Proposal for Composite Acoustic Board for Reducing Traffic Noise from Tunnel Mouth

K. Yamada
Project Engineering Department, Gaeart T・K Co.,Ltd., Shinjuku, Tokyo, Japan

H. Yano
Faculty of Information and Computer Science, Chiba Institute of Technology, Narashino, Chiba, Japan

M. Owaki
Technical Research & Development Institute, Kumagaigumi Co., Ltd., Shinjuku, Tokyo, Japan

ABSTRACT: Noise control in consideration for communities located along roads is a crucial issue for road administrators. It is especially important for roads that run through mountains or underground, where traffic noise concentrate through multiple reflection in tunnels and radiates outward from the tunnel mouths. In areas where houses are built near a tunnel mouth, the noise sometimes leads to complaints from the residents. As a means to reduce traffic noise from tunnels, we have developed a composite acoustic board, which is a combination of an acoustic board made of recycled glass that is effective in absorbing engine noise typically occurring in the low frequency bands, and a porous concrete acoustic board that absorbs noise generated from air pumping friction between tires and surface of pavement (hereinafter referred to as "road noise") that mainly occurs in the high frequency bands. A superior noise reduction effect of this composite acoustic board was demonstrated in actual application and its effectiveness in reducing traffic noise from tunnels was confirmed.

KEY WORDS: Silent eco panel, noise reduction, tunnel mouth, composite acoustic board.

1 INTRODUCTION

Inside tunnels, engine noise from cars and road noise reverberates and the pressure level of the noise increases before it is released outside from the tunnel mouths, as the inner surfaces of tunnels generally do not have good sound absorption properties.

This sometimes results in noise pollution for residents living along tunnels with high traffic volume. Possible measures for controlling traffic noise from tunnels include the following:

(1) High-performance pavement with noise reduction effect (reduction of noise generation)
(2) Sound insulation walls (reduction of noise by sound diffraction)
(3) Environmental facility zone (reduction of noise through sound attenuation with distance)
(4) Traffic flow control (reduction of noise sources by restricting traffic or speed limits)

The most common environmental measure used today for controlling road traffic noise is (1), high-performance pavement with a noise reduction effect. This technology, however, is not particularly effective in absorbing noise in the low frequency range of 250 to 500 Hz mainly attributable to engine noise, while it has been found effective in absorbing noise in the frequency bands around 1 kHz regarded as the center frequency of road noise. Another disadvantage of this technology is that the sound absorption performance is prone to degradation due to the clogging of voids in the pavement surface, thus requiring regular maintenance such as pavement washing. There is a strong need for noise control methods that can guarantee reliable noise absorbing effect while being economical in many aspects including operation and maintenance.

The following is a report on "Silent Eco Panel," an acoustic panel that can be installed on relatively small areas (from the mouth of a tunnel to about 30 meters inside the tunnel) of the inner walls of tunnels, and has been proven to be effective in reducing noise in a relatively wide frequency range including engine and road noise emitted from inside tunnels.

2 OVERVIEW OF SILENT ECO PANEL

Silent Eco Panel is an acoustic system consisting of two different types of acoustic boards, and is highly effective in reducing diverse noise occurring in a wide frequency range. Silent Eco Panel is a combination of an Eco Sound Panel, a light-weight acoustic board made of recycled glass and has adjusted back air space for increased sound absorption performance especially effective in reducing noise in the low frequency bands, and a Silent Porous Panel, a highly durable acoustic board made of porous concrete with a superior performance in absorbing noise occurring in the frequency bands 1 kHz, the center frequency of road noise. Silent Eco Panel has a significant sound reduction effect on diverse noise sources, owing to its characteristic that the sound absorption coefficient for the dominant frequency bands can be adjusted by changing the ratio of the installation areas between the two types of acoustic panels. Both types of acoustic panels are highly drainage capability and therefore eliminate the risk of the degradation of sound absorption performance due to moisture, which has been the problem with conventional fibrous sound absorbing materials such as glass wool. Silent Eco Panel also offers easy maintenance.

2.1 Characteristics of Eco Sound Panel

Eco Sound Panel is an acoustic panel consisting of fired foam glass made from recycled glass as the main material, and it is light-weight and highly workable. The panel thickness is only 10 mm and the air space at the back of the panel can be changed easily. The sound absorption coefficient for the dominant frequency bands can be adjusted even with this panel alone, by changing the thickness of the back air space. The sound absorption performance of Eco Sound Panel has been found especially high in absorbing noise in the frequency bands between 250 and 500 Hz, the dominant frequency bands of engine noise, when the thickness of the back air space is set to 200 mm.

Photo 1: Front view of Eco Sound Panel (a set of two panels)

Table 1: Standard specifications of Eco Sound Panel

Material	Recycle glass
Panel size	1,000×1,000×10 mm
Weight	10 kg/panel

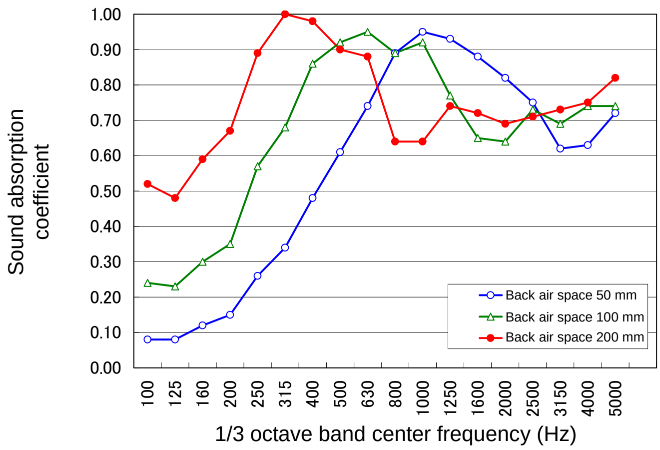

Figure 1: Sound absorption coefficient of Eco Sound Panel in a reverberation room

Table 2: Results of flexural strength test of Eco Sound Panel

Loading direction	Flexural strength (kgf/cm^2)	Flexural modulus (kgf/mm^2)
Obverse	150	460
Reverse	120	440

2.2 Characteristics of Silent Porous Panel

Silent Porous Panel is an acoustic panel made of porous concrete (permeable porous concrete) that is nonflammable and provides a high water drainage capability. Its sound absorption coefficient is particularly high in the vicinity of the frequency of 1 kHz, which is the center frequency of road noise, when the panel's back air space is set to 0 mm.

Photo 2: Silent Porous Panel

Table 3: Standard specifications of Silent Porous Panel

Material	Porous concrete
Panel size	1,000×500×50 mm
Weight	45 kg/panel
Porosity	24-30%
Maximum aggregate size	5 mm
Compressive strength	10 N/mm^2

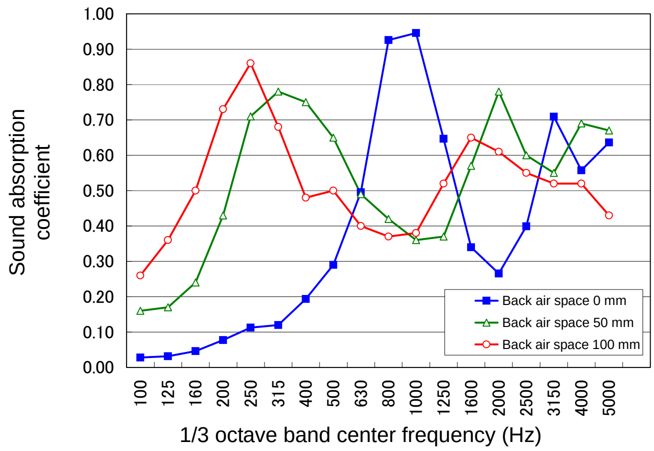

Figure 2: Sound absorption coefficient of Silent Porous Panel in a reverberation room

2.3 Silent Eco Panel combining Eco Sound Panel and Silent Porous Panel

As the specification to optimize the effectiveness of traffic noise reduction inside tunnels, we have determined that the thickness of the back air space for Eco Sound Panel and Silent Porous Panel should be set to 200 mm and 0 mm, respectively. With this specification, Eco Sound Panel is most effective in reducing noise in the frequency range of 250 Hz to 500 Hz consisting mainly of engine noise generated by vehicles, and Silent Porous Panel provides the best performance in reducing noise in the vicinity of the frequency of 1 kHz consisting mainly of road noise.

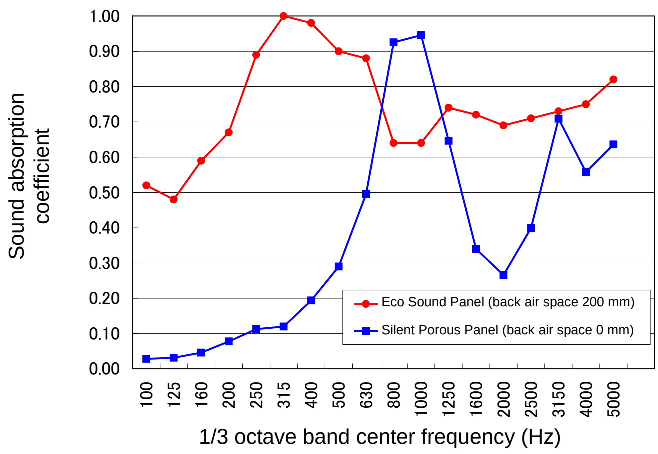

Figure 3: Sound absorption coefficient of Silent Eco Panel in a reverberation room

3 INSTALLATION AT NORTH CLEAN CENTER IN KYOTO CITY

3.1 Installation Summary and Preliminary Study

The installation of Silent Eco Panels took place from July to September 2006, at a tunnel near a waste disposal plant (Kyoto City North Clean Center) located in a quiet residential area in northern Kyoto City. The panels were installed on the inner walls immediately adjacent to the mouths (used for entrance and exit lanes) of the tunnel, which is built on a vehicle-only road for garbage trucks (packer trucks) entering and existing the Clean Center.

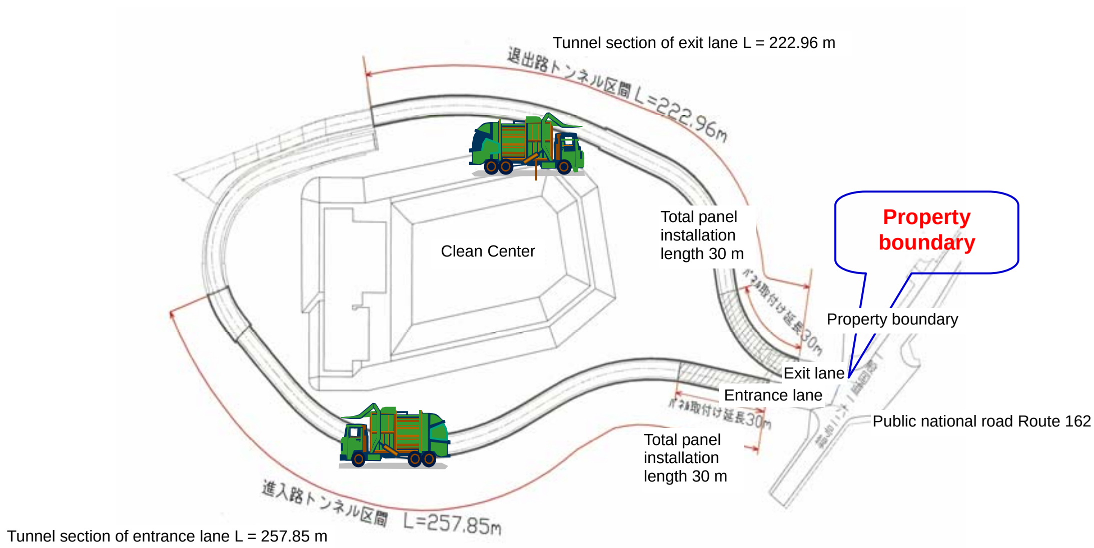

Figure 4: Overall plan view

The targeted level of this noise reduction measure was to reduce the noise generated by garbage trucks (packer trucks) travelling inside the tunnel by 7 dBA, when measured at the property boundary located 30 meters away from the mouths of the tunnel. Table 4 shows the result of the measurements taken inside the tunnel on the sound pressure levels of a packer truck (at a regular travelling speed) as the noise source. The measurements were taken at a location two meters from the noise source. As the result of a simulation using the panel configuration illustrated in Figure 5 and the prediction equations (1) - (3) with the tunnel mouth's square meters of 37.4 m^2 and the directivity factor of Q = 4, we have confirmed that the projected target level was achieved. The cross-sectional view of the standard installation specification is provided in Figure 6.

Table 4: Measurement result of packer truck noise

Unit:dB

	Octave band center frequency (Hz)						Noise level
	125	250	500	1k	2k	4k	
Measurement data	73	74	76	79	78	73	83

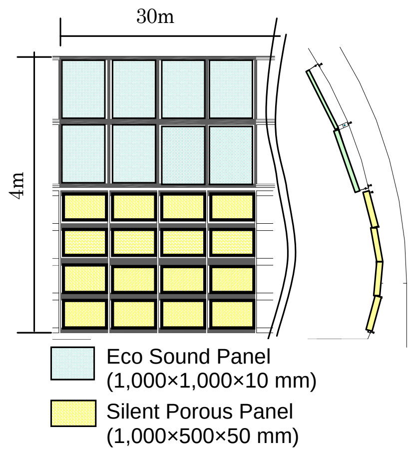

Figure 5: Front and side views of installed panels

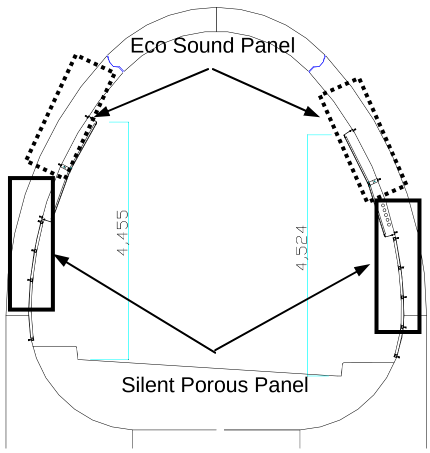

Figure 6: Cross-sectional view of standard installation specification

- Prediction equations

$$L_{p0} = L_w + 10\log_{10}(Q/4\pi r_0^{\ 2} + 4/R) \tag{1}$$

L_{p0}: Sound pressure level inside the tunnel measured at a location r_0(m) from the sound source (dB)

Lw: Power level of the sound source (dB)

Q: Directivity factor of the sound source

r_0: Distance between the sound source and the sound receiving point (m)

R: Room constant (Sα/(1-α)) (α: average sound absorption coefficient, S: total surface area (m^2))

$$L_{w1} = L_{p1} + 10\log_{10}(S_1) \tag{2}$$

L_{w1}: Power level at the tunnel mouth (dB)

L_{p1}: Sound pressure level at the tunnel mouth (dB)

S_1: Square measure of the tunnel mouth (m^2)

$$L_{p2} = L_{w2} + 10\log_{10}(Q / 4\pi r_1^{\,2}) \tag{3}$$

L_{p2}: Sound pressure level measured at a location r_1(m) from the tunnel mouth (dB)
L_{w2}: Power level at the tunnel mouth (dB) (=L_{w2}+10$\log_{10}$(S_{w1}))
(S_{w1}: Wall surface area (m^2))
r_1: Distance between the tunnel mouth and the sound receiving point (m)

3.2 Confirmation of Installation Result

Measurements were taken before and after the installation to confirm the sound absorbing effect of the panels. The swept-sine method was used for the measurement in anticipation of the high level of background noise due to the traffic on the national road in front of the tunnels. The measurements were taken by transmitting a swept-sine signal at each predetermined sound source point for the duration of 10 seconds for several times, and recording the signal at each measuring point with a nondirectional microphone. The results were analyzed to calculate the impulse response. With this method, measurements are less sensitive to the influence of background noise than conventional octave-band noise method. The measurement results were used to calculate the single-event sound pressure exposure levels to compare the noise reduction effect prior to and following the installation of the panels. The measurement results of the noise reduction effect at the tunnel mouth before and after the panel installation are charted in Figure 8.

Sound source points: 5 m (S1), 20 m (S2), 35 m (S3), 50 m (S4), 65 m (S5), 80 m (S6) and 95 m (S7) from the tunnel mouth
Sound receiving points: tunnel mouth (M1), 13.5 m (M2) from the tunnel mouth, and property boundary (M3)

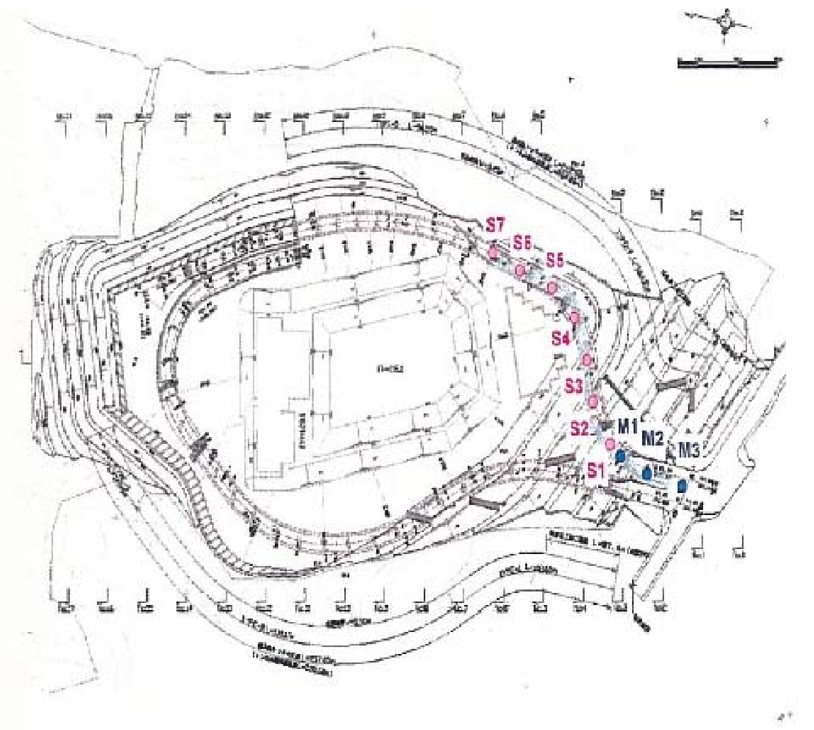

Figure 7: Measurement equipment arrangement plan

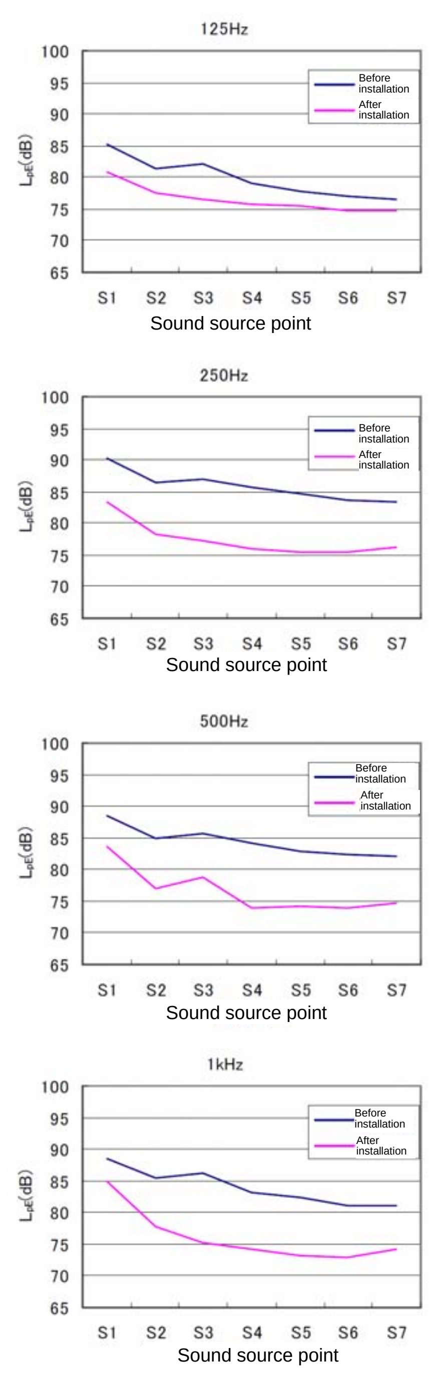

Figure 8: Measurement results prior to and following the panel installation

The following findings have been identified through the results presented in Figure 8:

1) A significant reduction in the single-event sound pressure exposure levels was confirmed after the acoustic treatment.
2) By using the swept-sine method, stable measurement results can be obtained even in areas with high background noise on account of heavy traffic.
3) The effectiveness of the panels was found high even in reducing noise from sound source points located further down the tunnel from the panel installation area, with reduction effect of more than 5 dB in a wide range of frequency bands.

Measurements were also taken by having an actual packer truck driving through the tunnel. As a result, the noise reduction effect of 9 dBA was recorded at the property boundary, which demonstrated a satisfactory level of performance compared with the predicted level of 7 dBA.

Photo 3: Before the installation of acoustic panels (exit lane)

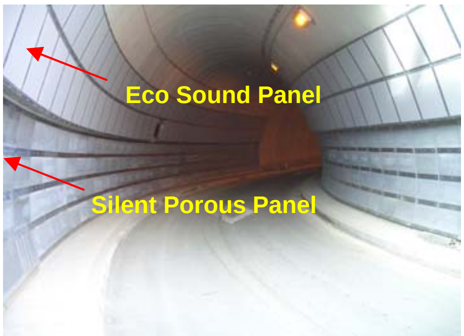

Photo 4: After the installation of acoustic panels (exit lane)

Photo 5: View of completed panel installation (left: entrance lane, right: exit lane)
(Taken from near the property boundary)

4 CONCLUSIONS

The properties of the materials for newly developed Silent Eco Panel were presented.

Silent Eco Panels were installed at the Kyoto City North Clean Center and the effectiveness of the panels was verified.

The close similarity was confirmed between the noise reduction target projected at the design stage of the tunnel and the actual noise reduction level achieved after the Silent Eco Panels were installed at the mouths of the tunnel.

Silent Eco Panels were installed on a road located in a mountain area of Nagano Prefecture during a period of October to November 2008. As in the case in Kyoto, the panels were applied to the inner walls of a tunnel from the tunnel mouths to 30 meters inside the tunnel.

Due to the fact that the tunnel was located on a public road, measurement methods that use speakers thus requiring a road closure for a certain period of time could not be used. Measurements were therefore taken by using vehicles equipped with measuring instruments and performing in-vehicle measurements of noise before and after the installation of the acoustic panels in the tunnel. Measurements were conducted using several vehicles and at different travelling speeds, and the results confirmed the noise reduction effect of 5-12 dBA compared to the levels observed prior to the panel installation.

Photo 6: Scenery along the road

Photo 7: View of completed installation

REFERENCES

1.Japan Concrete Institute. *Research Committee Report for the Establishment of Design and Construction Method for Porous Concrete.* Hokosha Corporation. May 2003.

2.Japan Concrete Institute. *Eco-Concrete Research Committee Report.* November 1995.

3.M .Owaki, A.Ito, H.Tanaka, S.Kondo and H.Goto. *Study on the Acoustic Property of Porous Concrete.* Synopses of the 61st Japan Society of Civil Engineers Annual Scientific Lectures. September 2006.

4. H.Tachibana and H.Yano. *Measurement of Environmental Noise and Architectural Acoustics.* Corona Publishing Co., LTD. March 2004.

5. H.Goto, M.Owaki. and H.Yano.*Study on Measures for Reducing Noise Radiation from a Tunnel Mouth.* The 27th Japan Road Congress. October 2007.

6. H.Yano, S.Yokoyama, H.Tachibana, and M.Owaki. *The effect of reducing noise radiation from a tunnel mouth by sound absorption treatment,* INTER-NOISE 2007, August 2007 (ISTANBUL, TURKEY)