Evaluation of Train Running Stability on Slab Track with Use of Vibration Exciter

Masahiro SHINODA
Foundation and Geotechnical Engineering Laboratory, Structures Technology Division

Hiroaki SAKAMOTO Norikazu MISAKI
West Japan Railway Company

Cyclic load by train causes subsidence of railway level in tunnels, which is due to ground deformation under roadbed concrete. In consideration of progress of track irregularities and core drilling results, the deformation of the roadbed concrete have been evaluated, but there has been no quantitative inspection method until the present. In this study, to develop a method for quantitative evaluation of train running stability on the slab placed on roadbed concrete, a method to survey roadbed concrete by vibrating it with small-sized and medium-sized vibration exciter was proposed. Vibration characteristic of roadbed concrete with accelerometers fixed near the vibration position was also evaluated. Then the correlation between progress of track irregularities considered to be correlated with the soundness of roadbed concrete and the results of vibration tests was confirmed, and a method for evaluation of the correlation was proposed.

Keywords: slab track, tunnel, vibration exciter, condition rating

1. Introduction

Maintenance of railway tunnels is conducted periodically in the few hours available at night. These restrictive working conditions create a huge burden on maintenance work. This is particularly true for the maintenance of civil engineering structures on Japanese bullet train, or Shinkansen lines, where maintenance is important due to the degradation of these structures. To make the maintenance efficient and to increase the ride quality of Shinkansen, slab track has been adopted. Slabs are supported on the roadbed concrete with cement asphalt (CA) mortar laid in-between. Figure 1 shows the schematic figure of slab and roadbed concrete.

Slab track maintenance must satisfy stringent displacement tolerances, although up to + 50 mm is permitted in the case of vertical slab track deformation.

Rail displacement on slab track in some cases is not negligible, due to subsidence of the roadbed concrete through cyclical loading from passing trains. This incurs higher maintenance costs and affects operational safety.

There are number of direct and indirect methods for examining the state of roadbed concrete exist. The indirect method measures rail displacement from on-board an inspection train. Rail displacement obtained from the inspection train includes deformation induced by the railway track and due to ground conditions under the roadbed concrete. These two deformations cannot be separated, and therefore maintenance of the slab track cannot be conducted efficiently.

The direct method is to drill directly into the RC concrete of the slab and roadbed concrete and visually inspect the ground conditions under the roadbed concrete. The problems of the drilling are that working time is limited and inspection of the ground condition is only localized.

This paper reports the development of non-destructive roadbed concrete inspection methods using a vibration exciter. The proposed method was applied to actual roadbed concrete in a Shinkansen tunnel. Based on the application results, a roadbed concrete evaluation method was proposed making use of both results from the proposed method and rail displacement measured from the inspection train.

Fig. 1 Cross section of slab track in tunnel for bullet train

2. Vibration test

2.1 Vibration exciter

Vibration tests in this research were to measure the vibration characteristics of a target structure vibrated by a vibration exciter, shown in Fig. 2. The specifications of the vibration exciter are given in Table 1. The weight of the vibration exciter was 48 kg. The frequencies used ranged from 0.1 to 1,000 Hz. Under the maximum acceleration, the frequency ranged from 3 Hz to 500 Hz.
2.2 Test procedure

Figure 3 shows vibration test procedure with the vibration exciter proposed in this study. Accelerometers were used to measure the roadbed concrete response when the roadbed concrete was vibrated by the vibration exciter. Frequency analysis was carried out to understand the frequency characteristics of the roadbed concrete. Using the results of frequency analysis, the evaluation of roadbed concrete was carried out, and is explained later on, below.

2.3 Structure of slab track and roadbed concrete

Figure 4 shows a vertical cross section of slab and roadbed concrete in a Shinkansen line tunnel. As mentioned before, the slab is supported on the roadbed concrete by an in-between CA mortar layer. The roadbed concrete in the examined case was 10 m in length in the rail longitudinal direction, 3 m in width and 0.3 m in thickness. The CA mortar was 50 mm thick. The slab was placed between adjacent circular stoppers of roadbed concrete. There were two vibration test methods to apply force from the vibration exciter. One placed the vibration exciter on the slab between the circular stoppers, the other had the vibration exciter on the circular stopper of the roadbed concrete, as shown in Fig. 5. Test results from method one include frequency characteristics of both the CA mortar and roadbed concrete. These two factors cannot be differentiated from each other. Test results by from method two give only the frequency characteristics of the roadbed concrete. Therefore, for the purposes of this research, method two was adopted.

2.4 Test results

Figure 6 shows a time history for acceleration of the vibration exciter put on the circular stopper of the roadbed concrete. The maximum acceleration of the vibration exciter was controlled to remain at around 1,000 cm/s². The maximum acceleration of the vibration exciter kept a con-
stant value in the period from 25 to 150 seconds after the test began, as shown in Fig. 6. At 175 seconds, acceleration peaked, which is probably due to resonance of the vibration exciter.

Figure 7 shows a time history for acceleration obtained from an accelerometer attached to the roadbed concrete near the tunnel lining. Several resonances of the roadbed concrete were observed in this test. The peak acceleration of the roadbed concrete was observed at about 130 seconds after the test commenced. This result clearly shows that the vibration exciter used in this study can vibrate the roadbed concrete. To confirm the repeatability of this test, the same vibration test was repeated three times. The frequency characteristics of the roadbed concrete in the three tests were almost the same as shown in Fig. 8, which indicates that the repeatability of this test is quite high.

\[
\int |x(t)|^2 \, dt = \frac{1}{2\pi} \int |X(\omega)|^2 \, d\omega
\]  

(1)

where \( t \) is time; \( x \), acceleration; \( X \), Fourier spectrum; and \( \omega \), angular frequency. In this research, the third evaluation method was adopted.

In practice, measurement of slab track deformation has been conducted from an inspection train. Inspection train measurements provide a number of indices related to slab track deformation. One of the representative indices of slab track deformation is a vertical displacement of rail level at 10 m intervals in the railway direction. Therefore, in this study, an increment of the vertical displacement of the rail in the longitudinal direction was used for investigations. It is to be noted that the measurement value obtained from the inspection train includes the influence of the track itself and the ground under the slab track, as mentioned before.

Figure 10 shows the relationship between the area of the Fourier spectrum obtained from the vibration tests and the vertical displacement increment of the rail at 10 m intervals in the longitudinal direction over 4 months, calculated from inspection-train data. Sensitivity analyses were conducted with the various frequency ranges to obtain Fourier spectrum area. From the results of these sensitivity analyses, the appropriate frequency range was determined to be from 3 to 50 Hz. The Fourier spectrum area obtained from the vibration tests revealed a good correlation with the vertical displacement increment of the rail.

3. Evaluation method

3.1 Vibration exciter

From Fig. 9, it can be seen that there are three possible indices to reflect the condition of the roadbed concrete. The first uses the predominant frequency of the roadbed concrete. A higher predominant frequency of roadbed concrete indicates good condition. The second indicator uses the amplitude of the predominant frequency of a passing train, which is essentially the same as the previous indicator. The third uses an area of the Fourier spectrum within a certain range of frequency. The area of the Fourier spectrum is highly correlated with vibration energy. Because the vibration energy calculated from the absolute value of acceleration of the roadbed concrete is equal to the area of the power spectrum divided by \( 2\pi \) as shown in (1):

\[
\int [x(t)]^2 \, dt = \frac{1}{2\pi} \int |X(\omega)|^2 \, d\omega
\]  

(1)
3.3 Condition rating

Figure 11 shows a slab track and roadbed concrete evaluation using the Fourier spectrum area and vertical displacement increment of the rail at 10 m intervals in the longitudinal direction. The relationship between the above two factors was classed into 4 categories; i.e. fair condition of both the track and the ground under the roadbed concrete; poor condition of the ground under the roadbed concrete; serious condition of the track and serious condition of the ground under the roadbed concrete. Using this evaluation, necessary work can be determined more efficiently before carrying out actual maintenance of the slab track.

4. Conclusions

This paper describes maintenance and evaluation methods for slab track in Shinkansen tunnels using frequency characteristics obtained from vibration tests and inspection trains, respectively. For the maintenance method, the Fourier spectrum of the roadbed concrete can be obtained from the vibration tests. Simple examples of vibration tests demonstrated the validity of this method. For the evaluation method, two factors were used: the first was the Fourier spectrum area obtained from the vibration tests and the other was the vertical displacement increment of the rail at 10 m intervals in the longitudinal direction. These two factors obtained from field measurements showed mutual correlation. Finally, the relationship between the above two factors was classed into 4 categories; i.e. fair condition of both the track and the ground under the roadbed concrete; poor condition of the ground under the roadbed concrete; serious condition of the track and serious condition of the ground under the roadbed concrete. The proposed evaluation method is of practical use for the maintenance of slab track in the Shinkansen tunnels.

References


Authors

Masahiro SHINODA, Dr. Eng.
Senior Researcher, Foundation and Geotechnical Engineering Laboratory, Structures Technology Division
Research Areas: Non-destructive test, Condition rating, Slope stability

Hiroaki SAKAMOTO
Section Chief, Structural Engineering Office, West Japan Railway Company
Research Areas: Non-destructive test, Condition rating

Norikazu MISAKI
Section Chief, Technical Research and Development Department, West Japan Railway Company
Research Areas: Non-destructive test, Condition rating