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Vertical Displacement of a Single Pile Due to Axial & Lateral Loads

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Abstract. Pile foundation supports the upper structure to the subgrade, generally vertical loads. Still, if horizontal loads are very dominant, such as bridges, tall buildings, and tower structures, it must be calculated. Pile foundations with combined loads are generally analyzed. The axial load is first to determine the axial carrying capacity and vertical displacement, then the lateral load to determine the lateral bearing capacity and lateral deflection. In the field, the two loads work together/simulant. In Indonesia, loading tests do not simultaneously, so in construction, it does not account for the additional vertical displacement and lateral deflection due to the load that works simulant. However, there has been an association in ASTM D3966-07 about the *simulant loading test*. This research will investigate the analysis and experimental laboratory, the effect of vertical displacement on a single pile foundation, as the effect of combined loads. Also, it gets a relationship that can be used as a reference for analyzing additional vertical displacement due to combined loads on pile foundations based on available independent loading test. The research will be divided into two stages. Stage I is an analysis with the Finite Element Method (FEM) approach. Phase II is a laboratory model experimental test, which is inbox $(100\times100\times80)$ cm^3 filled silty sand soil as an illustration of conditions in the field, single pile foundation using steel with a length of 50cm and 60cm, the diameter of 1.5cm and 2cm, with axial and lateral load variations and combined loads. The results obtained show that after adding vertical load (Pu) about 5x, lateral load (Hu) on (Pu/Hu > 5) and the vertical displacement stays like the loading test until it collapses. Another (Pu/Hu ≤ 5), the lateral load, will increase the significant vertical movement due to the combination load. With axial load five times greater than lateral load, there is no increase in vertical displacement. Still, at an axial load less than five times the lateral load, there is an increase in vertical displacement that needs to be considered.

1. Introduction

Pile foundation supports the burden of the upper structure to the subgrade, generally vertical loads. Still, if horizontal loads are very dominant, such as bridges, tall buildings, and tower structures, it must be calculated.

Pile foundations with axial and lateral loads are generally analyzed, not at the same time, at the axial load to determine the axial carrying capacity and vertical displacement—the lateral load to determine the lateral bearing capacity and lateral deflection. In fact, in the field, the two loads work together. In Indonesia, limitation in the test does not apply simultaneously but is carried out independently. In construction, it does not account for the additional vertical displacement and lateral

deflection due to the load that works simultaneously. However, there has been an association in ASTM D3966-07 about the simulant loading test.

Previous studies noted the combined load on a single pile, including the following, Pile foundation under combined loads, lateral deflection is reduced due to axial load. [1]. Pure lateral loading does not cause vertical movement, but in combined loads, the lateral load increases vertical direction. [2]. Lateral bearing capacity will be significantly reduced if the embedded pile is diminished, and lateral deflection will decrease with the increasing vertical load on the pile head. [3]. Three-dimensional finite element analysis which shows the significant influence of axial and lateral loads working together. The investigation was carried out in homogeneous clay soils and homogeneous sandy soils. The results show that the axial load on the pile's lateral bearing capacity significantly increases in sandy soil and slightly decreases in clay. In general, it was found that in sandy soils, the axial load effect was significant, even for piles along 30D, whereas for clay soils, the impact was less significant for piles above 15D length. [4]. Test results on the sand in the poorly graded sand (SP) classification, consisting of several variations of the pile and several variations of loading by several methods, showed an increase in the pile foundation's lateral bearing capacity as the vertical load increased. [5].

Some researchers have provided evidence that even though axial loads reduce deflection due to lateral loads, lateral loads increase the vertical reduction in load combinations.

This research will investigate the analysis and experimental laboratory, vertical displacement on a single pile foundation. Another factor is combined loads and a relationship that can be used as a reference for analyzing additional vertical displacement due to combined loads on pile foundations based on an independent loading test.

The research will be divided into two stages, stage I, analysis with Finite Element Method (FEM) approach, and phase II, laboratory model experimental test, which is inbox (100x100x80) cm^3 filled silty sand soil as an illustration of conditions in the field, single pile foundation using steel with a length of 50cm and 60cm, the diameter of 1.5cm and 2cm, with axial and lateral load variations and combined loads

2. Methodology

2.1. Stage I, Analysis With Finite Element Method (FEM)

Analysis with Finite Element Method (FEM), modeling a single pile foundation using the axisymmetry menu on Finite Element Method (FEM) as follows, axial loading, lateral loading, combined loads (axial and lateral), the variation of length and diameter of the pile, soft soil type, medium and dense, homogeneous soil and layered, submerged and not submerged in water. Interpretation of soil parameter and Variation of load in research with FEM can be seen in Table 1. and Table 2. below,

Tabel 1. Variation of soil parameter on FEM

Name			T5	T6				Pile
	Layer 1	Layer 2	Layer 1	Layer 1	Layer 2	Layer 3	Layer 4	
Material model	MC	MC	MC	MC	MC	MC	MC	LE Non-Porous
Condition	Drained	Drained	Drained	Drained	Drained	Drained	Drained	
γk kN/m^3	16	17	16,5	11,86	12,22	12,86	13,57	24
γsat kN/m^3	20	21	20	17,50	18,03	17,67	17,83	
E kN/m^2	1,2.10^5	1,2.10^5	8.10^4	1,6.10^6	1,6.10^6	1,6.10^6	1,6.10^6	25,33
Poisson Ratio, μ	0,3	0,3	0,3	0,3	0,3	0,3	0,3	0,3
c kN/m^2	1	1	1	2,05	2,30	0,05	0,02	
$\varphi(^\circ)$	30	33	31	30	30	35	40	
Interface, R_{inter}	1	0,7	1	0,4	0,35	0,7	0,7	

Tabel 2. Variation of load on FEM

Type of soil	Pile Dimensions		Load Kn until it collapses		
	D (m)	L (m)	Lateral (5-600) Kn	Axial (5-12.000) kN	Combined (kN)
T5 (soft soil) 1 layer	0,65	17	√	√	√
		30	√	√	√
T3 (medium) Two-layer	0,65	22	√	√	√
		26	√	√	√
		30	√	√	√
T3 (dense) 4 layer	0,6	17	√	√	√

2.2. Stage II, Laboratory Model Experimental Test

In this study, they were modeling a laboratory scale in a test box with a size $(1,0 \times 1,0 \times 0,8)$ m^3. It is filled with silt sand soil, as a description of conditions in the field (samples were taken in Karang, Kalitirto, Berbah, Sleman, Special Region of Yogyakarta), while the single pile foundation using steel with a length of 0,5m and 0,6m, the diameter of 0,015m and 0,02m. Given loads, axial, horizontal, and combined loads. The laboratory model can be seen in Figure 1. below,
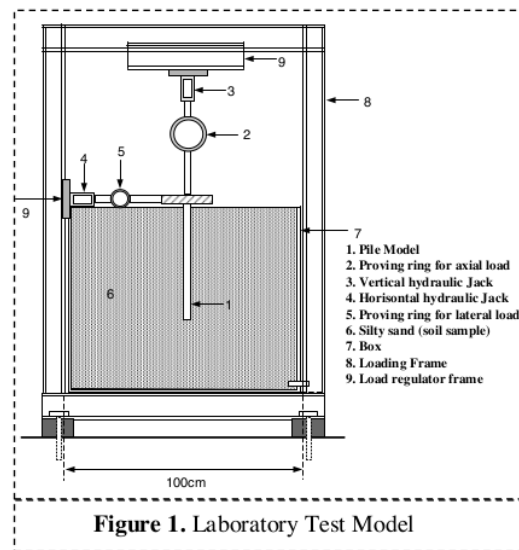

1. Pile Model
2. Proving ring for axial load
3. Vertical hydraulic Jack
4. Horisontal hydraulic Jack
5. Proving ring for lateral load
6. Silty sand (soil sample)
7. Box
8. Loading Frame
9. Load regulator frame

100cm

Figure 1. Laboratory Test Model

The test model has length and diameter variations of the pile, and combined loads, as shown in Table 3. below,

Tabel 3. Variation of load on the laboratory test model

Type of soil	Pile Dimensions		Load until it collapses		
	Dm	Lm	Lateral gr	Axial gr	combined loads gr
silty sand	0,015	0,5	√	√	√
silty sand	0,02	0,6	√	√	√

3. Result and Discussion

3.1. Result

Analysis with FEM, with axial loading, lateral loading, combined loads (axial and lateral), the variation of length and diameter of the pile, soft soil type, medium and dense, homogeneous soil and layered, submerged and not submerged in water, illustrates movement at the head of the pile due to axial and lateral loading as in Figure 2., Figure 3., Figure 4. and Figure 5. below this,
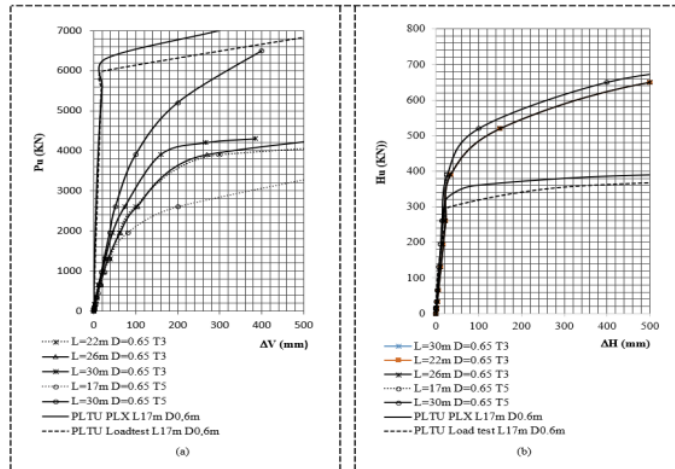

Figure 2. movement at the head of the pile (FEM)
(a) Displacement vertical without lateral load
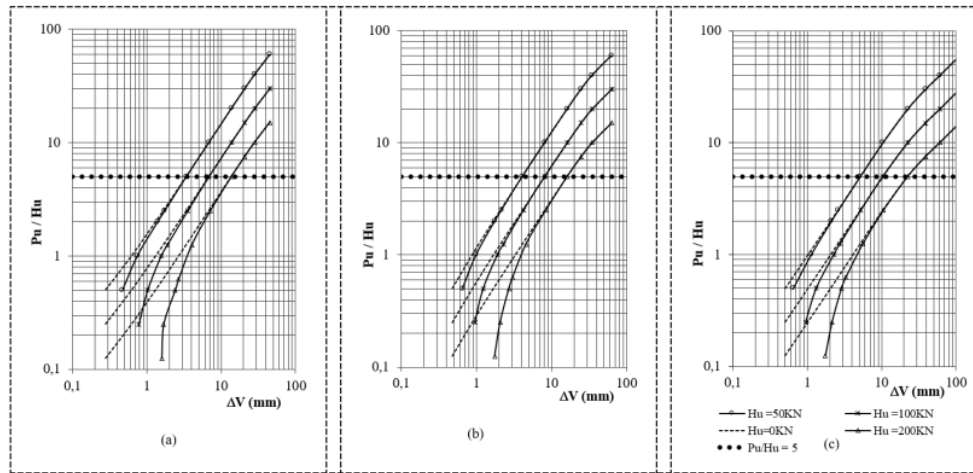(b) Deflection horizontal without axial load

Figure 3. Vertical displacement for T3 medium density (FEM)
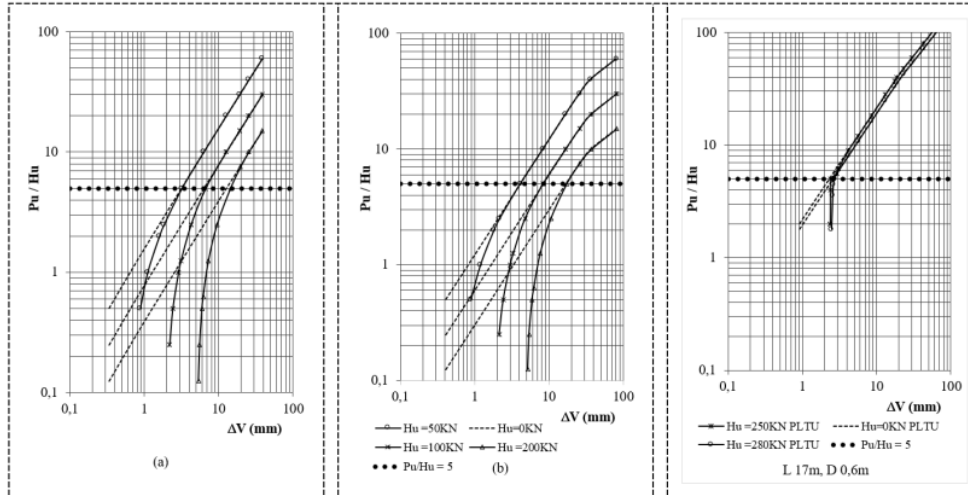(a) L 30m, D 0,65m
(b) L 26m, D 0,65m

(c) L 22m, D 0,65m

Figure 4. Vertical displacement for T5 Soft Soil (FEM)
(a)   L 30m, D 0,65m
(b)   L 17m, D 0,65m

Figure 5. Vertical displacement for T6 dense (FEM)

Experimental tests of laboratory-scale models, with silty sand as a description of conditions in the field, while the single pile foundation uses steel with lengths of 50cm and 60cm, diameters of 1.5cm and 2cm, movement at the head of the pile with variations in axial loads and lateral loads in Figure 6. and vertical movement because of the combination of loads in Figure 7. below this,
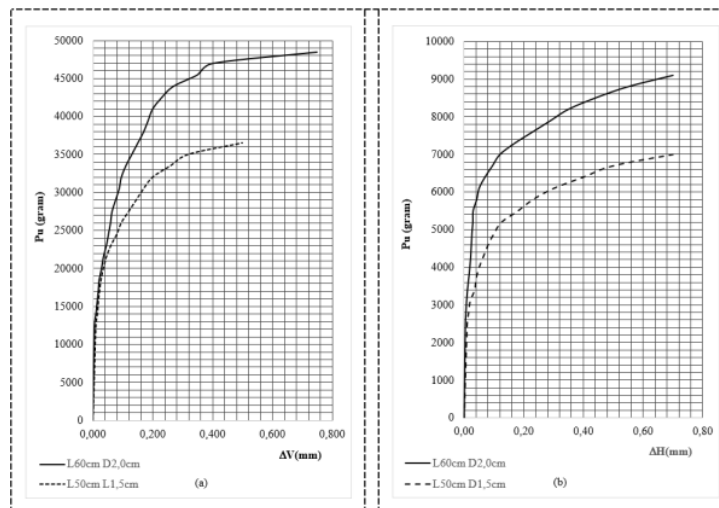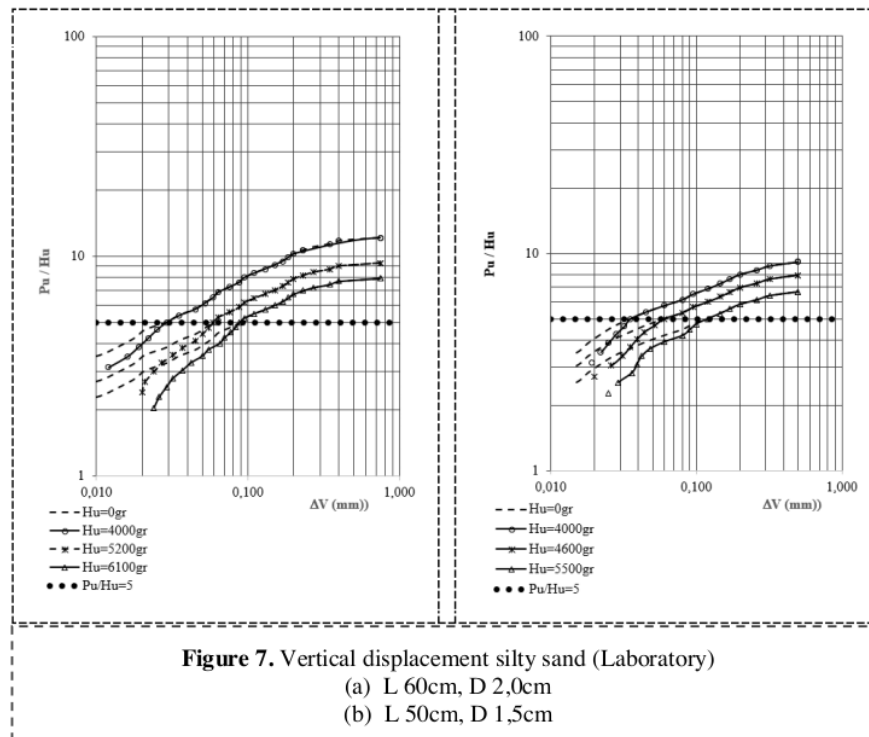

Figure 6. movement at the head of the pile (laboratory)
(a) Displacement vertical without lateral load
(b) Deflection horizontal without axial load

Figure 7. Vertical displacement silty sand (Laboratory)
(a) L 60cm, D 2,0cm
(b) L 50cm, D 1,5cm

3.2. Discussion

The FEM analysis result[11] and laboratory experiments show at specific comparisons of Pu (axial load) and Hu (lateral load), the lateral load will significantly increase the vertical displacement due to the combined limitations. At a particular ratio, due to axial load, pile dimensions, and elastic modulus of the soil, so lateral deflection increases significantly until it collapses. Precisely, the axial load about five times greater than the lateral load. There is no increase in vertical movement. Still, at axial load about less than five times the lateral load, there is an increase in the vertical movement that needs to be considered. Although axial load reduces deflection lateral in the combined load, lateral load adds to the vertical movement.

4. Conclusion

The results obtained show that after adding vertical load (Pu) about 5x lateral load (Hu), that[11] (Pu/Hu>5), the vertical displacement stays, like the loading test until it collapses and on (Pu/Hu≤5), the lateral load will increase the significant vertical movement due to the combination load, with axial load five times greater[8] than lateral load, there is no increase in vertical displacement, but at an axial load less than five times the lateral load, there is an increase in vertical displacement that needs to be taken into account

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