Water supply and water drainage system of the Gotthard Base Tunnel including a mini power plant: a complex, multipurpose scheme to ensure operational requirement and requirements in case of accident.

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ABSTRACT: To ensure operational and safety requirements a complex multipurpose water supply and drainage system scheme has been set in the 57 km long Gotthard Base Tunnel (GBT). The water supply system makes it possible to refill the fire-extinguishing-and-rescue trains at two locations in each single track tube, to provide cooling water for the underground installed cooling systems, as well as to provide 20 l/s in total for the steady flow in the waste water system, charged at the peak of the tunnel. This water flows down towards the portals, to prevent explosions of flammable fluids in the waste water drainage in case of an accident. The water drainage of the GBT, with separate systems for clean mountain water and for waste water from the single track tubes, is completed at both portals with absorption reservoirs and water treatment facilities. Those have the purpose to cool down the collected mountain water as well as to check the quality and quantity of the drainage water.

1 INTRODUCTION

The Gotthard Base Tunnel is a railway tunnel with two single track tubes, with connects the Italian with the German part of Switzerland and will be used for high speed rail and heavy freight trains (Figure 1).

A multipurpose water and drainage system scheme (Figure 2) has been implemented at the Gotthard Base Tunnel (GBT), with includes two water supply systems and at each portal a water treatment facility.

The water supply system makes it possible to refill the fire-extinguishing-and-rescue trains at two locations in each single track tube, to provide cooling water for the underground installed air conditioning and cooling systems, as well as to provide 20 l/s in total for the steady flow in the waste water system, charged at the peak of the tunnel. This water flows down towards the portals, to prevent explosions of flammable fluids in the waste water drainage, as well to avoid the propagation of burning fluids through the waste water drainage in case of an accident. A 200 kW mini hydro power plant in the multifunctional station of Sedrun will exploit the 800 m vertical height between Base Tunnel and the above water supply system.

The water drainage of the GBT, with separate systems for clean water from the rock mass and for waste water from the single track tubes, is completed at both portals with retention reservoirs and water treatment facilities.
Those have the purpose to cool down the collected mountain water to match the legal requirements for emission in inshore waters as well as to check the quality and quantity of the waste water. In case of pollution, in order to prevent environmental consequences, the polluted waste water is detained by the treatment facilities.

2 GOTTHARD BASE TUNNEL

The Gotthard Base Tunnel is a railway tunnel with two parallel single track tubes, with connects the Italian with the German part of Switzerland and will be used for high speed rail and heavy freight trains. The overall length is 57 km with a maximal coverage of 2.4 km. At the present, the rough works for the tunnel have been completed and the installation of the equipment (electromechanical equipment and railway equipment) is in progress. Accessory works at the portals and intermediate accesses are still going on.
The tunnel has been driven and lined from five sites (Figure 3), twice from the portals and as well as through three intermediate access tunnels. This divides the tunnel in five sections: Erstfeld, Amsteg, Sedrun, Faido and Bodio (north to south). The access to the level of the base tunnel in Sedrun uses a 1 km long access tunnel and two 800 m deep shafts, in Amsteg a 1.7 km long almost horizontal access tunnel, in Faido a 2.7 km long, 12.7% steep access tunnel.

3 REQUIREMENTS IN MATTER OF WATER

3.1 Primary requirements: Safety facility “Stetslauf” (steady flow)

The first requirement for actually installed water supply and treatment system was mandated by the Swiss federal office of transportation in 2002: each waste water drainage in the single track tube has to be charged at the peak of the tunnel and all the times with 5 l/s.

The charged amount of water at the peak of the tunnel had to be verified by field tests. Those tests have been done in 2004, with 1:1 models, to find the best solutions to prevent an explosion of flammable fluids or a propagation of burning fluids, in dependency of the flowing amount of water in the waste water tube.

The reason for those tests and safety features was a railway accident in 1994 with cauldron carts (filled with fuel) in Affoltern (Switzerland), where flammable, explosive liquids had flown in the town’s waste water system and exploded.

The second mandated requirement is that the waste water system has to ensure a drain capacity of approximately 70 l/s of the gutters and of 60 l/s (northern half of the tunnel) respectively 85 l/s (southern half) of the system. Field tests in the section Bodio of the tunnel in January 2012 confirmed the capacity of the waste water system (Figure 4).

The third mandated requirement is that at the portals redundant retention basins systems have to be installed, to prevent environmental impact due to an accident (see chapter 3.3).

If the water supply system fails to charge the tunnels waste water pipes, no trains with dangerous goods (liquids, flammable and explosive loads) are allowed to enter the tunnel.

3.2 Secondary water supply requirements

The water which is used to serve the steady flow is also used for other purposes in the section Sedrun: cooling of machines and rooms as well to provide cooling water for the underground installed air conditioning and cooling systems as well as for the refill of the fire-extinguishing-and-rescue trains. In the section Faido an extra water supply system accomplishes those purposes.

3.2.1 Water for cooling purposes

At three places in the section Sedrun and once in the section Faido is water from the water supply systems used for cooling purposes.

The installed air conditioning and cooling systems, when the tunnel ventilation system is not working, are transferring the collected heat to the exhausted air duct system. When the tunnel ventilation system is switched on, every connection between the both systems is closed and the collected heat has to be transferred to cooling water.

3.2.2 Extinguishing water supply

After the Simplon tunnel fire accident in 2011, considering the logistic difficulties and the loss of precious time for the refill of the fire-extinguishing-and-rescue trains outside the tunnel, the Swiss Federal Railways (SBB) ordered an upgrade of the water supply system.

The request, concerning both multifunction stations (Sedrun and Faido) and each single track tube, is to install standard hydrant-connections and to ensure 500 m³ of water during 4 hours in order to refill 10 times the for
a quick refill, 50 l/s with a pressure of 6 bar have to be available.

These requirements were implemented only at the end of 2011, after the howl system was set up.

The hydrants at both portals are not a part of the overall water supply system in the tunnel, but necessary to guarantee a fast reaction in case of an accident at those locations.

3.3 Secondary water treatments requirements
At the portals of the Gotthard Base Tunnel in Erstfeld and Bodio two water treatment facilities will be realized, in order to check and to ensure the respect of the environmental conditions, set up by law and to ensure an appropriate response in case of accident in the tunnel.

3.3.1 Quality- an quantity-check of waste water
All water from waste water drainage has to be tested prior discharging it into the rivers. In case of pollution, the water has to be stored, in a reservoir with 500 m³ capacity (considering the amount during 8 hours of 2x5 l/s steady flow, 250 m³ fluids from leaking cauldron carts and 100 m³ of firefighting water). Polluted water has to be treated on site, pumped to a local sewage facility or be brought to a special treatment facility for chemical waste.

3.3.2 Temperature control of mountain water
To reduce the influence on the river temperature, a requirement by law, active solutions to cool the water are necessary or the respect of the severe limits has to be proved by calculation. In the second case active solutions have not be improved.

The maximum allowed temperature difference caused by the discharging is normally 3 °C, in our case 1.5 °C because of the presence of sensible fish species in the rivers. A further requirement is the maximum temperature of the discharged water (30 °C) and the maximal river temperature after the discharge (25° C).

4 TYPES OF WATER AND DRAINAGE SYSTEMS

4.1 Mountain water
Mountain water is clean.

In the single track tubes mountain water is drained directly from the rock mass with a separate drainage system.

In the most places of the multifunctional stations of Sedrun and Faido as well as in the access tunnels of Amsteg and Faedo, mountain water and waste water are collected in the same drainage system (mixed water). Cause of this, this mountain water will be charged into the waste water system of the single track tubes.

4.2 Waste or tunnel water
The steady flow or mixed water from the multifunctional stations or access tunnels is normally unpolluted, but can contain some traces of oil or other chemicals. During an accident, the waste water is likely to be polluted.

It has continuously to be quality-checked and quantity-checked before it is discharged into a river.

4.3 Process water
Process water is a mixture of different clean waters (mountain, stream and river water) to ensure the requirements of the steady flow, cooling purposes and for the refill of the fire-extinguishing-and-rescue trains.

5 WATER SYSTEMS

5.1 Water supply systems
In general water supply systems are built with redundancy and have backup systems, to ensure the requirements are all the time under any circumstance guaranteed.

The howl system is automatic regulated, but each unit can as well operate independent, if necessary (chapter 7).

5.1.1 Water supply system at the section Sedrun
The water supply system at section Sedrun is on two different levels, connected by two 800 m long vertical shafts (Figure 5). The water support system and the waste water system are linked through those shafts.
The water supply system at section Sedrun is designed to deliver up to 30 l/s, but normally only 20 l/s are needed. The howl water supply system is divided in different parts (Figure 6):

- the basic supply, collecting the mountain water from the access tunnel and from the air extraction shaft are delivered at the pump reservoir (BTGS) and the compensation reservoir (SKFS)
- The additional water supply, a connection to the hydro power plant Vorderrhein and a secondary backup connection to the water supply system of the nearby town Sedrun can charge water to the pump reservoir (BTGS).
- Transmission from the upper level (compensation reservoir SKFS at the shaft head cavern) down to the level of the base tunnel (reservoir MFSS)
- Distribution to the waste water drainage in the single track tubes and to the hydrants for the refill of the fire-extinguishing-and-rescue trains.

In total the water supply system Sedrun has three reservoirs and three different sources of water; two of them are not owned and fully controlled by the operator of the tunnel. Each reservoir is also used for cooling purposes. The cooling water is recharged at it intake reservoir. In addition the pump reservoir BTGS (60 m³) (Figure 7) can, in case of overfilling, pump water back to the private owned hydro power plant and includes an oil separator for the waste water from the access tunnel.

The compensation reservoir SKFS (50 m³) in the shaft head cavern merge the waters from the pump reservoir BTGS and the air extraction shaft and is the upper basin for the mini hydro power plant. The water is additionally used to cool technical rooms, the four 32 t ventilators, the inspection hoisting equipment in shaft I and serves the maintenance staff with water.

The reservoir MFSS (700 m³) (see also Figure 15) at the base tunnel level stores sufficient water to charge for more than 8 hours the single track tubes waste water pipes, without been recharged in case of maintenance or a failure. This reservoir also delivers cooling water, water for maintenance staff and for the refill of the fire-extinguishing-and-rescue trains. The water for the refill of the fire-extinguishing-and-rescue trains is charged at the plugs in the single track tubes with two redundant 50 l/s pumps at 6 bars.

The system for the water transport in the 800 m high shaft changed four times during the design phase. First design was a delivery vertical pipe, later pipes with pressure reduction valves (tree in series), free hanging vortex drop shaft with a length of 700 m (DN 300) and finally a free hanging penstock (DN 125). The final solution with the free hanging penstock is coupled with a mini hydro power plant at the multifunction station Sedrun (chapter 6).
The shaft I is also used for fresh air ventilation (-20° C to +40° C), for power and communications cables (up to 132 kV) and the inspection hoisting equipment.

The waste water system of the section Sedrun discharge their water in three different rivers (and seas), depending in which part it come from. At two places are water switches installed, to prevent environmental damage to the river Vorderrhein in case of an accident.

The whole water system works full automatically and has various security and backup features implemented.

5.1.2 Water supply system at the section Faido

The water supply system at the intermediate access Faido uses the water from the exploration tunnel Piora and as backup the water from the small creek Vigera. Its main purpose is to serve the air-conditioning with average 2 l/s of water (max. 3.8 l/s).

The water is collected in a small tank at the portal, then piped to the reservoir ZGSF (100 m³) along the access tunnel, and further delivered to the air condition plant room at the multifunction station Faido (Figure 8).

5.2 Drainage system in the single track tubes

In the single track tubes are generally four water pipes (Figure 9 and Figure 10): at each side a drainage (PEHD, outer Ø 200 mm) to collect mountain water, which is discharged every 100 m into the main mountain water drainage (PEHD, outer Ø 630 mm); the forth pipe is the tunnel or waste water pipe (PEHD, outer Ø 315 mm), which contains normally only the steady flow of 5 l/s and will collect in a case of an accident the polluted liquids.
5.3 Waste water and water control Systems at the portals

At both portals water treatment facilities are installed, to check water quality, quantity and temperature, to cool down if required the warm mountain water and if necessary to retain polluted water. With those facilities the requirements forced by law can be guaranteed.

Due the topographical differences (rivers, road and landscape), the integration of existing structures from the construction phase and the different amount and temperature of water, the facilities at the portals have a different setting.

5.3.1 Waste water and water control Systems at the portal Erstfeld

The northern Portal has a waste water treatment and a merging part to discharge the controlled and mixed water.

The first quality and quantity control of the tunnel water occurs for each waste water tube separately after entering the water treatment facility. The water passes the small slowdown basins flows normally in one of the two regular (500 m³) retention reservoirs, in case of pollution in the smaller retention reservoir (250 m³). After passing all quality and quantity checks of the steady flow / tunnel water from the waste water system, the water is merged together with the mountain water.

The discharging of the mixed water can occur to three places, twice with gravity (to a river and a creek), or pumped (300 l/s) to the nearby sewage facility (Figure 11). The sensors detect a change of pH-value, amount of water, temperature, turbidity and conductibility. After a detection of a change of one or more values, the water has to be tested in situ, and discharged normally (false alarm), pumped to the nearby sewage plant or brought by road tanker to a special chemical treatment facility.

No cooling facilities are required, due the enough low mountain water temperatures and the sufficient minimum water flow of the river Reuss.

5.3.2 Waste water and water control Systems at the portal Bodio

At the southern portal a solution with a valves chamber close to the portal and three retention reservoir (each one with a capacity of 500 m³) solution to check the water at a distance from the tunnel entrance of approx. 700 m, will be constructed.

As in Erstfeld, if the water-quality requirements are satisfied, the steady flow / tunnel water is merged together with the mountain water and conducted towards the following three lines of cooling ponds (Figure 12). The once planned active cooling system has been removed from the project, due to effective lower temperature and amount t of the mountain water at the portal, compared with the forecast.

Figure 11: Overview over sections Erstfeld and Amsteg

Figure 12: Overview over section Bodio

The detecting system with redundancy, adapted to the light different layout of the waste water treatment in Bodio, is similar to the system in Erstfeld. In case of a detection of pollution, the procedure is as well the same. All clean water is discharged into the nearby river Ticino.
5.4 Dry firefighting pipes at the multifunction stations

In both multifunction stations an emergency stop is located in each single track tube. In these emergency stops a 450 m long dry firefighting pipe, with pipe-connections every 50 m will be optionally installed. These pipes reduce the workload of the firefighters to lay a up to 400 m long pipe, in case of a fire on a train. The dry firefighting pipe will be connected at one its ends directly with the fire-extinguishing-and-rescue train.

6 MINI HYDRO POWER PLANT

6.1 Why a mini hydro power plant in the largest railway tunnel?

To conquer the height between the upper and lower part of the water supply system at the section Sedrun, a mini hydro power plant has been implemented in this complex system (chapter 5.1.1). The main purpose is not the commercial production of electric energy: it is to reduce the water pressure in an ecological and smart way.

6.2 System of the hydro power plant

The system of the hydro power plant has to obey the same requirements as the howl system at section Sedrun: high reliability, stability and backup systems for system or material failures.

For maintaining reasons the intakes and discharge reservoirs are constructed with two chambers. Before the vertical, free hanging, 800 m long, 13 t heavy penstock begins, a security valve is installed. In the multifunction stations two axial compensators are installed, one for the vertical displacements, the other for the displacements of the 100 m long horizontal penstock. In the hydro power plant cavern, a former gallery for logistic reasons, the Pelton turbine and two bypasses with pressure reduction valves are installed (Figure 13).

6.3 Details of construction

The hydro power plant has three particularities:

- A Pelton turbine designed for a maximum flow of 30 l/s with a pressure of 80 bars
- Redundant by-passes (2) with 80 bar pressure reduction valves to ensure a constant water flow of 20÷30 l/s while the turbine is out of service (due to turbine failure, loss of connection with the main energy grid or maintenance work) and in case of contemporary failure of one of the two by-pass.

Figure 13: System of the mini hydro power plant at the section Sedrun

The operation of the aforementioned by-pass valves has been designed in order to ensure their opening also in case of loss of energy (positive opening operation); for this reason, oil-hydraulic control system has been adopted. Two different energy sources have been designed for the two by-pass. The first by-pass is controlled with a double-acting servomotor, in order to control the flow in normal operation; in emergency mode, the valve is opened with oil pressure supplied by an accumulator. The second by-pass valve is operated by a counterweight (opening) and a single-acting servomotor (closing).

The last change of the project replaced the 700 m vertical vortex shaft and a reservoir in shaft I with a mini hydro power plant to reduce the water pressure. The vortex shaft was replaced by an 800 m vertical and 100 m horizontal penstock. The penstocks only vertical
support is placed at the shaft head cavern (Figure 14), while in the shaft only lateral supports are installed (earthquake, buckling). A DN 125 pipe is sufficient to deliver 20 l/s (normally) and as well 30 l/s (exceptional). Using duplex steel EN 1.4462 (ferritic austenitic), the pipe thickness needed is of 5 mm only. The vertical penstock has already been successful installed.

As for the turbine, it’s worth to be mentioned that the design data (pressure 80 bar, discharge 20 l/s) are outside every possible standardized turbine chart in mini-hydro segment. The diameter of the injector is 18 mm, the pitch diameter of the runner is about 750 mm, buckets width is about 55 mm. Rotational speed is 1'500 rpm. The Pelton turbine, coupled with an asynchronous generator, produces about 140 kW with 20 l/s, and around 200 kW with 30 l/s.

In the hydro power plant cavern, equipment to deliver water for the fire-extinguishing-and-rescue trains, maintenance personal and the air conditioning plants (Figure 15) are also installed.

7 SYSTEM MANAGEMENT AND CONTROL SYSTEM (MSRL)

The water supply and drainage system is a fully automated system, managed by a hierarchical control process. All actuators and sensors are managed by local programmable logic controllers (ESR) that are able to fulfill all functionalities for their own domain. All local process controllers are supervised by a master water supply and drainage head calculator (KR) that will coordinate all local controllers and interface the equipment with the tunnel main GBT control system.

7.1 Control system GBT

The Gotthard Base Tunnel is managed with different tools: the overall tunnel control, the maintenance tools and the emergency operation center. The tunnel operators will normally work with these overall systems where only a set of fundamental information regarding the single systems is displayed. The operator will be notified if any kind of alarm or system failure occurs, and will be able to enter the single system to view and verify the details and eventually change settings or trigger commands. Data is managed by the single system head calculator and all process control is done by the single system equipment; a loss of communication between the main control system GBT and the single systems has no effect on the normal operation but could lead to a missing reaction in case of an event, since it cannot be reached by the event dispatching system. For this reason the single systems run on redundant head calculators and redundant communication networks.

The general management hierarchy of the Gotthard Base Tunnel can be seen in Figure 16.

![Figure 16: the hierarchy pyramid of the process control equipment of the Gotthard Base Tunnel](image-url)
The water systems are less subjected to events compared to other systems, as for example the ventilation. If an accident occurs, the ventilation system has to react immediately and apply a specific scenario that depends on the event kind and location (for example open / close dampers, apply air pressurization to specific sectors of the tunnel, apply smoke extraction, etc.). For the water systems an event will only trigger simple reactions that optimize the storage of a possible polluted water in dedicated collection reservoirs.

7.2 Water control system

7.2.1 Logic and requirements
The control, data-storing and management water control system is high reliable, autonomous and independent; it communicates with other systems (ventilation, cooling, electricity distribution, data network, etc.) in order to perform all necessary information exchanges.

The software is programmed to automatically handle possible errors occurring to sensors and actuators by applying alternative compensation processes; all failures are reported to the overall tunnel systems.

In order to fulfill all requirements, all calculators and controllers are connected to redundant data networks and power is supplied by redundant power grids (data network is displayed in Figure 17).

7.2.2 Head calculators
The System has two redundant head calculators at two different locations, one acting as master and the other set in standby, ready to take over in the case of a failure of the partner machine (hot standby). The master head calculator collects data and is able to dispatch commands or messages to and from all local controllers.

The master head calculator has a dedicated interface with the overall tunnel control systems that allows the communication of important data (including event notifications).

The head calculator has its own man-machine interface that can be remotely accessed in order to view detail information about the equipment.

7.2.3 Local controllers
The local controllers consist of programmable logic controllers (PLC), mainly equipped with redundant CPU; the controllers collect and evaluate all data from sensors, valves, pumps, turbine and generator and manage them according to programmed logics. They normally operate independently and autonomously, in order to gain the maximum security in case of a network failure. The controllers communicate with the head calculator that collects all status data and can issue commands.

7.2.4 Sensors and actuators level
All sensors and actuators are connected directly, or over a decentralized periphery, to a local controller. Sensors are used to read water flow rates, water levels, pH, temperature (water, air), conductivity, turbidity and pressure (up to 120 bar) values.

Sensible measurements are performed with indirect redundant sensors; for example the water quality can be measured twice in a row at different stages, or the water level is measured with two sensors placed in different chambers that are hydraulically connected.

7.3 Electric power grid
Four electric power grids ensure the distribution of electric energy in the Gotthard base-tunnel (Normal East and West, Priority East and West). Electric power supply is guaranteed from different external principal grids. The Priority grids are supported by eight no-break diesel generators and one hydro plant situated in Amsteg that are able to compensate possible blackouts.

All sensible parts of the water system are redundant, and each redundant component is connected with a different power grid in order to gain resilience.
7.4 Programmed cases and reactions

The failure of sensible parts of the system will cause the automatic switch of the functionality to the redundant partner; all failures are promptly notified to the Tunnel operator and the Maintenance services will be automatically advised on the necessary actions that have to be taken.

In case of an accident, the water systems receives from the overall control system the information about what happened, the location of the event and a forecast of the final stop position of the implicated train. On the base of this information, the system calculates the time of arrival of potentially polluted water at the portal. The dispositions of different parts occur automatically, for example:

- Fill and set in pressure the fire-extinguishing pipes in the multifunctional station Sedrun (normally dry)
- Prepare the water supply systems so that they will be able to deliver sufficient water for possible extinguishing purposes (refill of the fire-extinguishing-and-rescue trains)
- Empty and prepare the retention reservoirs for the polluted water that will eventually reach the portal

8 CONCLUSION

GBT will go alive in commercial use in December 2016 after 20 years of design and construction.

Rating the overall picture, the water systems of GBT are only a small part of the whole project, but at last they are a very important part in a very complex system of facilities to ensure tunnel operations.

Some of the parts shown in the previous chapters had to be implemented after the construction work had started already. This integration of new requirements at a very late stage of project development demanded an integrated coverage of the difficulties by all parties involved.

At the early design stages of big projects as the GBT the maximum attention is given to the bigger issues as for example the excavation methods, lining of the tunnel, muck management etc.

The experience we made now, as engineers and as client, shows very clearly that detailed design and the definition of all requirements of such a complex water supply and drainage system has as well to be performed to an early stage of the overall project.

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