# Experimental and Numerical Studies on Ground Vibration Isolation by PC Wall-Pile Barrier

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# EXPERIMENTAL AND NUMERICAL STUDIES ON GROUND VIBRATION ISOLATION BY PC WALL-PILE BARRIER

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**ABSTRACT**

PC wall-pile barrier was known to be effective to isolate ground vibration from traffic vibration sources. Filed measurement on the traffic vibration isolation by PC wall-pile barrier from a elevated road in the Higashi-Meihan Highway was performed, and field model experiments were also conducted to identify the effectiveness of PC wall-pile barrier. Factors affecting on the performance of ground vibration isolation barrier were understood from the field model experiments. Numerical analyses on both field measurement and field model experiment were carried out to identify the effectiveness of such barrier and they could quantitatively simulate and evaluate the effectiveness of PC pile-wall barrier.

## INTRODUCTION

An elevated road or road bridge sometimes causes ground vibration. The elevated road measured and simulated in this study is located on the west side of the Kuwana Higashi Interchange of the Higashi Meihan (Nagoya-Kobe) highway. Because the road was built on a relatively soft ground, the passing vehicles produce strong ground vibrations. Residents in the surrounding areas complained and requested that the disturbing vibrations should be urgently reduced.
A number of reports on the results of experimental and theoretical analysis on the effectiveness of PC-wall piles as ground vibration barriers is given by Hayakawa et al. [1998a, 1998b, 1999 and 2000]. Field measurement and numerical simulation are performed to identify the effectiveness of a PC wall-pile barrier. The source of the ground vibrations is discussed and then a finite element method is carried out to see whether it is possible to quantitatively identify the effectiveness of such barrier. The field model experiments and their simulation analyses are also carried out to investigate more deeply. Finally, main conclusions are summarized.

## FIELD MEASUREMENT OF GROUND VIBRATION CAUSED BY AN ELEVATED ROAD

### Location and assignment

The source of ground vibration in this study is an elevated road, hereafter simply referred to as the “bridge” with an its over-all span length is 294.5m with three continuous girders supported by 10 piers at interval of 32.5m shown in Fig. 1. Figure 2 shows piers, the ground, PC wall-piles as well as the positions where ground vibration was measured. The boring log shows the composition of the soil. The soil consists of a sandy layer with a N-value between 2 and 20 along a depth of 10.0m. From a depth of 32.5m, there is a thick soft-clay stratum having a N-value smaller than 5. Beneath this soft soil, a sandy bearing layer with an approximate N-value of 20 exists. 12m-long PC wall-piles were driven one after another to build the continuous wave barrier by using a similar commonly used technique for hollow piles. They were driven with a boring method using an earth auger passing through their hollows. The depth to which the piles were driven were determined in such a way that the barrier can effectively isolate the surface wave and it can also serve as a soil containment wall while work was in progress to build the footing of the bridge. About 300 piles were driven to build the barrier in total at 45 degrees from the ends of the lower work of the bridge.

### Outline of field measurement

An 8-ton sprinkler truck with a weight of 23 tons was used as a test vehicle generating vibration. Vibration was measured on

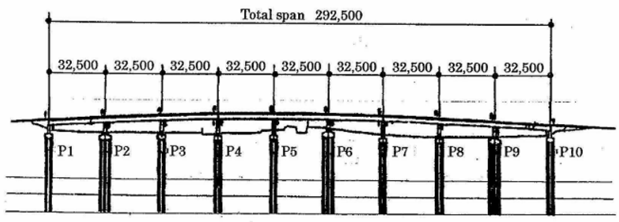



*Fig.1 General view of the bridge.*

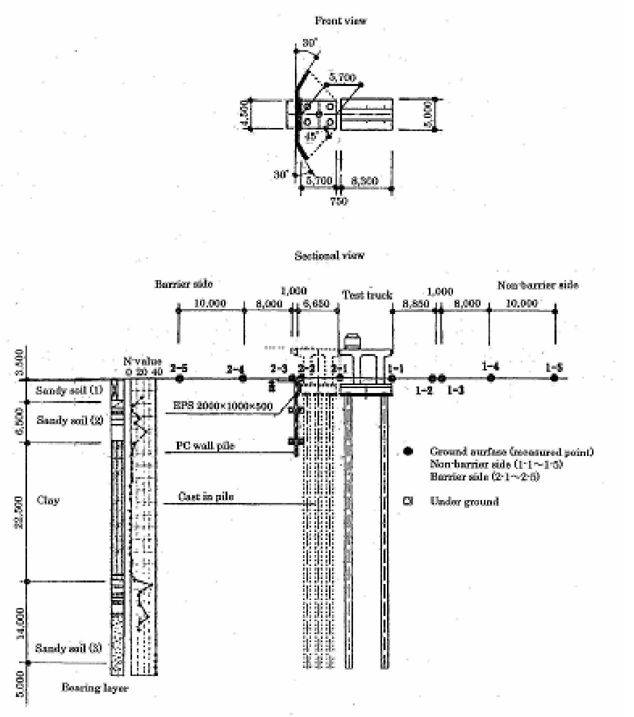



*Fig.2 Relative position of the pier, the barrier and the vibro-meters as set-up.*

ground surface as well as underground. 10 vibration-level meters were set up on ground surface in an equal pattern both on the barrier side and non-barrier side with respect to the bridge as shown in Fig.2. Underground vibration was measured by using vibro-meters especially designed for the experiment and set up on the inside faces and outside ones at depths of 5m and 10m.

Isolation effect of PC pile-wall barrier

Vibration levels were measured on the soil at four points along each of the two lines. One passing through pier number P1, the other pier number P4. Underground vibration at depths of 5m and 10m within the hollow of a pile were also measured. Because the vibration levels measured along the line intersecting P1 were roughly the same as those recorded along the line passing through P4, it was decided to address the former only. These are shown in Fig.3. It can be observed that on both sides, barrier and non-barrier sides. The levels were reduced as the distance from the footing or from the foot of the pier increases. The reduction was about 10dB at a distance of 25m. Furthermore, the vibration level on the barrier side was strongly reduced to the level reached a point immediately in front of the barrier, although it increased again after passing through the barrier. Overall, a reduction of about 5dB due to the barrier at 25m away from the footing is observed. Figure 4 shows the levels of underground vibration as measured in the hollow of the pile in three directions. X-direction is normal to the bridge. Y-direction is parallel to the bridge, and Z is the vertical direction. The vibration levels are higher than those at the further location from the bridge. It is noted that the

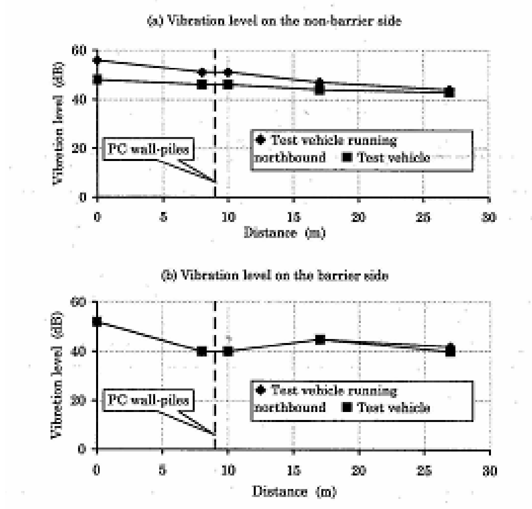



*Fig.3 Surface vibration level along the line passing through P1.*

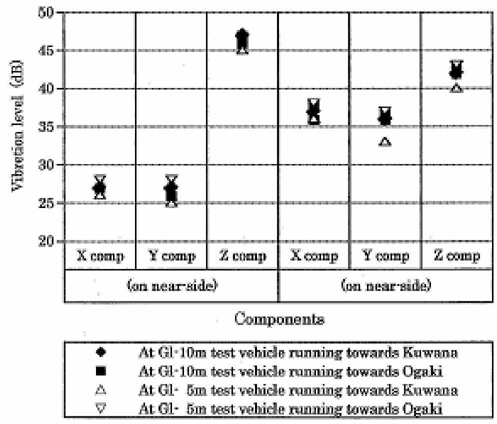



*Fig. 4 Vibration levels at underground*

difference is about 5dB in the vertical direction, which can be observed as the reduction effect of the barrier. At any rate, effect is seen to have been the largest on Z-component.

## NUMERICAL SIMULATION OF FIELD MEASUREMENT

Modeling and conditions for the analysis

As already mentioned, the ground vibration was measured on the ground surface just above the edges of footing. One measuring point is located just in front of the PC wall-pile barrier and another is located at its behind. Other two points were further away from the barrier. A dynamic response analysis was conducted using a finite element method. The acceleration recorded at the point just above edge of the footing was used as input excitation in order to reproduce the ground vibration at the barrier side and that on the non-barrier side (Kani & Hayakawa, 2002). Figure 5 shows the FEM model and the parameters of the elements involved in the analysis are given in Table 1.

Figure 6 shows the observation locations (indicated by the white circle symbol) and the location of applied load (indicated by arrows). Numbers (1) to (5) indicate the observation

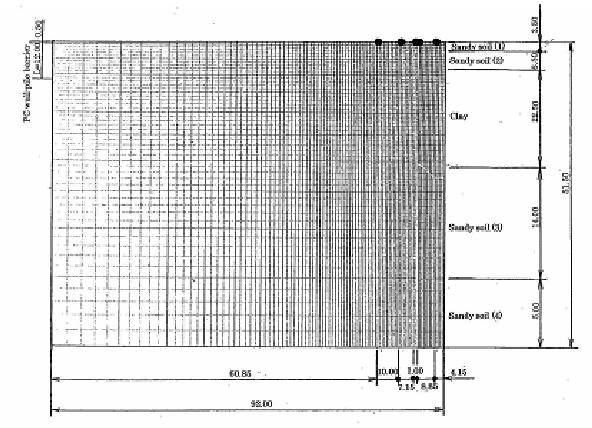



*Fig. 5 FEM model mesh.*

*Table 1 Parameters of FEM analysis.*

| Elements | Modulus of elasticity (N/m²) | Dynamic Poison ratio | Weight | Specific Remark |
|---|---|---|---|---|
| Sandy layer | 100 | 0.45 | 18 | N=18 |
| Sandy layer | 58 | 0.45 | 18 | N=18 |
| Clay layer | 56 | 0.49 | 17 | Saturated N= 1 |
| Sandy layer | 84 | 0.49 | 18 | Saturated N=15 |
| Bearing layer | 280 | 0.49 | 19 | Saturated N=30 |
| Footing | 23500 | 0.167 | 24.5 | |
| Piles as driven | 25000 | 0.167 | 24.5 | |
| PC wall-pile barrier | 19700 | 0.167 | 24.5 | |

locations in the area with wave barrier. Numbers (6) to (10) were located in the area without wave barrier. Figure 7 shows the input accelerations and Figure 8 shows the corresponding Fourier spectrum. The input acceleration was recorded at ground surface just above the footing. Accelerations at four locations of the ground surface, indicated by the arrows in Fig.6, are used as loading in the numerical calculation. Because many prominent peak are at frequencies around 3Hz and 10Hz, unit size of 1m for the elements over the distance from the accelerating point to the measuring was chosen to improve the accuracy of the response in the high frequency range. The analysis was conducted by using a direct integration technique. The considered response period was 20 sec.

Discussion and consideration

Fig. 9 shows the development of the maximum response with the distance from the source on the non-barrier side. It is seen that when acceleration was induced at a single location response was very strong at positions immediately behind the point. However, it rapidly decreased to a relatively low value. It indicates that the footing acted as a rigid body when subjected to the excitation generated by the traffic on the bridge. Numerical integration was conducted through an iteration using a Newtonian method at a time increment of 0.001 sec. to have the necessary convergence of the unbalanced forces in the equilibrium calculation. A discrepancy was clearly observed in the results as obtained without a calculation for convergence. Figure 10 shows the response on the barrier-side to induced

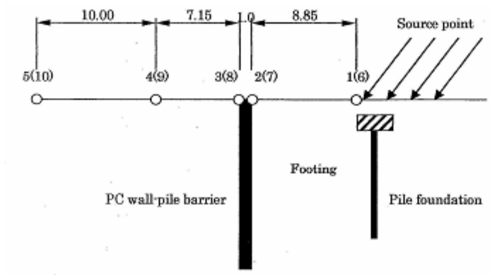



*Fig.6 Source point and measured point.*

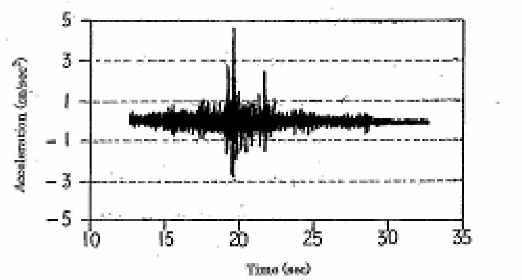



*Fig. 7 Waveform of the input acceleration.*

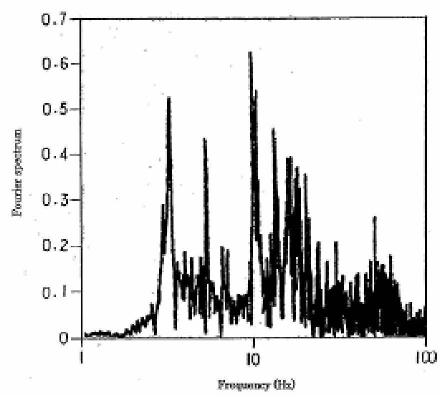



*Fig. 8 Fourier spectrum of the input waveform.*

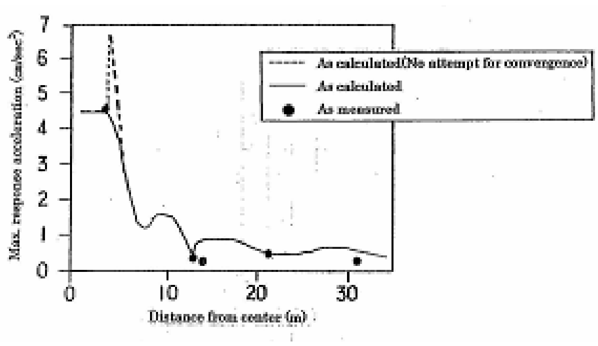



*Fig. 9 Response at non-barrier side.*

acceleration at the four locations.

The measured data and the calculated response are compared in Fig. 11. The broken line indicates the calculated response on the non-barrier side, while the solid line that on the barrier side. Data shown with white circle symbol are values as measured on the non-barrier side while those with black circle are those on

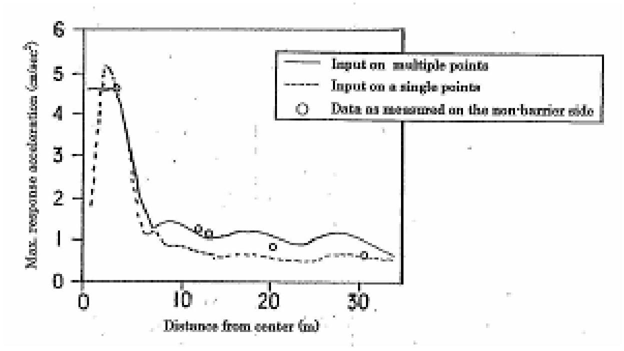



*Fig. 10 Response at barrier side (with induced acceleration at four locations).*

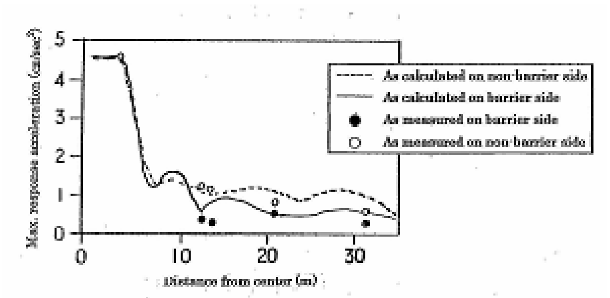



*Fig.11 Response of maximum acceleration.*

the barrier side. It is seen that the calculated results are in fairly good agreement with the data as measured. It can therefore be assumed that the model used in the analysis is capable of reproducing in a fairly accurate manner albeit with slight errors. Note should be taken that the observed ground vibration was amplified to some extent while it was transmitted from the source to the barrier through the ground. No explanation is possible at this stage on this phenomenon since no data are available. The phenomenon however may be assumed to have arisen from the combination of the ground vibration from source and a secondary one as reflected from the barrier.

## FIELD MODEL EXPERIMENTS OF PC WALL-PILE BARRIER

### Outline and procedure of field model experiment

A series of field experiments were conducted on ground in an area 420 cm long and 275 cm wide in front of Soil Mechanics Laboratory in Ritsumeikan University. The layout of the trench and measuring points are shown in Fig. 12. The soil conditions in the site was as follows; water content of 24.0%, wet density (or unit weight) of 1.95 g/cm$^3$, dry density (or unit weight) of 1.57 g/cm$^3$, and shear wave velocity of 149 m/sec. We excavated first a trench of 60 cm wide, 275 cm long and 150 cm deep between the measuring points No. 2 and 3, and constructed a subsurface wall in the trench by placing twelve PC wall-piles in an array. Each wall-pile is 150cm long with 15cm x 15cm square section and contains a cavity of 10 cm in diameter. The cross section (side view) of the PC wall thus constructed is shown in Fig. 13.

The ground vibration was measured with six vibration-level meters. As a vibration source, a weight of 5 kgf was dropped from the height of about 1 m, and the propagated waves in vertical acceleration levels in VAL (vibration acceleration level in dB) were measured. The measuring points were set along six lines from A to F at 60 cm interval, each interval between lines is 55cm. The measurement was conducted at three stages of construction of the wall, i.e. when the embedded height was 50cm, 100cm and 150cm from the bottom of the trench. Ground vibrations at every measuring points were measured when excited at the impact points A through F as well as G through L, and the acceleration levels on the same lines were compared. A series of measurements were conducted for the PC wall-pile with cavity and those with the

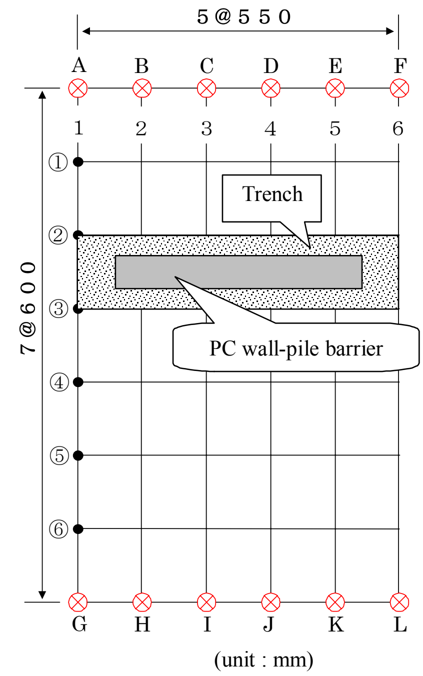



*Fig.12 Arrangement of measuring points.*

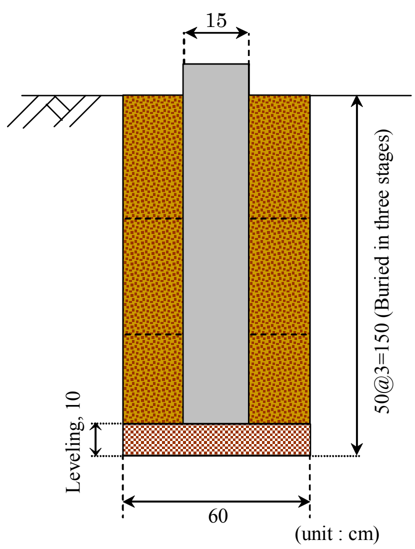
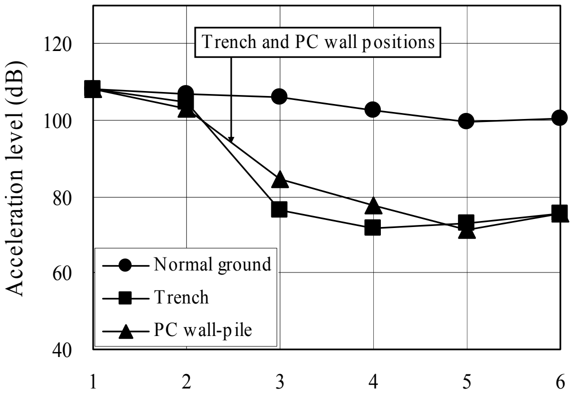
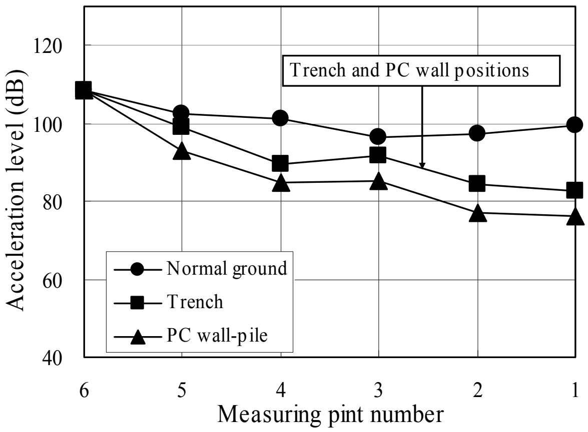



*Fig.13 Cross section of PC wall-pile.*



(a) Vibration source : point D



(b) Vibration source : point J

*Fig. 14 Reduction of acceleration level for the case with a subsurface wall.*

cavity filled by soil or water, and the results were compared with the cases for the natural ground as well as for empty trench.

Experimental results and discussion

In order to examine the screening effect of a subsurface PC wall-pile barrier, the distributions of acceleration levels on line A through L normalized by the level at point No.1 were compared. Two representative examples for the sources at D and J are shown in Fig. 14. Here the screening effect of the PC wall-pile barrier is compared with the cases for natural ground and for a empty trench. In the case of D, where the distance between the vibration source and the PC wall-pile barrier is relatively short, the levels behind the trench or the barrier are reduced by more than 20 dB. It is known that the isolation barrier placed near the vibration source can effectively screen body waves such as P- or S-waves, and the results described above are considered as such an example [Haupt, 1995; Woods, 1968].
In contrast, in the case of source at J, where the distance between the source and the wall is not short, the level in front of the wall fluctuates, which may reflects an interference of direct and the reflected waves from the wall. The levels behind the trench or the wall were reduced by about 8 dB. The reason for this is supposed that the incident wave to the wall has converted in part to a surface wave such as Rayleigh wave with low-frequency components on the path before arriving at the wall and such components are hard to screen.

NUMERICAL SIMULATIONS OF FILED MODEL EXPERIMENT

Outline of numerical simulation

A numerical simulation was conducted for ground vibration and its screening by various countermeasures. A three-dimensional analysis was conducted and the soil ground is modeled by laminar elements and the PC wall-pile barrier by three-dimensional shell elements. Impact force by weight dropping was estimated by inversion analysis based on the above model from seismograms obtained near the source. Parameters for ground for the three dimensional analysis are given in Table 2, and the model is shown in Fig. 15. The division of ground into lamina was chosen to let the thickness be less than 1/5 of wavelength of 250Hz component wave.

Table 2 Parameters in the numerical simulation.

| Unit weight ($tf/m^3$) | S-wave velocity | P-wave velocity | Poisson's ratio | Damping ratio (%) |
|---|---|---|---|---|
| 2.5 | 153 | 700 | 0.475 | 2.0 |

Discussion of numerical simulation results

Measured and calculated acceleration levels along the measuring line C-I are shown in Fig. 16. Calculated results are compensated to make the computed value at measuring point No. 1 equal to the measured value at the same point without countermeasure. The computed and measured values agree well for the cases without countermeasure implying that the assumed parameters are appropriate. In the case with countermeasure, although the computed values did not agree well with the measured values closely behind the wall, the other points agree appreciably well with the measured values, and the results on the whole may be seen as revealing the screening effect of PC wall-pile barrier.

CONCLUSIONS

In this study, a PC wall-pile barrier was addressed as a means for reducing ground vibration due to road traffics. Both field measurements and an FEM analysis of a elevated road were performed. Also, field model experiments and their simulation are performed. From this study, the following conclusions can be made.

[1] The PC wall-pile barrier was found to be capable of reducing both surface and underground vibration by about 5dB at a distance 25m away from the footing of the

considered bridge.

[2] Prominent peaks were observed in the spectra of both surface and underground vibration in the frequency range between 3Hz to 4Hz and 12Hz to 13Hz. A particularly remarkable reduction was attained underground vibration at these ranges of frequency.

[3] The results from the analysis suggested that the footing responded as a rigid body.

[4] The analytical method proved to be capable to fairly accurately reproduce the reduction of the maximum response acceleration on ground surface.

[5] The screening effect of subsurface wall depends on the distance between the vibration source and the wall. The wall can effectively screen P- and S-waves in the case where the distance between the vibration source and PC wall-pile barrier is comparatively short.

[6] The screening effect of the PC wall-pile barrier was quantitatively simulated by the three-dimensional finite element analysis.

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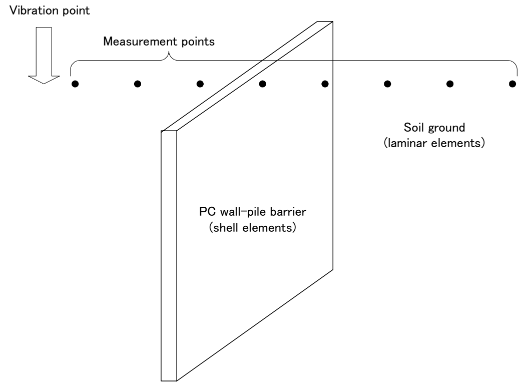


*Fig. 15 Numerical simulation model of field model experiment.*

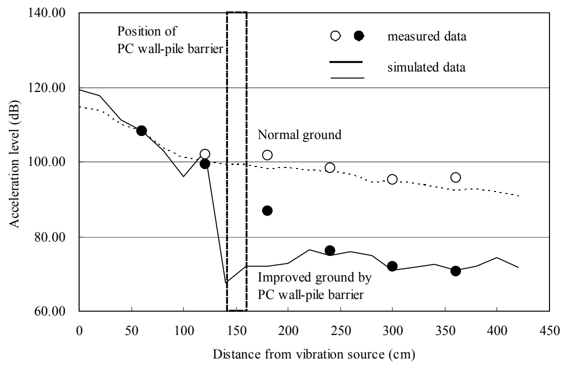


*Fig. 16 Comparison between measured and simulated data.*