

Prediction of Settlement of Bored Cast-in-situ RCC Pile using N-Values

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ABSTRACT: Design of RCC piles requires knowledge of load-settlement behaviour of the piles with respect to the sub-soil at the site of construction. This data is normally obtained by conducting load test on test-piles at the construction site. In order to save precious time consumed in construction of test pile and the load testing of pile theoretical methods of prediction of pile load-settlement behaviour are also in practice. The method proposed by Poulos and Davis based on elastic theory, later modified by Bazara and Kurkur, is tested in this work by conducting Standard Penetration Tests (SPT) and Pile load tests on bored RCC under-reamed piles at 6 different locations. The results of these tests and comparison of the actual and predicted pile load-settlement curves are presented. Based on the results and observations a simple modification to the predicted curves is proposed for better agreement of the predicted curve with the actual curve.

KEYWORDS: Bored Pile, Load-settlement, Prediction, SPT, N-Value

I. INTRODUCTION

Bored cast in situ RCC pile is the most commonly used deep foundation for housing projects in India. In order to assess the suitability of pile foundation at a location and to estimate the ultimate bearing capacity of piles, load tests are performed on test piles constructed at the location. Bureau of Indian Standards BIS Code 2911(Part 4)-1985 [1] has specified for the procedure and minimum number of initial and routine pile load tests to be conducted for any building project with pile foundation. But this exercise of carrying out pile load tests consumes great deal of time and money. Since the standard Penetration Test (SPT) is carried out at construction sites during reconnaissance stage an acceptable method of prediction of pile load settlement relation from SPT N-value will, in addition to financial benefits, save precious construction time.

II. RELATED WORK

A literature study reveals that traditional methods of estimating the settlement of a pile rely on either an arbitrary assumption of stress distribution along the pile and use of Terzaghi's one dimensional theory or on empirical methods. Meyerhof [2] proposed an equation for computation of settlement of single piles in sand from the diameter of the pile base. Vesic [3,4], in his empirical formula, included the effect of elastic compression of piles in estimation of the settlement of displacement piles in sand under normal load level (safety factor > 3). Kaniraj and Ranganatham [5] presented settlement solutions for piles in deep deposit of normally consolidated clay by assuming the pile to be rigid with negligible elastic settlement. The authors used Mindlin's [6] equations for stress distribution in soil to estimate the consolidation settlement of single pile. Coyle and Reese [7] applied load-transfer methods for predicting load-settlement curve of pile by dividing it into a number of segments and using measured relationship between pile resistance and pile movement at various points along the pile. Poulos and Davis [8] adopted the theory of elasticity to arrive at a prediction of load-settlement relationship of pile employing Mindlin's equations. In this approach the pile was divided into a number of uniformly loaded elements and the solution was obtained by imposing compatibility between the displacements of the pile and the adjacent soil for each element of the pile. The Poulos-Davis method was modified by Bazaraa and Kurkur [9] by including the effect of change in modulus of elasticity of the soil with increasing load on the pile on the settlement prediction. Guo and Randolph [10] presented exact closed form solutions

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of estimating the settlement of piles in a non-homogeneous soil using load transfer approach derived from elastic continuum theory and developed a computer program to facilitate evaluation.

The present study evaluates the applicability of the Poulos-Davis method modified by Bazara and Kurkur is estimating the load-settlement behaviour of single bored cast-in-situ RCC piles.

III. POULOS-DAVIS METHOD

Poulos and Davis [8], based on elastic theory, proposed the following expression for estimation of settlement, s , of top of an incompressible pile in a half space:

$$s = \frac{P \times I}{E_s \times d} \quad (\text{Eq. 1})$$

where, P = Applied axial load on pile, E_s = Elastic modulus of soil along pile shaft, d = Diameter of pile, $I = I_0 \times R_k \times R_h \times R_v$ for floating piles and $I = I_0 \times R_k \times R_b \times R_v$ for end-bearing piles, I_0 = settlement influence factor for incompressible pile in semi infinite mass for soil having poisson's ratio of 0.50, R_k = correction factor for pile compressibility, R_h = correction factor for finite depth of layer on rigid base, h = total depth of soil layer over rigid base, R_v = correction factor for poisson's ratio, R_b = correction factor for stiffness of stratum.

Values of I_0, R_k, R_h, R_v, R_b are obtained from the charts by Poulos and Davis [8] with the knowledge of the following:

L = length of the pile, d_b = diameter of bulb in under-reamed pile, K = pile stiffness factor = $(E_p \times R_A)/E_s$, E_p = modulus of elasticity of the pile material, E_s = modulus of elasticity of soil at base, R_A = (Area of pile section)/(Area bounded by outer circumference of pile). For solid pile $R_A=1$.

Simplified method for construction of pile load-settlement curve:

For normal piles having length diameter ratio greater than about 20, the load settlement curves are generally straight until load of about 50-70% of failure load is reached. A linear elastic analysis is, therefore, considered adequate for prediction of settlement at working loads of such piles. A simplified overall load-settlement curve of pile can be constructed as a combination of relationship between shaft load and settlement and base load and settlement, which are assumed to be linear up to failure of the shaft and the base respectively. In case of clay the consolidation settlement has to be taken separately.

Shaft load vs. Settlement:

The amount of load carried by the shaft, P_s , is related to the applied load P as,

$$P_s = P \times (1 - \beta) \quad (\text{Eq. 2})$$

where, β = proportion of load carried by the base.

Assuming a linear shaft load vs. settlement relationship up to failure of the shaft, the settlement of the pile up to ultimate shaft resistance, P_{su} , is found from Eq.1. as

$$s_s = \frac{I}{E_s \times d} \times \frac{P_s}{(1 - \beta)} \quad (\text{Eq. 3})$$

Base load vs. Settlement:

The load carried by the base, P_b , is related to the total load P as,

$$P_b = \beta \times P \quad (\text{Eq. 4})$$

Assuming a linear base load vs. settlement relationship up to failure of base, the relationship between settlement and base load of the pile is found from Eq.1. as

$$s_{b1} = \frac{I}{E_s \times d} \times \frac{P_s}{\beta} \quad (\text{Eq. 5})$$

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The compression settlement of the pile shaft that occurs subsequent to the development of ultimate shaft resistance, P_{su} , is to be added to base settlement in Eq.5. Assuming the pile to be perfectly elastic the compression of the shaft, Δs , is found as,

$$\Delta s = \left[P_b - \frac{P_{su}\beta}{(1-\beta)} \right] \times \frac{L}{A_p E_p} \quad (Eq. 6)$$

The settlement due to base load is, therefore, $s_b = s_{b1} + \Delta s$ (Eq. 7)

Overall load vs. Settlement:

The overall load vs. settlement curve is constructed by superposition of the shaft load vs. settlement and base load vs. settlement curves as shown in Fig.1.

Modification by Bazara and Kurkur:

The Poulos-Davis method was modified by Bazaraa and Kurkur [9] by including the effect of change in modulus of elasticity of the soil with increasing load on the pile on the settlement prediction. In order to estimate the change in modulus of elasticity of the soil with increasing load on the pile (E_s/E_{s1}) vs. (P/P_u) chart is given by the authors[9], where,

$$E_{s1} = \text{Modulus of elasticity of the soil prior to installation of pile} = (150 + 8N_s) \text{ in kg/cm}^2 \quad (Eq. 8)$$

N_s = Average SPT N value along the pile shaft.

E_s = Modulus of elasticity of soil around the pile shaft upon installation of pile., P = Axial load on the pile.

For estimation of the value of β Bazara and Kurkur prepared β vs. E_s chart.

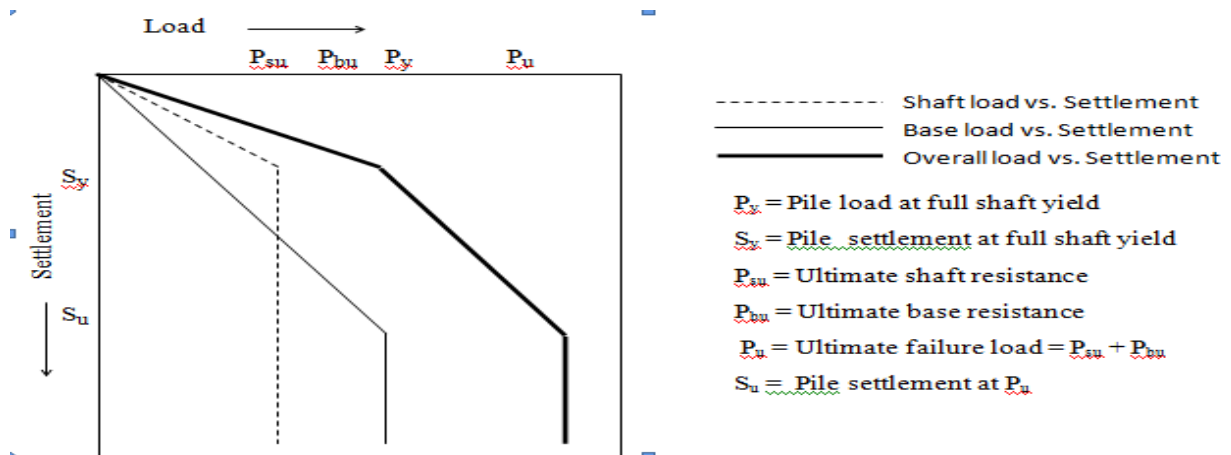


Fig.1. Overall load vs. settlement curve : superposition of shaft load vs. settlement and base load vs. settlement curve

P_y can be determined by trial and error. Assuming P_y equal to P_{su} as the first trial, (E_s/E_{s1}) is obtained from design chart [9]. With the knowledge of E_{s1} from Eq.8. E_s is calculated and then, the value of β is obtained from design chart [9]. From Eq.2, $P_y = P_{su} / (1-\beta)$. One or two cycles are usually sufficient to fix the value of P_y . The following correlations were proposed for prediction of the ultimate load of a single pile:

$$P_u = P_{su} + P_{bu} = (A_s \times q_{su}) + (A_b \times q_{bu}) \quad (Eq. 8)$$

where, P_{su} = Ultimate skin frictional load, P_{bu} = Ultimate base resistance load, A_s = Surface area of the pile, A_b = Base area of the pile, q_{su} = Ultimate intensity of skin friction, q_{bu} = ultimate intensity of base resistance.

The values of q_{su} and q_{bu} are determined directly from the correlations with SPT N value given by Bazara and Kurkur as below:

$q_{su} = 0.2 N_s$ and $q_{bu} = 4 N_b$ for bored piles, where, N_b is the SPT N value of the soil near the base of the pile.

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IV. METHODOLOGY

The methodology adopted for assessing the applicability of the method as described above was to compare the theoretical pile load-settlement curves based on SPT N-values at a location with the load-settlement curve obtained from field pile load tests in the same location. Standard Penetration Tests (SPT) and Pile load tests were conducted at altogether 6 different locations distributed over the city of Guwahati, Assam, India. The bore-logs are presented along with the N-values. Using the N-values the theoretical load-settlement curves were obtained by following the Poulos-Davis method modified by Bazara and Kurkur. The comparison of the theoretical and the actual pile load-settlement curves obtained from field tests are discussed and conclusion drawn on applicability of this procedure for estimating load-settlement behaviour of bored RCC piles.

V. PRESENTATION OF EXPERIMENTAL RESULTS , ANALYSIS AND DISCUSSION

The field work consisted of conducting Standard Penetration Tests on altogether six boreholes following the standard method laid down by Bureau of Indian Standards (BIS) in code IS:2131-1981[11]. The bore logs along with the corrected N-values are shown in Fig.2(a) for locations A, B and C.



















Depth From GL	Location - A			Location - B			Location - C		
	Bore Log	Description	Corrected N-Value	Bore Log	Description	Corrected N-Value	Bore Log	Description	Corrected N-Value
1.5m		Fill up soil	7		Loose silt	3		Silty clay	3
		Clay	6		Silty clay	6			2
4.5m		Silty Clay	5		Silty clay +org. Matr.	2		6	5
			4			3			6
7.5m		Clay	6		Clay	17		9	6
			8						
10.5m			6						
13.5m		Clay	11						

Fig.2(a) Bore logs obtained from SPT test conducted in Locations A, B and C with corrected N Values

The bore logs along with the corrected N-values are shown in Fig.2(b) for locations D, E and F.



















Depth From GL	Location - D			Location - E			Location - F		
	Bore Log	Description	Corrected N-Value	Bore Log	Description	Corrected N-Value	Bore Log	Description	Corrected N-Value
1.5m		Organic Clay	1		Clay	4		Silty soil	9
		Clay	9			4			Silty sand with clay
4.5m		Sandy Clay	15		Clayey Silt	5		26	25
			9			Sand	39		
7.5m		Clay	4		Clay	2			
			8			4			
10.5m			10			5			

Fig.2(b) Bore logs obtained from SPT test conducted in Locations D, E and F with corrected N Values

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Pile load test were conducted on six numbers of test piles located at six different locations A,B,C,D,E, and F. The tests were carried out as per the procedure detailed in Bureau of Indian Standards BIS Code 2911(Part 4)-1985. The detail description of the test piles are shown in Table 1.

Table 1 : Pile description and load-settlement estimations for Piles in locations A, B, C, D, E and F

Location of Test Pile		A	B	C	D	E	F
Pile Details	Type of pile	Cast-in-situ RCC Single Under-reamed Pile					
	Length of pile in mtr.	13.35	8.00	8.00	10.00	9.50	5.00
	Diameter of stem in mtr.	0.55	0.30	0.40	0.30	0.30	0.40
	Bulb Diameter in mtr.	1.00	0.75	0.80	0.90	0.90	1.00
Load-Settlement Estimation	P_{su} Ultimate shaft resistance in KN	323	85	80	150	185	170
	P_{bu} Ultimate base resistance in KN	347	230	190	230	305	780
	P_u Total ultimate load in KN	670	315	270	380	490	950
	P_y Applied load at full mobilisation of P_{su} in KN	490	120	130	195	240	274
	S_y Settlement of pile under P_y in mm	2.90	0.77	1.30	1.20	1.80	1.10
	S_u Settlement of pile under P_u in mm	7.45	10.00	5.90	9.50	13.80	19.50

The load-settlement curves of the piles located at Location A and Location B are plotted in Fig. 3(a) and Fig. 3(b). Based on the N-values obtained from SPT and the pile details the load-settlement behaviour is theoretically predicted following the Poulos-Davis method as detailed above. The estimated ultimate frictional resistance of pile shaft, ultimate base resistance, the total ultimate resistance of the pile and corresponding settlements for each pile are tabulated in Table 1. The predicted simplified linear load-settlement curves are also shown in Fig. 3(a)- and Fig.3(b) against the actual load-settlement curves obtained from field pile load tests on piles at location A and location B respectively.

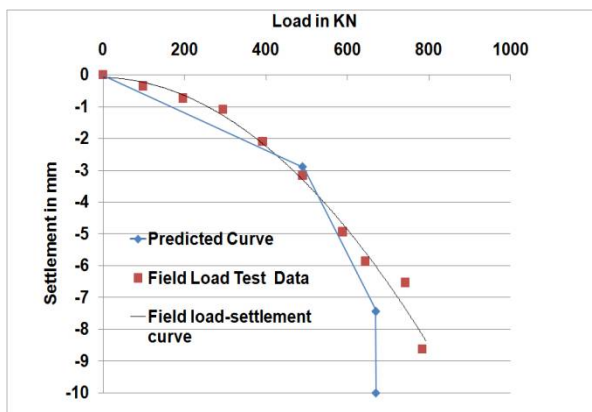


Fig.3(a): Actual and predicted curves at Location A

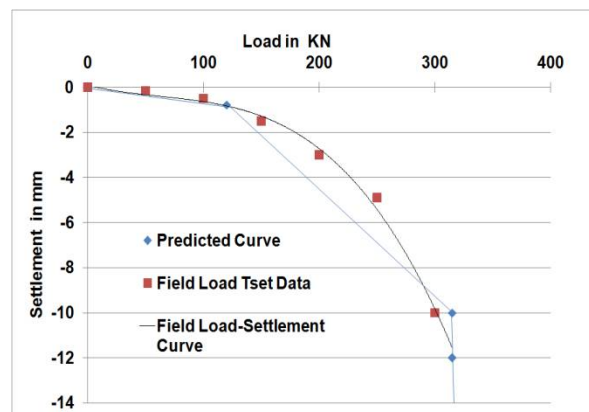


Fig.3(b): Actual and predicted curves at Location B

Similarly the predicted simplified linear load-settlement curves for piles at Location C and Location D are also shown in Fig. 3(c)- and Fig.3(d) against the actual load-settlement curves obtained from field pile load tests.

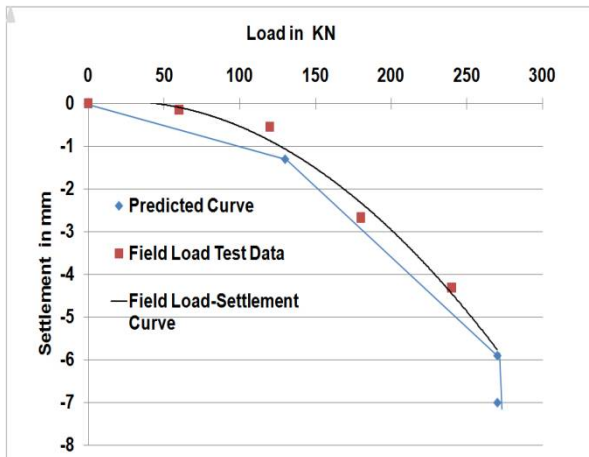


Fig.3(c): Actual and predicted curves at Location C

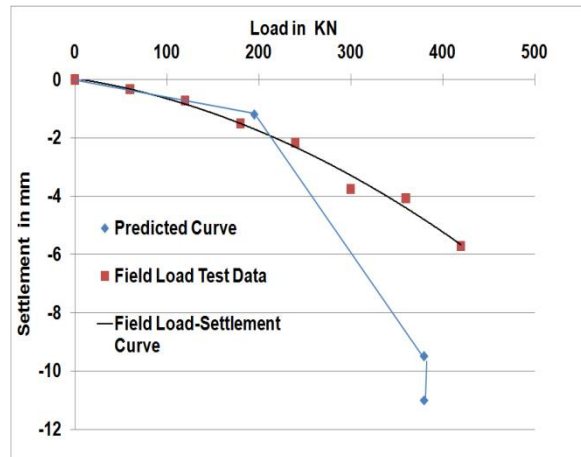


Fig.3(d): Actual and predicted curves at Location D

The predicted simplified linear load-settlement curves for piles at Location C and Location D are shown in Fig. 3(e) and Fig.3(f) against the actual load-settlement curves obtained from field pile load tests.

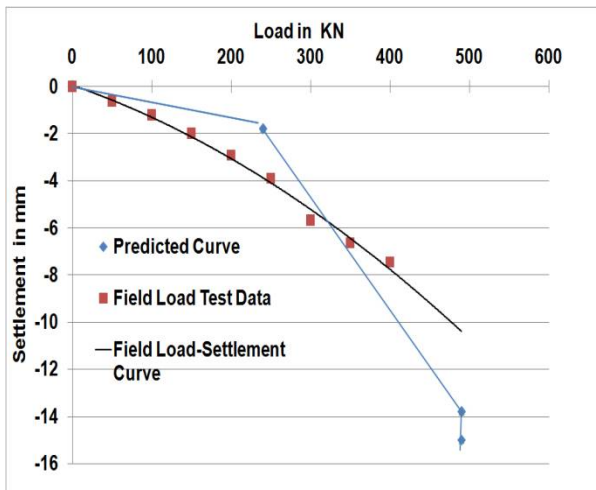


Fig.3(e): Actual and predicted curves at Location E

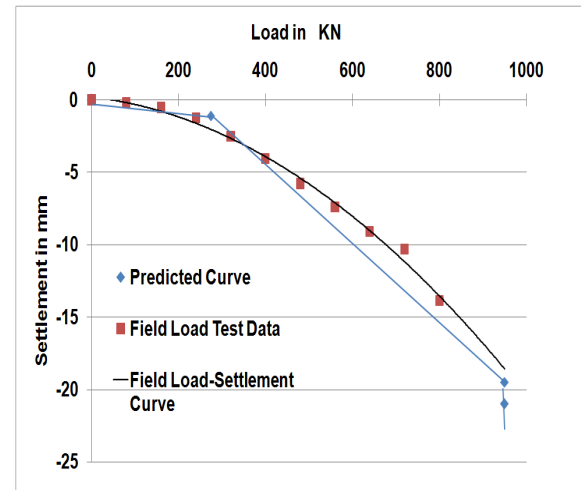


Fig.3(f): Actual and predicted curves at Location F

A study of the actual and predicted load-settlement curves in Fig.3(a)-(f) shows that due to the linear simplification the predicted curve does not fit well to the actual non-linear load-settlement data. A simple graphical modification to the Poulos-Davis prediction curve is therefore proposed in this study. In this graphical modification it is proposed to protrude back the straight prediction lines as shown in Fig.4. for the pile in location A. The external angles thus formed are bisected by straight lines as shown in Fig. 4 and the points of intersection of these angle bisecting lines are marked (as 'x' in the figure). These points are then connected with straight lines to obtain a modified prediction curve .

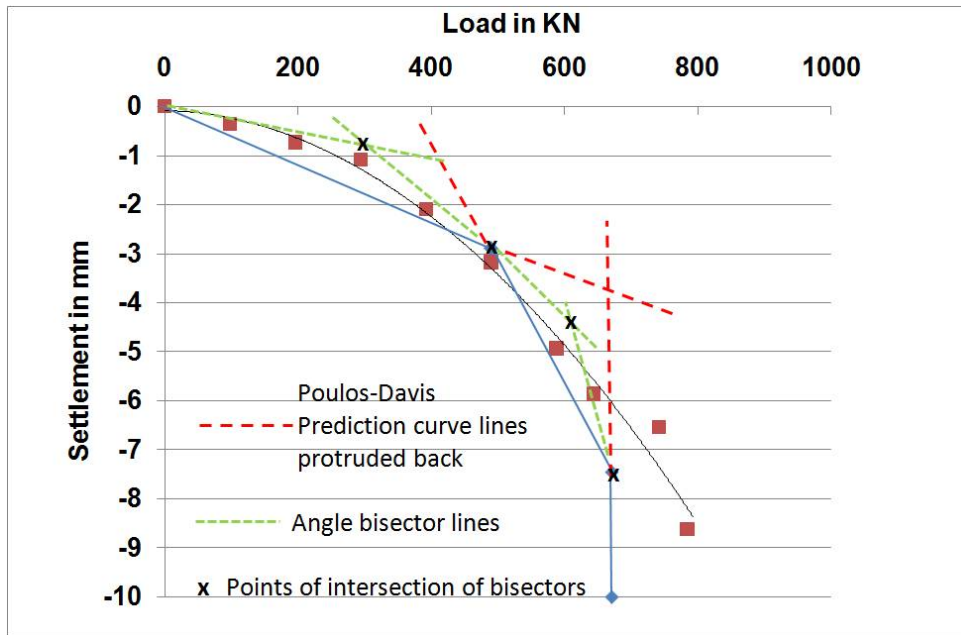


Fig.4. Construction of Modified Load-Settlement Curve for pile at location A

The points marked “x” are connected with straight lines to obtain a modified prediction curve as shown in Fig.5(a).

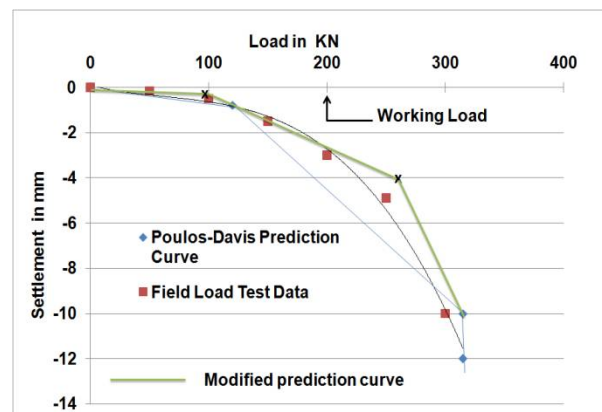
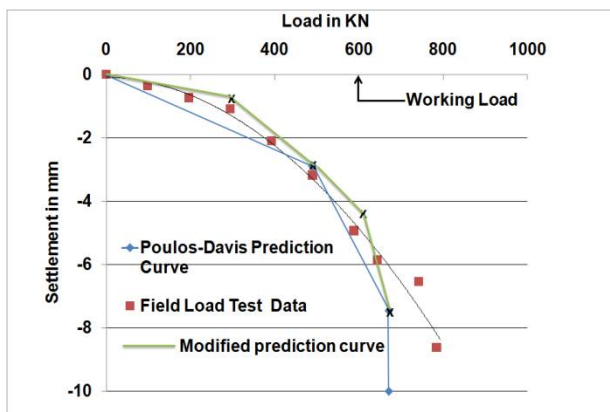


Fig.5(a) Modified prediction curve for pile at location A Fig.5(b) Modified prediction curve for pile at location B

This modified prediction procedure is applied to all the piles under study and the modified load-settlement prediction curves are shown in Fig. 5(a) –(f) for the piles in locations A to F along with actual field data obtained and the Poulos-Davis prediction curves. The working loads of the piles calculated as $2/3^{rd}$ of the ultimate load on the respective piles are also shown in Fig.5(a)-(f).

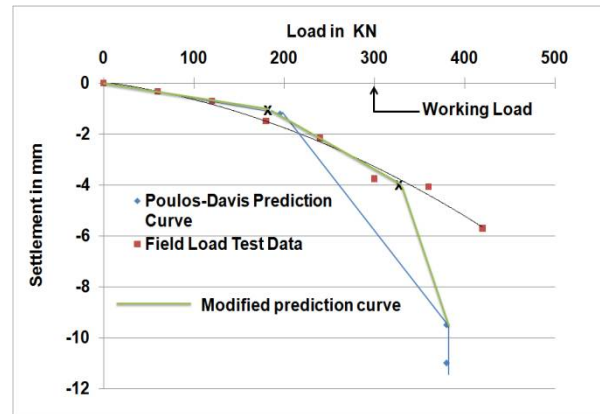
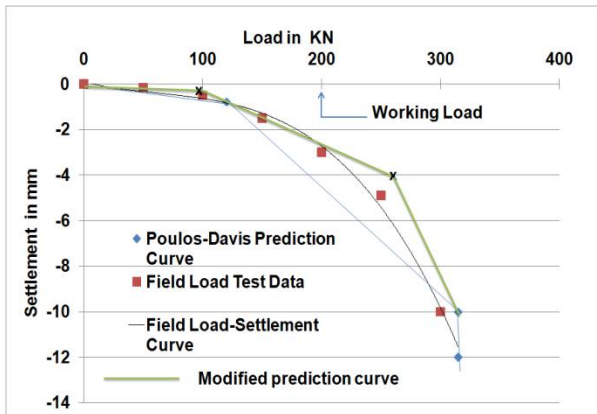


Fig.5(c) Modified prediction curve for pile at location C Fig.5(d) Modified prediction curve for pile at location D

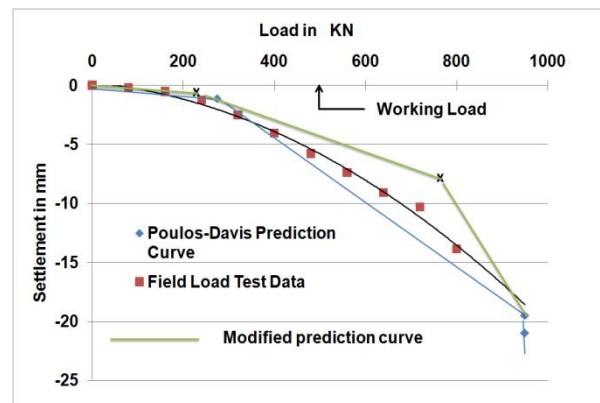
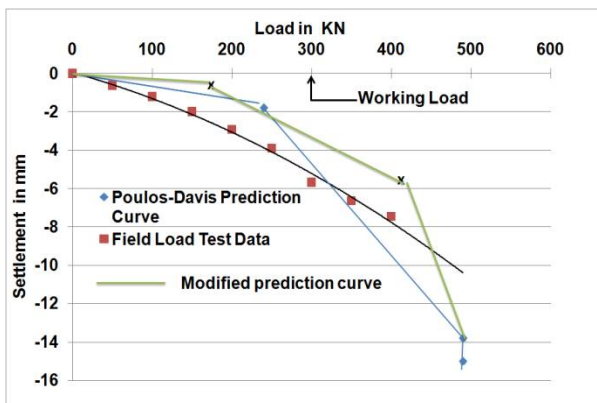


Fig.5(e) Modified prediction curve for pile at location E Fig.5(f) Modified prediction curve for pile at location F

In Fig.5(a), (b), (c), (d), (f), (g) it is observed that the predicted load-settlement curve after modification as proposed in this work closely fit the field pile load test data up to working load of the respective piles. The predicted curve in Fig.5(d) does not fit well with the field load test data at location E. The bore log of location E in Fig.2(b) shows a spike in the SPT data at 6m dept which may be due to presence of small boulder/ pebbles etc. , thus, giving a false N-value. This might have resulted in the deviation in the load-settlement prediction calculated based on SPT N-value. Beyond the working load value of the piles the predicted curves can not be taken as good fit curves of the actual field load-settlement data.

VI. CONCLUSIONS

The following conclusions are drawn based on the results and the discussions and analysis presented in this work:

- 1) Prediction of load-settlement curve from SPT N-value can be done based on elasticity solution given by Poulos-Davis with modification suggested by Bazara and Kurkur to account for the change in modulus of elasticity of the soil surrounding the pile with installation of the pile. However, the predicted bilinear curve does not compare well to the actual non-linear load-settlement curve.

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- 2) This simple graphical modification on the Poulos-Davis prediction curve proposed in this study shows better agreement of the predicted curve with the filed load-settlement curve. The predicted load-settlement curve after the modification closely fit with the field pile load test data up to working load of the pile
- 3) Beyond the working load value of the pile the predicted curves can not be taken as a good fit of the actual field load-settlement data.
- 4) The modification of the Poulos-Davis curve has been tested for in-situ RCC under-reamed piles only.

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