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Ultimate Lateral Load Capacity of Piles in Soils Contaminated with Industrial Wastewater

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Abstract

The present study devoted to determine the ultimate lateral carrying capacity of piles foundation in contaminated clayey soils and subjected to lateral cyclical loading. Two methods have been used to calculate the lateral carrying capacity of piles foundation; the first one is two-line slopes intersection method (TLSI) and the second method is a modified model of soil degradation. The model proposed by Heerama and then developed by Smith has been modified to take into consideration the effects of heavy loads and soil contamination. The ultimate lateral carrying capacity of single pile and piles group (2×2) driven into samples of contaminated clayey soils have been calculated by using the two methods. Clayey soil samples are contaminated with four percentages of industrial wastewater (10, 20, 40 and 100) % of the distilled water used in the soaking process, the soaking procedure of soil samples have been proceeded for 30 days. Also, two ratios of eccentricity to embedded length (e/L = 0.25 and 0.5) have been examined. The results obtained from two analytical methods are well agreed with those obtained experimentally. The ultimate lateral carrying capacity, Pu (analytical) /Pu (experimentally) ranged from (75-8) % and (77-80) % of single pile with e/L = 0.25 and 0.5 respectively. In the piles group the ratio ranged (67-80) % and (71-79) % for e/L = 0.25 and 0.5 respectively.

Keywords: Modeling; Clayey Soil; Cyclic Lateral Loading; Wastewater; Piles Foundation.

1. Introduction

The level of polluted soil increases essentially inside the zones of industrial activities because of the rapid extension and development of industrial activities, such as electrical power plants, oil fields and oil refineries. A method for determining the deflections at ground surface of flexible and rigid piles were presented by Broms [1]. A semi empirical, nonlinear, p-y (soil lateral resistance-pile deflection) approach developed by Reese et al. [2], in which degradation factors obtained empirically were used to predict the cyclical p-y relationships based upon degraded static p-y curves. A discrete element model used by Matlock et al. [3] to predict the p-y curve for the complete load-bearing history for each load cycle. The p-y approach improved by Long and Vanneste [4] to consider the effect of the number of loading cycles. Nevertheless, only 50 cycles, or less, of lateral loads were executed in most of the tests considered. Moreover, the use of p-y curves often fails to account for the permanent lateral displacement that tends to accumulate with increasing cycles. Yang and Jeremic [5] generated p-y curves describing the behavior of single pile in elastic-plastic soils by using finite element method.

Dewaikar et al. [6] studied the maximum lateral carrying capacity of a flexible free-head pile in soft clay subjected to cyclic loading. They observed that degradation was so high in the first few cycles. The behavior of piles group (2×2)

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subjected to lateral cyclic load in soft clayey soil has been studied by Basack [7]. The cyclic lateral loading causes a decrease in the lateral carrying capacity of the pile group. This alteration is represented by the degradation factor, which represents the ratio of ultimate lateral pile group capacities before and after the application of cyclic loading. The responses of a large-diameter single pile under one-way force of cyclical lateral loads was studied by Li et al. [8], they investigated the accumulated lateral permeant displacements and the pile's lateral secant stiffness. Karkush and Abdul Kareem [9] studied through experiments, the effects of lateral cyclical loading on the behavior of a single pile driven into clayey soil contaminated with 4 ratios of industrial wastewater. The results of study showed significant effects of contamination on the maximum lateral capacity and total and permanent lateral displacements of pile. Also, Karkush and Abdul Kareem [10] studied, through experiments, the effects of lateral cyclic loading on the behavior of piles group driven into intact and contaminated clayey soil with 4 ratios of industrial wastewater. The results of this study confirm the important of soil contamination on the ultimate lateral carrying capacity and total and permanent lateral displacements of piles group. Karkush [11, 12] studied the effects of axial loading on the lateral load capacity of single and piles groups driven into intact and contaminated soils. The presence of axial loading increases the lateral carrying capacity of piles and reduces the lateral displacement. Hung et al. [13] and Zhang and Ng [14] studied the response of single pile in kaolin clayey soil by using centrifuge to apply lateral cyclic loading. Increasing the cyclic loading causes increasing the maximum and residual movement of pile. The present study is devoted to calculate the lateral load-bearing capacity of a single pile and piles group installed in contaminated clayey soil and subjected to lateral cyclical loading. The ultimate bearing capacity of pile foundation is calculated by using two-line slopes intersection method and a proposed model. The proposed model simulates the degradation of soil strength resulting from the contamination. The results of two-line slopes and proposed degradation model are verified by experimental results presented by Karkush and Abdul Kareem [9, 10].

2. Research Methodology

Soil samples are obtained from a depth of 4 m below the existing ground level during the sub-surface exploration in AL-Musayib district (UTM: 33N515276, 44E28102). The contaminant is an industrial wastewater was obtained from AL-Musayib thermal power plant. The clayey soil samples are contaminated artificially in the laboratory with four ratios of the industrial wastewater (10, 20, 40 and 100) % calculated according to the weight of the distilled water used in the soaking process. The soaking process continued over 30 days in closed containers. The soil specimens used in this research are designated as C_0 (intact soil) and C_1, C_2, C_3, and C_4 are the contaminated soil samples with 10, 20, 40 and 100 % of industrial wastewater respectively. The pile used in this work of $L/D \geq 20$ is classified as long and flexible and free-head piles [15]. Also, two ratios of eccentricity to length ($e/L = 0.25$ and 0.5) have been studied. The geotechnical properties of soil samples, the details and specifications of the physical model, dimension and material properties of the pile model are given in Karkush and Abdul Kareem [9]. The physical model used in the test of ultimate carrying capacity of pile foundation subjected to lateral cyclic loading is shown in Figure 1. Also, the geotechnical properties of intact and contaminated soil samples are given in Table 1.

Figure 1. Setup of physical model to apply lateral cyclic loading on pile foundation

Table 1. Geotechnical properties of tested soil samples

Property	C`0	C1	C2	C3	C4
Gs	2.72	2.70	2.69	2.70	2.68
LL, %	56	54	53	49	48
PL, %	23	24	24	25	26
Sand, %	4	4	4	4	4
Silt, %	7	33	24	26	31
Clay, %	89	63	72	70	65
USCS	CH	CH	CH	CL	CL
k×10-8, cm/sec	1.54267	1.66037	2.19473	2.48857	2.8790
$\gamma_{dry,max}$, kN/m^3	16.96	16.90	16.70	16.64	16.60
w_{opt}, %	19	20	22	22.7	23
c_u, kN/m^2	90	84	79	72	63
E, kN/m^2	9500	8750	8000	7800	6200
K_s, kN/m^3	34600	32300	30770	27700	23000

3. Lateral Carrying Capacity

The displacements of piles head are obtained for different cycles of lateral loading at an eccentricity, e from the ground surface. The ultimate lateral carrying capacity of piles was computed for piles of embedment lengths of 335 and 400 mm (e/L=0.25 and e/L= 0.5) and number of loading cycles ranged from 1 to 100.

3.1. Two-Line Slopes Intersection Method (TLSI)

The relationship between lateral displacement and the lateral load of the pile is drawn in log-log scale paper for different studied cases of intact and contaminated soils. This process was hold from Indian Standard Code of Practice in Soil Engineering, the process of Load Test on Soils (IS 1888: 1988). Two direct lines with separate incline passing through most of the points are recognized. The intersection of the two lines gives the lateral load capacity, $Pu_{,TLSI}$.

3.2. Degradation Model

The degradation model shows the result of cyclic strength degradation of soil on the lateral carrying capacity of piles exposed to lateral cyclic loading [16 and 17]. The degradation model was designed as a function of number of loading cycles, ratio of elasticity modulus of soil to the undrained shear strength, and the degradation factor (D_f). Also, it depends on the ratio of pile-top displacement at 20% of the pile diameter and 10% of the ratio of the elasticity modulus of soil to the undrained shear strength. The equation for the model is as follows:

$$P_{u,N} = P_f\left[1 - A\left(1 - N^{-B\times\frac{\Delta}{0.2b}\times\frac{E}{c_u}\times 0.1}\right)\right] \quad (1)$$

Where:

$P_{u,N}$ is the resistance of soil sample after N number of cycles;

P_f is the resistance of soil to the load at failure point;

A: is a parameter that defines the remaining strength of soil after an unbounded number of cycles and is taken as 0.7. The remaining soil strength after an unbounded number of cycles is less than 30% of the initial strength value [18];

B: is an empirical constant derived after various trials, and is taken as 0.0273 [19];

Δ: is the lateral displacement in mm;

b: is the external diameter of the pile;

E: is Young's modulus;

c_u: is the undrained shear strength of soil.

In the present study, Equation 1 has been modified for the following reasons:

- To obtain the compatibility between the modified degradation model and the two-line slopes intersection method,
- Takes into consideration the effects of soil contamination, and

- Extend the effects of pile-top displacement to the diameter ratio at failure as 40% for a single pile and 20% of block width for piles group.

The modification of degradation model includes adding a non-dimensional factor, which is denoted (m) for a single or piles group in intact and contaminated soils for any eccentricity ratio and different cycles of loading. The modified equation is:

$$P_{u,N} = P_f \left[1 - A\left(1 - N^{-B\times\frac{\Delta}{F}\times\frac{E}{C_u}\times m}\right)\right] \quad (2)$$

Where:

F: is a factor taken as 0.4b for single pile and 0.2b for piles group,

m: is an empirical factor derived from the present work after various trails and is taken as 0.1, which is used for intact and contaminated soils, also, for a single and group of piles.

4. Results and Discussion

The relation between applied lateral loads and total lateral displacement of piles obtained from a two-line slopes intersection for single pile with e/L = 0.25 and 0.5 at N = 100 are shown in Figures 2 and 3 respectively [9]. The lateral carrying capacity of single pile with eccentricity ratios e/L = 0.25 and 0.5 obtained from two-line slopes intersection method are compared with those obtained experimentally as shown in Table 2. The wastewater contamination of soil causes degradation of soil which resulting in decreasing the shear strength parameters and modulus of elasticity. This degradation of soil leads to reducing the lateral carrying capacity of soil. The lateral carrying capacity of single pile reduced from 440 N and 320 N in soil sample C_0 to be 280 N and 220 N in soil sample C_4 for e/L equals 0.5 and 0.25 respectively. Also, the results of lateral carrying capacity obtained from TLSI are well agreed with those obtained experimentally as shown in Table 2. The lateral carrying capacity of single pile is calculated at the ratio of total lateral displacement to the pile diameter of 40 %. The ratio of maximum lateral load obtained theoretically to that obtained experimentally are ranged 0.75–0.80 and 0.77–0.80 for e/L = 0.25 and 0.5 respectively. Increasing the eccentricity ratio causes significant decrease in the lateral carrying capacity of single pile, where in intact soil sample the lateral carrying capacity was 440 N for e/L equals 0.25 and reduced to be 320 N for e/L equals 0.5. The ratio of lateral carrying capacity of single pile with e/L equals 0.5 is about 0.75 of that of e/L equals 0.25, this behavior beyond to increasing the free head of pile which affect diversely on the lateral carrying capacity of pile.

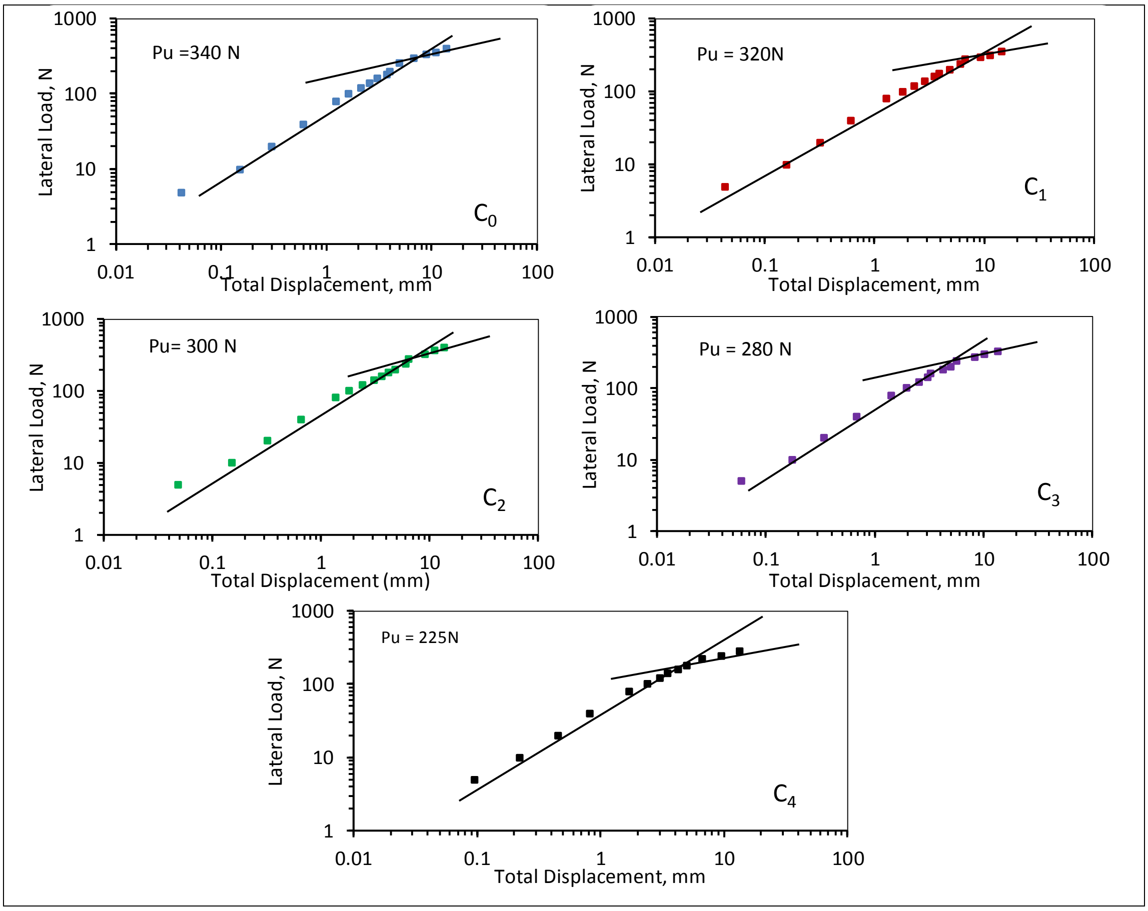

Figure 2. Lateral load capacity of single pile with e/L = 0.25 at N = 100

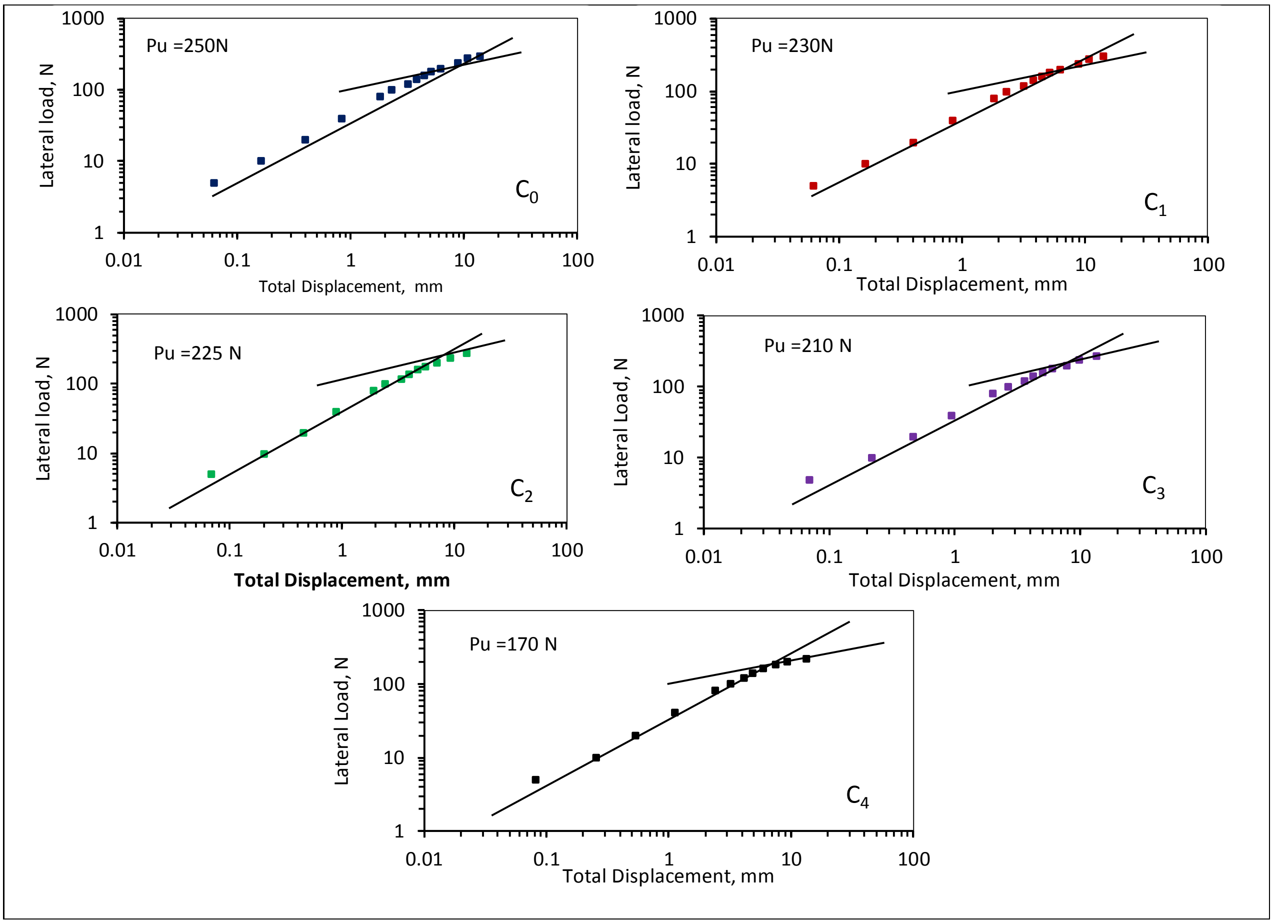

Figure 3. Lateral load capacity of single pile, with e/L = 0.5 at N = 100

Table 2. Comparison of lateral capacity of a single pile

Soil sample	P_f, N Experimental load		P_u, N TLSI	
	e/L = 0.25	e/L = 0.5	e/L = 0.25	e/L = 0.5
C_0	440	320	340	250
C_1	420	300	320	230
C_2	400	280	300	225
C_3	360	270	280	210
C_4	280	220	225	170

The relation between applied lateral loads and total lateral displacement of group of piles that was obtained from a two-line slopes intersection with e/L = 0.25 and 0.5 and N = 100 are shown in Figures 4 and 5 respectively [10]. The results obtained from TLSI method are well agreed with those obtained experimentally. The maximum carrying capacity of pile groups decreased significantly with increasing the percentage of contamination in the soil and with increasing the eccentricity ratio e/L. The lateral carrying capacity of piles group obtained by TLSI are compared with those obtained experimentally as shown in Table 3. The ultimate lateral carrying capacity of piles group is calculated at a ratio of lateral displacement of 20% of the block width of the piles group cap, which is 80 × 80 mm. A decreasing in the maximum lateral carrying capacity of piles group was 70-75% occurred as a result of changing the eccentricity from e/L = 0.25 to e/L = 0.5.

Table 3. Comparison of lateral capacity of group of piles

Soil sample	P_f, kN Experimental load		P_u, kN TLSI	
	e/L = 0.25	e/L = 0.5	e/L = 0.25	e/L = 0.5
C_0	1600	1200	1300	900
C_1	1500	1150	1200	850
C_2	1450	1100	1100	800
C_3	1350	950	900	750
C_4	1100	850	800	600

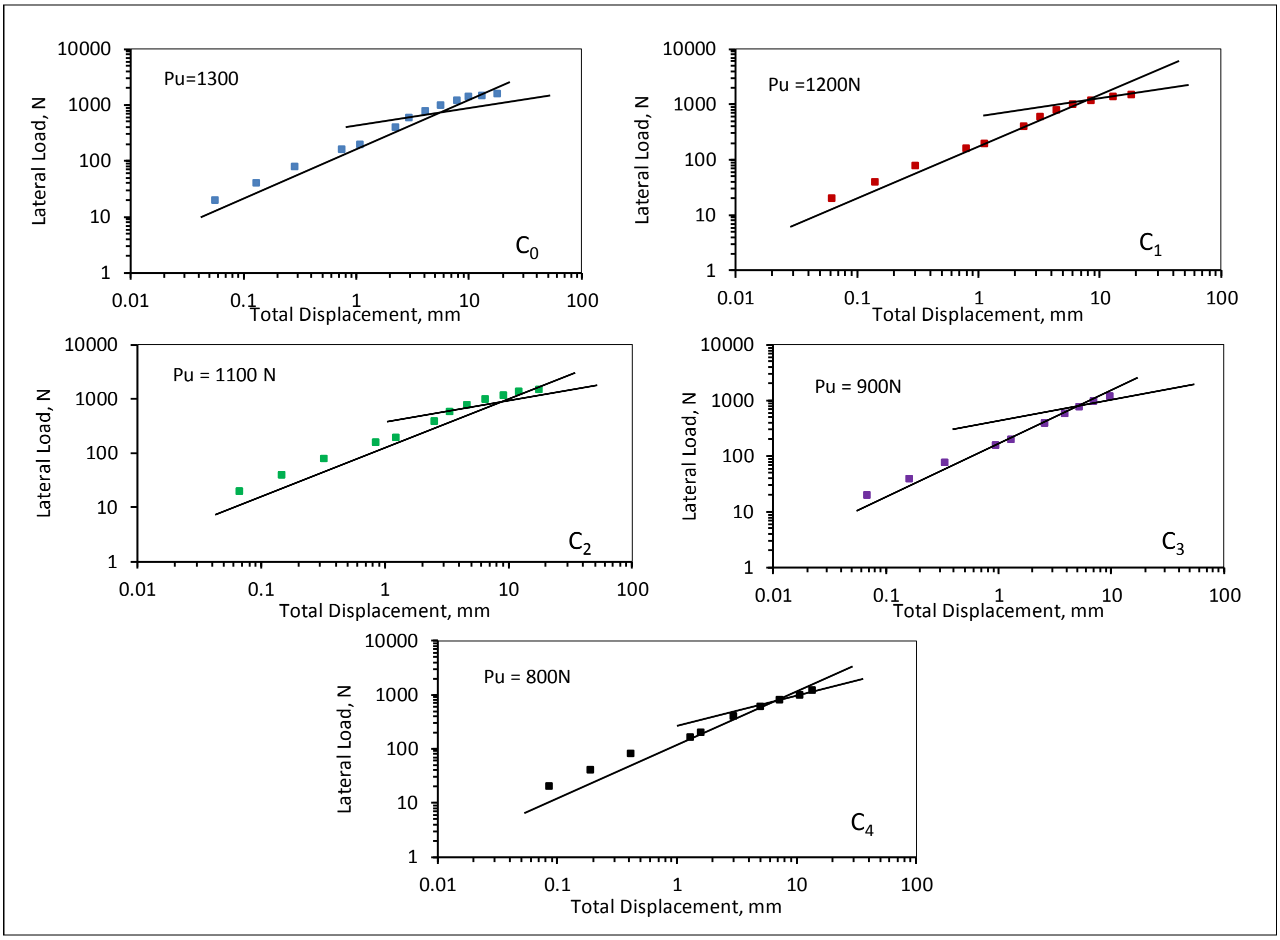

Figure 4. Lateral load capacity of a group of piles, with e/L = 0.25 and N = 100

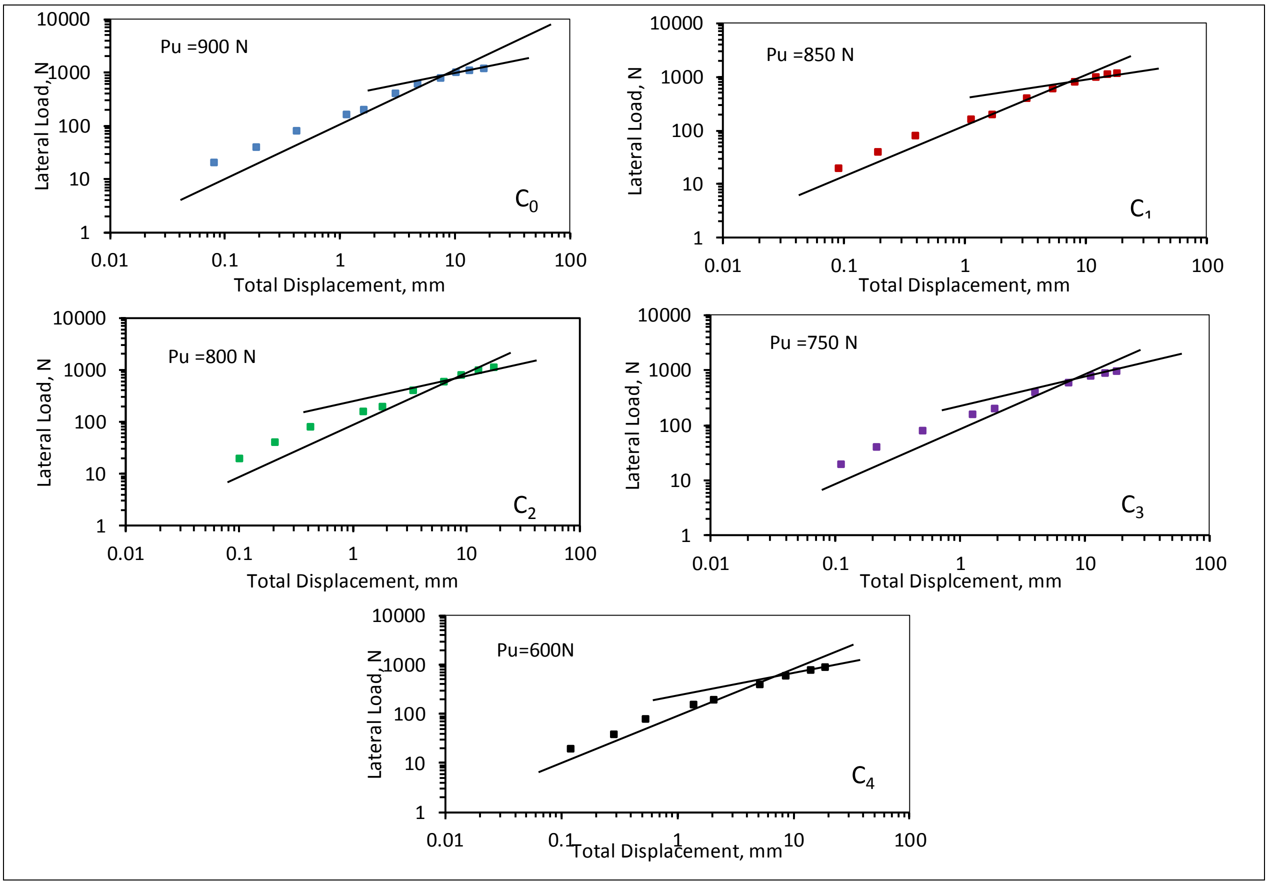

Figure 5. Lateral load capacity of a group of piles, with e/L = 0.5 and N = 100

The initial degradation is high from the first to tenth cycles. In the following 25 cycles, the degradation somewhat decreases until reaches to 50 cycles. After that, the decrease is semi-linearly decreasing in the maximum lateral load as shown in Table 4. Increasing the percentage of contamination, the number of loading cycles and the ratio of eccentricity to length ratio (e/L) caused a decrease in the maximum lateral load bearing capacity. The maximum lateral load-bearing capacity of single pile is compared with those obtained by a two-line slopes intersection and the proposed Equation 2 as shown in Tables 5 and 6 for e/L = 0.25 and 0.5 respectively. The results were obtained at the 100th cycle of lateral loading. The soil properties and results of experimental work are obtained from Karkush and Abdul Kareem [9]. The results showed good agreement between the maximum lateral load-bearing capacity obtained by TLSI and Equation 2.

Table 4. Variation of maximum lateral load-bearing capacity of single pile in intact soil with N

Cycle number	Pu, N (TLSI)	
	e/L = 0.25	e/L = 0.5
1	410	300
5	400	290
10	380	285
25	360	280
50	350	270
100	330	250

Table 5. Comparison of lateral capacity of single pile with e/L=0.25

Soil sample	Lateral displacement, mm	E/c_u	P_f, N Experimental	P_u, N	
				TLSI	Equation (2)
C_0	13.25	106	440	340	376
C_1	13.12	104	420	320	361
C_2	13.46	101	400	300	344
C_3	13.35	108	360	280	307
C_4	13.00	98	280	225	243

Table 6. Comparison of lateral capacity of single pile with e/L=0.5"

Soil sample	Lateraldisplacement, mm	E/c_u	P_f, N Experimental	P_u, N	
				TLSI	Equation (2)
C_0	13.40	106	320	250	273
C_1	13.20	104	300	230	257
C_2	12.84	101	280	225	242
C_3	13.10	108	270	210	231
C_4	12.90	98	220	170	191

The ultimate lateral carrying capacity of single pile decreased with increasing the number of applied loading cycles as shown in Tables 7 and 8 for e/L equals 0.25 and 0.5 respectively. The results obtained from modified degradation model (Equation 2) are more convergent from those obtained experimentally, while the results of ultimate lateral carrying capacity obtained from TLSI start to diverge from the experimental results with increasing the number of loading cycles. It's important to notice that ultimate carrying capacity of single piles obtained experimentally is the same but the resulting displacements are increased with increasing the number of loading cycles.

Table 7. Variation of lateral capacity of single pile in intact soil with N for e/L=0.25

Cycle number	Lateral displacement, mm	P_f, N Experimental	P_u, N	
			TLSI	Equation (2)
1	12.200	440	410	440
5	12.254	440	400	440
10	12.662	440	380	439
25	12.760	440	360	437
50	12.950	440	350	433
100	13.150	440	330	424

Table 8. Variation of lateral capacity of single pile in intact soil with N for e/L=0.5

Cycle number	Lateral displacement, mm	P_f, N Experimental	P_u, N	
			TLSI	Equation (2)
1	11.500	320	300	320
5	11.740	320	290	320
10	11.900	320	285	319
25	12.364	320	280	318
50	12.684	320	270	315
100	13.460	320	250	309

The variation in the maximum lateral capacity of a group of piles inserted in intact and contaminated soil samples with e/L = 0.25 and 0.5 at the 100th cycle of lateral loading is given in Tables 9 and 10 respectively. The maximum load-bearing capacity obtained by TLSI is well agreed with those obtained by the proposed Equation 2. Additionally, it is important to remember that Equation 2 is based on a strain of 20% of block width of the piles group (80 mm). The maximum carrying capacity of piles decreases with increasing the number of loading cycles and contamination percentage in the soil samples [9].

Table 9. Variation of lateral capacity of group of piles for e/L = 0.25

Soil sample	Lateral displacement, mm	E/c_u	P_f, N Experimental	P_u, N	
				TLSI	Equation (2)
C_0	17.80	106	1600	1300	1446
C_1	18.20	104	1500	1200	1355
C_2	17.60	101	1450	1100	1318
C_3	18.60	108	1350	900	1212
C_4	17.76	98	1100	800	1002

Table 10. Variation of lateral capacity of group of piles for e/L=0.5

Soil sample	Lateral displacement, mm	E/c_u	P_f, N Experimental	P_u, N	
				TLSI	Equation (2)
C_0	17.80	106	1200	900	1084
C_1	18.04	104	1150	850	1040
C_2	17.45	101	1100	800	1000
C_3	18.10	108	950	750	855
C_4	18.50	98	900	600	816

5. Conclusion

The results of ultimate lateral carrying capacity of single pile and piles group subjected to lateral cyclic loading in contaminated soils directed to the following conclusions:

- The ultimate lateral carrying capacity of single pile obtained from TLSI ranged 75-80% and 76-80% of the ultimate lateral carrying capacity obtained experimentally for e/L= 0.25 and 0.5 respectively.
- The ultimate lateral carrying capacity obtained from TLSI ranged 67-80% and 71-79% of the ultimate lateral carrying capacity of piles group for e/L=0.25 and 0.5, respectively.
- The ratio of ultimate lateral carrying capacity obtained from the TLSI method to the modified degradation model Equation 2) ranged 87-93% and 89-92% for single pile with e/L=0.25 and 0.5 respectively.
- The ratio of ultimate lateral carrying capacity obtained from the TLSI method to the modified degradation model (Equation 2) ranged 74-90% and 74-88% for piles group with e/L=0.25 and 0.5 respectively.
- The ultimate lateral carrying capacity decreases with increasing the number of loading cycles and the concentration of contaminant in the soil. The initial degradation is high especially in the first tenth cycles. For the following 25 cycles, the degradation somewhat decreases, until the point that it achieves 50 cycles.

6. References

[1] Broms, B. B. "Lateral resistance of piles in cohesionless soils." Journal of the Soil Mechanics and Foundations Division90, no. 3 (1964): 123-158.

[2] Reese, L. C., William R. Cox, and Francis D. Koop. "Analysis of laterally loaded piles in sand." Offshore Technology in Civil Engineering Hall of Fame Papers from the Early Years (1974): 95-105.

[3] Matlock, Hudson, and Stephen HC Foo. "Simulation of lateral pile behavior under earthquake motion." In From Volume I of Earthquake Engineering and Soil Dynamics--Proceedings of the ASCE Geotechnical Engineering Division Specialty Conference, June 19-21, 1978, Pasadena, California. Sponsored by Geotechnical Engineering Division of ASCE in cooperation with: no. Proceeding. 1978.

[4] Long, J. H., and Geert Vanneste. “Effects of cyclic lateral loads on piles in sand.” Journal of Geotechnical Engineering 120, no. 1 (January 1994): 225–244. doi:10.1061/(asce)0733-9410(1994)120:1(225).

[5] Yang, Zhaohui, and Boris Jeremic “Numerical analysis of pile behaviour under lateral loads in layered elastic-plastic soils.” International Journal for Numerical and Analytical Methods in Geomechanics 26, no. 14 (2002): 1385–1406. doi:10.1002/nag.250.

[6] Dewaikar, D. M., S. V. Padmavathi, and R. S. Salimath. "Ultimate lateral load of a pile in soft clay under cyclic loading." 12th International Conference of International Association for Computer Methods and Advances in Geomechanics (2008). 3498–3507.

[7] Basack, S. “Response of vertical pile group subjected to horizontal cyclic load in soft clay.” Latin American Journal of Solids and Structures 7, no. 2 (2010): 91–103. doi:10.1590/s1679-78252010000200001.

[8] Li, Z, S Haigh, and M Bolton. “Centrifuge modelling of mono-pile under cyclic lateral loads.” Physical Modelling in Geotechnics, Two Volume Set (August 17, 2010): 965–970. doi:10.1201/b10554-159.

[9] Karkush, Mahdi O., and Mahmoud S. Abdul Kareem. "Behavior of pile foundation subjected to lateral cyclic loading in contaminated soils." Journal of Civil Engineering Research5, no. 6 (2015): 144-150.

[10] Karkush, Mahdi O., and Mahmoud S. Abdul Kareem. "Behavior of pile group subjected to cyclic lateral loading in contaminated soils." International Journal of Geomate 10.21 (2016): 1943-9. doi:10.21660/2016.21.84844.

[11] Karkush, Mahdi O. "Impacts of soil contamination on the response of piles foundation under a combination of loading." Engineering, Technology & Applied Science Research 6.1 (2016): 917-922.

[12] Karkush, Mahdi. O. "Behavior of pile groups subjected to axial static and lateral cyclic loads in contaminated soils." Geo-China 2016. 166-174. doi.org/10.1061/9780784480083.021.

[13] Hung, Wen Yi, Chung Jung Lee, and Yu Ting Lin. “Centrifuge modeling on pile behavior subjected to cyclic lateral loadings.” Applied Mechanics and Materials 764–765 (May 2015): 1209–1213. doi:10.4028/www.scientific.net/amm.764-765.1209.

[13] Zhang, Yuting, and Charles W. W. Ng. “Centrifuge modeling of single pile response due to lateral cyclic loading in kaolin clay.” Marine Georesources & Geotechnology 35, no. 7 (February 21, 2017): 999–1007. doi:10.1080/1064119x.2016.1275894.

[15] Tomlinson, M., and John Woodward. “Pile design and construction practice, sixth edition” (October 13, 2014). doi:10.1201/b17526.

[16] Heerema, E. P. "Relationships between wall friction, displacement velocity and horizontal stress in clay and in sand, for pile driveability analysis." Ground engineering 12, no. 1 (1979).

[17] Smith, Trevor David. "Pile horizontal soil modulus values." Journal of Geotechnical Engineering 113, no. 9 (1987): 1040-1044.

[18] Grashuis, A.J., H.A. Dietermann, and N.F. Zorn. “Calculation of cyclic response of laterally loaded piles.” Computers and Geotechnics 10, no. 4 (January 1990): 287–305. doi:10.1016/0266-352x(90)90019-r.

[19] Little, R. L., and J. L. Briaud. “Cyclic horizontal load tests on 6 piles in sands at Houston ship channel.” Research Report 5640 to USAE Waterways Experiment Station, Civil Engineering, Texas A&M University, 1988.