ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 3, Issue 10 , October 2016

Analysis of Load Carrying Capacity of a Single Pile in Weathered Rock

Ramkripal Yadav

Graduate Student, Department of Civil & Environment Engineering, VJTI College, Matunga (E), Maharashtra, India

ABSTRACT: Pile foundations have been used as load carrying and load transferring systems for many years. More recently, the growing need for housing and construction has forced authorities and development agencies to exploit land with poor soil characteristics. This has led to the development of improved piles and pile driving systems. However determination of the ultimate load of large diameter piles is difficult.
This paper is based on the study of the pile load test data collected from the construction sites in Mumbai and Pune region (Mumbai Central and Lower Parel in Mumbai and Nanded city in Pune). In a typical region of Mumbai in Western India, such piles pass through soft clayey deposit and through highly weathered strata, before being socketed in discontinuous rocks like Basalts, Breccia's' or Tuff. In Pune region, piles pass through fine granular of murum which is plastic in nature, followed by weathered rock.
The load carrying capacity of these pile load tests has been determined by means of conventional load-settlement curve, De Beer's method (recommended by IS 14593) and five empirical methods (Vander Veen's method, Decourt's method, Fuller and Hoy's method, Shen's method and Chin's method). The results of the empirical methods have been compared with the recommendation of IS 14593 and the factor of safety for each method is determined. The most suitable empirical method is chosen and a plot of ultimate load v/s pile diameter is made. This graph can be extrapolated to determine the ultimate load for larger pile diameters.

KEYWORDS: Pile; Weathered Rock; Load Carrying Capacity; Empirical Methods; Factor of Safety.

I. INTRODUCTION

Bored cast in situ piles socketed in rocks are amongst widely used deep foundations in recent years. These piles offer best foundation solutions under situations involving heavy loads and under sub-surface conditions where a layer of loose soil overlies bedrock. This report is based on the study of pile data collected from the construction sites in Mumbai and Pune region. In a typical region of Mumbai in Western India, such piles pass through soft clayey deposit and through highly weathered strata, before being socketed in discontinuous rocks like Basalts, Breccia or Tuff. In Pune region, piles pass through fine granulars of murrum which is plastic in nature, followed by weathered rock. Such sub-surface conditions favour use of socketed piles as a very convenient foundations alternative. It is also observed that, this is an effective foundation system restricting the settlement tolerance well within the serviceability requirements. The embedded length of pile in the weathered rock, which is designed to transfer either part or full axial load by skin friction, is called socket length. Socketed piles are designed to support the applied load by

(i) Side wall shear comprising adhesion or skin friction on the vertical face of pile
(ii) End bearing on the material below the pile tip and
(iii) A combination of both

To ascertain the field performance and estimate load carrying capacities of socketed piles, in-situ pile load tests are conducted, where upon piles may be subjected to static, dynamic or cyclic loads. Such tests give the load settlement behavior upto some pre-assigned pile load or load upto failure. However, considering the number of piles involved at a construction site, these tests cannot be performed on every single pile because of the time and cost constraints.

The conventional method of finding ultimate load by analyzing data from pile load test for larger diameter piles is uneconomical and complex. Hence there is a need to establish a relationship to infer geotechnical capacity of a large diameter of pile from the results of load tests conducted on small diameter piles. The practical constraints and cost considerations have given greater impetus into search of alternative methods for determining the pile load-settlement behavior. Availability of advance information on load-settlement behavior of piles would greatly enhance the decision making process on site and increase confidence in the adopted technique.

In this paper the following objectives are targeted.

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 3, Issue 10 , October 2016

a) Analysis of static load tests of a single pile embedded in weathered rock by means of various empirical methods.
b) Establishing the relation and methodology to infer geotechnical capacity of a large diameter of pile from the results of load tests conducted on small diameter piles

The load carrying capacity of a single pile is determined from the static pile load test data by means of conventional load-settlement curve, De Beer's method (recommended by IS 14593) and five empirical methods. The results of the empirical methods have been compared with the recommendation of IS 14593 and the factor of safety for each method is determined. The most suitable empirical method is chosen and a plot of ultimate load v/s pile diameter is made. This graph can be extrapolated to determine the ultimate load for larger pile diameters.

The work in this paper is divided in two stages. 1) Case Study 2) Summary and discussion. The study was undertaken to know which empirical method is most suited to carry out the ultimate load analysis of a single pile in Mumbai and Pune region. The ultimate load carrying capacity of a single pile embedded only in weathered rock should be greater than load carrying capacity of a single pile embedded partially in soil stratum and weathered rock.

II. CASE STUDY

A. General

This chapter encompasses the analysis of the load carrying capacity of a single pile which has been embedded at sites in Nanded City, Pune, Mumbai Central and Lower Parel.

At these sites, piles were embedded through various soil stratum depths and socketed in the rock. Load–settlement curves[6] are plotted using dial gauge observations for evaluating ultimate loads. The load carrying capacity of the soil is evaluated theoretically and empirical methods are applied for estimating factor of safety. IRC -78[8] and IS -14593[6] are referred for evaluating the safe loads.

B. Static Load Test Analysis For Nanded City, Pune

At this site, piles were embedded through 6.80 m soil stratum depth and socketed in the rock for 0.75 to 0.95 m depth. Load–settlement curves[6] are plotted using dial gauge observations for evaluating ultimate loads. The load carrying capacity of soil is evaluated theoretically and empirical methods are applied for estimating factor of safety. IRC -78[8] and IS -14593[6] are referred for evaluating the safe loads.

a. Subsoil Profile at Nanded City

The layer-wise subsoil description, based on a typical bore log is given below.

a) Layer - I

This is a layer of yellowish brownish clay of medium stiff to stiff consistency. The SPT N values in this layer are varying between 8 to15. Recovery of the disturbed soil samples collected in the SPT shoe indicates cohesive nature of the formation. The stratum is quite cohesive and plastic in nature and the soil has slightly detrimental settlement characteristics.

The SPT values are erratic. At places where the rock fragments are located directly below the SPT shoe, the SPT count is high; otherwise when the clayey matter is below the shoe, the values are on the lower site.

b) Layer - II

This is a layer of highly weathered formation of basaltic origin with a thickness of about 0.30 to 0.50 m. It is termed as murrum in local terminology. It is a sort of transition layer between the overburden and rocky formation.

c) Layer – III

After the initial weathered layer, a basaltic formation brownish grayish in color with vesicular cavities filled with secondary minerals is observed. It has good core recovery and RQD values.

A typical bore log is shown in Appendix I.

b. Rock Test Results

Rock samples from 6.80 m to 11.80 m depth were collected for laboratory testing. Crushing strength tests were performed on rock cores and test results revealed that, unconfined compressive strength of rock at the location of pile tip is 148.1 kg/cm^2.

c. Dial Gauge Response (Load-Settlement Curve)

Pile load tests [6] are carried out for three times the design load (283T, 407T and 620T for 500, 600 and 750 mm pile diameters respectively). The dial gauges readings are recorded in Tables 3.1 to 3.3.Load vs. settlement relations [6] for different pile diameters are presented in Figs. 3.2 to 3.4. The maximum settlements that are observed are 12.66, 10.03 and 11.14 mm for 500, 600 and 750 mm pile diameters respectively.

ISSN: 2350-0328

International Journal of Advanced Research in Science, Engineering and Technology

Vol. 3, Issue 10 , October 2016

Table 3.1 Dial Gauge Readings Pile Diameter=500mm (MORTH-2013)

Date	Pressure Gauge Reading (kg/cm^2)	Loading (T)	Dial Gauge Reading (mm)				Average Settlement (mm)
			A	B	C	D	
07.12.10	0	0.00	0.00	0.00	0.00	0.00	0
07.12.10	20	35.46	2.23	4.18	2.47	2.54	2.86
07.12.10	40	70.91	4.96	4.55	4.10	4.22	4.46
07.12.10	70	124.09	6.35	6.25	5.50	5.70	5.95
07.12.10	100	177.28	8.85	6.66	6.12	7.37	7.25
07.12.10	130	230.46	10.12	8.55	8.37	9.58	9.16
07.12.10	160	283.64	13.65	11.51	11.24	14.25	12.66

Table 3.2 Dial Gauge Reading Pile Diameter=600mm (MORTH-2013)

Date	Pressure Gauge Reading (kg/cm^2)	Loading (T)	Dial Gauge Reading (mm)				Average Settlement (mm)
			A	B	C	D	
20.12.10	0	0	0	0	0	0	0
20.12.10	20	35.46	2.05	1.15	0.45	1.68	1.33
20.12.10	40	70.91	3.47	2.21	1.28	2.25	2.3
20.12.10	80	141.82	3.68	2.44	1.55	2.51	2.54
20.12.10	120	212.73	5.05	3.41	2.85	3.41	3.68
20.12.10	160	283.64	6.74	4.87	4.15	5.18	5.24
20.12.10	180	319.1	8.4	5.83	5.2	6.05	6.37
20.12.10	220	390.01	11.24	8.48	7.88	8.98	9.15
20.12.10	230	407.73	12.55	9.15	8.85	9.55	10.03

Table 3.3 Dial Gauge Reading Pile Diameter=750mm (MORTH-2013)

Date	Pressure Gauge Reading (kg/cm^2)	Loading (T)	Dial Gauge Reading (mm)				Average Settlement (mm)
			A	B	C	D	
24.09.10	0	0	0.000	0	0.00	0.00	0.00
24.09.10	40	70.91	1.15	1.58	2.74	3.15	2.15
24.09.10	80	141.82	2.37	2.69	4.82	4.98	3.71
24.09.10	120	212.73	2.56	3.15	5.35	5.20	4.07
24.09.10	190	336.82	4.14	4.58	6.15	5.54	5.11
24.09.10	230	407.73	5.00	5.30	6.73	6.89	5.98
24.09.10	270	478.65	6.11	6.87	8.15	8.24	7.34
24.09.10	310	549.56	7.77	8.21	9.42	9.55	8.74
24.09.10	350	620.47	9.11	9.21	12.88	13.37	11.14

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 3, Issue 10 , October 2016

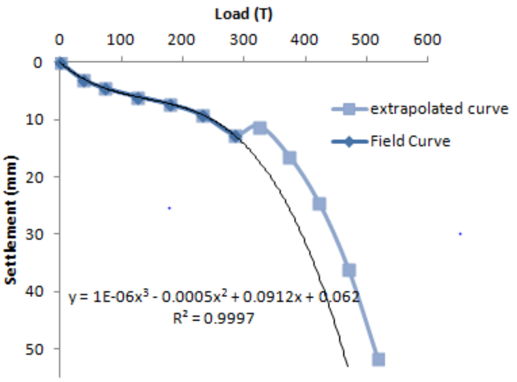

Fig. 3.2 Field Load vs Settlement Curve (Pile Diameter=500mm)

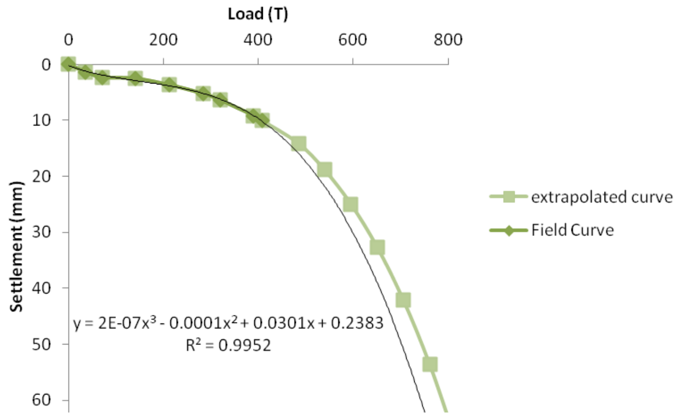

Fig. 3.3 Field Load vs. Settlement Curve (Pile Diameter=600mm)

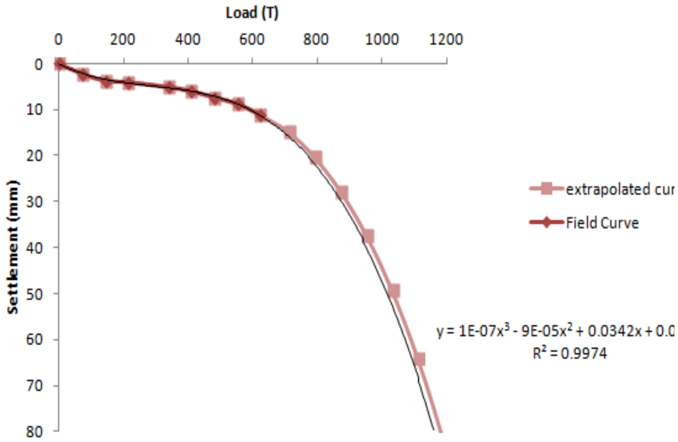

Fig. 3.4 Field Load vs. Settlement Curve (Pile Diameter=750mm)

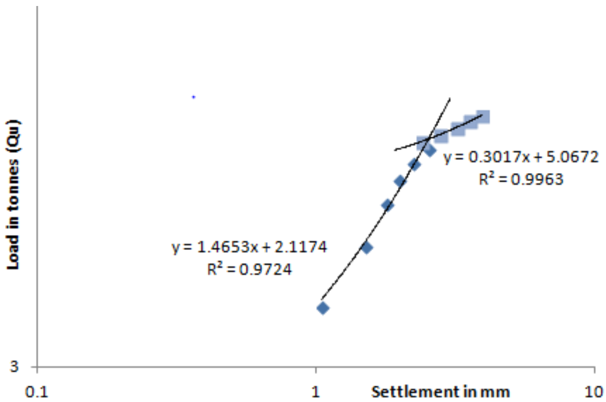

Fig. 3.5 Ultimate Load Calculation using De Beer's (1968) Method (Pile Diameter=500mm)

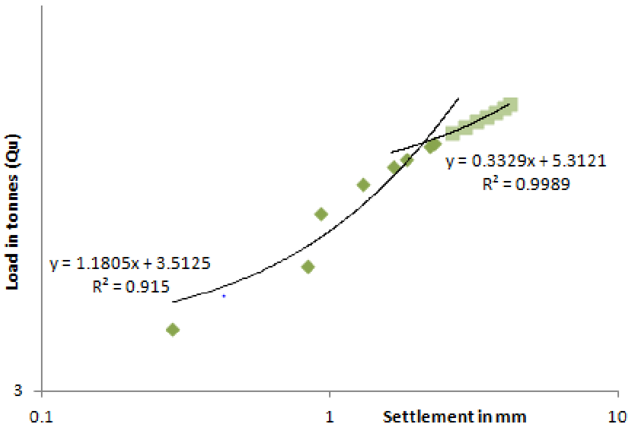

Fig. 3.6 Ultimate Load Calculation using De Beer's (1968) Method (Pile Diameter=600mm)

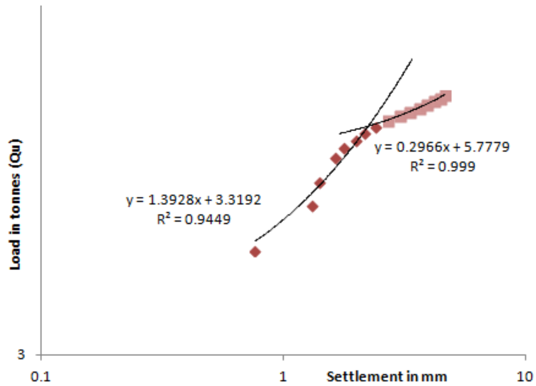

Fig. 3.7 Ultimate Load Calculation using De Beer's (1968) Method (Pile Diameter=750mm)

Ultimate loads are evaluated using De Beer's (1968) Method [2] as shown in Figs. 3.5, 3.6 and 3.7 and the results are presented in Table 3.4

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 3, Issue 10 , October 2016

Table 3.4 Safe Load Capacity for Various Pile Diameters (IS-14593)

Pile Diameter (mm)	1/3rd of Failure load (T)	50% of Load Corresponding to 12mm (T)	Safe Load (T)
500	170.7533	166.975	166.975
600	263.04	226.94	226.94
750	387.0267	327.675	327.675

d. Estimation of Ultimate Loads by Various Empirical Methods

Various methods of evaluating the ultimate load are discussed in the Section 2.2.4. The ultimate loads are evaluated using load – settlement curve[6] with the procedures of respective methods.[1][2][3][4][5]

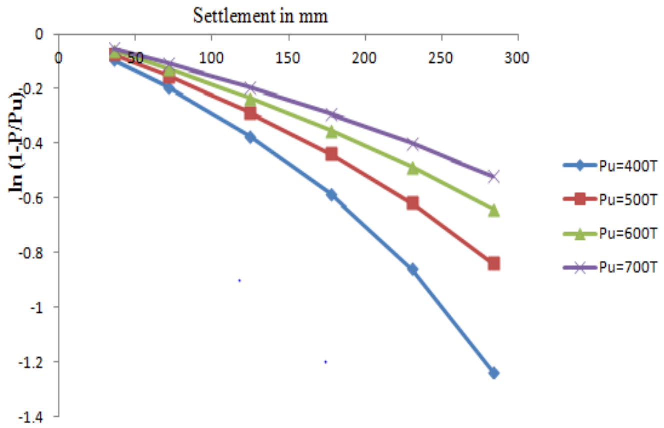

Fig.3.8 Ultimate load by Van der Veen's Method (1953), (Pile Diameter = 500mm)

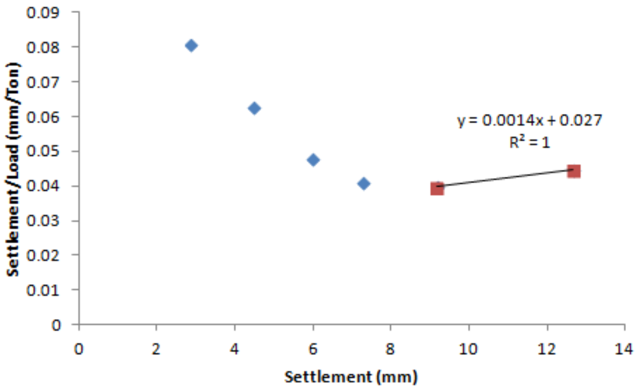

Fig.3.9 Ultimate Load by Chin's (1970) Method, (Pile Diameter = 500mm)

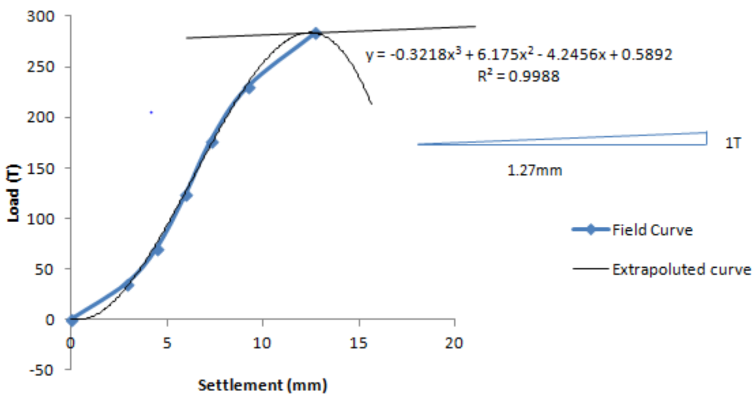

Fig.3.10 Ultimate Load by Fuller and Hoy (1970) method, (Pile Diameter = 500mm)

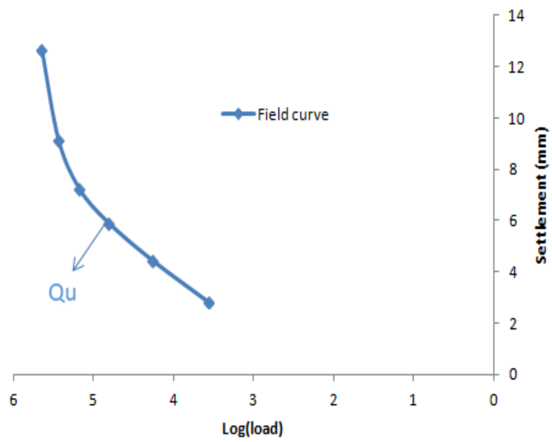

Fig.3.11 Ultimate Load by Shen's (1980) Method, (Pile Diameter = 500mm)

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 3, Issue 10 , October 2016

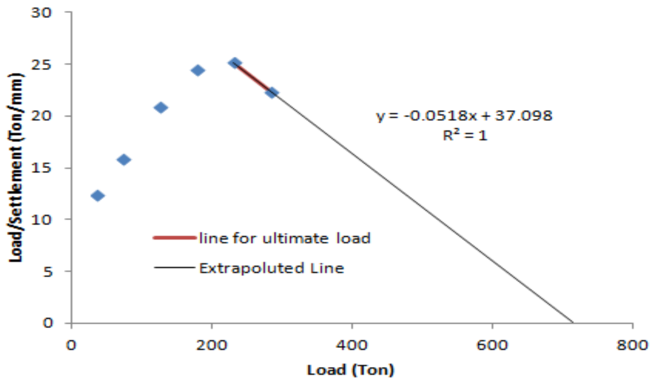

Fig.3.12 Ultimate Load by Decourt's (1999) Method, (Pile Diameter = 500mm)

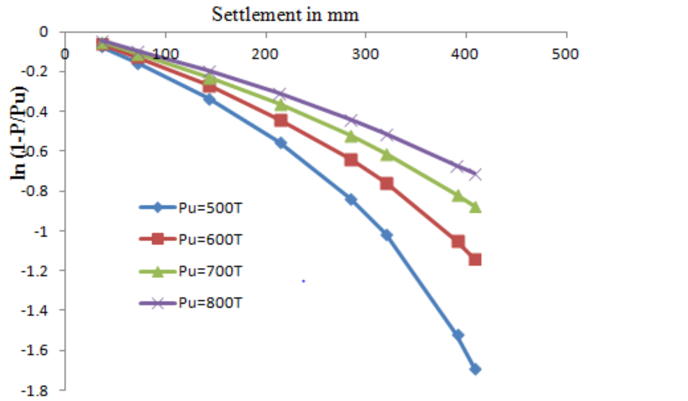

Fig.3.13 Ultimate load by Van der Veen's Method (1953), (Pile Diameter = 600mm)

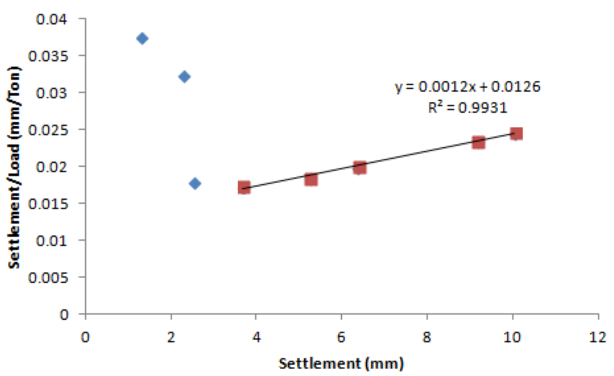

Fig.3.14 Ultimate Load by Chin's (1970) Method, (Pile Diameter = 600mm)

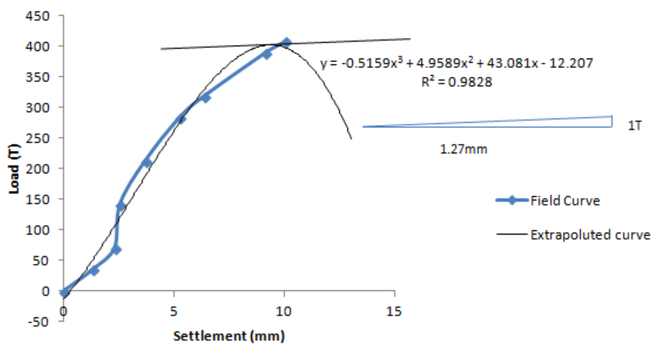

Fig.3.15 Ultimate Load by Fuller and Hoy (1970) method, (Pile Diameter = 600mm)

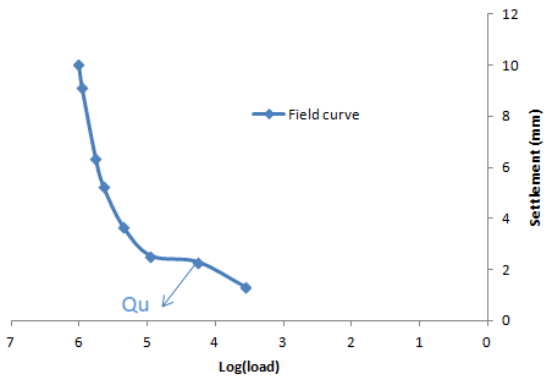

Fig.3.16 Ultimate Load by Shen's (1980) Method,(Pile Diameter = 600mm)

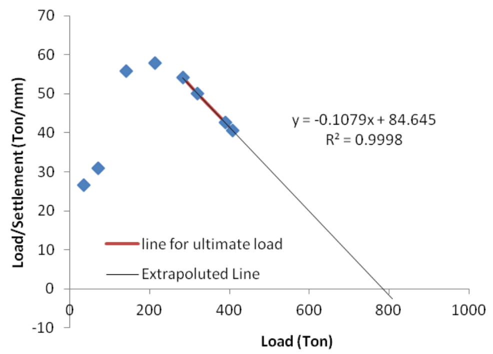

Fig.3.17 Ultimate Load by Decourt's (1999) Method, (Pile Diameter = 600mm)

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 3, Issue 10 , October 2016

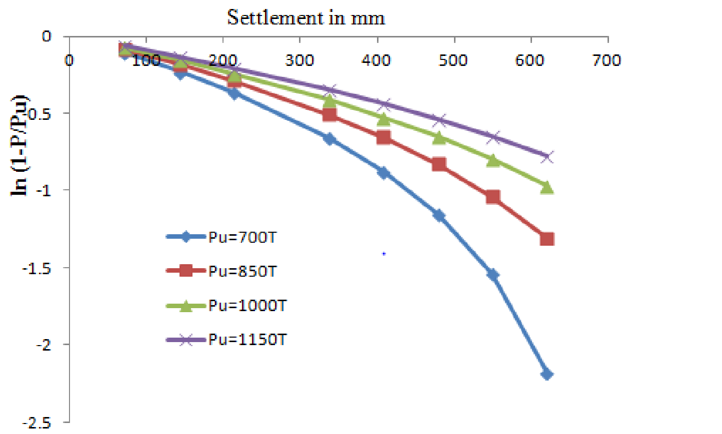

Fig.3.18 Ultimate load by Van der Veen's Method (1953), (Pile Diameter = 750mm)

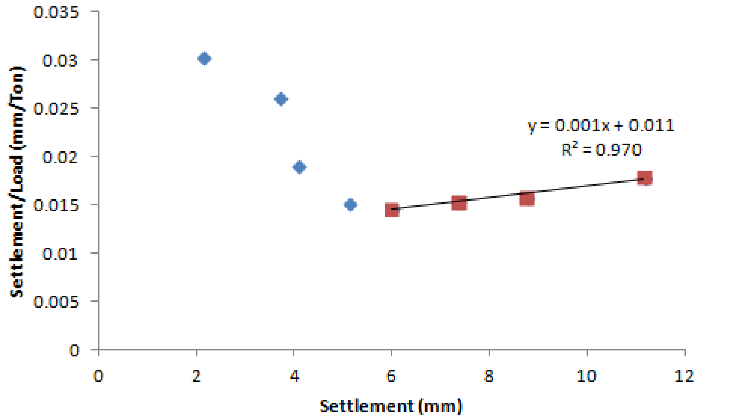

Fig.3.19 Ultimate Load by Chin's (1970) Method, (Pile Diameter = 750mm)

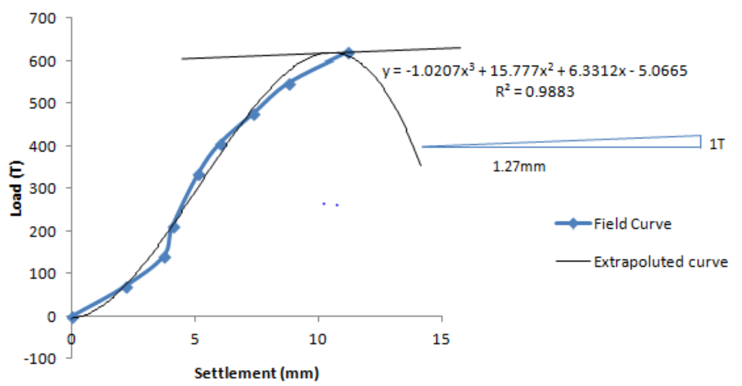

Fig.3.20 Ultimate Load by Fuller and Hoy (1970) method, (Pile Diameter = 750mm)

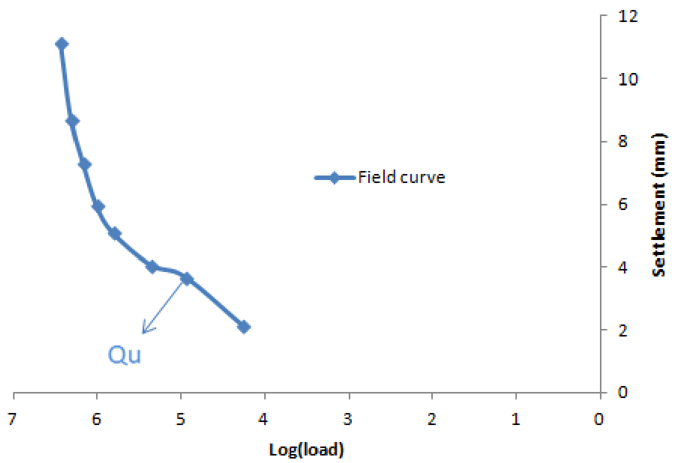

Fig.3.21 Ultimate Load by Shen's (1980) Method, (Pile Diameter = 750mm)

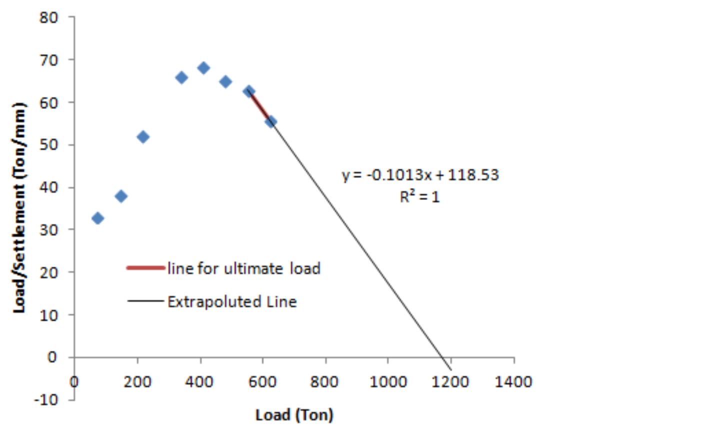

Fig.3.22 Ultimate Load by Decourt's (1999) Method, (Pile Diameter = 750mm)

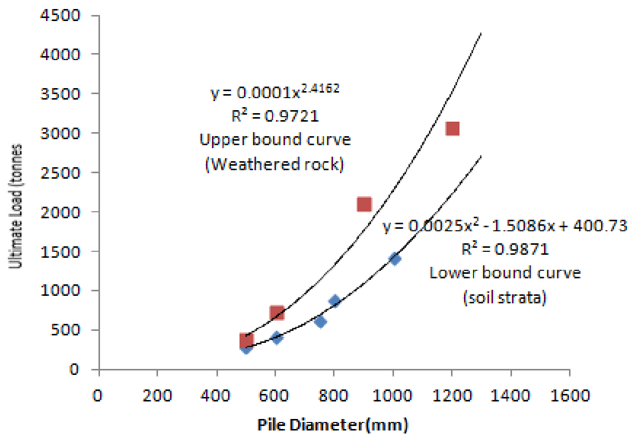

Fig. 4.1 Variation of Ultimate Load with Pile Diameter

All the above results are shown in Table 3.5.

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 3, Issue 10 , October 2016

Table 3.5 Ultimate Loads (T) Based on Different Empirical Methods

Pile Diameter (mm)	DeBeer Method (1968)	Van der Veen (1953) Method	Chin (1970) Method	Shen's (1980) Method	Decourt (1999) Method	Fuller and Hoy (1970) Method
500	341.05	700	714.28	177.28	716.18	283.8
600	411.12	800	833.33	390.01	784.48	402.38
750	628.38	1150	1666.67	549.56	1170.08	619.21

e. Comparison of Results from Various Empirical Methods with IS-14593

Factor of safety is obtained as the ratio of ultimate load by empirical methods to the safe load (IS 14593)[6] on pile and the results are presented in Table 3.6.

Table 3.6 Factors of Safety using Various Methods

Methods	Factor of Safety		
	Pile Diameter (mm)		
	500	600	750
De Beer (1968) Method	3	3	3
Van der Veen (1953) Method	6.161764706	5.834254144	5.497382199
Chin (1970) Method	6.279411765	6.082872928	7.979057592
Shen's (1980) Method	1.558823529	2.834254144	2.623036649
Decourt (1999) Method	6.294117647	5.718232044	5.607329843
Fuller and Hoy (1970) Method	2.485294118	2.933701657	2.952879581

f. Comparison of IS – 14593 and Empirical Methods

Factors of safety (ultimate load to safe load by IS – 14593)[6] are obtained using various empirical methods. It is seen that, factors of safety as computed by Fuller and Hoy (1970) method are in the range of 2.4 to 2.9. This shows that, Fuller and Hoy (1970) method is more suitable than other methods in respect to the study area.

III. SUMMARY AND DISCUSSION

A. Summary

The investigations that are reported in this study are confined to the analysis of static load tests on vertically loaded compressive piles in Pune cities. Bored cast-in-situ piles of diameter 500mm, 600mm, 750mm, 800mm, 900mm 1000mm and 1200mm were installed using suitable rotary drill rigs. Most of the piles were driven through soil stratum and socketed in weathered rock. The shaft friction in soil stratum and rock socket was measured using strain gauges welded on the pile reinforcement cage. The load settlement behavior was also plotted using dial gauge observations. IS -14593 were referred for evaluating the safe loads.

The results of the investigations for the sites Nanded City in Pune is summarized below.

B. Pile Diameter and Depth

Pile diameter and pile depth in soil stratum and socket for all the three sites are summarized below.

Table 4.1 Pile Depth in Soil Stratum and Rock Socket

Sr. No.	Site Location	Pile Diameter (mm)	Pile Length (m)	Depth of Soil Stratum (m)	Rock Socket Depth (m)
1	Nanded City, Pune	500	7.55	6.8	0.75
		600	7.65	6.8	0.85
		750	7.75	6.8	0.95

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 3, Issue 10 , October 2016

C. **Comparison of IS – 14593 (1998) and Empirical Methods**

Factors of safety (ratio of ultimate load to safe load by IS – 14593 are obtained using various empirical methods for all the sites. It is seen that, factors of safety as computed by Fuller and Hoy (1970) Method are in the range of 2.5 to 3.5 whereas, other methods such as De Beer (1968)Method, Van der Veen (1953) Method, Chin (1970) Method and Decourt (1999) Method give values higher than 3 whereas Shen's (1980) Method gives value less than 2. Therefore, Fuller and Hoy (1970) Method appears to be more suitable than the other methods in respect to the study area.

D. **Variation of Ultimate Load with Pile Diameter**

Based on the load-settlement curves of all the sites, the total ultimate loads as evaluated by Fuller and Hoy (1970) Method are compared with respective pile diameters and shown as Upper bound and lower bound curves in Fig.4.1.

In the upper bound curve, it is seen that higher ultimate loads are observed for piles embedded in weathered rock, whereas lower values are observed for piles embedded in soil stratum with socket depth as shown in the lower bound curve.

IV. CONCLUSION

Based on the above analysis for bored piles of three different sites, the following recommendations are suggested.

1 It is seen that, factors of safety as computed by Fuller and Hoy (1970) Method are more acceptable as compared to the other methods. Hence, it is recommended to use this method for the bored piles in Mumbai and Pune region.

2 It is recommended to use larger diameter piles with embedment in soil stratum and weathered rock and smaller diameter piles with embedment only in weathered rock.

3 The use of various empirical methods for computing ultimate loads requires extrapolation of the pile load-settlement data. It is therefore recommended to fit a best possible curve to the load- settlement data to facilitate the computation of ultimate load.

4 Pile Load tests on large diameter piles is expensive and inconvenient. The ultimate load for such piles can be determined from the load tests carried out on small diameter piles for the same soil. Hence, great economy can be achieved in the construction industry because we do not have to carry out pile load tests for such large diameter piles.

REFERENCES

[1] Chin, F.K.: Estimation of the Ultimate Load of Piles from Tests not Carried to Failure. Proceedings of Second SE Asian Conference on Soil Engineering., Singapore, 11-15th June 1970, pp. 81-92, 1970.
[2] De Beer, E. E.: Proefon der vindlij ke bijdrage tot de studie van het grensdra agvermogen van zandon der funderingen op staal. Tijdshift der OpenbarVerken van Belgie, No. 6, 1967 and No. 4, 5, and 6, 1968.
[3] Decourt, L.: Behavior of Foundations under Working Load Conditions, Proceedings of the 11th Pan-American Conference on Soil Mechanics and Geotechnical Engineering, FozDoIguassu, Brazil, August 1999, Vol. 4, pp. 453 – 488, 1999.
[4] Fuller, R.M. & Hoy H.E.: Pile Load Tests Including Quick -Load Test Method, Conventional Methods and Interpretations. HRB 333: 76-86, 1970.
[5] Chow, Y.K.: Analysis of Vertically Loaded Pile Groups, International Journal for Numerical and Analytical Methods in Geo-mechanics, 10, 1986, pp. 59-72.
[6] IS14593: Design and construction of bored cast in situ piles founded on rocks – Guidelines, 1998, Reaffirmed 2003.
[7] IS2911 (Part 4): Code of Practice for Design and Construction of Pile Foundation- Load Tests on Piles, 1985, Reaffirmed 1995.
[8] IRC: 78 – 2000: Standard Specifications and Code of Practice For Road Bridge Section – VII, Revised Clause 709.3.1.
[9] Teng, W. C.(): Foundation Design, Prentice-Hall, Inc., Englewood Cliffs, N. J., 1962.
[10] M.J. Tomlinson (1994): *Pile Design and Construction Practice*, Fourth edition, E & FN SPON, London, U.K. ,pp. 7-50.
[11] K.R. Arora (2011): *Soil Mechanics and Foundation Engineering*, Seventh Edition, Standard Publishers Distributors, India, pp.671-684.
[12] Fellenius, B.H.: The Analysis of Results from Routine Pile Load Tests, Ground Engineering, September, 1980.
[13] Fellenius, B.H.: What capacity value to choose from the results of a static loading test, Deep Foundation Institute, Fulcrum, winter 2001, pp. 19-22 and fall 2001, pp. 23-26, 2001.
[14] Static and Dynamic Load Test on Piles by Prof .D.M. Dewaikar and P.R. Bongirwar,
[15] Report submitted to The Director General (Road Development) Ministry of Road Transport and Highways Transport Bhavan (MORTH), New Delhi -2013