EVALUATION OF EFFECTIVE PARAMETERS ON VIBRATIONS INDUCED BY PILE DRIVING WITH FINITE ELEMENT METHOD

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ABSTRACT

Nowadays, using deep foundations is needed more than ever, due to increasing population and lack of suitable soils. Pile driving is oldest and one of the most reliable methods of pile installations. Unfortunately, environmental problems and vibrations induced by pile driving have limited using the pile driving in urban areas. The properties of pile driving system elements - pile, soil, and hammer- distance from pile, and the condition of adjacent structures affect on vibrations attenuation and damages to structures. In this research, using PLAXIS-2D software, the pile driving process has been modelled and the effects of some effective parameters such as soil type, diameter of pile, depth of penetration, pile material, and amplitude of dynamic load on vibrations are considered.

Keywords: Pile Driving, Peak Particle Velocity, PLAXIS

1. INTRODUCTION

Piles are used to support many major structures including large rail road and highway bridges and high rise buildings throughout the world. It is known that installation of driven piles creates soil vibrations and displacements that may affect adjacent and remote structures, people, and sensitive devices, and these dynamic effects range from benign to harmful. However, in most cases, harmful soil displacement and structural damages can be attenuated. [1]

The process of installing piles in the ground for any purpose usually causes the ground surrounding the pile to shake. Dynamic effects of piling on surrounding structures depend on parameters of the pile driving system, the soil medium through which waves propagate from the source, the distance from the source, soil-structure interaction, the condition of structures, and other factors. Vibrations can cause damage to structures and installations in the ground directly, but in most cases, structural damage is the result of soil displacement which results in differential settlement. [1, 2]

The most common criterion for assessment of ground vibrations is peak particle velocity. The three components of velocity can be combined into a single vector trace by taking the values of radial, transverse, and vertical velocities at each instant in time, and combining them to give the true peak particle velocity, PPV, (Equation 1). The vector direction is ignored.

$$PPV = \sqrt{v_r^2 + v_t^2 + v_v^2} \tag{1}$$

In equation 1, v_r, v_t, and v_v are radial, transverse, and vertical velocities, respectively. [3, 4]
Vibrations propagate from a piece of construction equipment through the ground to a distant vibration-sensitive receiver predominantly by means of Rayleigh (surface) waves and secondarily by body (shear and compression) waves. The amplitude of these waves diminishes with distance from the source. This attenuation is due to two factors: expansion of the wave front (geometrical attenuation) and dissipation of energy within the soil itself (material damping). [5]
In this research, firstly, pile driving modelling is described step by step. Then, the effect of some parameters on vibrations quantities caused by pile driving is studied. These parameters include type of soil, pile diameter, pile material, penetration depth, and magnitude of dynamic load.

2. REVIEW OF THE HISTORICAL EVIDENCE

Nowadays, finite element method is widely used in numerical analysis of geotechnical problems. One of the common softwares that works based on finite element method is PLAXIS-2D.
Mabsout, et al. and Mabsout and Tassouals (1994) studied the pile driving by finite element method. The results from the computational driving of a concrete pile below prebored holes in an undrained, normally consolidated clayey soil were presented. They used the non-linear, finite element model that simulates the penetration of the pile into the soil. [6]
Madheswaran et al. (2005) modelled a steel pile by finite element method and Plaxis software. They compared result of simulation with measurement of ground vibrations during prototype pile driving carried out at a construction site in Chennai. [7]
In addition, a similar simulation of the dynamic pile tests by Plaxis 2D software is done by Pinto et al. (2008), and the 1D and 2D finite element methods applied to the numerical modelling of high-strain dynamic load test are compared. [8]

3. MODELLING OF PILE DRIVING BY PLAXIS 2D

Plaxis-2D is geotechnical software that can simulate all structural elements and different models for soil behaviour. On this approach, the pile and soil are modelled by axisymmetric continuum finite elements. Both the soil and the pile are modelled with 15-noded elements. Since the effect of many parameters such as pile penetration depth, pile diameter, soil type, and energy of hammer is investigated, it is necessary to model different pile driving with varied condition. Table1 shows briefly the specifications of soil and pile used in the models. However, according to desired factor in each section, the modifications are applied to general model. For example, in section 4.1, the properties of soil and hammer are in accordance with general model, but the soil type is considered sand and clay, respectively.
Interface elements are used to allow relative movement between soil and pile. The boundaries need to absorb the incoming waves or to be placed far enough from the pile in order not to affect the results. Accordingly, standard absorbent boundaries are used at the bottom and at the right hand boundary to avoid spurious reflections.
A dynamic distributed load is created on top of the pile. In addition, Newmark's parameters are chosen based on the default of PLAXIS software, (α=0.3025, β=0.6). The axisymmetric continuum model of soil and pile and also the mesh networks are shown in Figure1.

Table 1. *Properties of soil and pile in modelling*

Parameter	Concrete	Steel	Wood	Clay	Sand	Unit
Model	Linear Elastic	Linear Elastic	Linear Elastic	Mohr Coulomb	Hardening Soil	-
Type	Non-porous	Non-porous	Non-porous	Undrained	Undrained	-
γ_{unsat}	24	78.5	12	16	17	kN/m^3
γ_{sat}	-	-	-	18	20	kN/m^3
E_{ref}	3x10^7	2.1x10^8	1.3x10^7	15000	50000	kN/m^2
E_{oed}	-	-	-	-	50000	kN/m^2
υ	0.1	0.2	0.3	0.3	0.2	-
c	-	-	-	5	1	kN/m^2
φ	-	-	-	20	32	degree

The analysis consists of three calculation phases. Prior the first phase, there is no pile, and the materials related to the pile are considered clay or sand. In the first phase, the pile is created and the pile properties are assigned to the pile cluster. In the second phase the pile is subjected to a single stroke with specified amplitude and frequency. In this model, the amplitude and frequency of dynamic load are supposed 4000 kN/m^2 and 40 Hz, respectively. In the third phase the load is kept zero and the dynamic response of the pile and soil is analysed. The load is applied for 0.6 ms and the results observed during 2 seconds above the ground surface. The last two phases involve dynamic calculations.

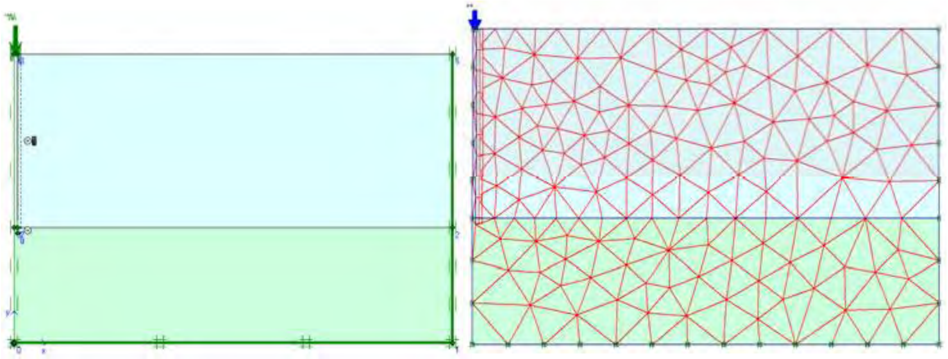

Figure 1. *Pile driving axisymmetric model in Plaxis*

4. DISCUSSIONS AND RESULTS

As noted, the value of PPV depends on many parameters, such as the properties of pile, soil, and hammer. In this section, considering a general model, the effect of one efficient parameter is studied, while the other parameters are assumed constant.

4.1. Effect of Soil Type

Soil as an environment that vibrations are transmitted through it, has an important role to attenuate amplitude of vibrations caused by pile driving. In this section, amounts of peak particle velocity, PPV, in sand and clayey soils are compared. This model involves driving a concrete pile. 15m long cylindrical pile with 400 mm diameter is driven into the soil. Once, the soil layer is considered sand and clay, respectively. Figure 2 shows the values of PPV versus distance from pile for both types of soil.

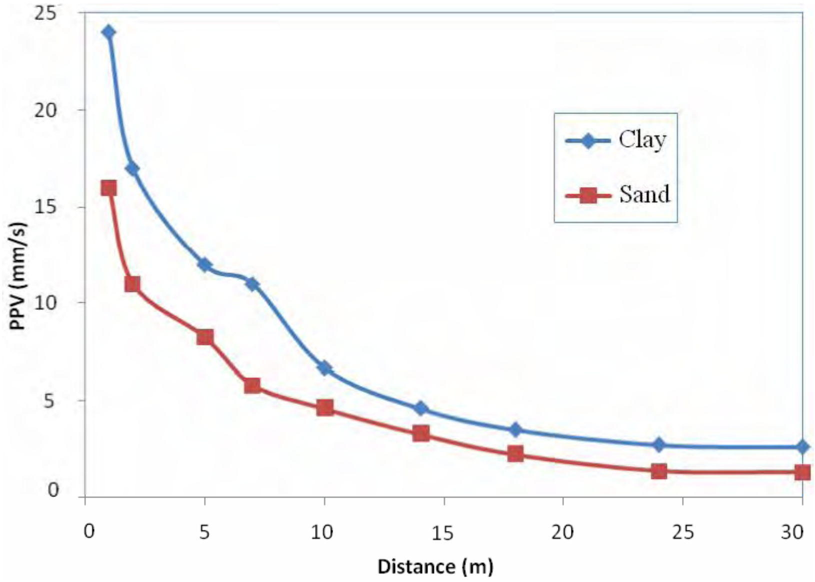

Figure 2. *Peak particle velocity vs. distance for sand and clay*

According to the results of modelling, in the same condition, peak particle velocities induced by pile driving in clayey soils are greater than peak particle velocities in sandy soils. Accordingly, the possibility of causing damage in areas with clayey soil is a little more than damages in sand.

4.2. Effect of Pile Diameter

Peak particle velocity by pile driving is strongly influenced by diameter and cross section of pile. In this section, a 15-meter pile is modelled to drive in sandy soil. To discuss the effect of pile diameter on vibrations, the pile diameter has changed from 20 to 70 centimetres. However, it should be noted that in modelling, the dynamic load has been considered as distributed load and the load has been applied on whole pile diameter. So, the presented results in this section are not completely independent of hammer energy. Figure 3 shows the results of modelling.

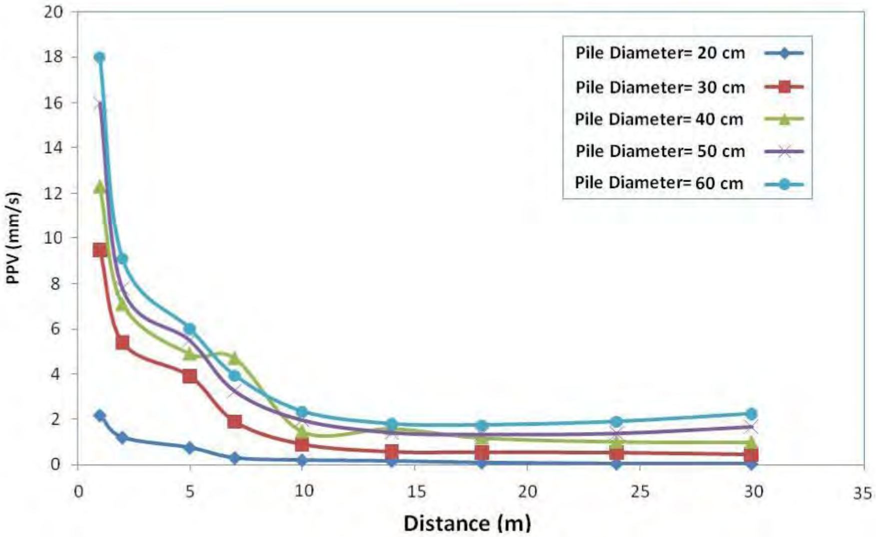

Figure 3. *Variation of PPV vs. distance for different pile diameter*

According to Figure 3, the peak particle velocity will increase with increase of diameter and cross section of pile. Increase of pile diameter is more effective in short distances from pile location, and with increase of distance, the slope will diminish. Diagrams of peak particle velocity versus distance for different pile cross sections are shown in Figure 4.

The correlation coefficient of greater than 0.95 for trend lines shows the best trend line for these diagrams is logarithmic that their slope reduces strongly with increase of distance from pile; therefore the diagram of PPV vs. cross section in 10 m distance is nearly linear.

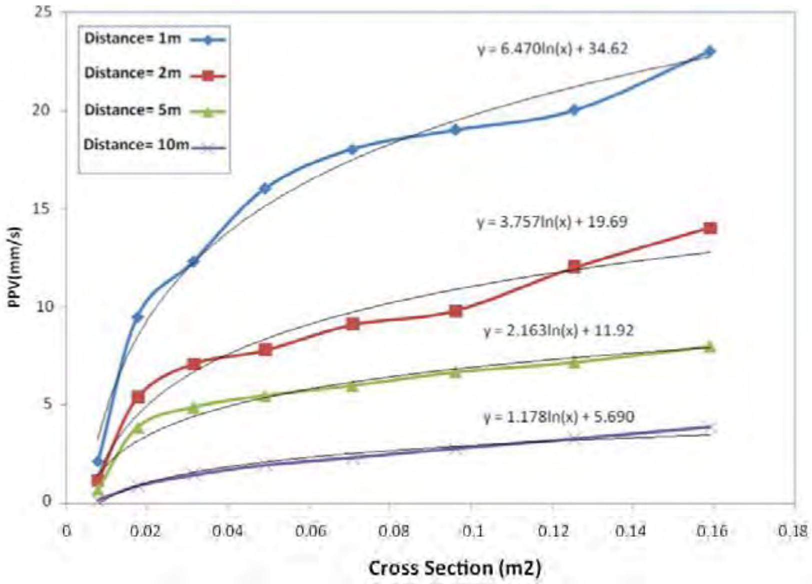

Figure 4. *Variation of PPV vs. pile cross section*

4.3. Effect of Penetration Depth

In this section, driving of a concrete pile with 400 mm diameter into the sandy soil is modeled. The specifications of model have been presented in Table 1. Pile penetration depth varies from 1 to 15 m, and the values of PPV for different distances are recorded in each step. Figure 5 depicts peak particle velocity versus distance from pile location for different pile penetration depths. Obviously, the rate of PPV decreases with increase of penetration depth. This result is due to the fact that interaction between soil and pile shaft become greater by gradually increasing the pile penetration depth.

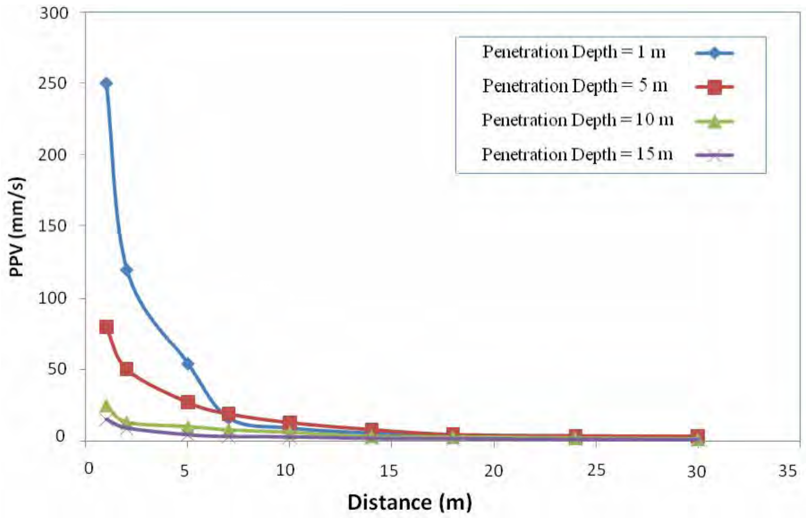

Figure 5. *Variation of PPV vs. distance for different pile penetration depths*

4.4. Effect of Pile Material

Piles are usually made of timber, concrete or steel. In this section, a 400 mm diameter pile of 15m length is driven into a layer of sand. In figure 6, the diagrams of PPV versus distance from pile for three piles with different materials are shown. It is notable that dimension and length of all piles have been assumed identical.

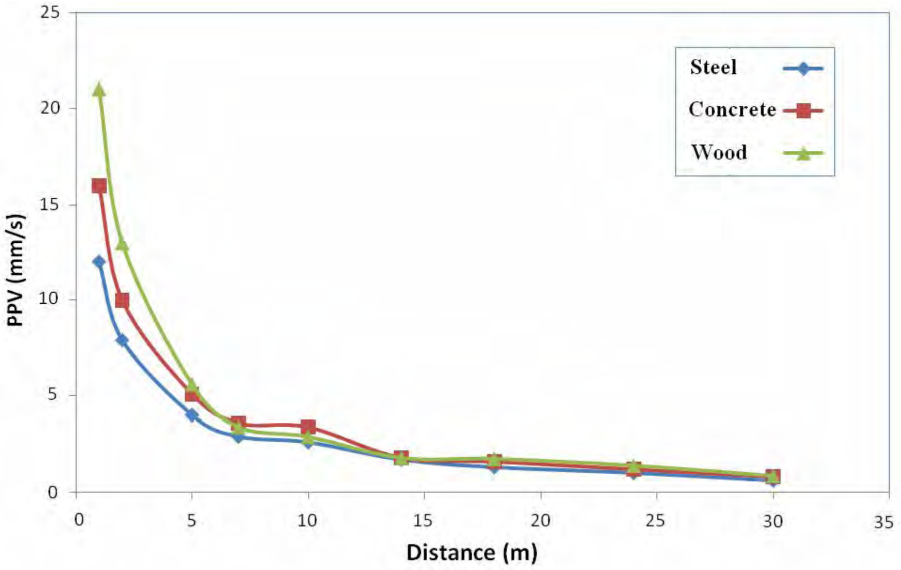

Figure 6. *Variation of PPV vs. distance for different pile materials*

According to the results, steel pile with most density causes minimal vibrations and the most vibrations are relevant to woody pile that has least density. However, this difference is clear in short distances energy source, and with increase of distance, the effect of type of pile material become negligible.

4.5. Effect of amplitude of dynamic load

Pile hammers have different rated energies. It is necessary to select suitable hammer with respect to type of pile and soil. In modelling by PLAXIS software, the values of amplitude and frequency of dynamic load should be imported to define applied load from hammer to the pile. In this section, driving a 400 mm diameter concrete pile with 15 m length into the soil (according to Fig.1) has been modelled. In calculation program, the amplitude of dynamic load has been changed from 2000 to 6000 kN/m^2. The results of modelling are shown in figure 7. Figure 8 shows the variations of PPV with amplitude of dynamic load for different distances.

According to these results, the values of peak particle velocity are increased with increment of amplitude of dynamic load. However, the variation of PPV with amplitude of dynamic load is linear and the rate of these variations is slight. Although the first empirical relations were only based on energy of pile hammer, next surveys show this factor is not the most important factor that affects on PPV. It means strong decrease of the hammer energy can be helpful to mitigate the vibrations, and slight reduction of the hammer energy will have a small effect on peak particle velocity.

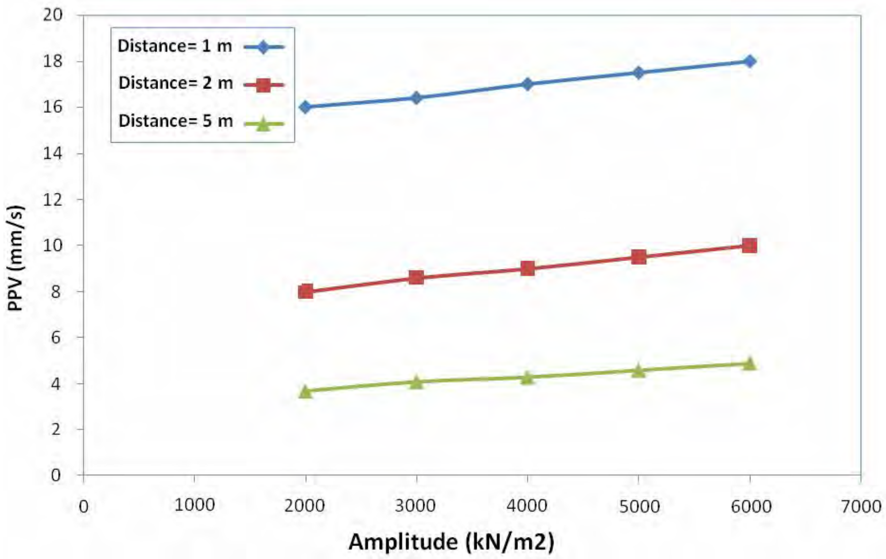

Figure 7. *Variation of PPV vs. distance for different dynamic load*

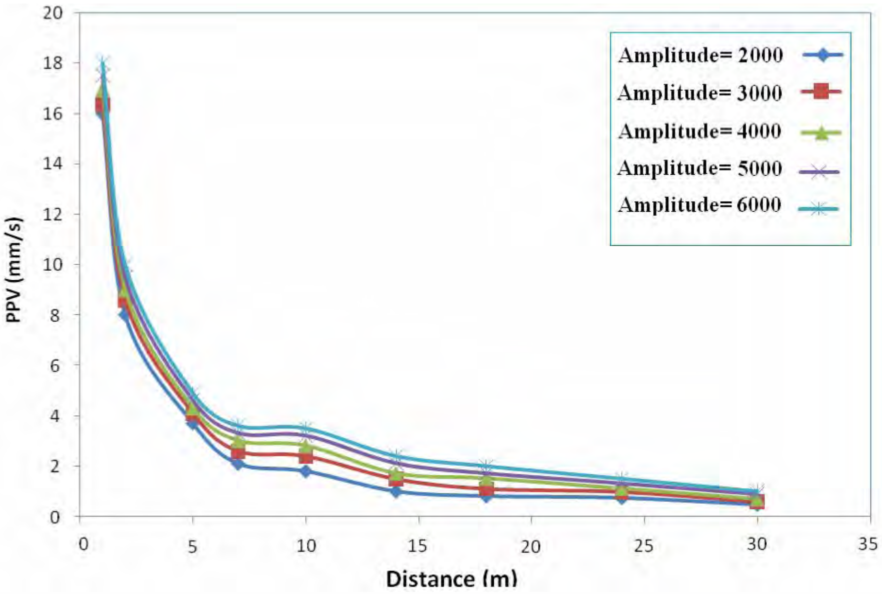

Figure 8. *Variation of PPV vs. amplitude of dynamic load*

5. CONCLUSION

1. According to properties of sandy and clayey soils expressed in this research, magnitude of vibrations induced by pile driving in clay is more than vibrations in sand. This trait is more specific in vicinity of the pile. With increase of distance, the values of peak particle velocities become near together. It means the clayey soils attenuate the vibrations more than sandy soils.
2. The results of modelling show with increase of pile diameter, peak particle velocity will increase. It is necessary to note, the dynamic load applied to pile is distributed load and it exerts to entire pile cross section. The trend of PPV variations with pile cross section is logarithmic that the slope of diagrams reduces with increase of distance from pile.
3. Pile penetration depth is an important factor in vibrations caused by pile installation. Large quantities of peak particle velocities usually happen at shallow depths. If the pile penetrates further, less vibrations and damages are caused in soil and adjacent structures. That's why, in

some pile driving operations, the pre-drilling method is used to remove the soils of shallow depths and attenuate intensity of vibrations.

4. According to the results of modelling, the vibrations induced by pile driving decrease with increase of density of pile materials. Accordingly, driving of a timber pile causes more vibrations. Concrete and steel piles are in the next places, respectively. It is necessary to note that the effect of pile material become inconsiderable by increase of distance.
5. One of the most important factors in evaluation of vibrations caused by pile driving is the energy of pile hammer. According to the results, the increase of amplitude of dynamic load applied to the pile causes the value of PPV increases too. Variations of PPV with amplitude is approximately linear and with low slope. Reduction of the hammer energy will have a small effect on peak particle velocity. For example, with increase of amplitude of dynamic load from 2000 to 6000 kN/m^2 at 2m distance from pile, the quantity of PPV parameter grows 2mm/s.

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