IFC-Tunnel Project

Report WP2: Requirements analysis report (RAR)

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1 Overview and methodology

The IFC-Tunnel project aims at extending the IFC data model in order to allow the precise description of the semantics and geometries of the different elements that make up tunnels, being, geotechnical subsoil conditions and treatments, civil engineering components and functional systems that equip them. It was initiated by the bSI Infra Room as a fast track project with a duration of two years.

This report documents the outcome of Phase 1 of the IFC-Tunnel project. It defines the scope of the project and the requirements for the IFC-Tunnel extension.

As such, it provides the basis for Phase 2 in which the conceptual model and the actual schema extension will be developed.

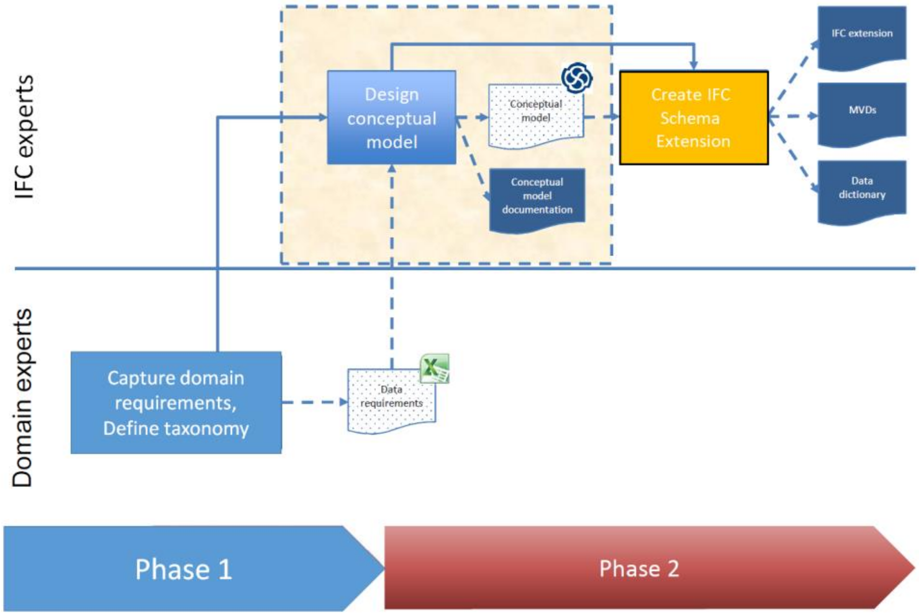


Figure 1-1-1: Ifc Extensions development process Phase 1 – Phase 2 (source: bSI)

Given the restricted project duration, it is necessary to focus on common and widespread tunnel types and to include only those use cases that provide a high value to the end users and require reasonable efforts for defining and validating the necessary IFC extensions.

The scope describes functions, geometries & domains semantics that are exchanged during the different tunnel development phases being programmatic, design, procurement, construction and reception (delivery & acceptance), and that are leveraged during the tunnel lifecycle through handover to assets mgt, maintenance (as-maintained information), rehabilitation (reference for future extensions) and operation (support to digital twin).

As a basis for defining the IFC-Tunnel extensions, the international project team identified the most important uses cases of the data exchange processes in underground infrastructures projects.

The project follows the guidelines set out in the IFC-Infra overall architecture project.

The main requirements for IFC-Tunnel have been consequently derived from the identified use cases with a focus on geometry representations and semantical descriptions. The use cases have been prioritized on the basis of balancing the value created versus the effort required for enabling the IFC data model to support them.

The starting point for the IFC-Tunnel extension is the schema published as IFC4.3 Candidate Standard[1], which has been developed in and harmonized across the IFC-Road, IFC-Rail and IFC-Ports and Waterways projects. In addition, the input from several national initiatives was taken into account.

The ultimate goal of the project is to create and provide the engineering and construction industry with an open BIM data exchange standard capable to exchange & archive tunnel models in a neutral ISO format that is vendor-independent and persistent for the long run.

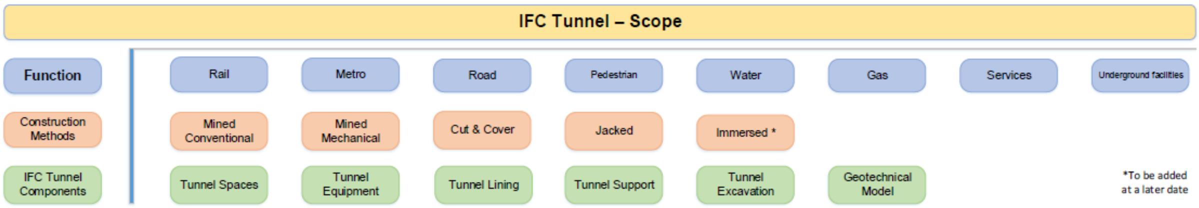
[1] https://technical.buildingsmart.org/standards/ifc/ifc-schema-specifications/

2 Scope

The project's scope is based on the industry's definition of tunnels, such as: Underground/underwater structures (***DIN 1076***), Artificial underground passage (***Oxford Dictionary***), Underground structure excavated to create a communication (***UIC***), Long enclosed transport route (***PIARC***) & Underground structures, shafts, chambers, passageways & cut and cover excavations (***OSHA***).

The IFC-Tunnel extension project's focus was set on those types of tunnels that are most widespread across the world and are of most interest to the stakeholders. The same applies for the tunnel subsystems to be considered.

The project team has identified the most relevant tunnel types and subsystems through internal discussions and surveys conducted with international expert panels.



This process formed the basis for deciding upon the prioritization as listed below.

2.1 Tunnel types

Tunnels can be classified according to their *function* and according to their *construction method*. Both are relevant criteria and must be considered when prioritizing tunnel types.

Prioritization according to *function*

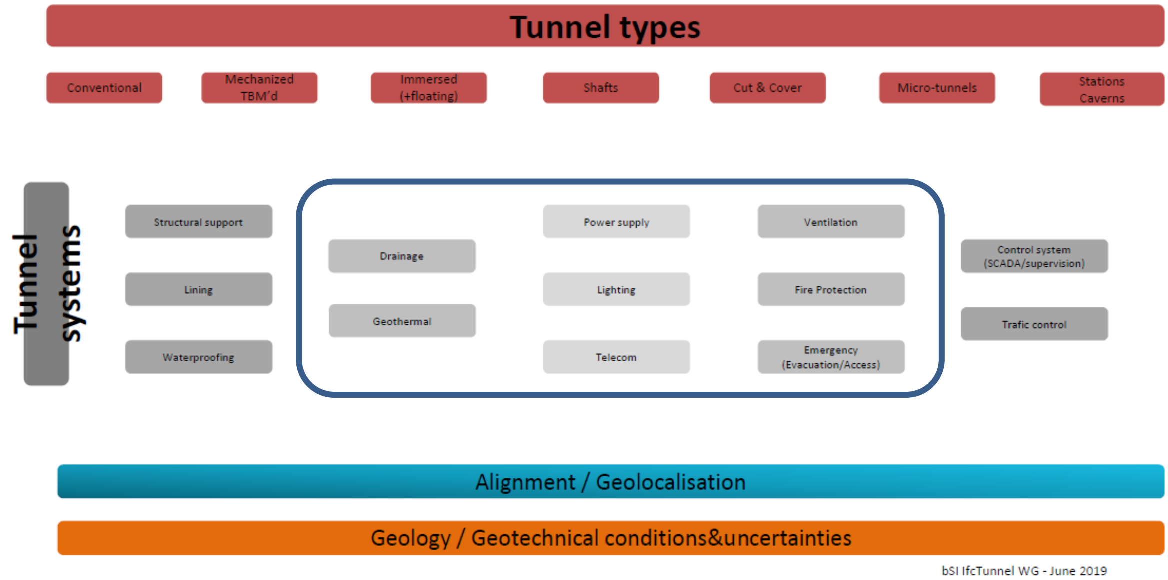
High priority	Low Priority	Out of scope
Road Tunnels	(Vertical) Evacuation Tunnels	Mining Extraction Tunnels
Railway Tunnels	(Vertical) Ventilation Tunnels	
Metro Tunnels	Water Tunnels	
Access Tunnels	Pedestrian Tunnels	
	Service Tunnels	
	Underground facilities	

Prioritization according to *construction method*

High priority	Low Priority	Out of scope
Conventional tunnelling	Jacked tunnelling	
Mechanised tunnelling	Immersed tunnelling	
Cut-and-cover	Vertical excavation	
	Micro tunnelling	

2.2 Tunnel subsystems

Regardless of its type, a tunnel is equipped with a series of technical sub-systems that allow to ensure the functions it is expected to provide vis-à-vis the roadway or railway that passes through; these are mandatory elements for operating the tunnel.



As such they represent specific requirements to be dealt with by the IFC-Tunnel.

High priority	Low Priority	Out of scope
Supervision	Geothermal	Traction
Ventilation		
Lighting		
Fire protection		
Emergency & safety		
Drainage		
Power supply		
Communication		

It should be noted that most of these systems are required and used through the construction phase as well (even if in a different, temporary manner).

Each system is made of a series of components with particular characteristics that can be regrouped in sub-systems for clarity purposes. Some of these components might already be identified in the IFC schema whereas others might be specific to tunnels.

A detailed taxonomy for each of these systems (sub-systems / objects / properties) and its associated requirements for IFC-Tunnel extension is proposed in §11.

3 Use cases

The following IFC-Tunnel use cases have been identified by the project team by analyzing the outcomes of the national tunnel projects and by discussions with the international expert panel. The table shows the priority of each use case and the complexity involved with defining the necessary data structures. This analysis formed the basis for the subsequent decisions regarding the scope of the project whose result is indicated by the color of the first column. A detailed description of each use case can be found in the appendix.

No	Use case	Description	Candidate exchange mechanisms	IFC exchange scenario	Required geometry representation	Required semantic information	Priority	Complexity
1	Initial state modelling	Initial data (terrain, existing structures etc.) from various sources (including GIS) are brought into BIM Tunnel design solution	SHP / CityGML / LandXML / InfraGML / IFC	From various sources into tunnel design SW	Explicit geometry (Faceted BRep, Triangulated Face Sets)	Minimal semantics on building and structures	High	Low
1b	Geologic factual data	Alignment planning, environmental assessment	AGS / GeoSciML / Geo3DML (?) / IFC	From GIS and geological modeling SW to BIM design SW	Explicit geometry (Faceted BRep, Triangulated Face Sets)	Detailed semantics on geological units, geotechnical properties etc. including uncertainties	High	Low
2a	Geologic and geotechnical modelling for planning	Assessment of geotechnical risk along tunnel route	AGS / GeoSciML / IFC	From GIS and geological modeling software to BIM design software	Explicit geometry (Faceted BRep, Triangulated Face Sets), Potentially voxel or octree representation	Detailed semantics on geological units, geotechnical properties etc. including uncertainties	High	Low

No	Use case	Description	Candidate exchange mechanisms	IFC exchange scenario	Required geometry representation	Required semantic information	Priority	Comple-xity
2b	Geotechnical modelling for design	Selection of tunneling method, Design of tunnel structure, Decision on ground improvement methods,	IFC	1. From GIS and geological / geotechnical modeling software to BIM design SW 2. From geotechnical modeling software to numerical analysis SW	Explicit geometry (Faceted BRep, Triangulated Face Sets), Potentially voxel or octree representation	Detailed semantics on geological units, geotechnical properties etc. including uncertainties	High	Medium
2c	Geotechnical modelling for construction and maintenance	Models with higher degree of detail, focusing on critical sections, Assessment of geotechnical risk during construction, Estimation of cause of tunnel damage and formulation of countermeasures in the maintenance stage	IFC	From geological and geotechnical modeling SW to construction and asset management SW	Explicit geometry (Faceted BRep, Triangulated Face Sets)	Detailed semantics on geological units, geotechnical properties etc. including uncertainties	High	Medium
3	Exchange of alignment and major road / railway parameters	Import of alignment and major road / railway parameters as a basis for tunnel design	LandXML / IFC	From roadway / railway design SW to tunnel modeling SW	Engineering description of alignment (V / H) with x-section-based sweeps for roadway / railway and kinematic envelops	Type of roadway / railway, Type of kinematic envelop	High	Low

No	Use case	Description	Candidate exchange mechanisms	IFC exchange scenario	Required geometry representation	Required semantic information	Priority	Comple-xity
4a	Technical visualization	3D technical visualization of the tunnel project for communicating design solutions between project partners , as a basis for design reviews / coordination	IFC	From Tunnel Design SW to Visualization SW	Explicit geometry (Faceted BRep, Triangulated Face Sets)	Component types, mostly required for coloring	High	Low
4b	Realistic Visualization	Photo-realistic visualization of the tunnel project for communicating design solutions to the public	IFC	From Tunnel Design SW to Visualization SW	Explicit geometry (Faceted BRep, Triangulated Face Sets)	Detailed information on materials, surfaces etc.	Low	Medium
4c	Safety visualization	Visualization of driver's view for safety reasons	IFC	From Tunnel Design SW to Visualization SW	Explicit geometry (Faceted BRep, Triangulated Face Sets)	Materials, reflectivity, road markings	Low	Medium
5	Design coordination	Coordination of domain-specific sub-models by combining models in coordination SW for detecting interferences	IFC	From Tunnel Design SW to Coordination SW	Explicit geometry (Faceted BRep, Triangulated Face Sets) with high accuracy, potentially NURBS geometry	Work breakdown structure, unique object identifier, ownership information	High	Medium

6a	Design to design w. reference models	Exchange reference model for further design activities, limited manipulation of the model	IFC	From design SW to (another) design SW	Precise explicit geometry; where possible with model design logic (alignment, axis, extrusions, etc)	Work breakdown structure, unique object identifier, ownership information	High	Medium
6b	Design to design w. full model logic	Exchange of fully parametric description of tunnel between two distinct design applications manipulation of the alignment, profiles etc. by receiving application	n/a	From Design SW to another design SW	Fully parametrized procedural geometry	n/a	Out of scope	Difficult
7	Structural & geomechanical analysis	Numerical (Structural and geomechanical) analysis of tunnels, slopes and retaining structures	IFC, others	From Design SW to structural and geomechanical analysis SW, FEM / DEM applications	Explicit geometry (Faceted BRep, Triangulated Face Sets) with high accuracy, pontentially voxel or octree rep.	detailed structural and geomechanical properties and boundary conditions	Low	Medium
8a	Air flow simulation	Numeric simulation of air flows in tunnels is used to model the aerodynamic, thermodynamic, exhaust gas and fire scenarios that occur during operation of the tunnel, ensuring safety and comfort for users	IFC, others	From design SW to CFD SW	Explicit geometry (Faceted BRep, Triangulated Face Sets).	minor	Low	Medium

8b	Hydraulic simulation	Analyse the behaviour of water in water transfer tunnels	IFC, others	From Design SW to hydraulic simulation SW	3D: Explicit geometry (Faceted BRep, Triangulated Face Sets), 2D: Dimensionally reduced model	minor	Low	Medium
9	Standards compliance	Automated checking of compliance of the tunnel design with norms and regulations	IFC	From Design SW to Model Checker	Procedural geometry based on profiles, axes and alignments	Strongly dependent on the type of code to be checked.	Low	Difficult
10	Quantity Take-Off	Basis for cost estimation, tendering, billing, logistics planning	IFC	From Design SW to QTO SW	Explicit geometry (Faceted BRep, Triangulated Face Sets).	Precise component types, combination with (national) classification system	High	Low
11	Construction sequencing (4D modeling)	Excavation volumes and functional parts are associated with the corresponding processes of the construction schedule.	IFC	From 4D modeling SW to 4D modeling / visualization SW	Explicit geometry (Faceted BRep, Triangulated Face Sets).	Temporal information (Schedule, Tasks, Durations)	High	Medium
12a	Design to tender: Construction Model	Provision of design models as part of the tender documents.	IFC	From design SW to model viewer and tendering applications	Hybrid: Procedural (cross-sections, axes) and explicit geometry	Detailed information on materials, properties, quantities	High	Medium

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12b	Design to tender: Geotechnical Model	Translation of the Geotechnical Baseline Report into a 3D geometrical representation	IFC	From the client/designer to the contractor's model viewer and tendering application	Explicit geometry (volume objects) ground sections: zones of similar ground behaviour	Definition of excavation- and support types and other measures, the corresponding structural analysis and the used geotechnical design model	High	Medium
13	Design to construction	Setting out construction projects, controlling earthmoving equipment, on-site decision making.	IFC / P5 / MP	From design SW to model viewer and set-out SW	Hybrid: Procedural (cross-sections, axes) and explicit geometry	Detailed information on materials, properties, quantities	High	Low
14	Prefabrication and manufacturing	Steering the production process on the basis of the digital design model	IFC	From (detailed) design software to segment / accessories manufacturer SW and machine steering SW	Hybrid: Procedural (cross-sections, axes) and explicit geometry; very detailed, high accuracy	Detailed information on materials, properties, quantities, Identification means	Low	Low
15a	Progress monitoring	A BIM model is used to report progress on site on a regular basis. .	IFC	From field SW to construction management SW.	Explicit geometry (Faceted BRep, Triangulated Face Sets)	Work breakdown structure; unique object identifiers, responsible trade, completion status.	High	Low

15b	Geological documentation	The geological model is updated throughout the whole cycle life of the project and especially during the excavation phase.	IFC	From surveying SW to geological / geotechnical modeling SW, visualization application	Explicit geometry (Faceted BRep, Triangulated Face Sets)	Detailed semantics on geological units, geotechnical properties etc., according to ISO standards	High	Medium
15c	Scanning during construction	Exchange of the scanned geometry of underground surfaces as a basis for determining over-break etc.	LAS / PLF	From scanning SW to an evaluation or recording / documentation software	Clored point-clouds and/or triangulated face sets	Only meta-data.	Low	Medium
15d	Quantity determination for billing / payment	Logging and calculating the quantities of work performed or completed and communicating such information to all parties involved.	IFC / CSV	From surveying SW / field SW to construction management / payment SW.	Explicit geometry (Faceted BRep, Triangulated Face Sets)	Quantities, work breakdown structure; unique object identifiers, responsible trade, completion status	High	Medium
16	Machine guidance & control	Steering a tunnel boring machine through the ground on the basis of the as-designed tunnel axis	IFC / CSV	From tunnel design SW to machine guidance SW, Machine guidance and on-field applications to design software and AIM-solutions (as-built)W;	Precise description of the alignment, both as-designed and as-built, as well as the allowable tolerances.	Minor	Low	Low

17	Damages recording	Damages control is done during construction, at acceptance of works and during operation. It aims at recording the damages affecting the quality of the structure during construction and operation.	IFC / SensorML	Field SW to BIM as-built SW	Explicit geometry (Faceted BRep, Triangulated Face Sets), precise localisation	Description of damages, photos, survey forms, responsible parties	Low	Medium
18	Settlement monitoring	Monitoring of ground deformations during tunnelling	IFC / SensorML	From authoring and coordination SW to Geographical Information Systems (GIS) and/or to geological/technical models management systems	Explicit geometry (Faceted BRep, Triangulated Face Sets), precise localisation of sensors	Sensor type, measurement, time stamp	Low	Medium
19	Handover to GIS	Provide the basis for regional/national transportation asset management (network level, programmatic needs analysis),	SHP / CityGML / LandXML / InfraGML	From authoring and coordination SW to Geographical Information Systems (GIS) and/or to geological/technical models management systems	Explicit geometry (Faceted BRep, Triangulated Face Sets), potentially with alignment / tunnel axis	Semantics on the built tunnel components, the terrain, the geology	High	Low

20	Handover to Asset Management	Handover of the as-built model, import into Asset management systems Advanced asset management is expected to leverage a Digital Twin of a tunnel, in the form of a continuously updated digital mirror of the current conditions	IFC / CityGML / InfraGML	From BIM-based tunnel design SW to BIM-based Asset management system	Asset management systems are regularly only capable to use explicit geometry descriptions. This results in limitations for the re-import into design applications.	Full semantics on the tunnel components and systems.	High	Medium

Figure 3-1: IfcTunnel use cases priorization analysis matrix

4 Use cases prioritization

Based on a careful analysis of the benefits of the individual use cases and the complexity and effort involved with defining the necessary data structures, the project team assigned priorities to the use cases that form the basis for the development of the IFC-Tunnel extension.

The following use cases have been assigned a high priority:

- 1a – Initial state modelling
- 1b – Geologic factual data
- 2a – Geologic modelling
- 2b – Geotechnical modelling for design
- 2c – Geotechnical modelling for construction
- 3 – Exchange of alignment and major road/railway parameters
- 4a – Technical visualization
- 5 – Design coordination
- 6a – Design to design w. reference models
- 10 – Quantity Take-Off (general)
- 11 – Construction sequencing (4D modeling)
- 12a – Design to tender: Construction Model
- 12b – Design to tender: Geotechnical Model
- 13 – Design to construction
- 15a – Progress monitoring
- 15b – Geological documentation
- 15d – Quantity determination for billing / payment
- 19 – Handover to GIS
- 20 – Handover to AMS

The following use cases have been assigned a lower priority:

- 4b – Realistic visualization
- 4c – Safety visualization
- 7 – Structural and geomechanical analysis
- 8a – Air flow simulation
- 8b – Hydraulic simulation
- 9 – Standards compliance checking
- 14 – Prefabrication
- 15c – Scanning during construction
- 16 – Machine guidance and control
- 17 – Damages recording
- 18 – Settlement monitoring

Due to overly high complexity, the following use case is out of scope of IFC-Tunnel:

- 6b – Design-to-Design with full model logic

It should be noted in particular, that the *full design-to-design* use case, which incorporates the model's design logic, is excluded here, as it would require software vendors to adapt modeling functionality, which is not deemed practical for reasons of competitive advantage, compatibility, and cost/benefit.

Currently, there is no well-defined industry need that would justify this effort.

5 Process map and exchange scenarios

The following process maps have been defined according to the IDM standard to clearly identify the exchange requirements and associate them with dedicated data exchange scenarios. Its purpose is to provide a general reference process, i.e. deviations in national or regional processes are possible.

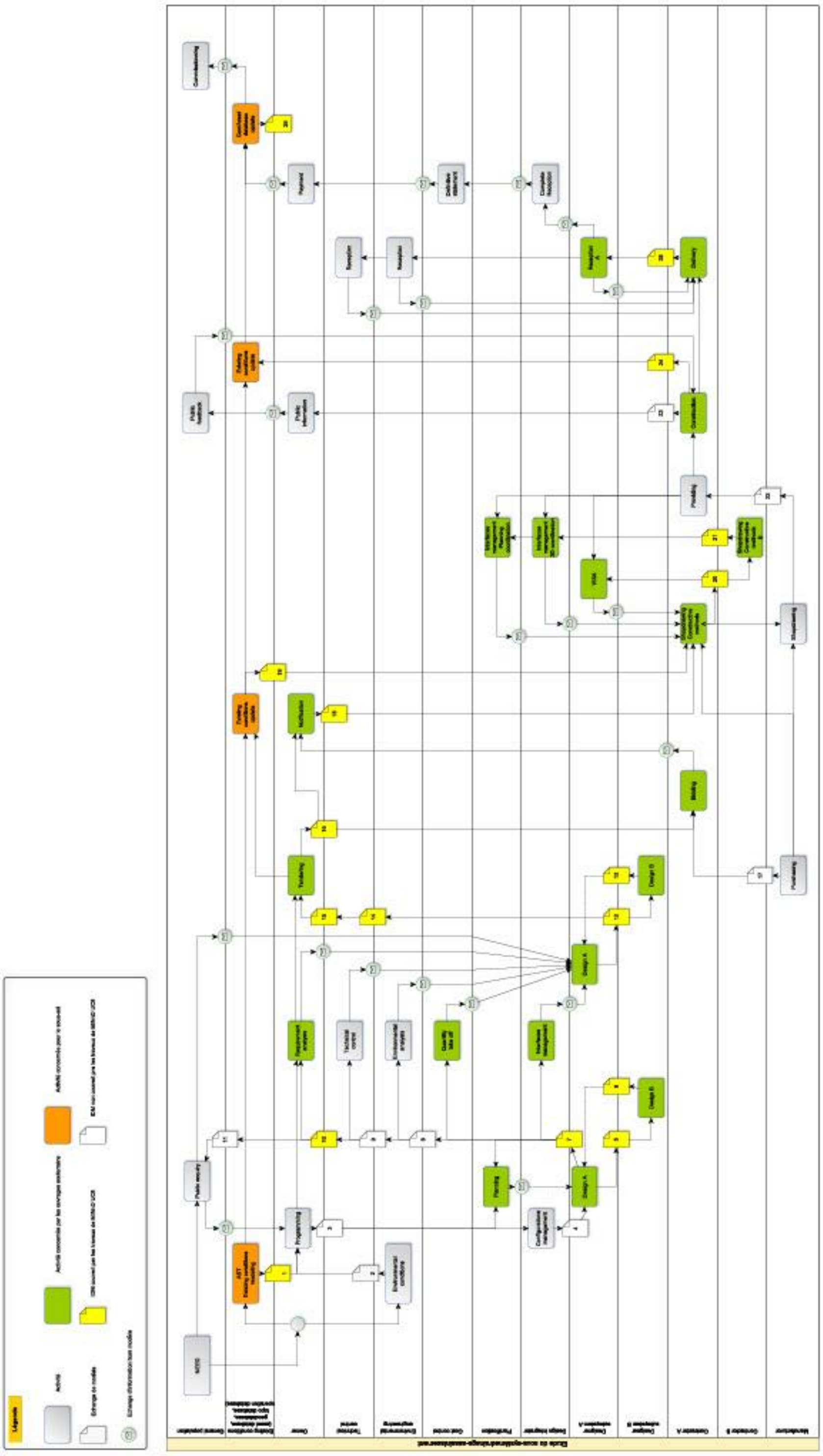


Figure 5-1: Process map describing Tunnel engineering processes and the exchange scenarios that IFC-Tunnel is supposed to support

As processes related to geological assessment and geotechnical engineering are particularly important for tunneling projects, these processes are depicted in detail in the following process map:

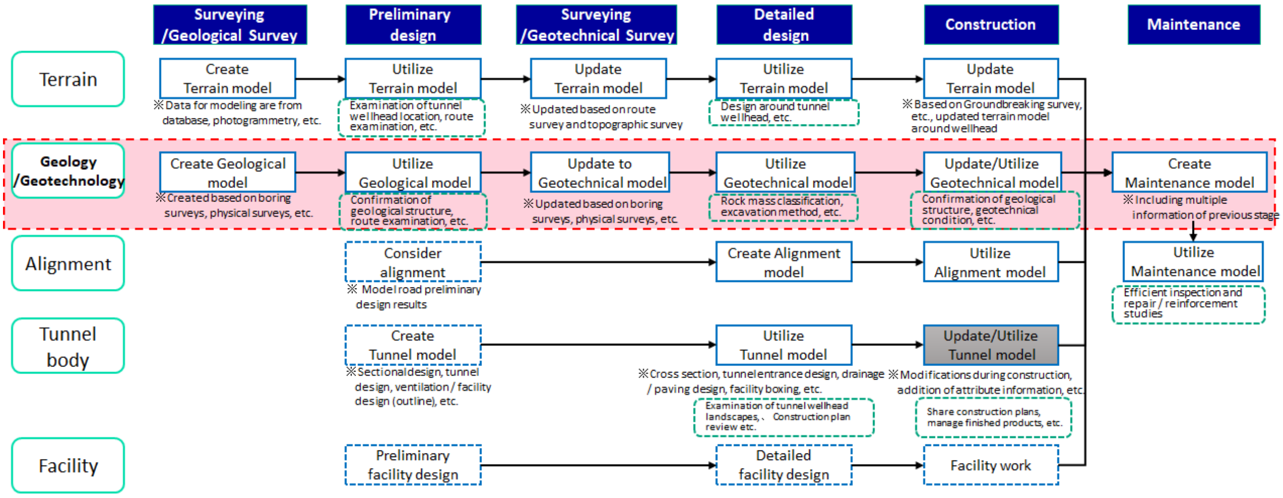


Figure 5-2: An example of the geotechnical process map. It is described based on ''CIM Introduction Guidelines (draft) Volume 6 The Mountain Tunnel'' by Ministry of Land, Infrastructure, Transport and Tourism Japan, 2020.

All processes are discussed in detail in their respective chapters.

6 Georeferencing, geometries and positioning requirements

6.1 Overview

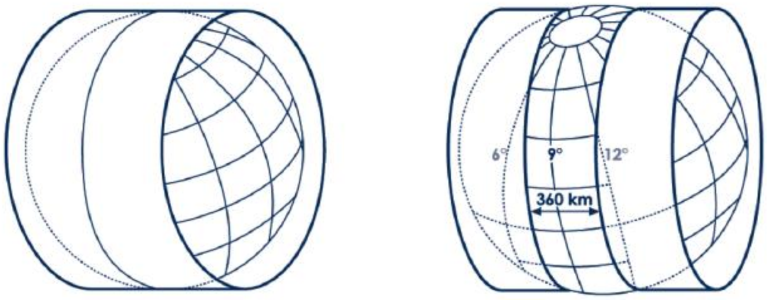
Tunnels as (potentially very long) linear infrastructure assets have specific requirements with respect to geo-referencing, geometry representation as well as positioning of objects along the axis (linear referencing). These requirements are detailed in this section.
Some aspects of linear infrastructure assets have been covered already in the previous IFC-Infrastructure extension projects, most importantly the IFC-Alignment, IFC-Bridge, IFC-Road and IFC-Rail projects. These works are referenced here where appropriate.

It is important to note that the requirements for representing geometry in IFC always depend on the use case to be implemented, or more specifically the exchange scenario to be supported. Where necessary, the respective UC is referred.

6.2 Georeferencing

The proper usage of geodetic coordinate reference systems (CRS) plays an extraordinarily important role for the design and construction of tunnels due to their potentially very long expansions. Geodetic CRS apply a transformation to project the earth surface approximated by an ellipsoid onto a flat map (map projection[2]), see Figure 6-1. In the case of the Universal Transversal Mercator (UTM) projection, a cylindrical surface is used as projection surface. The projection and the height reduction to an ellipsoid introduces distortions in lengths (see Figure 6-2). These distortions depend on the coordinate reference system applied and the location on the earth surface[3].

In consequence, tunnel models created in geodetic CRS are not 1:1 representations of the physical reality. This has to be taken into account for surveying, setting out, quantity take-off and any other kind of activity that translates model dimensions into the real world. Surveyors are experts in this field and can handle the required translations.



(a) GK projection. (b) UTM projection.

Figure 6-1: Different ways of projecting an ellipsoid on a cylinder (a: Gauss-Krüger projection, b: UTM projection). Source: GeoBremen (2015)

[2] Alternatively, Earth-centered, Earth-fixed (ECEF) coordinate systems can be used to avoid projections. However, current engineering practice still relies on projected (geodetic) coordinate reference systems.

[3] For more details, please refer to: Š. Jaud, A. Donaubauer, O. Heunecke, A. Borrmann (2020): Georeferencing in the context of Building Information Modelling, Automation in Construction 118C (2020) 103211

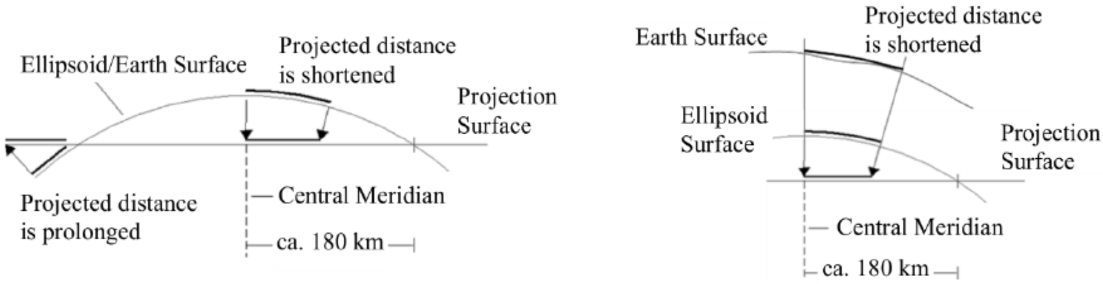


Figure 6-2: The distortions induced by the UTM projection (left) and the height reduction (right). Source: Kaden & Clemen (2017)

Data exchange standards, such as InfraGML, GeoSciML or CityGML, that are based on the Geographic Markup Language (GML) pay particular attention to the correct handling of geodetic reference systems, by providing the necessary meta-data and by using exclusively coordinate values in the underlying geodetic CRS[4]. This approach is also implemented by roadway and railway design systems.

BIM authoring systems for buildings are typically not able to handle geodetic CRS (large coordinates). For this reason, very often a mere translation of the coordinate system is applied by defining a local coordinate system on a local point of origin. Typically, the geodetic coordinates are provided for this point of origin. However, if the local coordinate system is created by a mere translation (shifting in x and/or y direction by subtracting a fixed value from x and y coordinates), it remains a projected coordinate system with length distortions as described above (see Figure 6-3). However, as now “small coordinates” are used, there is the severe risk that the tunnel model is erroneously interpreted as a distortion-free 1:1 model, potentially resulting in cost-intensive surveying errors on site[5].

Accordingly, for the proper use of the tunnel model represented by an IFC model, explicit information of the applied Coordinate Reference System is crucial. A strong requirement for using IFC in the context of tunnel projects is therefore the use of the entity *IfcProjectedCRS* (a subclass *IfcCoordinateReferenceSystem*) which has been introduced with version 4.0 of the IFC standard. Its attributes *GeodeticDatum* and *VerticalDatum* allow the specification of a code standardized by the European Petroleum Survey Group (EPSG), which unambiguously defines the CRS in use[6].

A typical instance of IfcProjectCRS is:

```
#17=IFCPROJECTEDCRS('EPSG:5835','EPSG:5835 - DHHN92 / 3-Degree Gauss-Krueger
Zone 5','EPSG:5681','EPSG:5783','Gauss-Krueger','5',#18);
#18=IFCSIUNIT(*,.LENGTHUNIT.,$,.METRE.);
```

[4] Colloquially called „large coordinates”. A typical example is (691052.452, 5336012.737) in UTM 32.
[5] There are Coordinate Reference Systems that have low (practically irrelevant) distortions. One example is the EUREF89 NTM (Norway Tranverse Mercator). However, this cannot be assumed in general for projection systems such as UTM.
[6] See the “User guide for geo-referencing in IFC” on https://www.buildingsmart.org/standards/bsi-standards/standards-library/

In addition, the IFC-Tunnel project team strongly recommends not to create a local coordinate system[7] in the IFC model (by using *IfcMapConversion*), but to only use “large” coordinate values in the original CRS. Doing so will reduce the risk of misinterpreting distances and lengths in the models. If the use of a local coordinate system is unavoidable, the IFC model should be clearly marked by setting an “*isDistorted*” flag. The IFC-Tunnel team proposes to add this attribute to *IfcGeometricRepresentationContext*.

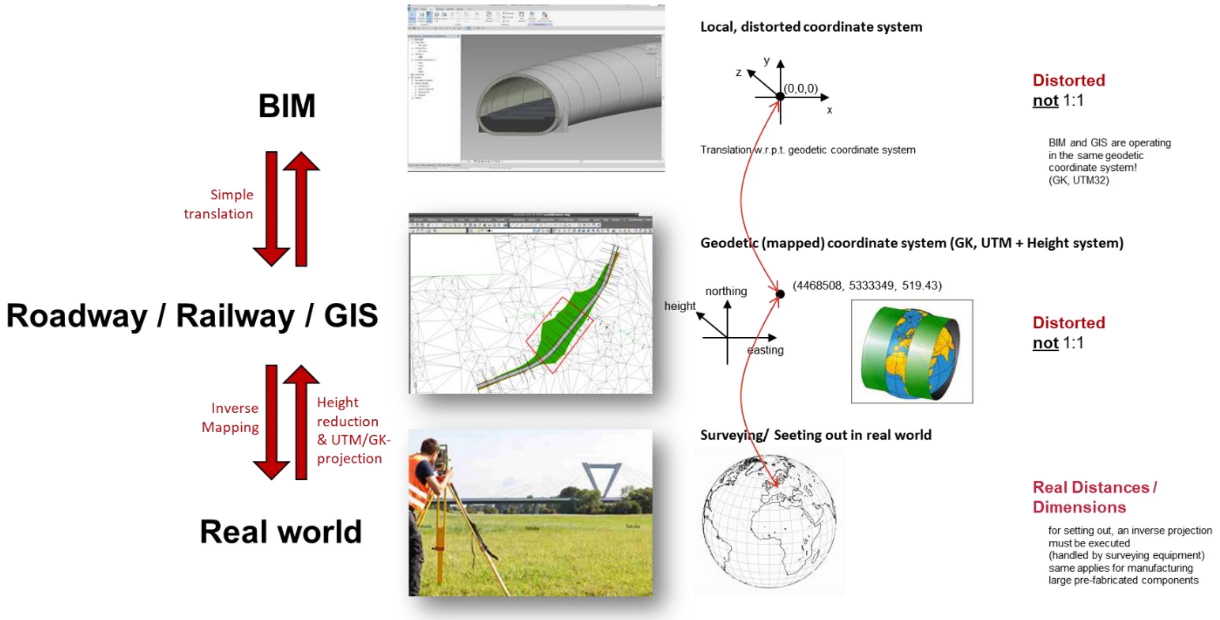


Figure 6-3: The application of a mere translation from the geodetic CRS to the local CS results in a distorted local coordinate system, i.e. lengths and dimensions may vary from that of the real world.

The application of the attribute *Scale* of *IfcMapConversion* is not recommended as it only allows the specification of a uniform scale factor in x, y and z direction (in its current version of IFC 4.3). Due to the nature of the applied geodetic projection, however, the scale factor is different in the three directions.

The bSI project “Model Setup IDM” recently proposed the introduction of the entity *IfcMapConversionSiteExtended* allowing to define three independent scale factors. The IFC-Tunnel project team supports this proposal. However, its documentation must unambiguously specify how exactly the scale factor is applied and whether it is supposed to result in an undistorted 1:1 model stored in the local coordinate system. It must also be noted that the scale factor varies with the geographic location, also along the tunnel. Accordingly, for long tunnels, the direct use of “large” coordinates as described above remains the preferred option.

[7] Disconcertingly, the local coordinate system is denoted as WorldCoordinateSystem in IfcGeometricRepresentationContext. The documentation states: “If an geographic placement is provided using IfcMapConversion then the WorldCoordinateSystem atttibute is used to define the offset between the zero point of the local engineering coordinate system and the geographic reference point to which the IfcMapConversion offset relates.” For the reasons provided in this manuscript, it is disouraged to apply any offset.

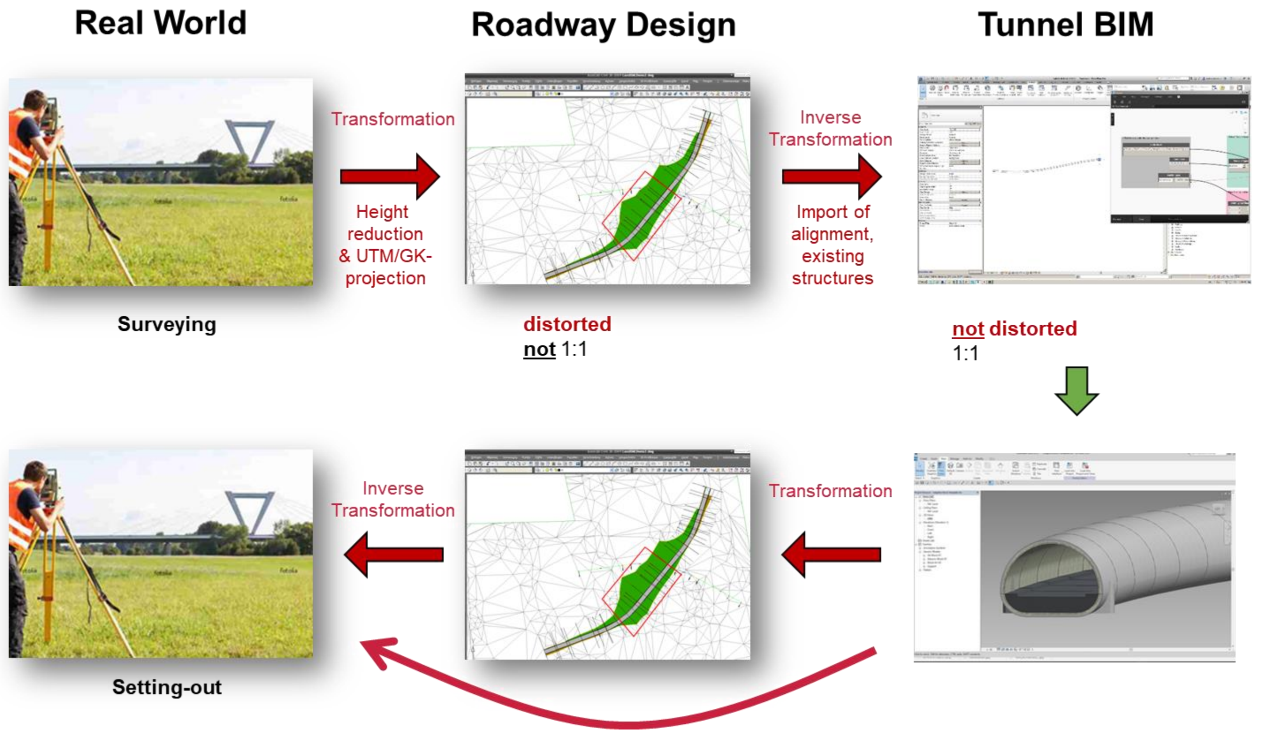


Figure 6-4: For short tunnels, an 1.1 modeling approach might be applied. However, for any data imported from GIS and other sources with geodetic CRS, an inverse transformation must be applied.

For short tunnels, also the use of a 1:1 modeling approach with an undistorted local coordinate system is possible. However, again this must be clearly specified in the IFC file, e.g. by setting the "IsDistorted" flag to FALSE. It is important to have in mind that for any data imported from GIS and other sources with geodetic CRS (e.g. digital terrain model), a re-projection must be applied to de-distort it (Figure 6-4).

For very large tunneling projects or for tunnels that cross national borders, project-specific CRS are applied that apply non-standard projections to minimize distortions between the projected CRS and the reality. A good example is the Brenner Base Tunnel that crosses the Austrian-Italian border[8]. This introduces the problem that for these project-specific CRS there are no EPSG codes defined. To nevertheless be able to unambiguously define the CRS in use, the IFC-Tunnel project team supports the proposal by Jaud et al. and the bSI project "Model Setup IDM" to make use of "Well-known text" (WKT) to specify the meta-data necessary to specify all parameters of a project-specific CRS[9].

The **Snake Projection** is a coordinate system, "which projects geographical coordinates onto an easting and northing grid. The parameters defining the Snake Projection must be tailored for specific projects; the most typical use is with large-scale linear engineering projects such as rail infrastructure, however the projection is equally applicable to any application requiring a low distortion grid along a linear route (e.g. pipelines and roads). The name of the projection is derived from the sinuous nature of the projects it may be designed

[8] For more details the reader is referred to:
Markič, Š., Borrmann, A., Windischer, G., Glatzl, R. W., Hofmann, M., Bergmeister, K. (2019). "Requirements for geo-locating long transnational infrastructure BIM models." Proc. of ITA-AITES World Tunnel Congress, Naples, Italy

[9] For more details the reader is referred to:
Š. Jaud, A. Donaubauer, A. Borrmann (2019): Georeferencing within IFC: A Novel Approach for Infrastructure Objects, In: Cho, Yong K.; Leite, Fernanda; Behzadan, Amir; Wang, Chao (Eds): Computing in Civil Engineering 2019: Visualisation, Information Modelling, and Simulation, American Society of Civil Engineers, 2019

for. Typical map projection distance distortion characteristics of a Snake projection are minimal over the whole route within approximately 20 kilometres of the centre line. The principal advantage of the projection is that, for the corridor defining the design space, distances measured on the ground have a one to one relationship with distances in coordinate space (i.e. no scale factor need be applied to convert between distances in grid and distances on the ground). The main disadvantage is that away from the design corridor the distortion of the projection is not controlled."[10]

The Snake Projection is the engineering coordinate system used for a significant proportion of primary rail routes in the UK, including that of the HS2 London to Birmingham line. For the London to Glasgow West Coast Main Line the distortion in the Snake Projection used is no greater than 20 parts per million within 5 kilometres of either side of the track.

Detailed and definite recommendations regarding CRS will be developed in Phase 2 of the IFC-Tunnel project.

6.3 Alignment and tunnel axis

The proper description of the alignment plays a major role for the digital representation of tunnels. A large number of use cases require the alignment to be represented as an explicit description as part of the IFC model to be exchanged. The alignment information is used for:

- procedural geometry descriptions where a cross-section is swept / extruded along an axis
- a linear reference system to position objects along the alignment

Both aspects are equally important. They are not necessarily implemented on the basis of the same geometric curve.

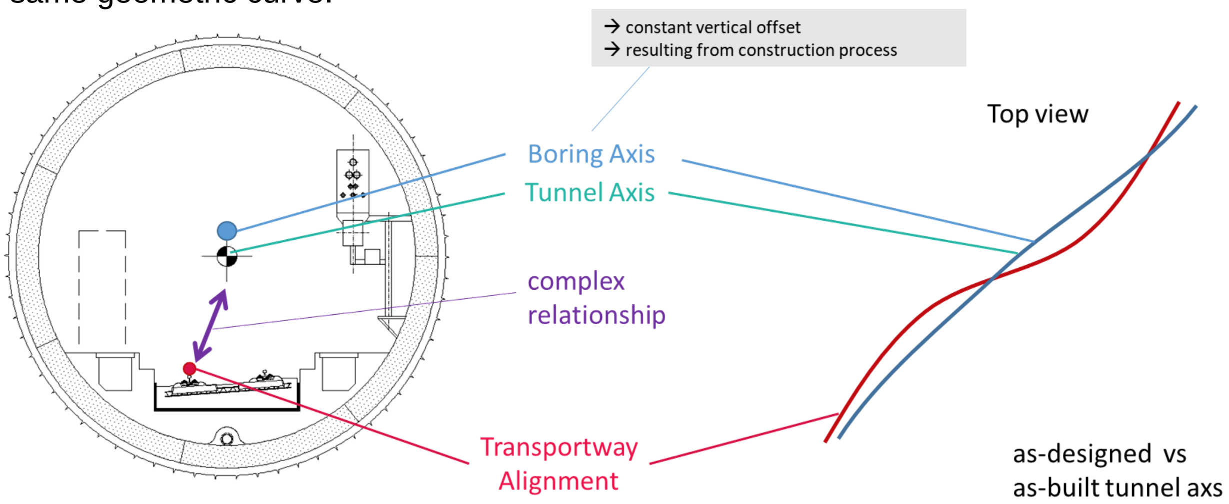


Figure 6-5: Differences between the boring axis, the tunnel axis and the transport alignment.

Especially for Mechanised tunnels, it is important to distinguish between the different axes and underlying alignment curves (see Figure 6-5):

- (1) the alignment of the roadway or railway encased by the tunnel
- (2) the tunnel axis ("theoretical axis")

[10] Source: https://en.wikipedia.org/wiki/Snake_Projection

* (3) the boring axis

The differences between (2) and (3) results from the fact that there is vertical displacement of the ring after it has been installed due to the gravitational forces. The tunnel accordingly must be bored in an axis that has a vertical offset from the resulting tunnel axis.
While there are dependencies between (1) and (2), they are usually too complex to be described by the IFC model in an explicit manner. For the in-scope use cases (see Section 3) it is also not necessary to express this dependency.
The capabilities of IFC to describe alignments as introduced with IFC 4.1 and refined with IFC 4.2 can be deemed sufficient for the requirements of representing the axes of tunnel models and implement the identified use cases.

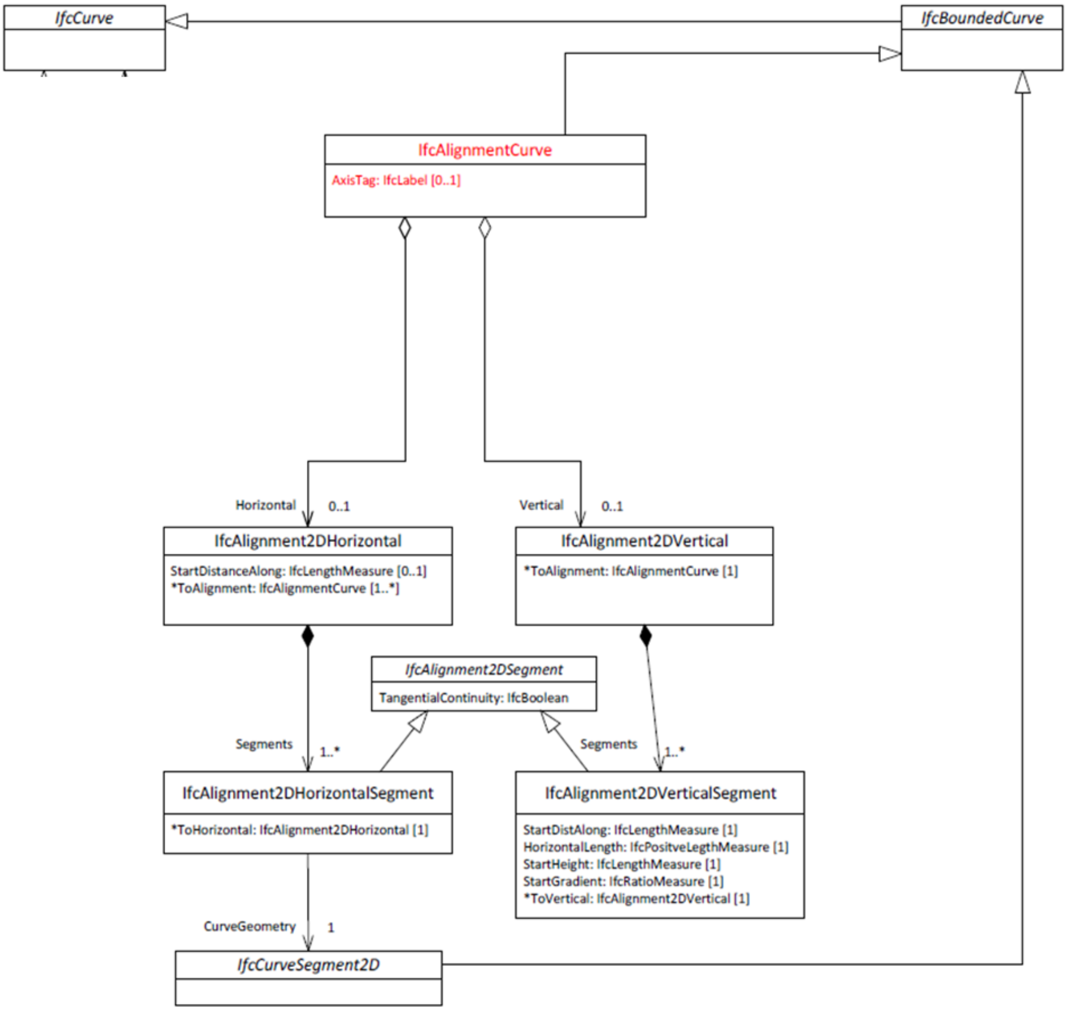


Figure 6-6: UML diagram of IfcAlignmentCurve and its subclasses

It is important to note that the IFC data model distinguishes between the IfcAlignment object as an abstract logical entity that can be used as a basis for linear referencing and/or for positioning and the IfcAlignmentCurve that represents the actual geometric curve of the alignment.
What distinguishes infrastructure alignment from other alignments (grids etc.) is the fact that it is usually described by separated horizontal and vertical 2D curves, reflecting the engineering approaches taken when designing the alignment. This notion is very well supported by the IFC data model. Both the horizontal and the vertical alignment are

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composed of a number of segments, including circular arc segments, line segments and transition curve segments. The latter can be one of the following types (IfcTransitionCurveType):

- BIQUADRATICPARABOLA,
- BLOSSCURVE,
- CLOTHOIDCURVE,
- COSINECURVE,
- CUBICPARABOLA,
- SINECURVE

The alignment curve cannot only be described by means of a separated horizontal/vertical 2D curves but also by 3D curves.
For as-built representations of the tunnel model (Use cases 19, 20) the applicability of straight-line segments in the alignment is a strong requirement.
IFC provide the capability that the alignment can be used as a basis for linear reference system compliant with ISO 19148. This means that all objects can be placed along the axis, which is the preferred way of localization in tunnels. It must be noted, that the reference curve of linear referencing in tunnels (chainage, tunnel meter) is the projection of the axis onto the horizontal plane.

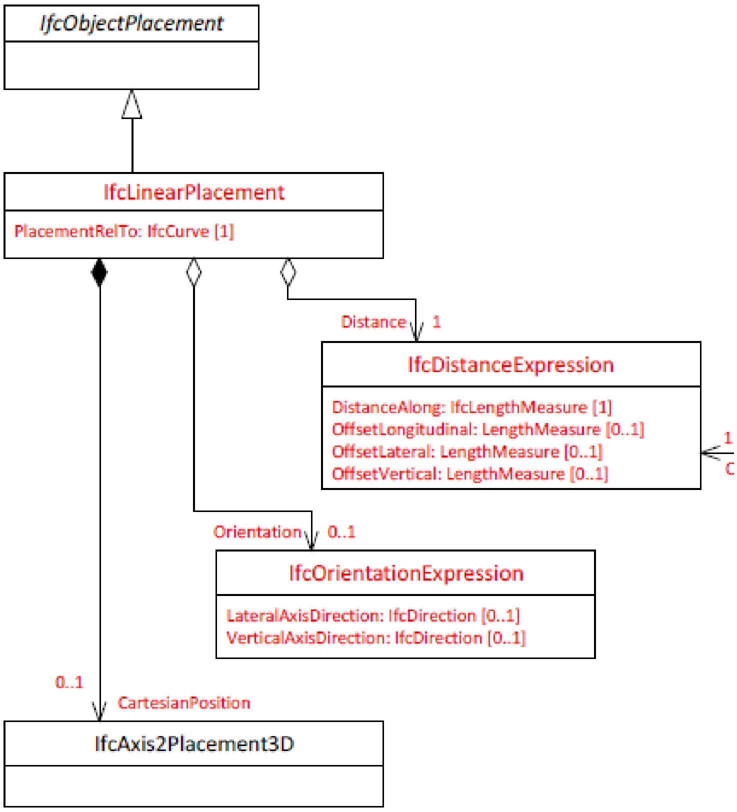


Figure 6-7: UML diagram of IfcLinearPlacement and related entities

6.4 Geometry

The IFC data model supports a wide range of geometry representations. They can be broadly separated into

- explicit representations that describe the geometry of volume objects by their surface
- implicit representations (also called procedural descriptions) that describe the construction history, i.e. the operations applied to create the geometry

Both representations have their advantages and disadvantages and are suitable for different use cases. This is discussed in more detail in the following subsections.

6.4.1 Explicit Geometry

Explicit geometry representations describe the resulting geometry, but not the construction process. As such, they are well applicable for use cases that do not require the geometry to be modified after receiving it as an IFC model. By contrast, for design-to-design use cases where the (user of) the receiving application is supposed to change the model, explicit representations are of limited use.

The IFC standard provides multiple options for describing explicit geometry:

- triangle-based geometry (IfcTriangulatedFaceSet): a very common and wide-spread representation based only on triangles
- BRep geometry (IfcFacetedBRep): A representation that allows the proper description of non-triangular faces and the topology relations between faces, edges and vertices. All faces are planar and all edges are straight lines.
- NURBS geometry (IfcAdvancedBRep): A representation that allows the description of solid objects with curved surfaces and curved edges on the basis of the mathematical description of Non-uniform rational B-Splines (NURBS).

Due to the construction methods applied, tunnel models typically have a high number of curved surfaces. This makes the application of NURBS geometry a natural choice. However, this representation is currently only to very low degree implemented by software vendors. Nevertheless, it is desirable for use case with high accuracy demands and should be demanded from software vendors in the future.

Accordingly, in most cases an approximation using triangle-based geometry will be applied. It must be noted however, that due to this approximation, there are deviation between the real geometry and the one represented by the model. The size of the deviations depends on the refinement of the triangular mesh. At the same time, it must be noted that models with a large number of triangles are heavy in terms of file and storage size.

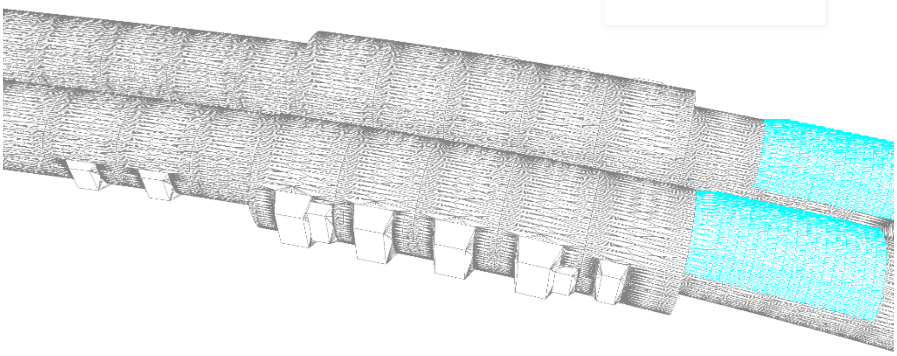


Figure 6-8: A tunnel model with geometry described by IfcTriangulatedFaceSet with a large number of triangles

TBM tunnels are composed of a large number of repetitive (identical) elements, such as the ring segments. The geometry of these elements should be represented only once, and subsequently instantiated, placed and rotated by means of the IfcObjectType mechanism.

6.4.2 Procedural Geometry

Both TBM tunnels as well as conventional tunnels can very well be described by procedural approaches based on the concept of sweeping a profile (cross-section) along an axis. This represents is the engineering approach taken when constructing a tunnel. Many use cases accordingly depend on this notion and require the explicit description of the cross-section(s).

The use of procedural geometry is a requirement of any exchange scenarios that require the modification of the tunnel geometry at the receiving side.
In comparison with a triangulated geometry description, a higher accuracy can be achieved by procedural descriptions while at the same time significantly lowering the data footprint (file size). However, the risk of diverging interpretations at the sending and the receiving application is significantly higher, potentially resulting in erroneous geometry.

An important aspect to be considered is the fact that the profiles of conventional tunnels may change along the axis. Accordingly, the transition between the profiles must be clearly and unambiguously described by the IFC model, such that it is interpreted in the same way at both the sending and the receiving side.

For the procedural description of tunnel models, the following aspects have to be considered:

- the definition of the sweeping behavior
- the description of the cross-section(s),
- the description of the sweeping axis,
- the description of interpolation between profiles,
- the description of spaces voiding the extrusion body.

Types of sweeps
The IFC data model provides different types of sweep representations. For tunneling, it is important that the cross-section is always perpendicular to the sweeping axis.

For tunnels with constant cross-section, IfcDirectrixDistanceSweptAreaSolid can be applied to produce the required sweep geometry.

For profiles with varying cross-sections, IfcSectionedSolidHorizontal can be applied. Here, the solid is generated by sweeping the CrossSections between CrossSectionPositions with linear interpolation of profile points. For cross-section with points varying independently, each profile may be of a different instance but of same type (e.g. IfcArbitraryClosedProfileDef), and may optionally have cross section points associated to string lines ("guide curves") using labels. The IFC-Tunnel extension must ensure that labels can be applied any of the required profiles.

The attribute FixedAxisVertical indicates whether Sections are oriented with the Y axis of each profile facing upwards in +Z direction (True), or vertically perpendicular to the Directrix varying according to slope (False). In case of tunnels, this attribute must be set to False.

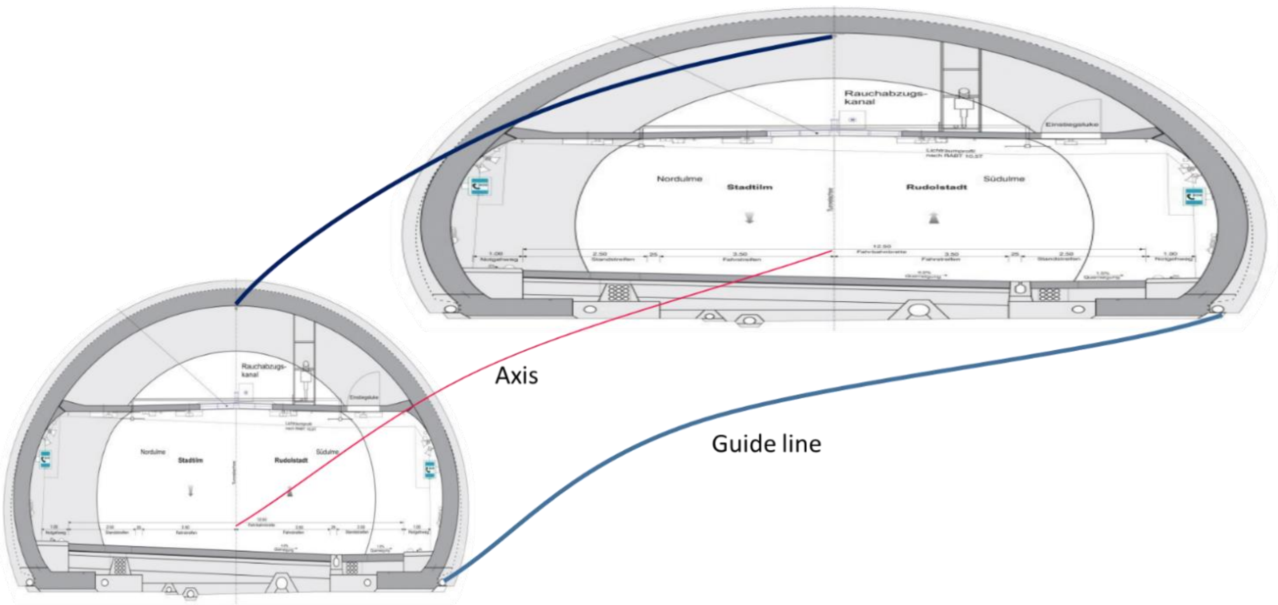


Figure 6-9: The use of guidelines to precisely describe the sweeping behavior between two consecutive cross-sections.

Cross-sections

Cross-sections are represented in IFC by means of the entities IfcArbitrayClosedProfileDef or IfcArbitraryProfileDefWithVoids. It is important to work with closed profiles as only closed areas result in volume objects when being extruded/swept along the axis.

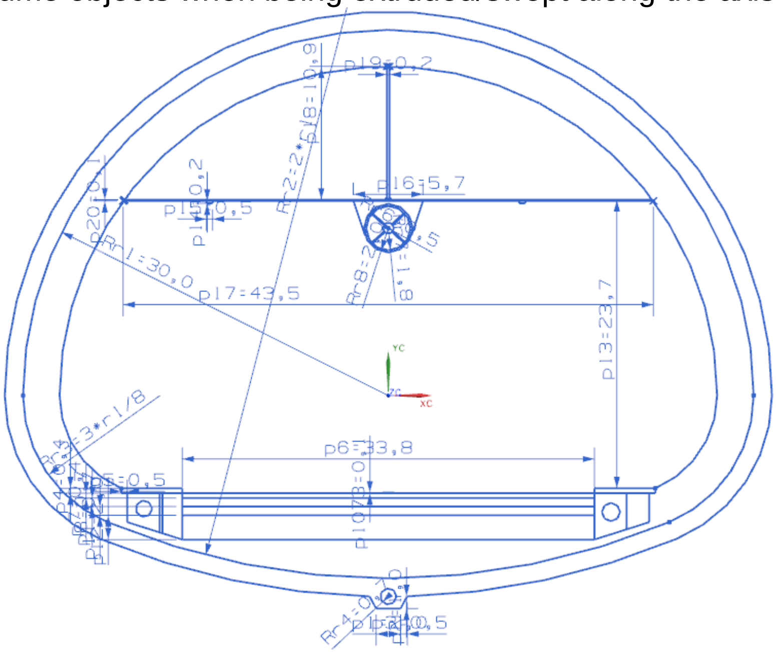


Figure 6-10: A typical cross-section of a conventional tunnel

For TBM tunnels, profiles are typically composed of straight lines and circular arcs.
For conventional tunnels, profiles are typically composed of straight lines, circular arc segments, and ellipsoidal segments. This is well covered by the IFC data model as it allows all subtypes of *IfcCurve* to be used as part of the profile. A circular arc segment is defined by using the *IfcTrimmedCurve* with *BasisCurve* being an *IfcCircle*. The same can be applied to *IfcElipse*.

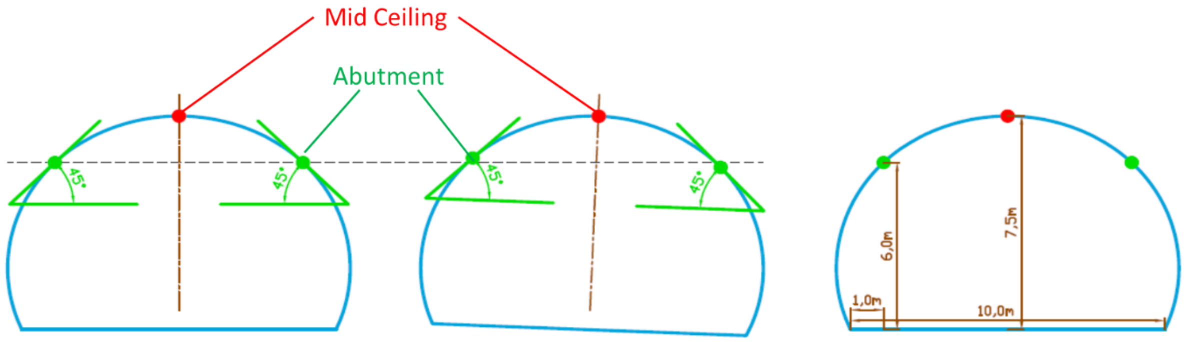


Figure 6-11: Particluar points in the cross-section can be labeled with corrresponding terms

To support machine guidance and developed geometry schemas e.g., it could be wise to include points in the cross-section representing the abutments and the mid ceiling.

Support for parametric cross sections could be considered. Relevant tunnel cross-section parameters could be: Wall height, wall curve radius, transition curve radius etc. This could be added as “Geometry-related property sets” e.g.. Based on experience, real “Parametric geometry” often doesn’t work properly in IFC-based data exchange.

The IREDES format is in active use for machine guidance systems for drilling jumbos today https://en.wikipedia.org/wiki/IREDES. Systems like Bever, Epiroc and Sandvik all support this format. The development of the cross-section definition part of IFC Tunnel must be harmonized with this format.

Special considerations for cross-sections defined by guide lines

Often the guide lines used for the arch footing points are the road surface edge lines from the road model.

For many software, the road width is given as the HORIZONTAL distance between the road surface edge lines. The user expects the tunnel base to be as wide as the specified distance between the road surface edge lines, shown as Bti in the illustration below.

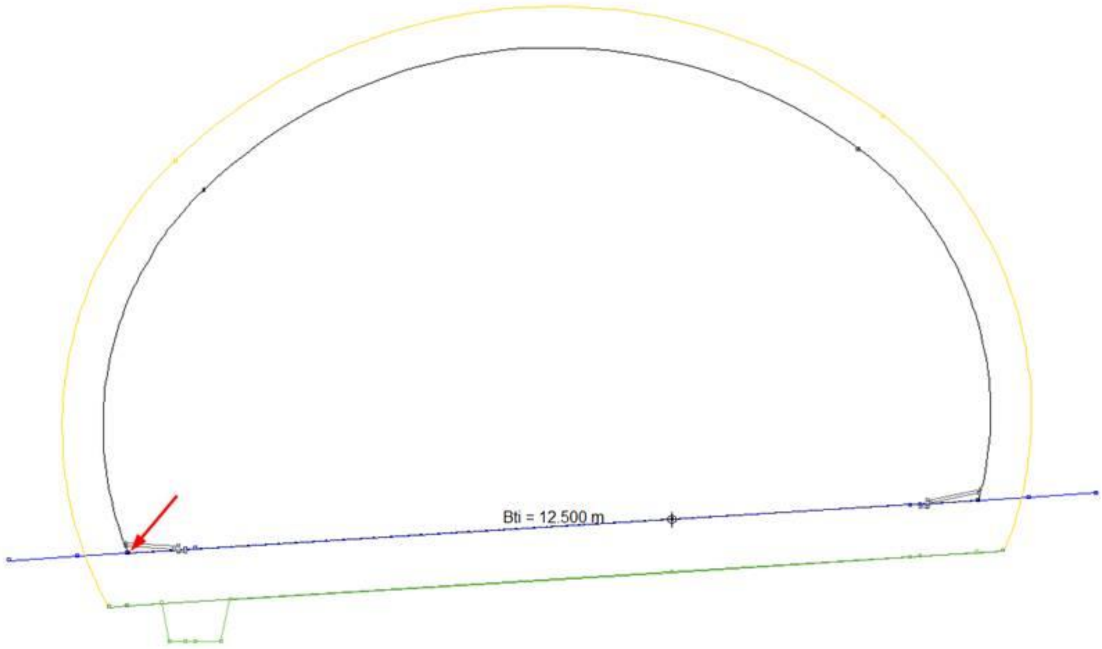


Figure 6-12: Rotated tunnel cross-section with inner base width equals to 12.5 meter in this example.

When the tunnel is rotated, following the cross fall of the road, the skew distance between the guide lines becomes larger than the HORIZONTAL distance between them. The factor is 1/cos (cross fall angle).
A solution COULD BE to move the arch footing points a little inwards so that the skew distance between the arch footing points equals the horizontal distance between the guide lines.
Here is an illustration of the detail marked with the red arrow above, showing that the inner lining arch footing point is moved 15mm inwards to allow for the inner lining base skew width of the tunnel to be the required 12.5m as an example.
The corresponding arc footing point on the other side of the tunnel is moved equally 15 mm inwards as well.

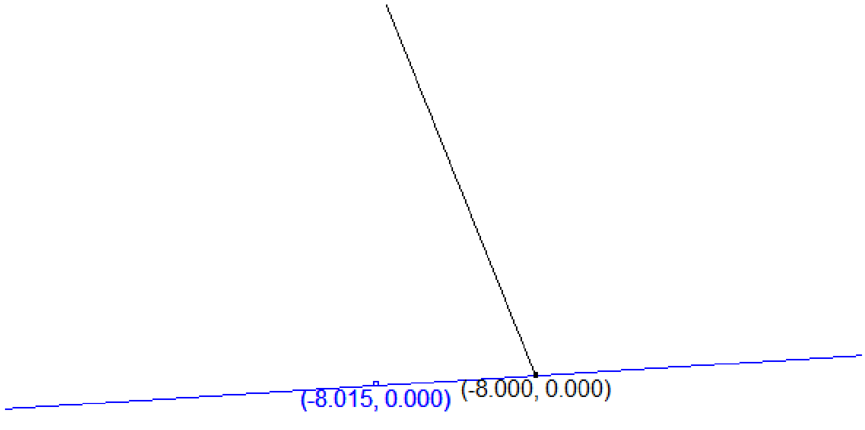


Figure 6-13: The inner lining arch footing point is moved 15 mm inwards

Sweeping axis (directrix)

In case of TBM tunnels, the sweeping axis is the tunnel axis (theoretical axis). It will typically be described by means of IfcAlignment and IfcAligmentCurve. However other curve types, such as 3D B-splines or 3D-Polylines can also be applied. The latter can be used to represent as-built models with a segmented view. Curves that do not have tangential continuity (such as polylines) might create issues in sweeps leading to gaps and/or overlaps.

In conventional tunnels, there are often changing cross-sections along the tunnel. In the simplest case, it is simple rotation of a fixed cross-section. In this case, the rotation angle and the rotation axis must be defined, but the cross-section itself might be re-used if identical.

In the more complex case of truly differing cross-sections, multiple cross-sections must be defined. Here, it is necessary to use labels for vertices in the cross-section in order to associate correlating points in the different cross-sections.
In addition, the use of “guide curves” may be necessary to precisely describe the sweeping behavior between two consecutive cross-sections.

Interpolation

When interpolating between two cross-sections, the break-points in the cross-section geometry are always interpolated with the linear formula; $x = x_1 + (x_2-x_1)/l)*delta(l)$ and $y = y_1 + (y_2-y_1)/l)*delta(l)$, where x and y are the local coordinates in the cross sections, l is the distance between cross-section 1 and 2 and delta(l) is the distance from cross-section 1 to the cross-section in question.

The interpolation formula for the curves differs however from software system to software system. Some software systems do a linear interpolation of the curve radius; $R = R_1 + ((R_2-R_1)/l)*delta(l)$. Other software systems interpolate the curve geometry based on this formula $C' = C_1+((C_2-C_1)/l)*delta(l)$, where $C=1/R$ or sometimes $C=1/R^2$.
There could be other formulas in use for interpolation of the radius values as well. Interpolation of the bulge value is one candidate. The bulge value is defined as the ratio of the arc sagitta (versine) to half the length of the chord between the two vertices.

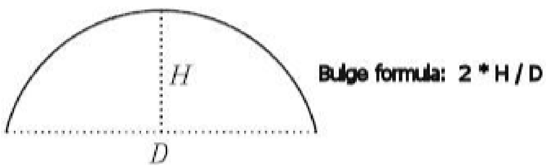


Figure 6-14: Definition of the bulge value

In some countries, it is important to always keep the tangents of two adjacent curves in the tunnel cross-section parallel. The cross-section interpolation given this restriction, can be controlled by interpolating the opening angels of the curves (shown as alpha and beta angles in the figure below) relative to the tunnel width. The tunnel width can be defined by specifying the two break points in the cross-section that constitute the lower left and right corners of the cross-section. In the figure below Bt is the cross-section width.

The alpha angle e.g. is then given as alpha1 + delta alpha/delta Bt, where alpha1 is the angle alpha in cross-section 1 and delta Bt is the difference of the tunnel width between the cross-section in question and cross-section 1. The value for delta alpha/delta Bt must be specified by the tunnel designer.

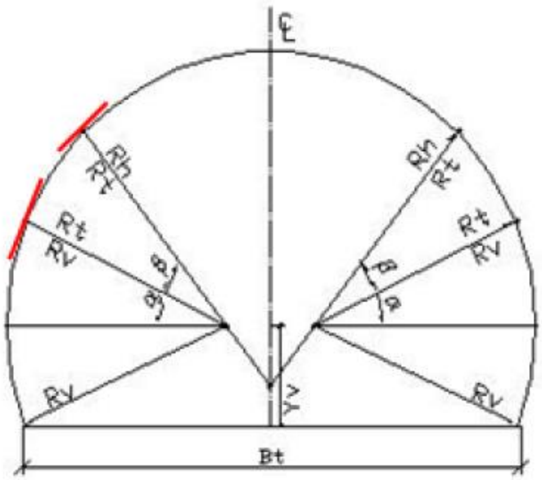


Figure 6-15: Tunnel cross-section showing the red tangents of the curves at the curve transition points

Note: When interpolating a cross-section based on guide lines for the base-wall points e.g., then at least one geometric value must be kept undefined by the user to allow the system to calculate the interpolated cross-section as a continuous line. The ceiling radius value is one candidate to be left undefined by the user.

Rotation

In some situations, the tunnel cross-section is rotated. This is often given by the cross fall of the road or maybe the cant for railroad.

The rotation of the tunnel is in most situations described independent of the cross-section geometry and follows different interpolation intervals than the interpolation of the cross-section geometry. The rotation values are typically defined by specifying the rotation at the chainage values where the rotation interpolation ratio or rotation direction changes. The interpolation of the rotation is always linear.

The rotation of the tunnel can be given with offset values from the tunnel axis or the reference line for the infrastructure inside the tunnel, as shown in the illustration below.

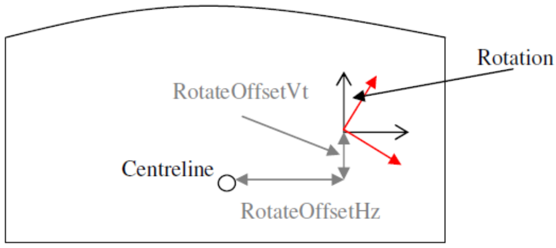


Figure 6-16: Illustration from the Leica LandXML to DB-X manual

Some software systems define a base line for the tunnel cross-section with an offset from the infrastructure reference line or tunnel axis. The tilting of the tunnel base line corresponds to the rotation of the tunnel at the chainage value in question. The tunnel base line is shown as a red dotted line in the figure below.

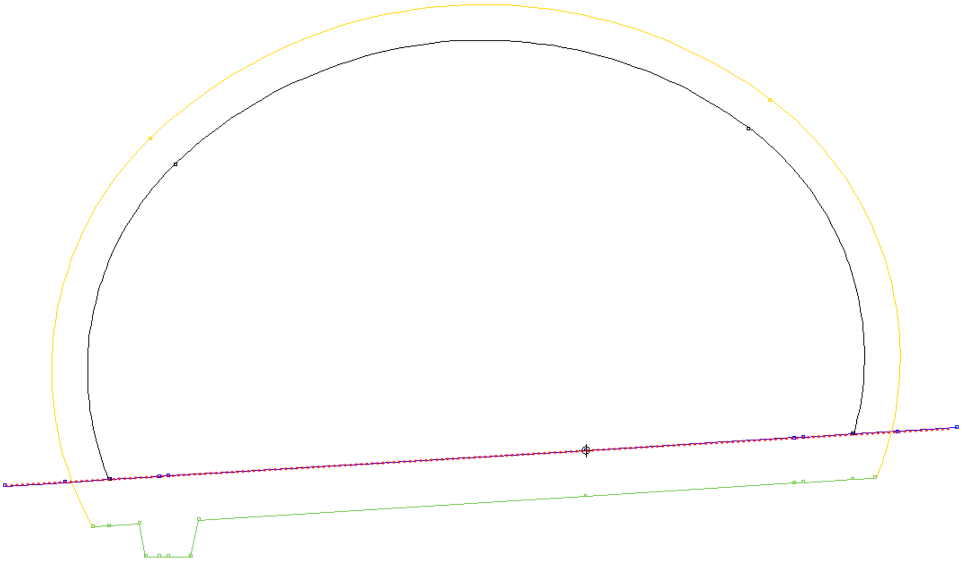


Figure 6-17: Tunnel cross-section showing the base line as a red dotted line

CSG operations

After the rough tunnel geometry is created by sweeping the profile(s) along the (theoretical) axis, Boolean operations such as union, intersection, subtraction are applied to create niches or tunnel joints and crossings.

This can be realized by applying the functionalities provided by the IfcCsgSolid entity.

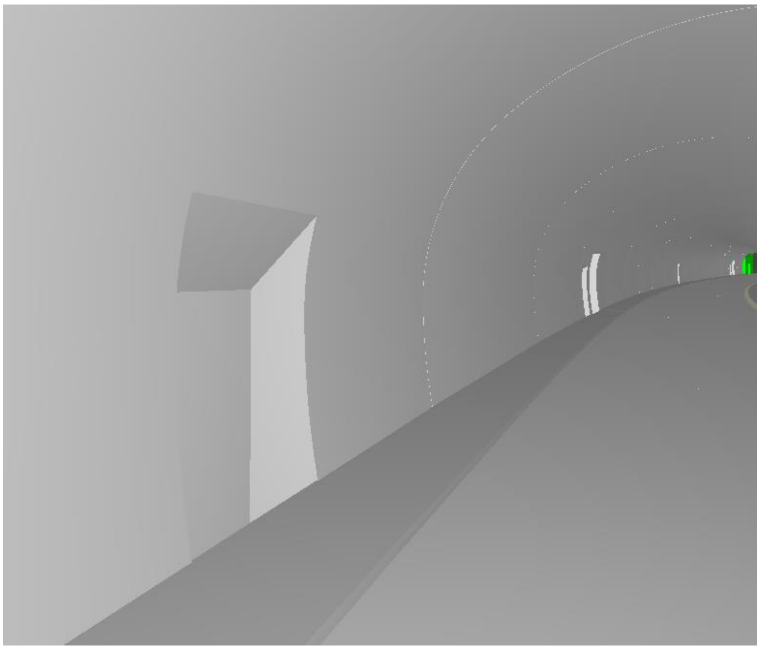


Figure 6-18: A niche is created by substracting a void from the sweeping geometry.

Developed description of inner tunnel surface

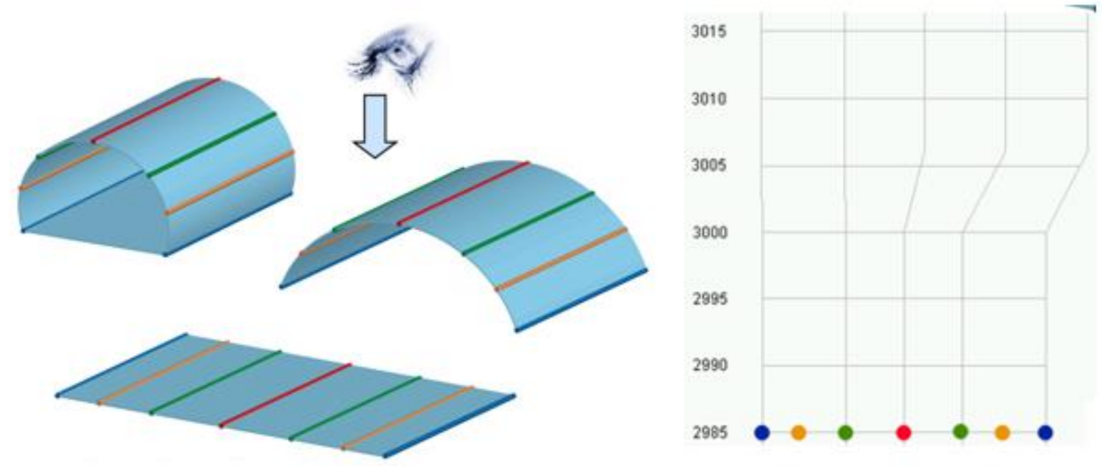


Figure 6-19: Developed representation of the inner tunnel surface. Blue: Transition wall / base, Orange: Middle of the wall, Green: Abutment, Red: Mid ceiling. On the figure to the right, the unfolded registration plan is shown.

All the registrations in the system are localized geometrically along the tunnel. The tunnel cross-section is developed (unfolded) so that the width of the registration plan corresponds to the arc length of the theoretical perimeter.

For the developed geometry, the horizontal curved geometry of the tunnel is straightened out make the resulting schemas better fit on a paper. Widenings of the tunnels are included in the developed geometry, but rotation of the tunnel (following the cross-fall of the road e.g.) is not taken into account. Developed geometry is used for geology registrations and rock support registrations e.g.

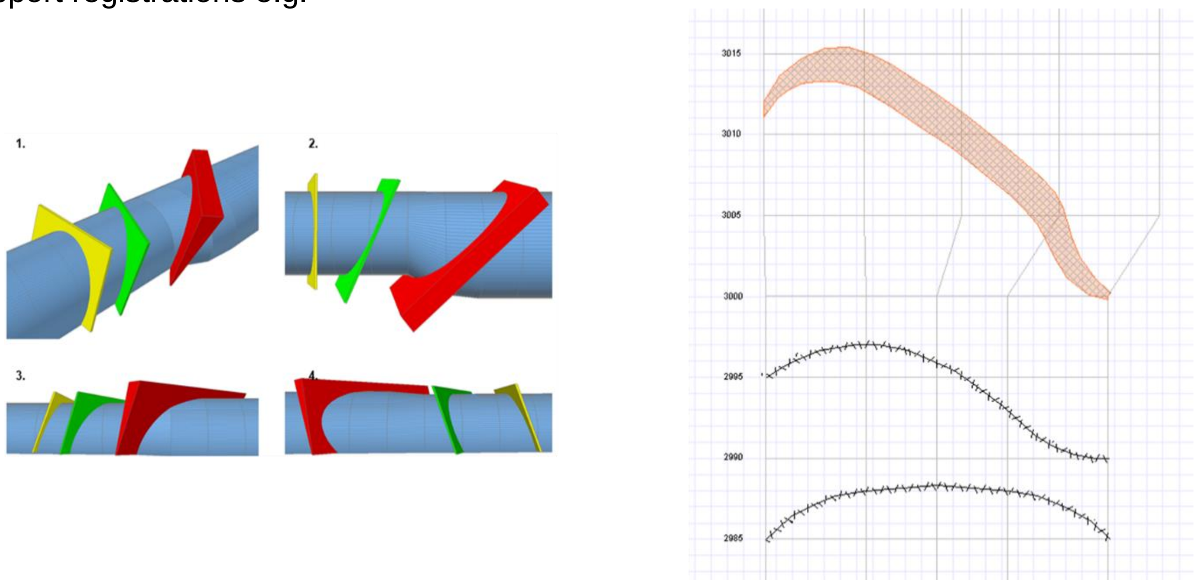


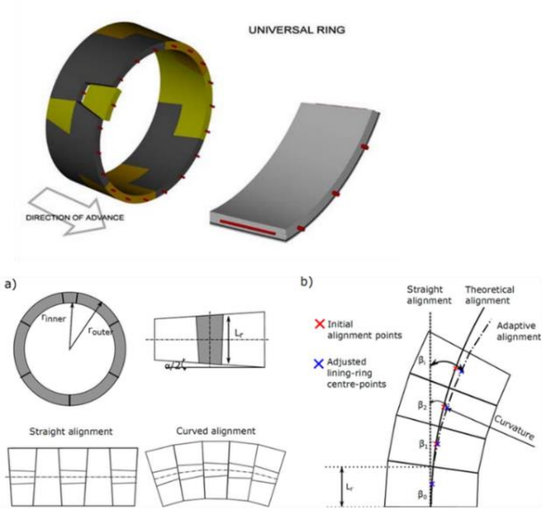
Figure 6-20: Mapping geology on an developed (unfolded) tunnel registration plan

TBM tunnel segments - property-supported geometry description

For the exact and detailed description of the segments of a TBM tunnel, the application of a hybrid approach is promising, which combines explicit geometry with properties representing the parameters that can be used for a procedural creation of the geometry by the receiving application.

This means that the ring segments are primarily represented by explicit geometry to allow straightforward visualization. However, along with the explicit geometry, the properties required to reproduce the geometry in a parametric CAD system are transported. This is required to support more advanced use cases such as UC 14 “Prefabrication and Manufacturing”. Figure 6-21 depicts the parameters that must be represented as properties.

The application of procedural geometry capabilities provided by IFC is discouraged here, as the required consecutive application of sweeping and clipping operations is too prone to errors and mis-interpretations.



- Universal rings = conic rings!
- **Property-driven geometry**
  - inner / outer radius (thickness)
  - conicity / tapered (left/right ring: two values)
  - ring width
  - slant angle
  - medium segment width
  - key segment angle
  - nof segments (5-7)
  - angles of each segment
  - number of dowel per ring
  - number of dowel in key segment

Figure 6-21: The properties required to reproduce the geometry of the ring segments in a parametric manner (Source of pictures: Ninic et al. 2019)

One of the most important parameters connected to the ring segments geometry is its conicity. From a geometrical point of view, the rings are portions of cylinders with surfaces that can be either parallel or non-parallel, identified below:

- parallel surfaces → straight ring
- non parallel surfaces → tapered trapezoidal ring / tapered universal ring

The geometric characteristic of a universal ring is its conicity, the difference between its maximum and minimum length. The universal rings of a particular geometry are known as “left-right” rings. These are truly universal rings from all points of view, but have been conceived in pairs. The geometry of the ring is equal for both, but the arrangement of the segments inside the “left” ring is diametrically opposite to that of the “right” ring, so that an alternation of left-right rings allows a straight-line alignment to be followed with the key segment always being at the top.

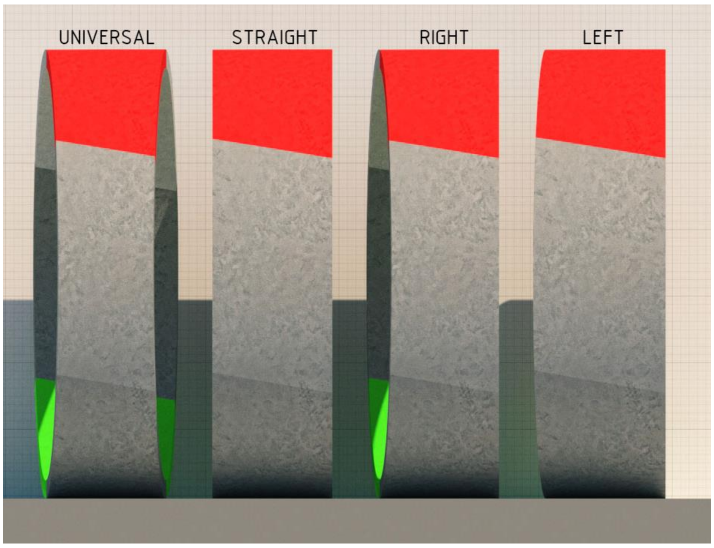


Figure 6-22: Conicity of TBM rings (Source: Geodata)

6.5 Voxel grids and octrees for representing geological data

As detailed in Section xy, there are specific use cases in the context of geological modelling that require the use of voxel representations to allow for a fine-grained description of varying soil/rock properties with high spatial resolution. Currently, such a geometry representation is not yet available in IFC. It should this be considered to extend the IFC schema accordingly. As storing voxel grids with high spatial resolution can be very expensive in terms of storage size and/or data throughput, typically hierarchical schemes such as octrees are employed to reduce the storage footprint. It is accordingly recommended to consider the extension of IFC by a respective schema. In addition, lossless compression schemes such as HDF5 can be employed to transport large voxel grids.

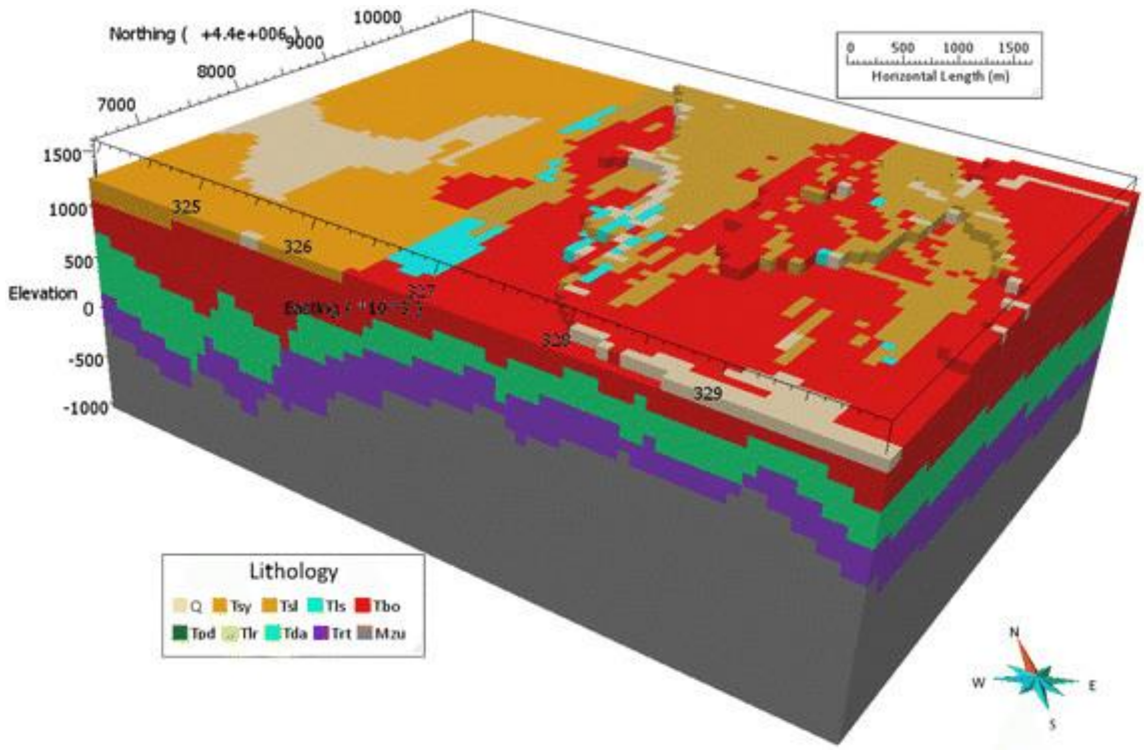


Figure 6-23: Voxel representation of a geological model (Source: Witter et al. 2016)[11]

7 Spatial structure and spaces

7.1 Spatial Structure / Project Hierarchy

The IFC data model comprises the notion of a spatial breakdown structure, which is often used in the sense of a project breakdown structure. It starts with IfcProject as a root object, aggregating any number of IfcSite objects, each of which can aggregate any number of IfcFacility objects, each of which can aggregate any number of IfcFacilityPart objects, each of which can aggregate any number of IfcSpace objects. All mentioned elements are subclasses of IfcSpatialStructure element. The resulting tree of objects represents the spatial breakdown structure.

In versions 4.2 and 4.3 of the IFC model, the spatial structure was extended to accommodate the needs of linear infrastructure projects. Most importantly, the entities IfcFacility and IfcFacilityPart have been introduced. They are designed as generalizations of the IfcBuilding and IfcStorey entities that are used to model the spatial structure of buildings.

In IFC 4.3, IfcFacility has the following subclasses: IfcBridge, IfcBuilding, IfcMarineFacility, IfcRailway, IfcRoad. Here an extension by IfcTunnel is necessary.

IfcFacilityPart provides the attribute PredefinedType to further specify its semantics. It is modeled as a SELECT entity providing the options IfcRailwayPartTypeEnum,

[11] Witter, Jeffrey & Siler, Drew & Faulds, James & Hinz, Nick. (2016). 3D geophysical inversion modeling of gravity data to test the 3D geologic model of the Bradys geothermal area, Nevada, USA. Geothermal Energy. 4. 10.1186/s40517-016-0056-6.

IfcBridgePartTypeEnum, IfcMarinePartTypeEnum, IfcRoadPartTypeEnum, IfcFacilityPartCommonTypeEnum. For including tunnel specific types, the IfcTunnelPartTypeEnum would be required. Potential predefined values would be:

- Portal
- Tunnel Section
- Crossway
- Ring Section / Round

For tunneling projects, it is important to allow for both, the longitudinal sectioning along the axis and the lateral sectioning in the cross-section. While longitudinal sections can be modeled by *IfcFacilityPart*, the lateral section can be modeled by means of *IfcSpace* objects.

For the spatial relationships between the tunnel and the roadway or railway in the tunnel the following options exist:

- The tunnel is part of the road/railway facility. The latter provides the spatial container containing the former. IfcRelContainedInSpatialStructure is applied.
- The road/railway is part of the tunnel facility. The latter provides the spatial container containing the former. IfcRelContainedInSpatialStructure is applied.
- Both elements are equivalent. They use IfcRelReferencedInSpatialStructure to indicate their spatial relationship.

All three options should be supported by IFC-Tunnel, as the selection of one of them depends on the particularities of the individual projects.

The following figures depict the longitudinal sectioning on high spatial segmentation level (several kilometers), medium level (hundreds of meters) and low level (a couple of meters).

- On the highest level, the tunnel might be decomposed into sections reflecting different construction methods.
- On the medium level, the different excavation classes can determine the sectioning.
- On the lowest level, individual rings (TBM tunnels) or rounds (conventional tunnels) represent an individual section.

The sections on the three different levels should be hierarchically grouped.

As the roadway or railway that is contained in the tunnel will also have a longitudinal decomposition structure, it may be considered to synchronize that with the longitudinal sectioning of the tunnel structure. However, this is not mandatory.

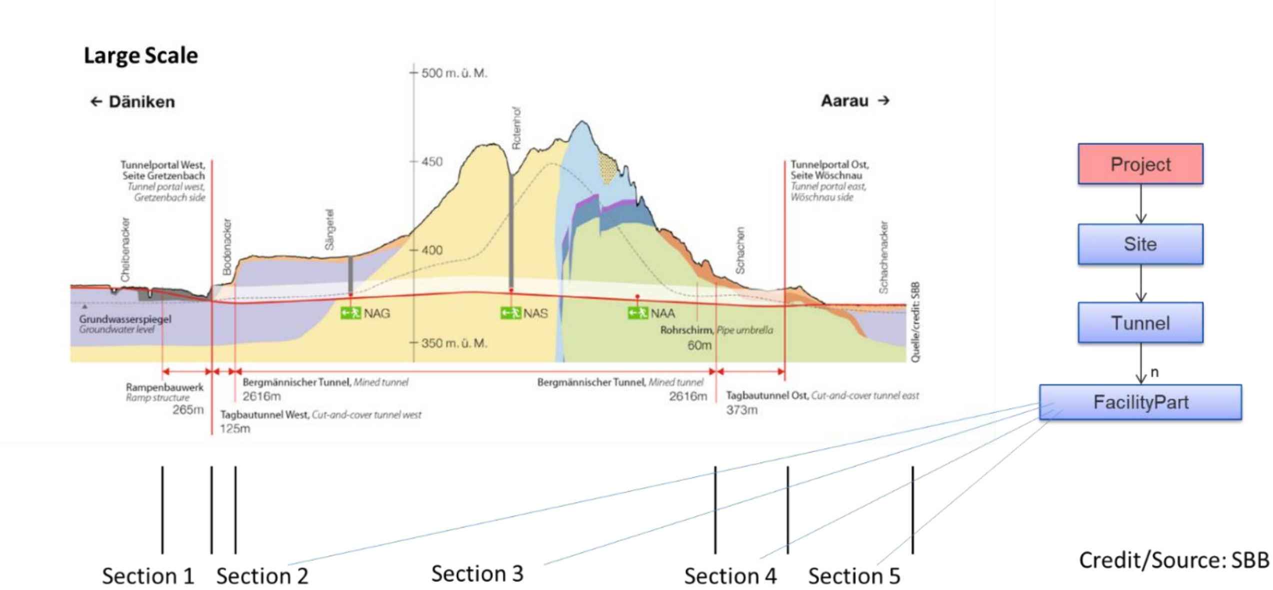


Figure 7-1: Large-scale longitudinal sections of the tunnel modeled by means of IfcFacilityPart instances (Source Picture: SBB).

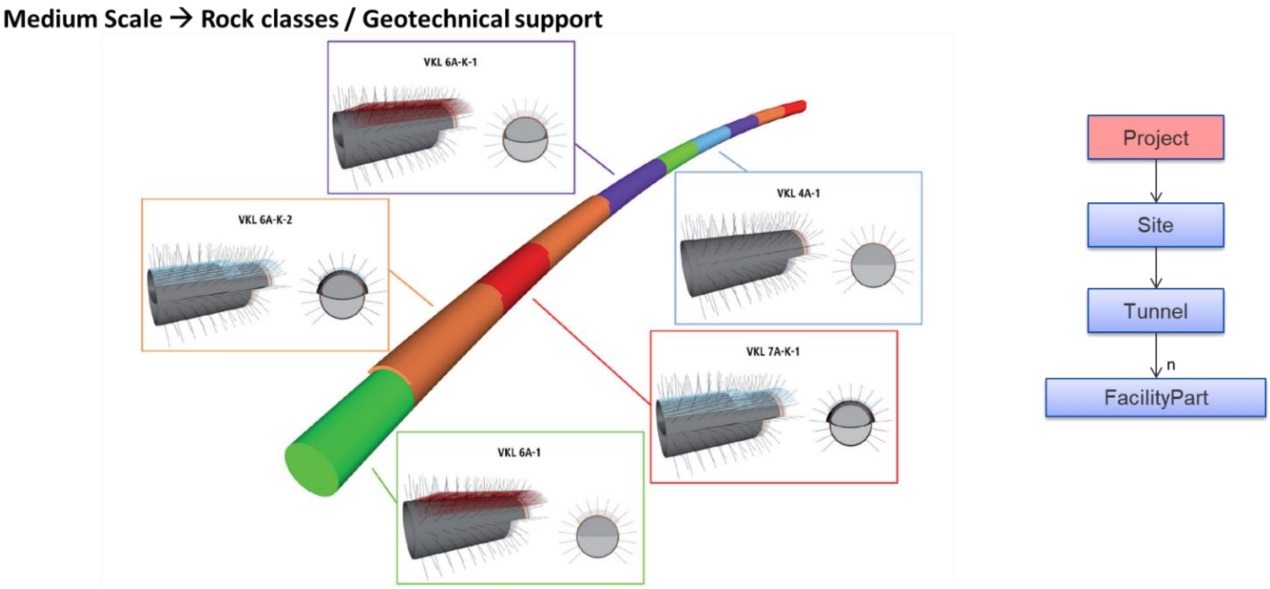
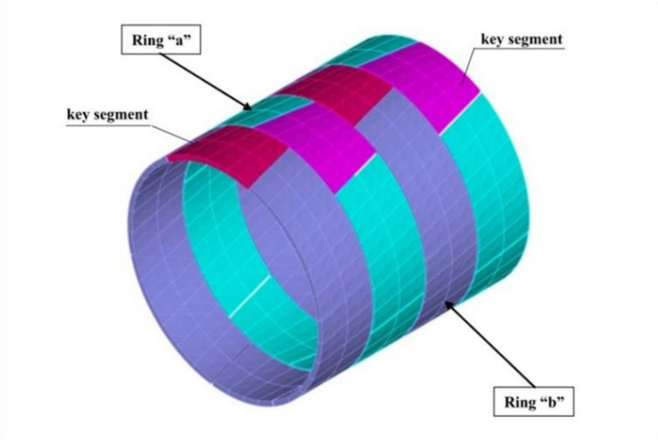
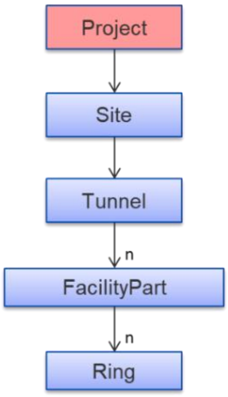


Figure 7-2: Medium-scale longitudinal sections representing differing rock classes and geotechnical support, modeled by means of IfcFacilityPart instances (Source: DAUB).

Small Scale → Rings / Blocks





Credit/Source: www.scsolutions.com

Figure 7-3: Small scale longitudinal sections representing individual rings or blocks/rounds. (Source: SCS solutions Inc)

The hierarchical relationship between the longitudinal and lateral sections must be considered. In most cases, the longitudinal sectioning is governing over the lateral section, resulting in a structure as follows:

- IfcProject
  - IfcSite
    - IfcFacility
      - IfcFacilityPart (longitudinal) 1
        - IfcSpace (lateral) 1
          - Physical object 1
          - Physical object 2
          - Physical object 3
        - IfcSpace (lateral) 2
          - Physical object 4
          - Physical object 5
          - Physical object 6
        - IfcSpace (lateral) 3
          - Physical object 7
          - Physical object 8
          - Physical object 9
      - IfcFacilityPart (longitudinal) 1
        - IfcSpace (lateral) 4
          - Physical object 10
          - Physical object 11
        - IfcSpace (lateral) 5
          - Physical object 12
        - IfcSpace (lateral) 6
          - Physical object 13
          - Physical object 14

For TBM tunnel models, the IfcSpace entity can also be used to model the longitudinal space representing a ring. In this case, the structure would be as follows:

- IfcProject
    - IfcSite
        - IfcFacility
            - IfcFacilityPart (longitudinal) 1
                - IfcSpace (Ring) 1
                    - IfcSpace (lateral) 2
                        - Physical object 1
                        - Physical object 2
                    - IfcSpace (lateral) 2

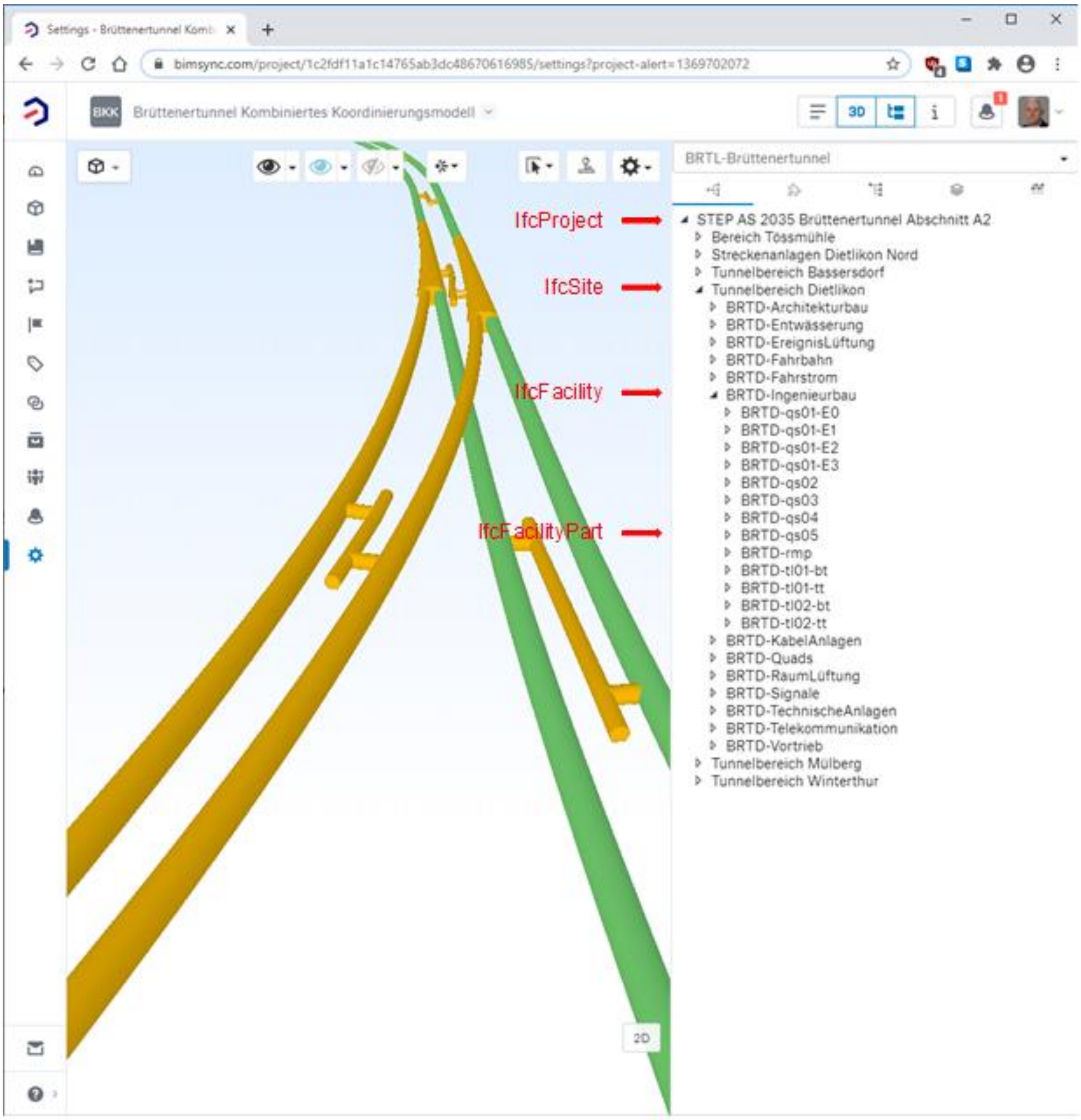


Figure 21: Typical spatial structure of a tunnel project (Source: SBB/ILF engineers).

7.2 Spaces

The notion of non-physical “spaces” is intensively used in tunnel engineering. There are three distinct types of spaces.

- Spaces identifying locations similar to rooms in buildings. The tunnel is typically divided longitudinally into "blocks" which can coincide with lining formwork dimensions and which are used to locate structures and systems in a tunnel. A tunnel is generally dived in blocks of 8 to 12.5 meters. Underground sub-stations will be divided into conventional rooms. On a smaller scale this longitudinal division can be the rings in a segmentally lined tunnel or the rounds in a conventionally excavated tunnel.
- Spaces required by regulations or design codes, such as kinematic envelopes, escape routes and safety spaces, niches, space for tolerances, allowance for deformations, allowance for future installations etc. See the following figure from the Swiss tunnel design codes.
- "Reserved" spaces. During the initial phases of a tunnel design, space can be reserved for items that may not be yet be designed in detail, or spaces reserved for installation and services that are only fixed at a later design phase. A space is reserved that will be filled with physical elements in a later stage of the design process or as more detail becomes available.

Typically, they are defined in a cross-section view. They are crucial for the design and sizing of the cross section.

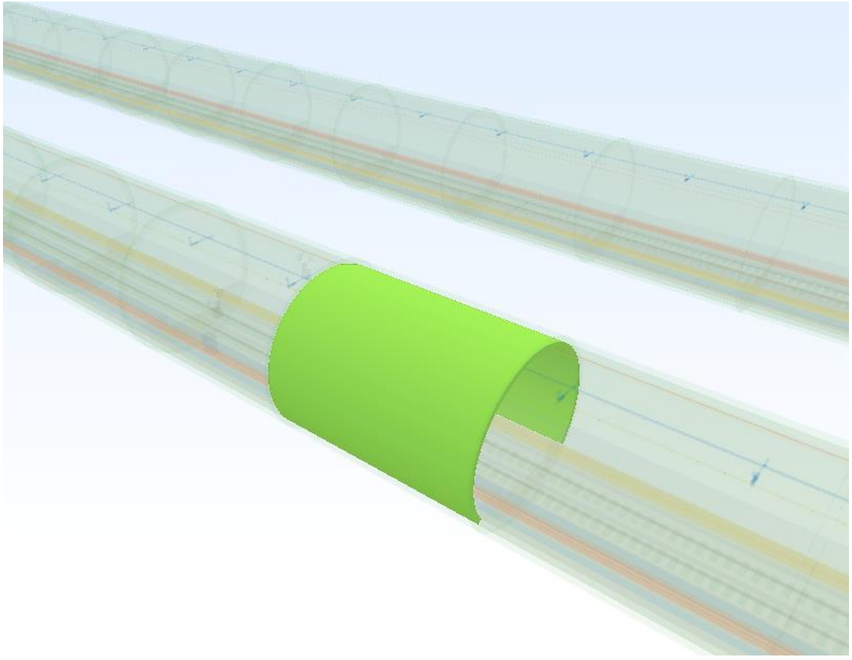


Figure 7-4: Typical block layout in a tunnel (Source: SBB/ILF).

Spaces in TBM Tunneling

The following figures give an overview of typical spaces in TBM tunnels required to represent reservation or safety spaces.

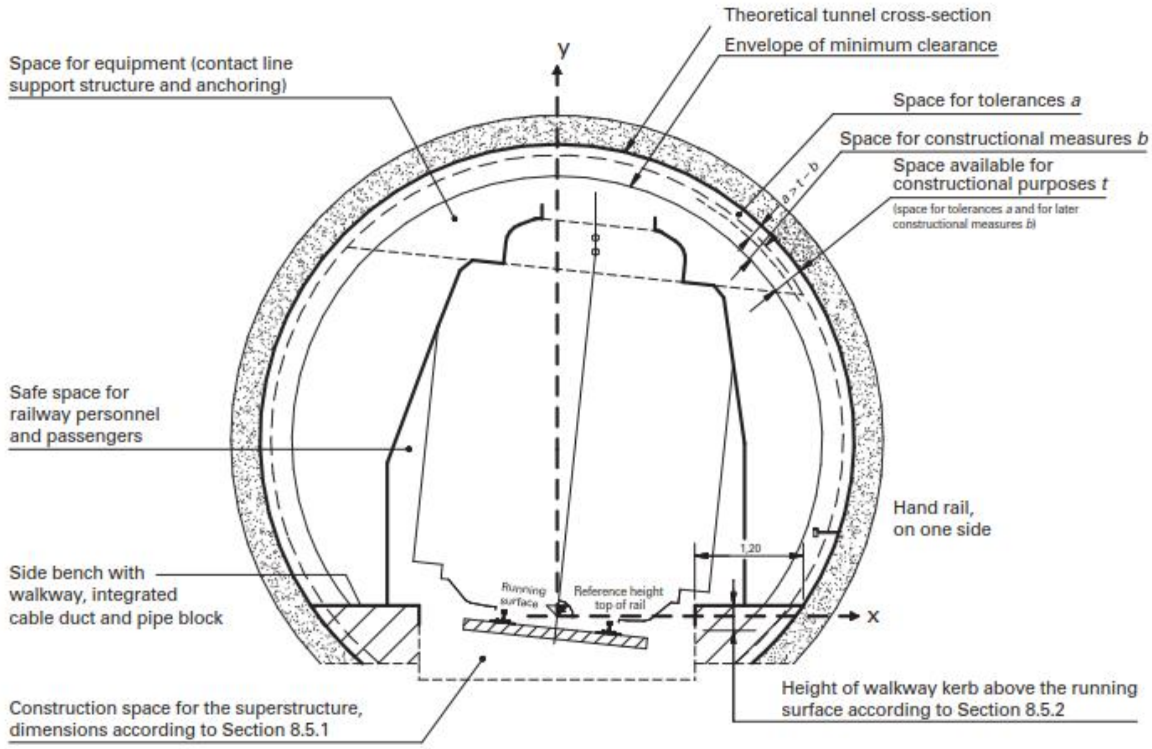
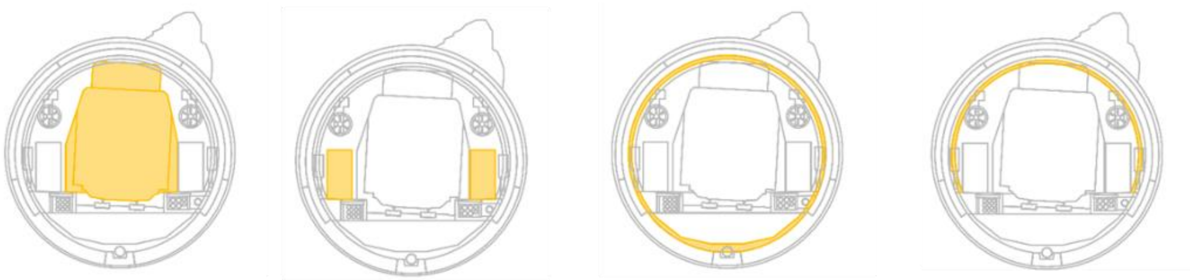


Figure 7-5: Typical code requirements for tunnel spaces (SIA 197-1 Design of Tunnels, Railway Tunnels, Switzerland).



Kinematic Envelope | Escape Routes | Space for tolerances and deformations | Space for future construction

Figure 7-6: Typical code and regulatory requirements for lateral tunnel spaces

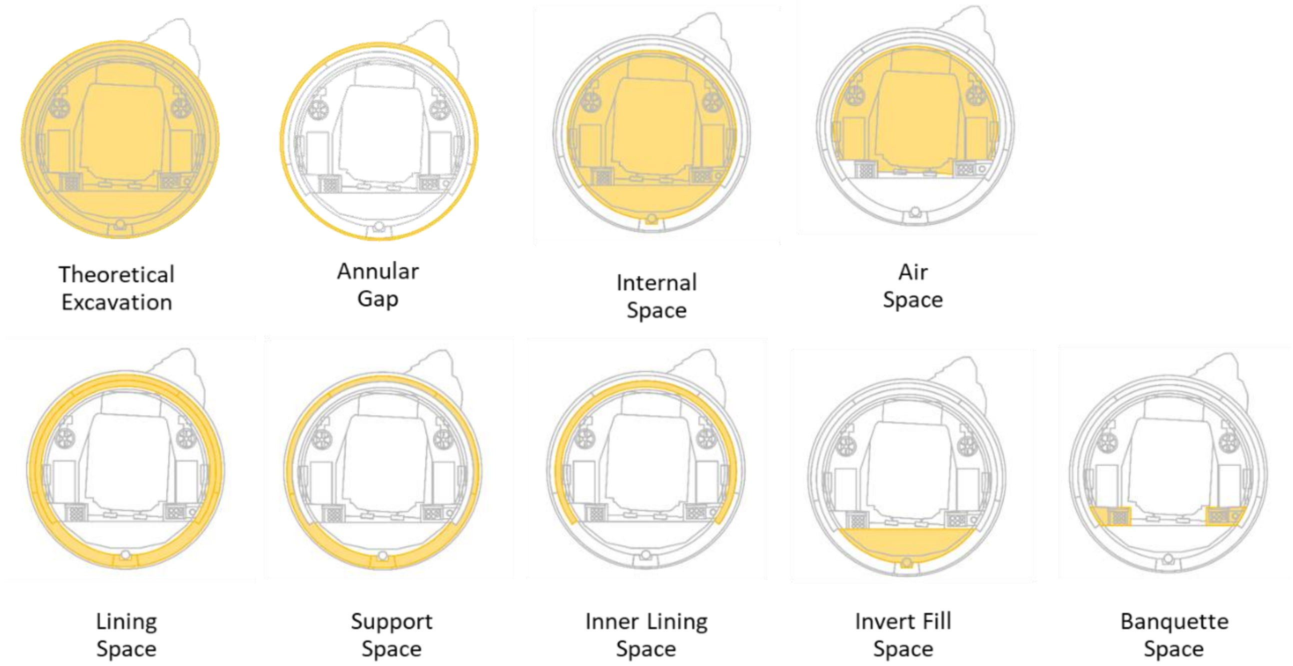


Figure 7-7: Typical spaces reserved for tunnel construction items.

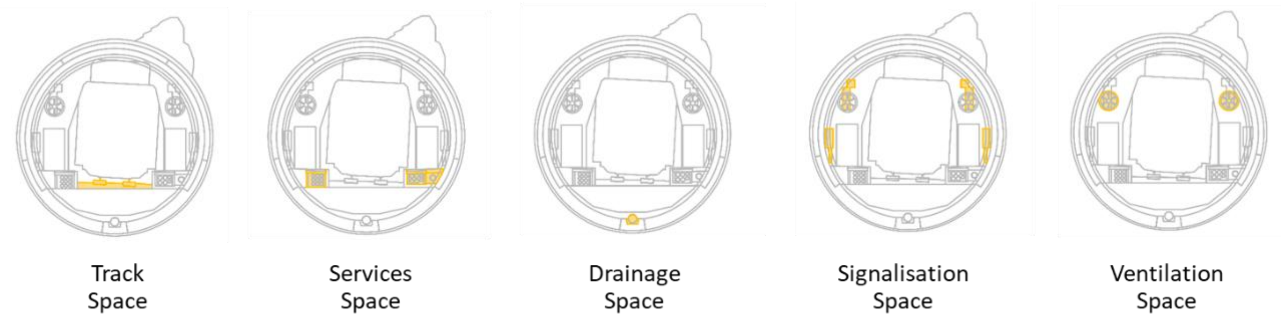


Figure 7-8: Typical spaces reserved for tunnel subsytems.

The spatial breakdown of such spaces is shown below.

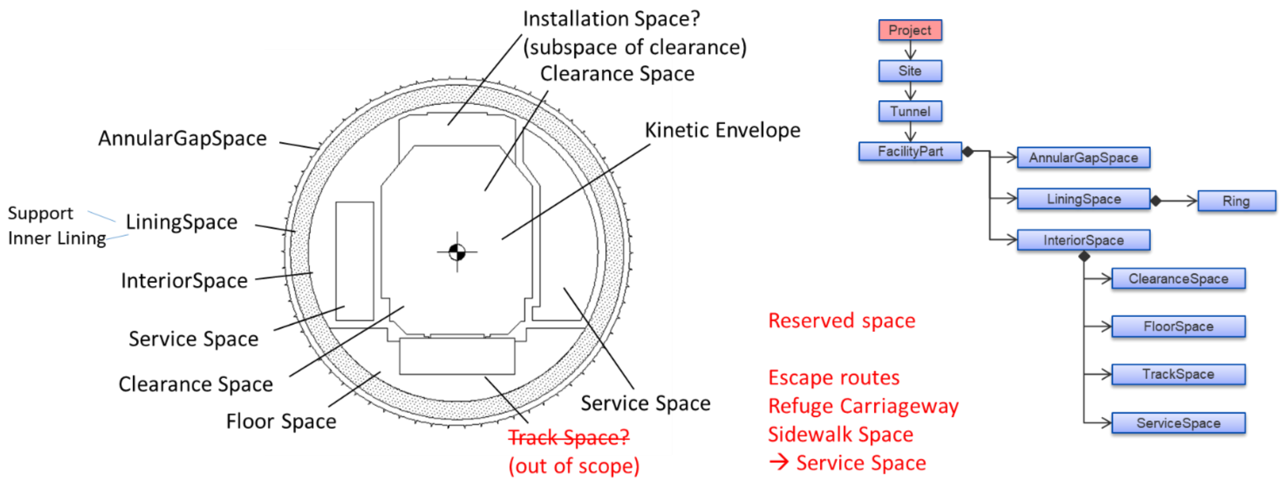
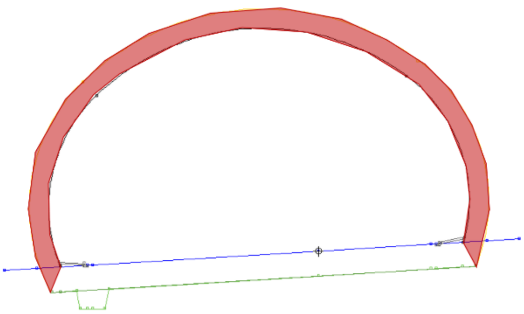


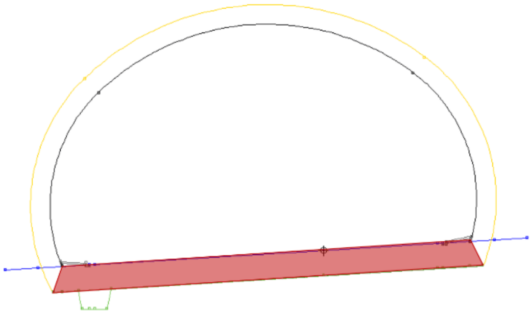
Figure 7-9: Hierarchy of spaces

Spaces in Conventional Tunneling

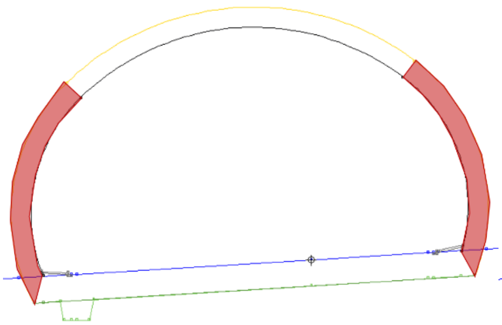
The below illustrations show the main zones/spatial structure for a conventional tunnelling cross-section. The zones are valid for both the inner lining and the excavated surface.



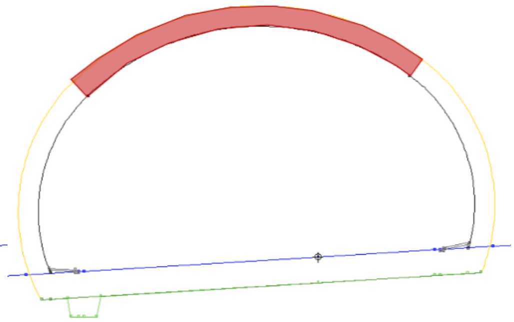
Vault



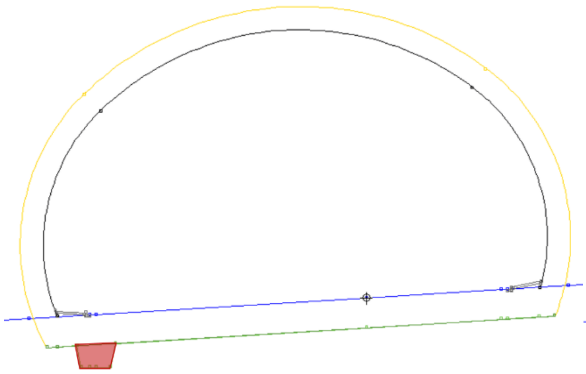
Base



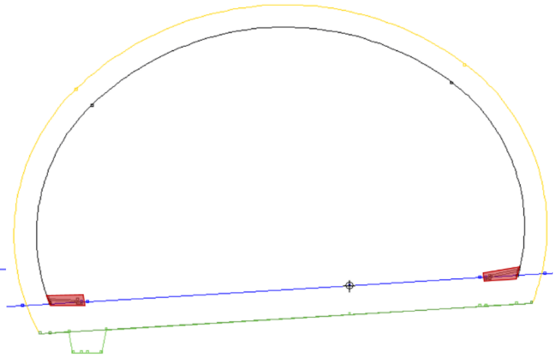
Walls



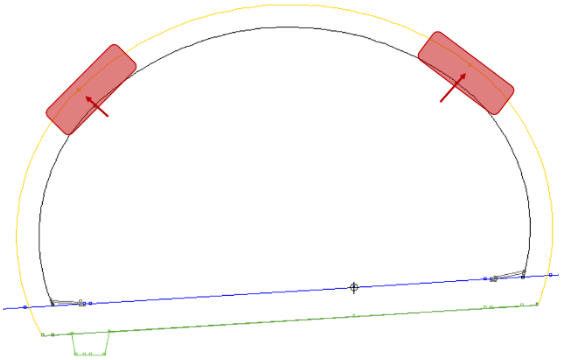
Ceiling



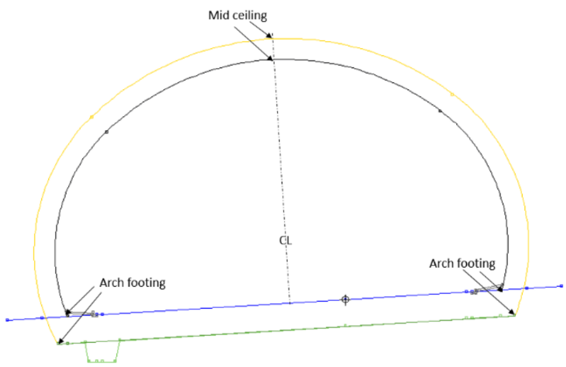
Closed drainage



Shoulder



Abutment (zone or point)



Characteristic points: Mid ceiling, Arch footing

8 Geology and geotechnics modelling requirements

8.1 Introduction

Requirements in a tunnel lifecycle

As detailed in the use case descriptions 1b, 2a, 2b, 2c, 12b and 15b, the geological and geotechnical modeling of the underground plays an important role throughout all phases of a project and is relevant for several decisions and design solutions.

Several kinds of risks are associated with geological conditions and uncertainties in predictions of the ground conditions (interpreted models), which have a significant impact on the costs of tunnel projects.

Furthermore, in tunneling the ground material can be seen as a part of the building. For these reasons, the geological and geotechnical information must be described and represented in a standardized way, paying attention to the compatibility with IFC-Tunnel and existing standards of the geology and geotechnics disciplines. As IFC has developed to a widely applied industry standard and the integration of ground models into BIM-Design environments is requested frequently (not only, but especially in tunneling), such models should be covered by IFC.

Special characteristics of the geological/geotechnical models

This creates challenges for developing the IFC-Tunnel extension as the underground is not a man-made artefact, but a natural one and thus exhibits a rather complex structure, in terms of geometry and of spatially diverging properties: In general, there are no “standard-materials”, but only superimposed classifications of an inhomogeneous ground material.

This classification can be based on geological categories like e.g. age, stratigraphy and structural-tectonic position or lithology (“Geological model”) or the mechanical material properties and aspects relevant for design and construction (“geotechnical design models”), see chapter below and ISO Guide 73:2009, Risk management — Vocabulary [4] .

These classifications depend on the purpose and requirements of a (construction-) project. Precise knowledge on the underground is only given by observation points (documentation, factual data). The modeling between these observation points is subject to assumptions:

- an interpretational model for the prediction of expected conditions, depending on the planned building (tunnel excavation / portal cut slopes) and
- applications (structural analysis / excavation methods and loading / time-cost estimates / material management /…).

This implies that commonly, different classification systems are used parallel in tunneling projects, and the ground can be described in by different overlapping interpreted models.

The nature of interpretational models for predictions involves vagueness and uncertainty, which is reduced throughout the project time with ongoing investigation and documentation of encountered conditions. An as-built model of the encountered ground conditions can be provided after completion of excavation and ground improvement works.

Terminology

For clarification, some key-terms for this chapter are defined below:

Factual Data: The results of site investigation campaigns and documentation conducted specifically for the project and pre-existing data (other sources), including measurements and observations. Examples are borehole data, test results and field mapping, geological tunnel documentation and other surveys.

Such data is often stored in detailed, specific database formats, especially when digital acquisition methods have been used. In many cases this data cannot be considered as being purely factual, since it has already been the subject of initial interpretation (by the geologist drawing up drill logs, the technician interpreting the tests, etc.)

Synonyms for "Factual Data": Input data, "Book A"

Geological Tunnel Documentation: Observations and measurements regarding geological and geotechnical conditions during tunnel excavation, e.g. during the mapping of tunnel face and walls, automated digital methods like scans and photogrammetry or indirect methods (inferred from sensors).

Synonyms/related terms: geological registration, frontage survey, face log

Geological Model: Geoscience includes many disciplines, and "geological models" can describe the ground in regard to different aspects, like age, stratigraphy, lithology and mineralogy or geochemistry etc. A geological model can represent the 2D maps of geological surveys that typically describe regional geologic units with defined tectono-stratigraphical position, age and lithologies. For applications in geotechnics and tunneling, the physical and mechanical properties of the ground are respected qualitatively in engineering geological models.

The IAEG Commission 25 (IAEG commission 25 (Parry, S., Baynes, F.J., Culshaw, M.G., Eggers, M., Keaton, J.F., Lentfer, K., Novotný, J., Paul, D. (2004): Engineering Geological Models – an introduction: IAEG Commission 25.
Link 12/2019: http://nora.nerc.ac.uk/id/eprint/508530/1/C25%20Final%20011013.pdf) [19] points out that "*the process* (for engineering geological model building) *must start by understanding the geology, before any attempts are made at geotechnical characterization".* This implies that a geological concept is essential before any classification and geometry is defined.

In this report, the term "geological model" describes the anticipated location and extent of geological units and other geological features. It includes information on lithology, mineralogy and general engineering characteristics, but not the quantitative description of mechanical properties and geotechnical parameters.

Geotechnical model: Model suitable for direct use in analysis or design. Normally based on development and interpretation of a geological model, taking into account uncertainty and requirements of design and construction methodology.
This model defines, for the specified purpose only, the location and extent of geological/geotechnical units, distribution of geotechnical parameters and anticipated ground conditions (including "sources of risks", see below)

Synonyms: Geotechnical design model, IAEG Analytical model

Risk-related terms: To minimise misunderstandings, it has been decided to use the terminology of both *ISO 31000:2018 [3]* and *ISO Guide 73:2009* [4] as well as *ITA WG 2: Guidelines for tunnelling risk management[5]* , as follows (extract from AFTES Recommendations GT32R2A1 [1] :

Risk: effect of uncertainty on objectives, considering that:

- An effect is a deviation from the expected - positive and/or negative.
- Uncertainty is the state, even partial, of deficiency of information related to understanding or knowledge of an event, its consequence, or likelihood.
- Objectives can have different aspects (such as financial, health and safety, and environmental goals) and can apply at different levels (such as strategic, organization-wide, project, product or process).
- Risk is often characterized by reference to potential events and consequences, or a combination of these.
- Risk is often expressed in terms of a combination of the consequences of an event (including changes in circumstances) and the associated likelihood of occurrence.

Risk source / Hazard: element which alone or in combination has the intrinsic potential to give rise to risk. In this document, the terms "risk source" and "hazard" will be used as synonyms.

Abbreviations

AFTES	Associations Française des Tunnels et de l'Espace Souterrain (French Tunnelling Committee)
IAEG	International Association of Engineering Geologists
ITA-AITES	International Tunneling Association
TBM	Tunnel Boring Machine

Focal points: exchanged geological/geotechnical information and models

The French "AFTES Working Group GT32" (AFTES GT 32, 2012. GT32R2A1-Characterisation of geological, hydrogeological and geotechnical uncertainties and risks. Tunnels et Espace Souterrain 232: 315-355.) [1] sets up a structure for geotechnical documents in the tender documentation, dividing them into three successive subsections or 'books', each using results from the previous one:

A: Factual Data (inputs, measurements and observations, before and during construction)
B: Interpreted models (geological, but for tunneling mainly geotechnical models)
C: Design solutions, applications and risk assessment based on these interpreted models

This classification schema for geotechnical documents and models has been applied for the subject analysis. The three “Books” are interconnected, and interfaces/data exchange formats need to be defined to connect them without disruptions.

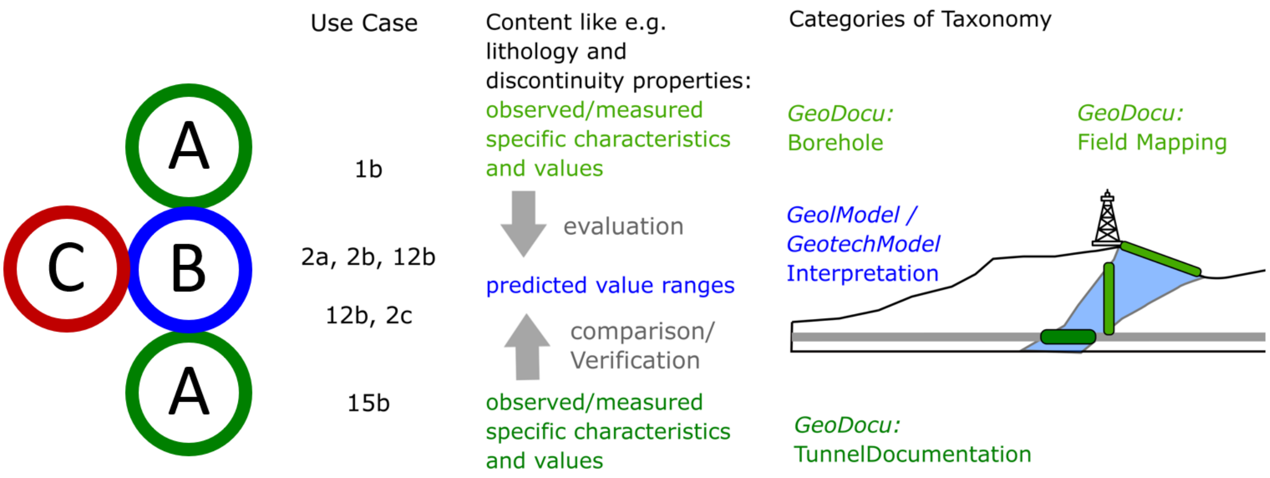


Figure 8-1: Schematic overview on difference and interaction of Book A, B and C

Factual data of (A) comprise on one hand important complementary information to proof how the models have been created and to quantify the uncertainty. On the other hand, they are used during construction to compare the encountered conditions to the prediction (interpreted model of (B))

The content of factual data sets like laboratory- and in situ test data is highly depending on applied methods, regional standards, etc., and specific standards, data structures and exchange formats exist (e.g. AGS, GeoSciML, RESQML and others, see below). A complete representation of such datasets in IFC is not intended and seems neither feasible nor required at the moment.

To which extend factual geological and geotechnical data will be integrated in IFC format needs to be clarified in the next phase of this project for each of the types of measurements/observations identified in the draft taxonomy. Placeholder-elements with links to databases, documents and other formats should be used, and interfaces to existing standards should be defined clearly.

Interpreted models of (B) describe the anticipated ground conditions (including the uncertainty) and can be the basis for design, structural analysis and definition of construction measures, or the representation of contract-relevant predictions of ground conditions.

Book C connects the anticipated conditions described in (B) with project-related applications.

The table below provides an overview of typical content, applications and updates for each of these "Books" during the lifecycle of a tunnel project.

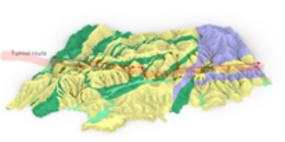
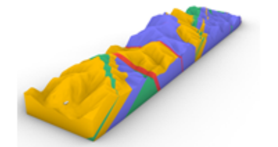
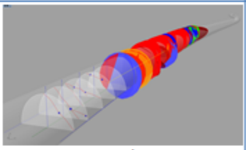
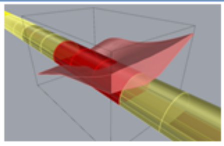
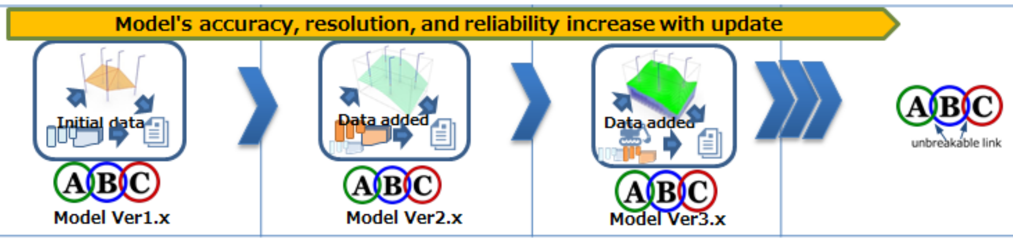
Lifecycle stage	Plan & Investigation	Investigation & Design	Construction	Maintenance
Primary objective of modeling	Tunnel routes / alignment studies (UC 2a)	Tunnel Design (UC 2b, 12b)	Construction management (UC 15b, 2c, 12b)	Measures to deformation and damage (2C)
Model example	 Regional-scale engineering-geological model	 Tunnel-scale engineering-geological model	 Geol. Tunnel Docu. /as-built model	 As-built model for specific area
Modeling area	Relatively wide area including potential tunnel routes	Around the tunnel corridor	Around the tunnel excavation	Selection of previous models around zones of interest
Approx. resolution required to the model	>10m mesh	<10m mesh	Down to 0.1m mesh	Down to 0.1m mesh
Input data for modeling **Book A: Factual Data**	• Previously existing data and first project-specific site investigation results	• Pre-existing data • Mainly project-specific site investigation results (including field mapping)	• Pre-existing data • Site investigation results • Geol. tunnel (and other) documentation, additional investigation	• Pre-existing data • Site investigation results • Data obtained during construction • maintenance data
Model content **Book B: Interpreted models**	• Regional topography, geology, hydro-geology, etc. • Engineering-geological aspects to be considered for tunnel route selection (potential hazards)	• Geological conditions and geotechnical design parameters (like rock mass strength, permeability, discontinuity pattern etc.) • Engineering-geological aspects to be considered for tunnel design and construction (potential hazards)	• Encountered geological and geotechnical conditions • Potential hazards during construction	• Relationship among damage area, geotechnical condition and tunnel
Implications **Book C: Design solutions and applications based on the interpreted models**	• Decisions on alignment, land acquisition, etc.	• Ground behaviour, construction method, support measures, ground improvement, system behaviour, excavation classes etc.	• Observation and interpretation of displacements • Adjusted prediction of expected geotechnical conditions • Safety management • Comparison to predicted conditions	• Safety monitoring, routine maintenance works, counter measures for damages etc.
Remarks	• The model (B) should be accompanied by the base data (A) to enable an update with new data and to evaluate the model's uncertainty • The implications (C) depend on the model and should be linked to it • Consequently, ABC should be linked as one package and be delivered next phase.			
Schematic drawing of the inheritance of the geological/Geotechnical models through the life cycle of a tunnel.				

Figure 8-2 : Overview of content, applications and updates during the lifecycle of a tunnel project

The process map developed for the geotechnics-related use cases (Appendix A) adopts this schema as well:

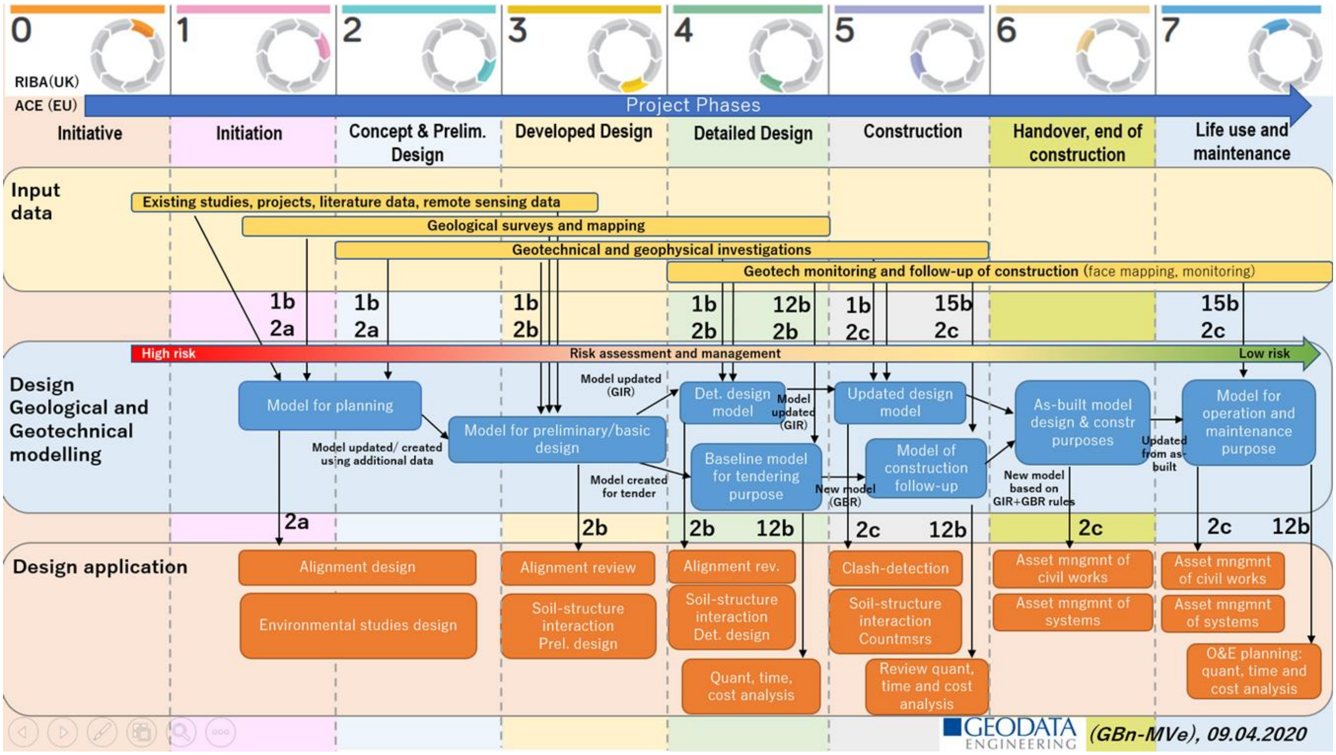


Figure 8-3 : Global process map for geotechnics use cases

Ground classification and risk assessment for tunneling: Important aspects

The characterization and handling of ground-related risks are an important application of geological and geotechnical models in tunneling.

Risks are defined at all stages of the project (design, tender, construction) for different purpose and require an adequate model of the ground conditions, i.e. an adequate exchange format to transport this information (terminology/definitions of risk and hazards see chapter above).

Several characteristics of the ground as well as spatial and geometrical aspects can represent risk sources: lithology and mineralogical composition, compaction and cohesion, discontinuities and their position relative to the tunnel, stress conditions, groundwater conditions etc.

Other conditions of the project environment can be additional risk sources for construction but are related rather to the alignment than to the properties of the ground itself. This includes e.g. the overburden, vicinity of man-made- and natural structures like traffic ways or rivers, or special aspects to be respected in urban areas.

A list of common sources of risks for a tunnel project related to the ground conditions is given below. These hazards need to be assessed, managed and mitigated both during tunnel design and construction phases. Additional aspects may be relevant depending on specific project conditions.

It is important to distinguish between the following:

"Geological aspects" that can represent sources of risks for the project:
Intrinsic properties of the ground that can be quantified or described in the geological/geotechnical models

- ➔ part of "Book B"

"Geotechnical and geomechanical consequences": Effects related to the construction in the before-described ground conditions, including ground behaviour, system behaviour (including support) and effects on construction/excavation methods.

- ➔ Part of "book C", including design solutions and risk assessment

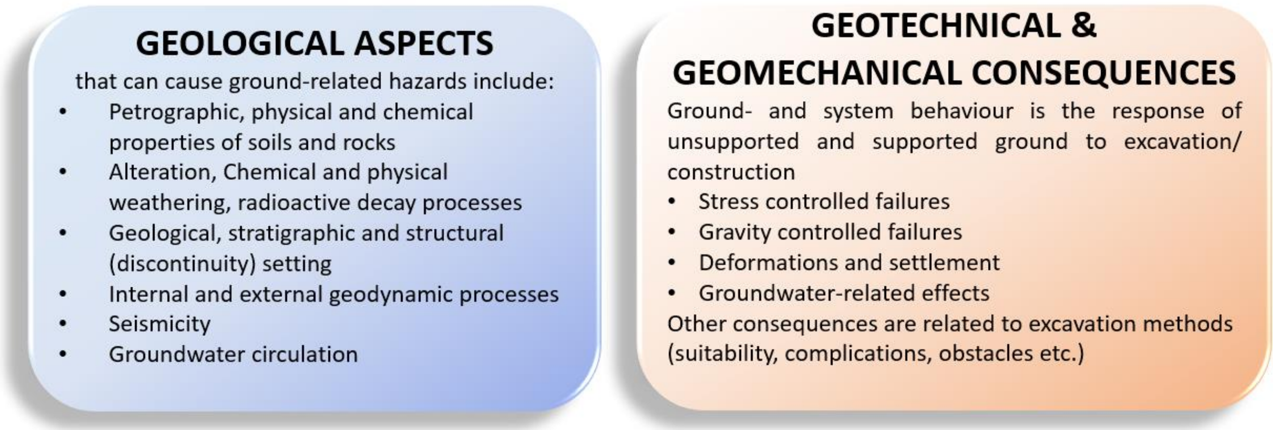


Figure 8-4 : Geological aspects and and geotechnical & geomechanical consequences

This is a complex topic, which needs to be addressed during the implementation to IFC. Two detailed tables on "Geological Aspects" that can cause hazards and "Geotechnical and Geomechanical Consequences" that are respected with design solutions are included in the Appendix.

The first table lists properties or potential for a certain ground behaviour that can be described or quantified in the Properties of Elements of the proposed Draft Taxonomy (e.g. in GeotechnicalUnits). The table proposes an approach how these aspects can be treated in the IFC-implementation.

The second table lists effects that need to be addressed together with the design of the intended building and are therefore not covered directly in the properties of the geological/geotechnical model elements.

Table 1: "Geological Hazards" can be described and quantified in the geological and geotechnical models and may include the following:

GEOLOGICAL ASPECTS / ➔ POTENTIAL HAZARD		Key factors	Investigations and studies	IFC-related representation
Tectonics, morphology				
A1	**SEISMICITY** Active faults as sources of earthquakes, shaking, ➔ asymmetric loads and displacements that need to be considered in seismic-resistant design.	Neotectonics, geodynamics activity, seismicity	Geological, seismic and seismotectonic studies	Geometrical representation in 2D/3D is relevant (GeoHazards). Semantics corresponds to the relevant information regarding faults.
A2	**ASYMMETRIC STRESS**			
	Tectonic related In situ stress anisotropy related to complex geological setting, strongly deformed and faulted areas, tectonic active zones	Internal geodynamic processes, tectonics, structural conditions	Geological and geophysical studies, in situ or lab geotechnical investigations	Geometrical representation in 2D/3D is relevant and it defines the hazard zone itself. (GeotechUnit, GroundSection) Semantics must transport information (principal stresses ratio, direction)
	Morphology related in situ stress anisotropy related to unfavourable morphologic conditions such as rock anisotropy, landslides or deep-seated gravitational slope deformation	External geodynamics processes, structural conditions	Geological and geomorphological studies. In situ geotechnical investigations and monitoring	Geometrical representation in 2D/3D is relevant and defines the hazard itself together with the surface geometry (GeoHazards). Semantics corresponds to the relevant information regarding landslides/motion.
A3	**INSTABILITY OF NATURAL SLOPES** Slope instabilities can occur in presence of saturated, unconsolidated, cohesionless or unstable ground. ➔ **Frequently encountered at p**ortals and tunnels with shallow overburden. Deep-seated, large scale landslides can be critical for the feasibility of a project.	Geological and geomorphological conditions. Soils and rock mass properties. External geodynamic processes.	Geological and geomorphological studies. Geotechnical investigation and stability analysis	Geometrical representation in 2D/3D is relevant (GeoHazards),

Fluids, temperature, etc.				
A4	**NOXIOUS AND DANGEROUS GAS** This hazard involves rock types which contain bituminous levels rich in organic matter. The presence of gases results from degradation of organic matter under low pressure conditions (CO, CO_2, CH_4). Poisonous gases can be produced by radioactive decay processes.	Geological setting, petrography and stratigraphy	Geological studies, In situ measurements and monitoring. Laboratory tests.	Semantics sufficient, associated to geological and geotechnical units is sufficient (Geological/ GeotechUnit, GroundSection) Link to in-situ measurements (GeotechInSituTest)
A5	**AGGRESSIVE WATER** such as sulphur rich water, abnormal pH values. ➔ has an adverse impact on construction equipment, support system and lining concrete durability.	Geological and Hydrogeological setting, water and ground chemistry	Geological and hydrogeological studies. Chemical analysis	Semantics sufficient, associated to GeologicalUnit, Aquifer or Ground Section. Link to in-situ measurements (GeotechInSituTest)
A6	**HIGH TEMPERATURE /HOT WATER** ➔ Occurrence within excavation can have an impact on design and during construction for safety, constructability and schedule.	Tectonic and geological setting, igneous intrusion, volcanic activity, groundwater circulation	Geological and structural study, geotechnical and geophysical surveys, in situ measurement	Semantics sufficient, associated to GeologicalUnit, Aquifer or Ground Section. Link to in-situ measurements (GeotechInSituTest)
Ground and rock mass conditions				
A7	**FAULTS AND/OR DISTURBED ZONES** Tectonically disturbed zones characterized by highly fractured rock mass, fault rocks (cataclasit, fault gouge, tectonic melange).Fault zones generally consist of a crushed or deformed fault core (core zone) surrounded by highly fractured “damage zones” where a groundwater circulation can take place due to the high permeability of rock masses. Weathering processes change the original properties of intact rock and shear strength of discontinuities. ➔ Commonly rock mass with poor geomechanical properties, possible water and debris inflows in tunnels etc.	Folded and faulted areas, weathered & highly jointed to completely crushed rock masses.	Geological and geophysical studies. Geotechnical investigations, face mapping	Geometrical representation in 2D/3D is relevant (FaultModel), with distinction between core and damage zone. Representation in GeotechUnits. Semantics is relevant as well in order to define their characteristics.

	A8	**HETEROGENEOUS GROUND** E.g. Flysch formations, fault affected zones and contact zones between intrusion and surrounding rock mass. ➔ Hazards related to heterogeneous ground conditions refer to the variability of the geological and (hydro-)mechanical properties of ground types that could lead to different ground behaviours.	Geology, stratigraphy, structural setting. Petrography and Intact rock properties, geostructural properties	Geological and structural studies, geotechnical and geophysical investigation.	Geometrical representation in 2D/3D is relevant, and it defines the hazard itself. Semantics is relevant as well in order to define their characteristics for some type of formations.
	A9	**KARST/ NATURAL VOIDS /CAVITIES** Karstic forms as a results of dissolution processes in carbonate and gypsum rock types. Water bearing zones can be associated to karstic groundwater circulation because of the high permeability of rock masses	Geological and hydrogeologic setting, petrography	Geological and hydrogeological studies, in situ and lab tests. Geophysical investigations	Semantics is sufficient to describe the risk (results of geological and hydrogeological studies). Geometrical information could be useful during construction (geophysical/geotechnical investigations and drillings).
	A10	**PRESENCE OF BOULDERS** e.g. in glacial or alluvial sediments or fault zones ➔ **TBM:** blocking or severe wear of cutter/cutterhead/mucking system we, problems in steering, excessive ground loss and settlements, lining/pipe damage in microtunnelling	Mineralogy, grain size distribution, morphology of boulders	Geological studies and settings, geotechnical and geophysical investigations, laboratory tests	Semantics is sufficient to describe the risk (results of geological and hydrogeological studies). Geometrical information could be useful during construction (geophysical/geotechnical investigations and drillings).
	A11	**PRESENCE OF VERY HARD ROCK** ➔ TBM jamming due to lack of thrust/torque, severe damage to cutters and cutterhead, problems in steering.	Geological and geomorphological conditions. Rock mass properties.	Geological studies and settings, geotechnical and geophysical investigations, laboratory tests	Semantics is sufficient to describe the risk (results of geological model and lab tests)
	A12	**ABRASIVE ROCKS** Usually high silica and quartz content in sedimentary, volcanic, intrusive or metamorphic rocks. ➔ **Strong influence on** excavation rate advancement, high consumption of cutters and drilling bits, health and safety (presence of fine ashes in tunnel)	Geological contest mineralogy; petrography	Geological and petrographic studies. Laboratory tests	Semantics sufficient, associated to GeotechUnit or GroundSection. Link to Factual data (LabTest / Sample)

	A13	**STICKY GROUND** presence of cohesive soil (clay, silt) with high plasticity and a certain mineralogical composition, ➔ combination with water, e.g. pressurized TBM tunnelling with EPB/Slurry machines. Hazards: blockage of the cutter wheel/cutters, increase of abrasiveness, creation of blocks in the excavation chamber/mucking system, blockage of parts of the separation plant	Mineralogy, grain size distribution, soil properties (Atterberg limits), groundwater	Geological study and petrographic, laboratory test	Semantics is sufficient to describe the risk (results of hydrogeological model and lab tests)
	A14	**SWELLING GROUND** Anhydrite or swelling clay dominant rocks, clayey fault rocks or weathering rock profile potentially can be affected by a change of volume in contact with water (chemical or physical processes) ➔ additional loads on lining and invert	Mineralogy, petrography, weathering processes	Geological study petrographic and Laboratory tests.	Semantics is sufficient to describe the risk (results of hydrogeological model and lab tests)
	A15	**NATURAL OCCURRING ASBESTOS** presence of rock formations containing asbestiform minerals ➔ health and safety (presence of cancerogenic dust)	Geological and structural contest, metamorphism, Petrography	Geological study, laboratory tests, X-Ray diffraction analysis (XRD)	Semantics is sufficient to describe the risk (results of geological study/mapping/lab tests)
	A16	**RADIOACTIVE MINERAL** This hazard is related to radioactive decay processes of some minerals (i.e. Uranium). Radioactive decay can also produce poisonous gas as Radon. ➔ health and safety, environment	Geological and structural setting, mineralogy and petrography	Geological Studies, petrographic analisis, in situ measurement and monitoring	Semantics sufficient, associated to GeologicalUnit, Aquifer or Ground Section. Link to in-situ measurements (GeotechInSituTest)
	A17	**HEAVY METALS** natural occurring heavy metals (e.g. cadmium) ➔ Leaching in rock mass, effects on pH of groundwater and leaching water from the muck have an impact on the environment.	Geological and structural setting, mineralogy and petrography	Geological Studies, petrographic analysis, chemical analysis	Geometrical representation in 2D/3D is relevant (GeotechUnit, GroundSection) Link to in-situ measurements (GeotechInSituTest)

Table 2: Geotechnical and Geomechanical Consequences (Hazards) can be assessed only based on the design with excavation geometry and support IN COMBINATION WITH ground conditions described in the geotechnical model (e.g. “Geological Aspects”) and cannot be treated as an intrinsic part of the latter.

The relevant information is transported in the semantics, and the POTENTIAL for the below-described consequences could be represented by simplified geometries along the alignment.

GEOTECNICAL AND GEOMECHANICAL CONSEQUENCES (RELATED TO EXCAVATION, SUPPORT, GORUND BEHAVIOUR, SYSTEM BEHAVIOR….)		**Key factors**	**Investigations and studies**
Gravity controlled failure			
B1	**BLOCK FAILURE (OVERBREAKS, FACE STABILITY)** The potential of rock block (wedge) failure is mainly associated to good /fair rock masses subjected to relatively low stress condition, i.e. when the response at excavation is dominated by the shear strength of discontinuities and a “translational” failure can occur (Bandis, 1997).	Fair to good rock mass properties, low rock pressure, shear strength of discontinuity	Geological and geomechanical surveys, geotechnical investigations, face mapping
B2	**CAVING (FACE / CAVITY COLLAPSE**) the term “caving” identifies generic gravitational collapse of portions of highly fractured rock mass from the cavity and/or tunnel face. Caving behaviour is associated to unfavourable rock mass classes with poor self-supporting capacity.	Poor rock mass conditions, gravity-controlled failure	Geological and geomechanical surveys, geotechnical investigations, face mapping
Stress controlled failure			
B3	**STRAINBURST/ ROCKBURST/SPALLING (→Brittle Failure**) Strainburst is a sudden and violent failure of rock caused by excessive straining of a volume of stiff and strong rock. Rockburst is defined as damage to an excavation that occurs in a sudden and violent manner with a mining induced seismic event	Good intact rock and rock mass properties, high ground overstress, seismicity, brittle behaviour	Geological and geomechanical surveys, geotechnical investigations, face mapping; monitoring

GEOTECNICAL AND GEOMECHANICAL CONSEQUENCES (RELATED TO EXCAVATION, SUPPORT, GORUND BEHAVIOUR, SYSTEM BEHAVIOR….)			**Key factors**	**Investigations and studies**
		Spalling is the development of rock damage and brittle failure process (i.e. visible extension fractures) under compressive loading**).** Spalling does not necessary lead to a violent event.		
	B4	**SQUEEZING, FACE EXTRUSION** Squeezing involves pronounced time-dependent deformations and is generally associated to poor rock mass properties under high ground overstress. Stress controlled failure with yielding and large deformations take place.	High ground overstress, poor rock mass properties, plastic behaviour	Geological and geomechanical surveys, geotechnical investigations, face mapping; monitoring
	Mainly water influenced			
	B5	**FLOWING GROUND** The presence of very poor and fractured rock masses with an intense groundwater circulation can trigger debris flow inside the tunnel	Geomechanical properties of rock masses; groundwater circulation	Geological and hydrogeological studies, geotechnical and geophysical investigation
	B6	**WATER INRUSH** Sudden heavy water and debris inflow, while crossing water bearing zones such as confined acquifers associate to high fractured rock layer, drastic change in permeability and high hydraulic charge.	Geological hydrogeological and structural setting, groundwater circulation	Geological studies, geotechnical and geophysical investigations
	B7	**PIPING** Collapse of tunnel face and/or cavity caused by water pressure	Geological hydrogeological and structural setting, groundwater circulation	Geological studies, geotechnical and geophysical investigations
	Load conditions, etc.			
	B8	**VISCOUS LOADS** The active load on supports/lining/TBM shield increases in time due to the occurrence of creep phenomena, generally more accentuated in the plastic zone surrounding the tunnel.	Geology, stratigraphy, structural setting. Petrography and intact rock properties, geostructural properties	Geological and structural studies, geotechnical and geophysical investigation.

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GEOTECNICAL AND GEOMECHANICAL CONSEQUENCES (RELATED TO EXCAVATION, SUPPORT, GORUND BEHAVIOUR, SYSTEM BEHAVIOR….)			**Key factors**	**Investigations and studies**
	B9	**SWELLING LOADS** The active load on supports/lining/TBM shield increases in time due to the occurrence of swelling, mainly accentuated in the zone of the invert.	Geology, stratigraphy, structural setting. Petrography and Intact rock properties, geostructural properties	Geological and structural studies, geotechnical and geophysical investigation.
	B10	**MIXED FACE CONDITIONS** Hazards related to the variability of the geological and mechanical properties of rock types on the face, that could cause problems related to face stabilization and tool consumption.	Geology, stratigraphy, structural setting. Petrography and Intact rock properties, geostructural properties	Geological and structural studies, geotechnical and geophysical investigation.
	B11	**DEFECTIVE BEARING CAPACITY** Excessive settlements of the support/lining system and/or of the TBM caused by high deformable ground.	Geology, stratigraphy, structural setting. Petrography and Intact rock properties, geostructural properties	Geological and structural studies, geotechnical and geophysical investigation.

8.2 Semantics

Based on the described use cases, a draft taxonomy has been created, defining required categories and terms used in the context of the exchange of geological/geotechnical data and models.

The taxonomy is subdivided in two main categories:

- GeoDocu (Factual- or Base Data, Book A) vs.
- Interpreted Models (GeolModel, HydroModel and GeotechModel, Book B), which provide the input to following analysis and application in Book C (e.g. use cases 7, 9, 11, 18)

This taxonomy is included in the Appendix C and comprises the following content and aspects:

General:

- The same properties are assigned to several elements of GeoDocu (depending on acquisition method) and Interpreted Model, to allow for a comparison of observations vs. interpretation (in all project phases) --> Linkage of A, B and C!
- Properties have been added but need to be specified in detail (general and geotechnical parameters etc.) in the next project phase. In this publication, only the modelled elements are displayed.

GeoDocu:

- includes site investigation (SI) as well as documentation during construction (tunnel face and wall mapping, cut slope documentation, boreholes, tests, etc.)
  The different way of geological documentation (like e.g. developed geometries of tunnel wall mapping) shall be covered.
- Some geological features of mapping / documentation can be described well with the terminology of GeoSciML
- Lab/In-Situ Tests: Included as "placeholder" elements with general information on test method and key parameters. Method-specific P-Sets are recommended but require a lot of details and linkage/harmonisation with existing standards, national- and discipline-specific practices.
- Borehole Data: Included as "placeholder" elements with general information on method and key parameters from documentation/logging (factual data)
  The representation of project-specific classifications, geotechnical units and interpreted model on borehole should be supported (linked, but not part of GeoDocu)
- Tunnel documentation: depending on the acquisition method and software used, the records can be attributed to various kinds of geometric representations, e.g. points (0D), lines (1D), surface (2D) and volumetric data (3D).
  The proposed semantics should be applied independently to several kinds of geometric representation

Interpreted Models:

As described above, the properties of the ground can be described and classified in alternative ways, depending on the purpose.

- GeolModel includes elements that can be described mostly with the terminology of GeoSciML
- GeoHazards include aspects like seismicity, flooding or landslides, but are not specified with properties etc. Such topics are commonly addressed with GIS-methods, and the coverage with IFC needs to be cleared. The definition of geometry, e.g. link to 2D maps/GIS or representation by 3D volumes (e.g. well-investigated landslides) needs to be specified
- HydroGeoModel includes aquifer (Vol) as well as water level (or piezometric-) surface
- GeotechModel includes beside the geological model two alternative approaches to exchange information on expected geotechnical conditions (interpreted models), which is also a way to deal with uncertainty in the prediction:

  - discretely modelled geotechnical units with defined geotechnical parameter sets, for structural analysis, along with discretely modelled discontinuities (faults). This model can cover the whole alignment or only key-locations / sections used for geotechnical analysis/calculations.

  - more generalized "ground sections" for specific applications like "geotechnical base line models" or models for time and cost analysis. The geometrical representation of these elements can be defined by spaces along the alignment, or envelope-zones of similar ground behaviour and act as containers for attributes. This kind of model can also be the base for risk assessments etc. in following use cases of Book C, and to address the potential hazards listed in Table 2.

An important topic is the description and representation of discontinuities. It must be distinguished between discontinuities as from factual data and from interpreted models:
In Factual Data, Discontinuities can be observed and measured either as discrete features or as sets (patterns), on various scales
For the elements of "Mapping" in the taxonomy, “Fault Surface” and “Fault Zone” were introduced separately, to differentiate this from discontinuities observed on outcrop-scale and "logged" in a geotechnical sense. FaultSurface could be described as subclass of DiscreteDiscontinuity as well.

In Interpreted Models, it must be distinguished between the following:

- Geological model:
  - Tectonic Faults is represented either by surfaces or volumes
- Geotechnical model:
  - Fault material in fault zone (e.g. fractured rock, cataclasite, fault gouge,…): Described as GeotechnicalUnit --> Volume
  - Discrete discontinuities, with associated shear strength parameters etc:
  - Modelled discretely or with a pattern. Element "Discontinuity" in GeotechModel, --> 3D surface
  - Or can be treated as intrinsic part of the rock mass ("smeared parameters"), thus be described in the attributes of GeotechUnit

Both options should be supported.

8.3 Geometry

For many elements especially of “Factual Data” (Book A, “GeoDocu” in Draft-Taxonomy), the geometric representation in IFC will only to a limited extend or not at all represent the real-world shape of the described object, but must be seen as a rough, idealized representation, transporting the associated information, localized to a specific location.

➔ Lines and points are essential for factual data, even if they could be replaced by simple volumetric bodies like spheres, cylinders, sweeps or extrusions, e.g. for borehole data.

It is preferred to use the explicit representations to exchange interpreted models in IFC-format, as the methods and technical background of developing implicit models (e.g. based on radial base functions) is highly software-specific and complicated.

The explicit geometry representation of both interpreted models and factual data will require volumes as well as surfaces (planar or curved).

The option to represent interpreted models along lines like borehole traces or a tunnel axis can be useful for many applications (e.g. use case 12b)

Requirements regarding geometric representations are listed in a separate table for the elements of the draft taxonomy. For each proposed element, the following is defined:

Geometric dimensions: Representation as

- 0D point,
- 1D line,
- 2D area/surface,
- 2.5 (e.g. elevation grid) or 3D surface
- 3D volume

Point Representation

- Cartesian point
- Point positioned along the alignment
- Annotation

Line Representation:

- IFC curve (with subclasses)

Surface Representations:

- Triangulated surfaces (IfcFaceBasedSurfaceModel)
- Parametric surfaces (IfcBSplineSurface)

Volumetric Representations

- Faceted Brep, as generic representation for volumes, especially with unstructured surfaces
- Extrusions (IfcSweptAreaSolid), for representation boreholes/borehole layers and disk.
- Advanced Breps (IfcAdvancedBrep), consisting of parametric surfaces

Decomposition Models

- Voxel representations (for Octree + kd-tree)
- Further decompositions, such as for FEM analyses

Important is the option to have several alternative representations for defined semantic elements:

Interpreted models:

- Geological / geotechnical units: Explicit geometry as either 3D solid models (closed) or 3D surfaces (layer top and/or bottom, open), in formats like Faceted BRep or TriangulatedFaceSet

- Depending on the modeling approach, both upper and lower boundary surfaces are needed in some cases when updating a stratigraphic model if additional factual data become available. This requirement is illustrated in the figure below.

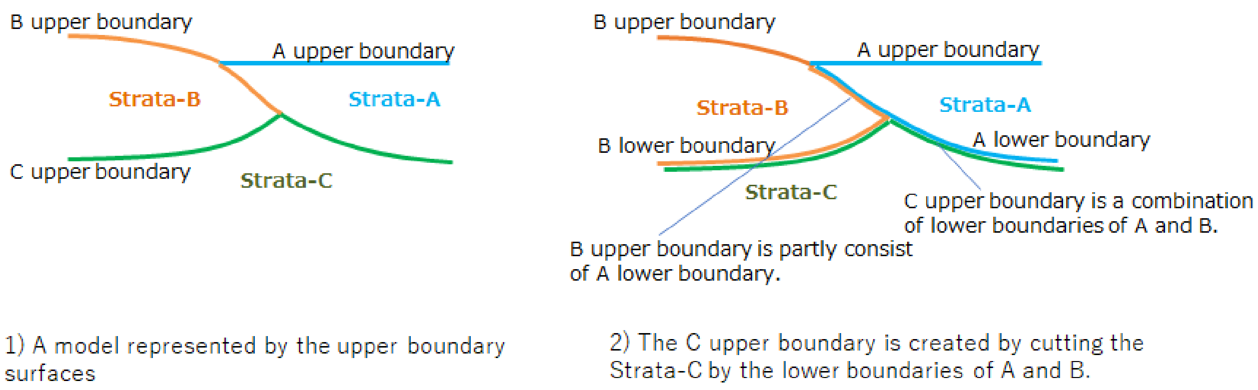


Figure 8-5 : Illustration of the necessity for lower boundary surfaces when updating the model

- Faults as either surfaces or volumes with real thickness

Decomposition Models:
Apart from surface-based or solid-based representations, also Decomposition models are required in order to transport cell-based information.

In Geostatistics the transportation of uncertainty and the exchange of underlying properties themselves are very important. An example is the analysis of the uncertainty resulting from a Kriging based ground interpolation of borehole data.

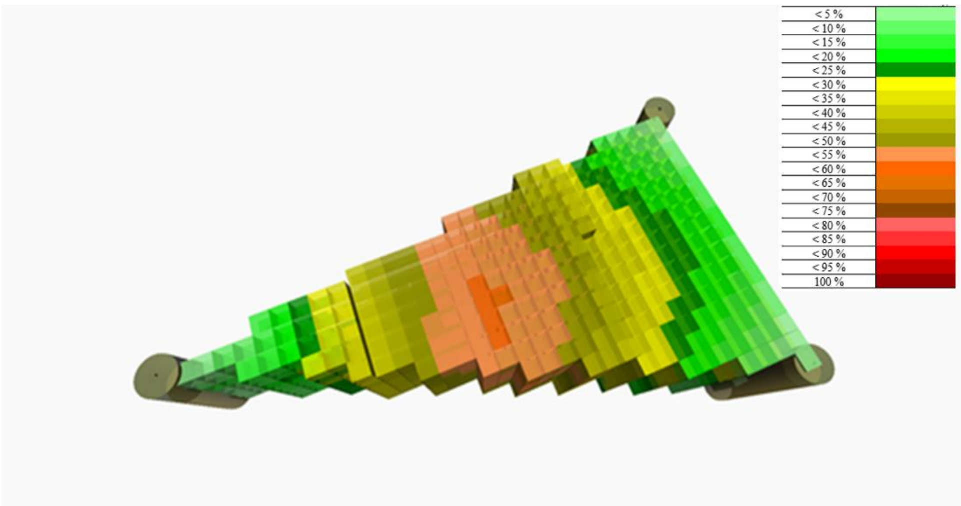


Figure 8-6: Uncertainty visualization from a Kriging interpolation (Mahmoudi et al., RUB).

Voxel models are also well established for transporting geophysical data, such as s-wave velocity (Fig 8-7), as well as for groundwater models.

Also, from the modelling perspective, decomposition models are very useful. Not only they allow to attach specific ground conditions, but they are easily to modify or to extend in local regions.

Nonetheless, decomposition models are usually having very high storage requirements, especially when using high resolution voxel models. That is why more efficient representation formats should also be considered, such as using octree representations, which allow the vary the resolution depending of the homogeneity of the ground region while preserving model accuracy.

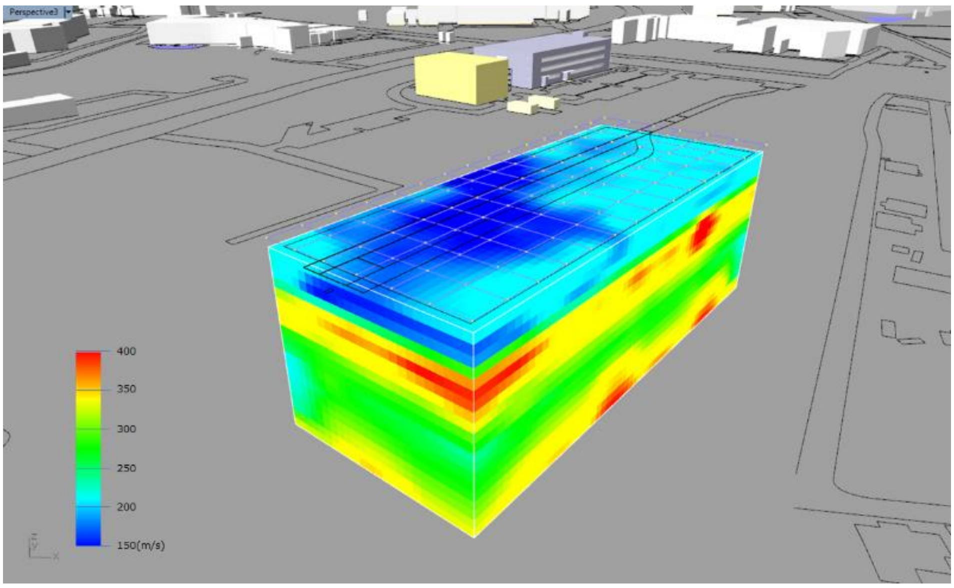


Figure 8-7 : S-wave velocity structures by a 3-D analysis of microtremor array data (voxel size = 2.5m each)(courtesy OYO)

8.4 Uncertainty

Different sources and kinds of uncertainty can be distinguished, and different ways to treat them are proposed:

Factual data:

- Resolution, inaccuracy and statistical and scatter are inherent to the methodology of acquisition, both regarding localization and measured parameters
- Resolution, scatter/uncertainty in measured values (depending on acquisition method)
- Inhomogenity in the ground and sample size / tested volume --> statistic variations
- Localisation (borehole deflection, spatial resolution of test methods, …)

Proposals for IFC Tunnel:

- Description of measurements by value ranges for properties (bounded value)
- Additional properties to quantify accuracy, scatter and methodological constraints

Interpreted models:

- Density and accuracy of site investigation/factual data
- Level of detail: Related to project phase, application (use case) and complexity of geological conditions. Will be specified in Phase 2, when a complete list of properties etc. is available.
- Classification system: based on the measured and assumed geotechnical properties and the engineering geological concept model, geotechnical units are defined for the specific project.
- Geotechnical parameters are defined based on heterogeneous input data, statistics and experience, including subjective influence.
- Discontinuities in the rock mass (cracks, joints, bedding, foliation etc., ISO 14689) can be treated either as discrete features (surfaces, volumes or geometrically defined patterns), or be respected in the properties of a continuum material (also a scale effect).
- Geometry and resolution: small-scale patterns such as intercalations or discontinuity patterns, faults and folding cannot be exactly predicted and located for the entire model area. Schematic illustrations and over-signatures commonly used in 2D sections are not simple to implement in 3D models. The argument of an "apparent accuracy" is often heard with reference to 3D models, although this applies just the same to 2D representations.
- Properties and boundaries are interpreted between locally known values/conditions with respect to the underlying geological processes, which implies that the uncertainty depends also on the complexity of the geological conditions. A rating of this effect (R-index) can for example be stored in a model in the properties (Bianchi, G.; Perello, P.; Venturini, G.; Dematteis, A., 2009. Determination of reliability in geological predictioning for tunnel projects: The method of R-Index and its application on two case studies. IAEG Italy, pp. 1–18**)**

Proposals for IFC Tunnel:

Geotechnical parameters:

- Definition of geotechnical design parameters by value ranges (bounded value)
- Rating of the complexity of the geological conditions

Geometry:

- Attributes for spatial uncertainty/resolution
- Visualisation of factual data/link in model
- Voxel-models with uncertainty-indices?

The link or joint visualization of models along with fact data is a well-established way to allow for a qualitative estimation.

8.5 Existing standards

In Geoscience, the handling of digital spatial data and information linked to 3D-geometries has a long tradition, and several standards exist not only in scientific applications, but also from the resource- and mining sector.

Such standards comprise e.g. RESQML which is mainly used in oil and gas industry (Ref: https://www.energistics.org/download-standards) or the Open Mining Format (OMF), developed by the Global Mining Guidelines Group (GMG)
(Ref: https://gmggroup.org/projects/data-exchange-for-mine-software/)

These standards cover the field of geotechnics only partially and are usually not used in the infrastructure- and tunneling sector.

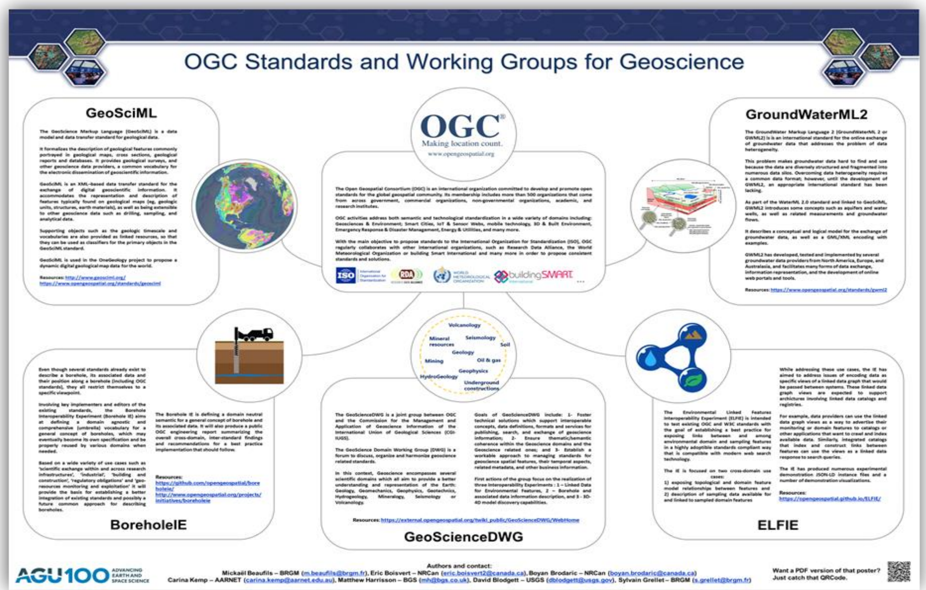
Well established in several countries is the AGS-format for the exchange of geotechnical site investigation data, which was developed first in the 1990ies and is frequently updated and extended (Ref: Association of Geotechnical and Geoenvironmental Specialists: AGS4, Electronic Transfer of Geotechnical and Geoenvironmental Data. Edition 4.0.4 – Feb. 2017. http://www.agsdataformat.com/datatransferv4/download.php.)

While this standard traditionally focused on factual data and did not include a format to exchange geometry along with semantics, an extension for interpreted models for BIM-applications is currently being developed (Ref: Chadwick, N., Farmer, D., Chamfrey, J., Miles, S., 2019: Extension of the AGS Format to Incorporate Ground Model and Interpreted Data. ICITG2019, 196, v4)

OGC-standards

The OGC geoscience package mostly relies on two standards: GeoSciML and GroundWaterML2 which themselves extend some thematic neutral standards like the ISO19156: Observations & Measurements.

The Geoscience Markup Language (GeoSciML) is mostly geology oriented, while the GroundWater Markup Language 2 (GroundWaterML2) is hydrogeology oriented. Both standards were incubated by the Commission for the Management and Application of Geoscience Information (CGI) to support interoperability of information served from Geologic Surveys and other geoscience data custodians. They are now endorsed and maintained by the OGC Geoscience Domain Working Group.



GeoSciML enables to describe geologic features related to factual data description such as boreholes, samples, analysis, but also interpretations with concepts like geologic unit, geologic structure, contact, earth material. GroundWaterML2 extends GeoSciML and introduces extra concepts including hydrogeologic unit, cavitie, fluid body, discharge and recharge. Geotechnical specific concepts like geotechnical units are currently absent in OGC data models, but the ongoing MINnD Geotechnique project is proposing some extensions for that purpose.

Important: OGC data models like GeoSciML focus on semantics and do not enforce the use of specific geometries (even if GML based are preferred). Indeed, they can be applied to any kind of geometry-format (including non-OGC geometries). During the bSI Summit Oct 19 the IDBE Geotech illustrated that approach by demonstrating the feasibility to have GeoSciML semantics combined with IFC geometries with a Linked Data approach.

The semantics and terminology as defined in GeoSciML are well established and suitable to describe geological models, field mapping data and documentations. The IFC-Tunnel extension aims to adopt the relevant elements and properties for both factual data and the interpreted geological model. If additional required details arise during the specification in the next project phase, extensions can be made.

The same applies to the hydrogeological model and boreholes with respect to GroundWaterML2.
The field of geotechnics is not covered yet by OGC - data models, and additional semantics need to be developed to cover the requirements of IFC tunnel, as proposed in the elaborated taxonomy. This needs to be in line with existing standards and guidelines, and a harmonization with similar intentions by OGC is recommended.

The IDBE-workgroup is seen as the appropriate platform to coordinate the bSi / IFC tunnel proposal with other initiatives.

Inspire

In Europe, the INSPIRE Directive from March 2007 aimed at organizing structuring the exchanges of environmental data to enfavor environment protection. One major output was the definition of data models and agreed semantics.

The INSPIRE data models cover a wide range of themes from administrative unit description to hydrology, mineral resources, ortho-imagery… including a Geology Theme. This one encompasses geology, hydrogeology and geophysics. INSPIRE data models were mostly based on existing OGC standards, in case they were already existing.

The Geology theme then introduces similar concepts to GeoSciML and GroundWaterML2. The geophysics package is based on the ISO19156 standard: Observations and Measurements.

In this analysis, two resources have been investigated in more detail and compared to the requirements as defined by the work group: The standards and data models of OGC and the proposed extension "IFC geotechnics" as developed by the common schema project and published as part of Ifc4.3 (June 2020).

IFC-geotech by Ifc4.3 (Common-schema) project

The report "Geotechnical Use Cases, Requirements and Implementation" is provided in the appendix and gives an overview of the history, scope and content of the proposed schema "IFC geotechnics" that was presented at the bSi Summit Oct 2018 and published Feb 2019.

The scope of this proposal intends "an initial representation of geology and hydrology" to be used for infrastructure projects in general, while the initiative came from the side of the "ports and waterways" work group.

The content is focused on soil material (not hard rock), earth works and the foundation of buildings and engineering structures in general, and should cover interpreted models (classifications of the subsurface). Geology and geotechnics are not distinguished clearly.

For the intended applications (representation of the environment or simple foundations of surface buildings, earthworks etc.), the concept might be sufficient, but it does not meet the requirements of tunneling projects.

The main shortcomings with regard to tunneling can be summarized as follows:

- Distinction between geology and geotechnical interpretation: It is not possible to have a geological model parallel to geotechnical design models
- The proposal covers only one interpreted model, no representations of factual data (input data, measurements and observations)
- "Misleading" term "BoreholeAssembly", as this is used as a 1D-representation of an interpreted model, and does not cover original borehole records or logging data (factual data)
- Groundwater not covered in a hydrogeological way: Only description of "water bodies" (free or subsurface), aquifers with relevant hydrogeological parameters are not covered.
-

- Description of hard rock not covered
- Discontinuities in a geotechnical sense are not covered
- Essential properties are missing (like e.g. elasticity modulus)
- Terminology of properties/elements based on soil / not according to tunneling and engineering geology guidelines (IAEG, ISRM, ISO 14689...)
- Lower contacts of modelled (geotechnical) units might be required depending on the modelling approach, as described above (chapter geometry).

Based on this analysis the project team has decided that the IFC-Tunnel extension must include additional content compared to “IFC-Geotechnics” of the Common Schema proposal.

Table 3: Comparison - Feature Matrix

The table below lists the requirements of IFC Tunnel and compares it to the discussed standards/proposals, which had both been defined for other purposes than tunneling and therefore cover only certain aspects.

	OGC GeoScience Standards	IFC4.3 Common Schema (bSi)	Requirements of IFC-Tunnel (bSi)
Semantics	**Detailed semantics for various disciplines Geotechnics currently not covered (*)**	Limited (only one interpreted model)	Formulated in use case descriptions, draft taxonomy and process map
Geometry			
3D geometry – TriangulatedFace or Brep	**Geometry not defined in the standards. The semantics can be applied to various geometrical representations (OGC and others)**	Covered	Required
3D geometry – Voxel		Covered	Required
2D geometry		Covered	Required
Factual Data, (A), GeoDocu			
Geological mapping	Covered (GeoSciML + GML for 2d geometry)	Not covered	Link/Required
Geotechnical Documentation	Not covered yet (*) GeoSciML: Lab Analysis and Specimens (ISO 19156) Bit not geotechnical tests and parameters	Not covered	Required: Mapping, key outcrops, discontinuities, Test results, Geophysics, Tunnel Docu, Slope Docu,…
Boreholes	GeoSciML: Borehole concept GroundWaterML2: GeologyLogCoverage based on ISO 19156: NO geotechnical properties for log yet (*)	Drilling methods and borehole equipment Representation of interpreted model (SolidStratum) NO original log NO factual data	Required, Including key parameters of Geologic and geotechnical log (factual data) link to external sources

	OGC GeoScience Standards	IFC4.3 Common Schema (bSi)	Requirements of IFC-Tunnel (bSi)
Interpreted Models (B)			
Geologic Unit	GeoSciML: GeologicUnit concept	Not covered	Required
Geologic Structure	GeoSciML: GeologicStructure concept (including faults, foliation, bedding etc.)	Not covered	Required
Hydrogeologic Unit	GroundWaterML2: HydroGeologicUnit	WaterStratum NO aquifer	Required, Aquifer and piezometric water level
Geotechnical unit	Not covered yet (*)	SolidStratum: Representation of interpreted model Properties NOT sufficient Adequate terminology?	Required, related to design purpose Including link to factual data
Discontinuities (geotechnical)	Not covered yet (*)	Not covered	Required
Properties			
Geological parameters	Stratigraphy, Age, Lithology, Mineralogy,… CGI vocabularies	Not covered	Required
Geotechnical parameters	Not covered yet (*)	Mainly selected soil parameters Hard rock parameters not covered Adequate terminology?	Comprehensive parameter lists for tunnel design - soil, rock (rock mass and intact rock), ground behaviour, TBM-specific
Uncertainty	Not covered yet (*)	Existing in form of properties for geoemetry/extend of geotechnical units, not sufficient	Required for factual and interpreted data, several aspects
Risk	Not covered yet (*)	Intended	Required Interaction with design and general risk register

(*) Proposed as an extension of GeoSciML (IDBE Geotech activity)

9 Excavation requirements

Tunnelling excavation can be realized with different methods. Chapter 10.1 shows the analysis of prioritization that leads IFC-Tunnel extension to give priority to the following list of construction methods:

- Conventional tunnelling
- Mechanised tunnelling
- Cut-and-cover tunnelling

9.1 Overview

9.1.1 Abbreviations

AFTES	Association Française des Tunnels et de l'Espace Souterrain (French Tunnelling Association)
DAUB	Deutscher Ausschuss für unterirdisches Bauen e. V. (German Tunnelling Committee)
ITA-AITES	International Tunneling Association
TBM	Tunnel Boring Machine

9.1.2 Conventional tunnelling

The excavation methods for Conventional Tunnelling are [6] :

- Drilling and blasting mainly applied in hard rock ground conditions
- Mechanically supported excavation mainly used in soft ground and in weak rock conditions.

Both excavations methods can be used in the same project in cases with a broad variation of ground conditions. In both excavation methods, the excavation is carried out step by step in rounds. The round length generally varies from 1 m or less in soil and poor ground conditions to 4m in good conditions.


Figure 9-1 : Excavation with road header and ventilation pilot tunnel (source ARGE Girsbergtunnel)

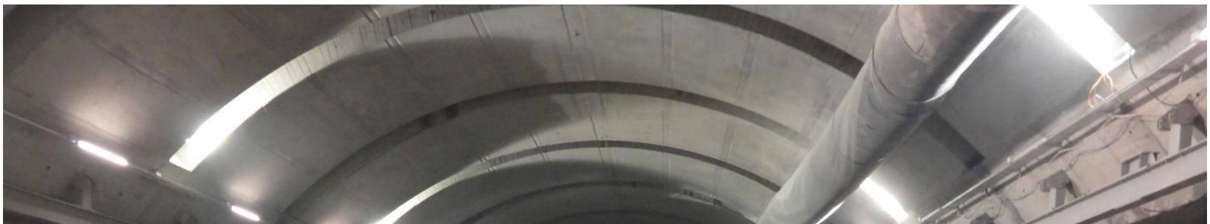


Figure 9-2 : Staged cavern excavation by drill and blast (source ILF)

9.1.3 Mechanised tunnelling

Mechanised tunneling is defined as excavation of tunnels performed with a Tunnel Boring Machine (TBM).

Tunnelling machines either excavate the entire tunnel cross-section with a cutterhead or cutting wheel or excavate partial sections using appropriate excavation equipment. The machine is either continuously or intermittently driven forward as it excavates.

According to ITA [5] and AFTES [6] main typology of TBMs are hereby listed.

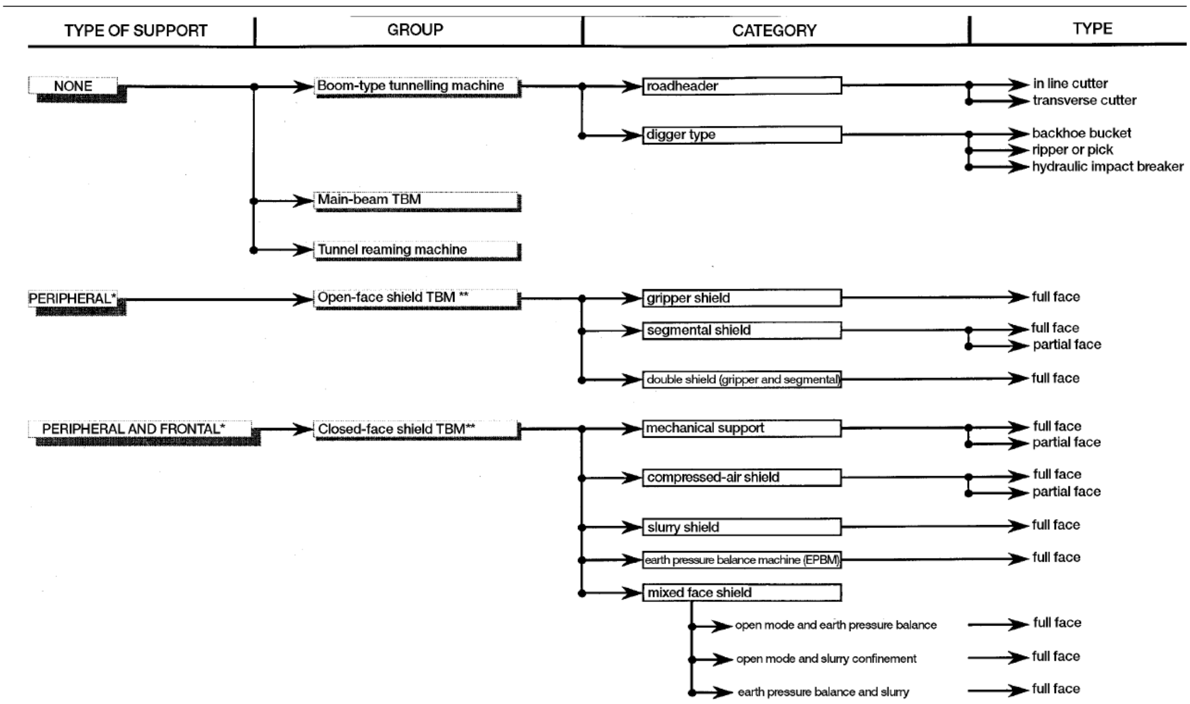


Figure 9-3 : Typologies of TBM according to ITA [6]

Tunnel Boring Machines (TBMs) can be differentiated into machines not providing immediate support, machines with peripheral support and machines with peripheral and face support.

Nowadays, great majority of tunnels are excavated with:

- Excavator / Roadheader (mounted in a shield)
- Gripper TBMs
- Single shield TBM
- Double shield TBM
- Slurry shield
- Earth Pressure Balance (EPB) Shield
- Variable Density Shield
- Hybrid Shield

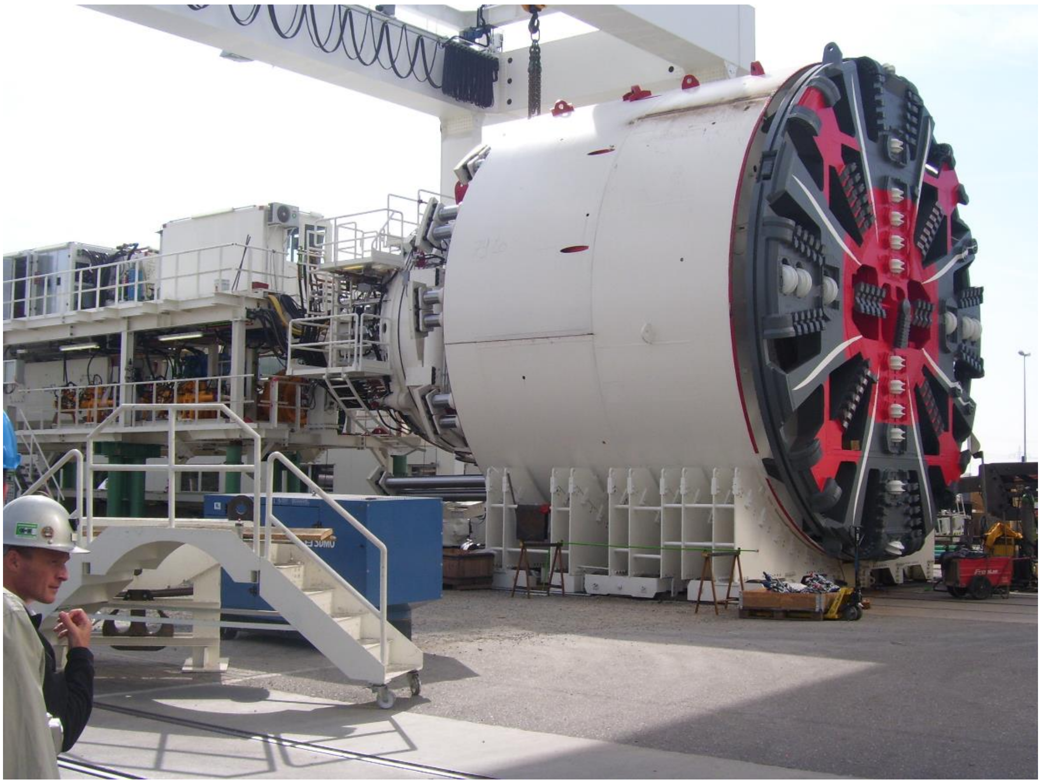


Figure 9-4 : Shielded TBM in suppliers' factory (source Herrenknecht)

Figure 9-5 : Double-shield TBM mounted on-site (source Brenner Base Tunnel)

DAUB recommendation [11] furnish an updated and comprehensive discussion about different types of machine.

Considering that the large majority of Mechanised tunneling is performed with Tunnel Boring Machines (TBM), it is often called TBM tunneling. It can offer a technically feasible and economic alternative to other methods of tunnelling especially in unfavourable geological conditions, for long tunnels/contracts, high production requirement or where high surface settlement control is applied [12] .

9.1.4 Cut-and-cover tunnelling

Cut and cover describes the tunnelling process where the alignment is exposed from the surface by excavating a trench, the tunnel structures constructed in place and then covered again by soil. It is generally the cheapest form of tunnelling up to depths of around 15 to 20 metres, where environmental and physical constraints allow removal of the ground above (and around) the tunnel.

The trench is excavated, if *necessary* in stages, the excavation supported and the tunnel lining constructed in the excavation, if required waterproofing installed and the tunnel excavation filled again.

The excavation generally takes 2 forms.

- Where space is sufficient, an open sided excavation with sloping embankments is often the easiest and cheapest solution
- Where space is limited, vertical or near vertical sides to the excavation are necessary. In this case, particularly in soft ground, a confined excavation is required. The vertical walls are generally braced or anchored to ensure their stability.

Confined excavations can be constructed conventionally with so called "bottom up" construction, where the trench is excavated, supported and the tunnel lining constructed or with "top down" construction where the walls are constructed, the tunnel roof slab placed on top of them and then backfilled and covered. Excavation then takes place under the roof slab. This method is useful in urban areas as it allows the surface utilities to be reinstated as soon as possible.

Figure 9-6 : Cut and cover construction in an open excavation (source ARGE Girsbergtunnel)

9.2 Semantics

Use cases related to excavation modelling in terms of semantics content are:

- Alignment (UC 3)
- Visualization (UC 4)
- Coordination (UC 5)
- Quantity take-off (UC 10)
- Construction sequencing (UC 11)
- Geotechnical modelling for time and cost estimation (UC 12)
- Progress monitoring (UC 15)
- Machine control and guidance (UC 16)
- Handover to GIS (UC 19)

9.2.1 Conventional tunnelling

Excavation in conventional tunnelling could exchange and transport a lot of information from different aspects as logistics, excavation, supports, lining etc...

They could be associated to portions of the alignment. Usually the alignment can be divided in minimum construction units, e.g. sections or excavation phases or rounds for rock tunnels. See appendix D on the semantic and the chapter 11 on "Spatial structures and spaces" for more details on the spatial breakdown structure.

9.2.2 Mechanised tunnelling

Excavation in mechanised tunnelling could transport a great number of information that are particularly important in different fields, from environmental aspects to logistics. They could be associated to portions of the alignment. Usually the alignment can be divided in minimum construction units, e.g. rings. See appendix D on the semantic and the chapter 11 on “Spatial structures and spaces” for more details on the spatial breakdown structure.

9.2.3 Cut-and-cover tunnelling

Cut and cover excavation is usually broken down into individual stages, generally as much as can be excavated before support needs to be installed. Depending on the detail required by the use case, the stages may need to be detailed in the model, if necessary, with construction program relevant information.

If the excavation can only take place after installation of a support component, this constraint should be indicated through preceding and following elements. The support type should be indicated (open/braced/anchored).

The excavation should inherit properties from the surrounding geotechnical model.

The excavation should contain quantity information, including volumes in place and any bulking factor to allow the transportation quantities to be determined.

9.3 Geometry

The excavation tunnel geometry is covered in detail for all three tunnel types in chapter 6.4 “Geometry”. Please refer to this chapter for more information on tunnel geometry.

Excavation in underground works is performed with large machines or by controlled explosions. Care should be taken not to model excavation with unnecessary accuracy that is not representative of the construction methods. Generally, small collisions and clashes can be perfectly acceptable given the roughness of the methods used to perform the excavation.

9.3.1 Conventional tunnelling

The main geometries to consider for conventional tunneling are the cross-sections for excavation and inner lining. These cross-sections are flexible due to the flexibility of the conventional tunnelling production method itself. The flexibility leads to some challenges regarding the interpolation between given cross-sections. This is discussed in detail in chapter 6.4.

In addition, the geometry of niches, technical rooms, cross passages etc must be merged/ superimposed with the geometry of the main tunnel. How to solve this is also described in chapter 6.4.

In the longitudinal direction, the tunnel is typically divided into excavation phases or rounds (blast) for hard rock tunnels. This spatial segmentation is mainly relevant for the construction phase but can also be reflected in the permanent tunnel structure, e.g. for rock support. The length of these segments varies from down to one meter and up to maybe 6 meters for long rounds.

The excavation can be performed over the full face or broken up into various stages. The most common excavation stages in conventional tunnelling are shown below.

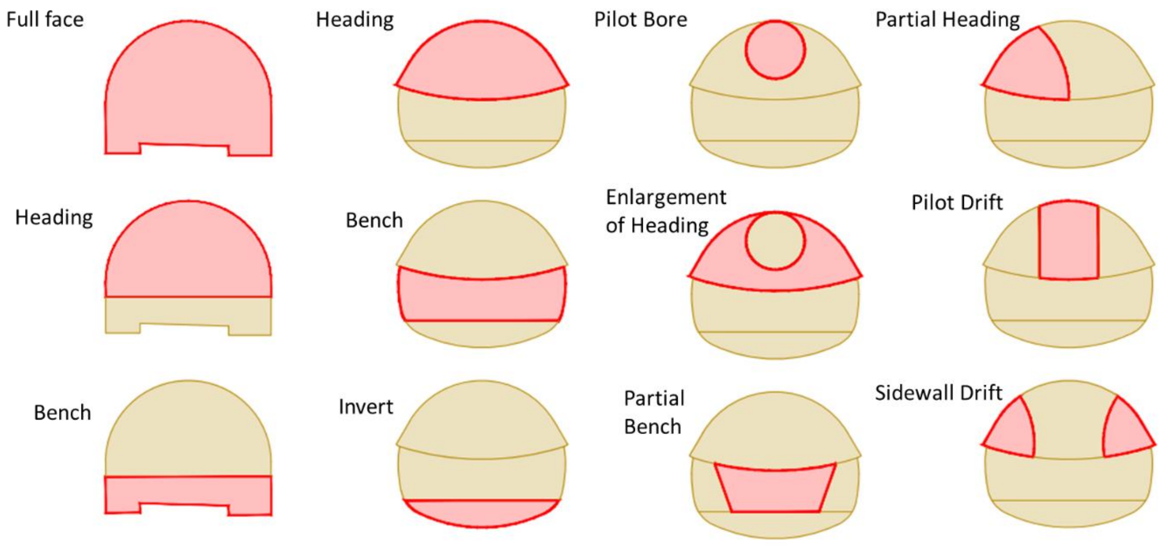


Figure 9-7 : Typical excavation stages of conventional tunnelling (source SBB/ILF)

9.3.2 Mechanised tunnelling

From geometrical point of view, Mechanised tunnelling can be described with these main elements:

- Excavation
- Lining
- Internal structures

Excavation is usually defined as a 3D volume constrained theoretically:

- In transversal direction, by TBM machine excavation diameter and eventually by its overcut;
- In longitudinal direction, excavation could be divided according to segmental lining ring length, that is minimum construction unit for TBM tunnelling, especially for specific applications like construction sequencing and quantity take off.

Minimum construction units can be integrated in a GIS platform and they can be used to transport other information (see figure below).

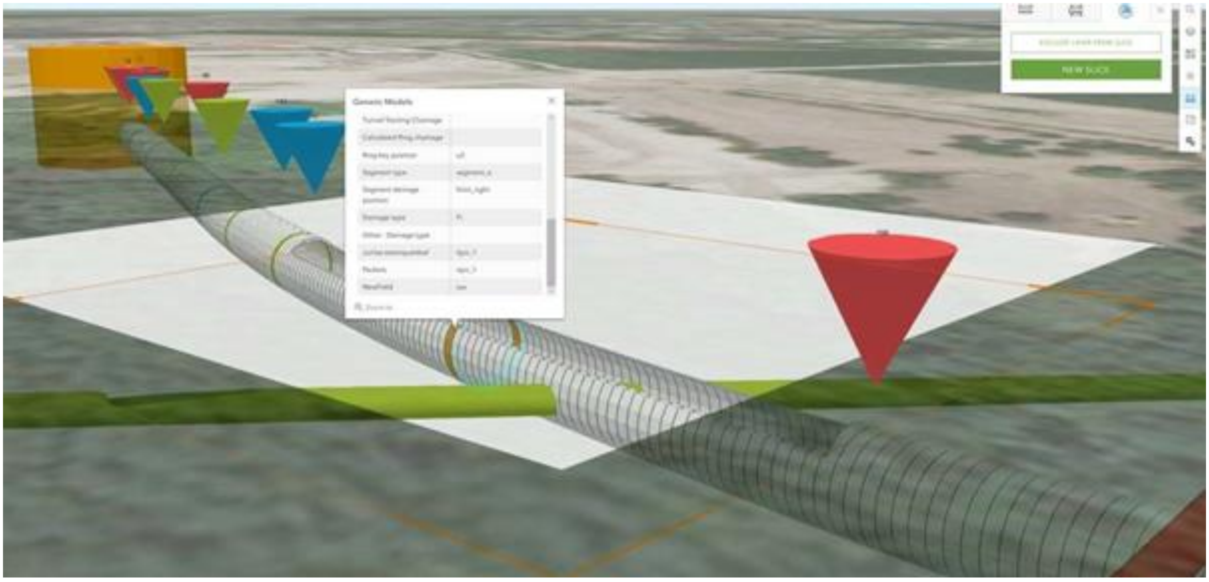


Figure 9-8 - Example of representation of mechanised excavation from integration GIS-BIM (courtesy Geodata)

Mechanical excavation is generally performed over the full face, but under circumstances can be proceeded by a pilot bore. The most common excavation stages in mechanical tunnelling are shown below.

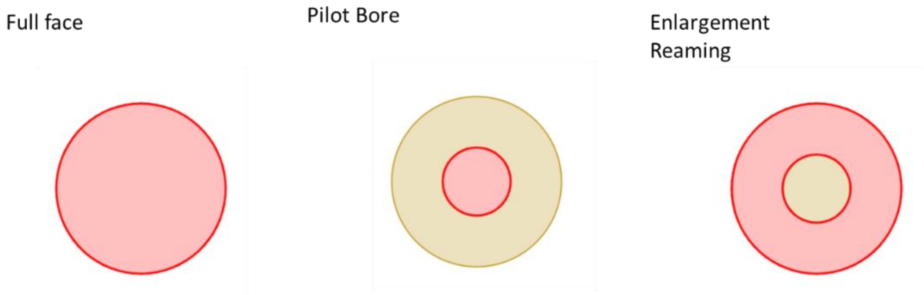


Figure 9-9 : Typical excavation stages of mechanical tunnelling (source SBB/ILF)

9.3.3 Cut-and-cover tunnelling

The geometry of cut and cover excavation is essentially straightforward. It can generally be described with simple extrusions and sweeps.

In most cases it is useful to describe the individual stages of the excavation. Generally, it is not necessary to extract complex forms due to protruding beams and anchor heads out of the simple excavation shape.

The most common excavation forms in cut and cover tunnelling are shown below.

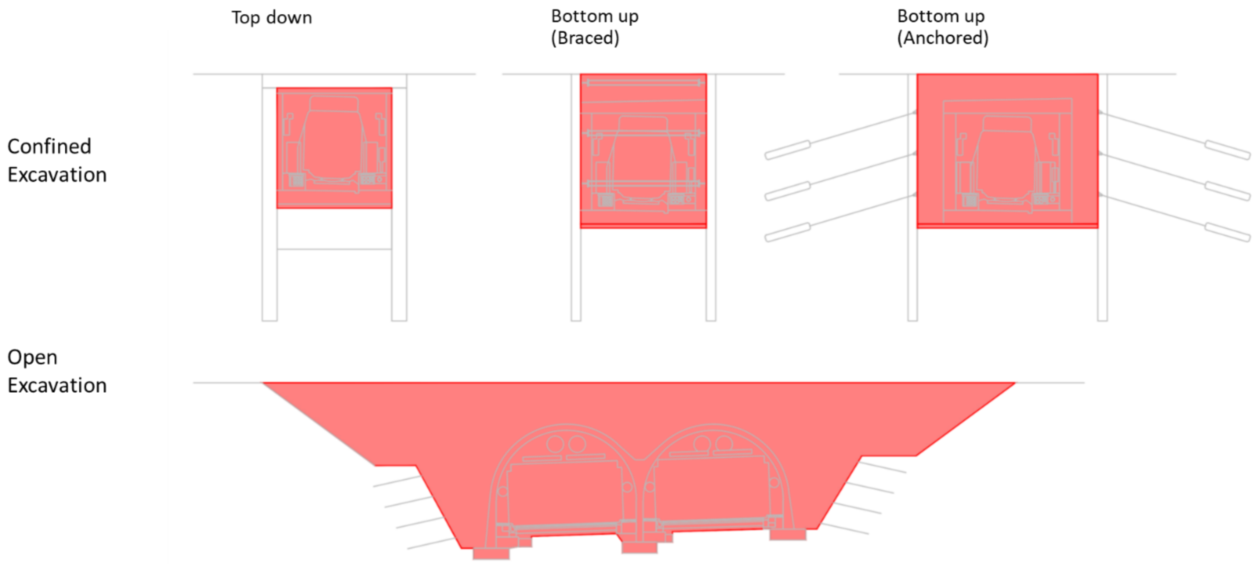


Figure 9-10 : Typical excavation geometries of cut and cover tunnelling (source SBB/ILF)

10 Excavation support, ground improvement, waterproofing and tunnel lining requirements

10.1 Excavation support

The purpose of the support is to stabilize the underground opening until the final lining is installed [7] . Thus, the support placement is primarily a question of occupational health and safety but it's also a question of the usability of the tunnel itself as well as of the protection of the environment (neighbouring buildings, lines of communications in or above ground facilities).

Support can be temporary or permanent. Whereas in the past it was often considered temporary, modern advances in shotcrete and precast concrete technology mean that it is now frequently considered permanent.

10.1.1 Conventional tunnelling

Due to the flexible nature the conventional method of excavation, there is a long list of possible support measures used in tunnels.

Here we divide them into three main groups of temporary support:

- **Pre-support**: Support measures done ahead of the tunnel face
- **Face support**: Support measures done at the tunnel face immediately after the blast or during the excavation.
- **Temporary/Permanent Support:** Support measures done after the excavation for temporary phase before lining (temporary support) or permanent support in the case of good quality rock conditions.

This following schema shows the definition between support, pre-support and face support [7] :

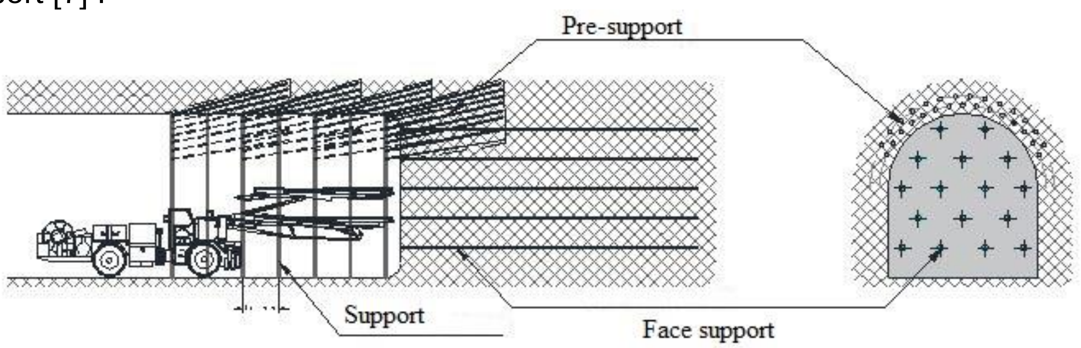


Figure 10-1 : AFTES (GT7) in revision version (in progress)

Pre-support

Pre-supports are "rigid" elements; the main characteristic is they are installed at the tunnel face at the top perimeter of the tunnel section, before the excavation of all or part of the section.

The most commonly used pre-support methods for conventional tunnelling in the soft soil and bad rock conditions are:

- Umbrella vault (petroleum tubes/jet grouting):
- Pre-vaults (including pre-cutting and jet-grouting):
- Forepoling (injected bars):
- Spiling bolts

Umbrella vault (petroleum tubes): Umbrella vaults are conventionally produced by 1 row (but in certain cases 2 rows) of boreholes armed with high inertia tubes, resting, on the one hand, on the advancement core (part of the ground not yet excavated at the front) and on the other hand, on a rigid support, placed behind the face. The operating mode is essentially that of a set of beams working in flexion with respect to radial pressures.

Figure 10-2 : Tunnel Descendant Ouest de Monaco (AFTES GT7)

Pre-vaults: (include: Jet grouting and pre-cutting): Pre-vaults are made, either by mechanical pre-cutting using a shearer/cutter and filling of the soil trench with sprayed concrete, which can be fiberized, or with the jet-grouting method, by a replacement of the ground by using a cement grout at high pressure, forming contiguous columns of "soil-cement". The operating mode of the pre-vaults is essentially of a vault stressed in orthoradial compression at the periphery of the section. Particular attention must be paid to the puncture resistance of the ground under the side wall of the pre-vaults.

Figure 10-3 : PERFOREX method (source : Insa Lyon, ENTPE, France)

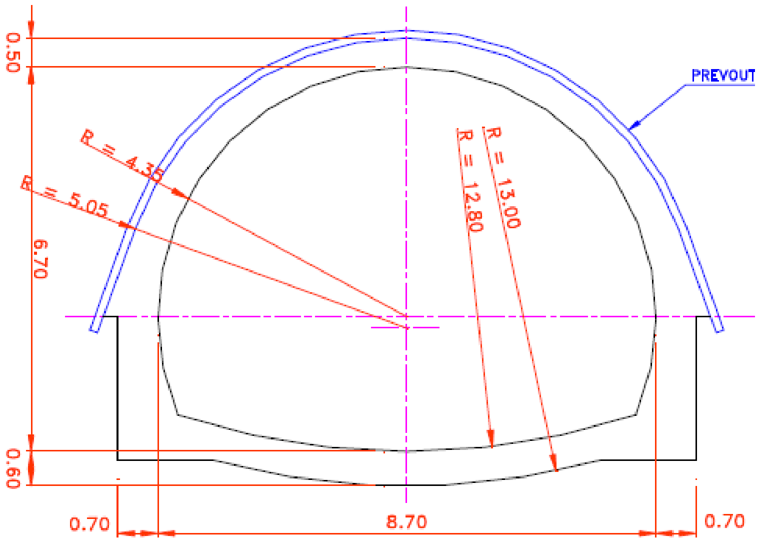


Figure 10-4 : Pre-vaults (PERFOREX method) Tunnel de Fontenay (France)

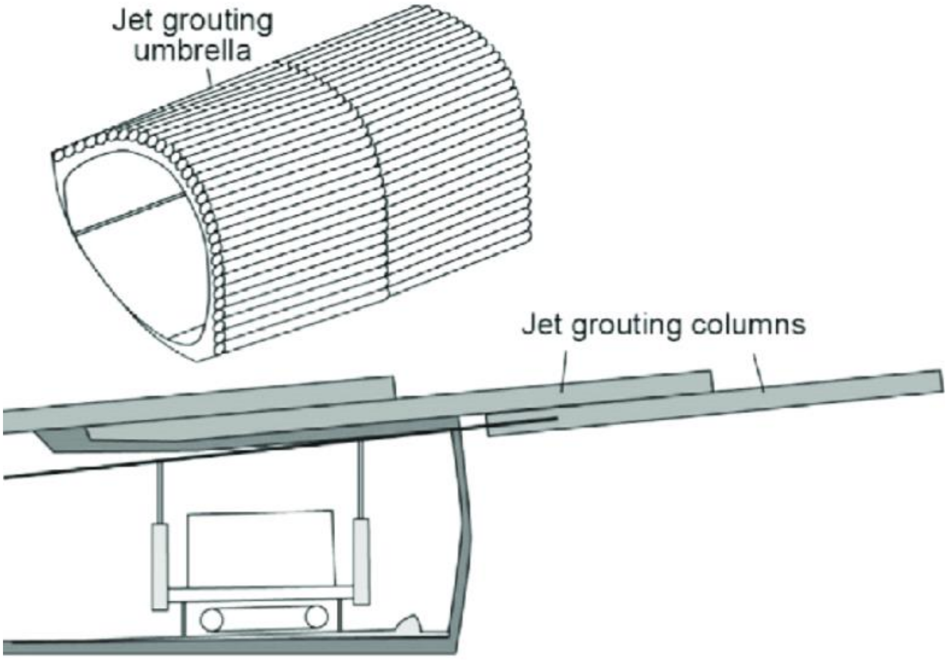


Figure 10-5 : Reinforcement of ground in a tunnel with subhorizontal jet grouting umbrellas (source ResearchGate)

Figure 10-6 : Sub-horizontal jet grouting (source ARGE Girsbergtunnel)

- Forepoling (injected bars):

The forepoling (injected bars) is a lightened variant of the umbrella vault, in which the tubes are replaced by bars of shorter length and capacity, generally of the “injected self-drilling bolt” type.

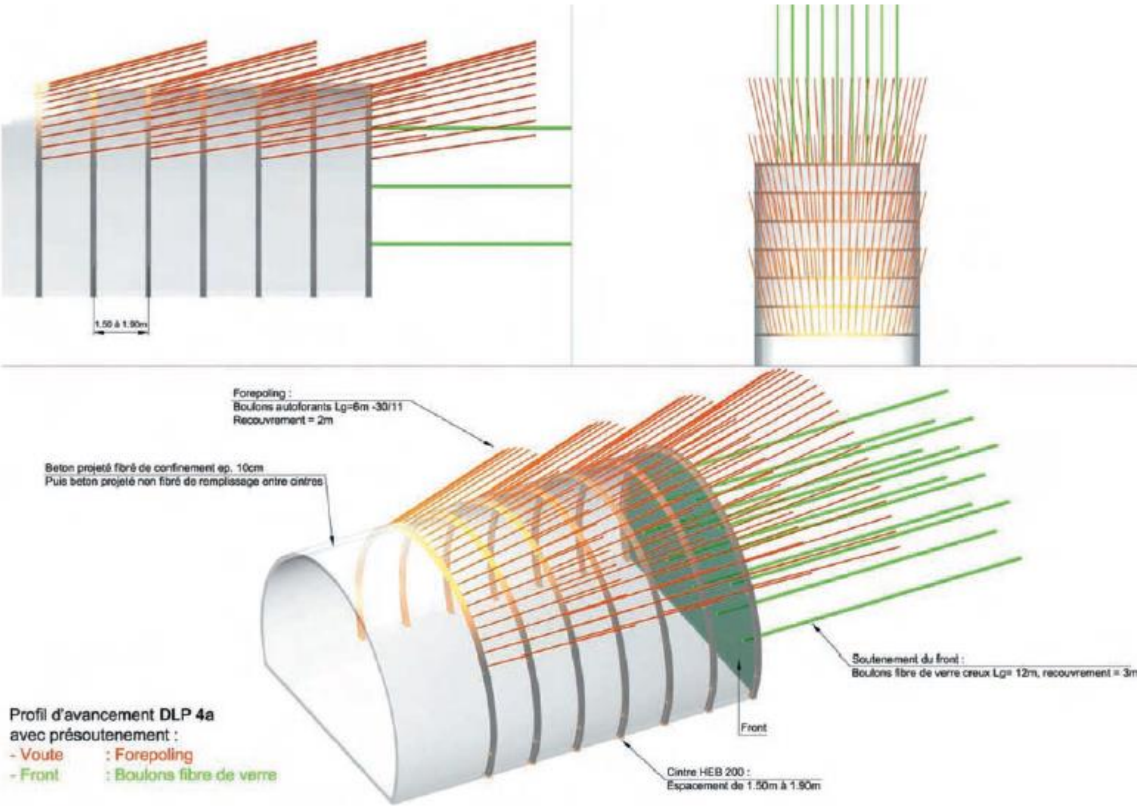


Figure 10-7 : 3D View of forepoling. Descenderie de la Praz (TOS 207, 2007)

Figure 10-8 : Conventional excavation with forepoling (courtesy Geodata)

- **Spiling bolts.** These bolts are drilled along the tunnel perimeter in the direction of the tunnel axis. They are typically 20 – 25 meter long. This rock support is applied where the rock conditions are poor. The spiling bolts works as permanent support too. Then they are fixed to the rock surface by steel straps or fixed to arcs/sprayed ribs.

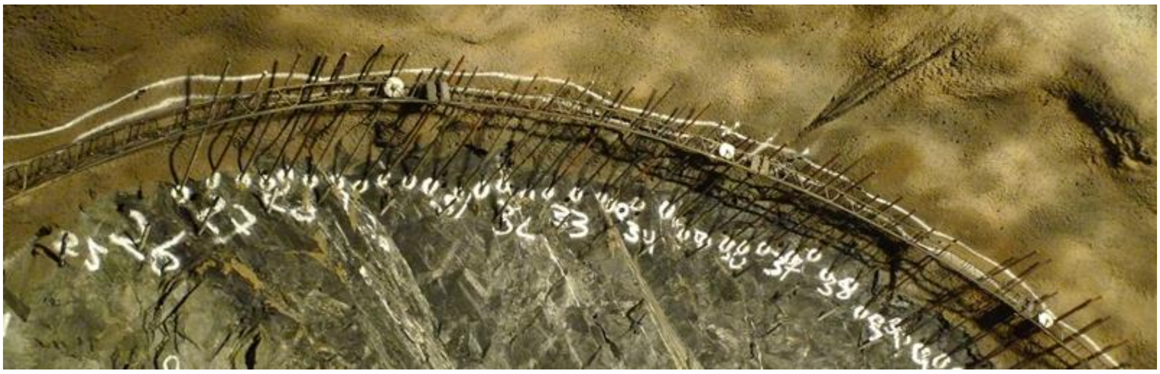


Figure 10-9 : Spiling bolts in Løren tunnel, Norway

The ***geometry representation*** of the spiling bolts could be 3D-representation of the bolts, the spiling bolt area draped on the tunnel rock surface or a schema representation of the bolted area in an unfolded tunnel perspective, called developed geometry.

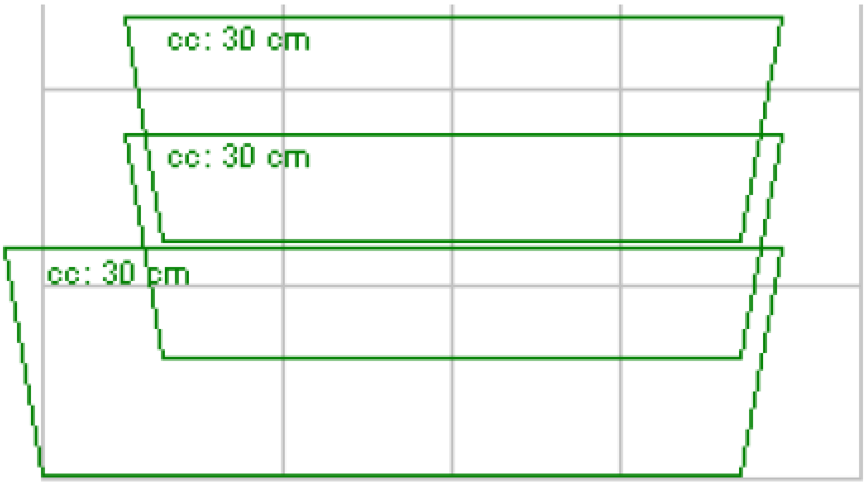


Figure 10-10 : Spiling bolts shown in a schema in unfolded perspective in Novapoint Tunnel

Face support:

The most commonly used support measures at face for conventional tunneling are:

- Jet grouting columns
- Glass fiber bolts
- Injection

Jet grouting columns: Depending on the soil conditions, the consolidation effect may be improved by jet grouted columns executed inside the section to reinforce the tunnel's nucleus, or by means of horizontal drains drilled at the bottom or around the section. The technique is similar to the umbrella vault described above and supplemented with jet grouting in the face area.

Jet grouting is a technique where a high-pressure injection of mortar, with or without other accompanying fluids (water, air), impacts the ground in a borehole. In most cases the original ground is thus eroded, mixed with the mortar and, in fluid form, partly evacuated to the surface (resulting on what is called "spoil"). The remaining soil-cement mixture sets "in situ", resulting on a stiffer, stronger, more impermeable and less ductile material than the original soil. The injection equipment is displaced along the borehole, thus creating a body of treated soil of columnar shape. Several such injections are combined to create the desired shape of treated soil: slabs, fiberglass, arches and walls are common examples.

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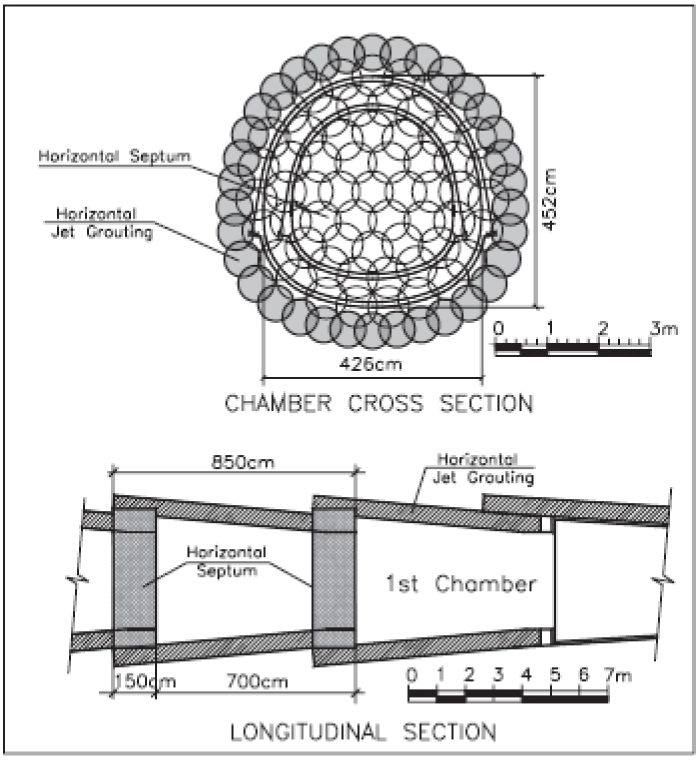


Figure 10-11 : Treatment scheme with full section septum
Source: Geotechnical Aspects of Underground Construction in Soft Ground – Ng, Huang & Liu (eds) © 2009 Taylor & Francis Group, London, ISBN 978-0-415-48475-6

- **Glass fiber bolts**: Glass fiber bolts are used to anticipate a deformation of the working face. The bolts are positioned perpendicular to the face. The resumption of tunneling in the bolted face requires the use of easily destructible bolts. These are generally in fiberglass and sealed over their entire length using cement grout. For geotechnical and stress reasons, these are generally very long bolts: 1,5 to 2 times the diameter of the excavation. As the works progress, the bolts are installed in such a manner as to maintain an overlap over approximately a third of their length.

Glass fiber bolts can be self-drilling, their main advantages are they are injectable, lightweight, do no suffer from corrosion, are easily destructible and therefore will adapted for temporary supports in areas that will subsequently be excavated.

Figure 10-12 : Sappanico Tunnel, Italy (source TES N°249, Juin/May 2015)

- **Injection.** The injection for consolidation and / or sealing injections can be carried out by impregnation, by breakdown or by repressing the ground with a cement grout under pressure.

- The nature of the grout depends on the nature of the ground to be injected: cement grout, or micro-cement, silicate gel or acrylic resins for the finest grounds. It is also used the swelling power of aqua-reactive resins (polyurethane) to fill voids or stop water inflows.

- Injections have been used extensively in the past to consolidate the soil, especially in urban tunnels.

The ***geometry representation*** of the injection could be modelled as a 3D-representation of the whole surface with area, length or a schema representation of the injection in a tunnel perspective

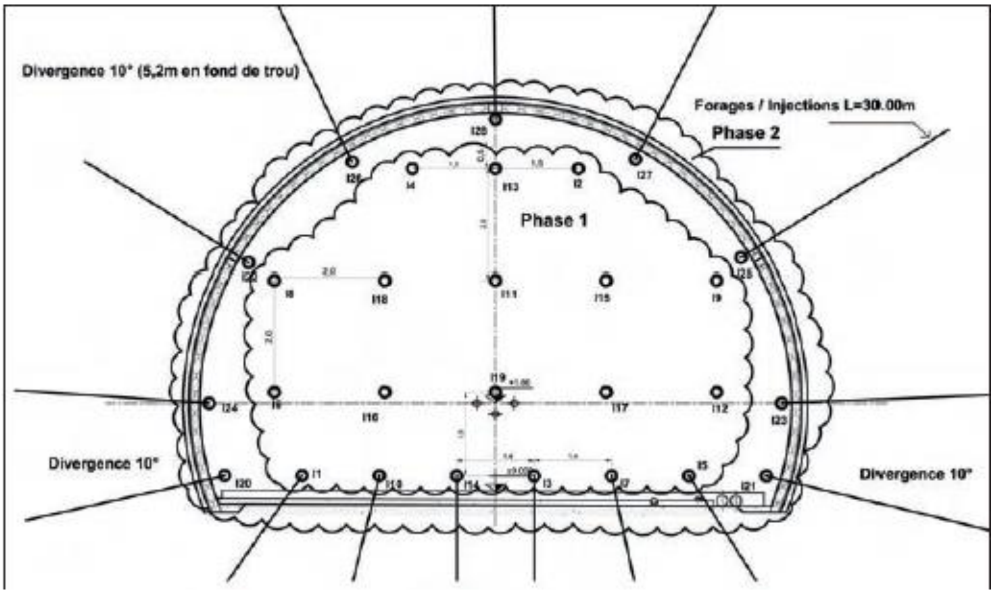
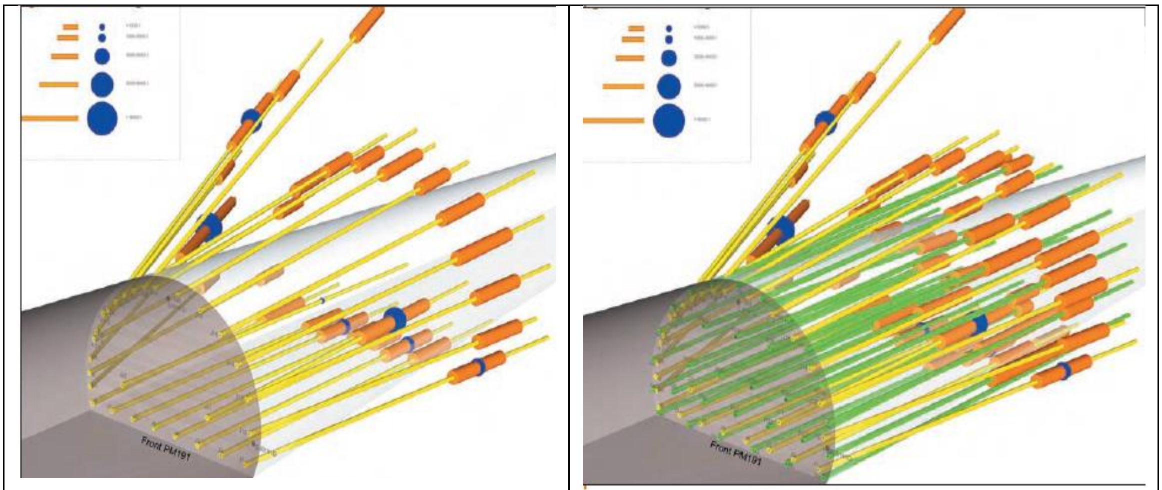


Figure 10-13 : Injection layout (Descenderie de la Praz (TOS 207, 2007)



Injection Phase 1	Injection Phase 2

Figure 10-14 : Descenderie de la Praz (TOS 207, 2007)

Temporary/permanent support:

We will talk here about the most usual supports, namely:

- Support bolts and anchors
- Shotcrete in the vault area or in the invert
  Casted inner lining
- Arches/Sprayed ribs/Lattice girders
- Bullflex
- Steel straps
- Wire Mesh
- Underpinning of arch footings

Several types of support can be used simultaneously on the same time. For instance, shotcrete is often associated with bolting, and that heavy hangers and shotcrete can be combined with pre-supports such as umbrella vaults, front bolting, threading bars, divergent bolts, etc.

- **Support bolts.** These bolts are drilled radially into the ground to prevent rock/soil blocks from falling into the tunnel. The bolts are provided with different anchor types and fastening mechanisms **Error! Reference source not found.** :
    - If needed, local anchor bolts (end-anchor bolts etc.)
    - Distributed anchor bolts:
        - Mortar sealing
        - Resin sealing
    - Mixed bolts (if needed local anchorage + sealing)
    - Friction bolts,
    - Combination bolts with anchor and grouting,
    - Self-drilling bolts:
        - Grass fiber bolts
        - Steel bolts,
        - Self-drilling friction bolts
    - Carbon bolts.

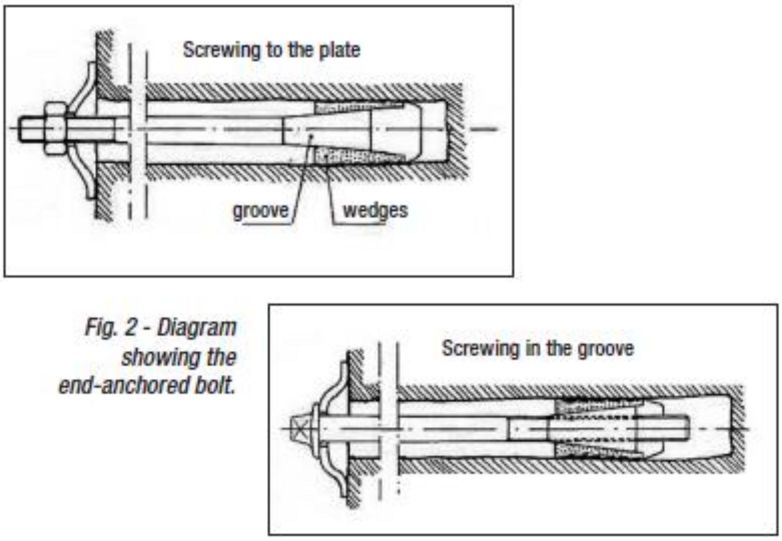


Figure 10-15 : Support bolts

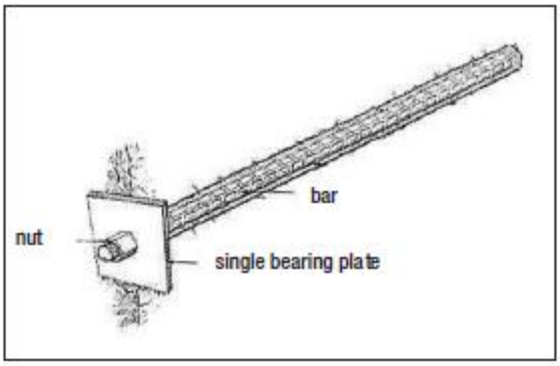


Fig. 3 - Distributed anchor bolt diagram.

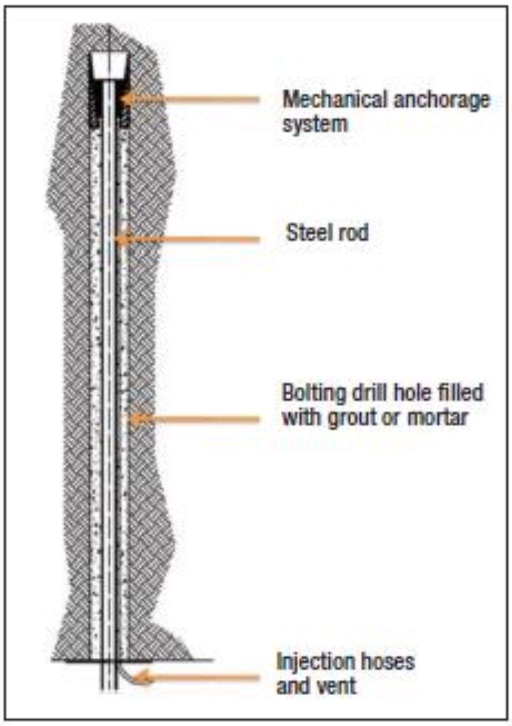


Figure 10-16 : Mixed bolts (AFTES, 2014) [9]

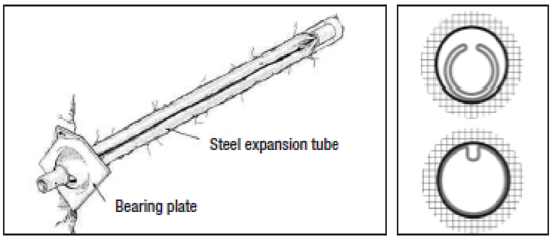


Fig. 7 - Diagram of a Swellex® type bolt.

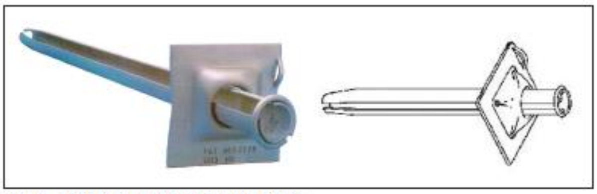


Fig. 8 - Diagram of a Split Set® type bolt.

Figure 10-17 : Friction bolts (AFTES, 2014) [9]

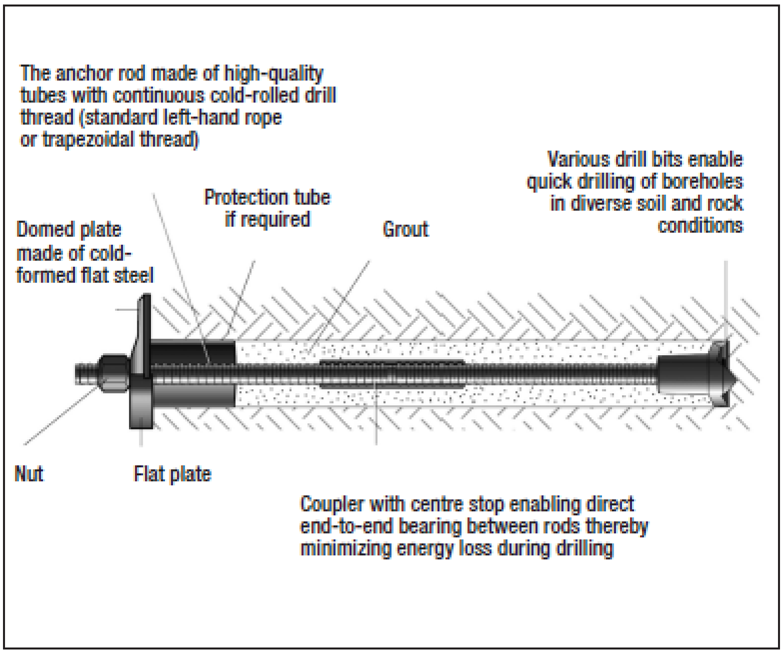


Fig. 4 - Diagram of a self-drilling bolt, type MINOVA SDA®.

A plate is attached to the bolts on the tunnel end of the bolts. The bolts are used both in the tunnel walls and in the roof. Support bolts work as permanent support too.

Figure 10-18 : Self driving bolts (AFTES, 2014) [9]

Figure 10-19 : Anchor bolts in Løren Tunnel, Norway

The ***geometry representation*** of the anchor bolts can be a 3D-representation of each bolt, the bolted area draped on the tunnel rock surface or a schema representation of the bolted area in an unfolded tunnel perspective, called developed geometry.

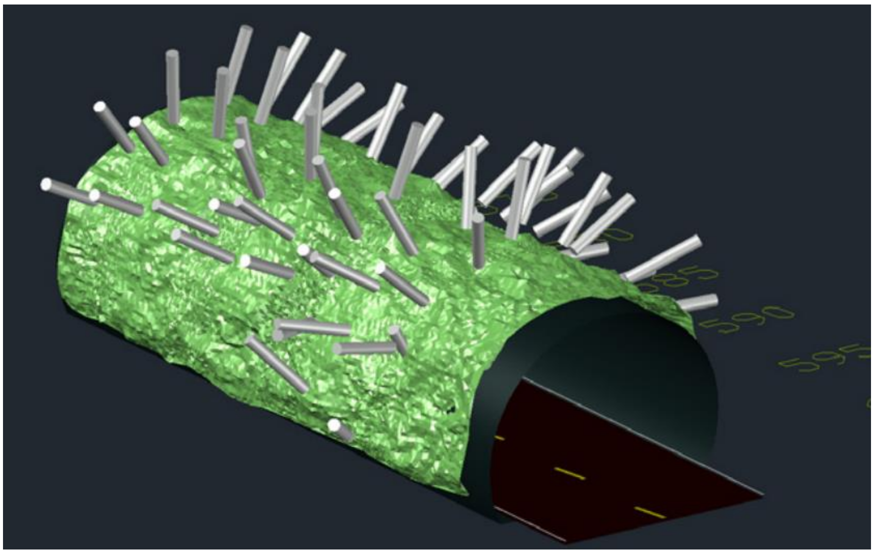


Figure 10-20 : 3D-bolts in Bever Team Online

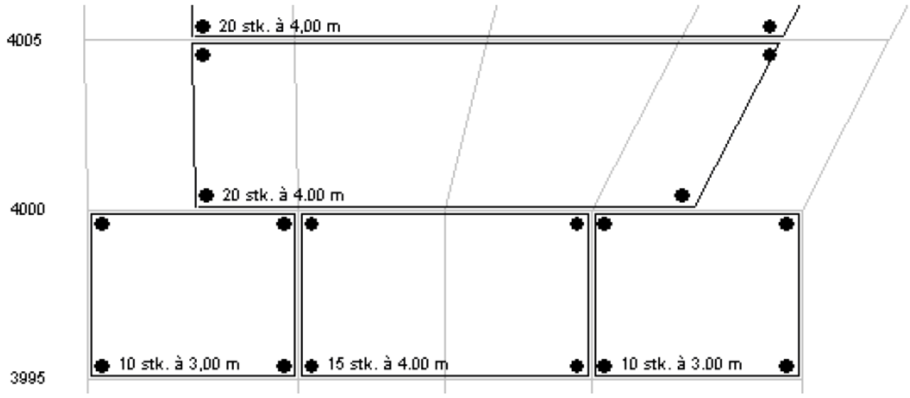


Figure 10-21 : Bolted areas shown in a schema in unfolded perspective in Novapoint® Tunnel

- **Shotcrete.** Shotcrete is often sprayed onto the rock surface immediately after a blast. This is done to secure the working environment. Shotcrete can be applied in several layers behind face as well for permanent support and for smoothening the rock surface before a membrane is applied as a part of casted inner lining e.g. The shotcrete can be wet mixed as in conventional concrete, or delivered as a dry mix in bags, with water added at the nozzle. The shotcrete sometimes can have conventional mesh reinforcement or contain fibers made of steel or polypropylene.

Figure 10-22 : Shotcrete work at face in a Norwegian tunnel.

The ***geometry representation*** of the shotcrete could be modeled as a 3D-representation of the shotcrete surface with thickness, the shotcrete area draped on the tunnel rock surface or a schema representation of the shotcrete area in an unfolded tunnel perspective, called developed geometry.

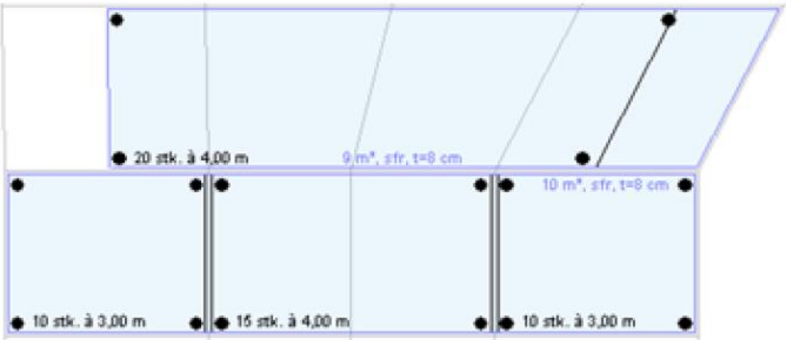


Figure 10-23 : Shotcrete areas (blue) shown together with bolts in an unfolded perspective in Novapoint Tunnel


Figure 10-24 : Mesh reinforcement (source ARGE Girsbergtunnel)


Figure 10-25 : Lattice girders and shotcrete support (source ARGE Girsbergtunnel)

- **Temporary inverted arch to top heading.** Generally, a temporary inverted arch closing the invert of the heading by shotcreting can stabilise the arch footings and reduce the associated ground loosening (caused by the bearing capacity of ground at the footing of supports being insufficient).

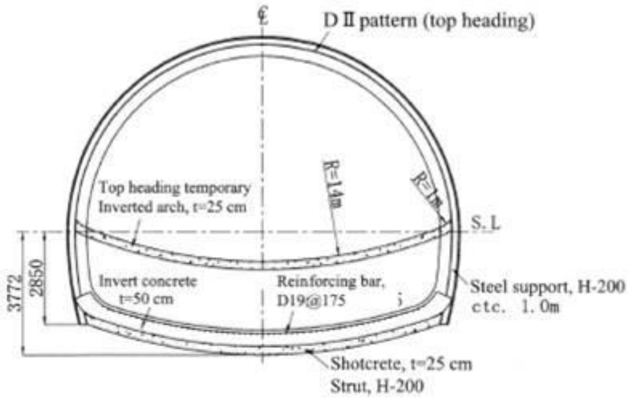


Fig. C5.8 Example of top heading temporary inverted arch

Figure 10-26 : source : Standard specifications for tunneling-2016: Mountain Tunnels, Japan Society of Civil Engineers

- **Cast in situ inner lining as support.** Casted inner lining is the strongest support measure for conventional tunnelling. The lining is often casted with special designed wagons including scaffolding, formwork and casting equipment. A waterproof membrane is applied between the casted lining and the rock surface. The rock surface is often smoothed with shotcrete first to prevent damages on the membrane. In many tunnels the inner lining is reinforced. Cast linings are generally used as permanent linings.

Figure 10-27 : Wagon for casted inner lining, Knappe Tunnel, Norway

The ***geometry representation*** of the casted inner lining could be 3D-representation of the lining including the lining thickness and maybe even the reinforcement or it could be represented as lining draped on the tunnel rock surface or a schema representation of the ling in an unfolded tunnel perspective, called developed geometry.

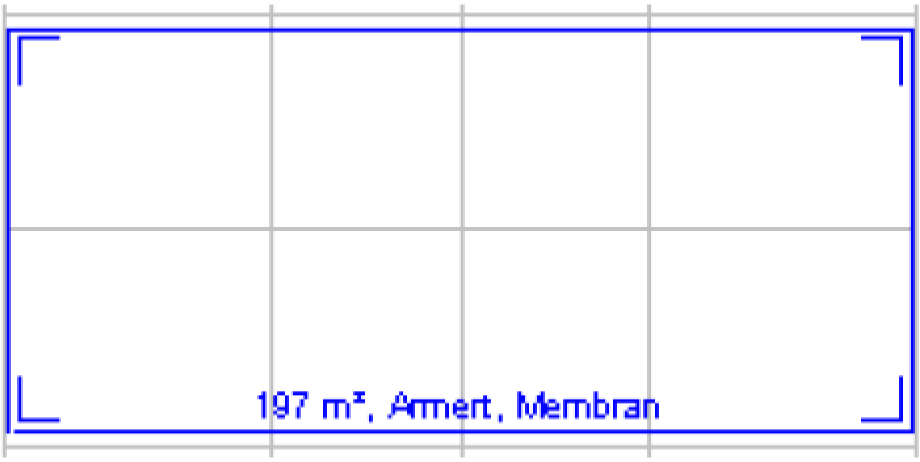


Figure 10-28 : Casted inner lining shown in a schema in unfolded perspective in Novapoint Tunnel

- **Arches / sprayed ribs.** A large number of different categories of arches can be distinguished according to the type of material of which they are made (wood, metal or concrete) or how their components are assembled. We can distinguish:
    - Wooden arches
    - Heavy metal arches: these are generally used as supporting or reinforcing arches.
        - Singles shapes: generally, standard commercial shapes are used: IPN, IPE, HEA or HEB.
        - Paired shapes
        - Lattice arches: there are many types of lattice arch made from commercially available shapes.
        - Telescoping arches
    - Lightweight metal arches: these arches have a limited bearing capacity and are highly deformable.
        - Sliding arches: in the case of sliding arches, deformability results from the way the element of a given arch are assembled, which allows controlled sliding of the metallic shapes against one another.
        - Arches made of lightweight shapes or rails
        - Arches made of folded sheet or sheet framing
    - Concrete arches
        - Arches with reticulated reinforcements: reinforcements bars formed with shotcrete sprayed to coat the whole skeleton.
        - Precast reinforced-concrete arches

* **Spayed ribs**: reinforcement cages or steel profiles are shaped as arcs along the rock perimeter of the tunnel. They are mounted to the rock surface by bolts and often sprayed with shotcrete. They sometimes work together with spiling bolts e.g. to form a supporting "cage" for the tunnel.

Figure 10-29 : Arches applied in the 39 Svegatjørn - Rådal project, Norway

The ***geometry representation*** of the arcs/ sprayed ribs could be 3D-representation of the arcs, the arcs draped on the tunnel rock surface or a schema representation of the arcs in an unfolded tunnel perspective, called developed geometry.

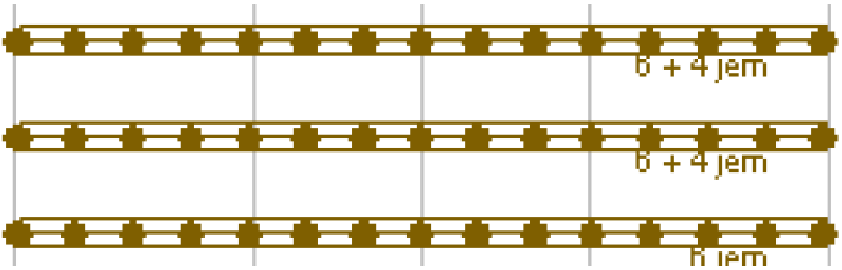


Figure 10-30 : Sprayed ribs shown in a schema in unfolded perspective in Novapoint Tunnel

* **Bullflex**: The BULLFLEX system has been developed as a special supporting system for underground excavation. It consists of patented textile groutable hoses made of high-strength fabric, which are subsequently filled with cement-bonded construction material, featuring an excellent load-bearing capacity. All system components are light-weight, easy to transport and to install, and are available in different dimensions. It can be used as roof support back filling, as support pillars etc.

Roof Support Backfilling

Support Pillars: Hard Rock

Figure 10-31 : Source https://www.dsitunneling.com/fileadmin/downloads/dsi-underground-canada/dsi-underground-systems-bullflex-system-us.pdf

- **Steel straps.** Steel straps are mounted to the rock surface witht bolts to prevent blocks from falling into the tunnel. They sometimes work in combination with spiling bolts as a fixation of these to the rock surface.

Figure 10-32 : Steel straps in Løren tunnel, Norway

The ***geometry representation*** of steel straps could straps draped on the tunnel rock surface or a schema representation of the straps in an unfolded tunnel perspective, called developed geometry

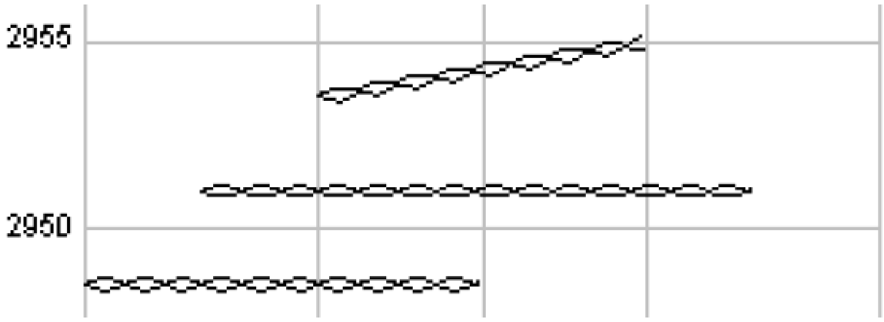


Figure 10-33 : Steel straps shown in a schema in unfolded perspective in Novapoint Tunnel

- **Wire mesh.** Wire mesh is mounted to the rock surface with bolts to prevent blocks from falling into the tunnel.

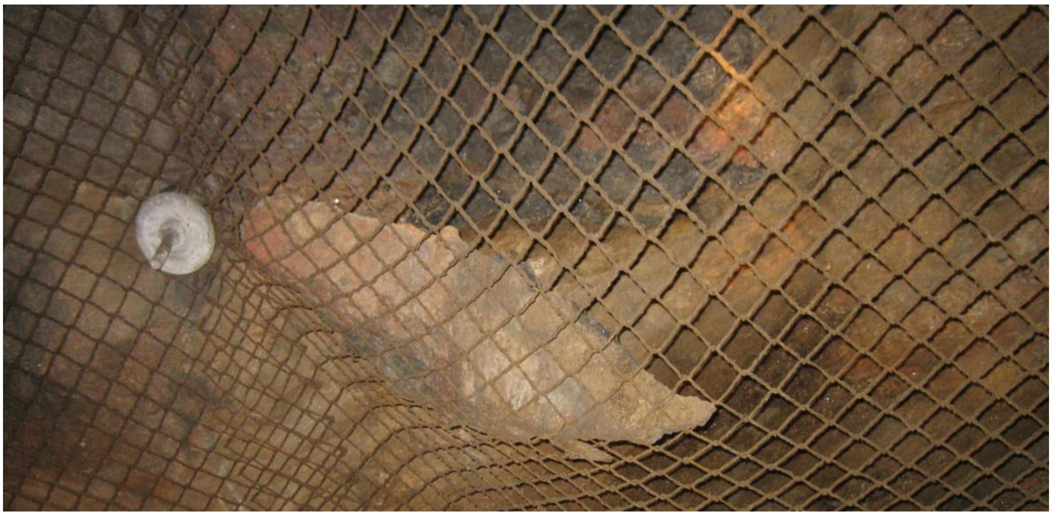


Figure 10-34 : Wire mesh in use in an old Norwegian tunnel

The ***geometry representation*** of wire mesh could be an area representation of the mesh on the tunnel surface or the mesh shown in a schema in an unfolded tunnel perspective, called developed geometry.

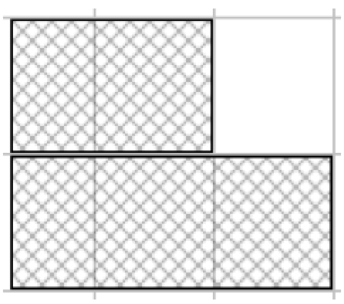


Figure 10-35 : Wire mesh shown in a schema in unfolded perspective in Novapoint Tunnel

- **Foot reinforcement bolting and piling.** Foot reinforcement bolting and piling (installation of downward-facing rock bolts at the footing of supports or small-diameter steel pipes, and jet grouting) are aimed at reducing the stresses in the contact ground of the top heading support and preventing the collapse of the ground during bench excavation and can help protect against damage caused by both foot settlement and the associated ground loosening (caused by the bearing capacity of ground at the footing of supports being insufficient).

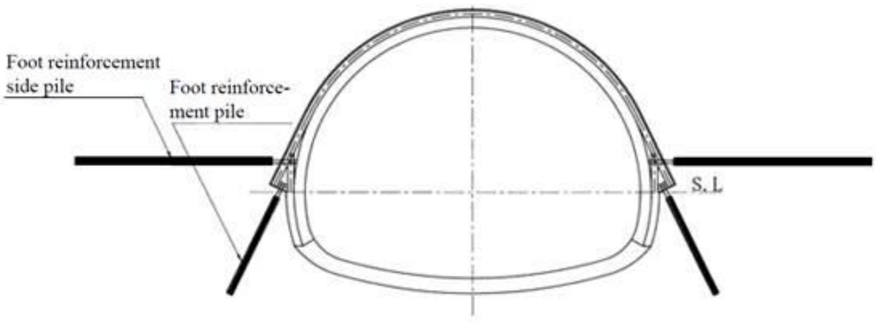


Fig. 6.2.8 Example of reinforcement piles

Figure 10-36 : Standard specifications for tunneling-2016 - Mountain Tunnels, Japan Society of Civil Engineers

Figure 10-37 : Reinforcement work (side pile) *Reinforcement work (foot pile)*

10.1.2 Mechanised tunnelling

In soft ground Mechanised tunnelling, a pressurized shielded TBM machine directly installs an immediately load-bearing segmental lining, without having any temporary support except from face pressure.

If an open gripper TBM is used, temporary support with shotcrete and rock bolts can be provided, using same approach described in previous chapter for conventional tunnelling.

In single/double shield TBMs, no support is needed except in case of shield jamming: in this case, the same approach described in the previous chapter for conventional tunnelling can be adopted.

In Mechanised tunnelling, the lining of tunnels can consist of one layer (single-layer) or two (double layer) or more layered construction.

Single-layer constructions mainly includes tunnels with a single-layer segmental (or extruded) concrete lining. In double-layer construction, the individual layers are constitutionally and functionally separate. The outer lining is installed as the tunnel advances and is designed to provide immediate support for the excavated cavity against the expected ground pressure. There are normally no serviceability requirements and thus no waterproofing requirements. These are complied with for the lifetime of the tunnel by the second inner layer installed as a permanent lining. For tunnels subject to water under pressure, the inner lining is designed to resist the applied water pressure. The inner lining also has to permanently support the ground pressure if the structural stability of the outer lining cannot be guaranteed for the lifetime of the tunnel. The inner lining is discussed in paragraph 9.4.

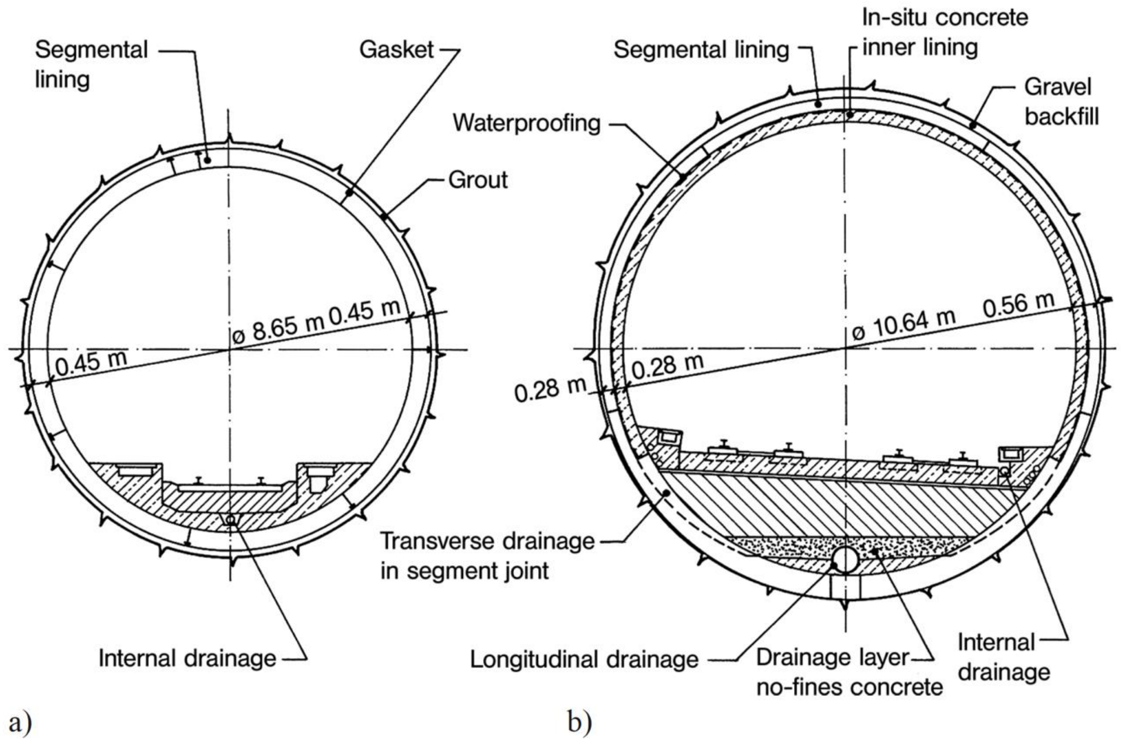


Figure 10-38 - Construction principle of tunnel lining : a) single-layer, b) double-layer (Maidl et al., 2013)

The construction of a segmental lining as the final tunnel support and lining is already common worldwide for pressurised shield tunnelling. Segments are precast elements, which are installed in a ring to serve as tunnel lining. The particular feature of a segment lining is the high degree of jointing, in addition to the segments themselves. The joints can be differentiated into longitudinal joints between the segments in a ring and ring joints between the rings.

The use of segments is essential in TBM tunnelling if the gripping of the machine into the rock mass in order to produce the thrust forces is not possible due to insufficient rock strength. In such cases, the thrust forces are resisted by the already installed lining, which then works as an abutment in the direction of the tunnel axis.

This requires immediately available loadbearing capacity, which cannot be provided by a shotcrete or in-situ concrete lining.

Following figure shows the spectrum of construction possibilities for segments for single- and double-layer construction in tunnelling.

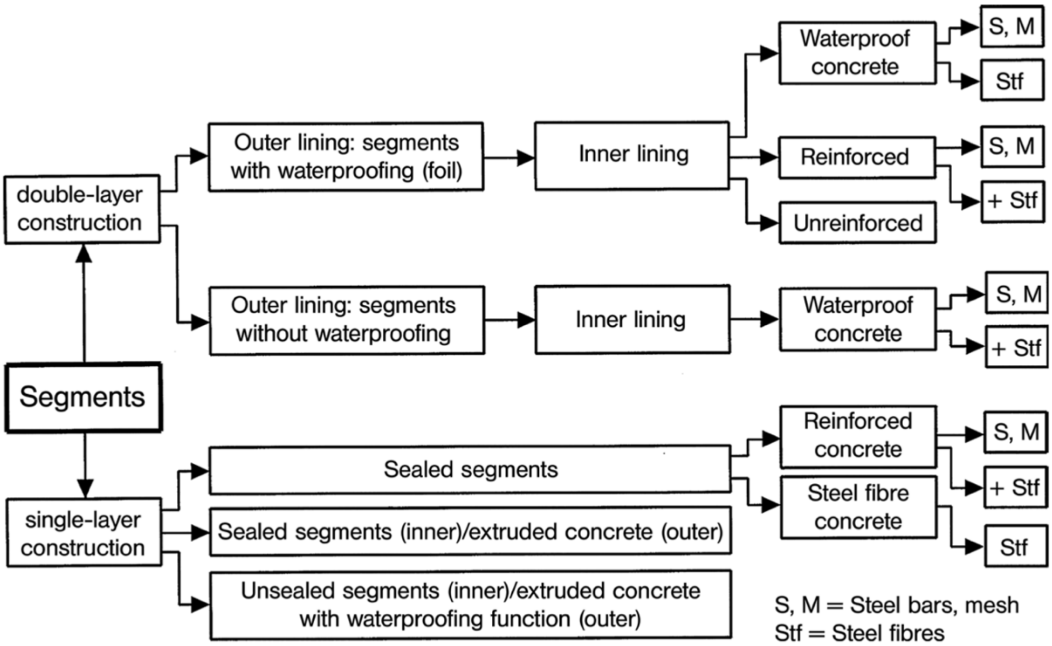


Figure 10-39 : Segments for single- and double-layer construction (Maidl et al., 2013)

Concrete segments are standard today and have mostly superseded steel and cast-iron segments for cost reasons. For further information about the use of steel and cast iron for tunnel linings.

Segments are usually installed using an erector in the protection of the tail skin of the TBM or braced directly against the rock mass behind the shield. In order to ensure that the segment ring remains intact and in compression underneath the shield skin, the individual segments of a single ring are either permanently or temporarily bolted together, as shown in the figure below.

Figure 10-40 : Detailed tunnel lining modelling for a 6+0 segmental ring (courtesy Geodata)

In a subsequent working step, the annular gap remaining between the segment ring and the sides of the excavation is filled or grouted with suitable material through appropriate openings in the segments or through the tail skin.

This limits the loosening of the surrounding ground, enables continuous transfer of the external ground pressure into the lining and provides the bedding required for the stability and structural safety of the tunnel tube.

Figure 10-41 : Tunnel lining, backfilling, internal structures and niches (courtesy Geodata)

Segmental ring system

Different systems exist for tunnel segmental lining rings, these include (according to WG2-ITA):

- parallel rings system
- parallel rings with corrective rings system
- right/left-tapered rings system
- universal rings system

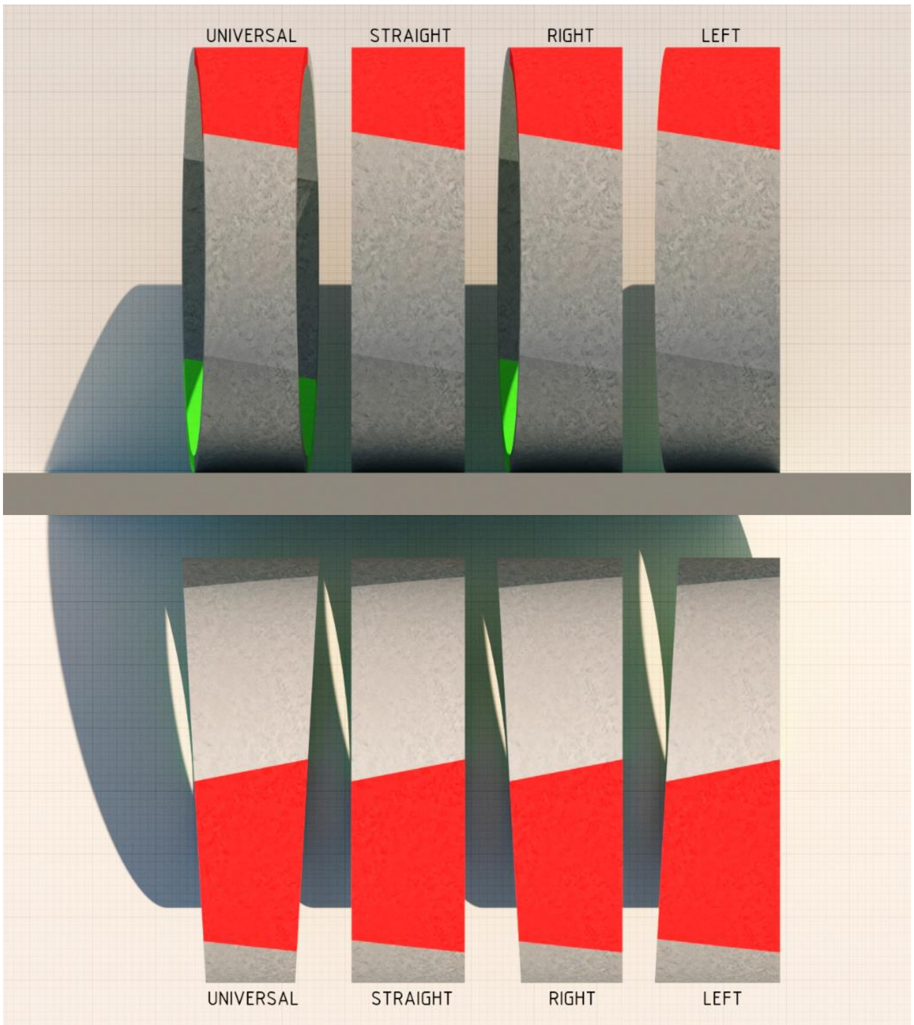


Figure 10-42 : Geometry of the various types of rings (courtesy of Geodata).

Segmental Geometry

The geometry of individual segments can be divided into four main category or systems (according to WG2-ITA):

- Hexagonal (not used so frequently anymore)
- Rectangular
- Trapezoidal
- Rhomboidal

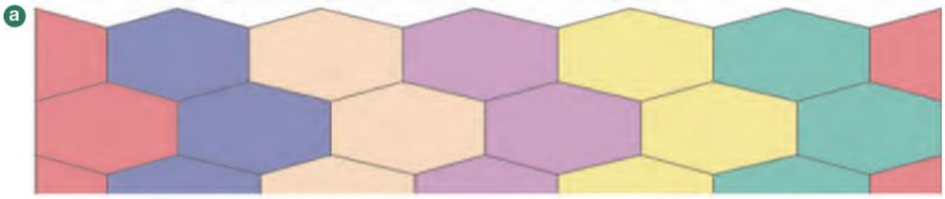


Figure 4a : Hexagonal system

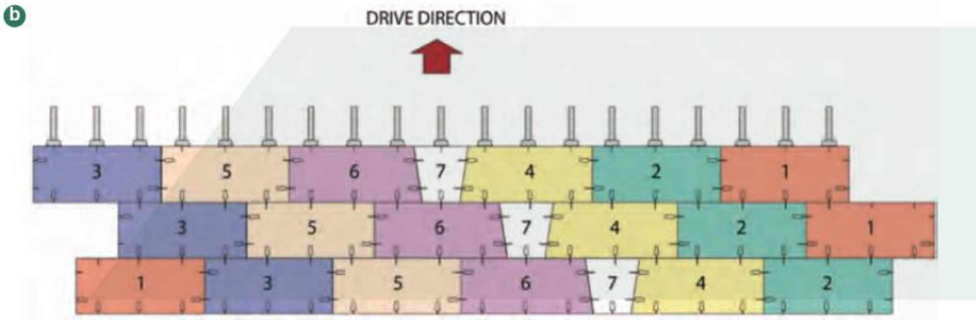


Figure 4b : Rectangular system

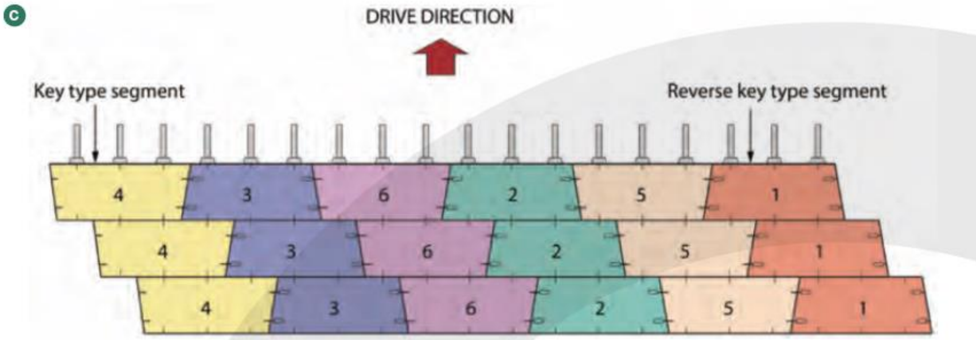


Figure 4c : Trapezoidal system

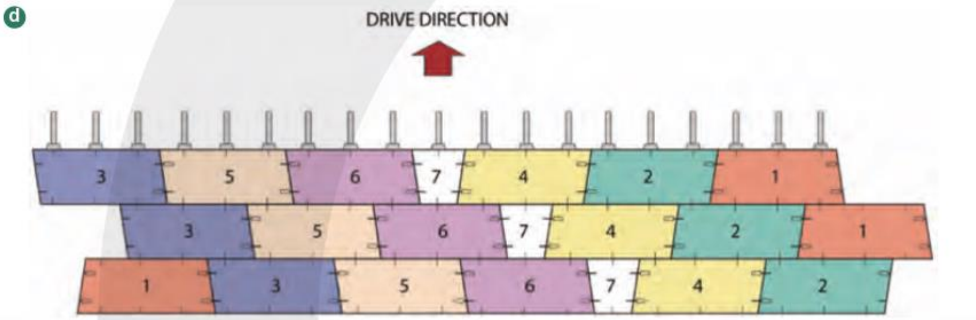


Figure 4d : Rhomboidal system

Figure 10-43 : Geometry of the various types of rings (ITA, 2019).

Geometrical aspects related to segmental lining in Mechanised tunnelling are described in detail in Chapter 6.

In hard rock TBM tunnelling, secondary inner lining can be used for different purposes, from corrosion protection to cut-off performance for water leakage, from uplift prevention to smoothness improvement (in case of hydraulic tunnels).

In this case, characteristics in terms of geometry and semantics are similar to final lining for conventional tunnelling. Temporary support for segmental lining cut can be also modelled, as shown in figure below.

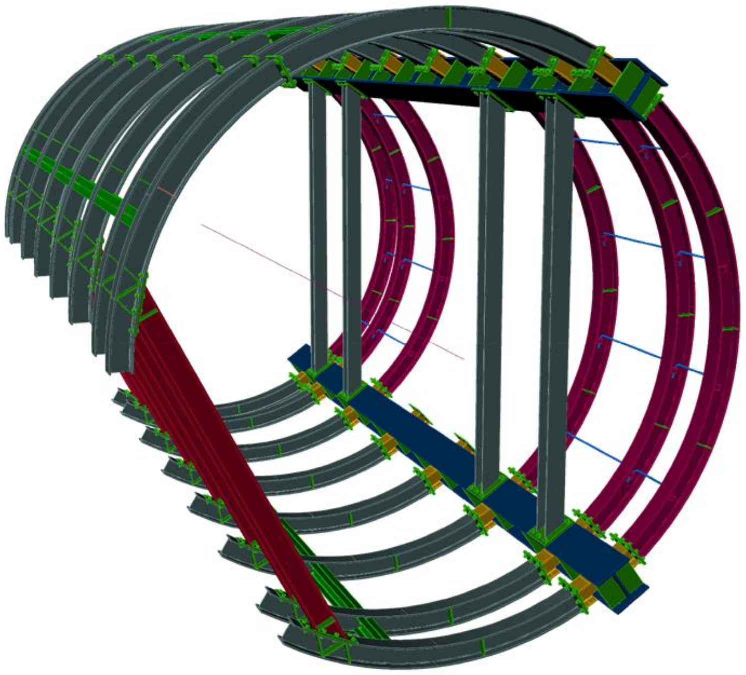


Figure 10-44 : Temporary support for segmental lining cut (courtesy Geodata).

10.1.3 Cut-and-cover tunnelling

Support of cut and cover excavations can range from unsupported open slopes to rigid concrete walls.

Figure 10-45 : Open excavation combined with soil nailing (source Electrowatt Engineering Services)

Open slopes are generally protected against erosion, either with physical measures or vegetation. Care has to be taken with the drainage of open slopes. As the slopes become steeper the most cost effective measure to support the slopes is soil nailing, consisting of mesh, shotcrete and unstressed rock anchors, similar to underground support.

Figure 10-46 : Typical soil nailing support (source Electrowatt Engineering Services)

Similar methods can be used for excavations in rock. See the illustration below where the upper layers are supported with pre-stressed anchors and the lower parts of the wall with shotcrete and unstressed nails.

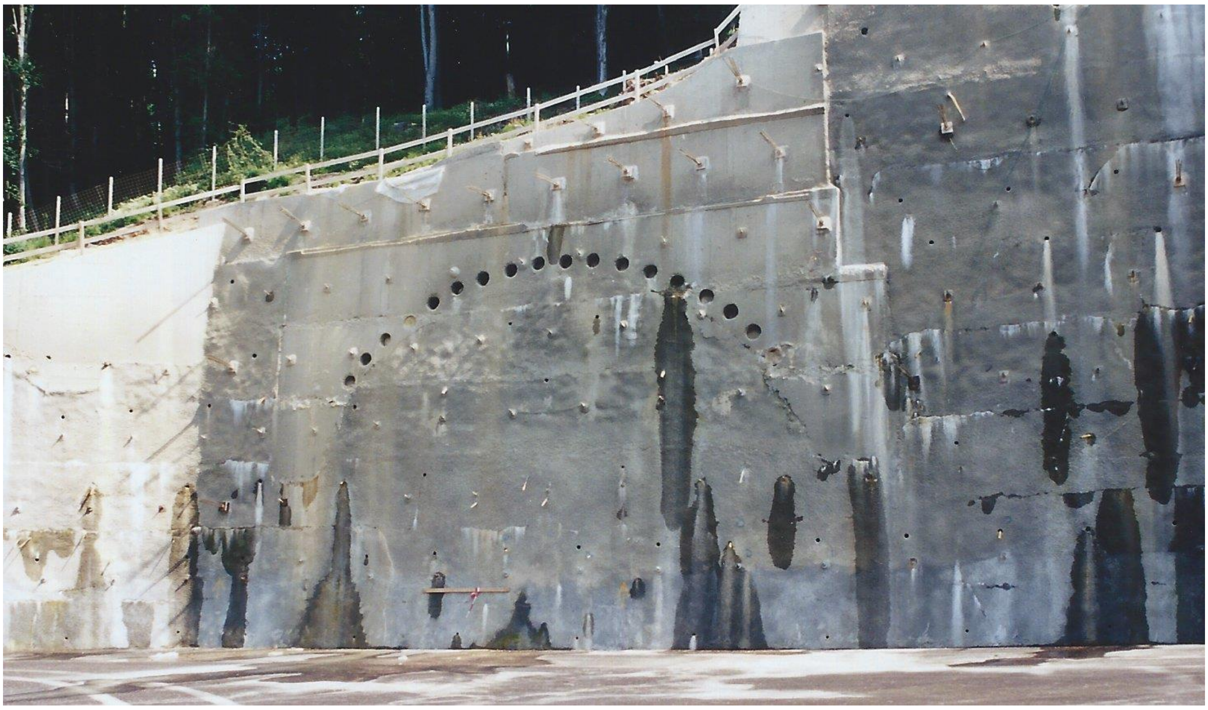


Figure 10-47 : Shotcrete support with pre-stressed anchors in upper strata and unstressed nails in denser soils (source Electrowatt Engineering Services)

The next option in suitable ground is sheet pile walls, either braced or anchored. In dense soils or boulders, pre-boring of the ground may be necessary. See the example below of a braced sheet pile wall for a shallow cut and cover tunnel. Spreader beams are required to distribute the loads.

Figure 10-48 : Braced sheet pile walls (source Electrowatt Engineering Services)

For deeper excavations, the most common systems are bored pile walls or diaphragm walls. The bored piles can be spaced apart or contiguous. The example below shows a spaced bored pile wall with shotcrete in-fill panels. The wall is retained by pre-stressed anchors, with the anchor loads distributed by concrete spreader beams.

Figure 10-49 : Bored pile wall with bracing (source ILF)

Figure 10-50 : Anchored bored pile wall (source ILF)

Walls that must be broken through, for instance with a TBM, can be reinforced with glass fibre reinforcement as shown in the illustration below.


Figure 10-51 : Glass fibre reinforcement cage (Extension line 12, Paris Metro, TES N°249, Juin.May 2015)

10.2 Ground improvement and water control

Ground improvement measures are carried out by drilling, generally in front of/and around the tunnel face. They are intended to reduce the permeability of the ground ("sealing"), or to improve its mechanical characteristics ("consolidation"), the two objectives can be sought at the same time.

The ground improvement can also consist of carrying out a simple treatment of filling cavities and voids (in the case of a karst in the rock ground, for example) located at the advancement of the section or on the perimeter of the excavation, in order to reconstitute a solid mass which mechanical properties are compatible with the excavation method.

10.2.1 Conventional tunnelling

The most commonly used technics for ground improvement are:

- Drainage
- Injections (this method is explained before)
- Jet-grouting (this method is explained before)
- Freezing

From a geometrical perspective, ground improvement could be modelled with the same strategy (main parameters will be the radius of influence, length, angle) while from informative point of view they would be different.

- **Drainage.** Drainage during excavation can meet several objectives, depending on the hydrogeological context:
    - Lower the water pressure in the ground, in order to avoid breaking up of fractures and loose materials.
    - Collect the water inflows from the massif in order to limit surface runoff from the tunnel face and facing.
    - Consolidate the massif by lowering the pore pressure in loose granular soils and very fractured rock masses.

- **Freezing.** Artificial ground freezing is used for waterproofing and/or temporary consolidation to support the excavation of underground structures under water in loose soils or in jointed rocks. It is suitable for any type of soil and fractured rock. Most used technologies are either direct method (liquid nitrogen) or indirect method (brine).

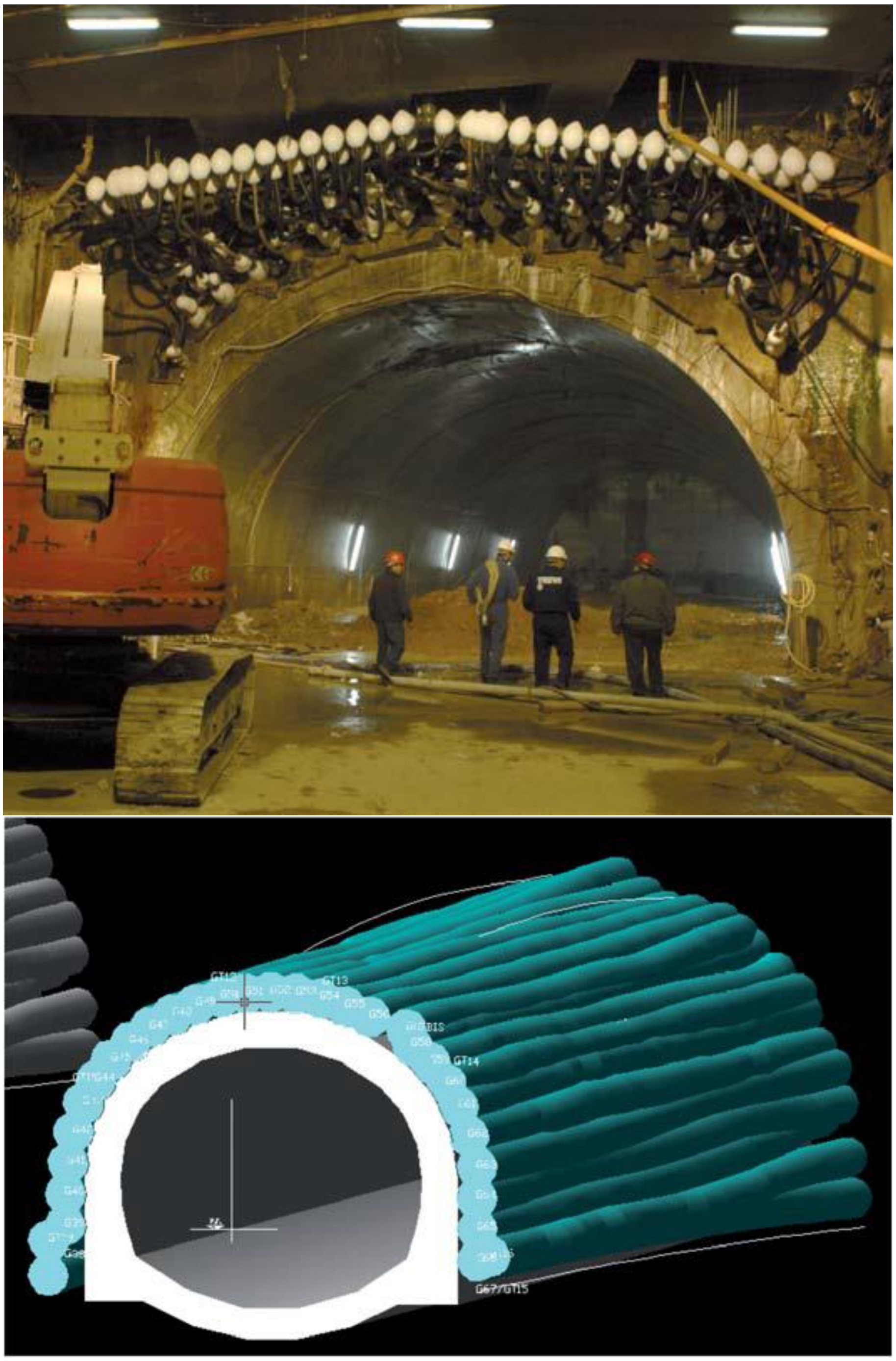
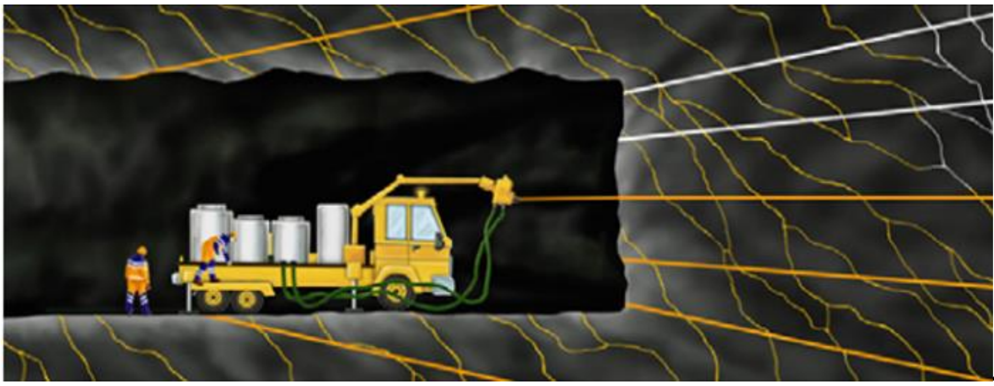


Figure 10-52 : Ground freezing in traditional tunneling for Metro Naples (Italy), courtesy Trevi

Figure 10-53 : Ground freezing in mechanised tunnelling in Slovacki Tunnel (Poland), courtesy Rodio

- **Pre-face water control:** The most commonly used pre-face waterproofing measures for conventional tunnelling are:
    - **Front drainage:** Drainage at advancement is achieved by holes of drilled drains, on the periphery of the tunnel face or across that, generally divergent and inclined, in successive overlaps, of an effective length comparable to the diameter of the excavation.
    - **Pre/post-grouting/ front injection**. Long holes are drilled slightly outwards along the perimeter of the tunnel in front of the tunnel in the direction of the tunnel axis. Typically 20–25 meter long holes. A cement based slurry is then pressed into these holes to fill all the cracks in the rock. Both systems with high pressure and lower pressure are in use.



A

Figure 10-54 : Principle sketch showing pre-grouting work (NTS)

The ***geometry representation of*** pre-grouting/ front injection could be a 3D-representation of the bore holes, or maybe a 3D-representation of the injection fans, or the grouting shown with arrow symbols e.g. in a schema in an unfolded tunnel perspective.

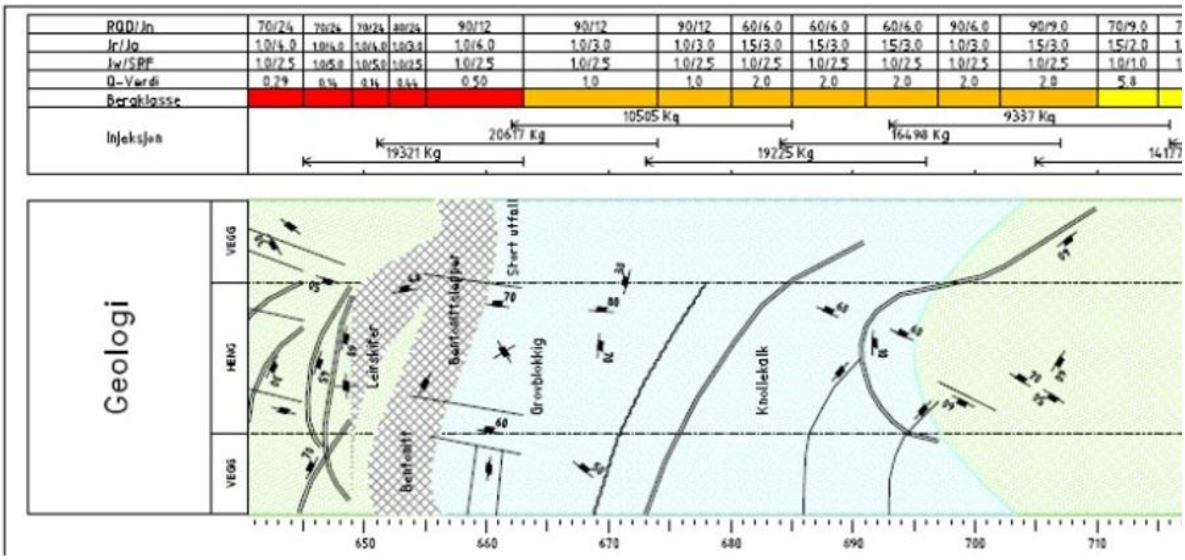


Figure 10-55 : Pre-grouting shown with arrow symbols above the geology in Novapoint Tunnel

- **Front jet grouting:** is described in the paragraph about pre-supporting

10.2.2 Mechanised tunnelling

In soft ground Mechanised tunnelling, pressurized shielded TBM machine installs directly an immediately load-bearing segmental lining. Ground improvement can be used for different purposes:

- Break-in and break-out;
- Excavation of cross-passages, enlargements, niches;
- Maintenance stops.

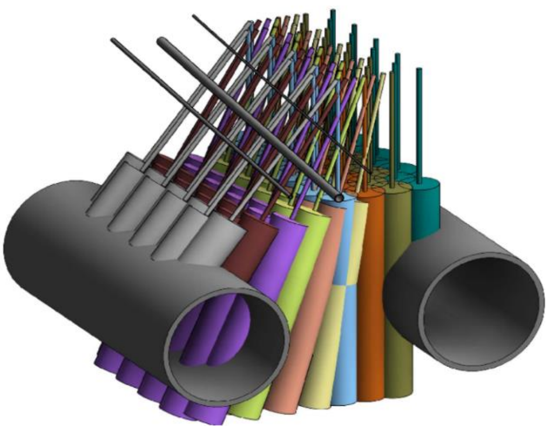


Figure 10-56 : Soil improvement from the surface in mechanised tunnelling (courtesy Geodata).

Ground treatment can be performed from the surface, from segmental lining or from the TBM itself (if designed with predisposition for soil improvement countermeasures).

In case of hard rock TBM tunnelling, ground improvement and drainage can be provided in case of faults crossing or TBM jamming. It can be done from segmental lining or from the machine itself (if designed accordingly), using the same approach described in previous chapter for conventional tunnelling.

10.2.3 Cut and Cover tunnelling

In cut and cover tunnelling, the most common form of ground improvement is the grouting of the tunnel invert to prevent water gradient reduced instability and flows. In addition, compensation grouting around the tunnel to compensate for surface and building settlements due to wall movements is often performed in inner city applications.

10.3 Waterproofing

Various waterproofing methods can be applied between the excavation support and the tunnel lining to limit inflows of water.

10.3.1 Conventional tunnelling

The most commonly used waterproofing measures for conventional tunnelling are:

- **Geomembrane Waterproofing system**. There are many different types of waterproof membranes in use. They are made of different materials. The drainage and/or water protection functionality differ between the different membrane types. Some membranes are mounted on the tunnel walls as “patches”, other are mounted behind different inner linings, like casted inner lining at site e.g.

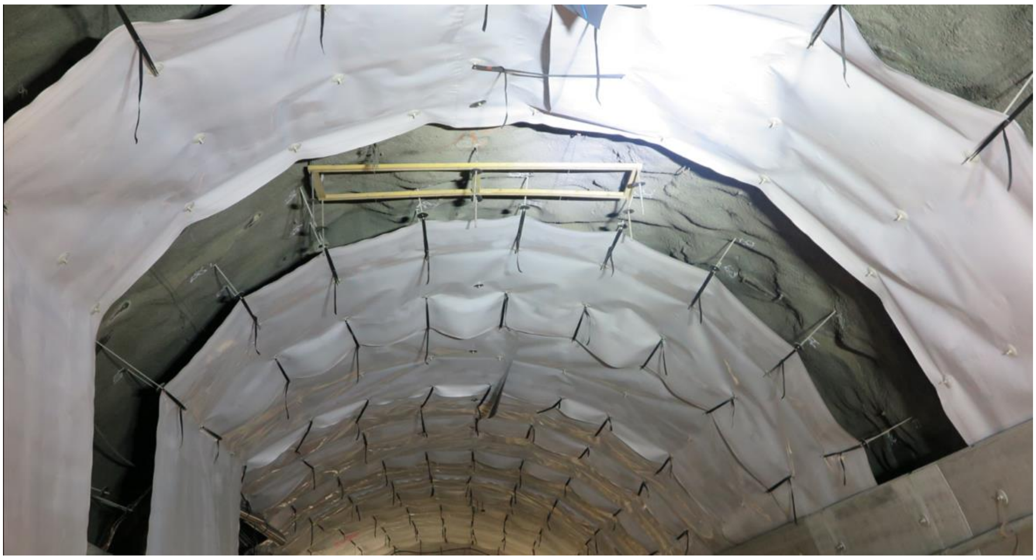


Figure 10-57 : Membrane before shotcrete is applied, Lyshorn tunnel, Norway

The ***geometry representation of*** membrane could be surfaces draped on the tunnel rock surface or the membrane shown in a schema in an unfolded tunnel perspective, called developed geometry.

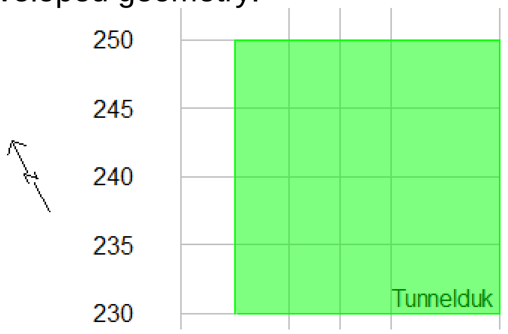


Figure 10-58 : Membrane shown on a schema drawing in Novapoint Tunnel in unfolded perspective.

Figure 10-59 : Membrane in place before cast in-situ concrete lining in main tunnel, (source Electrowatt Engineering Services)

Figure 10-60 : Membrane in place before cast in-situ concrete lining in cross connection, (source Electrowatt Engineering Services)

The other waterproofing techniques are:

- **Liquid sealing systems (SEL):** Reinforced Liquid Watertightness Systems (Système d’Etanchéité Liquide Armé, SEL-A). The reinforcement allows a degree of cracking to be withstood, so it acts an inner, adhesive waterproofing solution. No sooner than 12 hours after the primer applied, the impregnation layer must be applied with a roller. The roll of VP45 glass fabric must be offered up and rolled out along the layer of fresh resin.

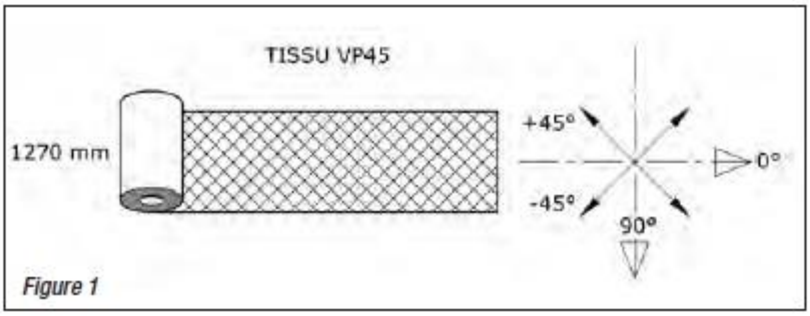


Figure 1

Photo 2 - Pose de l’armature en tissu de verre sur couche d’imprégnation / Installing the glass fabric reinforcement on the impregnation layer.

Figure 10-61 : TOS N°248 (Mars/Avril 2015)

- **Liquid impermeability system (SIL):** Anchored “Shell” type surface drainage solutions, consisting of a drainage mesh covered with a sprayed polymer resin (Liquid waterproofing/impermeability system), a layer of shotcrete and if necessary, an additional passive protection layer.

10.3.2 Mechanised tunnelling

In less critical applications, above the water table or when water pressures are limited, sealing gaskets between the segments can be relied upon to provide adequate water tightness. Otherwise similar methods to conventional tunnels are used.

10.3.3 Cut and cover tunnelling

Various methods are used for waterproofing cut and cover tunnels. The waterproofing can either aim to provide a completely watertight system or just an overhead protection to prevent water dropping on the carriageway, collecting the water at the tunnel walls and allowing it to drain freely. The most common examples used in cut and cover tunnelling are:

- Watertight concrete. The concrete and reinforcement are designed to keep cracking and crack widths to a minimum. This can be either by detailing the reinforcement and it's spacing to minimize cracking or by providing joints at predetermined locations and using targeted injection grouting to seal these cracks, or a combination of both.
- Flexible bitumen or polymer-bitumen membranes.
- Flexible plastic (PE/PVC) membranes
- Clay/bentonite panels
- Liquid membranes

Care must be taken to protect the waterproofing, particularly during filling operations. This is normally done with a protective layer of plastic membrane (often recycled plastic) or with shotcrete or concrete protection layers.

Figure 10-62 : PVC membrane waterproofing for cut and cover tunnel with recycled plastic protection membrane (source ARGE Girsbergtunnel).

10.4 Tunnel Linings

This section deals with predominantly final linings of tunnels, the inner surface that is visible to tunnel users. The actual requirements vary substantially between nations and it is becoming more common to rely on a single support as a final lining. However particularly in road tunnels a secondary lining is often used.

10.4.1 Conventional Tunnelling

For conventional tunnelling the inner lining is typically built up:

- Shotcrete with reinforcement and polyethylene (PE) isolation
- Concrete wall elements and/or roof elements
- Cast in situ inner lining

<u>Spray concrete with reinforcement net and PE-isolation</u>

The drawing below shows a Norwegian tunnel inner lining built up of spray concrete with reinforcement net and PE-isolation. Bolts are used to mount the inner lining in the specified distance from the rock surface.

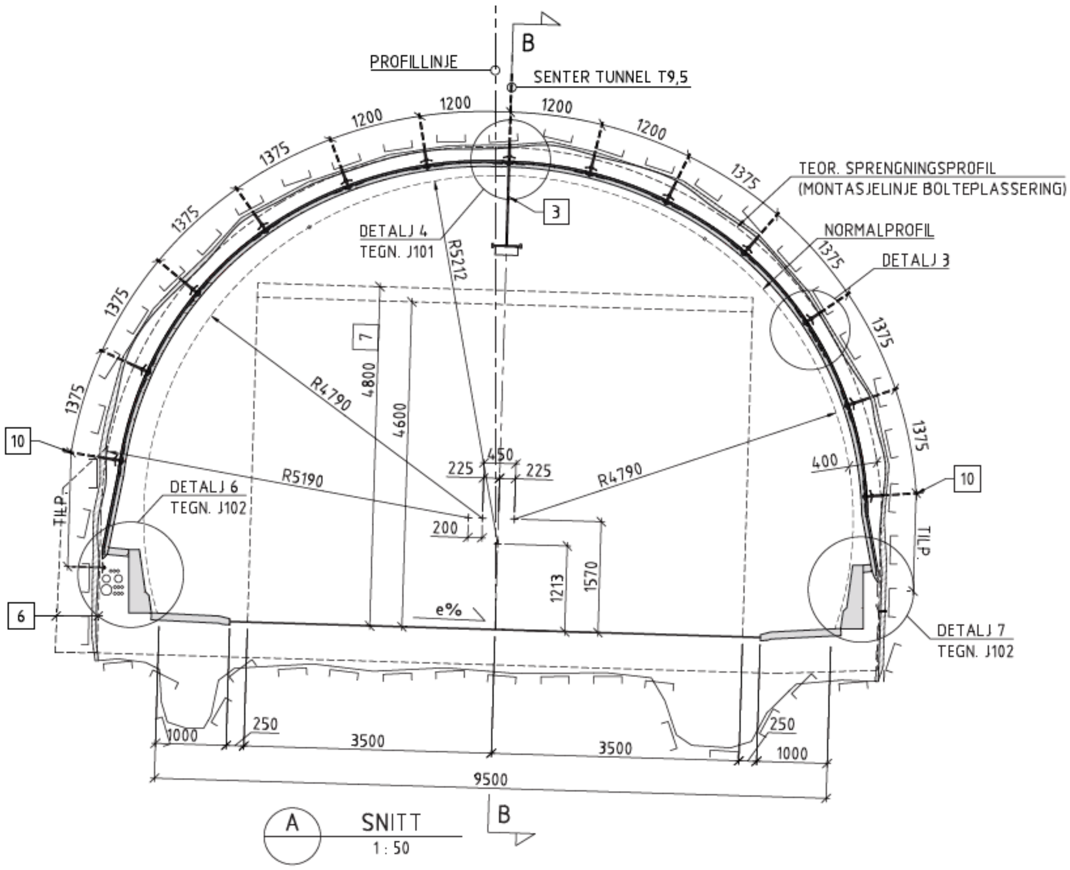


Figure 10-63 : Drawings from Report 510: Preferred solutions for water and frost protection in tunnels, The Norwegian Public Roads Administration

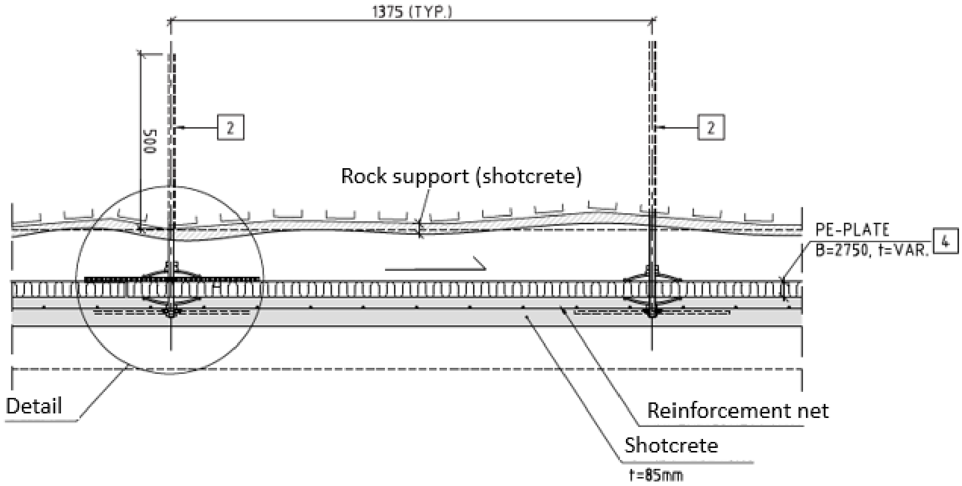


Figure 10-64 : Drawings from Report 510: Preferred solutions for water and frost protection in tunnels, The Norwegian Public Roads Administration

PE-isolation mounted directly on the rock surface is a simpler solution of inner lining used in older tunnels with low traffic. The PE-isolation is sometimes covered with a layer of shotcrete.

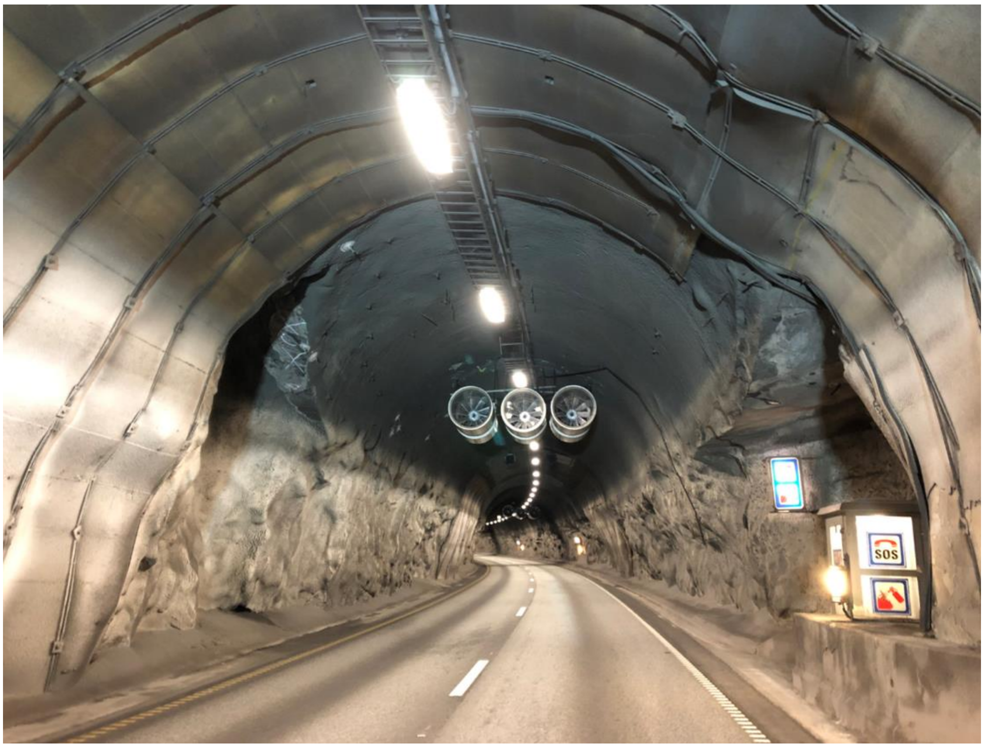


Figure 10-65 : PE-isolation mounted on the rock surface. Fløytunnel, Norway

Concrete wall elements and/or roof elements

The drawing below shows a Norwegian tunnel inner lining built up of concrete elements for the walls and spray concrete with reinforcement net and PE-isolation in the roof. The concrete foundations are placed at the joint between two elements supporting both wall elements. The elements are fixed to the rock with mounting bolts. A membrane is sometimes applied behind the elements.

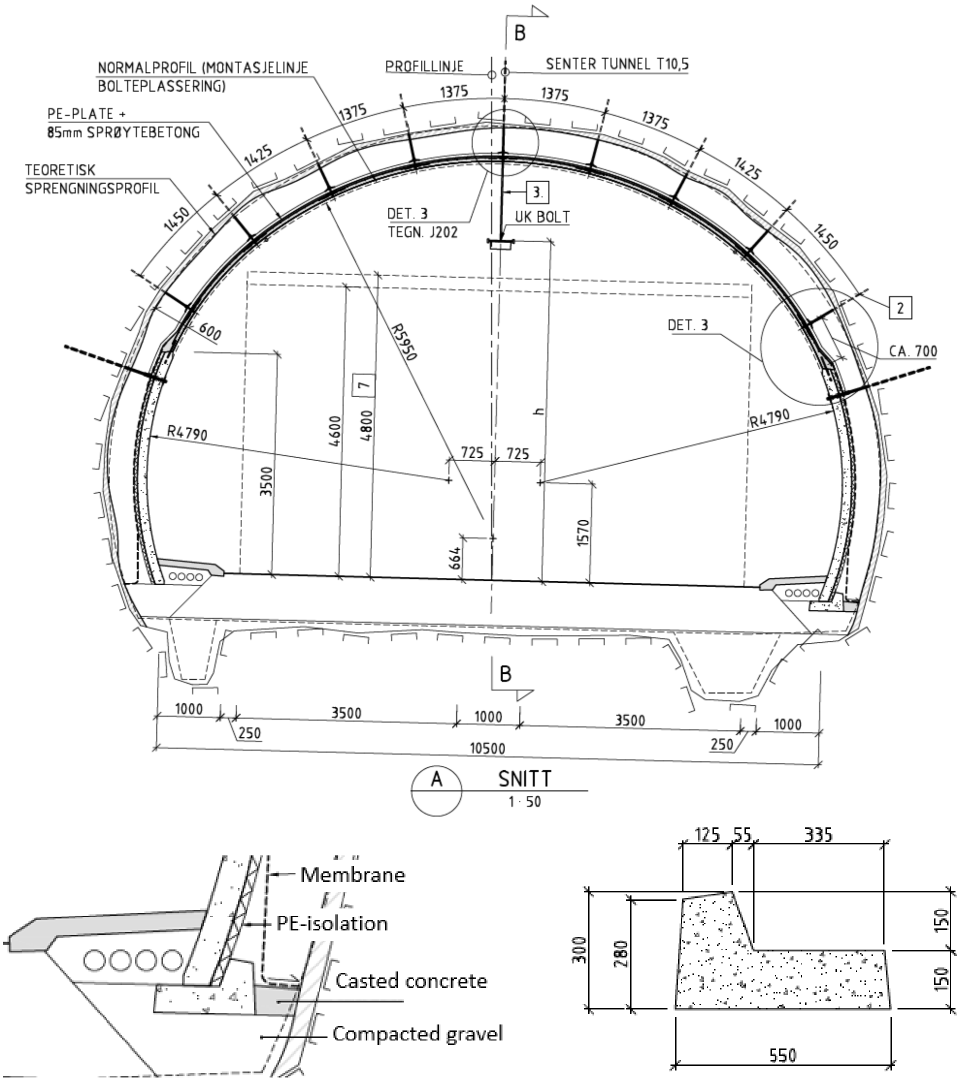


Figure 10-66 : Drawings from Report 510: Preferred solutions for water and frost protection in tunnels, The Norwegian Public Roads Administration

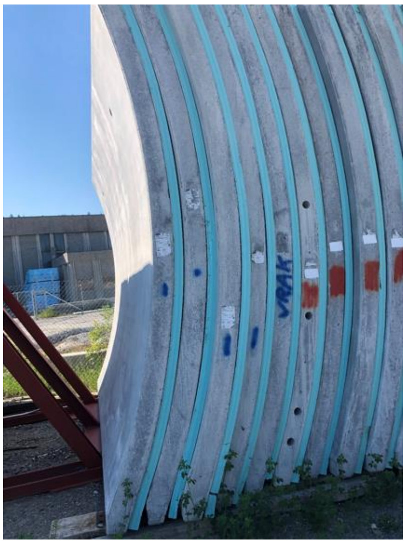


Figure 10-67 : Precast wall elements with PE-isolation at Spenncon factory, Norway

For some tunnels with high traffic volumes, concrete elements are used as inner lining in the roof as well. The illustration below shows a Tekla Structures model made by Spenncon. As can be seen the layout of these concrete elements can be rather complex. The roof elements are supported by the wall elements. In addition, mounting bolts are used to hang the elements in the rock vault.

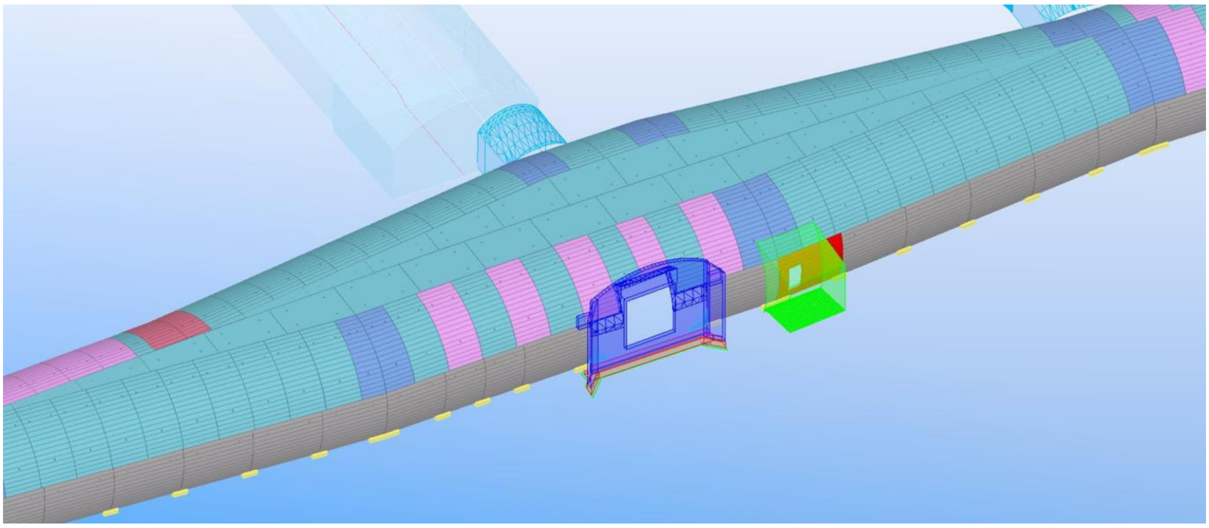


Figure 10-68 : Precast element layout by Spenncon, Hamang tunnel, Norway

Casted inner final linings

Casted inner lining as part of the rock support are described in the chapter listing different rock support measures. However, the final inner lining can have complex forms and detailed requirements. Components can include service galleries and ventilation canals in the ceiling. They can be reinforced or unreinforced. Unreinforced linings require special attention to the joints and to the concrete technology and construction practices and are more common in some countries than others.

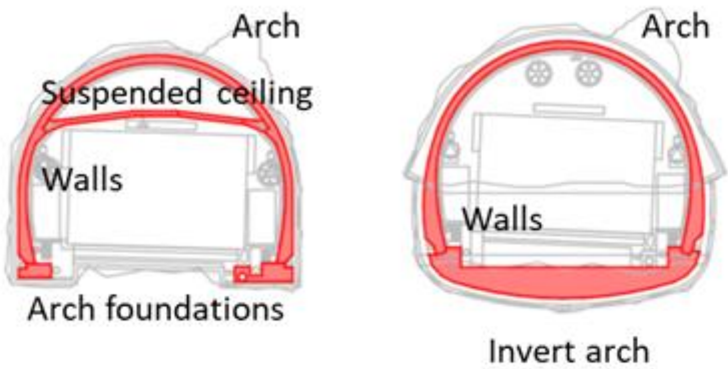


Figure 10-69 : Typical cast in situ inner linings in conventional tunnelling (courtesy ILF)

Figure 10-70 : Inner lining with ceiling supports (source ARGE Marti Belchen)

Figure 10-71 : Ventilation ceiling formwork (source ARGE Marti Belchen)

Figure 10-72 : Service gallery under carriageway (source ARGE Marti Belchen)

Figure 10-73 : Invert arch lining (source Electrowatt Engineering Services)

Figure 10-74 : Full round lining formwork in hydro tunnel (source ILF)

Figure 10-75 : Heavily reinforced tunnel lining (source ILF)

Figure 10-76 : Inner lining formwork (source ARGE Girsbergtunnel)

10.4.2 Mechanised Tunnels

In Mechanised tunnelling, where a second inner lining is used in addition to segments or shotcrete support, it is essentially identical to the linings used in conventional tunnelling.

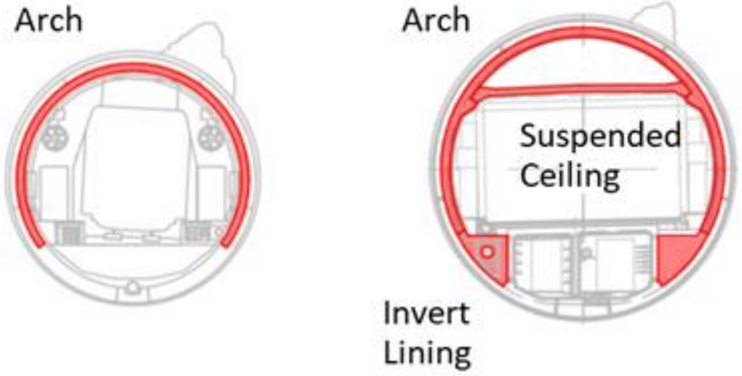


Figure 10-77 : Typical inner linings in mechanised tunnelling (source ILF)

10.4.3 Cut-and-cover Tunnels

The final lining of cut and cover tunnels is generally constructed in an open excavation. Typical configurations of cut and cover linings are shown below.

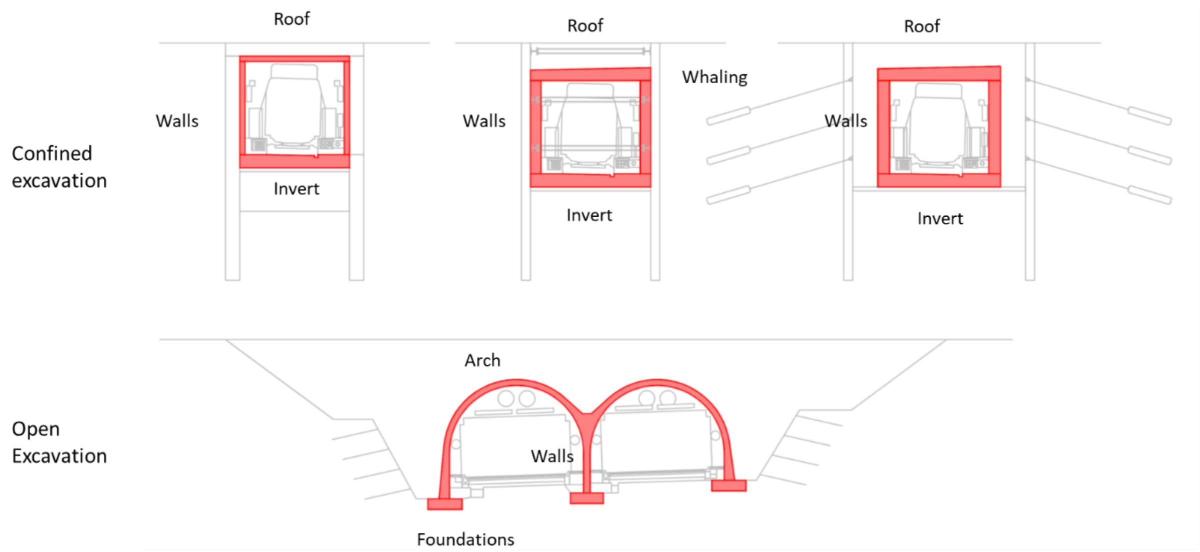


Figure 10-78 : Typical lining configurations in cut and cover construction (source SBB/ILF)

It differs from underground construction that the excavation support cannot always used as counter shuttering as in underground linings. In this case a separate external formwork must be used as shown below.

Figure 10-79 : External formwork for cut and cover construction in an open excavation (source ARGE Girsbergtunnel)

Figure 10-80 : Cut and cover tunnel lining in anchored confined excavation (source ILF)

A feature of most tunnels is that sub-stations are often installed in cut and cover at portal areas. These are similar to conventional buildings, but have particular requirements due to increased loading and waterproofing requirements that mean they are closer to cut and cover structures.

Figure 10-81 : Sub-station construction in portal areas (source ARGE Marti Belchen)

In addition, another common feature of all tunnels are the portal structures which are constructed in cut and cover.

Figure 10-82 : Portal formwork (source ARGE Girsbergtunnel)

Figure 10-83 : Portal fill and landscaping (source ARGE Girsbergtunnel)

11 Tunnel systems requirements

11.1 Systems, sub-systems, components & characteristics

Whatever its type, a tunnel is equipped with a series of functional systems that allows for it to ensure the functions it is expected to provide vis-à-vis the roadway or railway that passes through; they are mandatory elements for operating the tunnel.

As such they represent specific requirements to be dealt with by IFC-Tunnel extensions for:

- Power supply (HV)
- Power supply (MV/LV), excluding traction (railway)
- Supervision (SCADA)
- Communication (Telephones, interphones, radio, cellular)
- Ventilation
- Lighting
- Fire protection (passive, active)
- Safety & evacuation
- Groundwater drainage
- Carriageway drainage (wastewater)
- In-tunnel specific railway equipments (signalling, telecom), excluding railway track
- In-tunnel specific roadway equipments (signs, barriers, traffic lights), excluding roadway carriageway

Whilst identifying the different components, and their characteristics (geolocalization, geometries, functional parameters, interdependencies), that make up an operational system, we need to capture the information that relates to these at the time (the phases of the project) at which it becomes available, i.e.: during design, during construction, during delivery/reception, with a view to optimize the handover to operation & maintenance (O&M) by polishing of the data so to fit the assets management solution's capacities, and avoid re-capturing information at the start of O&M.

In addition, the exchange scenarii as they relate to components of operational systems should be evaluated from different perspectives, given the different project phases :

During <u>design</u>, leading to as-designed information exchanges:

- within one domain system optimization
- in between domains' systems coordination
- between domains' systems and civil engineering, including tunnel geometries support for simulations
- installation sequencing optimization

During construction, leading to as-built information exchanges:

- installation tolerances values
- accessibility / maintainability documentation (fit with maintenance requirements)
- nominal functional state (captured at delivery/reception of systems)
- identification & localization (captured at installation, e.g.: through RFID)

During testing & acceptance, leading to as-tested information exchanges:

- In-factory testing
- Temporary test environment
- On-site acceptance testing

During maintenance, leading to up-to-date as-maintained information exchanges:

- inspection documentation
- equipments monitoring recording (and support for analysis)
- events statistics (and support for analysis)
- planned maintenance (obsolescence)
- predictive maintenance (consequences analysis in support to digital twins)
- fixing (for identical functional performance)
- upgrade (for extended functional performance)

The main generic characteristics should be in a capacity to serve the need of engineers and maintainers through the different phases (design / construction-installation / testing & acceptance / maintenance); these would include:

- Design input/output parameters
- Functional (performance) nominal requirements
- Technical requirements (materials, power supply, etc.)
- Installation constrains (reservation, interdistance, clearance)
- Testing reporting & acceptance criteria compliance
- Dimensions & maintenance clearance (accessibility)
- Identification (manufacturer, RFID, other)

11.2 Systems required during construction

The different systems are also required and used through the construction phase, in somewhat different, temporary capacities. Their characteristics should be described so to optimize the exchange scenarios at construction time, including the sequencing of operation so to deal properly with the co-activity that exist during that phase.

Systems required during the construction of a Tunnel, like ventilation, water pumping/drainage, conveyor belts in a TBM context are required to maintain safe and tenable condition for workers.

Electrical systems provide power supply to all the equipment involved in the construction activities and to all sub-systems and devices necessary to preserve safe conditions in the working areas.

Monitoring and Control systems together with Telecoms provide the necessary supervision to allow for the operation of the site.

11.3 Existing Ifc4.3 objects vs specific IfcTunnel objects

Each system is made of a series of components with their own characteristics that can be regrouped in sub-systems for clarity purposes.

The purpose of the matrix below is to identify if some of these components might already be existing in the current Ifc4.3 schema (objects / relations / properties), whereas others might be specific to tunnels (objects / relations / properties).

	IfcTunnel 4.4	IfcRailway4.3	IfcRoad 4.3	Ifc4 (Buildings)
Power Supply (HV)	To be covered	Covered	n/a	Partly covered
Power supply (LV / MV)	To be covered	Covered	OoS	Covered
Traction	OoS	Covered	n/a	n/a
Supervision equipments	To be covered	Covered	OoS	Covered
Communication (radio/cell)	To be covered	Covered	OoS	Partly covered
Ventilation	To be covered	n/a	n/a	Covered
Lighting	To be covered	n/a	OoS	Covered
Signalling	To be covered	Covered	Partly covered	n/a
Fire protection	To be covered	n/a	n/a	Covered
Safety & evacuation	To be covered	n/a	n/a	Covered
Groudwater drainage	To be covered	n/a	n/a	Partly covered
Platform drainage	To be covered	OoS	Partly covered	n/a
Geothermal	OoS	n/a	n/a	n/a

To be covered	Discipline is to be covered by Ifc Tunnel (incl. in-tunnel railway/roads specifics)
Covered	Discipline is fully covered by the Ifc domain (poss. with in-tunnel specifics)
Partly covered	Discipline is partly covered by the Ifc domain
Out of Scope	Discipline is out of scope for the Ifc domain
n/a	Discipline is not relevant for the domain

Figure 11-1 : Current Ifc's level of coverage of main tunnel disciplines

11.3.1 Existing Ifc Railway objects

The in-scope/out-of-scope classification done by the IfcRailway Team led to:

Domain Track

In-scope

- Panels (Track, Turnout, Dilatation)
- Objects of Track (Rail, Sleeper, Fastening)
- Ballast
- Slab track
- Rack Railway
- Elements of turnouts
- Track covering (for level crossing, light rails, tramways)
- Track alignment stops like buffers
- Track bench
- Lubrication
- Special equipment for shunting yards
- Track spatial structures
- Survey element
- Alignment

Out of scope

- Subsoil (should be treated by ifcRoad)
- Underground (should be treated by ifc Earthworks)
- Drainage of track
- Temporary objects
- Functional views and conditions

Domain Energy

In-scope

- Substations
- Earthing and current return
- Overhead constructions and supporting structures
- Overhead lines
- Switching post
- Suffix post
- Fundation and Fundaments
- AC and DC Installations
- Protection devices (Birds, touch protection)
- Lineside signs and signals

Out of scope

- High voltage lines (Distribution network)
- Power plants
- Rigid catenary
- Catenary for Tramways and light rails
- Trolley bus overhead lines
- Induction lines (non-contact system)
- Third rail (mounted trackside / on track panel)
- Equipment for diesel powered trains

Domain Signalling

In-scope

- Lineside installations
- Main signals (as standalone objects, simplified modelled)
- Shunting signals
- Relays
- All types of trackside signals and signs as information for train driver (no specific function yet)
- ETCS/CTCS lineside equipment (Balises, signs etc)
- Barriers for level crossing
- Warning signals at level crossings for road and pedestrian traffic (lights and bell)
- Level cross protection signs for rail traffic
- Operation and Surveillance equipment (Computer, Cabinets, Video cameras)
- Turnout machines and mounting installation, incl. manual switch lever
- Turnout heating (only electrical)
- Signalling cables (incl. trench, cable canal)
- Trackside sensors (Hotbox, etc.)
- Axle counter

Out of scope

- Signal components (like aspect lampes etc.)
- Logical and functional detailed aspects
- Small electronical components (fuses, etc.)
- ETCS/CTCS on board equipment
- Mechanical signalling equipment (bares, steel cables)
- Rods / turnout lock
- Gas turnout heating
- Signals for tramways and light rails
- Natural hazards sensors/surveillance
- Dynamic axle weight device

Domain Telecom

In-scope

- Mainly trackside equipment
- Terminals
- Cabinets and shelters
- Cabling (cables and connectors)
- Cable Routing (Laying installations)
- Sensors (snow, wind etc.)
- Antennas
- Towers and Poles
- Active Networks
- Base Transceiver Stations (BTS)
- E-Utran Node B for LTE (4G)
- Lineside telephones
- Vending and ticket machines
- Tetra Networks (limited mobile network)

Out of scope

- Centrals (inside equipment)
- Servers, terminals, computers, consoles (inside equipment)
- Radio inside devices
- Operation and surveillance installations
- CCTV

Figure 11-2 : IfcRailway in-scope/out-scope summary

The IfcRailway initiative has identified the specific situation of a railway hosted by a tunnel, through a set of spaces:

- Track structure - no-overlap
- Sub-structure (excluded from IfcRailway) - no-overlap
- Kinetic envelope - potential overlap
- Power - potential overlap
- Signaling - potential overlap
- Telecom - potential overlap
- Lineside structure (excluded from IfcRailway) - no overlap

The following objects have been defined in the IFC-Rail project and can be used for tunnel models comprising rail equipment:

A - IfcRailway - TRACK components to be used:

IfcRailway - TRACK: in-tunnel specifics (Yes / Possible reuse / No)					
IfcRailway scope			IfcTunnel scope		
Component name	Component ID	In-tunnel specifics	Component name	Component ID	IfcRailway reuse
21 Track					
211 Ballast bed	RTR_OT_TR-200	No	n/a		No
212 Ballast bed strengthening	RTR_OT_TR-210	No	n/a		No
213 Banquet element Poss	RTR_OT_TR-380	No	tbd	tbd	Poss
214 Bias loaded inspector	RTR_OT_TR-600	No	n/a		No
215 Blade	RTR_OT_TR-440	No	n/a		No
216 Blocking device	RTR_OT_TR-580	No	n/a		No
217 Bonded joint	RTR_OT_TR-70	No	n/a		No
218 Bumper	RTR_OT_TR-390	No	n/a		No
219 Cess between rails Poss	RTR_OT_TR-350	No	tbd	tbd	Poss
2110 Check Rail	RTR_OT_TR-20	No	n/a		No
2111 Controllable retarder	RTR_OT_TR-570	No	n/a		No
2112 Dilatation panel	RTR_OT_TR-1030	No	n/a		No
2113 Dilatation superstructureNo	RTR_OT_TR_1008	No	n/a		No
2114 Earth mat Poss	RTR_OT_TR-220	No	tbd	tbd	Poss
2115 Earthing Terminal	RTR_OT_TR-540	No	n/a		No
2116 Embedded track for traffic	RTR_OT_TR-330	No	n/a		No
2117 Emergency fish plate	RTR_OT_TR-480	No	n/a		No
2118 Fastening	RTR_OT_TR-120	No	n/a		No
2119 Frog	RTR_OT_TR-40	No	n/a		No
2120 Gauge tie rod	RTR_OT_TR-140	No	n/a		No
2121 Guard Rail Poss	RTR_OT_TR-30	No	tbd	tbd	Poss
2122 Half set of blades	RTR_OT_TR-50	No	n/a		No
2123 Hollow sleeper	RTR_OT_TR-170	No	n/a		No
2124 Insulated joint	RTR_OT_TR-60	No	n/a		No
2125 Insulated joint with fish plate	RTR_OT_TR-460	No	n/a		No
2126 Lubrication	RTR_OT_TR-110	No	n/a		No
2127t Insulated joint with fish plate	RTR_OT_TR-470	No	n/a		No
2128 Panel strengthening Yes	RTR_OT_TR-190	Yes	IfcRailwayComponent	IfcRailwayClass	Yes
2129 Plain track super structure	RTR_OT_TR-1006	No	n/a		No
2130 Rack-rail	RTR_OT_TR-100	No	n/a		No
2131 Rail	RTR_OT_TR-10	No	n/a		No
2132 Rail brace	RTR_OT_TR-490	No	n/a		No
2133 Rail-pads	RTR_OT_TR-130	No	n/a		No
2134 Railway crossing	RTR_OT_TR-340	No	n/a		No
2135 Sleeper	RTR_OT_TR-160	No	n/a		No
2136 Sleeper Cap	RTR_OT_TR-180	No	n/a		No
2137 Sliding chair	RTR_OT_TR-150	No	n/a		No
2138 Sound absorption	RTR_OT_TR-370	No	n/a		No
2139 Speed regulator	RTR_OT_TR-560	No	n/a		No
2140 Spring-Damping system	RTR_OT_TR-260	No	n/a		No
2141 Stock rail	RTR_OT_TR-450	No	n/a		No
2142 Track Adjustment Layer Poss	RTR_OT_TR-520	No	tbd	tbd	Poss
2143 Track Base Yes	RTR_OT_TR-530	Yes	IfcRailwayComponent	IfcRailwayClass	Yes
2144 Track Elastic Cushion Yes	RTR_OT_TR-510	Yes	IfcRailwayComponent	IfcRailwayClass	Yes
2145 Track Isolation Layer Yes	RTR_OT_TR-500	Yes	IfcRailwayComponent	IfcRailwayClass	Yes
2146 Track concrete slab	RTR_OT_TR-240	No	n/a		No
2147 Track element at end of alignme	RTR_OT_TR-400	No	n/a		No
2148 Track panel	RTR_OT_TR-1010	No	n/a		No
2149 Track part	RTR_OT_TR-1005	No	n/a		No
2150 Track reference marker Poss	RTR_OT_TR-430	No	tbd	tbd	Poss
2151 Track scale	RTR_OT_TR-590	No	n/a		No
2152 Track slab	RTR_OT_TR-230	No	n/a		No
2153 Track system	RTR_OT_TR-1000	No	n/a		No
2154 Turnout panel	RTR_OT_TR-1020	No	n/a		No
2155 Turnout superstructure	RTR_OT_TR-1007	No	n/a		No
2156 Welded joint	RTR_OT_TR-80	No	n/a		No

Figure 11-3 : IfcRailway components potential reusabiity for tunnel disciplines

B – IfcRailway – POWER SUPPLY components to be reused:

IfcRailway - POWER SUPPLY: in-tunnel specifics (Yes / Possible reuse / No)					
IfcRailway scope			IfcTunnel scope		
Component name	Component ID	In-tunnel specifics	Component name	Component ID	IfcRailway reuse
24 Energy					
241 AC control panel	REN_OT_EN-10102021	No	tbd	tbd	Poss
242 Actuator	REN_OT_EN-1010203020	No	n/a		No
243 Anchoring bar	REN_OT_EN-1010101086	No	tbd	tbd	Poss
244 Anti trespassing guard	REN_OT_EN-1010431	No	tbd	tbd	Poss
245 Anti-Fall device	REN_OT_EN-1010426	No	tbd	tbd	Poss
246 AntiClimbing	REN_OT_EN-1010427	No	tbd	tbd	Poss
247 Automaton	REN_OT_EN-10102026	No	tbd	tbd	Poss
248 Autotransformer	REN_OT_EN-101020432	No	tbd	tbd	Poss
249 Auxiliary electric cabinet	REN_OT_EN-1010207011	No	tbd	tbd	Poss
2410 Auxiliary services	REN_OT_EN-10102070	No	tbd	tbd	Poss
2411 Auxiliary transformer	REN_OT_EN-101020433	No	tbd	tbd	Poss
2412 Balance weight tensioner	REN_OT_EN-1010101060	No	n/a		No
2413 Battery	REN_OT_EN-1010205010	No	tbd	tbd	Poss
2414 Battery charger	REN_OT_EN-1010207010	No	tbd	tbd	Poss
2415 Bearer Structure	REN_OT_EN-1010101038	Yes	IfcRailwayComponent	IfcRailwayClass	Yes
2416 Bird protection	REN_OT_EN-1010430	No	tbd	tbd	Poss
2417 Booster transformer	REN_OT_EN-101020431	No	tbd	tbd	Poss
2418 Boosting cable	REN_OT_EN-10106040	No	tbd	tbd	Poss
2419 Box type substation	REN_OT_EN-101023	No	tbd	tbd	Poss
2420 BusBar	REN_OT_EN-10103013	No	tbd	tbd	Poss
2421 Cable	REN_OT_EN-10103012	No	tbd	tbd	Poss
2422 Cable Chamber	REN_OT_EN-10105021	No	tbd	tbd	Poss
2423 Cable Gantry	REN_OT_EN-10105022	No	tbd	tbd	Poss
2424 Cable Sheathing	REN_OT_EN-10105020	No	tbd	tbd	Poss
2425 Cantilever assembly	REN_OT_EN-1010101040	No	n/a		No
2426 Capacitor	REN_OT_EN-1010205011	No	tbd	tbd	Poss
2427 Catenary system	REN_OT_EN-1010101090	No	n/a		No
2428 Catenary wire	REN_OT_EN-1010101053	No	n/a		No
2429 Combined transformer	REN_OT_EN-101020424	No	n/a		No
2430 Common protecting facility	REN_OT_EN-1010418	No	n/a		No
2431 Common supplying	REN_OT_EN-10102027	No	tbd	tbd	Poss
2432 Compensator equipment	REN_OT_EN-1010206030	No	tbd	tbd	Poss
2433 Contact wire	REN_OT_EN-1010101052	No	n/a		No
2434 Cross beam	REN_OT_EN-1010101036	No	tbd	tbd	Poss
2435 Cross bond	REN_OT_EN-10106079	No	n/a		No
2436 Current transformer	REN_OT_EN-101020421	No	n/a		No
2437 DC control panel	REN_OT_EN-10102022	No	n/a		No
2438 Decoupler transformer	REN_OT_EN-101020434	No	n/a		No
2439 Dropper	REN_OT_EN-1010101057	No	n/a		No
2440 Earth	REN_OT_EN-10106074	No	tbd	tbd	Poss
2441 Earth Electrode	REN_OT_EN-10106072	No	tbd	tbd	Poss
2442 Earth Grid	REN_OT_EN-10106076	No	tbd	tbd	Poss
2443 Earthing circuit	REN_OT_EN-10106070	No	tbd	tbd	Poss
2444 Earthing conductor	REN_OT_EN-10106071	No	tbd	tbd	Poss
2445 Earthing terminal	REN_OT_EN-10106073	No	tbd	tbd	Poss
2446 Electric Gutter	REN_OT_EN-10105019	No	tbd	tbd	Poss
2447 Electric distribution board	REN_OT_EN-1010207012	No	tbd	tbd	Poss
2448 Electric power converter	REN_OT_EN-101020410	No	tbd	tbd	Poss
2449 Electric storage device	REN_OT_EN-10102050	No	tbd	tbd	Poss
2450 Electrical conductor	REN_OT_EN-1010101058	No	tbd	tbd	Poss
2451 Electrical connector	REN_OT_EN-101030	No	n/a		No
2452 Elementary sector	REN_OT_EN-1010101025	No	n/a		No
2453 Emergency switch off	REN_OT_EN-1010203034	No	tbd	tbd	Poss
2454 Energy conversion device	REN_OT_EN-10102040	No	tbd	tbd	Poss
2455 Environnemental protection	REN_OT_EN-1010428	No	n/a		No
2456 Feeder line	REN_OT_EN-1010101064	No	n/a		No

Figure 11-4 : IfcRailway components potential reusabiity for tunnel disciplines

C – IfcRailway – SIGNALLING components to be used:

IfcRailway - **SIGNALLING**: in-tunnel specifics (Yes / Possible reuse / No)					
IfcRailway scope			IfcTunnel scope		
Component name	Component ID	In-tunnel specifics	Component name	Component ID	IfcRailway reuse
22 Signalling					
221 Axle counting equipment	RSI_OT_AX 73	No	n/a		No
222 Balise	RSI_OT_BA 74	No	n/a		No
223 Battery	RSI_OT_BAT 75	No	IfcRailwayComponent	IfcRailwayClass	Yes
224 Box	RSI_OT_BO 76	No	IfcRailwayComponent	IfcRailwayClass	Yes
225 Cabinet	RSI_OT_CA 77	No	IfcRailwayComponent	IfcRailwayClass	Yes
226 Cable and Wire	RSI_OT_CW 80	No	IfcRailwayComponent	IfcRailwayClass	Yes
227 Crocodile	RSI_OT_CRO 81	No	n/a		No
228 Derailer	RSI_OT_DER 82	No	n/a		No
229 Detector	RSI_OT_DET 83	No	n/a		No
2210 External locking device	RSI_OT_EL 83	No	n/a		No
2211 Fixing	RSI_OT_FI 84	No	n/a		No
2212 Full Electronic Execution Unit	RSI_OT_FEEU 84	No	n/a		No
2213 Impedance transformer	RSI_OT_IT 85	No	n/a		No
2214 Induction loop	RSI_OT_INI 86	No	n/a		No
2215 Input/Output device of track cir	RSI_OT_IOTC 87	No	n/a		No
2216 Insulating joint	RSI_OT_IJ 87	No	n/a		No
2217 Level Crossing Equipment	RSI_OT_LCE 88	No	n/a		No
2218 Local operation device	RSI_OT_LOD 89	No	tbd	tbd	Poss
2219 Lock	RSI_OT_LO 91	No	n/a		No
2220 Lock combination	RSI_OT_LCO 92	No	n/a		No
2221 Lockable device release	RSI_OT_LDE 92	No	n/a		No
2222 Marker	RSI_OT_MA 93	No	tbd	tbd	Poss
2223 Passive electronic component o	RSI_OT_PETC 94	No	IfcRailwayComponent	IfcRailwayClass	Yes
2224 Point closure detector	RSI_OT_SCD 94	No	n/a		No
2225 Point machine	RSI_OT_PO 95	No	n/a		No
2226 Point machine mounting device	RSI_OT_PMD 96	No	n/a		No
2227 Railway detonator	RSI_OT_RD 97	No	n/a		No
2228 Relay	RSI_OT_REL 97	No	IfcRailwayComponent	IfcRailwayClass	Yes
2229 Signal	RSI_OT_SI 98	No	tbd	tbd	Poss
2230 Signal aspect	RSI_OT_AS 102	No	tbd	tbd	Poss
2231 Signal frame	RSI_OT_SF 103	No	tbd	tbd	Poss
2232 Track Circuit	RSI_OT_TC 104	No	n/a		No
2233 Trackside vehicle barring device	RSI_OT_TVBA 105	No	tbd	tbd	Poss
2234 Trackside vehicle braking device	RSI_OT_TVBR 105	No	n/a		No
2235 Transformer	RSI_OT_TR 106	No	n/a		No
2236 Turnout heating	RSI_OT_TH 106	No	n/a		No
2237 UPS	RSI_OT_UPS 107	No	tbd	tbd	Poss

Figure 11-5 : IfcRailway components potential reusabiity for tunnel disciplines

D – IfcRailway – TELECOM components to be used:

IfcRailway - **TELECOM**: in-tunnel specifics (Yes / Possible reuse / No)

IfcRailway scope			IfcTunnel scope		
Component name	Component ID	In-tunnel specifics	Component name	Component ID	IfcRailway reuse
23 Telecom					
231 Abs_Telecom object	RTC_OT_ABSTO 108	No	IfcRailwayComponent	IfcRailwayClass	Yes
232 Access point	RTC_OT_AP 110	No	n/a		No
233 Anemometrograph	RTC_OT_ANE 111	No	n/a		No
234 Antenna	RTC_OT_ANT 111	No	n/a		No
235 Automatic gate	RTC_OT_AG 112	No	tbd	tbd	Poss
236 Base transceiver station	RTC_OT_BTS 113	No	IfcRailwayComponent	IfcRailwayClass	Yes
237 Baseband unit	RTC_OT_BBU 114	No	IfcRailwayComponent	IfcRailwayClass	Yes
238 Cable	RTC_OT_CABLE 115	No	IfcRailwayComponent	IfcRailwayClass	Yes
239 Cable fitting	RTC_OT_CFIT 116	No	IfcRailwayComponent	IfcRailwayClass	Yes
2310 Cabling accessory	RTC_OT_CABAC 116	No	IfcRailwayComponent	IfcRailwayClass	Yes
2311 Closure	RTC_OT_CLO 116	No	IfcRailwayComponent	IfcRailwayClass	Yes
2312 Coaxial cable	RTC_OT_COAX 117	No	IfcRailwayComponent	IfcRailwayClass	Yes
2313 Communication interface	RTC_OT_COMITF 118	No	IfcRailwayComponent	IfcRailwayClass	Yes
2314 Connector	RTC_OT_CON 118	No	IfcRailwayComponent	IfcRailwayClass	Yes
2315 Copper cable	RTC_OT_COPCAB 118	No	IfcRailwayComponent	IfcRailwayClass	Yes
2316 Copper connector	RTC_OT_COPCON 119	No	IfcRailwayComponent	IfcRailwayClass	Yes
2317 Copper patch cord	RTC_OT_COPPC 119	No	IfcRailwayComponent	IfcRailwayClass	Yes
2318 Copper symmetric pair cable	RTC_OT_COPSPCAB 120	No	IfcRailwayComponent	IfcRailwayClass	Yes
2319 Data transmission unit	RTC_OT_DTU 120	No	IfcRailwayComponent	IfcRailwayClass	Yes
2320 Desktop console	RTC_OT_DCONS 121	No	IfcRailwayComponent	IfcRailwayClass	Yes
2321 Distribution frame	RTC_OT_DF 122	No	IfcRailwayComponent	IfcRailwayClass	Yes
2322 Distribution port	RTC_OT_DPORT 123	No	IfcRailwayComponent	IfcRailwayClass	Yes
2323 Duct	RTC_OT_DUC 124	No	tbd	tbd	Poss
2324 E-utran node B	RTC_OT_eNB 124	No	IfcRailwayComponent	IfcRailwayClass	Yes
2325 Earthquake accelerometer	RTC_OT_EA 125	No	IfcRailwayComponent	IfcRailwayClass	Yes
2326 Equipment access zone	RTC_OT_EQAZONE 126	No	IfcRailwayComponent	IfcRailwayClass	Yes
2327 Fan out	RTC_OT_FANO 127	No	IfcRailwayComponent	IfcRailwayClass	Yes
2328 Feeder	RTC_OT_FED 127	No	IfcRailwayComponent	IfcRailwayClass	Yes
2329 Fiber	RTC_OT_FIB 128	No	IfcRailwayComponent	IfcRailwayClass	Yes
2330 Fiber endpoint	RTC_OT_FEP 129	No	IfcRailwayComponent	IfcRailwayClass	Yes
2331 Fiber tube	RTC_OT_FTU 129	No	IfcRailwayComponent	IfcRailwayClass	Yes
2332 Foreign object dual power netw	RTC_OT_FOS 130	No	IfcRailwayComponent	IfcRailwayClass	Yes
2333 Front side port	RTC_OT_FSPORT 130	No	IfcRailwayComponent	IfcRailwayClass	Yes
2334 Gutter	RTC_OT_GUT 131	No	IfcRailwayComponent	IfcRailwayClass	Yes
2335 IP network equipment	RTC_OT_IPN 131	No	IfcRailwayComponent	IfcRailwayClass	Yes
2336 Intelligent peripheral	RTC_OT_IP 132	No	IfcRailwayComponent	IfcRailwayClass	Yes
2337 Leaky coaxial cable	RTC_OT_LCX 132	No	IfcRailwayComponent	IfcRailwayClass	Yes

Figure 11-6 : IfcRailway components potential reusabiity for tunnel disciplines

11.3.2 Existing IfcRoad objects

The in-scope/out-of-scope classification done by the IFC-Road Team led to:

In-scope:

- Linear road types:
  - Controlled access highway;
  - Dual carriageway;
  - Single carriageway;
  - Street;
  - Bicycle path;
  - Footpath.
- Junction types:
  - Interchange (grade separated):
    - overpass;
    - underpass;
    - ramp.
  - Intersection (at grade):
    - Intersecting roads (3, 4, …, 7 way);
    - roundabout or traffic circle;
    - pedestrian crossing;
    - bicycle crossing.
- Road components, elements and equipment: Some of these concepts may be identified as being common and handed over to the common schema project and some may be developed by the IFC Road project team for the Common Schema project.
  - Road structure (road prism (road body)
  - Road guard elements
  - Road sign elements
  - Road paving components
  - Utilities
  - Lighting, telecommunications and power
  - Storm-, surface- water and drainage systems
  - Other underground facilities located in the road body.

Expected to be covered (but not subject to validation tests):

- paved surfaces of:
  - parking lots;
  - service areas;
  - toll plazas;
  - parking buildings;
  - ferry ports;
  - airports.

Out of scope:

- Equipment and buildings of the above listed paved surfaces;
- railway crossings;
- tramways;
- city scape / urban planning.

The following developments are out of scope for IFC Road because they are delivered through the Common Schema project:

- Earthworks cut and fill design;
- Geotechnical investigations;
- Geotechnical constructions.

Figure 11-7 : IfcRoad in-scope/out-scope summary

The IFC-Road project has not yet identified the specific situation of a roadway located in a tunnel nor the specific equipments associated to a roadway in such a situation.

The following matrix help identify potential scopes intersections with IfcTunnel:

• Road types & spaces	- no overlap
• Pavement & superstructure	- no overlap
• Subgrade	- potential overlap
• Sub-structure (excluded from IfcRoad)	- no overlap
• Resource materials	- no overlap
• Retaining walls	- no overlap (cut&cover)
• Foundations	- no overlap
• Geology	- potential overlap
• Drainage	- potential overlap
• Road guards	- no overlap
• Road marking & sign	- no overlap
• Lighting, telecom & power	- no overlap
• Traffic management (excluded from IfcRoad)	- no overlap

The following entities defined by the IFC-Road project can be used for modeling tunnels with road equipment:

IfcRoad – Components to be used:

IfcRoadway - COMPONENTS: in-tunnel specifics (Yes / Possible reuse / No)					
IfcRoadway scope			IfcTunnel scope		
Component name	Component ID	In-tunnel specifics	Component name	Component ID	IfcRailway reuse
1.2.1 Components					
Spacer		No	n/a		No
Tie Bar		No	n/a		No
Longitudinal joint		No	n/a		No
Transverse Contraction Joint		No	n/a		No
Expansion joint		No	n/a		No
Construction joint		No	n/a		No
Bed joint		No	n/a		No
Noise barrier, sound proof wall, Noise bund		No	n/a		No
Barrier element		No	n/a		No
Pedestrian parapet		No	tbd	tbd	Poss
Safety barrier		No	tbd	tbd	Poss
Vehicle parapet		No	tbd	tbd	Poss
Terminal		No	n/a		No
Transition		No	n/a		No
Road safety rail		No	tbd	tbd	Poss
Road gate		No	tbd	tbd	Poss
1.2.4 Signage					
SignAssembly		No	tbd	tbd	Poss
Delineator/Marker post		No	tbd	tbd	Poss
Gantry/Portal		No	tbd	tbd	Poss
Traffic mirror		No	tbd	tbd	Poss
Traffic sign		No	tbd	tbd	Poss
Traffic signal		No	tbd	tbd	Poss
1.2.5 Distribution elements					
Catch drain/grating		No	tbd	tbd	Poss
Culvert		No	tbd	tbd	Poss
Pipe		No	tbd	tbd	Poss
Channel		No	tbd	tbd	Poss
Gutter		No	tbd	tbd	Poss
Ditch		No	tbd	tbd	Poss
Retention/infiltration basin		No	n/a		No
Manhole		No	tbd	tbd	Poss
Collecting Well		No	tbd	tbd	Poss
Cable pit		No	tbd	tbd	Poss
Conduit/Duct		No	tbd	tbd	Poss
Post		No	tbd	tbd	Poss
Sensor		No	tbd	tbd	Poss
1.3 Systems					
Drainage (Systems)		No	tbd	tbd	Poss
Lighting, telecom and power (Systems)		No	tbd	tbd	Poss
Signage (Systems)		No	tbd	tbd	Poss
Transportation systems		No	n/a		No
Interchange		No	n/a		No
3.6.1 Physical					
IfcCourse		No	n/a		No
IfcMaterial		No	n/a		No
IfcKerb		No	n/a		No
IfcElementAssembly/SUMPBUSTER		No	n/a		No
IfcElementAssembly/TRAFFIC_CALMING_DEVICE		No	n/a		No
Paving		No	n/a		No
AnticapillaryLayer		No	n/a		No
AntifreezingLayer		No	n/a		No
BaseCourse		No	n/a		No
BinderCourse		No	n/a		No
CappingLayer		No	n/a		No
DrainingCourse		No	n/a		No
TackCoat		No	n/a		No
LayingCourse		No	n/a		No
RegulatingCourse		No	n/a		No
Sealing		No	n/a		No
SubBaseCourse		No	n/a		No
SeparationLayer		No	n/a		No
AnticrackingLayer		No	n/a		No
PrimeCoat		No	n/a		No
VergeFill		No	n/a		No

3.6.2 Pavement			
IfcPavement	No	n/a	No
3.6.3 Components			
IfcSurfaceFeature	No	n/a	No
IfcSurfaceFeature/PAVEMENTSURFACEMARKING	No	n/a	No
IfcSurfaceFeature/LINEMARKING	No	n/a	No
IfcSurfaceFeature/SYMBOLMARKING	No	n/a	No
IfcSurfaceFeature/HATCHMARKING	No	n/a	No
IfcSurfaceFeature/NONSKIDSURFACING	No	n/a	No
IfcSurfaceFeature/RUMBLESTRIP	No	n/a	No
IfcSurfaceFeature/TRANSVERSERUMBLESTRIP	No	n/a	No

Figure 11-8 : IfcRoad components potential reusabiity for tunnel disciplines

11.3.3 IFC4 (buildings) objects

The IFC 4.0 standard does not address the specific situation of systems hosted in underground buildings like metro stations or technical buildings connected to a tunnel, but it does provide object classes that can serve as a basis, e.g.:

- Power supply (MV/LV)
- Water supply
- Drainage
- Communication networks (Telephones, interphones, radio)
- Supervision (video) (SCADA)
- Ventilation
- Lighting
- Fire protection (passive, active)
- Safety & evacuation

11.4 Ventilation

Ventilation is one of the most important sub-system required in underground infrastructure to maintain a good quality of the environment and to protect users and structures in case of emergency as well as in normal operations and during construction phase.

11.4.1 Ventilation systems under tunnel operation

It has basically two main functions:

- In normal/congested operations, to verify that the temperature and air quality parameters inside the tunnels remain below prescribed threshold limits.
- In fire emergency conditions, during the self-rescue phase the ventilation system aims to create and maintain a tenable environment for the evacuation of tunnel users by controlling heat and smoke spread along the escape routes. Specifically, this environment consists of acceptable temperature, visibility and air quality levels.

Based mainly on tunnel length and traffic conditions (uni/bidirectional, average annual daily traffic, etc.) the main standards in terms of ventilation requirements impose different ventilation system type, which can be categorized in two main types: transverse and longitudinal.

Traditionally, the longitudinal system capacity is sized to prevent smoke backlayering. Usually, it is realized by means of jet fans installed along the tunnel or by “Saccardo nozzle”. Such systems are seen as providing reliable safety in case of a fire accident for unidirectional tunnel tubes. Although there is a slight possibility that the users can be affected by the smoke being pushed by the fans (for example, if they cannot leave the tunnel downstream of the fire due to a traffic jam in case of road tunnels), most users can be expected to be located in the upstream (smoke free) area of the tunnel.

The transverse system (which can be semi-transversal or fully transversal) is sized and operated to extract smoke from a stratified layer at the top of the tunnel space. The fans serving the ducts are often located in ventilation plants close to the tunnel portals or shafts; however, many variations can exist.

Generally, transverse ventilation uses ducts that run parallel to the tunnel. Two kinds of ducts are utilized:

- Fresh air ducts are used to inject fresh air into the tunnel in order to reduce temperature or dilute the polluted gases produced by the vehicles;
- Exhaust ducts are used to extract air from the tunnel volume. The main purpose of extraction is to remove the smoke and hot gases produced by a fire. Extraction capacity is usually concentrated to a zone smaller than the length of the duct by the addition of motorized, remotely controlled dampers.

The design of ventilation is connected with civil works, so during design constraints in terms of space reservation of tunnel x-section and all the works needed for ventilation (like ducts, shafts, ventilation plants) shall be coordinated with the civil engineers.

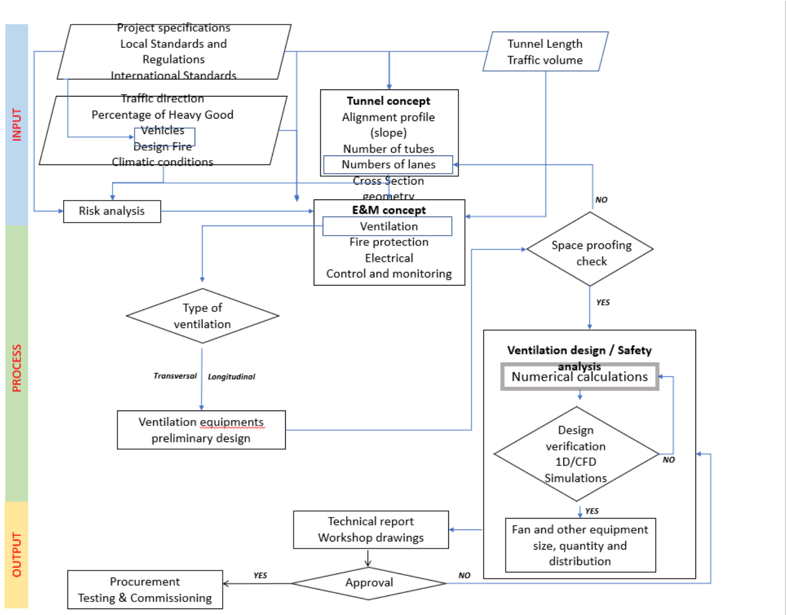


Figure 11-9 : ventilation definition process map (source: Andra)

Power supply system and distribution are affected by ventilation loads and interactions between electrical and mechanical engineer are very important during design.

The requirements aim at covering both road, railway & metro tunnels, whilst identifying the components and equipments installed in the tunnel, the shafts and the station.

For example, some components of the ventilation system (e.g.: dampers, axial fans, silencers, etc.) can be installed in stations or in ventilation buildings, and there is an interdependence with the civil engineering of these rooms.

The analysis describes such components but will not focus on the design of rooms.

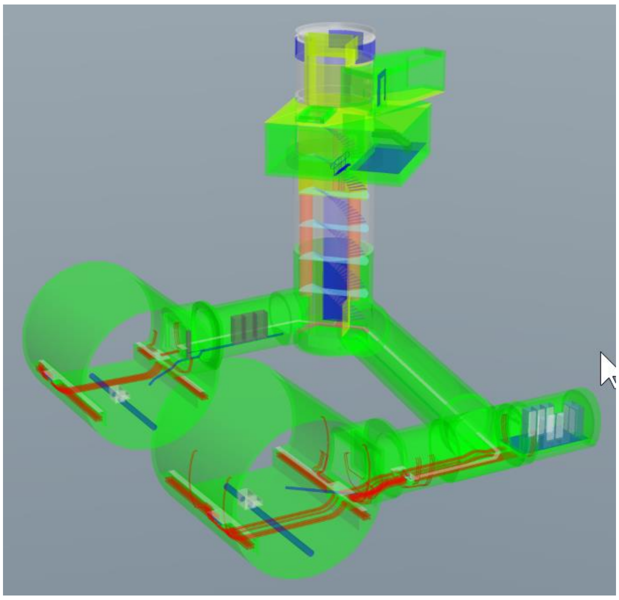


Figure 11-10: ventilation components hosted in shafts/galleries (source: Geodata)

In addition, the analysis conducted identifies as well those components/equipments that might already have been specified in the Ifc4 (Buildings) and/or Ifc4.3.

11.4.2 Ventilation systems during tunnel construction

Construction works always involve danger and their environment is not always clean. In tunneling works comprising drilling, blasting, excavation, shotcreeting and mucking, appropriate measures are absolutely necessary to secure safe and healthy working environment and to increase the construction efficiency. The ventilation system is the most effective method to settle the problem on the dust, smoke and gas in tunnel.

The followings are situations which aggravate the working environment in tunnel:

- Dust and gas caused by drilling, blasting, loading of excavated materials and shotcreeting
- Silicate particles in dust from mechanical excavation with roadheaders or open TBMs
- Exhaust gas and smoke discharged by diesel
- Poison gas made from explosive or organic solvent
- Flammable gasses or oxygen shortage gas in the ground. For example, methane, carbon monoxide and hydrogen sulfide
- High temperature and high humidity

The main objectives of providing temporary ventilation systems in tunnel during construction are:

- To provide the working crew an environment of fresh air.
- To exhaust out fumes and gasses, that is injurious to health and explosive in nature.
- To remove the drilling, mucking and blasting gasses emitted.

The design and installation of ventilation system depends on excavation method as well as on the relevant lows and regulations.

Other than the factors strictly related with the excavation method and its activities, there are mainly two factors, based on which the form and capacity of the ventilation system are dependent:

- The length of the tunnel and its size (area and volume where ventilation is necessary)
- The condition and rate of temperature and humidity inside the tunnel

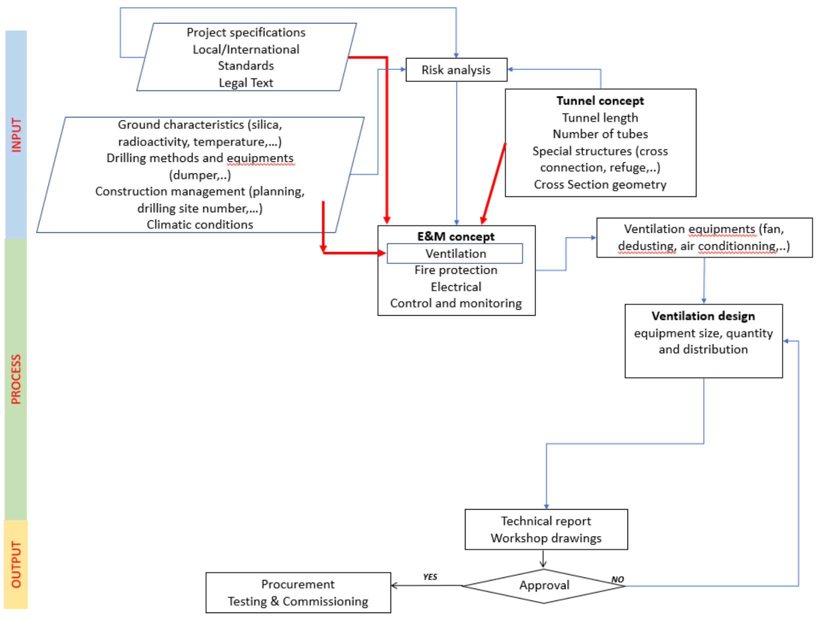


Figure 11-11: ventilation during construction definition process map (source: Andra)

Mechanical ventilation system employs mechanical devices like electric fans, exhaust, and blowers, which serves the function of removing the exhaust gasses within the tunnel and help in blowing fresh air into the tunnel. Whatever be the device employed, there are three main services they can provide:

- Blowing: fresh clean air is blown to the working face, with the help of pipes. When it flows back to the portal, it takes the dust and gasses with it. This system of ventilation help providing fresh air near the working face with ease. But in long tunnels, these systems have a disadvantage of fogging the atmosphere inside the tunnel when the smoke, dust and foul air move out.
- Exhausting: The system incorporates an exhausting duct near the working face, into which, the foul air and the dust are let. By this fresh air is maintained within the tunnel, through the entrance. Quick removal of dust and smoke is one advantage of the exhausting system.
- Combination of blowing and exhausting

11.4.3 Main components and characteristics

The following section proposes a classification of the main components and sub-components of a ventilation system (in normal, congested and emergency situations):

- Civil engineering associated to ventilation
  - Shafts, ducts, branches
  - Niches
  - Ventilation plants
- Electromechanical
  - Fans: jet fan, axial fan (supply & exhaust fans) and its control accessories
  - Disconnecting devices: fire dampers, motorized dampers, grilles

- Sensors
  - Air quality: CO, NOx
  - Air quality: opacimeter
  - Air velocity: Anemometer
  - Tunnel air temperature sensor
  - Weather station

- Acoustic attenuations
  - Silencers

The main components/sub-components of a ventilation system and the foreseen Ifc objects (existing Ifc4.3 objects or new IfcTunnel objects) required to represent them can be summarized as follows:

Ventilation system main components			Required Ifc objets		
ID	**Components**	**Sub-components**	**Existing IfcClass/Enum**	**Extension IfcClass/Enum**	**New IfcTunnel**
SYS-VEN-CEV-0100	Civil engineering associated to ventilation				
SYS-VEN-CEV-0110		Shafts, ducts, branches, ventilation plants, niches			IfcClassTUN
SYS-VEN-ELE-0100	Electromechanical				
SYS-VEN-ELE-0110		Fans: jet fan, axial fan (supply/exhaust fan)		IfcClassEXT	
SYS-VEN-ELE-0130		Disconnecting devices: fire dampers, motorized dampers, grilles	IfcClassEXI		
SYS-VEN-SEN-0100	Sensors				
SYS-VEN-SEN-0110		Anemometer	IfcClassEXI		
SYS-VEN-SEN-0120		Opacimeter	IfcClassEXI		
SYS-VEN-SEN-0130		Weather station	IfcClassEXI		
SYS-VEN-SEN-0140		CO/NOx sensor	IfcClassEXI		
SYS-VEN-SEN-0150		Thermometer	IfcClassEXI		
SYS-VEN-ACO-0100	Acoustic attenuation				
SYS-VEN-ACO-0110		Silencers			IfcClassTUN

Figure 11-12: foreseen existing and new Ifc entities for tunnel ventilation
(NB: IfcClassEXI, IfcClassEXT, IfcClassTUN reflects the foreseen mapping to existing Ifc entities and enumerations, to extensions of existing Ifc entities and enumerations, as well as to new IfcTunnel entities).

The main characteristics that relate to these components/sub-components over the life cycle of tunnel can be summarized as follows:

	Ventilation components main functional characteristics							
Design			**Construction**	**Testing**		**Maintenance**		
Input/output parameters	**Functional nominal performance**	**Technical requirements**	**Installation**	**Testing & acceptance**	**Dimensions & maintenance clearance**	**Identfication**	**Maintenance protocole**	**Parts availability & supply**
Civil engineering	Volume to be evacuated	Equipment material	Transportation volume	Protocole	3D dimensions	Manufacturer	Preventive (scheduled)	Stock level
	Power required	Fire resistivity	Fixation type	Functional requirement compliance	3D volume	Production type	Corrective (fixing)	Average supply time
		MTtF	Protection		3D accessibility	Serial#	Predictive (projected)	
						RFID		

(MTtF: Mean Time to Failure / RFID: Radio Frequency IDentification)

11.5 Power supply – High voltage

The Power Supply system is the backbone of the Electrical, Mechanical and Telecommunication sub-systems, providing energy to all the equipment installed in a tunnel. It can also provide energy to the Traction system for transportation infrastructures (e.g. Railways, Metros).

11.5.1 Power supply under tunnel operation

The Power Supply system is mainly composed by:

- High/Medium voltage section
- Low voltage distribution

The High/Medium voltage section includes all the facilities and equipment necessary for the delivery of the energy from a source or a network that is usually external to the Tunnel, and its distribution along the infrastructure. The same network can include one or more Tunnels.

The High/Medium voltage section comprises also the installation to transform voltage from High to Low (Transformer Substations).

The Low Voltage distribution system derives from the LV winding of the MV/LV Transformers and provides energy to all the equipment installed in the Tunnel. It consists mainly of primary and secondary LV switchboards (including protections), LV cables and earthing and bonding system.

In order to ensure an appropriate level of availability, the Power Supply system is designed with the necessary redundancies and it also provided with emergency power sources like Diesel Generators and Uninterruptible Power Supply system (UPS), to supply the critical loads even in case of failure of some equipment or even in case of loss of the primary source.

11.5.2 Power supply during tunnel construction

The Power Supply system during construction provides energy to all equipment involved in the activities and to all sub-systems and devices necessary to preserve safe conditions in the working areas.

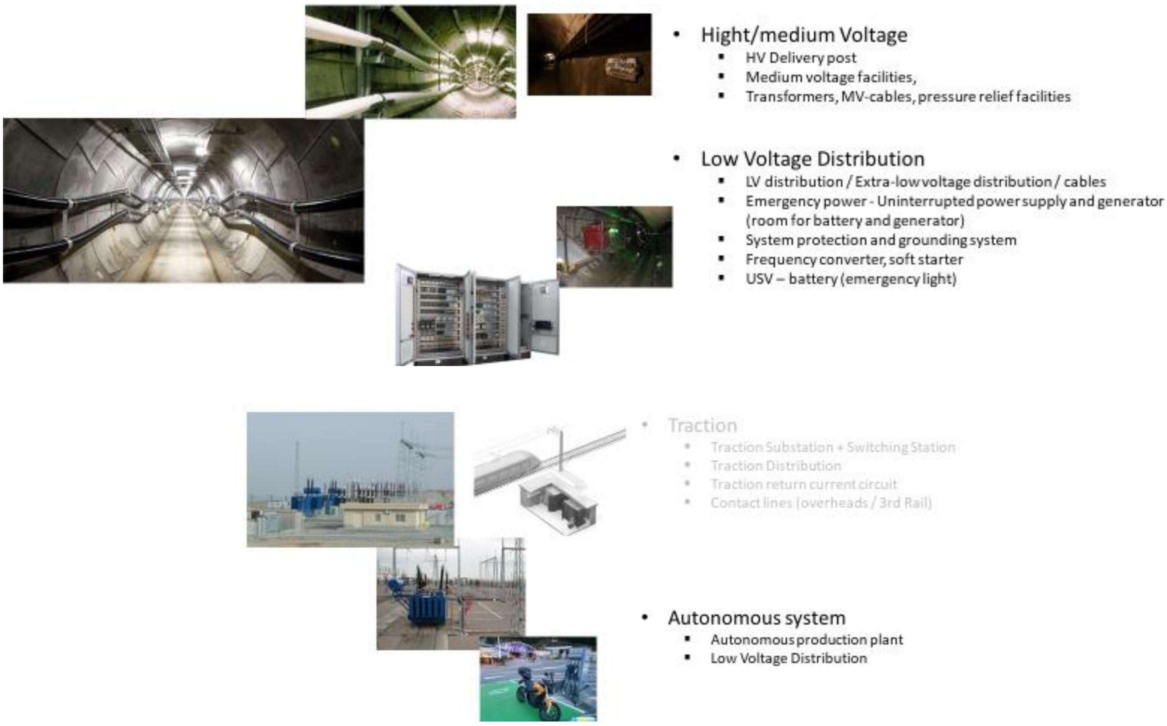
Energy is usually provided by means of one or more provisional delivery points or power sources. In some cases, it can be provided from the definitive connections to the Power network. Depending on the size of the site the delivery can be in MV or LV. In addition, an emergency power supply source is provided to maintain the necessary level of redundancy and availability even in the construction phase. Usually it's a Diesel generator.

A provisional LV distribution provides energy to lighting and to the all sub-systems and equipment in the construction site area.

The earthing and bonding system, together with the electrical protection devices ensure the safety of workers and protect the installation works.

11.5.3 Main components and characteristics

The following section proposes a classification of the main components and sub-components of a power supply system (traction is out-of-scope) :



The main components/sub-components of a power supply system and the foreseen Ifc objects (existing Ifc4.3 objects or new IfcTunnel objects) required to represent them can be summarized as follows:

Power supply system main components			Required Ifc objets		
ID	Components	Sub-components	Existing IfcClass/Enum	Extension IfcClass/Enum	New IfcTunnel
SYS-PSS-HMV-0100	High/medium Voltage				
SYS-PSS-HMV-0110		HV Delivery post			IfcClassTUN
SYS-PSS-HMV-0120		Medium Voltage facilities			IfcClassTUN
SYS-PSS-HMV-0130		Transformers			IfcClassTUN
SYS-PSS-HMV-0140		MV-cables			IfcClassTUN
SYS-PSS-HMV-0150		Pressure relief pacilities			IfcClassTUN
SYS-PSS-LWV-0100	Low voltage distribution				

Power supply system main components			Required Ifc objets		
ID	Components	Sub-components	Existing IfcClass/Enum	Extension IfcClass/Enum	New IfcTunnel
SYS-PSS-LWV-0110		LV distribution		IfcClassEXT	
SYS-PSS-LWV-0120		Extra Low Voltage distribution	IfcClassEXI		
SYS-PSS-LWV-0130		Cables	IfcClassEXI		
SYS-PSS-LWV-0140		Emergency Power – UPS	IfcClassEXI		
SYS-PSS-LWV-0140		Emergency Power – Generator	IfcCassEXI		
SYS-PSS-LWV-0150		System Protection	IfcClassEXI		
SYS-PSS-LWV-0160		Ground system		IfcClassEXT	
SYS-PSS-LWV-0170		Frequency converter	IfcClassEXI		
SYS-PSS-LWV-0180		Soft starter	IfcClassEXI		
SYS-PSS-LWV-0190		Battery (Emergency lighting)		IfcClassEXT	
SYS-PSS-LWV-0200	Autonomous systems				
SYS-PSS-LWV-0210		Autonomous production plant	IfcClassEXI		
SYS-PSS-LWV-0220		Low Voltage distribution	IfcClassEXI		

Figure 11-13: foreseen existing and new Ifc entities for tunnel power supply (NB: IfcClassEXI, IfcClassEXT, IfcClassTUN reflects the foreseen mapping to existing Ifc entities and enumerations, to extensions of existing Ifc entities and enumerations, as well as to new IfcTunnel entities).

The main characteristics that relate to these components/sub-components over the life cycle of tunnel can be summarized as follows:

	Power supply components main functional characteristics							
Design			Construction	Testing		Maintenance		
Input/output parameters	**Functional nominal performance**	**Technical requirements**	**Installation**	**Testing & acceptance**	**Dimensions & maintenance clearance**	**Identfication**	**Maintenance protocole**	**Parts availability & supply**
Civil engineering	Volume to be evacuated	Equipment material	Transportation volume	Protocole	3D dimensions	Manufacturer	Preventive (scheduled)	Stock level
	Power required	Fire resistivity	Fixation type	Functional requirement compliance	3D volume	Production type	Corrective (fixing)	Average supply time
	Availability & Redundancy aspects	MTtF	Protection	Stress tests (max. load)	3D accessibility	Serial#	Predictive (projected)	
						RFID		

11.6 Energized equipments

Under the definition of “Energized equipment” are placed all the mechanical, electrical and electronic equipments and devices necessary for the operation of the tunnel in normal condition and in case of an emergency. They pertain, from a functional point of view, to different sub-systems.

11.6.1 Energized equipments under tunnel operation

Main installations considered in this section are:

- Lighting system
- Data and Communication networks
- Surveillance systems, mainly CCTV and fire detection)
- Telecommunication systems, mainly radio system
- Signage and safety
- Monitoring and Control
- Auxiliary system and equipment (HVAC, fire-fighting, ventilation, doors, gates etc.)

The Lighting system, providing proper luminance level for normal operation and in case of evacuation of the tunnel, is mainly composed by lighting fixtures, cables, junction boxes and lighting control system (sensors, control devices etc.)

Networks for the transmissions of data and information can be local (I.e. lan) or infrastructure wide (I.e. multiservice network) and they are composed by cables and active equipment. Networks support the transmission of video, audio and data of subsystems like CCTV (video), radio, telephones/interphones and Emergency Calls (audio) and monitoring and control (fire detection and traffic monitoring, SCADA (supervisory control and data acquisition)). All the information is generally conveyed to a Central Monitoring and Control.

Some specific system is dedicated to clearly mark evacuation routes and safe places and guide people in the event of an emergency (Signage), whilst signs of a different type are dedicated to the control of traffic:

- Traffic lights for road tunnel
- Signals and signalling devices for railway and metro

No less importantly, Tunnels, related facilities and Control Center, are equipped with installation dedicated to fire protection, fire management and auxiliary equipment to support normal operation.

11.6.2 Energized equipments during tunnel construction

Main installation to be considered in the construction phase are:

- TBM-related power supply
- Conventional excavation drilling systems power supply
- Site installation, buildings accomodation
- Lighting system
- Data and Communication networks
- Surveillance systems (mainly CCTV and fire detection)
- Telecommunication systems (mainly telephones and radio system)
- Signage and safety
- Monitoring and Control
- Auxiliary system and equipment (HVAC, fire-fighting, ventilation, doors, gates etc.)

The Lighting system, providing proper luminance level for construction, installation activities and in case of evacuation of the tunnel, is mainly composed by provisional lighting fixtures, cables, junction boxes and lighting control system (sensors, control devices etc.).

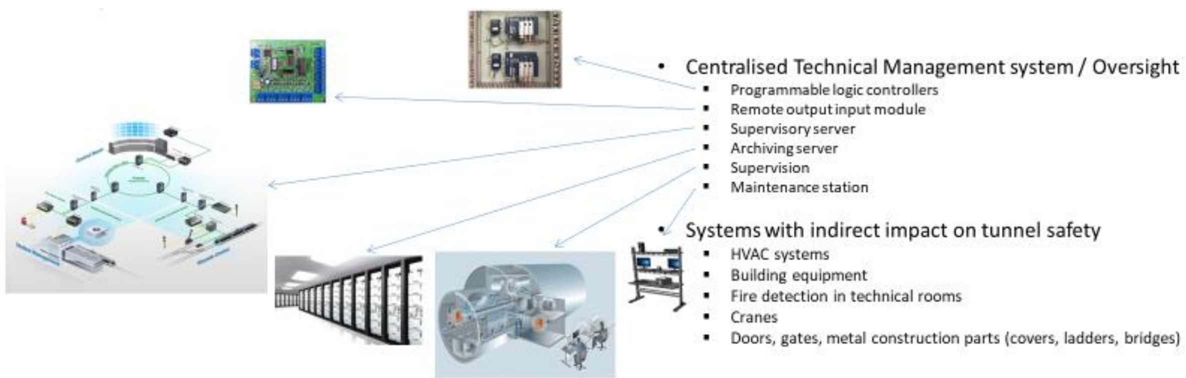
One or more networks for the transmissions of data and information are usually local (I.e. lan) in the construction stage and composed by cables and active equipment. Networks support the transmission of video, audio and data of subsystems like CCTV (video), radio, telephones, monitoring and control (fire detection and SCADA).

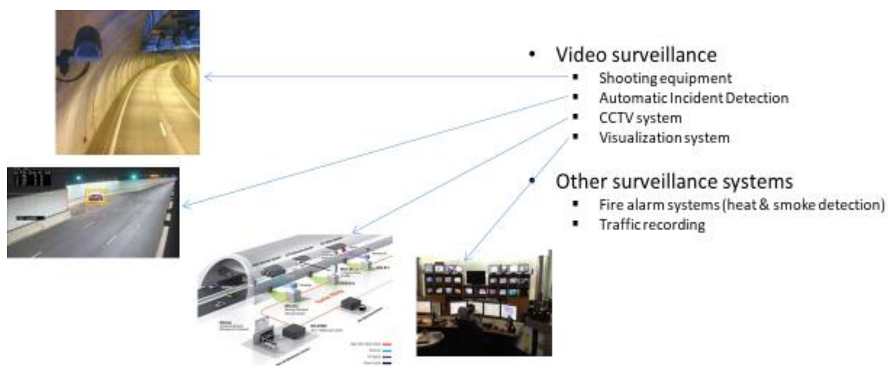
Some specific system is dedicated to clearly mark evacuation routes and safe places and to guide workers in the event of an emergency (signage).

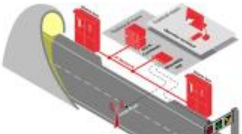
Some traffic lights can also be provided to handle traffic of operational vehicles in the worksite and inside the tunnel.

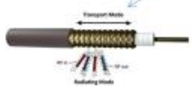
11.6.3 Main components and characteristics

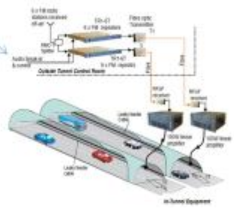
The following section proposes a classification of the main components and sub-components of energized equipments that serve operating a tunnel:



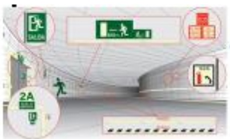








- Emergency Call Network
  - Business Continuity Plan (BCP)
  - Emergency Call Station
  - Server of Emergency Call Station
  - radiating cable
  - Mast
  - Antenna
  - Transmitter / receiver
  - Radio station
- Telecom equipments








- Signage and Safety Equipment
  - Closing and signalling (static and dynamic signage, stop lights, flashlights, emergency exit lighting, SOS-lighting)
  - Auto evacuation
  - Security niche
- Signalling:
  - Raodways
  - Railways
  - Metros
- Various local
  - Ventilation ducts
  - Technical premises
  - PAU and possibly sound device
  - Signage (after the tunnel gate to the assembly point)





- Lighting systems
  - Devices for main tunnel lighting, adaption lighting, emergency lighting, optical guide lighting, escape way lighting
  - Junction boxes, cables
  - Sensors (light density)
  - Lighting control systems
  - Runway lights




- Shelters with tracking
  - Sas
  - Waiting area
  - Geometry related to pedestrian traffic (connection with the outside, for users and rescue)
  - Doors
  - Ventilation of the shelter (including overpressure)
  - Ventilation of the path (direct connection with the outside)
  - Lighting
  - Fire resistance
  - PAU
  - Sound system (speaker)
  - Signage (after the tunnel gate to the assembly point)

The main energized equipments and the foreseen Ifc objects (existing Ifc4.3 objects or new IfcTunnel objects) required to represent them can be summarized as follows:

Energized equipments			**Required Ifc objects**		
ID	**Components**	**Sub-components**	**Existing IfcClass/Enum**	**Extension IfcClass/Enum**	**New IfcTunnel**
SYS-EQP-LHT-0100	Lighting system				
SYS-EQP-LHT-0110		Devices for main tunnel lighting			IfcClassTUN
SYS-EQP-LHT-0120		Junction boxes, cables			IfcClassTUN
SYS-EQP-LHT-0130		Sensors (light density)			IfcClassTUN
SYS-EQP-LHT-0140		Lighting control systems			IfcClassTUN
SYS-EQP-LHT-0150		Runway lights			IfcClassTUN
SYS-EQP-DCN-0100	Data and Communication network				
SYS-EQP-DCN-0110		Optical Fibre junction box		IfcClassEXT	
SYS-EQP-DCN-0120		Optical Fibre cable		IfcClassEXT	
SYS-EQP-DCN-0130		Switch	IfcClassEXI		
SYS-EQP-DCN-0140		Network Supervisor	IfcClassEXI		
SYS-EQP-DCN-0150		GSM Communication (radiating cable)	IfcClassEXI		
SYS-EQP-DCN-0160		Multiservice network	IfcClassEXI		
SYS-EQP-SUR-0100	Surveillance systems				
SYS-EQP-SUR-0110		Shooting equipment	IfcClassEXI		
SYS-EQP-SUR-0120		Automatic Incident Detection	IfcClassEXI		
SYS-EQP-SUR-0130		CCTV system	IfcClassEXI		
SYS-EQP-SUR-0140		Visualization system	IfcClassEXI		
SYS-EQP-SUR-0150		Fire alarm systems (heat & smoke detection)	IfcClassEXI		
SYS-EQP-SUR-0160		Traffic recording			IfcClassTUN
SYS-EQP-TLC-0100	Telecommunication systems				
SYS-EQP-TLC-0110		Telephones			IfcClassTUN
SYS-EQP-TLC-0120		Radio system			IfcClassTUN
SYS-EQP-SIG-0100	Signage and safety				
SYS-EQP-SIG-0110		Closing and signalling			IfcClassTUN
SYS-EQP-SIG-0120		Auto evacuation			IfcClassTUN
SYS-EQP-SIG-0130		Security niche			IfcClassTUN
SYS-EQP-MCS-0100	Monitoring and Control systems				
SYS-EQP-MCS-0110		Programmable logic controllers	IfcClassEXI		
SYS-EQP-MCS-0120		Remote output input module	IfcClassEXI		
SYS-EQP-MCS-0130		Supervisory server	IfcClassEXI		
SYS-EQP-MCS-0140		Archiving server	IfcClassEXI		
SYS-EQP-MCS-0150		Maintenance station		IfcClassEXT	

Figure 11-14: foreseen existing and new Ifc entities for tunnel energized equipments (NB: IfcClassEXI, IfcClassEXT, IfcClassTUN reflects the foreseen mapping to existing Ifc entities and enumerations, to extensions of existing Ifc entities and enumerations, as well as to new IfcTunnel entities).

The main characteristics that relate to these components/sub-components over the life cycle of tunnel can be summarized as follows:

	Energized equipments main functional characteristics							
Design			**Construction**	**Testing**		**Maintenance**		
Input/output parameters	**Functional nominal performance**	**Technical requirements**	**Installation**	**Testing & acceptance**	**Dimensions & maintenance clearance**	**Identfication**	**Maintenance protocole**	**Parts availability & supply**
Civil engineering	Volume to be evacuated	Equipment material	Transportation volume	Protocole	3D dimensions	Manufacturer	Preventive (scheduled)	Stock level
	Power required	Fire resistivity	Fixation type	Functional requirement compliance	3D volume	Production type	Corrective (fixing)	Average supply time
		MTtF	Protection		3D accessibility	Serial#	Predictive (projected)	
						RFID		

11.7 Drainage

In all underground systems, drainage has an important task in maintaining operation and function. They are composed of elements that have a function to collect and channel water within an underground transport infrastructure.

11.7.1 Drainage system during tunnel operation

The drainage system can have different functions:

- Collecting and draining groundwater/mountain water/penetrating water
- Collecting and draining of traffic related liquids (from vehicles/ from trains)
- Collection and discharge of accident water, foams, liquids (FFS)

In a tunnel under operation, it is always necessary to provide for the collection and disposal of sewage from the carriageway or railway platform (rain, washing of walls) to which may be added, if necessary, liquids from accidental spillages.

Sewage water comes mainly from water on the road or railway platform (rain, washing of pedestals). As this water is polluted by traffic residues, it has to be collected and evacuated in a separate network so that it can be treated before discharge into the natural environment.

The separation system also makes it much easier to deal with the collection and storage of dangerous and/or polluting liquids that may be accidentally spilled on the roadway.

The sewage collection device has four parts:

- a primary collection network on the roadside,
- siphons and their associated cover (to prevent fire spreading into pipes),
- a main drain,
- a retention device at the tunnel exit or at a low-point cavern (under the subgrade)

Whatever the quality of the lining set, water leakages from the ground/mountain need to be collected and either diverted to a dedicated drainage system or to the raodway/railway polluted water drainage system.

Drainage water from the soil/rock is generally collected by a double system of pipes:

- at the base of the walls, against the waterproofing membrane,
- under the roadway: the general drain is placed low enough to capture, by means of antennas, localized low points that may have been revealed during the invert stripping.

The design of drainage strictly connected with civil works, so during the design all the constraints in terms of space proofing of tunnel cross section and all the works needed for drainage (like catch drains, collecting wells, ditches/gutters, manholes, and retention basins) shall be coordinated and planned with the civil engineers.

These systems must be checked and cleaned 1-2 times a year (tunnel being closed to traffic). For this reason, the surveillance and maintenance protocol (access paths, maintenance clearance, protection) must be taken into account at design time.

11.7.2 Drainage system during tunnel construction

Drainage during the tunnel construction phase is carried out during the excavation phase, or even during the support phase. It makes it possible to anticipate the risks of break-up and flooding by modifying the natural pathways and facilitates the execution of the works. Occasional water inflows are picked up as close to the face as possible. The catchment consists of drilling holes that are arranged either in a halo or an umbrella, i.e. obliquely beyond of the face.

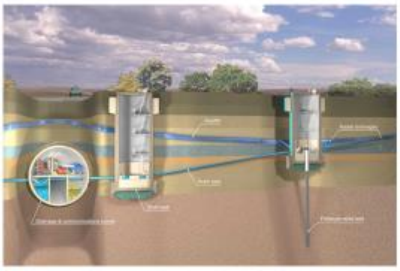
The drainage systems are designed so the water does not encounter any obstacles. The choice will depend on the flow rates observed, the length of the structure to be drained and the configuration of the longitudinal profile (rising or sinking attack).
In the sinking approach, pumps will be installed in sumps. The pumped water will be discharged into a temporary pipe.

In the rising approach, the water will be evacuated by gravity to the outside, either through a gully at the base of each side wall or in a temporary pipe.

The specifics of power supply used during construction needs to be described.

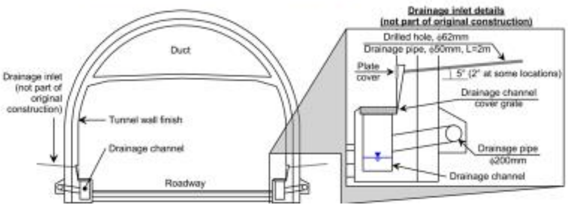
11.7.3 Main components and characteristics

The following section proposes a classification of the main components and sub-components of a drainage supply system that collect and channel terrain water and the roadway/railway platform waste water :



- Network of Drainage - Sanitation
  - Identification data of drainage-sanitation network
  - Typology of drainage-sanitation network
  - Information of network control
  - Information of network Implementation (Implementation)
  - Information of network construction (activities)
  - Information of Network Maintenance (Activities)
  - Information of Network dismantling (activities)
  - Transport of effluents
  - Absorption of effluents (terminals)
  - Acces to the Network Sewing
  - Management of effluent

- Drained Space
  - Typology of drained space
  - Typology of effluents
  - Liaisons between objects
  - Topological data of collected surface
  - Hydraulic surface data collected



- Water point
  - Typology of water point
  - Data of water point identification
  - Liaisons between objects
  - Hydraulic data of water point

The main components/sub-components of a drainage system and the foreseen Ifc objects (existing Ifc4.3 objects or new IfcTunnel objects) required to represent them can be summarized as follows:

Drainage system main components			Required Ifc objets		
ID	**Components**	**Sub-components**	**Existing IfcClass/Enum**	**Extension IfcClass/Enum**	**New IfcTunnel**
SYS-DRN-NET-0100	Drainage network				
SYS-DRN-NET-0110		Transport of effluents: pipes, pipes coating, frisking, trench fill,	IfcClassEXI ,	IfcClassEXT	
SYS-DRN-NET-0120		Absorption of effluents: punctual, linear, area absorption	IfcClassEXI		
SYS-DRN-NET-0130		Access to the sewing network: cover device, acces hopper for the	IfcClassEXI		
SYS-DRN-NET-0140		Management of effluent: containment	IfcClassEXI		
SYS-DRN-SPA-0100	Drained space				
SYS-DRN-SPA-0110		Typology of drained space		IfcClassEXT	
SYS-DRN-SPA-0120		Typology of effluents		IfcClassEXT	
SYS-DRN-SPA-0130		Liaisons between objects	IfcClassEXI		
SYS-DRN-SPA-0140		Topological data of collected surface		IfcClassEXT	
SYS-DRN-SPA-0150		Hydraulic surface data collected			IfcClassTUN

Drainage system main components			Required Ifc objets		
ID	**Components**	**Sub-components**	**Existing IfcClass/Enum**	**Extension IfcClass/Enum**	**New IfcTunnel**
SYS-DRN-PTS-0100	Water points				
SYS- DRN-PTS-0110		Typology of water point		IfcClassEXT	
SYS- DRN-PTS-0120		Data of water point identification		IfcClassEXT	
SYS- DRN-PTS-0130		Liaisons between objects	IfcClassEXI		
SYS- DRN-PTS-0140		Hydraulic data of water point			IfcClassTUN

Figure 11-15: foreseen existing and new Ifc entities for tunnel drainage (NB: IfcClassEXI, IfcClassEXT, IfcClassTUN reflects the foreseen mapping to existing Ifc entities and enumerations, to extensions of existing Ifc entities and enumerations, as well as to new IfcTunnel entities).

The main info exchanged related the components and sub-components of a drainage system can be classified as in the matrix below:

	Drainage system main functional characteristics							
Design			**Construction**	**Testing**		**Maintenance**		
Input/output parameters	**Functional nominal performance**	**Technical requirements**	**Installation**	**Testing & acceptance**	**Dimensions & maintenance clearance**	**Identfication**	**Maintenance protocole**	**Parts availability & supply**
Civil engineering	Volume to be evacuated	Equipment material	Transportation volume	Protocole	3D dimensions	Manufacturer	Preventive (scheduled)	Stock level
	Power required	Fire resistivity	Fixation type	Functional requirement compliance	3D volume	Production type	Corrective (fixing)	Average supply time
		MTtF	Protection		3D accessibility	Serial#	Predictive (projected)	
						RFID		

11.8 Safety & evacuation

In underground systems, such as road, train and metro tunnels, self-evacuation is critical. Due to comparatively long escape way in enclosed areas with high fire loads and usually high air/smoke speeds, it is crucial for people to act fast in direction to flee.

The quicker people react, the better their escape conditions are, because smoke can spread quickly in any direction.

11.8.1 Safety & evacuation during tunnel operation

Safety equipment in tunnels fulfill different functions. If possible, self-firefighting should be executed immediately. If no fire extinguisher is available on the vehicle that is on fire, SOS signals and pictograms lead to the next fire extinguisher and to the next emergency call telephone. If fire extinction fails, self-rescue should start immediately.

In this context, safety equipment helps to find the correct escape way and the nearest escape exits into a safe area. This task is taken over by static escape signals / pictograms, flash fires, guide chevrons and neons.

Escape doors normally have the signal color green, bordered with green lights, escape signals and flash fires. There are different types of escape doors available: swing doors, sliding doors and revolving doors with or without opening assistance. The door type normally depends on the boundary conditions in the tunnel like spacing, pressure profiles and ventilations strategies.

Escape doors lead into a safe area. Depending on the tunnel system, the parallel tube, the cross connections, safety rooms / safety spaces and escape tunnels can be defined as safe areas. Safe areas are characterized as smoke free areas.

To prevent smoke from entering they are normally equipped with pressurization ventilation systems, especially, when there is no direct exit to the outer environment available (save waiting room), when the escape tunnels are long or due to a high – difference buoyancy forces can be expected.

If a pressurization ventilation system is installed in a safe area the escape toward the outer environment way often passes through air looks.

Due to the relatively long time between a fire alarm and the arrival of fire fighting forces, fast self-rescue is of most importance. Rescue by fire fighters will start with a time delay. In some projects, if self-rescue and rescue by fire fighters can occur at the same time, escape ways for passengers and access path for fire fighters are separated.

11.8.2 Safety & evacuation during tunnel construction

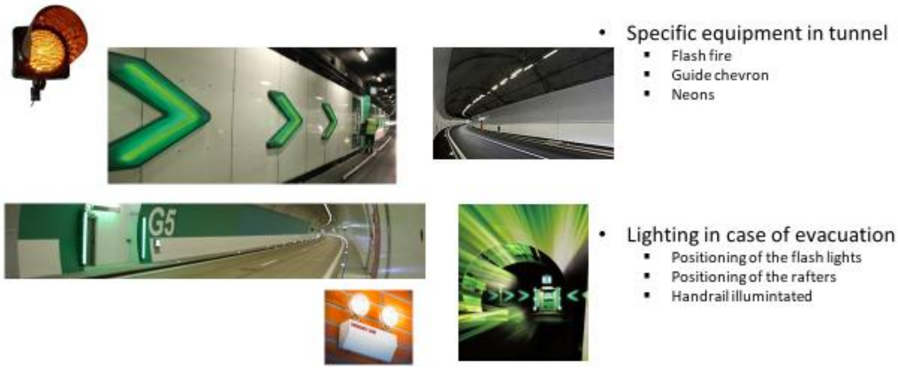
The specifics of safety & evacuation during construction needs to be described.

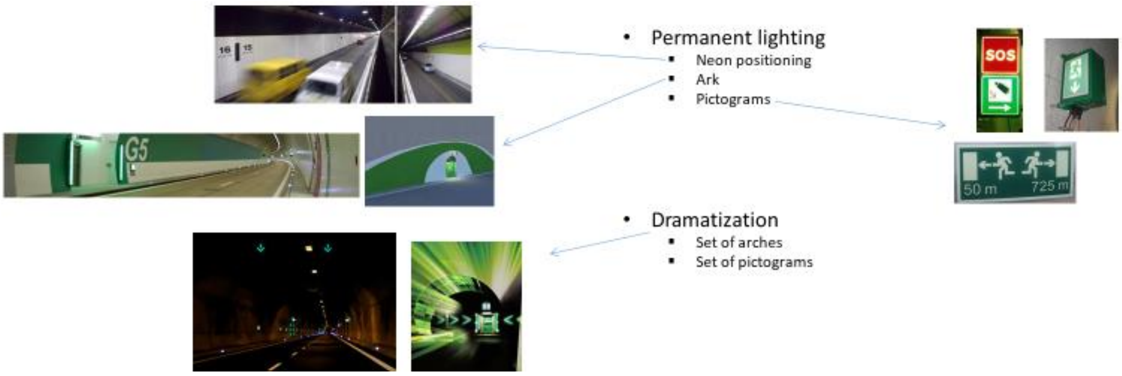
Compared with safety & evacuation during normal operation, the main difference during the construction phase lies in the fact, that only safety instructed persons are allowed on the construction site. Disaster recovery plans are provided.

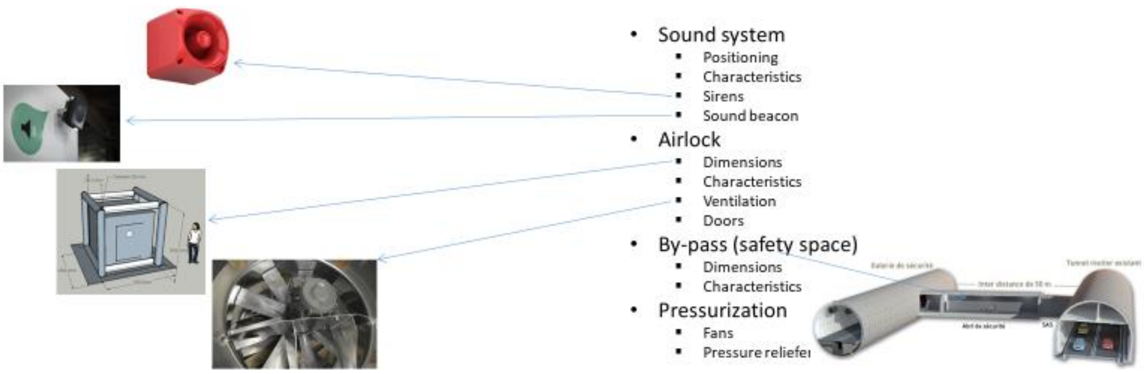
They define all measures that need to be fulfilled to ensure a safe working environment and a save evacuation from any location within the construction site, e.g.: personal protective equipment (incl. oxygen masks), gas sensors, provisional safety rooms, escape signals / pictograms, flash lights, horns, lightning, fire extinguisher. If available, escapeways are equipped with pressurization ventilation systems.

11.8.3 Main components and characteristics

The following section proposes a classification of the main components and sub-components of a safety & evacuation system in roadway, railway of metro tunnels:







The main components/sub-components of a safety system and the foreseen Ifc objects (existing Ifc4.3 objects or new IfcTunnel objects) required to represent them can be summarized as follows:

Safety & evacuation main components			Required Ifc objets		
ID	**Components**	**Sub-components**	**Existing IfcClass/Enum**	**Extension IfcClass/Enum**	**New IfcTunnel**
SYS-SAF-SIG-0100	Specific signalling				
SYS-SAF-SIG-0110		Flash fire			IfcClassTUN
SYS-SAF-SIG-0120		Guiding chevrons			IfcClassTUN
SYS-SAF-SIG-0130		Neons			IfcClassTUN
SYS-SAF-EVA-0100	Lighting during evacuation				
SYS-SAF-EVA-0110		Flashlights		IfcClassEXT	
SYS-SAF-EVA-0120		Rafters		IfcClassEXT	
SYS-SAF-EVA-0130		Illuminated handrails	IfcClassEXI		
SYS-SAF-LTG-0100	Permanent lighting				
SYS-SAF-LTG-0110		Neons	IfcClassEXI		
SYS-SAF-LTG-0120		Arcs	IfcClassEXI		
SYS-SAF-LTG-0130		Pictogramms	IfcClassEXI		
SYS-SAF-DRA-0100	Dramatization				
SYS-SAF-DRA-0110		Set of arches			IfcClassTUN
SYS-SAF-DRA-0120		Set of pictograms			IfcClassTUN
SYS-SAF-SOU-0100	Sound system				
SYS-SAF-SOU-0110		Sirens	IfcClassEXI		
SYS-SAF-SOU-0120		Sound beacon	IfcClassEXI		
SYS-SAF-AIR-0100	Airlocks				
SYS-SAF-AIR-0110		Ventilation	IfcClassEXI		
SYS-SAF-AIR-0120		Doors	IfcClassEXI		
SYS-SAF-BYP-0100	By-passes				
SYS-SAF-BYP-0110		By-pass	IfcClassEXI		
SYS-SAF-PRS-0100	Pressurization				
SYS-SAF-PRS-0110		Pressurization	IfcClassEXI		

Figure 11-16: foreseen existing and new Ifc entities for tunnel safety & evacuation
(NB: IfcClassEXI, IfcClassEXT, IfcClassTUN reflects the foreseen mapping to existing Ifc entities and enumerations, to extensions of existing Ifc entities and enumerations, as well as to new IfcTunnel entities).

The main info exchanged related the components and sub-components of a safety system can be classified as in the matrix below:

	Safety system main functional characteristics							
Design			Construction	Testing		Maintenance		
Input/output parameters	**Functional nominal performance**	**Technical requirements**	**Installation**	**Testing & acceptance**	**Dimensions & maintenance clearance**	**Identfication**	**Maintenance protocole**	**Parts availability & supply**
Civil engineering	Volume to be evacuated	Equipment material	Transportation volume	Protocole	3D dimensions	Manufacturer	Preventive (scheduled)	Stock level
	Power required	Fire resistivity	Fixation type	Functional requirement compliance	3D volume	Production type	Corrective (fixing)	Average supply time
	Conpliance with safety & evacuation concepts	MTtF	Protection		3D accessibility	Serial#	Predictive (projected)	
	Compliance with ventilation concept					RFID		

11.9 Fire protection

Fixed firefighting systems (FFS) are an active way of combating fires in tunnels and underground infrastructure.

11.9.1 Firefighting during tunnel operation

For fire protection in tunnel, water-based firefighting systems are the most widely used.

The main systems are Fire Hydrant Systems, Standpipe System, Automatic Sprinkler Systems, Water Spray Systems, Water Mist Systems and Foam Systems etc.

In addition, there exists the use of passive FFS equipments like siphons, retention tanks, oil capture separators.

FFS are normally installed to improve both life safety and asset protection. The general requirements for FFS are listed in the table below. Depending on the technology applied, the above-mentioned requirements can be met at different levels.

Requirement	Method	Effect
Improvement of self-rescue conditions	Immediate cooling of fire and surrounding volume Reduction of smoke production, better visibility Binding smoke and sooth Less toxic gases	Tunnel users have safer conditions for evacuating themselves or having better survivability conditions in case of being trapped
Improvement of access of fire services	Limiting heat release rate (HRR) Immediate cooling of fire and surrounding volume Reduction of smoke production, better visibility Blocking radiant heat	Fire and rescue services have easier access to the fire to fight the fire. Access can be done from both sides of fire with normal protective equipment. Systems increase fire fighters' safety significantly
Prevention of fire spread	Limiting heat release rate Immediate cooling of fire and surrounding volume Blocking radiant heat	Fire will be limited to the initial vehicle, which is very essential in case of HGVs (trucks) in road tunnel
Limiting damages to tunnel structure	Immediate cooling of fire and surrounding volume Blocking radiant heat	Tunnel structure and other equipment will not be under same time/temperature exposure as used without system. Enables shorter recovery time after fires

Figure 11-17: tunnel FFS requirements & means to address them.

The architecture of these systems basically consists in the following equipment:

- Water tank, to be installed near the pressurization group,
- Pressurization pump group,
- Pipeline network, that can be ring or linear type, including valves and accessories
- Discharge device (hydrant, nozzle, etc.)

In addition to water based firefighting systems, usually fire extinguishers are provided in the tunnel, in regular distance, to allow tunnel users and staff to contrast a small fire before the arrivals of fire brigades.

11.9.2 Firefighting during tunnel construction

During construction, fire risks exist even though the tunnel is not in operation yet. Some flammable materials are present during construction: waterproof geomembrane, jumbos, TBM, etc. with oil and fuel even though if electric power is favoured (with its own risks, fire included). The presence of hot spots (welding, cutting, etc.) increases the risk of fire.

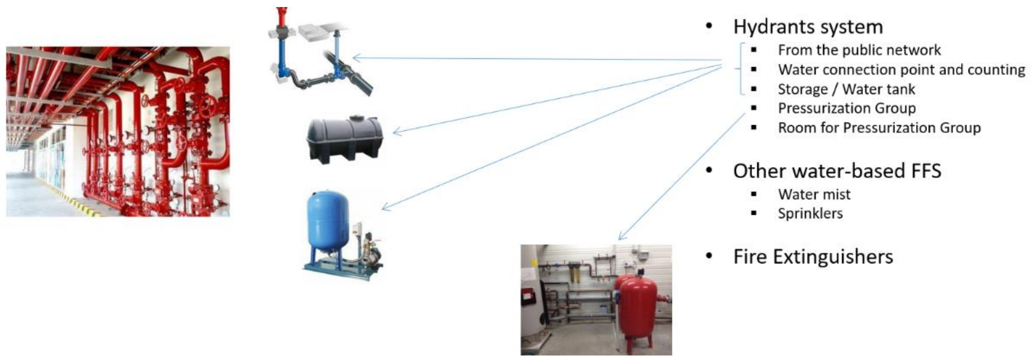
Prevention consists in reducing the presence of flammable materials. If fire still occurs, extinguishing means must be used. In addition to conventional extinguishers, specific devices can be found on the tunnel boring machines, such as:

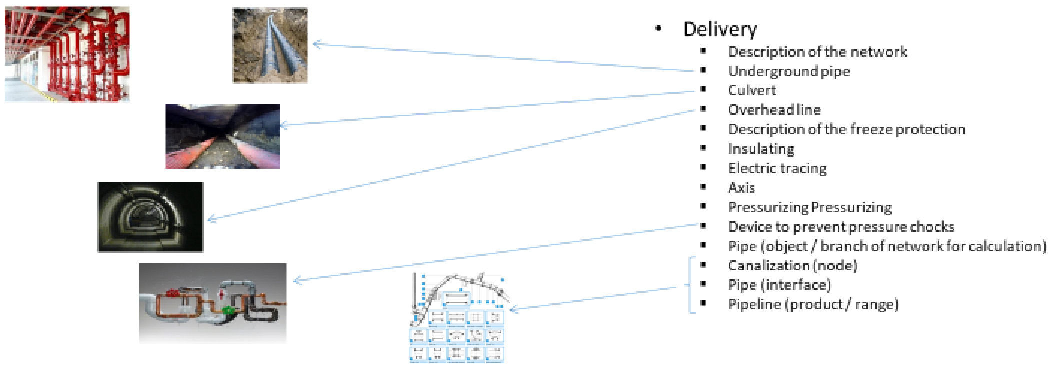
- a fire detection system covering the entire TBM,
- an extinguishing system,
- a water curtain at the rear of the TBM,
- pressurized survival cabins with air reserve,
- automatic foam diffusers to smother the fire at its origin.

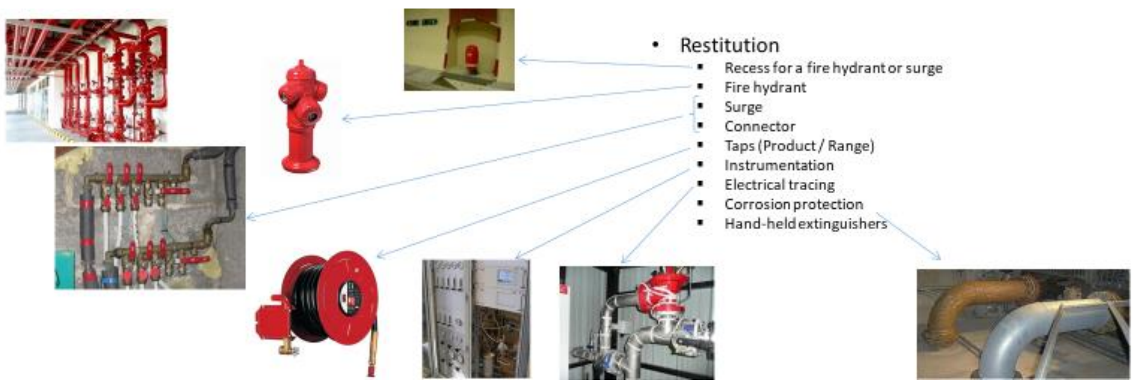
We can also mention the firefighter's wet column sockets, telephone sockets, tunnel fire alarm siren, emergency blocks, tunnel radio, badges and video surveillance at the tunnel entrance.

11.9.3 Main components and characteristics

The following section proposes a classification of the main components and sub-components of a fire fighting system that protects the underground infrastructure and the people who build it and the ones who use it :







The main components/sub-components of a fire fighting system and the foreseen Ifc objects (existing Ifc4.3 objects or new IfcTunnel objects) required to represent them can be summarized as follows:

Firefighting system main components			Required Ifc objets		
ID	**Components**	**Sub-components**	**Existing IfcClass/Enum**	**Extension IfcClass/Enum**	**New IfcTunnel**
SYS-FFS-HYD-0100	Hydrants systems				
SYS- FFS-HYD -0110		Public network		IfcClassEXT	
SYS- FFS-HYD -0120		Water connexion points			IfcClassTUN
SYS- FFS-HYD -0130		Storage & cisterns			IfcClassTUN
SYS- FFS-HYD -0140		Pressuring group			IfcClassTUN
SYS- FFS-HYD -0150		Pressuring group room			IfcClassTUN
SYS-FFS-SYS-0100	Other FFS				
SYS- FFS-SYS -0110		Water mist		IfcClassEXT	
SYS- FFS-SYS -0120		Sprinklers		IfcClassEXT	
SYS- FFS-SYS -0130		Fire Extinguishers		IfcClassEXT	
SYS-FFS-NET-0100	Water network				
SYS-FFS-NET-0110		Underground pipe		IfcClassEXT	
SYS-FFS-NET-0120		Culvert		IfcClassEXT	
SYS-FFS-NET-0130		Overhead line		IfcClassEXT	
SYS-FFS-NET-0140		Freeze protection			IfcClassTUN
SYS-FFS-NET-0150		Insulating			IfcClassTUN
SYS-FFS-NET-0160		Pressure shock prevention		IfcClassEXT	
SYS-FFS-NET-0170		Pipes & pipelines		IfcClassEXT	
SYS-FFS-NET-0180		Canalization nodes		IfcClassEXT	
SYS-FFS-DEL-0100	Delivery				
SYS-FFS-DEL-0110		Hydrant		IfcClassEXT	
SYS-FFS-DEL-0120		Surge		IfcClassEXT	
SYS-FFS-DEL-0130		Taps		IfcClassEXT	
SYS-FFS-DEL-0140		Instrumentation		IfcClassEXT	
SYS-FFS-DEL-0150		Corrosion protection		IfcClassEXT	
SYS-FFS-DEL-0160		Electrical components		IfcClassEXT	

Figure 11-18: foreseen existing and new Ifc entities for tunnel FFS
(NB: IfcClassEXI, IfcClassEXT, IfcClassTUN reflects the foreseen mapping to existing Ifc entities and enumerations, to extensions of existing Ifc entities and enumerations, as well as to new IfcTunnel entities).

The main info exchanged related the components and sub-components of a fire fighting system can be classified as in the matrix below:

	FFS system main functional characteristics							
Design			**Construction**	**Testing**		**Maintenance**		
Input/output parameters	**Functional nominal performance**	**Technical requirements**	**Installation**	**Testing & acceptance**	**Dimensions & maintenance clearance**	**Identfication**	**Maintenance protocole**	**Parts availability & supply**
Civil engineering	Volume to be evacuated	Equipment material	Transportation volume	Protocole	3D dimensions	Manufacturer	Preventive (scheduled)	Stock level
Fire Brigades requirements	Power required	Fire resistivity	Fixation type	Functional requirement compliance	3D volume	Production type	Corrective (fixing)	Average supply time
	Water tank capacity	MTtF	Protection		3D accessibility	Serial#	Predictive (projected)	
		Pressure requirements				RFID		

12 Model View Definitions

The IFC schema embeds a wide spectrum of concepts being objects definitions, relationships, and properties: it covers constructed components, sensors, conditions (states), activities, references to documents, etc.

Depending upon its focus, every software involved in one or several steps of the development of a tunnel will only implement import/export capacities in relation with its own internal model, thus only using of subset of the global IFC model. A model view definition (MVD) allows to specify the subset of the IFC schema that is supposed to be implemented for a specific use case.

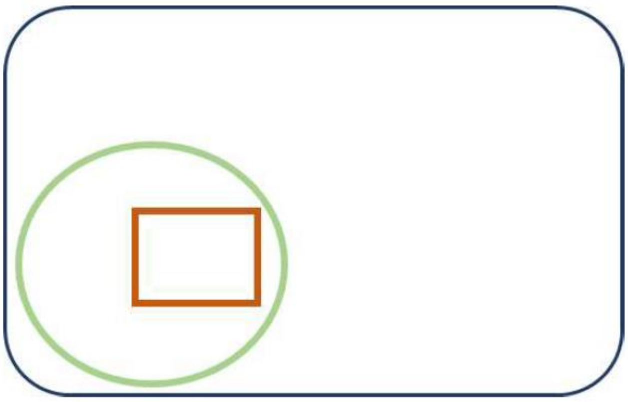


Figure 12-1: The schema (blue), subset MVD (green) and information requirements (orange), Source: L. van Berlo

An MVD also serves as a base for the certification of the software in question.

There exist today two main MVDs for IFC4:

- Reference view,
- Design transfer view,

Basically, they support/demand the representation of geometry on two different complexity levels: simple geometry conformance (Reference view), and advanced geometry with transferred parametric definitions (Design transfer view).

In order to facilitate the implementation of the required import/export functionalities in software applications , we propose a set of 4 to 6 MVDs, serving the main sub-domains and/or relevant use cases (alignment optimization, geotechnics, phasing, excavation/support/lining, systems, GIS/AM), e.g.:

- Tunnel Reference View (Tunnel RV)
- Alignment-based Tunnel Reference View (Tunnel ARV)
- Tunnel Design Transfer View (Tunnel DTV)
- Tunnel Asset Management Handover View (Tunnel AMV)

The Tunnel Sub-section Reference View and the Tunnel Design Transfer View should be aligned with the existing IFC4 MVDs, whilst extending them where necessary to capture the specifics of tunnels.

The basic differentiation between IFC4 RV and IFC4 DTV would also be applied to the Tunnel MVDs, as follows:

- *IfcCSGSolid* (Constructive Solid Geometry = Boolean Operations on Solids) would not be supported by the Tunnel sub-section RV, but by the Tunnel DTV.
- the support of *IfcAdvancedBrep* is only realized in the Tunnel DTV.
- *IfcPolygonalFaceSet* must be used for representing BRep geometry in RV.
- Curved surfaces (NURBS) are not supported by RV.

The Alignment-based Tunnel Reference View (Tunnel ARV) extends the IFC4 Reference View by supporting *IfcAlignment (IFC4.1)*. The reason for introducing these MVD lies in the importance of alignment for linear underground infrastructure.

However, basic non-infrastructure related IFC viewers would not support IfcAlignment but should still be capable to visualize tunnel BIM models. Therefore the basic Tunnel RV will not demand *IfcAlignment* be supported, but will instead support explicit geometry and Cartesian coordinates for positioning.

Phase 2 of the IFC-Tunnel project will deliver precise definitions of the MVDs as well as an assignment of the individual MVDs to the use cases defined in Section3 of this report.

13 Next Steps

Based on this report, in the next Work Package (WP3), the project team will develop the conceptual model of the IFC-Tunnel extension.

The team will identify the object types and attributes that are required for describing the various components and processes involved in the development, maintenance and operation of tunnels. The conceptual model will be based on the tunnel taxonomy that has been created as part of WP2 defining all necessary terms used in the context of tunnel engineering and operation. The development of the conceptual model will include the mapping of the identified concepts to existing or new IFC entities. The activities will also comprise to specify new IFC data structures (classes / enums) where necessary.

Once the conceptual model is finished, the actual schema extension can be developed on its basis. It will undergo an intense review process and finally be published as IFC 4.4 candidate standard. The implementation of the IFC-Tunnel extension in professional software packages will subsequently be fostered in the frame of bSI IR's Deployment project and the support services it offers.

14 Conclusion

The present report is featuring the final results of the work carried out by the IfcTunnel project Team for Phase 1, which focused on producing 31 tunelling domain-specific uses cases and on deriving from these a detailed requirements analysis, with a view to identify the necessary IFC schema extensions for tunnel-specific objects classes to be developed in the project Phase 2.

This Requirement Analysis Report details the necessity and feasibility to develop IfcTunnel with the concern to consolidate common concepts like geospatial positioning and geotechnics in order to derive common items between bridges, railways, ports and tunnels objects.

Although the opinions expressed during the process of assessing priorities for the use cases varied, we identified the most relevant ones through feedback from 3 expert panels, on the basis of 2 criterion: the use case's impact (the value it brings) and its feasibility (ease of development).

The IfcTunnel project Team investigated in details the required geospatial positioning requirements applicable for linear infrastructures to be organized from the viewpoint of a common understanding in all ongoing bSI InfraRoom projects (IfcRoad, IfcBridge, IfcTunnel) as well as in the IfcRail project.

The Team classified the tunnel object from the perspective of its function on one hand, being to support a railway, a roadway or utilities, as well as of its construction method on another hand, being TBM-based, conventional or cut-and-cover. Reason being that a tunnel with a given function might require a mix of construction technics given the underground conditions encountered.

A specific in-depth investigation was conducted around seizing the geotechnical situations, and their uncertainties, that obviously have an impact on the design process, and its iterations, and the construction of a tunnel in a soil-structure interaction context. The requirements which the IfcTunnel Team concluded to at that level led to the need for specific geotechnics objects classes (as extensions to the Ifc Common Schema) supported by a common semantic shared with similar OGC-driven forthcoming concepts.

As expected, the IfcTunnel project Team covered in detail the construction methods (most widely used today, or as innovative approaches eg, VBM for shafts) around 3 main aspects: excavation itself, excavation support and lining. This analysis was conducted both in a soft soil context as well as in a rock context, to reflect the different situations faced by the projects worldwide. The outcome is a detailed taxonomy of the components built given the methods used.

Last but not least, the Team made a complete assessment of the different functional systems (ventilation, lighting, drainage, safety, FFS, etc) that are necessary to operate a tunnel, given its function (roadway, railway, utilities), and the many equipments (and their characteristics) that make provide the functional capacities required. There too a detailed taxonomy has been developed.

The above mentioned taxonomies are the foundation for further work in Phase 2.

In Phase 2, we will proceed with the specification of the IfcTunnel conceptual model and the development of the Ifc schema extensions, as well as with their deployment with a detailed project execution plan covering both geometric and semantic information, with UML diagram, Property set definitions with bSDD, IFC schema extension for IfcTunnel , MVDs, software deployment support (part of bSI's Deployment project), testing, and the final version of documentation for IfcTunnel.

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List of annexes