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EFFECTS OF PILE LATERAL MOVEMENT, PILE SPACING AND PILE NUMBERS ON LATERALLY LOADED GROUP PILES

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ABSTRACT: Based on 3D finite element numerical analysis on 3x3 pile group Gouw and Hidayat (2015) suggested that that when base friction of the pile cap and the passive pressure acting against the pile cap are neglected, the effects of the pile cap thickness against group lateral efficiency is marginal and can be safely neglected. They also briefly mentioned that the center to center pile spacing and the lateral movement of the piles also affect the capacity of the laterally loaded group piles. To investigate the effect of the magnitude of pile lateral movement and pile spacing to larger pile groups, the study was continued by carrying further analysis on 5x5 and 9x9 pile groups, taking the same modelling assumption where base friction and passive resistance induced by pile cap were neglected. The study revealed that pile group lateral efficiencies were found to be larger when the center to center pile spacing were wider. It was also found the greater the number of piles in the group the lower the pile lateral efficiency. However, pile head lateral (horizontal) movement only have marginal effect on the lateral efficiency of group piles.

Keywords : Group piles, finite element, pile group lateral efficiency, pile lateral movement

INTRODUCTION

Many methods have been developed in estimating single pile lateral capacity, starting from Broms method (Broms, 1964a, 1964b), Reese and Matlock method (Reese and Matlock, 1956), Poulos and Davis method (Poulos and Davis, 1980), to many other researches, e.g. Kim and Kim, 1999; Kumar et al, 2000. For pile group lateral capacity, it is generally calculated by reducing the modulus of horizontal subgrade reaction of the soil, k_h (Prakash, 1962). Prakash method does not consider the effect of the thickness of the group pile cap, the number of piles in the group and the lateral movement of the piles. By employing 3D geotechnical finite element computer software, e.g. PLAXIS 3D, Gouw and Hidayat (2015) concluded that that when base friction of the pile cap and the passive pressure acting against the pile cap are neglected, the effects of the pile cap thickness against group lateral efficiency is marginal and can be neglected. They also briefly mentioned that the center to center pile spacing and the lateral movement of the piles also have effects on the capacity of laterally loaded single pile and group piles. Taking the same modelling assumption where base friction and passive resistance induced by pile cap are neglected, Gouw carried out further research by analyzing larger pile groups of 5x5 and 9x9 to investigate the effect of magnitude of pile head lateral movement, pile spacing and number of piles in the group on the pile group lateral efficiency in resisting lateral load. Effect of the moment induced by pile lateral load is not considered. This paper presented the results of the study.

RESEARCH METHODOLOGY

As presented in previous paper (Gouw and Hidayat, 2015), the research is carried out by employing PLAXIS 3D geotechnical finite element software (Brinkgreeve et al, 2015) with the following methodology:

(1) The piles are circular bored piles with 1m or 1000mm diameter.

(2) The subsoil is clay with an undrained shear strength, S_u, of 50 kPa and soil stiffness, E, of 500 times undrained shear strength, E = 25.000 kPa. The soil is assumed to be in undrained condition under the basis that the lateral load on building piles are normally induced by wind or earthquake loads which generally take place for a short duration.

(3) Mohr Coulomb soil model is used.

(4) Model and carry out single pile analysis subjected to lateral load. The lateral load carrying capacity of the single pile is determined at 6mm, 9mm, 12mm, 25mm, 40mm and 100mm lateral movement of the pile head. Named the single pile capacity at certain lateral movement as $Q1_{\delta h = x\ mm}$. Note that the chosen magnitudes of lateral movements are based on the following criteria:
   - 6 mm is normally adopted as allowable lateral movement under static condition.
   - 9 mm is allowable lateral movement under small earthquake shaking.
   - 12 mm is allowable lateral movement under medium earthquake shaking.
   - 25 mm is allowable lateral movement under strong earthquake shaking.
   - 40 mm is based on the local practice (Jakarta, Indonesia) that the pile ultimate load is determined at pile head movement of 4% pile diameter, i.e. 4% x 1000mm = 40mm.
   - 100mm is the original Terzaghi's 10% pile diameter failure criteria for lateral movement, i.e. 10% x 1000mm = 100mm.

(5) The piles are modelled as embedded beam with unit weight of 24 kN/m^3 and structural stiffness of 3x10^7 kN/m^2.

(6) Model 3x3, 5x5 and 9x9 piles group subjected to lateral load.

(7) Lateral load is applied at the side the of the pile cap. Magnitude of the load is adjusted until all piles in the group move laterally by 100mm or more.

(8) The center to center pile spacing is varied from 3D, 4D, 5D, 6D, 8D to 10D (D=pile diameter).

(9) Since it has been found that the effect of pile cap thickness is marginal, on this further study the pile cap thickness for all pile groups are taken as 2D. The pile caps are modelled as soil cluster with non-porous, linear elastic material model, with the unit weight of 24 kN/m^3, stiffness of 3x10^7 kN/m^2, and Poisson's ratio of 0.15.

(10) To eliminate the effect of soil friction between the base of the piles cap and the underlying soil, a 10-cm thin layer of dummy soil with nearly zero strength and zero stiffness is placed under the pile cap.

(11) To eliminate the effect of soil passive resistance acting on the pile cap, the pile cap is placed on the ground surface.

(12) The lateral movement of each pile in the group is then generated by Plaxis 3D. Then, load carrying capacity of each pile is derived at the corresponding pile head lateral movement of 6mm, 9mm, 12mm, 25mm, 40mm and 100mm.

(13) The group total lateral capacity at a certain magnitude of lateral movement, $Qg_{\delta h= x\ mm}$, is determined by summing up the load acting in each individual pile at the corresponding magnitude of the lateral movement.

The lateral pile group efficiency, η, then computed as,

$$\eta = Qg_{\delta h = x\ mm} / (n \times Q1_{\delta h = x\ mm}) \leq 1 \quad (1)$$

where:

$Qg_{\delta h = x\ mm}$ = group lateral capacity obtained by summing up each pile load carrying capacity at certain lateral movement of x, say at 6mm. It is derived from group pile finite element analysis.

n = number of piles in the group, i.e. 3x3 group → n = 9, 5x5 group → n = 25, 9x9 group → n = 81

$Q1_{\delta h= x\ mm}$ = single pile lateral capacity at certain lateral movement of x, say at 6mm. It is obtained from single pile finite element analysis.

THE FEM MODELLING

As mentioned in the research methodology, the analysis was first carried out to derive single pile movement, followed by carrying out analysis for 3x3 piles, 5x5 piles and 9x9 piles. Figure 1 shows the typical finite element modelling of 3x3 piles group. Figure 2 shows the pile head lateral (horizontal) movements of a single pile, 3x3 piles, 5x5 piles and 9x9 piles with pile spacing of 3D (3 times pile diameter) and pile cap thickness of 2D. Horizontal movements of the same pile group arrangement with pile spacings of 4D, 5D, 6D, 8D to 10D were analyzed and the results are presented in Figures 3 to 7. The graphs show that for the same spacing of piles, the larger the pile group, i.e. bigger number of piles, the lower the carrying capacity of each pile in the group. The load carried by each pile in the group was determined at the lateral movement of 6, 9, 12, 25, 40, and 100mm. It was then compared with the single pile capacity to derive the group efficiency as per equation (1).

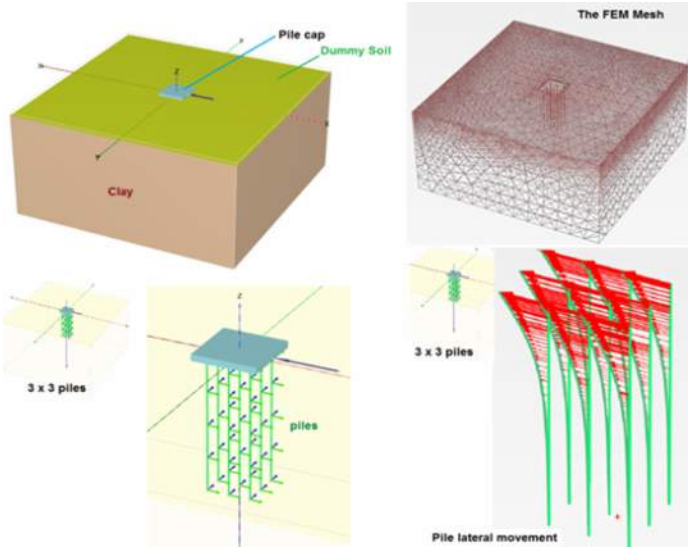

Figure 1. Typical Finite Element Model of the Pile Group (Gouw and Hidayat, 2015)

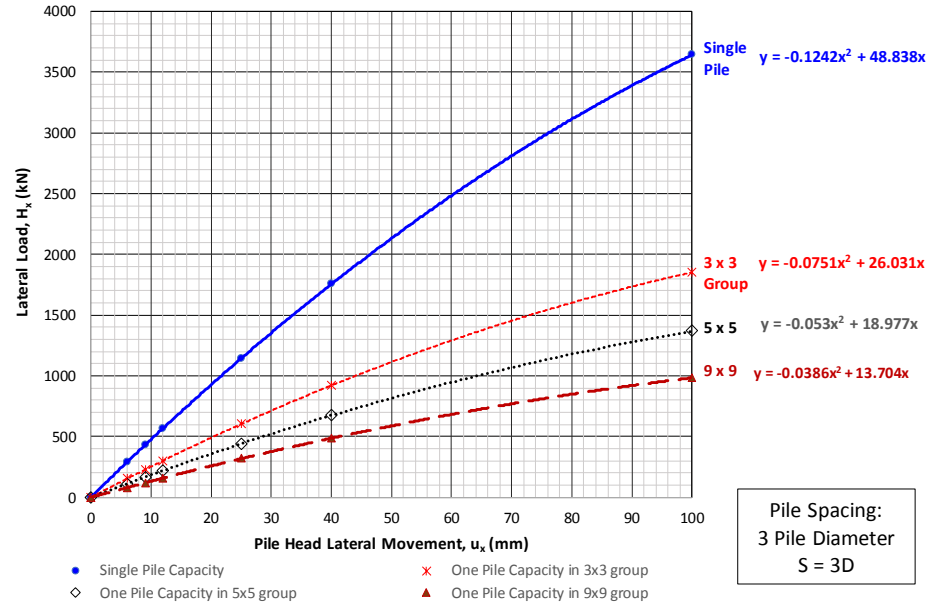

Figure 2. Pile Head Lateral Movement for Pile Spacing of 3 Pile Diameter

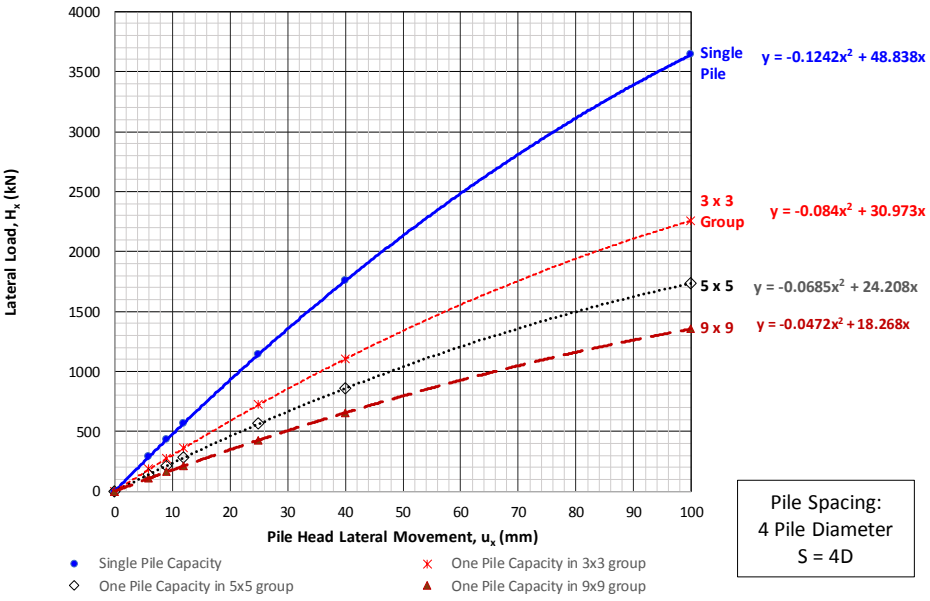

Figure 3. Pile Head Lateral Movement for Pile Spacing of 4 Pile Diameter

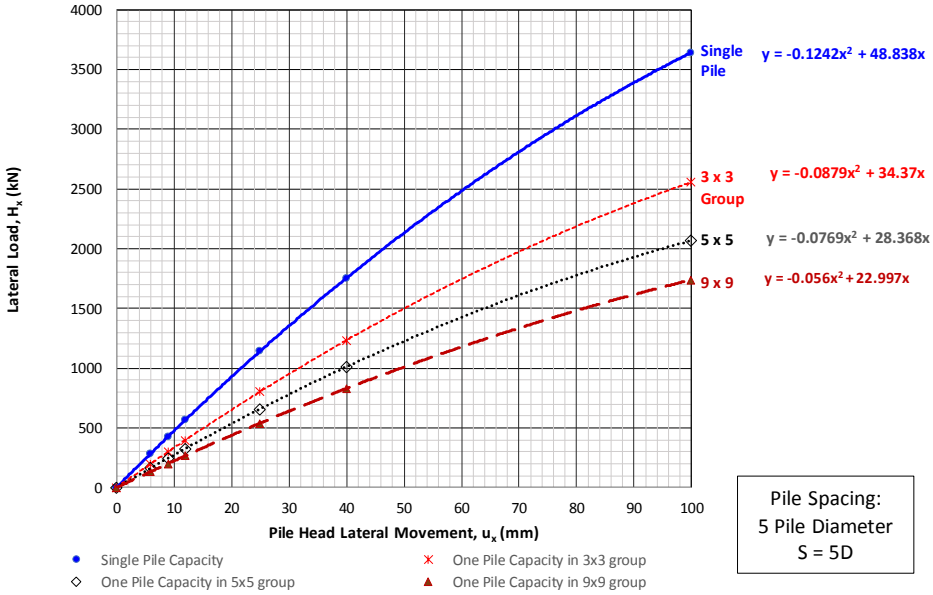

Figure 4. Pile Head Lateral Movement for Pile Spacing of 5 Pile Diameter

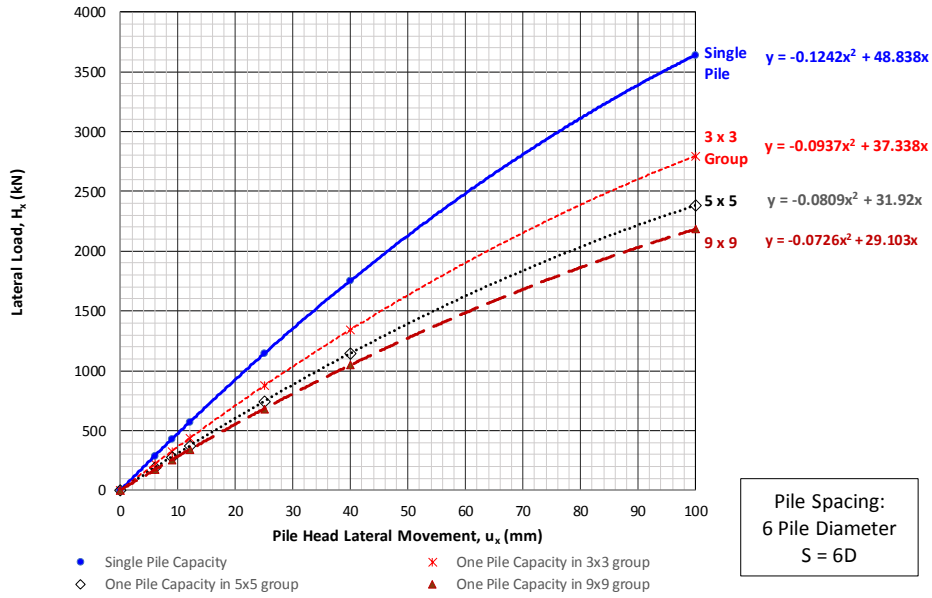

Figure 5. Pile Head Lateral Movement for Pile Spacing of 6 Pile Diameter

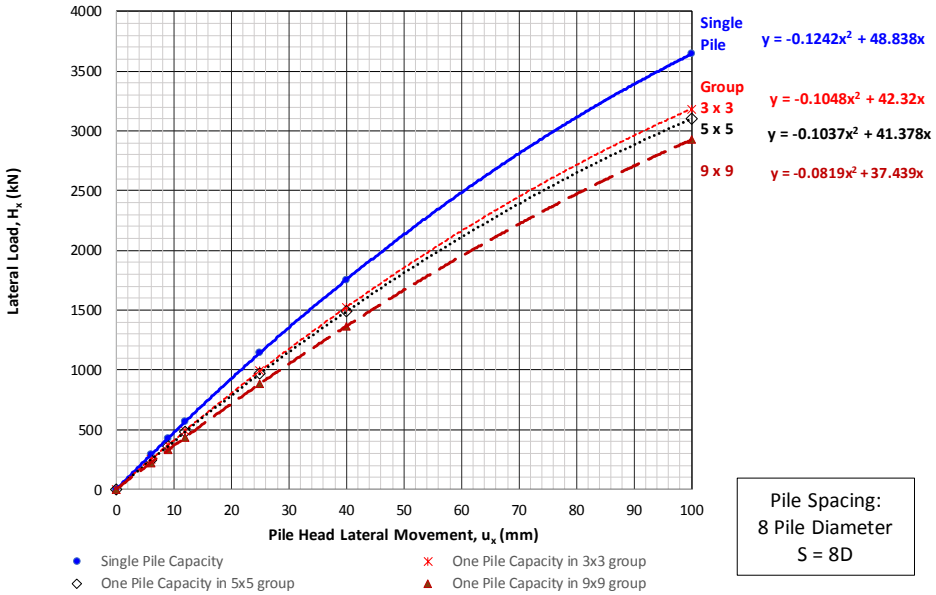

Figure 6. Pile Head Lateral Movement for Pile Spacing of 8 Pile Diameter

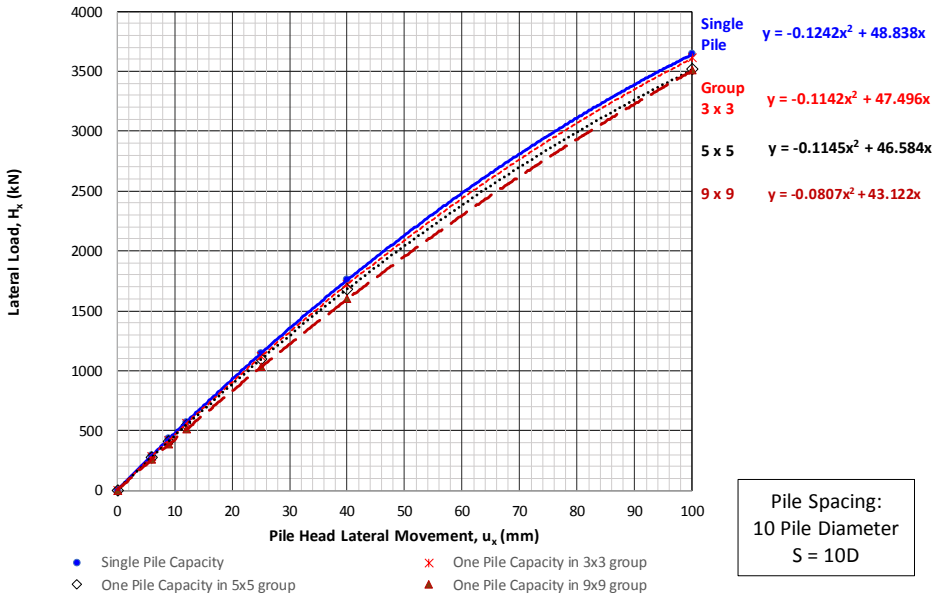

Figure 7. Pile Head Lateral Movement for Pile Spacing of 10 Pile Diameter

EFFECT OF PILE LATERAL MOVEMENT

The pile group lateral efficiencies are then plotted against lateral movement of pile head as presented in Figures 8 to 10, for 3x3, 5x5 and 9x9 piles, respectively. The results show that in term of pile center to center spacing, S, for all group piles the larger the pile spacing the higher the pile lateral efficiency, η.

In term of pile head lateral movement, for 3x3 and 5x5 group piles: up to pile center to center spacing of 5 pile diameters (S=5D), the larger the pile movement the lower the lateral efficiency. For spacing larger than 5 pile diameters (S>5D), the pile lateral efficiencies remain almost constant regardless of pile head movement. For 9x9 group piles: the lateral efficiencies reduce with pile movement for pile spacing up to 4D, remain almost constant for pile spacing of 5 to 6D, and then start to increase for pile spacing greater than 6D.

Closer examination on the magnitude of lateral efficiencies against pile movements show that the changes is marginal. For example: the group of 3x3 piles at pile spacing of 3D, for pile movement of 6mm to 100mm, the lateral efficiency only reduces by 0.023. For 9x9 piles at pile spacing of 10D, for pile movement of 6mm to 100mm, the lateral efficiency only increases by 0.076.

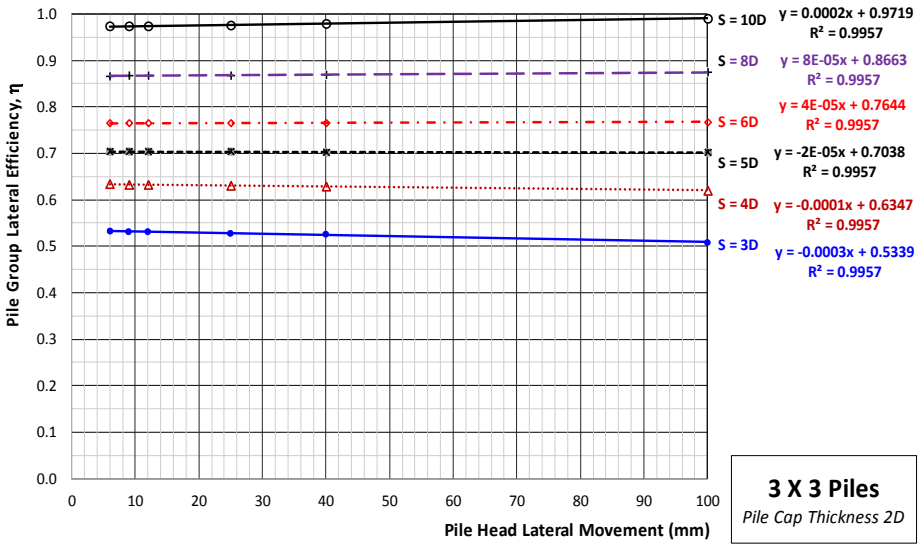

Figure 8. Pile Head Lateral Movement vs Group Efficiency for 3x3 Group Piles

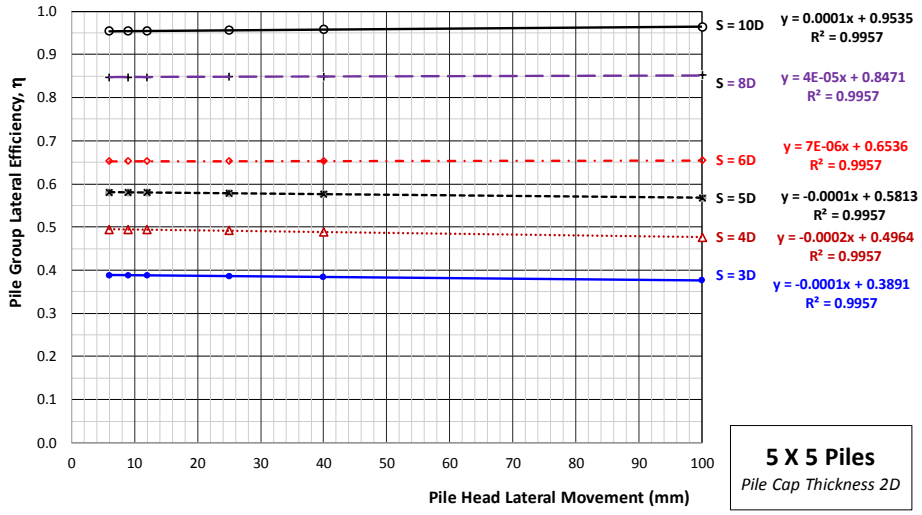

Figure 9. Pile Head Lateral Movement vs Group Efficiency for 5x5 Group Piles

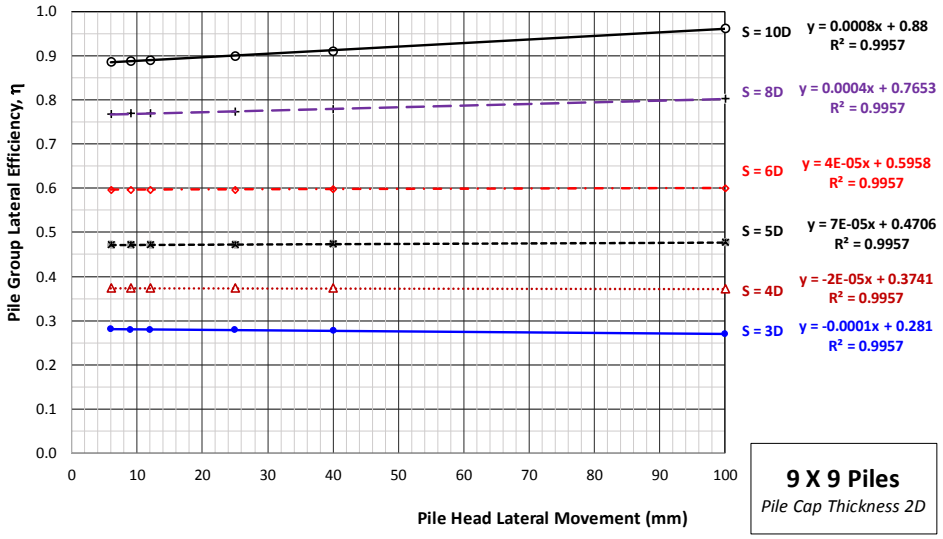

Figure 10. Pile Head Lateral Movement vs Group Efficiency for 9x9 Group Piles

EFFECT OF PILE SPACING

Figures 11, 12 and 13 show the results of analysis in term of pile spacing vs pile group lateral efficiencies for 3x3, 5x5 and 9x9 group piles, respectively. The graphs show that for each group piles, the wider the pile spacing the larger the pile group lateral efficiencies. However, for each pile spacing, the magnitude of pile movement only have marginal effect on pile lateral efficiency.

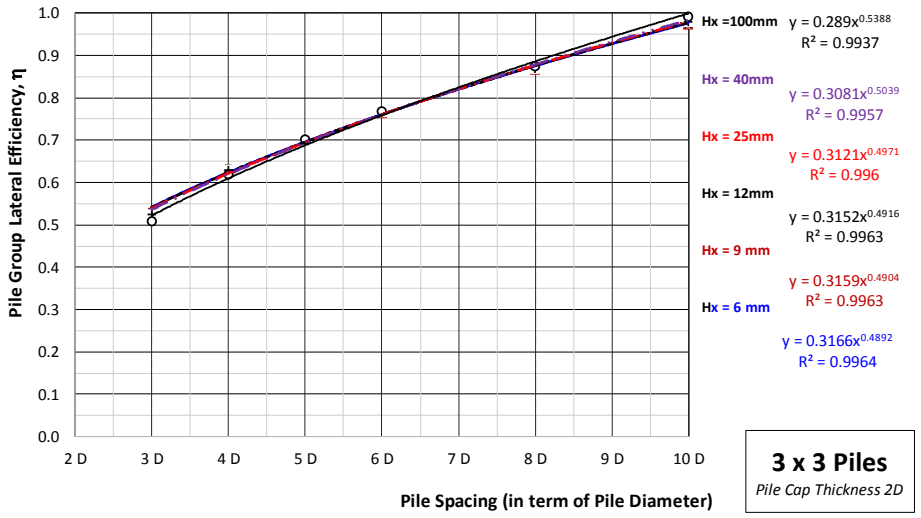

Figure 11. Pile Spacing vs Group Efficiency for 3x3 Group Piles

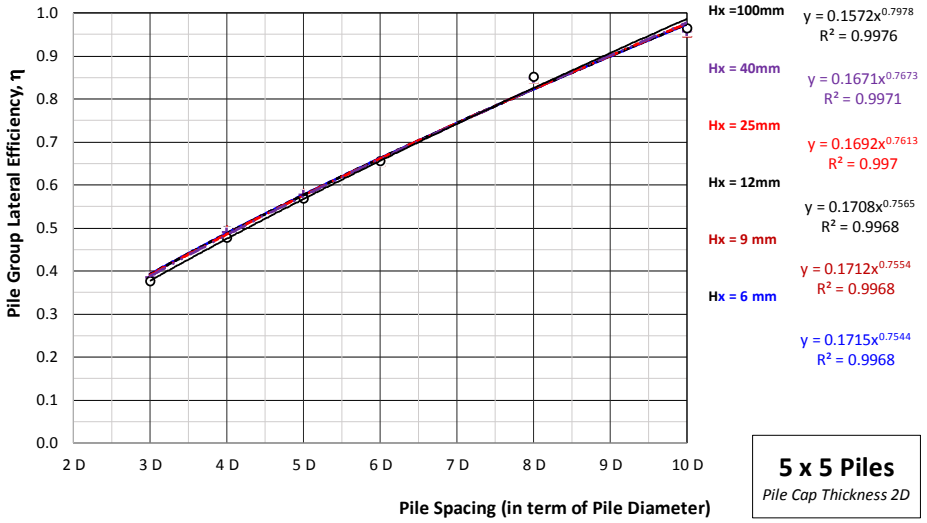

Figure 12. Pile Spacing vs Group Efficiency for 5x5 Group Piles

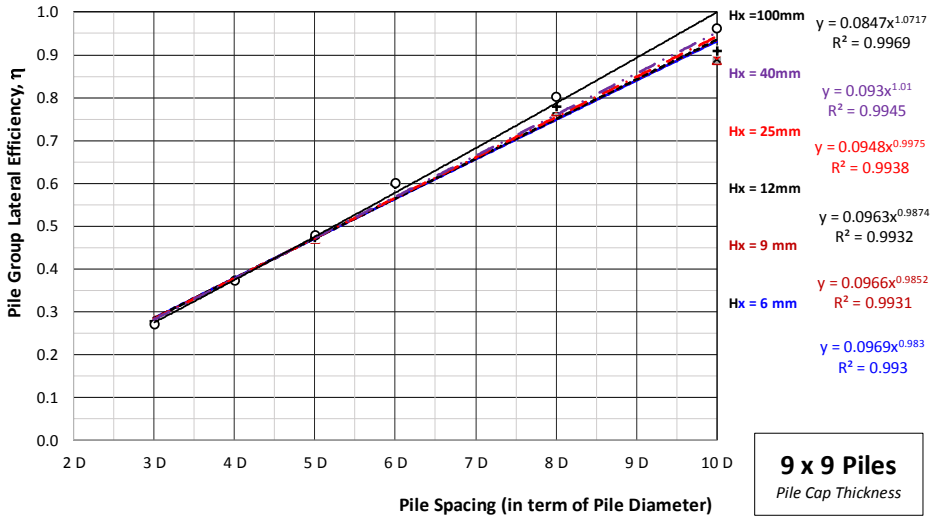

Figure 13. Pile Spacing vs Group Efficiency for 9x9 Group Piles

EFFECT OF PILE NUMBERS

Figure 14 shows the plot of group lateral efficiencies for all group piles. It shows that number of piles in a group also influenced the group pile lateral efficiency. The greater the number of piles in a group the smaller the lateral group efficiency.

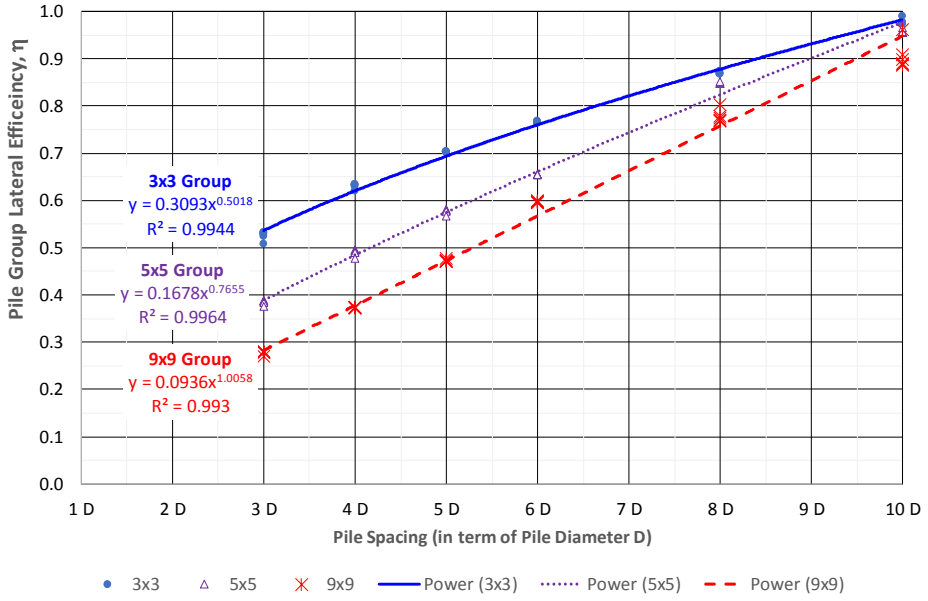

Figure 14. Effect of Number of Piles on Group Efficiency

CONCLUSIONS

The 3D numerical finite element studies reveal that when base friction of the pile cap and the passive pressure acting against the pile cap is neglected:

- The effect of the pile cap thickness against group lateral efficiency is marginal and can be safely neglected (Gouw and Hidayat, 2015).
- For pile spacing less than 5 pile diameters, the larger the lateral movement of the pile, the lower the pile lateral efficiency. For pile spacing of 5 to 6 pile diameters the lateral efficiency does not change with pile movement. For pile spacing larger than 6 pile diameters, the lateral efficiency increases with pile movement. However, the changes of the lateral efficiency is marginal and can simply be neglected.
- The center to center spacing of piles have significant effect on the group pile lateral efficiency. The lateral group efficiency increases with the pile spacing up to a maximum group efficiency value of one at pile spacing of around 10 pile diameters.
- The number of piles in a group also influenced the group pile lateral efficiency. The greater the number of piles in a group the smaller the lateral group efficiency.

Finally, it is to be noted that other than the lateral group efficiency, the moment induces due to lateral load also must be checked so as not to exceed the allowable moment capacity of the piles.

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