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TRACK DEFORMATION DUE TO SETTLEMENT OF EMBANKMENT ADJACENT TO BRIDGE IN EARTHQUAKE AND ITS EFFECTS ON RUNNING SAFETY OF TRAIN

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SUMMARY

This paper describes the criteria for the settlement of embankment due to earthquake established from a view point of track stability and running safety of train. The deformation of track behind the abutment of bridge due to the settlement of embankment is quite common in earthquakes. To make clear the characteristics of the track deformation and running safety of train running across there, a computer simulation was carried out. As the result, the stress in rail, the extent of lift-up or hang-down of track and the running safety according to the amount of deformation have been obtained.

INTRODUCTION

There are many types of deformations which the railway track suffer from earthquakes. These are mainly caused by the deformation of earth structures such as embankment. Especially, at the joint of the embankment and rigid structures such as viaduct or bridges, there often occurs a large settlement of embankment due to the consolidation of the soil material or inclination of abutment or wing of the embankment. At such a point, there occurs a large dislocation between the structures, resulting in the level irregularity of the track. This dislocation not only harms the running safety of train, but causes large bending stresses in rail under train load or gives rise to lifting up of sleepers on ballast, which decreases the lateral resistance of track and causes a lateral buckling of the track together with a thermal stress in rail or a longitudinal pressure in rail caused by the earthquake. Such track deformations would occur at many places in earthquakes, so, it is expected that some trains would probably come across such places in earthquakes. And in some cases, it would be necessary to move the train which stopped between stations to the nearest station after an earthquake hits. In these cases it would be necessary to examine the safety of structures or track themselves or the running safety of trains. This report describes the results of theoretical analyses on the deflection of the track and response of the running train in earthquakes.

ANALYTICAL METHODS

<u>Analytical model of the track and vehicle</u> Analytical model of the track where the dislocation occurs is shown in Fig 1. In this figure, the lefthand side shows the track on rigid structure (bridge, viaduct etc.) while the right hand side

shows the one on embankment. As can be seen in the figure, the track on the embankment near the bridge would lift up and no reaction force would act from roadbed. On the bridge, the track would occasionally lift up depending on the magnitude and the position of the wheels of the train. The deformations of the track are described as follows:

Lifting up section

$$EI\frac{d^4 y_i}{dx_i^4} - w = 0$$

Other sections

$$EI\frac{d^4 y_i}{dx_i^4} + k(y_i + H) = 0$$

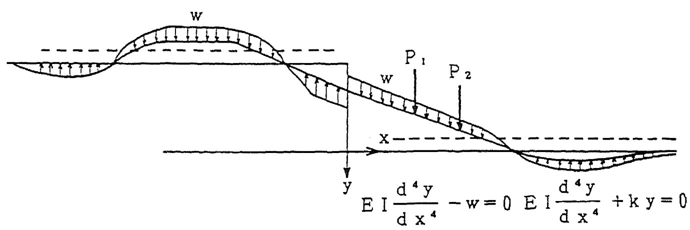

Fig.1 Analytical Model of Track

where

- yi : deflection of the rail at i section
- EI : bending rigidity of the rail
- k : bearing spring constant of the rail per unit length
- w : track weight per unit length
- H : height of roadbed

Analytical model of the vehicle Fig 2 shows an analytical model of the vehicle. This model considers half the length of a vehicle which is considered to be sufficient to analyze the vertical motion of rolling stocks.

The equations of motion for the vehicle model shown in Fig 2 have 5 variables which coincide with the degrees of freedom of the motion of the vehicle model. These are Z_B, Z_T, ϕ_T, and Zwi $(i=1,2)$ which represent vertical displacement of car body, that of truck, rotational displacement of truck and vertical displacement of first and second wheels respectively. Among these variables, Zw1 and Zw2 are equal to the deflections of the rail beneath the wheels which should satisfy the equation (1) or (2). When the vehicle runs over the joint of embankment and rigid structures as shown in Fig 1, the interactive force acting between wheel and rail varies dynamically. This force and the vertical displacement of wheel or that of rail beneath the wheel satisfy both the differential equations of track and the equation of motion of the vehicle. Considering these relationships, the dynamic response of vehicle and the deformation of track can be obtained by integrating the equation of motion of the vehicle in which the interactive force between wheel and rail and the vertical deflection of wheels satisfy the condition described above. The calculation was performed by using Runge-Kutta-Gill method.

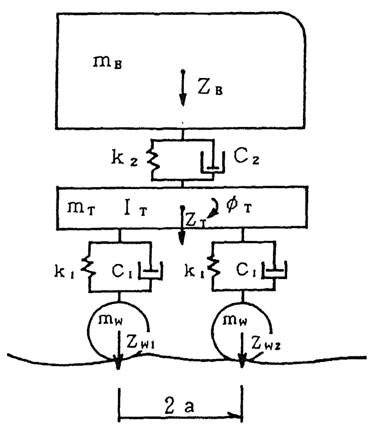

Fig.2 Vehicle Model

ANALYTICAL RESULTS

Condition of analysis In the analysis of train response, train speed and the amount of dislocation at the joint of structures are varied. In this analysis, the calculations were performed only for the condition that the reduction of the wheel load is less than 100%, (ie. wheel load is more than 0) and when the reduction of wheel load reaches 100% the calculation was stopped. It is because the safety limit of the reduction of wheel load is less than 100% and besides the equation of motion of the vehicle described above is no longer available if the wheel is detached from the rail. When the amount of dislocation between structures is large, reduction of wheel load reaches 100% for a relatively low train speed. So, in this case the calculations are performed only for low train speeds.

Bending moment and bending stress of rail Maximum bending moment of the rail according to the position of the vehicle calculated for H=10cm and V=30km/his shown in Fig 3. In this figure, the positive and the negative value are shown separately. As can be seen in the figure, the positions where the positive and negative bending moments reach their maximum values are different but the magnitude of the maximum values are almost the same.

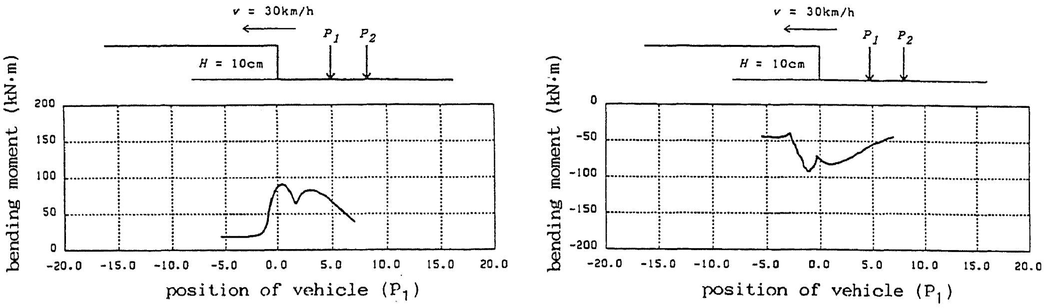

Fig.3 Bending Moment of Rail

Bending moment of the rail at the joint of structures dislocated due to the settlement of embankment in earthquake is shown in Fig 4.

As can be seen in the figure, the bending moment of the rail changes according to the position of the wheel. It also changes with train speed because the

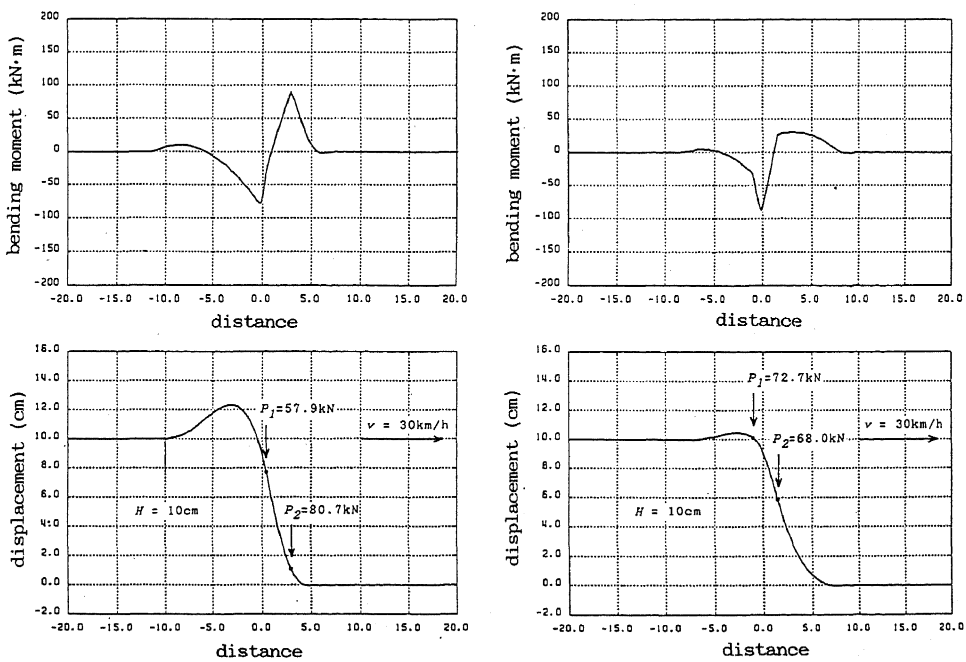

Fig.4 Bending Moment and Deflection of the Rail

interactive force between wheel and rail varies with train speed. Thus we can get the maximum bending moment for various values of the settlement of embankment and those of train speed. Fig 5 shows the calculated results about the rail stress which is proportional to the bending moment of the rail. As can be seen in the figure, the rail stress varies widely with the amount of the settlement of embankment but little with the train speed. Anyway, it remains under 300Mpa when the settlement of embankment is 10cm.

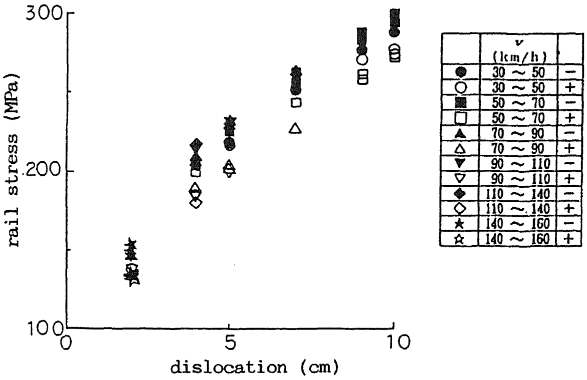

Fig.5 Rail Stress

Uplift of rail and uplifted track length As shown in Fig 3, the track on the bridge behind the joint of structures lifts up when a dislocation occurs there. As the lateral resistance of the track depends largely on the friction between ballasts and sleepers at its bottom, the uplifting of the track affects largeiy the lateral stability of the track. Fig 6 shows the uplifted length of the track (ie. the length of the track which loses the reaction force). It shows that the uplifted track length depends mainly on the amount of the settlement of embankment and very little on the train speed. At H=10cm, the uplifted length of the track is about 10m. In these sections, some countermeasures should be taken to prevent the lateral buckling of track.

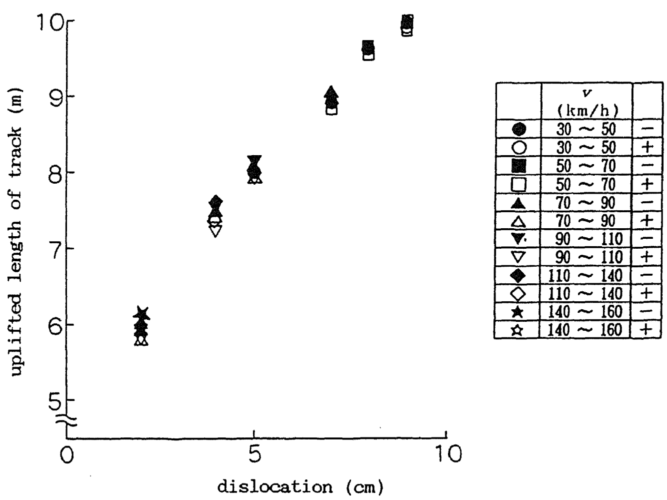

Fig.6 Unsupported Length of Track

Wheel load variation at the joint The ratio of the wheel load variation ($\Delta P/Pst$, Pst=static wheel load) obtained from the analysis is shown in Fig 7. As can be seen in the figure, the wheel load variation depends much on both the amount of the settlement of embankment and the train speed and reaches 100% at v=70km/h when H=10cm and at v=100km/h when H=5cm.

Vibration acceleration of car body Fig 8 shows the calculated results of vibration acceleration of car body. This figure shows that the vibration acceleration of car body is also affected both by the amount of the settlement of embankment and the train speed but it remains 2.5m/s for all the calculated conditions under which the wheel load variation does not exceed 100%.

Bending stress in rail As described above, in this analysis, calculation is performed so long as the wheel load diminution does not exceed 100%. When the dislocation at the joint caused by the settlement of embankment is large, the wheel load diminution reaches 100% at a relatively low train speed but the rail stress remains at a relatively low level in these cases. Maximum rail stress for 10cm of dislocation is about 300MPa which is 40% of its tensile strength and 65% of its yield stress. Therefore it is not likely that the rail breaks off unless the wheel load diminution comes under 100%.

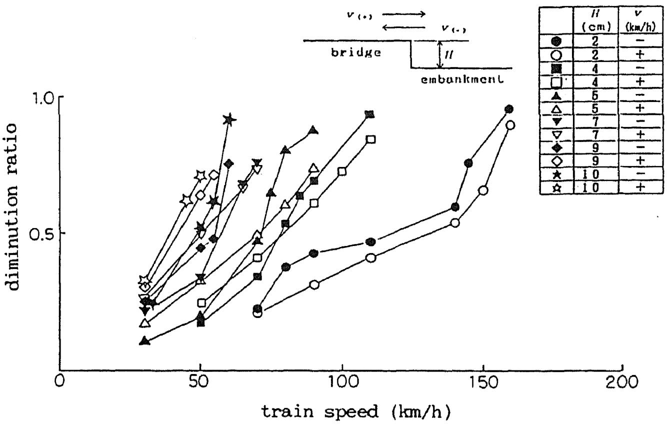

Fig.7 Wheel Load Diminution

Lift-up and hanging down of the track At the joint between bridge and embankment, where the dislocation occurs, the track lifts up on the bridge and hangs down on the embankment. The lengths of these sections are 5-10m when the dislocation is 5-10cm. As the lateral resistance of the track decreases in these sections, it is considered necessary to take some measures to prevent the buckling of track.

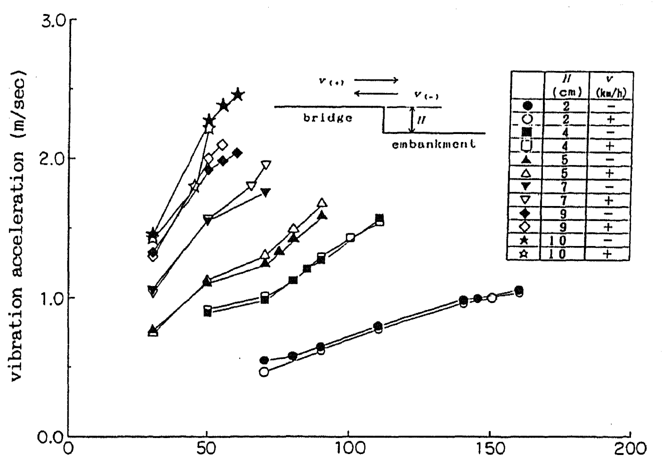

Fig.8 Vibration Acceleration of Car Body

Vibration acceleration of car body Vibration acceleration of the vehicle running over the joint of structures where the dislocation occurs is about 2.5 m/sec^2 (0-p) for the same amount of dislocation and train speed (H=10cm, v=70km/h) at which the wheel load diminution reaches 100%. Considering that the p-p value of car body vibration acceleration is 4/3 times the 0-p value, this is considered the critical value for SHINKANSEN.

Wheel load diminution Critical value for the wheel load diminution considering the running safety of train in earthquakes is considered to be 67%.1) From the analysis described above the critical speed of train at which the wheel load diminution reaches this value can be calculated for various amounts of dislocation. Fig 9 shows the calculated results of these values. As can be seen in the figure, the critical train speed is 75km/h for H=5cm and 45km/h for H=10cm.

CONCLUSIONS

Through the analysis described above, characteristics of the deformation of track at the joint of structures in earthquakes and its effects on the behavior of vehicles have been made clear. According to this, the dislocation between bridge and embankment caused by settlement of embankment near the bridge due to earthquake has an adverse effect on lateral stability of track and on running safety of train. 50mm of settlement can be tolerated for embankment from a view point of running safety of train even when the train speed is restricted to 70km/h.

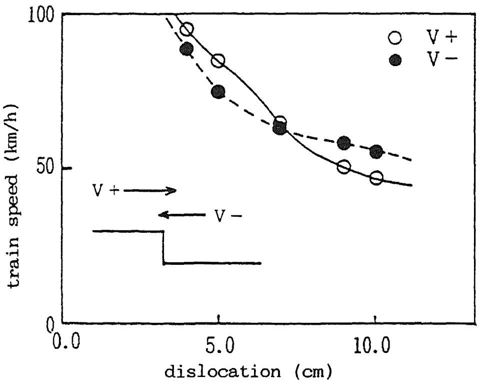

Fig.9 Safety limit

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