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Dynamic Effects of Pile Driving on Adjacent Pile Structures

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ABSTRACT

The effect of piling is a problem that involves several components related to ground vibrations. The process begins with the vibration that occurs due to the collision between the hammer and the pile which is then continued to the ground as a result of the interaction between the soil and the pile. The vibrations on the ground are then transmitted to the surroundings and have an effect on surrounding structures, such as houses, buildings, bridges or industrial infrastructures. With regard to oil and gas infrastructures, it would be necessary to pay attention to their tight safety factors. Therefore, estimation of the effect of piling vibrations on the nearby oil and gas industry infrastructures would be vital. In connection with the ORF infrastructure expansion plan, this research will investigate the effect of piles on the installation of the existing infrastructures. A finite element (FE) model is created using the Plaxis software to then simulate the driving and vibration effects on the nearby piles. Results of this simulation are interpreted in the form of peak particle velocity (PPV) values, then compared with the standard PPV values that are permitted in the existing regulations. The results of PPV value of the simulation results is smaller than 50 mm/s which is allowable based on the regulations of Eurocode 3.

KEYWORDS : pile driving, foundation vibration, peak particle velocity, numerical simulation

INTRODUCTION

A prediction of PPV from the effect of driven pile should be considered as an important factor during the construction [1],[2],[3]. The commonly method just used scale distance equation on calculation of safety factor foundation design. This gap should be solved by knowledge by using support of finite element method based on soil parameter characteristics such as soil Young's modulus, soil damping ratio and loading pulses number during pile driving process which induced ground vibrations. An axisymmetric finite-element model that utilizes an adaptive meshing algorithm has been introduced, using the commercial code Abaqus, to simulate full penetration of the pile from the ground surface to the desired depth by applying successive hammer impacts. The model has been verified by comparing the computed particle velocities with those measured in the field [4]. A finite element model, using Plaxis, with the ability of simulating continuous pile driving process from the ground surface, was introduced. The model was verified by comparing the computed peak particle velocities with those measured in the field. The results showed PPV as being directly proportional to the hammer impact force, pile diameter, friction angle and cohesion intercept and inversely proportional to the elastic modulus of the soil [5]. Figure 1 illustrates the propagation of vibration waves to the surrounding buildings when the hammer is hit on the head of pile. When a wave will occur that propagates at a certain frequency. This propagation would have an effect to nearby structures.

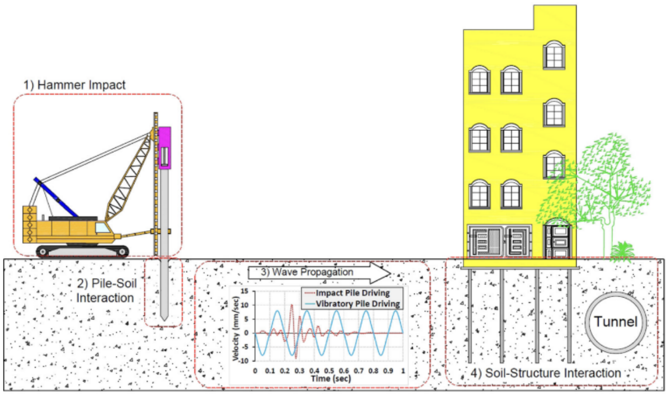


Figure 1. Vibration propagation due to the pile driving process [6]

VIBRATION THEORY AND STANDARD

Wave propagation on the ground due to foundation pilling ware influenced by several factor. First, the factor of hammer energy which relates to hammer type and weight, fall height and efficiency factors. Second, the factor of pile stiffness parameter which relates to pile dimension and material. Third, the factors of dynamic parameters. During its propagation, the waves experience attenuation due to the attenuation of the material (hysteretic damping) and geometric (geometric or radiation damping).

The general theory of time-dependent movement induced by dynamic loads of pile driving could be expressed by equation below.

$$\underline{\underline{M}}\,\underline{\ddot{u}} + \underline{\underline{C}}\,\underline{\dot{u}} + \underline{\underline{K}}\,\underline{u} = F \quad (1)$$

Where M is mass matrix from material in which soil, water, and any constructions, C is damping matrix, K is stiffness matrix, and F is load. Displacement function is expressed as u which can differentiate into velocity (ů) and acceleration (ü). By using finite element calculation, damping matrix can be calculated from function of mass and stiffness mass matrices.

During installation of pile foundation when hammer hit the pile induced a vibration to soil surroundings which triggers a soil particle velocity phenomenon. Several standards propose the allowable maximum peak particle velocity to prevent the damage of nearby structures. Table 1 below present of limits for peak particle velocity for vibration level toward human and structure are summarized by U.S. Department of Transportation (U.S. DOT), DIN 4150 (Germany) and Swiss Association of Standardization. The allowable vibration value has been determined by each standard and to obtain a safety factor, the maximum vibration should be under the allowable vibration.

SOIL STRATIGRAPHY AND PROPERTIES

For this study, the results a soil stratigraphy was simplified based on field soil investigation. The deep boring was performed to an approximate depth of 50 meters with the sea water inundated up to elevation 5 meters above the existing ground surface. Thickness of soil layers and related parameter (shear strength parameter) are summarized in Table 2.

To determine the physical value of soil parameters, several laboratory tests have been carried out by taking undisturbed samples from the Standard Penetration Test (SPT) field test. On the surface soil, the dry unit weight (γd) is 0.644 gr/cm^3, the water content (w) is 96.25%, the pore value (n) is 0.71, the void ratio (e) is 2.492. For the shear strength test using the Direct Shear Test, the cohesion value (c) is 0.37 kg/cm^3 and the shear angle value (φ) is 5°. Meanwhile, the shear strength value using the UU triaxial test resulted in a cohesion value (c) of 0.302 kg/cm^3 and a shear angle value (φ) of 0.733°. For the value of the compression coefficient obtained a value of 0.203.

The physical properties of the soil for soils assumed to be subgrade, based on the results of laboratory testing obtained dry unit weight values (γd) ranging from 0.632 gr/cm^3 to 1.207 gr/cm^3, water content values (w) ranging from 45.53% to 96, 69%, the pore value (n) ranged from 0.638 to 0.713, the void value (e) ranged from 1.19 to 2.484. For the shear strength test using UU triaxial testing, the cohesion values (c) ranged from 0.379 kg/cm^3 to 0.775 kg/cm^3 and the angle of internal friction (φ) were 0.56° to 1.147°.

Table 1. Allowable PPV value for each type of structure [6]

Number	Sensitivity degree	Structure	AASHTO (1990)	Swiss Standard SN640312 (SNV 1992)	British Standard BS 7385-2 (BSI 1993)	Eurocode 3 (CEN 1993)	FHWA Dynamic Compaction (Lukas 1995)	German Standard DIN 4150-3 (DIN 1999)	Minimum	Maximum
1	Highly	Historic-museum Hospital-library Nuclear-marine	2.54 (0.1)[a]	7.62 (0.3)	-	4 (0.15)	-	3 (0.1)	2.54 (0.1)	7.62 (0.3)
2	Upper-intermediate	Hotel/motel Residential building Church/mosque/synagogue	5.08-12.7 (0.2-0.5)	12.7-17.78 (0.5-0.7)	15-20 (0.6-0.8)	10 (0.4)	-	5 (0.2)	5 (0.2)	20 (0.8)
3	Intermediate	Commercial/industrial Underground tunnel Bridge-factory	25.4-38.1 (1-1.5)	17.78-30.48 (0.7-1.2)	50 (2)	20-30 (0.8-1.2)	-	20 (0.8)	20 (0.8)	50 (2)
4	Less	Gas/oil pipeline Waterpipe Electricity cable Telecommunication cable	-	-	-	40 (1.6)	76 (3)	-	-	76 (3)

[a]Units are mm/s (in/s)

Table 2. Summary of soil layer thickness

Layer Thickness (m)	Layer
0 - 28.5	Grey clayey silt with soft consistency
28.5 - 43.5	Brown clayey silt with stiff consistency
43.5 - 53	Hard grey clayey silt
53 - 65.5	Hard brown clayey silt
65.5 - 89	Hard brown grey clayey silt
89 - 100	Hard rock

METHODS

Peak Particle Particle

Peak Particle Velocity (PPV) is the vector resultant of velocities in 3D directions is used to measure the disturbance level of pile driving to the soils surroundings:

$$ppv = \sqrt{v_r^{\,2} + v_t^{\,2} + v_v^{\,2}} \tag{2}$$

where PPV is peak particle velocity (m/s), vr is velocity in radial direction (m/s), vt is velocity in transversal direction (m/s) and vv is velocity of vertical direction (m/s). The prediction methods to calculate particle velocity in general are referred to Attewell and Farmer (1973). Attewell and Farmer (1973) have analyzed the results of vibration measurements due to driving in all types of piles in various soil types. Attewell and Farmer (1973) suggest that the estimation of the due vibration velocity (v) based on the energy conservative method at a distance r from the pile driving energy source can be made with the relationship shown in Equation 3.1 and the illustration in Figure 2 below.

$$v = k\frac{\sqrt{W}}{r} \tag{3}$$

where v is vibration velocity (m/s), W is energy input from source vibration (J), k is empirical factor vibration ($m^2/s\sqrt{J}$) and r is pile distance (m)

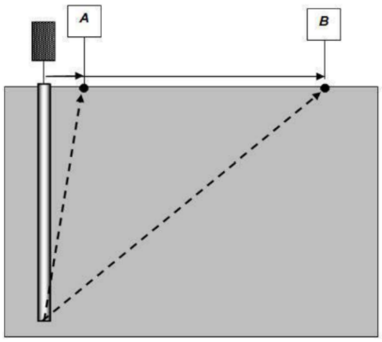


Figure 2. Influence of pile penetration depth on the distance to measuring points at two locations, A and B

Finite Element Method

In this article, to determine the continuous effect due to pile driving process utilize finite element method. In this analysis, the process of pile driving is assumed as a dynamic load. Some important points are used in the analysis using the finite element method are follows, first, during the calculation process utilize dynamic analysis to model the impact of the hammer on the pile. Second, for hammer of diesel machine, the ram weight is 13 tons, and the section area of spun pile diameter 600 mm is 0.2826 m^2. Thus, the maximum stress in the head of spun pile is 460 kN/m^2. This value is used as input amplitude multiplier in dynamic analysis. Third, representative time frame input is 5 seconds.

RESULTS AND DISCUSSION

Peak Particle Velocity Analysisi Based On Attewell And Farmer (1973)

During the installation pile in the field, the hydraulic hammer utilized has specification as follows, maximum energy was 82 kNm, maximum drop height was 1.2 m, number blows per minutes was 40 to 100, ram weight was 7000 kg and total weight was 11000 kg.

In calculating the PPV value by using empirical equation, two types of hammer efficiency are used, 60% efficiency (field implementation) and 100 % efficiency (worst scenario). The value of energy input from source vibration are 49.200 Joule and 82.000 Joule for the 60% efficiency and 100 % efficiency respectively. For the empirical factor vibration is 0.3 m2/s√J for both efficiencies. The results of analysis regarding two types of efficiency could be seen in Table 3.

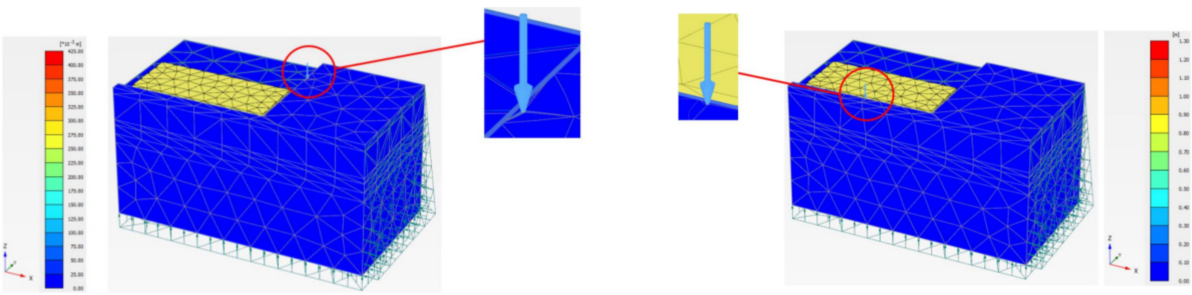
The results of analysis depicted the PPV maximum reached 2.210 mm/s to 12.747 mm/s for 60% hammer efficiency and 2.854 mm/s to 16.457 mm/s for 100% hammer efficiency. These results were analyzed when the horizontal distance from pile driving process location to pile existing nearby is 5m to 30 m at depth in between 1.5 m to 2.5 m. From this analysis could be said that the process of pile driven could be said to be safe for piles existing nearby since the value of PPV under 50 mm/s.

Table 3. The results of the analysis by using the Attewell and Farmer equation (1973)

Pile penetration (m)	Horizontal distance (m)	r (m)	PPV (mm/s)	
			60 % eff	100% eff
1.5	5	5.220	12.747	16.457
1.5	10	10.112	6.581	8.496
1.5	20	20.056	3.318	4.283
1.5	30	30.037	2.215	2.860
2	5	5.385	12.357	15.953
2	10	10.198	6.525	8.424
2	20	20.100	3.311	4.274
2	30	30,067	2.213	2.857
2.5	5	5.590	11,904	15.367
2.5	10	10.308	6.456	8.334
2.5	20	20.156	3.301	4.262
2.5	30	30.104	2.210	2.854

Vibration Effect Of Pile Driven By Finite Element Method

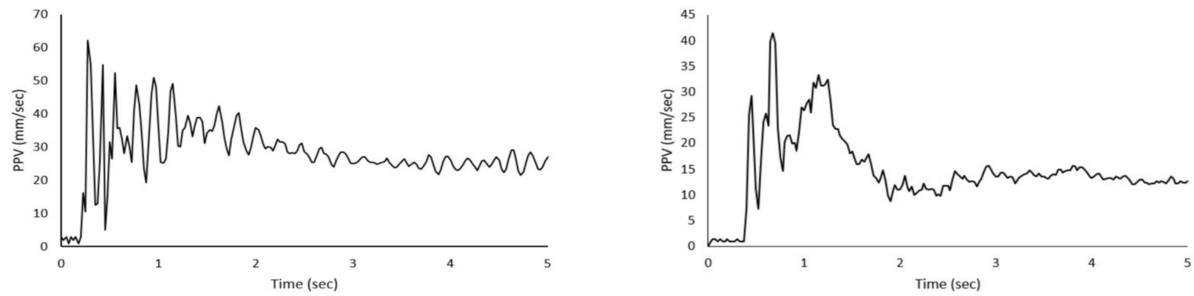
During pile driven process, the vibration of driven pile machine would have an impact to the adjacent structure. Numerical analysis by using the finite element methjod was carried out in this article to determine the prediction of ground motion due to the effects of vibration due to the piling process. The model of finite element method analysis could be seen in the Figure 3.



(a) (b)

Figure 3. The effect of vibration due to the pile driving using a 3-meter (a) and 5-meter (b) in horizontal distance of hydraulic hammer from pile existing nearby by using finite element method

In this article, five cross sections were analyzed to know the better understanding of PPV value in the location which assumed important during the construction process which be distinguished by horizontal distance from the driven pile process and pile existing. The depth of pile considered is 53 m and the distance is 3 m, 4.5 m, 7m. 9 m and 15 m.



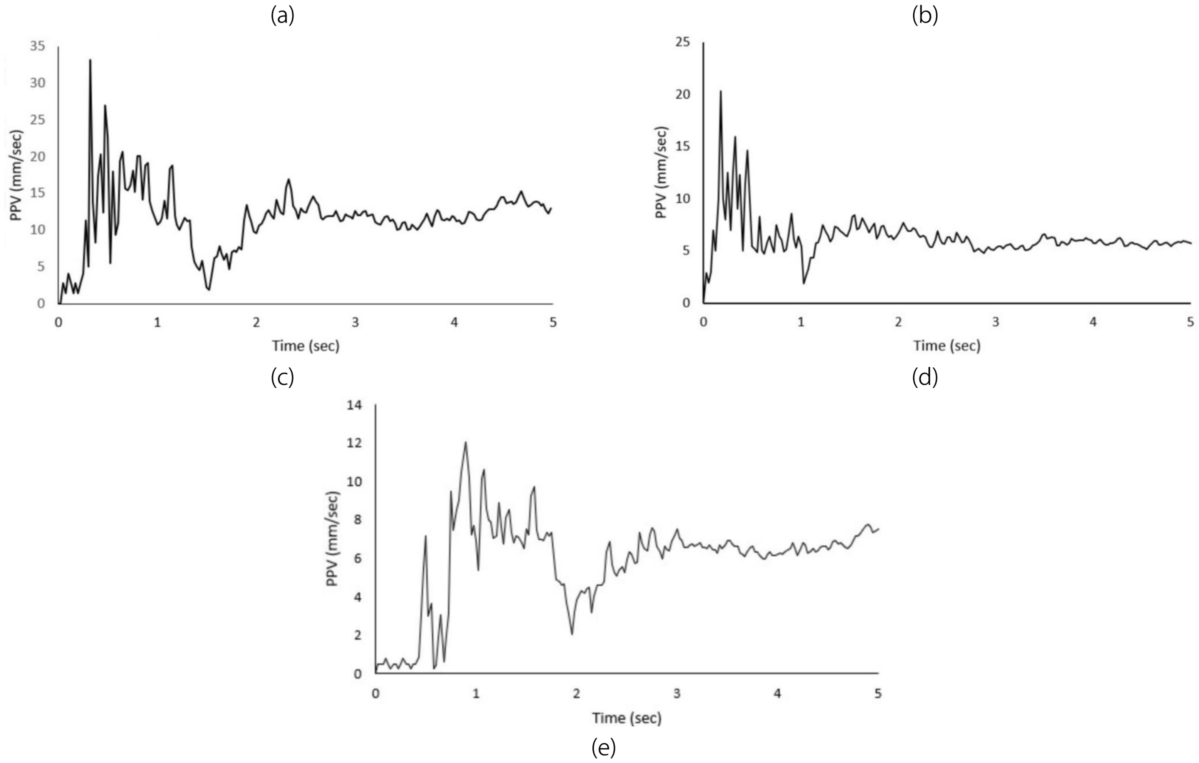


Figure 4. The PPV that occurred during the driven pile process with the horizontal results of pile existing nearby is (a) 3m, (b) 4.5 m, (c) 7m, (d) 9 m and (e) 15 m

The results of PPV by using the finite element method could be seen in Figure 4. From the analysis could be resume when the horizontal distance is 3 m, the PPV value is 62.26 mm/s and this value exceeds the allowable PPV of 50 mm/s. On the other hand, the PPV value at horizontal distance of 5 m, 7m, 9 m and 15 m is41.3 mm/s, 33 mm/s, 20.3 mm/s and 12.4 mm/s respectively. In this distance, the process of pile driven construction did not have any impact to pile existing nearby since the value PPV is allowable limit.

CONCLUSION

The aim of this research is to highlight the problems during the construction process associated with ground vibrations assessment. Furthermore, the finite element method is best way to predict the allowable distance from the impact of pile driven work from construction site to prevent the structural damage to nearby buildings. The allowable maximum PPV is also presented in this article from various standards. From the analysis results are identifies some prominent conclusion as follows:

1. Various activities during construction process generate the ground vibration. The PPV is important criteria for assessing ground vibration impact to existing structure nearby.
2. From the finite element analysis, the safety horizontal distance for pile driven activities from the existing structure is equal and more than 5 meters. In this distance, the PPV is more allowable limit based on various standard.

REFERENCES

[1] Zhang M and Tao M. "A Parametric Study on Factors Affecting Ground Vibrations during Pile Driving through Finite Element Simulations". GeoRisk 2011.

[2] Zhang M, Tao M, Gautreau G, and Zhang Z. "Statistical Approach to Determining Ground Vibration Monitoring Distance during Pile Driving". Practice Periodical Structural Design Construction 2013; 18(4): 196-204.

[3] Khoubani A, Ahmadi MMP. "Numerical study of ground vibration due to impact pile driving". Geotechnical Engineering 2011.

[4] Rezaei M, Hamidi A and Rooz FHA. "Investigation of Peak Particle Velocity Variations during Impact Pile Driving Process". Civil Engineering Infrastructures Journal 2016; 49(1): 59-69.

[5] Rooz AFH and Hamidi A. "Numerical Analysis of Factors Affecting Ground Vibrations due to Continuous Impact Pile Driving". International Journal of Geomechanics 2017; 17(12): 04017107

[6] Hamidi, Amir, Abtin Farshi Homayoun Rooz, and Majid Pourjenabi. "Allowable distance from impact pile driving to prevent structural damage considering limits in different standards." Practice Periodical on Structural Design and Construction 23.1 (2018): 04017029.