Development and Practical Application of a Sound Absorbing Panel Using Microperforated Aluminum for Shinkansen Tunnel Entrance Hoods

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A sound absorbing panel for Shinkansen tunnel entrance hoods has been developed using a sound absorbing material featuring microperforated aluminum. The conventional microperforated aluminum material was enhanced in terms of structural strength for use in Shinkansen tunnel entrance hoods. The developed microperforated panel was designed using finite element analysis, and was subjected to strength tests, which demonstrated the high safety standards of the product. It can be applied to the ceiling of entrance hoods installed at tunnel portals of Shinkansen tracks, where it has been shown to dampen noise dramatically.

Introduction

Reducing environmental noise is a great concern in society, in connection with the development of traffic infrastructure and the need for creating comfortable living environments. For more than two decades, we have developed various noise insulation technologies and products for many applications including Shinkansen bullet train systems and expressways. Our microperforated aluminum sound absorbing panel is one of our unique products in this field. This panel had found use in noise barriers for roads and conventional railroad lines, but never before in sound absorbing panels for Shinkansen lines.

On the other hand, installing sound absorbing materials on tunnel entrance hoods is one of the major measures against environmental noise around Shinkansen tracks. It is possible to achieve a tangible noise reduction around the tunnel portal by applying sound absorbing material to the entire inner arch of the entrance hood. Compared with similar materials used in open sections, sound absorbing material installed in tunnel entrance hoods are subjected to punishing conditions. A particularly safe structure is also required to eliminate the risk of such material being fragmented and falling off from the ceiling of the tunnel entrance hood.

The microperforated aluminum panel would be a suitable solution to meet the above requirements. However, the conventional product for noise barriers is structurally insufficient in both terms of strength and acoustic performance. This is why we have used the microperforated aluminum panel to develop a new sound absorbing panel with a high-strength structure for Shinkansen tunnel entrance hoods. The new product is the first microperforated aluminum panel to be selected as a noise control material for Shinkansen trains. It can be used on the inner walls, including the ceiling, of Shinkansen tunnel entrance hoods for a substantial noise reduction. This paper describes the development and practical application of the new panel and presents a real-life installation of the technology.

1. Sound absorbing technology using microperforated aluminum

1.1 Structure and sound absorbing principles of the microperforated aluminum panel [1)]

Unlike fiber-based porous sound absorbing materials such as glass wool, microperforated aluminum panels consist of microperforated aluminum plates and air space only. In other words, they are comprised of metallic materials alone.

The panel technology exploits the basic principles of Helmholz resonance, in this case the acoustic resonance generated in perforations in the aluminum materials and air space behind them. It absorbs sounds by exploiting two phenomena:

1) Sound energy from noise and other sources is converted into frictional energy in perforations; and
2) Eddies generated by the reciprocal movement of air in perforations cause pressure losses.

Compared with conventional sound absorbing systems using acoustic resonance in perforated plates, this technology features very small perforations (1.5 mm or less in diameter), which increase friction damping in the holes, enabling the panel to absorb sounds over a broad range of frequencies.

Fig. 1 shows an example of microperforated aluminum panel structure. The multilayer structure is comprised of, in the order from the outermost facing the sound source, a surface microperforated aluminum plate, air space, inner microperforated aluminum foil, air space, and a noise insulation back

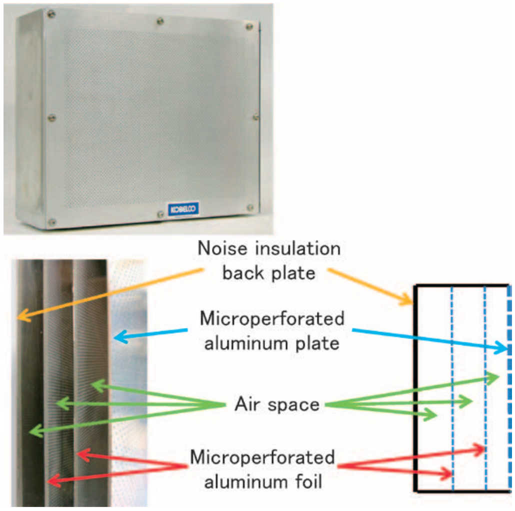

Fig. 1 Example of microperforated aluminum panel structure

plate. The multilayer structure of microperforated components gives the acoustic resonator multiple degrees of freedom, increasing the number of resonant frequencies and thereby ensuring a broader range of sound absorption.

1.2 Technical features

General features of a microperforated aluminum panel include:

1) Acoustic performance: sound absorption efficiency can be designed using parameters including the thickness, perforation diameter, and aperture ratio of the microperforated aluminum plate and foil as well as the thickness of the air space behind.
2) Strength properties: the panel features stable strength with no risk of components being fragmented and falling off.
3) Corrosion and weather resistance: it is suitable for prolonged outdoor use.
4) Burning quality: the panel is flame resistant.
5) Environmental compatibility: panel materials are recyclable without generating industrial waste.

In particular, the advantages, shown in items 2 to 5 above, over conventional fiber-based porous materials, which come from the fact that the entire panel comprises metallic materials alone, make the panel suitable for use in many different environments. It had therefore been developed and used in noise barriers for roads and existing railroad lines[2], but never before for Shinkansen tracks.

2. Development of a sound absorbing panel for use in Shinkansen systems

The above-mentioned features of the microperforated aluminum sound absorbing panel make it ideal for noise control near tunnel portals of Shinkansen systems. The panel's acoustic performance and strength properties, in particular, meet the relevant noise control requirements. These requirements and the details of the development project are presented in this chapter.

2.1 Noise near tunnel portals

While running on the track, Shinkansen trains generate various noise. To reduce the noise transmitted to surrounding areas, noise control measures for open rail sections (e.g., sections of elevated tracks), where direct transmissions from the train prevail, focus on noise barriers and others that address noise transmission paths. By contrast, measures implemented at tunnel portals must include more than direct noise control. The reason is that noise generated by the train passing through the tunnel reverberates in the tunnel and is emitted from the portal, which is combined with direct noise from the adjacent open section (**Fig. 2**). This is why it can be impossible to reduce overall noise near the tunnel portal by simply increasing the height of the noise barriers[3].

A similar phenomenon can be observed with a tunnel entrance hood (**Fig. 3**) installed to reduce tunnel booms generated as Shinkansen trains enter the tunnel. When tunnel portal emissions represent a large portion of near-portal noise, it is necessary to implement measures to reduce such emissions. A previous study[4] conducted using a model considers the possibility of reducing portal noise emissions by applying sound absorbing material to the entire inner arch of the entrance hood. The study shows that the soundproofing of these surfaces is particularly effective where the inner walls, e.g. ceiling, of the entrance hood can be seen through from the surrounding area.

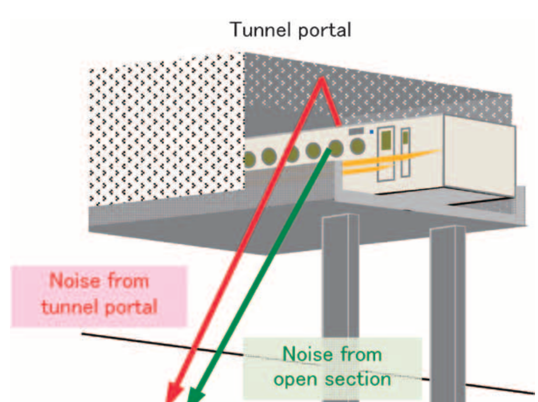

Fig. 2 Noise at points near tunnel portal

Fig. 3 Tunnel entrance hood for Shinkansen

To fulfill these noise control requirements, We used our microperforated aluminum sound absorbing technology to start developing a new sound absorbing panel for tunnel entrance hoods. The development processes and results of implementation are described in the following.

2.2 High-strength sound absorbing panel

2.2.1 Overview of new development

Fig. 4 shows the sound absorbing panel product for tunnel entrance hoods that has been developed in the project under review. The panel measures 990 mm in height and 969 mm in width (including fixtures), with a thickness of 100 mm (150 mm including fixtures). Component sheets other than microperforated aluminum plates are made of

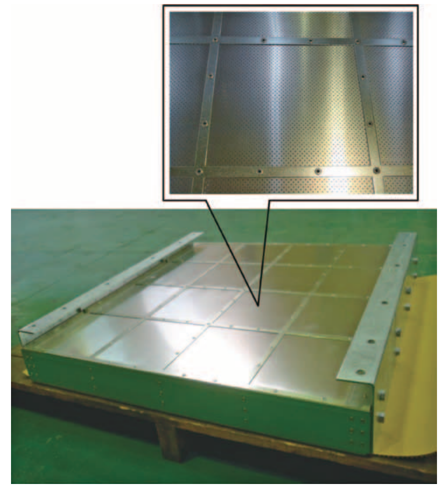

Fig. 4 Microperforated panel for tunnel entrance hoods

highly weatherable plated steel sheet, while fixtures are made of hot-dip galvanized steel. The weight of a single panel including the fixtures is as low as approximately 50 kg for easy handling during installation. To reflect the results of the strength design and endurance tests described below, the surfaces and inside areas of the sound absorbing panel are reinforced using steel members.

Fig. 5 shows general drawings of the new sound absorbing panel. During installation on a tunnel entrance hood, panels can be fed into installation beams (made of H-section steel) preinstalled in the main structure of the entrance hood and bolted onto the inner walls using locking nuts to ensure safety.

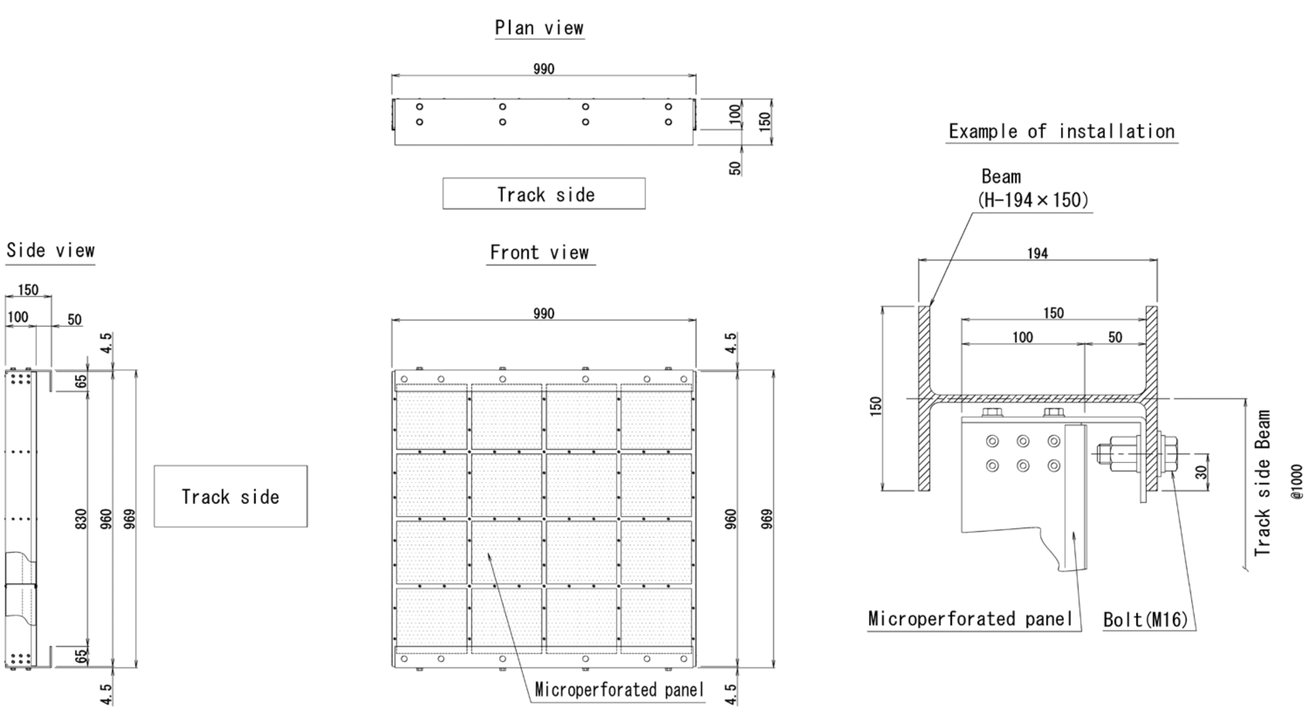

Fig. 5 General drawings of microperforated panel for tunnel entrance hoods

2.2.2 Development objectives

The development of the microperforated panel for inner walls of tunnel entrance hoods had three objectives to be achieved.

1) Design load: The panel must withstand a wind pressure of ±4.2 kPa in emergencies and ±2.1 kPa constantly.
2) Fatigue resistance: The panel must withstand three million repeated applications of a constant load of ±2.1 kPa.
3) Safety: The entire panel, including its fixtures and sound absorbing material, must consist solely of metallic materials to reduce the risk of the panel or broken pieces falling off.

By way of comparison, a design load of 3 kPa is specified for noise barriers installed on the side walls in open sections of Shinkansen tracks. One possible reason is that, unlike the partially closed space in tunnel entrance hoods, open sections are subjected to lower wind pressures. Another reason is that, located on the side walls of the track, such noise barriers are relatively easy to inspect and replace during maintenance work.

Compared with such noise barriers, the newly developed sound absorbing panel is more difficult to maintain, due to it being installed on the inner walls (including the ceiling) of Shinkansen tunnel entrance hoods, which cover part of the track entirely. It should also be noted that Shinkansen operators attach particular importance to safety. This is why we chose to employ microperforated aluminum sound absorbing panel technology; its stable strength and resistance to ageing were expected to help ensure safety. But again, the structure of the basic product, designed for roads and existing railroad systems, is insufficient in terms of strength and fatigue resistance. It was therefore necessary to design a more durable product and verify its suitability for the application in question.

2.2.3 Strength design

During the strength design of the new sound absorbing panel, the finite element method (FEM) was employed to analyze individual components in detail. In stress evaluation, we compared the stress values found in the analysis to be acting on members with allowable levels. Stress levels for microperforated plates and blind rivet joints were increased threefold for evaluation, by taking stress concentrations around the holes into account. **Fig. 6** shows the result of the FEM analysis.

The panel was analyzed on the assumption that the design loads for anomalies and normal situations

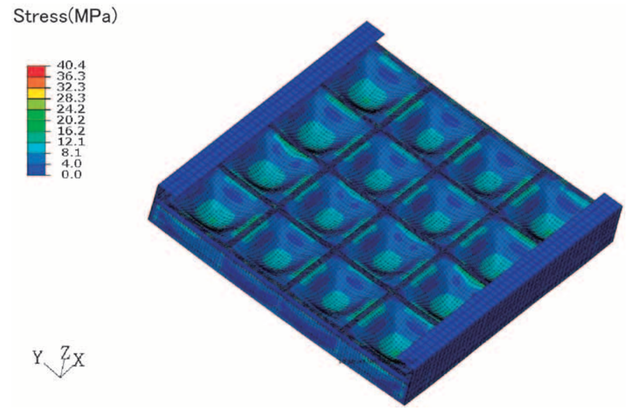

Fig. 6 Stress contours created by FEM analysis

shown in the previous section were applied to the panel's front and back surfaces. It was thus established that the stress acting on each member was not greater than the corresponding allowable level. It was also thus confirmed that, during the repeated applications of the load, the stress acting on each member did not surpass the corresponding fatigue limit. The above strength design phase of establishing the safety of the sound absorbing panel and its components was followed by endurance tests on real panels. These double testing procedures are designed for further verification of safety.

2.2.4 Endurance tests

1) Static load test

The microperforated panel was tested using sandbag weights to verify its safety against static loads. To accurately reproduce the panel structure as installed, test panel fixture samples included an installation beam and securing bolts. The front and back surfaces were each loaded with weights generating a pressure of 6 kPa, surpassing the design load for anomalies (4.2 kPa) and approximately 1.4 times the design load. **Fig. 7** shows the test of panel being subjected to the static load.

The test revealed that the panel was safe against the design load, causing no problems such as damage to or excessive deformation of any component.

2) Load fatigue test

A fatigue resistance test was required to verify the panel's safety against repeated load applications. It is practically impossible, however, to apply a pressure load repeatedly to the panel. As an alternative method, a panel loaded with weights was tested on a vibration test bench. Using a 150 kg sandbag, the weight was designed to generate a load equivalent to 3 kPa under an acceleration of 1 G. This load was applied to each of the panel's front and

Fig. 7 Static load test of microperforated panel

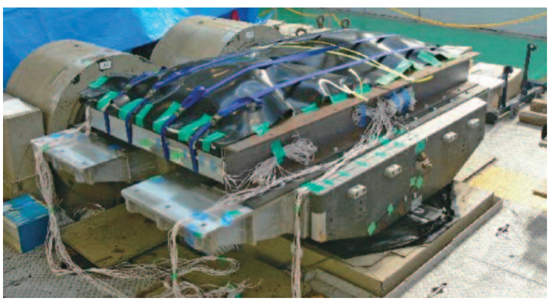

Fig. 8 Load fatigue test of microperforated panel

back surfaces three million times with a vibration frequency of 5 Hz. **Fig. 8** shows the panel during the load fatigue test.

The load fatigue test established that the panel was safe against the repeated load, causing no problems such as damage to or loosening of any component. In addition, the sound absorption performance of the microperforated panel was measured before and after the load fatigue test. **Fig. 9** shows the panel's sound absorption coefficient at normal incidence measured before and after the load fatigue test. It reveals that three million cycles of vibration causes no change in sound absorption coefficient.

Generally, the most vulnerable in structure are joints in surface microperforated aluminum plates fastened using blind rivets. The most punishing load conditions are generated by negative pressures from the inside of the microperforated panel to the track side. A similar trend was also observed during the FEM analysis described in the previous section. With a focus on the above-mentioned joints, a further load fatigue test was conducted under negative pressure load conditions. With a weight placed inside, the microperforated panel was vibrated three million times with a frequency of 5 Hz to apply a load generating a pressure of 2.1 kPa to the surface

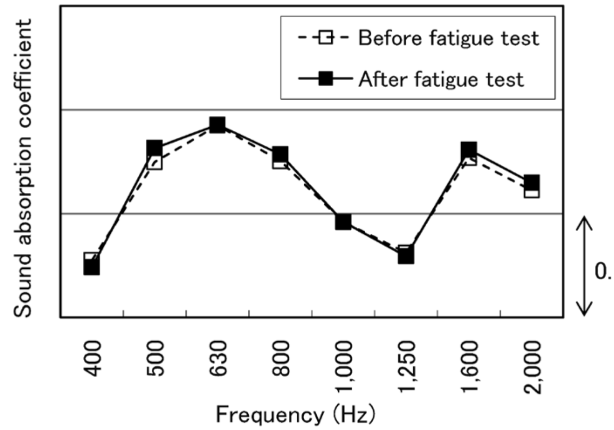

Fig. 9 Sound absorption coefficient after load fatigue test

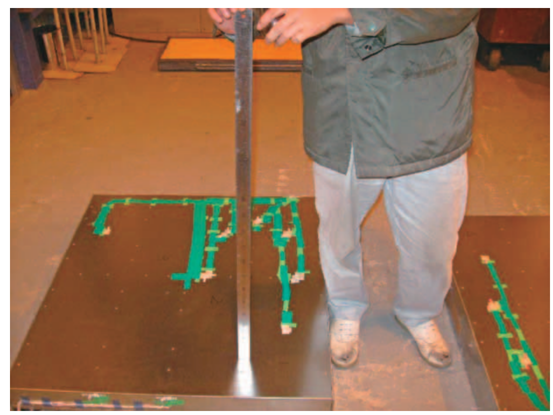

Fig.10 Impact test of microperforated panel

microperforated aluminum plate. Like the previous one, the second test shows no problems caused in the microperforated panel.

3) Impact test

Impact of foreign objects on the microperforated panel could cause components to be fragmented and fall off from the panel. An impact test was performed to verify safety in this regard. Specifically, an iron ball weighing 1 kg was dropped from a height of 1 m to hit several points on the front and back surfaces of the microperforated panel. **Fig.10** shows the panel during the impact test.

The impact test showed that the collisions only caused indentations in the impact surfaces, with no components broken and no fragments dropped off. Consisting entirely of metallic materials, down to the sound absorbing elements, the product can effectively prevent the components from being fragmented and falling off.

2.3 Acoustic performance

The "sound absorption coefficient in a reverberation room" (JIS A 1409, hereinafter simply "sound absorption coefficient") of the microperforated panel was measured using a real product. **Fig.11** shows the results. The panel's sound absorption coefficient reaches its peak around 800 Hz and remains 0.7 and above between 250 Hz and 4 kHz. This superb feature has been made possible by the panel's excellent acoustic design, which adapts sound absorbing performance to the frequency characteristics of Shinkansen noise sources. Using the real product, the test established that the microperforated panel has high sound absorption coefficients over a wide frequency range.

3. Application to a tunnel entrance hood

3.1 Installation in a real tunnel

The results of development described in the preceding chapter have made the microperforated panel technology the first of its kind to be used for noise control in a Shinkansen system. This section presents the real-life installation of the microperforated panel technology in a tunnel entrance hood [5), 6)].

3.1.1 Installation method

The tunnel entrance hood is 10 m in length and made of steel. Microperforated panels were installed over almost the entire length of the inner walls, including the ceiling, of the hood. **Fig.12** shows a view of microperforated panels being installed on the entrance hood, while **Fig.13** shows a view of the hood following panel installation.

The following is a brief description of the method employed to install the microperforated panels. First, set up a scaffold directly under the ceiling area where microperforated panels are to be installed. The reason is that the ceiling is as high as 8.5 m above the ground. A chain block is made available on top of the scaffold to hoist the materials. Use a crane to move the materials from outside the track close to the tunnel portal. Carry them further to the scaffold manually. Hoist the materials onto the top of the scaffold and install them as described above. Check the securing bolts for tightening torque and remove the scaffold. These steps are to be completed in a predefined nighttime period of a few hours during which no trains operate around the tunnel. The scaffold is installed and removed for each round of work. Working under these unusual operating conditions required great attention to safety. It took a few months to complete the installation work.

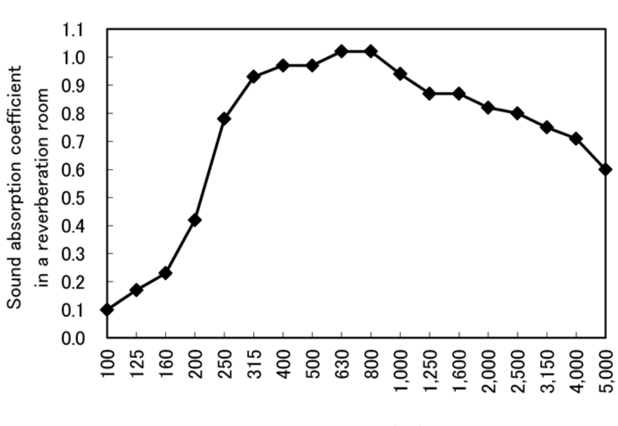

Fig.11 Sound absorption coefficient in a reverberation room


Fig.12 Installation of microperforated panels


Fig.13 Microperforated panels covering inner walls of tunnel entrance hood

3.1.2 Effects of microperforated panels

In parallel with the installation of microperforated panels, environmental noise levels were measured to see the effects of their installation. The work was executed to extend the sound absorbing installation step-by-step, starting from the tunnel side to the front edge of the entrance hood. The aim was to determine the relationship between an increase in sound absorbing installation length and the corresponding noise decrement.

During each test cycle, noise emissions from a total of 20 trains running in both directions were measured both before and after the increase in installation length. In ether phase, the ten highest values from among the maximum noise levels (Slow) measured from the 20 trains were power-averaged. The noise decrement was defined as the difference between both power average values. The above procedures were performed for several measuring points to see the distribution of amounts of noise reduction over a surface.

The above test showed that noise decrement tended to increase as the installation work progressed. Noise decrements varied depending on the measuring point locations. Points from which the inside of the entrance hood can be seen through registered greater noise decrements than the other points to which the above condition does not apply. A likely reason is that, at the see-through measuring points, tunnel portal noise emissions previously represented a large portion of near-portal noise. The increase in sound absorbing installation length therefore had a greater impact on noise levels. The completion of the entire design installation length led to a total noise decrement of up to approximately 4 dB, depending on the measuring point. By installing sound absorbing panels on the inner walls, including the ceiling, of the tunnel entrance hood, we have successfully achieved substantial reductions in near-portal noise levels.

3.2 Future developments

By installing sound absorbing panels on the inner walls, including the ceiling, of the tunnel entrance hoods described in the previous section, we have successfully achieved substantial reductions in near-portal noise levels. We believe it is necessary to improve this noise control method further for future applications. One possible way of improvement now under consideration is to implement soundproofing from outside the entrance hood [7]. The aim is to reduce installation work cost and improve safety and ease of maintenance. We are also studying possible improvements on the microperforated panel presented here. In addition, we will continue to increase the performance of technology for reducing noise emissions from tunnel portals.

Conclusions

This paper has presented the new sound absorbing technology developed using microperforated panels, which was adopted for use in a Shinkansen system for the first time. By taking advantage of the features of this noise control technology, such as acoustic performance and strength properties, we will develop more applications in traffic infrastructure including Shinkansen systems. We will build on the findings of the above development project and consider developing products that can accommodate environments which require even greater strength. We hope that this work serves environmental preservation purposes.

In developing the product, we received many useful pieces of advice from individuals from West Japan Railway Company and other organizations who were concerned with the project. We express our sincere thanks to these individuals.

References

1) I. Yamagiwa. *So-on Seigyo (Noise Control)*. 2012, Vol.36, No.6, pp.410-414.
2) T Yamada et al. *Nippon So-on Seigyo Kogakukai Kenkyuhappyokai Koenronbunshu 2007-9-12/13 (Proceedings of Meeting, the Institute of Noise Control Engineering of Japan, September 12/13, 2007)*. Nihon So-on Seigyo Kogakukai (Institute of Noise Control Engineering of Japan). 2007, pp.165-168.
3) K. Nagakura. *Tetsudo Soken Hokoku (Railway Technical Research Institute Report)*. 2013, Vol.17, No.11, pp.13-18.
4) S. Matsui et al. *Nippon So-on Seigyo Kogakukai Kenkyuhappyokai Koenronbunshu 2010-9-28/29 (Proceedings of Meeting, the Institute of Noise Control Engineering of Japan, September 28/29, 2010)*. Nippon So-on Seigyo Kogakukai (Institute of Noise Control Engineering of Japan). 2010, pp. 135-138.
5) S. Matsui et al. *Nippon So-on Seigyo Kogakukai Kenkyuhappyokai Koenronbunshu 2012-9-5/6 (Proceedings of Meeting, the Institute of Noise Control Engineering of Japan, September 5/6, 2012)*. Nippon So-on Seigyo Kogakukai (Institute of Noise Control Engineering of Japan). 2012, pp.281-284.
6) T. Nitta et al. *Doboku Gakkai Dai 67-kai Nenji Gakujutsu Koenkai Ronbunshu 2012-9-5/6/7 (Proceedings of the 67th Annual Conference of the Japan Society of Civil Engineers, September 5/6/7, 2012)*. Doboku Gakkai (Japan Society of Civil Engineers). 2012, pp.201-202.
7) K. Ikegashira et al. *Nippon Tetsudo Shisetsu Kyokaishi (Journal of the Japan Railway Civil Engineering Association)*. 2013, Vol.51, No.12, pp.929-931.