

A SWISS ENGINEERING TEAM DESIGNS A Ventilation System for the World's Longest Rail Tunnel

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When it opens in 2016, the 57-kilometer-long Gotthard Base Tunnel (GBT) will form an important part of the European high-speed rail network, linking the north and south of the Swiss Alps and reducing travel time from Zurich to Milan from 3.5 hours to 2.5 hours. Within the engineering group Gotthard Base Tunnel South, which consists of three companies, Pöyry Infra AG was responsible for designing the GBT ventilation system.

Pöyry Infra graduate engineer Reto Buchmann describes how he and his team used MATLAB® based fluid dynamics models to determine how the system should be operated under normal, maintenance, and emergency conditions.



GBT entry point at Bodio.

The GBT ventilation system must provide comfortable working conditions for maintenance staff and enable safe evacuation in the event of an emergency. If a fire breaks out in one of the main railroad tubes, the ventilation system raises the air pressure in the unaffected tube to keep it clear of smoke. The people in the tube with the fire move to the pressur-



urized tube, either through the emergency stations at one of the multifunction stations or through the cross passages.

One design challenge for our team was that the auxiliary shafts in Sedrun and Faido had to serve a dual role.

To reduce excavation time during construction, these shafts provide additional access to the tunnel. When the tunnel opens, they will serve as ventilation ducts.

Another challenge was that some design requirements, such as the temperatures to be maintained inside the cross connections, were modified several times while the project was under way. Our

design strategy had to accommodate the preset parameters but be flexible enough to adapt as the requirements changed.

Design Approaches

To design the system we needed to understand the aero- and thermodynamic behavior of the air in the tunnel tubes and its shafts. Given the size and complexity of the tunnel geometry, building a scale model and testing it under a wide range of conditions would have been virtually impossible. Simulation was the only viable approach.

Our simulations had to take into account many complex and uncertain boundary conditions, such as heat transfer between the air and the duct wall, the temperature of the rock, the flow of groundwater, and the evaporation or condensation of water. The transient behavior of the system meant that simulations need to be time-dependent. To take into account the uncertainty of some boundary conditions, such as rock temperature, they also had to support variant studies.

We needed to model the airflow through all 154 kilometers of tunnels and shafts simultaneously to determine, for example, how powerful the ventilation system would have to be to keep the escape route clear of smoke.

Pöyry Infra AG is part of the global Pöyry group. Based in Zurich, Switzerland, Pöyry Infra specializes in tunnel electromechanics, ventilation and safety, transportation, environment, civil engineering, and surveying.

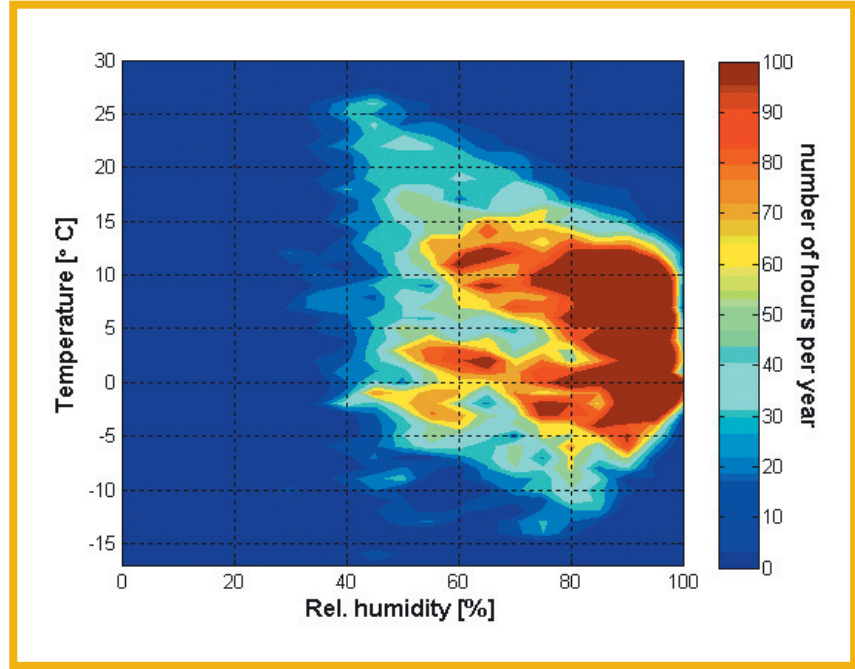


Figure 1. MATLAB visualization showing distribution of tunnel temperature and humidity throughout the year.

Developing Custom CFD Code

A general-purpose computational fluid dynamics (CFD) software package was not feasible because it could not easily be customized. An off-the-shelf package would have forced us to model the ventilation system as a 3-D problem. The enormous length of the shafts and tunnels would have resulted in a model with an unmanageable number of elements, and it would have taken weeks to simulate just one scenario.

We solved this problem by developing our own CFD model in MATLAB. Our MATLAB model typically runs in two hours on a standard PC—a fraction of the time required to provide the same level of accuracy with general-purpose CFD code. We implemented pressure losses through dampers or ventilator characteristics as look-up tables or functions based on experimental data, reducing calculation time and providing more accurate results. Our MATLAB model provides

additional efficiency by enabling us to reduce the tunnel to a single dimension, length. (Because the tunnel's width and height are small in relation to its length, omitting these dimensions has little effect on the simulation results.)

MATLAB predefined functions, such as lookup tables, interpolation, and equation solvers, enabled us to develop and run the code quickly. Ordinary and partial differential equations, which play an important role in fluid flow calculations, were easy to set up and calculate in MATLAB. We also relied on MATLAB data import and export functions and used MATLAB statistics functions for data preprocessing and interpretation. We visualized our results using MATLAB 3-D surface plots and contour plots (Figure 1).

Two Fluid Dynamics Algorithms

For computational efficiency, our CFD code uses a different fluid dynamics algorithm for each part of the computational domain. The finite volume method is used to model

the airflow in the shafts and tunnels, while the finite difference method is used to model thermal transfer in the surrounding rock. We solved the systems of equations required for both methods using Optimization Toolbox.

The airflow model determines the velocity, temperature, and humidity of the air in space and time for the entire ventilation duct. Mass flow in the shaft is determined by a boundary condition, the air density is constant, and flow is one-dimensional. As a result, the aerodynamic equations, mass conservation, and ideal gas law reduce to the mass conservation equation.

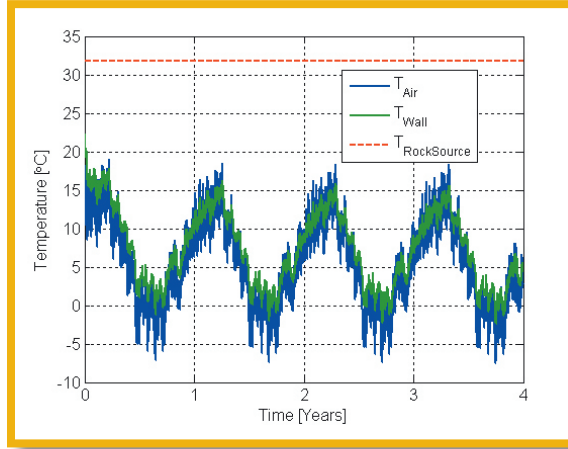


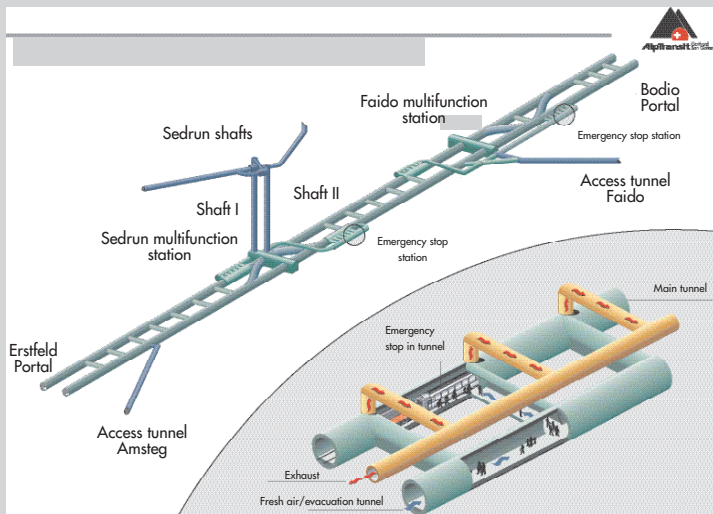
Figure 2. MATLAB plot of air and wall temperature fluctuations over four years.

The Gotthard Base Tunnel

The GBT is part of the Swiss AlpTransit project, also known as New Railway Link through the Alps, which also includes the Lötschberg Base Tunnel. Today, 67% of the GBT has been excavated.

Like the Lötschberg tunnel, the GBT is intended to establish a direct route suitable for high-speed rail and heavy freight trains. The GBT will increase the maximum weight of trains on the route from 2,000 tons to 4,000 tons.

The two single-track tunnels will be linked by cross passages about every 325 meters so that each tunnel can serve as an escape route for the other. Two multifunction stations at Sedrun and Faido will house ventilation equipment and technical infrastructure and will serve as emergency stops and evacuation routes.



In the thermal transfer model, which calculates the heat conduction through the ducts from the surrounding rock, the three sets of equations in the airflow model reduce down to a single Fourier heat conduction equation. The two models are coupled together by the heat exchange between the rock wall and the air in the duct.

Simulating the Model

We used our MATLAB models throughout the process to iterate on the design.

One simulation monitored the air temperature and humidity at various locations inside the tunnel (Figure 2).

Because the response of the surrounding rock is so slow, the calculations had to be carried out over four years. The impact of the initial rock temperatures would be lost after a longer time, and the outside temperature variation at the duct portals would roughly repeat every year, providing measurements over an entire year.

The results were used to design the HVAC devices for the technical rooms at Sedrun and Faido. We simulated the ventilation system operating at high- and low-flow levels, using two different ventilation strategies. The results showed that the lower airflow reduces the variation in temperatures more than the higher air flow. Other simulations evaluated the performance of the ventilators in various emergency scenarios, such as their ability

to pressurize either railway tunnel within three minutes.

Advantages of Simulation

We could not have designed a safe ventilation system for the tunnel without accurate fluid dynamics simulations. General-purpose CFD codes would have doubled the design time. With MATLAB,

we simulated the tunnel quickly and accurately, making it possible to design a system that will ensure the comfort and safety of passengers and staff.

The next challenge is to implement our approved MATLAB air flow models in Simulink® and then design the control algorithm for the GBT ventilation system. ◀◀

For More Information

- Gotthard Base Tunnel www.alptransit.ch
- Pöyry Infra AG www.ewi.ch/e

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