Effects of Pile Cap Thickness and Magnitudes of Lateral Movement on Laterally Loaded Group Piles

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ABSTRACT

The capacity of laterally loaded group piles are conventionally analyzed by simply reducing the lateral subgrade reaction of the soil, k_h. The lateral subgrade reaction is reduced to 0.35 k_h, when the piles center to center distance is at 3 pile diameter and linearly increases up to 1.0 k_h when the piles center to center distance is equal or higher than 8 pile diameter. It seems there is no consideration to the thickness of the pile cap and magnitude of lateral movement of the piles on this conventional approach. By using 3D finite element geotechnical software, the effect of these two factors can now be investigated. This paper presents the study on the impact of those two factors on lateral capacity of group piles. The study reveals that when base friction of the pile cap and the passive pressure acting against the pile cap is neglected, the effects of the pile cap thickness against group lateral efficiency is marginal and can be safely neglected. The center to center pile spacing and the lateral movement of the piles do play important roles in the capacity of the laterally loaded piles. The greater the pile spacing the greater the lateral group efficiency, so does the lateral movement.

KEYWORDS: pile lateral capacity, pile cap thickness, finite element 3D analysis

INTRODUCTION

The ultimate lateral capacity of a single pile is often calculated by using Broms method (Broms, 1964a, 1964b). PY curve method is used to derive the lateral capacity of piles in relation to the pile lateral deflection (Reese and Matlock, 1956; Poulos and Davis, 1980). Many researches on the behavior of laterally loaded single piles have been published elsewhere, both in printed or electronic journal of geotechnical engineering (e.g. Kim and Kim, 1999; Kumar et al, 2000). However, it is rather rare to find published paper on laterally loaded group piles. The lateral group capacity of laterally loaded piles is not simply obtained by summing up each lateral capacity of the individual piles. It is generally recognized that the group capacity is smaller than the sum of the individual capacity of the piles. In practice, the lateral group capacity is calculated by reducing the modulus of horizontal subgrade reaction of the soil, k_h, as proposed by Prakash, 1962 (Figure 1).

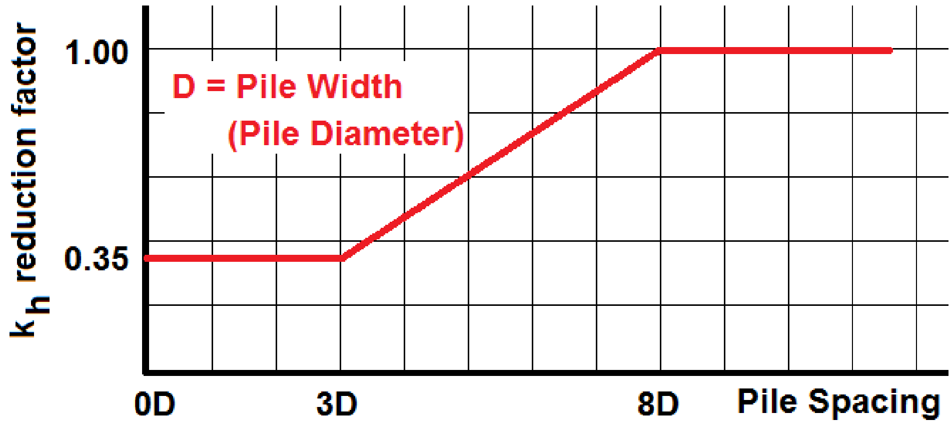

Figure 1: Reduction Factor of k_h

For examples, if a group m x n piles are spaced at 3D, where D is the pile diameter, then the modulus subgrade reaction of the soil, is to be taken as $k_{hg} = 0.35\ k_h$. The lateral capacity of each pile in the group is then calculated by employing kh_g. The total lateral group capacity of the pile is obtained by multiplying the single pile capacity (calculated through k_{hg}) by the number of piles in the group. This conventional method does not take into account the effect of the thickness of the group pile cap, the number of piles in the group and the lateral movement of the piles.

With the advance of computer technology and the 3D geotechnical finite element computer software, it is now possible to model the laterally loaded group piles and investigate the effect of the above factors. This paper presents the results of a 3D finite element modelling (by using PLAXIS 3D software) in investigating the effect of pile cap thickness and lateral movement of the piles towards the group capacity of laterally loaded piles.

RESEARCH METHODOLOGY

The numerical study 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 diameter.

(2) The subsoil is clay with an undrained shear strength of 50 kPa and soil stiffness, E, of 500 S_u = 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 earthquake loads. Mohr Coulomb soil model is used.

(3) Model and carry out single pile analysis subjected to lateral load. The lateral load carrying capacity of the single pile is determined at 6mm, 12mm, 25mm, and 100mm lateral movement of the pile head. Named the single pile capacity at certain lateral movement as $Q1_{\delta h = x\ mm}$.

(4) Model a 3x3 piles group subjected to lateral load. The piles are modelled as embedded beam with unit weight of 24 kN/m^3 and stiffness of $3x10^7$ kN/m^2.

(5) 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.

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

(7) The pile cap thickness is varied from 1D to 4D. 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.

(8) 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.

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

(10) 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, 12mm, 25mm, and 100mm.

(11) 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 group efficiency, η, then computed as,

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

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, in this study a 3 x3 piles is used. So, n = 9.

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

The chosen magnitudes of the lateral movement of the pile head is taken based on the following criteria:

(1) 6 mm is normally adopted as allowable lateral movement under static condition.
(2) 12 mm is allowable lateral movement under medium earthquake shaking.
(3) 25 mm is allowable lateral movement under strong earthquake shaking.
(4) 100mm is the original Terzaghi's 10% pile diameter failure criteria for lateral movement.

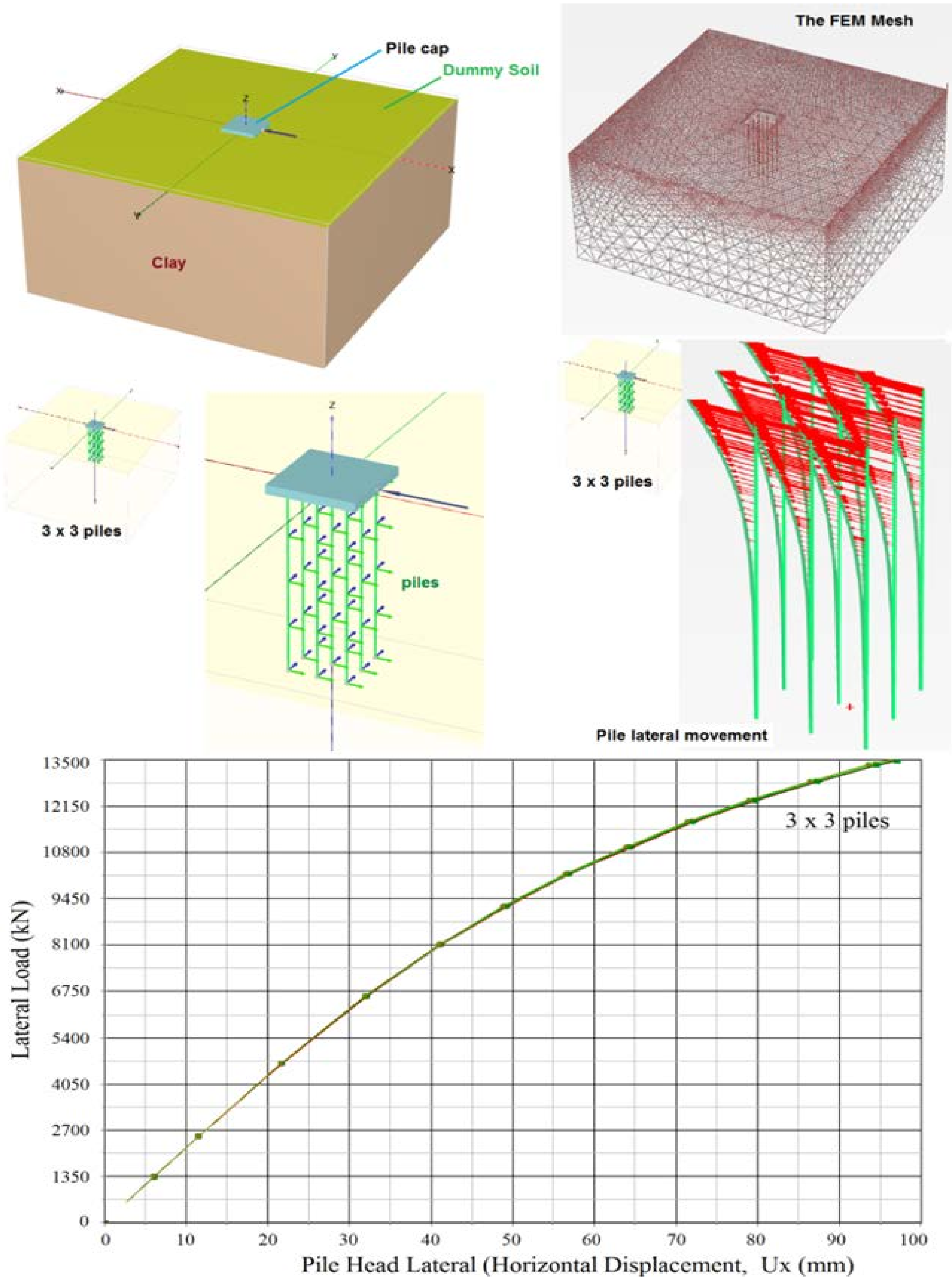

Figure 2: The Finite Element Model of 3x3 piles group and the Results.

THE FEM MODELLING

Figure 2 shows the modelling of the 3x3 piles group and its pile cap, the finite element mesh, the piles, the corresponding lateral movement of each pile when subjected to the lateral load, and the plot of each pile head movement against applied load. As mentioned before, the load carried by each pile in the group was determined at the lateral movement of 6, 12, 25, and 100mm. It was then compared with the single pile capacity to derive the group efficiency as per equation (1).

RESULTS OF ANALYSIS

The results of the study are tabulated in Table 1 which shows the group lateral efficiency derived from the analysis. Figures 3 to 6 showed the group efficiency for each lateral movement analyzed plotted against the pile spacing in the group, and also showing the corresponding pile cap thickness.

Table 1: Group Lateral Efficiency, η

Pile Cap Thicknes	Pile Spacing	Pile Head Movement (mm)			
		6	12	25	100
1D	3 D	0.370	0.376	0.402	0.394
	4 D	0.444	0.456	0.491	0.482
	5 D	0.515	0.528	0.549	0.542
	6 D	0.605	0.621	0.647	0.679
	8 D	0.736	0.760	0.802	0.873
	10 D	0.756	0.803	0.876	1.000
2D	3 D	0.369	0.374	0.399	0.392
	4 D	0.442	0.455	0.487	0.479
	5 D	0.513	0.525	0.546	0.539
	6 D	0.598	0.617	0.640	0.665
	8 D	0.735	0.755	0.793	0.867
	10 D	0.744	0.795	0.872	0.985
3D	3 D	0.368	0.374	0.399	0.391
	4 D	0.436	0.455	0.486	0.477
	5 D	0.513	0.525	0.543	0.538
	6 D	0.580	0.611	0.628	0.658
	8 D	0.734	0.751	0.787	0.855
	10 D	0.740	0.787	0.869	0.975
4D	3 D	0.365	0.371	0.395	0.390
	4 D	0.436	0.454	0.484	0.477
	5 D	0.511	0.522	0.543	0.535
	6 D	0.580	0.608	0.624	0.650
	8 D	0.729	0.744	0.771	0.847
	10 D	0.738	0.785	0.865	0.968
note: D = pile diameter = 1m					

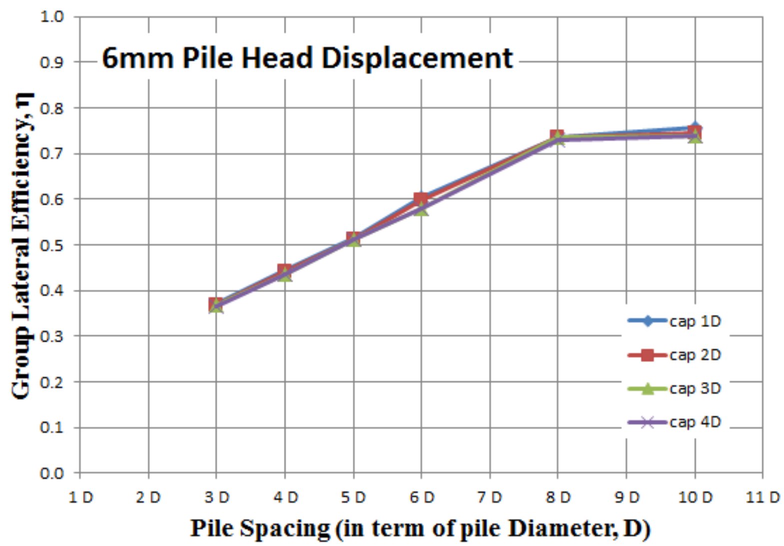

Figure 3: Pile Group Efficiency for 6 mm Pile Head Movement

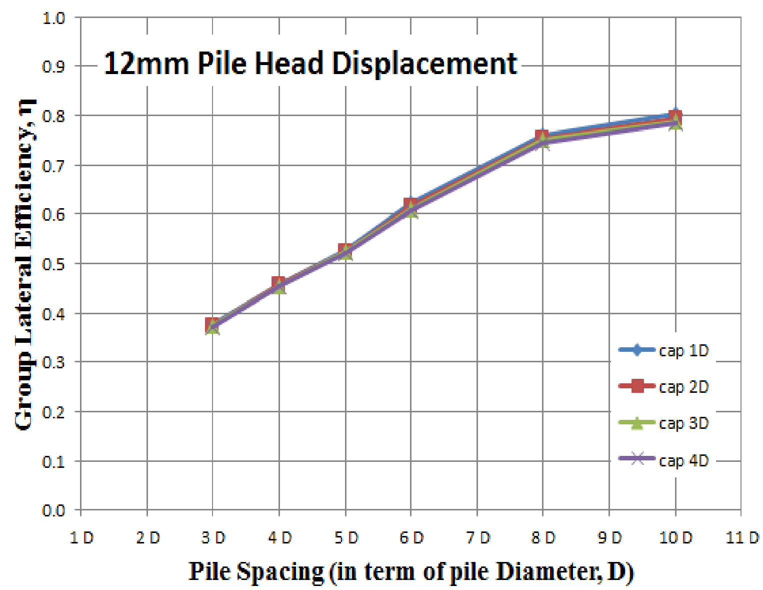

Figure 4: Pile Group Efficiency for 12 mm Pile Head Movement

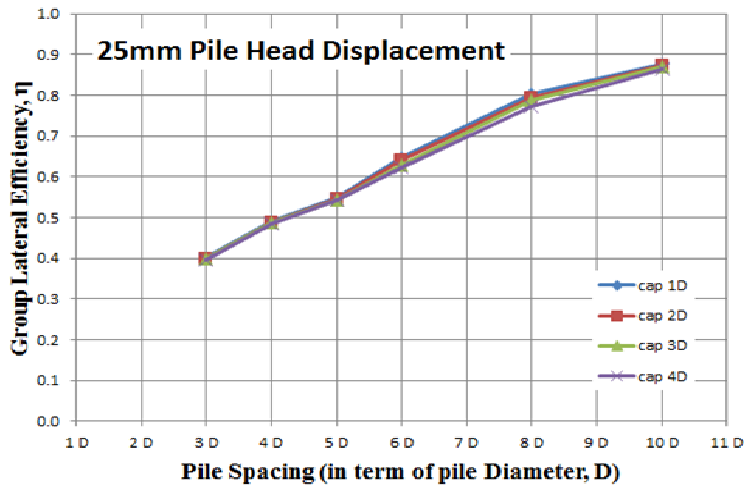

Figure 5: Pile Group Efficiency for 25 mm Pile Head movement

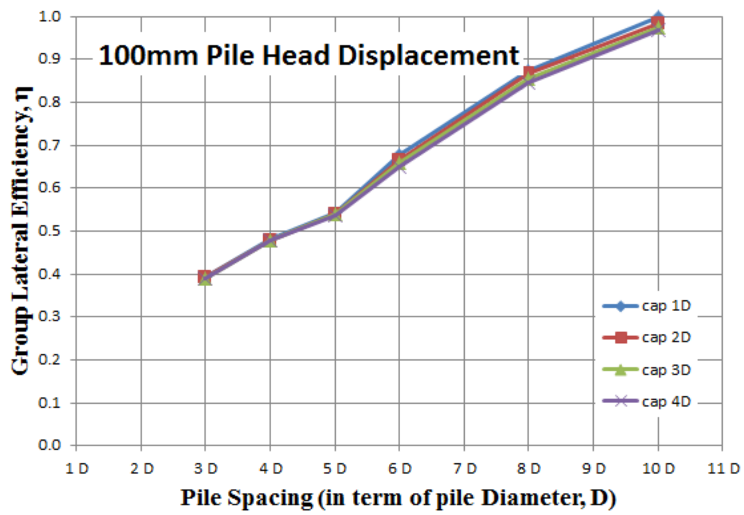

Figure 6: Pile Group Efficiency for 100 mm Pile Head movement

DISCUSSIONS

The impact of pile cap thickness is evaluated by comparing the group efficiency factor of each pile cap thickness to the pile cap thickness of 1D. For example, the group efficiency of pile cap thickness of 4D and pile spacing of 8D at 25mm lateral movement is 0.771, while at pile cap thickness of 1D is 0.802, hence, the reduction of the efficiency factor for the 4D pile cap against 1D pile cap is 1-0.771/0.802 = 3.9%. The result of such evaluation is presented in Table 2.

Table 2: Effect of Pile Cap Thickness against Group Lateral Efficiency, η

Effect of Pile Cap Thickness					
Pile Cap Thicknes	Pile Spacing	Pile Head Movement (mm)			
		6	12	25	100
2D	3 D	0.2%	0.5%	0.8%	0.6%
	4 D	0.5%	0.0%	0.8%	0.6%
	5 D	0.4%	0.7%	0.5%	0.5%
	6 D	1.2%	0.6%	1.1%	2.0%
	8 D	0.2%	0.7%	1.1%	0.7%
	10 D	1.6%	1.1%	0.5%	1.5%
3D	3 D	0.3%	0.4%	0.6%	0.8%
	4 D	1.8%	0.2%	1.0%	1.0%
	5 D	0.3%	0.6%	1.1%	0.7%
	6 D	4.1%	1.6%	2.9%	3.0%
	8 D	0.2%	1.2%	1.9%	2.1%
	10 D	2.1%	2.0%	0.8%	2.5%
4D	3 D	1.1%	1.4%	1.6%	0.9%
	4 D	1.7%	0.4%	1.4%	1.1%
	5 D	0.8%	1.2%	1.2%	1.3%
	6 D	4.1%	2.1%	3.6%	4.3%
	8 D	0.9%	2.1%	3.9%	3.0%
	10 D	2.4%	2.3%	1.3%	3.2%

It can be seen that the thicker the pile cap the greater the impact on group lateral efficiency. In other words, the thicker the pile cap the smaller the group efficiency. However, the maximum difference is only 4.3% as presented in Table 2. These differences are marginal, and it can be said the thickness of the pile cap is not an important factor to consider in relation to the group capacity of laterally loaded pile.

Careful examination on Figures 3 to 6, the spacing and the lateral movement of the piles do play important roles in the lateral group capacity of the piles. When the marginal reduction in group efficiency due to pile cap thickness is neglected and the data is replotted in term of lateral movement of the piles as presented in Figure 7, it can be seen that the greater the allowable movement of the pile head, the greater the group lateral efficiency is. Also the greater the pile spacing the greater the efficiency. Within 3D to 8D spacing, the efficiency factors are linearly increasing with a sharper angle, after which the slope of the increment is turning gentler. For 6mm lateral movement the maximum efficiency factor is in the order of 0.73, while for 100mm lateral movement the maximum efficiency is in the order of 1.0. For all lateral movement, the minimum efficiency factors seem to converge to a value of 0.37.

CONCLUSIONS

The study reveals 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. The center to center pile spacing and the lateral movement of the piles do play important roles in the capacity of the laterally loaded piles. The greater the pile spacing the greater the lateral group efficiency, so does the lateral movement.

CLOSURES

The paper has not covered the influence of number of piles in the group lateral capacity which is still under study. It shall be published in another paper when the study is completed.

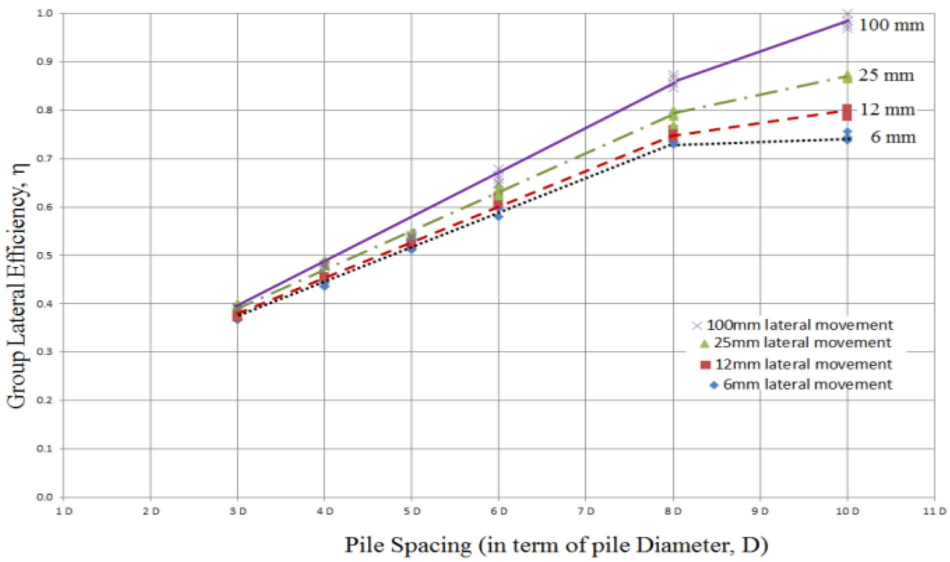

Figure 7: Lateral Group Efficiency against Lateral Movement

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