Scope of work for the Civil Engineering Scan for Einstein Telescope

Client

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Enclosures

none

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1 Project description and scope of work

The proposed underground scheme of the Einstein Telescope consists of various tunnels and caverns to host an underground laboratory. The arrangement of these underground structures forms an equilateral triangle with a side length of approximately 10 km. Each corner of the triangle hosts a large cavern structure.

The access to the underground scheme is provided either by an inclined tunnel or a vertical shaft.

The overall underground system is situated 250 m below the surface. The Civil Engineering Scan for Einstein Telescope [1] defines an internal clearance profile ($Ø_{INT}$ = 5,5 m) for the erection the vacuum pipes.

The actual design basis of the underground scheme is preliminary nature. The overall scope of work includes herby following general tasks:

- → description of the actual underground scheme layout,
- → basic geological study of the project area
- → proposal of preliminary excavation, grouting and lining concept
- → proposal of preliminary ventilation concept
- → proposal of preliminary logistical concepts
- → benchmark assessment of construction costs
- → identification of main project risks and specification of mitigation measures

2 Project-related documents, Standards and Literature

2.1.1 Project-related documents

[1] n.a., Civil Engineering Scan for Einstein Telescope, Date of compilation 4th June 2019;

2.1.2 Literature

Mitteregger, K., & Wäger, R. (2018). Allianzvertrag am GKI Erfahrungen aus der Vertragsumsetzung Ausgangslage. In *11. Österreichischer Tunneltag* (p. 19).

OEGG. (2016). *Guideline for the Cost Determination for Transportation Infrastructure Projects*. Salzburg. Retrieved from https://www.oegg.at/upload/Download/Downloads/OeGG_Guideline_Cost_Determination_2016_EN_web.pdf

3 The basic layout of the underground scheme

The underground scheme consists of an isosceles triangle of an approximate side length of 10'798m.

The access is granted in the form of an inclined access tunnel or a vertical shaft, which connects the caverns at the intersection points with the surface.

The access tunnels/ shafts are the main points of access during construction and operation. Several caverns of various geometry are situated in the vicinity of the intersection points. An additionally lined borehole offside the crucial and vibrational sensitive cavern structure is foreseen for water management during operation.

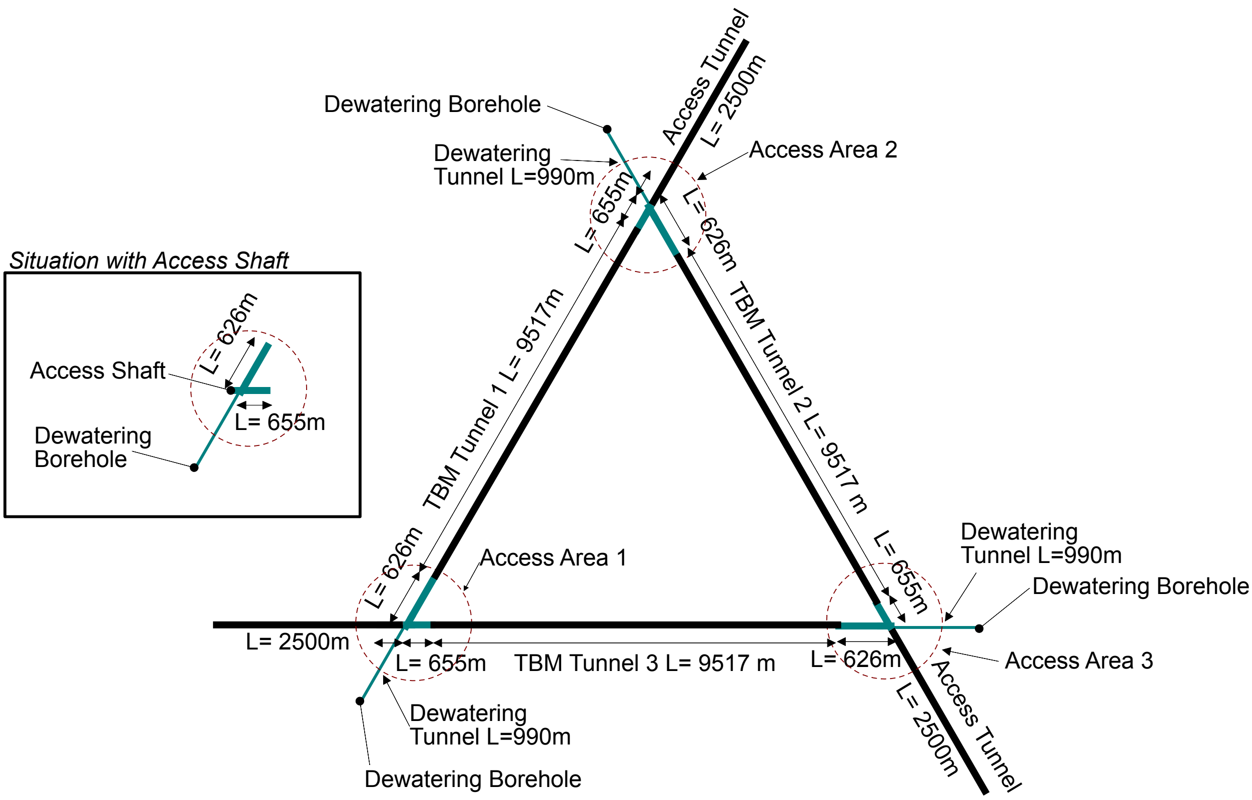

Figure 1: Schematic plan view of the underground structures

Figure 2 shows a plan view of the Access Area 1 with access via an inclined access tunnel, while Figure 3 indicates a shaft access solution.

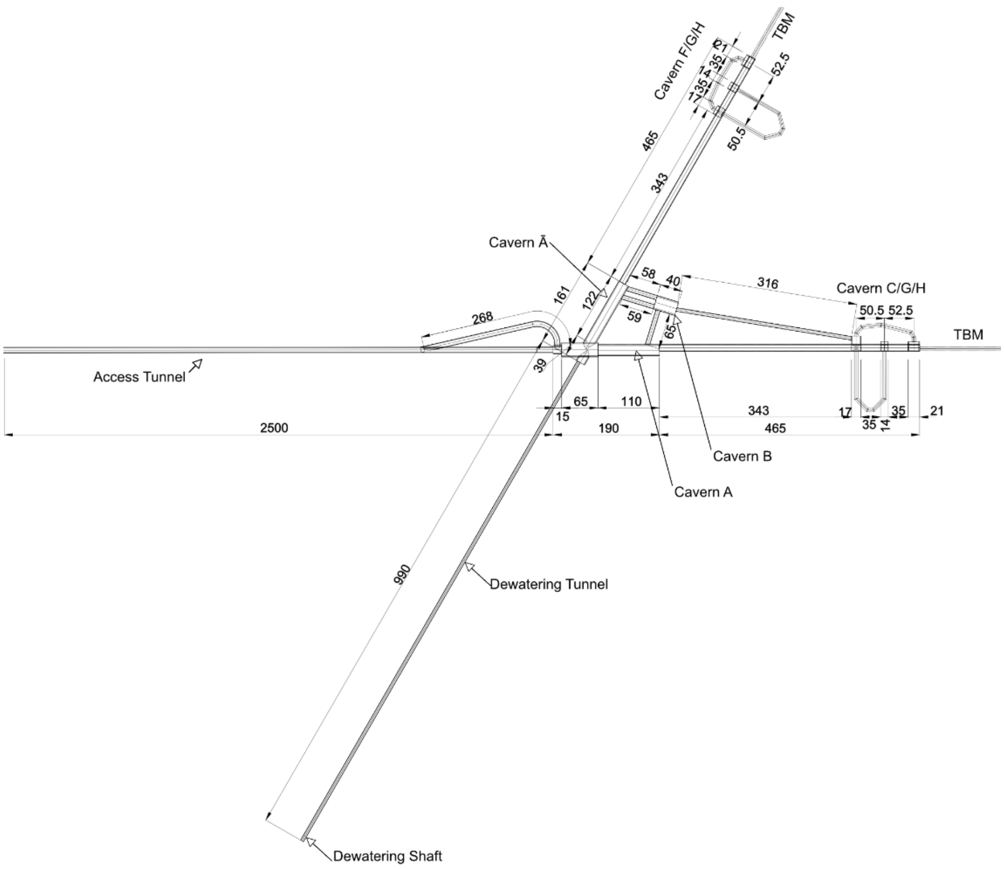

Figure 2: Schematic plan view of the Access Area 1 with an inclined access tunnel solution

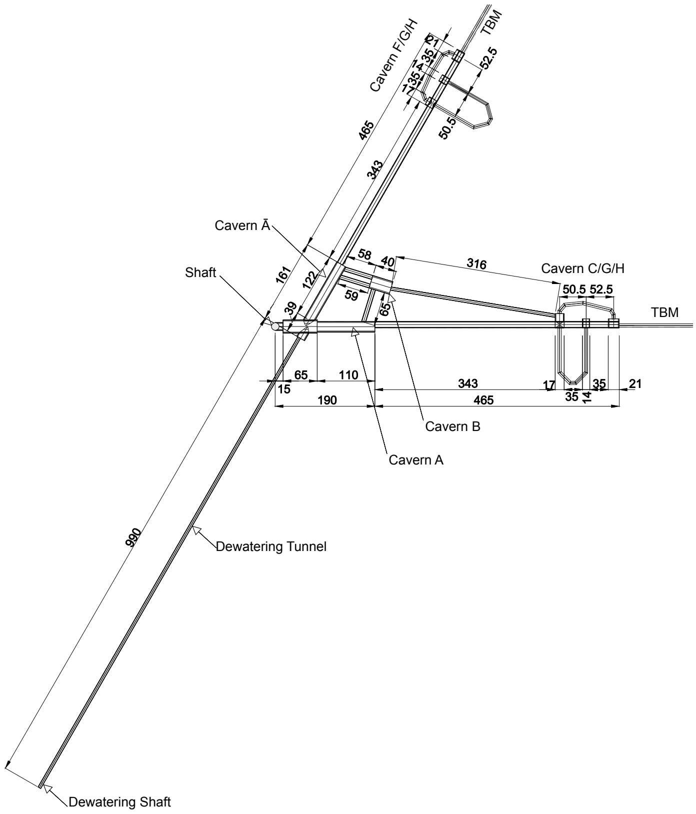

Figure 3: Schematic plan view of Access Area 1 with a shaft access solution

Both solutions can be taken as an identical template for the other two access areas. From a constructional perspective, both solutions are equivalent. Standard methods can be used for the excavation of an individually chosen type of access[1].

The inclined access tunnel is considered with 10% grade, resulting in an overall length of 2.5 km for an overburden of 250 m. The axis of the inclined tunnel does not necessarily need to form a straight line from the surface to the underground laboratory and may consist of a sequence of curves and straight sections too.

The access shaft is situated offside the cavern structure to minimise geotechnical influence. The depth of the shaft is 250 m.

The "Cavern A" is the main cavern structure of the underground laboratory and is formed by an intersection of two caverns with an identical layout at an acute angle of 60°. The length of the caverns is 190 m and 161 m.

The smaller cavern branch (Cross-Cavern Ā) withholds in prolongation a "Dewatering Tunnel" (DT) with a proposed length of 990 m, hosting at the end of the tunnel a vertical borehole aiming to dewater the Access Area separately.

[1] See also chapter 6.1 for comparision on the access of the underground area.

The length of the "Dewatering Tunnel" depends on the vibrational influence of the hydraulic pumping system further concerning the tolerable water ingress.

Two identical Revision Tunnels run in the prolongation of the branches of "Cavern A", with an identical length of 465 m. Each Revision Tunnel withholds a series of three caverns (Cavern C-F/G/H) at the transition to the TBM tunnel. The three caverns have a spacing of 35 m in between them. The distance between the caverns is mainly required from an operational point of view and is deemed to be adequate from a geomechanical perspective.

The "Cavern B" is located within the bisection line of the two branches of the "Revision Tunnels". The "Cavern B" is connected to two branches of the "Cavern A" and withholds an additional connection to the shorter branch of the Revision Tunnel with the Cavern C. The "Cavern C" is situated 343 m offside the "Cavern A".

The layout of the laboratory, regardless of the type of access, is considering the primary geometrical restraints of the underground laboratories and general aspects to avoid unfavourable geomechanical interaction.

A detailed geomechanical design of the underground laboratory shall verify the underlying assumptions of the layout as considered within this design stage.

The subsequent Figures illustrate the three-dimensional arrangement of the underground laboratory with the inclined access tunnel solution.

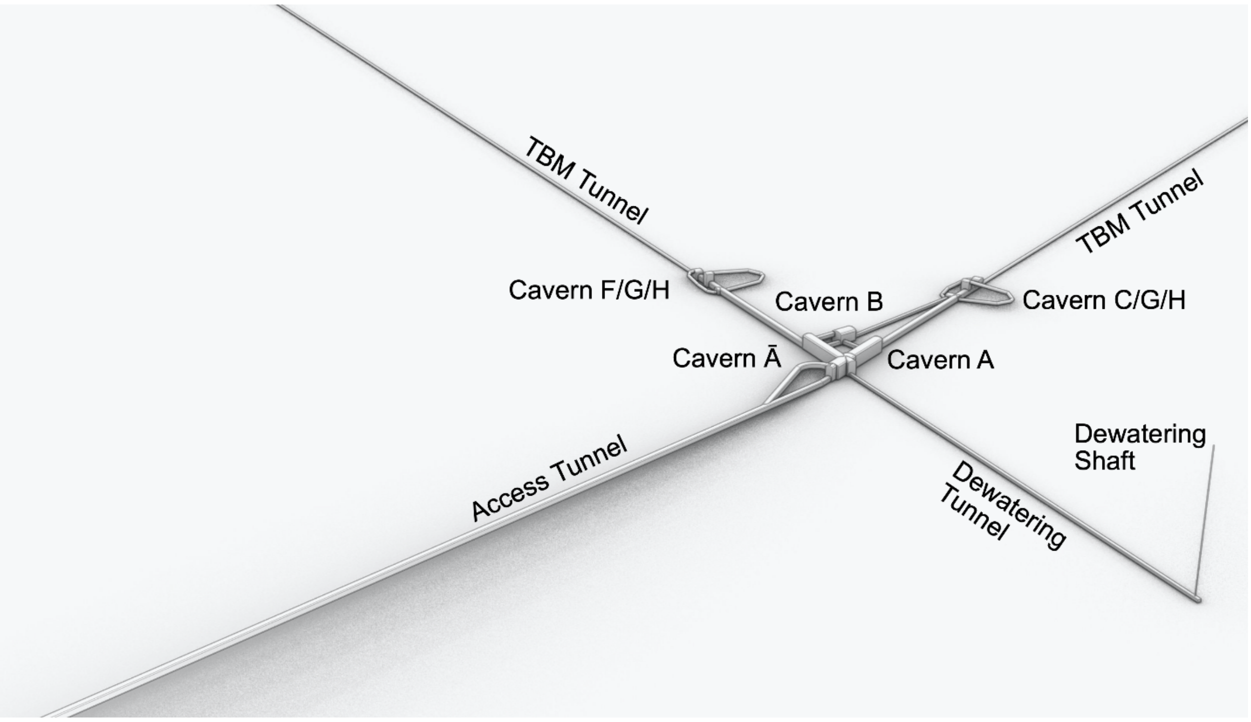

Figure 4: Perspective view of the underground structure at the intersection point with an inclined access tunnel

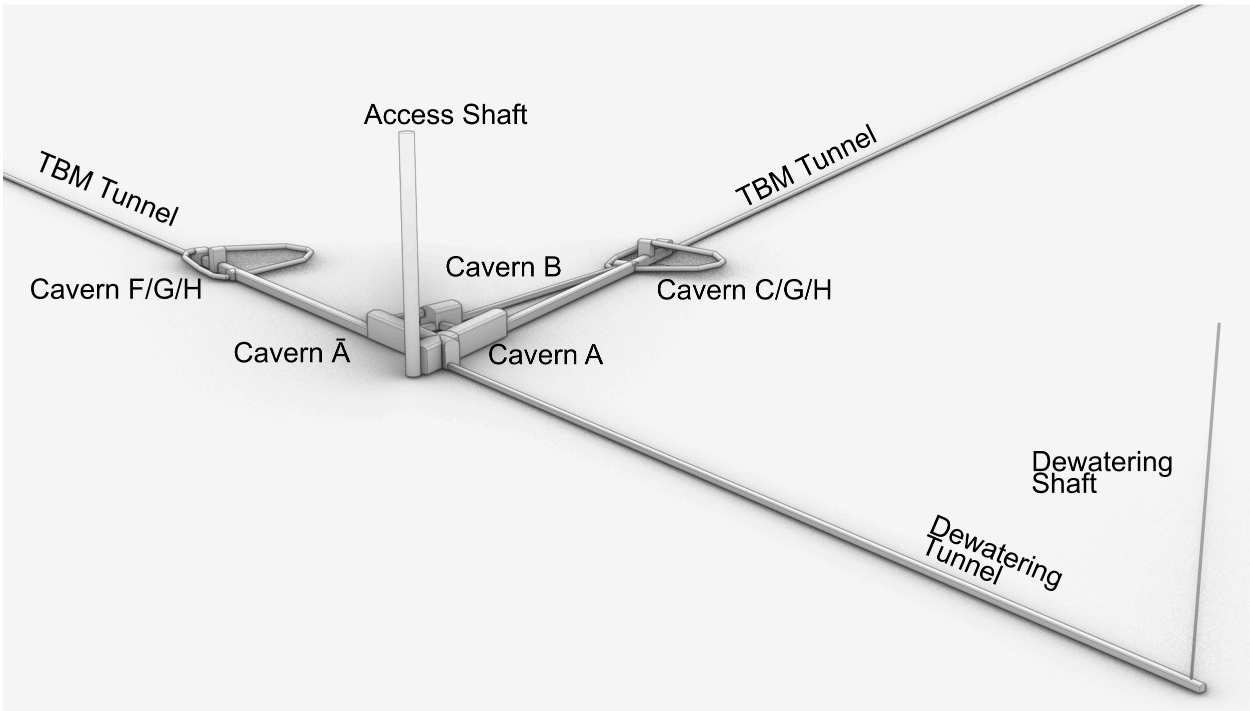

Figure 5: Perspective view of the underground structure at the intersection point with an inclined access tunnel

Figure 6 shows the labelling of underground structures. All labels in red refer to constructionally required galleries or tunnels. Additional required mucking shafts within the caverns are not indicated.

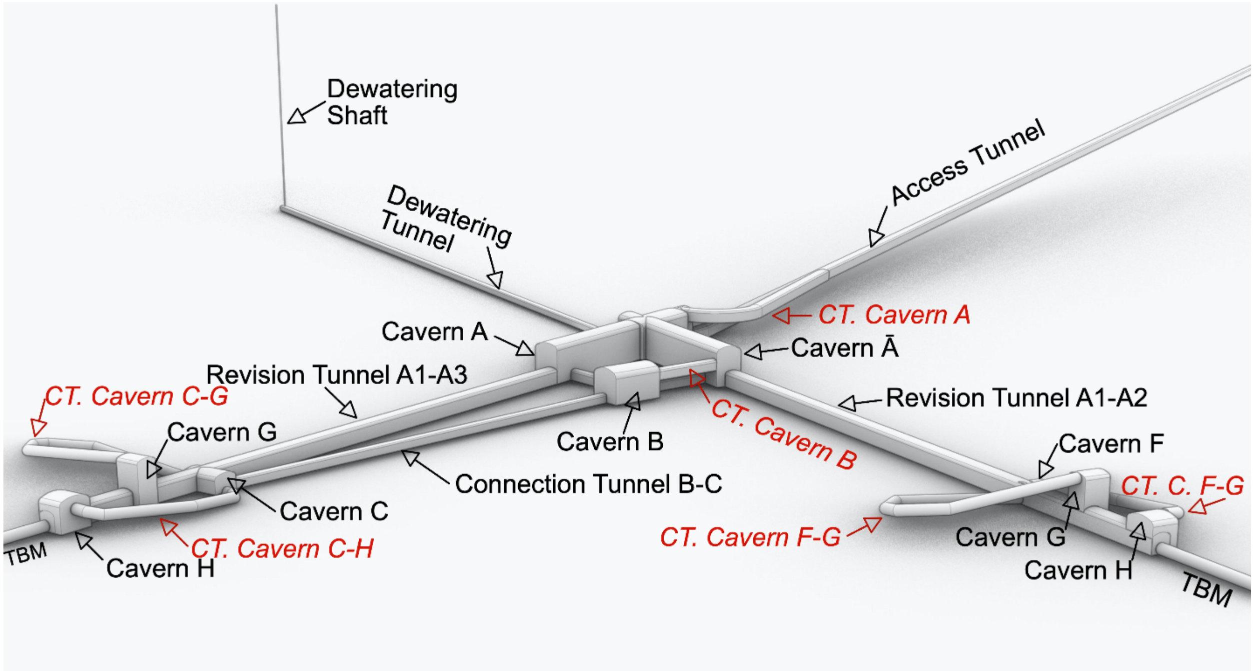

Figure 6: Perspective view of the underground structure at the intersection points with the classification of all caverns.

4 Limitations of the report

The scope of the report founds on several discussions on an appropriate layout and arrangement of the structures and indicate essential aspects of construction and logistical elements.

The operational and cost assessment is based on the experience of three recently completed excavations with the restriction of cavern structure as starting points for the excavation.

The assessment of costs for the TBM excavation sources also on three comparable projects. Varying size or cubature of excavation was down or upscaled. The prizes are escalated over time for the actual design basis.

Based on the findings of the proposed geological exploration campaign, geomechanical and structural design, deviations and modifications of this basic assessment are likely. The influences on the operational aspects and implications on costs must be adopted in such a case.

Regardless of incomplete detailed geological and geomechanical basis, the premises for the construction and costs were carefully assessed. As these circumstances demand, the time and cost analyses are based on a conservative basis, to avoid a later undesired increase of the estimated construction costs.

The actual cost is related to a Project Initiation Phase, with a cost benchmark assessment method (OEGG, 2016).

Although the prizes were carefully analysed, Implenia does not hold any liability for the overall costs and time for construction assessed within the report.

5 Premises and presumptions for the operational and cost analyses

5.1 Geological, geomechanical and hydrogeological presumptions[2]

The potential area for the Einstein Telescope is located in the South Limburg border region. The expected geological units in this area comprise of reasonable hard sandstone banks and medium hard shales of the upper Carboniferous (Namurian*) as well as of geological formations of the upper Devonian Famennian Condroz group.

The Famennian formations of Evieux and Monfort contain alternating large banks of very hard quartzites and hard mica shales. This 150m thick layer sits on top of the carbonate shale containing Esneux or Lambermont formations. Both formations are within the perimeter of the ET-tunnel.

Karstified Limestones and packstones from the Lower Carboniferous layers from the Visénian and even Tournaisian are also likely to be encountered. The area withholds a complex tectonic structure, with horst structures and extensional fault zones, may containing water-bearing formations.

5.1.1 Underlying geomechanical conditions of the project area and implications on the construction[3]

The geological conditions, as indicated withhold favourable conditions. Minor fault zones may comprise the utilisation of additional support or grouting measure to overcome unfavourable geological conditions. Extraordinary events, as multiple thrust and fault zones, are considered within a typical risk-based overhead for early project analyses.

The clearance profiles of the tunnels and galleries are not optimised towards the geological conditions. No distinct support classes were evaluated for the cost estimate. The utilisation of the support is chosen conservatively, based on the recent experiences of the construction of larger underground cavern structures.

5.1.2 Underlying hydrogeological conditions of the project area and implications on the construction

The hydrogeological conditions consist basically of tight rock types, with a typical storage coefficient of about 1 % for fractured systems. A certain number of discrete joints joins systems are expected during the tunnelling operation. These fractures zones demand sealing of the water paths to minimise water inflow to the underground laboratory. The overall permeability considered for the determination of long-term inflow to the underground laboratory is considered with 10^{-8} m/s, indicating no demand for additional sealing of the rock mass.

The shafts might protrude while shaft sinking or the excavation of the inclined access tunnels, different hydrogeological zones, which trigger defined water inflow. A tight pre-grouting as a part of the construction method is generally recommended, to prevent undesired hydraulic short circuits, with implications of tunnelling/ respectively shaft sinking or inclined tunnel excavation. Local grouting of the rock mass is considered for the actual design stage and cost analyses. A more or less similar design assumption is applicable for the construction of the underground structures excluding the TBM tunnels. Pre/- post grouting is deemed to minimise the inflow towards the structures with benefits of the overall lining system.

Especially for the TBM tunnel sections, a distinct number of fractured zones requiring additional pre or post grouting is considered. Pre-grouting and post grouting on TBM's imply custom solutions for TBM's, which is taken into account for the basic cost assessment for the TBM's already.

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[2] Basic geological information was provided by Dr. B. Vink of Anteagroup of Belgium.

[3] Basic geotechnical information was provided by Prof. Dr. F. Amann of RWTH Aachen.

5.1.3 Specific recommendations for subsequent geomechanical design and cost implications

A detailed geological programme is envisaged for the upcoming years, to determine a detailed geological and hydrogeological model. The geological and hydrogeological pre-investigation campaign is a critical element to reduce risk and allows to refine construction time and costs explicitly.

Especially from the perspective of best practice prognosis for cost and construction, the following aspects are recommended.

The assessment of long TBM drives implies the knowledge of intact strength of rock, the appearance of rock mass in terms of fracturing and the specific rock mass behaviour at the tunnel face for accurate prediction of penetration respectively advance rates. Therefore, a series of statistical representative rock mechanical strength tests perpendicular to foliation (a plane of anisotropy) needs be carried out. The drilling direction, to receive samples to allow later perpendicular loading needs to specified before the drilling campaign. Any sample damage needs to be communicated towards any bidder at later stage, to derive reliable estimation of advance rate and penetration.

Grouting operation, as a part of the construction works, implies some detailed and specific information on joint aperture and fillings, the distinct permeability of discrete joints with their distribution within geological formations.

The construction of caverns at intermediate overburden within a blocky rock mass implies detailed geomechanical analyses, mainly focussing on massive scale block failure and movement within several caverns, potentially leading to severe ground deformation rates.

6 Excavation Concept

6.1 Excavation Concept for Access of Underground Laboratory

6.1.1 Determination of Construction Method

The depth of the underground structure is considered throughout the analyses with 250 m. Due to the actual ground surface and the mutual height difference of the structure at each intersection point, a specific height difference of the shafts implies, which is not assessed within this stage[4].

Three construction methods are available to access the underground structure.

1. Access by Inclined Elongated Ramp
2. Access by Inclined Helical Ramp
3. Access by Vertical Shaft

ad 1 & 2) Inclined Elongated Ramp and Inclined Helical Ramp

An "Inclined Elongated Ramp" equally to an "Inclined Helical Ramp" connects the surface with the cavern structure situated 250 m below the ground surface. The length of the access tunnel is considered with 2,5 km based an overall slope of max. 10 % [5]. It is no required to drive the access tunnel as a straight line. Any combination of the straight and curved section is possible for construction.

The clearance profile of any inclined tunnel shall host all aspects of construction, mucking and ventilation. Due to the length and overall inclination over the entire range, a mucking system employing a conveyor belt is considered.

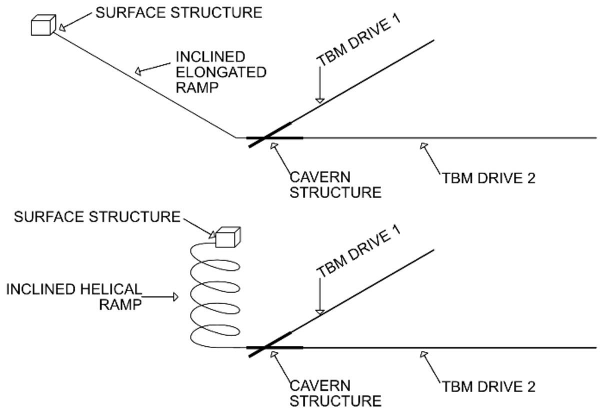


Figure 7: Schematic illustration of the Inclined Elongated Ramp and Inclined Helical Ramp

[4] The depth of overburden is related to a minimum overburden, any variations from the surface, will increase the depth of the shaft

[5] Due to descending nature of the ramp and rising mucking transport, the inclination was decreased from 12.5%b to compatible gradient of 10%.

ad 3) Vertical Shaft

Daylighting shafts are the shortest connection of the surface to the underground structure. The vertical shaft is considered as the single line of access during construction and operation. Nevertheless, for the long-term service, adoptions on the shaft hauling system are necessary to comply with the demands of the laboratory.

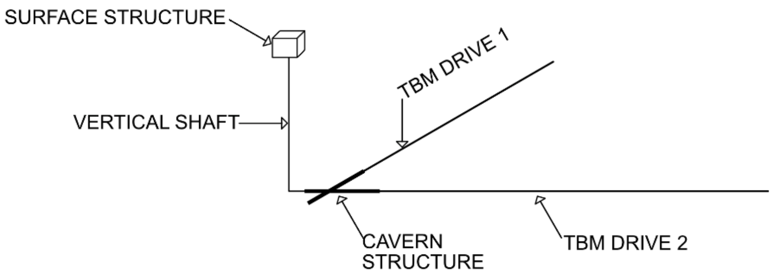


Figure 8: Schematic illustration of the Vertical Shaft

<u>The decision of underground access.</u>

Decision making on the best practice for the access area depends on a synapsis of environmental, logistical (linking roads), geological/-hydrogeological and monetary aspects.

Due to further triggering impact factors, only the monetary aspects of the access can be analysed. In any way from a constructional point of view, the inclined access tunnel is the most conservative layout. Both types of access can be accomplished with standard tunnelling equipment.

The shaft solution implies the utilisation of specialised equipment for shaft lowering, while the inclined access tunnel can be excavated with standard tunnelling equipment, as foreseen in any way for the excavation of the underground caverns.

As a basis for later decision making the costs for both access solutions are highlighted in the report.

6.1.2 Excavation method for the access shafts

6.1.2.1 General aspects of shaft sinking

Due to the depth of the shafts, only a conventional shaft sinking is applicable.

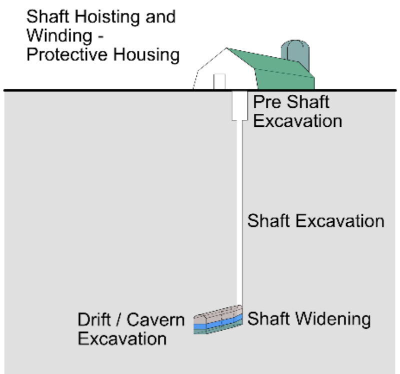


Figure 9: Schematic illustration of shaft elements

A typical daylighting shaft consists of 4 distinct elements:

- a shaft hoisting and winding,
- pre-shaft excavation,
- shaft excavation
- the shaft widening.

The shaft hoisting and winding systems are situated on surface. A bottom slap is required as the foundation of the equipment and ideally serves at a later stage as the foundation of the protective housing and shaft control centre.

The separation of environmental influences (e.g. rain, humidity, etc…) towards the underground laboratory during operation demands the necessity of surface housing during operation of the underground laboratory.

Anyhow a hosing on top of the shaft is also of an advantage during construction, to separate environmental and climatically influences on construction. Typical costs for a hosing on top of the shaft is included in the cost analyses.

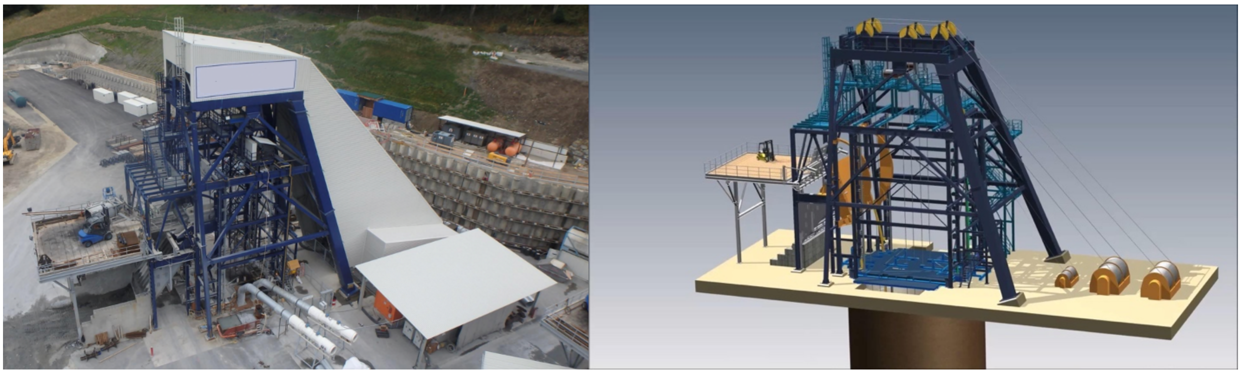


Figure 10: Shaft hoisting and winding system SBT 2.1 (© Implenia)

A pre-shaft is generally demanded to install the shaft sinking equipment. A complete embedding of the pre-shaft into solid rock is not required. Potential excavation within the soil is of no particular concern for conventional shaft sinking; the depth of the pre-shaft is considered with 20 meters for the actual design status.

The shaft is the central element of the access area. Due to the length of the shaft, a conventional shaft sinking excavation method is proposed [6]. Conventional shaft sinking sources on a cycle of blasting, skip based mucking of the excavation material and immediate lining of the shaft.

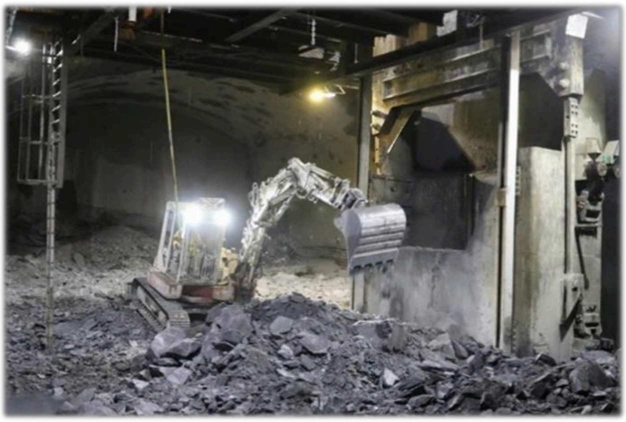


Figure 11: Skip based mucking of a shaft widening area with an excavator (© Implenia)

Due to the installation of various guiding rails and transportation pipes and the ventilation system, a prefabricated segmental lining is recommended in favour of a shotcrete lining system. The segmental lining systems demands a generally higher degree of mechanisation for shaft sinking.

Figure 12: Lowering of segments for installation of the shaft lining at the Paierdorf Exploration Shaft (© Wannenmacher)

[6] Mechanized shaft sinking machines of the first generation are currently used for some mines in England. Upon verification that mechanized systems for shaft sinking are reliable for the proposed depth, the usage of such machines may be appropriate from the perspective of time and budget.

6.1.2.2 Assessment of Shaft Excavation Diameter

The dimension of the shaft mainly depends on the constructional aspects. The main items for the underground laboratory to be lowered from the ground is a cylindrical shaped pill-box with 5.5 meters in diameter and a height of 4 meters. Further a single vacuum pipe in the range of 20 meters in height and 1.4 meters in diameter needs to be lowered from the ground.

For potential shafts with the necessity of lowering of parts of a TBM, a shaft diameter of 12 m is required. Shafts without the need of lowering a TBM a minor a shaft diameter of 10 m is required.[7]

The minimum thickness of shotcrete or segmental lining is considered with 30 cm, to guarantee a full mounting of guiding rods within the lining.

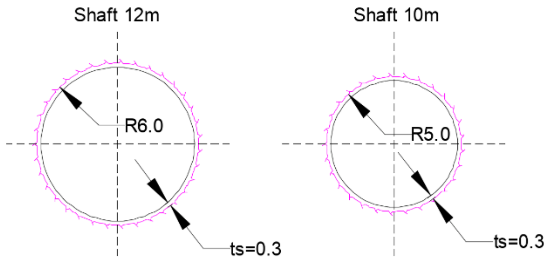


Figure 13: Schematical illustration of the clearance profile for the 12m and 10m shafts

[7] An excavation diameter less then 10 m for shafts of several hundred meters has experienced with mayor logistical drawbacks and is not recommended for construction.

6.1.3 Excavation method for an inclined access tunnel

6.1.3.1 General aspects of inclined tunnel excavation

The excavation of inclined tunnels requires standard tunnel equipment. Traffic reduction within the inclined tunnel, a conveyor belt is foreseen and shall be continuously prolonged during excavation. The conveyor belt is continually used throughout the construction for mucking.

Transport of working materials, rock support, concrete and segmental lining demands the usage of “MSV” Multi-Service Vehicles as shown in Figure 14. Due to wear of the bottom slap, a roller-compacted concrete is considered.

Figure 14: Multi-Service Vehicles (© https://www.herrenknecht.com/en/products/productdetail/multi-service-vehicles/)

The length of the inclined access tunnel does imply at least one, preferentially two additional horizontal areas, with a widening of the profile. Ideally, the areas allow for unhindered opposing traffic and withhold pumping station for process water and potential water inflows.

Before the junction of the inclined access tunnel to the “Cavern A” an additional horizontal section with a length of 50 m shall be considered. Further, a gallery for reversing all vehicles is required.

Based on the additional requirements for the inclined access tunnel, the overall length is approximately 150 m longer. This prolongation is considered within the cost estimate.

All material required for the laboratory can be lowered to the caverns and tunnels via the access tunnel without restrictions.

6.2 Excavation Concept of Underground Structures within the Access Shaft areas

6.2.1 Assessment of Excavation Method

All underground structures within the access area are excavated by drill and blast. The overall construction process must be grouped into various phases to guarantee access to all levels of the caverns.

The excavation of the caverns follows a standardised procedure for excavation. Figure 15 shows the general of driving an additional construction tunnel towards the crown of an individual cavern. The excavation concept relies on an extra mucking shaft to the invert. The cavern excavation follows a top-down sequence.

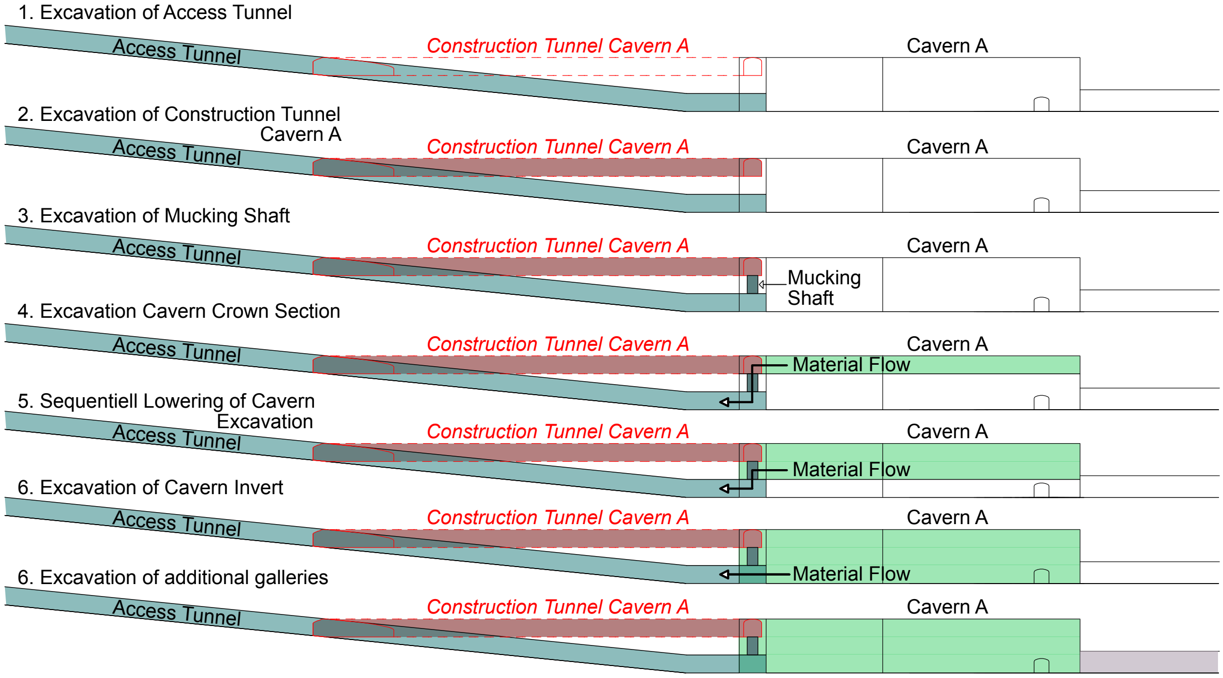
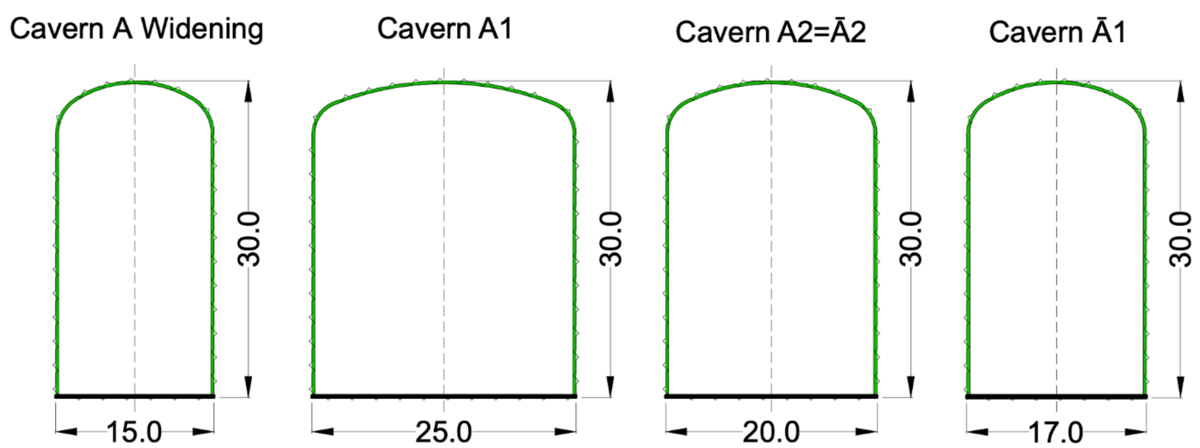


Figure 15: Operational scheme of Underground Structures within the Access Shaft Areas

6.2.2 Clearance Profile of Caverns, Revision Tunnel and Dewatering Tunnel

The caverns and underground structures, to be excavated by drill and blast are of various shape. The actual design foresees a horseshoe-shaped design of all cavern, tunnels and galleries. Based on the geological findings, the shape of these caverns and tunnels might demand a redesign to fit the geomechanical demands.

Figure 18 to Figure 19 give an overview of the various shapes of caverns and tunnels considered for the analyses.



Excavation and Geometry	
Exc. A.:	434.5m²
A. Shotcrete	20.71m²
A. Invert Concrete	3.00m²
Circumference	84.93m

Excavation and Geometry	
Exc. A.:	724.63m²
A. Shotcrete	23.47m²
A. Invert Concrete	5.00m²
Circumference	104.12m

Excavation and Geometry	
Exc. A.:	579.56m²
A. Shotcrete	22.07m²
A. Invert Concrete	4.00m²
Circumference	94.46m

Excavation and Geometry	
Exc. A.:	492.70m²
A. Shotcrete	21.24m²
A. Invert Concrete	34.46m²
Circumference	88.74m

Figure 16: Clearance Profile of Caverns A

The “Cavern A” comprises of multiple geometries. The position of the various clearance profiles is shown in Figure 17.

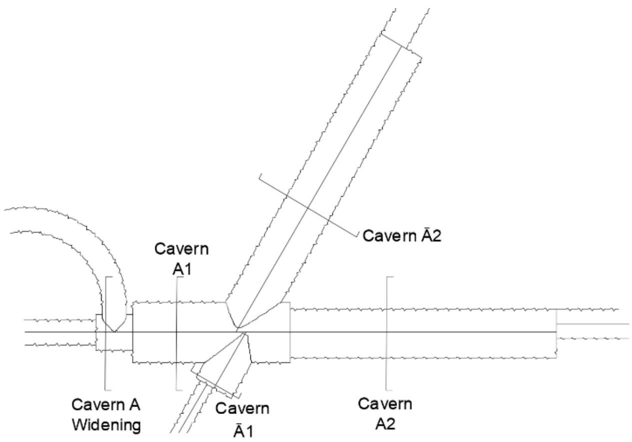
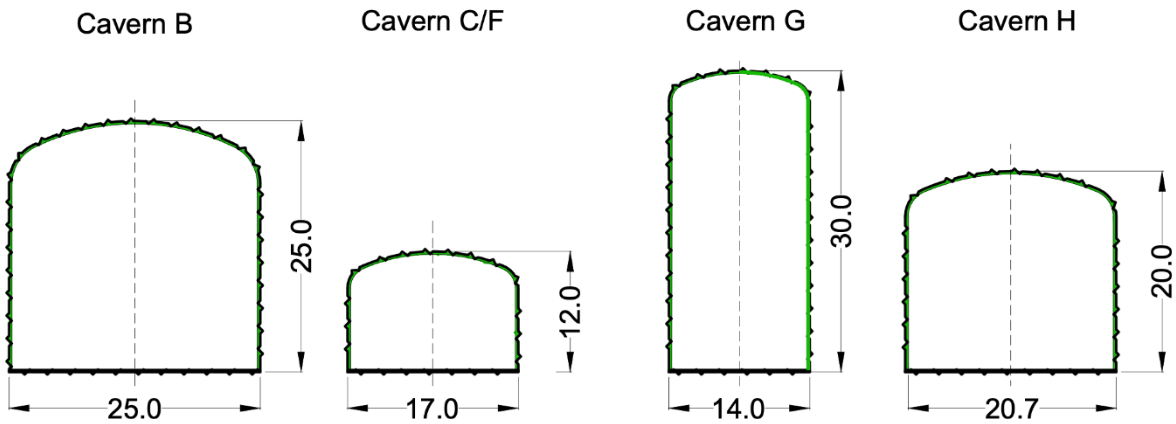


Figure 17: Position of the clearance profiles for “Cavern A.”



Cavern B

Excavation and Geometry	
Exc. A.:	592.60m²
A. Shotcrete	20.14m²
A. Invert Concrete	5.00m²
Circumference	93.03m

Cavern C/F

Excavation and Geometry	
Exc. A.:	191.31m²
A. Shotcrete	10.77m²
A. Invert Concrete	3.40m²
Circumference	53.77m

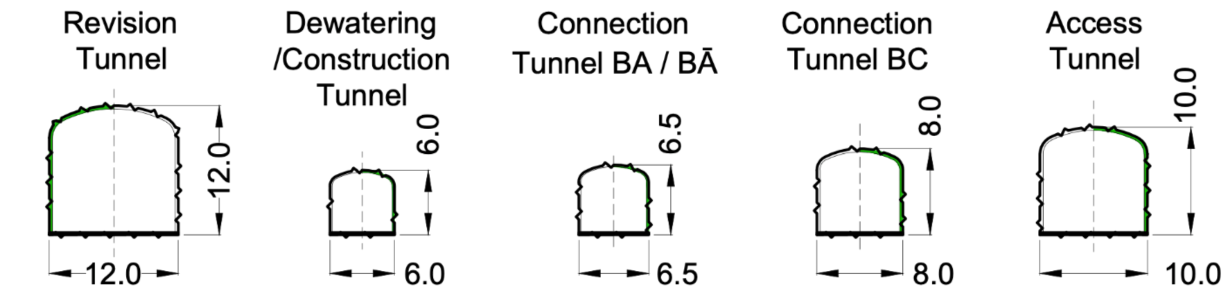
Cavern G

Excavation and Geometry	
Exc. A.:	411.39m²
A. Shotcrete	21.02m²
A. Invert Concrete	2.80m²
Circumference	84.51m

Cavern H

Excavation and Geometry	
Exc. A.:	400.63m²
A. Shotcrete	20.67m²
A. Invert Concrete	4.20m²
Circumference	76.77m

Figure 18: Clearance Profile of Caverns B, F, G and H



Revision Tunnel

Excavation and Geometry	
Exc. A.:	136.53m²
A. Shotcrete	9.52m²
A. Invert Concrete	2.40m²
Circumference	44.65m

Dewatering /Construction Tunnel

Excavation and Geometry	
Exc. A.:	34.13m²
A. Shotcrete	3.04m²
A. Invert Concrete	1.20m²
Circumference	22.32m

Connection Tunnel BA / BĀ

Excavation and Geometry	
Exc. A.:	40.06m²
A. Shotcrete	3.40m²
A. Invert Concrete	1.30m²
Circumference	24.18m

Connection Tunnel BC

Excavation and Geometry	
Exc. A.:	60.68m²
A. Shotcrete	6.26m²
A. Invert Concrete	1.60m²
Circumference	29.77m

Access Tunnel

Excavation and Geometry	
Exc. A.:	90.81m²
A. Shotcrete	7.90m²
A. Invert Concrete	2.00m²
Circumference	37.21m

Figure 19: Clearance Profile of the Revision Tunnel, Dewatering Tunnel and Connection Tunnels

The dewatering shaft is located about 1000 m offside the access area, depending on the vibrational influence of dewatering pumps on the sensitive equipment of the underground laboratory. A borehole diameter of 360 mm is considered for the actual design status. The borehole is lined throughout with a steel lining.

6.3 Excavation Concept of Gravitational Detection Tunnels

6.3.1 Assessment of Tunnel Boring Machine type and excavation diameter for excavation of "Gravitation Wave Detection Tunnel."

Due to the length of the TBM Tunnel (approximately 10'000 m), a mechanised excavation method utilising TBM's is considered for the design stage[8]. It is envisaged to excavate the whole length of the tunnel in one stretch without further points of intermediate access.

Two types of TBM's are feasible for construction, an open TBM (see illustrative Figure 20 left) and a shielded type of TBM (see indicative Figure 20 right) are generally applicable.

Shielded TBM (TBM-S / TBM-DS)

The concept of the shielded TBM type considers a continuous mining process with parallel installation of a segmental lining, which takes over the support of the rock mass.

A single-layer segmental lining with all-rounded preformed elastomer gaskets is considered to control water inflow to the tunnel. The thickness of the reinforced concrete segmental is as a result of this in minimum 30 cm.

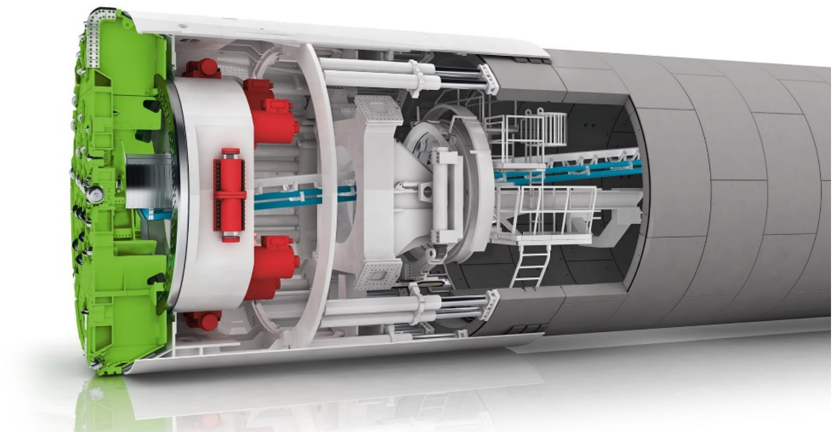


Figure 20: Shielded Tunnel Boring Machines [9]

[8] The consideration of a TBM as an appropriate excavation method is based on a generally stable rock mass, suitable for excavation by a TBM. The findings of a subsequent geological exploration campaign, must be reviewed on the presumption of feasible geological conditions.

[9] copyright Herrenknecht AG (https://www.herrenknecht.com/de/), download September 2019

Open TBM (TBM-O)

Contrary to a shielded TBM (TBM DS- TBM-s) the rock mass support for a TBM-O is based on shotcrete, steel ribs and rock bolts.

As part of the excavation concept, rock mass grouting is considered, to decrease the overall inflow of groundwater to the tunnel, since the shotcrete support is more prone to water inflow.

A thickness of a 30 cm thick shotcrete lining comprising of basically two layers is considered throughout the tunnel.

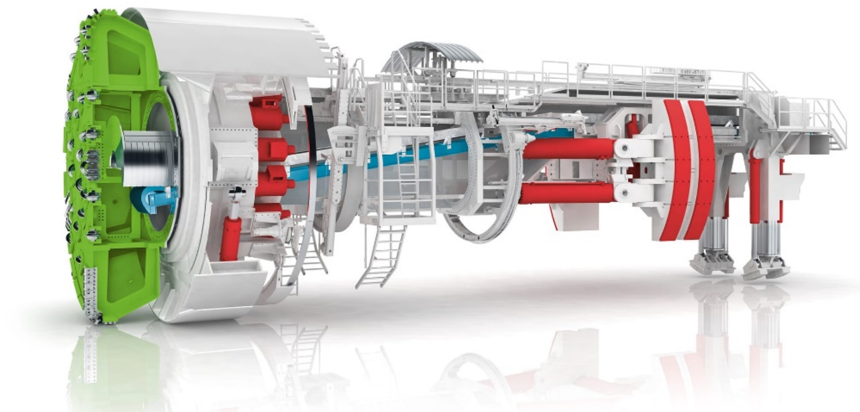


Figure 21: Open Tunnel Boring Machines [10]

Assessment of preliminary excavation diameter:

The premises for the mechanised excavation with a TBM, regardless of its type demands a straight direction for the later installation of steel tubes.

Nevertheless, the TBM excavation implies an inherent wriggling as a reaction to heterogeneous geological conditions while driving.

A predefined additional over-excavation is considered based on the TBM type, to avoid interference of the clearance profile of the tunnel with the working area of the steel tubes.

[10] copyright Herrenknecht AG (https://www.herrenknecht.com/de/), download September 2019

Shielded TBM:

The excavation diameter of the tunnel excavated by a TBM-S comprises of the clearance profile for the installation of the steel tubes ($r_{c.p.}$), a specific deviation range ($t_{dev\text{-}S.}$), a segmental lining thickness ($t_{seg.}$) and annulus gap ($t_{gap.}$).

$$D_{exc.\ TBM-S} = \left(r_{c.p.} + t_{dev-S.} + t_{seg.} + t_{gap.}\right) \cdot 2 = (3.25 + 0.5 + 0.3 + 0.15) \cdot 2 = 8.4m$$

Open TBM:

The excavation diameter of the tunnel excavated by a TBM-O comprises of the clearance profile for the installation of the steel tubes ($r_{c.p.}$), a specific deviation range ($t_{dev\text{-}O.}$) and lining thickness of the shotcrete shell ($t_{seg.}$).

$$D_{exc.\ TBM-S} = \left(r_{c.p.} + t_{dev-O.} + t_{scr.}\right) \cdot 2 = (3.25 + 0.1 + 0.3) \cdot 2 = 7.3m$$

The smaller deviation range considered for the excavation of TBM-O, sources on the ability of post-excavation grading with a small excavator with a drum cutter. Preferentially any demanded widening shall be accomplished prior the application of the final shotcrete liner already on the TBM. The prizes for a local widening of the clearance profile is included in the unit price of the excavation[11].

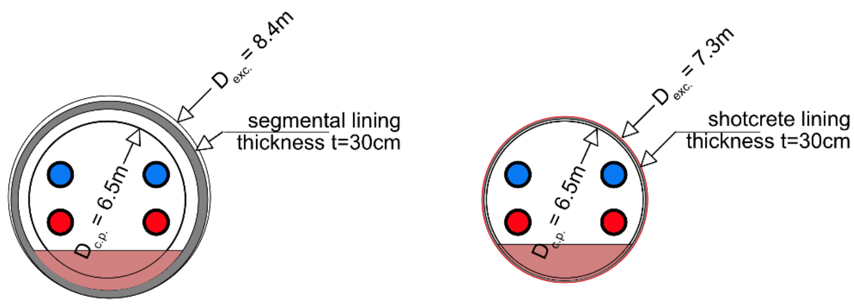


Figure 22: Determination of clearance profile for shielded and open TBM excavation

[11] The interplay of diameter increase to compensate deviation and to guarantee straightness of later installed pipes shall be analysed in much higher depth, since the diameter increase withholds a percentage of costs.

Figure 23: Example of a segmentally lined tunnel

Figure 24: Example of a shotcrete lined tunnel

7 Ventilation concept

The ventilation concept foresees direct ventilation of the shafts respectively of the access tunnels and the underground structures with a separated inlet and outgoing air via the shafts/tunnels.

The air demand for shaft sinking regardless of the proposed excavation diameters is in the range of 24 m^3/sec at a required pressure of 5500 Pa, based on the minimum exhaust speed of 0.22 m/s. The necessary duct diameter is ⌀ = 0.76 m.

The air demand for the access tunnel must be already dimensioned equally to the same size as required for the cavern excavation.

For cavern excavation, the duct diameter must be significantly increased to ⌀ = 2.0 m and diverged to the different branches. The average air demand is 48,2 m^3/s at a required pressure of 2422 Pa.

Upon completion of the caverns and a sole excavation of the TBM, the air demand can be lowered again to an air demand of 21 m^3/sec at a required pressure of 3675 Pa with a ⌀ = 1.6 m. A reduction of the duct diameter for the TBM excavation is reviewed further to costs for a replacement. The additional diameter provides some extra safety.

The costs for the ventilation are included in the unit prizes for the excavation of the underground laboratory.

8 Site installation

Typical site installation varies in between 6 to 7 ha. In general, larger storage areas facilitate operational constraints.

The three-point of access allows for the grouping of various infrastructure elements required. The main office, optional segmental lining production shall be separated to minimise land usage. For all points of access, a close link to public streets is of advantage.

For Einstein Telescope, following typical site installation can be considered.

Main Office	5'000m^2
Small Office	2'000m^2
Site Facilities (mechanics, electrical, etc.)	40'000m^2
Water treatment pond	3'000m^2
Accommodation	10'000m^2
Opt. Segmental Local Storage[12]	3'000m^2

In the case of segmental lining production following additional land usage is required.

Segmental Lining Production	10'000m^2
Segmental Lining Production Storage	20'000m^2

Figure 25 and Figure 26 show some examples of site installation plans for comparable infrastructure projects.

[12] Optional segmental lining storage is required in case of a decentralized segmental lining production, with the local necessity of segment storage

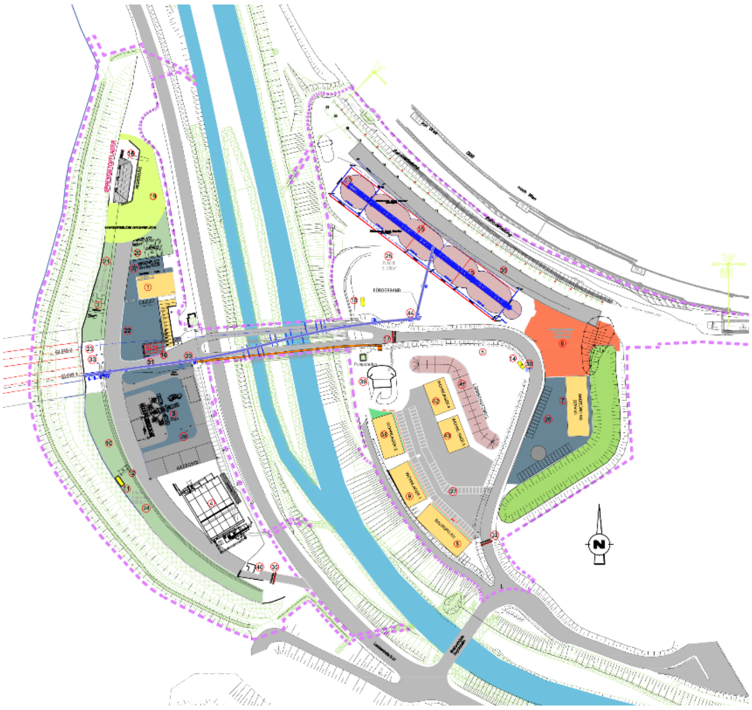


Figure 25: Site Installation Semmering Base Tunnel Lot 1.1 (Size: …..)

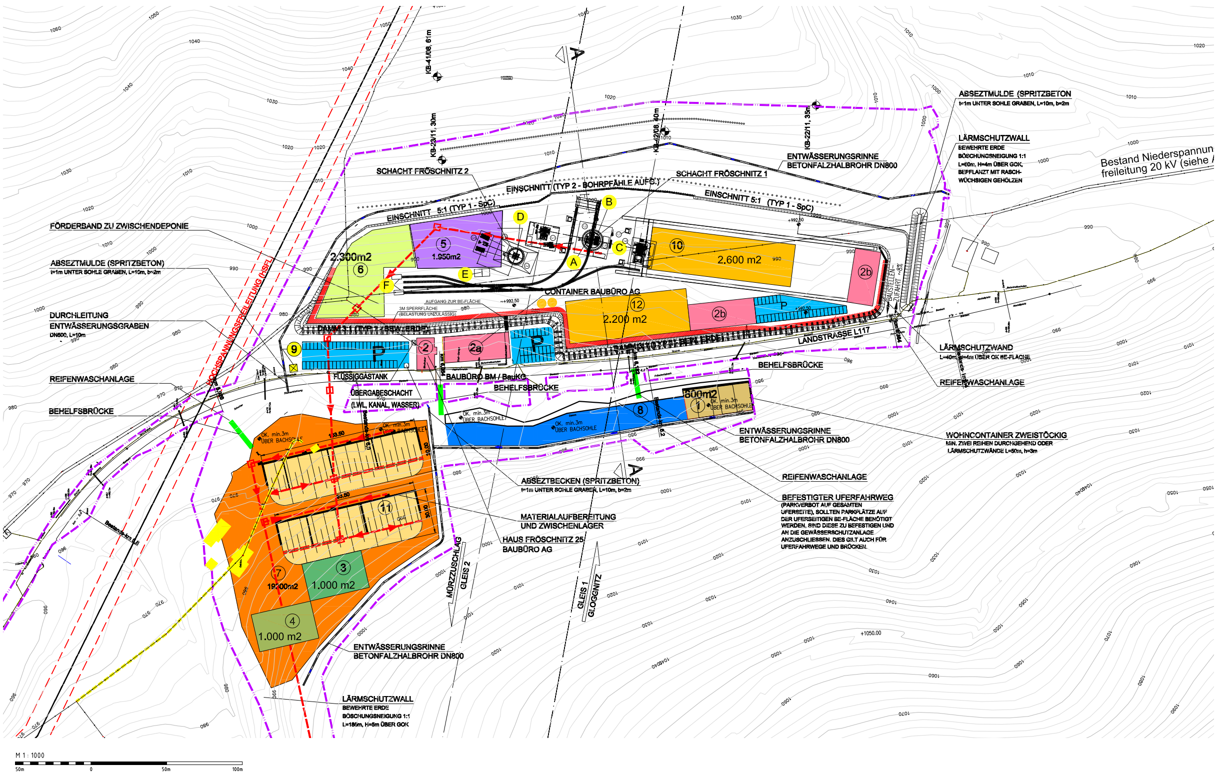


Figure 26: Site Installation Semmering Base Tunnel Lot 2.1 (Size: 8 ha)

9 Safety concept

9.1 Shaft access solution

The safety concept considers evacuation of 30 persons within 30 minutes to guarantee complete haulage of personal via the shaft.

The shaft evacuation relies on two separate transport facilities. One transport facility is related to the transport cabins, and secondary transport relies on the skip.

Considering a skip volume of 22 m^2 (0.25m^2/person) and a vertical speed of 0.5 m/sec with decelerating of 10 sec and climbing and descending of 120 sec a total of 89 persons can be evacuated within 21 min.

Additionally, safety chambers at the shaft low-point and additionally at the working area must be foreseen for construction.

The costs associated with the provision of the safety chambers for the construction are included in the cost analyses.

9.2 Inclined Tunnel Access

Input Hauer to be received Monday 11th

10 Transport of mucking material

The overall amount of excavation material is in the range of 3.6 to 2.6 Mio m^3 as specified within Table 1. It is assumed that the excavation material can be partially resued. No further expenses were considered for the deposition of the material.

Table 1: Compilation excavation material for option 1-4

	Option 1	Option 2	Option 3	Option 4
	TBM-O	TBM-O	TBM-S	TBM-S
	Access Tunnel	Access Shaft	Access Tunnel	Access Shaft
Branch 1	1'091'806.3 m3	876'449.6 m3	1'220'893.3 m3	1'005'536.6 m3
Branch 2	1'091'806.3 m3	876'449.6 m3	1'220'893.3 m3	1'005'536.6 m3
Branch 3	1'091'806.3 m3	876'449.6 m3	1'220'893.3 m3	1'005'536.6 m3
Subtotal	3'275'419.0 m3	2'629'348.9 m3	3'662'679.8 m3	3'016'609.7 m3

11 General Environmental Aspects

The nature of each construction site implies specific impacts on the environment. Mayor implications relate to dust, noise, groundwater and water usage and reuse.

Based on the site-specific environmental protection plan, particular tunnel specific measures need to be evaluated and considered within construction.

Dust can be controlled to a large extent if the necessary transport is limited and rail-based transport is used, wherever applicable. Standard measures to control dust implications refer, e.g. to truck washing installation on site.

Specific noise implications arise from transport and the tunnelling operation in general. Especially in portal areas, time limitations during the day for blasting are essential.

Environmental impacts can be minimised too large extent if the excavation material is transported either by rail directly from the construction site or by an encased conveyor belt to an excavation disposal site close to the site.

Preferentially the excavation material can be reused as a concrete agglomerate directly on-site.

Mayor impact from tunnelling is related to the groundwater. Local grouting operation may be demanded to minimise groundwater influence from a longterm perspective.

Water treatment plant guarantees non-polluted discharge of wastewater to natural river systems.

All these measures need to be carefully re-addressed after the first geological exploration and definition of construction measures to avoid unnecessary environmental and ecological impact.

12 Proposal for preliminary logistical concepts and construction time

The lining of the caverns and the galleries and tunnels withholds a vital component of the overall costs and time.

The lining of the caverns is considered solely by a shotcrete lining apart from a discrete house in house solution. The house in house solution is a part of subsequent laboratory installation. For the long TBM drives, shielded and open TBM are favourable for the anticipated rock mass. To guarantee a durability a 30 cm shotcrete and equal segmental lining thickness is considered for the analyses.

Based on the upcoming geological exploration, the thickness of the lining for caverns and tunnels shall be optimised anyhow.

The assessment of the construction time and costs includes the outlined four options for construction (see Table 2) The four options for the underground laboratory differ towards the two different types of TBM excavation and two options for accessing the laboratory.

The actuals design stage foresees a sequencing of the TBM excavation, relying on the usage of 2 TBM's with a general overhaul of the first TBM after TBM drive 1. Due to the immoderate long excavation time of the TBM's and staggering of the shaft excavations**Fehler! Verweisquelle konnte nicht gefunden werden.**, the driving factor for the critical time is solely the completion of TBM drive 2 with the TBM no.1.

The difference of the two TBM types, concerning the different diameter and lining types, towards their performance is hard to predict so that an overall construction time of 7.6 years for option 2 and option 4 is generally feasible. In case of the necessity of access tunnel, there is an additional time effort of about half of a year required (8.2 years).

Table 2: Options for construction (1 year is equal to 345 working days)

	TBM Type / ⦰	Access [-]	Duration [working days/ years @345wd/year]
Option 1	TBM- O/ 7.3 m	Access Tunnel	2823 wd. ~ 8.2 years
Option 2	TBM- O/ 7.3 m	Access Shaft	2605 wd. ~ 7.6 years
Option 3	TBM- S/ 8.4 m	Access Tunnel	2823 wd. ~ 8.2 years
Option 4	TBM- S/ 8.4 m	Access Shaft	2605 wd. ~ 7.6 years

The daily rates for excavation [m/wd.] as considered for the timely analyses are based on conservative values for excavation. Upon disposal of a detailed geological model, the excavation rates demand a certain refinement.

The average advance rate for shaft lowering is 0.8 m/wd. (shaft ⦰ =12 m) respectively 1.0 m/wd. (shaft ⦰ =10 m). The advance rate considered for the pre-shaft is considered with 0.5 m/wd regardless of the diameter.

The advance rate of the inclined access tunnels (slope 10%) to the crown is considered with 6.8 m/wd.

The excavation of the "Cavern A" depends significantly on the capability of the mucking system. Towards workability slightly higher productivity of the shaft is given. To equal, the productivity of the access tunnel towards the shaft solution, a decrease of the gradient would be required, which would lead to a significant increase of the construction time and cost of the access tunnel.

The overall amount of excavation material per working day is in the range of 864 m^3/day for the shaft and 800 m^3/day for the access tunnel.

The advance rate for the Revision Tunnel is considered 3.4 m/wd., while for the significantly smaller dewatering tunnel an advance rate 8.0 m/wd. is assessed.

The later widening of the cavern is accomplished via access to the crown and a conventional lowering of the caverns. The widening of caverns is considered with 1.0 to 2.0 m/w.d. regarding the excavation area of each cavern.

The most critical assumption for the schedule is the consideration of the advance rate of the TBM since the staggering of the TBM drive with one TBM excavating two branches triggers the critical path.

The advance rate of both TBM types was considered with 12.5 m/wd., which takes the scale effect of the length of the tunnel, the daily availability of the TBM into account.

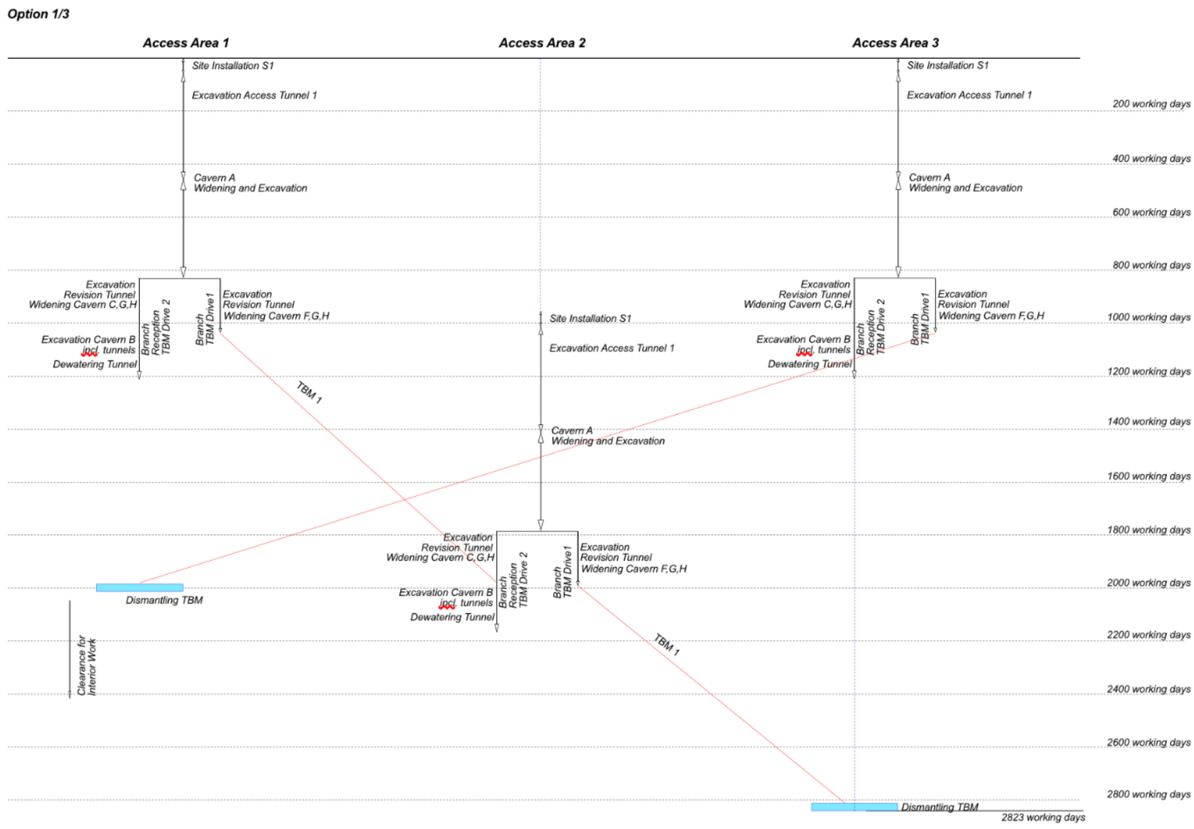


Figure 27: Construction schedule Option 1/3 (Access Tunnel)

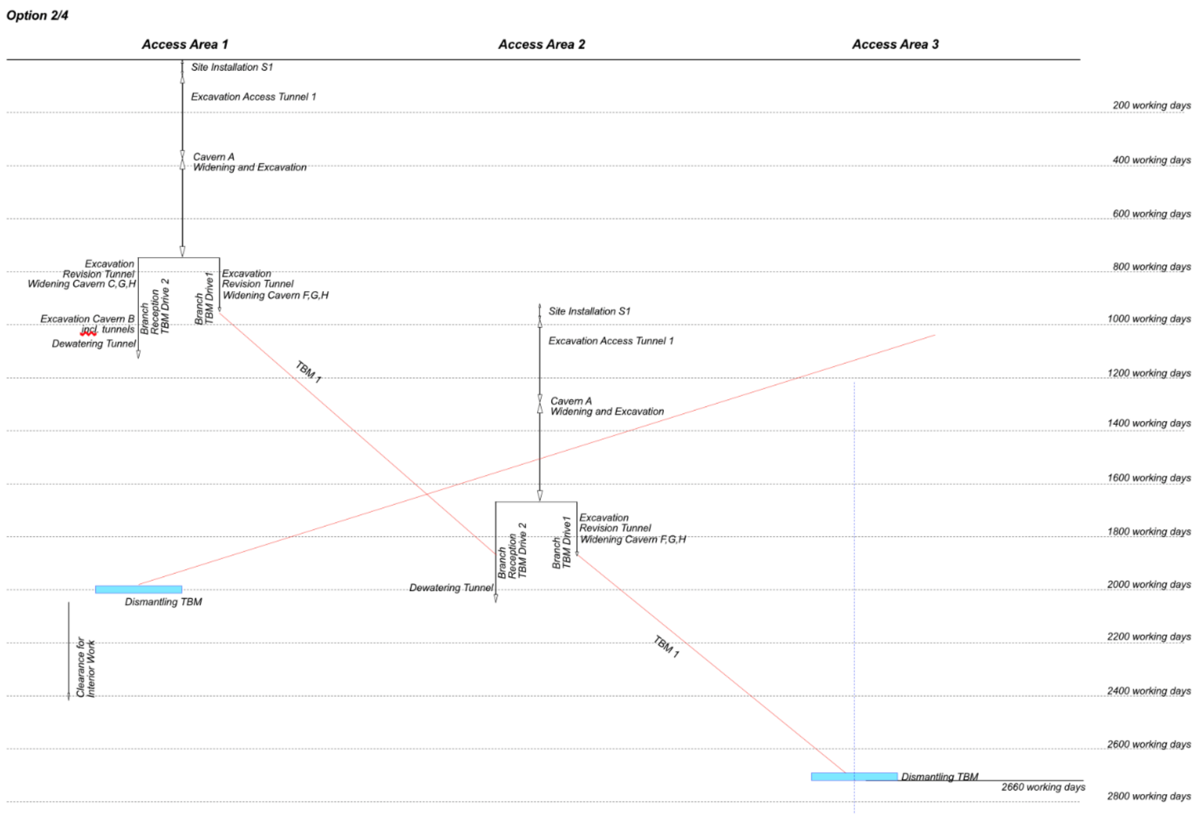


Figure 28: Construction schedule Option 2/4 (Access Shaft)

13 Preliminary assessment of construction costs

As-build costs and costs of actual projects, with a similar background of shaft excavation and associated excavation of caverns, as well as TBM excavation, form the basis of this preliminary assessment of costs.

Four overall options for construction, as shown in Table 2, prevail. The increased diameter of the shielded TBM to compensate wriggling of the TBM and the additional inner lining of the house in house solution are the driving parameters for the increased price for the option 3 and 4.

The overall costs do include a contingency of 10 % as an assumption and a typical total overhead of 12 % [13]. Table 3 summarises the prognosis of the total construction costs. The minimum construction costs are 686.6 Mio € for option 2, and the maximum costs are about 721.9 Mio € for option 4, which results in a prize difference of 60.7 Mio €.

Table 3: Total construction costs for the construction options 1-4

	Option 1	Option 2	Option 3	Option 4
	TBM-O	TBM-O	TBM-S	TBM-S
	Access Tunnel	Access Shaft	Access Tunnel	Access Shaft
Branch 1	191.9 Mio €	185.1 Mio €	201.4 Mio €	194.6 Mio €
Branch 2	177.6 Mio €	170.9 Mio €	186.1 Mio €	179.4 Mio €
Branch 3	191.9 Mio €	185.1 Mio €	201.4 Mio €	194.6 Mio €
Subtotal	561.3 Mio €	541.1 Mio €	588.9 Mio €	568.6 Mio €
Site Installation (3% of Construction Costs)	16.8 Mio €	16.2 Mio €	17.7 Mio €	17.1 Mio €
Subtotal including Site Instalaltion	578.1 Mio €	557.3 Mio €	606.5 Mio €	585.7 Mio €
Contingency Measures	10%	10%	10%	10%
Subtotal including Contingency Measures	636.0 Mio €	613.0 Mio €	667.2 Mio €	644.2 Mio €
Overhead	12%	12%	12%	12%
Total	712.3 Mio €	686.6 Mio €	747.2 Mio €	721.6 Mio €

The total overhead for the subsequent design of the construction is in the range of XX %, which is not included in the actual analyses.

[13] The total overhead was calculated as weighted average of latest projects of various construction companies.

The total construction costs per option compose of the construction costs for the shafts, the drill and blast excavation of the caverns, the Revision Tunnel / Dewatering Tunnel/ Borehole and the TBM excavation.

	Option 1	Option 2	Option 3	Option 4
	TBM-O/ ⃠ 7.3m	TBM-O/ ⃠ 7.3m	TBM-S/ ⃠ 8.4m	TBM-S/ ⃠ 8.4m
	Access Tunnel	Access Shaft	Access Tunnel	Access Shaft
Subtotal	561.3 Mio €	541.1 Mio €	588.9 Mio €	568.6 Mio €
Access Area 1/3	191.9 Mio €	185.1 Mio €	201.4 Mio €	194.6 Mio €
Access Tunnel	24.5 Mio €	18.0 Mio €	24.5 Mio €	18.0 Mio €
Cavern, Revision Tunnel & Dewatering Tunnel	48.4 Mio €	48.2 Mio €	48.4 Mio €	48.2 Mio €
TBM Excavation ⃠ 7.3m	119.0 Mio €	119.0 Mio €	128.5 Mio €	128.5 Mio €
Access Area 2	177.6 Mio €	170.9 Mio €	201.4 Mio €	179.4 Mio €
Access Tunnel	24.5 Mio €	18.0 Mio €	24.5 Mio €	18.0 Mio €
Cavern, Revision Tunnel & Dewatering Tunnel	48.4 Mio €	48.2 Mio €	48.4 Mio €	48.2 Mio €
TBM Excavation ⃠ 7.3m	104.7 Mio €	104.7 Mio €	128.5 Mio €	113.2 Mio €

Table 4: Composition of construction costs not including Site Installation; Contingency Measures and Overhead

14 Identification of main project risks and specification of mitigation measures

The accurate prognosis and evaluation of construction time and cost demands the distinct knowledge of the determining project parameters, in our case amongst others the specific geological conditions, which are the ultimate basis for the tunnel design.

The objective of the geological investigation is to create the base for the design and is therefore crucial for the project layout and development.

Variation of geological conditions, as well as misinterpretation of performance and behaviour of predicted geological conditions, can lead to significant project delays and increased constructions costs.

To implement a fair process of risk-sharing and ultimately for the success of the project (i.e. build it in required quality and at reasonable cost and time), it is highly recommendable, to include a capable construction contractor already in the design process, to receive best practice knowledge and experience, not only for overcoming certain detected and undetected problematic geological zones and risks, but also for a detailed operational analyses and planning e.g. on how to excavate the complex cavern structures.

The early contractor involvement is a risk shared approach to overcome foreseen and unforeseen obstacles with/as a best practice of the project and no dispute, since the contract defines the reimbursement of costs. Recent experiences have shown that a cost reduction for a hydropower project of approximately 9 % could be gained through this approach (Mitteregger & Wäger, 2018).

As a mitigation measure, it is highly recommended to consider an early contractor involvement to achieve a fair, transparent and efficient cost- and risk allocation throughout the design- and construction phase.

15 Summary

The review of actual design basis of the underground Einstein Telescope has provided general constructability. The construction of the shafts and associated caverns in their vicinity as well as the long TBM drives are highly encouraging and demand further operational clarification for optimisation of the overall construction schedule.

All underground structures can be excavated, based on the overall information given. The main critical path is related to the cost-optimised TBM excavation of two sides of the isosceles triangle, which forms the typical layout of the underground laboratory, with one TBM.

The estimate of the overall construction time is in the range of 7½ to 8 ¼ years, depending on the type of access tunnel

The costs for the excavation of the underground laboratory are estimated in the range of 686.6 Million € to 747.2 Million €, depending on the type of TBM excavation and lining of the caverns. All estimates are based on overall constructability within a favourable rock mass but do include a conservative assessment of advance rates and scope of work.

The costs do include additional risk-related costs for contingency measures and typical overhead costs for the erection of the underground laboratory. Not included within the operational, time and cost assessment are further installation or equipment of the underground laboratory.

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Managing Director	Geotechnical Expert