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Technical Brief

A Simplified Analytical Method for Detuning Periodic Pile Barriers

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Abstract. Detuning such as slight variations among unit cells often occurs in the construction of periodic structures. In order to study this kind of structures, a supercell is usually introduced, which requires tremendous amounts of computer memory and time. To simplify the calculation of detuning periodic pile barriers, the sensitivity analysis of geometric parameters to the first attenuation zone is conducted. A formula for calculating the equivalent radius of detuning periodic pile barriers is proposed. Modification by the BP neural network is completed in order to get a more accurate attenuation zone. The effectiveness and convenience of the equivalent radius formula are verified by studying the dynamic performances of detuning periodic pile barriers. The influence of the extent of detuning on the accuracy of the attenuation zone is discussed and some suggestions are given. This study shows that the attenuation zone of detuning periodic pile barriers can be easily obtained by using the formula established in this paper, which provides a simple way to find the dynamic property of this kind of barriers.

Keywords: Wave barriers; periodic structures; pile barriers; detuning structures; vibration attenuation.

1. Introduction

Ambient vibration has become one key environmental issue that people are concerned with. Vibrations induced by traffic loads and machine foundations can cause disturbances to nearby buildings and disrupt the performance of adjacent sensitive equipment [1, 2]. To prevent the unfavorable effects of ambient vibration, one of the effective methods is placing wave barriers between the source and the protected structures [3, 4], such as the use of pile barriers. Since then, many researchers have been carried out both experimentally and numerically to investigate the isolation effectiveness of pile barriers.

In the past two decades, the propagation of elastic waves in periodic structures has attracted a lot of attention due to its unique properties such as attenuation zones (AZs) [5, 6]. Taking the periodicity into account, Huang and Shi studied the dispersion characteristics of periodic pile barriers for elastic waves and suggested that the periodic pile barriers should be designed with AZs that match the environment vibration [7, 8]. Based on Biot's theory, Pu and Shi conducted a study on the attenuation mechanism of Rayleigh waves propagating in saturated soil by periodic pile barriers [9]. By using the modified finite element transfer matrix method to divide the layered soil into substructures, Duygu et al. reduced both the size of the soil matrix and the time of analysis of the periodic structure in layered soil [10]. Introducing a viscoelastic model, Jiang et al. suggested the complex band diagrams to analyze the transportation of vibration in the composite foundation, which could quantitatively evaluate the isolation effect of periodic barriers [11]. Huang et al. presented a novel kind of seismic isolation technique and conducted a 2D finite element simulation to study the performance of the barriers [12]. Palermo et al. demonstrated that the use of multi-mass resonators allows for enhanced performances of periodic pile barriers, in terms of amount and bandwidth of ground motion attenuation with a small array of resonators [13]. Zaccherini et al. investigated both experimentally and numerically the propagation and attenuation of elastic waves with small scale sub-wavelength resonators of different depths [14]. Muhammad et al. established analytical and full scales 3D numerical models, and investigated the effectiveness of engineered resonant periodic metabarriers in AZ [15]. Mariana et al. presented a non-iterative and novel methodology for the generation of some more complex periodic geometrics, which made Gyroid topological structures possible for numerous areas of engineering [16].

All the investigations mentioned above are focused on perfect periodic structures. However, there is no perfect periodic structure in practical engineering and almost all periodic structures are detuned. Xia et al. studied the plane elastic wave scattering by cylindrical piles with arbitrary diameters [17]. The structures with slight deviations/variations among unit cells and arranged periodically at the macro level are often called detuning periodic structures [18]. The detuning of periodic structures was first discovered in the investigation of solid state physical metals. Anderson found that the random detuning of the crystal periodic structure would lead to the localization of electron waves [19]. A supercell is usually introduced to calculate the dispersion relation of detuning periodic structures [20]. Detuning periodic pile barriers are formed by piles with detuned unit cells. However, there is not any study on detuning periodic pile barriers in civil engineering.

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In this paper, the vibration isolation characteristics of detuning periodic pile barriers with square supercells are studied. The organization of this paper is as follows: Section 2 presents the governing equations for elastic waves propagating in a homogenous isotropic medium and the Bloch theory used for analyzing periodic structure. A preliminary equivalent radius formula for simplifying the calculation of the AZ of detuning periodic pile barriers is proposed. In Section 3, BP neural network is introduced to improve the preliminary equivalent radius formula, and then the formula is verified. The frequency dispersion relationship is calculated directly based on the unit cell with a modified equivalent radius. After that, the dynamic characteristics of detuning periodic pile barriers are simulated and some suggestions on the impact of supercell size on the performance of this kind of barriers are given. Finally, some conclusions are drawn.

2. Theoretical Formulae

In this section, the basic theory for analyzing detuning periodic pile barriers and the corresponding numerical modeling scheme is built. The former belongs to the dispersion analysis of detuning periodic pile barriers. The latter provides numerical solutions to a model subjected to dynamic loadings, which is especially useful for verifying the isolation efficiency for detuning periodic pile barriers.

2.1 Basic theory of periodic structures

Neglecting the effect of damping, the governing equation of elastic waves propagating in a homogeneous linear elastic medium can be written as:

$$\nabla \cdot (\mathbf{C} : \nabla \mathbf{u}) = \rho \frac{\partial^2 \mathbf{u}}{\partial t^2} \tag{1}$$

where ∇ is a differential operator, $\mathbf{u}$ is the displacement vector, t is the time parameter, $\mathbf{C}$ and ρ are the position-dependent elastic stiffness tensor and mass density, respectively. According to the Bloch-Floquent theory of solid-state physics, the displacement field of periodic structures can be expressed as:

$$\mathbf{u}(\mathbf{r},t) = e^{i(\mathbf{k}\cdot\mathbf{r}-\omega t)}\mathbf{u}_\mathbf{k}(\mathbf{r}) \tag{2}$$

in which $\mathbf{r} = (x,y,z)$ is the position vector, $\mathbf{k}$ is the Bloch-Floquent wave vector in *the first Brillouin zone*, $i = \sqrt{-1}$, ω is the angular frequency, $\mathbf{u}_\mathbf{k}(\mathbf{r})$ is a modulation function of the displacement vector. For a given periodic structure, the modulation function has the same periodicity as the typical unit cell, which means:

$$\mathbf{u}_\mathbf{k}(\mathbf{r}+\mathbf{R}) = \mathbf{u}_\mathbf{k}(\mathbf{r}) \tag{3}$$

where $\mathbf{R}$ is the periodic constant vector. Then, the following expression can be derived from Eqs. (2) and (3):

$$\mathbf{u}(\mathbf{r}+\mathbf{R},t) = e^{i\mathbf{k}\cdot\mathbf{R}}\mathbf{u}(\mathbf{r},t) \tag{4}$$

Equation (4) is the so-called periodic boundary condition (PBC). Combining the governing equation of Eq. (1) and the PBC of Eq. (4), the dispersion problem of an infinite periodic system can be transferred into an eigenvalue problem of a typical unit cell of the periodic structure. The eigenvalues can be obtained by solving the following equation

$$(\Omega(\mathbf{k}) - \omega^2\mathbf{M})\cdot\mathbf{u} = 0 \tag{5}$$

where $\Omega(\mathbf{k})$ and $\mathbf{M}$ are the stiffness and mass matrices of the unit cell, respectively. The stiffness matrix $\Omega(\mathbf{k})$ is a function of the wave vector $\mathbf{k}$. Scanning the wave vector $\mathbf{k}$ in *the first Brillouin zone* of a periodic structure, the corresponding eigenfrequency ω can be found and thus the dispersion relation of the periodic structure can be obtained. Due to symmetry, it is enough to scan the wave vector just along the boundary of *the first irreducible Brillouin zone* [7].

2.2 Sensitivity definition

For a detuning periodic structure, a supercell is usually introduced to calculate the dispersion relation [20]. Detuning in plie radius often occurs in practical engineering. Therefore, the present paper focuses on periodic pile barriers with radius detuning. Sensitivity analysis of plie radius is conducted below.

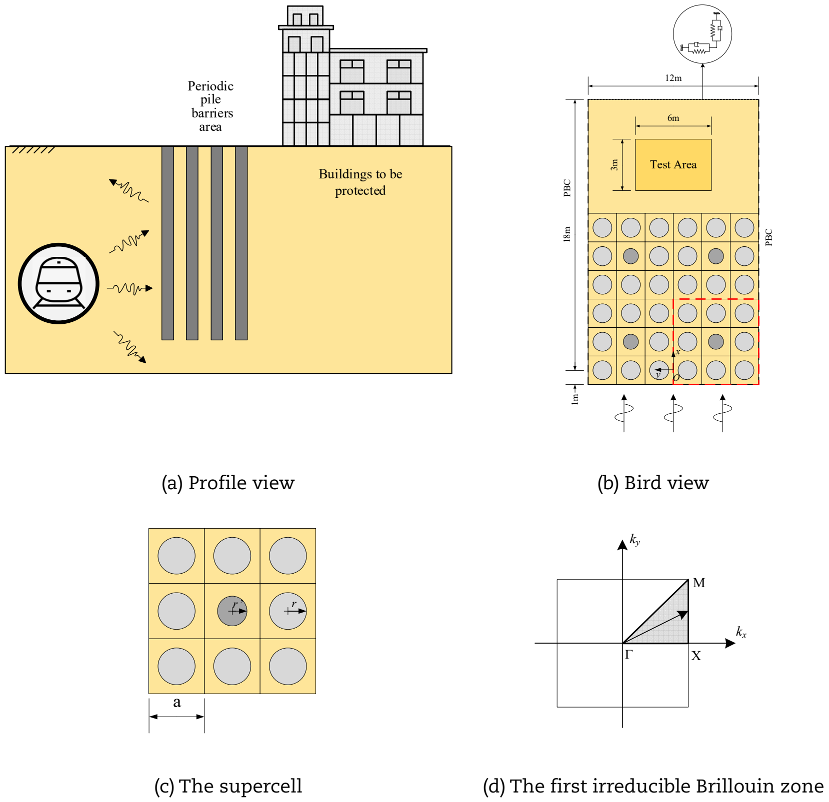
For a system, let $[x_i]$ represent an important parameter that determines the characteristics of the system, which can be represented as $F = f(x_1, x_2, \ldots, x_{n_x})$. For sensitivity analysis, first, a base state $X^* = (x_1^*, x_2^*, \ldots, x_{n_x}^*)$ can be defined, in which $[\bullet]^*$ is the base state. The corresponding reference characteristic can be established by $F^* = f(X^*)$. When one parameter varies within its reasonable range, the trend and extent of the variation of F from the reference value F^* represent the sensitivity of this parameter.

For a detuning periodic pile barrier, the system characteristic corresponds to its AZ which can be expressed as $F = f(a', r', E_s, \rho_s, E_c, \rho_c, s)$ with $X = (x_1, x_2, \ldots, x_{n_x}) = (a', r', E_s, \rho_s, E_c, \rho_c, s)$, where $a' = na$ is the size of the supercell, n is the square root of the number of piles contained in the supercell, a is the lattice constant of the typical unit cell, $r' = (1+\delta)r$ and r are the radius of the detuning and un-detuning piles, respectively; $\delta = (r'-r)/r$ is the detuning rate; E_s and E_c as well as ρ_s and ρ_c are the elasticity modulus and mass density of soil and concrete, respectively; s is the number of detuning piles in the supercell. Unless specified otherwise, a and r are taken as a = 2 m and r = 0.65 m, respectively. The benchmark corresponds to the case $X^* = (x_1^*, x_2^*, \ldots, x_{n_x}^*) = (a, r, E_s, \rho_s, E_c, \rho_c, 1)$, that is when $n = 1,\ \delta = 0,\ s = 1$.

2.3 Equivalent radius formula for the detuning periodic pile barriers

When the number of piles contained in a supercell is large, calculating the band structures of a detuning periodic pile barrier requires high computational effort. In order to reduce the cost of calculating the band structures and efficiently quantify the influence of detuning on the performance of periodic pile barriers, this paper proposes a simplified analytical method. Taking the lattice constant of the equivalent model the same as that of the un-detuning periodic pile barriers, for supercells containing an arbitrary number of piles but with only one pile having a different radius, the preliminary equivalent radius formula is proposed as:

$$\bar{r} = \frac{n^2-1}{n^2}r + \frac{1}{n^2}r' \tag{6}$$



(a) Profile view (b) Bird view

(c) The supercell (d) The first irreducible Brillouin zone

Fig. 1. Schematic configuration of finite soil with multiple rows of piles.

With this equivalent radius formula, the AZ of the detuning periodic pile barriers can now be easily calculated based on a unit cell.

2.4 Numerical modeling scheme

Figure 1 (a) is a schematic configuration of an application of periodic pile barriers from engineering point of view. Detuning such as slight variations among unit cells often occurs in the construction of these kinds of periodic structures. In order to study this kind of detuning structures, a supercell is usually introduced. Theoretically, the band structure of a supercell is valid for an infinite periodic system. However, the number of supercells is always finite in practice. Therefore, transmission analysis should be carried out to assess the performance of multi-row detuning periodic pile barriers. In this paper, COMSOL Multiphysics 5.5 is used to conduct finite element calculations. A triangle element is used and the mesh size of the model is set to be less than $a/6$. The modeling process includes: building the geometric model, assigning material parameters, setting boundary conditions, meshing and running analysis. Although it is a problem with 3D bulk wave propagation in practice, it can be simplified as a 2D plane strain problem when the piles are long enough [7, 8, 21]. The sizes of the numerical model as shown in Fig. 1(b) are chosen as 12m×19m and the supercell is selected and shown in Fig. 1(c). The first irreducible Brillouin zone mentioned in Section 2.1 is shown in Fig. 1 (d).

In this model, unless specified otherwise, the radius of detuning periodic pile barriers r' is taken as 0.585m. The mass density ρ, elastic modulus E and Poisson ratio υ of soil are taken as 1900 kg/m^3, 20 MPa, 0.35, respectively; and those of concrete are 2500 kg/m^3, 30 GPa, 0.2, respectively. The periodic boundary conditions are applied to the left and right sides of the model in Fig. 1(a). Viscoelastic boundary conditions are added to the upper boundary and the mechanical parameters for the viscoelastic boundary conditions [8] are adopted in this investigation. A harmonic displacement excitation is inputted at the lower boundary. The periodic boundary conditions are added to the boundary of the supercell shown in Fig. 1(c). A region with a size 6m×3m behind the detuning periodic pile barriers is selected as the detection area. The central coordinate of the test area is (13.5 m, 0 m). The frequency response function is defined as:

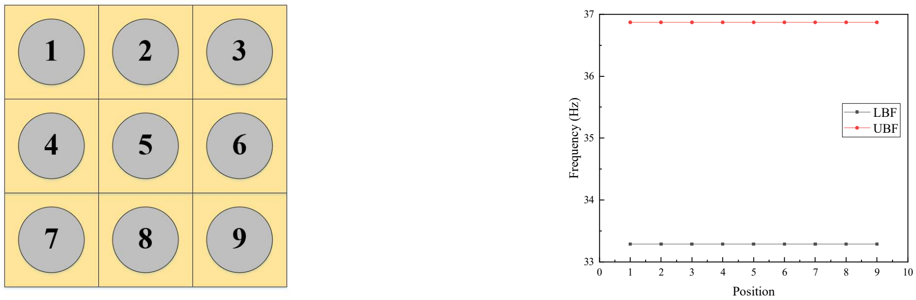
$$FRF = 20\lg(\bar{U}/U_0) \tag{7}$$

in which $\bar{U} = [\int_A U dA]/A$ is the average displacement amplitude in the y direction of the test area, U_0 is the displacement amplitude of harmonic excitation applied in the y direction.

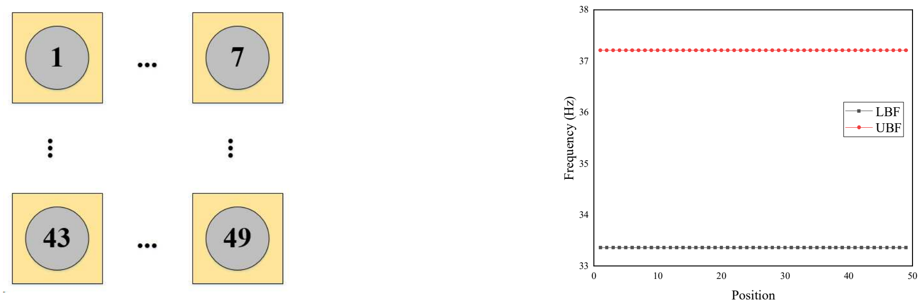
3. Comparison and Validation

3.1 Sensitivity analysis of the geometric parameters

Taking the material parameters as constants, the influence of the supercell's geometric parameters on the detuning periodic pile barriers is studied by comparing with the benchmark case. Firstly, the influence of the position of the detuning pile on the AZs is analyzed. Numbering the position of the unit cell in the supercell, Fig. 2 shows the AZs of supercells when the detuning pile is placed at a different position for n = 3 and n = 7, respectively. It is obvious that changing the position of the detuning pile does not have any influence on the AZs.

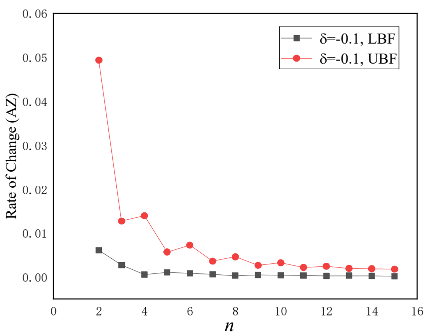


(a) n = 3

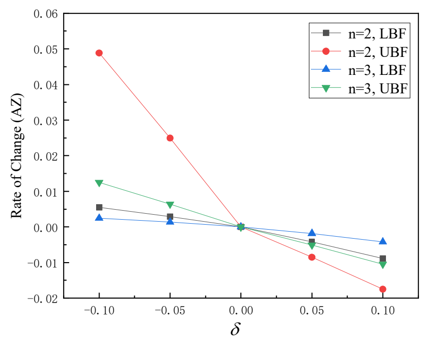


(b) n = 7

Fig. 2. The attenuation zones of supercells when the detuning pile is placed at different position for n = 3 and n = 7, respectively.



(a) Sensitivity to the parameter n



(b) Sensitivity to the parameter δ

Fig. 3. The sensitivity of the rate of change of AZ to different geometric parameters.

To do so, two important parameters are considered. One is the total number of piles (n^2) contained in a supercell, and another is the detuning rate δ. The impact of n^2 is investigated under the case when the parameters δ and s are assumed to be $\delta = -0.1$ and $s = 1$. The impact of the detuning rate δ is investigated under two cases, one with the parameters n and s assumed as (n = 2, s = 1), and another one with n = 3, s = 1.

Taking the periodic pile barriers without detuning as a benchmark case, Fig. 3 shows the sensitivity of the rate of change of AZ to different geometric parameters. Here, the rate of change of AZ refers to the relative change of the upper and lower boundary frequencies with respect to those of the benchmark case. Fig. 3(a) shows that with the increase of the square of the number of piles involved in the supercell, the rate of change of upper boundary frequency (UBF) of the AZ reduces greatly when n is small, and gradually becomes a constant when the square of the number of piles is large. The rate of change of lower boundary frequency (LBF) of the AZ remains relatively small for the entire range. That means that the UBF is more sensitive to the number of piles involved in the supercell, especially when the number of piles is small. Fig. 3(b) shows the sensitivity of the boundary frequencies to the detuning rate. It is clear that when the square of the number n is a constant, the rate of change of LBF changes more obviously with the increase of the detuning date. When the detuning rate remains constant, the rate of change of the boundary frequencies is more obvious when the detuning rate is negative. Therefore, when n is small, the square of the number of piles and the detuning rate plays a major role in the variation of the AZ.

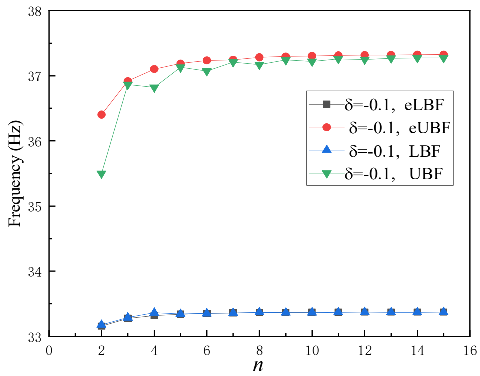
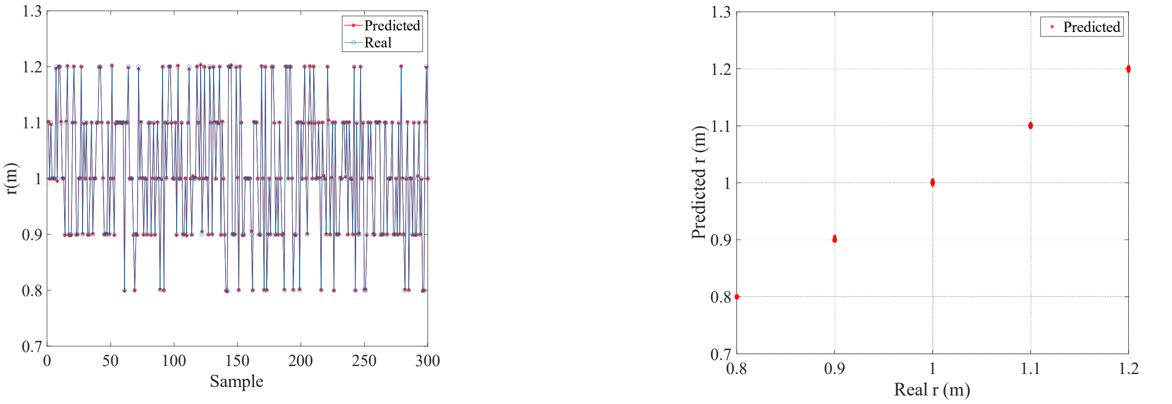


Fig. 4. Based on the equivalent model, the sensitivity of the LBF and UBF of AZ to the parameter *n*.



(a) Fit of predicted value *r* to real value

(b) Comparison between the predicted and real value *r*

Fig. 5. Matlab predicted value compared with real value.

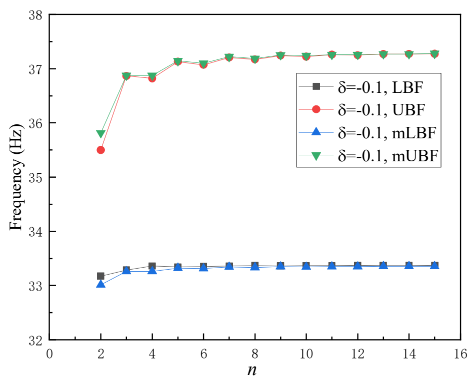


Fig. 6. Based on the modified model, the sensitivity of the LBF and UBF of AZ to the parameter *n*.

3.2 Verification and modification of equivalent radius formula

To improve calculation efficiency, the equivalent radius formula in Eq. (6) is used to calculate the AZ. Taking $\delta = -0.1$, Fig. 4 shows the sensitivity of the boundary frequencies of AZ to the parameter *n*. In Fig. 4, eLBF and eUBF represent the lower and upper boundary frequencies calculated based on the equivalent radius formula. Fig. 4 shows that the error in the UBF obtained by Eq. (6) cannot be neglected when the square of the number of piles *n* in the supercell is small. The main reason is that the equivalent radius formula only considers *n* involved in the supercell, namely the sparsity of the detuning pile, but does not take into account the influence of the detuning rate.

In order to take into the influence of the detuning rate, the equivalent radius of piles is predicted by BP neural network. BP neural network is a kind of feedforward neural network which is trained by an error back propagation algorithm [22]. It generally consists of three parts: input layer, hidden layer and output layer. The hidden layer can be set to multiple layers. BP neural network could carry out forward and reverse training. Its input layer, hidden layer, and output layer, are connected by weight number. The input layer transmits data to hidden layer, when the data reached hidden layer, it needs to be summed and a threshold determined as a condition that allows the activation function to move left or right. Then, the data has been transmitted to the output layer, the output result is obtained after weighting, summing and transferring. If the output deviates greatly from the expected result, the data needs to backpropagation along the original path and the weights and thresholds of neurons in the network need to be adjusted to make the error between the actual output and the expected meet the requirements. In this study, BP neural network predicts the equivalent radius of the piles based on a large number of training data, and established a more accurate equivalent radius. 7300 samples were selected which were generated by the Java program, 7000 samples of them are used for training and 300 samples are used for prediction.

First, the training parameters are initialized in the input layer. In this study, the pile radius r is obtained by inputting the lattice constant of the typical unit cell a, material parameters of soil and concrete, upper and lower boundaries frequencies (UBF and LBF) of the AZ.

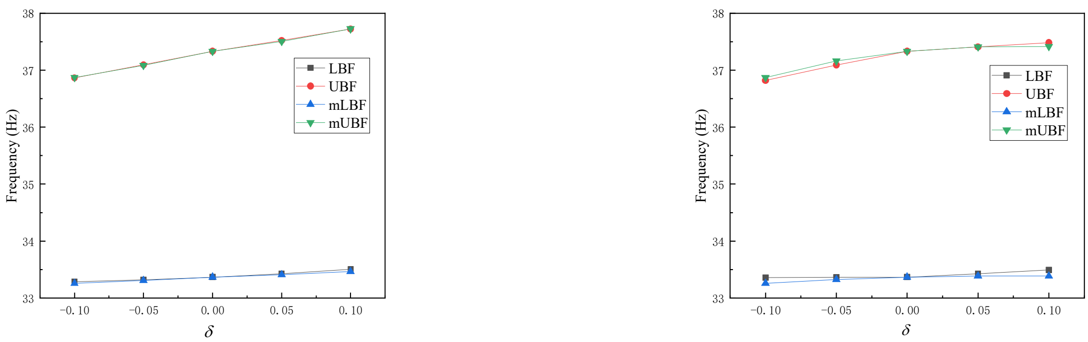
Second, multiple forward and reverse training in the hidden layer is conducted. As a result, the training error is gradually reduced, and the neural network could accurately fit the training data. In MATLAB 2021a, the corresponding input and output data are first read by loading folders, and then the input value, predicted value and output value are normalized to limit the maximum and minimum value of these in order to the limit range of hidden layer and output layer function. In this study, mapminmax functions are used to make the normalized values between -1 and 1. Finally, BP neural network is established, trained and simulated. The fitting diagram and contrast diagram of the predicted value of training are given. Fig. 5(a) and Fig. 5(b) show the fitting and comparison diagram of r between the predicted value and real value, respectively. The results show that the fitting error is very small, which indicates the correctness of the program code. Therefore, the pile radius r could design by setting the lattice constant of the typical unit cell a, the mass density ρ, elastic modulus E and Poisson ratio υ of soil and concrete, upper and lower boundaries frequencies of the AZ.

Third, a more accurate formula for calculating the equivalent radius is obtained according to the training results. Referring to the predictions, the equivalent radius $\overline{r}_m$ is modified as:

$$\begin{cases} \overline{r}_m = \left(\dfrac{n^2-1}{n^2}r + \dfrac{1}{n^2}r'\right)(1-\delta^3) & n \text{ is odd}, \\ \overline{r}_m = \dfrac{n^2-1}{n^2}r + \dfrac{1}{n^2}r' - 3\delta^2 n^{-(r/2+2r')} & n \text{ is even}, \end{cases} \tag{8}$$

Figure 6 shows the low and upper boundary frequencies of the AZ calculated by using the modified equivalent radius formula, denoted by mLBF and mUBF. The corresponding values obtained directly based on the supercell are also shown in the figure. It is obvious that the results obtained from Eq. (8) almost overlap with the results of a supercell with a relative error of less than 1%.

In order to further verify the performance of the modified formula, Fig. 7 shows the variations of the LBF and UBF of the AZ with the detuning rate for the two cases of n = 3 and n = 4. The results obtained by Eq. (8) are in good agreement with those calculated directly from the corresponding supercell. This means that it is possible to not only greatly reduce the memory and computational time requirements but also establish good accuracy when using the modified radius formula as shown in Eq. (8).



(a) n = 3 (b) n = 4

Fig. 7. Variation of the LBF and UBF of the AZ with the detuning rate.

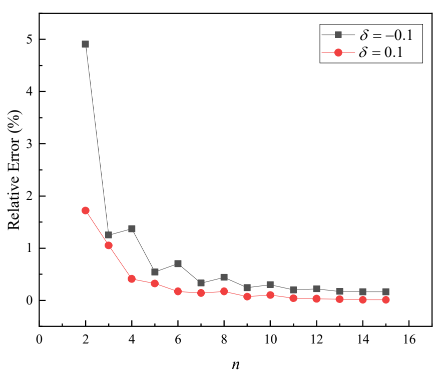


Fig. 8. Variation of the relative errors with n for two different detuning rates.

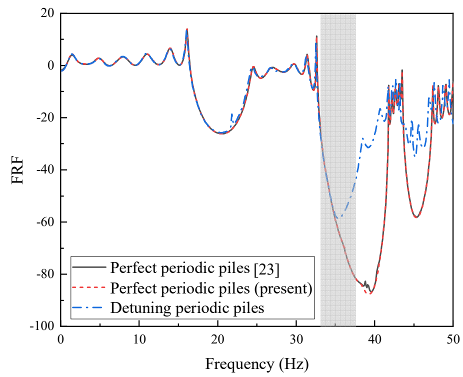


Fig. 9. The frequency response of detuning periodic piles under SV wave input.

It is easily understood that when the number of piles contained in the supercell is large, it means that the detuning pile is relatively sparse and therefore the detuning results in little influence on the AZ. In this case, one can directly choose a unit cell to calculate the AZ of the detuning periodic barriers. However, when the number of piles contained in the supercell is small, the detuning results in a significant effect on the AZ. In this case, the modified equivalent radius formula is recommended for approximate calculation.

In the analysis mentioned above, the modified equivalent radius formula is obtained under the assumption that the unit cell has the same lattice constant, and detuning occurs for the pile radius only. Fig. 6 shows that the LBF of the AZ obtained based on the modified equivalent radius formula is in good agreement with those from the supercell. Discussion on the influence of the number of piles contained in the supercell on the UBF is presented below. Defining the relative error of the UBF of the AZ as:

$$\alpha = \frac{|mUBF - UBF|}{UBF} \tag{9}$$

Figure 8 shows the variation of the relative errors with n for two different detuning rates. Taking a threshold of 0.5% for α, it is found that when the number of piles contained in the supercell satisfies $n < 7$, the equivalent radius formula should be considered. Otherwise, the detuning can be ignored, and the AZ can be directly calculated by using the unit cell.

3.3 Vibration isolation effect of detuning periodic pile barriers

The model as shown in Fig. 1(b) is introduced to conduct the numerical simulation of the isolation performance of the detuning periodic pile barriers. The n of a supercell is assumed to be 3 and detuning occurs on the radius in one of the piles as shown in Fig. 1(c). The PDE module in COMSOL Multiphysics 5.5 is used to calculate the frequency response of the model. In order to verify the correctness of the present method, the frequency responses of the corresponding perfect periodic pile barriers are also calculated by taking the detuning parameter δ as zero and plotted in Fig. 9. The solid line is the result in the literature [23] for the perfect periodic pile barriers. The dashed line and dash-dotted line are the results for the perfect and detuning periodic pile barriers, respectively. As can be seen the results obtained by the present method agree quite well with those in literature [23] for the perfect periodic pile barriers. On the other hand, the present model can be used to also analyze the frequency response of detuning periodic pile barriers. For both models (i.e., the model with detuning periodic pile barriers and the corresponding model with perfect periodic pile barriers), a harmonic SV displacement excitation with an amplitude of 0.01m is applied at the lower boundary, respectively, and Fig. 9 shows the average displacement responses in the y direction on the test area. It is obvious that the isolation performance of the detuning periodic pile barriers is weaker than that of the corresponding perfect periodic pile barriers. The AZ of the detuning periodic pile barriers is calculated by the modified equivalent radius formula and shown as the gray shaded zone. As can be seen, because of the existence of the detuning pile, the periodic characteristic of the pile barriers is destroyed and the AZ of the detuning pile barriers is narrower than that of the perfect pile barriers.

4. Conclusions

In this paper, the detuning periodic pile barrier was considered. To simplify the analysis, an equivalent radius formula was proposed. Sensitivity analysis was conducted and the correctness of the equivalent radius formula was verified. The following conclusions are drawn:

1. The attenuation zones and frequency response of a detuning periodic pile barrier can be approximated by using the corresponding perfect periodic barrier based on the equivalent radius formula given in this study.
2. When the number of piles contained in the supercell is small, e.g., when $n < 7$, the equivalent radius formula should be considered. The formula is general and has no limit on the number of piles contained in the supercell or the position of the detuning pile in the supercell.
3. The vibration isolation ability of the detuning periodic pile barrier is worse than that of the corresponding perfect periodic pile barrier. The main reason is that the detuning destroys the periodic characteristics of the periodic structures.

Author Contributions

J.H. Zhou: Validation; Methodology; original draft; Y.G. Gao: Investigation; As the corresponding author, Z.F. Shi: Project administration; Supervision; Funding acquisition; Review & editing. The manuscript was written through the contribution of all authors. All authors discussed the results, reviewed, and approved the final version of the manuscript.

Acknowledgement

Not applicable.

Conflict of Interest

No potential conflict of interest was reported by the authors.

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Data Availability Statements

The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

References

[1] AI-Hussaini, T.M., Ahmad, S., Active isolation of machine foundations by in filled trench barriers, *Journal of Geotechnical Engineering*, 122(4), 1996, 288-294.

[2] Dijckmans, A., Ekblad, A., Smekal, A., Degrande, G., Lombaert, G., Efficacy of a sheet pile wall as a wave barrier for railway induced ground vibration, *Soil Dynamics and Earthquake Engineering*, 84, 2016, 55-69.
[3] Liyanapathirana, D.S., Ekanayake, S.D., Application of EPS geofoam in attenuating ground vibrations during vibratory pile driving, *Geotextiles and Geomembranes*, 44, 2016, 59-69.
[4] Thompson, D.J., Jiang, J., Toward, M.G.R., Hussein, M.F.M., Ntotsios, E., Dijckmans, A., Coulier, P., Lombaert, G., Degrande, G., Reducing railway-induced ground-borne vibration by using open trenches and soft-filled barriers, *Soil Dynamics and Earthquake Engineering*, 88, 2016, 45-59.
[5] Zhu, R., Liu, X.N., Hu, G.K., Sun, C.T., Huang, G.L., Negative refraction of elastic waves at the deep subwavelength scale in a single phase metamaterial, *Nature Communications*, 5, 2014, 1-8.
[6] Krödel, S., Thoméa, N., Daraio, C., Wide band-gap seismic metastructures, *Extreme Mechanics Letters*, 4, 2015, 111-117.
[7] Huang, J.K., Shi, Z.F., Application of periodic theory to rows of piles for horizontal vibration attenuation, *International Journal of Geomechanics*, 10, 2013, 132-142.
[8] Huang, J.K., Shi, Z.F., Attenuation zones of periodic pile barriers and its application in vibration reduction for plane waves, *Journal of Sound and Vibration*, 332, 2013, 4423-4439.
[9] Pu, X.B., Shi, Z.F., Periodic pile barriers for Rayleigh wave isolation in a poroelastic half-space, *Soil Dynamics and Earthquake Engineering*, 121, 2019, 75-86.
[10] Ozturk, D., Bozdogan, K.B., A method for determination of the fundamental period of layered soil profiles, *Journal of Applied and Computational Mechanics*, 4(3), 2017, 267-273.
[11] Jiang, Y., Meng, F., Chen, Y.F., Zheng, Y., Chen, X.B., Zhang, J.S., Huang, X.D., Vibration attenuation analysis of periodic underground barriers using complex band diagrams, *Computers and Geotechnics*, 128, 2020, 103821.
[12] Huang, H.W., Wang, J.J., Zhao, C.F., Mo, Y.L., Two-dimensional finite-element simulation of periodic barriers, *Journal of Engineering Mechanics,* 147(2), 2021, 04020150.
[13] Palermo, A., Vitali, M., Marzani, A., Metabarriers with multi-mass locally resonating units for broad band Rayleigh waves attenuation. *Soil Dynamics and Earthquake Engineering*, 113, 2018, 265-277.
[14] Zaccherini, R., Palermo, A., Marzani, A., Colombi, A., Dertimanis, V., Chatzi, E., Mitigation of Rayleigh-like waves in granular media via multi-layer resonant metabarriers, *Applied Physics Letters*, 117, 2020, 254103.
[15] Muhammad, C.W., Lim, Zur, K.K., Wide Rayleigh waves bandgap engineered metabarriers for ground born vibration attenuation, *Engineering Structures*, 246(1), 2021, 113019.
[16] Flores-Jimenez, M.S., Delgado-Gutiérrez, A., Fuentes-Aguilar, R.Q., Cardenas, D., Generation of a quadrilateral mesh based on NURBS for Gyoids of variable thickness and porosity, *Journal of Applied and Computational Mechanics*, 8(2), 2022, 684-698.
[17] Xia, T.D., Sun, M.M., Chen, C., Chen, W.Y., Xu, P., Analysis on multiple scattering by an arbitrary configuration of piles as barriers for vibration isolation, *Soil Dynamics and Earthquake Engineering*, 31, 2011, 535-545.
[18] Zhu, H., Ding, L., Yin, T., Wave propagation and localization in a randomly disordered periodic piezoelectric axial-bending coupled beam, *Advances in Structural Engineering*, 16(9), 2013, 1513-1522.
[19] Anderson, P.W., Absence of diffusion in certain random lattices, *Physical Review*, 109(5), 1958, 1492-1505.
[20] Komsa, H., Pasquarello, A., Finite size supercell correction for charged defects at surfaces and interfaces, *Physical Review Letters*, 110(9), 2013, 095505.
[21] Liu, X.N., Shi, Z.F., Mo, Y.L., Comparison of 2D and 3D models for numerical simulatioon of vibration reduction by periodic pile barriers, *Soil Dynamics and Earthquake Engineering*, 79, 2015, 104-107.
[22] Zhang, Y.G., Tang, J., Liao, R.P., Zhang, M.F., Zhang, Y., Wang, X.M., Su, Z.Y., Application of an enhanced BP neural network with water cycle algorithm on landslide prediction, *Stochastic Environmental Research and Risk Assessment*, 35, 2021, 1273-1291.
[23] Gan, Y.Y., *Analysis of damping performance of periodic pile barriers with complex damping*, Beijing Jiaotong University, Beijing, China, 2018.

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