Analysis of Settlement Induced by Dissipation of Excess Pore Water Pressure Due to Piling in Soft Clay at Haldia

Akanksha Kesharwani[1], Abhijeet Gupta[1] and Ashok Kumar Khan[1]
[1]*National Institute of Technology, Jamshedpur – 831014*
Email:*akanksha102@gmail.com; abhijeetgupta911@gmail.com;akk.nitjsr@gmail.com*

Abstract: Consolidation settlement induced by dissipation of the excess pore water pressure due to pilling in soft clay and negative skin friction caused by it were analyzed. Piling or the pile driving process usually induces excess pore water pressure in the surrounding soil. When this excess water pressure dissipates later on after the pile driving process is complete, settlement of the surrounding soil take place and a negative skin resistance along the pile surface develops, which is undesirable. In this paper, PLAXIS 2D is used to take into account the nonlinear consolidation behavior of the soil. The pile-driving process was defined and analyzed in terms of the expansion in a cylindrical cavity. In general, the results based on the FEM method were consistent with the actual field measurements on site. However in response to the problem the permanent solutions are worked on.

Keywords: Settlement; Consolidation; PLAXIS 2D

1 Introduction

During geophysical investigation, soil is found soft and weak upto a great depth, shallow foundation is not suitable for the intended structure then it is required to considered economical option between (i) Soil stabilization and provide shallow foundation (ii) Deep foundation.

This study is focused on the later choice i.e. Deep foundation. Pile foundation transfers super structure load to deeper soil strata, to withstand lateral, vertical, uplift load and to minimize the settlement [2]. A structure can be founded on piles if the soil immediately beneath its base does not have sufficient bearing capacity to withstand the imposed structural loads. If it is represented in the results of site investigation that the soil at shallow depth is not stable or if the calculated settlement is beyond acceptable limits, a pile foundation will be required[1].

In this analysis, soft soil model theory and Mohr-coulomb theory has been utilized for study purpose. The soft soil model is suitable for materials that exhibit high degrees of compressibility such as normally consolidated clays, clayey silts and peat. Based on this dominant feature that should be considered in constitutive modelling of these materials is the volumetric hardening. Of course, a shear strength criterion also needed for these geomaterials and a Mohr-coulomb yield surface is considered for this purpose. The volumetric mechanism that captures the compressibility of the

material is simulated by an elliptical cap that is very similar to the modified cam clay model. While field settlements were taken by noting rail level at center of each oven by using total station at certain time interval.
An attempt has been made to study the foundation and allied structures supported on pile at Coke Oven Plant located near River Haldi, West Bengal. The plant was constructed over low-lying area filled up with flyash and dredged sand. Now it is facing excessive settlement due to consolidation and release of excess pore water pressure with time. It is having four rows of heat recovery type Coke Oven Batteries. Each row is having 88 ovens, having 480m long rail track on either side for pusher car and quencher car. During operation of the plant, settlement/undulations of rail track problem is faced in positioning of pusher car and quencher car at oven centre during pushing operation due to rolling of the car.
In the paper, no use of cavity expansion theory has been done to model the pile driving process.

1.1 Problem Statement

To ensure the smooth run of the coke oven plant unit there is need of proper working of different machinery and structures as well. However it was observed that oven rail track is facing problem of abrupt differential settlement. As preventive temporary method grouting of pedestal with Sika Microcrete was done also cracked concrete was dismantled and replaced with steel girders. Therefore this study was initiated to work out the permanent solution.

1.2 Need of the Present Study

1. Due to settlement/undulation of rail track problem is faced in positioning of pusher and quenching car at oven centre during pushing operation due to rolling of car.
2. Damage of power collector and failure of Pusher and Quenching car drive components.
3. Bending of thrust plates below the rail due to cracking of underlying concrete.
4. Breakage of foundation bolts.
5. Undulations in the rail track increases impact that in turn results in progressive settlement.

1.3 Geology of the Site

The site is situated near the bank of River Haldi (Branch of Hooghly River), and surrounded by back water channels made by the river. Top few meters are made up of very recent filled up and fallowed by the sediment made by the marine and the river deposits which evaluated from the bore holes. Top 10 to 12 (average) is made up to the marine sedimentary clay (mixed with Silt and Sand in the bottom of the strata), after this layer we may get silty sand with clay and silty sand due to past alluvium activity by the marine and river.

Table 1 Properties of soil strata

Soil	Depth(m)	Soil type	Properties

Strata			
1	4e-6	Silty Sand (SM)	C’=0, φ’=27^{o}, N=5, E_s=766×5=3830KN/m^3, ν=0.3, γ=18.8KN/m^3
2	03	Soft Clayey Silt (CI-OI)	C’=19.6 kPa, φ’=24^{o}, e_o=1.403,C_c=0.4659, C_r=0.097, P_c=83.4 kPa, ν=0.45, γ=17KN/m^3, E= 200 to 500 C_u =250×8 to 500×8=2000 to 4000 kPa; use E=3600kPa
3	13-20	Silty Sand (SM)	C’=0, φ’=34^{o}, N=26, E_s=766×26≈20000KN/m^3, ν=0.3, γ=20KN/m^3
4	20-31	Silty Clay (CH-OH)	C’=2 kPa, φ’=28^{o}, e_o=1.458,C_c=0.4543, C_r=0.03556, P_c=216 kPa, ν=0.45, γ=17KN/m^3, E= 450C_u =450×20.6=9270 kPa
5	>31	Silty Sand (SM)	C’=0, φ’=34^{o}, N=25, E_s=766×26≈20000KN/m^3, ν=0.3, γ=20KN/m^3

2 Numerical Analysis

Finite element analysis is a powerful mathematical tool that makes it possible to solve complex engineering problems. The finite-element method is a well-established numerical analysis technique used widely in many civil-engineering applications, both for research and the solution of real engineering problems[5].

In my study **Soft Soil model** and **Mohr coulomb model** has been used to model the soil. The elastic-plastic Mohr-Coulomb model involves five input parameters, i.e. Elastic modulus (E) and Poisson’s ratio (μ) for soil elasticity; Angle of internal friction (ϕ) and cohesion (c) for soil plasticity, and (ψ) as an angle of dilatancy. This Mohr-Coulomb model represents a 'first-order' approximation of soil or rock behavior[3]. Parameters for soft soil model and Mohr coulomb model are shown below. Also properties of concrete pedestal and pile are illustrated alongside.

Table 2 Parameters for soft soil model

Soft soil	CI-OI	CH-OH
Type	Undrained	Undrained
g_{unsat}	15.00	15.00
g_{sat}	17.00	17.00
k_x	8.64e-5	8.64e-5
k_y		8.64e-6
e_{init}		1.458
l*	0.084	0.080
k*	0.035	0.01258
C	19.60	2.00
J	24.00	28.00
Y	0.00	0.00

n_{ur}	0.200	0.200
K_0^{nc}	0.59	0.54
R_{inter}	0.67	0.67

Table 3 parameters for Mohr-Coulomb model

Mohr-Coulomb	**1 SM**	**2 SM**	**3 SM**
Type	Drained	Drained	Drained
$\mathbf{g_{unsat}}$	16.00	18.00	18.00
$\mathbf{g_{sat}}$	18.00	20.00	20.00
$\mathbf{k_x}$	0.900	0.900	0.900
$\mathbf{k_y}$	0.090	0.090	0.090
$\mathbf{e_{init}}$	0.500	0.500	0.500
$\mathbf{E_{ref}}$	3830.0	20000.0	20000.0
N	0.300	0.300	0.300
$\mathbf{G_{ref}}$	1473.077	7692.31	7692.31
$\mathbf{c_{ref}}$	0.10	0.10	0.10
J	27.00	34.00	34.00
Y	0.00	4.00	4.00
$\mathbf{R_{inter.}}$	0.67	0.67	0.67

Table 4 properties of concrete of pedestal and pile

Linear Elastic	**1 Concrete pedestal tie beam**	**2 Pile properties**
Type	Non-porous	Non-porous
$\mathbf{g_{unsat}}$	25.00	25.00
$\mathbf{g_{sat}}$	25.00	25.00
$\mathbf{k_x}$	0.000	0.000
$\mathbf{k_y}$	0.000	0.000
$\mathbf{e_{init}}$	0.500	0.500
$\mathbf{E_{ref}}$	24500000	24500000
N	0.150	0.150
$\mathbf{G_{ref}}$	10652173.91	10652173.91
$\mathbf{R_{inter}}$	0.670	0.670

3 Result And Discussion

3.1 Results from field observation

Settlement has gained different values throughout the rail track also differential settlement has been encountered between rails at same section. Given below fig. 1, demonstrate the graphical comparison of settlement of oven, outer track and inner track of Row 2 batteries and fig. 2 represents the graphical comparison of settlement of inner and outer track of Row 3. Both the graph shows increase in settlement as we proceed toward centre of the track i.e. settlement is least in the corners while attains its maximum value near to the centre. The maximum value taking place at the centre is due to presence of coal tower at the centre of the track, which is acting as point load and is also responsible for vibrations due to charging of coal.

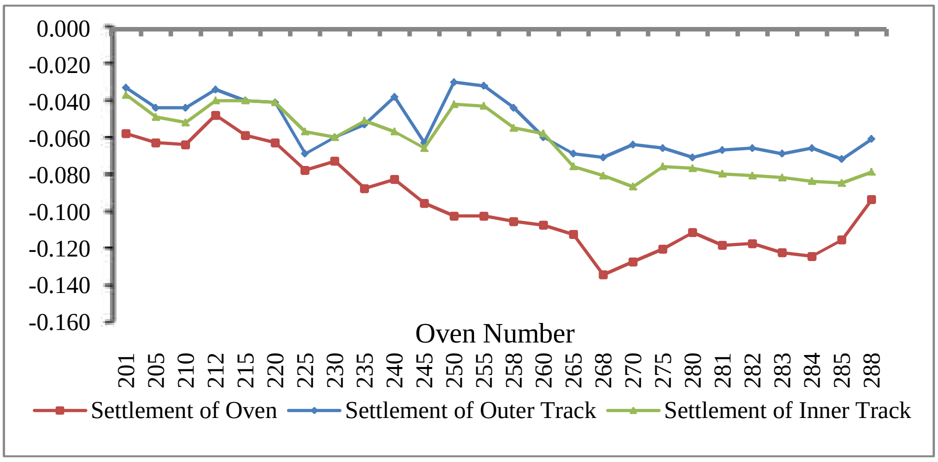

Fig. 1 Settlement of the battery and P-track(inner and outer) of Row 2

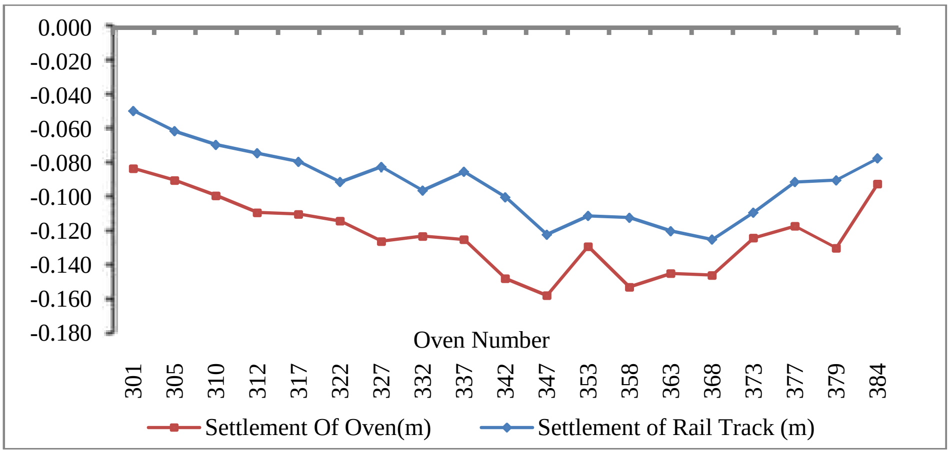

Fig. 2 Settlement of the P-track and battery of Row 3

3.2 Results from Numerical Analysis

Pusher Side

Fig. 3 gives the plot of time vs settlement for the right and left pedestal at the load of 700kN and 550kN on them respectively. Moreover, table 5 gives the logged data from the graph of the settlement of both the pedestal. It is observed that there is differential settlement of almost 10 mm between both the pedestal, that in turn impart twist to the outer pedestal and thereby settlement progresses. From the table it is observed that 5-6 mm settlement is about to take place in future coming years of plant life.

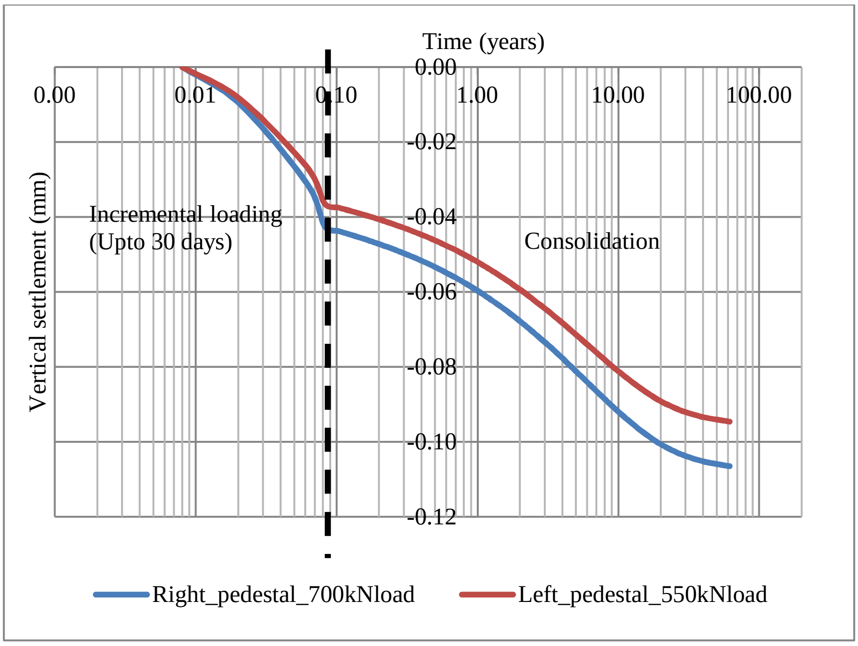

Fig. 3 Plot of time vs settlement

Table 5 settlement of left and right pedestal with time

Time (years)	Left Pedestal (mm)	Right Pedestal (mm)
5.16 (~5.00)	71.80	81.70
11.70	83.20	94.30
14.40(~14.00)	85.70	96.90
24.90 (~25.00)	90.90	102.00

Fig. 4 gives the graphical representation of time vs. excess pore pressure, for the first 30 days incremental loading was done for generation of excess pore pressure after that record for release of it was done. Table 6 gives the discrete values of excess pore pressure at different time interval. Table identifies that the excess PWP release is almost done to the acceptable limits.

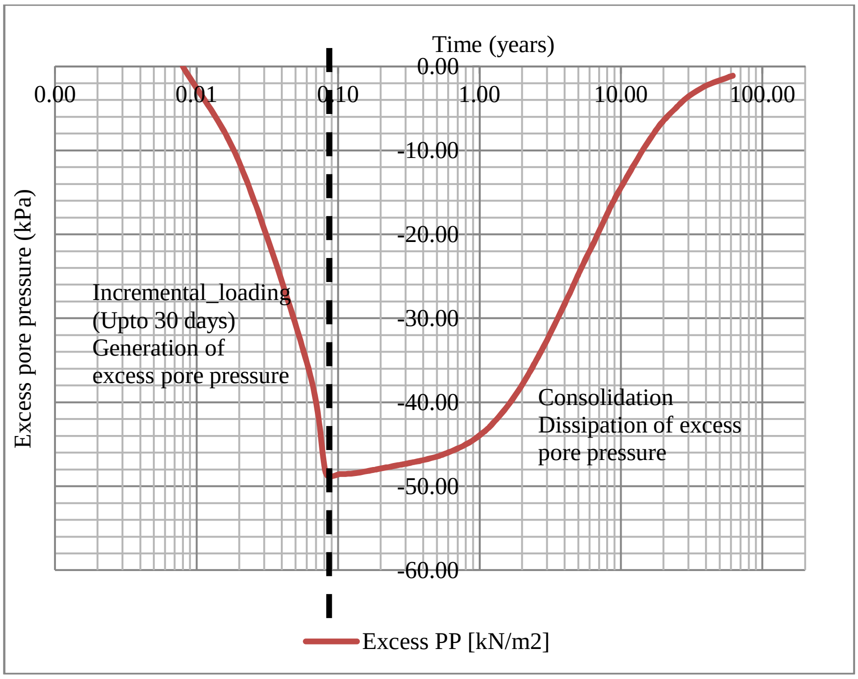

Fig. 4 Plot of Time vs Excess PWP

Table 6 Excess pore water pressure at time intervals

Time (years)	Excess Pore Pressure (kPa)
5.06(~5.00)	-24.30
11.70	-12.40
14.40(~14.00)	-9.89
24.90(~25.00)	-4.82

Quencher Side

Fig. 5 and table 7 gives the graphical and tabular values of the settlement of pedestal at quencher side. It can be noted that there is significant amount of settlement left to take place in future. The huge settlement predicted in future is because of the floating piles at the quencher side as the embedment length is 16 m only. Here, the piles do not rest on hard stratum instead ends at soft clay layer.

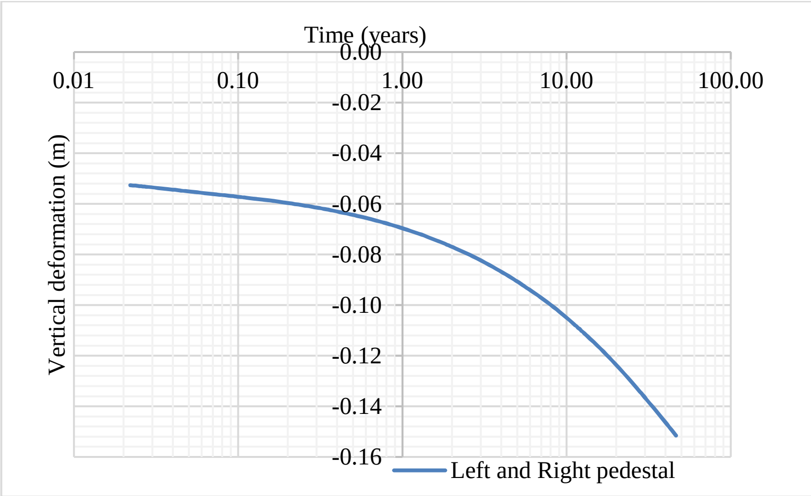

Fig. 5 Plot of time vs settlement

Table 7 Settlement of pedestal with time

Time (years)	Settlement (mm)
5.49	92.40
15.40	116
23.81	129

Given below, fig. 6 and table 8 provides continuous and discrete values of excess PWP with respect to time. It is observed that no significant decrease in excess PWP has taken place, it represent that there is ample amount of PWP release to happen.

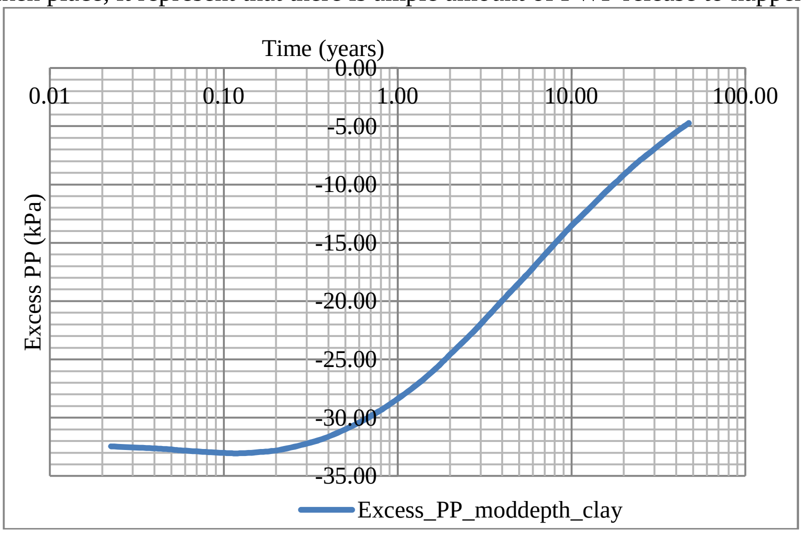

Fig. 6 Plot of Time vs Excess PWP

Table 8 Excess PWP at time intervals

Time (years)	Excess Pore Pressure (kPa)
6	-17
15.5	-11
24	-7

Battery Raft and Pile

It is observed from the fig 7 and table 9 that the settlement of battery that took place with time is less in comparison to the pusher and quencher track. The less value corresponds to the fact that piles below the battery is provided beneath the raft, that minimize the settlement by distributing the load over large area.

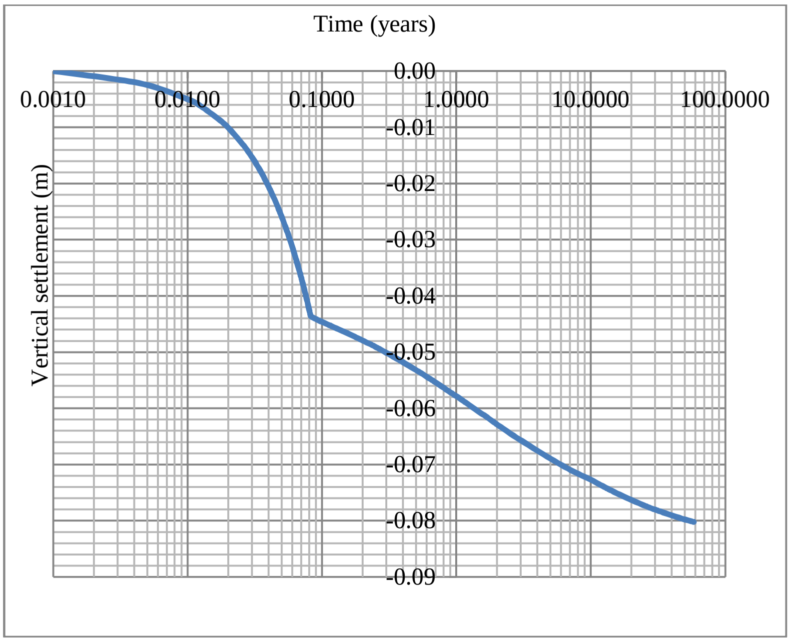

Fig. 7 Plot of time vs settlement of battery raft

Table 9 Settlement of raft with time

Time (years)	Settlement (mm)
4.49	68.3
13.70	74.4
24.20	77.2

Fig. 8 gives the plot of release of excess pore water pressure with time. It is observed that the PWP left for the release is comparatively very less as the consolidation beneath the pile-raft has almost taken place.

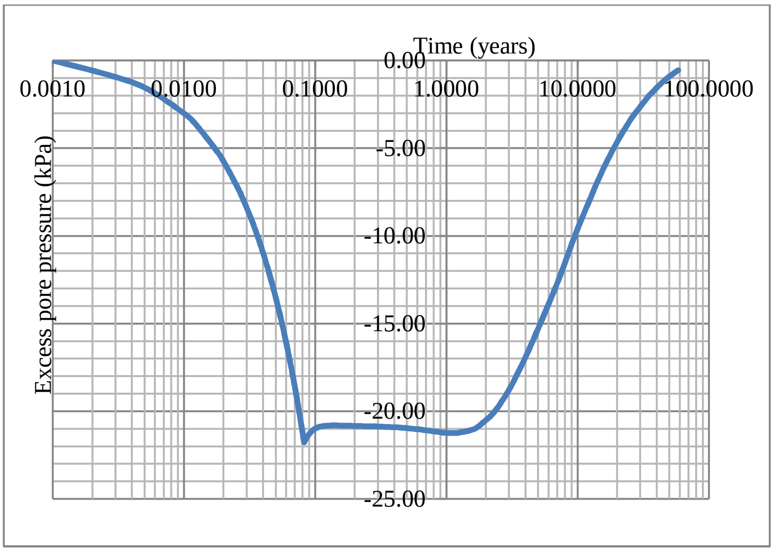

Fig. 8 Plot of time vs. Excess PWP

3.3 Comparison of Actual and Predicted Settlement

Table 10 below gives the comparison between the actual settlement on the site and settlement at present according to the numerical analysis. Also the settlement in the coming years is predicted. It is observed that the settlement in the field is less than the settlement noted from the numerical analysis. It was seen in the field that coal stamping tower imparts dynamic load, as dampers are provided dynamic loads were not included in the investigation. This may the implied reason behind the variation of the settlement in the field and the settlement predicted from the numerical analysis.

Table 10 Comparison of settlement based on study

	Pusher Track	Quencher Track	Battery
Max. avg. settlement observed	113*	113**	181*
Min. avg. settlement observed	21	42	73
Max. settlement predicted (14-15 years)	97	116	74.4
Max. settlement predicted after 25 years	102	129	77.2

[*] Settlement at oven number 45 at row 3

[**] Settlement at stamping post

4 Conclusions

The study is based on the data and drawings provided on the pile settlement case at Haldia. The study is based on the 2-D FEM analysis of the soil strata, loading pattern and settlement. The important conclusions obtained from the results are summarized as follows:

1. It was evident from the study that the settlement at P-track has attained almost its maximum value and it may settle 5/6 mm more in the next 10 years. The consolidation of the soil underneath the foundation has also been almost complete.
2. From the study on the Q-track it was found that since the length of pile below Q-track is only 18M long, the piles are floating on the underneath soft clay layer which has the maximum potential of settlement in future. As per the study this is the most critical area where the length of piles seems inadequate to meet the settlement criteria of design.
3. The study on the Coke oven battery area shows that the theoretical settlement calculated based on the design data is much smaller than the settlement observed in the field. This needs to be re-checked again after proper load calculation.
4. From the survey report to capture the settlement, it was observed that the settlement at the middle of the oven area was more than that of both ends. During the site visit it was observed that due to huge loading coming from the coal tower which is situated at the middle of the railway track, it may be contributing towards the settlement of the railway track. The detail study needs to be done on this.
5. Going further on the settlement part, the P-track and oven area does not possess any major settlement further (as per numerical results) whereas Q-track requires major attention to tackle the future settlement potential.
6. The settlement at Q-track can be arrested to a certain limit by a long term or a short term solution. The long term solution comprises of driving additional steel/FRP pipes along the existing piles of Q-track and filling them with concrete and integrating the additional pile with the existing pile cap/raft.
7. For short term solution it is suggested that the concrete pedestal at the P-track or Q-track are to be replaced by steel girder

5 Future Scopes

The present study has considered the static load application for the analysis of settlement in the foundation. Due to time constraints and availability of the data from the organization, study has been done without the application of dynamic load, as data were unavailable. Numerical modeling has been done to validate the field results. Due to more settlement in the site as calculated numerically, this study needs to be extended further, in following aspects:

1. Study the settlement for the dynamic loads.
2. Extend the study for the foundation structural health.

3. Investigate the reason and solution behind the maximum settlement at the centre of the rail near coal tower.
4. Study for the design of most promising steel girder and concrete grade to overcome elastic settlement of girder during loading.
5. To study for the design of pile for pile integration on the quencher side.

References

1. Gandhi S. R., “Observations on Pile Design and Construction Practices in India,” Indian Geotech. J., vol. 46, no. 1, pp. 1–15 (2016).
2. Henderson G. L., “Design and Construction of Driven Pile Foundations — Lessons Learned on the Central Artery / Tunnel Project” (2006).
3. Hongyuan F. U. and Xiaoyu L., “Analysis of settlement induced by dissipation of excess pore water pressure due to piling in soft clay” (2011).
4. Hosseini M. A. and Rayhani M., “Evolution of pile shaft capacity over time in marine soils,” Int. J. Geo-Engineering (2017).
5. Kishanrao W. M. and Prasad A., “Numerical modeling of single pile in a two-layered,” no. 6, pp. 105–107 (2016).
6. Seo H., Prezzi M., and Salgado R. "Settlement analysis of axially loaded piles", International Conference on Case Histories in Geotechnical Engineering. Paper 27 (2008).
7. Sri P. and Tjandra D., “Analysis of piled raft foundation on soft soil using PLAXIS 2D,” Procedia Eng., vol. 125, pp. 363–367 (2015).
8. Help manuals, Plaxis 2015.

Acknowledgement

I will like to pay my gratitude to Dr. A. K. Khan (Professor) and Department of Civil Engineering, NIT, Jamshedpur for their guidance and support throughout the project.