Characteristics of Compression Wave generated by a High-speed Train entering Tunnel

Mashimo, Shinya
West Japan Railway Company Ltd.

Iwamoto, Kengo
West Japan Railway Company Ltd.

Aoki, Toshiyuki
Department of Energy Conversion Engineering, Interdisciplinary Graduate School of Engineering Sciences, Kyushu University

Matsuo , Kazuyasu
Department of Energy Conversion Engineering, Interdisciplinary Graduate School of Engineering Sciences, Kyushu University

https://doi.org/10.15017/17419

出版情報：九州大学大学院総合理工学報告. 18 (4), pp.297-302, 1997-03-01. 九州大学大学院総合理工学研究科

九州大学大学院総合理工学研究科報告
第18巻 第4号 297-302頁 平成9年3月

Engineering Sciences Reports, Kyushu University
(KYUSHU DAIGAKU SOGORIKOGAKU KENKYUKA HOKOKU)
Vol. 18, No. 4 pp. 297 - 302 MAR. 1997

Characteristics of Compression Wave generated by a High-speed Train entering Tunnel

Shinya MASHIMO*, Kengo IWAMOTO*, Toshiyuki AOKI**
and Kazuyasu MATSUO**

(Received November 30, 1996)

When a high-speed train enters a tunnel, a compression wave at the inlet of the tunnel is generated ahead of the train and propagates along the tunnel. When this wave attains the outlet of the tunnel, part of it is emitted outward from the outlet as an impulsive noise. Entry compression waves are measured in actual Shinkansen tunnels. The effects of the shape of train head and structure of the track are clarified. Furthermore, the propagating compression waves are measured at plural locations in the tunnel and characteristics of compression wave propagated along the tunnel are clarified.

1. Introduction

When a high-speed train enters a tunnel, a compression wave at the inlet of the tunnel is generated ahead of the train and propagates along the tunnel as shown in **Fig.1.** When this wave attains the outlet of the tunnel, part of it is emitted outward from the outlet as an impulsive wave, which causes an impulsive noise. According to the aeroacoustic theory, the sound intensity of the impulsive noise emitted from the outlet is proportional to the maximum time rate of pressure rise by compression wave that has attained at the outlet, not the strength of compression wave [1]. In order to estimate the sound intensity of the impulsive noise and take useful measures to reduce it, it is important to clarify the formation mechanism of compression wave generated at the inlet of the tunnel (called entry compression wave bellow) and the characteristics of compression wave propagated along the tunnel (distortion and attenuation).

In this paper, entry compression waves are measured in actual Shinkansen tunnels. The formation process of entry compression wave in actual tunnel are examined, and the effects of the shape of train head and structure of the track are clarified. Furthermore, the propagating compression waves are measured at plural locations in the tunnel and characteristics of compression

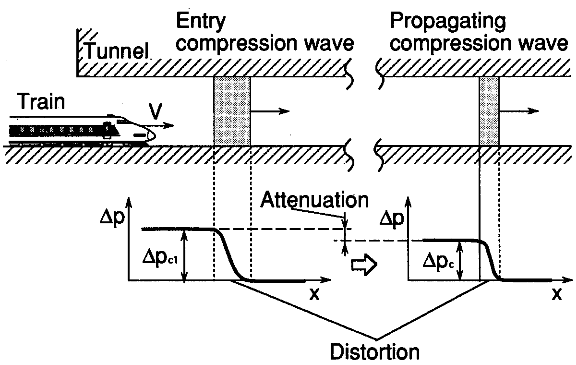

Fig. 1 Schematic sketch of entry compression wave and propagating compression wave in a tunnel.

*West Japan Railway Company Ltd.
**Department of Energy Conversion Engineering

Table 1. Test tunnels

Tunnel	L (m)	x_1 (m)	x_2 (m)	x_3 (m)	Track
A	3409	60	3329		Slab
B	346	60			Ballast
C	5132	200			Slab
D	8488	103	3261	6073	Slab
E	16250	80	11000	16170	Ballast
F	3207	100	3157		Slab
G	5389	90	5299		Slab
H	6822	100	3500	6700	Slab
I	8900	60	8830		Slab

wave propagated along the tunnel, i.e., distortion and attenuation, are clarified.

2. Field Tests

In this paper, compression waves are measured in actual tunnels as shown in **Table 1.** L is the length of the tunnel, x_1, x_2, x_3 are the distances between the inlet of tunnel and each measured points. The structure of ballast track is that railroad ties are set on the spread ballast, and rails are laid on the railroad ties. The structure of slab track is that concrete planks, called slab, are used in place of ballast, and rails are laid directly on it. A hood is set up around the inlet of tunnel C. In all tunnels, the line is double track, and the cross-sectional area of the tunnel A_1 is 63.4 km^2. There are two car types I and II of train which are used in this paper [2].

3. Results and Discussion

3.1 Wave forms

The pressure history with time at measured points x_1,x_2, and x_3 in tunnel D (slab track) are shown in **Fig. 2 (a)-(c)**, respectively, when the train of car type II entered it at a velocity of 215 km/h. The axis of ordinates and abscissa represent the gauge pressure and the time that is a arbitrary time, respectively. The figure shows that the longer distance the compression wave is propagated, the more it is attenuated. The maximum time rate of pressure rise of compression wave become larger in the order of **Fig. 2(a)-(c)**. On the other hand, the measured pressure history with time at measured points x_1, x_2 and x_3, in tunnel E (ballast track) are shown in **Fig. 3(a)-(c)**, when the train of car type I entered it at a velocity of 214 km/h. The axis represents same as in **Fig. 2**. The tendency of attenuation in ballast track tunnel is more remarkable than it in slab track tunnel in **Fig. 2.** The maximum time rate of pressure rise of compression wave are smaller in the order of **Fig. 3 (a)-(c)**. But this tendency is reverse to that of slab track tunnel in **Fig. 2**.

3.2 Strength of the Entry Compression Wave

The strength Δp_{c1} of entry compression wave by trains I and II, in the case of tunnels A and B against train velocity V are shown in **Fig. 4**. The meaning of marks in this figure are shown in **Table 2**. The solid and dotted lines represent the theoretical values for the train I and II, respectively, using the formula [2]

$$\Delta p_c=\frac{1}{2}\gamma p_1 M_t^2\left[\frac{1-\phi^2}{\phi^2+(1-\phi^2)M_t-M_t^2}\right] \qquad (1)$$

where γ is the ratio of specific heats of the air, p_1 is atmospheric pressure, M_t ($\equiv V/a_1$, a_1 is sonic speed of air) is train Mach number and ϕ ($\equiv(A_1-A_2)/A_1$, A_2 is the cross-sectional area

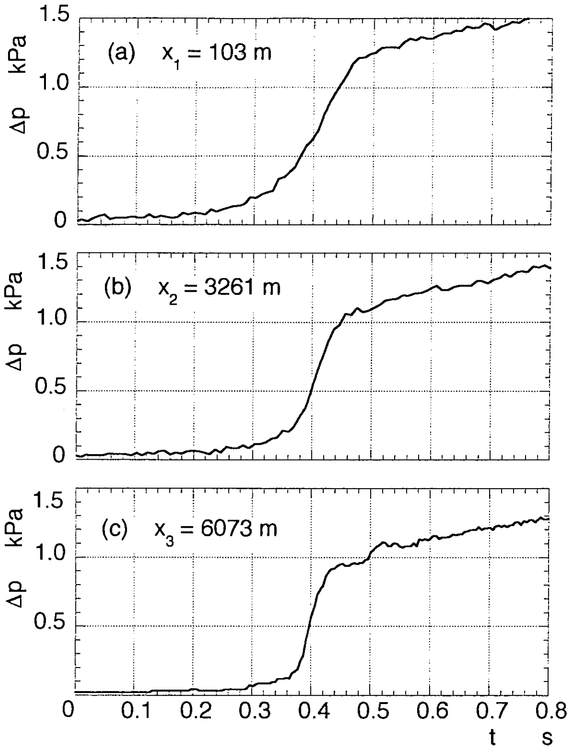

Fig. 2 Pressure history with time at points x_1, x_2 and x_3 in tunnel D (slab track).

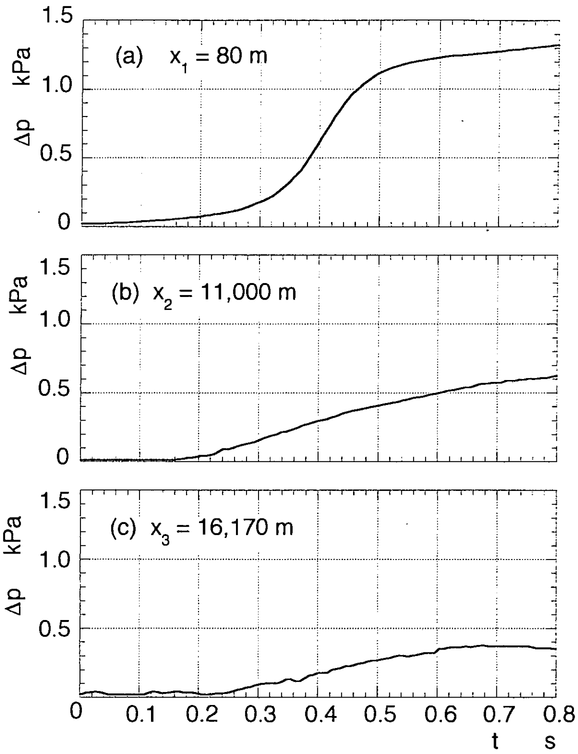

Fig. 3 Pressure history with time at points x_1, x_2 and x_3 in tunnel E (ballast track).

of train) is the ratio of cross-sectional area.

As shown in **Fig. 4**, the experimental values of Δp_{c1} increase generally with train velocity V and a little larger than theoretical ones. This may be related the fact that the flow separation on the head of the actual train and the substantial cross sectional area of air flow is smaller than geometrical one. The theoretical values of Δp_{c1} of type II are larger than those of train of type I, because the cross-sectional area of the type II train is larger than that of type I. But the experimental values of both type have not a significant difference. The experimental values of tunnel A are almost equal to those of tunnel B. It shows that there is no recognizable influence of the kind of track structure.

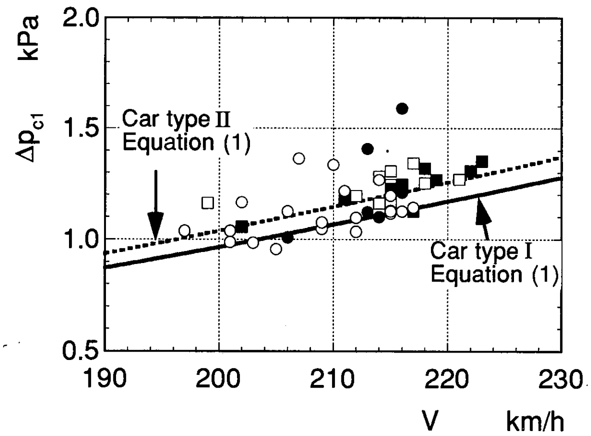

Fig. 4 Relation between strength of entry compression wave and train velocity.

3.3 Maximum Time Rate of Pressure Rise of the Entry Compression Wave

Maximum time rate $(d\Delta p/dt)_{max\cdot1}$ of pressure rise of entry compression wave is important to estimate the strength of impulsive noise from the outlet of tunnel. The relation between Δp_{c1} and $(d\Delta p/dt)_{max\cdot1}$, which are obtained from compression wave forms measured in tunnels A and B, are shown in **Fig. 5**. The meaning of the marks in the figure are shown in **Table 2**. As shown in this figure, there is no difference of experimental values by car type or tunnel. And there is a fairy proportional relation between Δp_{c1} and $(d\Delta p/dt)_{max\cdot1}$ in the meaning range ($1.0\ \text{kPa} < \Delta p_{c1} < 2.5\ \text{kPa}$). If you know Δp_{c1}, the strength of entry compression wave, you can suppose $(d\Delta p/dt)_{max\cdot1}$ by **Fig. 5** regardless of the car type or the kind of track structure.

Table 2　Symbols used in Figs. 4-8.

Reference	Tunnel	Car Type I	Car Type II
Present Experiment	A	○	●
	B	□	■
	C		▼
	D	△	▲
	E	◇	◆
	F	⧅	
	G	⊞	
	H		⊡
	I	▽	

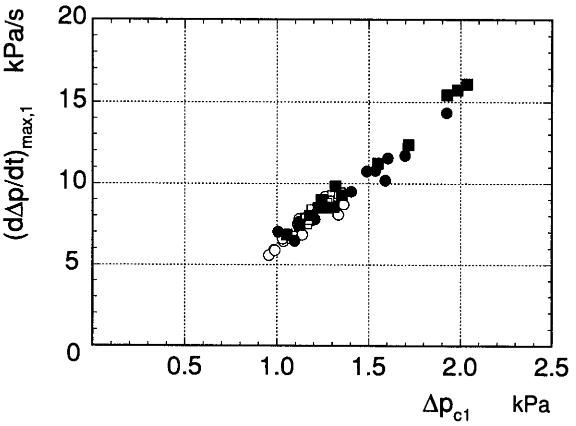

Fig. 5　Relation between maximum time rate of pressure rise and strength of entry compression wave.

3.4 Attenuation of Compression Wave Propagating in a Tunnel

The values of $\Delta p_c / \Delta p_{c1}$, the ratio of the strength of compression wave Δp_c to that of entry compression wave Δp_{c1}, measured at measured point x_1 are shown with the distance x-x_1 in **Fig. 6**. The values of slab and ballast track tunnels are shown in **Fig. 6(a)** and **(b)**, respectively. The meaning of the marks in the figure are shown in **Table 2**. There are experimental results by trains entering the tunnel at a velocity of 192～225 km/h. The curve ① and ② are plotted by substituting k = 4.5×10^{-4} and 6.5×10^{-4}, in the formula below [3], assuming that the value of $\Delta p_c / \Delta p_{c1}$ is attenuated exponentially with the distance x-x_1 at a train velocity of 215km/h.

$$\frac{\Delta p_c}{\Delta p_{c1}} = exp\left(-k\frac{x-x_1}{D}\right) \qquad (2)$$

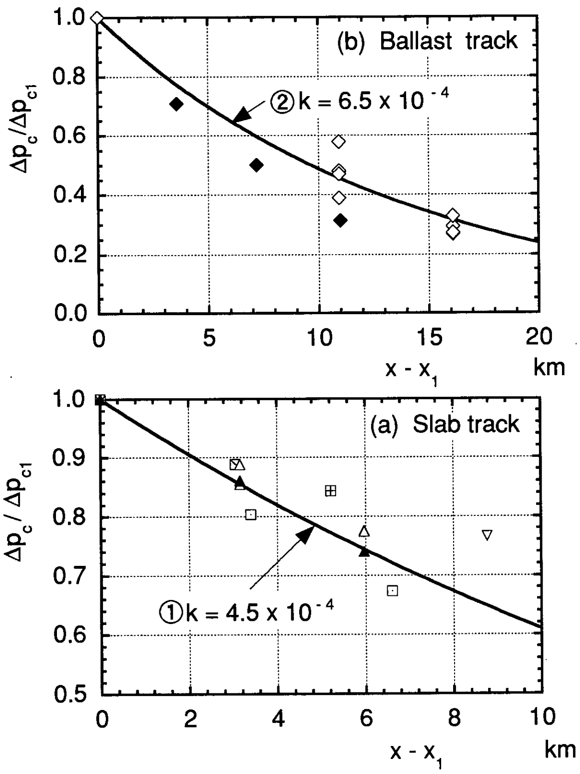

Fig. 6　Attenuation of compression wave with distance.

where k is coefficient of attenuation and D is the equivalent diameter of the tunnel. As shown in this figure, the experimental value of $\Delta p_c / \Delta p_{c1}$ decreases as the distances x-x_1 increase in both kind of track structure. The rate of decrease of the value of $\Delta p_c / \Delta p_{c1}$ with increase of the distance x-x_1 in ballast track tunnel is larger than the rate in slab track tunnel. It indicates that the compression wave propagated in the ballast track tunnel is attenuated more than one in the slab track tunnel [4].

Relation between the values of coefficient of attenuation k and train velocity V is shown in **Fig. 7**. The meaning of the marks in the figure are shown in **Table 2**. The axis of abscissas in **Fig. 7** shows the values which are obtained by transformation from train velocity V to Δp_{c1} using Eq. (1). In this figure, the coefficient of attenuation increases with velocity V, regardless of the kind of track structure, slab and track. But the values of k in ballast track tunnel is fairly

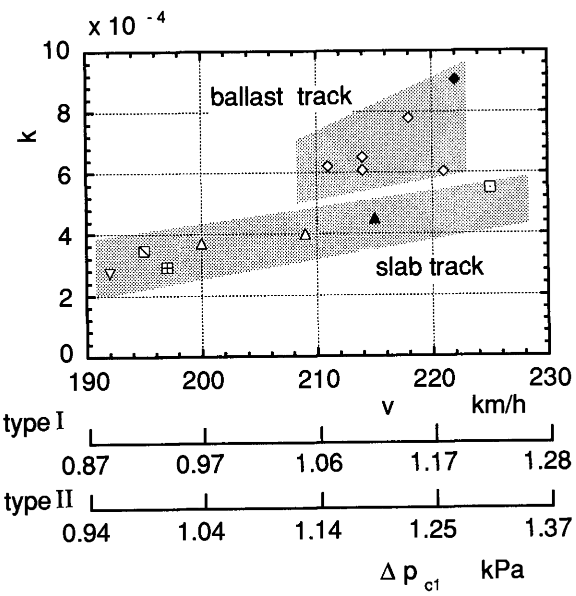

Fig. 7 Attenuation coefficient of propagating compression wave in tunnel.

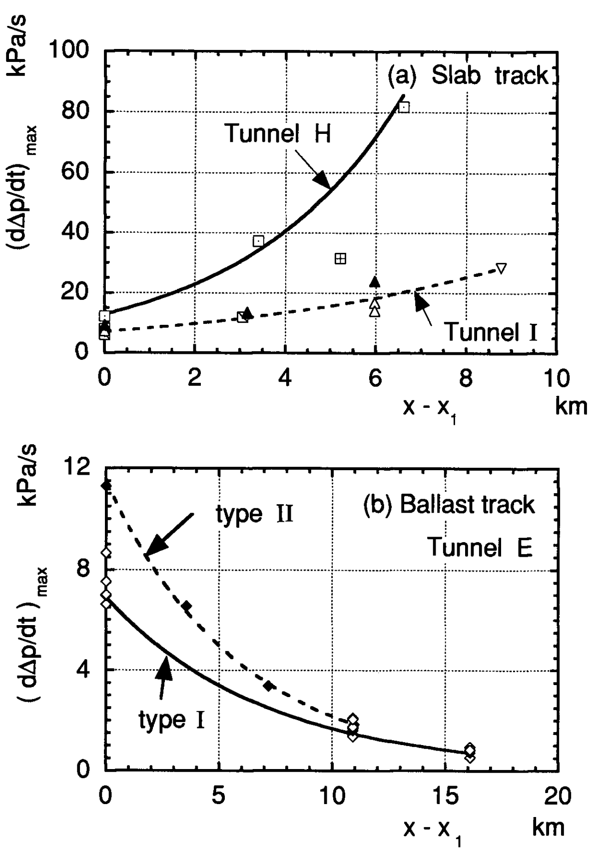

Fig. 8 Variation of maxmum time rate of pressure rise of compression wave with distance.

larger than values in slab track tunnel. This may be due to the fact that the ballast is porous and it has the effect of absorbing air.

3.5 Distortion of Compression Wave Propagating in a Tunnel

According to the aeroacoustic theory, the strength of impulsive noise emitted from outlet of the tunnel is proportional to maximum time rate of pressure rise $(d\Delta p/dt)_{max\cdot 1}$. The value of $(d\Delta p/dt)_{max}$ in slab and ballast track tunnels are shown in **Fig. 8(a)** and **(b)**, respectively. The meaning of the marks in the figures are shown in **Table 2**. As shown in **Fig. 8 (a)** of the slab track tunnel, the value of $(d\Delta p/dt)_{max}$ increases with the distance x-x_1. The more the value of $(d\Delta p/dt)_{max\cdot 1}$ (at $x=x_1$) increases, the more $(d\Delta p/dt)_{max}$ increases. It shows that the nonlinear effect of compression wave as the finite amplitude wave is superior to the effect of diffusion by viscosity and thermal conductivity [5)]. On the other hand, in the case of ballast track tunnel, experimental value of $(d\Delta p/dt)_{max}$ decreases with the distance x-x_1. This is due to the fact that the effect of absorbing of the ballast as porous is very strong and it is superior to nonlinear effect.

4. Conclusion

An experimental investigation was carried out on the characteristics of the propagating compression wave in a actual Shinkansen tunnel. The conclusions are summarized as follows.

(1) The strength of entry compression wave increases with the velocity of train entering tunnel. The experimental value of it are larger than theoretical ones by Eq. (1) . The difference between the cross-sectional area of type I and II has little influence on the strength of entry compression wave.

(2) The maximum time rate of pressure rise of entry compression wave increases linearly with the strength of entry compression wave in the range of measuring, and it is independent of the form of train head and the kind of the track structure.

(3) The strength of compression wave generated by train entering tunnel is attenuated exponentially with the distance along the tunnel. The degree of attenuation of compression wave in bal-

last tunnel is fairly larger than the degree in slab tunnel.

(4) In the case of slab track tunnel, the maximum time rate of pressure rise of compression wave increses and the wave form changes steeper as the wave is propagated longer distance along the tunnel. And the more this tendency is remarkable, the larger the maximum time rate of pressure rise of entry compression wave. On the other hand, in the case of ballast track tunnel, the wave form spreads with the distance.

References

1) K. Matsuo, T. Aoki, H. Kashimura, T. Yasunobu and S. Mashimo, Proc. of 8th Int. Symp. on Aerodynamics and Ventilation of Vehicle Tunnels, 199 (1994).

2) S. Mashimo, E. Nakatsu, T. Aoki and K. Matsuo, Trans. Jpn. Soc. Mech. Eng. (in Japanese), 61-590, B, 322 (1995).

3) K. Matsuo, T. Aoki, H. Kashimura, M. Kawaguchi and N. Takeuchi, Proc. of 7th Int. Symp. on Aerodynamics and Ventilation of Vehicle Tunnels, 239 (1991).

4) S. Ozawa, T. Maeda, T. Matsumura and K. Uchida, Proc. of Int. Conf. on Speedup Technology for Railway and Maglev Vehicles, 299 (1993).

5) B. B. Cary, J. Acous. Soc. Am., 43-6, 1364 (1968).