Improve Train Tunnels. A dynamical ventilation model.

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SYNOPSIS

Train tunnels and subways are an interesting field of ventilation.
Trains move air through tunnels at rates of 600 m^3/s (over 2 x 10^6 m3 per hour) which is much more than flow rates in buildings.
Air pressures can vary up to some 3000 Pa leading to air velocities in the range of 10 to 50 m/s. This can lead to unsafe situations and thermal discomfort.
The development of high speed trains causes more concern for better tunnel design.
Modern stations often house small shops and restaurants, that require lower air velocities for thermal comfort.
A dynamical ventilation model has been made to study effects of improvements.
An array of controlled fans seems to be a very effective draught remover.

The dynamical model is programmed to serve as a demo to give insight in the matter and can be shown in just a couple of minutes from a PC. A copy can be requested via e-mail to J.Phaff@bouw.tno.nl Subject: Train Demo. This demo version is just intended for demonstration purposes and must not to be used for the design of real tunnels.

1. INTRODUCTION

Train tunnels have always been the subject of calculations and optimizations. From the viewpoint of ventilation modelling, train tunnels are very interesting. Optimization of a train tunnel through a mountain is the tantalizing task for the engineer. A long tunnel low in the mountain, or first a long climb and shorter higher positioned tunnel. Long tunnels have a higher resistance, are longer and cost much more energy to drive through. The shorter high tunnel costs more energy to drive up the mountain. A wide tunnel will have less friction losses because much air can move around the train, but wider tunnels are more expensive to build.
High velocity trains in tunnels need an enormous extra amount of power to overcome the extra air resistance in a tunnel.
Unfortunately in Holland the mountain aspect is hard to find. Except for the South East appendix of the country, ground level is rarely elevated to more than a few times ten meter above sea level due to deposits in the ice ages. About half of the country is at or a few meters below the average sea level and as flat as a carefully baked pancake. Water levels are kept a few decimeter below the ground level by many ditches and a grid of canals that lead to locks that sluice the water out at low tide. This all is to prevent Holland to get back to it's medieval marsh land. In deeper polders electrical pumps remove the excess water.
In this muddy land there is also a need for tunnels and subways. One has measured that these tunnels move up and down a bit with the tide.

The subject we are looking at here is comfort in a train tunnel with a large station hall built at ground level over the subway platforms. As the tunnel is not far below ground level there are many ventilation openings to bypass the train's pressure wave. From the ventilation point of view these are very moderate tunnels. In the station hall are shops and restaurants. People sit there and expect a comfortable indoor climate. This is in contrast to stations a few years ago where every body stood, ran and waited, well dressed for weather, for their train. In winter the tunnel is below 10 °C and air comes at a moderate maximum of 5 m/s over the stair cases and person walkalators into the station hall, over the restaurant guests.

This is far from comfortable. A single entering train generates a few meter per second in the stair cases that lasts for a couple of minutes. Long enough to move out there from your restaurant seat, or start serious complaints. Even without Fanger in hand, every body will admit that this will not work long.

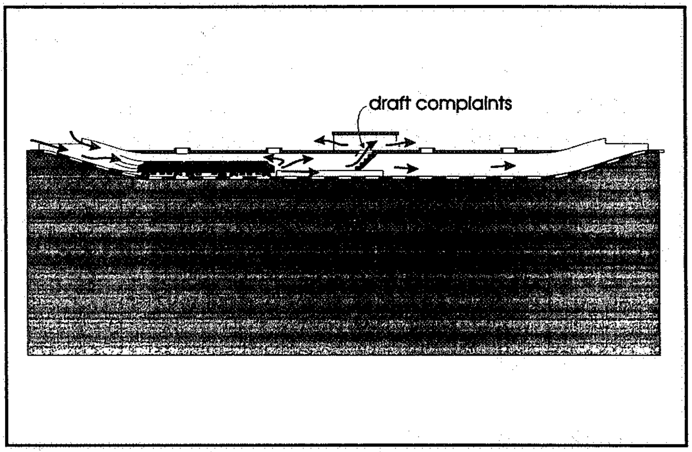

Figure 1 Tunnel with draft complaints

TNO has had a long time experience with train tunnels and models that predict the effect of design changes on energy, pressures and air velocities and start conditions for smoke movement in case of an emergency. This work has been done by dr. ir. H.B. Bouwman and was not published. This knowledge has been picked up again and converted in a set of PC programs.

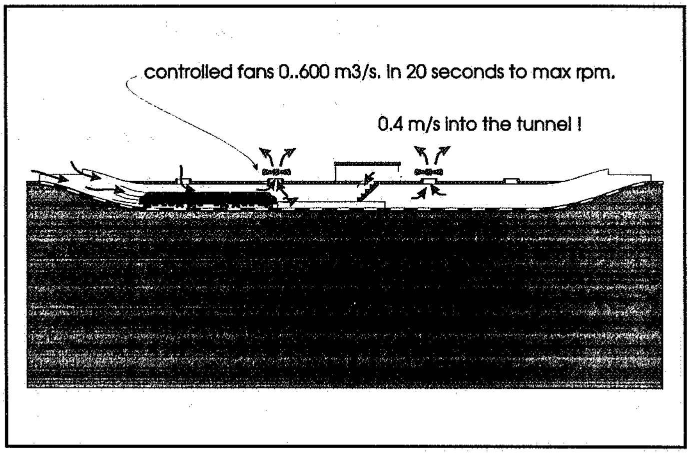

Figure 2 Tunnel with fans.

2. METHOD

The model is basically a dynamical bernoulli equation and the normal technical transport equations through ducts with side branches and air flow around bodies, mainly by a correct use of hydraulical diameters. The tunnel is subdivided in sections. Every section may have a ventilation duct to the outside. The train is modelled with its friction loss at the front, side and rear. A special concern is the air velocity along the train. The network of tunnel segments and side branches is numerically solved but the pressure losses per section are mostly analytical solutions. A very complex task for the program is

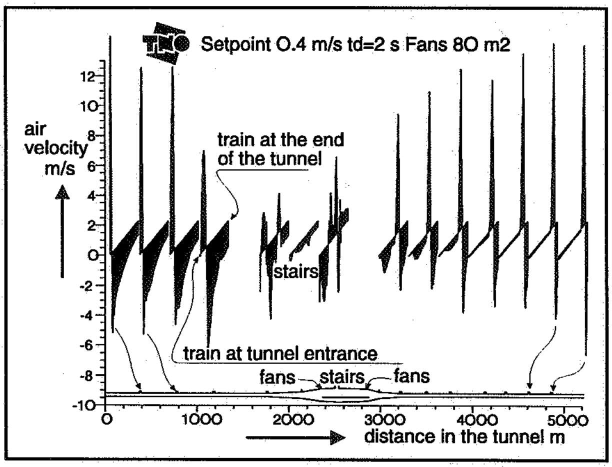

Figure 3 Simulated air velocities in the ventilation openings.

the administration of the movement of the train and subsequently the changing lengths occupied by the train while passing the sections and the many ventilation openings.
The model allows for any train, any shape of tunnel and ventilation openings. The train can be operated with a given speed profile in time or given brake characteristics and acceleration power.
The tunnel can also be operated with wind pressures at the openings, or a train can start just after or during the passage of another train.

3. DEMO

The DEMO is a full version of the actual program. It's input is limited to only a few variations and changes of parameters. The dimensions of train, tunnel and ventilation openings are fixed. What can be changed is:

1. a multiplication factor for the velocity profile of the train
2. the train can stop or drive through at constant speed
3. you can select 3 runs:
   - run 1 original situation
   - run 2 extra ventilation openings before and after the platforms
   - run 3 the TNO solution. Mount 20 to 40 axial low pressure fans of some 1.5 to 2 m diameter max 10 m/s air velocity in the fans or 20 m/s at smaller fans.

At the end of one run you must ESC the program and run again for a next setup.
The program explains which keys are active, but any key will move you to the next graph. Pressing ESC will give you the possibility to quit the program, even in the middle of a graph.
At the end of each run a small text file is created with some explanation. All graphs are written to HPGL files on disc. The program will thus run faster on hard disk in a separate directory.

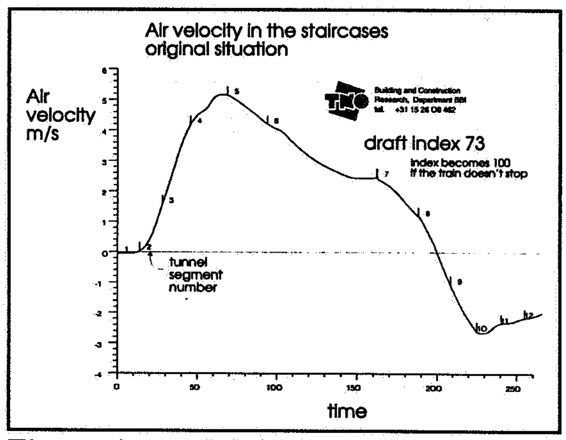

Figure 4 Original situation at the stairs. Run 1.

Run 2 gives a reduction of the draft, but does not eliminate it at high costs of the large ventilation shafts. Run 3 can fully eliminate any draft. It can even make sure there is a small air velocity from the station into the tunnel. Fans can be payed from saved costs for the smaller shafts.
The operation costs are despite the large flowrates, very low as the pressure differences across the fans is very low.

As the fouling with railway dust can be absolutely prevented with the fans, this saves much more than the electricity costs to run the fans.
The controller for the fans is very simple and stable. Time from low to full fan speed is

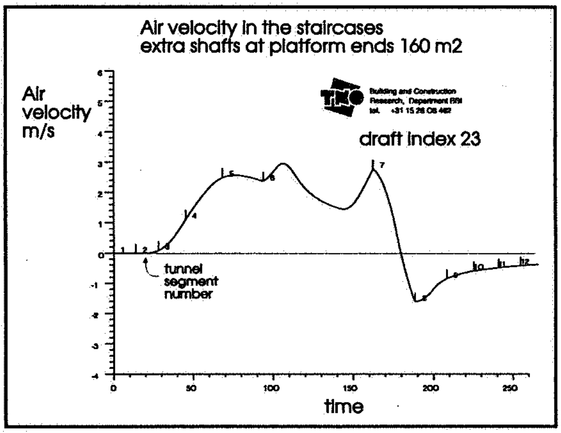

Figure 5 Extra shafts. Still draft complaints.

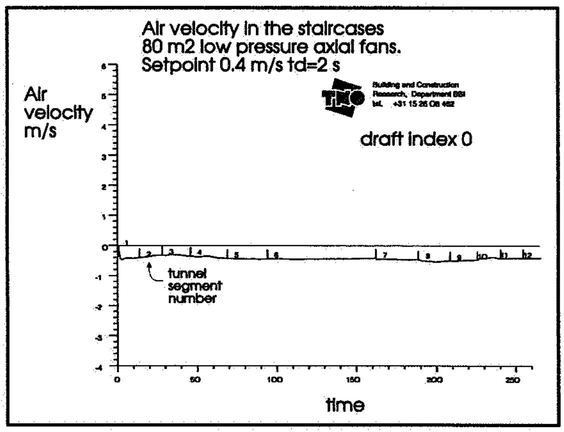

Figure 6 TNO solution, controlled fans. No draft.

some 30 seconds and for these fan sizes this is not any problem. There is no need for adjustable pitch of the blades of the fans.

Besides these luxury things like draft complaints the model also calculates the extra energy for the train to drive through the tunnel and the air pressures and pressure changes in the tunnel and around the train.

4. CONCLUSION

This tunnel program can give an insight in air velocities in tunnels and the influence of variations in the design. It is intended to find the optimum ventilation and airflow control in tunnels. With the aid of the program solutions can be tested and ideas for new approaches will be found.