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GUIDELINES FOR ROAD DESIGN, CONSTRUCTION, MAINTENANCE AND SUPERVISION

VOLUME I: DESIGNING

SECTION 4: TUNNELS

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1.4.1 SUBJECT OF DESIGN GUIDELINES

Tunnel construction is an exacting interdisciplinary job. The works are carried out in geological medium, which is never completely known. Plenty of works relating to the tunnel construction are similar to certain works connected with the construction of roads on the surface. However, due to the fact that the tunnel construction in carried out in a limited and specific space, its execution is quite aggravated. As the works are performed under the surface, some activities occur, which are never encountered on the surface. As a consequence of a wide range of possible conditions, numerous technological solutions have been developed in the tunnel construction.

The present design guidelines provide recommendations for different works occurring in the road tunnel construction:

- Principles of tunnel design: basic principles to be followed in the tunnel construction are indicated ,
- Basic design criteria: basic design criteria are provided relating to the number of tunnel tubes, clear dimensions of the tunnel cross-section, tunnel ascent and descent, and tolerances ,
- Investigation of the rock: investigation stages are indicated taking place after the road route has already been determined; they serve as support at the design stage ,
- Methods of planning and systems of rock classification: methods of planning the tunnel retaining system and the classification of rock masses are given; these methods play an important role in the tunnel design ,
- Tunnel excavation design: activities are presented, which are directly connected with the excavation stage and establishing the basic tunnel timbering (geotechnical model, monitoring and measurements of air in the tunnel, ventilation, excavation and basic timbering methods),
- Tunnel lining design: design and execution of inner tunnel lining, portals, waterproofing, drainage, and kinetes for installations are presented,
- Instruments and measurements: technical equipment intended for the measurements is described, and the purpose and the method of performing the measurements are presented
- Tunnel ventilation: basic guidelines for the execution of a tunnel ventilation system during the tunnel service life are given ,
- Tunnel lighting: fundamental guidelines for the execution of tunnel lighting are provided ,
- Tunnel management: basic guidelines for an optimum tunnel management are indicated
- Organization of tunnel operation .

1.4.2 DEFINITIONS – TERMINOLOGICAL VOCABULARY

ACCELERATOR	Powder or liquid admixture that accelerates the reaction of cement, especially to shorten the time of setting and increase the rate of early strength development in shotcrete. Different formulations and dosages can be used to regulate the rate of this reaction which, in shotcrete, can achieve initial set in a few minutes or less.
ACCESS TUNNEL	Passage from surface to areas of underground excavation. See also "adit"
ADMIXTURE	A material added to a concrete or shotcrete mix, which alters the properties of the mix or the final product.
ADVANCE	The distance excavated during a given time (shift or day) in tunnelling, drifting, or in raising or sinking a shaft.
ANCHOR BOLT	Bar, usually made of steel, used for the stabilization of rock. Placed into a drilled hole and anchored in the rock at the end (end anchorage) or along its whole length (grouted bolt). The visible extremity is often fitted with a plate.
AQUIFER	(1) A water-bearing layer of permeable rock or soil; (2) A formation, a group of formations, or a part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.
ARCH	The configuration of the upper portion of a tunnel section above the springline (crown, roof or back of a tunnel).
BACKFILL	Any material used to fill the empty space between a linning system and excavated rock or soil surface.
BENCH	A berm or block of rock within the final outline of a tunnel that is left after a top heading has been excavated.
BIT	A star or chisel pointed tip forged or screwed (detachable) to the end of a drill steel.
BLOCKY ROCK	Rock having joints or cleavage spaced and oriented in a manner such that it readily breaks into loose blocks under excavation conditions.
BORE	In reference to construction operations, the making of a relatively large hole in earth or rock with an excavating device, while removing the muck mechanically or with the aid of gravity. Distinguished from drill.
BREAK	Fragmentation of solid rock as a result or the explosion of an explosive mixture in drill holes at the heading.
CAGE	An enclosed platform, similar to an elevator car, used to transport men and miscellaneous material up and down a shaft.
CHAMBER	A relatively short, underground room-type opening of large cross-sectional area, generally built to house a special structure such as a hydroelectric power plant, hardened defense facility or storage for waste.
CHANGED CONDITIONS	Physical site conditions revealed by excavation to be substantially different from the conditions that could reasonably be anticipated from information in the contract documents. Common basis for litigation by contractor, sometimes resulting in an extra paid by owner.
CHEMICAL GROUT	A combination of chemicals that gel into a semi-solid after they are injected through drilled holes to strengthen incompetent ground (generally soil), or to prevent groundwater from flowing into the excavation.
CIRCULAR TUNNEL	A tunnel of circular cross section, generally made with a full circular shield or tunnel boring machine.
CO LIMIT	Maximum admissible limit of pollution produced by Carbon Monoxide.
CO, CO2	Carbon monoxide, carbon dioxide. Common pollutants monitored in urban areas. Work has been directed at understanding the total cost to society of the release of such pollutants

COHESION	A measure of the shear strength of a material along a surface with no perpendicular stress applied to that surface.
COMPENSATION GROUTING	A system by which grout is injected into the ground above a tunnel and below man-made surface features. The intention is to reduce the effects of surface settlement caused by the tunnelling works.
COMPETENCE OF ROCK / GROUND	A measure of its capacity to resist deformation under load
COMPETENT ROCK / GROUND	Rock/ground that can stand for relatively long periods with no support or only minimal support when a tunnel is excavated through it.
CONSOLIDATED MATERIALS	Earth materials, generally of sedimentary origin, which have been firmly densified or converted into rock by compaction, deposition of cement in pore spaces, and/or by physical and chemical changes in the constituents.
CONSOLIDATION	(1) In classical geology, any or all of the processes whereby loose, soft, or liquid earth materials become firm and coherent; (2) In soil mechanics, the adjustment of a saturated soil in response to increased load involving the squeezing of water from the pores and decrease in void ratio.
CONTRACT MODIFICATION	Change in a construction contract that either increase or decrease the scope of work, amount of materials, or length of performance time originally envisaged.
CONTROLLED BLASTING	Use of patterned drilling and optimum amounts of explosives and detonating devices to control blasting damage.
CONVENTIONAL EXCAVATION / MINING	Traditional, labor-intensive excavation such as hand mining in soft ground and drill-and-blast mining in rock. Distinguished from the more highly mechanized methods of mining.
CONVERGENCE	Changes in the distance between fixed points on a (cross-section of a) tunnel lining as a result of loading on the lining
CORE TEST	Compression strength test on a concrete sample cut from hardened concrete or shotcrete by means of a core drill.
CORRECTIVE MEASURES	Group of measures adopted in order to restore environmental damages caused in the construction.
COVER / OVERBURDEN	The material, including soil and/or rock, as measured along a perpendicular from the tunnel crown to the ground surface.
CROSS TUNNEL	Tunnel to give access between tubes for the operators and the emergency services
CROWN / ROOF / BACK	The configuration of the upper portion of a tunnel section above the springline.
CURBS	Small pour made on the bottom and at each side of a tunnel and generally located outside the minimum concrete line; used as a reference point and support for invert and arch pour in the tunnel.
CUT	A drilling pattern in the tunnel face which provides relief for an explosive charge.
CUT AND COVER CONSTRUCTION / METHOD	A sequence of construction in which a trench is excavated, the tunnel or conduit section is constructed, then covered with backfill.
CUTTERHEAD / CUTTING HEAD / CUTTING WHEEL	The rotating front end of a mechanical excavator which actually cuts through rock or soft ground.
DECISION MAKER	A person who makes decisions. The term usually refers to people making decisions on behalf of businesses or government.
DEFLECTOMETER	A device for precisely measuring the relative rotation of adjacent line segments along a common axis.
DEFORMATION	A change of shape of a structure or part of a structure or the ground. Usually refers to the change in shape with respect to load and time of the inner profile of the tunnel.
DESIGN	The information required to carry out engineering works.

DIESEL SMOKE	Carbon particles in suspension, main pollutant element of diesel engines.
DOWEL	Rock reinforcement, usually a reinforcing bar, that is inserted untensioned and fully grouted in place in a borehole.
DRIFT	A mined passageway or portion of a tunnel. In the latter sense, depending upon its location in the final tunnel cross section, it may be classified as a "crown drift", "side drift", "invert drift", etc.
DRILL	In reference to construction operations, the making of a relatively small circular hole in earth or rock with a cutting tool, while removing the cuttings by means of a circulating fluid. Distinguished from bore.
DRILL AND BLAST	A method of desintegrating rock by drilling small diameter holes on a planned layout, packing these with explosives and then firing to a fixed program to shatter the rock in a desired form.
DRILL JUMBO	In drill-and-blast tunnel construction, a rubber-tyred or track mounted movable frame with platforms to support men and drills.
DRILLABILITY	A specific value expressing the drilling properties of a rock in terms of the penetration rate with a certain type of bit and feed pressure.
DRIVING METHOD	Performing of underground space by means of drilling, blasting or by means of TBM
DRY-MIX SHOTCRETE	Shotcrete in which the mixing water is added at the nozzle.
DUCT	A term used to describe a cell, particularly for supply or exhaust ventilation, or for utilities.
DURABILITY	The ability of concrete or shotcrete to resist weathering action, chemical attack, abrasion, and other conditions of service.
DUST EXHAUST SYSTEM	Equipment designed to allow the elimination of dust in air.
EARLY STRENGTH	Strength of shotcrete usually as developed at various times during the first few hours after shotcrete placement.
EARTH TUNNEL	A tunnel driven in relatively easily excavated earth or soil rather than in rock. Also commonly referred to as a soft-ground tunnel.
EARTH-BALANCE SHIELD	A close-face shield designed for tunnelling in fine-grained soils by trapping excavated materials against the face and removing them at a rate slow enough to maintain pressures that counterbalance earth pressures, stabilize the face, and prevent ingress of water.
ELASTIC	Describe a material or a state of material where strain or deformation is recoverable, nominally instantaneously but actually within certain tolerances and within some arbitrary time. Capable of sustaining stress without permanent deformation.
ELASTIC ROCK ZONE	The zone outside the relaxed rockzonewhere excavation has altered the in situ stress field. Rock in the elastic zone undergoes recoverable elastic deformation.
ELEPHANT'S FEET	Enlarged bearing areas at the bases of partially constructed linings, normally of the crown section
EMISSIONS	Quantity of a substance that is thrown to the air.
EXHAUST	Gases from engines, pollutant emissions.
EXHAUST SCRUBBER	Equipment installed in all diesel vehicles working in underground works. It depurates gases from engines.
EXTENSOMETER	A device for precisely measuring the convergence or divergence of reference points along a common axis.
FACE	Vertical wall at the end of the excavation in a tunnel.
FAULT	A fracture zone in the rock mass within which differential movement of the two sides has occured relative to each other.
FIBER REINFORCED CONCRETE OR SHOTCRETE	Concrete or shotcrete (sprayed concrete) containing randomly dispersed fibers that are added while mixing.

FIBERS	Fibers for reinforcing concrete or shotcrete (sprayed concrete) are defined as short, discrete length of steel, glass, carbon, or synthetics, with any of several cross sections. They are sufficiently small to be randomly dispersed in an unhardened concret.
FILTER CARTRIDGE	Filter elements to eliminate dust particles in engines and vehicles.
FINAL LINING	Long-term shaft or tunnel support installed for permanent stability or other user requirement, often incorporating the initial support elements; also referred to as "permanent lining", permanent support", final support".
FIRE DAMP	Methane (CH4) - Also called explosive gas or marsh gas. It may be encoutered in coal regions; often is associated with shales; and occurs in the neighborhood of oil fields or rock salt deposits.
FLOOR	That part of any underground opening upon which one walks.
FLOWING GROUND	Flowing ground moves like a viscous liquid
FLY ASH	A fine residue that results from the combustion of ground or powdered coal.
FOLIATION	General term for a planar arrangement of textural or structural features in any type of rock, especially the planar structure that results from flattening of the constituent grains of a metamorphic rock. See also schistosity.
FORMWORK	Timber or metal surfaces which retain wet concrete to form desired shape
FULL FACE BORING	Tunnel excavation to full cross-sectional size with each blast or shove. Distinguished from heading, bench, and multiple drift.
FULL-FACE HEADING	An excavation of the whole face in one operation.
FUME	Smoke produced in the construction site.
GALLERY	One of a number of tunnels driven sequentially and in parallel. They are progressively connected one with another to form a single tunnel of larger cross-section. May also be called drifts
GIRDER OR RIB (LATTICE)	A steel (lattice) arch normally erected at regular centres as the tunnel advances. It is sequentially erected from component parts as the lining is progressively formed and encapsulated within the shotcrete. It is normally provided in the crown section to provide temporary protection to miners from the risk of collapse. The girders can be fully circumferential.
GOUGE	Finely abraded or pulverized rock particles and claylike altered rock found between the walls or within the fractures of a fault or shear zone; the result of grinding movements that crushe the affected rock.
GRIPPER SHIELD	A shielded rock or hard-earth tunnel boring machine equipped to move forward by reacting (i.e., exerting shove forces) against the tunnel walls through a hydraulic gripper reaction system.
GRIPPER TBM	A rock tunnel boring machine which generally utilizes roller disc cutters as excavation tools and which moves forward by reacting (i.e., exerting shove forces) against the tunnel walls through a hydraulic gripper reaction system.
GROUND ARCH	The rock located immediately above a tunnel which transfers the overburden load onto rock located on both sides of the tunnel. The zone of arching is usually equal in height to 1.5 times the tunnel diameter. Overburden rock / ground above the ground-arch remains unaffected by the tunnel operations.
GROUND WATER	Water contained in the ground below the upper level (the water table) of subsurface water.
GROUT	A pumpable slurry of neat cement or a mixture of neat cement and fine sand, commonly forced into holes drilled from a tunnel to strenghthen incompetent soil/rock or to prevent groundwater from flowing into the excavation. See also chemical grout.

GROUTING	Injection of grout through drilled holes, under pressure, to fill seams, fractures, or joints and thus seal off water inflows or consolidate fractures rock.
HARD AND INTACT ROCK	Massive rock containing no significant joints. When fractures by blasting, it breaks across sound rock.
HARD ROCK	In construction, rock having a strongly bonded nature such as to require excavation by blasting or the use of specially hardened cutters; generally includes igneous and metamorphic rock and the more strongly bonded sedimentary rocks.
HEAVE	Ground movement in a tunnel in the form of upward deflection of the invert
HEAVY GROUND	Very incompetent rock, usually found in faults or in shear zones; highly weathered or decomposed material having a tendency to move into the open tunnel area.
HIGH PRESSURE GROUTING	Consolidation grouting used to strengthen rock or cutt off water inflows.
HORSESHOE TUNNEL	A tunnel of roughly horseshoe-shaped cross section, oriented like an inverted "U". Many variations on the basic configuration are possible.
INCLINOMETER	A device for precisely measuring the inclination from vertical of a casing or structure to which the inclinometer is attached.
INCOMPETENT GROUND	Ground that requires support when a tunnel is excavated through it. Essentially the opposite of competent ground or firm ground.
INITIAL SUPPORT	Relatively short-term tunnel or shaft support installed for stability and safety during construction operations, with elements generally left in place and incorporated into the final linig. Initial support is often referred to as primary support.
INVERT	The lowest section of a tunnel, i.e., the floor. On a circular configuration, it is approximately the bottom 90 degree of the arc of the tunnel. On a square-bottom configuration, it is the bottom of the tunnel.
JOINT	In rock, a naturally occuring fracture or parting along which there has been no visible movement parallel to the fracture plane or surface.
LAYER	A term used for a discrete thickness of shotcrete (sprayed concrete), built up from a number of successive passes of the nozzle and allowed to set (see Pass).
LINING	A casing of brick, concrete, shotcrete, iron, steel, or wood placed in a tunnel or shaft to provide final everlasting bearing structure of underground space and/or to finish the interior.
LOAD CELL	A device for measuring axial loads by means of strain pages attached to an elastic structural member, for which a calibration curve between applied load and gage readings has been established.
LOOSENING (OF ROCK)	Non-reversible modifications suffered by the ground, resulting of the decrease of one or several stresses near an underground cavity
LOW-PRESSURE GROUT	Grout pumped through the concrete lining under low pressure to fill any voids between the concrete lining and the tunnel surface or between steel tunnel liners and backfill concrete.
MAINTENANCE	The act of caring for a facility or system to keep it in working order or to preserve its appearance or value
MASSIVE	In geology, the homogeneous structure of a rock without any planar, directional arrangement of textural or structural features.
MECHANICAL EXCAVATION	The removal of soil or rock by means of heavy cutting or digging equipment (not hand-held). Distinguished from hand mining and drill-and-blast excavation.
MISFIRE, MISSED HOLE	A drill hole in which all part of the explosive has failed to detonate.
OVERBREAK	Excavation that occurs outside of the "B" line of a tunnel owing to the irregular pattern of rock breakage; the definition also describes concrete required to fill this overexcavated space in lined tunnels.

PACKING	Any material used to fill the void between support members and the rock
PARTICULATES	Tiny, physical objects in the air of any kind, e.g. dust. High levels can represent a form of air pollution
PAVEMENT / SIDEWALK	The pedestrian movement area at the edge of a street.
PAY LINE	The line or tunnel section which constitues limits of payment for excavation and concrete lining. Overbreak is any excavation beyond the pay line, and overrun is any excess concrete placed beyond the pay line.
PILOT TUNNEL	A small tunnel excavated over the entire length or over part of a larger tunnel, to explore ground conditions and/or to assist in final excavation. May also be referred to as "pilot drift".
PLASTIC	Said of a body in which strain produces continous, permanent deformation without rupture.
PORTAL	The structure or the end of the structure at the two ends of a tunnel at the interface of the covered and open sections
POSTS	The vertical members of a steel rib or timber support system.
PRE-SPLITTING	A technique of inducing cracks roughly following the periphery of the rock shape to be excavated by the use of closely spaced holes and reduced explosive charges prior to main blasting; a subdivision of smooth blasting.
PREVENTIVE MEASURES	Measures that are undertaken in order to avoid an environmental impact.
PRIMARY LINING	The tunnel lining placed to support the ground as the excavation proceeds.
PYRAMID CUT	A method of blasting in tunnelling or shaft sinking in which the holes of the central ring (cut holes) outline a pyramid, their toes being closer together than their collars.
RAVELLING GROUND	Poorly consolidated or cemented materials that can stand up for several minutes to several hours at a fresh cut, but then start to slough, slake, or scale off.
ROCK BURST / POPPING ROCK	A spontaneous and violent detachment of a slab or slabs from over-stressed rock. See also popping rock.
ROCK QUALITY DESIGNATION (RQD)	A modified core recovery percentage in which only sound pieces of rock core 4 in. or more in length are counted as recovery. RQD is considered a more accurate gauge of a rock's engineering "quality" or competence than is the gross recovery percentage. It is stated as the cumulative percent of the core run occuring in pieces greater than 4 in. long.
ROCK TUNNEL	A tunnel driven in consolidated natural material (i.e., "rock") which requires use of rock excavation methods such as blasting, channeling, wedging, or barring, or a tunnelling machine making use of specially hardened cutters.
ROOF BOLTS	Bolts equipped with an expanded anchor at one end and a nut and washer at the other. Installed in drilled holes to tie rock together.
ROUND	A cycle of rock excavation consisting of drilling blast holes, loading, firing, and then mucking.
SCALING	The removal of loose pieces of rock adhering to the solid tunnel surface after blasting.
SECONDARY LINING	A permanent tunnel lining of concrete that is usually placed after mining operations have been completed.
SEGMENTS	Sections of iron, steel, or precast concrete which can be bolted or keyed together to make up a ring of support or lining. Iron or steel segments are generally referred to as "liner plates"; concrete segments may be referred to as "panels".
SHAFT	A vertical or near-vertical excavation or opening to provide access to an underground facility or construction operation

SHEAR ZONE	A local geologic structure resulting from the relief of earth stresses by he formation of a multitude of minute, closely spaced fractures with slight slipping or faulting along each.
SHIELD	A movable steel tube, framework, or canopy shaped to fit the excavation line of a tunnel and used to provide immediate support for the tunnel and protect the men excavating and providing the long-term support. May be fitted with a cutting device for excavating the tunnel lining. See also soft-ground shield and gripper shield.
SHOTCRETE	A mixture of cement, aggregate, and water projected pneumatically at high velocity from a nozzle onto a surface to produce a layer or layers of concrete. Shotcrete normally incorporates admixtures, especially accelerators, and may also include fibers. (also called Sprayed Concrete). (see dry-mix shotcrete, gunite, and wet-mix shotcrete)
SILICATE FUME	An extremely fine by-product of the manufacture of silicon metal as the gases escaping from the electric-arc furnace condense. It is used in concrete and shotcrete to improve their properties. In shotcrete its use reduces rebound increases thickness per pass, and improves properties of the hardened shotcrete.
SILICOSIS	A lung desease caused by breathing dust from rock drills over a long period of time. Rocks with high silica content are the most harmful.
SLABBY ROCK	Rock cut through by finely parallel joints and/or cleavage planes so that it breaks into tabular plates upon exposure in an excavation.
SLICKENSIDES	The polished and sometimes striated surfaces on the walls of faults and shear zones, resulting from rubbing during earth movements. Sometimes referred to by construction people as "slicks".
SLURRY SHIELD	A closed-face shield designed for tunnelling in very soft, wet, or running ground by use of circulating, pressurized clay slurry against the face to counterbalance earth pressures, prevent ingress of water, and also to carry away the cuttings.
SMOOTH BLASTING	A technique of using carefully controled shot hole drilling and specially prepared charges in peripheral blast holes to reduce overbreak. Se also pre-splitting.
SOFT-GROUND SHIELD	Any tunnel shield which moves forward by reacting (i.e., exerting shove forces) against the tunnel lining and generally utilizing drag type excavation tools that can be mounted on a backhoe, rotating wheel or oscillating arm.
SOFT-GROUND TUNNEL	Same as earth tunnel. The ground may be hard or soft in consistency, the word "soft" differentiating it only from "hard" rock.
SOIL	Any naturally occuring loose or soft deposit resulting from weathering or breakdown of rock formations or from decay of organic matter
SPAN	Part of a structure between two supports
SPRAYING	Process of placing shotcrete (sprayed concrete) by projecting the shotcrete from the nozzle to the surface receiving the shotcrete (also called shooting or gunning)
SPRINGLINE	The point where the curved portion of a tunnel roof meets the top of the wall. In a circular tunnel the springlines are at the opposite ends of the horizontal centerline.
SQUEEZING GROUND	Weak material, generally clayed, that behaves plastically under the weight of overlying ground and tends to close a tunnel opening by slowly advancing into it without perceptible volume increse.
STAND-UP TIME	The time that elapses between the exposure of an area at the roof of a tunnel and the beginning of noticeable, unprovoked inward movement of the ground above this area; sometimes described as "bridge-action time".
STEMMING	Inert material packed in a drilled hole on top of the explosive charge. Its purpose is to contain the force of the explosion in the rock.
STRUTS	Compression supports placed between tunnel sets.

SUBSURFACE / UNDERGROUND	Underground, beneath the surface
SUBSURFACE MAPPING	Mapping of subsurface spaces (results of underground human activities) from the various point of view (location, dimensions, geological conditions, environmental impact, actual technical state, reusing possibilities, etc.)
SUMP	Sumps (reservoirs) are provided at the portals and at low points (nadirs) to contain quantities of run-off and leakage water compatible with storage requirements of the pumps provided. Oil-water separators are usually required, and sumps within a tunnel most often discharge to portal sumps.
SWELLING	Increase in volume upon exposure to water.
SWELLING GROUND	Material that expands in volume by absorbing or adsorbing water so that it tends to move into a tunnel opening or to exert great pressure upon the supports.
TEMPORARY BALLAST	Material used to temporarily increase the effective weight ot the tunnel or a tunnel element during the fabrication and installation phases until replaced by backfill or permanent ballast. The material may be solid or liquid
TEMPORARY SUPPORT	Essentially the same as initial support, except that the elements can be (and sometimes must be) removed because on non-contribution to or incompatibility with the final lining.
TILMETER	A device for precisely measuring rotation, or chage in orientation, at a specific location on a structure or the ground surface.
TOP HEADING	The upper portion of a tunnel, often extending from springline to crown, pre-excavated in order to install arch support before opening the tunnel to full size.
TOP HEADING CONSTRUCTION	A tunnelling method in which a complete top heading is excavated end-to-end before excavation of the lower bench is begun.
TUBE	Roadway, track and service cells are each often referred to as tubes.
TUNNEL	A tunnel, strictly speaking, is a subterranean passage open at both ends. Often used as a synonym for adit, drift or gallery
TUNNEL BORING MACHINE (TBM)	A machine that excavates a circular tunnel by cutting and/or abrading the heading to full size in one operation. Also referred to as a mole. The term has so commonly been associated with rock tunnelling that when a TBM is used in earth it is often prefaced by qualifier "soft-ground".
TUNNELLING CYCLE	In rock tunnelling, the 6-part excavation cycle is drilling holes for explosives, loading, blasting (shooting), ventilating, mucking, and erecting supports.
UNDERGROUND SPACE	Space created or used underground
VENT LINE	Large-diameter pipe used to furnished fresh air or exhaust polluted air from an underground opening
VENTILATION	The provision of air circulation/fresh air to an enclosed space. This can provide cost implications when comparing underground and surface solutions
VENTILATION (LONGITUDINAL VENTILATION)	A system in which fresh air is supplied at one end of the tunnel and the polluted air is expelled at the other
VENTILATION (SEMI-TRANSVERSE VENTILATION)	A system in which a separate ventilation duct is used for the supply of fresh air through many supply vents along the tunnel. The polluted air is discharged through the end of the tunnel. Also used to describe a system where fresh air is supplied from the end of the tunnel and polluted air is drawn out over the length of the tunnel by exhaust fans
VENTILATION (TRANSVERSE VENTILATION)	A system in which separate supply and exhaust duct systems are used, so that fresh air is distributed and polluted is collected over the length of the tunnel by supply and exhaust fans

VENTILATION DUCT	Pipeline used to ventilate the tunnel, eliminating polluted air.
WASTE WATER	Polluted water that has to be eliminated through the drainage system.
WATER POLLUTION	Contamination of a liquid effluent which needs treatment before disposal
WATERTIGHTNESS	A measure of the capability of a tunnel to resist the penetration of water (leakage)
WEATHERING	Destructive processes, such as the discoloration, softening, crumbling, or pitting of rock surfaces brought about by exposure to the atmosphere and its agents.
WET-MIX SHOTCRETE	Shotcrete (sprayed concrete) in which all of the ingredients, including water and fibers, are mixed then conveyed through the delivery lhose, either pneumatically or by positive displacement, then projected at high velocity to the surface being shot.

1.4.3 PRINCIPLES OF TUNNEL DESIGNING

Design of underground structures in general and tunnels in particular has to reconcile the various demands and restraints emanating from the requirements of a modern tunnel structure:

- o The tunnel has to fulfill its functional requirements, e.g. allow a certain quantity of traffic to pass through it at a certain speed while respecting all regulations pertaining to road safety.
- o The design of an underground structure has to take into account the ground conditions, including hydrology and local tectonics. Ground conditions may dictate the vertical and horizontal alignment, the shape, cross section or even size of the tunnel.
- o The tunnel design must consider feasible construction methods and excavation procedures. Construction of the tunnel must be possible in an economic, efficient and safe manner. The design must also deal with other requirements for construction work such as temporary adits, site access, situation of work sites and deposition of excavated material.
- o The tunnel design has to assure safety for users and maintenance personnel during standard operations and in emergency cases.
- o The tunnel design has to assure the possibility of adequate maintenance of all tunnel facilities
- o The tunnel design has to assure that the tunnel can be constructed and operated with minimal impact on the environment.
- o All the above has to conform to appropriate national and/or international standards and codes of practice.

The following " Guidelines and Design Criteria" were established to provide a uniform basis for design of road tunnels in BiH.

1.4.4 GENERAL DESIGN CRITERIA

1.4.4.1 NUMBER OF TUBES AND LANES

The main criteria for deciding whether to build a single or a twin-tube tunnel shall be projected traffic volume and safety, taking into account aspects such as the percentage of heavy goods vehicles, gradient and length.

In any case, where, for tunnels at the design stage, a 15-year forecast shows that the traffic volume will exceed 10 000 vehicles per day per lane, a twin-tube tunnel with unidirectional traffic shall be in place at the time when this value will be exceeded.

With the exception of the emergency lane, the same number of lanes shall be maintained inside and outside the tunnel. Any change in the number of lanes shall occur at a sufficient distance in front of the tunnel portal; this distance shall be at least the distance covered in 10 seconds by a vehicle travelling at the speed limit. When geographic circumstances prevent this, additional and/or reinforced measures shall be taken to enhance safety.

1.4.4.2 TUNNEL CROSS SECTION

The size of the tunnel cross section is essentially determined by the defined clearance profile. The width of the roadway should be designed according to Slovene guidelines or as shown on the table below. The vertical height of the clearance envelope above the carriageway is defined with 4.70 meters.

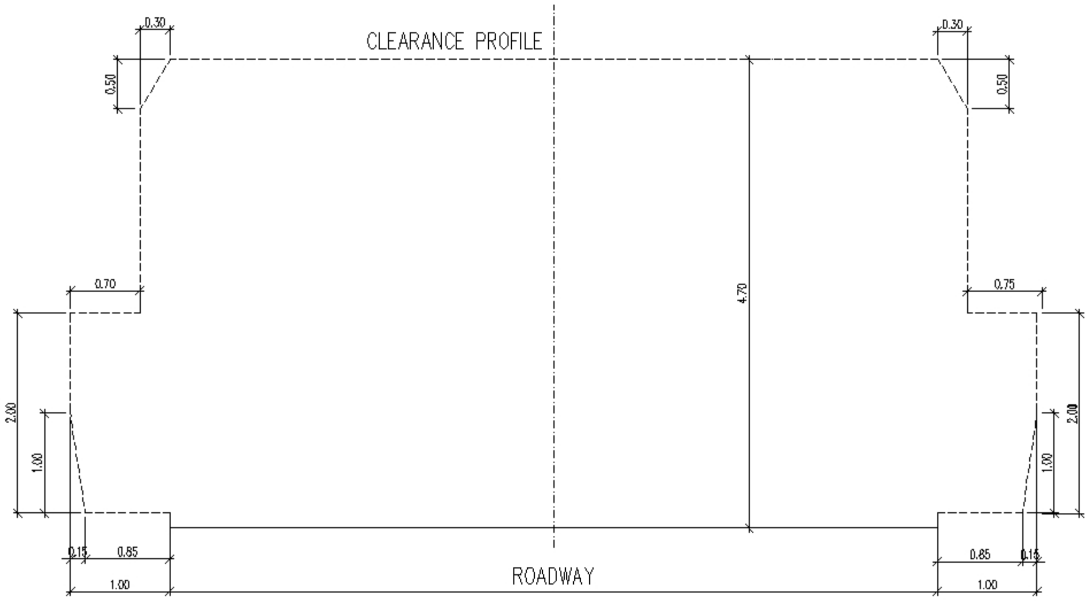


Fig. 1: Clearance Profile

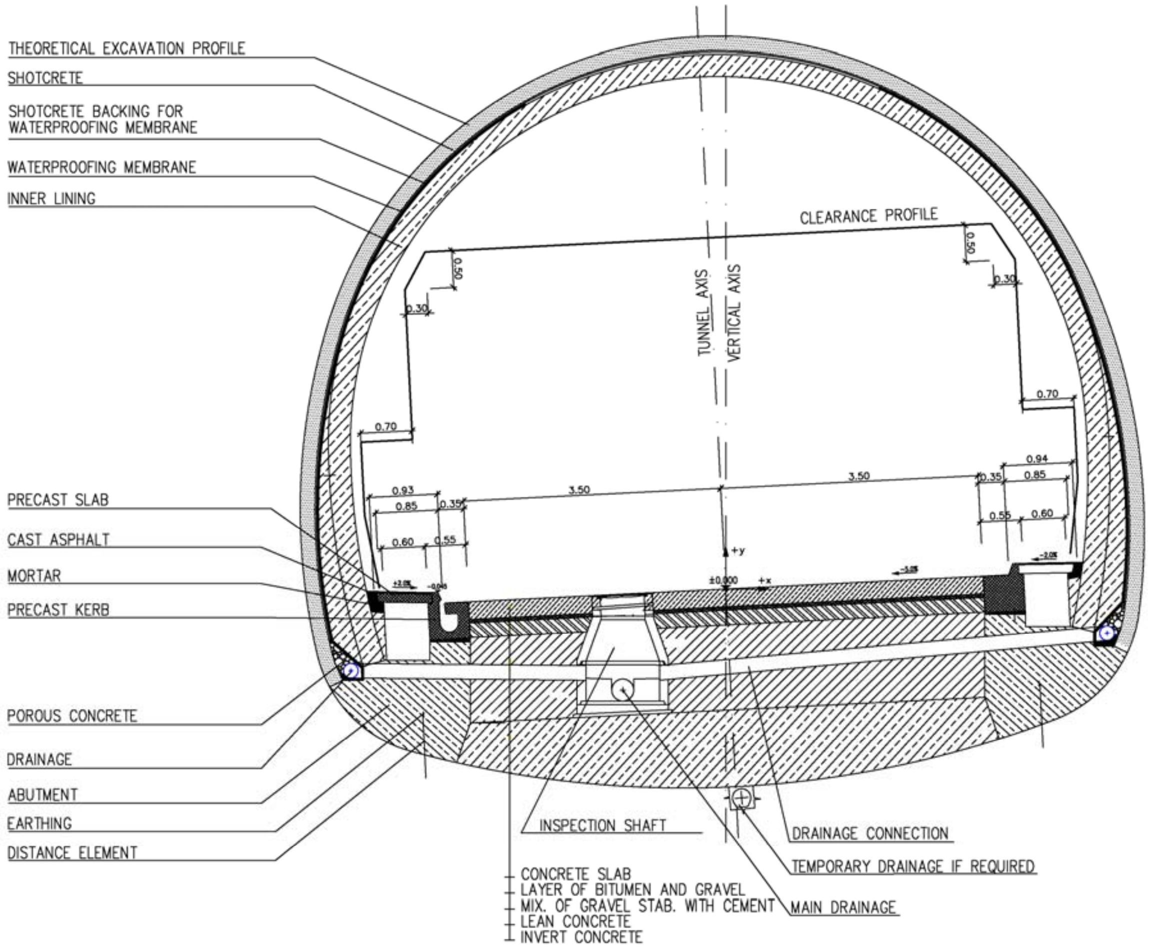


Fig. 2: Tunnel cross-section

The width of the driveway of tunnels depends on the design speed and on the number of busses and trucks rolling on the highway.

According to the Austrian guidelines, RVS 9.23, the following road way widths shall be applied (for two lane tunnels):

		design speed	
number of trucks and busses per hour	below 50 km/h	50 to 80 km/h	80 to 100 km/h
below 50	5.50 m	6.00 m	6.50 m
50 to 150	6.00 m	6.50 m	7.00 m
above 150	6.50 m	7.00 m	7.50 m 7.00 m **

** for tunnels with two lanes and one-way trafficin the same direction

In addition, shoulders of minimum width 25 cm are to be considered on both sides of the roadway.

On each side of the roadway walkways are foreseen for emergency and maintenance purposes. Normal pedestrian traffic is not allowed in the tunnels. The walkways (sidewalks) are elevated; they are located 0.15 meters above the road surface with a minimum superelevation of 2 percent. The clearance envelope of the sidewalks is defined with 0.85 meters minimum width and 2.0 meter vertical headroom. The practical width, however, could be more due to the space requirements for the cable ducts located under the walkways. The minimum dimensions of the cable ducts govern the practical walkway width.

The minimum superelevation of the pavement is defined with 2.5 %. The superelevation may be maintained to one direction for reverse curves with a radius bigger than 2,500 meters.

Beside the specified clearance profile the selected ventilation system could have an influence on the dimensions of tunnel cross section. Specially for transverse and semi-transverse systems the tunnel cross section has to be enlarged in the roof.

1.4.4.3 Alignment

1.4.4.3.1. Horizontal Alignment

The horizontal alignment of short tunnels should be straight, if possible. In long tunnels the length of tangent sections (straight alignment) should not exceed 4.0 kilometres. Horizontal curves should be designed at exit portals of long tunnels in order to eliminate the psychological effect for tunnel users of seeing a dot of light.

The radii of highways should be chosen as big as possible, in order to achieve the following goals:

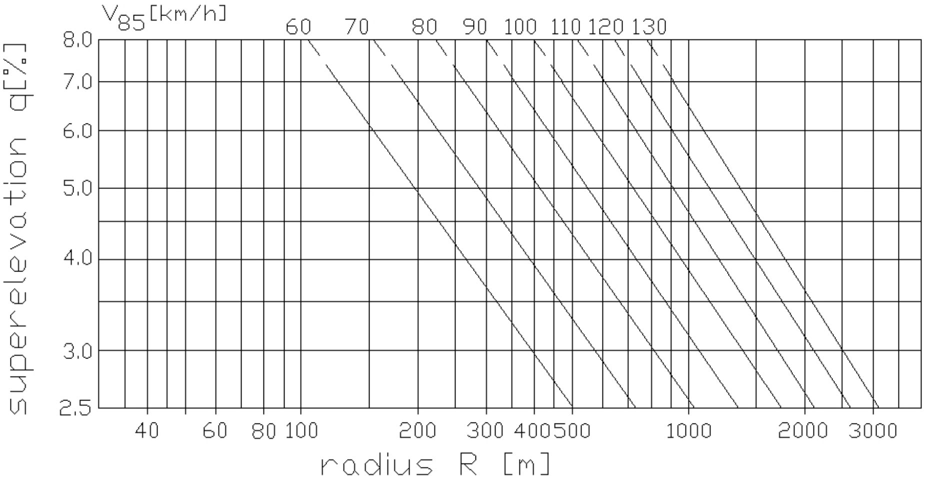
- short construction length
- sufficient sight length for overtaking manoeuvres and breaking (stop sight distance)
- a continuous drivage, where abrupt steering is not required

The German guidelines, RAS-L-1, allow the following minimum radii, depending on the speed and the superelevation of the highway.

According to RAS-L-1, the minimum radius for a design speed of 100 km/h is 500 m with an associated maximum superelevation of 7 %. However, this value is valid for general highway design. In tunnels, the minimum radius at design speed of 100 km/h should be 1000 m and an associated superelevation of 4 % is recommended. The superelevation in highway or freeway tunnels should be kept at a maximum of 4 %.

If curves are required, the minimum radius is determined by stopping sight distances and the superelevation in relation to the design speed. The effect of long downgrades on stopping sight distance should particularly be addressed in tunnel sections where the greater height of eye of the truck operator is of little value and the truck speeds may closely approach or exceed those of passenger cars.

Exit ramps should be located a minimum of 350 meters from the tunnel exit portals to allow sufficient distance for guide signs and vehicle lane changes. Horizontal and vertical clearances are normally not sufficient for placing guide signs within the tunnel section.



Above figure 3 is valid for openfree field highways and for tunnels as well.

Geological and geotechnical conditions should be considered for designing the space between parallel tubes. As a rule of thumb the spacing from centreline to centreline of two parallel tubes should not be less than three tunnel diameter. In this case there will be no interference from one tube to the other. At and close to the tunnel portals it might be more economical (considering land acquisition, right-of-way, portal structures, adjacent structures of the open highway, topography etc.) to reduce that distance.

Tunnels should not follow valley slopes with a close distance to the surface. Whenever possible, tunnel alignments underneath buildings shall be avoided if the overburden is less than 4 to 5 tunnel diameter. In portal areas, high portal slopes and cuts should be avoided if possible, but the rock cover should increase fairly quick over the first few tunnel meters to facilitate tunnel start-up.

1.4.4.3.2. Vertical Alignment

Vertical alignment, or gradient, is influenced by both construction costs and operation and maintenance costs. The gradient of the tunnel roadway, the length of the tunnel, the elevation of the tunnel, the vehicle speed and traffic volume will all have a very significant effect on the tunnel ventilation requirements. Generally, a 3.0 percent maximum gradient is desirable to maintain reasonable truck speed and practical ventilation requirements.

The following criteria recommended for maximum gradient in relation to tunnel length can be utilized during feasibility studies or early design stages to provide general guidelines for the purpose of aintaining an economical balance between construction costs, investment for electro-mechanical facilities and operation and maintenance costs.

For tunnels 3,500 meters or more in length the maximum gradient should not exceed 1.5 percent. For tunnels less than 3,500 meters in length the maximum gradient should not exceed 3.0 percent, preferably with a lower gradient as tunnel length approaches 3,500 meters. For tunnels 1,000 meters or less in length the maximum gradient can be increased to 4.0 percent, if required, and for very short tunnels, 200 meters or less in length, the maximum gradient can approach the maximum gradient recommended for the approach highway or freeway. The minimum tunnel gradient shall be 0.5 percent.

For hilltop and trough the following minimum radii are given in the Austrian guidelines, RVS 3.23:

	hilltop	trough
speed in km/h	minimum radius in m	minimum radius in m
100	12500	5000
120	20000	8000
140	35000	12000

In addition to the above criteria, which are dictated by the requirements of smooth and safe traffic flow, tunnel alignment is also affected by topography. Both excessively high rock cover (more than 1000 m) and very shallow overburden (less than one tunnel diameter) should be avoided.

1.4.4.4 TOLERANCES

1.4.4.4.1. General

A certain degree of inaccuracy is unavoidable in practical tunnel construction. Tunnel design has to consider these inaccuracies by foreseeing adequate geometric tolerances for initial and final tunnel lining.

Modern design practice tends to include tolerances on all drawings, especially for the final lining. Alternatively, tolerances can be left out of drawings and their definition may be left to the contractor or to the owner's site representatives. In any case, drawings have to show clearly whether their dimensions include or do not include tolerances.

1.4.4.4.2. Tolerances for Initial Lining (Primary Support)

Initial lining construction is an operation that is subjected to several sources of inaccuracy. As indicated below, most of them are strongly related to site conditions and thus to changes during construction. It may therefore sometimes be better practice no to include the tolerances in the drawings for the initial lining and define them on site. Prefabricated parts, like steel arches and lattice girders, however, have to be produced including proper tolerances.

Tolerances for Initial Lining fall into four categories:

- Survey tolerances
- Construction tolerances
- Deformation tolerances
- Unavoidable overbreak

Survey tolerances:

Survey tolerances are most strongly affected by the general survey grid layout. Survey accuracy increases significantly if the survey grid is closed, e.g. by the existence of a pilot drift. Survey accuracy also depends on the quality of instruments, the visibility in the tunnel, the possibilities of finding good stations and sightlines and on the general survey operating conditions. Survey tolerances are thus strongly site related. The designer may have to modify survey tolerances if the contractor performs the survey significantly better or worse than expected in the design stage.

Construction tolerances:

Construction tolerances include all difficulties connected to geometrically accurate excavation and support installation. Construction tolerances are strongly affected by ground conditions, tunnel shape and size, complexity of temporary construction stages, construction equipment and quality of prefabricated parts (e.g. steel arches). Very unfavourable ground conditions, like strong water ingress can affect construction tolerances adversely. Construction tolerances are strongly site related and may have to be adjusted to individual site conditions.

Deformation tolerances:

The designer must make a reasonable estimate of expected ground deformations and include them in his design. The amount of expected deformation increases with rock class. In adverse ground conditions, deformations may be very large and may necessitate modifications to the design tolerances during construction.

Unavoidable overbreak:

Unavoidable overbreak is not a tolerance in the strict sense of the word. It has, however, significant contractual implications and therefore has to be included in the design. Unavoidable overbreak does not necessarily increase as rock conditions worsen, the use of steel arches and forepiling elements in such rock conditions decreases the amount of overbreak.

1.4.4.4.3. Tolerances for Final Lining

Final lining construction demands tighter tolerances than initial lining construction. Since final lining construction is performed under less constricted and difficult operating conditions, these tolerances can usually be met.

There are three main sources of inaccuracy in final lining construction:

- o Survey tolerances
- o Formwork tolerances
- o Effect of curves

Survey tolerances:

For final lining construction, the sources of survey inaccuracies are similar to those for initial lining construction. Two tolerance classes can be defined: Closed survey network and open, or "flying" survey network. The accuracy of a flying survey network is greatly affected by tunnel length.

Formwork tolerances:

This class of tolerances is affected by three main factors:

- o Manufacturing tolerance of formwork
- o Inaccuracies during formwork placement
- o Deformation of formwork during concreting

Effect of curves:

Since tunnel formwork is straight, a curved tunnel is actually of polygonal shape. There will therefore be a deviation from the theoretical shape with a maximum at the centre of a concreting block. This tolerance depends on block length “L”, width of clearance envelope “B” and radius “R” of tunnel alignment. The "Curve Tolerance C" can be calculated according to the following formula:

$$C = \frac{R}{\frac{B}{2} - \sqrt{\left(\frac{R}{B/2}\right)^2 - \left(\frac{L}{2}\right)^2}} \quad \text{[in mm)}$$

1.4.4.4.4. Other Tolerances

Niches, maintenance shafts and other facilities have to be positioned with an accuracy of +/- 5 cm. Size of niches has to be accurate to +/- 1 cm.

Prefabricated parts, cable trenches and other installations have to be placed with an accuracy of +/- 1 cm.

1.4.5 GROUND INVESTIGATIONS

1.4.5.1 INTRODUCTION

The alignment studies have already been performed and the location of the tunnel(s) have been largely decided. The chapter on ground investigation will therefore not cover geological investigation works during feasibility and route selection studies.

1.4.5.1.1. Purpose

The aim of geological site investigation is to determine the distribution of the various types of soils and rocks in the area of the proposed tunnelling works, and their relevant physical and chemical properties. It is not sufficient to identify the strata by their stratigraphical terminology, but the soils and rocks need to be described by their mechanical properties and their expected short- and long-term behaviour related to the construction.

Main targets of ground investigations for tunnels are:

- to develop a three dimensional geological model of the area where the tunnel is to be excavated, including all relevant details of the hydrogeological situation
- to define the physical characteristics of the geological materials through which a tunnel is to be driven, so to establish the geotechnical model including the provision of specific rock and soil design parameters.

1.4.5.1.2. Steps and Methods of Investigation

Depending on the type, size and state of the concerned project, specific investigations have to be executed. The typical steps of a complete investigation program for a tunnel project are as follows:

- Search and evaluation of available literature and records
- Aerial photograph interpretation
- Geological and hydrogeological mapping
- Excavation and logging of investigation trenches
- Geological interim report with interim geological model
- Geophysical survey
- Investigation drilling
- Exploratory adits, shafts and tunnels
- Sampling and in-situ testing
- Laboratory testing
- Final geological and geotechnical report

1.4.5.2 PRELIMINARY STUDY

1.4.5.2.1. Desk Study

1.4.5.2.1.1 Literature Review

Before field work commences a thorough review of information about the geology, groundwater, seismic history, and existence of structures in the project area should be made. In urban areas, detailed knowledge of the history of the site is also important, as it can identify old landfills or alterations to drainage patterns which may affect the project. Geological and soil maps are especially useful.

1.4.5.2.1.2 Aerial Photographs Interpretation

A variety of techniques are used in aerial reconnaissance, such as vertical, oblique, colour and infrared photography as well as side-looking radar. Detailed interpretation of aerial photographs requires the services of a specialist. Many relevant features can be readily recognized, as there are: topography, drainage pattern, vegetation cover, land use, potential construction material sources, landslides and fault zones.

To use aerial photographs, the scale, shadow orientation, compass orientation and date of the photography must be known; the photographs are best studied as vertical stereoscopic pairs viewed in reflected light with a stereoscope.

1.4.5.2.2. Field Study

1.4.5.2.2.1 Geological Mapping and Outcrop Studies

The geological mapping is the most important step of the ground investigation which will further lead to economic use of more costly investigation methods such as geophysical studies and investigation drilling. The geological mapping (scale 1:5.000, 1:2.000 or even 1:1.000) has mainly to focus on engineering geological needs. It has to cover relevant geological, petrographical, hydrogeological and engineering geological features such as:

- Distribution of soil and rock types with a clear identification of rock outcrops
- Indication of strike and dip of bedding, schistosity, major joints and slickensides, structural details according to ISRM classification
- Indication of zones with intense folding and/or fracturing
- Indication of faults and fault zones
- Indication of zones of intensive weathering
- Hydrogeological features such as springs with indication of water temperature, quantity, electrical conductivity, location of seeps, swamps, sinkholes etc.
- Geological hazards, such as unstable slopes, areas with significant settlement, emanation of gases, hot/mineralized (corrosive) waters, swelling ground, karstic phenomena, seismic active fault zones/areas etc.

Geological mapping may not be restricted to the close proximity of the future tunnel but must be performed in a strip wide enough to understand all relevant aspects. It should include detailed studies of the portal areas, as well as of geological hazardous zones such as mass movements and major faults affecting the tunnel alignment.

1.4.5.2.2.2 Investigation Trenches

Pits and trenches, performed during the filed mapping campaign, are frequently the cheapest and quickest way of examining soft natural deposits and made ground above the water-table or to uncover the bedrock surface. They are especially valuable where the ground is very variable or natural rock outcrops lack. They often serve as major source for structural data (degree of fracturing, orientation and characteristics of discontinuities, persistence of discontinuities etc.).

They can be opened by mechanic backhoe excavator if access is easy, or by hand with pick and shovel. Their size may vary from one to five meters in depth and their width may be chosen according to local conditions. They have to be logged by a geologist, and during/after excavation the stability of the walls shall be monitored.

1.4.5.2.3. Geological Interim Report

Based on the mapping results including the investigation trench/pit studies and the results of the desk study geological longitudinal and cross sections as well as horizontal sections have to be established. Such sections should include all relevant structural data as well as lithological and tectonic boundaries and expected hydrogeological conditions.

At this moment an interim geological model is established. It has to display all areas with specific doubts about the geological situation as well as to provide the boundaries of zones to be treated homogeneous in terms of structural geology, lithology, hydrogeology, geological hazards etc..

The interim geological model is the basis for planning any further investigation activity. The following investigation steps (mainly geophysical surveys and drilling investigation, possibly trial pits, trial access tunnels etc.) have to be specified in terms of investigation targets and proposed investigation methods. The program is a part of the geological interim report and has to be forwarded to the client for approval.

1.4.5.3 DETAILED STUDY

1.4.5.3.1. Geophysical Survey

1.4.5.3.1.1 General

Geophysical methods yield results in terms of the local distribution of specific physical parameters (such as seismic velocities, magnetic field, gravity, resistivity, conductivity, gamma radiation, heat flow etc.). Their application has to be carefully planned jointly with the engineering geologist, and interim results are jointly interpreted by the geophysicist, the geologist and the hydrogeologist involved. In any case a final geological interpretation of the geophysical data has to be performed at the end of the investigation campaign when all results of direct investigation methods (geological mapping, outcrop studies, logging of investigation trenches, investigation drilling, exploratory adits etc.) are available.

Typical applications of geophysical surveys for the ground investigation for tunnelling are

- assistance in the reconnaissance of geologic (tectonic) structures including their three-dimensional configuration (mainly by seismic, geoelectric, [micro]gravimetric and/or geothermal studies as well electromagnetic mapping)
- assistance in interpretation of hydrogeological conditions
- seismicity studies
- determination of dynamic rock mass parameters
- vibration studies and monitoring during tunnel construction
- resources studies for construction materials
- For the reconnaissance of geological structures the application of geophysical methods is useful surveying
- lithologic boundaries within overburden materials
- interface between overburden materials and bedrock
- lithologic boundaries within the bedrock
- tectonic features such as faults or fault zones
- depth of creeping or sliding masses

The knowledge of the distribution of the p-wave (longitudinal waves) velocities is important for determination of qualitative dynamic properties and may help in evaluation of the degree of rock mass fracturing. Velocity measurements of p- and s waves (shear waves) are used for the determination of dynamic parameters (Young's Modules of elasticity, shear modules, compression modules and Poisson's ratio). Adequately planned seismic investigation programme can help to create a three dimensional model of the distribution of dynamic properties of the ground.

1.4.5.3.1.2 Geophysical Methods

1.4.5.3.1.2.a) <u>Seismic Investigations</u>

Seismic investigations provide important geophysical data about the quality of the ground and present basic geophysical methods to assist in solving geotechnical problems. For engineering purposes following seismic techniques are commonly used: engineering refraction survey, shallow reflection survey (surface techniques), down hole, up-hole cross-hole and seismic tomography (measurements in and in-between boreholes). The usual equipment for seismic investigations is consisted of: sources of seismic waves (sledge hammer, drop weight or accelerated weight, explosives), seismic wave detectors (geophones), recording devices (seismographs), which enable recording of seismic signals in chosen time intervals. The most commonly used seismographs have 24 registration channels (also 12- or 48-channels). Each of the channels represents a single measuring point (geophone), which is located along the seismic line (profile).

Furthermore, seismic investigations provide data for evaluation of dynamic properties of the ground. Refraction measurements provide, with known geometry and time/duration of seismic waves, data about relation between depth of ground (seismic boundaries) and seismic velocities. Refraction measurements can be evaluated correctly in case of seismic velocity increase with depth. In case of inverse velocity development (i.e. seismic velocities of lower layers are smaller than velocities of layers above) the calculation of depth will likely be incorrect. Reflection recording is effective for structural-tectonic evaluations, but requires time demanding field works and is therefore not applied for engineering purposes as routine measurements.

1.4.5.3.1.2.b) **Geoelectric Survey**

Geoelectrical investigations usually provide supplementary information to seismic investigations. For engineering purposes most commonly following resistivity measuring techniques are used: geoelectric depth sounding, geoelectrical mapping and geoelectrical tomography. With geolectrical methods the definitions of layers regarding their electrical resistivity is performed. This quality mainly depends on the presence and the amount of clay minerals and water in the ground.

The results of geoelectrical depth sounding is a list of single point measurements which represent the vertical layout of the individual electrical resistivity of each layer and thus enables the determination of a resistivity/depth ground model.

Geoelectrical mapping gives information about qualitative horizontal and vertical variation of electrical resistivity.

Electrical tomography provides continuous data as a combination of geoelectrical depth sounding and mapping. The method is suitable for determination of orientation of major discontinuities (faults) as boundaries between different lithologic layers, specifically for the detection of clayey layers.

1.4.5.3.1.2.c) **Electromagnetic Survey**

Electromagnetic investigations provide information about electrical conductivity of the ground. The essential parts of the measuring equipment are the transmitting and receiving coils. Both do not need to have direct contact to the ground during measurement. An electromagnetic field is generated by the transmitting coil while the receiving coil measures the secondary electromagnetic field. Regarding the frequency of the electromagnetic waves different measuring techniques are used for engineering purposes such as georadar, electromagnetic low induction measuring etc.

The measurements are quick and easy to perform, they are usually quite effective in determination of relatively shallow geometrical boundaries of different geologic materials. Due to uncertainties in interpretation, they should not be applied without combination of other investigation measures.

1.4.5.3.1.2.d) **Geophysical Borehole Logging**

Borehole logging is a term for geophysical measurements in boreholes. For engineering purposes following methods are most frequently applied: gamma-gamma log for continuous material density measurements, neutron-neutron log for continuous porosity assessment, measurements of borehole diameter (for determination of borehole wall configuration as geomechanical information), electric log measurement as well as natural radioactivity logs (for determination of lithologic boundaries) and the temperature measurement in the borehole. Temperature measurements are of assistance in evaluation of underground water flow and the degree of fracturing of the rock mass.

1.4.5.3.2. Investigation Drilling

1.4.5.3.2.1 General

Investigation drilling is the main source for direct information about conditions concerning the ground deeper than some 5 m below surface, which is usually the maximum depth of investigation trenches. Investigation drillholes provide detailed knowledge of the ground and its variations, of its physical properties and hydrogeological conditions, as well as allow sampling of disturbed and undisturbed samples for laboratory testing.

Once the layout for the drilling program has been established, the specifications for the work must be prepared. These specifications have to take into consideration the different purposes of investigation drillholes such as geological, hydrogeological and/or gas sampling, borehole testing in soils and/or rock as well as installations for stability monitoring such as inclinometers, extensometers and finally groundwater monitoring equipment.

Certainly all recovered drill cores have to be carefully stored in sound boxes (e.g. wooden cases lined with plastic to prevent from drying) with proper labelling of site, drillhole, depth etc.. Such core-boxes have to be stored in a dry clean place for inspection at any time until the completion of the tunnel construction. Logging of drill cores has to be performed as soon as the cores are recovered in order to monitor their fresh appearance (original humidity, colour, strength etc.).

After the completion of each core-drilled hole the drill cores in the boxes have to be photographed with colour film, properly indicated name of drillhole and depth intervals.

The success of the boring (sampling and field testing-) program depends on the quality of site supervision during the drilling operation. Trained and experienced persons have to be in charge of the technical aspects of a drilling program.

1.4.5.3.2.2 Drilling in Soil

Depending on the type of ground in terms of grain sizes, density or consistency, and ground water conditions, different methods are used.

Wash boring and rotary drilling are common methods applied mainly in fine grained (clayey, silty, sandy) soils. Stabilization of the bore hole, which usually is necessary below the groundwater table or in non-cohesive soil, is provided either by the flushing medium (soil-water slurry with clay additive) or by casing. The utilization of auger drilling, which is used in case of stable drill holes above ground water or in high plastic soils, is very often limited by the required drilling length.

Percussion and grab drilling are common methods for coarse grained soils. Clay slurry or casing is compulsory.

For soils of larger grain size (coarse gravel, boulder and blocky ground) drilling and sampling can be quite cumbersome. Rock boring techniques with casing or large diameter drilling with bored pile drilling equipment may be applied.

1.4.5.3.2.3 Drilling in Rock

The most common method of drilling in rock is by rotary core drilling. The flushing medium is usually water, but where erosion of the core is to be avoided, air-flush may be adopted. However, air is not as effective as water for cooling and lubricating the bit. In unstable ground, casing is normally used to keep the hole open and standard dimensions have been established for a nesting series of casings and corresponding bits. Alternatively, mud can be used as a flushing medium which, if properly constituted, will prevent the hole from collapsing.

Vertical drillholes are the most common ones. For special purposes, inclined or horizontal drillings are needed.

Destructive drilling, i.e. percussion drilling is used as geological investigation tool only under certain conditions. Such may be the determination of a boundary of soft to hard materials. The results are qualitative only, however performance is quick and cheap.

1.4.5.3.3. Exploratory Adits, Shafts or Tunnels

Exploratory adits and shafts provide direct access to the material through which a tunnel is to be excavated. Cross-sections of exploratory adits and tunnels, which may run through parts or the entire alignment of the future tunnel, should not be less than 2 x 2 meters.

Such detailed engineering geologic analysis and large scale in-situ rock mechanical tests may be performed as well as tests on the effectiveness of various types of support systems, and of excavation methods. Groundwater monitoring, sampling and drainage may be targets as well as monitoring of gas conditions. Further the pre-treatment of sections with difficult ground can be performed. It also allows bidders to observe rock conditions in-situ, supporting responsive bids.

1.4.5.3.4. Sampling

1.4.5.3.4.1 Disturbed Samples

Disturbed samples serve mainly for soil identification. They are obtained from percussive or rotary drills, wash-borings or materials extracted in a shell and/or auger. The quality of such samples depends on the drilling method.

If water flush has been used, fines may have been lost, or if the flush is inadequate, coarser material may fall back and be ground by the bit in finer material. Grab samples from the surface or pits are also considered as disturbed samples.

Split spoon samples can be used for classification purpose and determination of the unit weight. They are in general applied for soils finer than gravel.

The method of sampling should be stated in the report. Samples are usually stored in airtight tins or jars, or in bags, and suitably identified.

Core samples extracted from the core barrel and continuous disturbed samples are stored in the correct order in wooden or metal core-boxes with the top and bottom depth of each run clearly marked. Selected portions of core may be waxed to preserve the moisture content. For rock cores subject to deterioration colour photographs of selected clean fresh cores should be taken.

1.4.5.3.4.2 Undisturbed Samples

By usage of thin wall tube samplers undisturbed samples can be obtained in soft to stiff cohesive soils, with size range from 50 to 150 mm in diameter and 600 to 750 mm in length. The sample size depends on the specimen size to be tested. For smaller diameter samples, a larger ratio of perimeter disturbance (change of original conditions in terms of strength etc. at the outer perimeter of the sample) must be considered. At selected depths during drilling operation or from the bottom of test pits or shafts sampling tubes are pressed by pneumatically or hydraulically applied force. Driving force is not acceptable.

Common types of samplers are the Shelby tube and piston samplers. The Shelby tube is an open sampler which is applied in firm to stiff soils. The tube of the piston sampler contains a piston which is operated by a rod passing through the drill rod. More advanced piston samplers (e.g. Osterberg type) are hydraulically controlled. The piston prevents soil from entering the tube and contamination of the sample until the desired depth of sampling is reached. It also creates a vacuum to hold the sample. Piston samplers are used in very soft to firm cohesive soils.

In very stiff and hard soils undisturbed samples can be obtained similar to procedures in rock by a double tube (Denison) core barrel. It consists of a rotating outer barrel and a cutting bit, which contains a fixed inner barrel attached with a cutting ring. Due to the stiffness of the soil the cutting ring can advance the cutting bit.

Undisturbed rock samples are obtained from the rotary core drilling. The core is collected in a core barrel immediately behind the bit. Single tube core barrels are only applicable in hard homogeneous rock. In general, double or triple tube core barrels give much better results and are preferable. Also available are double tube core barrels with stationary inner barrel, and orienting core barrels. The latter allow orientation of the removed rock core.

Core samples extracted from the core barrel and continuous disturbed samples are stored in wooden or metal core-boxes with the top and bottom depth of each run clearly marked. Selected portions of core may be waxed to preserve the moisture content. For rock cores subject to deterioration colour photographs of selected clean fresh cores should be taken.

1.4.5.3.5. In-situ Testing

In situ testing in rock is performed to determine the rock mass properties. Such will help to convert results obtained from laboratory tests on (small) rock samples.

1.4.5.3.5.1 Standard Penetration Testing (SPT)

The application of the SPT is restricted to soils lacking gravel or boulders. The test may recover disturbed samples in a split-barrel sampler driven into the ground by a hammer. The number of blows for a penetration of 30 cm is an indicator of end resistance and. shaft friction and thus for the stiffness or density of the soil. Due to its wide application and existence of different empirical correlations to other soil parameters, it is a very common test.

1.4.5.3.5.2 Vane Shear Testing

Useful in very soft soil, where it is difficult to obtain good quality undisturbed samples. In stiff clays or soils containing gravel it should not be used.

1.4.5.3.5.3 Plate Loading Test

Plate loading tests measure the in situ deformation characteristics of a material and allow to evaluate its strength and bearing capacity.

1.4.5.3.5.4 Pressiometer and Dilatometer Testing

The deformation properties of materials (soil and soft rock) can be studied in-situ by using a pressiometer. In this type of instrument, the deformation of the soil is measured by the change in volume of the pressure cell as gas pressure is varied. The accuracy to which the volume change can be measured limits the effective range of the method to materials with a modules of deformation (tangent or secant modules) of less than 3.5 GPa.

In case of anisotropic conditions in hard rock a dilatometer probe is preferred to a pressiometer probe.

1.4.5.3.5.5 Flat Jack Testing

The state of stress which exists in the earth's crust is changed by engineering operations which produce a new distribution of induced stresses within the surrounding rock mass. This readjustment of stresses can give rise to stress concentrations which can have major influence on the stability of underground excavation.

Flat-jacks are hydraulic pressure cells which are used to measure stress in rock mass. The flat-jack is usually placed in a slot cut into a rock wall, the object being to relieve the rock of ambient stress. Stresses in a biaxial field may be measured by cutting two slots at right angles. The stress present is then calculated by relating the strain to a known modules of deformation, or by applying a pressure until the rock is strained back to its approximate original shape and assuming that the pressure required to force the rock back to its original shape is equivalent to the stress released when the confining medium was removed. Due to relatively high costs and considerable time request for proper application such tests are not used as routine application but only in case of expected irregularly high stresses or asymmetric stress development.

1.4.5.3.5.6 Other measurements of stress and strain in rock masses

All commonly used methods of measuring in situ stress in a rock mass assume that the release of confining stress results in rock is strain that is elastically reversible.

The overcoring technique measures strain recovery in the rock by means of an electrical or photoelastic instrument. Such a strain meter is set in a small-diameter borehole. It is isolated from the existing rock stress field by drilling a large-diameter hole around it.

The CSIRO "door-stopper" drillhole strain cell can be used in a 60 mm drillhole. It is implemented in an oriented way to measure strains in the vertical, horizontal and 45 degree directions.

Hydraulic fracturing tests work as stress-change measurements. The tests are carried out by sealing off sections of a drillhole at the depth required by an inflatable packer. Fluid pressure then is applied to the section selected and the pressure is increased gradually until the rock mass surrounding is fractured. This fracturing at a certain pressure level is related to the in-situ state of stress in the rock mass.

However, as mentioned above such measurements are not necessarily part of a routine ground investigation programme.

1.4.5.3.5.7 Permeability Testing (mainly Soils)

Field permeability tests in general are conducted during drilling operation at specified depth intervals in the bore hole. In general the variable head test is the preferred testing method. This is carried out either as a falling or rising head test.

To define the intake area, a casing, closely fitted to the bore hole, is required. In the simplest form of the test the bottom of the borehole is cleaned and the test is conducted by measuring the flow rate through the open end of the casing (open-end test). This test, which can be carried out quickly should be used for qualitative information only. For more accurate measurements it is recommended to perform the test over a certain length (about 1 m). Due to instability of the test zone usually a second tube with a screen area has to be installed and attached water tight to the casing. The screen will be surrounded by a granular filter to prevent erosion of the soil. Above the filter the borehole must be sealed.

By measurement of the changing water table with time, the permeability can be determined. A plot of the variation of the head with time in a semilog graph typically shows a straight line. Numerous formulas, partly empirical, have been published. A widely used formula is the one by Hvorsley.

1.4.5.3.5.8 Pumping Tests (mainly Soils)

Permeability is the most variable of all soil properties. Great care must be taken to minimize sources of errors during permeability tests and in the assessment and extrapolation of the results to the real ground condition. Therefore, in sensitive cases the performance of a pumping test is required.

The following information can be obtained from the pumping test:

- o Transmissibility (and permeability)

- o Storage coefficient
- o Yield of the well
- o Relationship between the actual water table in the well and the pumping rate
- o Radius of influence
- o The gradient of the draw down curve

In principle, the pumping test involves pumping at a steady flow from the well and observing the drawdown effect on ground water levels by means of piezometers at some distance from the well.

A pumping test requires the proper installation of a pump well and several arrays of piezometers. Other equipment required for the test are the pump and its power supply and discharge pipe, a water tank, a flow measuring apparatus, stop watch, probes to measure the water tables in the well and piezometer. For settlement measurements a levelling instrument might be required.

The layout of the test site and of all equipment should be based on preliminary test results. Before the test a survey has to be made to detect any other source of influence to the ground water, e.g. existing water extractions, rivers, ponds, tidal effects, etc..

A full test program consists of short term pumping tests with non-steady state conditions, staged pumping tests and long term pumping tests. In addition, the recovery should be observed.

1.4.5.3.5.9 Water Pressure Tests in Bore Holes (mainly Rock Mass)

For the measurement of the local in-situ permeability of a rock mass single or double packer tests are utilized. Single packer tests limit the risk of uncontrolled water losses. Packer spacing depends on rock conditions, to be decided by careful drill core logging.

At certain depths a pneumatic borehole packer is implemented in the borehole and then water is pressed into the concerned section of the borehole with known borehole diameter. Water consumption and water pressure in the test section are recorded. Such Lugeon testing configuration may be applied with usually five steps in terms of increasing and decreasing pressures. For each of such steps a constant pressure level should be achieved for at least 5 minutes with recording of water consumption.

Its interpretation is based upon the use of the "steady-state type" formula:

$$K = 1.85 \times 10E\text{-}5 \times (Q/L) / p$$

with:

K	- permeability, in m/s
Q/l	- flow rate per unit length of drill hole, in L/min x m
p	- overpressure in the test chamber, in meters of water

1.4.5.3.6. Laboratory Testing

1.4.5.3.6.1 Laboratory Testing on Soils

Assessment of design parameters and evaluation of the ground behaviour during tunnelling in soil are largely based on the soil parameters obtained from laboratory tests. At least following parameters are required:

- o General physical properties moisture content, unit weight, grain size distribution, specific gravity and Atterberg limits.
- o Shear strength under drained and undrained conditions determined by direct shear tests, uniaxial and triaxial compression tests.
- o volume change behaviour under drained and undrained conditions determined by triaxial and oedometer tests.
- o consolidation determined from oedometer tests.
- o permeability determined by permeability and oedometer tests.

1.4.5.3.6.2 Laboratory Testing on Rock

Mechanical laboratory tests usually on drilled cores have to yield at least following parameters:

- o dry density
- o natural density
- o uniaxial compressive strength

- deformation modules
- secant modules
- effective shear strength
- residual shear strength
- tensile strength
- Poisson's ratio

Depending on the subject ground conditions further targets of the laboratory testing may be:

- shear strength along distinct discontinuities
- swelling potential/pressure
- permeability
- porosity
- resistivity against slaking (slake durability testing)
- resistance against freezing/thawing (frost resistance)
- Los Angeles and/or Deval testing

Mineralogical and petrographical investigations on typical rock samples, thin sections for microscopic analysis and X-ray-analysis of rock powders including fault gouges have largely already been performed during the geological field mapping. Such study has to be completed at this stage. Special emphasis has to be put on engineering geological aspects of rock such as swelling potential, slaking, erodibility, etc.. For abrasivity and drillability assessments quantitative mineral analysis and microcrack studies are required. In certain locations paleontological investigations may be required for age dating and possibly for preservation of historic sites.

1.4.5.3.7. Final Geological and Geotechnical Report

This report has to display all factual data in great detail and to provide a clearly separated interpretative analysis of investigation results.

It includes the final geological model in plans, longitudinal, cross and horizontal sections and a written report emphasizing all engineering geological and hydrogeological aspects to the tunnel project. This report is the basis for rock mass classification and geotechnical design operations. For this it has further to provide the final geotechnical model with the assignment of soil, rock and rock mass parameters for design.

Finally, it has to specify requirements for further investigations, schedules for monitoring of slopes by topographic surveys, inclinometers, extensometers, groundwater monitoring by ground water level observation, monitoring of discharge water quantities, water chemistry etc..

1.4.6 DESIGN METHODS AND ROCK CLASSIFICATION SYSTEMS

1.4.6.1 General

Basically, there are three different groups of design methods:

- o Empirical Methods
- o Observational Methods
- o Analytical and Numerical Methods

In deep tunnels (with high overburden), which usually implies rock tunnels, the design is predominantly empirical based on experience and using a rock classification system.

For shallow tunnels, where surface structures, utilities or roads have to be considered, mostly analytical or numerical design methods are used. These design methods serve both for the design of the lining and the prediction of settlements. If settlements exceed allowable limits, corrective or protective measures have to be designed.

Observational methods rely mainly on observations and monitoring results during construction to verify or adjust design assumptions.

1.4.6.2 Empirical Design Methods

Empirical design methods relate practical experiences gained on previous projects to the conditions anticipated at the proposed site.

Rock mass classifications form the backbone of the empirical design approach and are widely employed in rock engineering.

In an empirical design the ground to be encountered is first classified based on site investigation results and relying on the experience of the design engineer. The type of rock, rock strengths, primary stress state, overburden, degree of weathering and fracturing, discontinuities, local tectonic and hydrological conditions are to be considered for the classification. Based on the rock classification and taking into consideration factors such as tunnel size, excavation methods and construction sequence, standard support types are designed for the different ground types anticipated. This design is usually accompanied by specifications of construction sequences and sequence of support installation. A geomechanical instrumentation and measuring program is developed as part of the design, to be executed during construction.

During construction, the rock is classified each round based on the original prognosis, the actual geology (mapped by the geologist at the face), the general behaviour of the ground during excavation of the last rounds, the presence of water and the measurement results in recent monitoring sections. A standard rock support class is assigned to the next round, support measures are modified locally if dictated by rock conditions.

1.4.6.3 Analytical And Numerical Analyses

1.4.6.3.1. General

The construction materials "rock" and "soil" are natural, non-homogeneous materials. In most cases, rock deformations are partly elastic and partly plastic. Mathematical modelling of the main support elements like shotcrete, rock bolts, etc. is also very complex and still unsatisfactory. It is well recognized that rock and shotcrete show a very distinct rheological behaviour in general.

Therefore, approximations and simplifications must be made in mathematical modelling of rock tunneling, in particular for application of closed form solutions. The result of such computations cannot conform exactly to reality.

A variety of analytical tools has been introduced for design of tunnels, each of which has certain advantages and drawbacks, which have to be balanced depending on the nature of the actual problem.

Analytical tools fall into five main categories:

- o Analytical "closed form" solutions
- o Limit state analysis
- o Embedded frame analysis

- o Numerical continuum models
- o Numerical discontinuum models

1.4.6.3.2. Analytical Solutions

Generally, closed form solutions are based on an elastic or elasto-plastic continuum under plain strain conditions. Specific methods include the "Rock Support Interaction Analysis" by Hoek and Brown, the "Tunnel Support Analysis" by Erdmann and the "Convergence Confinement Method" by Gesta et al. The method of Feder enables consideration of certain discontinuity and rock failure influences.

Closed form solutions have the advantage of being easy and quick to use. However, they are often restricted to certain tunnel shapes (usually circular or elliptical), simple material laws, simplified stress conditions or homogenous ground conditions. They are thus well suited for preliminary design and parameter studies. For detailed lining design more advanced methods should be used.

1.4.6.3.3. Limit State Analyses

Limit state analyses consider simple models like blocks on inclined surfaces, sliding wedges etc. Since they require only a few simple mechanical laws, they can be developed on the spot by the design engineer and applied for quick parameter studies or examinations of particular situations at the face. The most advanced limit state method is the Block Theory by Goodman and Shi.

1.4.6.3.4. Embedded frame analysis

Embedded frame analyses model the tunnel lining as a sequence of elastic or elasto-plastic beams and the surrounding ground as springs. A number of computer codes are available and analyses can be performed quickly and with fairly small computational effort. There are no restrictions regarding tunnel shape and temporary lining structures (e.g. temporary invert, side drifts etc.). On the other hand, modelling of the surrounding rock or soil is unsatisfactory, even if non-linear springs are used. The ground has no bearing action of its own and deformations of the lining do not reduce lining loads, contradicting some elements of NATM philosophy. Bedded beam analyses generally render very conservative results for lining loads.

1.4.6.3.5. Numerical Methods

Numerical methods are the most advanced analysis tools available to date. They have been traditionally classified into continuum and discontinuum approaches. However, many contemporary methods and computer codes incorporate continuum and discontinuum elements in their formulation. In borderline cases, it is good practice to examine a problem from a continuum and a discontinuum mechanical point of view.

Classified according to their mathematical and mechanical formulation, the main numerical methods are:

1.4.6.3.5.1 Finite Element Method (FEM)

The FEM is the best known numerical method. Originally applicable only to continuum mechanic problems, most modern FE-programs include the possibility to use "slide lines" or "gap elements" to model large joints and faults. Alternatively, special material models allow the "smearing" of joints if they are very closely spaced compared to typical tunnel dimensions. Most FEM programs provide a wide variety of linear and non-linear material models, different element types, groundwater modelling and the capability to solve thermal problems. Since most FEM programs are matrix based, they require powerful computers.

1.4.6.3.5.2 Boundary Element Method (BEM)

In the BEM, only the surface or boundary of a structure is discretised. Boundary Element Methods can be suitable if the necessary simplifications regarding homogeneity of ground conditions are permissible.

1.4.6.3.5.3 Finite Difference Continuum Models

Finite Difference Methods differ from Finite Element Methods in the way in which the basic equations are derived. When using the programs, the user will notice little difference between the two methods. FD codes also provide different non-linear material models, slide lines, groundwater modelling and thermal capacity. However, most Finite Difference codes can incorporate complicated material laws and large deformations with less computational effort than FE programs. Additionally, they can be run on fairly small computers - standard PCs are usually sufficient. For simple, linear-elastic problems, however, Finite Difference programs may take significantly longer to reach a solution than FE programs.

1.4.6.3.5.4 Finite Difference Discontinuum Models

Originally, these programs were developed to model assemblies of rigid blocks. These blocks could move and rotate relative to each other, new contacts were automatically detected. The method has since developed to allow block deformation and block failure according to material laws similar to those used in continuum approaches. FD discontinuum models are best suited to model moderately to strongly jointed rock masses, both close to the surface and at great depth.

1.4.6.4 Rock Classification Systems

An underground excavation is an extremely complex structure and the theoretical tools which the designer has available to assist him are a number of grossly simplified models of some of the processes which interact to control the stability of the excavation. It is even theoretically many times impossible to determine the interaction of those processes and the designer is faced with the need to arrive at design steps and decisions in which engineering judgement and practical experience play an important part.

Out of the desire to relate own experiences to conditions encountered by others, a large number of classification system have been developed over the years. As it is the case with design methods also the different classification systems do not provide a "cook book" for tunnel construction to the inexperienced user and caution has to be exercised if they are applied. Nevertheless, most of the systems do have their merits and surely improve understanding of the ground conditions

The various classification systems described below have been developed for various purposes and their original intentions must be understood.

In general there are three distinct types of classification systems:

- Geologic, geotechnical descriptions, where one or several parameters are standardized.
- Quantitative descriptions of significant parameters of the rock mass which can directly or indirectly be used as design input.
- Descriptions of the qualitative behaviour of the rock mass during and after excavation, including the influence of the support.

In principle, it is the order of magnitude of significant parameters and their mutual influences as well as the difficulty to obtain objective instead of subjective input parameter, what makes rock mass classification so difficult.

1.4.6.4.1. Overview of Systems

1.4.6.4.1.1 Terzaghi's classification

In 1946 Terzaghi proposed a simple rock classification system for use in estimating the loads to be supported by steel arches in tunnels. He described various types of ground and, based upon his experience in steel-supported railroad tunnels in the Alps, he assigned ranges of rock loads for various ground conditions.

It must be emphasized, however, that while this classification is appropriate for the purpose for which it was evolved, that means for estimating rock loads for tunnels with steel support, it is not suitable for modern tunnelling using shotcrete, rock bolts, segmental linings etc. The system takes into account poor tunnelling customs which allow formation of loosening zones and disregards the requirement for proper rock/support interaction and full rock/support contact. In the case of proper tunnelling techniques the given rock loads are too conservative, while in high overburden the stresses may be underestimated.

1.4.6.4.1.2 Deere's Rock Quality Designation (RQD)

Deere proposed a quantitative index of rock mass quality based upon core recovery by diamond drilling. This Rock Quality Designation (RQD) has come to be very widely used in particular in the English speaking countries.

The RQD is defined as the percentage of core recovered in intact pieces of 100 mm or more in length in the total length of a core run.

It is normally accepted that the RQD should be determined on a core of a least 50 mm (NX) diameter which should have been drilled with double barrel diamond drilling equipment. An RQD value would usually be established for each core run of say 2 meters. This determination is simple and quick and, if carried out in conjunction with the normal geological logging of a core, it adds very little to the cost of the site investigation.

Deere proposed the following relationship between the numerical value of RQD and the engineering quality of the rock:

RQD	Rock Quality
25 %	Very poor
25 - 50 %	Poor
50 - 75 %	Fair
75 - 90 %	Good
90 - 100 %	Very good

It is quite obvious that an arbitrarily selected length of core piece alone can not describe rock mass conditions properly. Consequently, without detracting from the value of RQD as a quick and inexpensive practical index, it is suggested that it does not provide an adequate indication of the range of behaviour patterns which may be encountered when excavating underground.

1.4.6.4.1.3 Bieniawsky's classification

The Geomechanics Classification or the Rock Mass Rating (RMR) system was developed by Bieniawski in 1973. This engineering classification of rock masses, utilizes the following six parameters:

- Uniaxial compressive strength of intact rock material
- Rock quality designation (RQD)
- Spacing of discontinuities
- Condition of discontinuities
- Groundwater conditions
- Orientation (dip and strike) of discontinuities

To apply the geomechanics classification, the rock mass along the tunnel route is divided into a number of structural regions, e.g., zones in which certain geological features are more of less uniform within each region. The above six classification parameters are determined for each structural region from measurements in the field and entered into the standard input data sheet.

The first five parameters are grouped into five ranges of values. Since the various parameters are not equally important for the overall classification of a rock mass, importance ratings are allocated to the different value ranges of the parameters, a higher rating indicating better rock mass conditions. These ratings were determined from 49 case histories (Bieniawski, 1976).

After the ratings of the classification parameters are established, the ratings for the five parameters are summed up to yield the basic rock mass rating for the structural region under consideration.

At this stage, the influence of the strike and dip of discontinuities is included by adjusting the basic rock mass rating. This step is treated separately because the influence of discontinuity orientation depends upon engineering application e.g., tunnel (mine), slope, or foundation. It will be noted that the "value" of the parameter "discontinuity orientation" is not given in quantitative terms but by qualitative descriptions.

After the adjustment for discontinuity orientations, the rock mass is classified by assigning the final (adjusted) rock mass ratings (RMR) to one of the five rock mass classes.

1.4.6.4.1.4 The Geological Strength Index (GSI)

For the design of underground excavations, reliable estimates of the strength and deformation characteristics of rock mass are required. In 1980, Hoek and Brown proposed a method, based upon an assessment of the interlocking of rock blocks and the condition of the surfaces between these blocks. The significant contribution of the two authors was to link the equation to geological observations in form of Bieniawski's RMR.

The method was modified over the years, with special attention on rock masses of poor quality. The application of the method required a development of new classification called the Geological

Strength Index - GSI as a replacement for Bieniawski's RMR. The last stage of this development reflects in a new GSI chart for heterogeneous weak rock masses. Besides, a freeware Windows program called "Rocklab" is developed which enables calculation of the cohesive strength, angle of friction and al over deformation modulus of rock mass. The program is based on relationship between the Hoek-Brown and Mohr-Coulomb criteria.

1.4.6.4.1.5 Barton's classification

The Q-system of rock mass classification was developed in Norway in 1974 by Barton, Lien and Lunde, all of the Norwegian Geotechnical Institute. Its development represented a major contribution to the subject of rock mass classification for a number of reasons: the system was proposed on the basis of an analysis of some 200 tunnel case histories from Scandinavia, it is a quantitative classification system, and it is an engineering system enabling the design of tunnel supports.

The Q-system is based on a numerical (quantitative) assessment of the rock mass quality using six different parameters:

- RQD
- number of joint sets
- roughness of the most unfavorable joint or discontinuity
- degree of alternation or filling along the weakest joint
- water inflow
- stress condition.

The above six parameters are grouped into three quotients to give the overall rock mass quality Q as follows:

$$Q = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF} \quad [\ ]$$

where:

RQD = rock quality designation;

J_n = joint set number;

J_r = joint roughness number;

J_a = joint alteration number;

J_w = joint water reduction number;

SRF = stress reduction factor.

The numerical values of each of the above parameters are interpreted as follows:

The first two parameters represent the overall structure of the rock mass, and their quotient is a relative measure of the block size. The quotient of the third and the fourth parameters is said to be an indicator of the interblock shear strength (of the joints). The fifth parameter is a measure of water pressure, while the sixth parameter is a measure of:

- loosening load in the case of shear zones and clay bearing rock,
- rock stress in competent rock, and
- squeezing and swelling loads in plastic, incompetent rock.

This sixth parameters are regarded as the "total stress" parameters. The quotient of the fifth and the sixth parameters describes the "active stress".

Barton et al. (1974) consider the parameters, J_n, J_r, and J_a, as playing a more important role than joint orientation, and if joint orientation had been included, the classification would have been less general. However, orientation is implicit in parameters J_r, and J_a, because they apply to the most unfavourable joints.

A correlation has been provided between RMR and the Q-value (by Bieniawski in 1976). As the Q system and the RMR system include somewhat different parameters they cannot be strictly correlated. The approximate relationship proposed by Bieniawski is based upon a study of a large number of case histories (standard deviation = 9.4).

$$RMR = 9 \ln Q + 44 \ [\ ]$$

A comparison of the stand-up time and the maximum unsupported span reveals that the RMR classification is more conservative than the Q-system, which is a reflection of the different tunnelling practice in Scandinavia based on generally excellent rock and a long experience in tunnelling.

1.4.6.4.1.6 Austrian Classification

This classification system has been developed by Rabcewicz-Pacher to suit the requirements and principles of the "New Austrian Tunnelling Method". Its aims have been defined by the authors as follows:

- to render information about rock mass distribution along a tunnel to allow cost and schedule estimates at early design stages
- to form a basis for tendering, allowing realistic cost estimates by the contractors and guidelines for payment
- to allow measures during construction to adjust excavation and support requirements
- to minimize differences of opinion between the contract parties and avoid claims.

These aims set the system apart from other ones. The lack of quantitative input data could be considered as a shortcoming and experienced personnel is certainly needed to apply the system. On the other hand it is superior to quantitative systems since it uses the following main criteria :

- actual behaviour of the surrounding rock during and after excavation
- rock conditions and discontinuities outside of tunnel cross section
- primary stress conditions
- size and shape of the tunnel

A detailed description and specification of rock class types in design and tender documents should contain the following information:

- Quality and structure of rock formations
- Influence of water and the effect of air contact on newly exposed surfaces regarding the strength and behaviour of the rock
- Average anticipated quantities of support elements for each rock class type (standard support provisions)
- Sequence of installation of support elements
- Possible methods of driving: full face or subdivided cross section, together with the expected length of round
- Expected deformations
- Details about possible complications which might influence construction costs e.g. expected water inflow, gas etc.

In the new Austrian Standard ÖNORM B 2203 following classification of "rock mass types" is specified.

Rock Mass Type A1:	stable rock conditions
Rock Mass Type A2:	fractured rock with local fall-out
Rock Mass Type B1:	friable rock conditions
Rock Mass Type B2:	heavy friable rock conditions
Rock Mass Type B3:	non-cohesive ground conditions
Rock Mass Type C1:	rock burst phenomena
Rock Mass Type C2:	pressure exerting rock conditions
Rock Mass Type C3:	heavy pressure exerting, squeezing rock conditions
Rock Mass Type C4:	flowing ground conditions
Rock Mass Type C5:	swelling rock conditions

1.4.6.5 Principles of the New Austrian Tunnelling Method

The New Austrian Tunneling Method (NATM) is both a design philosophy and a general, but practical approach to tunneling. Its goal is to achieve a technically sound, safe and economical design.

It is a concept which considers the geological formation surrounding the tunnel excavation as both a load and a load carrying ring. This aspect sets NATM apart from many other philosophies of tunnel design, in which the ground mass is assumed to transfer all or part of its weight to the lining.

When a tunnel is excavated, the in-situ state of stress in the surrounding ground is transformed through several intermediate steps of stress redistribution until a new state of equilibrium is reached. Successful application of NATM requires that certain principles are followed:

- Choice of appropriate tunnel shape must consider the existing conditions of stress and ground mass strength. As a result, a proper tunnel shape reduces stress concentrations and contributes significantly to stability.
- Sequencing of excavation and installation of support must be handled in such a manner that deformations of the surrounding material remain small enough to prevent a decrease in strength.
- Careful excavation methods and procedures must be employed to minimize disturbance of the ground outside the limits of excavation.
- Hydrogeological conditions have to be considered. Water, especially when occurring at high pressure, has to be drained away to prevent a negative influence on rock strength and to reduce the water pressure.
- Linings must be relatively thin and flexible and in full contact with the surrounding ground in order to minimize bending moments absorbed by the lining. Tunnel lining components such as shotcrete and light steel ribs must be selected and dimensioned to assist the ground in maintaining its inherent strength.
- The support elements must be selected for their adaptability to changing geological conditions along the tunnel alignment in order to minimize drastic alterations in the general support system as tunneling proceeds.
- Measurement of deformations is an integral part of NATM, and necessary not only in assuring the safety of the tunnel but also in verifying design assumptions before placement of the final lining. Instrumentation commonly used includes convergency pins and reflectors for optical 3-D deformation monitoring to determine deformations in the initial tunnel lining, extensometers to evaluate the behaviour of ground around the excavation, pressure cells, strainmeters, inclinometers, levelling etc.

These general principles are not related to any particular support or excavation technique. Historically, experience has shown that shotcrete and rock bolts satisfy the technical requirements of NATM most economically. However lightweight steel ribs and welded wire fabrics are also commonly used as lining components besides other supplementary support elements.

The application of NATM foresees two separate lining operations. The initial lining is installed immediately or very shortly after excavation. In addition to providing stability during construction, the initial lining becomes part of the overall lining system. The initial lining has to be sufficient to stabilize ground deformations. The final lining increases the safety of the tunnel lining system and provides a uniform interior surface and improves the watertightness of the tunnel. The smooth, final lining serves for the air flow in the tunnel and satisfies aesthetic and maintenance requirements. For total watertightness a membrane lining is installed between the initial and the final lining.

NATM takes an active design approach that demands a close contact between the designer and the site once the initial design package is completed. NATM design is not completed with the tender design, the final design is developed during excavation in a "design as you go" approach. Interpretation of monitoring results, verification of design assumptions and feedback into design have to be performed by the designer while tunnel construction proceeds.

Much of the success NATM has enjoyed in the past three decades can be attributed to its adaptability to nearly all types of ground conditions while providing maximum flexibility in the choice of tunnel lining and construction methods. Also, NATM can be applied to tunnels of all sizes and various shapes permitting prompt, economical adjustments to changing ground conditions and thereby improving feasibility of tunnel projects even in areas of very sensitive rock conditions.

The NATM design approach is illustrated on Fig. 4.

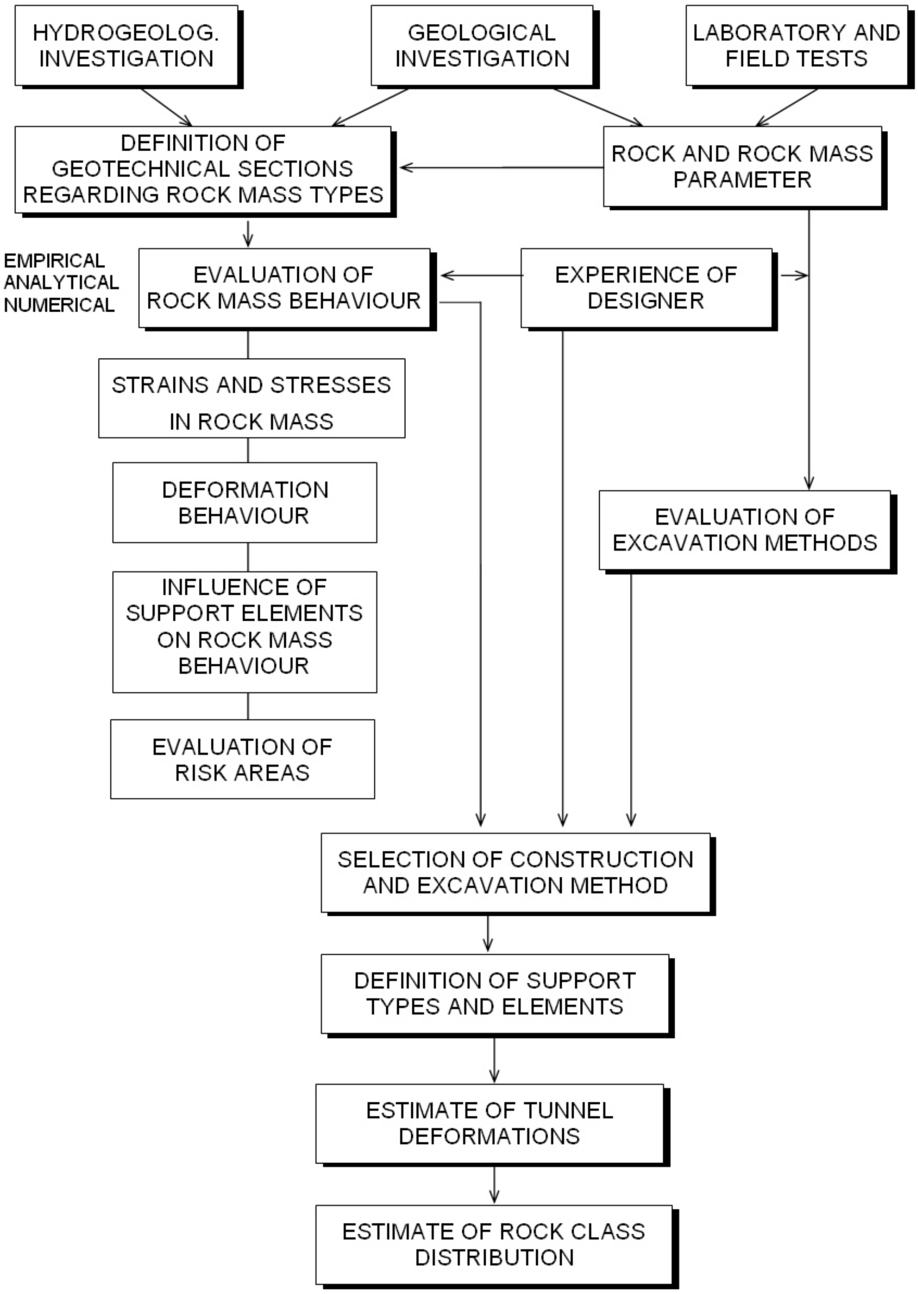


Fig 4: NATM Design Approach

1.4.7 EXCAVATION DESIGN

1.4.7.1 Geotechnical Model

1.4.7.1.1. Tunneling in Rock

The establishment of the geological model has the task of defining which geotechnical rock mass properties are to be used as design parameters for the coming design steps. The values obtained by site and laboratory investigations do not form a direct basis for further computations. Rock parameters (e.g. from laboratory tests) are maximum values which have to be evaluated before they can be used as design criteria or geotechnical design parameter.

The whole rock mass is affected by a number of influences, usually affecting the physical and rock mechanical properties to the worse, such as:

- Weathering
- Tectonic processes
- Influences of pore- and groundwater
- Slope instabilities
- Changes in state of stress
- Dynamic loads
- Temperature changes

Based on the geological model and taking into consideration laboratory tests and results of situ tests geotechnical rock mass properties have to be established.

Empirical (qualitative or quantitative), analytical or numerical design procedures or a combination thereof can be used for carrying out the geotechnical tunnel design.

Since geological (hydrogeological, tectonical, etc.) conditions vary widely from site to site as do the influences of the individual geology-related parameters on the underground structure, an examination of their impacts on the project must be performed, to achieve a rating or classification which is custom tailored for the individual project.

For each tunnel project, the importance (influence) of each geology-related parameter must be rated individually, because this influence depends on

- Size of the opening
- Applied construction method and excavation method
- Type of support
- Orientation of the underground opening towards the discontinuities
- Primary stress conditions

For the tender design a geotechnical longitudinal profile has to be prepared. Elements of the tunnel with similar geotechnical behaviour are now recognizable in this longitudinal profile and the chainages where they will be encountered. This achieved knowledge now forms the basis for the assessment of design parameters and the classification in design stage.

This task requires an intimate cooperation of the engineering geologists and the geotechnical engineers. The classification is concentrated upon the geotechnical behaviour of the rock mass surrounding the excavation and the mode and sequences of excavation as well as the sequences and items of stabilization.

Using an empirical, qualitative design method the result is a classification concept considering the rock mass behaviour ranging from stable conditions to friable and further on to squeezing conditions. These conditions have to be divided up into several rock type classes for which the general geological conditions and the expected behaviour of the ground as well as the requirements of support and its designed function has to be defined.

1.4.7.1.2. Tunneling in Soil

For design of tunnels in soil analytical or numerical method are a reliable tool, especially when the tunnels are driven with a shallow overburden and under buildings or other structures (e.g. bridges, gas pipe lines etc.). In such case the design of excavation methods (e.g. length of round, subdivision of excavation, necessary auxiliary support) and tunnel lining shall be carried out or at least supported by structural analyses.

For the definition of different load cases, short term and long term conditions as well as a possible range of design parameters must be considered (e.g. drained or undrained conditions, low and high ground water table).

Several auxiliary methods of ground improvement, like dewatering, installation of advanced lagging, pipe roofing, grouting, compressed air and artificial ground freezing may be adopted for safe tunneling.

1.4.7.2 Gas Monitoring

The table below provides an overview of most frequent air pollutions occurring in underground works: :

Substance	Properties	Action	LAC (limiting admissible concentration)
dust	fly dust particles > 5μ fast falling < 5 μ slow falling, penetrating lung	silicosis; siliceous material and certain silicates hazardous	for dust particles < 5 μ depending on percentage of silica; at 70 % of silica less than 1 mg/m^3
carbon dioxide (CO_2)	predominantly in large quantities in blasting products and exhaust gases of diesel generators	odourless; in high concentrations (> 4 vol. ‰) headache , which gradually leads to unconsciousness	5000 ppm
carbon monoxide (CO)	a product of an incomplete combustion; can be found in blasting products in substantial quantities	odourless ; in concentrations above > 1 vol. ‰ (1000 ppm) hazardous , the weakness develops to unconsciousness and, after that, to death	50 ppm
nitrogen oxides	a mixture of and other higher nitrogen oxides ; occurring in blasting products and exhaust gases of diesel generators	In concentrations above 10 – 50 ppm irritating (cough), which develops to lung oedema and death	NO 25 ppm NO_2 5 ppm
aldehydes	formaldehyde (H_2CO) and higher aldehydes and acrolein (CH_2:CH·CHO); products of exhaust gases of diesel generators	irritating (cough, eyes and throat)	formaldehyde 5 ppm acrolein 0,1 ppm
sulphur dioxide (SO_2)	from diesel oil sulphur	strong smell, irritates to coughing, in higher concentrations causes lung oedema	5 ppm
methane CH_4	coming out from rock ,	combustible, forms explosive mixtures	up to 0,5 % by volume at construction site

1.4.7.2.1. Exhaust gas from machines

For verification of the ventilation system during construction, especially if machines with diesel engines are operating inside the tunnel, the following measurements have to be carried out:

- o pollution measurement (gases, dust)
- o climatic conditions (temperature and velocity of air stream and barometric pressure)
- o function of ventilation and their power supply
- o carbon monoxide (CO) in exhaust gases

1.4.7.2.2. Explosive gases in the rock mass

During site investigation, it is possible to combine geotechnical evaluation with a preliminary study and risk assessment in respect of hazardous gas. Detection and sampling may be made during drillinginstallation of boreholes, and the installation of simple standpipe piezometers can allow for longer-term monitoring in locations where it is recognized that the presence of gas may be a risk.

During mining of tunnels, some form of constant monitoring for gas is required in sections, where the occurrence of gas is expected. This may take the form of simple multi-gas electronic detectors, or, in higher risk situations, more sophisticated detector heads linked to provide shut-down of equipment in the event that gas is encountered.

Forward probing by regular drilling ahead of the working face has to be employed in tunnel sections, where gas is expected. This practice ensures that excavation proceeds into ground that has been investigated to some degree. Probing can be carried out up to, and even in excess of, 50 m from the tunnel face.

All measurements of methane gas and other measurements in tunnels must be performed according to local regulations and the „safety program“ elaborated by the contractor.

1.4.7.3 Construction Ventilation

The ventilation system has to be designed and operated in accordance with the local regulations.

The ventilation system has to be designed to suit the length of the tunnel, excavation method and equipment used and number of labourers working inside the tunnel. Toxic gases, smoke and dust particles indicated by measurements at the working site shall not exceed permissible concentrations.

For tunnels with the occurrence of explosive gases (e.g. methane gas), the ventilation system shall be designed and operated to achieve an adequate dilution of hazardous gases. Measurements of gas concentration shall be carried out by portable and fixed installed measuring devices.

Only well instructed personnel shall be allowed to work in tunnels with possible gas occurrence. Smoking inside the tunnels is prohibited.

1.4.7.4 Survey Works

In this section, basic requirements to establish a geodesic system of coordinates are provided for all the surveying-technical works in the tunnel construction, and the quality requirements for this system are given.

1.4.7.4.1. Geodesic system of coordinates

The geodesic system of coordinates is a three-dimensional system of coordinates or three-dimensional positions of points, which specify this system of coordinates. These positions can be determined on the basis of classical, i.e. terestric methods, or by the methods of satellite survey such as the GPS (Global Positioning System).

The geodesic system of coordinates is represented by the positions (coordinates) of points. In addition to the methods of measurements and data processing, which enable attaining the required accuracy of positions of points of the base of coordinates, it shall also be ensured, that the points of the system of coordinates be stable. In this view it is required to select suitable locations and an adequate stabilization of points. The stability of points of the system of coordinates is established by means of periodical measurements. In case that certain point is not stable, its shifting shall be reliably found out. The system of coordinates shall be of such quality (accuracy) as to allow carrying out the survey works prior to, during, and after the completion of construction of tunnels or any other structures on the considered road section:

- o staking-out of portals and structures within the portal area,

- directing the tunnel axis,
- monitoring of movements (deformations) in the tunnel influence area ,
- monitoring of convergences in the tunnel ,
- monitoring of movements after completion of tunnel construction .

A geologist or a geo-technician shall be present when the position of points is determined. He shall assess the overall and local stability of the slope, where placing of primary points of the system of coordinates is foreseen. .

1.4.7.4.1.1 Establishing the system of coordinates by means of terestric methods

A terestric method enabling winning the horizontal positions of points of an adequate quality, is a triangulation together with a trilateration. . The horizontal part of the system of coordinates shall be established as a national trigonometric network of the highest ranking. Observations shall be carried out by means of compared and faultless instruments of the highest quality, and they shall be correctly processed and levelled.

The height part of the system of coordinates shall be established with by means of instruments, methods, and processing of observations, as they apply to the level net of high accuracy. .

The establishing of the system of coordinates in case of terestric methods shall be performed by logical implementing the international standard ISO 4463. .

The coordinates of points in the national cartographic projection and the height levels of points in the national level system are the result of the abovementioned activities. .

1.4.7.4.1.2 Establishing the system of coordinates by means of the GPS technology

In case of establishing the system of coordinates on the basis of GPS observations, this shall be executed by means of adequate GPS receivers, by appropriate duration of the observations, and by a correct processing of the GPS observations. The observations shall be linked to a global high-accuracy terestric system of coordinates, e.g. ETRS 89, and accurate ephemerides of the GPS satellites shall be used, such as CODE or IGS ephemerides. In case of determining the position by the methods of satellite survey, the system of coordinates is represented by the spatial positions of points determined in the global terestric reference system of coordinates. For the application of these positions in the system of coordinates, in which the structure is designed, and particularly for the connection with the terestric measurement methods, it is required to establish a link between both systems.

In case that the system of coordinates is established by adopting the methods of the satellite survey, this shall be carried out by logical implementing the international standard ISO 4463. In addition, the following recommendations for the GPS geodetic measurements shall be adhered to: *Federal Geodetic Control Comitee, 1988. Geometric Geodetic Accuracy Standards and Specifications for Using GPS Relative Positioning Techniques, Ver. 5.0, Federal Geodetic Control Comitee, ZDA.*

The coordinates of points in the national cartographic projection and the height levels of points in the national level system are the result of the abovementioned activities

Accuracy of the system of coordinates

A geodesic system of coordinates shall be established to accuracy as required by different tasks, whose execution shall be enabled and ensured by the system of coordinates:

- the required accuracy of staking-out the axis of the tunnel and other structures, ,
- the required accuracy of monitoring of eventual movements in the construction influence area, ,
- the required accuracy of monitoring the convergences ,
- the required accuracy of determining the displacements of points after completion of the tunnel construction .

The required accuracy of the staking-out of the structure and the expected magnitude of movements (displacements, convergences) shall be specified by the tunnel designer. .

1.4.7.5 Support Elements

1.4.7.5.1. General

Whether in rock or soil, initial (primary) lining design combines different support elements into "typical support types"cross sections. The initial lining is considered to be a part of the complete tunnel lining system.

Ground conditions and geometric conditions (e.g. height of overburden, buildings, utilities or other structures above or close to the tunnels etc.) should be considered for the decision whether to design a "stiff" or "flexible" initial lining. Tunnels with shallow cover and situated underneath buildings or other structures required basically a stiff support (thick, stiff lining, quick ring closure, sometimes early installation of the inner (secondary) lining in order to limit or minimize ground deformations and surface settlements. For tunnels with medium to high overburden the allowance of deformations by application of flexible support types (using thin flexible linings, rock bolts, delayed invert closure etc.) leads to an economical design.

Each of the rock or ground types predicted by the geological model are assigned to a support class. Support classes may differ in shotcrete thickness, number of layers of wire mesh, placement and spacing of steel arches, pattern and length of rock bolting, other support measures, length of excavation rounds, excavation sequence and type of subdivision of the face. Later on, these support classes are applied according to the classification during excavation and will be modified or adjusted if required by the actual ground behaviour or indicated by monitoring results.

In the tender design drawings with typical support elements have to be prepared for each rock type specified. Possible round lengths, sequences of excavation and support installation are also shown on those drawings.

During construction shop drawings will be necessary for supporting elements that have to be manufactured specifically for an individual tunnel, such as steel arches and lattice girders.

In modern tunnel construction, the main supporting elements are:

- Shotcrete, either plain or reinforced by wire mesh, steel or composite fibres. Reinforcement by wire mesh is done in order to improve shear- and tensile strength of the shotcrete. In special cases steel or composite fibres are added mainly for the purpose of increasing the ductility and improving post failure behaviour.
- Rock bolts, which are available in various designs, such as:
    - Expansion bolts
    - Fully embedded bolts, using either resin or mortar as bonding medium between steel and rock
    - Injection bolts (made of steel bars or pipes)
    - Bolts can be further divided into non-prestressed and prestressed rock bolts. In special cases, such as very large openings, prestressed cable anchors, can be used too
- Steel arches, usually light weight, are used in different forms:
    - H-shaped bent structural steel
    - U-shaped special tunnel profiles
    - Lattice girders

Auxiliary supporting elements are:

- Lagging sheets, made from 3 - 6 mm steel sheets and used in cohesionless material as a temporary support installed ahead of the face for prevention of material flow-out during excavation
- Forepoling pipes or bars, which serve a similar purpose as the lagging sheets, but used in slightly cohesive or blocky material to avoid overbreaks.

1.4.7.5.2. Shotcrete

Shotcrete is applied to avoid loosening of the surrounding rock mass and as a bearing member. The shotcrete lining covers and closes rock joints and prevents fall-out and overbreaks. Maintaining the initial rock strength is essential to forming a rock arch close to the excavation profile.

Basically, shotcrete lining of ordinary tunnels can be considered as unreinforced concrete. Practical experience shows, that a tunnel lining does not fail due to bending, but due to excessive compressive stresses resulting in shear failure. Excessive bending moments are reduced by creep and redistributed by forming cracks, thus creating a hinge-system. Such a multiple hinge-system of a tunnel lining is stable with regard to kinematic principles, provided it is “fully embedded“ in the surrounding rock or soil and the tunnel lining is properly shaped, having a smooth, curved roof and side walls.

A minimum compressive strength (cube strength) of 25 MPa after 28 days as specified for many projects can be achieved by using 350 to 400 kg Portland cement per cubic meter dry mix.

Conventional accelerating admixtures with high alkaloid content for earlier setting and higher compressive strength at the beginning influence and reduce the final compressive strength. They are therefore only suitable for shotcrete without structural function (e.g. sealing layers, back-fill of excessive overbreaks etc.). Alkalic accelerators endanger the health of the workers and pose a long term environmental hazard.

Non-alkalic accelerators and low-alkalic accelerators offer significant advantages in working conditions, environmental compatibility and technological properties. They cause only a slight reduction of the final compressive strength of the shotcrete.

Recent developments are shotcrete applications with quick-setting cementsts without any accelerator. There is no reduction of the final compressive strength.

Taking into consideration environmental protection issues, health of the workers and maintenance (e.g. of drainage pipes) either non-alkalic accelerators or quick-setting cements only shall be used.

1.4.7.5.3. Wire Mesh

Wire mesh is applied as structural reinforcement of the shotcrete lining. It also has the following functions:

- Improvement for adhesion of shotcrete layers
- Stabilization and strengthening of applied shotcrete layer until setting and hardening
- Increase of shear strength
- Reinforcement of construction joints
- Reduction and limitation of cracks due to creep and overstressing
- Reinforcement of tunnel lining in longitudinal direction to be utilized at boundaries of construction stages (e.g. top heading/bench)
- Preventing fallout of shotcrete portions after cracking or failure of the lining
- Protection of workers and equipment prior of shotcreting.

Only if shotcrete is applied as local support (e.g. in excellent, stable conditions) or as sealing wire mesh may be omitted for thin layers (less than 5 cm).

To minimize rebound and achieve a good quality of shotcrete the spacing of the wires welded to a mesh should be no less than 100/100 mm, a grid of 150/150 mm is preferable. To be effective the diameter of the wires should not be less than 5 mm. For practical application, bending, fixing etc. the diameter of the wires should not exceed 8 mm.

1.4.7.5.4. Fiber Reinforced Shotcrete

For special applications of shotcrete, adding steel or composite fibres can be required. The addition of fibres to shotcrete improves considerably the flexural strength, shear strength, impact strength, direct tensile strength, shock resistance, ductility and failure toughness. By using fibre reinforced shotcrete, wire mesh will usually be omitted.

Comparable advantages are: - a faster execution of the initial support, i.e. better effects and safer execution, as the tunnel construction labour is not exposed to the hazard of working under only partly protected open space, to which they would otherwise be exposed upon placing the mesh reinforcement.

1.4.7.5.5. Steel Ribs

In modern tunneling the function of steel ribs is confined to the role of reinforcement and load distributing member in the shotcrete lining and to immediate support of those areas directly at the excavation face, where the shotcrete has not yet been sprayed or not developed sufficient bearing capacity.

Therefore the steel ribs mainly serve as temporary supporting elements to secure the working area at the face until the shotcrete is put in place, and has set and hardened. Where forepoling pipes are required the steel ribs should be used to direct the drilling and to support the pipes after excavation of the next round.

There are several types of steel ribs:

- H-shaped
- U-shaped
- Lattice girders

H-beams can be manufactured as welded or rolled profiles. The connection of the different segments forming a ring, is achieved by bolting end plates. H-shaped ribs allow only relatively small deformations. In case of high deformations, H-shaped ribs are affected by buckling.

U-shaped profiles enable sliding connections, which are necessary in tunnels with expected large deformations. Also, in tunnels where side galleries are constructed in advance, these profiles are to be selected for the top heading part for easier installation and connection in the crown.

Due to their lower weight, lattice girders can more easily be assembled and set up. The slender structure, however, is more prone to mechanical damage during transport, storage and erection. In case of large deformations, lattice girders are affected by buckling - like H-shaped ribs.

1.4.7.5.6. Rock Bolts

Rock bolts are one of the main supporting elements in modern tunneling in rock apart from the surrounding rock mass itself. Rock bolts can be installed locally in order to support single blocks or to reduce the span of thin layers of rock or they are applied systematically as a part of the standard support system.

Rock bolts improve the rock quality by increasing the shear strength and, if prestressed, create quasi-three-dimensional stress conditions by applying a confining pressure.

The design of the anchor plate is of special importance. It should be neither too small nor too large. The anchor plate has to distribute the anchor force onto the lining or rock and has to provide warning where the anchors are overloaded. In this connection the anchor plate must be able to deform plastically without breaking in the event of stresses close to the breaking point.

1.4.7.5.6.1 Friction anchored rock bolts

These rock bolts are held in place by friction, either locally or along their whole length. They are not imbedded in grout, and thus have reduced corrosion resistance. On the other hand, they provide support immediately after installation and are not affected by problems with grouting in the case of heavy water inflow.

1.4.7.5.6.1.a) Wedge yoke anchors (expansion bolts)

This type possesses a wedge yoke or a similar element in order to divert bond forces into the rock.

Expansion bolts must be selected to conform with the particular type of rock. The anchor can be subjected to load and can be prestressed immediately after installation.

The free elongation length corresponds to the anchor length. The spring constant is thus considerably less than in the case of a fully embedded anchor, which reduces its efficiency.

As these anchors are not fully embedded in mortar or resin, they can only act as temporary supporting elements not protected against corrosion.

1.4.7.5.6.1.b) Swellex bolts

The Swellex rock bolt consists of a mechanically folded steel tube which expands in the drill hole by means of high-pressure water. During the swelling process the Swellex bolt adapts its shape to fit the irregularities of the drill hole, thereby increasing the strength of the rock by providing a full frictional and mechanical interlock throughout the whole bolt length. Its unique flexibility makes it suitable for ground conditions varying from medium to strong rock.

The main advantage of SWELLEX bolts compared to grouted bolts is the fact that they can be installed quickly after excavation and that they are effective and can take loads immediately. Their main field of application is local protection of unstable sections or blocks at the excavation face.

1.4.7.5.6.2 Fully embedded anchors

Due to their action these rock bolts can be divided into non-prestressed and prestressed anchors. For prestressed rock bolts, accelerator cartridges or resins have to be used for the bond zone. Nowadays, rock bolts are only prestressed when they are used in excellent to good rock conditions. Prestressing forces are up to 100 kN or 150 kN. In fair and poor rock conditions prestressing is not necessary as the bolts are tensioned by the radial deformations of the lining.

1.4.7.5.6.2.a) SN-bolt

The type of rock bolts most widely used is the SN-type. (SN: because this bolt type was first used in the hydropower project Store Norfors, in Sweden). SN-bolts are bolts which, when in place, are bonded to the rock over their entire length by means of suitable mortar grout. The entire bore hole is grouted prior to installation of the bolt using a grouting. The bolt can be prestressed or non-prestressed.

The ratio of the diameter of a SN anchor to the borehole diameter amounts to approximately 1 : 1.5-2.

1.4.7.5.6.2.b) IBO bolt (injection-bore-bolt)

IBO bolts are a combined system of rock bolt and drill rod. During drilling, the hollow IBO bolt is used as the drill rod. At the end of the bolt, a drill bit is welded. The drill bit is available in various diameters. Rod and bit remain in the hole as a rock bolt. The large hole diameter inside the IBO bolt ensures easy and effective grouting. During drilling, this is used as a flushing conduit and than as an injection tube. In case of collapsing boreholes, this system shows all its advantages, since the drill rod has not to be taken out and a new rock bolt has not to be inserted.

1.4.7.5.6.2.c) Injection bolt:

Injection bolts are bolts which, when in place, are bonded to the rock over their entire length by means of cement grout, similar to the SN-bolt, but the grout is injected into the bore hole after inserting the bolt. This type of rock bolts are successfully applied in areas with considerable water inflow, which normally occurs in zones of heavily fractured, crushed rock and in soft ground. Due to the fact that accelerating cartridges cannot be used along with injection bolts, they have to be considered as non-prestressed rock bolts.

In fractured, crushed rock with mountain water the efficiency of successfully and well grouted injection bolts is proved to be higher than ordinary, prestressed SN-bolts, which can hardly be grouted properly in these conditions. The grout injected under low pressure penetrates and fills the cracks, joints and voids around the rock bolts, thus increasing the strength of the rock mass which compensates for the deficiency in prestressing.

The difference of an injection bolt to an IBO bolt is mainly that an injection bolt is a full steel rod, which has a plastic tube attached to the steel rod, which is acting as grouting hose, while the IBO bolts are hollow and the hole in the bolt is serving as grouting hose.

The ratio of the anchor diameter to the borehole diameter amounts to approximately 1 : 2.

1.4.7.5.7. Cable Anchors

In tunnel construction cable anchors are mainly applied in large tunnels and intersections in soft ground or rock. They may be a temporary or permanent support. For permanent cable anchors special attention must be paid to corrosion protection of the strands in the bond length, in the free length, at the anchor head and for the anchor head itself.

1.4.7.5.8. Forepoling and Lagging

Forepoling and lagging are temporary support elements installed in longitudinal direction of the tunnel prior to excavation. These elements reduce the free span of the unsupported excavation surface. Forepoling and lagging are only support aids for the excavation and have less function after installation of the initial lining (shotcrete, wire mesh, rock bolts).

Steel forepoling pipes, forepoling rods and lagging sheets are mainly used. They can be driven into the ground or, for forepoling, installed in pre-drilled holes. If installed in pre-drilled holes, the space between forepoling pipes (or bars) and borehole surface should be grouted.

The distance (spacing) between forepoling or lagging sheets depends mainly on the round length, the rock loads (overburden) and geological conditions.

The length of forepoling and lagging sheets should not be less than 2 to 2 1/2 times the round length.

1.4.7.5.9. Pipe-roof

A pipe roof, consisting of steel tubes, is installed in case of low rock cover (up to 2 to 3 tunnel diameters) below houses and utilities, in order to reduce settlements and to increase the excavation and face stability. Normally, pipe roofs are used in soil and very weak rock (decomposed or completely weathered, completely sheared, fractured or mylonited rock).

A pipe roof is not suitable for groundwater control in water bearing formations. In such conditions, the pipe roof has to be combined with additional ground water control measures (e.g. wells for groundwater lowering, vacuum pipes, etc.)

Principally two different methods exist:

1.4.7.5.9.1 Large diameter steel pipes

The pipe roof is installed as an umbrella in the roof of the top heading, ahead of the tunnel excavation. The steel tubes are set by micro tunneling methods and afterwards filled with concrete.

Small diameter steel pipes

The pipe roof is installed as an umbrella in the roof of the top heading, ahead of the tunnel excavation. The steel tubes are drilled and afterwards filled with grout. In loose ground or soil, the steel pipes can be used as „manchette tubes“ for grouting (pressure grouting) the ground between and around the pipes.

Generally, the spacing of small diameter steel pipes is between 20 and 40 cm, depending on the cohesion of the rock or soil mass.

The grouted umbrella is generally installed in lengths of 12 to 20 m. The overlap should be 3 to 4 m.

The void between borehole wall and steel pipe should be filled with grout.

1.4.7.6 Excavation Methods

This chapter deals with excavation methods for road tunnels in rock or soil.

The excavation methods described in the following chapters that can be applied in different geological conditions are shown in the Table below1.

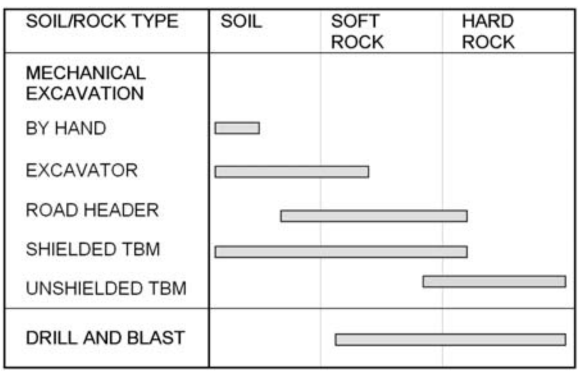


Table 1

1.4.7.6.1. TBM - Tunnel Boring Machines

Generally two different types of TBM exist:

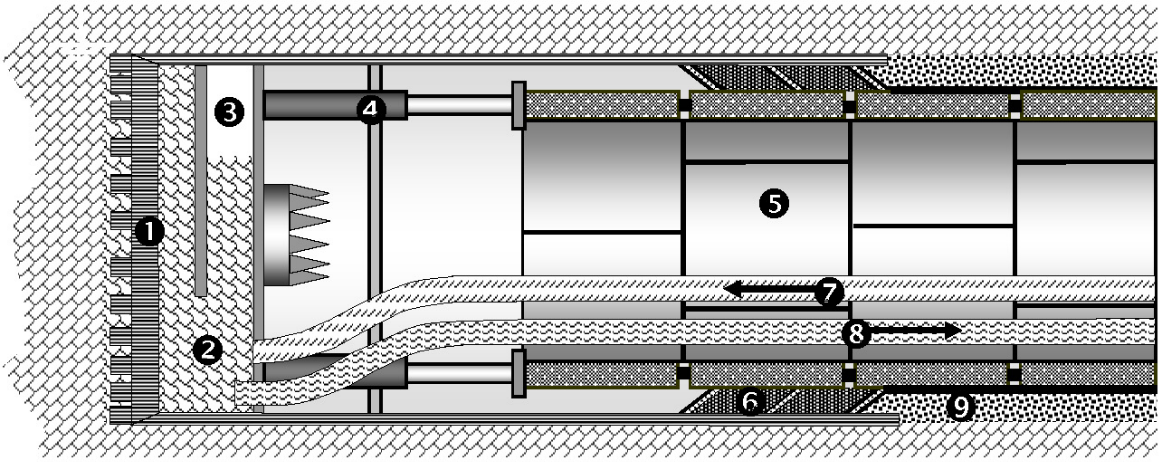
- o open type (unshielded) TBM

- o shielded TBM

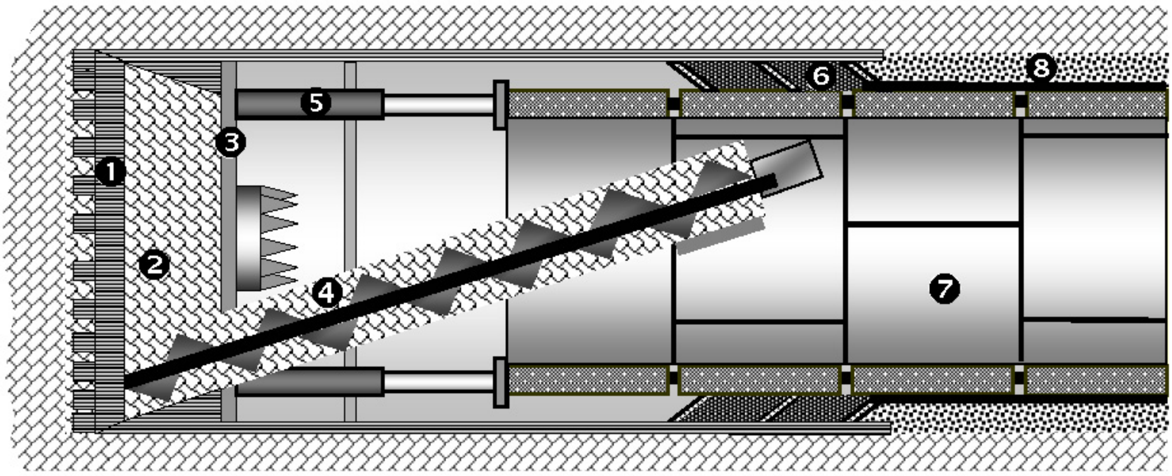
In case an open type TBM is used, the rock support is achieved by rock bolts, steel arches, wire mesh and shotcrete. It is possible to adjust the rock support to the varying rock conditions. This method has its technical and economical limits as soon as heavily friable rock conditions prevail.

Tunnels excavated by shielded TBMs are supported by a segmental lining. The advantage of this method is that it can be applied in tunnels with relatively low rock cover. A precondition of the application of a shielded TBM is that homogenous ground conditions prevail (e.g. soil or completely weathered rock). The main disadvantage is that the type and thickness of the support can not be adjusted to varying ground conditions and has always to be designed for the most unfavourable load combinations.

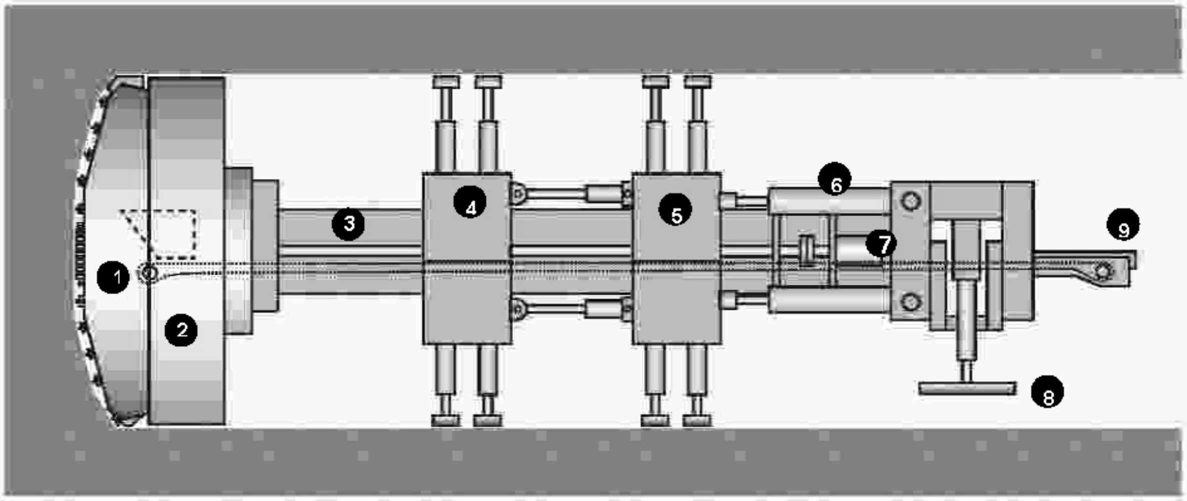
With present technologies, TBM driven tunnels can be constructed up to a diameter of about 12 m, but the rentability has to be investigated very carefully, considering the high investment costs of such machines.



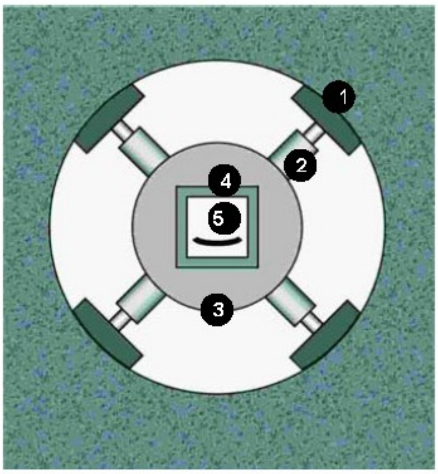
Picture 5: Schematic Representation of Slurry Shield Machine: 1. cutterhead, 2. bentonite slurry/soil, 3. air bubble, 4. thrust arms, 5. segments, 6. tail sealant, 7. bentonite slurry feed, 8. bentonite slurry/soil return and 9. annulus grout

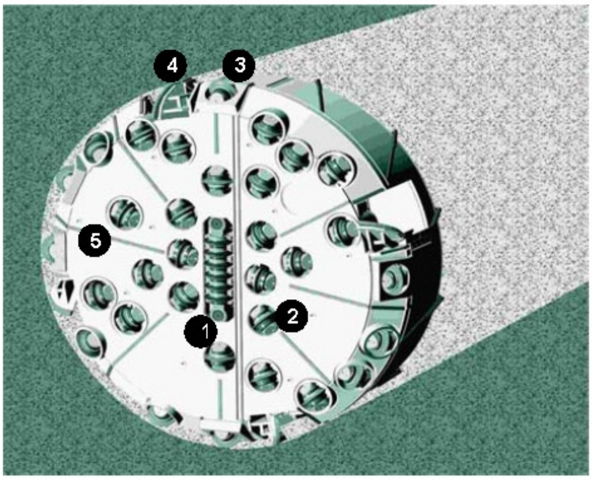


Picture 6: Schematic Representation of Earth Pressure Balanced Machine (EPBM): 1. cutterhead, 2. working chamber, 3. pressure wall, 4. screw conveyor, 5. thrust arms, 6. tail sealant, 7. segments 8. annulus grout



Picture 7: Side View of a Hard Rock TBM: 1. cutterhead, 2. cutter head jacket, 3. inner Kelly, 4. front gripper system, 5. rear gripper system, 6. thrust cylinder, 7. CH-drive motors, 8. rear support, 9. muck conveyor





Picture 8: a) Gripper System: 1. gripper pad, 2. gripper cylinder, 3. outer Kelly, 4. inner Kelly, 5. muck conveyor; b) Cutter Head front View: 1. centre cutter, 2. face cutter, 3. gauge cutter, 4. scraper, 5. wear plates

1.4.7.6.2. Roadheaders and excavators

1.4.7.6.2.1 Roadheader

In soft and medium hard rock the excavation can be carried out by means of roadheaders. This equipment is crawler mounted. The rotating cutter head, equipped with cutter teeth or pits, is mounted on a heavy movable beam. Mucking and loading is done by means of mucking aids to a conveyor belt. The excavation material is deposed into mucking cars (dump trucks) positioned behind the road header.

Considering the direction of the rotation axis of the cutter head, road headers are divided into tow categories:

- o road header with longitudinal cutter head
- o road header with transverse cutter head

The performance of road headers depends mainly on the following factors:

- o amount of quartz content and other wear minerals
- o particle size of wear materials
- o deformation behaviour of rock
- o petrographic structure
- o tensile strength of rock

- ductility of the rock mass
- strain and fracture mechanism of rock

1.4.7.6.2.2 Excavator

Excavators can be used in soft ground (soil) and soft rock. Generally all types of hydraulic back hoe excavators can be employed. Depending on the excavation material, different buckets will be mounted. Telescopic excavators are often used in small, narrow galleries. The boom should be telescopable and be turned 360°.

1.4.7.6.3. Drill and Blast Method

Performance of blasting is one of the most crucial items for achieving high progress rates and successful completion of works in road tunnels. Poor workmanship leads to following improprieties:

- Underprofile: in this case re-blasting is necessary, leading to loss of time and money. The profile after re-blasting is generally too big.
- Overprofile: means loss of time and money in shotcreting or additional quantities for inner concrete lining. Quality of the shotcrete lining is affected as the nozzle man needs to spray a thicker layer, which will settle, thus leaving a gap between shotcrete and rock. Undesired deformations of the surrounding rock mass will be possible. If the blasted profile is very irregular, the fixing of the wire mesh close to the rock surface can be a problem, thus leading again to voids behind the lining.

Smooth blasting is the most widely used technique: the contour holes are more closely spaced and lightly loaded with well distributed charges. During construction the blasting pattern needs to be continuously adjusted to actual conditions encountered and the results obtained in the field.

As drilling equipment hydraulic hammers are used. Modern hydraulic drill hammers are mounted on hydraulic, movable booms of so called drilling jumbos. Usually the hammers use rotation-percussion drilling technique. Modern jumbos are electrically powered for operation and diesel powered for driving. They have two or more drilling booms, which are automatically controlled for parallel drilling and most of them are equipped with an additional boom carrying a basket for charging explosives.

1.4.7.7 Design of Excavation Procedures

1.4.7.7.1. Measures for Increasing Stability

1.4.7.7.1.1 Subdivision of Excavation Section

In poor ground conditions is can be necessary to subdivide an excavation section (e.g. top heading - bench) into smaller sections as required by the rock conditions encountered.

1.4.7.7.1.2 Face Support

In case of poor geological conditions and unfavourable discontinuities an excavation face might become unstable and requires temporary support.

In tunnel excavation by drill and blast or using road headers or backhoes, one possibility for a temporary face support is to leave a supporting body. Loosening of the supporting core should be avoided. A loosened or even backfilled supporting body will have only a limited function. Attention should be paid to sufficient working space above and beside the supporting body. For proper shotcrete application the required space is at least 2 m.

Another possibility of supporting the face is to apply a shotcrete sealing. It should be considered that a face sealing must be demolished again during excavation of the next round.

An effective mean for face support in squeezing rock conditions are horizontal rock bolts placed parallel to the tunnel. They can be combined with shotcrete sealing. Since the bolts are cut after each excavation round and the plate has to be fixed again IBO-bolts are preferred.

In TBM tunneling, stability of the excavation face can be provided either by a „closed“ cutting wheel or by using a „slurry“ or „earth-pressure-balanced“ shield. The type of machine to be used depends mainly on the ground conditions and existing water pressure at the face. For ground water control the shield machines can also be equipped with compressed air.

1.4.7.7.1.3 Temporary invert

Temporary shotcrete arches in the invert are necessary in unstable tunnels with multiple headings (as top heading, benches and invert) to achieve an earlier (temporary) ring closure for stability (e.g. underneath buildings). Normally, a temporary inverts consist of wire mesh and shotcrete. If the time for installation is too short, due to excessive deformations, they can quickly be installed as invert strips with interruptions in longitudinal direction.

1.4.7.7.1.4 Drainage

Water inflow in tunnels complicates and affects construction procedures. Shotcreting on a wet (dripping) surface is only possible by increase of accelerator dosages, which means reduction of the final shotcrete strength. In general, the seepage water should be collected by pipes or hoses and diverted to the invert before shotcreting.

Water inflow may also influence the stability of the excavation face and complicate rock bolt installation. Long relief drainage holes drilled in the face can be applied as remedy measures. In order to prevent the holes from collapsing due to crushed rock or during blasting, perforated PVC-pipes could be inserted.

1.4.7.7.2. Supplementary Measures in NATM Tunnelling

Special technologies have been developed to supplement tunnelNATM driving under extremely unfavourable subsurface and/or groundwater conditions. Such supplementary measures comprise:

- Compressed air
- Jet grouting
- Artificial ground freezing
- Grouting (using cement and/or chemicals)
- Groundwater lowering.

The choice and design of supplementary measures depend mainly on subsurface conditions, groundwater conditions, type and size of the tunnel, height of soil cover, environmental conditions and surface constraints.

1.4.7.7.2.1 Compressed Air

Compressed air in combination with NATM is the most widely used supplementary measure for tunneling in soil and under the groundwater table. In recent years the combination NATM and compressed air has proved to be an economical and effective method to retain groundwater conditions, to stabilize the excavation face and to minimize surface settlements.

The application of compressed air for tunnels submerged into ground water has several advantages:

- the air pressure can be adjusted exactly to the hydrostatic pressure
- compressed air can be combined with other supplementary measures
- no affect of the ground water level and chemism
- reduction of surface settlements
- compressed air acts as support of the exposed soil at the excavated face

But the application of compressed air in tunnel construction contains some risks which have to be minimized by precautions and systematic control measures. Such risks are:

- sudden drop of the air pressure (hazardous for health)
- blow-out of compressed air
- danger of collapse and water inflow in case of uncontrolled drop of air pressure

If possible, the air pressure should not exceed 1.2 bar. Higher air pressure requires longer time for lock-in and lock-out of the labourers and reduces the effective working time of each shift. Combined tunneling under compressed air with partly lowering of the ground water was a successful method at several construction sites for minimizing the air pressure.

1.4.7.7.2.2 Jet Grouting

Jet grouting can be used as a type of forepoling to maintain or achieve stability of the excavation face, and to provide a temporary support for the newly excavated round until the initial tunnel support (shotcrete) has developed sufficient strength. For this purpose cement grout is injected under high pressure through horizontal or slightly inclined pipes (actually drill rods) which are drilled just outside the tunnel profile.

1.4.7.7.2.3 Grouting using Cement or Chemicals

Grouting may be necessary in extremely soft or non-cohesive ground to improve the ground quality to such an extent to allow excavation, to increase the stand-up time with respect to tunneling and to improve the bearing capacity. Reducing the permeability to prevent excessive water inflow to the tunnel area is another field of application for grouting. However, it must be kept in mind that the grouting can affect the groundwater flow and groundwater quality permanently. Where the groundwater body is used for public water supply, chemical grouting is normally prohibited.

The success of a grouting method depends a lot on the selected grout material and drilling accuracy. Layout of hole distance, selection of grouting material and grouting pressure can be decisive for success or failure of such an expensive measure.

The following ground (soil) characteristics have to be taken into consideration for selecting a suitable grouting material:

- Type of ground or soil
- Boundaries and thickness of layers
- Chemical-mineralogical composition
- Distribution of particle size
- Compactness
- Void ratio
- Water permeability
- Groundwater conditions: such as groundwater level, variation, direction and speed of flow, chemical property
- Temperature

1.4.7.7.2.4 Ground freezing

Artificial ground freezing combines both desired effects - soil improvements and groundwater management - in one. A frozen ring of soil yields considerable strength and is more or less impermeable. Liquid nitrogen or sodium brine can be used as coolant. The use of sodium brine is cheaper but takes a longer time for creating a continuous ring. The coolant circulates through a number of steel pipes, which are placed along the perimeter of the tunnel profile. The pipes are connected to a freezing plant, where the coolants are generated and stored.

Such a frozen ring is able to take over the pressure exerted by the overburden soil and groundwater. The tunnel lining inside the frozen soil ring is loaded in a time-dependent manner, as the rheological (creeping) behaviour of the frozen soil causes a slow, continuous deformation resulting in a steady load transmission. The water-stop function exists as long as a closed ice ring is maintained around the tunnel.

Special attention has to be paid to soil heaving. In order to minimize heaving the cooling procedure has to be evaluated carefully. The use of sodium brine as coolant allows intermittent cooling after build-up of the frozen ring around the tunnel. The maintenance of the ice ring must be controlled and guided by thermal sensors placed into special steel pipes to monitor the temperature. Each freezing pipe can be charged individually thus providing the possibility to react to heaving and non-uniform thaw.

Due to high costs application of freezing is limited to excessively difficult ground conditions. It has also to be mentioned, that continuous improvements of tunneling methods take place and make artificial freezing less attractive compared to some years ago.

1.4.7.7.2.5 Groundwater lowering

To reduce the groundwater impact on tunnel stability during excavation or to reduce the required pressure for compressed air, a partial or total lowering of the groundwater should be taken into consideration. However, surface settlements and impacts on buildings and the groundwater body itself should be carefully evaluated.

1.4.7.7.2.6 „Elephant Foot"

Widening of the top heading foot of the outer lining (i.e. shotcrete shell) is recommended in certain cases in order to reduce the subgrade reaction onto the rock mass surrounding the tunnel opening. In this way punching of the shotcrete shell into the rock mass is prevented. This method is used in ground conditions with low bearing capacity.

1.4.7.7.3. Excavation Sequences

The selection and design of proper excavation sequences depends on several parameters, first of all on ground conditions and tunnel size. Main parameters are listed below:

- Size of tunnel
- Type of rock or soil
- Deformation limitations
- Vibration (blasting) limitations
- Equipment types and capacities
- Experience of contractor/client

1.4.7.7.3.1 Good (Stable) Rock Conditions

Small tunnels (cross section area up to 25 m^2)

Small tunnels usually are excavated full face in drill and blast method. Vibration limitations near buildings and in urban areas may require the use of rock breakers or the subdivision of the face into several blasting zones in order to limit the charges per delay.

Medium sized tunnels (cross section area: 25 - 60 m2)

In good rock conditions, tunnels of this size still can be excavated full face, but considerations about tunneling equipment might already lead to a division of the excavation into top heading and bench. Support still will be limited to local support by rock bolts and a thin layer of shotcrete.

Large and extra large tunnels (cross section area > 60 m2)

For large tunnels and caverns a subdivision of the excavation is necessary even in good rock conditions mainly due to operational reasons. Drilling, sealing, installation of support would require special equipment for oversized tunnels.

For two-lane or three-lane highway tunnels and double-track railroad tunnels, a separation into top heading and bench excavation is usually sufficient, while for caverns a multi-bench excavation and frequently also a subdivision into single excavation levels is preferred.

In good rock conditions the decision, whether a short or long bench should be selected, is nearly exclusively determined by operational reasons and usually in favour of a long bench (min. 100 m distance between top heading face and bench excavation).

1.4.7.7.3.2 Weak or heavily jointed rock

Small tunnels

Tunnels up to a height of 4 - 5 meters will be still excavated in full face, but excavation rounds reduced. Support is installed close to the face and generally consists of a combination of rock bolts and shotcrete in order to strengthen the rock mass and to prevent overbreaks.

Medium sized tunnels

Under weak rock conditions a full face excavation for medium sized tunnels is not feasible due to stability problems. A top heading - bench excavation has to be applied in all cases, with installation of initial support round by round.

Large and extra large tunnels

Weak rock conditions require a very careful excavation in smaller steps and installation of support prior to excavation of the next part. Excavation steps have to be adjusted to the standup-time of the rock in such a way as to allow installation of support safely within this time lag. With increasing span and height of tunnels, rock bolts become increasingly important, while the function of shotcrete is limited to prevent loosening of the rock mass and to seal joints and other discontinuities.

Side galleries are frequently used as well as subdivisions of the face into smaller sections.

For shorter tunnels it is recommended to finish the side galleries prior to the start of the main top heading, while for longer portions a simultaneous excavation will be unavoidable due to time requirements. Excavation at different faces should be separated by a suitable distance in order to minimize the interference between the headings (minimum distance is about 30 m).

Invert

In weak and/or heavily jointed rock the excavation of the invert and ring closure by installation of a concrete invert is required. In comparatively fairgood condition, the invert will be excavated at a certain distance behind d the bench excavation face and in most cases the concrete will be poured, without forming a closed shotcrete ring first.

In case of very poor geological conditions, ring closure immediately behind bench excavation my be necessary. In this case, a closed shotcrete ring will be formed first. The invert concrete can be poured independently from, many meters behind rin ring closure requirements.

The decision whether to use shotcrete or in-situ concrete for the “invert arch” depends also on the size of the tunnel cross section, selected construction sequence and excavation method.

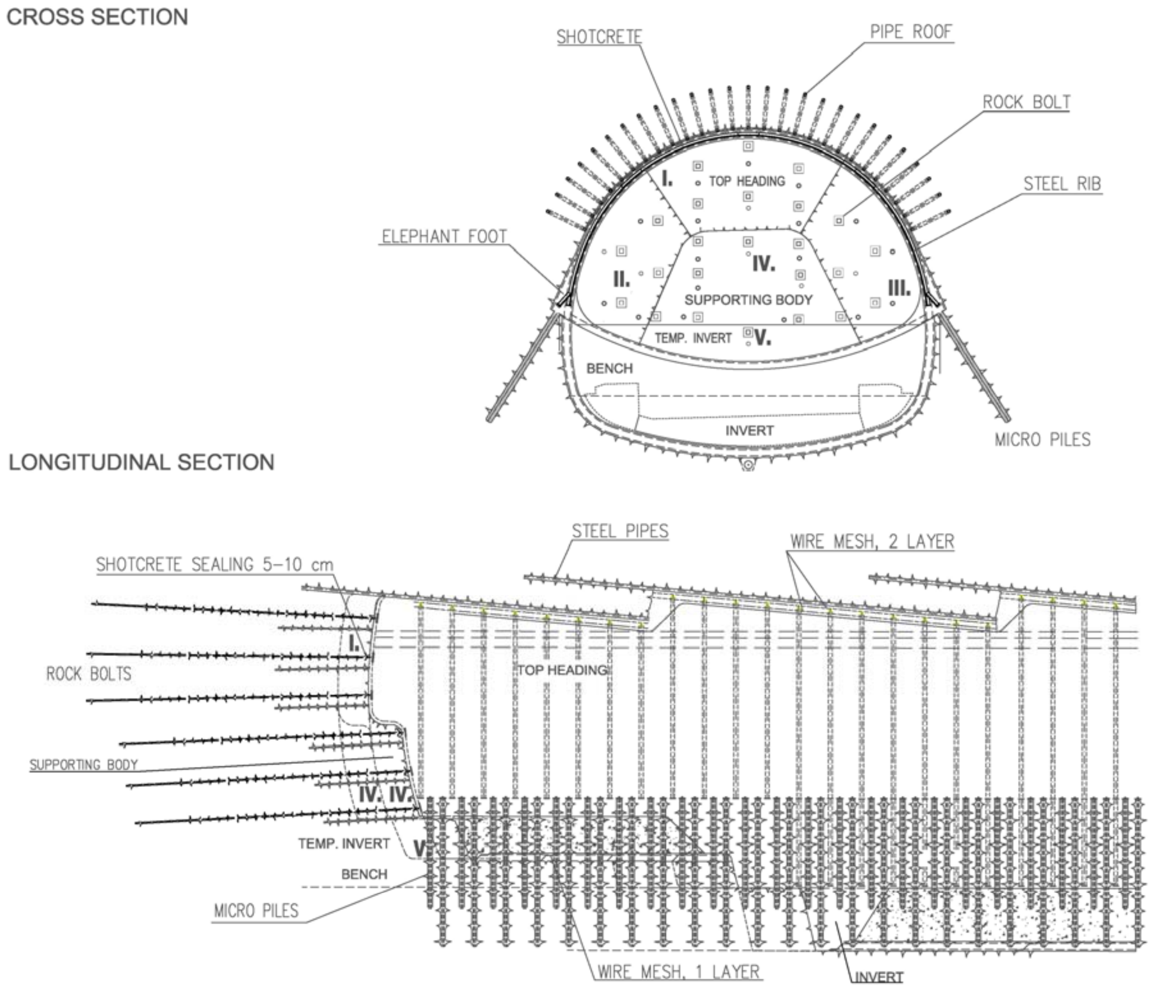


Fig. 9: Design of excavation procedures – an example of excavation in a rock of low bearing capacity where the entire excavation cross-section is divided in excavation stages of top heading, bench, and invert, and of the use of pipe roof, excavation of top heading in stages, anchored supporting body, temporary invert, micro piles, and elephant foot

1.4.8 TUNNEL LINING DESIGN

1.4.8.1 Final Inner Concrete Lining

1.4.8.1.1. General

Although stability for the tunnels will be achieved with the initial or primary lining, a secondary or final lining is usually designed. The inner lining increases the safety of the tunnel lining system and provides a uniform and smooth interior surface. Furthermore it allows the installation of a membrane lining system to achieve a watertight tunnel. A smooth interior surface is important for ventilation of the tunnel as well as for maintenance reasons (tunnel washing) and aesthetic reasons.

The inner lining can be executed as reinforced concrete or unreinforced concrete. The tunnel lining can be executed as a watertight (water pressure loaded) tube or as a drained (non water pressure loaded) tube. The decision on construction principle depends on the following factors:

- Possibility of a free, restrained or pumped discharge of ground or mountain water into a surface drainage
- Amount of water to be expected
- Water pressures encountered
- Effects on the hydrological environment, such as the influence on wells, public and private water supply, groundwater and surface drainage patterns
- Cost of pumping operations, if necessary

Tunnels not loaded by water pressure are generally equipped with unreinforced inner linings. Water pressure loaded tunnels and tunnels in urban areas are usually furnished with reinforced inner linings. The inner lining of tunnels in urban areas submerged in ground water has to be designed as water impermeable concrete lining.

In the portal areas, where the tunnel tubes are extended and constructed as cut and cover tunnels, the nominal thickness of the lining normally has to be increased. The tunnel lining will be reinforced in these areas, regardless of the water pressure situation. Thickness and reinforcement must satisfy structural demands according to the designed backfilling (height, symmetrical or asymmetrical backfilling, construction equipment on backfill).

If an invert is required for stability of the tunnel, a concrete arch is provided. For two-lane road tunnels the minimum thickness of the invert arch shall not be less than 50 cm. Longitudinal construction joints of the main lining must coincide with construction joints of the invert arch, however, the invert arch may be further subdivided.

In tunnels with high overburden, the inner lining is cast after deformation have ceased. Deformations with a speed of less than 4 mm/month are generally regarded as "having ceased". This is not valid in swelling or creeping ground. In case of ongoing deformations, one of the following measures can be taken:

- Additional rock support to slow down deformation rates
- Installation of a "knobbed" membrane or other deformation elements between outer and inner lining in order to allow deformation during setting and hardening of the inner concrete lining, however available tolerances and clearance requirements must be observed
- Design measures (increased concrete strength, ductile reinforcement)

In shallow tunnels the lining shall be cast as soon as possible to minimize settlements.

1.4.8.1.2. Design Mix

Depending on the thickness of the inner lining, the grain size distribution and maximum grain size shall be chosen. For reinforced inner linings, maximum grain size of 32 mm and for unreinforced inner lining maximum grain size of 45 mm are recommended.

The following grain sizesieve line distributions are recommended:

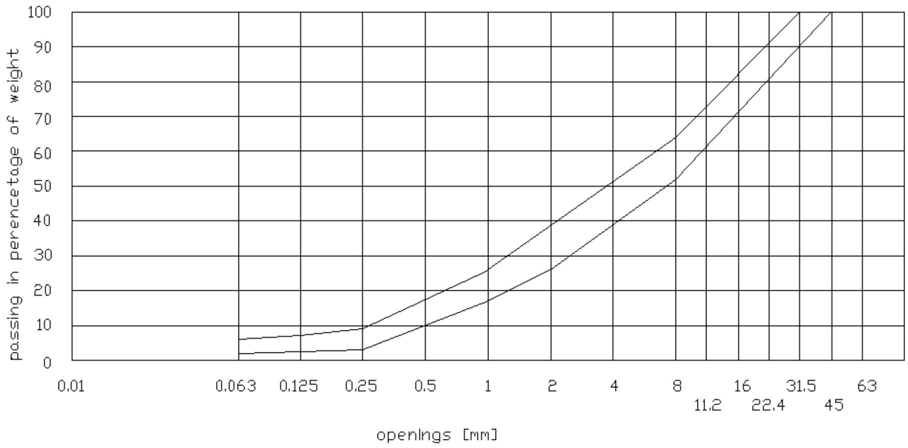


Fig. 10: Grain Size Sieve Line Distribution for Reinforced Inner Concrete Lining

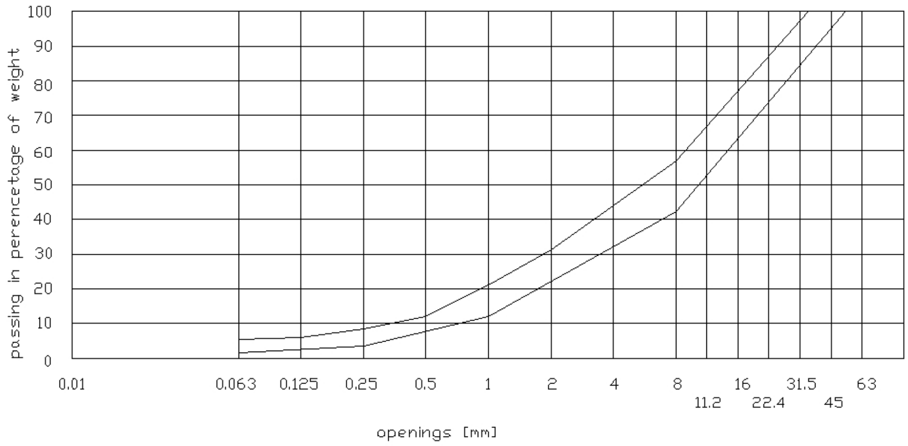


Fig. 11: Grain Size Sieve Line Distribution for Unreinforced Inner Concrete Lining

Portland Cement should be used, with an average specific surface (after BLAINE) of 3500 to 5000 cm^2/g.

Fly ash should be used for the inner lining. In case of unreinforced inner lining, fly ash shall be 15% to 25% of the total amount of cement + fly ash. For reinforced inner lining, the content of fly ash can be increased by 10 %.

Additives shall be used in order to reduce the total amount of water used for the inner lining concrete (max. 170 l/m^3 water). Above all, plastifiers and aerents are used.

For structural reasons, the concrete grade MB 30 shall be used for the inner lining.

If the climatic conditions indicate so, there should be made a segment of a resistant inner concrete lining at the portal. The length of the lining is determined with the consideration of the microclimatic conditions.

1.4.8.1.3. Minimum Design Requirements for Inner Lining

The following table is an excerpt from the Austrian "Guidelines for Inner Lining Concrete" issued by the Austrian Concrete Society. The values given below are valid for excavation cross sections of 30 to 120 m2.

Criteria	**Unreinforced Lining**		**Reinforced Lining**		**Watertight Concrete**
Membrane	**without**	**with**	**without**	**with**	**--**
Min. Thickness	20 cm	25 cm	30 cm	30 cm	30 to 40 cm
Max. block length	12 m	12 m	12 m	12 m	10 m

Min. shuttering duration	8 h	8 h	8 h	8 h	8 h
Regular shuttering duration	10 h	10 h	10 h	10 h	12 h
Crack control a) Separation layer b) Reinforcement	 recomm. in Portal area -	 via membrane -	 recomm. Min. rein-forcement or as required (Eurocode 2)	 via membrane Min. rein-forcement or as required (Eurocode 2)	 required min. 0.1% of concrete cross section in both directions on both sides crack width: < 0.2 mm
Construction joints	contact	contact	contact	contact	gaskets in work and block joints
Concrete cover	-	-	40 mm both sides	40 mm "air side" 30 mm "rock side"	40 mm both sides

1.4.8.1.4. Water Tight Inner Concrete Lining

Watertight inner lining is a lining system that has to be impermeable without the use of a membrane lining. Watertight concrete must fulfill the design requirements of the above table plus extra requirements regarding concrete technology and method of execution, which are contained in the applicable codes and standards. Additional requirements are listed below.

Inner linings are regarded as watertight, if only local areas of dampness can be noticed on the inside of the lining. Strong water leaks have to be treated by grouting.

A reinforcement grid with a minimum grid size 100 mm has to be provided on the "rock side" and on the "air side" of the lining. Reinforcement exceeding the minimum reinforcement has to take the form of single rebars with diameters less than 20 mm. If the actual concrete cover on the rock side exceeds 100 mm, one of the following measures has to be taken:

- An extra reinforcement layer
- The designed reinforcement is adjusted in position and cross sectional area
- An extra layer of shotcrete has to be sprayed before placing the inner lining

1.4.8.1.5. Inner Lining Structural Analysis

In deep tunnels, as defined in the chapter before, the inner lining has to be designed for the following loads:

- Self weight (dead load) of the lining itself
- Water pressure, depending on the drainage system
- rock load, depending on rheological behaviour of surrounding rock mass
- Shrinkage and creep of concrete
- Installations, such as jet fans or ventilation ducts
- Loads caused by utilization of tunnel (traffic loads, braking forces)
- Fire loading

In shallow tunnels, all of the above loads have to be applied, in addition, it is usually assumed that the initial lining will loose part or all of its strength and shed those loads to the inner lining. Other loads in shallow tunnels are:

- o Traffic loads on surface
- o Loads caused by new construction
- o Changes in ground stresses and bedding caused by deep excavation close to the tunnel
- o Earthquake loads.

They are generally unproblematic in tunnels but may be significant if:

- o The tunnel is situated in a sedimentary layer
- o The tunnel alignment passes from a very stiff layer into a soft layer
- o The tunnel is situated at the interface between a stiff and a soft layer

Loads occurring after completion of inner lining are distributed between initial and inner lining according to actual stiffness and any assumption made regarding loss of initial lining strength.

Structural analyses for lining of shallow tunnels in built-up areas shall be carried out in accordance with the Austrian design guideline RVS 9.32 (Geschlossene Bauweise im Lokergestein unter Bebauung). Inner lining structural analysis can be performed either by embedded frame analysis, analytical analysis or numerical analysis. An embedded frame analysis can be loaded according to the results of a numerical analysis by using the contact forces between ground and initial lining as a load to the inner lining, usually with a reduction factor.

Advanced mathematical modelling of the ground or rock is only required if significant changes to the state of the surrounding ground are expected after placing of the inner lining. This can be due to creep, earthquake loading, changes in groundwater levels or construction of other structures close by.

In case of reinforced inner concrete lining calculation of necessary steel reinforcement shall be carried out in accordance with the local law regulations.

1.4.8.2 Membrane Lining

A waterproofing system should be designed for all underground structures in order to prevent leakage of ground water into tunnels, and to protect the inner concrete lining against deleterious chemical impact. The surface of the primary support should be straightened with final jet of the drainage concrete. At the places where the visible flows of the water are seen a plug foil is put, which reaches the height of the layer of the drainage concrete that surrounds the side drainage tube. The water proofing system will consist of two layers, the outer layer being a non-woven geotextile fleece backing and the inner layer the waterproofing membrane. The fleece is required to protect the membrane against damage from contact with the shotcrete surface and to drain off the mountain water. The membrane placed between outer lining (initial tunnel support or segmental lining) and in-situ concrete lining prevents seepage into the tunnels.

1.4.8.3 Drainage System

Generally a tunnel drainage system has to collect and divert groundwater from the surrounding rock as well as water and other fluids from the carriageway through the tunnels to the portals and the recipient respectively. Groundwater is collected from the surrounding rock by drainage pipes situated on both sides of the tunnel cross section and if necessary in the invert as well.

Water from the carriageway consist of rain water brought into the tunnel by the vehicles or water from tunnel washing operations or from fire fighting. Additionally other fluids as e.g. oil or similar from normal tunnel operation or from accidents in the tunnel (e.g. leaking tanks) must be collected by inlets and must be diverted to the tunnel portals in the main collector pipe located under the roadway.

For environmental reasons, it is not allowed to mix the groundwater and the water of the carriageway in one system, but two separate systems have to be installed: one for groundwater and another for water from the carriageway.

Groundwater is diverted directly into the recipient.

Roadway drainage is provided by slotted kerb stones which are located at the lower side of the motorway or on both sides where it is required by the tunnel alignment. The drainages run along the entire length of the tunnel to a shaft in front of the portal. Cleaning and „fire protection" shafts should be located every 65 m. These shafts have the function to stop the escalation of a possible fire of liquids spoiled on the roadway and to retain oil and sand from the street water. From the last shafts at the tunnel entrance PVC-pipes with a diameter of at least 250 mm are running to the „tunnel waste water reservoir". The pipes must be resistant to oil derivatives, acids and lyes.

Of strong concern with regard to the environmental protection are the waters from tunnel washing operations and fluids (oil and other chemical fluids) from possible accidents in the tunnel. Tunnel washing waters, which occur at regular intervals, are highly contaminated and therefore do affect the environment negatively. For that reason catch basins must nowadays be provided to collect such waters for special treatment prior to the diversion into the recipient. Mobile treatment plants are provided during tunnel washing for physical and chemical treatment. After treatment the water may be discharged into rivers, the highly contaminated mud requires special disposal. In case of accidents associated with leaking fluids occurring in the tunnel, the catch basin is used to collect the leaking fluids. After identification of the fluids proper disposal is possible.

During construction the contractor shall manufacture, maintain and operate required facilities and plants to treat and clean all contaminated water discharged at the tunnel portals during construction. Such facilities and plants shall include two sedimentation basins, oil trap, neutralization plant and necessary control stations. The neutralization plant shall be designed and operated to maintain the ph-value of the treated water between 6.5 and 8.5 prior to dischargement.

1.4.8.4 Inspection Shafts For Mountainwater Drainages

Inspection shafts are required on both sides of each carriageway in the tunnels. They serve for maintenance of the side wall drainages for the groundwater. They are to be spaced approximately 50 meters apart to satisfy operation demands with regard to the locally available technology. Such shafts are required for all tunnels with longitudinal sidewall drainages.

At every second cleansing niche, the longitudinal sidewall drainages are connected to the drainage water collecting pipe placed below the overtaking lane. The joint between the collecting pipe and the transverse connection is carried out in a shape of a debris-trapping shaft. .

1.4.8.5 Tunnel Portals

1.4.8.5.1. General Design Philosophy

The alignment of the motorway and therefore also the alignment of the tunnels should be refined during the early design stage based on site investigation results and topographic conditions. Since most of the tunnel portals require pre-cuts (portal cuts) the geological and hydrogeological situation in those areas shall be investigated carefully. Special attention shall be paid to local tectonic structures (faults, shear zones), creeping or sliding slopes, active or dormant land slides etc.

Main principles to be applied for the portal designs are:

- The shape of the lateral cuts of slopes shall be continued in the immediate portal areas.
- Maximum possible reduction of permanent open cuts, especially in unstable portal areas (slope debris, rock debris, creeping slopes). Extension of the tunnel tubes by cut and cover construction.
- The size of temporary cuts shall be reduced by using adequate support arrangements.

During the tender design (PZR) for the tunnel portal cuts different slope geometries shall be checked (analysed) to consider local geological conditions encountered in portal areas. In case the actual conditions found during excavation of the portal cut are different from the design parameter assumed in the tender stage the design of slope stabilization measures has to be adjusted accordingly.

Slopes of the portal cuts shall be included into the monitoring program. If possible, measurement results shall be used for final design of cut slopes and retaining structures.

1.4.8.5.2. Design Interfaces

In general, match lines between Tunnel Design and Motorway Design should be located in front of the portal cuts, that means the portal cuts shall be part of the Tunnel Design. Because of prolonged tunnels, staggered portals and complex design approach to portal areas, matchlines must be agreed individually at each portal.

1.4.8.5.3. Cut and Cover Tunnels

It is recommended to extend the tunnels by short cut and cover sections where it is necessary for improving slope stability conditions.

If possible, cut and cover sections shall have the same inner cross-section as the inner lining of the tunnel tubes.

In case, there is no cut and cover tunnel the first ring of the inner concrete lining (length approx. 10 - 12 m) shall be made of reinforced concrete.

The cut and cover concrete structures shall be covered with a waterproofing membrane of the same quality as in the tunnel. Prior to back-filling the membrane shall be covered with protective geotextile and lean concrete.

1.4.8.5.4. Retaining Structures

Special arrangements will have to be made to protect the temporary and permanent slopes of the portal cuts. In principle, the following elements can be considered:

- o Rock bolts
- o Anchors
- o Shotcrete with wire mesh
- o Grouting
- o Retaining walls (reinforced concrete structures)
- o Reinforced earth

All retaining structures have to be subjected to structural and stability analysis by suitable calculation or computer methods.

1.4.8.6 Cable Ducts

In road tunnels the space underneath the sidewalks is normally used for accommodation of cable ducts. In long tunnels it could be necessary to increase the minimum width of the walkways (0.85 m) in order to provide sufficient space for cables (high voltage, low voltage, communication, traffic and ventilation control etc.) and other utilities (e.g. water main for fire fighting system). Fig. 6 shows a typical detail of a cable duct underneath a walkway.

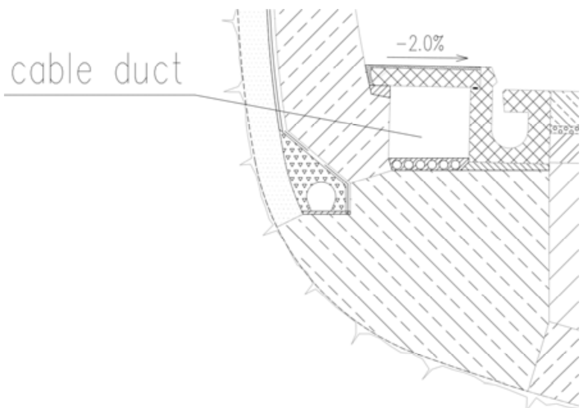


Fig. 12: Typical Detail of a Cable Duct

1.4.9 INSTRUMENTATION AND MONITORING

1.4.9.1 Introduction

Instrumentation and measurement programs are an integral part of modern tunneling, especially of tunneling with NATM.

The objectives of measurements comprise the following:

- Verification of design assumptions including the design model and design parameters
- Adjustment of construction methods, support systems, and supplementary measures to the actual ground conditions and requirements
- Verification of stability of excavated structures
- Minimization of construction hazards
- Prevention of harmful impact on the environment

1.4.9.2 Monitoring Parameters

Considering the specific requirements and stages of construction the following groups of parameters must be observed:

- Ground water:
  - Observation of the groundwater table, water pressure, groundwater chemism and temperature before and during construction
  - Observation of water infiltrations through tunnel lining and tunnel face.
  - Record of volume and discharge of water if dewatering is used
- Ground deformation:
  - Surface and subsurface settlements
  - Deformation and strains of the ground around a tunnel
  - Movement of slopes at tunnel portals (inclinometers, extensometers, etc.)
- Soil-structure interaction:
  - Anchor loads
  - Distortion of the tunnel lining
  - Possible heaving of the invert
  - Extension of the loosening zone around the tunnel
  - Measurement of radial and tangential lining stresses
  - Water pressure on the lining
- Observation of environment (adjacent buildings and structures), mainly in the vicinity of portal zones and in case of shallow tunnels:
  - Survey of building conditions before start of construction
  - Measurement of settlements and heave
  - Tilt measurement
  - Vibration due to blasting
- Progress monitoring

For correct interpretation of the various monitoring data, information pertaining to the relevant construction stages is necessary. The following information should be observed and recorded during construction:

- Predicted and actual ground condition
- Specified rock class type
- Driving method and advance rate
- Supporting elements for each excavation round
- Temporary support measures and any additional ground improvement
- Position of the different excavation faces
- Extraordinary incidents

1.4.9.3 Monitoring Sections

The location of monitoring sections must be selected to optimize the interpretation of the monitoring data. This is best done by arrangement of several different monitoring devices in one monitoring cross section. There should be two to three classes (types) of monitoring sections, which are ranked in relation to the number of devices installed and parameters observed (e.g. A: regular, B: intermediate, C: main monitoring section).

In a regular monitoring section, only lining deformations are recorded. This can be done by:

- o Convergence measurements using a convergence tape and bolts (pins), which are fixed in the tunnel lining. Convergence readings are normally combined with levelling of the crown.
- o Optical 3-D deformation monitoring by trigonometric method and using reflectors fixed on bolts similar to the convergence pins.

The optical 3-D deformation monitoring is preferred, as it yields absolute deformation values for each point and therefore geotechnically more valuable results.

In case of shallow tunnels these measurements are accompanied by settlement measurements of the ground surface. Information provided by these measurements are very helpful for the evaluation of the overall performance of the construction method. Regular monitoring sections should be distributed regularly along the alignment.

In a main monitoring section all parameters should be monitored. In rock tunnels, in addition to the instruments of the regular section, it should include extensometers, pressure cells for the tangential and radial stresses, strain measurements in the lining, measuring bolts (anchors), and piezometers (if necessary). The pressure cells are arranged in a regular pattern around the tunnel perimeter.

Main monitoring sections will be placed at the start of the tunnel drive to evaluate the selected tunneling method and support system, and at locations of special interest due to the ground condition, structural layout or built-up on the ground surface.

For shallow tunnels extensometers or equivalent instruments together with inclinometers and piezometers will be installed from the ground surface and ahead of the tunnel drive.

In case of pilot tunnels, access shafts, adits, or if two parallel tunnel drives are carried out, it is also possible to install certain instruments in bore holes, ahead of the main tunnel drive.

1.4.9.4 Measuring Devices

Many kinds of instruments and recording systems have been developed, ranging from simple survey methods to very sophisticated pressure and deformation devices. The essential requirements of any instrument are reliability, simplicity, easy and fast installation, operation and calibration. The instruments must be durable in the long term and not prone to damage during and after installation.

Some of the specific measuring devices are listed below. Considering the monitoring parameters mentioned above, it is obvious, that several of the instruments can be used to observe different parameters.

1.4.9.4.1. Lining Deflection

1.4.9.4.1.1 Convergence measurement using tape extensometer

Application:

Convergence measurements yield the relative displacements of points on the tunnel lining. They are not suitable for evaluation of the actual movement of a point, but they are a very sensitive tool for stability analysis.

Operating principle:

The instrument which is portable, measures displacement between pairs of reference bolts grouted into shallow drillholes or shotcreted together with the lining.

Advantages and limitations:

- o Simple, reliable and easy to read with positive tape tensioning.
- o Can in many cases be operated by one person and read from one end only.
- o Measurements from 1 m to 20 m.

- Intended for relative measurements only. Accuracy is affected by change in temperature.
- Construction operations are obstructed during measurement.
- Zero reading may be obstructed by supporting core at the excavation face. Shotcrete and pin mortar have to harden before zero reading can take place.

Performance:

Overall measuring accuracy is 0,1 mm with operator experience. The tape extensometer is robust and proof against mechanical damage under reasonable field conditions. Average readings take only 2 - 3 minutes by single operator.

1.4.9.4.1.2 Optical 3-D deformation monitoring by using trigonometrical devices

Application:

Optical deformation monitoring yields absolute movements of selected points on the lining in three coordinate directions (cross sectional and longitudinal).

Operating principle:

Reflective targets are fixed to the lining or rock via convergence pins. There absolute position is surveyed with a precision theodolite with coaxial distance measuring capabilities. Targets are usually of the "bireflex" type, where both sides of the target are covered by a reflective surface. For very short or very long sighting distances, prism targets are used. An accuracy of +/- 1mm can be achieved.

Advantages and Limitations:

- Absolute deformations are measured. This allows an accurate geotechnical interpretation of the cause of the movements. The support pattern can then be adjusted accordingly.
- Since a large number of targets can be monitored quickly and from just a few positions, more regular monitoring sections can be placed without extra effort.
- Site operations are hardly affected by monitoring operations.
- Zero readings can be taken immediately after the target is put in place.
- The reading results can also be used for profile control.

1.4.9.4.1.3 Settlement measurements of the lining

They are usually carried out together with the geodetic tunnel measurements as precision level measurements.

In most cases the crown and footing points of the top heading are monitored, sometimes invert levels are included.

1.4.9.4.2. Stress Measurements in the Tunnel Lining

1.4.9.4.2.1 Hydraulic pressure cell

Application:

For measurements of stress distribution in tunnel linings two arrangements are used; one for the determination of the pressures between rock and shotcrete lining acting in radial direction, the other one for the measurement of stresses in the shotcrete lining acting in tangential direction.

Operating principle:

The hydraulic cell consists of a flat jack, which is placed at the rock surface or into the shotcrete, so that increasing concrete stresses can act onto the flat jack. A common type is the „Glötzl Cell“, which consists of a flat cell connected to a pressure chamber. A diaphragm separates the hydraulic system of the cell from that of the measuring device. The pressure in the cell is determined by balancing it with an oil pressure on the other side of the diaphragm. This pressure can then be read at a precision manometer.

1.4.9.4.2.2 Shotcrete strain meters

Application:

Measurement of shotcrete strains acting in tangential direction. Stresses can be calculated from the strains considering load history, lining thickness, creep and age of shotcrete. The devices can also be used for strain measurements in concrete linings.

Shotcrete Strain Meter (e.g. SSM-1) have been designed to match the special requirements of both the material properties of young shotcrete and the loading process within the shotcrete lining during tunnel construction.

Operating Principle of SSM-1:

The SSM-1 shotcrete strain meter, consists of two parallel rebars which are, after installation, fully embedded in shotcrete, and a centre tube with a low extension stiffness. Shotcrete deformation causes a relative movement of the two rebars, with a corresponding deformation of the centre tube. This deformation is measured by means of strain gages which are glued to the centre tube in a full-bridge, temperature-compensated arrangement.

The readout cables from several instruments are connected to a central distribution box that is placed in a wooden box. In order to minimize delays to the construction process, final installation of the readout plugs can be performed as a separate operation.

The zero reading can be taken immediately after the spraying of shotcrete or the removal of formwork.

The subsequent readings can be taken as often as required without disturbance of other working processes.

Evaluation:

The readings are recorded on appropriate (special) forms. Thus, differences from previous readings as well as the cumulative results can be immediately identified. The recording of these results by means of time-deformation diagrams makes possible a fast evaluation of the actual state-of-stress in the observed structure. This includes immediate recognition of the following items:

- Type and size of stresses (tension, compression, bending)
- Stress distribution around the circumference of a tunnel

Calculation of stresses from the measured strains also requires accompanying laboratory tests, particularly when used in shotcrete. With these tests it is possible to obtain the specific stress-strain relationship of the shotcrete applied on site. The tests also consider the creep-and relaxation behaviour.

A special software is available for computing stresses from strain histories in connection with the test results. The software also includes the computation of bending moments and normal forces.

Advantages and Limitations:

The shotcrete strain meter is an excellent tool for recording the shotcrete load development over time. It has a number of advantages:

- Fast reading
- Zero reading immediately follows shotcreting or pouring of concrete
- Higher accuracy and better reliability of measuring results

The instrument can record tensile as well as compressive strains. Thus, it is a valuable tool for the evaluation of the state of stress in tunnel linings, particularly because it is also possible to measure bending stresses by using a suitable arrangement of the strain meters (double installation).

As mentioned above, a meaningful calculation of lining stresses from strains is possible only in combination with laboratory creep tests.

1.4.9.4.2.3 Strain measurements on steel ribs

Application:

Strain gauges attached directly to steel ribs and strain measurements can be used to calculate the stresses, bending moments and normal forces in steel ribs.

There are different arrangements of strain gauges possible which depend on the type of steel rib used.

Strain measurements on steel sets are mainly used when applying the „American Steel Support Method“.

1.4.9.4.3. Anchor Forces

1.4.9.4.3.1 Measuring bolt

Application:

The instrumented anchor is a combination of an anchor and an extensometer. Its task is to determine the ranges of depths, where the load is taken up due to loosening effects of the rock. It is therefore suitable for the determination of the most favourable anchor lengths.

Operating Principle:

The mechanical measuring anchor consists of a hollow anchor body, the sectional area and material of which corresponds to the respective system anchor type. In the inner of this body measuring rods can be fixed to the anchor body at 4 optional points. Miniature measuring rods lead up to the anchor head. By means of a mechanical dial gauge the length changes due to extensions or compressions between the individual anchor points can be determined.

The construction length should correspond to the length of system anchors. Any inclination between horizontal and vertical installation is possible. The measuring bolt is grouted on the whole length in the same way as the system anchors.

The reading accuracy with a dial gauge is 0,01 mm.

Advantages:

- Replaces a system anchor
- No special borehole required, standard drilling equipment can be used
- Simple mechanical reading

1.4.9.4.3.2 Load cell

Applications:

The measurement and control of loads in rock bolts and tension in cable anchors and tendons.

Operating principle:

The centre-hole cells have a robust steel body either filled with oil (hydraulic cells) or with steel springs (mechanical cells). Anchor forces (loads) are calculated from the measured deformation of the load cell. Each load cell must be calibrated before use.

Advantages and Limitations:

- Simple, robust and reliable
- Ideal for remote reading, scanning and data logging.

Performance:

Heavy load cells are available measuring up to several 1000 KN.

1.4.9.4.4. Ground Deformation

1.4.9.4.4.1 Extensometer

Application:

- Determination of displacements in order to establish origin and actual amount of the movements of a point of the tunnel lining (for combination with convergence readings).
- Evaluation of strains in the surroundings of a tunnel including creep and relaxation phenomena.

Operating Principle:

The single rod extensometer employs a rod, anchored at one end of a drillhole, passing into a reference tube fixed in the hole collar. Relative movements between the anchor head and the reference tube are measured with either a dial gauge or an electric transducer inserted through the reference tube and registering on to the free end of the rod.

Multiple rod extensometers are installed to monitor displacements at various portions in a single hole. Each rod is individually isolated by a close-fitting plastic sleeve.

Extensometers are reliable, accurate, simple to install and to read. Readout accuracy is 0,01 mm.

Calculation of Ground Strains:

The strains are calculated from the difference in displacements of the single extensometer sections over the length of each section.

1.4.9.4.4.2 Inclinometer

Application:

Measurement of lateral movements along a borehole axis.

Operating Principle:

An access tube with four internal "keyways" is grouted in a borehole. The inclinometer probe which is fully waterproof travels along the length of the tube with its wheels located in one pair of "keyways" depending on the required measuring direction. A sensor within the probe responds to changes in tube alignment. Displacement readings may be taken at intervals of 0,5 m or 1 m along the tube and displayed on a portable digital readout.

Advantages and Limitations:

- Reliable, simple to install and to read.
- The probe calibration can be checked at any time.
- One probe reads at many locations; only the access tubes are permanently installed in the ground.
- Gives a displacement profile along the complete length of the access tube, movements are detected wherever they occur.
- Measures in two orthogonal directions
- Sections of access tube may be removed or added during construction
- Not suitable for continuous or remote readings.

Performance:

Access tube should be vertical +/- 30^{o} or horizontal +/- 30^{o}. Lengths up to 200 m may be used. Sensitivity: 0,01^{o} = 0,175 mm/m.

1.4.9.4.5. Ground Water

1.4.9.4.5.1 Groundwater Measurements during drilling operations

Groundwater measurements shall be performed every working day before starting drilling works. After installation, surveying of the installed stand pipes and piezometers (coordinates, elevation) should be done. Subsequently, groundwater measurements should be performed in a weekly interval at least one year (better two or three years) in order to investigate the natural groundwater regime during dry and wet seasons.

1.4.9.4.5.2 Borehole Installations for groundwater measurements

1.4.9.4.5.2.a) Standpipes/Piezometers

General

Depending on the permeability of the aquifer either standpipes or piezometers shall be installed to measure water levels or pressures. The kind of installation used as well as installation details, like depth and length of the perforated tube (screen), grain size distribution of filter pack, application of clay seals between different aquifers, etc. shall be advised by the site geologist after the borehole is finished. After installation standpipes and piezometers shall be put into function by removal of fines, e.g. by pumping or by applying compressed air. Subsequently the functioning shall be controlled by a seepage test as described above.

If distinct aquifers (separated by layers of low permeability) are detected during drilling works, a piezometer shall be installed in the lower aquifer and a supplementary borehole for an installation in the upper aquifer shall be considered.

Standpipes

In soil of high or medium permeability (e.g. silty gravel or sand) standpipes shall be installed as shown in Figure 7. A standpipe mainly consists of a perforated tube (screen), which is surrounded by a gravely or sandy filter pack. the inner diameter of the tube shall be 3'' in minimum (as to allow short-time pumping tests, if required). Therefore a borehole diameter of 6'' to 7'' is necessary. The upper end of the screen shall be about 1 m above the highest groundwater level to be expected. The screen length has to be adjusted to the expected groundwater fluctuations and shall be specified by the field geologist.

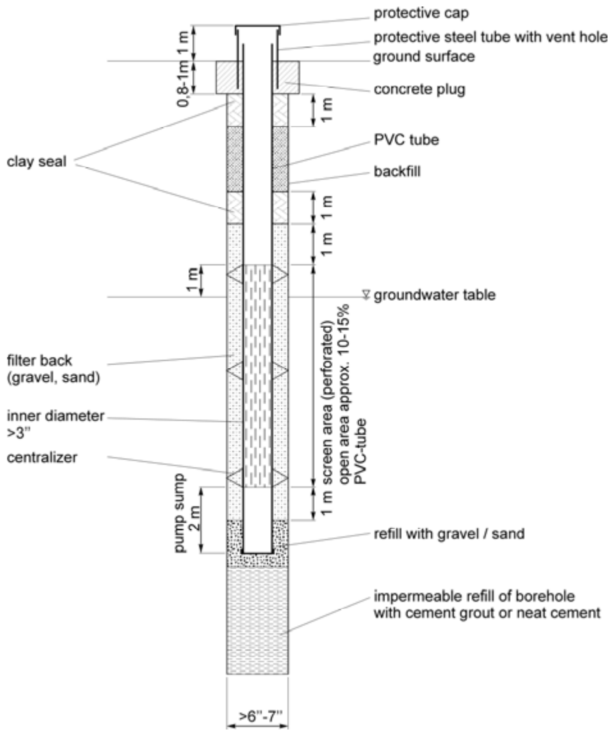


Fig. 13: Standpipe

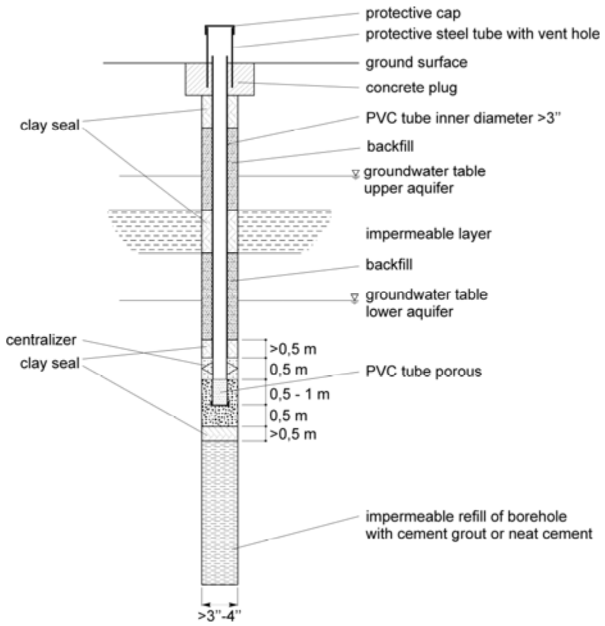


Fig. 14: Piezometer

Piezometers

In low-permeable soil (e.g. silt of clayey silt) and in bedrock open-hydraulic piezometers shall be installed according to Figure 8. A piezometer consists of a slotted tube of 1'' - 1,5'' inner diameter, therefore the borehole diameter shall be 3'' - 4'' in minimum. The length of the screen shall be 0.5-1 m. The screen is surrounded by a filter sand pack, which is bounded by an upper and lower bentonite seal of 0,5 m minimum height.

1.4.9.4.6. Building and Structure movements

1.4.9.4.6.1 Settlement Measurements

Application:

Settlement measurements of buildings, structures and utilities are commonly carried out by leveling of settlement points (settlement pins) by means of optical instruments. For reference, benchmarks should be installed within a certain distance of the monitoring zone.

Operating Principle:

Regular measurements of all measuring stations shall be taken before, during and after construction. Intervals may be from one week to one month, depending on the construction stage. More frequent measurements, once or even twice a day, should be taken at critical construction stages, e.g. when the tunnel face is within a distance of 10 m from the measuring station or the structure.

Levelling with standard instruments can be done quickly and without special skill. An accuracy of less than 5 mm is easy to achieve; an experienced surveyor, will be able to measure to an accuracy of 1 - 2 mm. With high precision instruments, it is possible to measure to an accuracy of 0.1 mm.

Settlement Stations:

Settlement stations are pins, which are fixed at a solid surface. They must be installed such that no changes in elevation will occur due to poor installation or movements other than from construction. Further free sight and easy access is important. As the placement usually is done before construction, changes of the environment, which may happen during construction and possible traffic diversions must be considered.

The number of measurement stations installed, depend on the dimension, and structural system of a building. As building damage are a result of differential settlements, four settlement stations, one at every corner, are considered as a minimum number. For a detailed assessment of differential settlements at least three stations are necessary in one direction.

1.4.9.4.6.2 Tiltmeter

Application:

Tiltmeters, which measure the tilt (rotation) of a structure, are an additional tool for evaluation of differential settlements of a building or structure. They are installed at the wall or slab of one or several floors of the building.

Operating Principle:

The equipment includes the tilt plate (ceramic or brass), which is cemented to the surface, and the portable tiltmeter sensor and the indicator. The plate contains pegs which are the reference points for aligning the sensor, which senses the change in tilt (angular deflection) of the plate. The tiltmeter should be able of bi-axial measurements. For continuous long-term observation the tiltmeter sensor can be permanently installed.

1.4.9.4.7. Vibration of Blasting

1.4.9.4.7.1 Seismograph

Application:

The most common type of blasting damage is caused by ground vibrations. When an explosive detonates in a blasthole, it generates intense stress wave motion in the rock. Vibrations from blasting and the effects of such vibrations can become harmful if tunnels are passing through residential areas and close to buildings or structures. The intensity of seismic motion that can be tolerated by various kinds of structures must be established in order to determine acceptable charging plans at various distances from the structure (or object). Calculations on vibration effects can only be theoretical and thus questionable in case of claims. In such cases in-situ vibration measurements should be carried out during construction. They can be also used to improve the blasting and excavation system.

Depending on the actual conditions several monitoring installation stations are set up. Some will be located directly on the structure or building concerned, some closer to the point of blasting. In general recording stations will be located within a distance of 500 m. For modification of the excavation and blasting system seismographs can be installed near the blasting point in niches of the tunnel.

Operating Principle:

The particle motion associated with seismic waves can be measured with seismographs. In principle the instrument makes an enlarged record of the motion of the base on which it rests, relative to an inertial member or heavy weight that remains essentially at rest. The seismograph records the motion in three directions, two horizontal at right angles and one vertical.

Velocity seismographs, which measure the change of the wave amplitude in relation to time, are most widely used for measuring the ground motion by blasting. Other types are the displacement and the acceleration seismograph.

It is important that the monitoring device is fixed with full contact to its base. All connecting cables must be installed water tight.

Permissible vibration velocity:

The level of motion required to damage a structure depends on its construction. Following some information is given on the standards of permissible vibration velocities causing no damage on structures.

West German standard (DIN 4150): Frequency is 50-100 Hz:

40 - 50 mm/sec for industrial buildings

15 - 20 mm/sec or residential buildings

8 - 10 mm/sec for structures classified as monuments

Swiss standard (SN 640 312): Frequency is 60 - 90 Hz

30 - 40 mm/sec for industrial building (concrete) and tunnels with or without concrete inner lining

18 - 25 mm/sec for brick structures with concrete floors

12 - 18 mm/sec for brick structures with wooden floors

8 - 12 mm/sec for structures classified as monuments

Austrian standard (ÖNORM S 9020): is (for c=500-3000 m/sec):

30 - 39 mm/sec for industrial building

20 - 26 mm/sec for residential buildings

10 - 13 mm/sec for residential buildings (low stiffness)

5 - 7 mm /sec for structures classified as monuments

1.4.9.5 Data Filing

1.4.9.5.1. General

Geotechnical and geodetical measurements yield an extensive amount of data. While processing of these data can be performed manually for small projects, major projects require computerized data handling.

Measurement data filing and processing includes the following tasks:

- Filing of raw data in a clear order
- Calculation of results required for interpretation
- Graphical presentation of results

1.4.9.5.2. Manual Data Filing

Where monitoring data are not recorded automatically, they are generally noted down by the measurement technician as the readings are taken. It is good practice do have notes from previous readings at hand while taking new readings, so common errors can be avoided as the readings are taken.

The raw data are then transferred into standardized data sheets. Sheets are available for each type of instrument. Sample sheets are often provided by the instrument manufacturers. The numerical data from the sheets are then plotted versus time. Purely manual filing procedures are hardly used nowadays. "Manual" filing thus usually utilizes computer spreadsheets for filing, calculating and plotting.

1.4.9.5.3. Computerized Data Filing

In large projects, computerized data filing is the only possibility of attaining a good overview of the monitoring results. Even in small projects, computerized filing is an advantage, since monitoring results can be plotted instantly and in different scales and combinations. This saves time and eases the task of interpretation.

Monitoring results measured by hand are typed into the data base, electronically gathered data can usually be transferred directly from the instrument or via storage media. In the case of contactless deformation monitoring, which is the practical standard for lining deflection measurements, data are transferred directly from the theodolite into the computer, where an evaluation program performs the required mathematical calculations and then transmits the deformations into the data base.

A computer program for filing and display of monitoring results should have at least the following features:

- Organization of data base according to site, subsite and monitoring section
- Possibility of storing the data from all instruments used on site, like extensometers, piezometers, inclinometers, convergencies, contactless monitoring etc.
- Possibility of storing construction related events such as advance rate, works stoppages, special occurrences.
- Evaluation of most raw results (calculating rock strains from extensometer readings, applying temperature correction to convergency readings, including calibration values).
- If extensive processing of raw results by a different program is required, the filing software should have a direct interface to the output of this program or at least a neutral interface that can be used by both programs.
- Plotting of data on screen, on all common output devices (plotters and printers) and on file for inclusion in reports.
- Plotting of data against time, within the cross section and along longitudinal sections of the tunnel.

1.4.9.6 Interpretation of Measurement Data

1.4.9.6.1. General

Interpretation of measuring results from related to tunnel has the following tasks:

- Analysis of stability of the complete tunnel structure
- Analysis of rock mechanical phenomena together with stress redistribution and ground failure
- Analysis of support element loading, e.g. rock bolts, shotcrete, steel ribs, etc.
- Risk assessment for any building or structure in the vicinity of the tunnel

1.4.9.6.2. Relevance of Monitoring Method

The suitability of the various methods of monitoring for the individual tasks differs. Various measurements provide the basis for interpretation:

1.4.9.6.2.1 Contacless deformation monitoring

The knowledge of absolute displacements of several points on the circumference of the tunnel lining is the best basis for thorough interpretation. This method is very informative as particular geological conditions are reflected in the measurements and a very sensitive adjustment of support can be performed.

1.4.9.6.2.2 Convergencies

Convergency readings are a very sensitive tool for assessment of general stability. Convergency measurements provide no details about absolute displacements, because only relative displacements are determined. However, as all contributing elements of the tunnel structure are summarized in the convergency result, stabilization of convergencies means stabilization of the whole structure.

Due to the time dependent properties of rock and support, there may be temporary stability and significant deformations may occur in steps without obvious influences of any tunnelling activities.

1.4.9.6.2.3 Levelling

Levelling renders indispensable information together with convergencies. In some conditions (e.g. shallow tunnel in weak ground), where settlement of the top heading is most critical, crown levelling and levelling of the abutments of the lining is the first choice for stability analysis. The relative settlement of crown and abutments is an indication for the kind of rock mechanical phenomenon, (load transfer, zones of loosening and plastification).

1.4.9.6.2.4 Borehole extensometers

Borehole extensometers provide information about deformations within the ground. The amount and distribution of those deformations along the length of the extensometer enable a qualitative assessment of the state of ground loading. The output of this evaluation depends on the number of anchors within the borehole. The shorter the relative distance of the anchors, the more accurate the results. Frequently, borehole extensometers enable determination of the depth of a failure zone around the tunnel. This is important for decisions on rock bolt length, as rock bolts are usually designed to cross the failure zone.

1.4.9.6.2.5 Measuring rock bolts

Readings give the relative displacement of fixed points within the length of a rock bolt. For elastic conditions an average force can be calculated from the average strains. Sometimes, strains exceed the yield strength. In this case Hooke's law is no longer valid. Force then corresponds to the yield force. In rock tunnelling the deformation of a fully grouted rock bolt is very variable along its length. In this case the force calculation is often a rough simplification.

1.4.9.6.2.6 Strain measurements

Loading of the shotcrete lining is mainly introduced within the first few days or even only hours after application. During this period, the most critical degree of utilization of the shotcrete lining is usually reached. For this reason, the determination of the early loading is essential for the assessment of the local and overall stability of the temporary support.

Evaluation of shotcrete stresses by means of pressure cells are not satisfactory due to the disturbance of the weak shotcrete by the relatively stiff cell and because of poor bedding caused by temperature changes. The shotcrete strain meter has been developed to enable a better evaluation of the loading within the first few days. If strain measurements are combined with interpretation of lining deformations, extensometer readings, etc. a quite complete understanding of the structural behaviour of the combined system ground-support can be gained.

1.4.9.6.3. Data Plotting

The graphical display of data is of particular importance for interpretation. In addition to the data plots, the location of excavation headings (crown, benches, invert) must be shown in relation to time. The estimation of predeformation prior to the zero reading are of importance to quantify the overall displacement.

For displacement data the following plots are useful:

- Measurements versus time
- Measurements versus tunnel cross-section and time
- Measurements versus distance to face
- Measurements versus chainage and time
- Display of geotechnical trends (for example: readings 15 m behind the face)

For main monitoring cross-sections containing rock bolt measurements, borehole extensometers and other devices, the measurement data are usually also plotted in the tunnel cross-section.

1.4.9.6.4. Measurements during Operation

In special areas (major fault zones, areas with swelling, etc.) the following measurements should be taken at regular time intervals:

- stress/strain in the inner lining
- deformation of the lining(e.g. invert hieve)

1.4.10 VENTILATION OF TUNNELS

Ventilation of tunnels should be dimensioned for all tunnels so that the prescribed low level of pollution with carbon monoxide (CO), nitrogen monoxide (NO), aldehydes and other non-combusted hydrocarbons (CH) and satisfactory visibility in normal functioning of the tunnel is provided in the tunnel.

Several factors should be taken into account in calculation of required quantities of fresh air and selection of the appropriate ventilation system in tunnels: vertical layout of the tunnel, number of tunnel tubes and traffic lanes in the direction of driving, the projected composition of traffic flows, calculative speed and traffic flow density as well as the level and length of the tunnel, which all affects the concentration of harmful substances in the tunnel.

Table 1: Spheres of application of different ventilation systems

VENTILATION SYSTEMS IN VIEW OF THE TUNNEL LENGTH		
	Tunnel length in m	
	Two-way traffic (single tunnel tube	One-way traffic (double tunnel tube)
Natural longitudinal ventilation	up to 400	up to 600
Mechanical longitudinal ventilation	400 - 600	600 - 3000
In view of the threat assessment a) by means of axial fans b) sucking out through a shaft c) sucking out through lowered ceiling by controlling the outlet openings	600 - 1200	/
sucking out through lowered ceiling by controlling the outlet openings	above 1,200	/
Longitudinal ventilation by means of spot sucking out < 2000 m, or sucking out through lowered ceiling by controlling the outlet openings	/	above 3,000

Additionally, the selected ventilation system (longitudinal, semi-transversal, transversal or combined ventilation) should in case of tunnel fire provide the possibility for directing smoke, heat and gases.

In case no regulations regarding vehicle emissions exist and data on measurements of actual emissions are not available, the basic emission values specified in the PIARC recommendations shall be used.

As regards tunnel design in Slovenia, values on exhaust emissions of vehicles specified in Table 2 should be used.

Table 2: Values of exhaust emissions of vehicles used for planning ventilation in tunnels

Year	2000		2005		2010		2015		2020	
	CO $m^3/h \times voz$	Particles $m^3/h \times voz$	CO $m^3/h \times voz$	Particles $m^3/h \times voz$	CO $m^3/h \times voz$	Particles $m^3/h \times voz$	CO $m^3/h \times voz$	Particles $m^3/h \times voz$	CO $m^3/h \times voz$	Particles $m^3/h \times voz$
Personal vehicles – petrol	0.075	0	0.043	0	0.033	0	0.029	0	0.028	0
Personal vehicles – diesel	0.014	20.6	0.010	13.9	0.009	9.53	0.009	7.30	0.008	6.49
Freight vehicles – diesel	0.063	71.1	0.037	36.3	0.024	16.9	0.019	8.88	0.018	6.91

Table 3: Values of permitted concentrations of CO and visibility for individual traffic situations

Traffic situation	CO concentration PPM	Visibility m^{-1}
Smooth traffic (50 – 100 km/h)	70	0.005
Daily dense traffic with potential jams	70	0.007
Exceptionally dense traffic with potential jams	100	0.009
Maintenance work in the tunnel below traffic*	20	0.003
Blockage of the tunnel	200	0.012

* Also applies to tunnels intended for pedestrians and cyclists in addition to motor vehicles.

For each project values of emissions should be valuated with regard to the year of design, projected traffic volumes, age of vehicles, quantity of kilometres driven, position of the tunnel and state-of-the-art achievements regarding engines of vehicles.

Traffic criteria regarding dimensioning of the tunnel's ventilation system include CO concentration, NO_X concentration, reduction of visibility and speed of airflow in normal operating conditions and in case of a tunnel fire. By complying with requirements regarding quantity of CO, NO_X and dust particles (from exhaust gases of vehicles and other dust particles) other standards on emissions, e.g. on non-combusted CH, shall also be complied with.

1.4.10.1 Minimum Criteria for Ventilation Planning

The PIARC recommendations allow varying standards for air quality in tunnels depending on the traffic situation. The ventilation system should be dimensioned so that the following criteria are met in normal operating conditions:

Smooth traffic (speed between 100 km/h and 30 km/h)

- o Concentration limit of CO: c = 100 ppm
- o Concentration limit of NO_X: n = 25 ppm
- o Limit coefficient of reduced light: k = 0.007 m^{-1}

As regards tunnels between larger cities, the traffic control and management system should in normal traffic conditions prevent traffic jams. In such tunnels the speed of vehicles should always exceed 30 km/h.

In case of any changes, the most recent applicable PIARC recommendations should be taken into account.

1.4.10.2 Air Quality Control in Tunnels

The following should be planned for every ventilation section in each tunnel tube where mechanical ventilation system is to be installed: two measurement systems for measuring CO and dust particles in the air and the measurement system for measuring the speed and direction of air in the tunnel.

Signals should be transmitted to the ventilation control unit, traffic control and the command centre.

As regards longitudinal ventilation systems, the air speed in normal operating conditions should not exceed 8 m/s. Measurement devices shall be installed in each ventilation section for controlling the air speed and monitoring operations of the ventilation system.

Although tunnel fires are rare, their possibility should be taken into account in dimensioning of the ventilation system and preparing of the plan for ventilation implementation. When the control system in the tunnel detects fire, it should switch from normal operating regime to the operating regime in case of fire. In accordance with the PIARC recommendations, the lower half of the traffic area should be free of smoke and hot gases for as long as possible, thereby providing a safe area and visibility for evacuation of people from the tunnel. As regards tunnels with one-way traffic and longitudinal ventilation, the ventilation system should operate so that the air speed in the tube in case of fire does not exceed 1.5 m/s. In two-way traffic, the longitudinal airflow in the tunnel must be stopped.

As regards tunnels with length of 2000 m or more with two-way traffic, transverse or semi-transverse ventilation should be planned, which enables continuous suction of smoke and hot gases through ventilation ducts in the initial stages of fire, when the smoke is concentrated only under the ceiling of the tunnel tube. The recommended suction capacity in case of fire according to PIARC is 80 m^3/s/km.

The ventilation management system should be planned so that the air speed, and dust particles and CO concentration in the tunnel are measured and the measured values are compared with the previously determined limit values for operating of ventilation devices. In case of values exceeding the limit values, the control-management system should respond accordingly.

No ventilation is required in tunnels not intended for traffic of motor vehicles.

1.4.11 TUNNEL LIGHTING

Tunnel lighting should be planned by sections along the tunnel so that it is suitable for adjustment of the driver's eyes to change between daylight at the entry in the tunnel and dark interior of the tunnel. (Figure 15). In tunnels with two-way traffic it is required to take account of the transitions of the light intensity – entrance into the tunnel - at both portals. For each individual tunnel, a calculation of the required illumination in compliance with the CIE (International Illumination Commission) shall be performed.

In case a relevant technical specifications for tunnel lighting is prepared in Slovenia, the preparation of technical documentation and implementation of lighting shall take into account provisions of any such specifications.

As conditions regarding the light in the tunnel significantly affect the lighting and consequently consumption of electrify, tunnel walls are in principle coloured with a light colour (RAL 9001) up to 4 m.

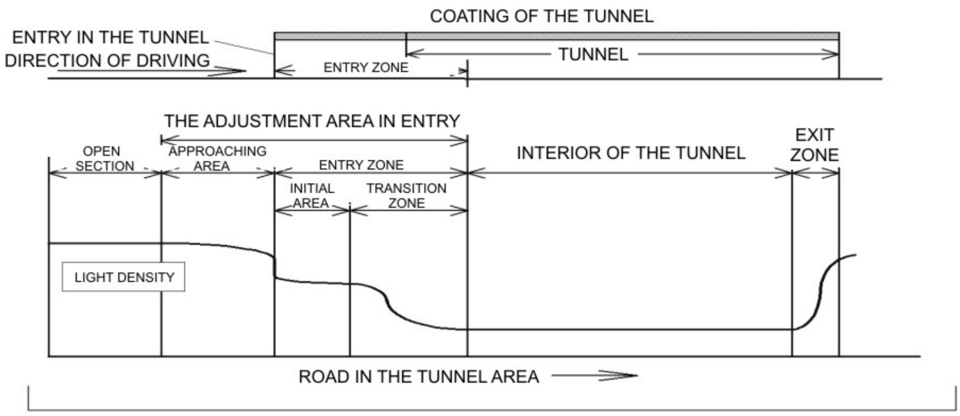


Figure 15: Schematic presentation of course of light density in driving through a tunnel – during the day

1.4.11.1 Tunnel Areas

1.4.11.1.1. Entry zone of the tunnel – initial

The entry zone of the tunnel is the most critical as regards lighting for it requires the largest level of lighting so that occurrence of shadows and the black hole effect in the driver's approaching to the tunnel are prevented. On the basis of recommendation by CIE (International Commission on Illumination) values between 3000 cd/m^2 and 5000 cd/m^2 may be assumed for luminosity of the approaching area before the tunnel's portal in cases when no measured values are available. The ratio between lighting of the entry zone and the approaching area of the tunnel depends on the stopping path and lighting in the approaching area.

1.4.11.1.2. Entry zone of the tunnel – transitional

In the transitional area, the level of luminosity gradually decreases between the entry zone and the interior of the tunnel. The length of the transitional area depends on the vehicle's speed and the time required by the driver's eye to adjust to the changed luminosity between the external zone and the interior of the tunnel.

1.4.11.1.3. Interior of the tunnel

In tunnels with one-way traffic, the interior of the tunnel is part of the route between the transitional area and the exit portal, the area in which the adjustment of the eye to changed luminosity has no effect on visual perception.

In tunnels with two-way traffic, the interior of the tunnel is part of the route between both transitional areas. The luminosity of the interior should be at least 4.00 cd/m^2.

As regards the exit portal, increased lighting is recommended in cases when the tunnel's position allows direct sunlight in the exit portal, which would result in difficult visibility conditions.

If required, lighting before and after the tunnel shall be implemented by managing from the tunnel's control centre.

1.4.11.2 Tunnel Lighting Systems

Lighting of entry and exit zones of the tunnel shall be equipped with counter beam lighting (CBL) with installed high pressure sodium illuminants. High pressure sodium illuminants with symmetric lighting shall be used for interior of the tunnel.

In lay-by areas metal-halogenoid illuminants with white light shall be used.

Illuminants of emergency lighting shall be powered by an UPS system via fire resistant cables.

1.4.11.3 Tunnel Lighting Adjustment

1.4.11.3.1. Entry: initial and transitional zone

Lighting of the entry – initial and transitional – zone shall be adjusted with regard to the difference in luminosity between the exterior and interior of the tunnel. Luminosity outside and inside the tunnel shall be measured by devices for measuring roadway luminosity and luminosity of the portal area. Photometric measurements outside and inside the tunnel shall be performed continuously and control devices should constantly compare the measured values and adjust the lighting accordingly. Manual and automatic adjustment of tunnel lighting should be enabled.

Adjustment of lighting in the initial and transitional areas shall have five levels (100%, 75%, 50%, 25%, 0%) or several levels. For that purpose, illuminants shall be equipped with appropriate lighting regulators by which the light flux can be reduced by 50%.

1.4.11.3.2. Interior zone

Lighting of the interior zone shall be regulated in relation to traffic density and time of the day. Adjustment of lighting in the interior zone shall have three levels (100%, 50%, 25%). Illuminants shall be equipped with appropriate lighting regulators by which the light flux can be reduced by 50%.

Tunnels in which traffic of motor vehicles is not permitted (tunnels for pedestrians and cyclists) shall also be equipped with lighting providing sufficient visibility required for normal use of the tunnel.

1.4.11.4 Mechanical Construction of Illuminants

If possible, equal housing for illuminants should be used for all three lighting zones (entry, transitional, interior). Illuminants should be placed above the roadway, parallel to the traffic area, and so that servicing is enabled by closing only one traffic lane.

All the installations, devices, and equipment shall be adequately finished for the anticipated working and operating conditions.

Housing of illuminants shall be resistant to atmospheric effects inside the tunnel and should have at least IP 65 level of protection.

Stainless steel sheet and profiles shall be Cr-Ni-Mo-Ti alloy of material grade 1.4571 according to the DIN 17440. " "

Stainless fixing materials shall be of Cr-Ni-Mo alloys of material grade 1.4401 according to the DIN 17440, or of epoxy resins of adequate mechanical resistance complying with the DIN 4102 concerning the fire resistance.

Aluminium alloy used only when explicitly indicated by the Investor as the construction material shall be Al.Mg-Si 05 according to the DIN 1725 with the strength F25 and H14 according to the DIN 1748 for profiles, and Al.Mg3 according to the DIN 1725 for aluminium sheet. "Aluminium" is an aluminium alloy complying with the above-mentioned specifications unless specified otherwise.

The aluminium alloy shall always be "sandblasted" as indicated in the further text unless specified otherwise. Galvanized steel shall only be used where this is explicitly defined. It shall always be zinc hot-dip galvanized steel.

1.4.12 TUNNEL MANAGEMENT

1.4.12.1 Basic Requirements

The tunnel management system should be devised so that optimal traffic conditions are established on road sections where tunnels are positioned, given the current and planned conditions on those sections.

Tunnel management should plan for procedures regarding:

- Normal operating conditions;
- Maintenance or foreseeable extraordinary situation (e.g. extraordinary transport);
- Unforeseeable extraordinary events (accidents, driving in the opposite direction, stopped vehicles...);
- Tunnel fire;

For the following purposes:

- Better traffic safety;
- Increased comfort and economics of transport of people and goods; and
- Direct reduction in strain on the environment.

1.4.12.2 Functions of the Tunnel Management System

Main functions of the tunnel management system, which are interactively linked are as follows:

- Collection (perception) of traffic and environmental data on extraordinary events in front of the tunnel and inside it (traffic accidents, fires, maintenance work, air quality inside the tunnel...);
- Extraordinary events management;
- Control over the current traffic situation in front and inside the tunnel by using communication devices (three-piece traffic lights, one-piece traffic lights – flashers, changeable traffic information signs – CTIS, radio, SOS, video surveillance, sound system...);
- Ventilation management (if available);
- Lighting management (daily, night, emergency...);
- Providing for electricity supply (from the network or emergency supply);
- Traffic flow management and informing of road network users inside and outside the tunnel.

In case the tunnel management system is a part of a wider system (e.g. a system for control and management of motorways or other roads), it shall enable communication and linking to other systems.

The system shall provide control and management of traffic when:

Traffic characteristics reach critical levels (inside the tunnel or in the zone where the tunnel is located);

Environmental conditions endanger the safety of road users (poor visibility, excessive concentration of CO...);

Foreseen or unforeseen events on the road occur (work on the road, traffic accidents, fires...).

1.4.12.3 Data Obtained by Measurements

Measurement devices for collecting traffic and environmental data shall be installed on places providing the overview of the real traffic situation along the entire length of the tunnel. Particular attention should be given to entry and exit zones of tunnels:

- Measurement devices for collecting traffic data – in real time – shall provide: counting data, data on vehicle speed, traffic structure for each traffic lane;
- Measurement devices for collecting environmental data: reporting fires, measuring CO and visibility, longitudinal speed of air in tunnel tube, information on weather conditions outside the tunnel to the extent they can influence the traffic conditions inside the tunnel.

Measurement devices for collecting environmental data shall be located inside the tunnel tube and niches as well as in power centrals and in the area of influence outside tunnels.

1.4.12.4 Traffic Management Inside Tunnels

Traffic management system inside tunnels consists of the following:

- Traffic information signs;
- Three-piece traffic lights and one-piece traffic lights (flashers);
- Changeable traffic information signs (CTIS) (multipurpose);
- Changeable traffic signs (CTS); (multipurpose)
- Control management system(CMS);
- Data transfer network;
- Tunnel management centre (TMC).

Traffic information signs should provide display of contents, which is adapted to current situation on the road and enable management of traffic flows and informing of road users in front and inside the tunnel.

Size, luminosity and position of traffic information signs in relation to their location (portal of the tunnel, circumference of the tunnel tube) shall provide the best possible visibility of signs at the highest permitted speed of vehicles in all environmental conditions.

Controllers of the control management system shall appropriately process data obtained from traffic and environmental measurement devices, communicate with other devices in the management system and manage traffic information signs, lighting and ventilation.

Data transfer network shall enable the following:

- Transfer of collected traffic and environmental data from measurement devices to the tunnel management centre in real time;
- Transfer of those data from the tunnel management centre(s) to traffic information signs, which then display particular traffic contents in case of automatic or manual actions taken by the system;
- Linking with higher levels of traffic control and management on motorways (regional traffic control and management centre on the motorway);
- Linking with other information systems (main traffic control and management centre on the motorway).
- The network and individual system elements shall use an uniform protocol for communication, which shall also enable upgrading the system with new devices.
- The tunnel management centre(s) (TMC) shall be adapted to local circumstances and requirements with regard to the tunnel(s) under management. It shall continuously accept, analyse, store and display data from measurement devices and other information systems, such data may be in text, audio or video digital format. The TMC shall have the system for timely measures and warning in cases of critical situations in traffic, projections and simulations systems for traffic and extraordinary events, and the system for alarming emergency groups (police rescue services, firemen, media...).

1.4.12.5 Management in Extraordinary Events

Foreseen extraordinary events (e.g. maintenance work, extraordinary transport) and unforeseen extraordinary events (accidents, driving in the opposite direction, stopped vehicles, fires...) may be expected in a tunnel.

In case of an extraordinary event occurring in the tunnel, the system shall in addition to the automatic (if installed) enable manual taking of appropriate measures for tunnel management and informing of users (traffic accidents, maintenance work).

In case of closing of a tunnel (single-tube tunnel, two-way traffic), a special area for rescuing participants in the extraordinary event shall be envisaged in the portal plateau, and also the area for helicopter landing in case of tunnels for which a special study has established that it is required.

1.4.12.5.1. Tunnel surveillance systems

Tunnel control systems and safety devices shall be planned in accordance with the EU Directive (table of equipment is specified in Enclosure 2).

1.4.12.5.1.1 SOS call system

SOS telephones shall be placed in front of portals and in the tunnel at the distance of 150 m along one side of the tunnel tube.

SOS telephones inside the tunnel shall be placed in niches closed by doors. SOS telephones near portals shall be on columns as along the road outside the tunnel or in special cabins.

SOS system shall be linked to the command centre.

1.4.12.5.1.2 Video surveillance (CCTV- closed circuit television)

A video surveillance system shall be installed in tunnels longer than 500 m.

Video surveillance enables operators in the command centre to constantly monitor the situation along the entire tunnel and in the area of both portals. Video cameras inside the tunnel shall be static while in both portals they shall be rotating and equipped with zoom lenses. Cameras inside the tunnel should be installed on locations, enabling optimal overview of the situation in the tunnel and in such distances enabling upgrading of the video surveillance system with the system for automatic detection of extraordinary events.

In extraordinary events, SOS calls or fire alarms, the picture on the monitor in the control centre shall automatically switch to the camera on the affected location.

1.4.12.5.1.3 Automatic detection of extraordinary events

Installation of equipment for automatic detection of extraordinary events is recommended in tunnels longer than 1000 m on roads in the technical group A.

Tunnel radio devices.

A radio system shall be installed in tunnels longer than 500 m, enabling communication on separate frequencies for emergency services (police, firemen, rescue services) and maintenance service and the national radio broadcasting service with the possibility for communicating in the programme from the command centre.

1.4.12.5.1.4 Sound system

As regards tunnels longer than 1000 m on roads in the technical group A, it is recommended that speakers are installed on locations enabling good reception for communicating messages in cases of extraordinary events (e.g. on portals and lay-by areas).

1.4.12.5.1.5 Traffic signs and signals

Traffic signs shall be implemented in accordance with the requirements specified in the EU Directive. The description and required form are presented in Enclosure 3.

The size of traffic signs shall be limited by the space between the tunnel's wall and its clearance, generally to 50 cm.

1.4.12.5.1.6 Transport of hazardous substances

The following measures should be taken with regard to transport of hazardous substances:

- Signs describing the permitted/prohibited substances should be placed in front of the last exit before tunnel;
- Risk analysis should be made whereby measures for transport of hazardous substances are specified (confirmation before entering the tunnel, forming convoys of vehicles, accompanying transports…);
- Adjusted tunnel management for transport of hazardous substances.

1.4.12.5.1.7 Distance between vehicles

The minimum safety distance from the vehicle in front applicable for road users at the maximum permitted speed shall be 50 m for personal vehicles and 100 m for heavy lorries, under normal driving conditions and also in cases of defects, dense traffic, accidents or fire in the tunnel.

In cases when the traffic stops inside the tunnel, the applicable safety distance shall equal at least half the distances specified above.

1.4.12.5.2. Tunnel safety facilities

1.4.12.5.2.1 Emergency routes and exits

The possibility for evacuation of tunnel users in cases of accident or fire in the tunnel shall be provided for.

Passengers shall be enabled to leave the tunnel without their vehicles through:

- Exits from the tunnel to outside;
- Transversal connections to the other tunnel tube;
- Exits to safety shafts (optionally also to pilot or research gallery for the planned second tunnel tube);
- Shelters with rescue paths separated from tunnel tubes.

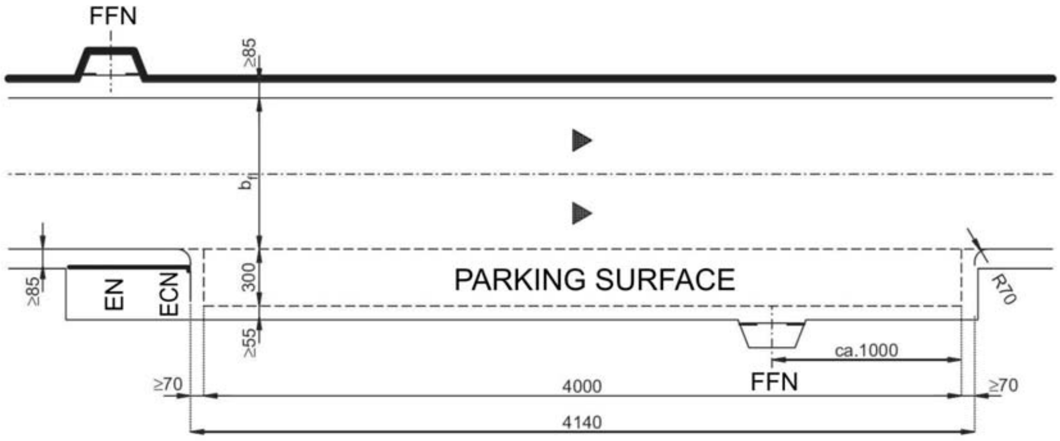
Shelters without exits to evacuation paths leading to the open shall not be built.

Measures on entrances to emergency exits (doors) shall prevent spreading of smoke and heat to emergency exits so that tunnel users may safely escape and rescue teams may safely enter the tunnel.

1.4.12.5.2.2 Lay-by areas

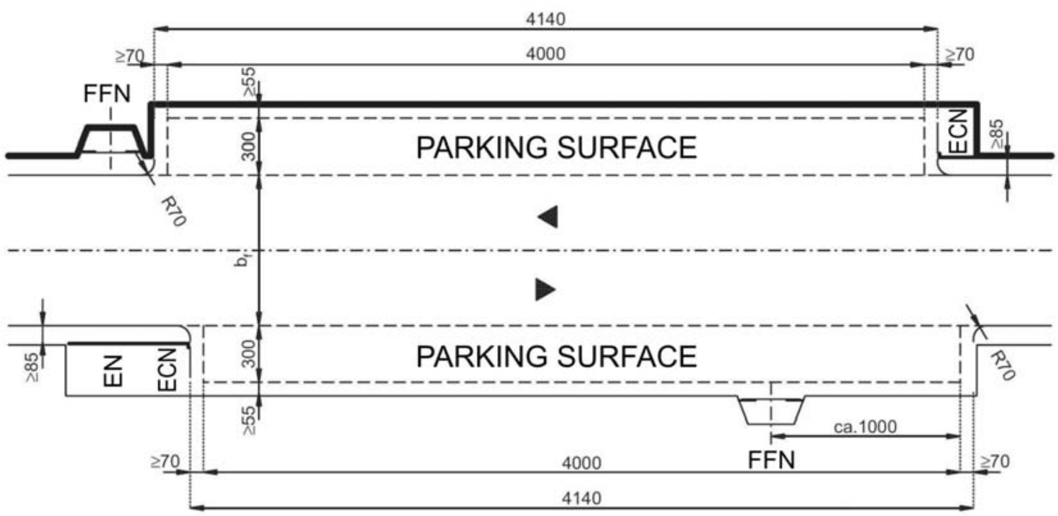
In tunnels longer than 1000 m, lay-by areas shall be implemented, enabling stopping in emergencies and maintenance. Lay-by area shall be roughly 40 m long and at least 2.5 m wide (Fig. 16-21).. The distance between lay-by areas in long tunnels shall not exceed 1000 m.

The niche for SOS calls shall also be included in the lay-by area.



(FFN - Fire Fighting Niche, EN - Electrical Niche, ECN - Emergency Call Niche)

Figure 16: Parking Bay Niche in One-Way Traffic Tunnel – Ground Plan



(FFN - Fire Fighting Niche, EN - Electrical Niche, ECN - Emergency Call Niche)

Figure 17: Parking Bay Niche in Two-Way Traffic Tunnel – Ground Plan

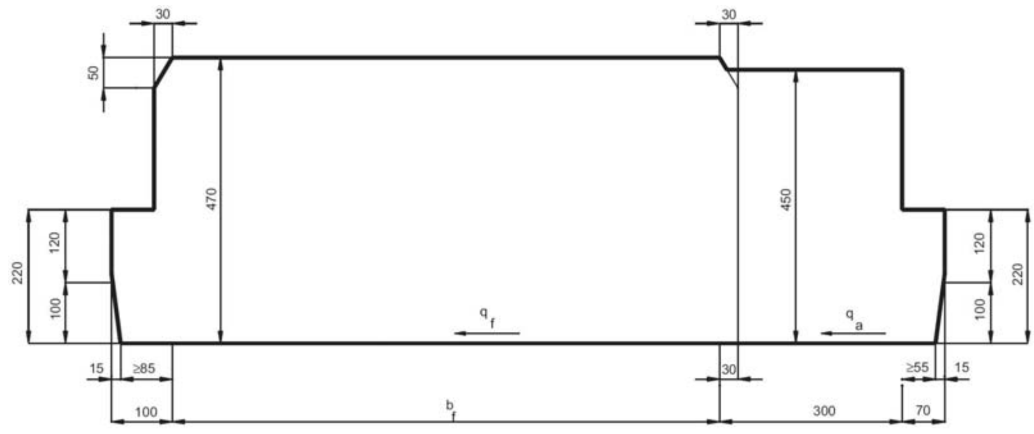


Figure 18: Clearance Profil in the Area of One-Way Traffic Parking Bay Niche

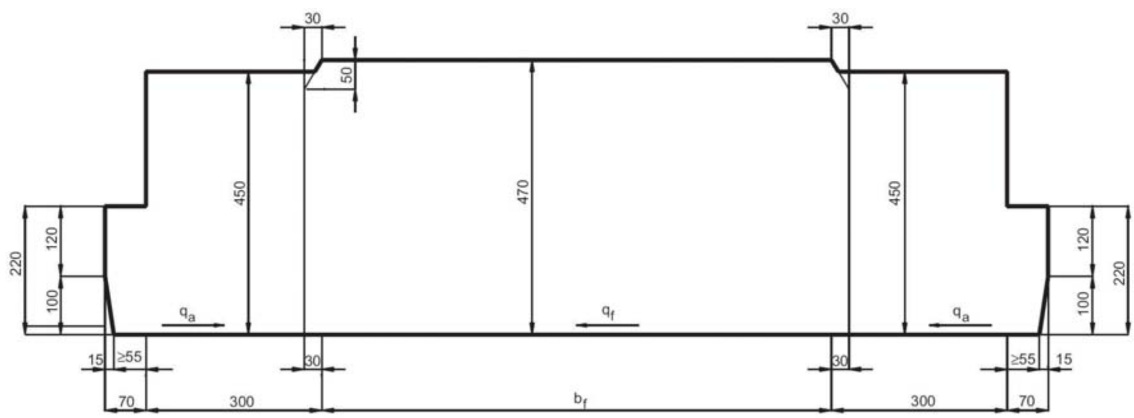
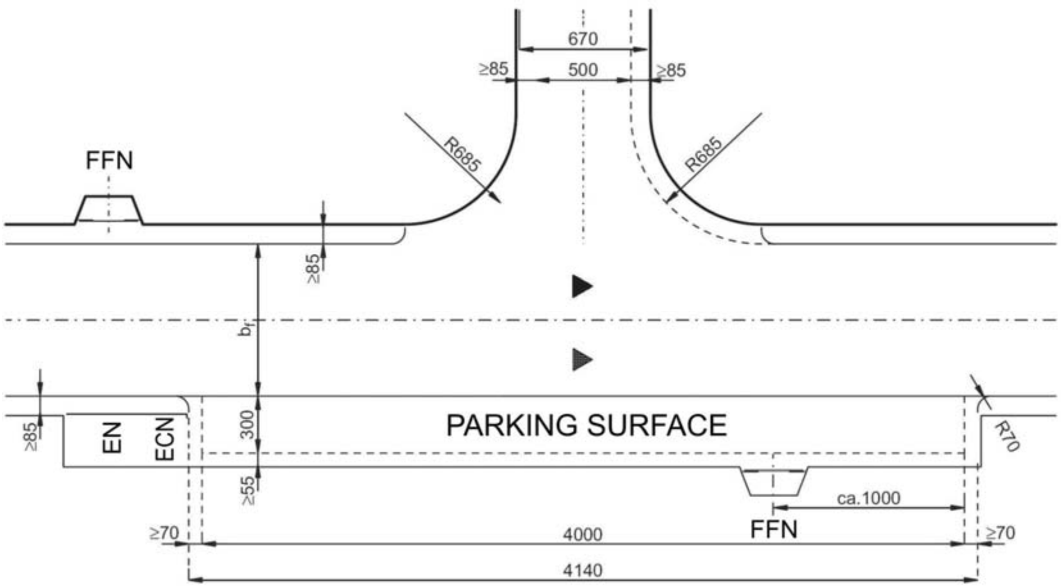


Figure 19: Clearance Profil in the Area of Two-Way Traffic Parking Bay Niche



(FFN - Fire Fighting Niche, EN - Electrical Niche, ECN - Emergency Call Niche)

Figure 20: Connection of the Cross Pasages for Vehicles – Ground Plan

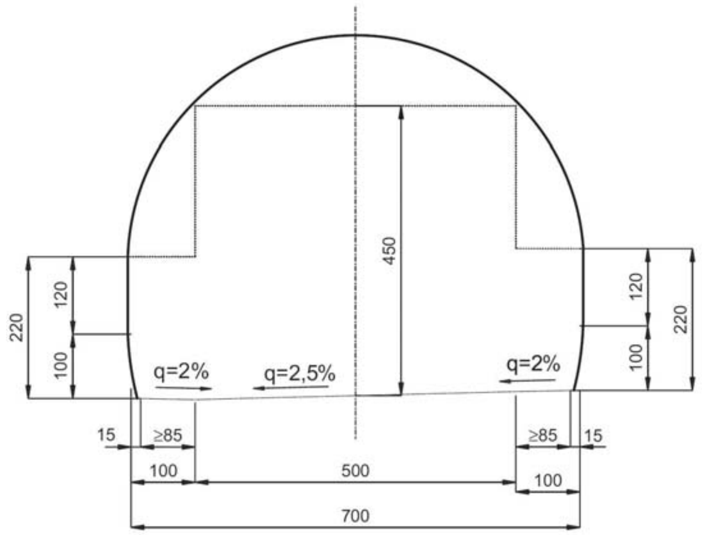


Figure 21: Cross Passages for Vehicles – Cross Section

1.4.12.5.2.3 Tunnel transversal pedestrian crossings

Tunnel transversal pedestrian crossings shall be envisaged for all tunnels longer than 1000 m for emergencies and for maintenance purposes. The distance between transversal pedestrian crossings shall not exceed 500 m.

1.4.12.5.2.4 Tunnel transversal vehicle crossings

Tunnel transversal vehicle crossings shall be envisaged for all tunnels longer than 2000 m. Usually, such crossings are implemented at each second lay-by area or at each third transverse girder (max. 1500 m). These crossings shall enable all vehicles to leave the tunnel area through the other tunnel tube in case of emergencies.

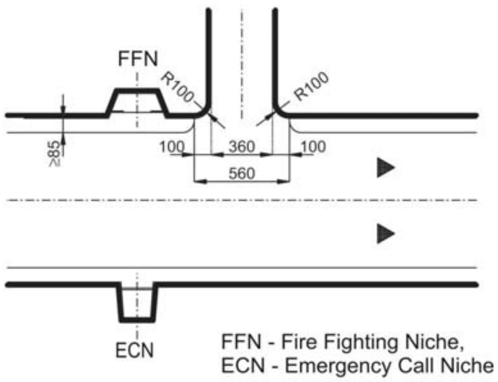


Figure 22: Connection of the Cross Pasages for Emergency Vehicles – Ground Plan

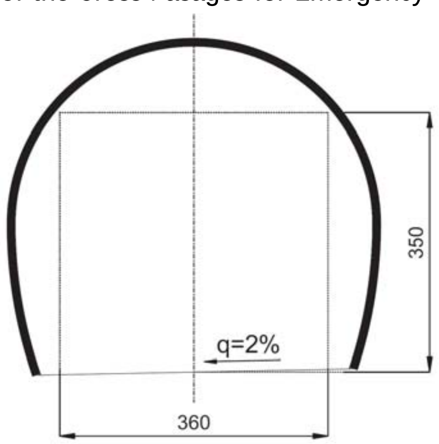


Figure 23: Cross Passages for Emergency Vehicles – Cross Section

1.4.12.5.2.5 SOS calls niches

The locations of SOS calls niches in the tunnel shall be envisaged so that the distance between them does not exceed 150 m and their distance from portals or entries to the tunnel does not exceed 200 m.

Dimensions of lay-by areas, fire-fighting niches, SOS calls niches and transversal crossings shall comply with requirements of the *Directive*.

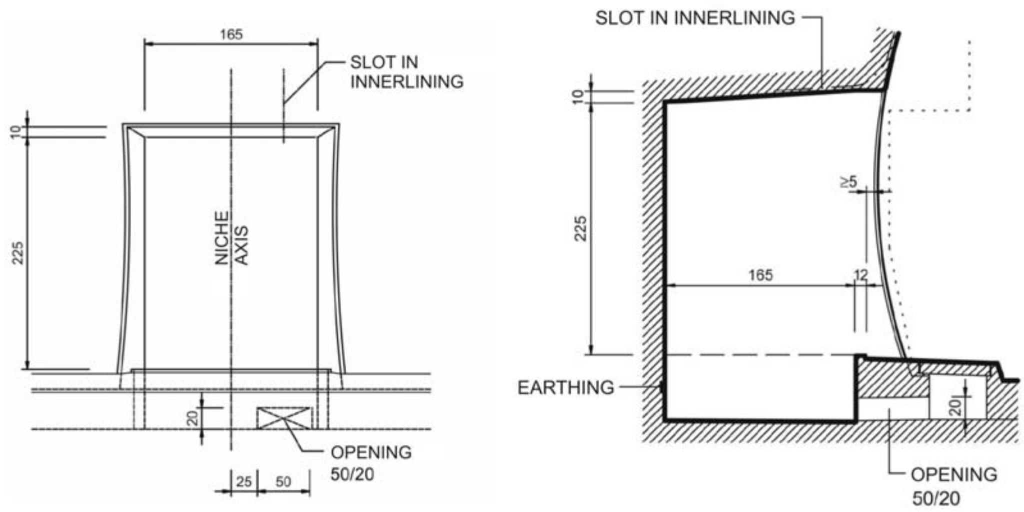


Figure 24: Emergency Call niche – Sight on and Cross Section

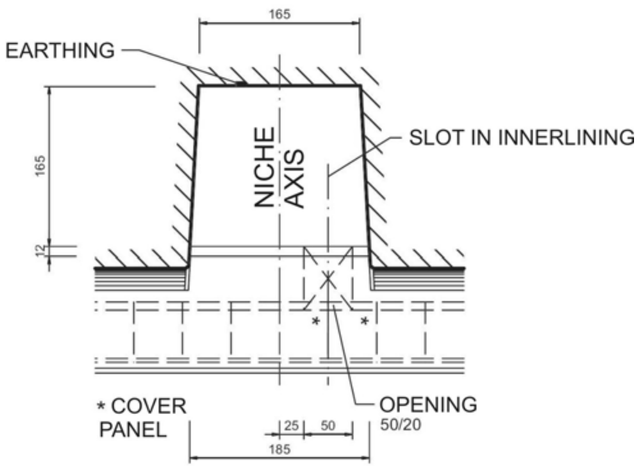


Figure 25: Emergency Call Niche – Ground Plan

1.4.12.5.3. Electricity supply

Main energy supply of the tunnel

The tunnel's energy supply shall be planned economically. Long tunnels or a system of several tunnels shall be supplied by energy through two independent energy sources, which shall each be capable of supplying the entire system of tunnels. A single energy source shall suffice for shorter tunnels.

Emergency energy supply of the tunnel

In case of defects in energy supply, the system for uninterrupted power supply (UPS) shall ensure that there is no blackout or interruption of control in the tunnel.

The UPS – consisting of routers, inverters and AKU batteries – shall enable operations of the command centre, control management system and safety devices (traffic signs, safety lighting) of the tunnel for at least one hour. The UPS should be implemented in all power centrals / energy stations of the tunnel.

1.4.12.6 Providing Fire Safety in Tunnels

Tunnels shall be for the purpose of providing fire safety equipped with fire alarm and fire fighting systems. They shall be planned in accordance with requirements of the European *Directive*.

Fire resistance equalling 400°C for 20 minutes shall be required for equipment, which must be operational in case of fire.

1.4.12.6.1. Hydrant network

In tunnels longer than 500 m – or in accordance with requirements of the Directive with regard to the risk analysis – the fire fighting system shall comprise the pressure pipeline and lifting pipes/hydrants with reliable water supply along the entire length of the tunnel. The pressure pipeline shall be as a rule installed in an installation duct under the pavement. In tunnels with two tubes, pressure pipelines of both tunnel tubes shall be connected to the joint water system. Water pressure in hydrants shall equal 6 to 12 bar. The pressure pipeline shall be connected to the local water supply system or a water reservoir. Dimensions of the water reservoir and the pressure pipeline shall suffice for providing constant flow of 1200 l/min for at least one hour.

Fire fighting niches shall be installed at the distance not exceeding 150 m along the entire tunnel. Fire fighting niches shall include connection to the pipeline equipped with 120 m long fire hose and spraying nozzle.

In case systems for automatic putting out of fires in road tunnels are deemed suitable, the possibility for their installations shall be studied.

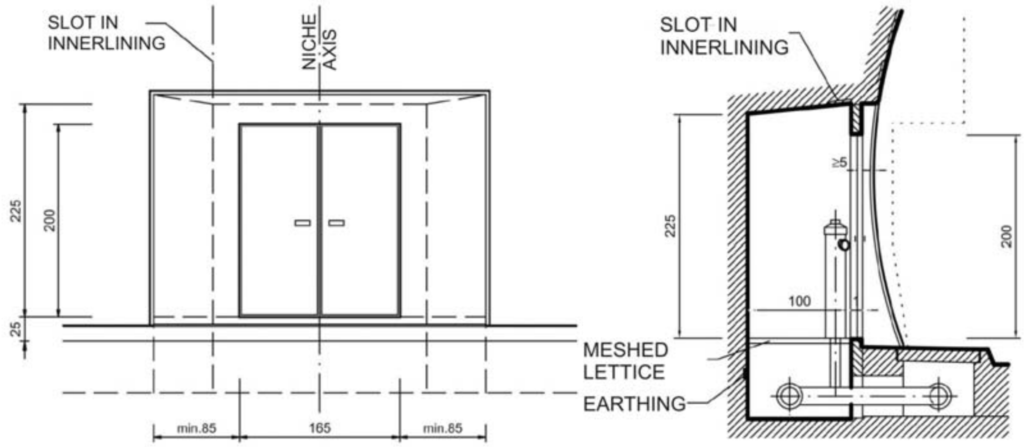


Figure 26: Fire Fighting Niche – Sight on and Cross Section

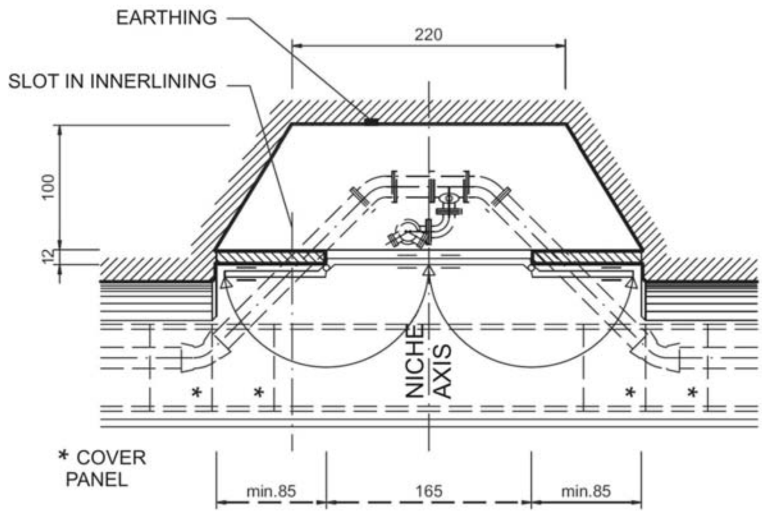


Figure 27: Fire Fighting Niche – Ground Plan

1.4.12.6.2. Portable manual fire extinguishers

Portable manual fire extinguishers shall be installed in all tunnels for immediate putting out of small fires. Two portable manual fire extinguishers shall be installed in each SOS call niche. Signals communicating lifting of a fire extinguisher shall set off the fire alarm.

1.4.12.6.3. Fire warning systems

The key for fire alarm – manual fire warning device – shall be installed in each SOS call niche and near portals.

The automatic fire warning system (line fire warning device) shall be envisaged in all tunnels longer than 500 m and shall include the option for determining the location of fire.

Automatic smoke detectors shall be installed in all electricity niches, SOS call niches, power centrals and the command centre.

Fire alarm signal shall automatically activate the fire fighting programme and shall be submitted to the command centre from where competent services shall be alarmed in accordance with the Informing and Alarming Plan.

1.4.13 TUNNEL OPERATIONS ORGANISATION

1.4.13.1 Tunnel Operations Plan

During the initial or detailed planning, the tunnel operations plan shall be prepared, which shall include answers to all foreseeable situations possibly occurring during the tunnel's operations. Such plan shall specify the method of tunnel management with regard to any traffic and environmental data, which the system detects and processes. Operations of the tunnel's systems in normal operating conditions and in standard emergencies shall be regulated automatically through local units for management of individual systems (lighting, ventilation, traffic signs, fire detection, etc.).

Any data obtained from local control units shall be through the data transmittance system submitted to the tunnel management centre (TMC).

The tunnel operations plan shall include procedures for:

- Normal operating conditions;
- Maintenance and other foreseeable situations in the tunnel (extraordinary transport…);
- Unforeseeable events in the tunnel (accidents, fire in the tunnel).

All data regarding current operations of tunnel systems shall be displayed on surveillance monitors in the tunnel management centre after previous computer processing. Operators shall have constant insight in current condition of all tunnel systems and shall have the possibility to manually control any device via a computer in case of any extraordinary situations. All data on operations of devices and systems in the tunnel shall be constantly recorded and stored in the computer.

In addition to computer surveillance, the tunnel management centre shall also include video system monitors, SOS call system and a radio station for maintenance staff and apparatus of the tunnel radio system.

In case of any defects on the system of links and signal transmittance between the tunnel and the tunnel management centre, tunnels shall be managed through local management units.

1.4.13.2 Roles of Individual Services

1.4.13.2.1. Administrative authority

An ***administrative authority*** shall be established, responsible for providing all safety aspects in tunnels and adopting necessary measures for implementation of requirements of the EU Directive.

The administrative authority may be established at the national, regional or local level.

Each tunnel located in a particular country shall be under competence of a particular administrative authority. As regards tunnels located in two countries, each country in question may establish its own administrative authority or the two countries may establish a joint administrative authority.

The administrative authority shall have the competence to limit the use of the tunnel should safety conditions prove to be inadequate. It shall prescribe measures on the basis of which normal functioning of the tunnel can be established.

Tasks of the administrative authority shall be:

- Regular testing and examination of tunnels and prescribing appropriate measures on the basis thereof;
- Putting to use organisational and operational schemes (including action plans for extraordinary events) for training of emergency services;
- Specifying procedures for closing of tunnels in case of extraordinary events;
- Establishing the required measures for reducing risks.

As regards the organisational level, the administrative authority shall for the purpose of co-ordination and control of accidents / management of extraordinary events in tunnels do the following:

- Specify requirements for inspections of tunnels with regard to safety;
- Control organisational and operational programmes (including action plans for emergencies) for training of guards and use of safety measures;
- Define duties of guards;

- o Control and implement the required measures for reducing risks;
- o Close the tunnel during exercises for emergencies and fire testing.

1.4.13.2.2. Tunnel manager

A ***tunnel manager*** (state- or privately-owned entity) shall be appointed for each tunnel, being in the planning, implementation or operational stage, responsible for tunnel management. The administrative authority itself may also assume such function.

Any significant foreseen or unforeseen event shall be the subject of a report prepared by the tunnel manager. The report shall be forwarded, not later than within one month, to the safety engineer, administrative authority and the competent emergency services.

Should the tunnel manager receive a report including the analysis of circumstances of an extraordinary event or conclusions following such report, it shall submit it to the administrative authority, the safety engineer and emergency services not later than within one month following the receiving of such documents.

1.4.13.2.3. Safety Engineer

The tunnel manager shall appoint a ***Safety Engineer*** for each tunnel subject to prior approval of the administrative authority.

The safety engineer shall co-ordinate all preventive and safety measures for providing safety of users and tunnel staff. Such person may be a member of the tunnel staff or services in charge of acting in case of extraordinary events, however he shall be independent form all services responsible for safe operations of the tunnel.

The safety engineer may be appointed for several tunnels in the region.

Each safety engineer shall perform the following functions:

- o Provide co-ordination between organisation of emergency services and co-operate in preparation of operational schemes;
- o Co-operate in planning, implementation and evaluation of emergency operations;
- o Co-operate in preparation of safety schemes and descriptions (specifications) of structures, equipment and operations for new tunnels as well as for reconstructions of old ones;
- o Check whether staff (operators) and emergency services are adequately trained and co-operate in scheduled exercises;
- o Co-operate in selection of structure, equipment and operations of the tunnel;
- o Check whether the tunnel's facilities and equipment are adequately maintained;
- o Co-operate in evaluation of all significant extraordinary events, and in particular assess and store data in case of fire and submit them to the administrative authority in sufficient details.

1.4.13.2.4. Inspection services

Inspection services shall provide supervision, assessment and testing. The administrative authority itself may also assume these tasks. Any service carrying out these tasks shall posses the expertise and have a high level of competence and be independent from the tunnel manager.

1.4.13.3 Documentation, Putting the Tunnel in Service and Scheduled Exercises

1.4.13.3.1. Safety documentation

The tunnel manager shall at all times keep the safety documentation for each tunnel. A copy of safety documentation shall be forwarded to the safety engineer.

The safety documentation shall include preventive and protective measures for providing safety of people, by taking into account characteristics of the road, configuration of structures, their surroundings, traffic characteristics and the scope of activities of external emergency services.

The safety documentation shall in the design stage of the tunnel include the following:

- o Description of planned structures and access to them, together with plans required for understanding of their design and envisaged preparations for the tunnel's operations;

- Traffic projections studies, establishing and explaining reasons for conditions expected in transport of hazardous substances, together with a comparative analysis of dangers, which could occur in different arrangements for such transports;
- Study of special dangers describing any accidents, which could occur during the tunnel's operations and characteristics and scope of their potential consequences, such study shall define and substantiate measures for reducing the probability of such accidents and their consequences;
- Safety opinion submitted by an expert or organisation, specialised in the field.
- For the tunnel currently under construction, the safety documentation shall also include all measures providing safety of persons working on the site.

The safety documentation for the tunnel in service shall include the following:

- Description of the built tunnel and access to it, together with plans required for understanding of design and operational solutions;
- Analysis of existing traffic and envisaged changes, including conditions applicable for transport of hazardous substances;
- Special studies regarding dangers, description of any accidents, which could occur during the tunnel's operations and characteristics and scope of any potential consequences, such study shall define and substantiate measures for reducing the probability of such accidents and their consequences;
- Description of organisation, required human resources and material as well as instructions defined by the tunnel manager in order to ensure operations and maintenance of the tunnel;
- Action and safety plan prepared in co-operation with emergency services;
- Description of the system of constant feedback information on experience whereby significant extraordinary events and accidents may be recorded and analysed;
- Report and analysis of significant extraordinary events and accidents;
- The list of performed safety exercises and analysis of findings.

The appropriate administrative service shall, prior to the first opening of the tunnel for the public (putting the tunnel to service) and after any significant changes in construction or operations or following larger-scale reconstruction work in the tunnel which may significantly alter any of the constituent parts of the safety documentation, in addition to the documentation specified above also approve the analysis performed by an expert or organisation specialised in road tunnels safety, whereby measures included in this documentation with regard to safety requirements are approved.

1.4.13.3.2. Scheduled exercises

The tunnel manager shall in co-operation with the safety engineer at least once a year organise scheduled exercises for staff employed in the tunnel and for emergency services.

Exercises shall be:

- As realistic as possible and comply with defined scenarios of extraordinary events;
- Produce clear results;
- Implemented in co-operation with experts in maintenance and from emergency services whereby preventing any damage to the tunnel and reducing to minimum any effects to the traffic flow;
- Optionally in part also implemented in tabular form or as computer simulations, whereby obtaining complementary results.

The safety engineer shall supervise such exercises, prepare a report and if required submit appropriate proposals to the tunnel manager, which shall take appropriate action on the basis thereof.

1.4.13.4 Extraordinary Events in the Tunnel

1.4.13.4.1. Work in tunnels

Partial or complete blockage of traffic lanes due to construction or maintenance work planned in advance shall always commence and end outside the tunnel. The use of traffic lights inside the tunnel for planned blockages shall not be permitted and is allowed only in cases of extraordinary events/accidents.

Blockage of traffic lanes shall be marked before the road enters the tunnel. Traffic information signs, traffic lights and mechanical obstacles may be used for that purpose.

1.4.13.4.2. Management in cases of accidents

In case of a serious extraordinary event, the tunnel manager or the safety engineer shall close the tunnel forthwith (all tubes). It shall be done not only by activating the equipment referred to above in front of entries, but also with changeable traffic information signs, traffic lights and mechanical obstacles inside the tunnel, should such equipment exist, whereby the traffic is stopped as quickly as possible outside or inside the tunnel.

1.4.13.4.3. Blockage of the tunnel

In case of a blockage of the tunnel (short- or long-term), users shall be via simply available information systems appropriately informed on the best alternative routes.

In case of an extraordinary event in a two-tube tunnel, the traffic shall be stopped and redirected in both tubes so that the tube other than the one in which the extraordinary event occurred may be used as the evacuation and rescue path.