Sensors & Transducers, Vol. 179, Issue 9, September 2014, pp. 29-35

Sensors & Transducers

Study on Dynamic Characteristics of Heavy Machine Tool-Composite Pile Foundation-Soil

[1] CAI Li-Gang, [1,2] TIAN Yang, [1] LIU Zhi-Feng,
[2] WANG Quan-Tie, [1] NING Yue

[1] Beijing University of Technology, No.100, Pingleyuan, Chaoyang District, Beijing, 100124, China
[2] Liaoning Engineering Vocational College,
Xincheng District, Tieling City, Liaoning Province, 112000, China
[1] Tel.: +86-010-67396753, fax: +86-010-67396753
[1] E-mail: lgcai321@yahoo.com.cn

Received: 9 June 2014 /Accepted: 31 July 2014 /Published: 30 September 2014

Abstract: Heavy duty computer numerical control machine tools have characteristics of large self-weight, load and. The insufficiency of foundation bearing capacity leads to deformation of lathe bed, which effects machining accuracy. A combined-layer foundation model is created to describe the pile group foundation of multi-soil layer in this paper. Considering piles and soil in pile group as transversely isotropic material, equivalent constitutive relationship of composite foundation is constructed. A mathematical model is established by the introduction of boundary conditions, which is based on heavy duty computer numerical control machine tools-composite pile foundation-soil interaction system. And then, the response of different soil and pile depth is studied by a case. The model improves motion accuracy of machine tools. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Heavy duty machine tools, Layered soil, Composite pile foundation, Constitutive equation, Dynamic response, Motion accuracy.

1. Introduction

The dynamic foundation-soil-foundation interaction phenomenon has long been recognized as an important factor machine vibration response of environment. Hence, Heavy-duty machine tools-pile foundation-soil interaction effects need to be considered to avoid excessive overestimation of portions of the machining response in design project.

At present, the research on structure-foundation-soil is mainly used in the field of civil engineering, the mathematical model for the machine-foundation-soil interaction system of machine is less. LIU Jingbo, et al [1] presented three dimensional finite element methods for analysis of dynamic response of large dynamic machine foundation considering soil-structure interaction. Quantitative analysis of major factors which affects dynamic response of large machine foundation was performed by numerical experiments and some useful conclusions. Wang Zanzhi [2] calculated the soil foundation displacement under vertical vibration power of harmonic disturbance force. HUO Xu-ping, et al [3] studied the effects of initial membrane stress and thermal stress considering weakening deformation. Wei, Wen-Hui, et al [4] analyzed dynamic response of large dynamic by nonlinear vibration time historical method. Salah, et al [5] studied effects of these parameters on the foundation natural frequencies by changing reinforced foundation shape. Mark, et al [6] studied measures of mitigating dynamic effects on impact machine foundations. Pradhan et al [7] presented equation of dynamic model considering soil – machine interaction in layered soil. Jaya [8] presented equation of dynamics model using cone frustums foundation. Kumar et al [9] designed experiments of the effect of two different combinations of a spring mounting base and a rubber pad sandwiched between the machine base and its concrete footing block.

This paper presents a study on the dynamic response of interaction system. A mathematical model is established by the introduction of composite pile foundation, as well as effect of boundary conditions of joint surface. These solutions can be used to calculate dynamic response of different size of composite pile foundation.

2. System Modeling

For foundation vibration analyses simple models, which fits the size and economics of the project and require no sophisticated computer code are better suited. Considering piles and soil in pile group as transversely isotropic material, a combined-layer foundation model is created to describe the pile group foundation of multi-soil layer in this paper (Fig. 1). The contact features of joint surface are simulated with a spring-damping element.

Motion equations:

$$M\ddot{u}(t)+C\dot{u}(t)+Ku(t)=F(t)$$

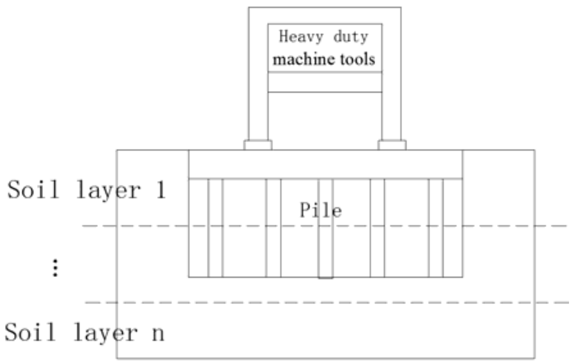


Fig. 1. System model.

2.1. Inter-structure Boundary

Joint surface of heavy duty machine tools is calculated with Yoshimura method [10], first of all, the parameter identification method of multi-support excitation is used to identify the dynamic parameters of joints of small-size samples. The joint surface stiffness and damping per unit area are acquired by the experiments. Then, the stiffness and damping values of joint surface is obtained by unit area of surface stiffness and damping integral. The equivalent stiffness and equivalent damping coefficient can be expressed:

$$\left.\begin{matrix} C_x=\iint c_1\left(P_n\right)dxdz=C_z \\ C_y=\iint c_2\left(P_n\right)dxdz \end{matrix}\right\} \left.\begin{matrix} K_x=\iint k_1\left(P_n\right)dxdz=K_z \\ K_y=\iint k_2\left(P_n\right)dxdz \end{matrix}\right\},$$

where P_n is the normal pressure of joint surface, $k_1(P_n)$ is the equivalent stiffness of tangential unit area, $k_2(P_n)$ is the equivalent stiffness of normal unit area, $c_1(P_n)$ $k_2(P_n)$ is the equivalent damping of normal unit area, $c_2(P_n)$ is the equivalent damping of normal unit area.

Parameters of boundary conditions are obtained by above method (Table 1).

Table 1. Parameters of boundary conditions.

Joint surface name	X (N/mm)	Y (N/mm)	Z (N/mm)
Column-beam	55453	2e12	2e12
Column-sliding seat	39825	457982	2e12
Beam-sliding plate	8700	1	1
The-slide seat	45000	2e12	2e12
Bed-cap	4e9	4e9	4e9

2.2. Pile-soil Structure Boundary

Goodman et al. [11] studied a zero-thickness four node rock joint element (Goodman element) to describe the shear displacement of two dimension rock joint, and the stiffness matrix expression was given by normal and tangential.

$$\left[K_{in(\tau)}\right]=\begin{bmatrix} 2k_{n(\tau)} & k_{n(\tau)} & -k_{n(\tau)} & -2k_{n(\tau)} \\ k_{n(\tau)} & 2k_{n(\tau)} & -2k_{n(\tau)} & -k_{n(\tau)} \\ -k_{n(\tau)} & -2k_{n(\tau)} & 2k_{n(\tau)} & k_{n(\tau)} \\ -2k_{n(\tau)} & -k_{n(\tau)} & k_{n(\tau)} & 2k_{n(\tau)} \end{bmatrix},$$

where n for normal; τ for tangential

Wang Man-Sheng et al. [12] studied damping simulation based on Goodman element, considering the problem of dissipation of energy under the interaction between soil structures. Damping matrix of contact element:

$$\left[C\right]_i=\frac{\lambda_i}{\omega_i}\left[K\right]_i,$$

where λ_i is the damping ratio of soil-structure, ω_i is the vibration frequency of soil.

2.3. Compute Artificial Boundary Conditions

Compute artificial boundary conditions of foundation is the prerequisite to build a mathematical model of heavy-duty machine tools-cushion cap-composite pile foundation-soil system. Deeks [13] presented the artificial boundary condition of stick-elastic under the assumption that two-dimensional scattering wave was cylindrical. It is equivalent to set the damper and spring at the same time on the artificial boundary. The spring and damping coefficient is as follows:

$$K_{bi} = G_{si} / (2R_{bi}) \quad C_{bi} = \rho_i V_{si}$$

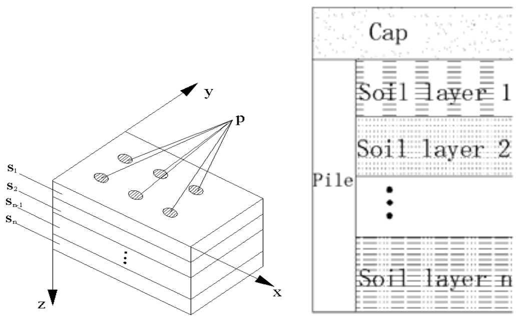
where $R_{bi} = \sqrt{x^2 + y^2}$ is the distance from node to source, C_{bi}, K_{bi} is the stiffness and damping of artificial boundary node, G_{si} , ρ_i is the shear modulus and mass density of the i layer soil, $E_{si} / [2(1+v_i)] = V_{si}^2 \rho_i$ is the relationship between spring modulus and Poisson ratio.

2. Pile-Soil Composite Foundation Model

The modulus of composite foundation are necessary parameters to design and compute composite foundation, extension and application of this technology and its application had created good social and economic efficiency [14-16].

2.1. Constitutive Equation of Composite Pile Foundation

Pile foundation of heavy duty machine tools can be considered as composite materials at the macro level [17, 18].



(a) (b)

Fig. 2. Pile-soil composite foundation model.

Make assumptions as follows

1) Assume that materials are linearly elastic material, the average stress is:

$$\bar{\sigma}_{ij} = \frac{1}{V}\left(\int_{V_P} \sigma_{ij}^{p} dV + \sum_{n} \int_{V_{s_n}} \sigma_{ij}^{s_n} dV \right), \tag{1}$$

The average strain is:

$$\bar{\varepsilon}_{ij} = \frac{1}{V}\left(\int_{V_P} \varepsilon_{ij}^{p} dV + \sum_{n} \int_{V_{s_n}} \varepsilon_{ij}^{s_n} dV \right), \tag{2}$$

where V is the total volume, V_p, V_{sn} are the volume of material P and S_n; n is the number of piles, r is the radius of the pile; σ_{ij}^{P}, ε_{ij}^{P} are the stress and strain of P; σ_{ij}^{Sn}, ε_{ij}^{Sn} are the stress and strain of S_n.

The ratios of the volume:

$$\lambda_{Sn} = \frac{V_{Sn}}{V}, \quad \lambda_P = \frac{V_P}{V} = \frac{n\pi r^2 h}{V}, \tag{3}$$

That is $V = V_p + V_{Sn}$, $\lambda_p + \sum_{n=1}^{n} \lambda_{Sn} = 1$

2) The material is assumed to be a transverse isotropic material, isotropic in x-y plane and anisotropic in z direction, the composite material approximately has the mechanical property in x-y plane.

3) Assuming that heterogeneous material continuous at boundaries, ignore the existence of the interface, there is no relative movement between soil and pile foundation. Then heterogeneous material can be considered as deformable coordination in the pile deformation direction that means the deformation is equal. According to the assumption (2), stress equivalent conditions can be expressed as:

$$\left.\begin{array}{l} \bar{\sigma}_x = \sigma_x^p = \sigma_x^{s_n} \\ \bar{\sigma}_y = \sigma_y^p = \sigma_y^{s_n} \\ \bar{\tau}_{xy} = \tau_{xy}^p = \tau_{xy}^{s_n} \\ \bar{\tau}_{yz} = \tau_{yz}^p = \tau_{yz}^{s_n} \\ \bar{\tau}_{zx} = \tau_{zx}^p = \tau_{zx}^{s_n} \end{array}\right\}, \tag{4a}$$

where $n = (1, \cdots n)$.

According to the assumption (3), strain coordination condition can be expressed as:

$$\left.\begin{array}{l} \varepsilon_x^p = \frac{1}{E_p}\sigma_x^p - \frac{\mu_p}{E_p}\sigma_y^p - \frac{\mu_p}{E_p}\sigma_z^p \\ \varepsilon_x^{Sn} = \frac{1}{E_{Sn}}\sigma_x^{Sn} - \frac{\mu_p}{E_{Sn}}\sigma_y^{Sn} - \frac{\mu_{Sn}}{E_{Sn}}\sigma_z^{Sn} \\ \varepsilon_z^p = -\frac{\mu_p}{E_p}\sigma_x^p - \frac{\mu_p}{E_p}\sigma_y^p + \frac{1}{E_p}\sigma_z^p \\ \varepsilon_z^{s_n} = -\frac{\mu_{s_n}}{E_{s_n}}\sigma_x^{s_n} - \frac{\mu_{s_n}}{E_{s_n}}\sigma_y^{s_n} + \frac{1}{E_{s_n}}\sigma_z^{s_n} \\ \varepsilon_z^{s_n} = \varepsilon_z^p \end{array}\right\}, \tag{4b}$$

When isotropic surface of isotropic foundation is level, constitutive equation of composite foundation:

$$\{\bar{\varepsilon}\} = [A]\{\bar{\sigma}\}, \quad (5)$$

where $\{\bar{\sigma}\}$ is the average stress matrix, $\{\bar{\varepsilon}\}$ is the strain matrix. $[A]$ is the flexibility matrix, expressed in matrix equation:

$$\begin{Bmatrix} \bar{\varepsilon}_x \\ \bar{\varepsilon}_y \\ \bar{\varepsilon}_z \\ \bar{\varepsilon}_{xy} \\ \bar{\varepsilon}_{yz} \\ \bar{\varepsilon}_{zx} \end{Bmatrix} = \begin{bmatrix} \frac{1}{\bar{E}_1} & -\frac{\mu_1}{\bar{E}_1} & -\frac{\mu_2}{\bar{E}_2} & 0 & 0 & 0 \\ -\frac{\mu_1}{\bar{E}_1} & \frac{1}{\bar{E}_1} & -\frac{\mu_2}{\bar{E}_2} & 0 & 0 & 0 \\ -\frac{\mu_2}{\bar{E}_2} & -\frac{\mu_2}{\bar{E}_2} & \frac{1}{\bar{E}_2} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{2(1+\mu_1)}{\bar{E}_1} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{\bar{G}_2} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1}{\bar{G}_2} \end{bmatrix} \begin{Bmatrix} \bar{\sigma}_x \\ \bar{\sigma}_y \\ \bar{\sigma}_z \\ \bar{\sigma}_{xy} \\ \bar{\sigma}_{yz} \\ \bar{\sigma}_{zx} \end{Bmatrix} \quad (6)$$

where $\bar{E}_1$, μ_1 are the average young modulus and the poisson ratio of heterogeneous material in Isotropic surface; $\bar{E}_2$, μ_2 the average young modulus and the poisson ratio of heterogeneous material in normal direction; $\bar{G}_2$ is the average shear modulus of heterogeneous material .

Obtained from the Eq. (2):

$$\bar{\varepsilon}_x = \frac{1}{V}\left(\int_{V_P} \varepsilon_x^p dV + \sum_n \int_{V_P} \varepsilon_x^{Sn} dV\right), \quad (7a)$$

Obtain:

$$\bar{\varepsilon}_x = \lambda_P \varepsilon_x^p + \sum_n \lambda_{Sn} \varepsilon_x^{Sn}, \quad (7b)$$

According to the formula (4 b), for the material P we can get:

$$\varepsilon_x^p = \frac{1}{E_p}\sigma_x^p - \frac{\mu_p}{E_p}\sigma_y^p - \frac{\mu_p}{E_p}\sigma_z^p, \quad (8a)$$

For the material S_n:

$$\varepsilon_x^{Sn} = \frac{1}{E_{Sn}}\sigma_x^{Sn} - \frac{\mu_p}{E_{Sn}}\sigma_y^{Sn} - \frac{\mu_{Sn}}{E_{Sn}}\sigma_z^{Sn}, \quad (8b)$$

According to Eq. (6):

$$\bar{\varepsilon}_x = \frac{1}{E_1}\bar{\sigma}_x - \frac{\mu_1}{E_1}\bar{\sigma}_y - \frac{\mu_2}{E_2}\bar{\sigma}_z, \quad (9)$$

Substituting Eq. (8) into Eq. (7b) yields:

$$\begin{aligned} \bar{\varepsilon}_x = {} & \lambda_P\left(\frac{1}{E_p}\sigma_x^p - \frac{\mu_p}{E_p}\sigma_y^p - \frac{\mu_p}{E_p}\right) + \\ & \sum_n \lambda_{Sn}\left(\frac{1}{E_{Sn}}\sigma_x^{Sn} - \frac{\mu_{Sn}}{E_{Sn}}\sigma_y^{Sn} - \frac{\mu_{Sn}}{E_{Sn}}\sigma_z^{Sn}\right) \end{aligned}, \quad (10)$$

Substituting Eq. (4a) into Eq. (10) yields:

$$\begin{aligned} \bar{\varepsilon}_x = {} & \lambda_P\left(\frac{1}{E_p}\bar{\sigma}_x - \frac{\mu_p}{E_p}\bar{\sigma}_y - \frac{\mu_p}{E_p}\sigma_z^p\right) + \\ & \sum_n \lambda_{Sn}\left(\frac{1}{E_{Sn}}\bar{\sigma}_x - \frac{\mu_{Sn}}{E_{Sn}}\bar{\sigma}_y - \frac{\mu_{Sn}}{E_{Sn}}\sigma_z^{Sn}\right) \end{aligned}, \quad (11a)$$

Obtain:

$$\begin{aligned} \bar{\varepsilon}_x = {} & \left(\frac{\lambda_P}{E_p} + \sum_n \frac{\lambda_{Sn}}{E_{Sn}}\right)\bar{\sigma}_x - \left(\frac{\lambda_P \mu_p}{E_p} + \right. \\ & \left.\sum_n \frac{\lambda_{Sn}\mu_{Sn}}{E_{Sn}}\right)\bar{\sigma}_y - \frac{\mu_p}{E_p}\sigma_z^p - \sum_n \frac{\mu_{Sn}}{E_{Sn}}\sigma_z^{Sn} \end{aligned}, \quad (11b)$$

Comparing Eq. (9) with (11b):

$$\frac{1}{\bar{E}_1} = \frac{\lambda_P}{E_p} + \sum_n \frac{\lambda_{Sn}}{E_{Sn}}, \quad (12a)$$

$$\frac{\mu_1}{\bar{E}_1} = \frac{\lambda_P \mu_p}{E_p} + \sum_n \frac{\lambda_{Sn}\mu_{Sn}}{E_{Sn}}, \quad (12b)$$

The solution of (12) is given by:

$$\bar{E}_1 = \frac{E_p}{\lambda_P + E_p \sum_n \frac{\lambda_{Sn}}{E_{Sn}}}, \quad (13a)$$

$$\mu_1 = \frac{\lambda_P \mu_p \sum_n E_{Sn} + E_p \sum_n \lambda_{Sn}\mu_{Sn}}{\lambda_P \sum_n E_{Sn} + E_p \sum_n \lambda_{Sn}}, \quad (13b)$$

According to Eq. (4b) give rise to:

$$\frac{\sigma_z^p}{E_p} = \sum_n \frac{\sigma_z^{s_n}}{E_{s_n}}, \quad (14)$$

According to Eq. (1) give rise to:

$$\bar{\sigma}_z = \lambda_p \sigma_z^p + \sum_n \lambda_{sn}\sigma_z^{s_n}, \quad (15)$$

Substituting Eq. (14) into Eq. (15) yields:

$$\bar{\sigma}_z = \left(\lambda_p + \frac{\sum_n \lambda_{sn} E_{s_n}}{E_p} \right) \sigma_z^p , \quad (16)$$

For material P, the solution of (4b) is given by

$$\varepsilon_z^p = -\frac{\mu_p}{E_p}\sigma_x^p - \frac{\mu_p}{E_p}\sigma_y^p + \frac{1}{E_p}\sigma_z^p , \quad (17a)$$

For material S_n

$$\sum_n \varepsilon_z^{s_n} = \sum_n \left(-\frac{\mu_{s_n}}{E_{s_n}}\sigma_x^{s_n} - \frac{\mu_{s_n}}{E_{s_n}}\sigma_y^{s_n} + \frac{1}{E_{s_n}}\sigma_z^{s_n}\right) , \quad (17b)$$

The solution of (6) is given by

$$\bar{\varepsilon}_z = -\frac{\mu_2}{E_2}\bar{\sigma}_x - \frac{\mu_2}{E_2}\bar{\sigma}_y + \frac{1}{E_2}\bar{\sigma}_z , \quad (18)$$

Substituting Eq. (17) into Eq. (18) yields:

$$\bar{\varepsilon}_z = -\left(\frac{\lambda_p \mu_p}{E_p} + \sum_n \frac{\lambda_{s_n}\mu_{s_n}}{E_{s_n}} \right)\left(\bar{\sigma}_x + \bar{\sigma}_y\right) + \frac{\lambda_p}{E_p}\sigma_z^p + \sum_n \frac{\lambda_{s_n}}{E_{s_n}}\sigma_{s_n}^p , \quad (19)$$

Substituting Eq. (14) and Eq. (15) into Eq. (19) yields:

$$\bar{\varepsilon}_z = -\left(\frac{\lambda_p \mu_p}{E_p} + \sum_n \frac{\lambda_{s_n}\mu_{s_n}}{E_{s_n}} \right)\left(\bar{\sigma}_x + \bar{\sigma}_y\right) , + \frac{1}{\lambda_p E_p + \sum_n \lambda_{s_n} E_{s_n}} \bar{\sigma}_z \quad (20)$$

Comparing Eq. (9) with (11b):

$$\bar{E}_2 = \lambda_p E_p + \sum_n \lambda_{Sn} E_{Sn} , \quad (21a)$$

$$\mu_2 = \left(\frac{\lambda_p \mu_p}{E_p} + \frac{\sum_n \lambda_{Sn}\mu_{Sn}}{E_{Sn}} \right) \left(\lambda_p E_p + \sum_n \lambda_{Sn} E_{Sn} \right) , \quad (21b)$$

For material P and S_n:

$$\varepsilon_{yz}^p = \frac{\sigma_{yz}^p}{G_p} , \quad (22a)$$

$$\varepsilon_{yz}^{Sn} = \frac{\sigma_{yz}^{Sn}}{G_{Sn}} , \quad (22b)$$

The solution of (2) is given by:

$$\bar{\varepsilon}_{yz} = \lambda_p \sigma_{yz}^p + \sum_n \lambda_{Sn}\sigma_{yz}^{Sn} , \quad (23)$$

Substituting Eq. (4) into Eq. (23) yields:

$$\bar{\varepsilon}_{yz} = \left(\frac{\lambda_p}{G_p} + \frac{\lambda_{Sn}}{G_{Sn}} \right) \bar{\sigma}_{yz} , \quad (24)$$

The solution of (6) is given by:

$$\bar{\varepsilon}_{yz} = \frac{1}{\bar{G}_2}\bar{\sigma}_{yz} , \quad (25)$$

Comparing Eq. (6) with (24):

$$\bar{G}_2 = \frac{G_P G_{Sn}}{\lambda_P G_{Sn} + \lambda_{Sn} G_P} , \quad (26)$$

When the pile material all made up of material P, which means $\lambda_P = 1$, $\lambda_{Sn} = 0$, hence $E_1 = E_p$, $\mu_1 = \mu_p$, $\bar{E}_2 = E_p$, $\mu_2 = \mu_p$, $\bar{G}_2 = G_P$.

This shows that elastic constant of composite material is the same as material P, it also explains that composite material degenerates into an isotropic box-foundation.

2.2. Composite Foundation Element Stiffness Matrix

Composite foundation element is 4-node quadrilateral element, stiffness matrix is given by:

$$K^e = \int_{A^e} B^T D B dA \cdot t , \quad (27)$$

where $D = A^{-1}$.

2.3. Composite Foundation Element Damping Matrix and Mass Matrix

Composite foundation media damping is the dynamic performance of the structure, though the media damping is objective, it has very complex mechanism. Therefore, it needs to abstract the media damping as a mathematical model convenience to calculate. Damping model of Rayleigh is most widely used in media damping, based upon equivalence principle to determine parameter.

$$[C]=\alpha[M]+\beta[K]$$

Four nodes unity mass matrix is used in element mass matrix:

$$M^e=\frac{\rho At}{36}\begin{bmatrix}4&0&2&0&1&0&2&0\\0&4&0&2&0&1&0&2\\2&0&4&0&2&0&1&0\\0&2&0&4&0&2&0&1\\1&0&2&0&4&0&2&0\\0&1&0&2&0&4&0&2\\2&0&1&0&2&0&4&0\\0&2&0&1&0&2&0&4\end{bmatrix}$$

3. Dynamic Response of Different Soil Layer

For example, a heavy-duty machine tools with dimension of the profile 10 m×5 m, composite pile foundation is constituted by two-layer horizontal soil with different soil parameters. This paper analyzes the dynamic response on the premise that the first layer of soil property remained unchanged, changing the second layer of soil to three different soil property. This paper uses surging force to simulate the shock load generated from the starting of heavy duty machine tools. The point of machining cutting tool as observation point, and analyze the influence rules of soil property and depth of pile on the precision of machine tools. Where modulus of compression, poisson ratio and mass density of soils as follows [19]:

Table 2. Parameters of soil properties.

Soil \ Parameters	$E_1(N/m^2)$	ν	$\rho(\mathrm{kg}/m^3)$
The First kind of soil	4.91×107	0.35	1850
The Second kind of soil	3.59×107	0.3	1800
The Third kind of soil	2.3×107	0.35	1750

3.1. Dynamic Response of Different Soil

In this paper, the maximum amplitude in the z direction was collected from time 0 till the amplitude is 0, ignoring the scatter beyond the trend. Notice that from Fig. 3, when the soil property of second layer of soil was changed, the maximum amplitude in the z direction increased to 0.28 mm from 0.19 mm, the response time reduced to 0.7 s from 2.2 s, that shows the dynamic response of heavy duty machine tools was effected by the stiffness of foundation. The maximum amplitude increases with decreasing the stiffness of foundation and decreases with time .The oscillation times of heavy-duty machine tools decreases significantly according to the number of the maximum amplitude, that shows the soft soil is provided with the ability of reducing vibration while hard soil magnify the shock. To avoid the shock magnified and the maximum amplitude increased to much, it is important to choose appropriate soil property. Notice that soil property plays a key role in machining of heavy duty machine tools.

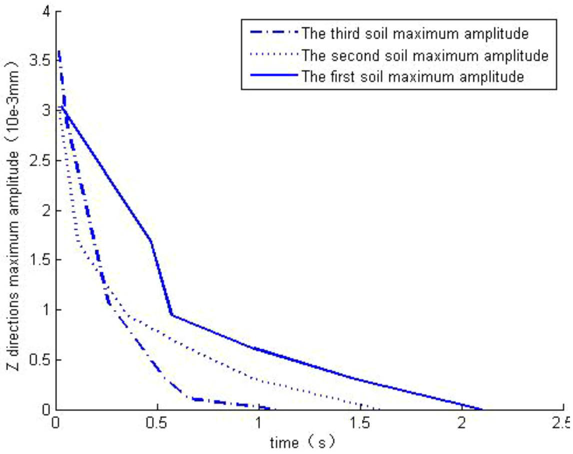


Fig. 3. The maximum amplitude from three kinds of soil effect.

3.2. Dynamic Response of Different Pile Depth

Dynamic response of System is studied by Keeping the first layer of soil and changing in second layer soil depth. Dynamic response can be calculated by changing the kinds of soil depth from 5 m to 10 m. With the increase of the second soil depth, especially between 5 m and 8 m, Z direction vibration amplitude is getting smaller. The effects of amplitude becomes smaller and smaller and the kinds of soil can be ignored when the pile depth approaches to a certain extent.

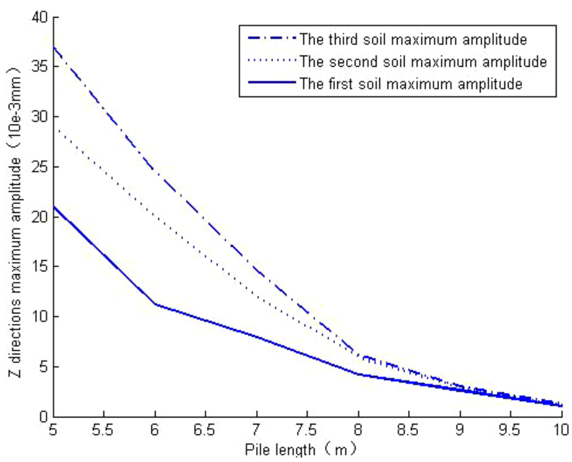


Fig. 4. The maximum amplitude in Z direction.

4. Conclusions

1) In this paper, a method is proposed applicable to pile group foundation of multi-soil layer, which is used to calculate constitutive equation of composite pile foundation. Considering piles and soil in pile group as transversely isotropic material, equivalent constitutive relationship of composite foundation is constructed. The constitutive equations of composite pile foundation of different soil properties can be simulated by changing the parameters of soil constitutive. The model reduces the difficulty of the finite element calculation.

2) Considering boundary conditions of joint surface and artificial boundaries, heavy duty machine tools – composite pile foundation-soil interaction system model was created. Influence degree on precision can be calculated by the model. Thus important theoretical basis is provided for improving precision of machine tools reasonably and economically.

3) The dynamic responses of the three different soil and size of pile were analyzed. Results show that vibration time decreases and vibration peak increases with weakening soil. Vibration peak decreases with i the increasing size of pile. A law of dynamic characteristics of heavy duty machine tools-composite pile foundation-soil Interaction System is developed.

Acknowledgements

Major national science and technology projects (2013ZX04013011).

References

[1]. Liu Jingbo, Wang Zhenyu, Zhang Kefeng et al, 3D finite element analysis of large dynamix machine foundation considering soil-structure i interaction, *Engineering Mechanics*, Vol. 19, Issue 3, 2002, pp. 34-38.

[2]. Wang Zanzhi, Study on random vibration of subsoil under dynamic machine, *Mechanics in Engineering*, Vol. 27, Issue 4, 2005, pp. 18-21.

[3]. Huo Xuping, Shen Huishen, Dynamic response of initially stressed moderately thick plates with four free edges resting on tensionless elastic half-space foundations, *Engineering Mechanics*, Vol. 26, Issue 6, 2009, pp. 65-69.

[4]. Wei Wenhui, Yu Weifang, Simulation of load on power-machinery and nonlinear analysis on dynamic interaction in soil-foundation-machine system, *Journal of Vibration and Shock*, Vol. 28, Issue 11, 2009, pp. 126-129.

[5]. Thamir Salah, Suhair G. Hussain, Wedad Ialazzawy, Machine tools foundation static and free vibration analyses, *Transactions on Applied and Theoretical Mechanics*, Vol. 7, Issue 2, 2012, pp. 93-105.

[6]. Mark R. Svinkin, Dynamic effects of impact machine foundations, in *Proceedings of the ASCE Conference on Geotechnical Earthquake Engineering and Soil Dynamics IV*, Sacramento, California, May 18-22, 2008, Vol. 181, pp. 1-17.

[7]. P. K. Pradhan, A. Mandal, D. K. Baidya, D. P. Ghosh, Dynamic response of machine foundation on layerd soil, *Journal of Geotechnical and Geology Engineering*, Vol. 26, 2008, pp. 453-468.

[8]. K. P. Jaya, A. Meher Prasad, Embedded foundation in layered soil under dynamic excitations, *Soil Dynamics and Earthquake Engineering*, Vol. 22, 2002, pp. 485-498.

[9]. Jyant Kumar, Vikas Boora, Dynamic response of a machine foundation in combination with spring mounting base and rubber pad, *Journal of Geotechnical and Geology Engineering*, Vol. 27, 2009, pp. 379-389.

[10]. P. Capo Luongo, C. Ambrosino, S. Campopiano et al, Modal analysis and damage detection by fiber Bragg grating sensors, *Sensors and Actuators A*, Vol. 133, Issue 2, 2007, pp. 415-424.

[11]. R. E. Goodman, R. L. Tayler, T. L. Brekke, A model for the mechanics of jointed rock, *ASCE Journal of Soil Mechanics and Foundation Division*, Vol. 94, Issue 3, 1968, pp. 637-660.

[12]. Wang Mansheng, Zhou Xiyuan, Hu Yuxian, Studies on contact model of soil-pile dynamic interaction, *Chinese Journal of Geotechnical Engineering*, Vol. 27, Issue 6, 2005, pp. 616-620.

[13]. A. J. Deeks, M. F. Randolph, Axisymmetric time-domain transmitting boundaries, *Journal of Engineering Mechanics*, Vol. 120, Issue 1, 1994, pp. 25-42.

[14]. Zhang Yiping, Wang Yang, Li Tao, Study of equivalent elastic parameters of composite foundation, *Rock and Soil Mechanics*, Vol. 32, Issue 7, 2011, pp. 2106-2110.

[15]. Yu Jin, Qi Zhibo, Cai Yanyan, et al, Study on consolidation calculation of low-grade concrete-cored sand-gravel pile composite foundation, *Engineering Mechanics*, Vol. 29, Issue 6, 2012, pp. 218-240.

[16]. Ding Jihui, Guo Jing, Xu Chengjie, Study on bearing capacity reliability of composite foundation with granular soil pile based on random field theory, *Engineering Mechanics*, Vol. 24, Supplementary Issue, 2007, pp. 108-113.

[17]. Zhang Junfa, Huang Yu, et al, Composite materials model research on grouped piles foundation, *Rock and Soil Mechanics*, Vol. 28, Issue 9, 2006, pp. 1064-1069.

[18]. Hu Qi, Ling Daoshen, Chen Yunmin, Theoretical study on pile-soil homogeneous transversely isotropic model, *Chinese Journal of Rock Mechanics and Engineering*, Vol. 26, Issue 4, 2007, pp. 854-859.

[19]. Xiong Hui, Zou Yinshen, Xu Zhenyu, The simulation of interactive effect on pile-soil-structure by whole dynamic finite-element method in layered soil-field, *China Civil Engineering Journal*, Vol. 37, Issue 9, 2004, pp. 55-61.