Special edition paper

Efforts in Development of a Construction Method for Ground Vibration Reduction

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The problem of ground vibration is expected to increase as trains operate at faster speeds. We have, in the past, studied vibration control work for installation near structures and proposed assessment methods for the effects of such work. There are, however, no actual records of ground vibration caused by train operation being measured and reviewed continuously and in the same manner. We thus carried out continuous ground vibration measurements at the same location and in the same manner. The measurement results confirmed that the frequency characteristics of ground vibration are greatly affected by different train sets, while the vibration transmission characteristics within the ground are not affected so much.

●Keywords: Ground vibration control, Vibration level, Vibration frequency bandwidth characteristics

1 Introduction

When a train runs fast, vibration propagates from the viaduct to the piers and then to the ground from the piers as oscillation sources. That often subsequently causes vibration of doors and windows of nearby houses and buildings.

Ground vibration propagated from piers to ground is expected to increase as trains operate at faster speeds. Thus, ground vibration control has come to be an important issue to overcome in achieving further speed increases with high-speed trains.

Since 2007, the Frontier Service Development Laboratory has proposed methods of analytically considering ground vibration, with an aim of establishing a design and construction method for more effective ground vibration control work. Those include a method of assessing effects of vibration control work (continuous underground wall) to be carried out near structures as shown in Fig. 1.[1) 2)]

In order to refine the method of forecasting ground vibration propagation, we are now conducting long-term measurement and analysis of actual ground vibration and its propagation from structures to the ground.

This article will cover knowledge obtained from the measurements and analyses conducted.

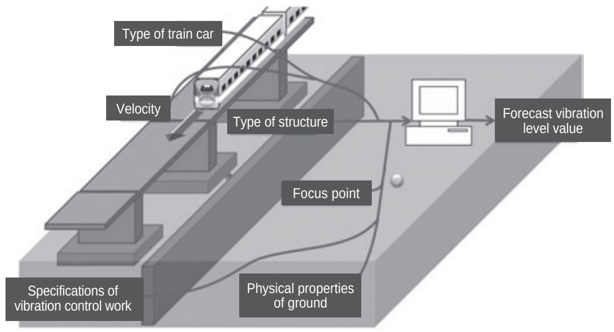

Fig. 1 Overview of Assessment of Effects for Vibration Control Work

Factors that cause variation in the measurement values of ground vibration could include the following items.

· Difference in oscillation sources
· Difference in physical properties of vibration media
· Difference in measurement methods

Difference in oscillation sources could include the differences in speed of running trains, axle arrangements, and weight of cars.

Difference in physical properties of vibration media could include change of ground characteristics due to change of temperature and groundwater level.

Difference in measurement methods could include the difference in measurement devices used and how they are installed.

2 Overview of Measurement

2.1 Objective of Measurement

Ground vibration caused by a running train is not constant, and it likely varies due to different factors. We have carried out ground vibration measurement to examine vibration control work in the past, but that was done only once before and after installation respectively. There has been no continuous measurement and statistic analysis of measurement results so far. Thus, in order to identify ground vibration variations, we decided to conduct continuous ground vibration measurement at the same location and in the same manner.

2.2 Selection of Measurement Devices

JIS Z 8735 "Method of measurement for vibration level" is provided as the standard for measurement of ground vibration related to vibration nuisance. Here, vibration level (decibel notation of the RMS of vibration acceleration weighted for human sensory characteristics) is generally measured using a vibration level meter specified in JIS C 1510 "Vibration level meter."

However, acceleration data is necessary in dynamic response analysis conducted for design and assessment of vibration control work, so we decided to use a servo-type accelerometer for vibration measurement this time. The vibration data was calculated in the manner stipulated in JIS C 1510 by post-processing the measured acceleration time history data.

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2.3 Device Installation Method

In measuring, we had to minimize measurement result variation that occurs due to the difference of measurement methods. As there are no detailed standards on the method of installing acceleration sensors on the ground, the difference in installation could affect measurement results. We thus first examined the effects the acceleration sensor installation method has on measurement results.

Table 1 shows the installation methods we examined, and Fig. 2 shows simplified diagrams of them.

Table 1 Acceleration Sensor Installation Methods

Case	Installation method
1	Place sensor directly on leveled and compacted ground surface
2	Spike sensor to compacted ground surface
3	Place sensor on stone plate on compacted ground surface
4	Install sensor as in Case 2 and place sandbag on it
5	Install sensor as in Case 1 and place a sandbag on it
6	Install sensor as in Case 3 and place sandbag on it
7	Place sensor directly on ground surface that is not leveled nor compacted
8	Spike sensor to ground surface that is not leveled nor compacted

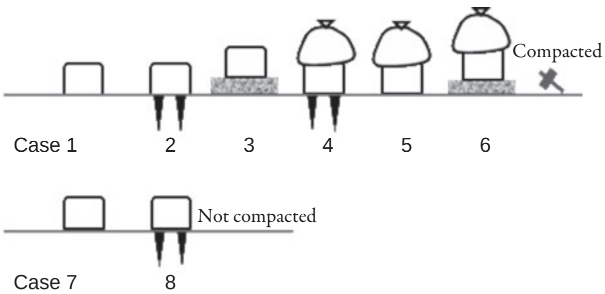

Fig. 2 Diagram of Acceleration Sensor Installation Methods

We measured three times as Tests A, B, and C. In each test, the same vibration was recorded using accelerometers installed differently.

In Test A, we made comparisons of Cases 1 to 4. In Tests B and Test C, one of the cases used in Test A was included. In Test B, Cases 4 to 6 were compared; in Test C, Cases 2, 7, and 8 were compared.

Fig. 3 to 5 show the vibration measurement results. The horizontal axis is the frequency (compiled in 1/3 octave-bands), and the vertical axis is the vibration level ratio that is the sense-weighted level of vibration acceleration (vibration level) normalized with the overall value.

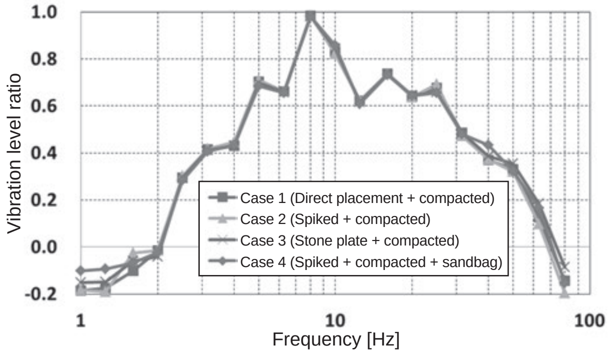

Fig. 3 Effects of Sensor Installation Methods (Test A)

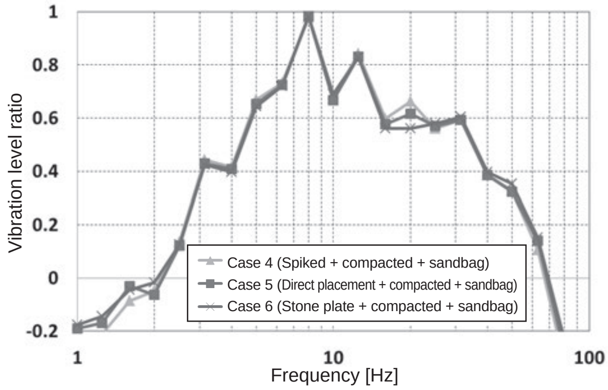

Fig. 4 Effects of Sensor Installation Methods (Test B)

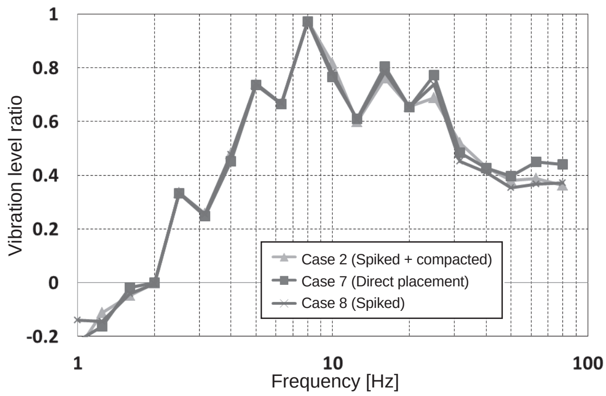

Fig. 5 Effects of Sensor Installation Methods (Test C)

Fig. 3 shows the results of comparison between Cases 1, 2, 3, and 4. In any of the cases, shape and value indicated in the frequency range near the peak are almost equal, demonstrating that the sensor installation method has little effect on the measurement value. Fig. 4 shows the results of comparison between Cases 4, 5 and 6. As in Fig. 3, the shape and value indicated in the frequency range near the peak are almost equal, demonstrating that the sensor installation method has little effect on the measurement value either. Fig. 5 shows a comparison between Cases 2, 7, and 8. Here, in Case 7, the vibration level measurement value in the high-frequency range greater than 50 Hz tends to be higher than that in other cases. This could be because mounted resonance occurred with the installation method of Case 7.

The results of Tests A, B, and C proved that difference in the acceleration sensor installation methods could affect the measurement value, except in Case 7. We thus decided to adopt the installation method of Case 8 for the measurement, taking into account the workload of installation.

2.4 Sensor Installation Points

Fig. 6 is a planar view of the acceleration sensor installation points. We measured vibration using the acceleration sensors installed at the points shown as Ground 1 to 3 and Pier 1.

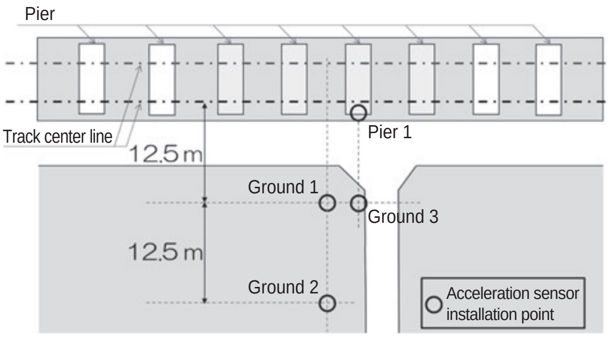

Fig. 6 Planar View of Acceleration Sensor Arrangement

3 Measurement Results

3.1 Vibration Frequency Band Characteristics

Fig. 7 and 8 show the 1/3 octave spectrum distribution of the vibration level ratios that were obtained from measurement values of perpendicular acceleration on the ground at 12.5 m from the track center. In the figures, Train Set A is a train consisting of 10 cars (car length 25 m) and Train Set B is a train of 16 cars (10 cars of 25 m car length and six cars of 20.5 m car length). The running speed of those trains is 230 km/h to 240 km/h.

Fig. 7 is a chart compiled to identify the effect of the train set and operation time of day by focusing on a specific day. The figure shows that the peak frequency band stayed the same regardless of the operation time of day. The octave band levels of the frequency range near the peak also are almost equal to each other. In contrast, looking at the effect of different train sets, the vibration levels at 3 Hz and 10 Hz are different. Those results reveal that the difference in the train sets affected the measured ground vibration value, while the operation time of day did not.

Fig. 8 is a chart compiled to identify the effect of operation time (date), focusing on a specific train. As seen in Fig. 7, the peak frequency band stayed the same regardless of the operation date. The spectrum shapes in the frequency range near the peak are equal, while the vibration levels vary a little in that range. In contrast, as seen in Fig. 7 again, the vibration levels at 3 Hz and 10 Hz are different from when comparing the effects of different train sets. As 10 Hz, in particular, is the frequency band where the second largest value was measured, we can conclude that the difference in train set greatly affects the measurement value of ground vibration.

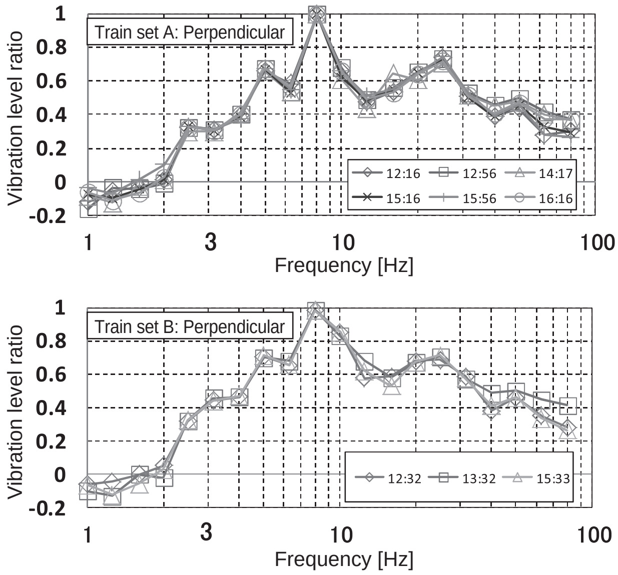

Fig. 7 Measurement Results per Train Set 1

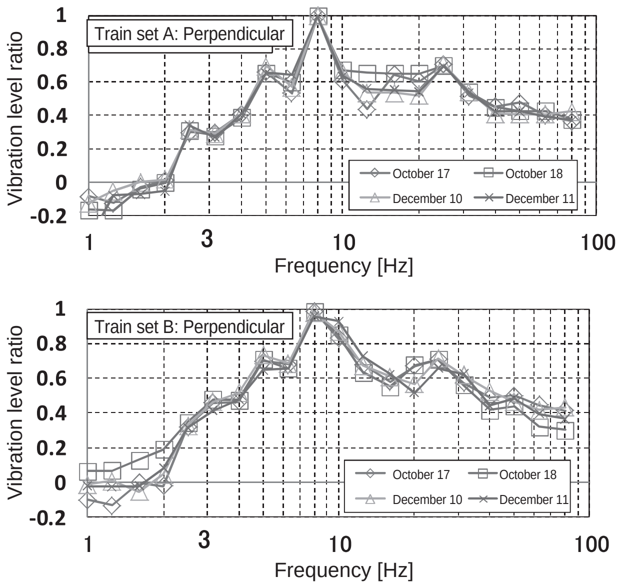

Fig. 8 Measurement Results per Train Set 2

3.2 Vibration Propagation Characteristics

In past ground vibration analyses, the ground was modeled as a viscoelastic body. In order to verify the consistency between that modeling and actual phenomena, we checked vibration propagation characteristics in the ground.

Fig. 9 and 10 show the transfer functions of acceleration at the output points of the checked ground (Ground 2 and 3) corresponding to the input points (Ground 1 and Pier 1) so as to indicate the vibration propagation characteristics of the ground. In those compiled figures, the horizontal axis is the frequency, and the vertical axis is the ratio of the acceleration Fourier spectrum.

Fig. 9 shows the transfer functions between Ground 1 and 2 per train set. With each train set, the transfer function tended to be amplified at around 4 Hz, 5 Hz, and 10 Hz. The positions of the peak frequency indicated by the transfer function agreed with each other and the shapes were almost equal with each train set. We thus believe that the difference in train sets only slightly affects the propagation characteristics in the ground of the vibration caused by a running train.

Fig. 10 shows the transfer functions between Pier 1 and Ground 3 per train set. With each of the train sets, the vibration tended to attenuate in the low frequency range less than 5 Hz and be amplified around 6 Hz and 8 Hz. This result also confirms that the difference of train sets only slightly affects the propagation characteristics in the ground of the vibration caused by a running train.

We can therefore determine that, in the ground vibration analysis, modeling the ground as a viscoelastic body based on ground structure and physical properties is consistent with the actual phenomena measured this time.

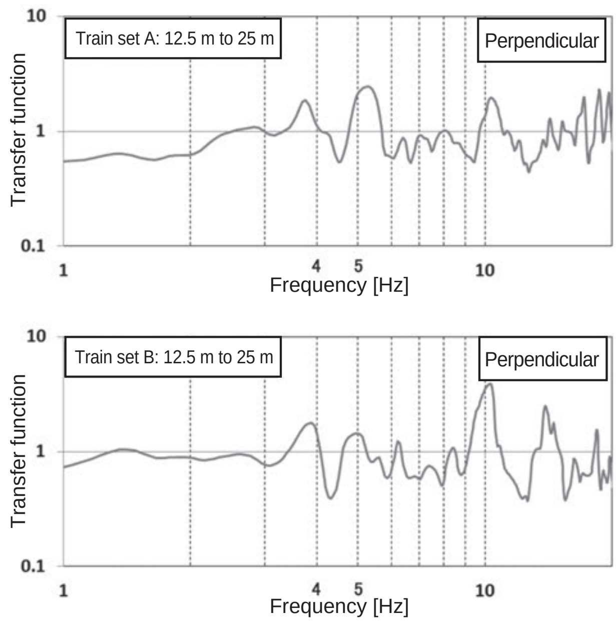

Fig. 9 Transfer Function (between Ground 1 and 2)

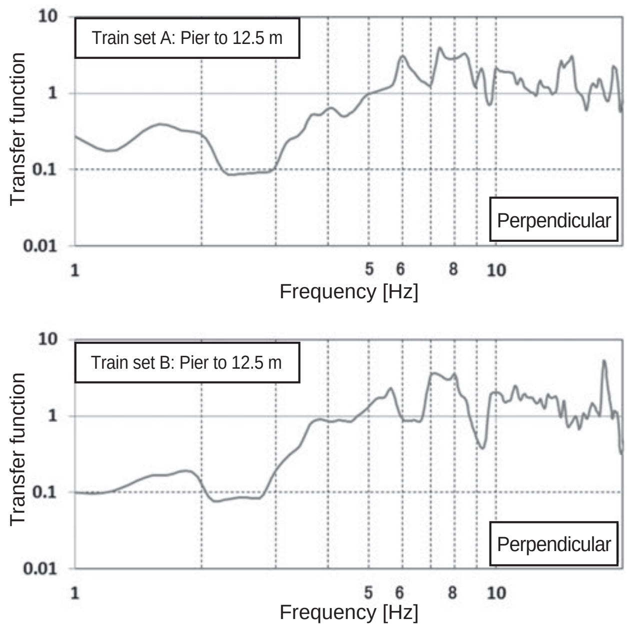

Fig. 10 Transfer Function (between Pier 1 and Ground 3)

4 Conclusion

In the efforts to measure ground vibration at the same location, we obtained the following findings.

(1) In installation of acceleration sensors, deviation of vibration level in the high-frequency range that is presumed to be the mounted resonance can be eliminated by tightly compacting the ground surface or embedding spikes.

(2) In the ground near a bridge, the difference in train sets affects the frequency characteristics of the vibration caused by a running train.

(3) The difference in train sets has little effect on the transfer functions between grounds with vibration caused by a running train.

(4) Within the range of the data analyzed this time, the vibration frequency characteristics are almost the same with the same train set and speed. The difference according to the date and time of train operation also only slightly affects those characteristics.

Finally, in conducting this research, we owe much to our co-researchers, Professor Kunio Saitoh and Mr. Kazuhito Yamada (Faculty of Science and Engineering, Chuo University), and Professor Takeshi Ishii (Research and Development Initiative, Chuo University). We would like to take this opportunity to acknowledge those people for their outstanding contributions.

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