Basic Research on Construction Method for Reduction of Ground Vibration

Reduction of ground vibration is a major issue that arises with train speed increase. In the past, we have studied the effects of and developed an assessment method for a vibration-isolating wall. A large amount of data is necessary to refine the assessment method, but it is difficult to obtain that due to the expense of installing a full-scale model. Therefore, we tried assessing its effects using a smaller model. We have succeeded in evaluating differences in the effect of the vibration control wall by material, using bender elements to evaluate one-dimensional vibration propagation characteristics. We have also succeeded in evaluating two-dimensional distribution of the wall’s effect using a model.

**Keywords:** Ground vibration, Underground vibration control wall, Vibration reduction effect

1 Introduction

When a train runs, vibration propagates from the girders of 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 worked on this issue with an aim of establishing a design and construction method for more effective ground vibration control work. Our efforts include test construction of vibration control work, on-site measurement of ground vibration, prediction of ground vibration near structures, and development of a method of assessing effects of vibration control work. [2][3]

When installing underground vibration control wall to reduce ground vibration, we have to decide specifications of the wall such as thickness, depth, length, and material, and the vibration reduction effects of the wall is assumed to vary according to the elements of those. Thus, in order to improve prediction accuracy of vibration reduction effect of the underground vibration control wall, we need to appropriately model the impact each element of specifications of the wall has on reducing vibration.

To check the impact different elements of specifications have on vibration reduction, it is desirable to actually install underground vibration control walls of varied specifications. But, due to the large labor and cost required to install full-scale underground vibration control walls, it is difficult to check in that manner to any significant extent.

We therefore attempted to evaluate vibration reduction effect of underground vibration control walls in the laboratory.

We carried out two tests: an element test using bender elements to check the impact on vibration reduction effects of major types of material of the wall and a test using a soil tank to check the impact of the wall on underground vibration propagation characteristics. We will introduce the details of those tests from the next chapter.

2 Test Using Bender Elements

2.1 Test Overview

Fig. 1 shows an overview of a bender element. A bender element has structure whereby piezoelectric elements polarized in the direction of thickness are bonded on both surfaces of a shim made of materials such as nickel. The shim gives elastic reinforcement and works as an electrode. Since a piezoelectric element expands or contracts as voltage is applied in the polarization direction, bending deformation occurs on the bender element when voltage is applied. Furthermore, when piezoelectric elements expand or contract due to external force, potential difference on the surfaces in the direction of polarization changes. Thus, when bending deformation occurs with a bender element, potential difference occurs on the surfaces of the bender element according to the amount of deformation.

By using such characteristics of bender elements, we can use a bender element as an oscillator element or a vibration receptor element.

![Fig. 1 Overview of a Bender Element](image)

Fig. 2 is an overview of a bender element test piece. The test piece of ground material was cylindrically shaped with a diameter of 5 cm and height of 12 cm. Near the center in the direction of height, a type of vibration control material was inserted. A bender element is set at the upper and lower ends of the cylindrically shaped test piece. The bender element at the top was used as an oscillator and the bender element at the bottom as a vibration receptor element.

In this test, we used the test piece shown in Fig. 2 to compare ratios of vibration amplitudes received at the receiving point to vibration amplitudes at the oscillation point. By comparing those ratios, we checked vibration reduction effect with and without vibration control walls and with differing materials.
2.2 Test Results

Fig. 3 shows the test results. The horizontal axis is the vibration frequency oscillated by the oscillator bender element, and the vertical axis is the vibration frequency received by the receptor bender element. By arranging the results, we can obtain the vibration amplitude (with vibration control walls) divided by the vibration amplitude (without vibration control walls). Here we call the quotient “amplitude ratio”. The amplitude ratio varies per frequency, so we deal with the average amplitude ratio here as a representative amplitude ratio.

Fig. 4 shows the impact different materials of vibration control walls have on vibration reduction. The vertical axis is the amplitude ratio, and the horizontal axis is the impedance ratio. Here, the impedance is the product of material density multiplied by vibration propagation velocity, and the impedance ratio is the ratio of impedance of ground material and vibration control wall material. The solid line, dotted line, and broken line in the figure are all theoretical lines, and W and $\lambda_2$ are vibration control wall thickness and wave length in the wall respectively. The theoretical lines reach the maximum value of 1 when the impedance ratio is 1. As impedance has strong correlation with material hardness, larger difference between hardness of ground material and wall material brings about greater vibration reduction.

Fig. 4 shows the average amplitude ratios of five types of vibration control wall material tested (urethane, mortar, acrylic, aluminum, brass). The test results indicated that average amplitude ratio becomes larger with material that has an impedance ratio closer to 1, proving a similar tendency between test results and theoretical values.

3 Test Using a Soil Tank

3.1 Test Overview

The test using bender elements covered in the previous chapter is a one-dimensional modeling test focusing on a part of vibration propagation from a pier to ground. Actually, however, vibration is horizontally propagated from a pier as the oscillation source. Therefore, we decided to perform a test to check the impact specifications of underground vibration control walls have on the characteristics of horizontal vibration propagation on the ground surface. In this test, we checked the impact of wall length in particular among the specifications of underground vibration control walls.

As shown in the test overview in Fig. 5, we measured the vibration propagated to the ground from the oscillator set on the model ground in a soil tank using accelerometers placed horizontally.

Fig. 6 shows the placement of the oscillator and accelerometers and test conditions. Test parameters were whether or not vibration control walls are installed and position of the oscillation point. The impact of wall length was reproduced by shifting the position of the oscillation point. As the positions of...
accelerometer 2 and accelerometer A were overlapped in Case B4, we shifted accelerometer A to the right by 62 mm. The details of the test tools and material are as follows.

(a) Soil tank
In order to minimize impact of external noise and wall reflection waves, we attached Styrofoam as cushion to the bottom and side surfaces of the soil tank. Internal dimensions of the tank after Styrofoam was attached were 1.645 m wide, 2.728 m long, and 1.5 m high.

(b) Model ground
Model ground was formed with air-dried Onahama sand using the pluviation method with a hopper so as to be 1.25 m high and have relative density of 60% in the soil tank.

(c) Vibration control wall
To look at the possibility of identifying the vibration reduction effect in the test, it is desirable to use a vibration control wall of material with large vibration reduction effect. The results of the bender element test demonstrated that urethane has the best vibration reduction effect; however, the issue remained of how to install in the ground material softer than the ground. In this test, we thus decided to use brass as the material of the vibration control wall as that had the best vibration reduction effect among the materials harder than the ground.

(d) Oscillator and input waveform
The oscillator was secured to the model foundation set on the model ground. Fig. 7 shows the fixed oscillator. On the model foundation, accelerometers to check input were attached as well. We applied sine wave vibration of 126 Hz (equivalent to 4 Hz in the actual situation) in the vertical direction.

(e) Accelerometer
Accelerometers used were PV93 and PV87 piezoelectric acceleration pickups by Rion. We attached a spike under each of the accelerometers and inserted the spike into the ground to place the accelerometers. We then measured acceleration in the vertical direction.

(f) Data logger
With a sampling frequency of 20 kHz, we recorded a log for 0.5 sec. (10,000 data instances). Recording was started after confirming vibration became stable after turning the oscillator on.

3.2 Test Results
We sorted out the measurement results for amplitude of acceleration at the measurement points by dividing by amplitude of acceleration at the oscillation point on the model ground. Here we call the quotient “propagation amplitude ratio”. Fig. 8 to 12 show the results. In the figures, the direction at a right angle to the vibration control wall is the X axis, and the direction in parallel to the wall is the Y axis. The locations of the oscillation point and the reception points are indicated by the distance along the axes from the oscillation point (the center of the model foundation) of Case A as the standard.

Fig. 7  Setting of the Oscillator and Accelerometers

Fig. 8  Measurement Results (Case A)

Fig. 9  Measurement Results (Case B1)

Fig. 10  Measurement Results (Case B2)

Fig. 11  Measurement Results (Case B3)

Fig. 12  Measurement Results (Case B4)

(a) Case A (with no vibration control wall)
We can see that vibration was propagated while being attenuated according to the distance from the oscillation point.

(b) Case B1 (with a vibration control wall)
The difference between Case A and Case B1 is simply whether or not a vibration control wall was installed.

The propagation amplitude ratio in Case B1 was greatly reduced
compared with Case A in the area of $X \geq 124$ after vibration passed the wall. The tendency that the propagation amplitude ratio was reduced according to the distance from the oscillation point was the same as seen in Case A, while the value of the propagation amplitude ratio was smaller.

(c) Case B2 to 4 (with a vibration control wall and different oscillation point)

We did not compare the propagation amplitude ratios with and without vibration control wall in Case B2 to 4 as was done in Case A and B1. Comparing the propagation amplitude ratio in those cases with that of Case B1, it was generally larger than that in Case B1 within the area of $X \geq 124$. We therefore can assume that vibration reduction effect of a vibration control wall would be smaller than that in Case B1. In Case B3 and B4 in particular, attenuation tendency according to the distance from the oscillation point varied according to the direction of propagation. The test results revealed that attenuation was smaller on the side of shorter distance from the oscillation point to the wall end (on the left side of the oscillation point in the figure) than on the side of longer distance (on the right side of the oscillation point in the figure).

3.3 Consideration

In consideration, we defined a traverse line focused on, distance from the wall end, and propagation distance as shown in Fig. 13. The line segment from the oscillation point to the reception point focused on is the traverse line focused on; the shortest distance between the point where traverse line focused on and wall intersect to the wall end is the distance from the wall end; and the distance from the oscillation point to the reception point is the propagation distance. With those, we checked the impact the distance from the wall end had on vibration reduction effect.

Fig. 14 shows the relation between the distance from the wall end in the case where the traverse line focused on is at a right angle to the wall and the vibration reduction rate according to the propagation distance. Here, the vibration reduction rate is the difference between the propagation amplitude ratio on the traverse line focused on in Case A (the “response amplitude ratio”) and the propagation amplitude ratio on the traverse line focused on in other Cases divided by the relative amplitude ratio. The greater this value is, the greater vibration reduction effect is.

Fig. 14 shows that, with some exemptions, vibration reduction rate increases as distance from the wall end becomes longer. Conversely, vibration reduction rate decreases as distance from the wall end becomes shorter.

Also, vibration reduction rate decreases as propagation distance becomes longer. The rate of reduction of vibration reduction rate according to distance from the wall end varies per propagation distance. That rate of reduction becomes greater as propagation distance becomes longer to some extent.

These results revealed distance from the wall end impacts vibration reduction effect and the extent of that impact varies according to propagation distance. Thus, when we actually install an underground wall to control vibration, we need to evaluate such impact and reflect the evaluation results on the wall design.

4 Conclusion

With an aim of confirming vibration reduction effect of underground vibration control walls in the laboratory, we carried out an element test using bender elements and a test using a soil tank. As we could quantitatively identify the impact of different wall materials and wall lengths, we can say that we were able to confirm the effectiveness of the evaluation of vibration reduction effect in the test.

As reported in this paper, we carried out the tests to identify the possibility of evaluating vibration reduction effect, and the tests were done under conditions we assumed would have large vibration reduction effect. In the future, we will work on experiments under conditions taking into account actual wall construction based on the results of research being done at the same time on prediction of points where ground vibration will increase with train speed increase. In that way, we will aim to establish a reasonable design and construction method for vibration control structures.

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Reference: