Wayside Environmental Measures for Shinkansen Speed Increases

**Introduction**

The Research and Development Center of JR East Group has been carrying out R&D in view of achieving commercial operation of Shinkansen trains at 360 km/h as set out in the “JR East Group Management Vision V - Ever Onward.” Currently, we are deducing issues to overcome for further expansion of the 320 km/h operation area and considering measures to solve those.

Environmental measures required for Shinkansen speed increases include measures for rolling stock and wayside equipment. This article will report on an overview of R&D on tunnel micro-pressure waves and noise along the line, which have to be dealt with by wayside equipment.

**Countermeasures Against Tunnel Micro-pressure Waves**

Fig. 1 illustrates the mechanism of micro-pressure wave generation. First, a high-speed train entering a tunnel generates a compression wave at the entrance of the tunnel. That compression wave then propagates through the tunnel while changing the pressure gradient at the speed of sound. When the compression wave reaches the exit of the tunnel, most of the wave reflects off the end of the exit and propagates back to the entrance, but part of the wave is emitted to the outside of the tunnel as a pulsing pressure wave. This pulsing pressure wave is a micro-pressure wave, which causes an explosive sound if large.

The pressure of a micro-pressure wave is proportional to the pressure gradient of the compression wave that reaches the exit and also to the cross-sectional area of the tunnel. The basis of countermeasures against micro-pressure waves is, therefore, making the gradient of pressure propagating through the tunnel gentler.

For these reasons, we are focusing on the following in developing noise control measures: (1) preventing large pressure gradients (countermeasures at train entering tunnel), (2) preventing increases of pressure gradients (countermeasures against propagation), and (3) reducing energy emitted from the exit (countermeasures against radiation).

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Fig. 1  Mechanism of Micro-pressure Wave Generation

2.1 Tunnel Entrance Hoods with Ducts (Countermeasure at Train Entering Tunnel)

A common countermeasure at trains entering tunnels is to flatten the waveform of the pressure wave generated first when a high-speed train enters a tunnel. Conventionally, that has entailed means such as constructing tunnel entrance hoods at the entrances of the tunnels.

One measure for controlling tunnel micro-pressure waves that increase as Shinkansen train speeds increase is lengthening existing tunnel entrance hoods. However, the effect of micro-pressure wave reduction becomes smaller once hoods reach a certain length. From the viewpoint of cost, too, there are issues with lengthening existing tunnel entrance hoods due to the need to move existing equipment that would interfere the hoods and to carry out nighttime construction work over a long period of time.

Tunnel entrance hoods with ducts are entrance hoods where chimney-like ducts are added to the ceiling. They can reduce micro-pressure waves with a shorter length than conventional tunnel entrance hoods (Fig. 2).

Past simulation test results using models of this tunnel structure demonstrated effectiveness in reducing micro-pressure waves when the length of the tunnel entrance hood with ducts is less than 40 m, and tunnel entrance hoods of this type have been constructed at seven tunnel entrances between Omiya...
and Morioka on the Tohoku Shinkansen. In order to handle Shinkansen speed increases, we will test the effect of micro-pressure wave reduction using models when ducts are provided to a long and large tunnel entrance hood with an aim of extending the scope of application of ducts to tunnel entrance hoods longer than 40 m. We also plan to carry out field tests using high-speed trains with actual tunnel structures that have ducts added to long and large tunnel entrance hoods.

2.2 Installation of In-tunnel Acoustic Tubes (Countermeasure Against Propagation)

When taking measures to control micro-pressure waves of high-speed trains using only tunnel entrance hoods as countermeasures at trains entering a tunnel, there are concerns about difficulty of construction due to site conditions such as bridges being located nearby. As an approach to dealing with such cases, we are investigating measures to reduce micro-pressure waves by making the pressure gradient of compression waves propagating through the tunnel gentler. This is in addition to countermeasures for at trains entering a tunnel.

An in-tunnel acoustic tube is a tube with one end closed installed in a tunnel in a direction parallel to the tracks. By installing that, compression waves propagating through the tunnel will branch to the tunnel and to the in-tunnel acoustic tube, shifting the propagation timing, and resulting in a gentler pressure gradient (Fig. 3).\(^5\)

In order to shift the propagation timing of waves reflected from the in-tunnel acoustic tube and compressions waves propagating through the tunnel, however, such an in-tunnel acoustic tube must have sufficient length. Furthermore, the larger the cross-sectional area of the in-tunnel acoustic tube and the longer the tube, the larger the micro-pressure wave reduction effect becomes. We thus need to examine this approach of using an in-tunnel acoustic tube in terms of clearance gauge and maintenance.

Fig. 3 Image of Compression Wave Reduction by an Acoustic Tube

2.3 Spreading Ballast (Countermeasure Against Propagation)

As another supplementary measure for tunnel entrance hoods in addition to installing in-tunnel acoustic tubes, we are studying a measure where ballast is spread on slab track. The pressure gradient of compression waves in slab track tunnels differs from that in ballasted track tunnels, becoming sharp while the waves propagate through the tunnel and then attenuating. It is usually assumed that compression wave propagation maximizes the pressure gradient with tunnels up to 8 km long and attenuates the gradient with tunnels longer than that.\(^5\) Tunnels 3 km to 4 km long, which are often found in the JR East operation area, tend to generate large micro-pressure waves because the compression waves reach the tunnel exit before attenuation.

On the other hand, measurements by the Railway Technical Research Institute (RTRI) revealed that, in a ballasted track tunnel, the wave front of a compression wave becomes gentler and the pressure gradient on the wave front becomes smaller as a compression wave propagates. They also revealed that the initial rise of the pressure gradient becomes smoother and more rounded as the compression wave propagates.\(^5\)

Based on those findings, we spread ballast on slab track and checked whether that could bring about the same effects as on ballasted track.

From fiscal 2013 to fiscal 2014, we are carrying out field tests in a 2,930 m long section with frame-shaped slabs in a 3,330 m long tunnel. Specifically, we spread ballast in nets along the frames of the frame-shaped slabs, at the bottom of the tunnel wall, and in the center passage in that section (Fig. 4).

Fig. 4 Image of Spreading Ballast

In the tests, we will clarify the micro-pressure wave reduction effect according to the area ballasted and location of placement (Fig. 5) to see whether this approach will be feasible, including from a perspective of cost.

Fig. 5 Steps in Spreading Ballast

2.4 Tunnel Entrance Hoods with Inside Partitions (Countermeasures against Radiation)

Tunnel entrance hoods with inner walls are countermeasures against radiation that RTRI proposed as a supplementary measure for tunnel entrance hoods, which are countermeasures at trains entering tunnels.\(^5\) The pressure value of tunnel micro-pressure waves is in proportion to the radiation cross-sectional area (cross-sectional area of the tunnel exit). Therefore, the smaller the cross-sectional area of a tunnel exit is, the more the micro-pressure waves can be reduced. A tunnel entrance hood with an inside partition is of a structure where a hood with a cross-section larger than the tunnel cross-section is constructed at the tunnel exit. The hood is divided with the inside partition and closed at its end (Fig. 6). Such a structure reduces the cross-sectional area on the micro-pressure wave emission side and shifts the propagation timing of the compression waves by securing sufficient length of the inside partition, thereby reducing micro-pressure wave generation.
We are currently studying a structure outline and costs of adding external partitions that will cover existing tunnel entrance hoods.

![Fig. 6 Overview of Tunnel Entrance Hood with Inside Partitions](Image)

The former Environment Agency (current Ministry of the Environment) announced environmental standards for Shinkansen railway noise in 1975. The standard values are less than 70 dB for Category I (residential area) and less than 75 dB for Category II (commercial area).

As running speeds increase, noise levels increase too. Cars of the series E5, our current core series of Shinkansen rolling stock, demonstrate excellent environmental performance and cause much smaller levels of noise than the series E2 cars do. However, locations where noise is estimated to be of a level exceeding standards at higher operation speeds require wayside countermeasures in addition to measure for rolling stock. And when building future noise control measures, construction costs need to be lower than with the conventional construction methods.

Increasing sound barrier height is the usual approach to Shinkansen noise reduction using wayside equipment. To raise the height, concrete or polycarbonate panels are added to the top of noise control measures that reflect car noise, reducing the noise transmitted to the area along the line. Increasing of the height by 1 m is confirmed in our measurements after construction to bring about 2 dB noise reduction at a height of 1.2 m from the ground 25 m from the center of the track. Some different shapes of sound barriers such as upright type and inverted L-shape type have been constructed, and those demonstrated good results. For further noise reduction, however, those have to be made higher, leading to the concerns of construction restrictions such as insufficient strength of viaducts and interference with power equipment. In order to achieve further Shinkansen speed increases, it is necessary to study and develop noise control measures that can produce large noise reduction effects even with limited height.

Noise reduction devices utilizing sound interference have been installed to the top of sound barriers in some sections as a noise reduction approach for Shinkansen lines in addition to increasing sound barrier height. As they are of a shape that requires installation space outside of the sound barrier, limiting locations where they can be installed, we developed “NIDES” (Noise reduction device using Interference and Diffraction Effect for Shinkansen) where that problem was improved on, and we are currently proceeding with installation of those.

In addition to those, we picked out noise control measures considered to be installable (Table 1), and when possible, we are testing those using models to assess their effects. We will further carry out field tests of noise control measures considered to be effective so as to check their noise reduction performance and durability.

### Table 1 Noise Control Measures Under Consideration

<table>
<thead>
<tr>
<th>Noise control measures</th>
<th>Shape</th>
<th>Features</th>
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<tbody>
<tr>
<td>NIDES</td>
<td></td>
<td>• Multi-diffraction and interference type</td>
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<tr>
<td></td>
<td></td>
<td>• Heavy weight (50 kg/m)</td>
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<tr>
<td>Y-shape sound barrier</td>
<td></td>
<td>• Diffraction and interference type</td>
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<tr>
<td>Edge-improved noise reduction</td>
<td></td>
<td>• Edge-effect control type</td>
</tr>
<tr>
<td>device</td>
<td></td>
<td>• Light weight (17 kg/m)</td>
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<tr>
<td>Sound absorption and insulation panel</td>
<td></td>
<td>• Sound absorption and insulation type</td>
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<tr>
<td>Trackside low-rise sound barrier</td>
<td></td>
<td>• Sound absorption and insulation type</td>
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</tbody>
</table>

#### 3.1 NIDES

NIDES is the name for Shinkansen noise reduction devices we jointly developed with a railway equipment manufacturer. By installing those on the top of sound barriers, noise can be reduced through multi-diffraction and interference.

Past multi-diffraction and interference noise reduction devices have a problem in that they project outside the sound barrier by 800 mm, protruding past the property boundary. NIDES has been improved to a shape that does not project outside the barrier, so the scope of installation is broadened. We have confirmed that, by the sound reduction mechanism shown in Fig. 7, noise can be reduced by 2 dB with NIDES alone and by around 5 dB with NIDES combined with a sound barrier with 1 m increased height.\(^5\)

NIDES already has been installed on a 1.3 km section of reinforced concrete (RC) upright sound barriers, but it has not been installed on inverted L-shape sound barriers with ceilings or on steel reinforced concrete (SRC) sound barriers with panels between steel H-beam support columns yet. We will thus install NIDES on sound barriers of different structures and shapes to assess items that are not clear such as installation methods, ease of construction, long-term durability, and installation cost.

![Fig. 7 Mechanism of Noise Reduction by NIDES](Image)
3.2 Y-shape Sound Barriers

Y-shape sound barriers are sound barriers of a shape deemed most appropriate for Shinkansen sound barriers based on the results of model tests by RTRI.6)

A Y-shape sound barrier has a noise reduction mechanism that utilizes the effect of double diffraction of sound and of interference to incident sound and reflected sound on the upper part of barriers, and this type and many variations of it have been put into practical use for road noise reduction. Unlike with road noise, Shinkansen noise has characteristics particular to railway noise such as many noise sources (such as near rails and around pantographs) as well as multi-reflection of sound due to the small area between car bodies and sound barriers. It was thus not clear how effectively sound barriers for roads would work for Shinkansen noise reduction, but RTRI tests using models proved that their noise control effect is large.

Installation of Y-shape sound barriers on viaducts requires purchase of land and other measures as they project outside the sound barriers, but it would be a favorable noise control measure on embankments and cuts slopes and in front of tunnels where sufficient space is secured (Fig. 8). Currently we do not yet have data such as the dimensions, angle of Y branches, installation intervals, and height that will bring about the maximum noise reduction effect, so we will investigate by model tests the optimal shape if installing those on cuts slopes.

Y-shape sound barriers can be installed at relatively low cost compared to NIDES. In snowfall regions, however, we need to make careful consideration of the impact of snow.

![Fig. 8 Y-shape Sound Barrier Installed on Cut Slope](image)

3.3 Edge-improved Noise Reduction Devices

Edge-improved noise reduction devices are noise reduction devices based on the newly proposed edge-effect suppression theory.7) The devices do not insulate or absorb sound. Instead, they change the direction of sound so as to create an area with reduced noise.

We will carry out field tests to identify the optimal installation conditions and check durability.

3.4 Sound Absorption and Insulation Panels

We improved sound absorption panels on the inside of existing concrete sound barriers by attaching sound insulation panels to the back of them. Such panels were developed to replace existing SRC roadbed concrete will be constructed near bogies, so appropriate consideration is also needed on issues such as reduction of snow storage volume in snow storing sections and blocking the view of rails from work passages.

We will conduct field tests to check items such as the noise reduction effect, ease of construction, and environments where installing them will be effective.

3.5 Trackside Low-rise Sound Barriers

These low sound barriers are installed near rails with an aim of preventing propagation of noise from the lower part of cars to high spaces along railway lines. They have been installed on conventional lines of some private railways. Tests using scaled-down models confirmed noise reduction effects. When applied to Shinkansen lines, walls approx. 1.5 m high above roadbed concrete will be constructed near bogies, so appropriate consideration of the structure and method of installation taking account of wind pressure resistance will be needed. Further consideration is also needed on issues such as reduction of snow storage volume in snow storing sections and blocking the view of rails from work passages.

4 Conclusion

This article has introduced wayside environmental measures for Shinkansen speed increases for which the Frontier Service Development Laboratory is studying feasibility. Specifically, those are measures to control tunnel micro-pressure waves and noise along lines. As the environment along lines and the wayside equipment used vary by individual location, we must be well aware of the characteristics of individual locations and select the optimal measure based on examination of demanded performance and implementation costs. With a goal of greater Shinkansen speed increases, we will go forward with R&D to further clarify features and performance of noise control measures.

Reference: