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Research Article

“An Approach for Settlement Analysis by Various Methods: An Immense Review”

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Abstract

The design of the high-rise buildings is necessary for the assessment with the base foundation requirements and techniques so that the ultimate load can be transferred to the subsoil and to make such designs safe against all static loadings. This article presents a detailed review of the literature on pile foundation of high-rise buildings under multiple soil strata, and also describes the estimation of settlement through various theoretical, experimental and software approaches**.** Under the present study a rigorous review has been made on the different approaches used by various researchers to find out the correlation between theoretical and actual settlement values of piles and to predict the limit before failure. The study shows that various statements Duncan-Chang model, Mindlin–Geddes method, Bowles, Schmertmann methods, Hook’s law used in literature survey helps in finding out the optimized range of pile settlement through numerical approach which is 40% to 75% and no suitable correlation is found between the theoretical and actual settlement analysis of pile foundation. Factors considered: load on pile top, pile material grade, pile length and soil properties. The software ABAQUS and PLAXIS approach also adopted by few researchers to get the quick and prototype results.

Keywords: Correlation, Pile, Settlement, Software Approach, Static Loading.

1-Introduction

The settlement of the foundations should be assessed with great attention to high-rise buildings, towers, power plants and similar expensive buildings. Settlement analysis plays an important role in the construction of foundations, despite the fact that only a few modern buildings have been destroyed by excessive settlements, frequent cases of partial collapse or localized destruction of the structural element. With the exception of random coincidences, soil subsidence calculations are only the best estimates of deformations that can be expected when applying a load. Prediction of pile settlement can be achieved as a sum of pile settlement and elastic deformation of the pile. The main factor that significantly complicates the design of the foundation is that the soil parameters must be obtained on the construction site before calculating the project. Theoretical equations of pile construction, diagrams and various soil factors and

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parameters are based on previously conducted research. If the approach of theoretical pile settlement is similar to actual pile load test, it has easy to predict the load and settlement and reducing the time and money in field test.

2- Objectives of the Study

The objectives decided for the review of literature and their analysis for the study of settlement criteria are as follows:-

- To study the static loading criteria for the elimination of the actual pile testing for settlement of in-situ site conditions.
- To study the correlation between theoretical and actual pile settlement by different model approaches.

3-Literature Review

The different searches based on the diverse aspects with their key point consideration. They are as follows:

1-The settlement calculation was computed by (Binhui Ma & et al. 2021) [1]by Duncan-Chang model and Hook's law of soft clay foundation for N^{th} number of various layers by mathematical calculations and the theory of wedge stress. Main parameter considered was stresses, vertical load and settlement.

2-The settlement on sloppy area for the vertical loaded single pile under vertical load and settlement was proposed by (Chong Jiang& Wen-yan Wu et. al. 2020) [2].Research based on the shear displacement method and the principle of deformation control, the displacement and deformation of a composite long and short piles foundation was presented.

3- Based on the shear displacement method and the principle of deformation control, a composite long and short piles foundation was presented (TianzhongMa &Yanpeng Zhu et. al. 2020) [3] for 4 and 8 numbers of piles. The calculation of the displacement and application of load accordingly was their main parameter.

4-The relationship between the compression modulus and soil gravity stress and cone penetration resistance was done on Wuqi–Dingbian expressway using post-grouted piles (Zhijun Zhou et. al. 2019) [4]. Based on parameter considered, q_c and $E_{s,z}$, for the determination of settlement.

5- The study of capped piles composite foundation under embankment for settlement analysis was done by Es and Ep method, settlement reducing pile method and by field tests methods. ABAQUS software was used to validate the accuracy of these methods. (Ming-Quan Liu et. al. 2020) [5]

6- A review report was summarized for the typical type of tall and super tall building based on their fundamental geotechnical parameters and correlations have done based on SPT calculations on pile ultimate shaft resistance, ultimate base resistance, soil Young's Modulus below raft level, along and below pile under vertical loading. La Azteca Building in Mexico City, Mexico, Burj

Khalifa in Dubai, The Incheon 151 Tower in Incheon, South Korea, Tower in Jeddah, Saudi Arabia have been selected. (Harry G. Poulos 2016) [6]

7- Correlation effect between E_u and un-drained strength S_u have established (Gopal Ranjan and A.S.R. Rao) [7] for the evaluation of settlement by the given range of Modulus of Elasticity of Soil Es. They have provided computations for normally consolidated sensitive clay, normally over consolidated clay and heavily over consolidated clay by field value tests and hit and trial approach.

8- Site investigation was performed (Hisham T. Eid and Khaldoon Bani-Hani 2012) [8] for the correlation of analytical and experimental settlement of axially loaded piles entirely embedded in rock. Main parameters considered were the Modulus of Elasticity of soil Es, Modulus of Elasticity of pile material Ep, influence factor I and L/D ratio.

4- Data Collection

Data was collected from the selected papers for various parameters considered in the literature review.

4.1 Settlement calculation for Mth soil layer

It was obtained by using combine model considering various input parameters: soil layer, poisons ratio, unit weight, cohesion, frictional angle, initial porosity, initial deformation modulus. Table 1 shows input parameters considered for settlement.

$$S = \sum_{j=1}^{M} sj$$

Model A

Where, S is settlement (in mm) and $\sum_{j=1}^{M} sj$ is sum of settlement values in j=1 to Mth soil layer.

Table 1: Parameters Taken for Calculation

Soil layer	Poisson’s ratio, μ	Unit weight, γ (kN·m^3)	Cohesion, C (kPa)	Friction angle, φ	Initial porosity, e_0	Initial deformation E_0 modulus,(MPa)
Zhanjiang clay	0.38	17.3	36	23.5	1.45	3.4

4.2 Settlement on sloppy area for the vertical loaded single pile.

The estimation the settlement on sloppy area for the vertical loaded single pile obtained by using

$$\Delta Sij = \frac{Pi\Delta hj}{Et}$$

Model B

Where, ΔSij is change in settlement at ijth layer, Pi is load applied in KN, Et is Modulus of elasticity on test material and Δhj is change in length of pile. Table 2 shows soil and pile properties.

Table 2: Soil and pile properties

Material Young's Modulus (Pa)	Poisson's ratio D	Density (kg·m−3)	Cohesion (Pa)	Cohesion (Pa)	Friction angle (°)	Dilatation angle (°)
Pile	3.0×10^3	0.1	2500	-	-	-
Soil	1.2×10^7	0.4	1800	3.0×10^4	35°	5°

4.3 Settlement by composite long and short pile comparison

Estimation of comparison of Load settlement by considering composite pile foundation with long and short piles

$$S = Sst\left(\frac{d}{Deq}\right)^{-0.15}$$

Model C

Where, S_{st} is settlement of single pile, S is wrinkle's ground coefficient, d=diameter of pile and D_{eq} is equivalent displacement. Table 3 shows test schemes of composite pile foundations with long and short piles.

Table 3: Test schemes of composite pile foundations with long and short piles

Operating conditions	Number of piles	Number of long piles	Number of short piles	Number of long piles participating in the operating conditions	Number of short piles participating in the operating conditions
(1)	2	1	1	7	2
(2)	4	2	2	4,10	5,9
(3)	8	4	4	1,3,11,13	2,6,8,12

4.4 Settlement by modulus of elasticity of soil material and load carrying capacity

$E_{s,z=}$ 2.631 q_c + 7.177
Model D

Where, $E_{s,z}$is modulus of elasticity of soil material and q_c is the load carrying capacity of pile material

4.5 Settlement by initial elastic settlement observations

Total settlement of calculation can be calculated by

$S = S_1 + S_2$

Model E

$$S_1 = \Psi s1 \sum_{i=1}^{n} \frac{\Delta Pi}{Espi} li$$

$$S_2 = \Psi s2 \sum_{i=1}^{n} \frac{\Delta Pi}{Esi} li$$

Where, S_1 and S_2 are settlement (in mm), ΔPi is change in load application, li is settlement influence factor, Esi and Espi are modulus of elasticity of soil and soil-pile interaction, $\Psi s1$ *and* $\Psi s2$ are initial elastic settlement observed.

4.6 Settlement by shaft resistance, base resistance, young’s modulus below raft and along pile.

For Pile ultimate shaft resistance

$f_s = a\ .\ [2.8\ N_s + 10]$ kPa

For Pile ultimate base resistance

$f_b = K_2\ .\ N_b kPa$

For Soil Young’s modulus below raft level

$E_{sr} = 2N\ \ MPa$

For Young’s modulus along and below pile under vertical loading

$E_s = 3N\ \ MPa$

Model F

Where,

Nr = average SPT (N60) value within depth of one half of the raft width, Ns = SPT value along pile shaft, Nb = average SPT value close to pile tip, K1, K2 = factors shown, a = 1 for displacement piles in all soils and non-displacement piles in clays, a = 0.5–0.6 for non-displacement piles in granular soils.

4.7 Correlation effect for the evaluation of settlement by the given range of Modulus of Elasticity of soil Es.

Total settlement of calculation can be calculated by

$S = \left(\frac{P}{L\ Es}\right) I$

Model G

Where, S is settlement (in mm), I is settlement influence factor, P is load applied in KN, L is length of pile and Es is Modulus of Elasticity of pile material. Table 4 shows typical range values of E_s for clay soil.

Table 4: Typical range values of E_s for clay soil

Soil	Es **kg/sq cm**	Es **MN/sq m**
Clay (selected ranges of medium soil)	150	14.71
	185	18.14
	220	21.57
	255	25.01
	290	28.44
	325	31.87
	360	35.30
	395	38.74
	430	42.17
	465	45.60
	500	49.03

4.8 Influence factor affecting for the evaluation of settlement

Table 5 shows values of influence factor for frictional resistance and end bearing piles.

Table 5: Values of influence factor for frictional resistance and end bearing piles

L/D	**Frictional resistance only**					**Frictional resistance and end bearing**			
	Ep/Es	**10**		**500**		**10**		**500**	
	b	**0.2**	**1**	**0.2**	**1**	**0.2**	**1**	**0.2**	**1**
2		0.593	0.470	0.457	0.367	0.550	0.446	0.407	0.337
30		0.543	0.377	0.110	0.079	0.543	0.377	0.109	0.078

5- Data Analysis

1- By using Model A, settlement of each soil layer found upto M^{th} layer was 15 cm and 15.6 cm by analytical equation and actual settlement respectively. Parameters taken shown in Table 1.The current study model evaluated 17.53 cm and 15.16 cm for the same and comparison found to be increment of 16.86% on comparing with actual readings.

2- Settlement computed by Model B on sloppy area for the vertical loaded single pile under parameter shown in Table 2. The sloping angle α ranges from 10^0 to 40^0 with increment in load. The maximum settlement for 1000 KN load was 35 mm to 37 mm for 0.5 D, 1.5 D and 2.5 D respectively.

3- Parameters consider for test schemes of composite pile foundations with long and short piles have shown in Table 3. The theoretical settlement value was about 23.5% and 26.03% larger than the actual settlement value for 4 and 8 Nos. of pile group respectively. Model C used to calculate the displacement and deformation of a composite long and short piles foundation. The pile displacement was comparatively small and the test curve shows theoretical settlement and actual settlement at 16 KN load was 10.5 mm and 8.5 mm respectively.

4- Relationship established between ultimate load q_c and $E_{s,z}$ as shown in Model D and Figure 1 below. Static Pile load test was conducted from loading range 2000 KN to 12000 KN and average settlement observed was 0.21 mm to 30.12 mm respectively. Figure 1 shows relationship established between q_c and $E_{s,z}$.

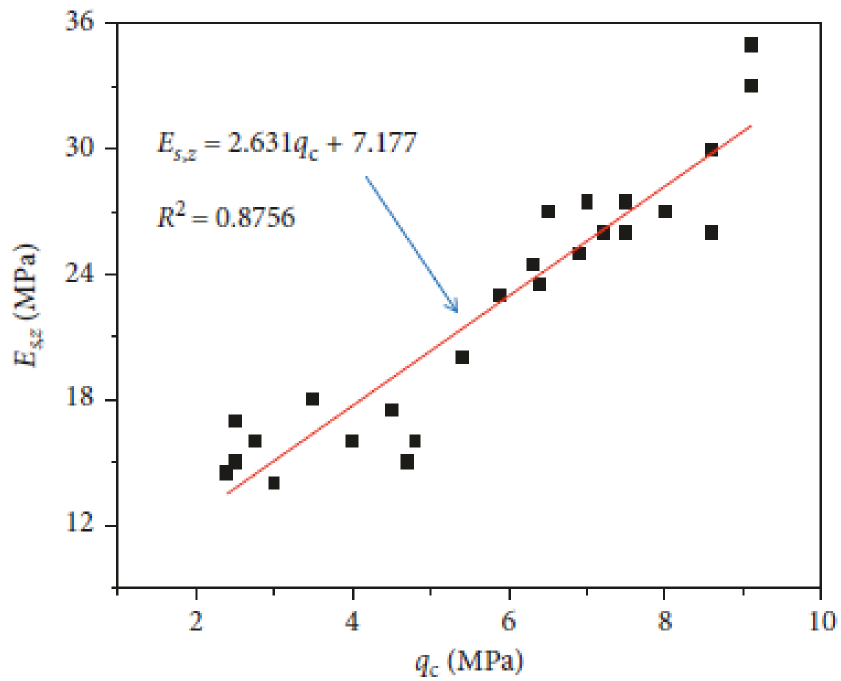

Figure 1: Relationship established between q_c and $E_{s,z}$.

5- A method for calculation of total settlement shown in Model E. By usage of Es and Ep method, 181.3 mm settlement with 88.1% error observed. 73.8 mm settlement and the error was 23.4% respectively. By using settlement reducing pile method, 137.8 mm with error of 42.9% observed. Finally by field tests, 98.7 mm for point 1 and 94.1 mm for point 2 with no error was evaluated.

6- Three stage analysis from given for 5 super high-rise buildings design requirements were given and settlement analysis have suggested by the help of Model F respectively and taken into account.

7- Table 4 shows typical range values of E_s for clay soil along with Model G used for the calculation of settlement by given range values of Es from 150 kg/sq cm to 500 kg/sq cm. Figure 2 used for settlement influence factor I ranges from 0.5 to 20, calculation by L/D ratio ranges from 1 to 200 and stiffness factor K. Figure 2 shows settlement influence factor determination chart

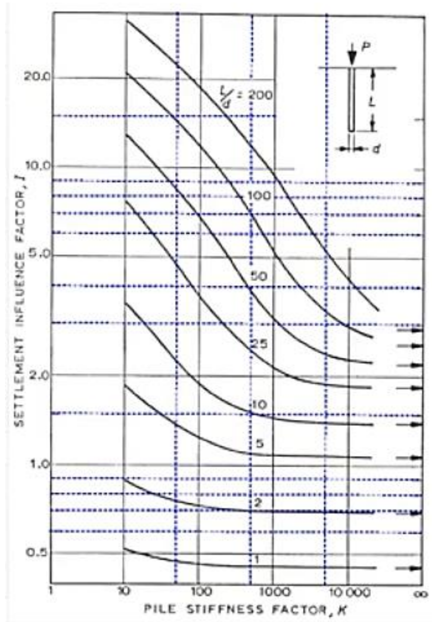

Figure 2: Settlement influence factor determination chart

8- Table 5 shows values of influence factor for frictional resistance and end bearing piles. For frictional resistance, 9.2% decrement observed when L/D was 2 to 30, Ep/Es was 10 and b was 0.2. Again, 75.93 % decrement observed when Ep/Es was 500. For end bearing piles 1.2% decrement observed when L/D was 2 to 30, Ep/Es was 10 and b was 0.2. Again, 73.21 % decrement observed when Ep/Es was 500.

Conclusions

Based on the study of all eight research papers by using various techniques and methods to evaluate settlement of pile foundation following conclusions have drawn:

- The study shows that all researchers followed the static loading criteria for the settlement analysis of pile foundation and results through numerical approach shows optimized range of pile settlement 40% to 75%, which helps in eliminating the actual pile testing.

- The study shows that no suitable correlation is found between the theoretical and actual settlement analysis of pile foundation.

Future Scope

The following work the carried out in future to get the soil and building behaviour and use of settlement concept.

- Case study of a particular area and approach to find out the settlement using empirical models and correlate with actual pile load test using software statistical tool.
- Case study various zonal soil strata for new and pre existing structures.
- Establishment of correlation between theoretical and actual settlement under various

loading conditions.

- Programming methodology for settlement under various loads cases and type of foundation.
- Proposed new theory for settlement of pile under super structure load.

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