Simulation of Field Vibration in the Vicinity of HST Viaduct Foundation and its Countermeasure with Honeycomb WIB

Student member of JSCE Bian Xuecheng, Ph.D Candidate, Okayama University
Member of JSCE Hirokazu Takemiya, Professor, Okayama University

Background

In the last decades, with the convenience and efficiency improvement provided by the remarkably growing construction of high speed train(HST) all along the world comes the negative effect of the vibration emitted from the train running to the residence, sensitive equipments and high-tech production facilities in the vicinity of the train track, which propels the researches in the prediction and evaluation of field vibration from engineering and environmental aspects. At present, some vibration mitigation have been proposed, among them, the Wave impeding Barrier(WIB) is a promising technology to meet the requirement.

Therein, a three dimensional axisymmetric finite element program has been developed to simulate the field vibration excited by the motion of pile foundations which are designed to support high speed train viaduct structure. The field test results of the ground vibration in vicinity of pile foundation which subject to the horizontal shaker loading at footing top are used to verify the simulation results. The mitigation effectiveness of the installation of honeycomb shape WIB structure is also studied.

3D Axisymmetric FEM model

The interaction analysis model for piles foundation and surrounding soils is constructed with the substructure concept[1]. As to the pile group subject to the foundation head loading in arbitrary direction, the semi-analytical solution of axisymmetric finite element with Fourier expansion in azimuth is advantageous for the memory size and computation efforts over the full three dimensional simulation methods without losing the acceptable precisions. The vertical and torsional loadings take the Fourier order of 0 while the horizontal and rocking loadings take the Fourier order of 1. For each Fourier series, the movement equilibrium has been transformed into two-dimensional plane, the equivalent stiffness of ring piles and soil ring element are superposed at the corresponding interface nodes. Thereafter, the dynamics equations can be solved with conventional finite element procedures.

For the field vibration, the wave propagation along ground surface in form of Rayleigh wave is predominant, and the P wave in vertical direction does not contribute much to the field surface responses. Hence, in current model, at the curtain depth a rigid base support is assumed. The transmitting boundary elements are arranged at the side boundary of the near field modeled by finite elements. The hybrid method of the finite element and thin layer element is advantageous for the solution of wave propagation in infinitely-extended soil media. Because the thin layer element is accurate in the horizontal direction, while in the vertical direction, has the same accuracy as the finite element method. Comparing to the boundary element method(BEM), the thin layer method needs no fundamental solution and can satisfy the conditions at the infinitely extended boundary with the layer interface. The stiffness matrix obtained from the thin layer method can be naturally integrated into the finite element formula which is used to describe the near field structure. All the formulations are conducted in the Fourier frequency domain.

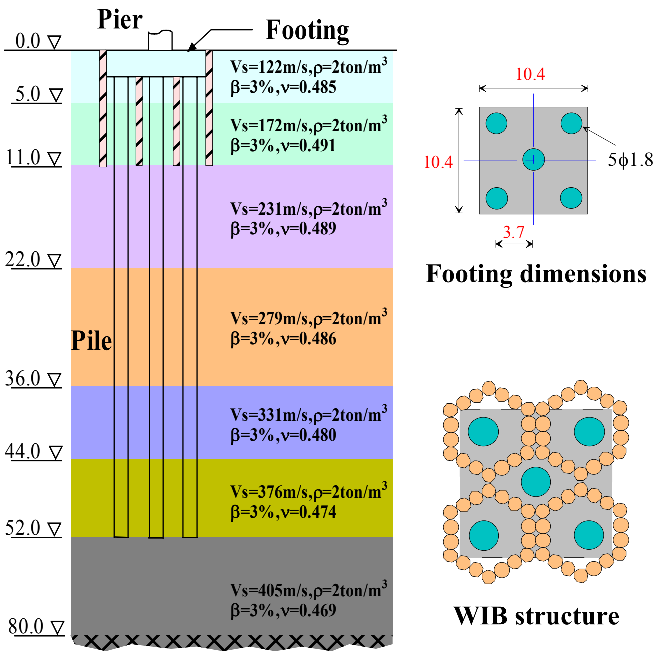


Fig.1 Pile foundation and site condition

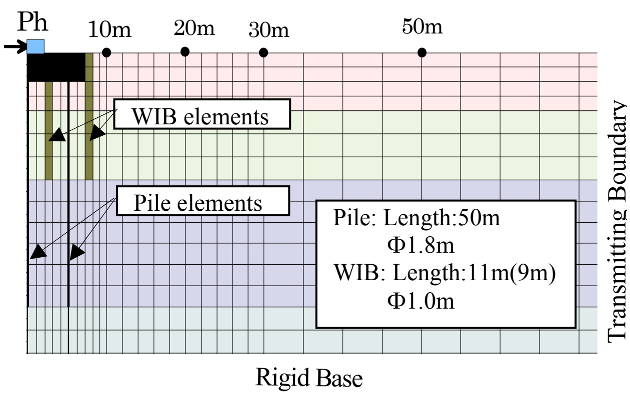


Fig.2 Simplified FEM model

The honeycomb WIB[2] is a new developed type of WIB, which is an arrangement of soil-cement columns that make honeycomb configurations in the horizontal plain view and is embedded in the soil at an appropriate depth. The honeycomb configuration is well balanced in force flow within the section. The size of cells is determined in view of the targeted wavelength beyond which the wave propagation is impeded because of the kinematic constrain by the stiff soil-cement columns. This design aims at modulating waves, essentially shifting the wavelengths of incoming waves into smaller ones and releasing the wave energy while the

KEY WORDS: Axisymmetric FEM, Ground vibration, Shaker test, WIB
〒700-8530 岡山市津島中 3-1-1 岡山大学環境理工学部環境デザイン工学科 Tel(Fax) 086-2518146

vibrations are transmitting across the WIB zone. Consequently, the WIB works for reducing the vibration amplitudes across it.

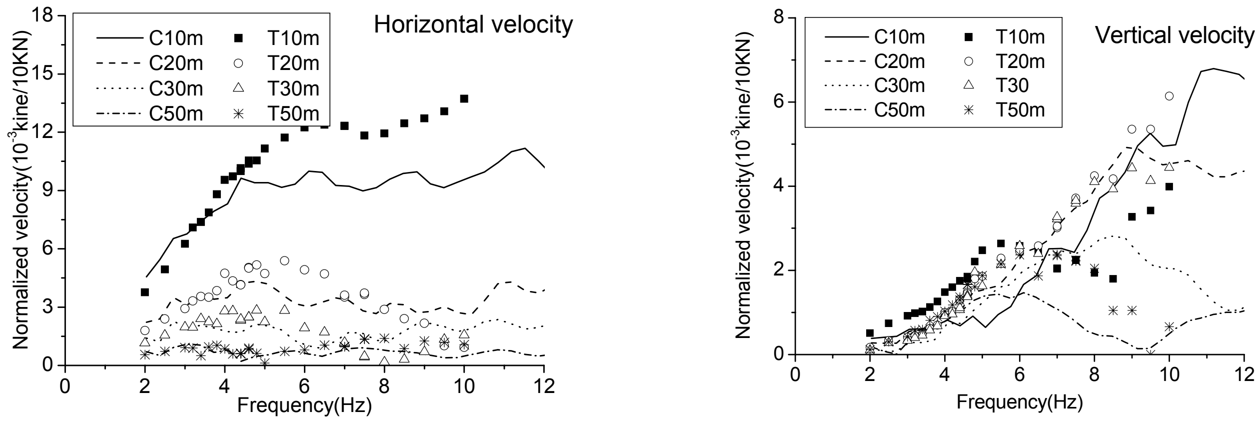
Analysis and field test

The soil condition is shown in Fig.1, also the detail of the footing dimension and WIB arrangement are depicted. The piles are modeled into two rings of beam elements as shown in Fig.2. Because of the high rigidity of the footing structure, it's regarded as a rigid block. The motions of the footing are transferred to the interface soil nodes with the master-slave relation. The amplitude of the harmonic exerting load is 10KN to keep accordance with the output force from the shaker in field test.

In the actual scale model test[3] conducted in Tainan Science Part, the ground surface responses under the harmonic horizontal loads on the footing top are recorded at the positions of 10m, 20m, 30m and 50m distances. The test data are normalized to 10KN exerting force for all driven frequencies. The horizontal and vertical velocity responses of the simulated results and the field test data are presented in Fig.3. Generally, the simulation results fit the field test data quite well. The field vibrations before and after the construction of honeycomb WIB are shown in Fig.4, and the velocity values are expressed in logarithmic form to illustrate the far field mitigation effects.

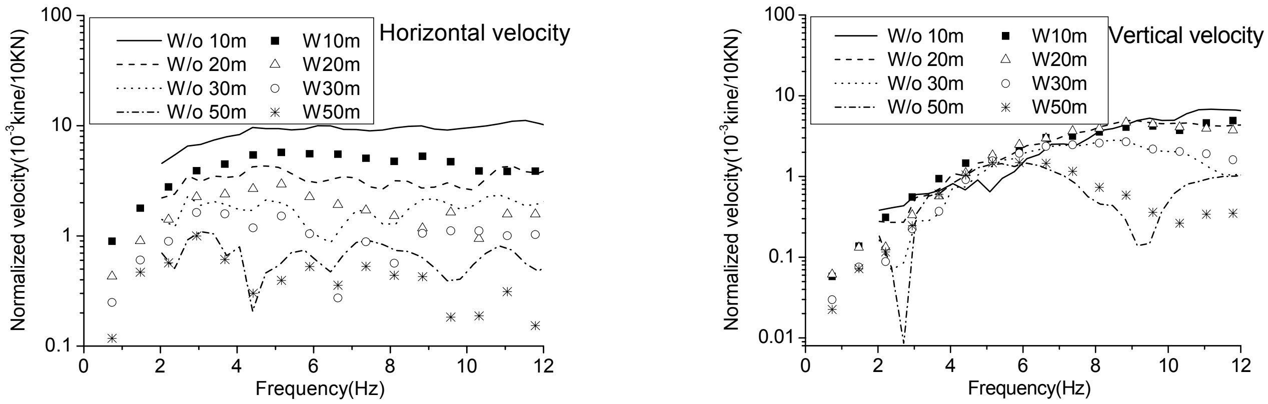
Conclusions

A good agreement is found from the comparison of the simulated results with the field recorded data, which prove the reliability of the axisymmetric 3D finite element program to predict the field vibration with the consideration of pile-soil interaction. This becomes the basis for further engineering interpretation of the field vibration phenomena, and facilitate the design optimization of the wave impeding barrier structures. Generally, for the pile supported structures, the vertical motion is comparative small because of the high rigidity of the foundation, so the main target of the installation of WIB is to reduce the horizontal motion due to the swaying and rocking motions of pile foundation. From the comparison of the ground surface responses under the conditions before and after the WIB construction, the honeycomb-shaped WIB structure is shown to be very effective to mitigate the horizontal motion.



('C' prefix stands for Computation result, 'T' prefix for Field test data)

Fig.3 Comparison of the velocity responses due to the horizontal loading



('W' prefix stands for WIB structure, 'W/o' prefix for without WIB)

Fig.4 Comparison of the velocity responses with/without WIB due to the horizontal loading

References:

1) Takemiya, H. Ring pile analysis for grouped piles subjected base motion. Structural Eng. Earthquake Eng. Vol.3, No.1 JSCE, 195s-202s, 1986.
2) Hirokazu Takemiya, Field vibration mitigation by honeycomb WIB for pile foundations of a high-speed train viaduct. Soil Dynamics and Earthquake Engineering, 24(2004), p69-p87.
3) Chen CH, Lee YJ, et al. Report on forced vibration test on actual scale model of a viaduct foundation at Tainan Science Part. National Earthquake Engineering Center Report, NCREE-00-001; 2002.