EXPERIMENTAL ANALYSIS OF GROUND VIBRATION DUE TO TAPERED PILES DRIVING

Omid TAVASOLI
PhD Graduated, Department of Civil Engineering, Science and Research Branch,
Islamic Azad University, Tehran, Iran
o.tavasoli@srbiau.ac.ir

Mahmoud GHAZAVI
Professor, Department of Civil Engineering, Khajeh Nasir Toosi University, Tehran, Iran
ghazavi_ma@kntu.ac.ir

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ABSTRACT

Piles are normally driven into the ground using appropriate tools such as free-fall hammers or diesel pile driver and then loaded. Use of this method may create some different problems in environmental cycle such as noise, air pollution and ground vibration. The ground vibration induced by hammer impact is too important to consider during pile driving and it may cause serious effects on adjacent area. In this paper, the drivability of tapered and cylindrical piles and the ground vibrations induced in the adjacent area are investigated using experimental, analysis and field tests. To record induced pile and soil velocity during driving, different instruments were used: (a) the pile driving analyzer (PDA) with two accelerometers and strain transducers, and (b) Seistronix RAS24 seismograph and 4*100 Hz geophone devices. Geophones arrays are the linear radial with distances of 8, 12 and 16 times of pile diameter. The results of wave propagation and the induced velocity in the soil at different distances from the pile-C and pile-T are measured and after analyzing the data recorded by the devices and the processing and filtering of waves, wave-induced velocity will be obtained. It is important to notice that the pile shape and geometry have direct effect on ground vibrations. Also, with comprising soil particle velocity in different time, it is concluded that the vibration amplitude and radius decrease with increasing the distance from the pile. Due to material damping in the soil and pile and radiation damping, the propagated waves are dissipated.

INTRODUCTION

Pile driving is one of the conventional methods for the construction of deep foundations. Pre-cast steel or concrete piles with different geometries are penetrated to the specified depth by appropriate tools such as free-fall hammers or diesel pile driver and then loaded. Use of this method may create some different problems in environmental cycle such as noise, air pollution and ground vibration. The ground vibration induced by hammer impact is too important to consider during pile driving and it may cause serious effects on adjacent area. Despite of difficulty to estimate and mitigate the vibrations, the determination of driving resistance provides important information by pile penetration. It is necessary to model and analyze full-scale pile driving problem with numerical methods to achieve more accurate results. In recent years, the advantages of tapered piles compared to cylindrical ones have been investigated. The axial response of such piles under static loading has been analyzed using 1-D finite element method by Ghazavi et al. (1997). Wei and El Naggar (1998) had done some laboratory tests on different shaped piles. Ghazavi, (2000) have investigated the kinematic response of such piles under earthquake loading. The numerical analysis of pile driving for tapered piles was presented by Ghazavi and Tavasoli (2012). A three-dimensional finite difference analysis for taper angle and geometry effects has been used on pile driving response of tapered piles. Generally speaking, tapered and partially tapered piles offer better drivability performance than cylindrical piles of the same volume and length. A soil-pile system has been simulated for pile driving phenomenon using a three dimensional model for non-uniform cross section piles using FLAC3D.

To determine the characteristics of ground vibrations induced by pile driving, several investigations have been also performed during recent decades. The main criterion to evaluate area vibrations during driving is peak particle velocity (PPV) when waves move in the soil. The PPV is the maximum velocity that a soil particle experiences during the driving of a pile from the ground surface to the desired depth. Different analytical, numerical and experimental studies has been preformed in this area by Wiss (1981), Woods and Jedele (1985), Uromeihy (1990), Massarsch and Fellenius (2008). The numerical model to predict the time history of the vibration velocity due to impact and vibratory pile driving has been done by Ramshaw et al. (2000). Madheswaran et al. (2005 & 2009) developed the finite element model to investigate ground acceleration time history due to impact pile driving in sand by considering the elastic and the elastic–plastic behaviour for the pile and the soil respectively. Masoumi et al. (2007 & 2009) have developed a linear boundary elements model to predict free field vibrations in terms of PPV due to pile driving by linear and non-linear elastic constitutive behaviour was considered for the soil and the pile. It was shown that considering non-linear behaviour for the soil adjacent to the pile will lead to a better estimation of the level of vibration. The non-linear finite element model has been developed by Serdaroglu (2010) to study impact pile driving vibrations in saturated cohesive soils. Khoubani and Ahmadi (2012) have modelled the penetration of the pile from the ground surface to the desired depth using ABAQUS. They have analyzed the effects of plastic deformations in the soil adjacent to the pile and large slip frictional contact between the pile and the soil on the amplitude of vibrations. In all of these studies, the pile shape was uniform, so that the effect of pile geometry has not investigated on wave propagation in the soil during pile driving.

In this paper, the drivability of tapered and cylindrical piles and the ground vibrations induced in the adjacent area of them are investigated by experimental analysis and field tests.

EXPERIMENTAL ANALYSES OF TAPERED PILE DRIVING

The drivability of cylindrical and tapered piles is considered for experimental tests. Pile T is fully tapered with and pile C is cylindrical one. All piles made by steel, have the same length (Lp= 250 cm) and volume. Their properties are in Table 1. The single acting hammer with a 300 kg weight falling through a distance of 1m is used to install all piles to the embedded length of 0.5m to 2m. The pile driver is made by different part such as mounting frame, hammer and electric motor which lifted the ram to the selected falling height, and the hammerhead fell to induce an impact on the hammer components. The field was located in Vardavard-Tehran with maximum specific weight (gd,max), 2.16 kg/cm^3 and relative density of about 93%. The soil parameters are shown in Table 2.

Table 1. Piles dimensions and properties

Pile ID	Taper Angle (°)	Diameter (mm)		Thickness (mm)	Length (mm)	Modulus of Elasticity (GPa)	Specific Weight (kN/m^3)
		D_t	D_b				
C	0.0	162.0	162.0	5.0	2500	210	78.50
T	1.12	212.0	115.0	5.0	2500	210	78.50

Table 2. Soil properties

Material	°	c	¤=	Dr	w
	(kN/m^3)=	(MPa)	(°)=	(%)	(%)
Soil	19.30	8	33	93	2.5

Figure 1 indicates the pile driving system in tests. The pile driving analyzer (PDA) with two accelerometers and strain transducers was used to record induced pile velocity and strain. The PDA takes results from for every impact velocity and a force signals obtained by sensors attached to the pile. To measure forces and velocities at the pile, they were attached externally along the pile shaft at 32.4cm from the pile head in two opposite directions.

(a) (b)

Figure 1. Oblique view of the field deposit, tested piles and hammer (a) Pile C (b) Pile T

The signal matching result of pile-C driving is illustrated in Figure 2. As observed, the best matching is concluded between the force and Z.V diagram under per hammer blow, which Z=E.A/C is impedance coefficient of pile and V is pile top velocity.

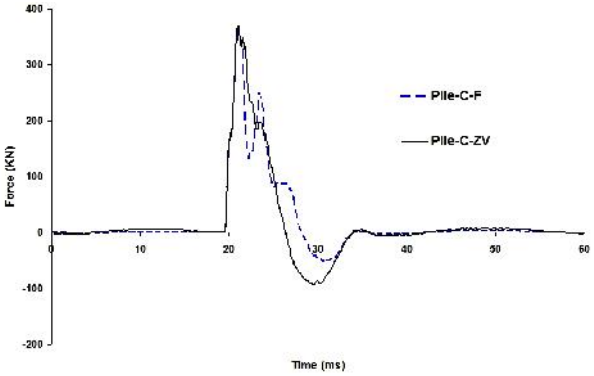

Figure 2. Signal matching of pile-C

The variation of the piles displacement and velocity versus time were indicated for final hammer blow in Figures 3 and 4. The residual set of pile C and pile T are respectively 9.59mm and 11.17mm. Therefore, the displacement and velocity of tapered pile were greater than cylindrical one and they had better performance and effect in pile penetration and economical saving by increasing velocity and residual set per blows.

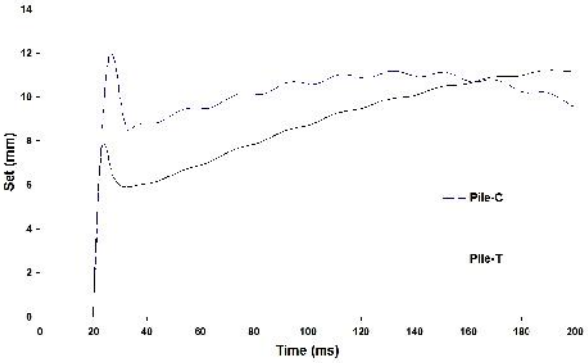

Figure 3. Comparison of piles set between cylindrical and tapered pile

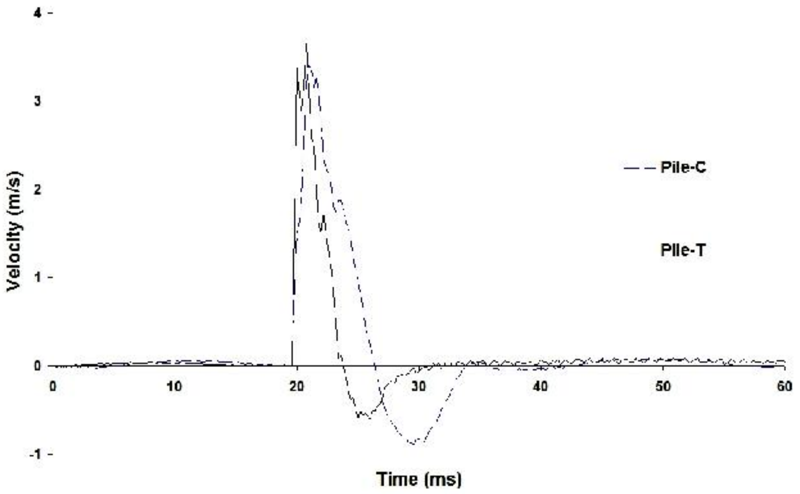

Figure 4. Comparison of piles velosity between cylindrical and tapered pile

EXPERIMENTAL ANALYSES OF GROUND VIBRATION DUE TO PILE DRIVING

As mentioned above, driven piles have better performance than cast-in place one but, use of this pile may cause ground vibration. In this section, by performing the real tests on the effect of pile geometry in wave propagation in soil, the ground vibration due to pile driving has been analyzed. To record induced soil velocity during pile driving, Seistronix RAS24 seismograph and 4*100 Hz geophone devices arrayed the linear radial with distances of 8, 12 and 16 times of pile diameter as shown in Figure 5 and 6.

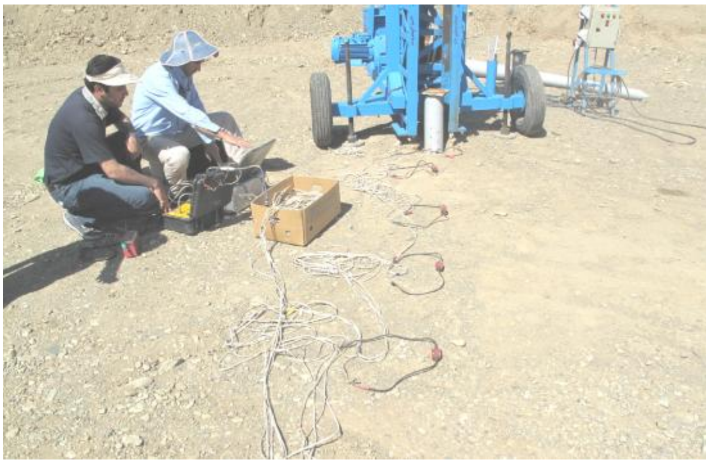

Figure 5. Geophones arrays in ground vibration tests

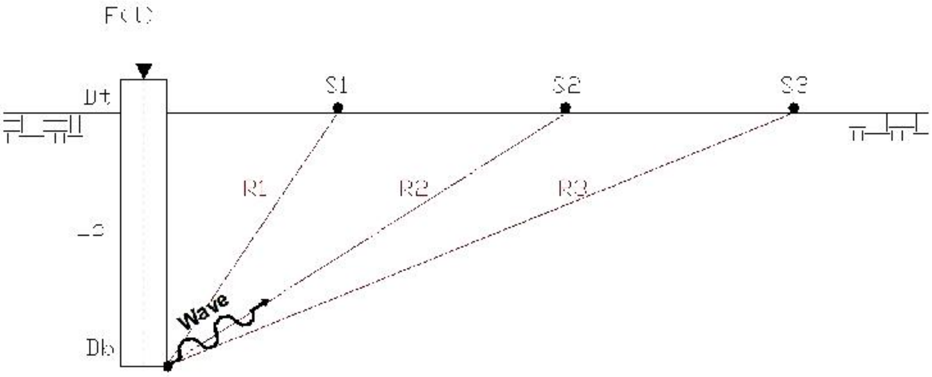

Figure 6. Plan of geophones arrays and distance form the axis of driven pile

After hammer impact on pile head, waves transmit in the pile and propagate in the adjacent area, and geophones rapidly receive induced soil particles velocity and send data to the seismograph to record. The results of particle soil velocity due to pile driving with different shape and geometry are illustrated in Figures 7, 8 and 9.

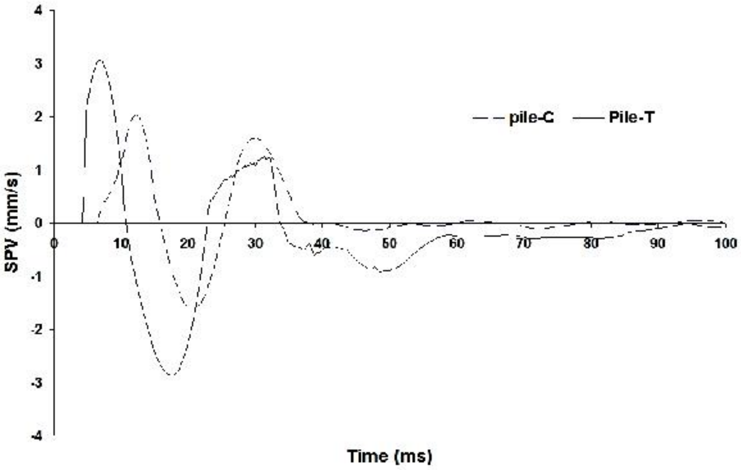

Figure 7. Comparison of soil particle velocity at $8D_p$ away from pile centerline induced by pile driving

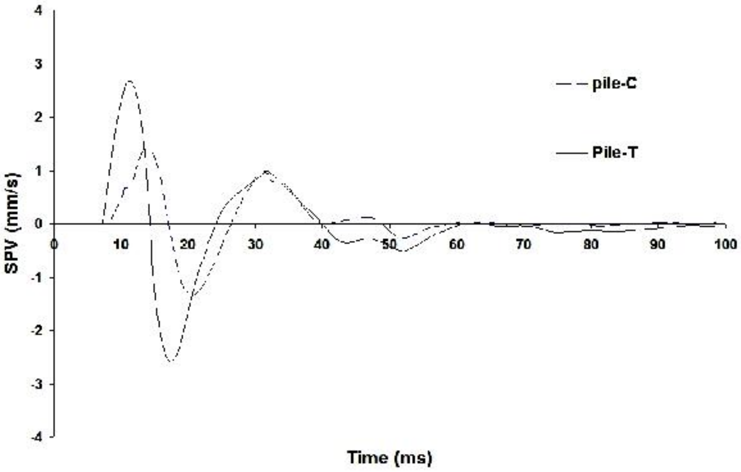

Figure 8. Comparison of soil particle velocity at $12D_p$ away from pile centerline induced by pile driving

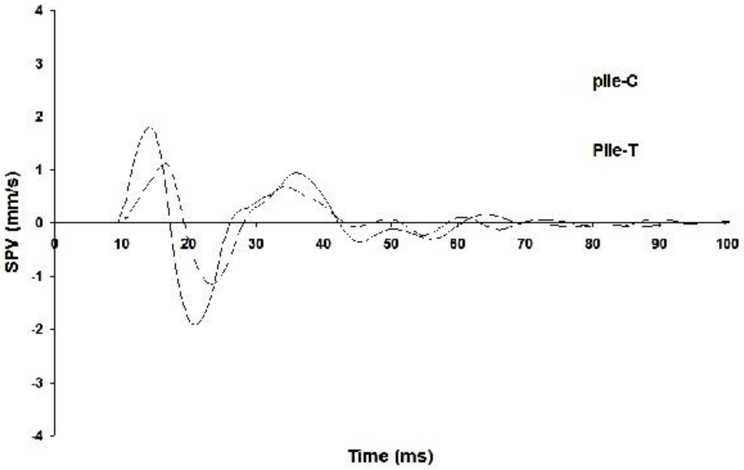

Figure 9. Comparison of soil particle velocity at $16D_p$ away from pile centerline induced by pile driving

With comparing the period of particle velocity diagrams because of Pile-C and Pile-T driving, the frequency ranges were calculated between 50 and 55 Hz. As seen in Figures 7 to 9, the time of first signal recorded by geophones and seismograph were variable according to the pile shape. Wave speed in the soil is calculated based on these times and distance from source as shown in Table 3 for Pile C and Table 4 for Pile T. In pile driving phenomenon, pile acts as a line source and propagates different types of waves from shaft and toe in the soil. The average wave speed in the ground was also measured 346.26 and 427.43 m/s during the driving of pile-C and pile-T.

Table 3. Calculation of wave speed in the soil due to Pile-C driving

Station	Horizontal Distance (m)	Time (ms)	Distance from pile toe (m)	Wave Speed (m/s)
S1	$8D_p$=1.296	6.25	2.383	381.31
S2	$12D_p$=1.944	8.25	2.789	338.07
S3	$16D_p$=2.592	10.25	3.274	319.41

Table 4. Calculation of wave speed in the soil due to Pile-T driving

Station	Horizontal Distance (m)	Time (ms)	Distance from pile toe (m)	Wave Speed (m/s)
S1	$8D_p$=1.296	5.00	2.396	479.20
S2	$12D_p$=1.944	6.75	2.805	415.56
S3	$16D_p$=2.592	8.50	3.294	387.53

The effect of source shape is seen obviously in these cases. With comprising particle velocity of piles in different distance and time, it is concluded that the soil particle velocity and ground vibration because of tapered pile driving is more than cylindrical one and, the vibration amplitude and radius decrease with increasing the distance from the pile. It is also seen that due to material damping in the soil and pile and radiation damping, the propagated waves are dissipated in distance greater than at least $20D_p$.

CONCLUSIONS

Experimental tests in the field have preformed to analyze the drivability of tapered and cylindrical piles, and also the ground vibrations induced in the adjacent area. All steel piles have the same length and volume. Different instruments such as PDA, Seistronix RAS24 seismograph and 4*100 Hz geophone devices were used to record induced pile and soil velocity during driving. All piles have been installed from the embedded length of 0.5 m to 2 m by using 300 kg hammer impact. Geophones were installed in linear radial arrays with distances of 8, 12 and 16 times of pile diameter. The results of wave propagation and the induced velocity in the soil at different distances from the pile-C and pile-T are measured. The displacement and velocity of tapered pile were greater than cylindrical one and they had better performance and effect in pile penetration and economical saving by increasing velocity and residual set per blows.

It is also important to notice that the pile shape and geometry have direct effect on ground vibrations. Also, with comprising soil particle velocity and wave speed in different distance and time, it is concluded that the vibration amplitude and radius decrease with increasing the distance from the pile. The propagated waves are dissipated because of material damping in the soil and pile and radiation damping.

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