Measurements of the effect on pressures of a porous tunnel entrance using a moving model rig.

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Summary

Tests have been undertaken to investigate the effect on pressure waves generated by a train entering a tunnel fitted with a short porous entrance section. A 45 m 1/25 scale model tunnel was mounted on the AEA Technology Rail moving model rig. The first 2 m of the tunnel was perforated to allow its porosity to be varied. A 1/25 model high speed train was fired through the tunnel at speeds up to 49 m/s.

The effect of varying the tunnel entrance porosity on the propagation of the train nose entrance wave is described in terms of its amplitude, shape and gradient. It is shown that such devices may be usefully fitted to real tunnels to reduce pressure wave gradients where these are of importance to train passenger comfort.

Keywords

Aerodynamics, transient effects, model scale simulations, pressure pulse, pressure gradient, pressure waves.

1 Introduction

As a train enters a tunnel, the nose entry generates a compression pressure wave in the air, (ie above ambient atmospheric pressure), that travels at sonic speed ahead of the train. When the wave meets an interface with the open air, eg at a portal or the top of an air shaft, it reflects back into the tunnel becoming a rarefaction wave, (ie below ambient atmospheric pressure), and continues reflecting and changing sense at each open air interface until it becomes completely attenuated. A similar process occurs when the tail of the train enters, except that this time, a rarefaction wave is generated. More pressure waves are generated by the exit of the train from the tunnel. The train therefore travels through a complex series of pressure changes. These pressures become more complicated if a second train enters the tunnel as the first is still in it.

If the train is completely unsealed, the external pressures are felt by passengers travelling in the train without reduction. Modern high speed trains tend to be pressure sealed to some extent, so the full range of external pressure changes are not transmitted into the passenger areas of the train.

Most high speed railway operators apply some limits on the pressure changes to which passengers may be exposed to ensure their aural comfort. Some operators apply limits to the rates of change of pressure experienced in the train as well. Such rates of pressure change can be controlled by applying an appropriate degree of train sealing. However, there is also merit in controlling the pressure gradients of the waves generated by the train by incorporating suitable devices in the tunnel.

Controlling the gradient of the initial pressure wave generated by the entry of the train nose is also an effective way to limit the possibility of *train sonic boom.* This may occur for high-speed train operations in long, smooth lined tunnels. In this case, the initial pressure wave emits energy in the audible spectrum as it reflects from the opposing tunnel portal, which may create a loud booming noise that is unacceptable for people living near the tunnel. The strength of the noise depends upon the steepness of the initial pressure wave at generation.

This paper overviews the AEA Technology Rail Moving Model Rig (MMR) facility and describes the results of a series of model tests in a tunnel with a variable porosity entrance section. The effect is described of porosity variations in this section on the gradient of the initial pressure wave generated by the train in the tunnel.

2 Description of the MMR

2.1 Overview

The MMR is a unique test facility, which catapults 1/25 scale model trains at full-scale speeds along a track 150 m long. Trains can be simultaneously fired in both directions in the open air and in tunnels, allowing the simulation of combined passing speeds over 600 kmh^{-1}. Investigations can be made of the effect of passing trains on platforms, cuttings and other trackside structures. Model tunnels can also be built to accurately match real tunnels and their portals. The model trains are sufficiently detailed to allow investigations of the effects of train shape and variations of design. Instrumentation allows measurements to be made of onboard and ground-based pressures, air velocities and the model position.

Plate 1 shows a photograph of the MMR with a high speed train model in the acceleration section and the tunnel, with porous entrance section, in the background.

Plate 1 Porous tunnel entrance test configuration

2.2 Acceleration

Propulsion for the MMR models is provided by large elastic bungee cords that are operated like a catapult. The bungees are tensioned using an electric winch. A 4:1 gearing is applied to the firing cable which transmits the movements of the bungee and those of the model. This amplifies the linear movement of the bungees into a corresponding fourfold movement of the model.

2.3 Braking System

The braking force for the models is provided by a tightly fitting piston that is drawn by the model movement, through a plastic deforming tube. The braking piston is attached by a rope to a loop that is picked up by the moving model. This draws the piston into the tube and slows the model.

2.4 Instrumentation

The MMR has software-driven hardware to control safety, firing and data sampling. Up to 14 channels of pressure measurements may be made, as well as up to 8 channels of hot wire anemometry to measure air velocities. The train position and velocity is recorded using light emitting and receptor devices. All signals are simultaneously digitised and recorded using the control software.

An onboard data logger, currently being updated, will allow up to 16 channels of measurements to be made on the moving train.

A more extensive description of the MMR is provided in Reference 1.

3 Validation of numerical predictions of pressure waves in tunnels.

The MMR has been extensively validated against full-scale measurements for a variety of tunnel and open air measurements.

One comparison was made of the MMR test data with full-scale measurements gathered during the TRANSAERO project tests (Reference 2). Pressures were measured 80 m from the entrance of the Terranuova le Ville Tunnel as a 9 coach

ETR500 passed through travelling at 180 km/h. This was compared to MMR model data, which was sampled at an identical position in an empty 1/25 scale (but reduced length) model of the tunnel as it was passed by a 4 vehicle ETR500 model travelling at 185 km/h.

The solid line in Figure 1 shows the pressure time history at full-scale in the tunnel and the dotted line shows the pressure time history measured on the MMR.

After the nose has passed, the MMR data has been cut and displaced along the time axis to account for the shorter train length.

Shortly after the tail passes the measurement position, the MMR pressure shows the effect of the reflection of the nose entry wave from the end of the tunnel. As the model tunnel is much shorter than the full-scale tunnel this effect is not seen in the full-scale trace and after this time comparison between the two traces becomes inappropriate

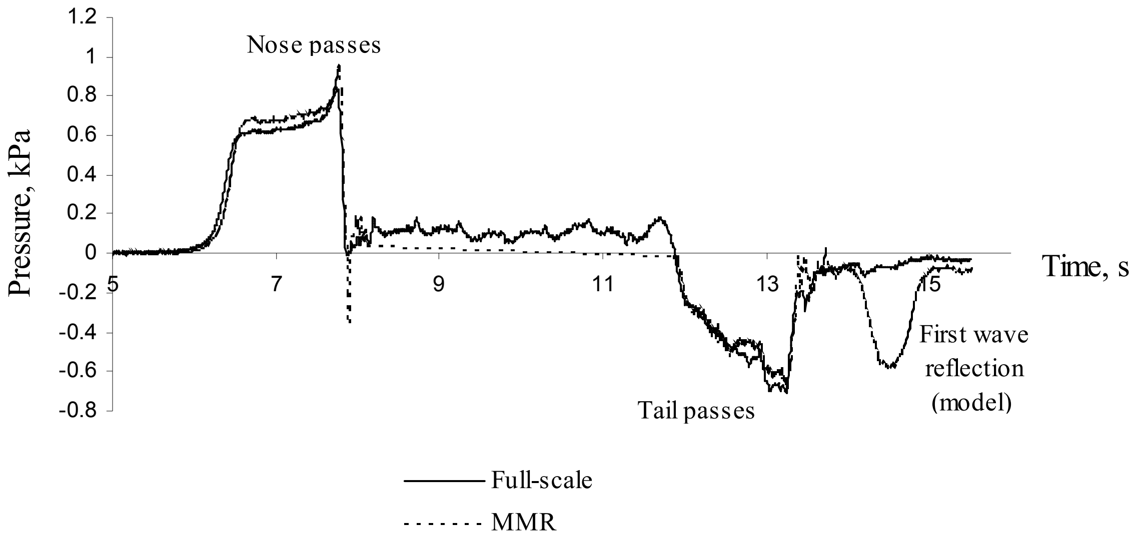


Figure 1 Comparison between data from the Terranuova le Ville Tunnel and the MMR.

In overall terms, the agreement between the MMR data and full-scale is very good. The small differences between the two sets of data are attributed to the fact that in the MMR tests the train speed was slightly higher than in the full-scale tests, and that the model was travelling closer to the tunnel wall where localised effects were recorded more strongly.

4 Previous tests undertaken on the MMR

The MMR has been used for a number of different tests on trains in the open air and in tunnels. These have included:

- The determination of the nose pressure loss coefficient for various designs of British and European high speed trains and multiple units. These trains have included both existing and speculative designs.
- Investigation of the lateral force exerted on a container train by the induced airflow through a lateral duct in the Channel Tunnel.

- Investigation of the boundary layer behaviour around a modern high speed train using laser sheet illumination.
- Determination of the aerodynamic effects generated on SWAP body freight vehicles by passing high-speed trains in tunnels.
- The effects of various designs of locomotive cab and multiple unit corridor connections on the open air pressure pulse generated by the nose of the train as it passes trackside infrastructure or other trains.
- Evaluation of the effectiveness of fitting airshafts to a tunnel to reduce transient pressures felt by passengers on trains using the tunnel.
- Investigations of the slipstreams generated by high speed trains on open track and in cuttings with and without the presence of cross-winds.
- Validation of a one dimensional tunnel pressure prediction program.

In addition, the rig has also been used to determine the effect of tunnel modifications on the pressures generated by trains in tunnels. This paper looks at porous tunnel entrances and how they affect the pressure wave generated by train entry into a tunnel.

5 Tests on a porous tunnel entrance

5.1 Test set-up

A 1/25 scale model was constructed of a 1125 m single bore tunnel. The full-scale cross-sectional area of the tunnel was 26.4 m^2. The first 2 m of the model tunnel had 576 six millimetre diameter holes drilled in it to simulate a porous tunnel entrance. The holes were bevelled to be sharp-edged. The open area was not directly scaleable to full-scale because of Reynolds number effects. The concept of *effective open area* was therefore introduced. It was assumed that the air passed through the holes in a similar way to air passing through sharp holes in a thin plate and having a contraction coefficient of 0.62. The effective open area is scaleable to a full-scale equivalent. The holes could be plugged or left open as desired, to simulate different porosities. Five porosity levels were actually tested.

Four pressure tappings were located in the tunnel as shown in Figure 2. The first tapping was in the porous entrance section and the train entered from this direction.

The train was a 1/25 model of a modern European high speed train. It was 65.5 m full-scale length and consisted of a power car plus coach plus power car. The ratio of the train cross-sectional area to that of the tunnel was 0.39.

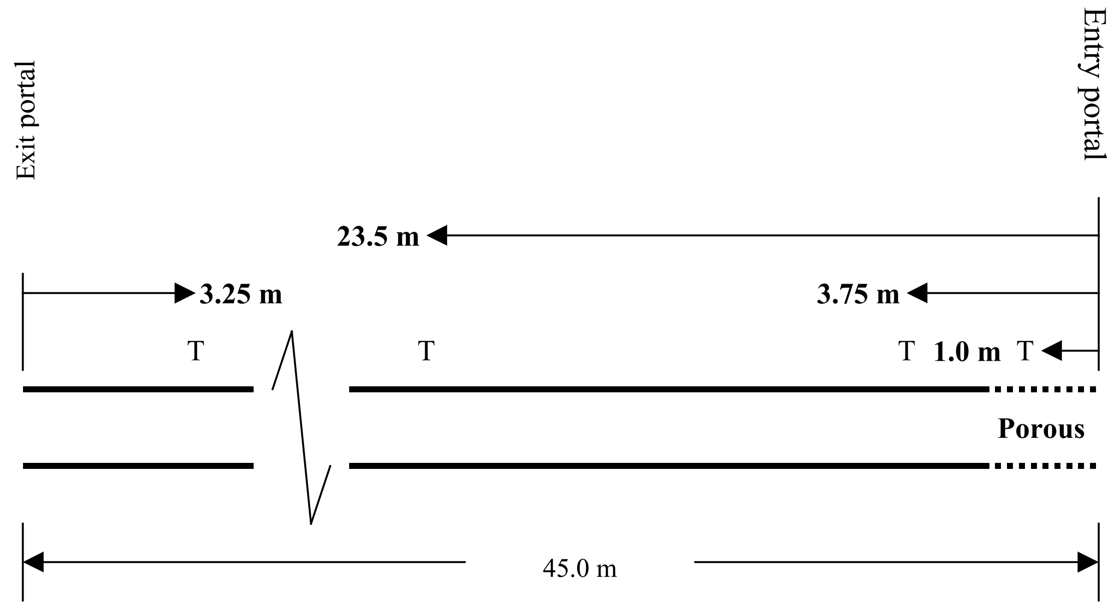


Figure 2 Diagram of the tunnel with porous entrance section, ('T' denotes pressure tapping)

The train model was fired at two speeds for each of the five tunnel entrance porosities. Only the firings at the highest train speeds are considered in this paper. These runs are summarised in Table 1. (The tests are described in greater detail in Reference 3).

Table 1

Run number	Porosity, (full-scale effective open area), m^2/m	Entry Speed, m/s
12	0.000	49.7
14	0.031	49.8
16	0.063	49.0
18	0.125	49.7
20	0.250	49.7

5.2 Results

The effect of the porous entrance section is best observed at the second tapping position. Here the full train entry pressure signature became developed before the train started to pass the measuring position and before pressure waves, reflected from the tunnel exit portal, interfered with the pressure signature.

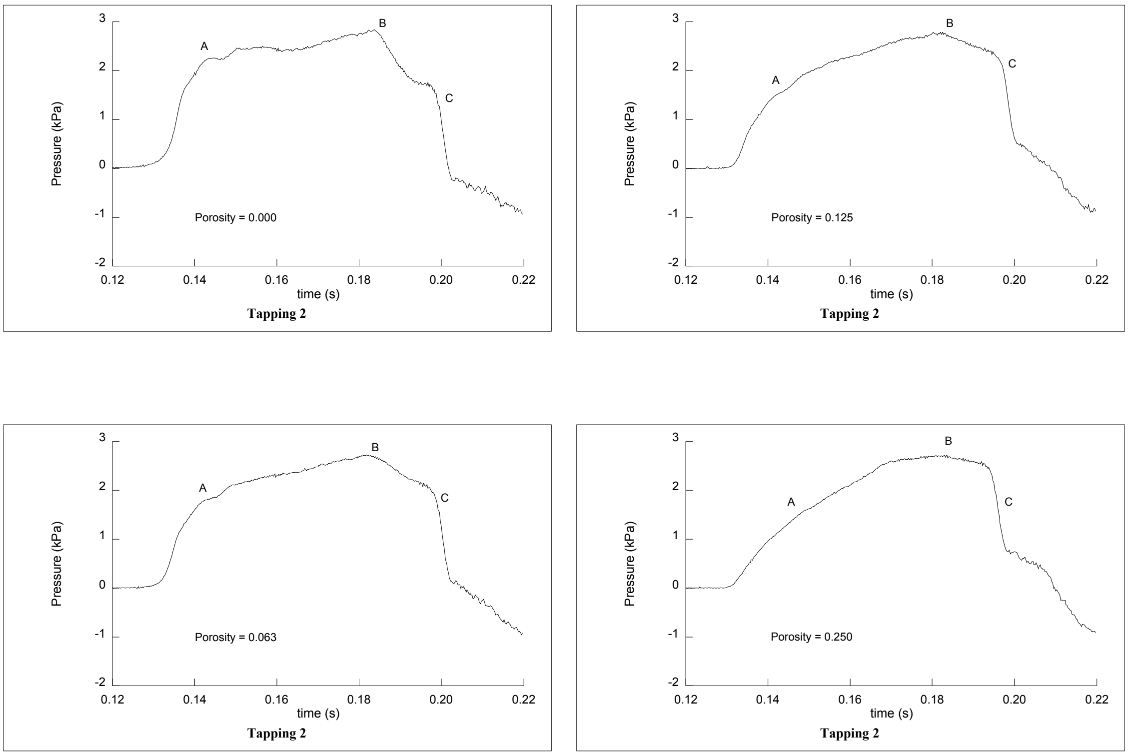


Figure 3 The effect of entrance section porosity on the train entry pressure signature

Figure 3 shows the pressures measured at the second tapping position (93.75 m full-scale distance from the entry portal), for Runs 12, 16, 18 and 20. (Run 14 has been omitted for clarity and because the results are similar to those for Run 12). Three events A, B and C have been marked on the train entry pressure signatures. The event A is the time when the train full cross-section is just inside the tunnel. B occurs when the train frictional pressure rise is completed by the train tail entry wave passing the second tapping position. Event C is when the nose of the train passes the tapping.

When there is no porosity in the tunnel entrance section, the events A, B and C are quite distinct and distinguishable. As the porosity increases, event A occurs with a reducing pressure rise. However, the overall increase in pressure associated with event B is not significantly changed. The nett effect is that the rate of change of the pressure associated with train entry is significantly reduced. The results are summarised in Table 2.

Table 2

Run number	Pressure rise associated with events, kPa	
	A	B
12	2.26	2.82
16*	1.82	2.70
18	1.55	2.76
20	1.23	2.67

* lower speed run

In order to quantify the effect of the porous entrance on the pressure gradient, some further analysis was necessary.

5.3 Analysis

Firstly, it should be noted when relating the MMR results to full-scale that velocities and pressures correspond directly to full-scale values. However, model times occur 25 times faster than full-scale because of the length scaling.

The data was low-pass filtered with a cosine-squared filter having a full-scale equivalent cut-off frequency of 20 Hz to remove excess noise. The gradient of the nose entry pressure rise was then evaluated simply according to the following formula:

$$\left(\frac{dp}{dt}\right)_i = \frac{(p_i - p_{i-1})}{\Delta t}, i = 1,2,3.....$$

where p_j is the pressure at the jth timestep and Δt is the timestep increment. Results for Runs 12 and 20 are shown in Figure 4. There is a distinct peak value in the gradient of the nose entry wave. This is associated with the entry of the rounded part of the train nose into the tunnel.

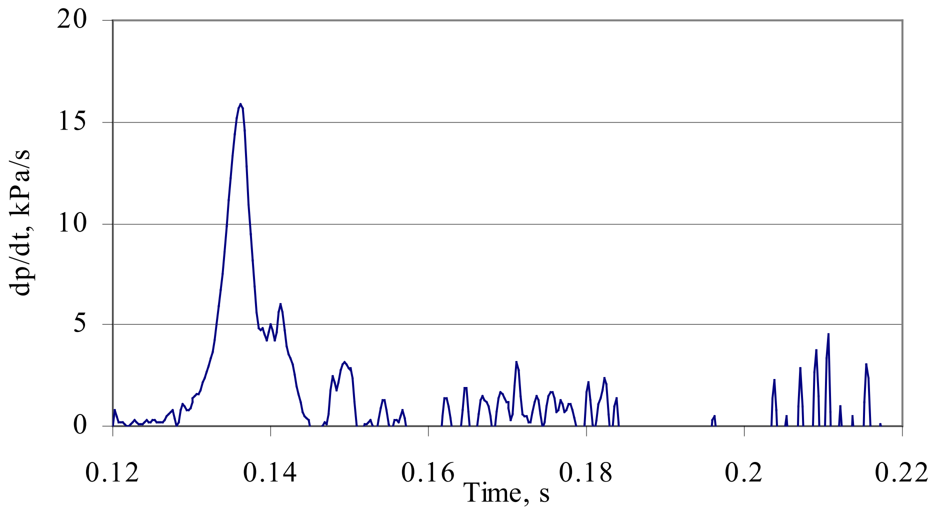
In Figure 5, the peak values of the gradient are plotted against tunnel entrance section (full-scale effective open area) porosity. It can be seen that the effect of the porous tunnel entrance section is very powerful, reducing the gradient of the nose entry pressure wave by 68% when the maximum porosity is used compared with the non-porous tunnel entrance.

6 Conclusions

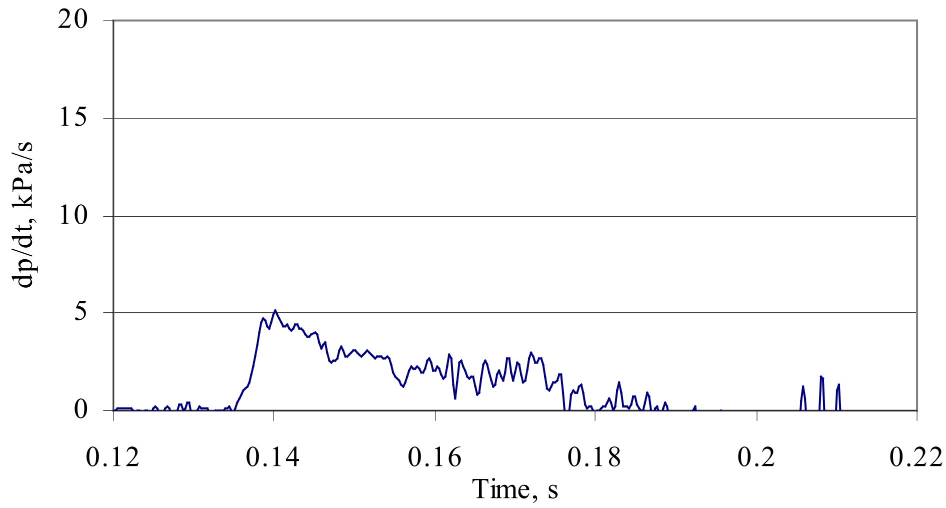
The MMR at AEA Technology Rail offers a uniquely flexible facility for the study of transient railway aerodynamics. In this application, it was used to study the effect of a short entrance section to a tunnel for which the porosity could be varied.

It was found that when applying porosities up to 0.25 m^2/m, a significant effect resulted. The initial pressure rise associated with the train entry, measured at a point in the tunnel, was reduced by 46%. However, the overall pressure rise associated with complete train entry was reduced by only 5%. In addition, the gradient of the pressure rise during the entry of the train nose was reduced by 68% in the most porous case compared to that occurring for the non-porous entrance

The results indicate the potential benefits of using such entrance designs to reduce the gradients of train-generated pressure waves. They could be of use in ensuring passenger aural comfort and reducing the potential problem of train sonic boom.



Run 12



Run 20

Figure 4 Calculated train nose entry pressure wave gradient for Runs 12 and 20

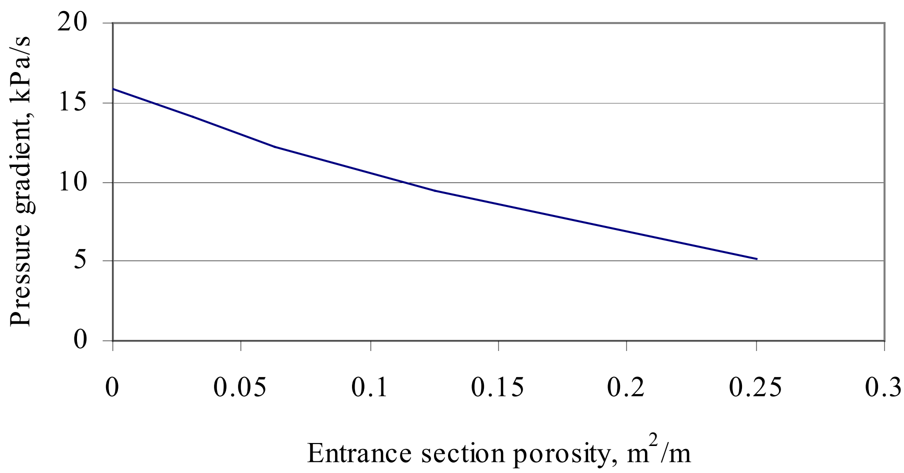


Figure 5 Variation of nose entry pressure gradient with entrance section porosity

7 Acknowledgements

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