

Dynamic Analysis of Pile Driving

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ABSTRACT

A pile driving is a mechanical process used to drive piles into soil to provide foundation support for buildings or other heavy structures. Pile driving includes a heavy weight placed between guides so that it is able to freely slide up and down in a single line. It is placed above a pile. The weight is raised, which may involve the use of hydraulics, steam, diesel, or manual labour. When the weight reaches its highest point, it is then released and smashes on to the pile in order to drive it into the ground.

Due to this driving force various stresses are induced into pile at the time of installation. Many analytical methods are widely been developed to analyse the dynamic installation process of pile. But this are the numerical methods with numerous assumptions so could not used for field work. Also, the main problem with the traditional Finite Element analysis are the contact problem and large deformation of finite element mesh taking place. So, the simulation of pile driving from initial unpenetrated position is carried out by commercial softwares.

In this study initial unpenetrated condition of pile is considered and hypoplastic soil model is considered for loading and unloading condition. For each blow stress are induced at pile tip and soil drifting is monitored.

As pile driving is a dynamic process which causes the vibration in a surrounding soil. Moreover, excess pore water pressure are generated due to the quick stress increased around the pile. In this study focus is placed on irreversible deformation below the pile in order to simulate these process most realistically. The behavior of sand or any soil layer is model in means of the hardening soil model in plaxis (2D).

Key Words: Pile Driving, Unpenetrated Pile Condition, Hypoplastic Soil Model.

1. INTRODUCTION

Pile installation causes severe variations in the state variables of soil. In addition to it, the structures adjacent to it may also get affected, due to changes in the soil state variables. Hence it has been recognized over the past years, the necessity of developing a reliable method for the analysis of the installation process. One of the most traditional methods for supporting structures resting on soft soils is the use of piles. They generally work by transferring the loads to deeper soil layers, which can provide sufficient bearing capacity when mobilized. This type of foundations has been commonly used throughout the world and also in the western part of the Netherlands due to the typical soil profile which consists of a thick (10-20 m) soft soil layer underlain with a stiff bearing stratum composed mostly of quartz sand. In this perspective, this study sheds a light on the behaviour of piles installed in various soils. The bearing capacity of a pile depends on the soil properties and the stress state it is surrounded with. This is because the behaviour of granular material is governed by the packing of the grains and the contact stresses in between. The mean stress and the density can be described as the soil state, and the soil behaviour is determined on the basis of this state and the loading conditions. In the case of a displacement pile, the installation process causes a considerable amount of soil displacement and high levels of (reaction) stresses. These effects of pile installation are transmitted to soil through the interaction between soil grains and the pile, resulting in an altered soil state and properties. A more realistic behaviour and therefore an improved design would be achieved by considering the installation effects in the analyses than performing the analysis considering a geostatic stress state around the pile(s) modelled.

In current practice, the installation effects are taken into account by some empirical design methods in order to estimate the bearing capacity of foundation piles. Several field and model tests performed to investigate the influence of pile installation on the bearing capacity, have led to an evolution of the empirical models to estimate the bearing capacity of displacement piles. Recent attempts to investigate the change in the soil state were also limited either to the measurement domain (generally close to the pile) or resolution as well as the variables (e.g. displacement, strain, stress, density) that can be quantified. However, the behaviour of piles during installation, the interaction with the surrounding soil and the resulting alteration of soil properties during installation are still not well known. This information is essential, not only to make better predictions of the pile bearing capacity and its behaviour in the soil under different loading conditions, but also to be able to predict the (side) effects of pile installation on the neighbourhood.

In this paper, a 2D simulation of the pile driving process from its initial unpenetrated position has been carried out, using the plaxis (2D). The soil is modelled and for modelling the complex behaviour of soil, hypoplastic constitutive relations are used. The penetration is carried out force controlled, by modelling hammer blows as impulsive load and is applied on the pile top. The complex behaviour of soil during loading and unloading conditions is monitored.

2. LITERATURE REVIEW

1. S.P.Dasgupta(2016)“A numerical and experimental study of hollow steel pile in layered soil subjected to vertical dynamic loading” He carried out investigations on dynamic response of single pile of different lengths subjected to vertical dynamic load numerically and experimentally. The experimental investigations are compared with the results obtained by the numerical analysis to verify the performance of the model. Although this study is carried out on small scale piles, which may not simulate the exact response of the full scale pile foundation, it enabled to understand the nature of response of the pile foundation under vertical dynamic load. Important findings from the numerical and experimental investigation are compared after completion of work.

2. Benamar A. (2000) “Influence of driving impact on the axial response of piles” He carried out experimental study work in laboratory on pile driving because of disadvantages caused by pile top driving, a new pile driving technique by which the hammer is inside the pile has been developed. The so called a “down-the hole” piling system is used to drive a tubular pile in an experimental set-up in the laboratory. This new technique is tested and compared with pile top driving using similar hammer energy. A reduction of noise and the opportunity to save steel are confirmed during a field test program. Also, a reduction in driving time and a higher bearing capacity have been observed. Some similar conclusions are arrived at in the laboratory study, specially the low level of stresses in the pile and the shaft friction.

3. Fursan Hamad (2016) “Formulation of the axisymmetric CPDI with application to pile driving in sand” He Carried out the two-dimensional Convected Particle Domain Interpolation (CPDI) formulation for an axisymmetric problem where a pile is driven into sand that is modelled as a hypoplastic model. The extended formulation is tested, validated and compared to that for the case of the two-dimensional plane-strain within the framework of the method of manufactured solution. The hammer blows on the pile are represented by a periodic forcing function. In contrast to earlier studies on pile installation using advanced models, deep penetration is achieved in the present analysis. A non-regular distribution for the particle domains is suggested to avoid unnecessary computation. A frictional contact algorithm is introduced to describe the pile–soil interaction.

4. Jakub Konkol (2016) “large deformation finite element analysis of undrained pile installation” He Carried out a numerical undrained analysis of pile jacking into the subsoil using Abaqus software. Two different approaches, including traditional Finite Element Method (FEM) and Arbitrary Lagrangian–Eulerian (ALE) formulation, were tested. In the first method, the soil was modeled as a two-phase medium and effective stress analysis was performed. In the second one (ALE), a single-phase medium was assumed and total stress analysis was carried out. The fitting between effective stress parameters and total stress parameters has been presented and both solutions have been compared.

5. Ernesto Gauder (2012) “A review on the driving performance of FRP composite piles” He suggested that composite piles have longer service life, require less maintenance, and environmental friendly. These inherent characteristics made them a viable option in replacing traditional piles in harsh environmental conditions. Just like other types of composite piles, hollow Fibre Reinforced Polymer (FRP) piles show high potential in load-bearing applications. These piles provided significant advantages in terms of cost efficiency and structural capabilities. However, these piles have not yet gained wide acceptance because of the lack of design guidelines especially on their installation techniques.

It was found that the type of driving hammers used, resistance offered by the soil, the pile impedance, and the impact strength of the pile materials are the main factors that affect the driving performance of composite piles. Their effect however on the driving performance of hollow FRP piles are not fully investigated. Consequently, the possibility of damaging the fibre composite materials during the process of impact driving is still imminent. Further research studies on the impact behaviour of this

type of composite pile ranging from materials to full-scale levels should be conducted to understand their driving performance. This information will provide a more systematic understanding on the impact behaviour of fibre composite materials and eventually help researchers and engineers in developing installation guidelines for their optimum use and wider application.

3. PROBLEM STATEMENT

Now a days in Nashik city large amount of constructions of heavy massive structures likes bridges and high rise buildings are going on which rests on various types of soil strata. For such a structures generally piles are provided in group to support & to transfer the load upto hard stratum. While installing the piles in group by using hammering process some impact of new installed pile on is going to takes place on preinstalled piles. Some displacement of soil and pile tip is taking placed and prediction of such displacement is difficult by using analytical and numerical methods. So for accurate results various softwares are used in which Plaxis (2D) is used to find same results. For dynamic analysis of piles actual site conditions from Nashik city are considered.

4. OBJECTIVE

- 1.To study the effect of dynamic process of pile driving from its initial unpenetrated position to its final penetration depth by using commercial software, Plaxis (2D).
- 2.To study the effects taken placed at the tip of preinstalled piles at the time of installation.
- 3.To study and check the dynamic effects on preinstalled piles with actual soil stratification in Nashik region.
- 4.To study the effect of Parametric variation of pile such as spacing and diameter of piles for above soil stratification.

5. METHODOLOGY

This chapter contains available type of pile foundation and dynamic analysis of pile installation using software and problem statement. It also consists of simulation of dynamic driving of a concrete pile into a soil. For this purpose, the hypoplastic constitutive model is considered. The pile model is tested for dynamic loading by using plaxis (2D) and result obtained are displayed in the form of load vs settlement graph. For completing project successfully within stipulated time, following methodology have been adopted.

- 1.Collecting the actual site condition data of soil strata in Nashik region.
- 2.Preparing the software based model for soil and pile with dimensions.
- 3.Fixing the properties of soil and pile model in Software.
4. Generating mesh for prepared model for fine node analysis.
5. Generating water pressure for prepared soil model.
6. Dynamic analysis calculation done in 3 phases, Phase 1 the pile is created. In the Phase 2 single stroke is given to the pile, which is simulated by activating half a harmonic cycle of load. In the Phase 3 the load is kept as zero and the dynamic response of the pile and soil is analysed for given time.
7. Observing the obtained results for given loading conditions.
8. Summarized the results, prepare the graphs of time vs settlement.
9. Interpretation of the findings from the obtained results.
- 10.Finally, recommendations based on the conclusions and finding results.

6. DATA COLLECTION

(A)Basic Soil Properties

This includes the soil stratification and properties collected from two sites from Nashik region in which first is Hospital building at Govindnagar and second one is Shivansh buildtech, behind Indian oil petrol pump, Jailroad, Nashik.

Table 1. layered soil properties at Govindnagar site

Depth of strata		Type of strata	Properties of soil strata			
From (m)	To (m)		C (kPa)	$\Phi^{(o)}$	γ_u (kN/m ³)	γ_s (kN/m ³)
0	3	Black clayey soil	4	19	16	19
3	4.5	Brown clayey soil	4	20	16	18.5
4.5	6	Soil+ sand	1	32	17	20
6	11	Calciuous sand stone	1	33	19	21
11	13	Weathered rock boulders	0.32	30	18	20
13	14	Black basalt rock	0.22	28	19	22

Table 2. layered soil properties at Jailroad site

Depth of strata		Type of strata	Properties of soil strata			
From (m)	To (m)		C (kPa)	$\Phi^{(o)}$	γ_u (kN/m ³)	γ_s (kN/m ³)
0	1.5	Black clayey soil	3	18	16	19
1.5	7	Crushed moorum	2	28	17	21
7	11	Moorum boulder	1.82	35	16	18
11	13	Weathered rock boulders	0.33	30	17	20
13	16	Black basalt rock	0.18	26	18	22

7. SOFTWARE BASED MODEL FOR SOIL AND PILE WITH DIMENSIONS

(A)Pile parameters used:

Following are the minimum and maximum parametric considerations of pile models taken into considerations.

Table 3. Parameters of pile

Attribute	Pile Parameter	
	Min. (m)	Max. (m)
Dia.	0.3	0.9
Spacing	0.9	2.7

(B)Properties of pile model:

Table 4. Properties of pile

Linear Elastic		Pile
Type		Non-Porous
<input type="checkbox"/> unsat	[kN/m ³]	25.00
<input type="checkbox"/> sat	[kN/m ³]	25.00
<input type="checkbox"/>	[-]	0.280
R_{inter}	[-]	1.000
Permeability		Impermeable

(C) Geometry of Soil & Pile model with their properties:

Following are the geometrical model of soil and pile of size 20x20m with soil stratification layer and its properties. Horizontal boundary of model are fixed and vertical boundaries are acting as rolling support.

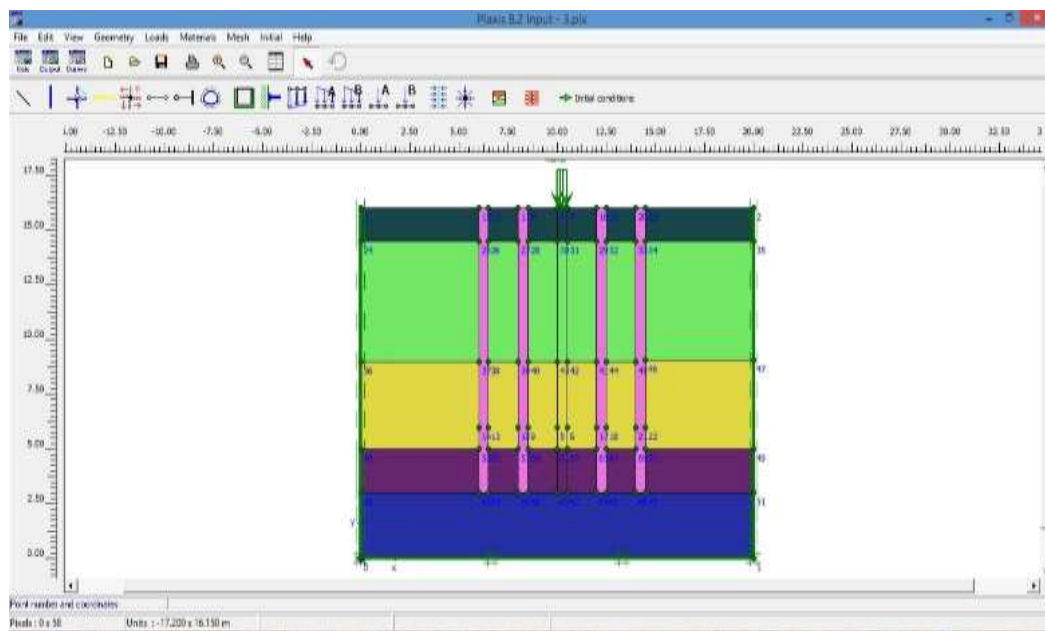
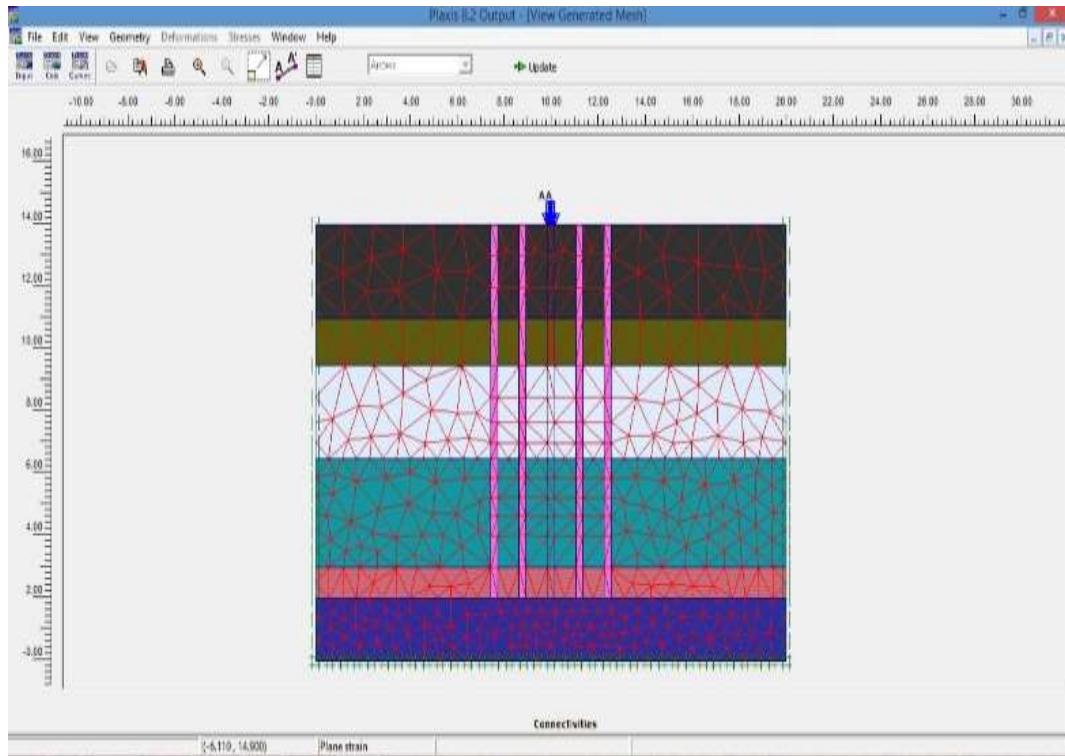


Image 1: Soil-Pile modelling along within their properties

(D) Model meshing:

After preparing soil-pile model meshing is done to surrounding soil and pile and for better result cluster is refined.



• **Image 2: Mesh generation of Pile and san**

• **(E) Generating water pressure:**

Water pressure is generated in soil by using phreatic line and fully saturated condition is considered.

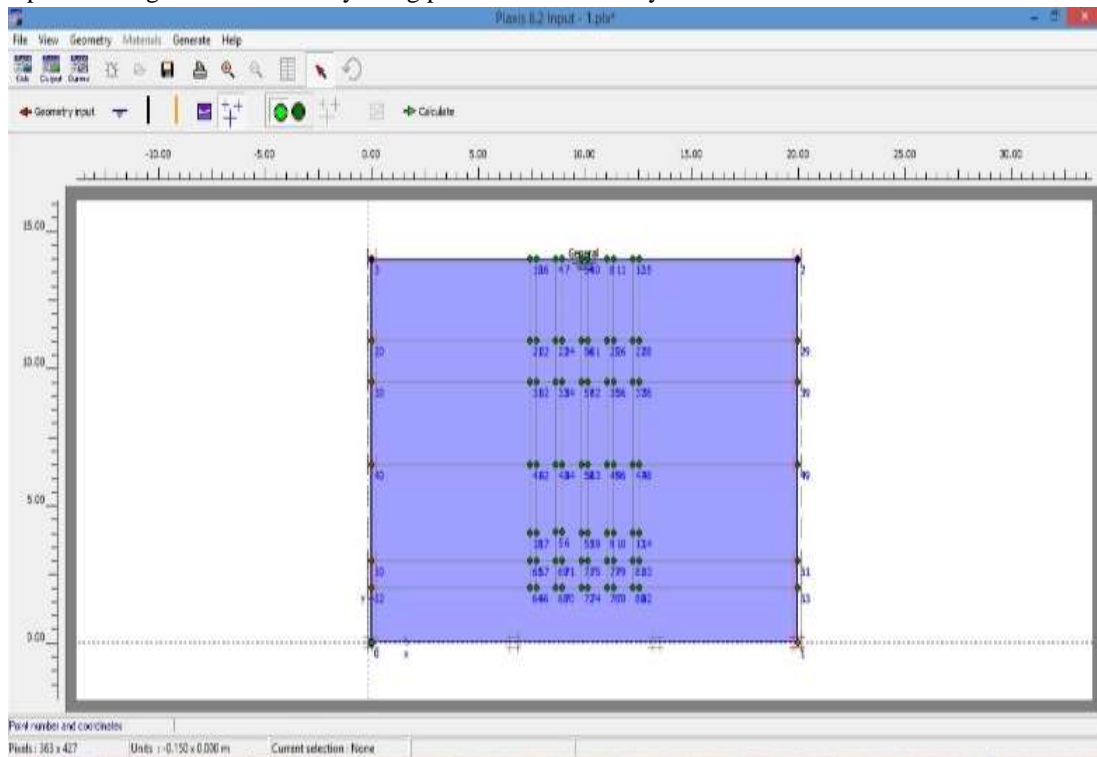


Image 3: Water pressure generation in soil model

(F) Dynamic analysis calculation phases:

Dynamic analysis calculations are done in 3 phases, Phase 1 the pile is created. In the Phase 2 single stroke is given to the pile, which is simulated by activating half a harmonic cycle of load. In the Phase 3 the load is kept as zero and the dynamic response of the pile and soil is analysed for time of 10 sec.

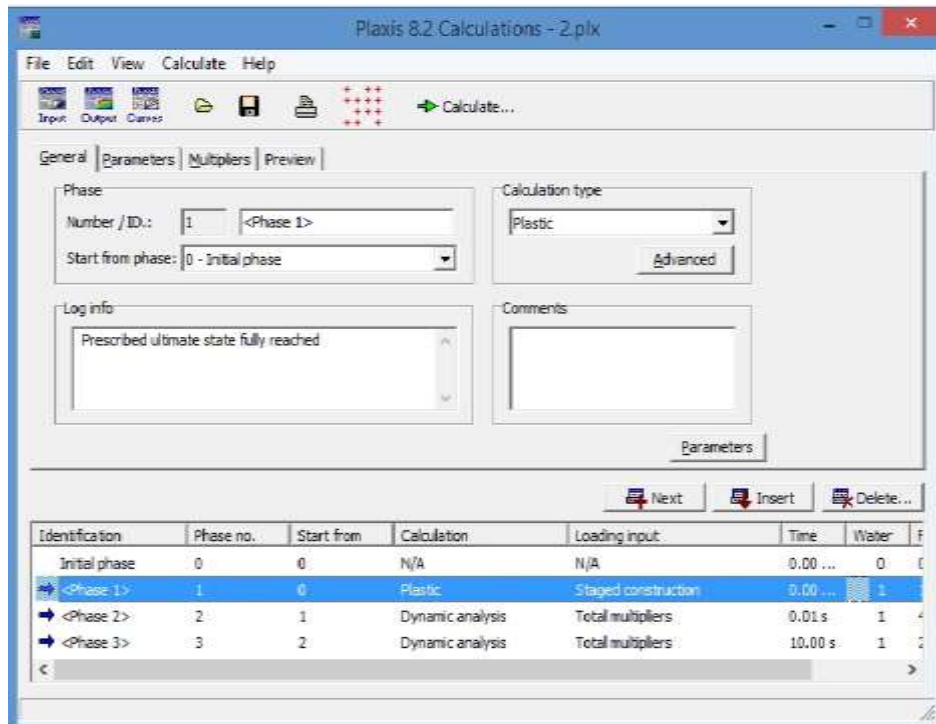


Image 4: Dynamic analysis calculation phases

8. RESULTS AND DISCUSSION

After pile and soil modelling from two different site locations from Nashik region and testing models for different parametric variations, following results are obtained, of which further analysis and discussion is as given below.

As various soil-pile models were prepared and dynamic pile installation effects are studied on preinstalled piles by changes various parameters such as diameter of pile. The detailed results are summarized in graphical and tabulated forms along with their analysis as below.

Following model are generated after completion of dynamic installation of last pile between preinstalled piles which causes displacement of pile which also affects surrounding piles and soil.

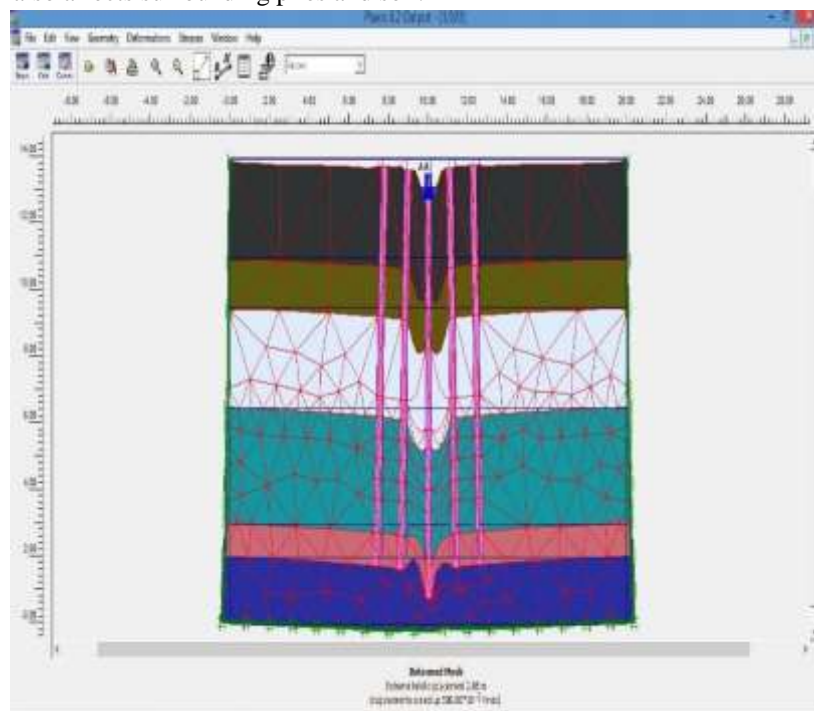


Image 5: Mesh deformation of pile after installation

A. COMPARATIVE RESULTS IN TABULAR FORM:

a) For Govindnagar site:

i) Diameter Variation

Table 5. Displacement of pile tips

Dia. (m)	X Displacement (m)		Y Displacement (m)	
	1 st Pile	2 nd pile	1 st Pile	2 nd pile
At				
0.30	0.127	0.079	1.461	0.884
0.60	1.411	0.923	2.807	1.835
0.90	1.854	1.256	3.886	2.038

ii) Spacing Variation

Table 5. Displacement of pile tips

Spacing (m)	X Displacement (m)		Y Displacement (m)	
	1 st Pile	2 nd pile	1 st Pile	2 nd pile
At				
0.9	0.967	0.746	1.950	1.276
1.8	0.886	0.377	1.458	1.109
2.7	0.481	0.128	0.824	0.678

b) For Jailroad site

i) Diameter Variation

Table 6. Displacement of pile tips

Dia. (m)	X Displacement (m)		Y Displacement (m)	
	1 st Pile	2 nd pile	1 st Pile	2 nd pile
At				
0.30	0.586	0.118	1.328	1.105
0.60	0.987	0.386	2.310	1.912
0.90	1.645	1.173	2.823	2.332

ii) Spacing Variation

Table 7. Displacement of pile tips

Spacing (m)	X Displacement (m)		Y Displacement (m)	
	1 st Pile	2 nd pile	1 st Pile	2 nd pile
At				
0.9	1.206	0.867	3.751	1.689
1.8	0.845	0.637	1.131	0.822
2.7	0.560	0.235	0.658	0.615

B. COMPARATIVE RESULTS BETWEEN GOVINDNAGAR AND JAILROAD SITE:

a) Diametric Variation:

Table 8. Horizontal displacement of pile tips

Diameter (m)	X Displacement (m)			
	Govindnagar site		Jailroad site	
	1 st Pile	2 nd pile	1 st Pile	2 nd pile
At				
0.30	0.127	0.079	0.586	0.118
0.60	1.411	0.923	0.987	0.386
0.90	1.854	1.256	1.645	1.173

Table 9. Vertical displacement of pile tips

Diameter (m)	Y Displacement (m)			
	Govindnagar site		Jailroad site	
At	1 st Pile	2 nd pile	1 st Pile	2 nd pile
0.30	1.461	0.884	1.328	1.105
0.60	2.807	1.835	2.310	1.912
0.90	3.886	2.038	2.823	2.332

b) Spacing Variation

Table 10. Horizontal displacement of pile tips

Spacing (m)	X Displacement (m)			
	Govindnagar site		Jailroad site	
At	1 st Pile	2 nd pile	1 st Pile	2 nd pile
0.9	0.967	0.746	1.206	0.867
1.8	0.886	0.377	0.845	0.637
2.7	0.481	0.128	0.560	0.235

Table 11. Vertical displacement of pile tips

Spacing (m)	Y Displacement (m)			
	Govindnagar site		Jailroad site	
At	1 st Pile	2 nd pile	1 st Pile	2 nd pile
0.9	1.950	1.276	3.751	1.689
1.8	1.458	1.109	1.131	0.822
2.7	0.824	0.678	0.658	0.615

9. CONCLUSION

Based on this study results are drawn and compared for both the sites and based on the results obtained, following conclusions are drawn from above software analysis.

1. For Govindnagar site:

- [1] As diameter of pile is increased from 0.3 to 0.9 m displacement of preinstalled pile also increased along horizontal and vertical directions.
- [2] Horizontal displacement of first pile increased from 0.127 to 1.854m and 0.079 to 1.256 m for second pile. Vertical displacement of first pile increased from 1.401 to 3.886 m and 0.884 to 2.038 m for second pile.
- [3] As centre to centre spacing of pile increased from 0.9 to 2.7 m displacement of preinstalled pile decreased along horizontal and vertical directions.
- [4] Horizontal displacement of first pile decreased from 0.967 to 0.481 m and 0.746 to 0.128 m for second pile. Vertical displacement of first pile decreased from 1.950 to 0.824 m and 1.276 to 0.678 m for second pile.
- [5] Based on the results vertical displacement is more than horizontal displacement at Govindnagar.

2. For Jailroad site:

- [1] As diameter of pile is increased from 0.3 to 0.9 m displacement of preinstalled pile also increased along horizontal and vertical directions.
- [2] Horizontal displacement of first pile increased from 0.586 to 1.645 m and 0.118 to 1.173 m for second pile. Vertical displacement of first pile increased from 1.328 to 2.823 m and 1.105 to 2.332 m for second pile.
- [3] As center to centre spacing of pile increased from 0.9 to 2.7 m displacement of preinstalled pile decreased along horizontal and vertical directions.
- [4] Horizontal displacement of first pile decreased from 1.206 to 0.560 m and 0.867 to 0.235 m for second pile. Vertical displacement of first pile decreased from 3.751 to 0.658 m and 1.689 to 0.615 m for second pile.
- [5] Based on the results vertical displacement is more than horizontal displacement at Jailroad.

ACKNOWLEDGMENT

The author of this paper is highly obliged to the Department of Civil Engineering, Matoshri College of Engineering and Research Center, Eklahare, Nashik and the Management of MCOERC. Authors are thankful to Principal, Head of the Department and the other staff of the Institute. Author would like to express their deep sense of gratitude towards my friends and family for their support.

REFERENCES

- [1] S.P.Dasgupta et al. (2016) "A numerical and experimental study of hollow steel pile in layered soil subjected to vertical dynamic loading" Department of Civil Engineering, Indian Institute of Technology Kharagpur, 721302, India.
- [2] Manna B et al. (2016) "Vertical vibration of full-scale pile – an analytical and experimental study" J Geotech Geoenviron Engg, ASCE 2009;135(10):1452–61.
- [3] Dasgupta S. P. et al. (2016) "A numerical and experimental study of hollow steel pile in layered soil subjected to lateral dynamic loading" Soil Dynamic Earthquake Engg. 2013;53:119–29.
- [4] Ernesto Gauder et al. (2012) "A review on the driving performance of FRP composite piles" Faculty of Engineering and Surveying, University of Southern Queensland, Toowoomba, Queensland 4350, Australia.
- [5] Daesung park et al. (2016) "Analyzing load response and load sharing behavior of piled rafts installed with driven piles in sands" School of Civil and Environmental Eng., Yonsei University, Seoul 120-749, Korea.
- [6] Cheng-Yu Hong et al. (2016) "Application of distributed optical fibre sensor for monitoring the mechanical performance of a driven pile" State Key Laboratory of Earthquake Dynamics, Institute of Geology, Beijing 100029, China.
- [7] D. S. Liyanapathirana et al. (2015) "Application of EPS geofom in attenuating ground vibrations during vibratory pile driving" Geotextiles and Geomembranes 44 (2016), pp 59-69.
- [8] Benamar A. (2000) "Influence of driving impact on the axial response of piles" Proceedings of the 4th Conference of the European Association for Structural Dynamics, Prague, June 1999, Vol. 2, pp. 1019-23.
- [9] Benamar A. (2000) "Dynamic pile response using two pile-driving techniques" Soil Dynamics and Earthquake Engineering (2000), pp243-247.
- [10] Fursan Hamad (2016) "Formulation of the axisymmetric CPDI with application to pile driving insand" Institute of Geotechnical Engineering, University of Stuttgart, Germany, Computers and Geotechnics 74 (2016) 141–150.
- [11] Barden Hagen S. et al. (2000) "The material-point method for granular materials" Computer Methods & Applied Mech Engg 2000;187(3–4):529–4.
- [12] Jakub Konkol et al. (2016) "large deformation finite element analysis of undrained pile installation" Department of Geotechnics, Geology and Marine Civil Engineering, Studia Geotechnica et Mechanica, Vol. 38, No. 1, 2016.
- [13] H.R. Masoumi et al. (2005) "Numerical modeling of free field vibrations due to pile driving using a dynamic soil-structure interaction formulation" Journal of Computational and Applied Mathematics 215 (2008) 503 – 511.
- [14] Yanlin Zhao et al. (2016) "Permeable piles: An alternative to improve the performance of driven piles" Department of Civil Engineering, Queen's University, Kingston, Canada.
- [15] Rodrigo Salgado et al. (2016) "Pile driving formulas based on pile wave equation analyses" Journal of Computers and Geotechnics 81 (2017) 307–321.
- [16] Jean Chung et al. (2013) "Pile fatigue assessment during driving" 5th Fatigue Design Conference, Fatigue Design (2013).
- [17] Liqiang Sun et al. (2016) "Prediction of pile running during the driving process of large diameter pipe piles" Laboratory of Soft Soil Characteristics and Engineering Environment, Tianjin, China.
- [18] Harald Klammler et al. (2013) "Reliability based design of driven pile groups using combination of pile driving equations and high strain dynamic pile monitoring" Department of Civil and Coastal Engineering, University of Florida, Gainesville, FL, USA.
- [19] Kazem Fakharian et al. (2007) "Application of a continuum numerical model for pile driving analysis and comparison with a real case" Department of Civil and Environmental Engineering, Amirkabir University of Technology, Iran
- [20] Goble, G.G. et al. (1980), "The analysis of pile driving" A state of the art, Proceedings of the International Seminar on Applied Stress-Wave Theory on Piles, Stockholm.
- [21] Mabsout, assoulas et al. (1994), "A finite element model for the simulation of pile driving" International Journal for Numerical Methods in Engineering, 37, pp. 257-278.