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Cost Modeling of a Cast-In-situ Piles in North Eastern part of Tamil Nadu: A Case Study at a Selected Pile Construction Site

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Abstract:
Background*: The pile construction is a complicated process in comparison open foundation construction, insufficient or inaccurate data collection from a geotechnical investigation may lead to unforeseen delays and cost variations during the pile installation. The characteristics of a soil influences the depth of pile, size of the pile, grade of the concrete, quantity of reinforcement in addition to super structure load. While, casting the pile, preventive measure shall be planned, practiced from pile side wall collapse and also verticality of drilling pile bore must be maintained. The excavated soil should be disposed as per contract agreement. In this paper work, the relationship (i.e. a model) among various factors have been constructed to assess the quantity of steel and also a equation (i.e. a model) among the factors constructed to assess the cost of the pile based on it's depth, reinforcement quantity, grade of concrete and concrete quantity.*
Methods*: The secondary data has been collected from a ongoing project (contracted to M/s.XYZ Pvt. Ltd.,), situated in North Eastern part of Tamil Nadu. The Annova test on MS-Excel has been carried out, considering collected secondary data and the model has been generated.*
Results*: There is strong correlation among data and significance value is less than 0.05($p<0.05$), hence data is acceptable.*
Conclusion: *The constructed Regression model will be helpful in quantifying the reinforcement quantity (i.e. equation - 1) and cost of the Piling works (i.e. equation - 2). Parameters may vary over the extent of land, hence, the constructed model is regional specific.*
Key Word*: Pile foundations; Bored piles construction; Cost of pile.*

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I. Introduction

The super structure load is transferred to the sub soil through a foundation on to the hard strata. Considering the total load of the structure, soil characteristics the foundation will be designed as open foundation or pile foundation. Wherever the poor soil condition met, it may demand to have group of pile and then connected with group pile cap. The construction of pile foundation might be expensive, but still preferred due to shorter time frame required for completing the work or in other words speedy progress shall be observed. To carry out such exclusive works the works specialist is required, heavy duty machinery required to be deployed on work site. The pile construction is a complicated process in comparison to open foundation construction, insufficient or inaccurate data collection from geotechnical investigation may lead to unforeseen delays and cost variations during the pile installation. The characteristics of soil influence the depth of pile, size of the pile, grade of the concrete, quantity of reinforcement will be influenced by soil characteristics, in addition to super structure load. While, casting the pile, preventive measure of pile side wall collapse should be planned, practiced and also verticality of drilling pile bore shall be maintained. The excavated soil should be disposed as per contract agreement. In this paper work, the relationship (i.e. a model) among various factors have been constructed and also the a equation (i.e. a model) among the factors constructed to assess the cost of the pile based on it's depth, reinforcement quantity, grade of concrete and concrete quantity. The soil is of saline coastal alluvium in nature.

II. Scope

The scope of the work is
a) To study the characteristics of the pile foundation
b) To collect foundation depth, shape of the pile, rebar quantity, grade of concrete

III. Objective

The objective of this study is

a) To find the variables and to study them
b) To develop a cost relationship among Depth, S.B.C and reinforcement of the piles
c) To develop a cost relationship among reinforcement, Depth of Pile, S.B.C and R.C.C of the Piles

IV. Limitation

Peurifoy et al. have identified the Soil type (i.e. sand, clay, stiff clay, etc), drill type, method of spoil removal, pile axis adjustment, equipment operator efficiency, weather conditions, concrete pouring method and efficiency, waiting time for other operations (i.e. pile axis adjustment), job and management conditions and cycle time as cost influential factors in Cast in Bored pile construction. This paper work has been carried by considering depth of pile, total cost, S.B.C, reinforcement and cost of concrete factors. The data collected from a ongoing project (M/s.XYZ), which is situated in North eastern part of Tamil Nadu. Hence, the equation generated will be holds good for mentioned location only.

V. Review of Literature

David J. Lowe , Margaret W. Emsley, and Anthony Harding in their paper work "Predicting Construction Cost Using Multiple Regression Techniques" it is found number of a minimum of eight variables, a maximum of fourteen variables were considered for developing the regression models and concluded that regression model is bit inferior to the neural net work models but the differences were small.

Tarek M. Zayed and Daniel W. Halpin in their article titled "Productivity and Cost Regression Models for Pile Construction" it is found that to assess cycle time, productivity, and cost of pile construction using regression technique in the light of the factors like unseen subsurface obstacles; lack of contractor experience; site planning; pile equipment maintainability and concluded that the developed charts and models are useful in developing schedule and constructing price.

S.Surenth, R.M.P.P.V. Rajapakshe, I.S. Muthumala and M.N.C. Samarawickrama in their work titled "Cost Forecasting Analysis on Bored and Cast-In-situ Piles in Sri Lanka (Case Study at Selected Pile Construction Sites in Colombo , Sri Lanka)" it is found that cost prediction model developed for most influential factors like size of pile, pile drilling time, depth of pile, concrete pouring time, rock socket length, drilling type and weather conditions and concluded that there is strong relationship between cost of pile and pile size drilling time, depth of pile, concrete pouring time and rock socketing.

Zayed, Tarek & Halpin, Daniel in their article titled "Deterministic models for assessing productivity and cost of bored piles" and found that piling process personnel with a tool for assessing piling process productivity, cycle times, and cost of the piling process using the deterministic analysis technique and concluded that the dveloped charts were very handy to contractor and the client in planning and bidding their works.

B. B. Scfilmming and W. A. Garvey in their paper work titled "Monte Carlo Simulation of Pile Performance" In this study, the Monte Carlo simulation technique was discussed and applied to a specific example. The replacement of analytical inference with observation via simulation was emphasized. The example consisted of the prediction of design variables such as mean length, etc., for friction piles driven into a two-layer soil deposit overlying rock. The strength of the soil and depth to rock were treated as stochastic variables. The importance of the size of the sample required for a competent simulation was discussed. The purpose of this paper was to explain and demonstrate the use of the Monte Carlo simulation technique rather than solve a particular problem.

K. W. Chau in his paper work titled "Monte Carlo simulation of construction costs using subjective data" it is found that researchers completely rejected the use of subjective data and concluded that subjective estimates are not perfect substitutes for objective data.

VI. Foundation

To transfer the super structure load as well as weight of foundation on to the hard strata and for further distribution in to the sub soil, foundation concept has been developed and designed and implemented. The specific structure may remain same under ideal condition, but the soil characteristics may not remain same across the strata, hence foundation design may change from a place to other within few meters, hence sub soil study is mandatory to capture the subsoil characteristics. To capture the details bore log report with its proper interpretation is recommended. In normal constructions, the foundation like stepped footing, raft footing may be executed but if the sub soil founds weak, the it is recommended to transfer the load along the perimeter and total length of the pile, instead of a point load. The pile shall be of cast- in -situ or pre-casted one, the option of selecting a suitable pile depends on structural designers, project owners, project developers, soil condition and project importance. But in general it is in practice to cast-in-situ. Site conditions may demand for a group pile to be casted within a small distance (i.e. apart) and they should be connected by casting a pile cap. Pier will bottom/footing will rest in to this pile cap.

Soil

Tamil Nadu is being next sea, the soil is of saline coastal alluvium in nature.

Standard Penetration Test

Standard Penetration Tests (SPT) was conducted as per IS: 2131 – 1981. SPT split spoon sampler of standard dimensions was driven into the soil from the borehole bottom using 63.5 kg Hammer (doughnut hammer with rope and pulley having efficiency of 75%) falling from 75 cm height. The SPT weight was mechanically lifted to the specified height and allowed to fall freely on the anvil with the use of cat-head winch with one to one and half turn of the drum. Blow counts for the penetration of every 15 cm were recorded and the N is reported as the blow counts for 30 cm penetration of the sampler leaving the first 15 cm penetration as seating drive. When the number of blows exceeded 50 to penetrate the first or second 15 cm length of the sampler, the SPT N is regarded as more than 100. The test is terminated in such case and a record of penetration of the sampler under 50 blows or more is made. SPT refusal is recorded when there is no penetration of the sampler at any stage and also when a rebound of the sounding system is recorded. SPT 'N' values are correlated with relative density of non-cohesive stratum and with consistency of cohesive stratum. The consistency of soil with SPT depicted in Table 1

Table 1. Consistency / Relative density of Soil with SPT values

Correlation for Clay/ Plastic silt		Correlation for Sand/ Non-Plastic silt	
Consistency	Penetration Value (Blows/300 mm)	Relative Density	Penetration Value (Blows/300 mm)
Very Soft	0 to 2 Blows	Very loose	0 to 4 Blows
Soft	3 to 4 Blows	Loose	5 to 10 Blows
Medium Stiff	5 to 8 Blows	Medium	11 to 30 Blows
Stiff	9 to 16 Blows	Dense	31 to 50 Blows
Very Stiff	17 to 32 Blows	Very Dense	Above 50
Hard	Above 32		

Calculation of safe bearing capacity of soil (S.B.C) Values: It is compiled in Table 2

The data arrived from the geotechnical report for bore hole (BH)-42 and the No. of Piles is 28 and the depth of the Pile is 35.375m; No. of blows upto 44.29ft from 3.94ft = 39

Using Meyerhoff's Equation:- K=1+(0.33D/B); K=1+(0.33*(40.35/1.2)); K=12.10; Q_a=(N/4)/k

Qa = ((39/4)/12.10) ; Qa=0.814Kpi/sq.Ft; Converting Kpi/sq.ft to KN/m^2 ; Qa=47.88*0.814=38.99KN/m^2

Table 2: S.B.C value calculations sheet

Sl.No	Bore Hole	Pile No	No. of Piles	Depth as per drawing	Depth in Ft		No. Of blows or SPT Values	Meyerhof's Equation for Calculating S.B.C		
					From	To		K=1+0.33(D/B)	Qa=(N/4)/K in Kpi/Sq.Ft	Qa=(N/4)/K in KN/Sq.m
1	BH-36	P-143 to P-146A	32	28.375	0.00	3.28		1.90	0.00	0.00
					3.28	14.76	12	4.16	0.72	34.55
					14.76	24.61	18	3.71	1.21	58.13
					24.61	49.21	39	7.77	1.26	60.11
					49.21	77.10	51	8.67	1.47	70.42
					77.10	86.94	14	3.71	0.94	45.21
					86.94	108.27	100	6.86	3.64	174.38
2	BH-37	P-147 to P-151	32	29.375	0.00	9.84		3.71	0.00	0.00
					9.84	39.37	73	9.12	2.00	95.81
					39.37	49.21	48	3.71	3.24	155.01
					49.21	59.05	43	3.71	2.90	138.86
					59.05	68.90	31	3.71	2.09	100.11
					68.90	73.82	22	2.35	2.34	111.90
					73.82	93.50	50	6.41	1.95	93.32
					93.50	103.35	83	3.71	5.60	268.03
3	BH-38	P-152 to P-157	24	27.375	0.00	3.94		2.08	0.00	0.00
					3.94	9.84	9	2.62	0.86	41.06
					9.84	34.45	37	7.77	1.19	57.02
					34.45	44.29	42	3.71	2.83	135.63
					44.29	63.98	52	6.41	2.03	97.05
					63.98	73.82	81	3.71	5.46	261.58
					73.82	93.50	95	6.41	3.70	177.31
4	BH-39	P-156 to P-159	56	26.375	0.00	3.94		2.08	0.00	0.00
					3.94	49.21	45	13.45	0.84	40.05
					49.21	63.98	45	5.06	2.22	106.45
					63.98	73.82	42	3.71	2.83	135.63
					73.82	118.11	100	13.18	1.90	90.82
5	BH-39	P-160 to P-162,P-167 to P-171	56	36.375	0.00	3.94		2.08	0.00	0.00
					3.94	49.21	45	13.45	0.84	40.05
					49.21	63.98	45	5.06	2.22	106.45
					63.98	73.82	42	3.71	2.83	135.63
					73.82	118.11	100	13.18	1.90	90.82
					118.11	123.03	80	2.35	8.50	406.91
6	BH-39	P-158 to P-171	56	25.375	0.00	3.94		2.08	0.00	0.00
					3.94	49.21	45	13.45	0.84	40.05
					49.21	63.98	45	5.06	2.22	106.45
					63.98	73.82	42	3.71	2.83	135.63
					73.82	118.11	100	13.18	1.90	90.82
					118.11	123.03	80	2.35	8.50	406.91
					123.03	131.23	100	3.26	7.68	367.68
7	BH-40	P-172 to P-178	28	38.375	0.00	3.94		2.08	0.00	0.00
					3.94	54.13	54	14.80	0.91	43.66
					54.13	67.26	22	4.61	1.19	57.14
					67.26	131.23	60	18.59	0.81	38.63
8	BH-41	179 to 203		34.375	0.00	3.94	0	2.08	0.00	0.00
					3.94	8.20	8	2.17	0.92	44.07
					8.20	44.29	43	10.92	0.98	47.12
					44.29	47.57	5	1.90	0.66	31.46
					47.57	78.74	16	9.57	0.42	20.01
					78.74	88.58	35	3.71	2.36	113.03
					88.58	131.23	100	12.73	1.96	94.04

Table 3: S.B.C value calculations sheet (Continuation)

Sl.No	Bore Hole	Pile No	No. of Piles	Depth as per drawing	Depth in Ft		No. Of blows or SPT Values	Meyerhof's Equation for Calculating S.B.C		
					From	To		K=1+0.33(D/B)	Qa=(N/4)/K in Kpi/Sq.Ft	Qa=(N/4)/K in KN/Sq.m
9	BH-42	185 to 191	28	35.375	0.00	3.94	0	2.08	0.00	0.00
					3.94	44.29	39	12.10	0.81	38.59
					44.29	54.13	22	3.71	1.48	71.05
					54.13	67.26	45	4.61	2.44	116.87
					67.26	83.66	62	5.51	2.81	134.66
					83.66	93.50	73	3.71	4.92	235.74
					93.50	131.23	100	11.38	2.20	105.23
10	BH-43	192 to 201	40	37.375	0.00	3.94	0	2.08	0.00	0.00
					3.94	44.29	38	12.10	0.79	37.60
					44.29	63.98	19	6.41	0.74	35.46
					63.98	131.23	100	19.50	1.28	61.40
11	BH-44	202 to 209	61	33.375	0.00	3.94	0	2.08	0.00	0.00
					3.94	18.04	27	4.88	1.38	66.23
					18.04	44.29	45	8.22	1.37	65.55
					44.29	47.57	6	1.90	0.79	37.76
					47.57	67.26	17	6.41	0.66	31.73
					67.26	77.10	31	3.71	2.09	100.11
					77.10	131.23	100	15.89	1.57	75.35
12	BH-45	209-A to 211	17	32.375	0.00	3.94	0	2.08	0.00	0.00
					3.94	39.37	0	10.74	0.00	0.00
					39.37	59.05	17	6.41	0.66	31.73
					59.05	131.23	100	20.85	1.20	57.41

Bar bending schedule (BBS): It is depicted in Table 4, Table 5, Table 6 and Table 7 for various lengths.

Table 4: B.B.S for a length of 25.375m

BAR BENDING SCHEDULE FOR PILE OF PIER P200 TO P203(PILE LENGTH - 25.375 m)																		
S.NO	ID MARK	DIA OF BAR	SHAPE OF BAR	NO.OF BAR	LENGTH IN m	LAP LENGTH IN m	NO.OF LAPS	TOTAL LAP LENGTH IN m	CUTTING LENGTH IN m	8mm	10mm	12mm	16mm	20mm	25mm	32mm	REMARKS
1	MAIN ROD - 1A & 1B	16	12	12	25.225	1.216	2		27.657				331.884				
2	MAIN ROD - 1A & 1B	16	8	12	25.225	1.216	3		28.873				346.476				
3	HELICAL STEEL 2	12	150 mm	–	445.900				445.900			445.900					N*3.14(D+d)+8d
4	HELICAL STEEL 3	16	90 mm	–	152.900				152.900				152.900				N*3.14(D+d)+8d
5	INNER RING	16	1.003	18	3.247				3.247				58.442				
TOTAL LENGTH NOF BAR										0.000	0.000	445.900	889.702	0.000	0.000	0.000	
UNIT WEIGHT OF BAR IN kg										0.395	0.617	0.889	1.580	2.470	3.858	6.320	MT
TOTAL WEIGHT OF BAR IN kg										0.000	0.000	396.405	1405.729	0.000	0.000	0.000	1.802

Table 5: B.B.S for a length of 26.375m

BAR BENDING SCHEDULE FOR PILE OF PIER P212 TO P240(PILE LENGTH - 26.375 m)																	
S.NO	ID MARK	DIA OF BAR	SHAPE OF BAR	NO.OF BAR	LENGTH IN m	LAP LENGTH IN m	NO.OF LAPS	TOTAL LAP LENGTH IN m	CUTTING LENGTH IN m	8mm	10mm	12mm	16mm	20mm	25mm	32mm	REMARKS
1	MAIN ROD - 1A & 1B	16	12	12	26.375	1.216	3		22.727				272.724				
2	MAIN ROD - 1A & 1B	16	8	12	26.375	1.216	4		21.511				258.132				
3	HELICAL STEEL 2	12	150 mm	_	521.250				521.250			521.250					N*3.14(D+d)+8d
4	HELICAL STEEL 3	16	90 mm	_	152.900				152.900				152.900				N*3.14(D+d)+8d
5	INNER RING	16	1.003	13	3.247				3.247				42.208				
TOTAL LENGTH NOF BAR										0.000	0.000	521.250	725.964	0.000	0.000	0.000	
UNIT WEIGHT OF BAR IN kg										0.395	0.617	0.889	1.580	2.470	3.858	6.320	
TOTAL WEIGHT OF BAR IN kg										0.000	0.000	463.391	1147.023	0.000	0.000	0.000	1.610

Table 6: B.B.S for a length of 28.375m

BAR BENDING SCHEDULE FOR PILE OF PIER P200 TO P203(PILE LENGTH - 28.375 m)																	
S.NO	ID MARK	DIA OF BAR	SHAPE OF BAR	NO.OF BAR	LENGTH IN m	LAP LENGTH IN m	NO.OF LAPS	TOTAL LAP LENGTH IN m	CUTTING LENGTH IN m	8mm	10mm	12mm	16mm	20mm	25mm	32mm	REMARKS
1	MAIN ROD - 1A & 1B	16	12	12	28.225	1.216	2		30.657				367.884				
2	MAIN ROD - 1A & 1B	16	8	12	28.225	1.216	3		31.873				382.476				
3	HELICAL STEEL 2	12	150 mm	_	517.930				517.930			517.930					N*3.14(D+d)+8d
4	HELICAL STEEL 3	16	90 mm	_	152.900				152.900				152.900				N*3.14(D+d)+8d
5	INNER RING	16	1.003	18	3.247				3.247				58.442				
TOTAL LENGTH NOF BAR										0.000	0.000	517.930	961.702	0.000	0.000	0.000	
UNIT WEIGHT OF BAR IN kg										0.395	0.617	0.889	1.580	2.470	3.858	6.320	MT
TOTAL WEIGHT OF BAR IN kg										0.000	0.000	460.440	1519.489	0.000	0.000	0.000	1.980

Table 7: B.B.S for a length of 33.375m

BAR BENDING SCHEDULE FOR PILE OF PIER P200 TO P203(PILE LENGTH - 33.375 m)																	
S.NO	ID MARK	DIA OF BAR	SHAPE OF BAR	NO.OF BAR	LENGTH IN m	LAP LENGTH IN m	NO.OF LAPS	TOTAL LAP LENGTH IN m	CUTTING LENGTH IN m	8mm	10mm	12mm	16mm	20mm	25mm	32mm	REMARKS
1	MAIN ROD - 1A & 1B	16	12	12	33.225	1.216	2		35.657				427.884				
2	MAIN ROD - 1A & 1B	16	8	12	33.225	1.216	4		38.089				457.068				
3	HELICAL STEEL 2	12	150 mm	-	761.460				761.460			761.460					N*3.14(D+d)+8d
4	HELICAL STEEL 3	16	90 mm	-	152.900				152.900				152.900				N*3.14(D+d)+8d
5	INNER RING	16	1.003	18	3.247				3.247				58.442				
TOTAL LENGTH NOF BAR										0.000	0.000	761.460	1096.294	0.000	0.000	0.000	
UNIT WEIGHT OF BAR IN kg										0.395	0.617	0.889	1.580	2.470	3.858	6.320	MT
TOTAL WEIGHT OF BAR IN kg										0.000	0.000	676.938	1732.144	0.000	0.000	0.000	2.409

VII. Model development

The data of Reinforcement and SBC and Depth are collected from the M/s. XYZ Pvt. Ltd., (for confidentiality, it is renamed) project is furnished in the following Table 8

Table 8: Data of Depth of Pile, S.B.C and Reinforcement

S.No.	Depth of Pile (m)	S.B.C (KN/m^2)	Reinforcement (MT)	S.No.	Depth of Pile (m)	S.B.C (KN/m^2)	Reinforcement (MT)
1	24.375	85.84	1.784	9	33.375	53.82	2.409
2	25.375	163.94	1.802	10	34.375	49.96	2.388
3	26.375	74.59	1.610	11	35.375	100.31	2.471
4	27.375	109.95	1.913	12	36.375	129.98	2.56
5	28.375	63.26	1.980	13	37.375	33.62	2.6
6	29.375	120.38	2.099	14	38.375	34.86	2.62
7	30.375	121.74	2.135	15	39.375	37.44	2.704
8	32.375	22.29	2.495				

VIII. Annova out put

The depth of pile, S.B.C and reinforcement is considered to carry out the test. The Annova test has been performed on MS-Excel and the summary of output displayed in Table 9 and Table 10

Table 9: Regression statistics

Regression Statistics	
Multiple R	0.962684501
R Square	0.926761449
Adjusted R Square	0.914555023
Standard Error	0.103718536
Observations	15

Table 10: Anova output

	df	SS	MS	F	Significance F
Regression	2	1.633512	0.816756	75.92407	1.54326E-07
Residual	12	0.12909	0.010758		
Total	14	1.762602			

From the above table it is clear that there is a significant difference between the variables.

The depth of pile, total cost, S.B.C, reinforcement and cost of concrete is considered to carry out the test. The Annova test has been performed on MS-Excel and the summary of output displayed in Table 9 and Table 10

Table 11: Regression statistics

Regression Statistics	
Multiple R	1
R Square	1
Adjusted R Square	0.909090909
Standard Error	5.56241E-11
Observations	15

Table 12: Anova output

	Df	SS	MS	F	Significance F
Regression	4	1.35924E+11	33980968530	1.46436E+31	8.7018E-154
Residual	11	3.40344E-20	3.09404E-21		
Total	15	1.35924E+11			

From the above table it is clear that there is a significant difference between the variables.

IX. Model construction

Regression equation for depth of pile, S.B.C and reinforcement variable. The quantity of reinforcement calculated based on the equation -1

Multiple Regression equation, $Y=(0.068608) * (X_1) - (0.00016) * (X_2) + (0.06183)$ --------- equation-1

Y= Quantity of reinforcement in MT; X_1=Depth in m; X_2= S.B.C in KN/m^2

Regression equation for pile, total cost, S.B.C, reinforcement and cost of concrete. The cost of pile calculated based on the equation -2

Multiple Linear Regression equation, $Y=(1.843) * (X_3) + (68943) * (X_4) + (1) * (X_5) - (4.65)$ --------- equation -2

Y= Cost of Pile in Rs; X_3= S.B.C in KN/m^2; X_4= Reinforcement in MT; X_5= R.C.C Cost of Pile in Rs

X. Findings

Findings : The findings from the study is as follows

- R is the correlation coefficient, its level varies between +1 to -1. The more it is nearer to +1, the better correlation is established, here r = 0.9977 indicates a very strong correlation between the set of samples.
- R^2 indicates the amount of change in dependent variable that can be attributed to the independent variable. R^2 of 0.995 indicates that 99.5% of the variation of y-values around the mean are explained by the x-values, in other words it verifies the fast that there is very strong correlation between the variables.

- Since the significance F value is less than 0.05, it indicates that the model can accurately explain variation in the dependent variable.

XI. Conclusion

The constructed Regression model will be helpful in quantifying the reinforcement quantity (i.e. equation -1) and cost of the Piling works (i.e. equation -2). This model is regional specific, hence not possible generalize across the universe due to varying parameters.

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