

## Increasing the train speed on the new "Westbahn" Line - aerodynamic loads in tunnels

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### SUMMARY

The "Westbahn" Line from Vienna to Salzburg has been designed for a train speed of 200 km/h including a 25% margin. In 2004 extended field measurements with train speeds up to 300 km/h were performed to assess if an increase of the maximum train speed to 250 m/h is possible.

In the 1845 m long Tunnel Melk with a cross section of 78 m<sup>2</sup> a freight train was exposed to more than 100 passages of an ICE train at high speeds. The pressure drop at the passage of train head was measured and compared with data from earlier measurements. Additionally the freight train was monitored (movement of sliding doors, carry off of wood chips from an open wagon, damages).

The paper presents the measurements as well as the main conclusions.

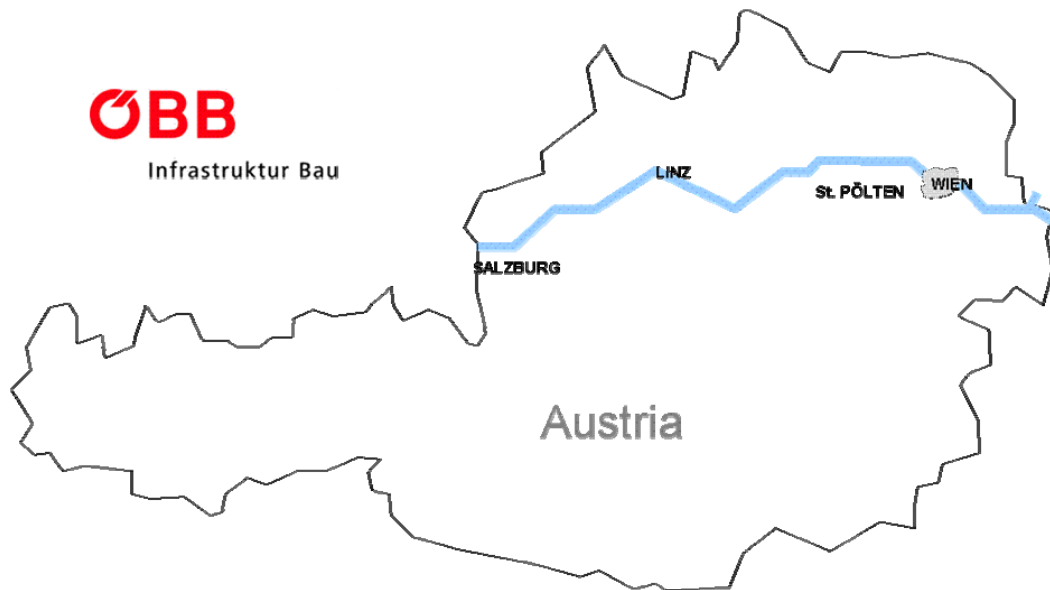
### 1 INTRODUCTION

#### 1.1 The new "Westbahn" Line

Austria's "Westbahn" Line, linking Western Europe with regions in the east and southeast, is a key component in the continental transport network. The EU has classified it as a route of major importance to European interests and therefore a development priority.

Built for the most part in the 19<sup>th</sup> century, the railway line between Vienna and Salzburg has reached the limits of its capacity in some sections today. The east-west axis, which is among the most heavily frequented routes in Austria, is simply not equipped to meet the demands of the 21<sup>st</sup> century. Upgrading it from a two to a four-track high-capacity line for running speeds of up to 200 km/h is one of the country's top transport policy goals.

Efforts have been underway for several years now to convert the entire "Westbahn" Line into a high-capacity route by improving sections and laying new ones.



**Figure 1:** The "Westbahn"-Line

## 1.2 Train speeds up to 250 km/h?

At the beginning of the 21<sup>st</sup> century the maximum train speed in Austria during normal operation was 160 km/h. With the gradual opening of new sections of "Westbahn" Line the call for train speeds above 160 km/h became more pronounced.

Between September 2001 and August 2002 in the section "Prinzersdorf - Ybbs on the Donau river" of the "Westbahn" Line a series of test runs with conventional locomotive hauled trains with train speeds up to 250 km/h were carried out. These first test runs have shown that the infrastructure is adequate for accommodating increases in train speeds from 160 km/h to 200 km/h.

For higher train speeds modern high speed trains are employed. Therefore in August 2004 an extensive measuring campaign with an ICE train was carried out to assess the performance of the infrastructure (built according to the Austrian Guidelines for high speed lines, [1]) with this train category and train speeds up to 250 km/h.

The following measurements were carried out:

- TSI-type testing of the catenary with a validated measuring system,
- measurements at the track bed and at selected switches,
- noise generated by the train body and the pantograph,
- dynamic vibrations of bridges,
- vibrations of railroad,
- aerodynamic measurements.

The aim of the measurements was to assess if the infrastructure is suited to train speeds of 250 km/h respectively to identify the additional measures which would be necessary to reach this goal.

The measurements were accompanied by computer simulations of the pressure fluctuations to assess the aural comfort level inside the trains and to confirm that the maximum pressure difference during a train passage is lower than the 10 kPa health criterion [2].

The purpose of this paper is to present the results of the aerodynamic measurements in tunnels.

## 2 AERODYNAMIC MEASUREMENTS 2004

### 2.1 Aims

The aerodynamic measurements of August 2004 had the following aims:

- Crossing of high speed trains and freight trains in a tunnel:  
The aerodynamic forces induced on a freight train by a crossing high speed train in a typical tunnel of the "Westbahn" Line should be assessed and compared with the forces in existing older tunnels with significantly smaller cross sections. Additionally it should be determined if these forces lead to damages to a typical freight train and its cargo.
- Aerodynamic loads on people standing on an open train station platform:  
The aerodynamic forces on people standing on an open platform induced by a passing high speed train should be assessed and compared with the present forces from aerodynamically poor freight trains.

This paper contains the findings from the tunnel measurements. The measurements on the open platform will be published in a separate paper.

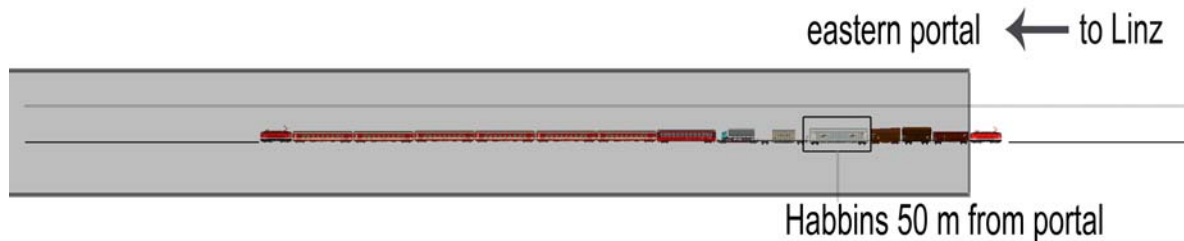
### 2.2 Measurements in the Tunnel Melk

The aerodynamic forces on a freight train during a crossing event (trains passing in opposite directions) were measured in the Tunnel Melk. This tunnel has a cross sectional area of 78 m<sup>2</sup>, which is typical for the "Westbahn" Line and a length of 1845 m. The distance between the track centrelines is 4.70 m.

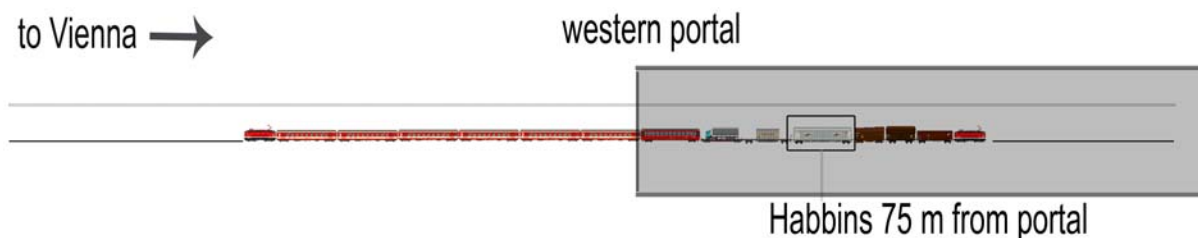
Two crossing situations were tested:

- Freight train at rest:  
The freight train was positioned close to the tunnel entrance. An ICE train was passing the freight train. The train speed of the ICE was stepwise increased from 200 km/h up to 300 km/h during the test runs. Two configurations were tested:
  - Configuration A: Freight train standing at eastern portal (see figure 2).
  - Configuration B: Freight train standing at western portal (see figure 3).

- Running freight train:  
The freight train running at 100 km/h passed by the ICE train travelling at 250 km/h through the tunnel.



**Figure 2:** Configuration A: Freight train standing at the eastern portal of the Tunnel Melk



**Figure 3:** Configuration B: Freight train standing at the western portal of the Tunnel Melk (the Habbins wagon is a freight train wagon with big sliding doors)

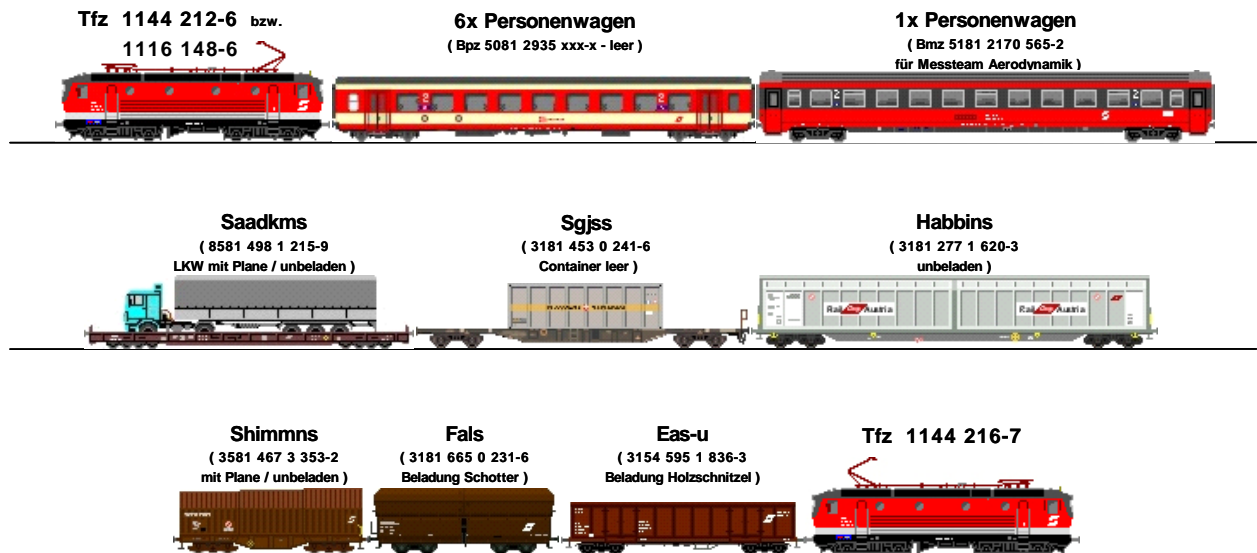
### 2.3 Trains

An ICE-S train (special ICE test train for homologation testing and inspection runs in the DB network, owned by DB Systemtechnik) was used for the measurements. The ICE-S train running at speeds up to 300 km/h served as the generator of the aerodynamic forces. The following two train configurations were used:

- ICE short: Standard configuration of the ICE-S with two power cars and one monitoring coach (total length 67.5 m)
- ICE long: ICE-S with two power cars, the monitoring coach and six additional coaches (total length 225.7 m)

To monitor the effects of the aerodynamic forces a freight train with different wagons was used (see figure 4). On one of the wagons (Saadkms) was loaded with a truck-trailer and the open "Eas-u" wagon was loaded with wood chips.

Ordinary wagons were used constructed without any particular attention to achieving air tightness. No attempt was made to make the wagons air tight for the measurements.



**Figure 4:** Freight train consisting of 2 locomotives, 7 passenger coaches and 6 freight wagons used in the measurements.

## 2.4 Number of test runs

In the following table, the number of standing and running passages during the measurements campaign in the Tunnel Melk is shown.

**Table 1:** Number of train crossings during the measurements in the Tunnel Melk

Pressure generator	$V_{ICE}$ [km/h]	$V_{freight\ train}$ [km/h]	number of crossings
ICE (short)	200 - 300	0	50
ICE (long)	200 - 280	0	39
ICE (long)	250	100	15

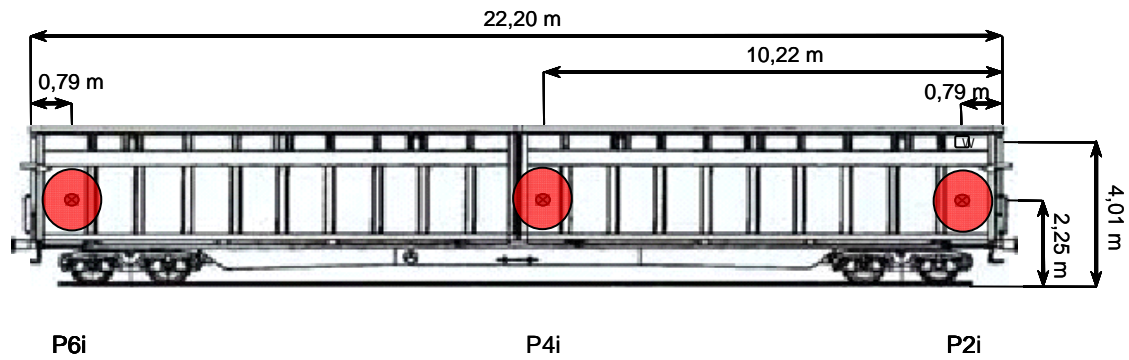
## 2.5 Measuring equipment on the freight train

The freight train was equipped with the following measuring equipment:

- Pressure: Pressure fluctuations during a train passage on the surface of and inside of the Habbins wagon (wagon with big sliding doors) and Shimmns wagon (wagons with a movable tarpaulin) as well as on/inside the container on the Sgjs wagon was measured at three points (front, middle and end of the wagon).
- Airflow: The airflow velocity around the open Fals wagon was measured with an ultrasonic anemometer mounted at a distance of 30 cm above the top of the wagon.
- Door movement: The movement of sliding doors of the Habbins wagon was measured using a laser displacement transducer.

Figure 5 shows the position of the measuring equipment of the Habbins wagon. The pressure fluctuations (outside and inside) were measured at three points (front, middle and end of the wagon). In a number of ICE crossings the movement of the doors was recorded on video.

The measurements were carried out by Deutsche Bahn AG, Technik/Beschaffung, DB Systemtechnik, TZF 13.1, Aerodynamic Measurements.



**Figure 5:** Sketch of the Habbins wagon with the positions of measuring equipment.



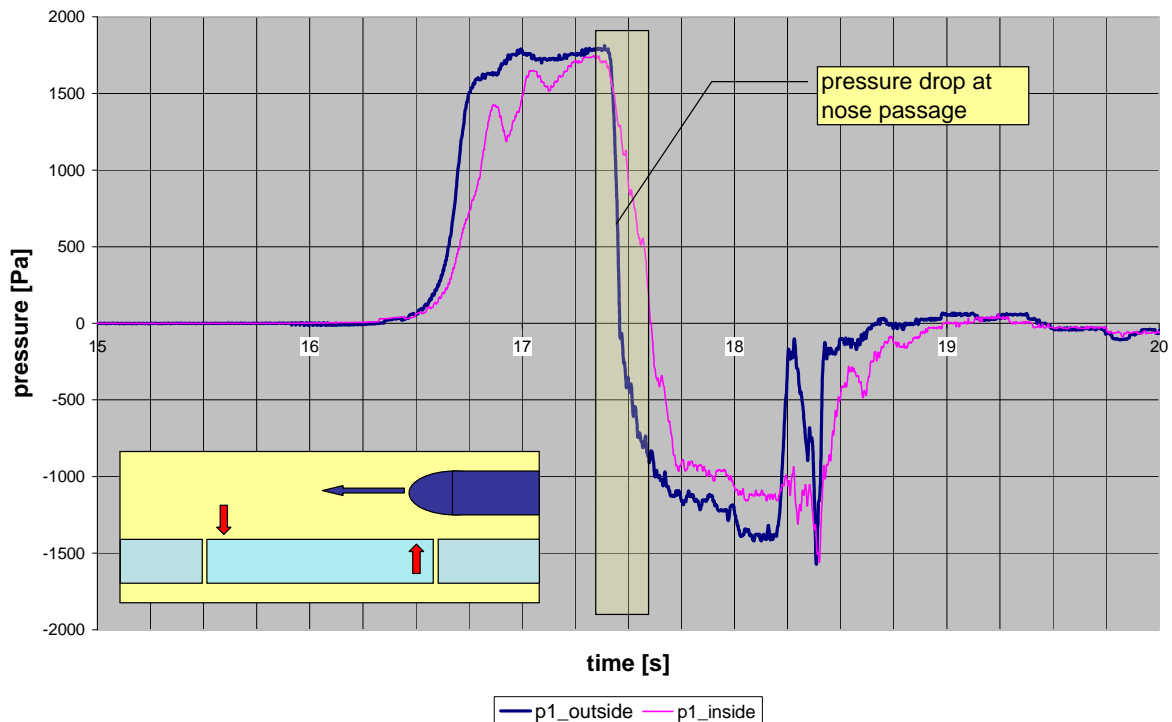
**Figure 6:** Habbins Wagon

### 3 PRESSURE DROP DUE TO NOSE PASSAGE

During the passage of the nose of the ICE train past the Habbins wagon, a pronounced pressure drop occurs. This leads (with some delay) to a similar pressure decrease inside the wagon (see figure 7). The consequence of the delay is a pressure difference resulting in a force pushing the door outwards at the front end of the freight wagon.

As the pressure drop propagates axially inside the wagon at the speed of sound, whereas the pressure drop at the outer surface moves along the freight train at the slower speed of the passing train only, at the rear end of the freight wagon a transverse force, acting in the opposite direction occurs (pushing the door inwards).

The pressure change which occurs during the passage of the rear of the ICE train (pressure recovery) is of a reduced magnitude and is thus not relevant for the determination of the maximum load.

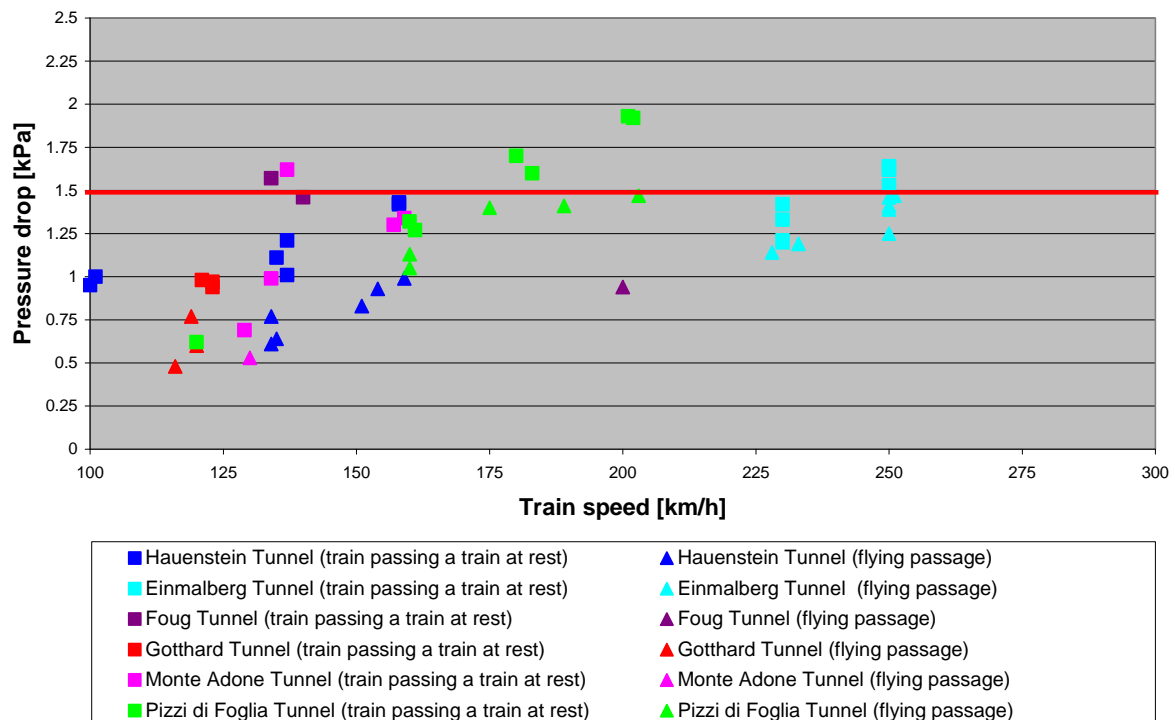


**Figure 7:** Measured pressure drop at the surface of the Habbins wagon (bold line) and inside the wagon (thin line) - measured at the first measuring point.

The pressure fluctuations inside the wagon and the resulting forces on the doors or windows are thus not only dependent on the quality of the air-tightness of the wagons but also on the wagon's length.

To compare the situation in the tunnels of the "Westbahn" Line with existing data from other tunnel tests, the pressure drop during the passage of the nose at the outer surface of the freight train is, therefore, used and not the forces acting on a particular freight wagon which is depending on the type and the construction (e.g. sealing) of the wagon.

For this pressure drop extensive data from measurements of the ERRI Working group C 206.2 [3, 4] exist. In figure 8 the maximum pressure drop measured in different tunnels of the European railway network is shown as a function of the speed of the passing train. The train speed in these older tunnels with - compared to modern tunnels - significantly smaller cross sections is relatively low. However due to the small cross sections significant pressure fluctuations during train crossings occur.



**Figure 8:** Maximum pressure drop measured in existing tunnels (from [3], [4])

A detailed analysis of the data shows that, in normal operation, pressure drops up to 1.5 kPa occur regularly in these tunnels. During the test runs, maximum pressure drops up to 2.0 kPa have been produced without any damage observed to the freight trains or the cargo.

Based on these findings, a value of 1.5 kPa is proposed as a limit for the pressure drop during the passage of the nose of the train. This limit seems to be withstood by normal freight trains independently of the air-tightness of the vehicles. If the 1.5 kPa value is not exceeded systematically in normal traffic conditions no problems should occur.

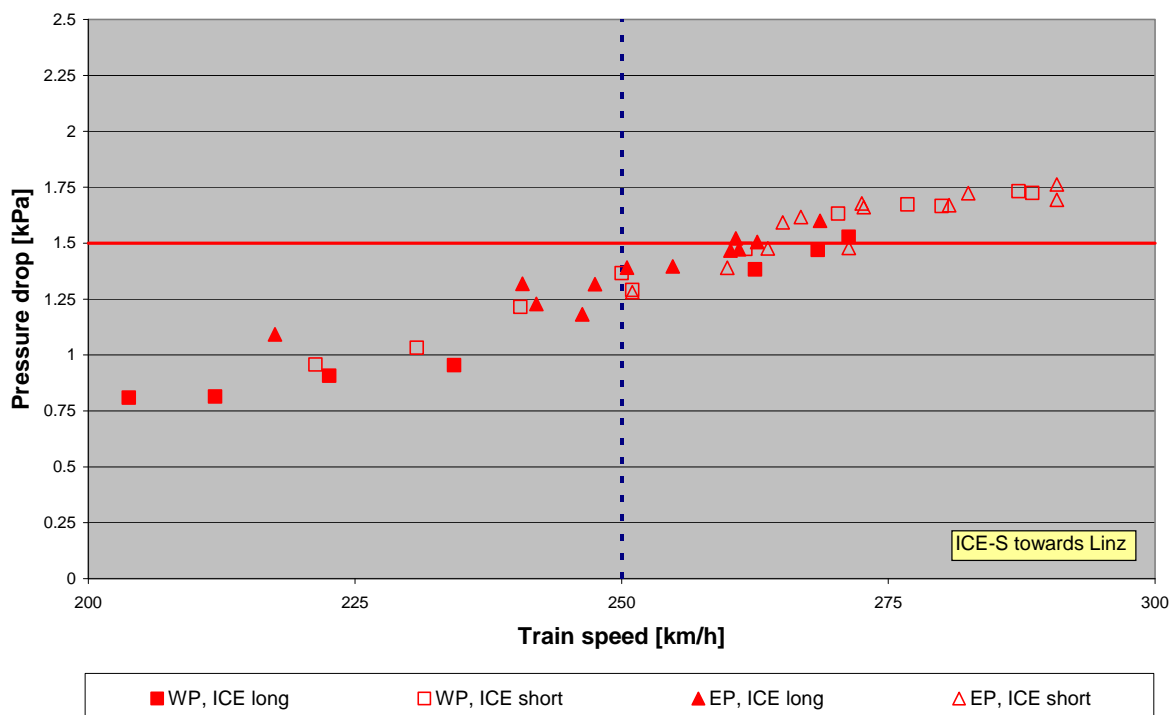
## 4 RESULTS FROM THE TUNNEL MELK

### 4.1 Pressure drop on the Habbins wagon

In figure 9 the pressure drop measured at the first measuring point of the Habbins wagon during the passage of the nose of the ICE train in the Tunnel Melk is shown as a function of the speed of the passing ICE-S train travelling towards Linz (freight train at rest).

It can be seen that the pressure drop increases gradually with the speed of the passing train. At 250 km/h the pressure drop is clearly below the 1.5 kPa limit. There is no significant difference between the data from the ICE long and the ICE short trains.

A small but systematic difference can be observed between the data obtained from the tests with the ICE long train. The pressure drop with the freight train standing at the eastern portal (EP) is slightly higher than the pressure drop at the western portal (WP). Compared to the passes at the eastern portal, where the tunnel air is at rest when the train is entering the tunnel, an airflow in the direction of the train has been induced at the western portal where the ICE is leaving the tunnel. The relative speed is thus lower in this situation leading to a reduced pressure drop.

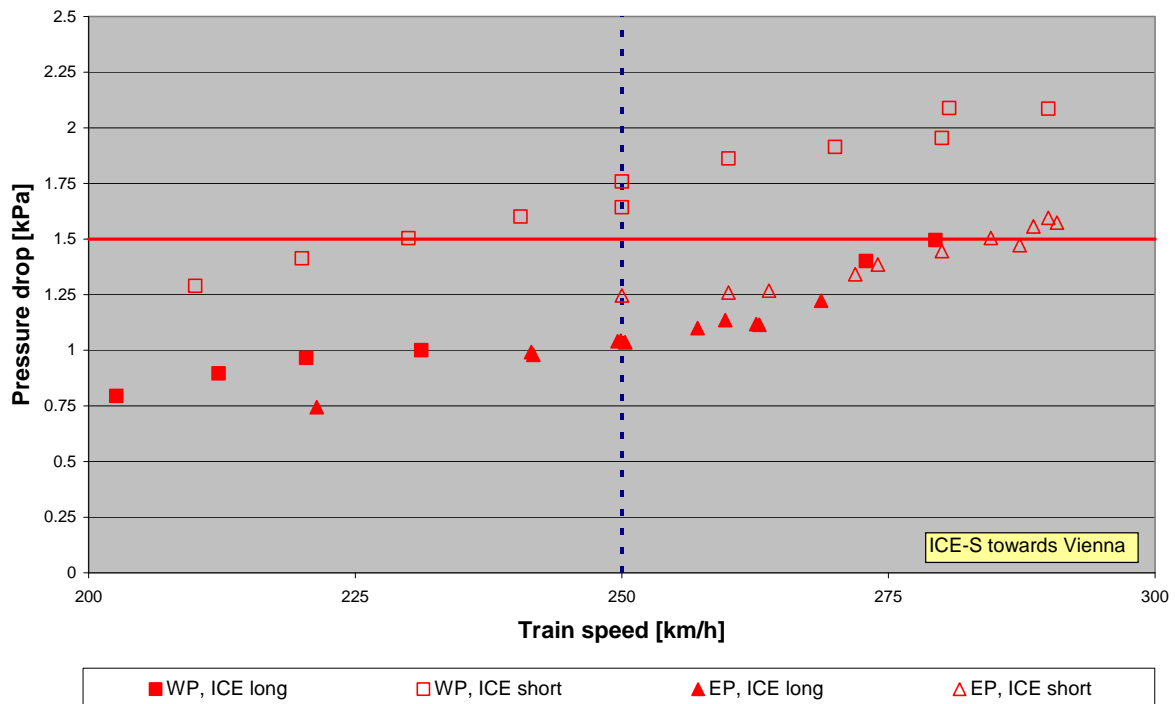


**Figure 9:** Pressure drop at the first measuring point of the Habbins wagon for different positions of the freight train (WP = western portal, EP = eastern portal).

It should be noticed that the measured maximum pressure drop is increasing approximately proportional to  $v_{tr}^2$  as expected, even though the data plotted in the speed range from 200 km/h to 300 km/h in figure 9 might indicate a linear increase.

In figure 10 the same data for the ICE train travelling towards Vienna is shown. It is striking that the pressure drop produced by the ICE short with a standing freight train at the western portal is significantly higher (up to 1.75 kPa at 250 km/h). A closer inspection of the data shows that in this case the pressure drop produced by the nose passage is superposed by the negative pressure wave generated when the rear of the ICE train enters the tunnel.

However this superposition occurs only stochastically when the trains pass each other at a distinct position inside the tunnel. The measured pressure drop at 250 km/h in the Tunnel Melk under normal circumstances is not higher than the limit of 1.5 kPa.

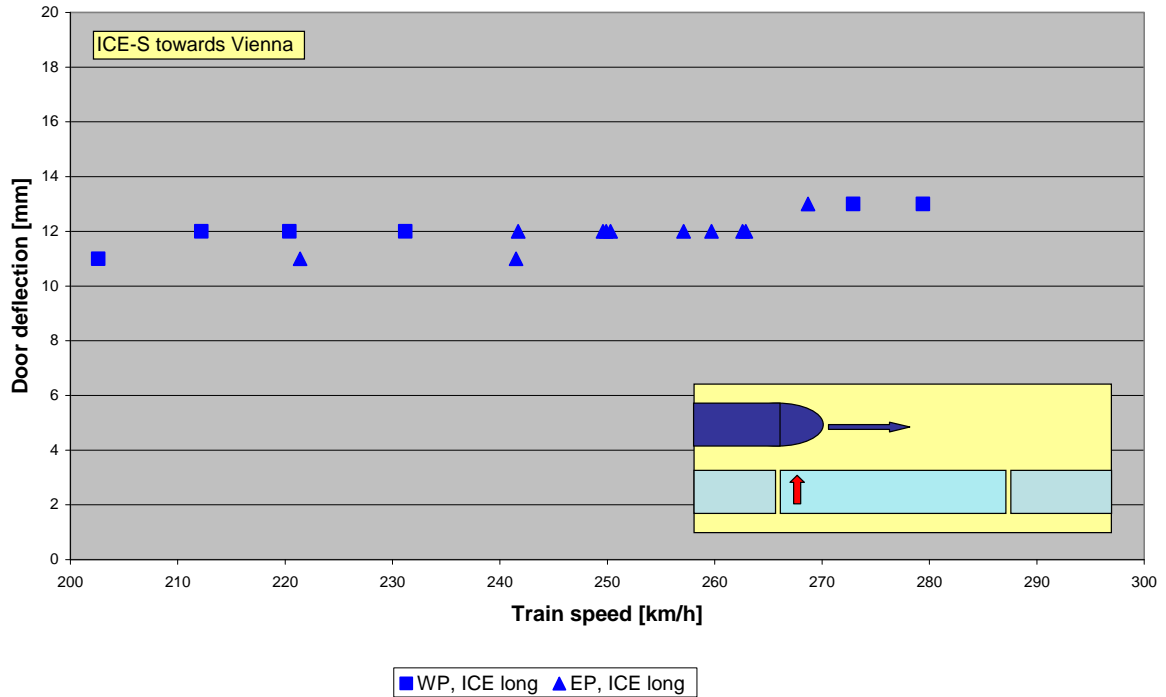


**Figure 10:** Pressure drop at the first measuring point of the Habbins wagon for different positions of the freight train (WP = western portal, EP = eastern portal).

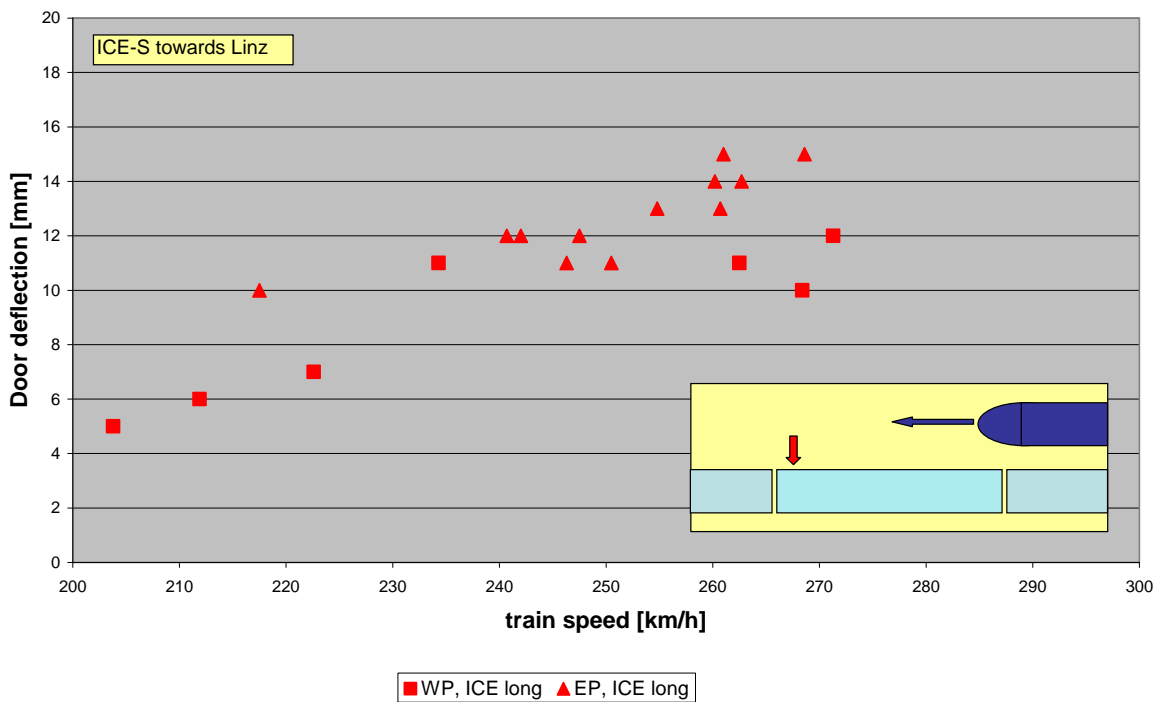
#### 4.2 Movement of sliding doors of Habbins wagon

In addition to the measurement of the pressure fluctuations, the deflection of the large sliding doors of the Habbins wagon was monitored. A maximum deflection of the door of 18 mm has been observed (movement of the door perpendicular to the tunnel axis).

It is striking that for the ICE train running towards Vienna there is almost no dependence of the measured deflection from the train speed (figure 11), whereas in the opposite direction a gradual increase can be observed (figure 12).



**Figure 11:** Door movement as a function of train speed for different positions of the freight train (WP = western portal, EP = eastern portal) with the passing ICE long travelling towards Vienna



**Figure 12:** Door movement as a function of train speed for different positions of the freight train (WP = western portal, EP = eastern portal) with the passing ICE long travelling towards Linz

In the case of figure 11, where the movement of the door is measured on that end of the Habbins wagon which is first passed by the ICE train, the outward movement of the door is due to the sudden pressure drop during the passing of the nose of the ICE train. The movement of the door, in this case, begins from the normal position of the door.

In the second case (figure 12), where the deflection is measured at the end of the wagon, the door is first pushed inwards, towards the frame of the door. When the train nose passes, the outside pressure drops and the tension on the door is immediately released in the opposite direction which leads to a higher deflection than from the normal position.

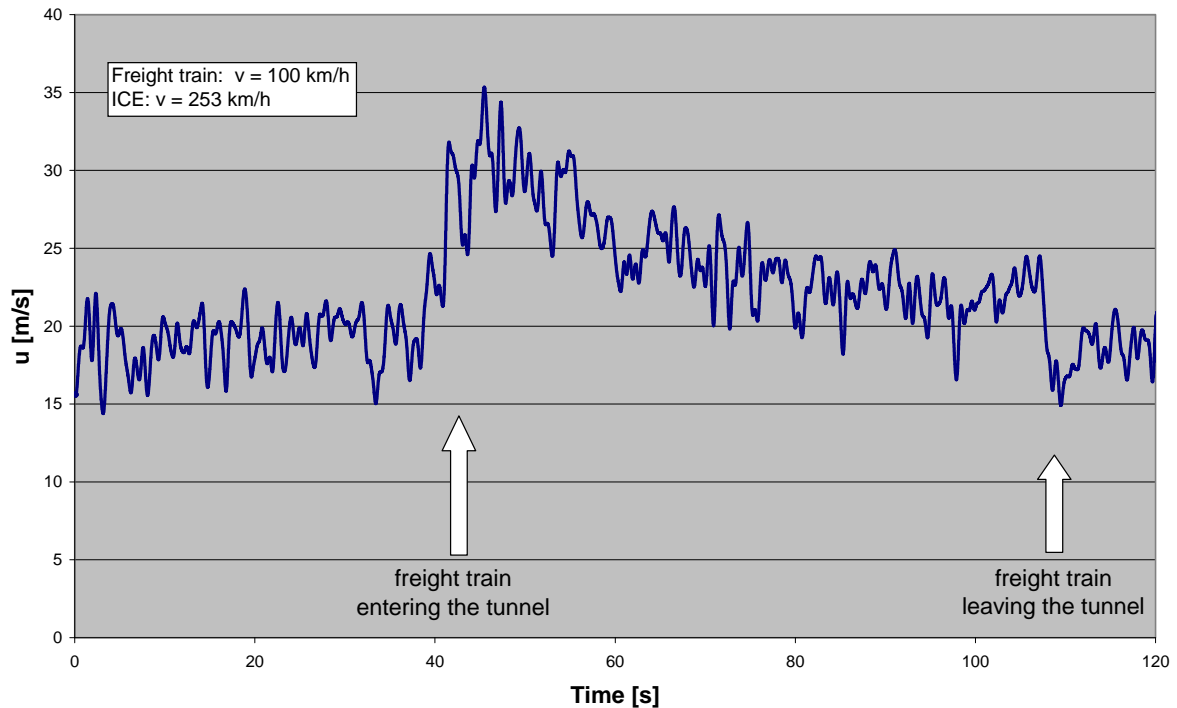
This demonstrates that the measured deflection of a door is not an appropriate criterion which can be used to determine aerodynamic loads during train passing situations in general. The deflection depends not only on the aerodynamic conditions but also on the construction of the door.

### **4.3 Carry off of wood chips from an open Eas-u wagon**

The open Eas-u wagon was loaded with wood chips. During the high speed passing of the ICE train with the freight train at rest no substantial unloading of wood chips was observed. In flying crossings (both trains moving) however, especially in critical passing situations (passing near the portal with the freight train is entering the tunnel and high speed train is leaving the tunnel) where the passing train has accelerated the air inside the tunnel in the direction opposite to the entering freight train, a certain unloading of wood chips was observed.

Figure 13 shows the airflow velocity measured at the top of the Fals wagon traveling with a constant speed of 100 km/h for such a critical train crossing with the ICE long leaving the tunnel at a speed of 250 km/h. The steep rise in the airflow velocity at the entry to the tunnel is clearly seen.

It has to be noted that such passing situations not only occur with high speed trains. Similar airflows can be induced if two freight trains are crossing each other in a tunnel. The observed unloading of wood chips is therefore not an issue which is limited to high speed traffic.



**Figure 13:** Airflow at the top of the Fals wagon during the entrance in the Tunnel Melk

#### 4.4 Monitoring of the freight train

No damage to the sliding doors of the Habbins wagon or at the tarpaulin of the Shimmns wagon was observed, although, a large number of train passings were carried out with some train speeds well above 250 km/h.

No severe damage was observed to the truck trailer loaded on the Saadkms wagon. In a number of passing situations one of the tarpaulin bows jumped out of his fittings (figure 14). There was no indication, however, that the tarpaulin could break free.



**Figure 14:** Wooden tarpaulin bow after a high speed train crossing

Despite the large number of train crossings with train speeds well above 250 km/h no damage to the freight wagons or to the passenger coaches was observed.

#### **4.5 Damages to infrastructure**

With increased train speeds the tunnel infrastructure and equipment are also subjected to higher aerodynamic forces. Therefore the state of the tunnel before and after the high speed passages was inspected.

No major damage to the tunnel infrastructure was observed. Only the fire extinguishing water pipe covering which consists of protective panels, was slightly affected (see figure 15). Some of these panels, which have a little weight compared to their surface area, were torn off during the test runs. However, before the measurements took place some of these panels showed slight damages. The higher loads experienced during the measurements revealed the vulnerability of the panels. The fixing of the panels will be improved in the future.



**Figure 15:** Damages to the protective coverings for the extinguishing water pipe

## 5 CONCLUSIONS

The following conclusions can be drawn from the measurements:

- The pressure drop during the passage of the train nose may be used to assess the maximum aerodynamic loads in a situation involving passing trains.
- The measurements in the Tunnel Melk and the results from older measurements in existing main line tunnels indicate that regularly occurring pressure drops up to 1.5 kPa are acceptable for typical freight train wagons.
- The comparison of the measured pressure drops with the older measurements in existing tunnels and the fact that no damage to the freight train was observed in a large number of high speed train passing situations gives strong indication that, from a structural standpoint, the train speed can be increased to 250 km/h in the new tunnels of the "Westbahn" Line.
- The numerous test runs with train speeds well above 250 km/h and maximum pressure drops up to 2 kPa without resulting in damage indicate that even higher pressure loads may be acceptable for modern freight trains.
- A certain unloading of light goods transported in open wagons can occur especially in critical crossing situations. This effect, however, occurs not only in high speed traffic situations but also at much lower speeds.
- Although there are no fundamental objections to high speed train passages at 250 km/h a stepwise increase of the speed accompanied with a systematic monitoring program is recommended.

## LITERATURE

- [1] Richtlinien für das Entwerfen von Bahnanlagen, Hochleistungsstrecken, HL AG- ÖBB - BEG, Mai 2002
- [2] TSI, Technical specification for interoperability relating to the infrastructure subsystem, 2002/732/EC, 12.09.2002
- [3] Aerodynamische Belastungen von Güterfahrzeugen im Mischverkehr, Auswirkungen aerodynamischer Phänomene auf die Ladung ERRI C 206.2 / DT327, Utrecht, Dezember 1995
- [4] Aerodynamische Belastungen von Güterfahrzeugen bei der Begegnung mit schnellen Reisezügen im Tunnel, Ermittlung des Ist-Zustandes, Auswirkungen aerodynamischer Phänomene auf die Ladung ERRI C 206.2 / DT352, Utrecht, August 1997