

Development of New Tunnel Entrance Hoods



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Tunnel entrance hoods are structures that reduce tunnel micro-pressure waves by easing the pressure gradient of the compression wave that high-speed trains generate when entering a tunnel. As the effect of tunnel entrance hoods depends on their length, they need to be extended with train speed increases. In this report, we will explain the development of technologies to shorten the required extension and reduce construction costs and thus cut total construction costs for installing tunnel entrance hoods.

The technology developed to shorten the required extension is tunnel entrance hoods with ducts. We confirmed the effect of easing the pressure gradient of compression waves and the control mechanism of compression waves in model tests and on-site tests.

The technology to reduce construction costs is lightweight panel tunnel entrance hoods using large, light and highly durable panels. It was developed with the aim of reducing construction costs of tunnel entrance hoods and of the main structural members that account for a large percentage of total costs.

●Keywords: Tunnel entrance hood, Tunnel micro-pressure wave, Pressure gradient, Duct, Lightweight panel, Membrane material

1 Introduction

When a train enters a tunnel at high speed, an explosive sound sometimes occurs at the exit of the tunnel, shaking windows and doors of houses in the vicinity. This phenomenon is caused by a tunnel micro-pressure wave (hereafter “micro-pressure wave”), the mechanism of which is shown in Fig. 1. First, a high speed-train entering a tunnel generates a compression wave at the entrance of the tunnel. That compression wave propagates through the tunnel while deforming.

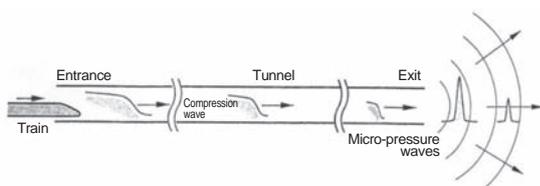


Fig. 1 Tunnel Micro-Pressure Wave Phenomenon

Part of the wave is emitted as a pulsing pressure wave when the compression wave reaches the exit of the tunnel. This pulsing pressure wave is a micro-pressure wave.

Countermeasures for micro-pressure waves are one of the most important issues in achieving further speed increases of high-speed trains. Optimizing the nose shape of the train brings about some effect in reduction of micro-pressure waves, but the extent to which we can do such optimization is limited if we are to maintain the functions of a train. Accordingly, other approaches to reduce micro-pressure waves are required on wayside facilities to handle micro-pressure waves that cannot be sufficiently reduced by such optimization of the nose shape of the train.

Tunnel entrance hoods, which are a typical wayside approach to micro-pressure waves, are hood structures constructed at the entrance of tunnels as shown in Fig. 2. The size of a tunnel

entrance hood perpendicular to the track (cross sectional area) is 1.4 to 1.5 times that of the main tunnel. Tunnel entrance hoods conventionally used (hereafter “conventional entrance hoods”) achieve some reduction of micro-pressure waves by securing longitudinal length. However, train speed increases require new entrance hoods or extension of existing entrance hoods. This results in the problem of large costs because much work has to be done near the track and poles and other obstacles must be moved.

In light of these circumstances, we needed to develop new tunnel entrance hood forms that can be shorter than conventional entrance hoods and constructed at lower cost when aiming for further speed increases of high-speed trains. Here we will report an overview of the new tunnel entrance hoods (duct type, lightweight panel type) that we worked on.



Concrete structure (prestressed concrete) Steel structure

Fig. 2 Structure of Tunnel Entrance Hood

2 Development of Tunnel Entrance Hoods with Ducts

2.1 Overview of Development of Tunnel Entrance Hoods with Ducts

Tunnel entrance hoods with ducts are tunnel entrance hoods equipped with external tubes (ducts) leading to the inside of the hood. The aim of this type of hood is to shorten the length of the hood by reducing the pressure gradient of the compression wave generated when a high-speed train enters a tunnel. In the

development, we carried out model tests and constructed test ducts on an existing tunnel entrance hood in Shinkansen high-speed running tests to examine the effect of easing of pressure gradient of compression waves. For the model test, we used the micro-pressure wave model testing equipment of the Railway Technology Research Institute (RTRI).

2.2 Test of Tunnel Entrance Hood with Ducts Using Models

In the model tests, we checked the effects of ducts of different shapes on reducing the pressure gradient of the compression wave. Fig. 3 shows photos of model tests of entrance hoods with ducts. First, we used a simplified model to identify the basic phenomena related to tunnel entrance hoods with ducts and confirm the effects of those. Then, we carried out examination using a model reproducing the tunnel entrance hood that was temporarily constructed in the field (details explained later).

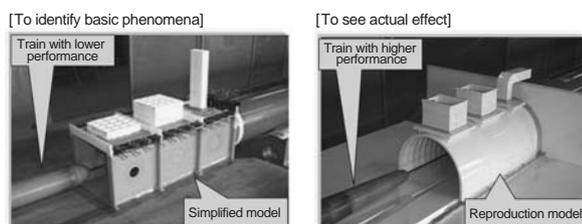


Fig. 3 Model Tests of Tunnel Entrance Hoods with Ducts

Fig. 4 is an example of model test results using the reproduction model, and the results are equivalent to those of a 25 m tunnel entrance hood with a 360 km/h train speed. The car model used was a model of a Shinkansen high-speed test train. The entrance hood with ducts retained a steep pressure gradient for a longer time than a conventional entrance hood, and consequently the peak value of the pressure gradient of the entrance hood with ducts was smaller than that of a conventional entrance hood. In this way, we confirmed that adding ducts to a tunnel entrance hood could reduce the peak value of the pressure gradient. In other words, adding ducts provides effects equal to those of conventional entrance hoods, even in a short length. Various model tests gave us the following information.

- (1) Among ducts near the entrance, at an intermediate location and near the main tunnel (locations shown in Fig. 5), the duct near the main tunnel produces the largest effect. The duct near the entrance showed little effect and the effect of the intermediate location duct did not justify the size (installation costs).
- (2) Installing a duct near the main tunnel with its length and diameter adjusted brings about effective reduction of the peak value of the pressure gradient.
- (3) A tunnel entrance hood with a duct longer than 40 m does not produce much reduction effect.

We did not verify the effect of reduction of pressure gradient of ducted entrance hoods shorter than 20 m. This is because we supposed that a tunnel entrance hood of shorter length involved

only little length saving by installing ducts. Installation cost of ducts would thus not justify the length reduction.

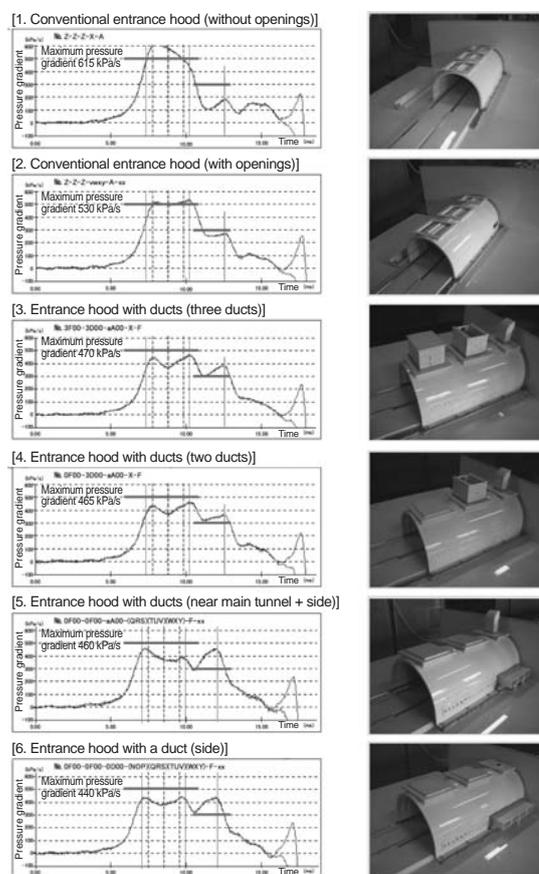


Fig. 4 Model Test Results of Tunnel Entrance Hoods with Ducts

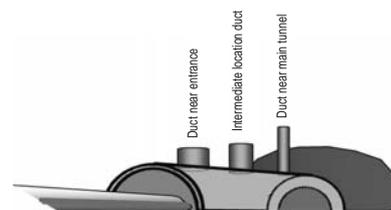


Fig. 5 Examined Locations of Ducts

2.3 Field Tests on Tunnel Entrance Hoods with Ducts

We test constructed three ducts on an existing tunnel entrance hood on the Tohoku Shinkansen. Those ducts were adjustable in length and diameter by opening and closing them. Fig. 6 shows the installation of ducts to the existing entrance hood.

Field tests were held in conjunction with Shinkansen high-speed-running tests. In those, we adjusted the length and diameter of the ducts and measured at a point approx. 80 m inside from the entrance of the main tunnel the pressure history before and after trains entered

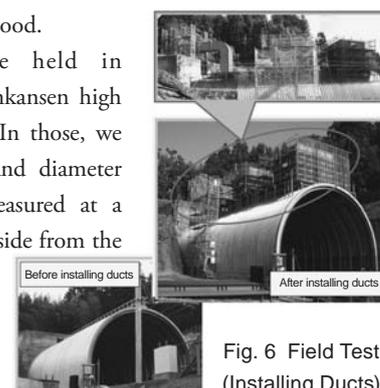


Fig. 6 Field Test (Installing Ducts)

the tunnel. We also recorded train speed.

The pressure gradients of the compression waves obtained from the pressure histories proved that tunnel entrance hoods with ducts ease the pressure gradient more than conventional entrance hoods. We also confirmed that the pressure gradient could be eased with just a duct near the main tunnel.

2.4 Deployment Target for Tunnel Entrance Hoods with Ducts

Based on the examination of position and size of ducts in model tests and field tests, we made the following provisions for deployment of tunnel entrance hoods with ducts.

- (1) The duct is to be installed near the main tunnel.
- (2) Tunnel entrance hoods with ducts are to be applied in cases where the hood length is 20 to 40 m.
- (3) Reduction of the peak value of the pressure gradient at the entrance of the tunnel is estimated to be approx. 10% compared to that of conventional entrance hoods.

By applying a duct to a tunnel entrance hood that required 27 to 49 m length, the total length can be shortened to 20 to 40 m, achieving a 7 to 9 m reduction. That shortens the total length; therefore, total construction cost including duct installation cost can be reduced.

3 Development of Lightweight Panel Tunnel Entrance Hoods

3.1 Overview of Lightweight Panel Tunnel Entrance Hood Development

Lightweight panel type tunnel entrance hoods are a tunnel entrance hoods that use large-sized, lightweight and highly durable panels. The aim of such structures is to reduce construction costs of the main structural members that account for a large percentage of total costs.

3.2 Membrane Material and Overview of Structure

3.2.1 Characteristics of Membrane Material

Membrane material is used for station buildings and recently for large-scale architectural structures (Fig. 7). Fig. 8 shows the composition of membrane material. The material is plain-woven glass fiber fabric coated with fluoro-resin, and it has excellent durability. Its weight is 1.3 kg/m², light compared to the 20 kg/m² of conventional deck plates.



Fig. 7 Examples of Structures Using Membrane

3.2.2 Overview of Structure

The interval of main components is increased from the 2.5 m of conventional entrance hoods to 3.8 m, allowing for reduced

construction costs. We selected a panel structure form (hereafter “lightweight panel”) to enable easy replacement of panel material in case of damage to the membrane.

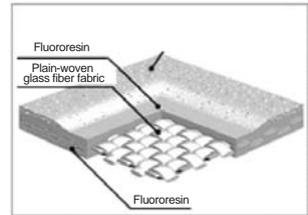


Fig. 8 Magnification of Membrane Material

We carried out a variety of load bearing tests on the lightweight membrane panels during development. Those were needed if we are to increase the size of the roofing material.

3.3 Confirming Load Bearing Ability and Performance of Lightweight Panels

To confirm load bearing ability, we examined the following items.

- ① Applied load
- ② Static tensile strength
- ③ Static tensile strength (change over time)
- ④ Fatigue strength
- ⑤ Fatigue strength (change over time)
- ⑥ Performance

①, ③ and ⑥ were examined in field tests and ②, ④ and ⑤ were examined in laboratory tests. Here we will explain ①, ⑤ and ⑥.

3.3.1 Applied Load

In the examination of load bearing of lightweight panels, we identified the applied load of a tunnel entrance hood. In particular, we needed to know the applied load by pressure change caused by a train entering the tunnel (hereafter “in-car pressure load”).

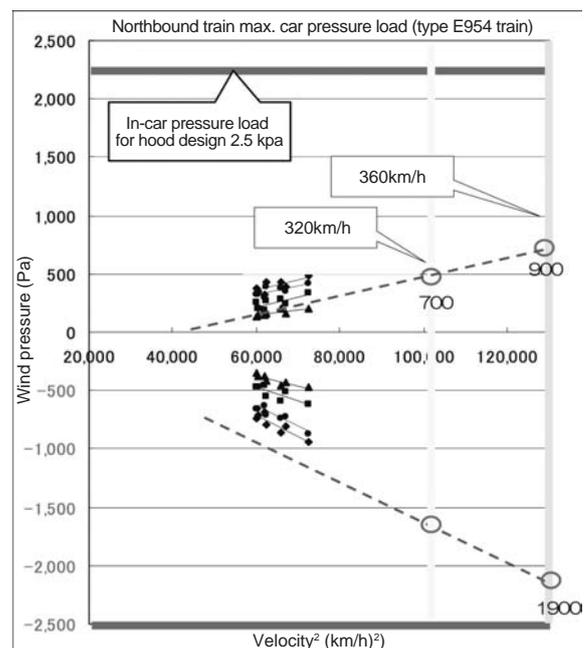


Fig. 9 Example of Measurement Results of In-car Pressure Load for Hood Design

We made the applied load to be a design load that satisfactorily meets the required applied load obtained from the actual values measured with a pressure gauge in an entrance hood in field tests and traditional theory formulae.

Fig.9 shows the measurement results of in-car pressure load.

3.3.2 Examination of Fatigue Resistance

Since membrane material for tunnel entrance hoods receives repeated loads from the in-car pressure load of running trains, we examined fatigue resistance of the material. In the examination, we identified the fatigue limit in the repeated loading test shown in Fig. 10. Here, fatigue limit is 95% probability of non-destruction in repeating the loading test two million times. We checked fatigue resistance with unused material and material that received accelerated exposure.

Comparison of the fatigue limit identified in this test and the design tensile strength proved that the fatigue limit is larger. Also, in the test using the material that received accelerated exposure, we were able to confirm that the fatigue limit taking into account 70 years worth of deterioration was larger than the design tensile strength.

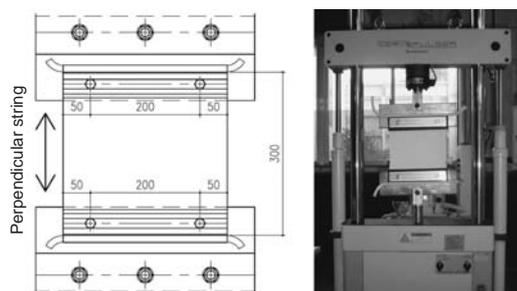


Fig. 10 Repeated Loading Test (Left: Sample, Right: Testing Equipment)

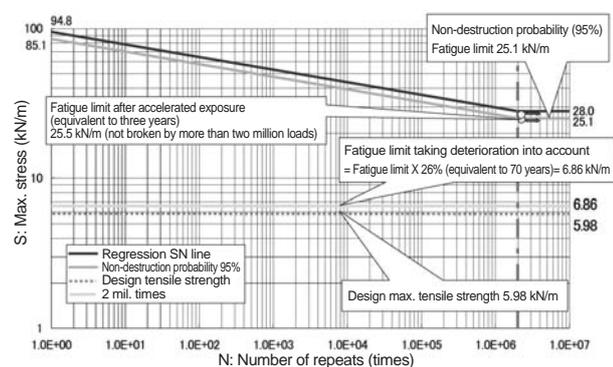


Fig. 11 Repeated Loading Test Results

3.3.3 Performance Check (Test Construction of Full-scale Tunnel Entrance Hood)

We carried out test construction of a full-scale tunnel entrance hood of 15 m length on an operating line to check performance of the hood. The check results proved performance equal to that of conventional entrance hoods could be secured. Fig. 12 shows the construction (at completion).



Fig. 12 Test Construction (at Completion)

4 Conclusion

We checked performance of tunnel entrance hoods with ducts in model tests and field tests, and we conducted development on those. Based on the results so far, we have prepared a design manual for tunnel entrance hood with ducts and introduced hoods as a measure to reduce tunnel micro-pressure waves with the increase in Tohoku Shinkansen speeds.

For lightweight panel tunnel entrance hoods, we confirmed satisfactory load bearing and performance in basic experiments and test construction. We have also prepared a design and construction manual for lightweight panel type tunnel entrance hoods and introduced hoods as a measure to reduce tunnel micro-pressure waves with the increase in Tohoku Shinkansen speeds.

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