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LOW-FREQUENCY NOISE RADIATED FROM A HIGH-SPEED TRAIN RUNNING IN AN OPEN SECTION

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Abstract

When a high-speed train runs in an open section, low-frequency noise is radiated from the train toward the way-side area. The observed low-frequency noise, which is defined here as the noise of below 80Hz including the infrasound of 1-20Hz, consists of hydrodynamic pressure variation (also called a "train passing pseudo-sound") around the nose and tail part of the train and acoustic pressure wave (also called a "low-frequency pressure wave") by aerodynamic sound of the train as well as vibrating surfaces of a viaduct structure. We investigated the characteristics of the way-side low-frequency noise by conducting field measurement in the wide range of the train speed of 150~400 km/h. From the measured characteristics of spectra, distance attenuation and velocity dependency, the major component of the low-frequency pressure wave is found to be aerodynamic sound emitted from a line source, in a high-speed region of over 350 km/h in the far field.

INTRODUCTION

When a high-speed train (called "Shinkansen" in Japan) runs in an open section, low-frequency noise is radiated from the train toward the way-side area. The observed low-frequency noise, which is defined here as the noise of components below 80Hz including the infrasound of 1-20Hz, consists of hydrodynamic pressure variation and acoustic pressure wave as shown in Figure 1.

The hydrodynamic pressure variation (also called a "train passing pseudo-sound") is caused by the moving quasi-steady pressure field around the nose,

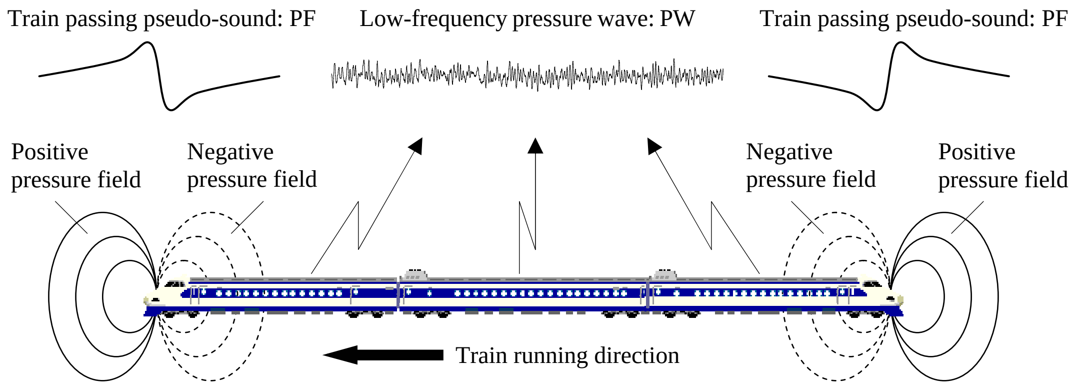

Figure 1 - Schematic of train passing pseudo-sound and low-frequency pressure wave

tail, and other uneven part of the train. We use an acronym PF (Pressure Field) for this phenomenon in this paper. On the other hand, the acoustic pressure wave (also called a "low-frequency pressure wave") is caused by the sources whose strength varies with time such as unsteady disturbed flow around the train and vibrating surfaces of a viaduct structure. We use an acronym PW (Pressure Wave) for this phenomenon.

In the past, we measured the wayside low-frequency noise caused by trains running in a fully open section in the range of train speed of 240~340 km/h [1][2]. The measurements were carried out based upon the manual issued by the Ministry of the Environment of Japan in October 2000 [3]. The measured results showed that major component of the low-frequency noise in the near field was the PF (the train passing pseudo-sound) and that in the far field was the PW (the low-frequency pressure waves). However, the causes of the PW still remained to be fully clarified.

In this study, we investigate the characteristics (spectra, velocity dependency and distance attenuation) of the way-side low-frequency noise by conducting field measurement in the wider range of train speed of 150~400 km/h than the previous measurements.

FIELD MEASUREMENT

The field measurement was performed at the site close to a viaduct of Shinkansen in a fully open air section as shown in Figure 2. The viaduct is about 15 m high and each girder is 30 m length, with simple straight sound barriers of 1 m height attached to both sides of the viaduct. The track alignment is straight and the track structure is a non-ballasted slab type.

The low-frequency noise was measured with two types of low-frequency sound pressure level meter, namely RION XN-12A (a measurement frequency range is 0.2 ~ 1,000Hz) and RION NA-18A (1 ~ 500Hz) [4]. Four measurement points M1, M2, M3 and M4 with RION XN-12A were located at 4 m, 12.5 m, 50 m and 75 m respectively from the center line of the down-track, the only point M1 was on the viaduct. The point M5 with RION NA-18A was located at just under the center line of the viaduct, and the

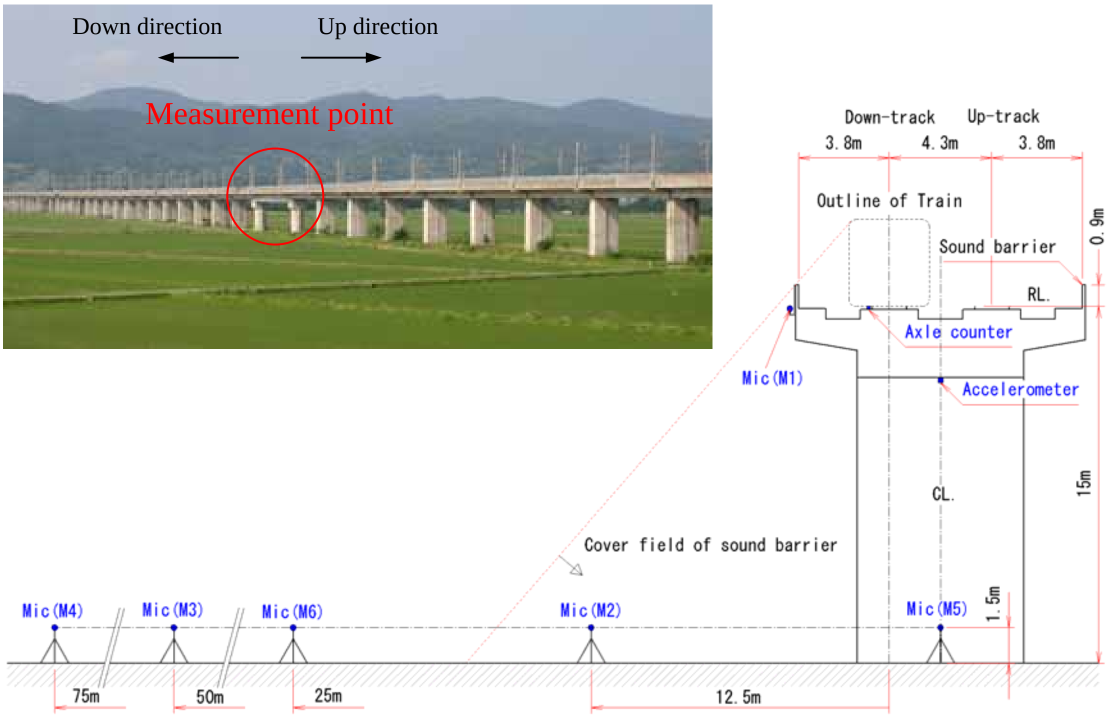

Figure 2 - Measurement points

M6 with RION NA-18A was located at 25 m from the center line of the down-track. In addition, viaduct vibrations were measured with RION UV-05 vibration level meter on the lower surface of the girder. The measured data were recorded as time histories of sound pressure and vibration acceleration, from which we are able to obtain SPL (Sound Pressure Level), VVL (Vibration Velocity Level), spectra of 1/3 octave band and spectrogram.

Table 1 shows the specifications of measured Shinkansen trains. There are three types of train, type-A and type-B are commercial trains and type-C is experimental train which can run much faster than type-A and type-B. Type-A train is usually coupled to type-B; for a down-train, type-A is in the front side, and type-B is in the rear side.

Results of Sound Pressure and Viaduct Vibration

The left side of Figure 3 shows the time histories of sound pressure value and the SPLs

Table 1 - Specifications of the trains

Train	Type-A	Type-B	Type-C
Cross-sectional area	10.3 m^2	11.2 m^2	10.8 m^2
Nose length	6 m	8.9 m	16 m
Overall length	146 m (6 cars) + 250 m (10 cars)		200 m (8 cars)
Speed range	150 - 275 km/h		280 - 400 km/h

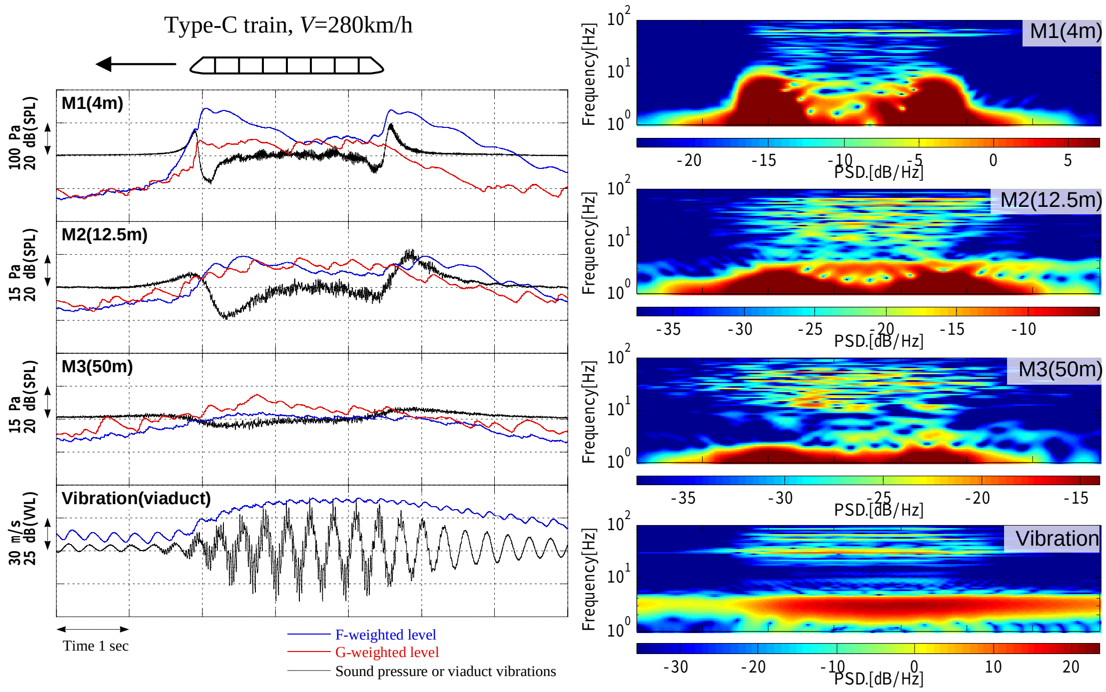

Figure 3 - Time histories of SPL, VVL, sound pressure and viaduct vibrations (Type-C train, V=280 km/h)

of low-frequency noise (F-weighted: flat in 1 - 100 Hz and G-weighted: ISO7196 [5]). This figure also shows the time histories of viaduct vibration velocity (calculated by integrating the measured vibration acceleration) and the VVL. The constant in time weighting for the sound and the vibration level is 0.125s (FAST). The right side of Figure 3 shows the spectrogram of sound pressure and viaduct vibrations. In this figure, the horizontal axis and the vertical axis indicate observation time and frequency respectively, and power spectrum density is shown by the color mapping. Figure 3 is based on the measurements of the down-train of type-C at the speed of 280 km/h.

A large pressure variation due to the passage of train nose and tail corresponds to the PF (the train passing pseudo-sound). On the other hand, pressure waves of small amplitude occurring during the passage of train intermediate part corresponds to the PW (the low-frequency pressure wave). The F-weighted SPL exhibits two distinct peaks at the train nose and tail corresponding to the PF in the near field (M1 and M2). However, the PF significantly decreases in the far fields (M3), and the F-weighted SPL shows only one gradual flat-top peak at the intermediate part of the train corresponding to the PW. The G-weighted SPL doesn't exhibit distinct peak at any measurement points.

As shown in the spectrogram of sound pressure, the infrasound by the PF is dominant in the near field (M1) at the passage of train nose and tail. But, in the far filed (M3), the PF damps, and the 10~80 Hz sound pressure waves by the PW are observed during the passage of the train intermediate part. There is not a difference of amplitude of the PW depending on the position of a part of the train.

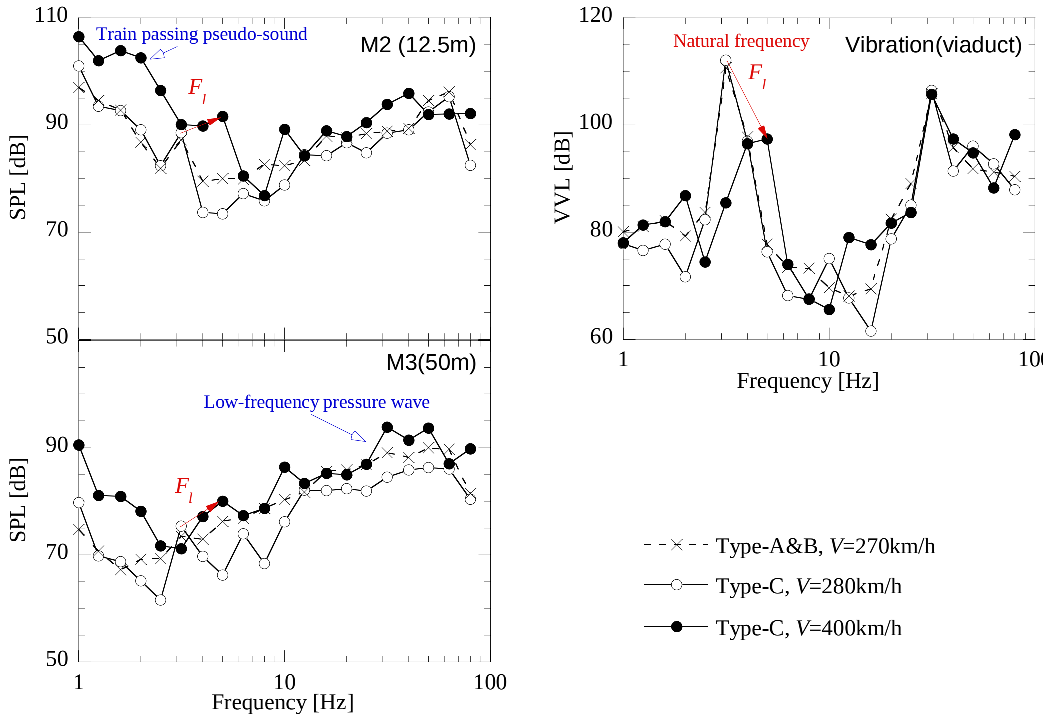

Figure 4 - Spectra of 1/3 octave band

On the other hand, about 3 Hz viaduct vibrations continue before and after the passage of the train and a primary natural frequency of the viaduct is regarded as about 3 Hz. It is an approximately proper value, considering that the natural frequency of usual viaducts is measured as 3-6 Hz [6]. The viaduct vibrations during the train passage become a remarkable magnitude of more than 40 m/s in the case of train speed 280 km/h because of resonance, while they remain small in the case of slower or faster than 280 km/h (not shown here).

Analysis of 1/3 Octave Band Spectra

Figure 4 shows the examples of measured spectra of 1/3 octave band for the low-frequency noise and the viaduct vibrations. The SPL and the VVL of each band in Figure 4 are the maximum value measured during the passage of the down-train. The infrasound below 3Hz by the PF is seen, and a wide peak of 20~80 Hz by the PW is seen in the far field (M3).

We have regarded that the PW is caused by a structural vibratory sound from the viaduct as well as an aerodynamic sound from the train. The repeated wheel loads with the passage of the train act as vibration forces on the viaduct, and the structural sound is generated by superposition of several resonances of the viaduct vibrations. In the case of a concrete viaduct, it is thought that the structural sound is dominant in the infrasound because of large size and heavy weight of the structure. The frequency that is determined from the axle arrangement which is expressed as F_l, is calculated by the train speed divided by the body length. This value of F_l in the case of train speed

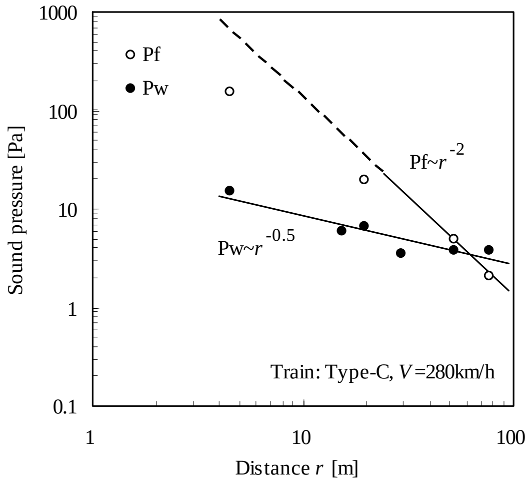

Figure 5 - Relation between distance and representative value (PF: train passing pseudo-sound, PW: low-frequency pressure wave)

V=270 ~ 280 km/h almost accords with the natural frequency of the viaduct vibrations estimated from Figure 3. Therefore, we can see that the viaduct resonates at 3 Hz and the vibrations grow large in this frequency range. When the train speed is higher than 280 km/h, the F_l shifts from the natural frequency of the viaduct to the high frequency side, so that the amplitude of vibrations at F_l is attenuated. However, the amplitude of sound pressure level at F_l grows large. The reason can be that the structural sound by the viaduct vibrations has a different emittance rate depending on frequency.

By comparing the sound spectra in the case where only aerodynamic shape is different, but a structural sound is almost the same, we can estimate the contribution from the aerodynamic sound. As type-A+B (V=270 km/h) is approximately equal to type-C (V=280 km/h) in train speed and wheel load, two types of train will cause almost the same viaduct vibrations, except for 4~10 Hz where a difference of the each train body length has an effect. Therefore, it is thought that type-A+B (V=270 km/h) is approximately equal to type-C (V=280 km/h) with respect to the structural sound, except for 4~10 Hz. However, in the far field (M3), there is a clear difference in the sound pressure of 20~60 Hz. The difference is presumed to be caused by an influence of the aerodynamic sound from the train. From the measurement points in the near field, the difference in the sound pressure level caused by the aerodynamic sound is not clear, because the train is blocked by the viaduct and the sound barrier as shown in Figure 2 and the structural sound probably has directivity.

Analysis of Distance Attenuation and Velocity Dependency

As mentioned before, the low-frequency noise due to the passage of the train consists of the PF and the PW. Two phenomena overlap in the measured data, so that it is necessary to separate two phenomena for calculating each characteristic. As the two phenomena are different in duration and frequency, representative value of each phenomenon can be obtained by an appropriate band pass filter. Dominant frequencies

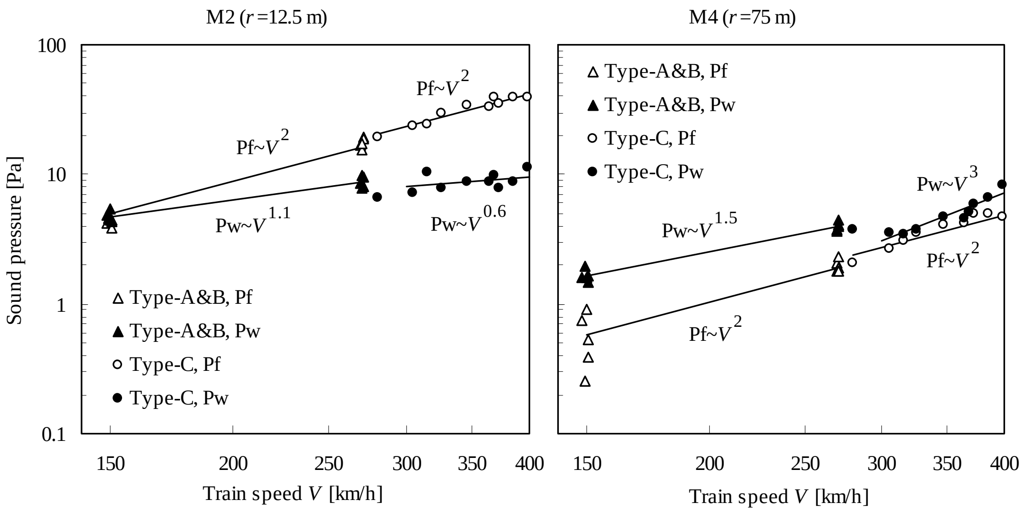

Figure 6 - Relation between train speed and representative value (PF: train passing pseudo-sound, PW: low-frequency pressure wave)

of the PF and the PW are estimated from the frequency analysis shown in Figure 3, and cut-off frequencies of the filtering are set to 0.1~10 Hz for the PF and 10~100 Hz for the PW. The PF after the filtering exhibits a wave pattern of a positive pulse followed by a negative pulse in the nose part (signs are reversed in the tail part), so that a representative value of PF is defined as a peak (for a positive pulse) to peak (for a negative pulse) value. On the other hand, the PW after the filtering is continuous pressure wave in the train intermediate part, so that a representative value of PW is defined as the maximum of amplitude of individual wave, namely the maximum of the difference between local minimum value and next local maximum value.

Figure 5 shows the distance attenuation of representative values of the PF and the PW for the down-train of type-C, V=280 km/h. Here, r is the distance from the train center to each microphone. The distance attenuation of PF is obtained from the measurements in the far field only (M3 and M4), because the PF observed in the near field is influenced by the viaduct and the sound barrier which block the train, and also by the nose shape of the train. As a result, the distance attenuation of PF is equal with the theoretical attenuation of r^{-2} [7]. The distance attenuation of PW is similar to the theoretical attenuation of an acoustic line source of $r^{-0.5}$. When the absolute values are compared in the near field, the PW is much smaller than the PF, but in the far field, the PW is larger than the PF because of the difference of distance attenuation.

Figure 6 shows the velocity dependency of representative values of the PF and the PW for the down-train. The velocity dependencies are obtained for the two cases, namely the speed range of 150~270 km/h of type-A+B and the speed range of 300~400 km/h of type-C. The reason why we countered the two cases is that there is some possibility that a dominant contribution to the low-frequency noise will change by train type and speed range. As a result, the velocity dependency of PF is equal to the theoretical dependency of V^2 [7] in the all case of train type, speed range and measurement points. The velocity dependency of PW in the near field is similar to the empirical dependency of a structural sound of $V^{1\text{-}1.5}$ [8], but in the far field in a high-speed region, it is similar to the theoretical dependency of aerodynamic sound of V^3. Such a difference between the measurement distance points is considered to be caused by the influence that the aerodynamic sound is blocked by the viaduct and the sound barrier in the near field and that the structural sound has directivity. Therefore, the major component of the PW is found to be aerodynamic sound emitted from a line source, in a high-speed region of over 350 km/h in the far field.

CONCLUSIONS

In this study, we investigated the characteristics of the way-side low-frequency noise based on the results of field measurement in the wide range of train speed of 150~400 km/h. The observed low-frequency noise consists of the train passing pseudo-sound (PF) around the nose and tail part of the train, and the low-frequency pressure wave (PW) by the aerodynamic sound of the train as well as the vibrating surfaces of the viaduct structure. From the measured characteristics of spectra, distance attenuation and velocity dependency, the major component of the PW is found to be aerodynamic sound emitted from a line source, in a high-speed region of over 350 km/h in the far field.

REFERENCES

[1] Kikuchi, K., Takasaki, T. and Iida, M., Characteristics of low-frequency pressure waves radiated from a train passing an open section (in Japanese), Transactions of the Japan society of mechanical engineers, Series B, **70**-691 (2004), 672-677.

[2] Kikuchi, K., Iida, M., Takasaki, T. and Takami, H., Field measurement of wayside low-frequency noise emitted from tunnel portals and trains of high-speed railway, Journal of low frequency noise, vibration and active control, **24**-4 (2005), 219-231.

[3] The ministry of the environment of Japan, Manual for measuring low-frequency noise (in Japanese), (2000).

[4] Iwahashi, K. and Ochiai, H., Infrasound pressure meter and examples of measuring data, Journal of low frequency noise, vibration and active control, **20**-1 (2001), 15-19.

[5] ISO7196, Acoustics-frequency weighting characteristics for infrasound measurements, (1995), 1-6.

[6] Ohashi, K. and Nishimura, T., Relation between static displacement and natural frequency (in Japanese), Kouzoubutsu sekkei shiryo, **49** (1977), 6-9.

[7] Kikuchi, K. and Iida, M., Simple numerical method to calculate pressure fluctuation due to train passage (in Japanese), Transactions of the Japan society of mechanical engineers, Series B, **71**-708 (2005), 2022-2029.

[8] Nagakura, K. and Zenda, Y., Prediction model of wayside noise level of Shinkansen, Wave2002, A.A.Balkema Publishers, (2003), 237-244.