

Climate in very long railway tunnels

Dr. Rudolf Bopp, Gruner GmbH, Vienna (Austria)
Verena Langner, Gruner GmbH, Vienna (Austria)
Manuel Burghart, ÖBB Infrastruktur AG, Graz (Austria)

Abstract

Temperature and humidity are important parameters for safe operation and efficient maintenance of a tunnel. With increasing tunnel length and greater overburden the internal climatic conditions become more and more adverse. To assure that adequate countermeasures can be taken the climate must be predicted with the use of computer simulations and a strategy for the sealing of the tunnel lining developed on this basis.

Introduction

For safety reasons modern railway tunnels exceeding a certain length are usually built as twin bore tunnel systems with cross passages between the two tubes. In the case of an emergency the opposite tunnel tube can then be used as a safe area for the passengers of a train. In very long tunnels such as the Koralm Tunnel in addition to this twin bore design, one or more emergency stations are built to provide a place where fast evacuation of a train under controlled safe conditions is possible.

But very long tunnels demand not only high attention regarding issues related to tunnel safety. Attention should also be paid to the tunnel climate. In long and deep tunnels extreme climatic conditions can become a serious threat for reliable operation and thus also for the tunnel safety. High tunnel temperatures and humidity may not only reduce the life expectancy of the technical equipment in the tunnel but also impair the health of the workers and thus cause severe limits for the maintenance of the tunnel.

Adequate measures are therefore necessary to control the climate in a long tunnel. It is however difficult to decide which measures are most suitable to limit the temperatures and the humidity as these two quantities are strongly interdependent. Cooling the air will for example automatically lead to a higher relative humidity. To decide if measures are really mandatory the expected climate must be known and the effect of the selected measure must be quantified.

Since the climate in the tunnel depends on a great number of aero- and thermodynamic processes, prediction of the expected temperatures and humidity is only possible through numerical analysis using computer models specially developed for this purpose. But even with a modern model the forecast of the climate in a long railway tunnel remains a demanding task. There are many parameters which are only roughly known and the model itself is based on a number of assumptions and simplifications.

In the following some of the main physical processes which govern the climate in a tunnel and which are thus relevant for a computer model, are described and one of the processes - the heat transport of the trains - is selected to illustrate the difficulties associated with an accurate prediction of the climate.

Some results of the simulations for the Koralm Tunnel are then shown and the influence of the tunnel lining on the climate is discussed.

Koralm Tunnel

Austria's government defined, in conformity with European intentions, five main railway axes to be improved. One of the key railway connecting lines is the so-called Pontebbana corridor. It represents the easternmost crossing of the Alps and links several Central-eastern European countries, Vienna, southern Austria and northern Italy (see Figure 1).

In order to improve this interconnection, efforts were focused on several stretches along the line. One of these projects is the Koralm railway in the south of Austria. This new stretch will have a total length of approximately 130 km, and will connect the provincial capitals of Graz and Klagenfurt.

The Koralm railway route planning is characterised by large radii and minimum gradients which makes it possible to run both fast passenger trains and heavy freight trains.

The design speed amounts to $V_{max} = 250$ km/h, the maximum gradient is restricted to 10 ‰.

The most prominent tunnel along this stretch will be the Koralm Tunnel. It will underpass the Koralpe, a mountain range between the provinces of Carinthia and Styria. The maximum overburden will reach almost 1'200 m. This double tube tunnel will have a length of approximately 32.8 km. The separated tubes are connected by cross passages approximately every 500 m.

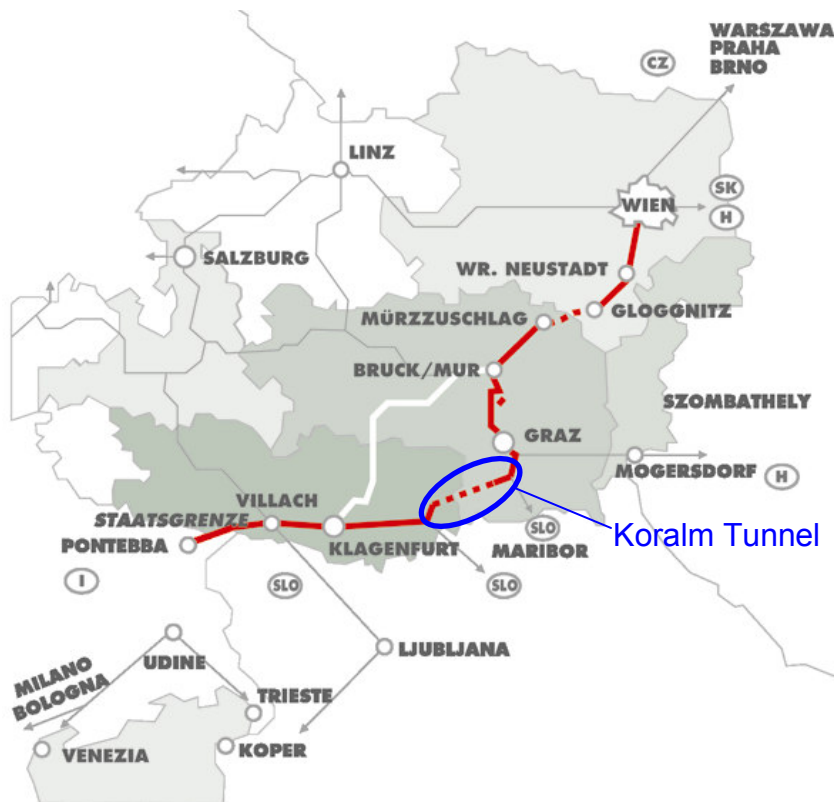


Figure 1: The Pontebbana corridor

Modelling of the tunnel climate

For the climate simulations the one-dimensional simulation program IDA Tunnel [1] was used and adapted for the special conditions of a long railway tunnel.

The program is able to calculate both long-term trends (e.g. temperature development in the rock over a period of 30 years) and short-term variations (e.g. temperature fluctuations due to a single train passage or daily changes of meteorological conditions).

Some of the most important physical processes which determine the tunnel climate and which are modelled with IDA Tunnel are briefly described below (cf. [3], [4], [5]):

- *Air renewal:* Due to the piston effect, trains running through the tunnel induce an air flow in the direction of the trains with air speeds up to 7 m/s. Fresh air is brought into the tunnel and the air inside the tunnel is transported from one portal to the other. The rate of the air renewal depends mainly on the density of the traffic, the train speed and on the tunnel cross-section and tunnel length.
- *Cooling / heating of the surrounding rock:* The temperature of the rocks surrounding the tunnel increases with the height of the rock overburden. In deep tunnels the initial rock temperature can be very high. Temperatures up to 50°C are possible. In such an extreme case the rock acts as a heat source. Especially during the construction phase (and also the first years of operation) high amounts of heat flow from the rock to the cooler air in the tunnel. As this energy is removed by the air through flow,

the rock in the vicinity of the tunnels is gradually cooled. These temperature changes in the surrounding rock must therefore be incorporated in the model. In the case of the Koralm Tunnel only moderate initial rock temperatures around 30 °C are expected (cf. Figure 2).

- *Phase change of water:* The water seeping through the tunnel lining evaporates on the tunnel surface. The heat of evaporation which is extracted from the air, leads to a reduction of tunnel temperature and at the same time to an increase of the relative humidity in the tunnel. Evaporation can also take place with water that is transferred into the tunnel by trains on rainy days or during the cold winter season (snow, ice). On the other hand condensation can occur, when the temperature of the tunnel air decreases below the dew point.
- *Heat transport of trains:* During its journey through a tunnel a train deposits heat due to friction (rolling resistance, aerodynamic resistance) and to the locomotive efficiency. On the other hand especially in winter time the train body warms up due to the higher tunnel temperatures. Due to the large mass of the train, even small temperature changes lead to significant amounts of energy being transported out of the tunnel.

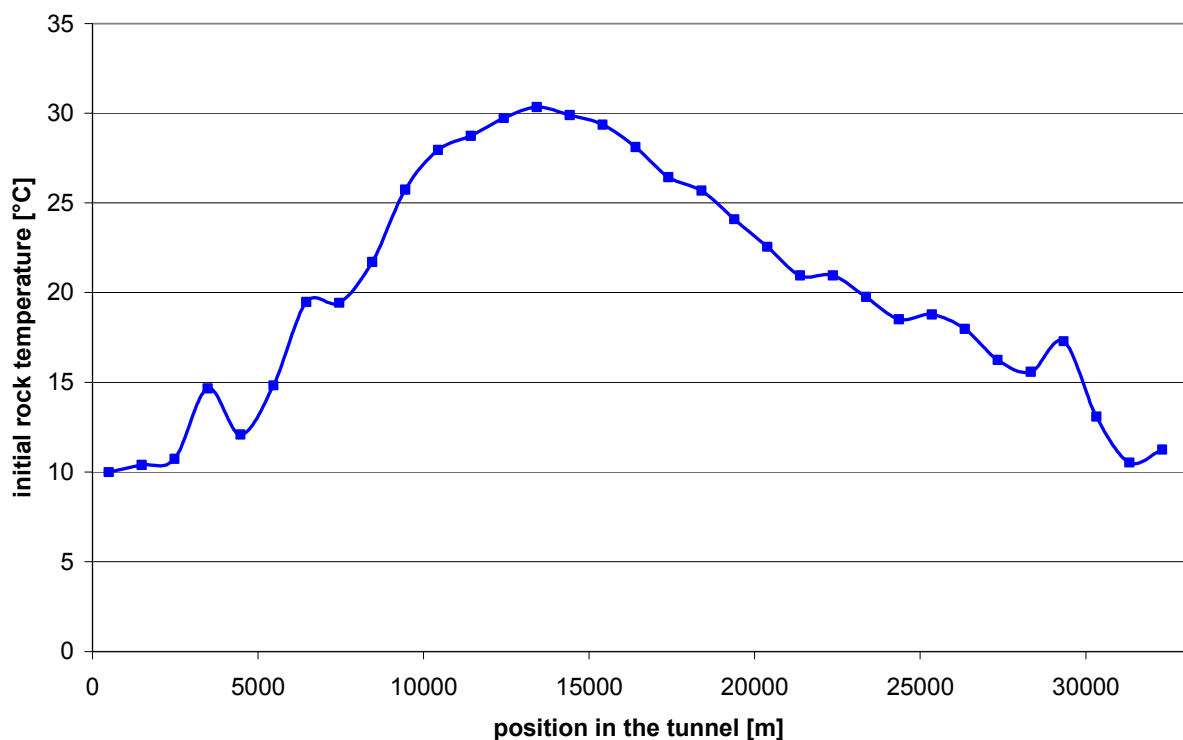


Figure 2: Initial rock temperature of the Koralm Tunnel

There are a large number of additional processes, which influence the climate, such as the waste heat from technical equipment in the tunnel (lighting, signals, electronic equipment, etc.), the meteorological conditions at the portals and the amount of water brought in the tunnel by the trains (rain, ice).

Most of the input parameters needed for the modelling are difficult to fix and only very few of them are known precisely. To determine the influence of the traffic on the air flow and the heat transport of the trains

for example, a large number of parameters are needed which describe the traffic scenarios (number of trains per days, headways, velocities, train parameters such as front areas, lengths, skin friction coefficients, mass, etc).

The consequence is that the accuracy of the prediction is limited not only by the limitations of the model itself but also by the possible variation of the input parameters. To highlight these limitations the process of the heat transport of the trains is described in more detail in the following.

Example: Heat transport of the trains

The heat transfer Q [W] from a train to the tunnel air can be described by the following equations (cf. [5]):

$$Q = \alpha \cdot A_{th} \cdot (T_{air} - T_{train}) \text{ and } \frac{dT_{train}}{dt} = \frac{1}{m_{th} \cdot C_{spec}} \cdot Q$$

with

T_{train} [K]:	temperature of the train,
T_{air} [K]:	temperature of the tunnel air,
C_{spec} [J/(kg*K)]:	specific heat capacity,
α [W/(m ² *K)]:	heat transfer coefficient,
m_{th} [kg]:	thermal active mass of the train,
A_{th} [m ²]:	thermal active surface of the train.

The difficulty in modelling the heat transfer lies in the uncertainty of the relevant parameters of the formulas above, which are:

- **Thermally active mass:** A train consists of different materials with different thermal behaviour and different exposure to the tunnel climate. The goods transported in a closed freight wagon for example will only marginally heat up. The thermally active mass - defined as that part of the train mass that takes actively part in the heat exchange - is thus only a small percentage of the total mass in this case.
- **Thermally active surface:** The surface of a train which is in contact with the ambient air is generally called the thermally active surface. The heat flow between tunnel and train is proportional to this surface multiplied by the heat transfer coefficient. Both factors are largely unknown. Due to the different surface roughness and the different air velocities and flow regime close to the wagon surface the heat transfer coefficient is expected to vary in a wide range. The active surface for example of the bogies or of other complicate segments of the cargo can only be estimated. Normally the thermally active surface is much larger than the train surface.

Expected climate in the Koralm Tunnel

The expected temperature profile in one tube of the Koralm Tunnel is shown in Figure 3. These calculations are based on a set of parameters which is believed to closest represent the actual conditions.

The temperature rises steadily from the entry portal (0 km) to the exit portal (32.8 km) where it reaches the maximum of about 20°C. At the entry portal the tunnel temperature is determined by the ambient temperature. This form of the temperature profile is determined by the steady airflow from the entry portal to the exit portal which is induced by the trains running through the tunnel. The waste heat from the trains and the equipment in the tunnel and in some extent also the heat flowing from the surrounding rocks to the tunnel lead to the continuous increase in the temperatures which is observed.

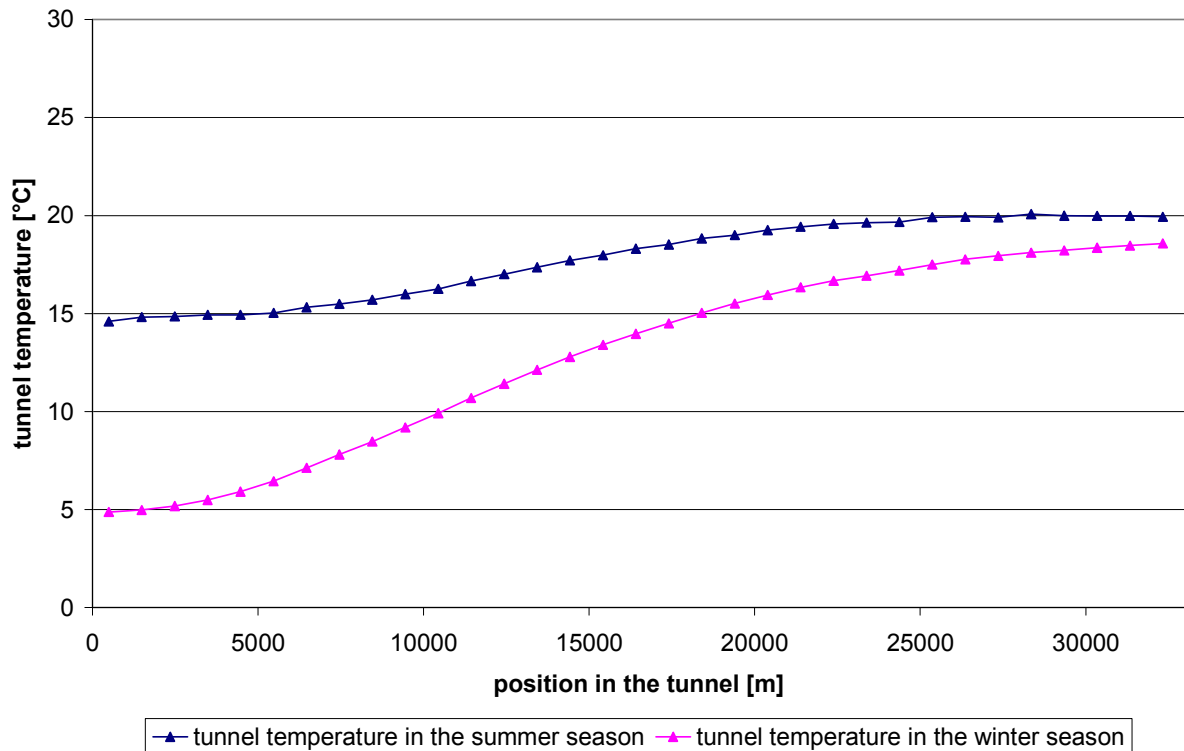


Figure 3: Expected temperatures in the Koralm Tunnel for the standard parameters in winter and summer.

The results for the expected relative humidity along the tunnel are shown in Figure 4. In the winter case the relative humidity decreases in the direction of the train traffic. Due to the increase in temperature the air can take on more water than what seeps through the rock. In the summer case the relative humidity remains approximately constant. The evaporation of water seepage is compensated by the reduced relative humidity due to the increase in temperature.

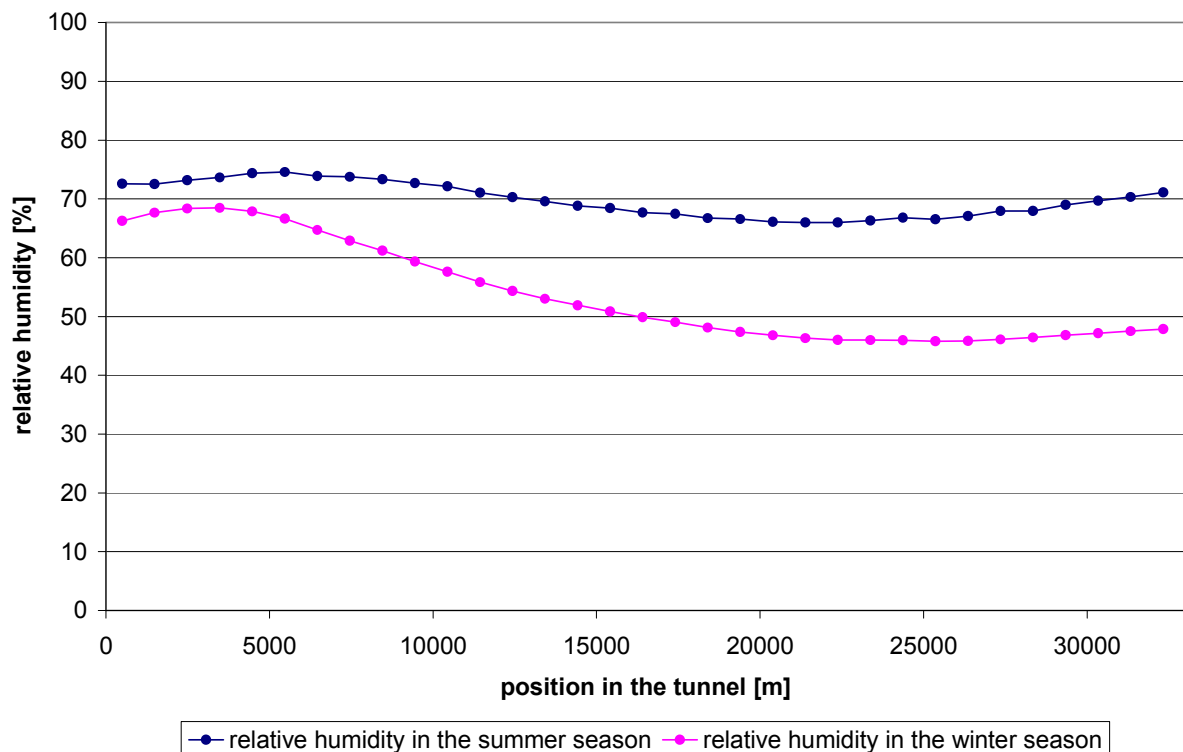


Figure 4: Expected relative humidity in the Koralm Tunnel for the standard parameters in winter and summer

Parameter studies have been made to evaluate the variation of the temperature and the humidity with other than the standard input parameters. The tunnel temperature is relatively insensitive to parameter variations. The humidity is more critical as can be seen in the following.

Water seepage

One of the determining factors for the climate in a long railway tunnel is the amount of water which is evaporated inside the tunnel. Already small quantities of water seeping through the tunnel lining may have severe consequences on the climate of the tunnel. The heat of evaporation extracted from the air leads to lower tunnel temperatures (evaporative cooling) and the absolute humidity is increasing.

Figure 5 shows the effect of water seepage on the temperature profile of the summer. The temperature at the exit portal gradually falls from a maximum value of about 23°C when no water seepage at all is assumed, to about 17°C with a water seepage of 70 g/(km s).

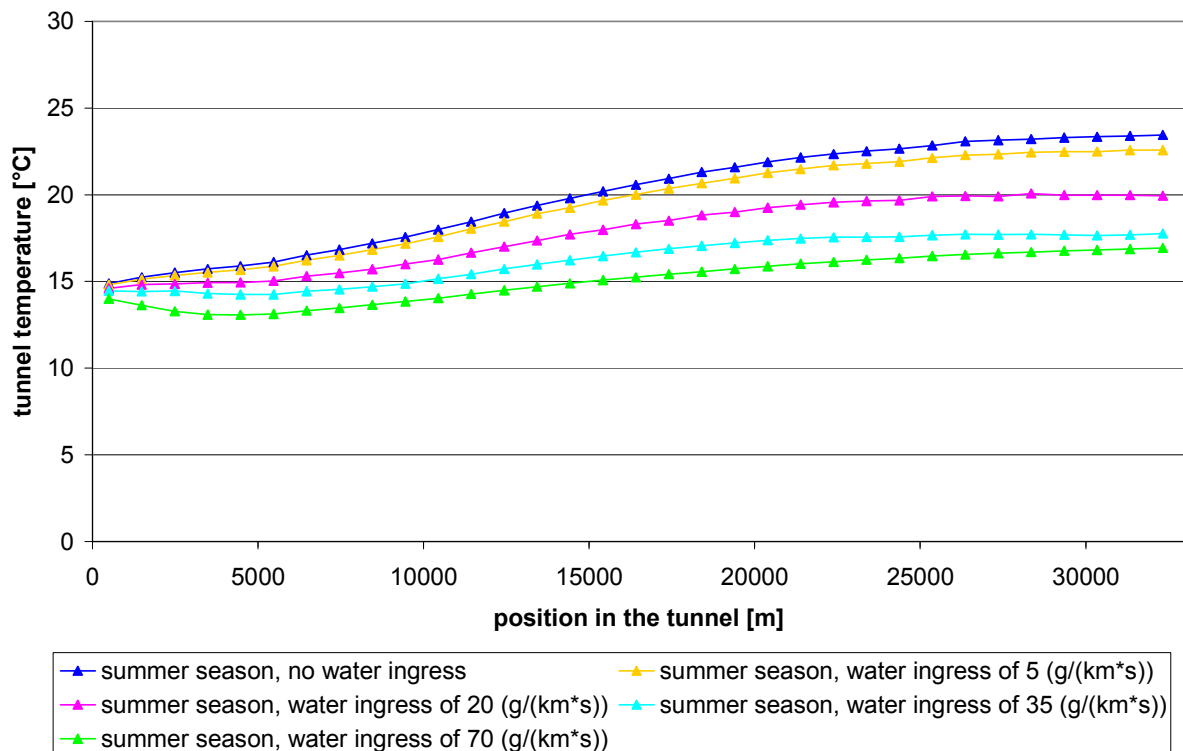


Figure 5: Tunnel temperature profile for different amounts of water seeping through the tunnel lining (summer case)

The influence on the humidity is even more dramatic as can be seen in Figure 6. With no water seeping through the lining a dry tunnel climate is expected, with a relative humidity as low as 40% at the exit portal. In the winter season even lower values (around 20%) for the relative humidity are possible. On the other hand a very high relative humidity, near saturation, must be expected over a big part of the tunnel when water seepage is not controlled ($\geq 70 \text{ g/(s km)}$).

It should be noted that even in an apparently widely dry tunnel a water seepage of about 20 to 30 g/(s km) must realistically be expected.

To minimize the risk of very humid tunnel conditions the Koralm Tunnel will be sealed (cf. [2]). This will lead to slightly higher temperatures. As the expected temperature level is relatively low in the case of the Koralm Tunnel an increase can be accepted as long as the temperature remains below 28°C.

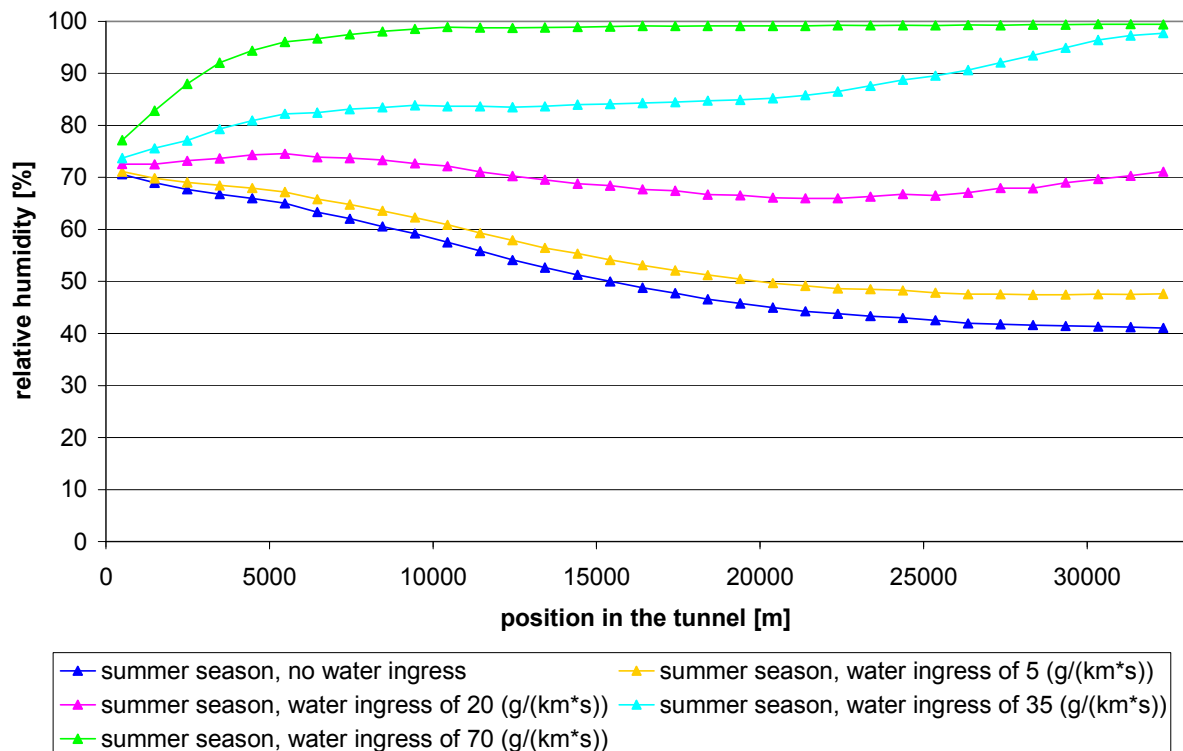


Figure 6: Humidity profile for different amounts of water seeping through the tunnel lining (summer case)

Conclusions

From the studies and simulations of the climate the following general conclusions can be drawn:

- The climate is one of the critical factors in the design of long railway tunnels. Especially the relative humidity may reach unacceptably high values if no countermeasures are taken. In very deep tunnels with a dense traffic and a good sealing also the temperature may rise above the tolerable level.
- A forecast of the climate in long tunnels is a complex task which demands a high level of experience and can only successfully be achieved with a suitable computer model.
- Even small quantities of water evaporating inside a long tunnel may lead to a very high relative humidity. Long tunnels need thus to be sealed to avoid water seeping through the lining (invert, crown). Even in a visibly dry tunnel the water seepage by diffusion and through small cracks can be high enough to cause unacceptably high humidity.
- A sealing of the tunnel lining leads to higher tunnel temperatures as there is less water available for evaporative cooling. A good sealing may thus cause unwanted high temperatures in extreme cases and necessitate special measures for cooling. Computer simulations to estimate the tunnel climate should therefore be used in long tunnels to optimise the quality of the sealing and the tunnel sections where eventually a reduced sealing of the lining is possible.

- As the climate forecast is limited in accuracy, it is necessary to map out a strategy to define the degree of the sealing during the construction phase. Computer simulations of the tunnel climate can be of a great help to define such a strategy and to support the decision process during the construction phase.

For the Koralm Tunnel the following specific conclusions can be drawn:

- The climate of the Koralm Tunnel is expected to remain within acceptable limits for temperature and relative humidity. The planned sealing guarantees that even during the critical summer months the mean relative humidity will be around 70%. The temperature is less critical. Maximum values around 20°C are expected. Even with a perfect sealing of the tunnel the temperatures in the Koralm Tunnel will be lower than 28°C.
- A strategy to define the quality of the sealing based on the better knowledge of the characteristics of the rock and the aquiferous strata accompanied by computer simulations of the climate during the construction process can contribute to an optimisation of the sealing and save construction costs.

References

- [1] IDA Tunnel, EQUA Simulation AB, Stockholm, Sweden, www.equa.se
- [2] Considerations for Development of the Typical Cross Section for the Koralm Tunnel, G. Harer, K. Mussger, B. Hochgatterer, R. Bopp, Geomechanics and Tunneling, Volume1 Issue 4, August 2008
- [3] Thermodynamische Untersuchungen über Tunnelanlagen, E. Singer, Dissertation Universität Graz, 1990
- [4] Verdunstungsvorgänge - Theorie und technische Anwendung, R. Hiecke, M. Schubert, VEB Deutscher Verlag für Grundstoffindustrie, Leipzig, 1976
- [5] Tunnel climate simulation for railway tunnels, R. Bopp, J. Burri, BHR Group, Vehicle Tunnels, 1997