International Journal of Civil and Structural Engineering– IJCSE
Volume 2 : Issue 1 [ISSN : 2372-3971]
Publication Date: 30 April, 2015

Evaluation of short piles bearing capacity subjected to lateral loading in sandy soil

[Jafar Bolouri Bazaz, Javad Keshavarz]

Abstract

Almost all types of piles are subjected to lateral loads. In many cases, however, the applied lateral loads are comparable with gravity loads. Lateral loads and moments are generally induced from wind and earthquake. All piles which are subject to lateral loads are usually divided into two categories: long piles and short piles. The general methods to estimate lateral bearing capacity of piles are based on ultimate bearing capacity and allowable horizontal displacement for short and long piles respectively. Several theoretical methods including Hansen, Broms, Petrasovits, Meyerhof, Prasad and Chari have been proposed to predict lateral bearing capacity of piles in cohesion-less soils. All these theories are based on simplified soil pressure distribution assumption along the pile length. In practice the Broms method is most popular, since it is simple and applicable for both of short and long piles.

In the present research steel pipes are used as pile in laboratory to evaluate lateral capacity of piles subjected to horizontal loads. Steel model piles, with two different outside diameters of 21.7 mm and 27 mm, wall thickness of 2.4 mm and lengths of 400, 600, 800 mm were used for tests. The soil, in which piles were embedded, was fine sand with friction angle of 33^o and 41.5^o for loose (γ = 13.8 kN/m^3) and medium dense (γ = 15 kN/m^3) states respectively. The sand container was cylindrical in shape with 0.7 m diameter and 1.0 m height. Thin wires, attached to the pile at different levels, were utilized to measure horizontal displacement of piles within the soil. According to theories and experimental test results, the behavior of piles with different length and diameter, embedded in sand was evaluated. A comparison between experimental test results and different theories reveals that Prasad and Chari method is more suitable for estimation of lateral bearing capacity. It is shown that with Increasing the length and diameter of piles and also density of soil, the lateral bearing capacity increases as well, but the soil density is more effective than the other parameters. In addition, it is shown that the location of pile rotation point is not affected by changes in diameter and soil density.

Keywords— Short piles, Lateral load, Bearing capacity, Cohesionless, Rotation point

Jafar Bolouri Bazaz / Associate Professor, Civil Engineering Department
Ferdowsi University of Mashhad, Mashhad
Iran

Javad Keshavarz / M.sc Student, Civil Engineering Department
Ferdowsi University of Mashhad
Iran

I. Introduction

Piles are made from steel, concrete, reinforce concrete and wood. If the bearing capacity for shallow foundation not to be adequate, piles, as deep foundations, are used to increase bearing capacity. When the soil layers are highly compressible and lateral loads are applied to the structure, piles help to increase bearing capacity and reduce lateral displacement. Rrelatively to the vertical load, in many structures the magnitude of lateral load is insignificant and can be neglected. Piles in many structure are subject to lateral loads including bridges, tall buildings and especially offshore structures and sign boards. There are several methods to estimate the lateral bearing capacity of piles. The general methods to estimate lateral bearing capacity of piles are based on ultimate bearing capacity and allowable horizontal displacement.

All piles which are subject to lateral load are usually divided into two categories: long piles and short piles. Bearing capacity of short piles depends on soil resistance, while long pile bearing capacity depends on pile strength [1]. Free-head short piles under lateral load act as a rigid body and rotate around a center of rotation.
Several theoretical methods, including Hansen, Broms, Petrasovits and Award, Meyerhof, Prasad and Chari have been proposed to predict lateral bearing capacity of piles in cohesion-less soils [2, 3, 4, 5, 6, 7 & 8]. Except Broms method, others are more appropriate for short piles. However, modulus of sub-grade reaction approach [9], elastic approach [1], Randolph method [10], characteristics and modified load method [11, 12 & 13], k_{hmax} [14] are applicable for long piles.

II. Criteria of Piles Behavior

Short piles under lateral load act as a rigid body and they are expected to rotate around a center of rotation, while long pile will bends under lateral loads. The behavior of both short rigid piles and long flexible piles is based on the relatively stiffness of the soil–pile system [15]. Table 1 classifies various criteria which are normally adopted to identify the rigid and flexible piles behavior.

TABLE I. CRITERIA FOR CLASSIFICATION OF PILE BEHAVIOR

No.	Source	Criterion for flexible behaviour	Criterion for rigid behaviour
1	[3 & 4]	$L / T \geq 4$	$L / T \leq 2$
2	[1]	$K_r < 10^{-2}$	$K_r > 10^{-2}$
3	[16]	$L / B > 6$	$L / B < 6$
4	[17]	$S_H > 5$	$S_H > 5$
5	[18]	$L > 1.5BK^{0.36}$	$L < 1.5BK^{0.36}$
6	[19]	$L > L_c$	$L < L_c / 3$

where

$$T = (E_p I_p / n_h)^{0.2} \quad (1)$$
$$K_r = (E_p I_p / E_s B^4) \quad (2)$$
$$S_H = (L / B)(E_p / E_s)^{0.25} \quad (3)$$
$$K = (E_p / E_s) \quad (4)$$
$$L_c = 4.44(Ep\ Ip / Es)^{0.25} \quad (5)$$

In these equations L is pile length (m), B is pile diameter (m), E_p is pile elastic modulus (kPa), I_p is pile moment of inertia (m4) and Es is elastic modulus of soil (kPa). The magnitudes of n_h which are required to calculate T (equation 1) is given in table 2.

TABLE II. RECOMMENDED NH VALUES [20]

n_h (kN/m^3)		
Loose sand	Medium sand	Dense sand
2600	7700	20000

The second criterion in table 1 contains almost all effective parameters including length, diameter and relative hardness of soil and pile. It seems this criterion is able to predict more accurately the behavior of pile. In contrast, the third criterion in table 1, suffers from enough precision which is due to the ignoring the soil and pile parameters.

III. The Aim of the Study

There exist many theories to estimate ultimate bearing capacity of piles subject to lateral load which have proposed by various researches. Due to the complexity of these theories, it is difficult for engineers to choose a suitable method. experimental and theoretical efforts have been made to clarify the precision of these theories. Many of these relationships, however, are based on the theoretical assumptions. Experimental efforts have been made to clarify more precisely theses theories.

In the present research, laboratory tests have been conducted to evaluate the bearing capacity and behavior of piles under lateral load. Also the point of rotation, force-displacement phenomena and the effect of parameters such as soil bulk density, length and diameter of piles been have been investigated

IV. Equipment and Material Testing

To study experimentally the behavior of piles under lateral load, it is required to develop a set of devices in such a way to be able to apply horizontal force and also measure horizontal displacement of the pile at the soil surface and at different depths of pile. For this purpose an experimental apparatus was designed. The following sections describe the details of the apparatus, materials and equipment used in this research.

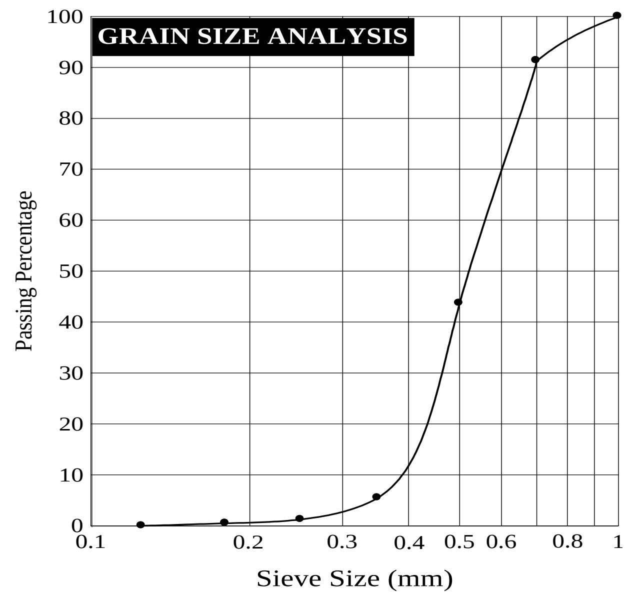

Figure 1. *Firuzkooh sand grain size distribution*

TABLE III. INTERNAL FRICTION (DIRECT SHEAR TEST)

Unit weight (kN/m^3)	Relative Density (%)	Internal Friction (Degree)
13.8	28±1	33
15	91±1	41.5

A. *Soil*

Standard Firuzkooh sand with a specific gravity of 2.66 was used for the present investigation. The grain size distribution of this sand is shown in Figure 1. Also given in table 3 is the direct shear test result. The results of direct shear test have good agreement with those obtained from triaxial tests carried out on this sand by other researchers [21].

B. *Pile*

Galvanized and aluminum pipe were used as pile for the experimental tests. The embedded lengths of piles were 400, 600 and 800 mm. The outside diameters of pipes were of 21.7, 24.8 and 27 mm, while their wall thicknesses were 1.4 and 2.4 mm. Tensile tests were performed on these pipes and the results are shown in table 4.

TABLE IV. PILES CHARACTERISTICS

No.	weight (kg/m)	Outside diameter (mm)	Wall thickness (mm)	Young's modulus (GPa)
1	1	21.7	2.4	196
2	1.3	27	2.4	196
3	0.4	24.8	1.4	68

C. *Experimental Setup*

When a pile is subject to lateral load the lateral stress is distributed in the soil behind of the pile. The diameter and depth of the soil reservoir must be large enough to allow soil pressure distribution freely. If the diameter of soil reservoir is 10 times of pile diameter in the direction of lateral loading, this condition will be satisfied [1]. Hence, the tests were conducted in a test tank having a diameter and height of 700 mm 1000 mm respectively. For measuring the horizontal displacement of the pile at various depths, small holes at intervals of 200 mm in the direction and opposite direction of loading was established on the wall tank.

The static lateral load was applied by means of dead weights placed on a hanger connected to a flexible steel wire, strung over a pulley supported by frame. Before filling the reservoir of sand, the thin wires were attached to the pile at regular intervals to measure the horizontal displacement in depth. The pile was then placed inside the tank. The reservoir was filled by slow raining of sand through air and was then compacted at 15 cm layer to get uniform density. During the horizontal load application to the pile at the top surface of sand, an LVDT was used to measure the horizontal movement of the pile.

Each of test is specified with a unique code of "Ga-L*D*" or "Al-L*D*". "Ga" and "Al" indicate that the substances of pile is galvanized and aluminum respectively. The letter "L" and"D" represent the embedment length (cm) and outer diameter (mm) of the pile respectively. For example "Ga-L40D27" indicates that the pile is galvanized with 40 cm embedment length and outer diameter of 27 mm.

V. Test Result

The laboratory test results indicate that, except two piles (Ga-L80D21.7 and Ga-L80D27), all other piles act as short pile. With the exception of third and sixth criteria, all criteria shown in table 1, predict the behavior of all piles as short pile. It seems that the first criterion predicts the behavior of pile much better than the others.

The ultimate bearing capacity of all tested piles has been estimated from Hansen, Broms, Petrasovits and Award, Meyerhof, Prasad and Chari theories. If the load-displacement curve has been produced in the laboratory tests, it is easy to determine the lateral load capacity of the piles. It has been suggested that the load corresponding to displacement equivalent to 20% of pile diameter, is the lateral load capacity of piles [3 & 4]. The ultimate bearing capacity of all piles obtained from different theories is listed in table 5. It is worth mentioning that these theories do not predict the amount of displacement corresponding to the ultimate capacity of the piles. For comparison and better understanding of the laboratory test results, the ultimate capacity obtained from these theories has been specified on the laboratory force-displacement curves (figures 2 and 3).

TABLE V. ESTIMATED BEARING CAPACITY OF PILES SUBJECT TO LATERAL LOAD

Ultimate bearing capacity (N)							
φ=33°, γ=13.8 kN/m3, e=270 mm, D=21.7 mm							
Test No.	**L (mm)**	**Brinch Hansen [2]**	**Broms [3,4]**	**Petrasovits [5]**	**Meyerhof [6,7]**	**Prasad & Chari [8]**	**Broms (20% Diameter)**
Ga-L40D21.7	400	50	49	41	31	27	30
Ga-L60D21.7	600	151	126	110	88	74	62
Ga-L80D21.7	800	320	243	213	184	147	95
φ=33°, γ=13.8 kN/m3, e=270 mm, D=27 mm							
Ga-L40D27	400	58	60	51	36	34	44
Ga-L60D27	600	176	156	136	106	92	94
Ga-L80D27	800	375	302	265	221	182	135
φ=41.5°, γ=15 kN/m3, e=270 mm, D=21.7 mm							
Ga-L40D21.7	400	130	77	65	67	60	110
Ga-L60D21.7	600	417	199	175	199	163	180
Ga-L80D21.7*	800	928	384	341	399	322	220
φ=41.5°, γ=15 kN/m3, e=270 mm, D=27 mm							
Ga-L40D27	400	146	95	81	77	74	145
Ga-L60D27	600	468	248	218	238	203	300
Ga-L80D27*	800	1046	478	424	490	401	370
φ = 33 , γ = 13.8 kN/m3 , e = 270 mm , D = 24.8 mm							
Al-L40D24.8	400	55	55	44	33	31	44
Al-L60D24.8	600	156	144	117	90	85	85
Al-L80D24.8	800	332	278	230	183	167	85

* *This pile does not act as short pile*

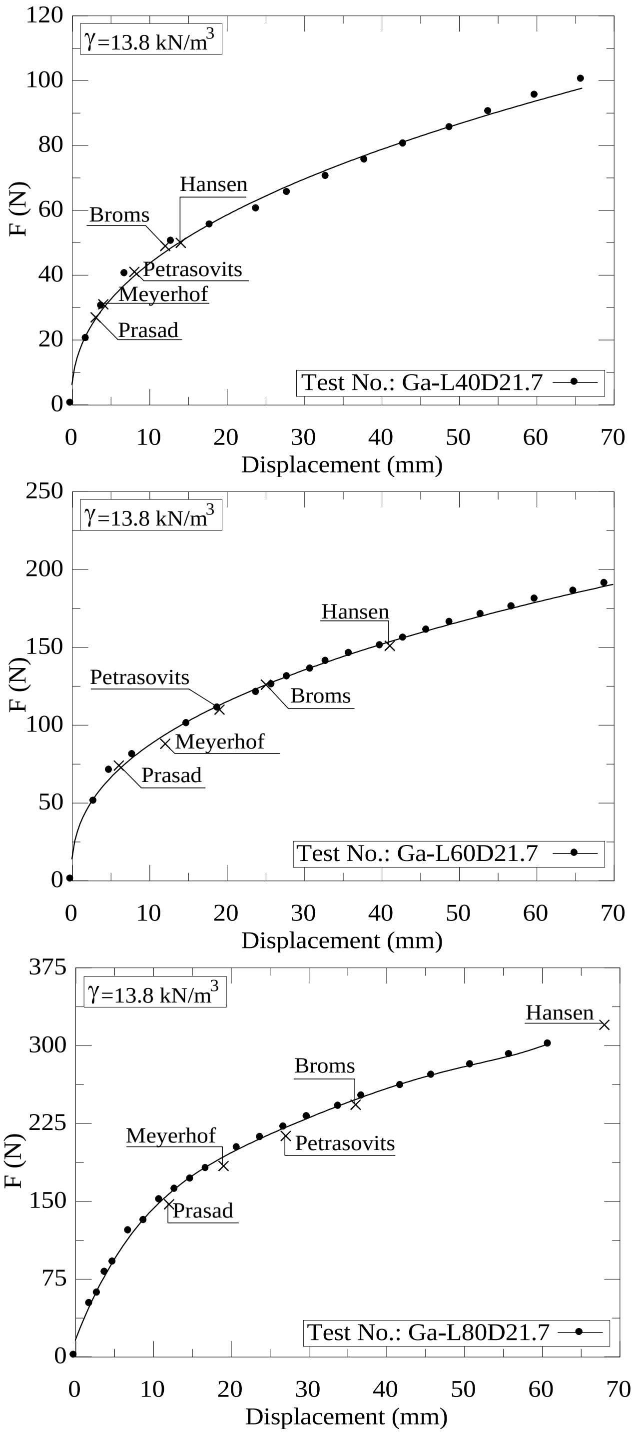

Figure 2. *Force - Displacement curves in soil surface*

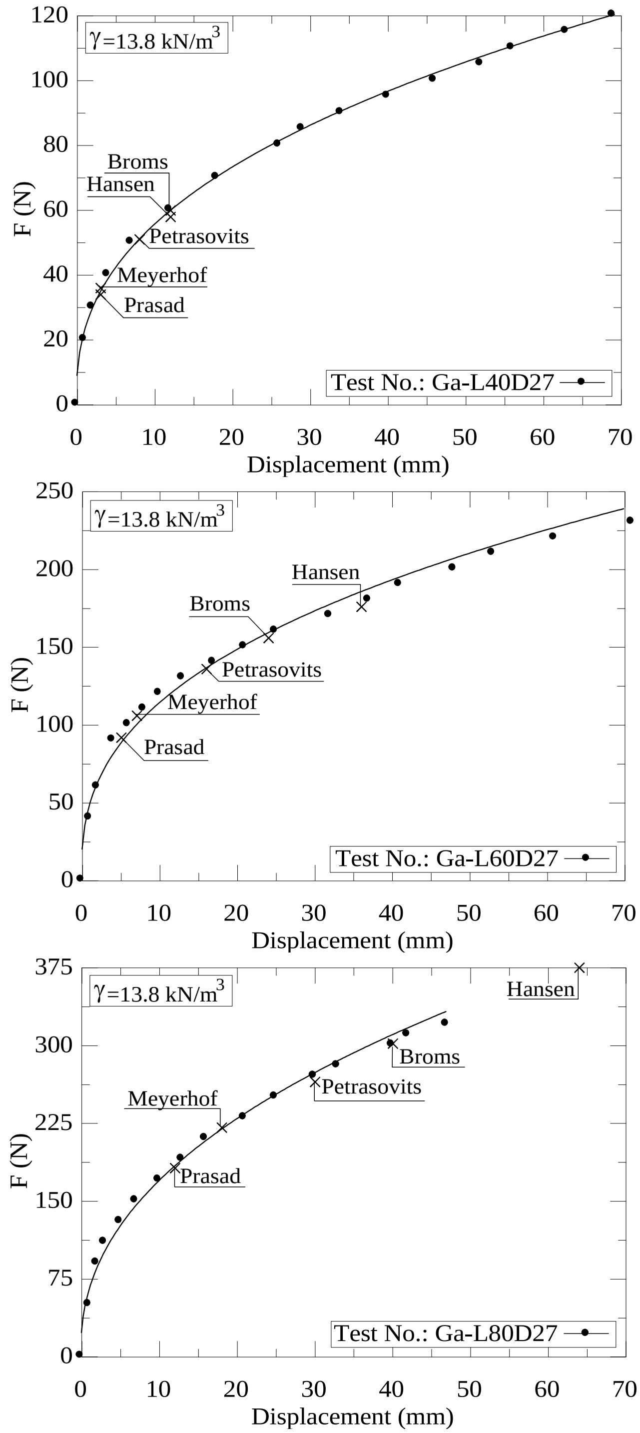

Figure 3. *Force - Displacement curves in soil surface*

Among the presented theories, the ultimate bearing capacity of piles which has been calculated from Hansen's method corresponds to the maximum horizontal displacement. Afterwards, Broms, Petrasovits and Award, Meyerhof and Prasad and Chari stand for the higher horizontal displacement respectively.

Prasad and Chari's method relate to minimum horizontal displacement in comparison with other theories. Based on the test results, it seems the Hansen's method is not an appropriate method for practical purposes, especially when displacement of the pile is very important to be determined. In contrast, Prasad and Chari methods are the most precise for engineering design.

International Journal of Civil and Structural Engineering– IJCSE
Volume 2 : Issue 1 [ISSN : 2372-3971]
Publication Date: 30 April, 2015

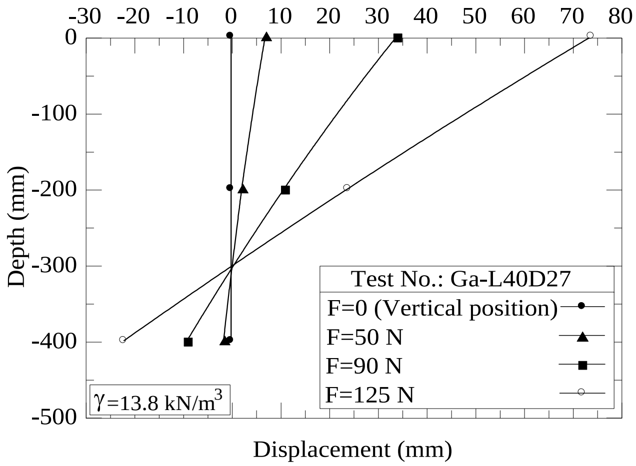

Figure 4. *The horizontal displacement of the pile at different depths*

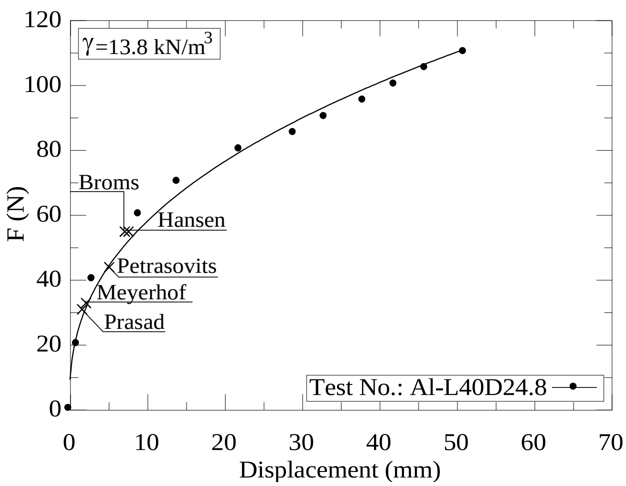

Figure 5. *Force - Displacement curves in soil surface*

VI. Conclusion

According to tests carried out and comparisons made with the available theories the following points may be concluded from the present research.

1. The theoretical equations which contain more parameters such as pile diameter, pile length, pile and soil stiffness, predict more accurately the behavior of the pile in terms of short and long piles.
2. It seems that Prasad and Chari methods, in comparison with other proposed methods are more appropriate for determining the load capacity of short piles.
3. The ultimate lateral load capacity of piles obtained from Hansen method is the maximum. Due to the large horizontal displacement piles in this method, it is recommended that this method must be used especially when the horizontal displacement is important to be determined.
4. To estimate the point of rotation in pile all of the existing theories can be used. The Prasad and Chari methods, however, are simpler than the other methods.
5. The unit weight of soil and pile diameter do not affect significantly on the location of pile rotation.

References

[1] H. G. Poulos, and E. H. Davis, "Pile foundation analysis and design", John Wiley and Sons, New York, NY, 1980.

[2] B. J. Hansen, "The ultimate resistance of rigid piles against transversal Forces", Danish Geotech. Institute, Bull, Copenhagen 12, pp 5-9, 1961.

[3] B. Broms, "The lateral resistance of piles in cohesive soils", J. Soil Mech. Found. Div., ASCE, Vol. 90, No. SM2, pp 27-63, 1964a.

[4] B. Broms, "The lateral resistance of piles in chesive soils", J. Soil Mech. Found. Div., ASCE, Vol. 90, No. SM3, pp 123-156, 1964b.

[5] G. Petrasovits, and A. Award, "Ultimate lateral resistance of a rigid pile in cohesionless soil", Proc., 5th European Conf. on SMFE, Madrid, Vol. 3, pp 407-412, 1972.

[6] G. G. Meyerhof, S. K. Mathur, and A. J. Valsangkar, "Lateral resistance and deflection of rigid wall and piles in layered soils", Canadian Geotech. J., Vol. 18, pp 159-70, 1981

[7] G. G. Meyerhof, "Behaviour of pile foundations under special loading conditions", Canadian Geotech. J., Vol. 32, pp 204-22, 1995.

[8] V.S.N. Prasad, and T. R Chari, "Lateral capacity of model rigid piles in cohesionless soils", Japanese Geotechnical Society, Vol. 39, No. 2, pp 21-29, 1999.

[9] L. C. Reese, and H. Matlock, "Non-dimensional solutions for laterally loaded piles with soil modulus assumed proportional to depth", 8th Texas Conference on Soil Mechanics and Foundation Engineering, Austin, TX, pp 1-41, 1956.

[10] M. F Randolph, "The response of flexible piles to lateral loading", Geotechnique, Vol. 31, No. 2, pp 247-259, 1981.

[11] L. T. Evans, and J. M. Duncan, "Simplified analysis of laterally loaded piles", Report No, UCB/GT/82-04, Civil Engineering Department, University of California, Berkeley, CA, 1982.

[12] S. Wang, "Simplified analysis of laterally loaded piles in cohesionless soils", MS. Thesis, Hawaii University at Manoa, Honolulu, 2000.

[13] B. K. F. Chang, "Simplified procedure for analysis of laterally loaded single piles and pile groups", MS. Thesis, Hawaii University at Manoa, Honolulu, 2003.

[14] S. Kumar, L. Lalvani, and M. Omar, "Nonlinear response of single piles in sand subjected to lateral loads using k_{hmax} approach", Geotechnical and Geological Engineering Journal, Springer, Vol. 24, pp 163-181. 2006.

[15] A. Boominathan, R. Ayothiraman, "An experimental study on static and dynamic bending behavior of piles in soft clay", Geotechnical and Geological Engineering, Springer, Vol. 25, pp 177-189, 2007.

[16] M. Bierschwale, H. Coyle, and R. Bartowkewitz, "Lateral load tests on drilled shafts founded in clay", Drilled Piers Caissons ASCE, pp 98-113, 1981.

[17] R. Dobry, E. Vicente, JM. O'Rourke and Roesset, "Horizontal stiffness and damping of single piles", J. Geotech. Eng Div ASCE, Vol. 108, pp 439-459, 1982.

[18] T. Davies, and M. Budhu, "Nonlinear analysis of laterally loaded piles in heavily over consolidated clay", Geotechnique. Vol. 36, pp 527-538, 1986.

[19] H. G. Poulos, and T. Hull, "The role of analytical geo-mechanics current principles and practices", ASCE, Vol. 2, pp 1578-1606, 1989.

[20] K. Terzaghi, "Evaluation of coefficient of subgrade reaction", Geotechnique, Vol. 5, pp 297-326, 1955.

[21] M. Movahedifar, and J. Bolouri-Bazaz, " An estimation of passive pressure against integral bridge abutments considering arching effects", ACTA Geotechnica Slovenica., In Press

Prasad and Chari methods, in comparison with other proposed methods are more appropriate for determining the load capacity of short piles