loads (operating state)		270 to 279	Level 7
Live Loads (operating state)		280 to 289	Level 8
Live Loads (E&M in operation)		490 to 520	-
Live Loads (E&M maintenance)		310 to 319	Level 1
Live Loads (E&M maintenance)		320 to 329	Level 2
Live Loads (E&M maintenance)		330 to 339	Level 3
Live Loads (E&M maintenance)		340 to 349	Level 4
Live Loads (E&M maintenance)		350 to 359	Level 5
Live Loads (E&M maintenance)		360 to 369	Level 6
Live Loads (E&M maintenance)		370 to 379	Level 7
Live Loads (E&M maintenance)		380 to 389	Level 8
Accidental Loads (ex. Earthquake)		410 to 419	Level 1
Accidental Loads (ex. Earthquake)		420 to 429	Level 2
Accidental Loads (ex. Earthquake)		430 to 439	Level 3
Accidental Loads (ex. Earthquake)		440 to 449	Level 4
Accidental Loads (ex. Earthquake)		450 to 459	Level 5
Accidental Loads (ex. Earthquake)		460 to 469	Level 6
Accidental Loads (ex. Earthquake)		470 to 479	Level 7
Accidental Loads (ex. Earthquake)		480 to 489	Level 8

5.7 Load Case Descriptions

This chapter contains detailed descriptions of the loads, especially for the different live load and operation load cases.

For the load size the corresponding reference, according to chapter 1.3, will be given.

5.7.1 Dead Loads

Dead Loads include all permanent loads. Specific Dead Loads of materials are defined based on the specific weight "γ" (density) as given in Table 9 and must be applied in the structural analysis.

Table 9 Specific Weights of Dead Loads

Material	γ	Unit
Mass Concrete	24.0	kN/m³
Reinforced Concrete	25.0	kN/m³
Steel	78.5	kN/m³
Brickwork	20.0	kN/m³
Screed	22.0	kN/m³

5.7.2 Prestressing Action

The prestressing action depends on the rigidity analysis and the stiffness requirements as mentioned in chapter 6, and will be updated based on the calculation results. Prestressed concrete must remain over pressed the whole lifetime.

5.7.3 Permanent Loads – Operation

Permanent Loads for the Powerhouse are defined in Table 10.

Table 10 Permanent Loads

Load Case	Load size	Type	Unit
Pipes and permanent Installations	[L1]	Surface Load	kN/m²
Screed[1]	[L1]	Surface load	kN/m²

[1] Screed is defined with 10.0cm all over the powerhouse

5.7.4 Construction Loads

Construction Loads are load cases during the construction time and will not be part of the ultimate limit state during operation or the installation of E&M parts. These loads are set as surface loads, line loads, and concentrated loads as shown in Table 11.

Table 11 Construction Loads

Load Case	Load size	Type	Unit
Formwork	[L1]	Line Load	kN/m
Scaffolding	[L1]	Line Load/Surface Load	kN/m(²)
Fresh concrete pressure[2]	[L1]	Hydrostatic Load	kN/m²
Construction Load	[L1]	Surface Load	kN/m²

[2] For the fresh concrete pressure, the partial safety factor γ is limited to 1.35

Construction Loads as surface loads must be applied unfavorable and for worst case scenarios. The construction loads mentioned in Table 11 must be applied if the detailed loads of formwork, scaffolding and the fresh concrete pressure are not considered.

Where walls are subjected to liquid concrete (e.g., walls next to draft tube mass concrete) a hydrostatic load shall be applied on these walls to consider concrete pressure. This can be separated based on the concreting sequences which also would reduce the load.

It needs to be clarified by the CIVIL-contractor how many floor levels scaffolding supports are kept in place during concreting of a slab. At least one additional floor level of scaffolding below a concreted slab is recommended. In case this information cannot be provided, structural analysis shall consider no additional floor level scaffolding below.

If the surrounding walls of the mass concrete in Level 1 and 2 are serving as formwork they must be designed for fresh concrete pressure.

Construction loads (as load case) for the construction state include the loads of machines, material and persons acting at the same time.

5.7.5 Prestressed Parts – hydraulic steel construction

Prestressed parts of the hydraulic steel construction are defined in the E&M drawings [L2].

5.7.5.1 Spiral Case

The spiral case needs to be pre-pressurized before concreting with min. 50% of operation pressure. The exact inside pressure of the spiral case during concreting need to be specified by the spiral case supplier.

5.7.6 Live Loads Powerhouse

Live Loads of the Powerhouse need to be separated into:

- Imposed Loads in accordance with [3] and [4] - Table 12
- Operation Loads - Table 13
- E&M Loads – for further information see 5.7.6.2

Table 12 Imposed Loads

Traffic Loads	Load size	Type	Unit
Escape routes	[L1]	Surface Load	kN/m²
Staircase Loads	[L1]	Surface Load	kN/m²
Imposed Loads	[L1]	Surface Load	kN/m²

Table 13 Operation Loads

Operation Loads	Load size	Type	Unit
Full Drainage Pit	[L1]	Hydrostatic Load	kN/m²
Full Oil Pit	[L1]	Hydrostatic Load	kN/m²

In case of a full drainage pit a hydrostatic load must be applied on the walls and the slab at Level 1 and Level 2.

The same loads must be applied for the Oil pit. There will not be considered any reducing factor for oil.

5.7.6.1 Handrailing

For the railings, horizontal live loads according to Table 14 must be applied at the height of the top handrail bar.

Table 14 Live Loads Handrailing

Handrail Loads	Load size	Type	Unit
Handrail Loads	[L1]	Line load	kN/m

5.7.6.2 E&M Loads (Installation and Maintenance)

The electrotechnical and mechanical (E&M) loads must be considered in two load cases:

- Installation
- Maintenance

These load cases are only for installation and maintenance.

The loads to be applied are mentioned in Table 15. All E&M loads must be considered in different limit states as mentioned in chapter 8.

Table 15 E&M Loads

E&M Loads	Load Size	Type	Unit
Rotor	[L1]	Surface Load	kN/m²
Stator	[L1]	Concentrated Load	kN/m²
MIV	[L1]	Surface Load	kN/m²
Turbine	[L1]	Surface Load	kN/m²
Machine Cavern GENO slab[3]	[L1]	Surface Load	kN/m²
Machine Cavern GENO slab[4]	[L1]	Surface Load	kN/m²

[3] must be applied on the slab if detailed loads of mounting areas are considered
[4] must be applied on the slab if detailed loads of mounting areas are not considered

For the detail design, the surface loads for E&M parts must be applied as realistic small-surface loads (small load areas). This is particularly important for mounting areas, but also for all other areas that are temporarily exposed to high loading E&M components.

5.7.6.3 E&M Loads – Operating State

The E&M loads during the operating state are defined by the contractor of E&M parts (VOITH) in their load drawings [L2] and [L3]. Table 16 displays the loads of E&M equipment, given by VOITH.

Table 16 E&M Loads – Operating State

E&M Loads – Operating State	Load Size	Type	Unit
Power Unit (VOITH)	[L2]	[L2]	[L2]
Generator Loads (VOITH)	[L3]	[L3]	[L3]

5.7.7 Slab Opening Covers

The slab opening covers must support the maximum load case of the E&M parts during installation or maintenance. That concerns e.g., MIV and rotor.

Table 17 Slab Opening Cover Loads

E&M Loads	Load size	Type	Unit
Slab Opening Covers	[L1]	Surface Load	kN/m²

5.7.7.1 Crane Loads

The crane in the powerhouse is supported on the rock and therefore not part of the concrete structure at all. Crane loads are hence not considered further.

The small crane is only used for maintenance of the transformer, is not utilized for lifting or moving it.

5.7.7.2 Truck Loads

Truck loads result in the case of the delivery of E&M parts. Therefore, a suitable load model (LM) according to [11] and [12] and should be used for the upper generator slab.

Alternatively, a surface load according to Table 18 can be used.

Table 18 Truck Loads

Truck Loads	Load size	Type	Unit
Truck Loads (heavy duty)	[L1]	Surface Load	kN/m²

5.7.8 Wind Loads

The powerhouse is located underground. Therefore, no wind loads are considered.

5.7.9 Snow Loads

The powerhouse is situated underground. Therefore, no snow loads are considered.

5.7.10 Hydrostatic Loads

There is no water pressure considered. The water from the rock is drained away via drainages.

The water pressure from outside is only considered for Level 1. This covers the most unfavorable case in which the drainage pit is emptied but the water pressure from outside is present. This load case is only examined for the ULS - Ultimate Limit State, but not for the SLS - Serviceability Limit State.

5.7.11 Earth Loads

The powerhouse is located underground. Therefore, no earth pressure loads are considered.

5.8 Accidental Loads

Accidental loads are shown in Table 19 and could be:

- Explosion from transformers considering pressure relieve openings in walls or slabs
- The load case fire is addressed by the respective design standards for concrete or steel

Table 19 Accidental Loads

Load Case	Load size	Type	Unit
Explosion Load	[L1]	Hydrostatic Load	kN/m²

Explosion loads must be verified and specified by the E&M designers.

5.9 Earthquake

The seismic action is to be applied according to [19] and [21].

5.9.1 General Notes for Seismic Loads

Seismic loads must be considered on all parts of the structures that may cause damage on the performance of the power plant and/or can endanger human life.

5.9.2 Seismic Design

For the seismic design, a distinction must be made between:

- OBE (Operating Basis Earthquake)
- MCE (Maximum Credible Earthquake)

The peak ground acceleration (PGA) values from [R1] are listed in Table 20.

Table 20 Earthquake Load Cases

Earthquake Load Case	Return period	PGA
OBE	1:475 year	0.22*g
MCE	1:2475 year	0.50*g

The calculations are based on [19], [21] and on the basis of [R1].

Additional Note:

- Inertia forces from the water fillings are not considered in case of seismic action.

6 Stiffness Requirements

The stiffness requirements are specified for concrete support of certain components by the contractor for hydraulic steel parts and E&M-parts, VOITH. Reference is made to the corresponding requirements and drawings given by E&M-contractor.

The stiffness requirements are verified in a separate report (Rigidity Analysis) by BAC's engineer.

6.1 Draft Tube and Draft Tube Gate

According to VOITH, there is no stiffness requirement to be considered.

6.2 Spiral Case

Reference is made to the Load Drawings [L1]

6.3 MIV

According to [L2], there are no stiffness requirements given by VOITH.

6.4 Generator Support

According to [L3].

7 Structural Analysis

This chapter provides a brief description for the FEA modeling.

7.1 General Notes for modelling

For the calculation of inner forces of the structures, parts of the structures or structural elements ultimate state design in accordance with European Standard EUROCODE, see chapter 1.3, shall be applied. For the calculation of respective deformations, elasticity theory shall be employed.

Structural analysis will be performed using solid and shell models. Stiffness of uncracked sections is used.

Supporting action of neighboring soil/rock may be simulated by spring supports in the design calculations. Spring constants in that case will be derived from the sub-grade reaction modules of soil/rock.

In designing massive, water retaining or conveyance structures, such as dams, spillways, intakes and tunnels, some deviations from the normal building codes and practices for reinforced concrete will be required. The design will be based on proper engineering judgment, proven design principles and precedence cases.

In general, a comprehensive three-dimensional (3D) finite element model (FE) of whole PWH needs to be setup for performing structural calculations three dimensions, taking into account load branching effects.

7.2 Slabs

Slabs should be modeled as shell elements.

7.3 Walls

Walls should be model as shell elements.

7.4 Mass Concrete

Mass concrete should be modelled as a 3D volume element.

7.5 Columns

Columns should be modelled as beams. Depending on the location, the end of the beam should be modelled as hinged or a fixed support.

7.6 Connection of Structural Components

A rigid construction is assumed for the entire modeling.

8 Combination of Actions

Load combinations are determined based on the valid EURCODE [1] and [2] in chapter 1.3. Therefore, two limit states must be examined: the Ultimate Limit State (ULS) and the Serviceability Limit State (SLS).

8.1 Partial safety factors for actions and combination of actions

The partial safety factors for actions and combination of actions are based on the semi-probabilistic safety concept. The design value of action is thereby defined as:

$$\boldsymbol{E_d = E_k \times \gamma_{G,Q}}$$

Symbol / Letter	Description/Meaning
E_d	Design value of action
R_d	Design Resistance
E_k	Characteristic value of action
$\gamma_{G,Q}$	Partial Safety Factors for Permanent and Temporary Situations

The values for the γ-factors for actions, according to [1] and [2], are shown in Table 21.

Table 21 values for γ-factors for actions and combination of actions

Load		symbol	value
permanent	unfavorable	γ_G	1.35
	favorable	γ_G	1.00
variable	unfavorable	γ_Q	1.50
	favorable	γ_Q	1.00
Variable loads which can be clearly specified or only act during limited durations such as construction (e.g.: fresh concrete pressure)	*unfavorable*	γ_Q	*1.35*
	unfavorable	γ_Q	*1.00*

8.2 Combination Factors

Combination factors ψ_i are used to determine the probability of different, non-correlated, variable actions occurring at the same time. Values of ψ-factors for the most common categories according to [1] and [2], to be used in combination of actions for buildings, are shown in Table 22.

Table 22 Combination factors according to [1]

Action	Ψ_0	Ψ_1	Ψ_2
Category B: Office Buildings	0.7	0.5	0.3
Category C: Meeting Rooms	0.7	0.7	0.6

Category E: Storage Rooms	1.0	0.9	0.8
Category G: Vehicles 30kN – 160kN	0.7	0.5	0.3

However, since this is not conventional building construction, the combination factor of ψ_i= **1.0** is chosen for all load combinations.

8.3 ULS – Ultimate Limit States

The ultimate design method shall be used, according to [1] and [2]. For the design of the Ultimate Limit State, the following Partial Safety Factors will be used:

$$\boldsymbol{E_d < R_d}$$

In the ULS, the following states must be considered:

- actions for permanent and temporary design situations
- actions for accidental design situations
- actions for seismic design situations

8.3.1 Combination of actions for permanent and temporary design situations

The Permanent Situation includes all loads and load combinations, that occur during the normal operating and temporary condition, (e.g., state during construction, maintenance).

$$E_d = \sum_{j\geq 1} \gamma_{G,j} * G_{k,j} \text{ "+" } \gamma_P * P \text{ "+" } \gamma_{Q,1} * Q_{k,1} \text{ "+" } \sum_{i>1} \gamma_{Q,i} * \psi_{0,i} * Q_{k,i}$$

Table 23 describes the separate terms for the combination of actions for permanent and temporary design situations.

Table 23 Symbols and Description for Combination of Actions – permanent and temporary

Symbol / Letter	Description/Meaning
$+$	Shall be combined
Σ	Combined impact
$G_{k,j}$	Characteristic value of the permanent loads
P	Pre-stressing force
$Q_{k,i}$	Characteristic value of the imposed loads
$\gamma_{G,Q,j}$	Partial Safety Factors
$\psi_{0,i}$	Combination Factors

8.3.2 Combination of actions for accidental design situations

The accidental situation includes all loads and load combinations, that cause accidental stress for the construction (fire, explosion, impact, etc.)

$$E_d = \sum_{j\geq 1} G_{k,j} \text{ "+" } P \text{ "+" } A_d \text{ "+" } (\psi_{1,1} \text{ or } \psi_{2,1}) * Q_{k,1} \text{ "+" } \sum_{i\geq 1} \psi_{2,i} * Q_{k,i}$$

Table 24 describes the separate terms for the combination of actions for accidental design situations.

Table 24 Symbols and Description for Combination of Actions – accidental

Symbol / Letter	Description/Meaning
$+$	Shall be combined
Σ	Combined impact
$G_{k,j}$	Characteristic value of the permanent loads
P	Pre-stressing force
A_d	Design value of accidental action
$Q_{k,i}$	Characteristic value of the imposed loads
$\psi_{i,i}$	Combination Factors

8.3.3 Combination of actions for seismic design situations

The earthquake situation includes all loads and load combinations that are decisive for earthquake.

$$E_d = \sum_{j\geq 1} G_{k,j} \text{ "+" } P \text{ "+" } A_{Ed} \text{ "+" } \sum_{i\geq 1} \psi_{2,i} * Q_{k,i}$$

Table 25 describes the separate terms for the combination of actions for seismic design situations.

Table 25 Symbols and Description for Combination of Actions – seismic

Symbol / Letter	Description/Meaning
$+$	Shall be combined
Σ	Combined impact
$G_{k,j}$	Characteristic value of the permanent loads
P	Pre-stressing force
A_{Ed}	Design value of accidental action
$Q_{k,i}$	Characteristic value of the imposed loads
$\psi_{2,i}$	Combination Factors

For the combination of actions for seismic design situations, a distinction is also made between OBE and MCE. The partial safety factors for the design value A_{Ed}, which are used for OBE and MCE, are listed in Table 26, which are in line with [30] approach that an OBE shall not result in necessary repair works.

Table 26 Partial Safety Factors for Seismic Design in the ULS

Earthquake Load Case	γ_{AEd}
OBE	1.20
MCE	1.00

The design value of the earthquake effect A_{Ed} is defined as:

$$\gamma_{A_{Ed}} * A_{Ed} = \sum G_{k,j} \text{ "+" } \sum \psi_{E,i} * Q_{k,i}$$

The combination factors $\psi_{E,i}$ are defined as $\psi_{E,i} = \varphi * \psi_{2i}$ and consider the probability that $\psi_{E,i} * Q_{k,i}$ are not present, everywhere in the construction during the earthquake. The value for φ is defined in [19].

The MSPP must be classified to following importance class according to [19] and [21]. The importance factor γ_I shall be applied.

Table 27 Importance class

Importance classification	value
Importance class	IV
importance factor γ_I	1.40

8.4 SLS – Serviceability Limit States

The SLS – Serviceability Limit States concern, according to [1] and [2]

- the functioning of the structure or structural members under normal use
- the comfort of people
- the appearance of the construction works

According to [1] and [2] the verification of serviceability limit sates should be based on:

- deformations that affect:
    - appearance
    - comfort for users
    - function of the structure or that causes damage to finishes of non-structural members
- vibrations
    - that causes discomfort to people
    - that limit the functional effectiveness of the structure
- damage that is likely to adversely affect
    - the appearance
    - the durability
    - the functioning of the structure

8.4.1 Characteristic combination

This combination is generally used for irreversible impacts or damages (e.g., cracks) on the structure, deformations and vibrations.

$$E_d = \sum_{j\geq 1} G_{k,j} " + " P_k " + " Q_{k,1} " + " \sum_{i>1} \psi_{0,i} * Q_{k,i}$$

8.4.2 Quasi-permanent combination

This combination is generally used for long term impacts and appearance of the structure.

$$E_d = \sum_{j\geq 1} G_{k,j} " + " P " + " \sum_{i\geq 1} \psi_{2,i} * Q_{k,i}$$

9 Joints

Joints must be distinguished between the types to be applied. All types require a water stop.

9.1 Expansion/Movement Joints

This type of joint has no continuous reinforcement and should be provided in large structures and/or structures which are sensitive to differential settlements and/or dimension changes. They ensure an independent structural behavior of elements e.g., in case of thermal expansions. These joints are not able to transmit forces.

9.2 Construction Joints

This type of joint has continuous reinforcement and will be defined in the workshop drawings. Construction joints are manufacturing-related joints during the execution and ensure full load transfer within. Separate deformation differences are not possible. Construction joints must fulfil to the same requirements, e.g., density, as the structural component itself. They can be executed with or without construction joint seals. The verification of construction joints is to be conducted in accordance with [15] and [16].

9.3 Compression Joint

This type of joint has no continuous reinforcement and will be defined in the execution plans. These type of construction joints can only transfer compression forces. Separate deformation differences are not possible. Construction joints must fulfil to the same requirements, e.g., density, as the structural component itself. They can be executed with or without construction joint seals. The verification of construction joints is to be conducted in accordance with [15] and [16].

9.4 Injection Joints

This type of joint is a kind of expansion/movement joint and should be used to introduce compressive stress into adjacent parts and is injected subsequently. E.g., between the shotcrete in the cavern and the concrete parts of the powerhouse in areas where rigidity and stiffness must meet high requirements.

10 Serviceability Checks

The following serviceability checks must be carried out:

- Crack control

Cracking due to temperature and shrinkage is controlled by satisfying the minimum reinforcement requirement. Cracking due to the design loads is controlled by keeping the calculated crack widths smaller than the allowed limits.

- Deflection control
- Settlement check

For structures founded on sound rock, no further investigations are required.

For structures founded on soil, the maximum loads shall not exceed the allowable bearing capacity q_a. In addition, they shall be designed in a way that differential settlements do not hinder the function of the structure e.g., the structures shall be designed monolithic, and no contraction joints shall be placed in the weir fields so that gates can get jammed.

10.1 Minimum Reinforcement

The minimum reinforcement is determined independently of the structural analysis required reinforcement and is defined in [15] and [16]. Both ULS and SLS the minimum required reinforcement must be installed. Minimum reinforcement according to [15] results from:

- Stress limitation
- Crack control
- Deflection control

Other limit sates (e.g., vibration) are not covered in this Design Criteria.

The minimum reinforcement according to the cross-section height is shown in Table 28.

Table 28 Minimum Reinforcement

If not other specified, bar spacing will be 15cm	
Cross section height [m]	Ø
0,20	10
0,30	10
0,40	10
0,50	12
0,60	12
0,70	14
0,80	14
0,90	16
1,00	16
1,10	16
1,20	20
1,30	20

1,40	20
1,50	20/30 + 25/30
1,60	20/30 + 25/30
1,70	20/30 + 25/30
1,80	20/30 + 25/30
1,90	25
2,00	25
2,50	28
>2,50	32

Minimum reinforcement must also be installed in case of prestressing.

10.2 Crack Control

Cracks must be limited to not impair the function or durability of the structure. Therefore, a limiting value – w_{max} – is considered. Limits for crack width according to [15] and [16] are given in Table 29.

Table 29 crack width

Environment	w_{max} [mm]
Interior of structure under normal environmental condition	0.4
Interior of structure under moist and exterior of structure und normal exterior environmental conditions	0.3
Exterior of structures under moist environmental conditions	0.2
Interior and exterior of structure under unfavorable (aggressive) environmental conditions	0.1

For the powerhouse, a maximum crack value of **0.3mm** shall be used.

The prestressing in the upper generator slab, Level 5, must be designed so, that no cracks occur in the load bearing area of the generator support and structural members which are calculated as uncracked. The concrete must remain pressurized the whole lifetime.

10.3 Deflections

Deflections are specified in [1] and [2] and/or by manufacturer of hydraulic steel structures (e.g., [L2]).

The allowable deflections according to [1] and [2] are listed in Table 30. The letter "l" symbolizes the span.

Table 30 allowable deflections

Structure	Material	Allowed Deflection
Slabs, Beams	Concrete	w ≤ l/250
Beams	Steel	w ≤ l/300
Crane Beams	Steel	[22], Israeli Standard - SI 1735

In certain cases, the requirements for the allowable deflections specified by the manufacturer must be observed. This applies to components of hydraulic steel structures (e.g.: VOITH, [L2] or [L3]).

10.4 Settlements

Geotechnical Settlements are not defined in this report or considered at the structural analysis. For further information have a look at chapter 3.

10.4.1 General note

The powerhouse cannot rotate or settle, but in case low strength or highly deformable rock layers are present below the powerhouse, further investigations must be carried out.

11 Execution

This chapter contains constructive notes that have no direct impact on the structural analysis.

11.1 Grouting

Grouting should be used for rock areas whose stiffness behavior or maintenance of stiffness behavior is essential for requirements from hydraulic and/or electrical equipment. This needs to be specified later/during the design phase.

11.2 Drainages

To prevent the accumulation of water and the resulting water pressure, any water that may be present must be drained outside of the caverns using appropriate drainage systems.

11.3 Electric Shielding Panels - Grounding

If the installation of grounding is required by the electrotechnical engineering, their installation must be carried out in such a way that:

- the ULS of the structure is still guaranteed and
- the design requirements of the SLS specifications of [15] and [16] continue to be met.

11.4 Injection Tubes

Injection tubes shall be in accordance with specification of Owners [26]