Behavior of Railway Cars in Running (Report 5)

—— Spacing of Tracks ——

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Abstract

On passing each other, a train or passengers in it are influenced by the other train in many respect, i.e., noise, vibration, air pressure or visual disturbance. These influencial elements vary with span of spacing between the two tracks.

Two factors, in relation to movement of car-body, are picked up and used to fix the minimum span of spacing between tracks. They are ; 1. Vibration coming from the next track, 2. Airpressure variation produced by the front and the rear part of passing train.

The experimantals were carried out with service train on service line, in 1963, 1965 and 1966. How to fix the lateral spacing of two tracks, in view point of passenger riding comfort, can be obtained from the results of experimental and analysis.

1. Forword

On passing each other, a train or passengers in it are influenced by the other train in many respect, i.e., noise, vibration, air pressure or visual disturbance. These influencial elements vary with span of spacing between the two tracks.

Two factors, in relation to movement of car-body, are picked up and used to fix the minimum span of spacing between tracks.

They are ;

1. Vibration coming from the next track
2. Air-pressure variation produced by the front and the rear part of passing train

The experimantals were carried out with service train on service line, in 1963, 1965 and 1966.

2. Vibration of Track*1)

This chapter deals with the track vibration, especially in lateral, generated by passing train on the next track.

To examine the matter, the data of the model line testing of the New Tokaido Line or the Shinkansen were used.

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*1) Data are picked up from "Study on the New Tokaido Trunk Line" Vol. 4, pp. 107-117

2.1 Track Structure

Track structure and its cross section are shown in Fig. 2.1.

2.2 Measurement of Track Movement

(1) Track vibration at the high embankment around 61,250 km spot of the Tokaido Shinkansen Line, was recorded in March, 1963.

The cross section of the track at the measurement spot is shown in Fig. 2.2, and its plan view in Fig. 2.3.

Vibrational lateral displacement of the track, during train passing with various speeds from 50 to 200 km/h, were recorded and plotted as in Figs. 2.4-2.7.

Fig. 2.4 shows the lateral displacement of track at point "A", in the right and the left direction.

Fig. 2.5 shows the lateral displacement of point "B", track surface. These data in the figures are 25 m in wave length and also 20-25 Hz in frequency. As the measurement devices are different at "A", "B" and at "C", "D", Fig. 2.4 and 2.5 are shown by each amplitude in right and in left, whereas Fig. 2.6 and 2.7 by full amplitude.

Fig. 2.6 shows the full amplitude of the track surface displacement at point "C".

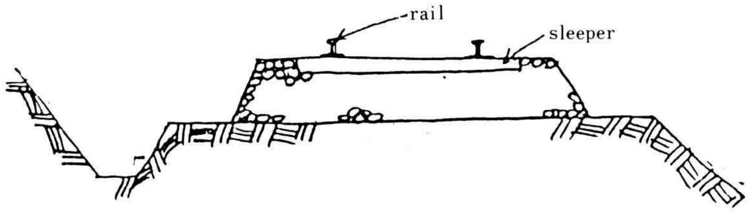


Fig. 2.1 Shinkansen track structure, cross section

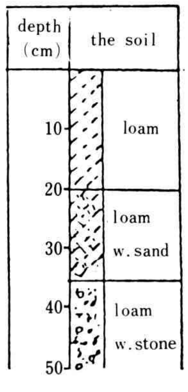


Fig. 2.2 The track cross section

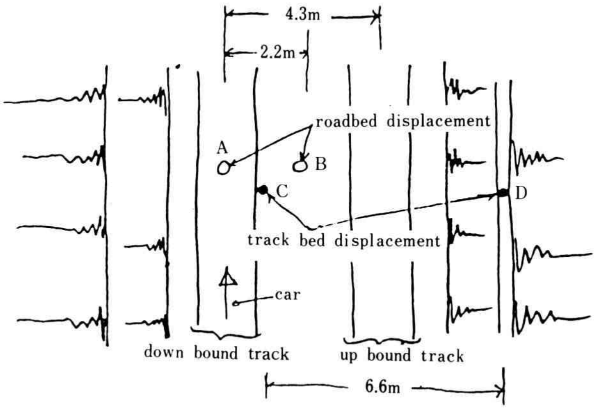


Fig. 2.3 Plan view of vibration measurement spot of track

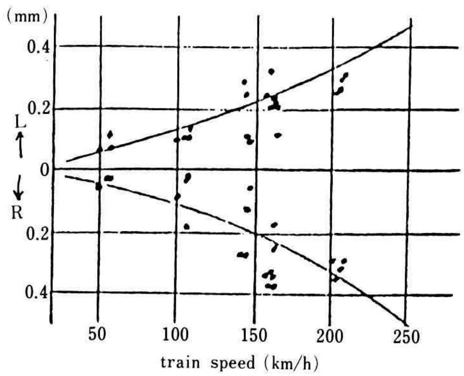


Fig. 2.4 Lateral displacement at "A"

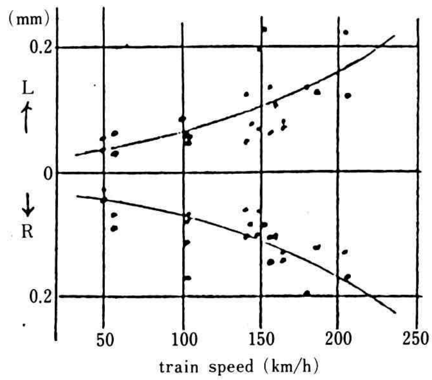


Fig. 2.5 Lateral displacement of track surface at "B"

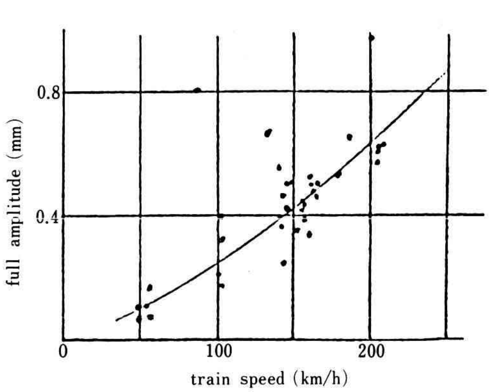


Fig. 2.6 Track displacement at "C"

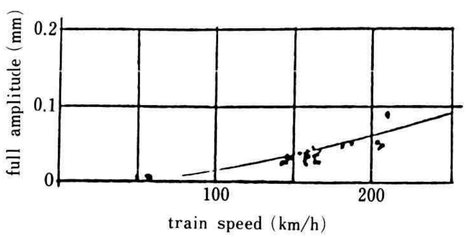


Fig. 2.7 Track displacement at "D"

Fig. 2.7 shows the full amplitude of the track surface displacement at point "D" in Fig. 2.3.

(2) Track vibration at the high embankment around 51,300 km spot of the Tokaido Shinkansen Line, was measured in June, 1963 and in March, 1964

Proto-type train was used for the test in 1963 and a massproduction-type train was in 1964*2).

Fig. 2.8 is the plan view of testing spot. In the figure, measurement spot of sign "o" is for proto-type train and spots of sign "●" are for mass-production train.

Fig. 2.9 shows the lateral displacement of track at "A", and Figs. 2.10, 2.11 show the full amplitude of lateral movement at "C" and "B", where the abscissa is train speed in km/h and the ordinate is full amplitude of track lateral displacement in mm.

(3) Record charts of lateral track displacement

The lateral displacement records are shown in Figs. 2.12-2.15. The conditions of these

*2) From "Study on the New Tokaido Trunk Line" Vol. 5, pp. 81-86

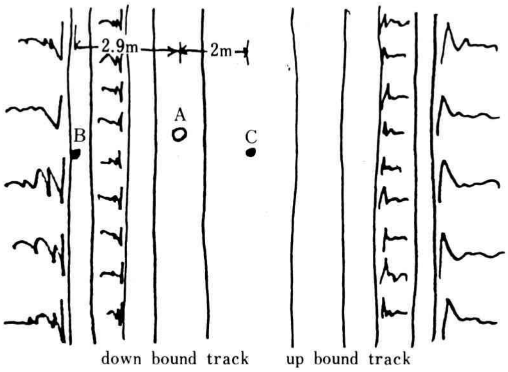


Fig. 2.8 Plan view of measuring spot

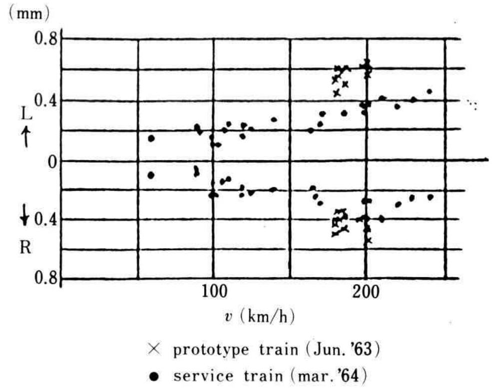


Fig. 2.9 Lateral displacement of track at "A"

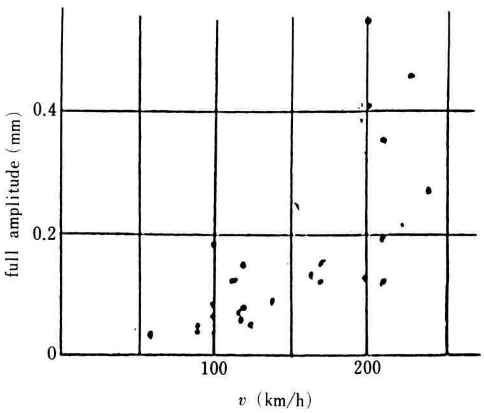


Fig. 2.10 Lateral movement at "C"

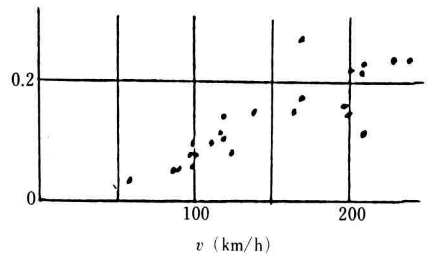
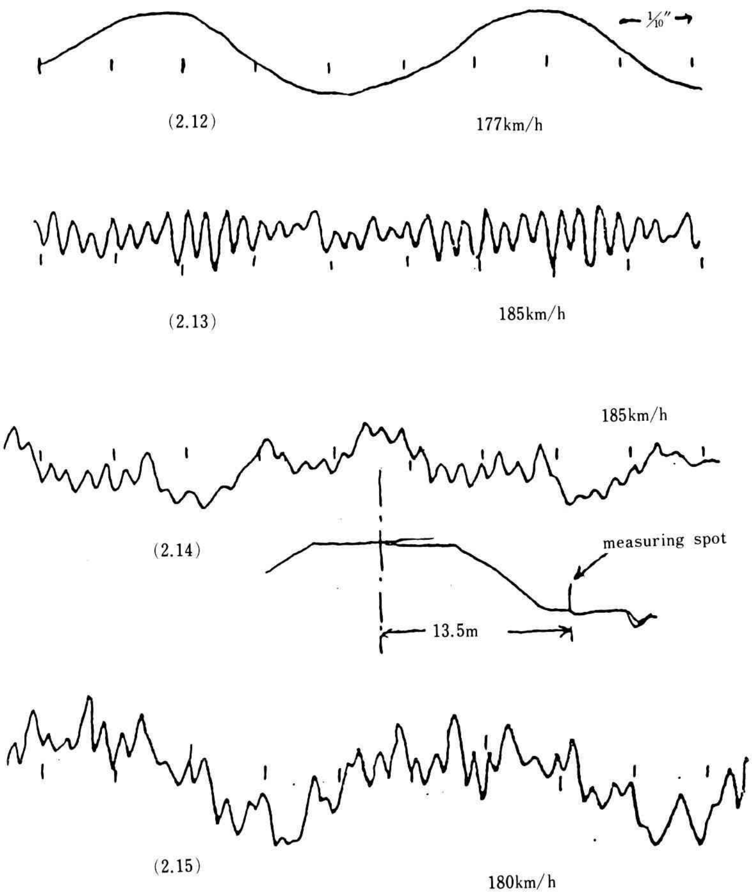


Fig. 2.11 Lateral movement at "B"

Table 2.1. Wave form condition

Figure Fig.	location km	train speed km/h	amplitude mm	measuring spot
2.12	47.863	177	a=0.37	15 m under high beam bridge
2.13	77.786	185	a=.0019	just overhead of tunnel
2.14	129.314	185	a=0.027	banking
2.15	131.039	180	a=0.049	just below beam bridge

recorded in Mar. 1965 by Geological Feature Lab. Railway Technical Research Inst., JNR



Figs. 2.12-15 Lateral displacement to time

figures are listed as on Table 2.1.

2.3 Remarks

(1) Diminution of vibrational amplitude with distance

Assuing that diminution of the amplitude of vibrational displacement is in exponential order, we can express;

$$a = a_0 \cdot \exp(-bx) \qquad (2.1)$$

where "x" represents distance from vibrated track, "a_0" represents the vibrational amplitude at the center of vibrated track and "a" represents amplitude at x apart.

To fix the number "b" in the expression (2.1), we applied the data at speed 200 km/h in Figs. 2.6, 2.7 as follows;

$2a_0 = 0.63$ (mm), $x = 6.6$ (m), and $2a = 0.063$ (mm), which deduced as $b = 0.35$.

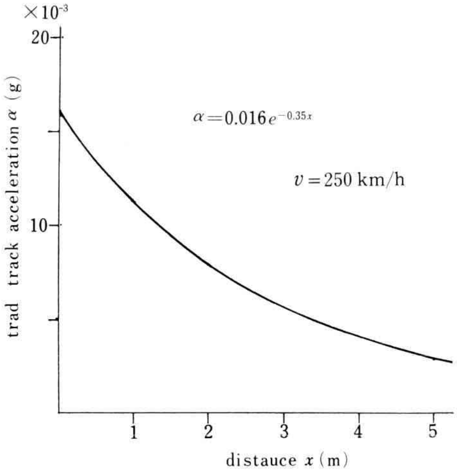


Fig. 2.16 Track lateral acceleration to distance between tracks

So

$$a = a_0 \cdot \exp(-0.35x) \qquad (2.2)$$

This shows that 2 m apart, the track movement reduce about a half.

(2) Evaluation of minimum amplitude of track vibration

The value of generated vibration at the speed of 250 km/h is about 0.016 g, which is obtained from $a_0 = 0.5$ mm, $f = 2.8$ Hz.

3. Air Pressure Effect

Passenger in a train feel vibration in lateral when a high speed train is passing through on the next track. This behavior will be one of the main elements for fixing the lateral span between two tracks. We investigated the vibration diminution, on that point of view, and studied by experiment with a test train running on the service line.

3.1 Experimental

(1) Condition of the test

A test train was set at 33.230 km of down bound track, on Jan. 24, 1966. The condition of the track is as follows:

(a) The lateral span between tracks of up bound and down bound is 4,240 mm.

(b) The hight of bank is 2,500 mm.

(c) The grade of track bed is the lower of middle class.

Car body acceleration in lateral, in vertical, and axle-box acceleration in lateral, were measured four times during the trains were passing through the spot position of up bound track. The speeds of passing trains were 206, 209, 204 and 160 km/h.

(2) Positions of measuring pick-up

Accelerometers were set at the spots as shown in Fig. 3.1. Car-body vertical acceleration was measured on the floor above the rear bogie of the first front car. Axle-box lateral acceleration was measured at the first axle of the train. Car-body lateral accelerations were picked up above each of the front bogie and the rear bogie of the first car and the second car.

(3) Experimental data

The results of measurement are shown in Figs. 3.2 and 3.3, where Fig. 3.2 shows the car-body accelerations, in lateral, on passing through the front edge of the passing train and Fig. 3.3 shows those on passing through the rear edge . The values of acceleration are in "g" unit by full amplitude.

(4) Form of vibrational wave

Fig. 3.4 shows the wave form of acceleration on each measuring spot and in each vibrational direction, at the speed of 209 and 160 km/h. All the scale of acceleration in Fig. 3.4 are the same.

(5) Analysis with simple modeling

Air pressure test shows its variation as Fig. 3.5, where the lateral span of tracks is 4.2 m,

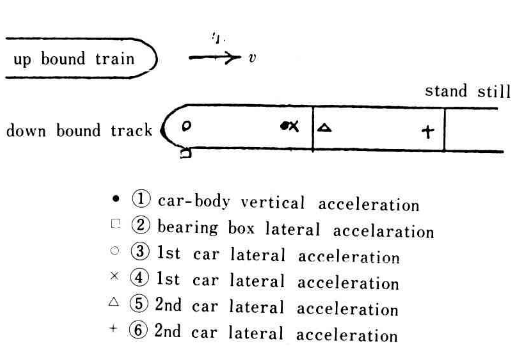


Fig. 3.1 Position of pick-up

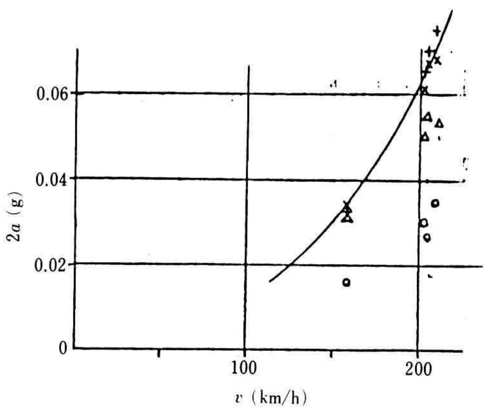


Fig. 3.2 Car-body acceleration at the beginning

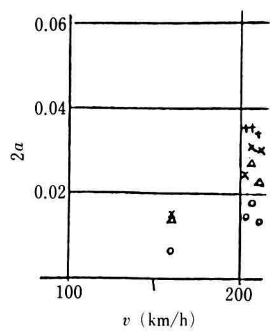


Fig. 3.3 Car-body acceleration at the ending

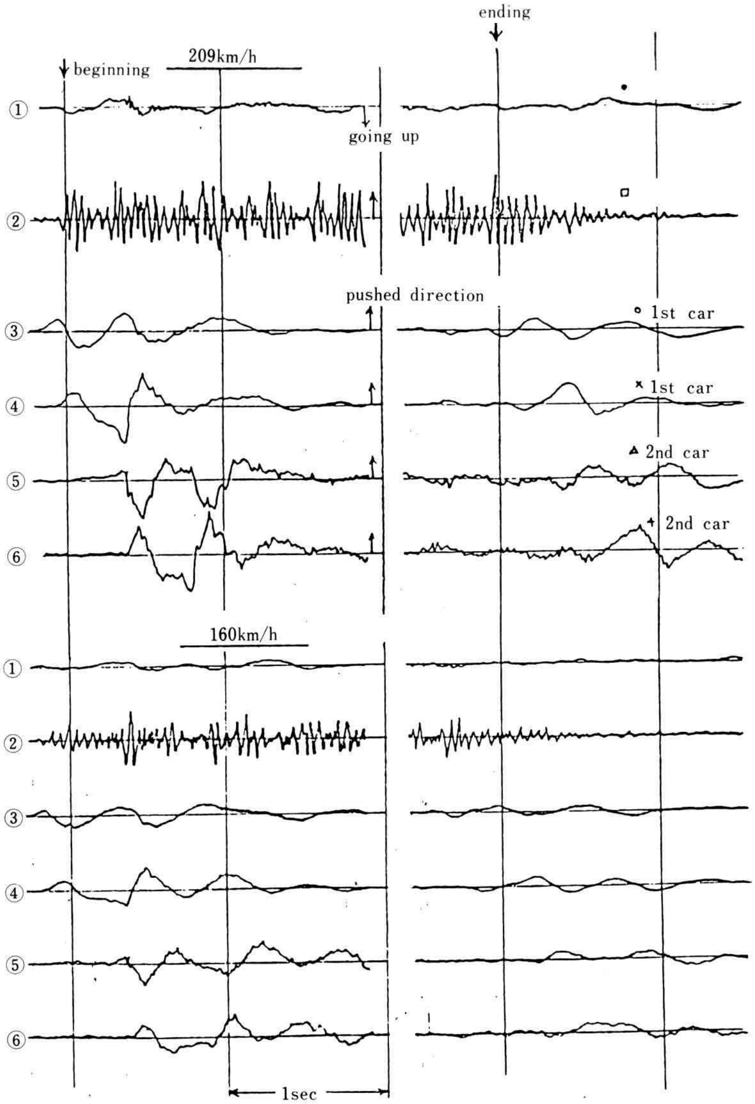


Fig. 3.4 Car-body acceleration chart

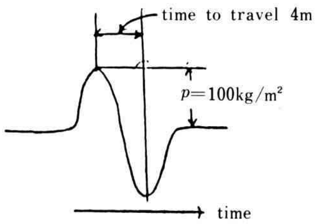


Fig. 3.5 Air pressure variation

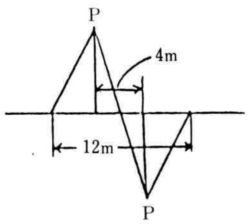


Fig. 3.6 Air pressure model

the speed of passing train is 200 km/h.

By simplifying this air pressure variation we may get a pressure changing curve model to time as Fig. 3.6. Using this simple model of pressure, which is similar to field test data, we can evaluate the car-body vibration generated by the passing train with a certain speed. The detail of calculation is mentioned in Appendix.

The resutts of calculation are shown in Fig. 3.7, where the conditions are set in the same way as running test, i.e., the span between two tracks is 4.2 m and speed of passing train is 209 km/h. The wave forms and the extreme values in Fig. 3.7 are compared with these of the curves (5), (6) in Fig. 3.4.

Because that the first car in the test train has smooth front shape of car-body and its weight distribution is unbalanced, the car-body acceleration is small, and so we take the second car data, i.e., (5), (6).

The comparison of the lateral acceleration of running test with the calculation curves shows almost coincidence with each other, and so we can evaluate the acceleration at any other speed.

Fig. 3.8 shows the calculation results under the conditions that the both speeds of test train and passing train are 250 km/h, that is 500 km/h of relative speed, and the lateral span

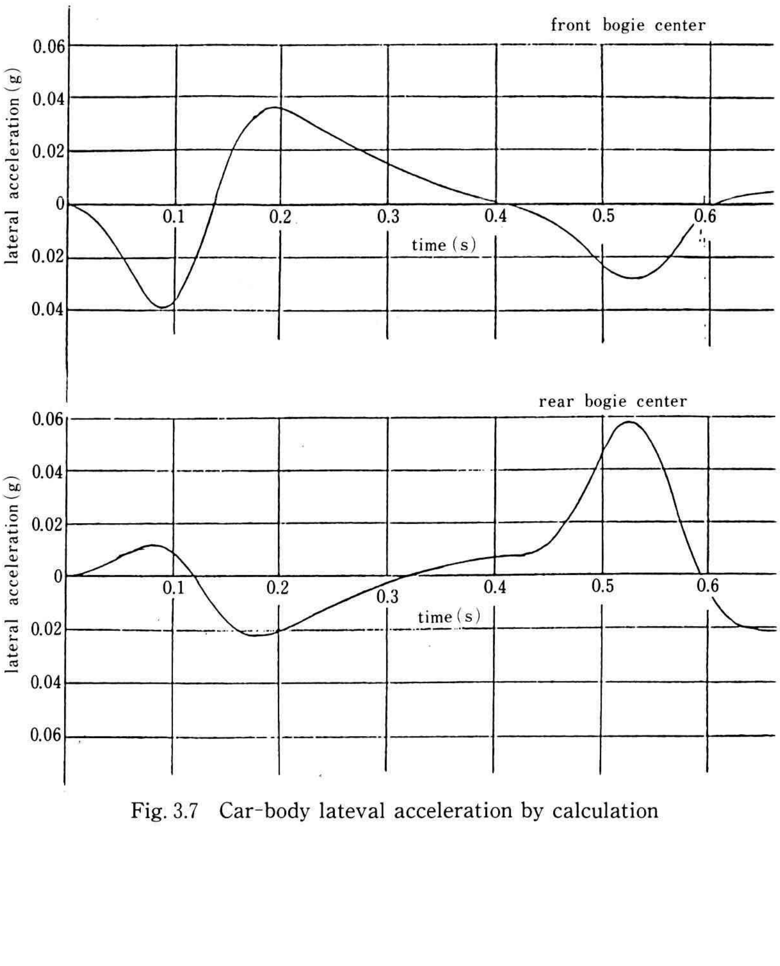


Fig. 3.7 Car-body lateval acceleration by calculation

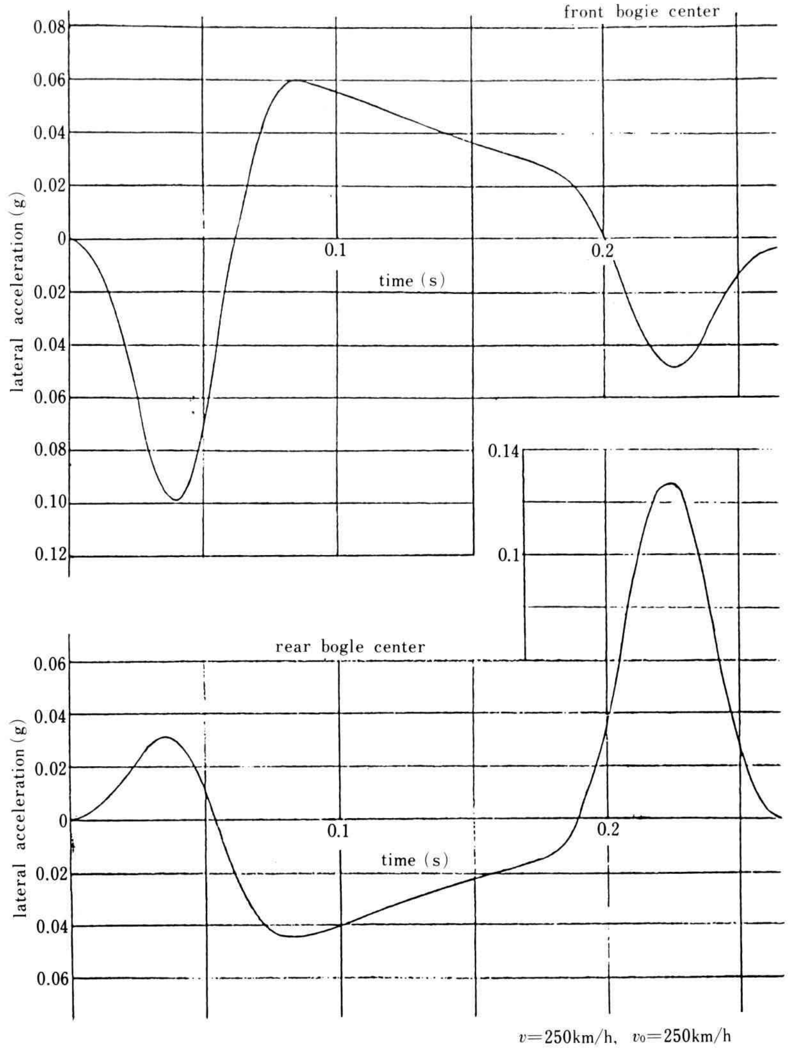


Fig. 3.8 Car-body lateral acceleration by calculation

of tracks is 4.2 m.

The acceleration at higher speed can be assumed from the calculation, as the test data with passing train almost coincide the results of analysis.

4. Concluding Remarks

(1) Car-body vibration in lateral by a passing train has been studied in view of track vibration and the effect of air pressure wave.

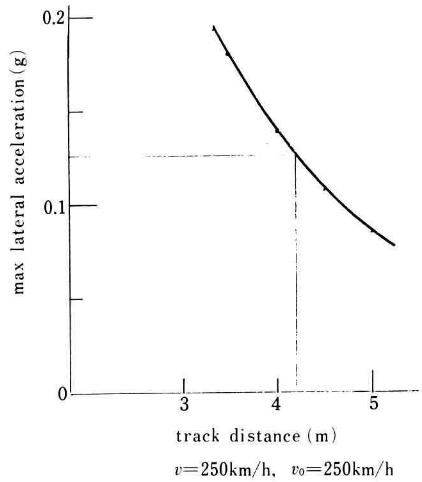


Fig. 3.9 Car-body lateral vibration diminution

(2) Track vibration is continuous, that is, continuing for a certain seconds.

(3) Car-body vibration, generated by the air pressure wave, is only two shots, that is, one for the beginning of train passing through other side track and another for the ending.

(4) In view point of passenger riding comfort, the track vibration is added to the basic vibration of car-body in running, and the air pressure produced vibration is considered to affect the passenger riding comfort alone.

(5) Track vibration magnitude diminished by distance as in Fig. 2.16. This shows the relation between track distance and riding comfort.

(6) Air pressure vibration magnitude diminished by distance as in Fig. 3.9. This also shows the relation between track distance and riding comfort.

(7) The lateral span of tracks is fixed with the consideration of above (5), (6) by setting the allowable acceleration in view of passenger riding comfort.

Appendix

Calculation of Car-body Lateral Vibration by Air Pressure Variation

1. General

Suppose the air pressure variation and its relation to the speed of passing train are known. By simplifying the air pressure variation, the equations of motion can be solved.

2. Nomenclature

c : car-body damping coefficient in lateral (for a bogie)

h : effective hight of car

i_{BZ} : radius of gyration of car-body about z axis

k : spring constant of body in lateral (for a bogie)

m_B : body mass (for a car)
p : air pressure variation for unit area
t : time
v : train speed
x : distance in longitudinal in car-body
y : displacement in lateral in car-body
F : force in lateral
I_{BZ} : moment of inertia of car-body around z axis
L : half distance between front and rear bogie centers
L_0 : half of the effective car length
M : moment
ψ : anguler displacement in yaw of car-body
ξ : distance in longitudinal

3. Assumption
(1) Car-body moves in lateral and in yaw.
(2) Car-body model is as Fig. A.1.
(3) Air pressure change model is as Fig. A.2.
(4) Air pressure rises in proportion to the square of passing train speed, in case testing car is at a standstill. In case the testing car is in running, air pressure rises as 1.5 times high as at a standstill for the same passing train speed.

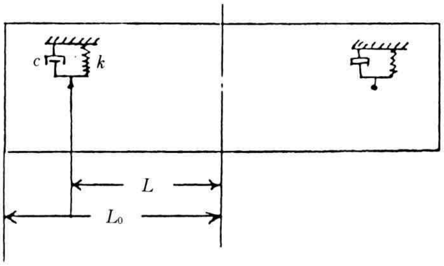


Fig. A.1 Car-body model

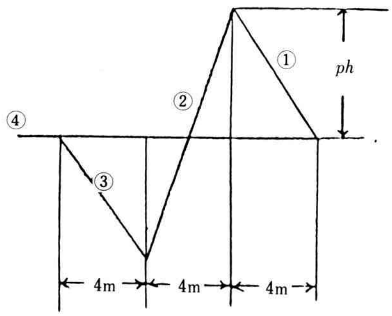


Fig. A.2 Air pressure model

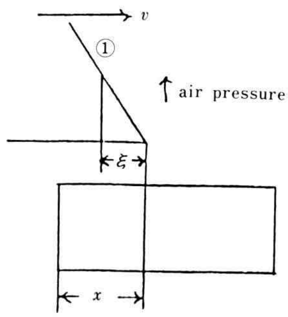


Fig. A.3Air pressure partial model

(5) Air pressure change with the distance between tracks is given.

4. Equations of Car-body Motion

Motion of car-body in lateral and in yaw will be expressed at the following equations :

$$m_B\ddot{y}+2c\dot{y}+2ky=F \tag{A4.1}$$

$$I_{BZ}\ddot{\psi}+2cL^2\dot{\psi}+2kL^2\psi=M \tag{A4.2}$$

Air pressure change 1 in Fig. A.2 is chosen as a representative, then we can calculate with similar way for (2), (3) and (4) by addition or subtraction.

For the part (1), refering Fig. A.3 and attatching 1 as subscript, the force by air pressure will be obtained ;

$$F_1=\int_0^x \frac{ph}{4}\xi d\xi=\frac{ph}{8}x^2=\frac{n_1}{2}(vt)^2 \tag{A4.3}$$

where $n_1=\frac{ph}{4}$ (cf. Fig. A.2).

In case $x>2L_0$, the air pressure in opposit direction may be added to the range over $2L_0$.

For the part (1) in Fig. A.3, also, the moment by air pressure will be ;

$$M_1=\int_0^x (L_0-x+\xi)n_1\xi d\xi=n_1\left(\frac{x^2}{2}L_0-\frac{x^3}{6}\right) \tag{A4.4}$$

At $x>2L_0$, M_1', moment by the wind of opposit direction, is surposed to be added ;

$$M_1'=\int_0^{x'} \{-(L_0+x'-\xi)n_1'\xi\}d\xi=n_1'\left(-\frac{x'^2}{2}L_0-\frac{x'^3}{6}\right) \tag{A4.5}$$

where $n_1'=-n_1$, $x'=x-2L_0$

Substituting $x=vt$, equations (1) and (2) are expressed by the following form of equation ;

$$\ddot{\eta}+2\alpha\dot{\eta}+(\alpha^2+\omega^2)\eta=Bt^2+Dt^3 \tag{A4.6}$$

Laplace transformation results, being $\eta=0$, $\dot{\eta}=0$ at $t=0$,

$$s^2\bar{\eta}(s)+2\alpha s\bar{\eta}(s)+(\alpha^2+\omega^2)\bar{\eta}(s)=\frac{2}{s^3}B+\frac{6}{s^4}D \tag{A4.7}$$

Concerning acceleration ;

$$s^2\bar{\eta}(s)=\frac{a_1}{s}+\frac{a_2}{s^2}+\frac{a_3s+a_4}{s^2+2\alpha s+\alpha^2+\omega^2} \tag{A4.8}$$

$$\left.\begin{aligned}&a_1+a_3=0\\&2\alpha a_1+a_2+a_4=0\\&(\alpha^2+\omega^2)a_1+2\alpha a_2=2B\\&(\alpha^2+\omega^2)a_2=6D\end{aligned}\right\} \tag{A4.9}$$

Inverse transformation of (A4.8) leads ;

$$\ddot{\eta}(t)=a_1+a_2t-e^{-\alpha t}\left(a_1\cos\omega t+\frac{a_1\alpha+a_2}{\omega}\sin\omega t\right) \tag{A4.10}$$

5. Numerical Values

$m_B = 42.0 \times 10^3$ kg

$I_{BZ} = 1.88 \times 10^6$ kg.m^2

$k = 7.06 \times 10^3$ N/m

$c = 9.81 \times 10^2$ N.s/m

$L = 8.75$ m

$L_0 = 12.5$ m

$p_0 = 7.36$ Pa

$h = 3$ m

$p = (V/200)^2 \cdot p_0 \times r_0$

where

$V = 3.6$ v

$r_0 = 1$ at $v_0 = 0$

$r_0 = 1.5$ at $v_0 = v$

The results of calculation with above mentioned values are shown in Fig. 3.7 and Fig. 3.8.