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BUCKLING STABILITY OF RAILWAY TRACK IN EARTHQUAKE

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SUMMARY

It has been reported so far that large lateral deformations were caused in railway track in time of earthquake even when the roadbed did not show any obvious damages. These has been considered a problem of stability of track to longitudinal force in earthquake. To make clear the circumstance, the lateral ballast resistance of track in vibration is measured in several conditions. Then, by examining the concept of ballast resistance in earthquake, an analysis is done. Finally, the buckling strength of railway track in earthquake under temperature rise is calculated considering the susidence of subgrade.

INTRODUCTION

Most of track damages in earthquake are caused by the deformation of road-bed, but it is fairly well known fact that there were large lateral deformations in earthquake even when the roadbed did not show any obvious deformation. On this phenomenon one of the authors gave an explanation based on the hypothesis that it was cused by the longitudinal force in track and a decrease of lateral resistance of ballast in time of earthquake (Ref. 1).

To supplement this, a series of new experiments were executed with use of track with two ties and full section of ballast. The frequency range was that of earthquake. In these experiments, the effect of the buckling-proof (BP) plate which is considered a preventive method for the decrease of lateral ballast resistance at special places such as the adjacent area to a bridge abutment was also checked.

In the process of the analysis, the concept of ballast resistance in earthquake is examined. Finally, the stability of Shinkansen track is calculated in relaion to the settlement of roadbed based on the experimental results and on the proposed concept.

EXPERIMENTATION

Procedure The experiment was performed with use of a real track with two ties laid in the testing box of the Embankment shaking Test Equipment, as shown in Fig. 1. In this experiment, the lateral pulling force of the track to get data on ballast resistance in vibration, the displacement of ties and the vibrational acceleration at the floor of the equipment were measured. The experiment was proceeded on the cases without BP-plate and with them at one end or both ends of ties in the conditions that the track was not pulled-up or pulled-up 40 mm or 80 mm high. The pulling-up of the track simulated a track hanging above the subsided roadbed at the adjacent area to a brdge abutment.

Embankment Vibration Test Equipment

The equiment shown in Fig. 1 is set in the Railway Technical Research Institute. It consists of a vibration table of 12 m long and 8 m wide and a testing box for accommodating scale model embankment. Capacities of the equipment are as follows: the maximum loading mass is 300 t; the maximum acceleration, 4.0 m/s^2; the frequency range, 1-20 Hz.

Test Track The track used for test is shown in Fig. 2 and Table 1. It is composed of only two ties, but has the same structure in section as the one of Tokaido Shinkansen. The skeleton of track is rigidified so as to be able to give its lateral ballast resistance as one body. The setting of BP-plates is shown in Fig. 3.

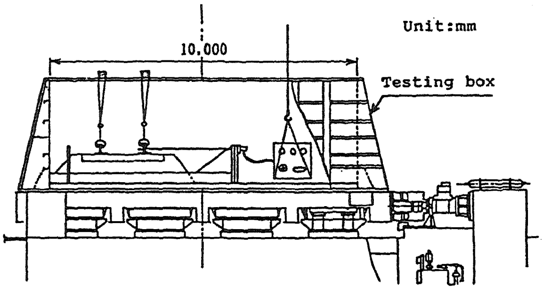

Fig. 1 Embankment Shaking Test Equipment

Table 1 Items of test track

Item	Material
Rail	60 kg/m
Tie	PC-3Ta
Rail fastening device	Type 102 (For high speed)
Ballast	Crushed stone 250 mm

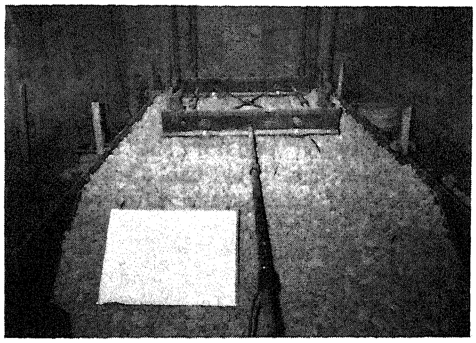

Fig. 2 Track for test

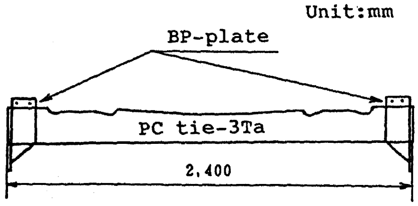

Fig. 3 Setting of BP-plates

TEST RESULTS AND ANALYSIS

Record An example of the test record is shown in Fig. 4. The displacement of ties and lateral pulling force in the figure are different from the static ones in that the former are in vibration with the frequency coinciding with the excitation by the vibration table. The vibrational component of ultimate lateral pulling force increases with the vibrational acceleration and the average of it decreases with the latter as shown in Fig. 5. They are solely dependent on the acceleration. The effect of frequency is trivial. Here, the upper extreme value of lateral pulling force maintains the value of static one, but the lower one comes to zero at the acceleration 8-10 m/s^2 akin to the gravitational one.

Concept of Lateral Ballast Resistance

The lateral pulling force F is expressed as

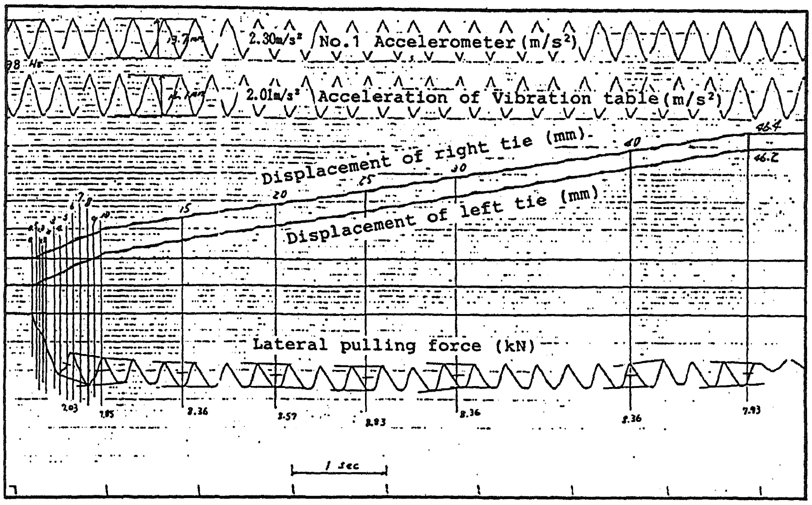

Fig. 4 Example of test rechord (3Hz, 2.0 m/s²)

$$F = G(Y) + my \qquad (1)$$

where G(Y) is the lateral ballast resistance between ballast and ties; Y, the measured displacement between the tie and testing box; m, the mass of track skelton; y, the displacement of track in inertia space. As in the actual track the lateral force due to the longitudinal force etc. is increased by the inertia force due to the acceleration in earthquake, the effective lateral ballast resistance in vibration corresponds to the lower extreme value of the vibrating lateral pulling force. In the following, the ballast lateral resistance is represented by this.

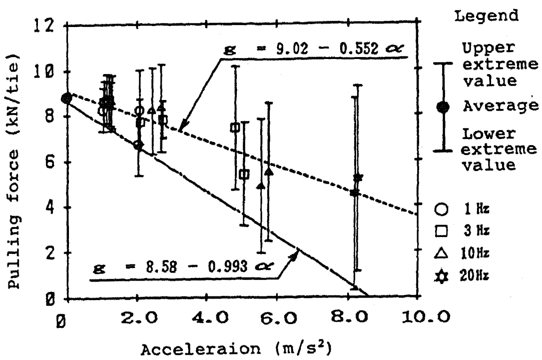

Fig. 5 Ultimate lateral pulling force

ANALYZED RESULTS

<u>Characteristics of Lateral Ballast Resistance to Displacement</u> Examples of lateral ballast resistance in above-mentioned concept are shown in Fig. 6. From this figure, we can say that the BP-plate is effective to increase the lateral ballast resistance but the difference of it between the track with BP-plates at one side and that with BP-plates at both sides is not so large and that the increase of lateral ballast resistance with displacement is steeper in the track with BP-plates at both sides than in the one with them at one side.

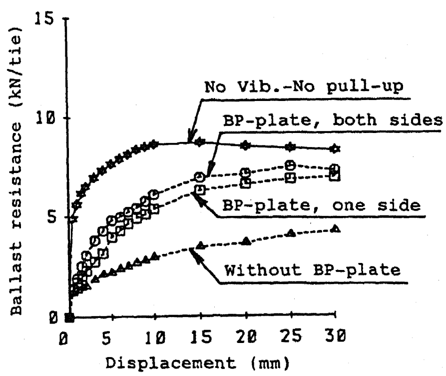

Fig. 6 Lateral ballast resistance
- Pulling-up, 40 mm
- 3 Hz - 2.3 m/s²

Effect of BP-plate The effect of BP-plate is shown in Fig. 7. This figure shows the effective ballast resistance at the displacement of 3 mm at which the lateral ballast resistance of Shinkansen track is defined. When the pulled-up height is 40 or 80 mm, the lateral ballast resistance of track without BP-plate decreased to 21-27 % of normal one. The adoption of BP-plate holds it to 35-55 %. Although the difference in values does not appear between the tracks with BP-plates at one side and both sides at the time of no pulling-up whether they are in vibration or not, the difference appears in the pulling-up of them.

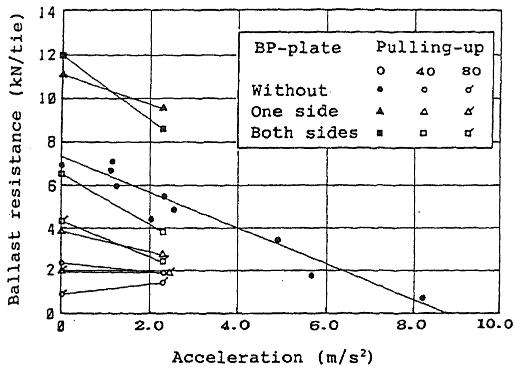

Fig. 7 Effect of BP-plate

TEMPERATURE RISE CORRESPONDING TO BUCKLING STRENGTH

Calculation under Sufficient Condition
So far the track stability for buckling has been discussed for the acceleration in earthquake about a structure design with use of the average of ballast resistance in vibration (Ref. 1, 2). In this paper it is shown that the lower extreme value of ballast resistance must be used. Further, the stability of track to buckling is to be discussed to the predicted Tokai Earthquake. The calculation with use of the existing buckling theory (Ref. 3) is shown in Table 2. In this, the temperature rise coresponding to minimum buckling strength at the acceleration for structure design is 52 °C, but that at the acceleration expected in Tokai Earthquake is 30 °C. This is less than the expected maximum rise of 40 °C.

Table 2 Buckling strength of track without BP-plate

Condition		Train stop	Structure design	Tokai Earthquake
Acceleration		0.8m/s²	2.0m/s²	6.3m/s²
Decreasing ratio of lateral ballast resistance	Ref.1	0.934	0.834	0.477
	This paper	0.907	0.769	0.271
Minimum buckling strength by Ref. 3	Ref.1	952 kN	896 kN	664 kN
	This paper	1043 kN	954 kN	547 kN
Corresponding temperature rise	Ref.1	60℃	56℃	42℃
	This paper	57℃	52℃	30℃

Calculation under Necessary Condition The above-mentioned calculation guarantees the prevention of track buckling but it is not the necessary condition causing a buckling. Therefore, even when the temperature rise surpasses the calculated one, it does not mean the cause of buckling. The cause of track buckling can be calculated with a recently developed new theory (Ref. 4). In this theory, the variation of lateral ballast resistance is assumed as follows;

$$g = g_o \cdot y / (y + a) \qquad (2)$$

where g is lateral ballast resistance; g_o, ultimate lateral ballast resistance; y, lateral displacement and 'a', the displacement at which g reaches 1/2 of g . An example of g_o and 'a' is shown in Fig. 8 for the case of no pulling-up. As g_o shows good coincidence on lines, the formulas shown in the figure are used in calculation. On the contrary, as 'a' disperses, this is treated as a parameter. The calculation is done for the initial track deformation of 8 mm as shown in Fig. 9.

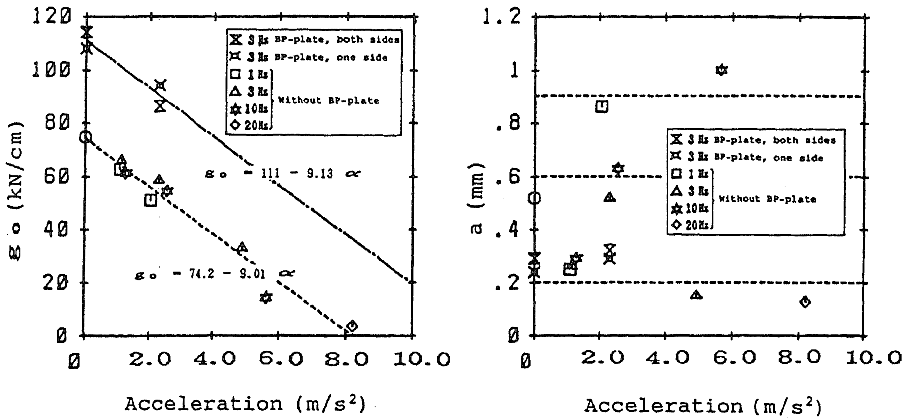

Fig. 8 Characteristics of g_0 and a

<u>Stability of Existing Track</u> The calculated result for the existing track is shown in Table 3. This table shows the nearly all the values comes well above the expected maximum temperature rise of 40 ℃, but there is a value of 39 ℃ at 'a' of 0.9 mm. Thus, as a whole the track on the normal roadbed will maintain the stability for buckling even when the temperature is high at the happening of a fairly big earthquake. Here, the decrease of initially existing track irregularity and the decrease of 'a' by solidification of ballast are effective to increase the temperature rise corresponding to the cause of buckling.

<u>Countermeasure for Settlement of Roadbed</u> When the roadbed is subsided, for example at an adjacent area to the bridge abutment, the track stability for buckling decreases. As one countermeasures, BP-plates can be set at the end of tie. The effect of BP-plate is calculated as shown in Table 4. In this table nearly all the values except that for 'a' of 4.0 mm at pulling-up of 40 mm and those at 80 mm in forseeable Tokai Earthquake surpass the expected maximum temperature rise of 40 ℃. Thus, in the preventive work for subsidence in roadbed which is now underway, the target is considered to be less than 5 cm.

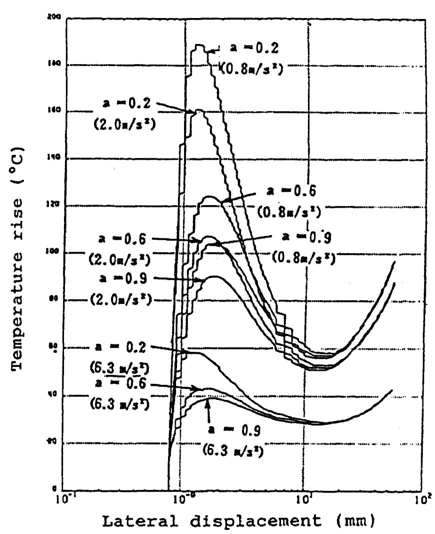

Fig. 9 Example of calculation for temperature rise causing track buckling

Table 3 Temperature rise by Ref. 4 for track without BP-plate

Condition		g_o (kN/cm)	a (mm)	Temperature rise(℃)
Train stop	0.8 m/s²	67.0	0.2	189
			0.6	124
			0.9	104
Structure design	2.0 m/s²	56.2	0.2	161
			0.6	107
			0.9	90
Tokai Earthquake	6.3 m/s²	16.5	0.2	58
			0.6	43
			0.9	39

Table 4 Temperature rise by Ref. 4 for track with BP-plates at both sides of ties

Condition		Pulling-up, 0 mm			Pulling-up, 40 mm			Pulling-up, 80 mm		
		g_0 (kN/cm)	a (mm)	Temperature rise(℃)	g_0 (kN/cm)	a (mm)	Temperature rise(℃)	g_0 (kN/cm)	a (mm)	Temperature rise(℃)
Train stop	0.8 m/s^2	104	0.3	>200	83.7	2.0	85	71.7	4.0	55
						4.0	62		6.0	*46~
Structure design	2.0 m/s^2	92.7	0.3	>200	72.7	2.0	76	60.7	4.0	49
						4.0	56		6.0	*41~
Tokai Earthquake	6.3 m/s^2	53.5	0.3	133	33.5	2.0	44	21.5	4.0	*27~
						4.0	34		6.0	*25~

CONCLUSION

Through this study, the characteristics of buckling stability of railway track has benn made clearer than so far. In the predicted Tokai Earthquake, the track on normal roadbed will maintain the stability as a whole under the expected maximum temperature rise. At the place of subsidence of roadbed, such as the adjacent area to a bridge abutment, the use of buklinmg-proof plate will be effective.

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