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"Correlation Analysis of Theoretical and Actual Pile Foundation Settlement using Standard Penetration Test Blow Count Value by Value Prediction Model"

KishanWidhani* ,Dr. Basant Kumar**

Abstract

The present study is focused on the evaluation of theoretical pile load settlement based on different approaches and analyzed the elimination of actual pile load test, which is costly and time-consuming. Under the suggested approach, actual pile load tests were performed at15thbattalion SAF, Indore, Madhya Pradesh, India over an area of 1034 Sqm, on eleven bore holes with 20.00 meters at shallow depth. Soil samples were collected for all bores, and a complete investigation was made to understand the type of soil. Corrected Standard Penetration Test Blow Count(SPT-N) values were analyzed through geotechnical investigation reports done at the site. Modules of elasticity of soil and pile material were evaluated by using corrected STP-N values and predefined grade of pile concrete, respectively. Pile stiffness and settlement influence factors were calculated by using a model graph. Actual settlement values were determined on different load ranges vary from 0 to 150 Tons. Finally, a conclusive table for all value prediction models for different given SPT-N was used for theoretical settlement and established a correlation. The result shows that there is a positive correlation between theoretical and actual settlement values. With the application of increment constant, actual settlement is equal to the theoretical settlement with accuracy for CL and CI soil values.

Keywords: Correlation, Pile Settlement, Software Approach, Value Prediction Model.

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*Ph.D. Scholar, Department of Civil Engineering, SIRT, SAGE University Indore (MP) India, kishu_widhani@yahoo.co.in

**Professor, Department of Civil Engineering, SIRT, SAGE University Indore (MP) India, basantkumarochani@gmail.com

1-Introduction

One of the most widely used foundations, Pile foundations, has now often been used in high-rise buildings, transmission towers, bridges and other valuable structures. These structures are often transmitting the load to the ground. In modern years, based on the theoretical methods described below, many researchers have supported the theoretical methods will be necessary to eliminate the pile load test for the calculation of the pile settlement. At present, the preponderance studies focus on the theoretical calculation methods of the pile settlement, such as the layer-wise summation method, the load transfer method, the elastic theory method and the shearing displacement method. Also, the ultimate bearing capacity of the pile tip is based on the pile displacement under the same load. As a result, the calculation methods of the pile settlement in the flat ground in terms of the theoretical approach needs more investigation due to its limitation. It can be useful to save time and cost if there will be a solution by theoretical sets of equations or research design models for a particular soil.

2-Objectives

The objectives decided for the study of settlement criteria are as follows:-

- To evaluate the SPT_N values from the soil investigation reports.
- To perform an actual pile load tests for settlement analysis.
- To evaluate theoretical settlement by SPT-N values.
- To correlate settlements between SPT-N value by actual pile load tests.
- To create value prediction models for SPT-N value settlement

3-Methodology and Data collection

Under the suggested methodology, actual pile load tests were performed at the site over an area of 1034 Square metres with eleven number of bore holes with a shallow depth of 20.00 metres approximately. Soil samples were collected for all boreholes, and a complete investigation was made to understand the type of soil. Table 1 shows the pile specification used for the pile load test. Table 2 shows the datasheet of different boreholes. Fig. 1shows a model of a graph for the determination of settlement influence factor. Fig.2 shows a flow chart of determination of settlement by SPT-N value model. Fig.3 shows pile load test at site. Fig 4 shows pile loaded beam with jack application. Table 3 and Table 4 show soil sample results for percentage material passing, Atterberg Limits respectively for borehole 1 (BH 1) with Disturbed soil sample (D) and Undisturbed Soil Sample (U.D.). Table 5 shows wet bulk density, original moisture content and dry bulk density for borehole 1.

Table 1: Pile specification used for pile load tests

Parameters	Values
Diameter of pile	400 mm
Length of pile	13000 mm

Grade of Concrete	M30
Grade of Steel	Fe 500
Minimum Clear cover	50 mm

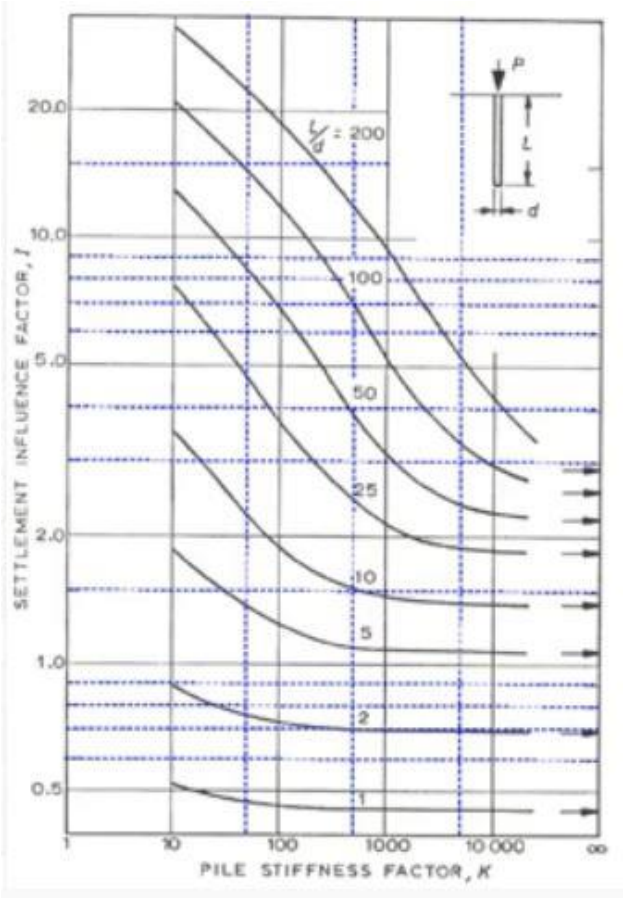

Figure 1: Model graph for determination of settlement influence factor

Table 2: Datasheet for different boreholes

Bore Hole no.	Depth below G. L. (m)	Type of sample	Group
1	12.35 to 12.80	S.P.T.	CL
2	12.35 to 12.80	S.P.T.	CI
3	12.35 to 12.80	S.P.T.	CL
4	12.35 to 12.80	S.P.T.	CI
5	12.35 to 12.80	S.P.T.	CI
6	12.35 to 12.80	S.P.T.	CI
7	12.35 to 12.80	S.P.T.	CI
8	12.35 to 12.80	S.P.T.	CI
9	12.35 to 12.80	S.P.T.	CI
10	12.35 to 12.80	S.P.T.	CI
11	12.35 to 12.80	S.P.T.	CI

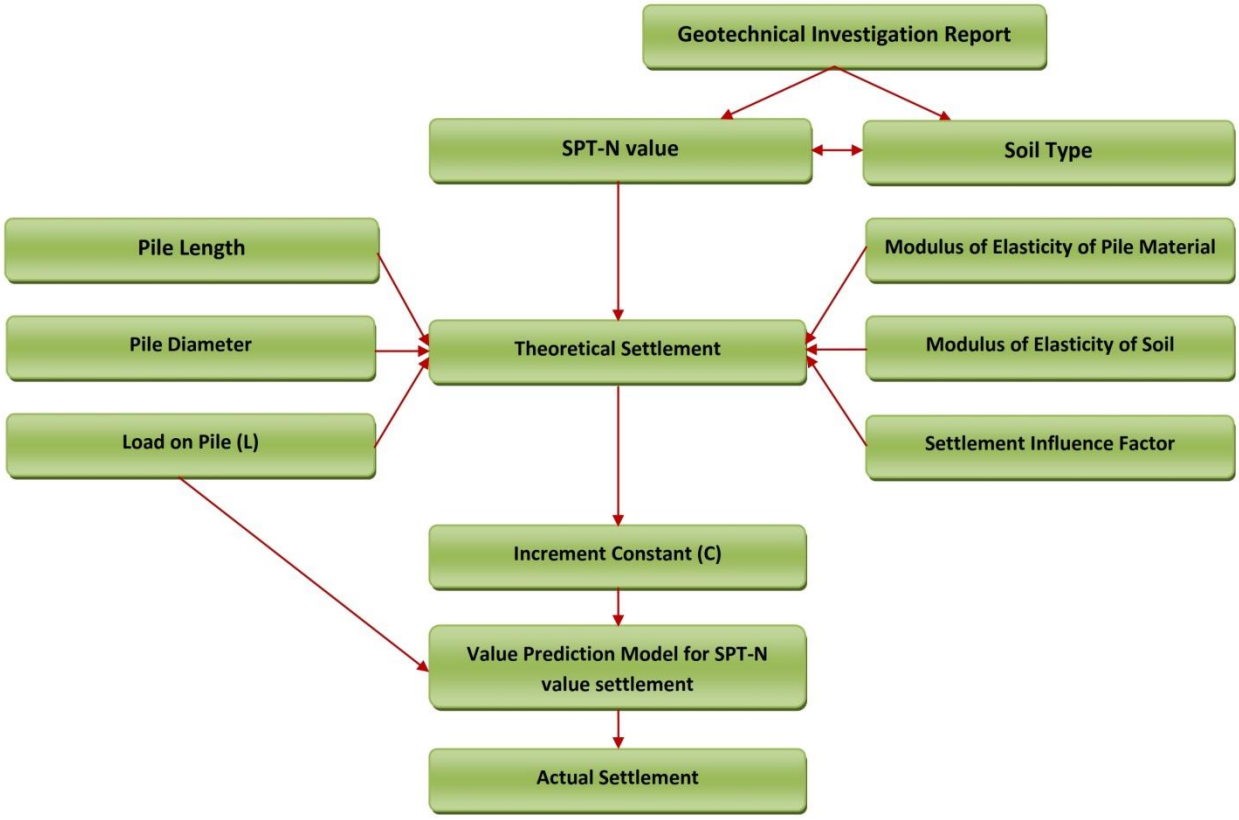

Figure 2**:** Flow chart of determination of settlement by SPT-N value model

Figure 3: Pile loaded at site

Figure 4: Pile loaded beam with jack application

Table 3: Data collected from a sample soil investigation for borehole1 with percentage material passing

Sample no.	Depth in meters below G.L.	Type of sample	% material passing			
			4.75mm	2mm	0.425mm	0.075mm
1	0 - 0.5	D.	97	96	92	87
2	1.5–1.85	U.D.	96	90	84	78
3	1.85 – 2.30	S.P.T.				
4	3 – 3.35	U.D.	97	92	88	82
5	3.35 – 3.80	S.P.T.				
6	4.50 – 4.85	U.D.	96	90	88	80
7	4.85 – 5.30	S.P.T.				
8	6 – 6.35	U.D.	100	100	100	99
9	6.35 – 6.80	S.P.T.				
10	7.50 – 7.85	U.D.	100	100	97	95
11	7.85 – 8.30	S.P.T.				
12	9 – 9.35	U.D.	100	100	98	96
13	9.35 – 9.80	S.P.T.				
14	10.50 – 10.85	U.D.	100	98	96	94
15	10.85 – 11.30	S.P.T.				
16	12 – 12.35	U.D.	90	82	76	62
17	12.35 – 12.80	S.P.T.				

18	13.50 – 13.85	U.D.	89	81	74	66

Table 4: Data collected from a sample soil investigation for borehole1 with soil Atterberg Limits

Sample no.	Depth in meters below G.L.	Type of sample	Atterberg limits		
			LL%	PL%	PI%
1	0 - 0.5	D.	38	23	15
2	1.5 – 1.85	U.D.	33	22	11
3	1.85 – 2.30	S.P.T.			
4	3 – 3.35	U.D.	44	23	21
5	3.35 – 3.80	S.P.T.			
6	4.50 – 4.85	U.D.	26	22	4
7	4.85 – 5.30	S.P.T.			
8	6 – 6.35	U.D.	38	23	15
9	6.35 – 6.80	S.P.T.			
10	7.50 – 7.85	U.D.	40	22	18
11	7.85 – 8.30	S.P.T.			
12	9 – 9.35	U.D.	40	22	18
13	9.35 – 9.80	S.P.T.			
14	10.50 – 10.85	U.D.	40	22	18
15	10.85 – 11.30	S.P.T.			
16	12 – 12.35	U.D.	30	22	8
17	12.35 – 12.80	S.P.T.			
18	13.50 – 13.85	U.D.	30	22	8

Table 5: Data collected from a soil sample investigation borehole 1 with wet bulk density, original moisture content and dry bulk density

Sample no.	Depth in meters below G.L.	Type of sample	Wet bulk density (gm/cc)	Original Moisture (%)	Dry Bulk Density(gm/cc)
1	0 - 0.5	D.	-	-	-
2	1.5 – 1.85	U.D.	2.05	16.70	1.76
3	1.85 – 2.30	S.P.T.			
4	3 – 3.35	U.D.	2.03	19.20	1.70
5	3.35 – 3.80	S.P.T.			
6	4.50 – 4.85	U.D.	1.98	18.40	1.67
7	4.85 – 5.30	S.P.T.			
8	6 – 6.35	U.D.	2.04	17.80	1.73
9	6.35 – 6.80	S.P.T.			
10	7.50 – 7.85	U.D.	2.05	17.20	1.75
11	7.85 – 8.30	S.P.T.			
12	9 – 9.35	U.D.	2.07	18.80	1.74
13	9.35 – 9.80	S.P.T.			
14	10.50 – 10.85	U.D.	2.09	19.50	1.75
15	10.85 – 11.30	S.P.T.			
16	12 – 12.35	U.D.	2.08	17.30	1.77
17	12.35 – 12.80	S.P.T.			
18	13.50 – 13.85	U.D.	2.08	16.80	1.78

4-Data Analysis

Data analysis was done on the basis of soil investigation reports, physical, visual and theoretical properties of soil and corrected STP N values were analyzed through geotechnical investigation reports done at the site. Modules of elasticity of soil and pile material were evaluated by using corrected STP N values and decided grade of pile concrete, respectively. Pile stiffens and settlement influence factors were calculated by using a model graph. Actual and theoretical settlement values were determined on different load ranges vary from 0 to 150 Tons. Finally, a conclusive table for all value prediction models for different given SPT-N was used to establish a correlation.

4.1 Evaluation of SPT-N values from the soil investigation report.

To determine safe allowable pressure for the foundation soil, a complete investigation was made on the geotechnical properties of soil in both infield and laboratory. The fieldwork consisted of eleven boreholes of13 meter depth each and soil sample was collected for all bores. Based on the results of the soil investigation report, we have SPT N-values, and settlement analysis of single pile was performed. Table 6 shows the datasheet for corrected SPT-N values. Fig. 5 shows pile load test results for BH1 to BH11

Table 6: Datasheet for corrected SPT-N values

Bore Hole no.	Depth below G. L.	Type of sample	Group	SPT values

	(m)			
1	12.35 to 12.80	S.P.T.	CL	38
2	12.35 to 12.80	S.P.T.	CI	75
3	12.35 to 12.80	S.P.T.	CL	43
4	12.35 to 12.80	S.P.T.	CI	67
5	12.35 to 12.80	S.P.T.	CI	57
6	12.35 to 12.80	S.P.T.	CI	81
7	12.35 to 12.80	S.P.T.	CI	49
8	12.35 to 12.80	S.P.T.	CI	54
9	12.35 to 12.80	S.P.T.	CI	50
10	12.35 to 12.80	S.P.T.	CI	57
11	12.35 to 12.80	S.P.T.	CI	38

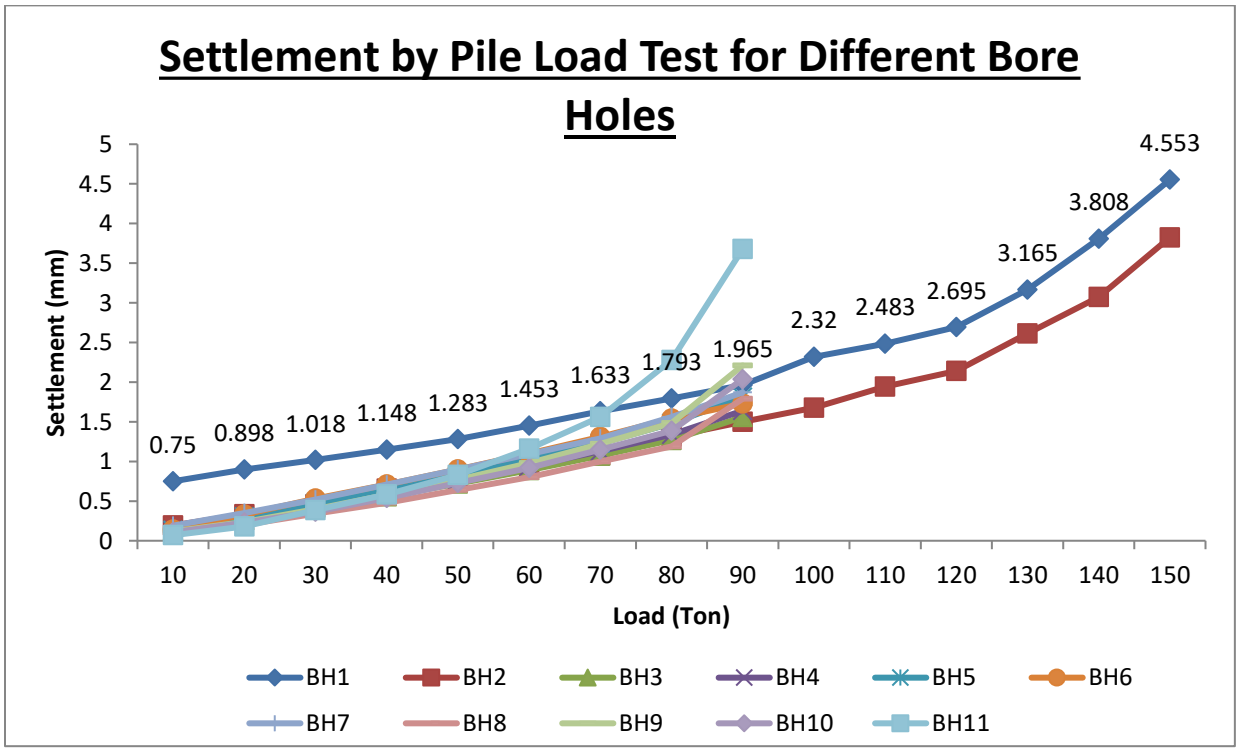

Figure 5: Pile load test result values for BH 1 to BH 11

4.2Analysis of settlement by SPT-N value.

With the help of geotechnical investigation report done at the site, various physical properties, visual properties along with theoretical properties evaluated, and predefined grade of pile concrete and depth, the corrected SPT-N values were analyzed to understand the type of soil and modulus of elasticity of pile and soil material were evaluated. The pile stiffness was calculated, and the settlement factor was found with the help of the influence chart. Table 7 shows the estimation of theoretical settlement for different boreholes with respect to given SPT-N values. Fig. 6 shows a

graphical representation of estimation of theoretical settlement by SPT-N value for different boreholes.

Table 7: Estimation of Theoretical settlement for different Bore Holes with respect to given SPT N values

Bore Hole no.	**SPT N value**	**Soil Type**	**Ep (KN/sq m)**	**Es (KN/sq m)**	**K=Ep/Es**	**I**
Bore Hole 1	38	CL	27386127.875	11406	2401.028	2.4
Bore Hole 2	75	CI	27386127.875	22506	1216.837	2.6
Bore Hole 3	43	CL	27386127.875	12906	2121.969	2.6
Bore Hole 4	67	CI	27386127.875	20106	1362.087	2.6
Bore Hole 5	57	CI	27386127.875	17106	1600.966	2.6
Bore Hole 6	81	CI	27386127.875	24306	1126.723	2.6
Bore Hole 7	49	CI	27386127.875	14706	1862.242	2.6
Bore Hole 8	54	CI	27386127.875	16206	1689.876	2.6
Bore Hole 9	50	CI	27386127.875	15006	1825.012	2.6
Bore Hole 10	57	CI	27386127.875	17106	1600.966	2.6
Bore Hole 11	38	CI	27386127.875	11406	2401.028	2.4

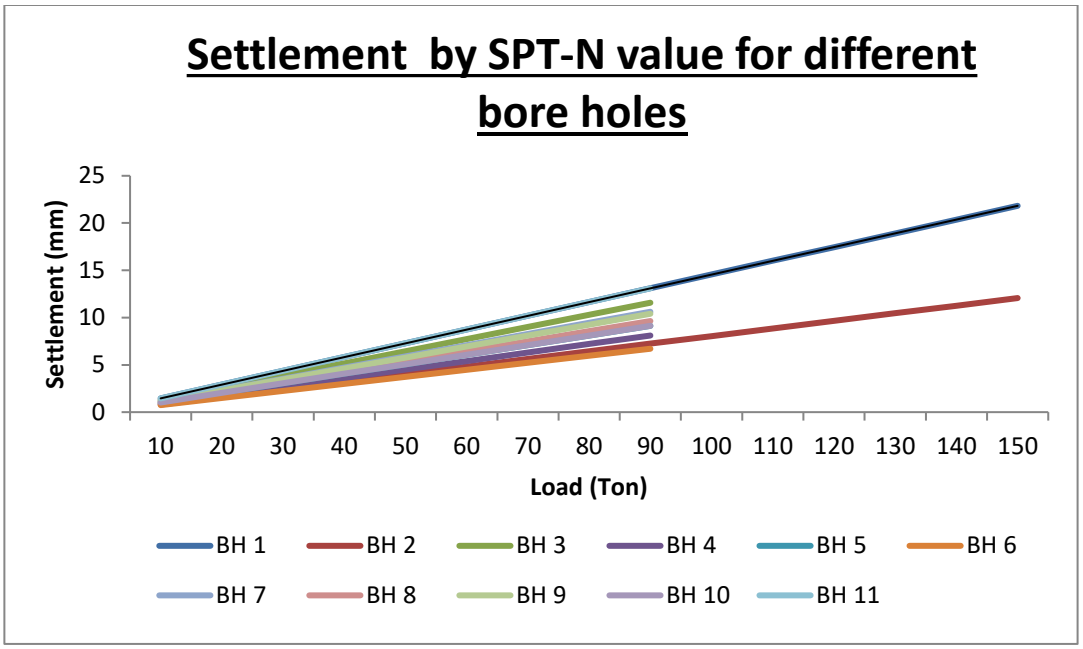

Figure 6**:** Graphical representation of estimation of theoretical settlement by SPT-N value for different boreholes

4.3 Correlation between settlements by SPT-N value and by actual pile load test.

Correlation analysis has been performed between actual settlement results by pile load test of the given area, and estimation of theoretical settlement for different boreholes with respect shared given SPT N values. After analysis, it has been found that there is a positive correlation between Theoretical settlement and Actual Settlement values with the value of correlation coefficient r with the number of correlating values N = 9. Table 8 shows Pearson's correlation coefficient between actual and theoretical settlement by SPT N values for different boreholes.

Table 8: Pearson's correlation coefficient between actual and theoretical settlement by SPT N values for different boreholes

Bore Hole no.	SPT N values	Coefficient of Correlation (r)
Bore Hole 1	38	0.956**
Bore Hole 2	75	0.966**
Bore Hole 3	43	0.994**
Bore Hole 4	67	0.995**
Bore Hole 5	57	0.994**
Bore Hole 6	81	1**
Bore Hole 7	49	0.995**
Bore Hole 8	54	0.967**

Bore Hole 9	50	0.965**
Bore Hole 10	57	0.968**
Bore Hole 11	38	0.924**
Result limiting values (r)	**Ranges from -1 to 1**	**Conclusion**
	1	Perfect Positive Correlation
	-1	Perfect Negative Correlation
	0	no Correlation
	0 to 1	Strong Positive Correlation
	-1 to 0	Strong Negative Correlation

**Correlation is significant at the 0.01 level (2-tailed).

4.4Analysis of theoretical settlements by SPT-N values using prediction models

Using all prediction models mentioned below for different SPT-N values and soil types; the theoretical settlement computations have been analyzed. Finally, a conclusive table for all value prediction models for different given SPT-N was used to establish a correlation. Table 9 shows value prediction models as per different SPT-N values**.** Table 10 shows a conclusive theoretical settlement for all Value Prediction Models for different SPT-N values**.** Fig.7 shows a comparative analysis of Theoretical and Actual settlement for different value prediction models based on SPT-N values.

Table 9: Value prediction models as per different SPT-N values

SPT N values	Model no.	Value prediction model
38	A1	$\mathbf{S_i} = \frac{(0.1455 \text{ x } L)}{(1+C)}$
75	B1	$\mathbf{S_i} = \frac{(0.0804 \text{ x } L)-0.0002}{(1+C)}$
43	C1	$\mathbf{S_i} = \frac{(0.1286 \text{ x } L)+0.0004}{(1+C)}$
67	D1	$\mathbf{S_i} = \frac{(0.09 \text{ x } L)-0.0003}{(1+C)}$
57	E1	$\mathbf{S_i} = \frac{(0.1014 \text{ x } L)+0.0002}{(1+C)}$
81	F1	$\mathbf{S_i} = \frac{(0.0745 \text{ x } L)+0.0001}{(1+C)}$
49	G1	$\mathbf{S_i} = \frac{(0.118 \text{ x } L)+0.0002}{(1+C)}$
54	H1	$\mathbf{S_i} = \frac{(0.1071 \text{ x } L)+0.0002}{(1+C)}$
50	I1	$\mathbf{S_i} = \frac{(0.1156 \text{ x } L) + 0.0002}{(1+C)}$

Table 10: Conclusive theoretical settlement for all Value Prediction Models for different SPT-N values

S no.	Soil type	SPT-N Value	Depth (m)	Increment constant 'C'	Value Prediction Model for SPT-N value settlement	Theoretical Settlement (mm)
1	CL	38	13	3.7935	A1	4.553
2	CI	75	13	2.1548	B1	3.820
3	CL	43	13	6.4185	C1	1.560
4	CI	67	13	3.9414	D1	1.640
5	CI	57	13	4.0431	E1	1.810
6	CI	81	13	2.8751	F1	1.730
7	CI	49	13	4.6781	G1	1.870
8	CI	54	13	4.3827	H1	1.790
9	CI	50	13	3.7086	I1	2.210
10	CI	57	13	3.4789	J1	2.038
11	CI	38	13	2.5604	K1	3.678

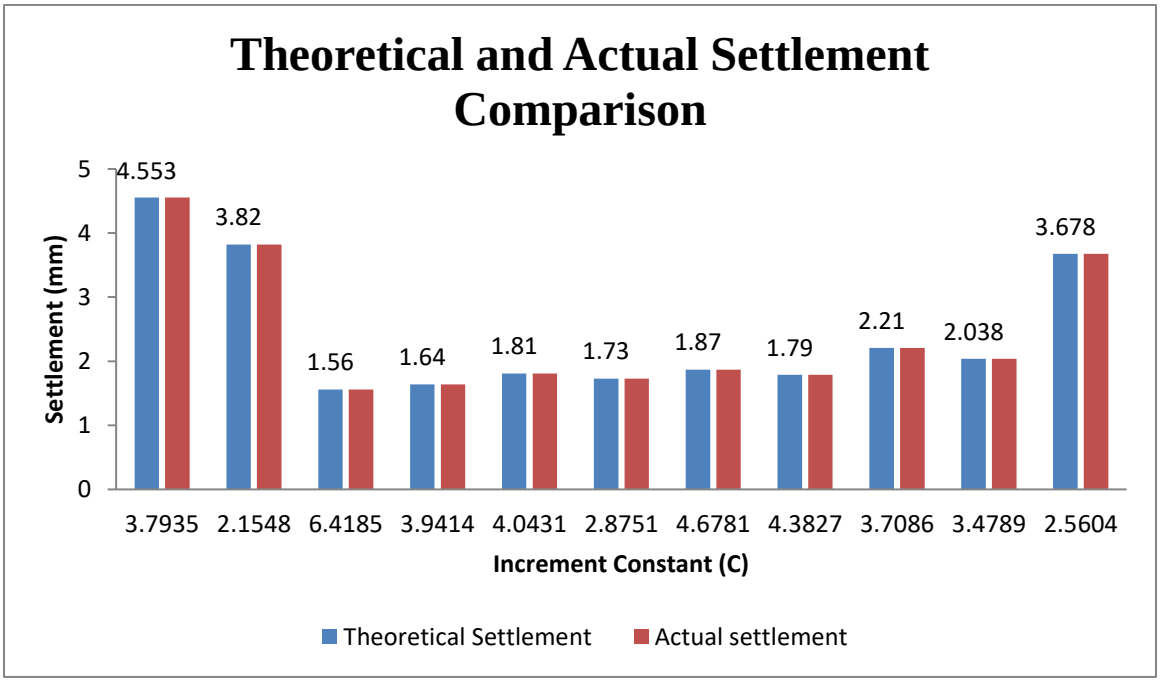

Figure 7: Comparative analysis of Theoretical and Actual settlement for different value prediction models based on SPT-N values

5-Conclusions

Based on the study on settlement analysis of pile foundation, by using various Value Prediction Models (VPM) to evaluate it, the following conclusions have been drawn:

- From the soil investigation report, it has been observed that CL and CI soil was found as per the USC system with different SPT-N values for all 11 boreholes.
- By performing the actual pile load test, the actual settlement value has been determined under

the load range of 0 to 150 Ton for BH1 &BH2 and under the load range of 0 to 90 Ton for BH 3 to 11, respectively.

- For the calculation of settlement by SPT-N value, the modulus of elasticity of pile material was estimated as 27386127.875(KN/sq m) with different Es and K values. The settlement influence factor has been found in the range of 2.4 to 2.6 for 11 boreholes.
- By observing the correlation analysis between the theoretical SPT-N value and actual settlements by pile load test, the Pearson's correlation coefficient (r) for 11 boreholes has been estimated in the range of 0.956 to 1, which is a perfect positive correlation and significant at the 0.01 level (2-tailed).
- For the settlement analysis, the approach is followed by Value Prediction Models (VPM) for SPT-N value that help helps in eliminating the actual pile testing.

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