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Analysis of the Influence of Pile Cap Thickness to Deflection due to Lateral Load in Sand

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Abstract

Analysis of the pile groups in noncohesive soil consisting of dense sand with varying pile cap thickness is presented small scale model through the experimental study in the laboratory of soil mechanics and geology. Pile groups (PG) of 2x2, 3x3, 4x4, and 5x5, of pile arrangement with spacing 3D and pile cap thickness (PC) 2D, 3D, 4D and 5D where D is the diameter of pile. This study shows the significant effect of various parameters of pile groups to lateral load and lateral displacement.

The more piles in total number of pile groups, the smaller deflection of pile occurred in the same PC. The thicker of Pile cap, the smaller deflection of pile occurred in the same PG. PC thickness of 5D will give the smallest deflection if compared 2D, 3D and 4D in PG of 2x2, 3x3, 4x4 and 5x5.

Keywords: Lateral load, pile groups, pile cap thickness, deflection

INTRODUCTION

Pile foundations are the part of a structure used to carry and transfer its load to the bearing ground located at some depth below ground surface. Pile foundations have been principally used to carry and transfer loads from superstructures in years. A Group of piles is subjected to lateral load or eccentric vertical load or combination of vertical and lateral load such as bridge pillar constructions, piles installations for marine structures, jetties or bridge piers, and bored pile retaining walls.

One of stability determinations in piles supporting lateral loads is deflection which should be within acceptable limits. The deflection of pile groups due to lateral loads has been revealed in studies by Hararika, P. J. and Nath, U.K. (Finite element, 2010), Mahmoud N. Husein, Tetsuo Tobita, Susunu Iai (numeric, 2011), Syros Giannakos, Nikos Gerolymos, George Gazetas (numeric, experimental, 2011), H.S. Chore, R.K. Ingle and V.A. Sawant (finite element, 2012), Bhavik S. Parsiya, Dr. S. P. Dave (finite element, 2012), Karsan R. Hirani (finite element), Abhijit Deka (finite element, 2016) and so forth.

Hararika, P.J and Nath, UK conducted research by using Finite Element Analysis of Pile-Soil-Pile Cap interaction because of lateral load. Element analysis up to 2D with aid of PLAXIS 2D software done to know the endurance toward lateral load by varying the pile cap position and the pile length. It was observed from the research that, pile group that hold back good and interesting lateral load, this resistance increase along with the increase of pile position from the soil surface [1]. H.S. Chore, R.K and Ingle and V.A. Sawant (finite element, 2012), conducted parametric study toward pile group given lateral load by using finite element model, for this purpose, the model is simplified similar with suggestion of Desai et al (1981) used to idealize various system element. The pile group is idealization of one dimension beam, the pile as the two dimensions plate element and soil as independent linear element. Analysis considered the effect of interaction between pile group and soil. The pile group is considered as embedded at cohesive soil. Parametric study done to know the influence of pile distance, pile diameter, amount and pile arrangement, at the response of pile group. The obtained results including the transfer and flexible moment at the pile group. The finite element analysis approach compared with the analysis result of 3D finite element [2]. Bhavik S. Pariya, Dr. S.P Dave (2012), used finite element to research the pile group. The paper presented analytical study about lateral behavior of pile group for different group configuration given with lateral load. In the research, it was used equal group number with configuration of four different piles (pile group of 12x3, 6x6, 9x4 and 4x9) with four group value of 2D, 3D, 4D and 5D and four different elasticity modulus value of soil that is 5000, 1000, 15.000 and 20.000 kN/m2. The group configuration influence, pile distance and soil elasticity were observed their influence toward the pile group transfer and pressure in soil.

The conclusion is, the pile group distance and soil elasticity modulus mostly influence the lateral transfer and pressure in soil with equal lateral load [3]. Manjula Devil, Chore H.S, V.A. Sawant, with research title of Analysis of Laterally Loaded Pile Group (parametric study) by using pile group parameter, dried sand, pile distance, pile size, and pile group configuration. The study showed the significant influence of various pile group parameters such as pile distance, pile size, and pile group configuration at the pile group that is given with lateral load [4]. Abhijit Deka (2016), conducted research by using finite element at pile group foundation is construction that consist of three elements; pile, pile cap and soil. The research presented element analysis up to three pile foundation dimension under lateral load by using ANSYS software. Soil is modeled as pure clay soil and considered as homogenous and isotropic in analysis. Elasto-plastic of soil numerically modeled according to Drucker-Prager Yield criteria. The study did not consider the pore water pressure development in soil because of instant load applied. Based on the results, concluded that the L/D pile ratio increase did not give capacity increase of pile group lateral load capacity if the diameter still constant and length change, lateral load capacity of pile group increase with the increase of pile diameter, lateral load capacity of pile group increase along with the increase distance among pile, passive resistance given by pile group depend on pile orientation at group, if the soil volume between pile increase, the pile group resistance toward lateral load also increase, and etc. at the pile planning, the planners did not consider the thickness of pile cap either for vertical load or for lateral loading [5]. Robert L. Mokwa, and J. Michael Duncan (2001), with research title Experimental Evaluation of Lateral Load Resistance of Pile Cap with parameter of pile size and pile cap, the soil condition and loading condition with lateral load with full scale at pile group and single pile, with pile cap embedded and pile cap not embedded. Thirty one test is done. By considering pile group response with cap embedded fully and with soil is removed from around pile cap. The obtained results from pile group response with the cap embedded fully receive lateral more than group responses with soil removed from pile cap [6].

In this study designing of piles do not calculate pile cap thickness either for vertical and lateral loads. Some researchers have published elsewhere the influence of pile cap to the lateral deflection of pile groups using software (Tommy Ilias and Hardjanto with FL-PIER software, Christian Hadiwibawa, Gouw Tjie Liong with Plaxis, PJ Hazarika and UK Nath with finite element (2010). Ilias and Hardjanto examined the effect of the differences in force on the pile cap and deflection and the bending moment occurring on the pile cap [7]. Christian Hadiwibawa and Gouw Tjie Liong confirmed that the thickness of pile cap affects the efficiency value [8]. PJ Hazarika and UK Nath stated that group a fully embedded pile will be expected to provide significant resistance under the lateral load [1].

Lateral carrying capacity [9] Broms method: this calculation method by using soil pressure theory which is simplified by considering that along the pile depth, the soil reach ultimate value.

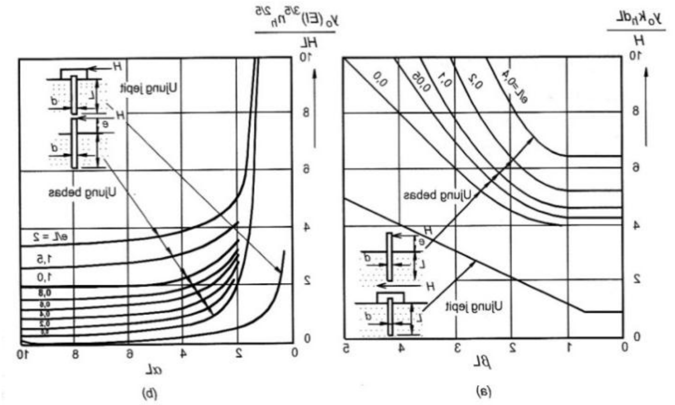

Figure 1: Pile lateral deflection above soil surface
(a). For pile at cohesive soil (φ=0), (b). Fore pile at granular soil (c=0) (Broms, 1964b) [9]

For pile at granular soil (sand, gravel), pile deflection because of lateral load, connected with the nondimensional magnitude of αL with:

$$\alpha = \left(\frac{n_h}{E_p I_p}\right)^{1/5}$$

1. Free end pile and fixed end pile are considered as short (rigid) pile if $\alpha L < 2$.

(1.a). Lateral deflection of end pile above soil surface.

$$y_o = \frac{18H(1+1{,}33e/L)}{L^2 n_h}$$

$$\theta = \frac{24H(1+1{,}5e/L)}{L^3 n_h}$$

(1.b). Lateral deflection of fixed end pile

$$y_o = \frac{2H}{L^2 n_h}$$

2. Free end and fixed end pile are considered as long pile (not rigid) if $\alpha L < 4$.

   (2.a). Lateral deflection of free end pile (Poulos and Davis, 1980)

$$y_o = \frac{2{,}4H}{(n_h)^{3/5}(E_p I_p)^{2/5}} + \frac{1.6He}{(n_h)^{2/5}(E_p I_p)^{3/5}}$$

$$\theta = \frac{1{,}6H}{(n_h)^{2/5}(E_p I_p)^{3/5}} + \frac{1.74He}{(n_h)^{1/5}(E_p I_p)^{4/5}}$$

(2.b). Lateral deflection of fixed end pile

$$y_o = \frac{0.93H}{(n_h)^{3/5}(E_p I_p)^{2/5}}$$

Lateral carrying capacity of pile group [10]

In supporting the building load, pile is not single pile, but pile group. Lateral carrying capacity of pile group consist of n pile Q (group) = n x Q (single, reduced),where Q (single, reduced) is carrying capacity of single pile which has considered group effect. To consider the influence of pile group toward lateral capacity of single pile, then soil resistance used, either in the form of "Subgrade Modulus" or "p-y Curves",should be weakened by multiplying with reduction factor whose value ≤ 1. The reduction factor is different with efficiency factor, where reduction factor always ≤ efficiency factor. The most simple and conservative reduction factor given by NAFAC DM-71, where the reduction factor is only function of pile spacing/diameter pile (s/d). The reduction factor changes linearly between 0,25 for s/d= 3 up to the highest value, that is 1 for s/d= 8.

More accurate reduction factor given by Reese et.al based on full scale test at sereval piles, where according to Reese et al, reduction factor is influenced by s/d ratio, working lateral force, pile position viewed toward around piles so there is "Side by Side Reduction Factor" and "Line by Line Reduction Factor" as illustrated at figure 2.

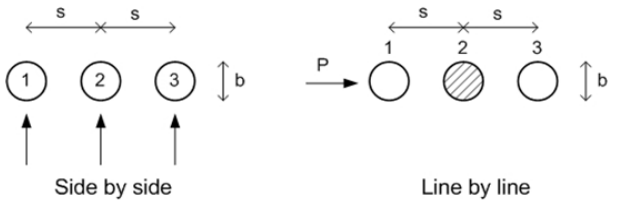

Figure 2: Pile position is viewed toward piles around [10]

Reese et. al also differentiates the piling layout as "Square Pattern" and "Triangular Pattern" as shown in figure 3. By using empirical formulation, it is calculated the reduction factor for each pile by considering the around piles.

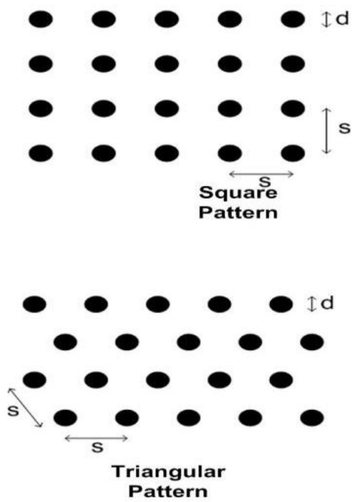

Figure 3: Pilling layout [10]

Reduction factor used for a pile group is average value of reduction factor for each pile a the group. For big pile group, the smallest reduction factor for piles at center, or with other words, piles at the center has lateral capacity minimum. In design, lateral capacity of pile group equal with pile amount multiply with the lateral capacity minimum single pile. Figure 4 presented reduction factor for various s/d value, either for "square pattern" or "triangular pattern".

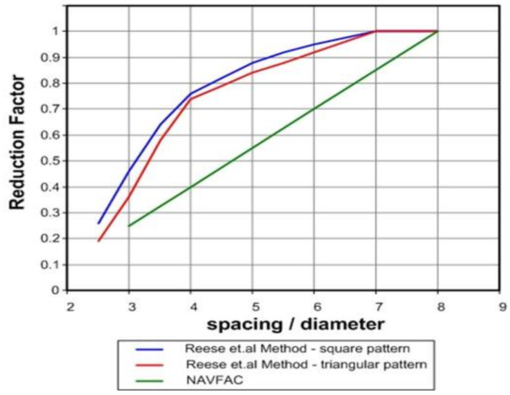

Figure 3: Reduction factor for various s/d value, For square pattern and triangular pattern [10]

From the plotting it can be seen, "Square Pattern always produced reduction factor more than Triangular Pattern for same s/d value, it means the soil resistance at Square Pattern more optimally used in supporting the lateral load. It means that pile group same with Square Pattern will give more lateral carrying capacity compared with the pile group with Triangular Pattern, if the s/d is same. At the figure 3 it is also given plotting of reduction factor vs s/d according to the NAFAC DM-71. The complete summary of Reese et al method can be seen in manual program GROUP 3D ver 7 developed by Ensof,,Inc, Austin, Texas, USA. No Code, Standard or formula-formula to calculate the efficiency factor for a pile group that support the lateral load. Three is the way to calculate "reduction factor" soil resistance to calculate the group effect at the lateral carrying capacity of single pile, as given above. So the efficiency factor should be calculate by obtaining the group carrying capacity, as follow:

$$\text{Eff. Factor} = \frac{Q_{(group)}}{n \times Q_{(single)}} = \frac{n \times Q_{(single,reduced)}}{n \times Q_{(single)}} = \frac{Q_{(single,rediced)}}{Q_{(single)}}$$

Where: Q (group) = lateral bearing capacity of group pile, n = pile amount in group, Q(single = single pile lateral bearing capacity, Q (single, reduced) = lateral bearing capacity of single pile that has considered group effect.

Scope of study, this research was conducted in the laboratory by using small scale experimental model intended to understand the influence of pile cap thickness in different pile groups and deflection pile in dense sand types. To determine total number of pile groups, pile cap thickness in piles diameter, length of piles and a certain dense sand on small deflection pile. To find out the most dominant factor that the in affecting performance pile groups loaded by lateral loads.

METHODS

This research was conducted in the Laboratory of Soil Mechanics and Geology of University of Brawijaya Malang. Using a container (cube) 1 x 1 x 1 m, filled with sand where optimum water content of 7.8% and bulk density of 1.2 t/m3. Sand was put in layers, in this research, sand was divided into 5 layers. Each layer was compacted so that density reached 1.2 t/m3. In the sand was installed pile groups (PG) of configuration 2x2, 3x3, 4x4, 5x5. The space between the piles was 3D, a steel pile cap D=3cm, length of embedded pile (L) 40 cm. Pile groups was fixed with Pile Cap (PC) which thickness varies 2D = 6 cm, 3D = 9 cm, 4D = 12 cm and 5D = 15 cm. Loads were applied 10 to 280 kg. Deflections on the dial gauge were recorded.

Table 1: Model test sand soil

Group	Pile Length L (cm)	Pile Diameter D (cm)	Pile Group (PG)	Pile Cap (PC)	Load (kg)
A.1	40	3	2x2	2D	10-80
A.2	40	3	2x2	3D	10-80
A.3	40	3	2x2	4D	10-80
A.4	40	3	2x2	5D	10-00
B.1	40	3	3x3	2D	10-150
B.2	40	3	3x3	3D	10-150
B.3	40	3	3x3	4D	10-150
B.4	40	3	3x3	5D	10-150
C.1	40	3	4x4	2D	10-250
C.2	40	3	4x4	3D	10-250
C.3	40	3	4x4	4D	10-250
C.4	40	3	4x4	5D	10-250
D.1	40	3	5x5	2D	10-280
D.2	40	3	5x5	3D	10-280
D.3	40	3	5x5	4D	10-280
D.4	40	3	5x5	5D	10-280

RESULTS

The results of the study are shown in tables 2 to 5 and figures 5 to 9. Table 2 and Figure 5: Deflection of piles in sand of groups A.1, A.2, A.3 and A.4. Table 3 and Figure 6: Deflection of piles in sand of groups B.1, B.2, B.3 and B.4. Table 4 and Figure 7: Deflection of piles in sand of groups C.1, C.2, C.3 and C.4. Table 5 and Figure 8: Deflection of piles in sand of groups D.1, D.2, D.3 and D.4. Figure 9: Deflection of piles in sand of groups A.1, B.1, C.1 and D.1

Table 2: Deflection of piles in sand of groups A.1, A.2, A.3 and A.4

Load (kg)	Deflection (mm)			
	PG 2x2, PC 2D=6 cm	PG 2x2, PC 3D=9 cm	PG 2x2, PC 4D=12 cm	PG 2x2, PC 5D=15 cm
0	0	0	0	0
10	0	0	0	0
20	0.06	0.05	0.04	0.02
30	0.20	0.18	0.12	0.08
40	0.60	0.49	0.27	0.2
50	1.10	0.90	0.57	0.42
60	1.70	1.27	0.90	0.64
70	2.50	1.85	1.32	0.90
80	3.48	2.60	1.91	1.37

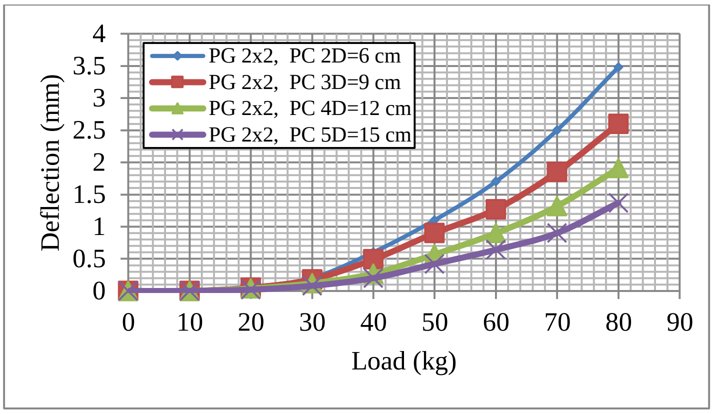

Figure 5: Deflection of piles in sand of groups A.1, A.2, A.3 and A.4

Table 3: Deflection of piles in sand of groups B.1, B.2, B.3 and B.4

Load (kg)	Deflection (mm)			
	PG 3x3, PC 2D=6 cm	PG 3x3, PC 3D=9 cm	PG 3x3, PC 4D=12 cm	PG 3x3, PC 5D=15 cm
0	0	0	0	0
10	0	0	0	0
20	0	0	0	0
30	0	0	0	0
40	0.01	0	0	0
50	0.06	0.01	0	0
60	0.11	0.02	0	0
70	0.18	0.05	0	0
80	0.25	0.10	0	0
90	0.37	0.15	0	0
100	0.52	0.22	0.05	0
110	0.68	0.4	0.1	0
120	0.81	0.52	0.26	0.05
130	1.03	0.68	0.49	0.22
140	1.34	0.97	0.69	0.36
150	1.68	1.35	0.93	0.44

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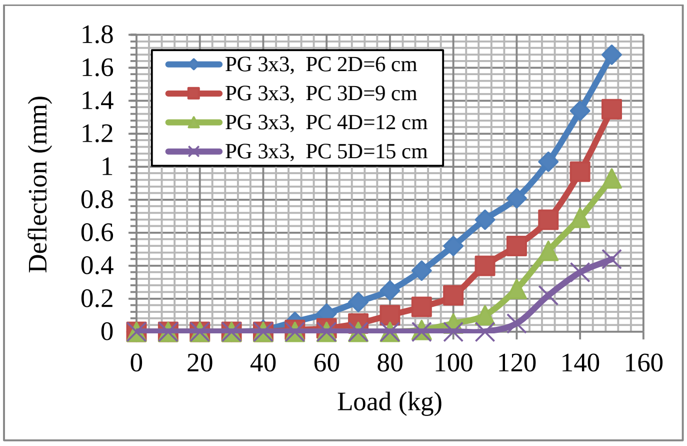

Figure 6: Deflection of piles in sand of group B.1, B.2, B.3 and B.4

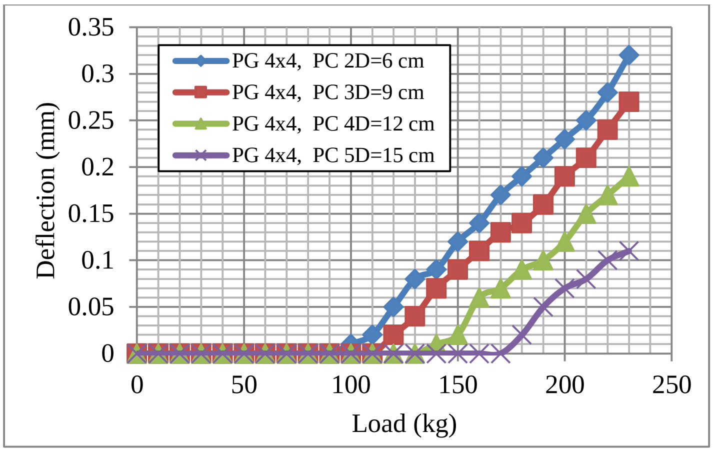

Figure 7: Deflection of piles in sand of groups C.1, C.2, C.3 and C.4

Table 4: Deflection of piles in sand of groups C.1, C.2, C.3 and C.4

Load (kg)	Deflection (mm)			
	PG 4x4, PC 2D=6 cm	PG 4x4, PC 3D=9 cm	PG 4x4, PC 4D=12 cm	PG 4x4, PC 5D=15 cm
0	0	0	0	0
10	0	0	0	0
20	0	0	0	0
30	0	0	0	0
40	0	0	0	0
50	0	0	0	0
60	0	0	0	0
70	0	0	0	0
80	0	0	0	0
90	0	0	0	0
100	0.01	0	0	0
110	0.02	0	0	0
120	0.05	0.02	0	0
130	0.08	0.04	0	0
140	0.09	0.07	0.01	0
150	0.12	0.09	0.02	0
160	0.14	0.11	0.06	0
170	0.17	0.13	0.07	0
180	0.19	0.14	0.09	0.02
190	0.21	0.16	0.1	0.05
200	0.23	0.19	0.12	0.07
210	0.25	0.21	0.15	0.08
220	0.28	0.24	0.17	0.10
230	0.32	0.27	0.19	0.11

Table 5: Deflection of piles in sand of groups D.1, D.2, D.3 and D.4

Load (kg)	Deflection (mm)			
	PG 5x5, PC 2D=6 cm	PG 5x5, PC 3D=9 cm	PG 5x5, PC 4D=12 cm	PG 5x5, PC 5D=15 cm
0	0	0	0	0
10	0	0	0	0
20	0	0	0	0
30	0	0	0	0
40	0	0	0	0
50	0	0	0	0
60	0	0	0	0
70	0	0	0	0
80	0	0	0	0
90	0	0	0	0
100	0	0	0	0
110	0	0	0	0
120	0	0	0	0
130	0	0	0	0
140	0	0	0	0
150	0	0	0	0
160	0.01	0	0	0
170	0.02	0	0	0
180	0.04	0	0	0
190	0.05	0.02	0	0
200	0.06	0.04	0	0
210	0.08	0.05	0	0
220	0.09	0.06	0.02	0
230	0.11	0.07	0.03	0
240	0.13	0.09	0.04	0.01
250	0.14	0.1	0.05	0.02
260	0.16	0.11	0.06	0.03
270	0.17	0.13	0.07	0.04
280	0.19	0.15	0.08	0.05

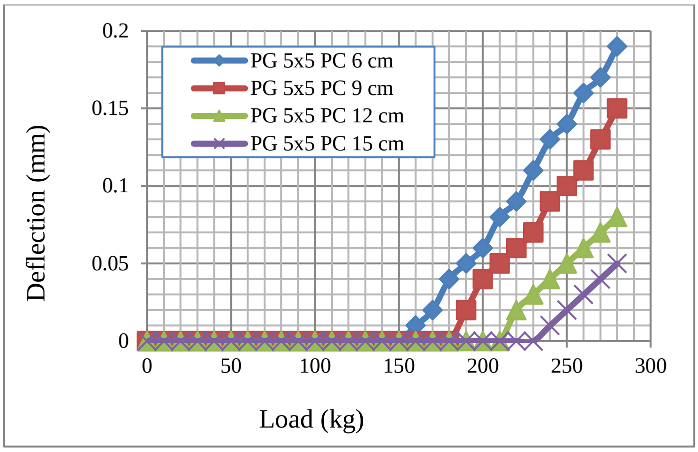

Figure 8: Deflection of piles in sand of groups D.1, D.2, D.3 and D.4

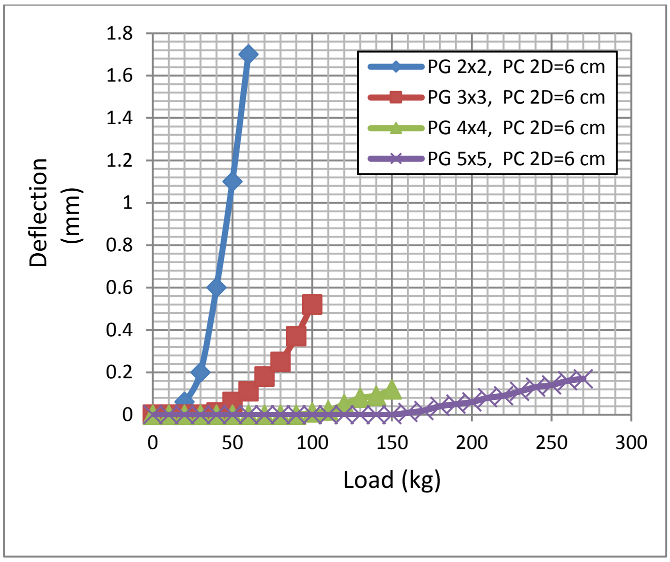

Figure 9: Deflection of piles in sand of groups A.1, B.1, C.1 and D.1

DISCUSSION

Piles at the sandy land of group A.1, the occurred smallest deflection at the load of 20 kg that is 0.06 mm and the biggest at the load of 80 kg that is 3.48 mm. At group A.2 the smallest deflection at load of 20 kg is 0.05 mm and the biggest at load of 80 kg that is 2.60 mm. At group A.3 the smallest deflection at load of 20 kg is 0.04 mm and the biggest at load of 80kg is 1.91 mm. At group A.4 the smallest deflection at load of 20 kg that is 0.02 and the biggest 80 kg that is 1.37 mm [Table 2, Figure 5]. Piles at the sandy soil group of B.1 at the occurred smallest deflection at the load of 40 kg that is 0.01 mm and the biggest at load of 150 kg that is 1.68 mm. At group B.2 the smallest deflection at load of 50 kg that is 0.01 mm and the biggest at load of 150 kg that is 1.35 mm. At group B.3 the smallest deflection at load of 100 kg that is 0.05 mm and the biggest at load of 150 kg that is 0.93 mm. At group B.4 the smallest deflection at load 120 kg that is 0.05 mm and the biggest at load 150 kg that is 0.44 mm [Table 3, Figure 6]. Piles at the sandy soil group of C.1 at the occurred smallest deflection at the load of 100 kg that is 0.01 mm and the biggest at load of 230 kg that is 0.32 mm. At group C.2 the smallest deflection at load of 120 kg that is 0.02 mm and the biggest at load of 230 kg that is 0,27 mm. At group C.3 the smallest deflection at load of 140 kg that is 0.01 mm and the biggest at load of 230 kg that is 0.19 mm. At group C.4 the smallest deflection at load 180 kg that is 0.02 mm and the biggest at load 230 kg that is 0.11 mm [Table 4, Figure 7]. Piles at the sandy soil group of D.1 at the occurred smallest deflection at the load of 160 kg that is 0.01 mm and the biggest at load of 280 kg that is 0,19 mm. At group D.2 the smallest deflection at load of 190 kg that is 0.02 mm and the biggest at load of 230 kg that is 0.15 mm. At group D.3 the smallest deflection at load of 220 kg that is 0.02 mm and the biggest at load of 280 kg that is 0.08 mm. At group D.4 the smallest deflection at load 240 kg that is 0.01 mm and the biggest at load 280 kg that is 0.05 mm [Table 5, Figure 8].

CONCLUSIONS

The results of experiments in the laboratory can be concluded as follows :

The more piles in total number of pile groups, the smaller deflection of pile occurred in the same PC.

The thicker of Pile cap, the smaller deflection of pile occurred in the same PG.

PC thickness of 5D will give the smallest deflection if compared by PC of 2D, 3D and 4D in PG of 2x2, 3x3, 4x4 and 5x5.

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