

INVESTIGATING THE OPERATION MANAGEMENT OF VARIOUS HEAVY EQUIPMENT ENGAGED IN FOUNDATION WORK IN THE CONSTRUCTION

A Thesis

Submitted in partial fulfillment of the requirements for the award of
Master of Architecture degree in Building Management

by

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SATHYABAMA

**INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)**

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ABSTRACT

Foundation is the major and important phase of the building since its the base for the building to stand up. For the construction of foundation for different type of building requires different types of equipments. There are different types of foundations. The design and the construction of a well-performing foundation must possess some basic requirements. The selection of the foundation type is based on different criteria. Based on the type of the foundation selected the equipments are selected considering different criteria. For instance, A tall building like a skyscraper or a building constructed on very weak soil requires deep foundation. Shallow foundation are Individual footing or isolated footing, Combined footing, Strip foundation, Raft or mat foundation. Deep Foundation are Pile foundation, Drilled Shafts or caissons. This study is based on the overall learning of different types of equipments engaged in the different types of foundation. And the productivity analysis is done for backhoe along with comparative study.

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

A Piling is the process of drilling hole for foundations of the buildings through the ground to provide more structural strength to the soil with low bearing capacity underneath. Piling prepares the ground to carry heavy loads, incase of inability of the soil. Foundations provide support for structures, transferring their load to layers of soil or rock that have sufficient bearing capacity and suitable settlement characteristics to support them. There are a very wide range of foundation types suitable for different applications, depending on considerations such as: The nature of the load requiring support, Ground conditions, The presence of water, Space availability, Accessibility, Sensitivity to noise and vibration. Very broadly, foundations can be categorised as shallow foundations or deep foundations. earth drills based on crawler cranes designed specifically for the construction of foundations for structures at various construction sites.

1.2 AIM OF THE RESEARCH

The aim is to analyze the different types of foundation and the equipments used for the its construction. The narrow study on operation management of the heavy equipments, procedures, codes, selection criteria, cost analysis, fuel consumption and productivity analysis.

1.3 OBJECTIVES AND SCOPE OF THE RESEARCH

1. To understand the various equipment involved in the foundation.
2. To create the selection criteria to reduce the cost time and increase productivity with good quality.
3. To understand the operation of the equipment and analysis of the risk associated with it.

4. Identifying the components of the equipments and study on it along with usage, advantages and disadvantages of each type.
5. It has the scope on criteria identification to reduce the cost, time and increase in the quality of the service.
6. Eligibility of the operators, owning cost, rental cost, planning for operation of the equipment.
7. Safety consideration to reduce the risk of accidents and effective work.

1.4 RESEARCH QUESTIONS

1. What are the factors responsible for increasing the equipment productivity?
2. What are considered to be the important criteria for the selection of the equipment ?
3. How the activities are preplanned and schedule is prepared to carryout the work?
4. What are the different types foundation and heavy equipments engaged in the construction of each type?
5. What are the steps to be followed for the maintenance of the equipments?

1.5 RESEARCH APPROACH

1.5.1 Qualitative analysis

- Interviews with the backhoe operator, manufacturer, project manager, site engineer to know the operation of the equipment.
- Open ended questions to grab informations.
- Observation data of equipment with handling.
- Case studies analysis to know the operation, safety consideration, usage hours.
- Preparing the questionnaire for the better understanding.

1.5.2 Quantitative analysis

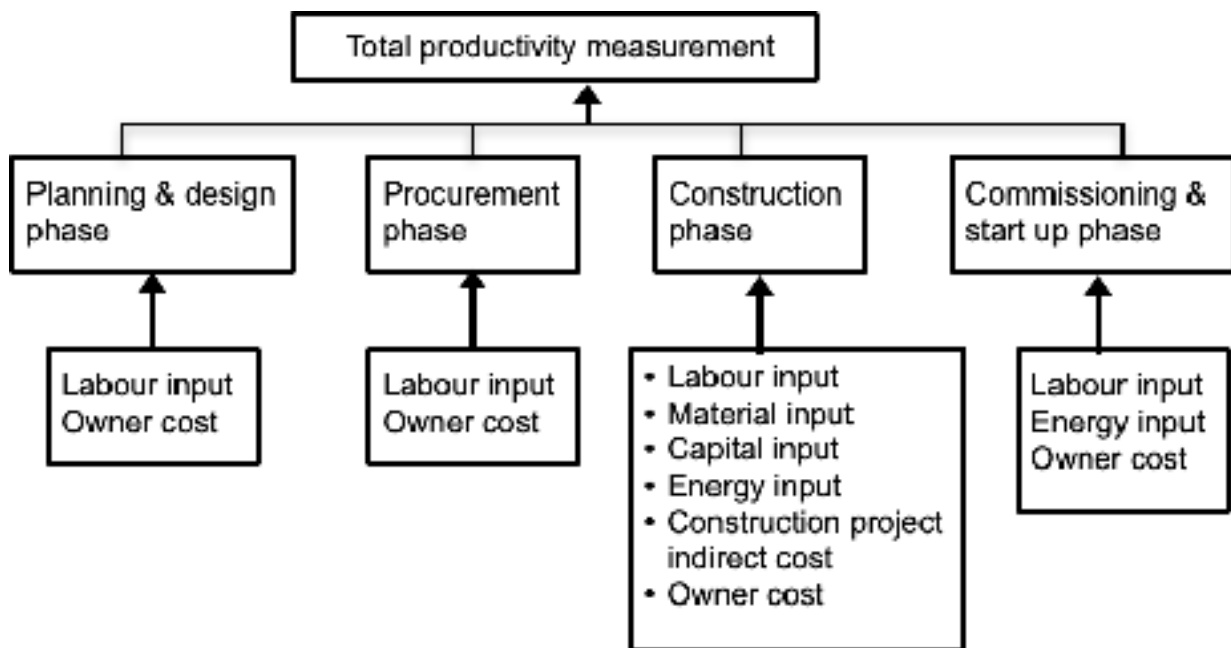
- Forming a database with acquired information.
- Performance data of the equipment

- Statistical analysis, by taking on site reading based on the operation and capacity analysed.
- Monitoring of the backhoe while operating.
- Pile driving equipments statistical informations.
- Study with the help of bar chart, graph and pie chart.

1.6 TOOLS AND TECHNIQUES

1. Flow chart for methodology
2. The mobilization plan preparation
3. Bar Graphs, Pie chart, Tables
4. Interviews with the Project managers
5. Efficiency of load calculation
6. Diagram showing components of the backhoe, piling rig etc.,

1.7 FRAMEWORK FOR PRODUCTIVITY



1.8 RESEARCH METHODOLOGY

1.8.1 Stage 1 - Framing research problem

- Determine Aim and objectives of the Research
- Research approach towards the analysis
- Scope and Need of the research

1.8.2 Stage 2 - Literature study

- Study of the components of heavy equipments and its working.
- Load calculation and analysis
- Risk and safety management
- Skilled labour and their job.

1.8.3 Stage 3 - Data collection

- Codes and standards Identification of Case studies to learn effective usage of selected equipments used for the foundation construction.
- Referring Books to calculate the efficiency of different types of equipment used for the foundation construction.
- Journals, Magazines, Research paper, Websites.

1.8.4 Stage 4 - Analysis of data

- Interpretation of collected data identified
- Comparative study on the equipments
- Usage of tools and techniques identified
- Analysing the observed data.

1.8.5 Stage 5 - Conclusion

Final report on the analysis done with conclusion. coming up with the effective solution for the risk identified. Suggesting an alternative to increase the productivity.

CHAPTER 2

RESEARCH PAPERS / JOURNALS

2.1 Estimation of capital and operation costs of backhoe loaders

2.1.1 Abstract

Material loading is one of the most critical operations in earthmoving projects. A number of different equipment is available for loading operations. The backhoe shovel is very popular for digging, loading and flattening tasks. Adequate cost estimation is one of the most critical tasks in feasibility studies of equipment fleet selection. This paper presents two different cost models for the preliminary and detailed feasibility study stages. The UVER cost model is suitable for quick cost estimation at the early stages of project evaluation, while the MVLR cost function, which is more detailed, can be useful for the feasibility study stage. Independent variables of MVLR include bucket size, digging depth, dump height, weight and power. Model evaluations show that these functions could be a credible tool for cost estimations in pre feasibility and feasibility studies of mining and construction projects.

2.1.2 Introduction

Earthmoving operations are an important part of construction and mining projects, and mainly include excavation, loading, site preparation, embankment construction, compacting, backfilling, surfacing and hauling. Moreover, machine owners seek to minimize the cost of operation by optimum selection of the equipment. The UVER cost model is useful for quick cost estimation at the early stages of a project. While the MVLR, based on principal component analysis (PCA), is suitable for detailed estimates at the feasibility study stage.

2.1.3 Literature review

A number of models have been established in attempts to shortcut the construction and mining cost estimating process. These relate the cost to certain factors in a process or a unit. For instance, the cost of an excavator may be related to its bucket capacity. The relationship may be expressed in a formula or a graph. Multivariate cost estimation models, on the basis of up-to-date data, will overcome these shortcomings.

Proposed by	Year	Application
Hwang	2011	Prediction of cost indexes for construction projects using time series
Asmar <i>et al.</i>	2011	Estimation of highway project costs using project evaluation and review technology
Thal <i>et al.</i>	2010	Prediction of the required cost contingency for air force construction projects, using multiple linear regression
Sayadi <i>et al.</i>	2010a	Estimating maintenance cost of loading and hauling equipment using multiple linear regression
Sayadi <i>et al.</i>	2010b	Estimation of hoisting equipment cost for underground mines
Sonmez and Ontepeli	2009	Cost estimation of urban railway projects
R.S. Means Company	2005	Presenting cost data for all phases of building construction
Wilmat and Mei	2005	Estimation of highway construction costs indexes using neural network
Pratt	2004	Pricing construction equipment
Mular	1982	Estimation of capital costs of mining and mineral processing equipment using UVER method
Mular and Poolin	1998	
Carman	1991, 1994	Development of UVER cost functions for surface and underground mining
Noakes and Lanz	1993	Estimating the costs of mining and milling industry, using graphical or formulation methods
O'Hara and Suboleski	1992	Development of cost formulas as estimators of capital and operating costs of mining and milling
Petrich and Dewey	1987	A computer model which utilizes O'Hara's cost estimation model
Srebhina	1987	Using univariate exponential regression method for small placer mines cost prediction
USBM	1987	Estimation of mining and milling cost items, using regression analysis
Collier	1987	Fundamentals of building and construction estimating and cost accounting
Mular	1982	Estimation of mining and milling costs using regression analysis
O'Hara	1980	
	1981	Surface and underground mining cost estimation using exponential regression
Infomine ¹	Annually	Cost estimation guide for mine and mill equipment

Table 1: The various applications of construction and mining cost estimation.

2.1.4 Data

32 different sizes of backhoe shovels, working in construction and mining projects in the United States are considered and their economic data as well as machine specifications are considered. The economic data are classified into two types, as capital (CC) and operating costs (OC). The CC is based on the US dollar (2010) while the OC is based on US dollars per hour. The operating costs items include overhaul (parts and labor), maintenance (parts and labor), power, lubrication and wear on parts (the cost of the operator's time is not included here) and the technical parameters are bucket size (BS), digging depth (DD), dumping height (DH), weight (W) and power (HP) (Noakes, Lanz 1993). The average and standard deviation of all the parameters and data ranges are given in Table 2.

Parameter		Min	Max	Mean	St. dev.
Capital cost (CC)	M\$	0.113	16.2	3.69	3.67
Operating cost (OC)	\$/h	12.14	656	220.23	191.04
Bucket size (BS)	cu m	0.28	39.8	12.61	11.45
Digging depth (DD)	m	4.1	16.2	9.248	2.68
Dump height (DH)	m	5.1	15.9	10.22143	3.16685
Machine weight (W)	ton	8.03	811	240.5	210.6
Power (HP)	hp	54	3800	1109.8	983.16

Table 2: Parameters and data ranges.

2.1.5 Research Framework

This paper presents two different cost models for backhoe shovel shovels. Figure 1 shows a normal material loading operation using a backhoe shovel and dump truck. The first model estimates the costs based on the bucket size of the backhoes, using the UVER technique. The second model is useful for in-depth estimations, and estimates the costs as functions of different specification parameters of backhoe shovels, including the bucket size (BS), digging depth (DD), dump height (DH), power (HP) and weight (W) of the machine. This model is presented using MVLr, based on PCA.

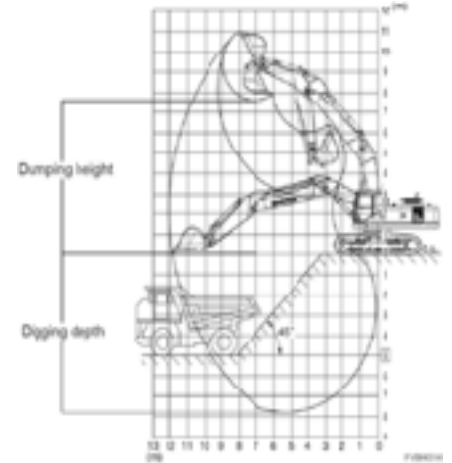


Figure 1: Normal material loading

2.1.6 Case example

Sungun Copper Mine is located in East Azerbaijan province approximately 125 Km east of the city of Tabriz is one of the main copper deposits of Iran. This project needs about 1.3 million m³ of excavation and overburden removal operation including soil and rocky soil removal operations. The equipment fleet used in this project is listed.

Equipment	Number
Backhoe shovel	20
Wheel loader	14
Dumper	17
Truck	62
Grader	4
Compactor	4
Tractor	1
Truck, water	2

Table 3 Equipment used in project

Model	Number	BS (cu. m)	DD (m)	DH (m)	HP (Kw)	W (ton)
Komatsu PC200	8	0.28	4.7	5.03	51.54	148
Komatsu PC220	4	0.17	4.45	4.94	26.53	135
Hyundai 220LC	2	0.07	4.43	5.83	23.49	143
Hyundai 220LC	2	0.14	4.75	5.68	35	207
New Holland E253 IM	1	0.1	7.84	7.7	23.17	184
New Holland E213 IM-SE	2	0.213	6.7	5.47	21.7	120
Doosan 220	1	0.09	4.43	4.93	21.6	143

Table 4 Backhoe shovels used in the project

Model	Estimated operational cost (\$/hr)	Estimated operational cost (\$/hr)	Ratio (%)
Komatsu PC200	24.88	27.14	11.10%
Komatsu PC220	36.44	32.24	-11.80%
Hyundai 220LC	23.79	24.72	3.91%
Hyundai 220LC	28.44	27.32	-3.91%
New Holland E253 IM	18.14	18.74	3.31%
New Holland E213 IM-SE	11.14	10.73	-3.68%
Doosan 220	21.44	22.24	3.73%
Average		24.44	
Average		24.44	

Table 5: Estimated vs actual operational cost

2.1.7 Conclusion

The objective of this paper was to establish reliable cost estimating models for backhoe shovels which are popular for material handling in mining and construction projects. These models are quick, easy and accurate tools and can be useful for making accurate decisions about the size of the loading equipment fleet in construction and mining projects. The UVER model presents a rough estimate suitable for preliminary cost estimations while the MVLR model is more detailed with reasonable accuracy.

2.2 A review of pile machines and their selection criteria

2.2.1 Introduction

The piles are frequently used for transmitting external loads onto deeper layers or for improving mechanical properties of the ground. Ground anchors against the buoyancy force. stabilization of landslides – piles are driven to the layer below the slide surface. simplification of foundation or surface object, e.g. introduction of piles to the level of bridge bearing may simplify the design and performance of a pillar. among other specialist foundations, it is the deep foundation based on piles which can be the most efficiently mechanized and quickly performed.

2.2.2 Division of piles

SDP and VDP PILES		
PREFABRICATED	MONOPILE FOUNDATION	
(ready to drive)	In permanent casing	In temporary casing
– reinforced steel – reinforced steel–rebar segments – prestressed – steel–pipe – steel–profiled	– steel pipe driven from the bottom through the plug or from the top through the oak core – thin pipe introduced on the core – prefabricated thin pipe introduced on the core – prefabricated thin pipe (after underreamed)	– steel cage driven from the top – steel cage driven from the bottom through the plug – as above – with a larger pile base

Table 6: Piles division

Piles can be classified on the basis of the way in which loads are transmitted onto the ground, the kinds of pile load, performance, material, performance.length:1* short (to 6 m), 2* medium or normal (to 25 m), 3* long (over 25 m). Piles classified according to the character of work in ground are divided into: piles driven in a bearing layer, supported piles (poles), suspended piles.

2.2.3 Review on pile machines



Figure 2: Components of pile driving machine

2.2.4 Pile machines - case study

A number of companies produce specialist pile machines, e.g. Soilmec offering SR series, where the successive numerical denotations stand for the weight of the machine in megagrams. These machines are applicable to: large diameter piles (LDP), full displacement piles (FDP), CFA piles and cased auger piles (CAP, CSP). Presently, the biggest pile machine of this type is SR-100 for CSP with a double head. Soilmec offers pile machines of SF series which are designed for making only multifunction pile machines.

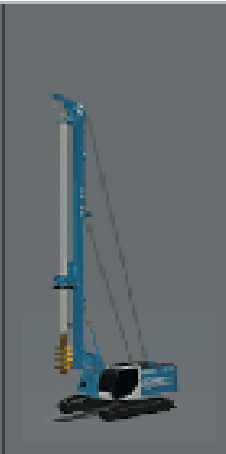
				
	SR-20	SR-45	SR-80	SR-100
Installed power [kW]	119	201	328	480
Weight [Mg]	27	42	83	148
Torque [kN·m]	114	185	292	452
Main winch [kN]	103	165	260	370
CCS pull up/down [kN]	124/68	207/240	300/220	417/330
Depth of LDP [m]	40	63	77	92
Diameter of LDP [mm]	1200	2000	2000	3500
Depth of CFA pile [m]	15	21.5	24	31
Diameter of pile CFA [mm]	750	900	1200	1400

Table 7: Multifunction soilmec pile machine with their specifications and technology available

Large-diameter piles tripped with a rotary head	+	+	+	+
Large-diameter piles tripped with an oscillator	+	+	+	+
CFA piles	+	+	+	+
CSP piles	+	+	+	+
Full Displacement Piles (FDP)	+	+	+	+

Table 8: Available technologies for Multifunction soilmec pile machine

2.2.5 Selection criteria

While performing geo engineering works it is important to select an appropriate machine. The optimally selected pile machine guarantees fast and efficient performance of assumed tasks at a lower cost. The optimization can be realized on the basis of technical parameters of the machines and their rank. The machines for making piles or other geoenengineering works can be selected on the basis of the multi-criteria optimization method with synthetic measure of the device. Using this method one can practically compare various criteria in view of their measures and significance.

Calculations	1	2	3	4	5	6	
Significance criterion (B _j)	3.1	3.8	3.5	1	1.2	0.5	
Pile machines	CCE pull up/ down [kN]	Torque [kN-m]	Max depth [m]	Min. diameter [cm]	Power [kW]	Max. weight [kN]	Evaluation rank
1	Sollmax SR 25	125	11.5	60	1200	119	0.00
2	Bauer BG 1 P 31	140	12.5	60	1800	153	0.15
3	Canagrade BRT 5 NP	148	12.5	50	1500	164	0.12
4	Bauer BG 20 31	280	28.0	51	1800	205	2.18
5	Sollmax SR 45	240	18.5	63	2300	201	0.65
6	Sollmax SR 32	330	28.2	77	2300	324	2.62
7	Bauer BG 24	330	27.3	71	2100	324	3.17
8	Canagrade B300 NP	430	38.1	90	2500	483	5.25
9	Canagrade B400	430	35.4	87	3300	498	6.35
10	Sollmax SR 120	417	43.2	92	3800	488	9.77
11	Bauer BG 45	480	46.0	111	3100	558	8.45
12	Canagrade B310 NP	620	52.0	100	3300	863	9.31
13	Bauer BG 50	620	58.8	82	3300	878	9.32

Table 9: Selection criteria

1. Establish significance of particular criteria $[x'_{jk}]$ of a machine; its sum should equal to unity.
2. Establish minimum and maximum values for particular criteria:

$$x_{jk}^{\min} = \min x'_{jk} \quad x_{jk}^{\max} = \max x'_{jk} \quad (1)$$

3. Calculate the range of values for particular criteria:

$$r_k = x_{jk}^{\max} - x_{jk}^{\min} \quad (2)$$

4. Transform the matrix $[x'_{jk}]$ of particular criteria into a matrix of normalized values following the equation:

$$y'_{jk} = \begin{cases} \frac{x'_{jk} - x_{jk}^{\min}}{r_k} & \text{dla } k = \min \\ \frac{x_{jk}^{\max} - x'_{jk}}{r_k} & \text{dla } k = \max \end{cases} \quad (3)$$

5. Calculate synthetic values of measures d'_j being relative distances of particular criteria from the respective optimum values for successive machines:

$$d'_j = \sum_{k=1}^h y'_{jk} \quad (4)$$

6. Calculate synthetic values of measures D^i being relative distances of respective values in groups of machines:

$$D^i = \sum_{j=1}^l d'_j \quad (5)$$

7. Calculated synthetic measures y'_{jk} should be multiplied by established values (B_j) for the respective criteria:

where:

l – number of analyzed machines, for $i = 1, 2, \dots, z$,

j – number of machines in analyzed population, for $j = 1, 2, \dots, n$,

k – number of assumed criteria, for $k = 1, 2, \dots, h$.

2.2.6 Conclusion

Their principal aim lies in transmitting outer loads onto layers deposited at greater depths or improving the mechanical properties of soil. Bauer, Casagrande and Soilmec dominate in the production of pile machines. The most suitable pile machine fit for performing large-diameter piles at great depth should be selected on the basis of the multi-criteria optimization with synthetic evaluation of measures.

2.3 Environmental Emissions of Construction Equipment Usage in Pile Foundation Construction Process—A Case Study.

2.3.1 Abstract

Construction industry is a major contributor to the environmental emissions due to the extensive use of construction equipment. Pile foundation is extensively used in high-rise buildings construction and it involves operation of heavy construction equipment. This study developed a process-based model to quantify environmental emissions of equipment usage in a typical pile foundation construction using the US EPA methodology. It is seen that careful selection of machines and equipment can reduce the emissions up to 10 %. These findings of the study could be effectively used for minimizing the environmental emissions by careful selection of suitable equipment and technology

2.3.2 Introduction

As a critical phase in the development of high-rise buildings, foundation construction involves activities like demolition of existing structures if any, excavation, piling works, extensive concrete works which take time and use heavy construction equipment and techniques. Therefore, foundation construction accounts for a considerable amount of environmental emissions. Pile foundation is suitable for soils which have low bearing capacity and when the heavy loads are to be transferred to the hard rock or to the surrounding soil directly. Pile foundation can be of two basic types i.e., bored pile and driven pile.

2.3.3 Past Research on Emissions at Construction Phase

A greenhouse gas emissions throughout its life cycle (Chau et al. 2012; Mao et al. 2013; Yan et al. 2010). (Guggemos 2003; Guggemos and Horvath 2006). Guggemos et al. in their studies conclude that CO and NO₂ pollutant substances are pre dominant in non-greenhouse gas emissions at the construction stage. Guggemos et al. compared the environmental emissions in concrete and steel building construction. Very few studies have concentrated on emissions at foundation construction.

2.3.4 Research method

The section covers the data collection framework development, explanation of the scope and the limitations of the study and the methodology development for the case study

Topic covered	1	2	3	4	5	6	7	8	9
Material phase	x			x	x	x	x	x	
Construction phase	x		x	x	x			x	
Use phase	x			x	x	x	x	x	
End of life phase	x			x	x			x	
Emissions from construction equipment		x							x
Topic covered	10	11	12	13	14	15	16	17	18
Material phase					x	x	x	x	x
Construction phase		x							
Use phase					x	x		x	x
End of life phase						x		x	x
Emissions from construction equipment	x		x	x					

Table 10 Methodology development

2.3.5 Framework development for data collection



2.3.6 Scope of study and limitation

Excluded section	Reason
Energy and emissions from materials	Out of the scope for this paper
Emissions from construction waste	Out of the scope for this paper
Installation of temporary casing	No temporary casing was installed in the case study
Removal of temporary casing	No temporary casing was installed in the case study
Delivery of labor to the site	Labor was using public transportation as the project was in urban area

Table11 : Scope exclusion

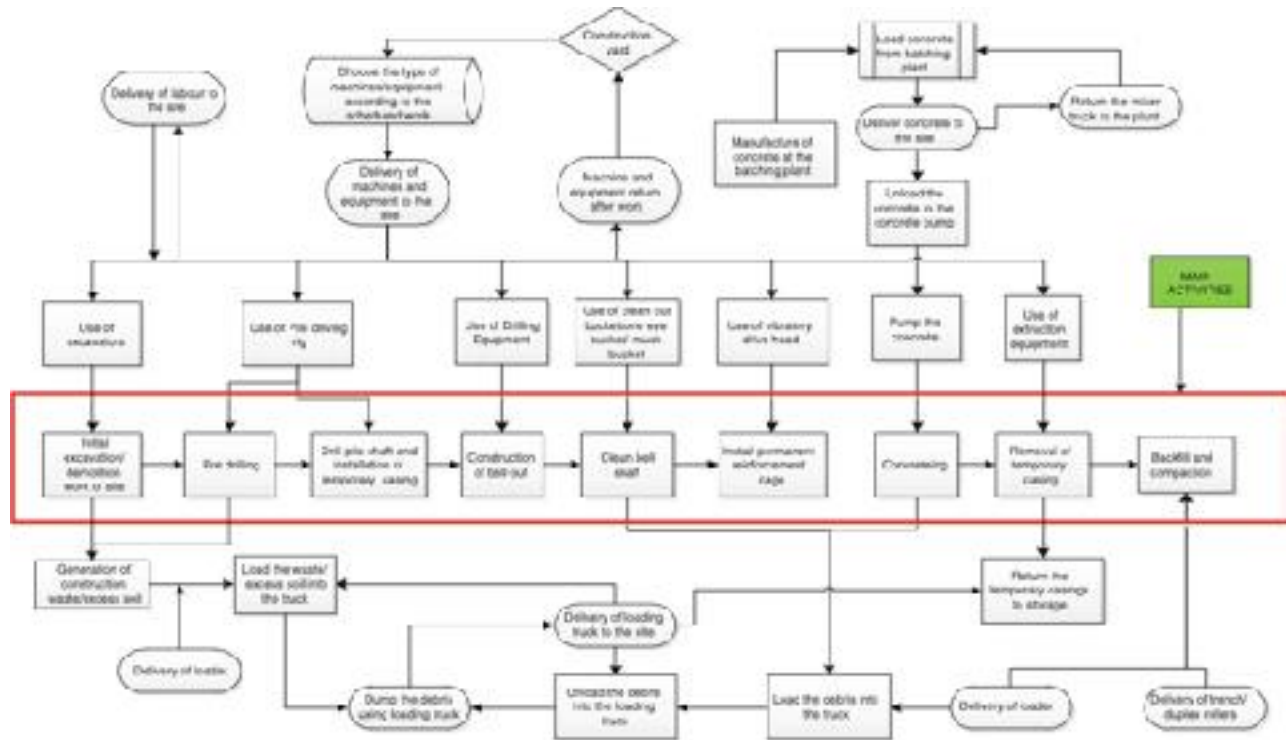
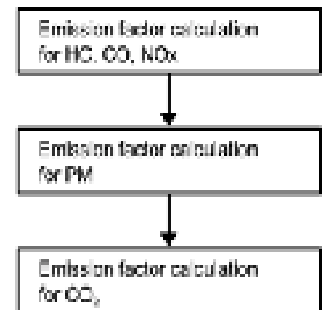


Figure 3: Major activities related to environmental emissions in a typical bored-pile foundation construction.

2.3.7 Methodology development

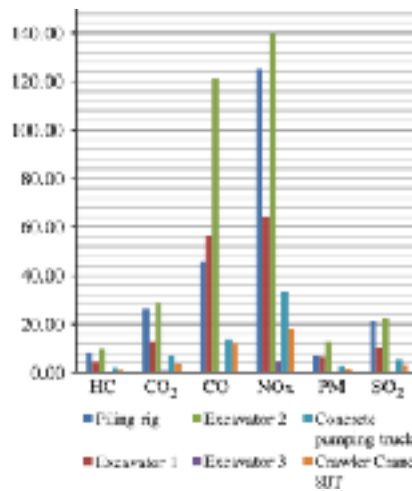
The case selected is a typical high-rise construction in Melbourne. The foundation consists of 84 piles of 750 mm diameter. The depth of a pile is around 20 m. The advantage of this construction site is that the water table is below the designed depth of the pile. A capping beam of size varies from 480 to 1000 mm width to 500 to 1300 mm depth is placed to connect all the piles. Among the construction of 84 piles, 54 were closely monitored and data were collected. Some piles were taken more time to complete construction, largely due to underground disturbance, rain and minor equipment malfunctions. The emissions are compared with respect to the activities as well as according to the machines.



2.3.8 Case study

Machine used	Label	Power (kW)	Total operation (h)	Total idle time (h)	Idle operation (%)
Excavator 1	A	260	139.85	5.7	4.08
Excavator 2	B	210	153.20	8.8	5.74
Excavator 3	C	30	80.20	6.2	7.23
Piling rig	D	328	113.37	6.2	5.47
Crawler crane	E	212	24.86	1.5	6.04
Concr. pumping truck	F	431	23.64	1.75	7.4

Table12 : Details of machines used during pile construction



2.3.9 Conclusion

From this study it can be concluded that carbon dioxide emission level governs the total emissions in construction activities such as piling foundation. careful selection of equipment can reduce the emissions at construction phase up to 10 %.

Figure 4: Emission variations based on the machine.

2.4 RESEARCH PAPER REVIEW

AUTHOR	YEAR	TITLE OF RESEARCH PAPER	ABSTRACT	INFERENCE
Behrooz Ghahremani, Ahmad Reza Sayadi, Ali Lashgari	2011	Estimation of capital and operation costs of backhoe loaders	The UVER cost model is suitable for quick cost estimation at the early stages of project evaluation, while the MVLK cost function, which is more detailed, can be useful for the feasibility study stage.	The UVER model presents a rough estimate suitable for preliminary cost estimations while the MVLK model is more detailed with reasonable accuracy.
Andrzej Gonet, Stanislaw Stryczek	2015	A review of pile machines and their selection criteria	The machines for making piles or other geotechnical works can be selected on the basis of the multi-criteria optimization method with synthetic measure of the device.	Their principal aim lies in transmitting outer loads onto layers deposited at greater depths or improving the mechanical properties of soil. Bauer, Casagrande and Solimex dominate in the production of pile machines.
Maifeng Sandanayake, Sujeeva Setunge, Guomin Zhang	2015	Environmental Emissions of Construction Equipment Usage in Pile Foundation Construction Process—A Case Study	It is seen that careful selection of machines and equipment can reduce the emissions up to 10 %. Construction industry is a major contributor to the environmental emissions	From this study it can be concluded that carbon dioxide emission level governs the total emissions in construction activities such as piling foundation

Table13 : Research paper review on study

CHAPTER 3

GENERAL LITERATURE STUDY

3.1 INTRODUCTION ON FOUNDATION

The foundations of the building transfer the weight of the building to the ground. A foundation (or, more commonly, foundations) is the element of an architectural structure which connects it to the ground, and transfers loads from the structure to the ground. Foundations are generally considered either shallow or deep.

3.2 OBJECTIVE OF FOUNDATION DESIGN

To ensure that the structural loads are transmitted to the subsoil safely, economically and without any unacceptable movement during the construction period and throughout the anticipated life of the building or structure.

3.3 FUNCTIONS OF FOUNDATION

- Distribution of loads
- Stability against sliding & overturning
- Minimize differential settlement
- Safe against undermining
- Provide level surface
- Minimize distress against soil movement

3.4 TYPES OF FOUNDATION

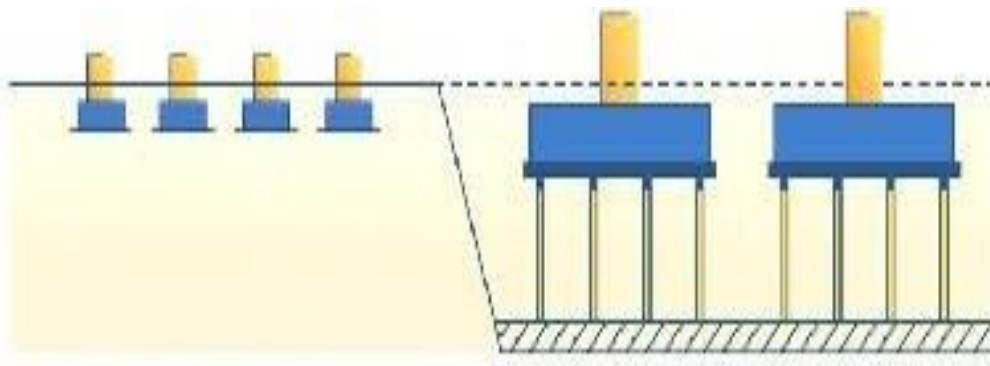


Figure 5: Types of foundation

3.4.1 Shallow foundation

It is often called footings, are usually embedded about a metre or so into soil. Used in smaller building where top layer can bare the weight.

- Isolated footing

This foundation is constructed for a single column and also called a pad foundation. Suitable for most subsoil except loose sand, loose gravels and fill areas. Usually constructed of reinforced concrete, square in plan.

- Combined footing

Combined footing is constructed when two or more columns are close enough and their isolated footings overlap each other. It is a combination of isolated footings, but their structural design differs. Footing is rectangle in shape

- Strip foundation

Suitable for most subsoil & light structure loadings. Suitable for those encountered in low to medium rise domestic dwellings where mass concrete can be used. Also known as Spread footings or Strip footings and Wall footings. The wider base of this footing type spreads the weight from the building structure over more area and provides better stability.

- Raft or mat foundation

Raft or mat foundations are the types of foundation which are spread across the entire area of the building to support heavy structural loads from columns and walls. Particularly useful where low bearing capacity soils are encountered & where individual column loads are heavy. Types of raft foundation are Solid slab raft, Beam & slab raft.

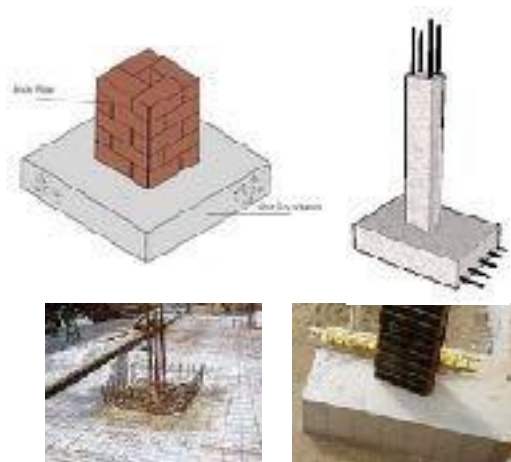


Figure 6: Isolated footing

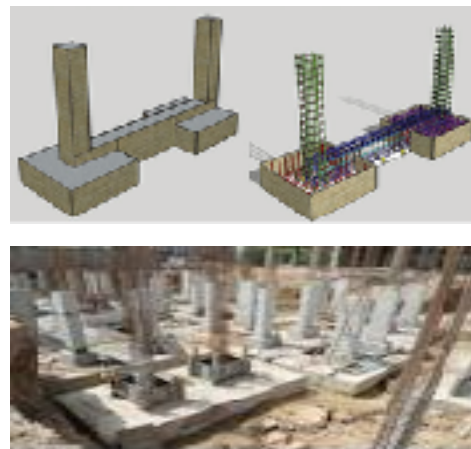


Figure 7: Combined footing

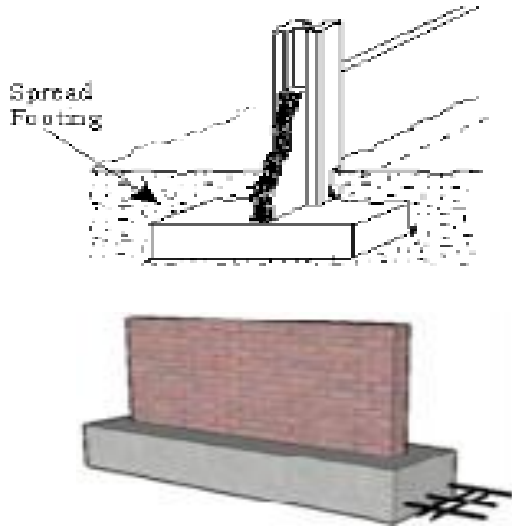


Figure 8: Strip footing

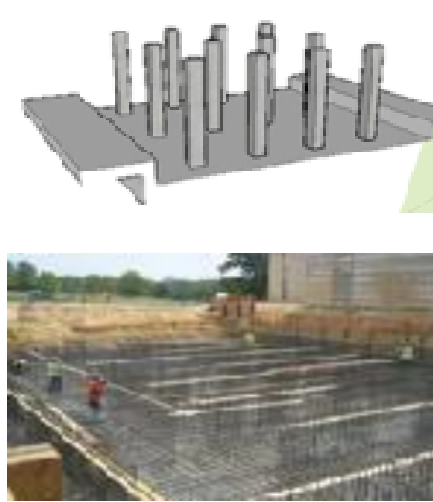


Figure 9: Raft / Mat foundation

3.4.2 Deep Foundation

It is used to transfer the load of a structure down through the upper weak layer of topsoil to the stronger layer of subsoil below. There are different types of deep footings including impact driven piles, drilled shafts, caissons, helical piles, geo-piers and earth stabilized columns.

- Pile foundation

The main components of the foundation are the pile cap and the piles. Piles are long and slender members which transfer the load to deeper soil or rock of high bearing capacity avoiding shallow soil of low bearing capacity. The main types of materials used for piles are Wood, steel and concrete.

classification of piles - based on functional behaviour

- End bearing piles also known as (point bearing piles)
- Friction piles (cohesion piles)
- Combination of friction and cohesion piles

classification of piles - based on materials

- Timber
- Concrete
- Steel
- Composite piles.

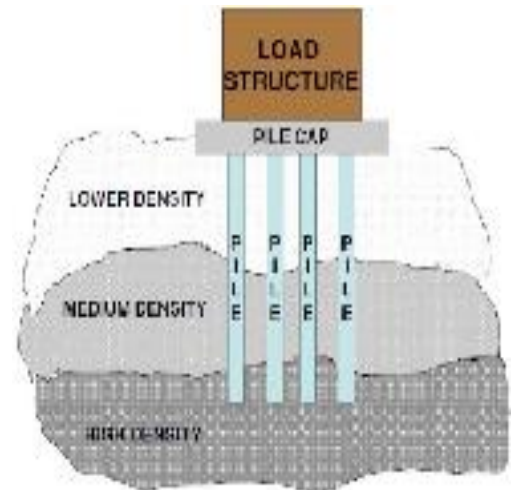


Figure 10: Basic principles of pile foundation

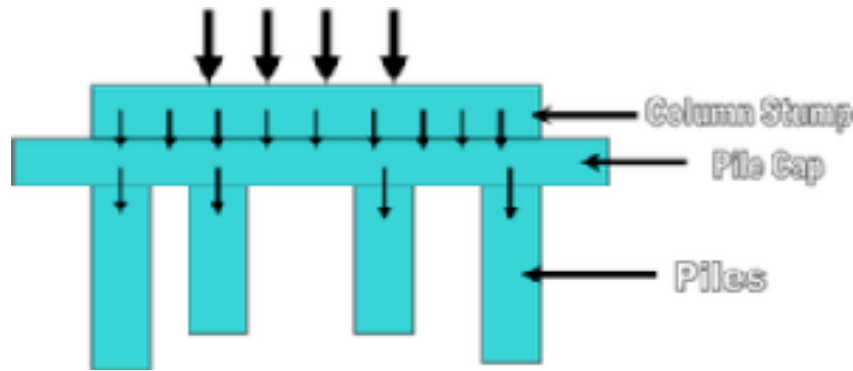


Figure 11: Load on pile foundation

- Drilled Shafts or caissons

A **caisson** foundation also called as pier foundation is a watertight retaining structure used as a bridge pier, in the construction of a concrete dam, or for the repair of ships. It is a prefabricated hollow box or cylinder sunk into the ground to some desired depth and then filled with concrete thus forming a foundation.

Types of caissons foundation

- Box Caissons
- Excavated Caissons
- Floating Caissons
- Open Caissons
- Pneumatic Caissons
- Sheeted Caissons.

Advantages of caisson foundation

- Economics
- Minimizes pile cap needs
- Slightly less noise and reduced vibrations
- Easily adaptable to varying site conditions
- High axial and lateral loading capacity.

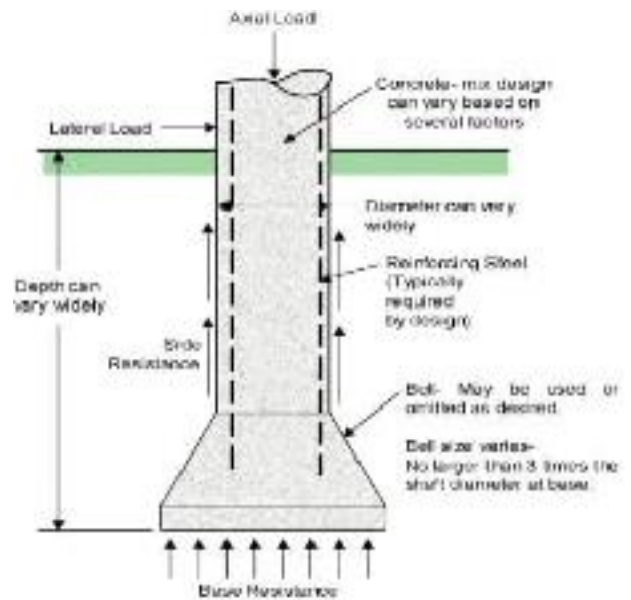
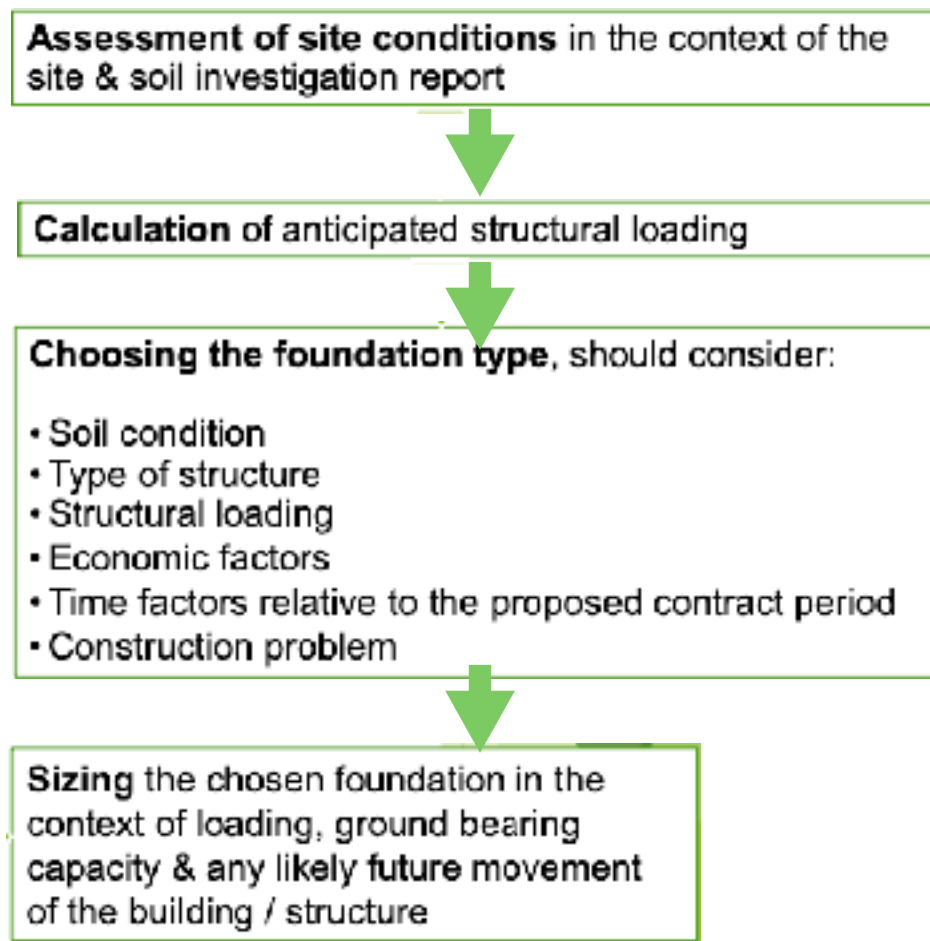


Figure 12: Caisson foundation

Disadvantages of caisson foundation

- Extremely sensitive to construction procedures
- Not good for contaminated sites
- Lack of construction expertise
- Lack of Qualified Inspectors.

3.5 BASIC DESIGN PROCEDURE



3.6 EXCAVATION EQUIPMENTS

3.6.1 Power Shovels

It is used to excavate earth of all classes except rock and load it into wagons. They are mounted on crawler tracks. It consists of a mounting, cab, boom, dipper stick and hoist line.

3.6.2 Back Hoe

The backhoe is hydraulic excavator with a bucket attached to the hydraulic controlled boom and stick. In this excavator, the excavation bucket moves in downward and backward direction during excavation. It is used to excavate below the natural surface to keep precise control of depth of excavation at close range work.

3.6.3 Draglines

They are used to excavate soft earth from below the ground and to deposit or load into wagons.

3.6.4 Clamshell

Clamshell consists of a bucket of two halves, which are hinged together at top. the bucket halves can be attached to the shovel-crane units or the boom of the dragline. Clamshell is used to excavate soft to medium materials and loose material at or below the existing ground surface.

3.6.5 Motor grader

This is used for levelling and finishing earth-work. They can be either towed type or motorised type. The working principle of a motor grader is it uses its moldboard, or blade, for rough or fine grading.

3.6.6 Trenchers

A trencher is a piece of construction equipment used to dig trenches, especially for laying pipes or electrical cables, for installing drainage, or in preparation for trench warfare. Trenchers may range in size from walk-behind models, to attachments for a skid loader or tractor, to very heavy tracked heavy equipment.

3.6.7 Bucket excavators

A bucket-wheel excavator (BWE) is **a large heavy equipment machine used in surface mining**. What sets BWEs apart from other large-scale mining equipment, such as bucket chain excavators, is their use of a large wheel consisting of a continuous pattern of buckets used to scoop material as the wheel turns.

3.6.8 Dredgers

These are the equipment used for excavation of the river, lake or sea for the purpose of deepening. Dredging can be done to recover gravel that are used by the construction industry.

3.6.9 Bull dozers

These machines are high powered tractors with caterpillar or crawler tracks fitted with a mould board or blade at the front for stripping excavation up to a depth of 400mm.

3.6.10 Rippers

Ripper is used for ripping of rock which is an alternative to the costly and time-consuming drilling and blasting process. The ripper can be wheel mounted or towed type.

3.6.11 Scrapers

It is a self-sufficient machine which can dig, load, haul, and discharge the material in uniformly thick layers.

3.6.12 Crawlers vs wheeled

Crawler track has a very strong grip with any kind of surface. Its carrying machine has a low ground pressure. In case of wheel type machine, where machine runs on four tires and has a high ground pressure.



Figure 13: Power shovels



Figure 14: Backhoe



Figure 15: Dragline



Figure 16: Clamshell



Figure17: Motor grader



Figure 18: Trenchers



Figure19: Bucket excavators



Figure 20: Dredgers



Figure21: Bull Dozers

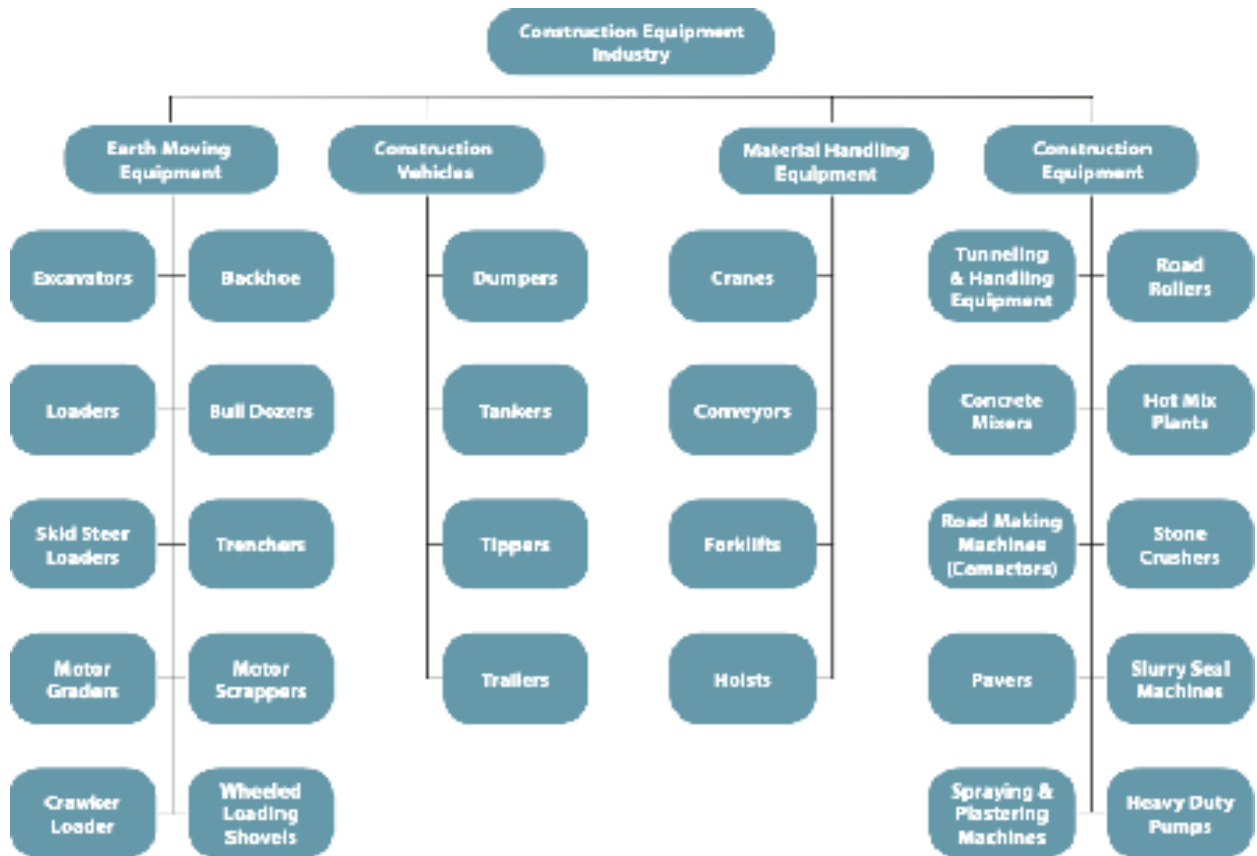


Figure 22: Rippers



Figure 23: Scrapers

3.7 FLOW CHART EXPLAINING THE DIFFERENT TYPES OF HEAVY EQUIPMENTS USED FOR DIFFERENT PURPOSE. EXTENSIVE STUDY ON EXCAVATORS



3.8 EVOLUTION OF BACKHOE LOADERS

3.8.1 Introduction

A backhoe loader, also called a loader backhoe, digger in layman's terms, or Informally shortened to backhoe within the industry, is a heavy equipment vehicle that consists of a tractor-like unit fitted with a loader-style shovel/bucket on the front and a backhoe on the back. Due to its (relatively) small size and versatility, backhoe loaders are very common in urban engineering and small construction projects (such as building a small house, fixing urban roads, etc.) as well as developing countries. This type of machine is like and derived from what is now known as a TLB (Tractor-Loader-Backhoe), which is to say, an agricultural tractor fitted with a front loader and rear backhoe attachment.

The true development of the backhoe began in 1947 by the inventors that started the Wain-Roy Corporation of Hubbardston, Massachusetts. In 1947 Wain-Roy Corporation developed and tested the first actual backhoes. In April 1948 Wain-Roy Corporation sold the very first all hydraulic backhoes, mounted to a Ford Model 8N tractor, to the Connecticut Light and Power Company for the sum of \$705.



Figure 24: Before Backhoe invention



Figure 25 : The first backhoe loader.

3.9 COMPONENTS OF BACKHOE LOADERS



Figure 26 : Components of Backhoe Loader

3.9.1 Cab

The cab, located on top of the tractor, is where you find the controls for the front loader backhoe. Some cabs are completely enclosed by safety glass, while others use an open canopy structure to protect the operator. Inside the cab, an operator can monitor their entire surroundings from a safe position. The chair inside the cab can rotate, allowing you to switch from using the front loader to the backhoe easily.

3.9.2 Tractor

Without the tractor, a backhoe loader would have a difficult time manoeuvring in terrain. The tractor consists of large tires, a cab, and a powerful engine. The main function of the tractor is to get the machine around the construction site. Once in position, the operator will park the tractor before using the backhoe or loader.

3.9.3 Front Loader

Whether you're moving earth, pushing snow, or picking up debris and materials, you'll use the backhoe's front loader. A front loader is mainly just the large bucket used to move and transport materials from one spot to another. You might also find operators using the front loader to smooth out surfaces as well.

3.9.4 Backhoe

The backhoe excavates or lifts heavy materials. The backhoe portion of the machine consists of three main components: the boom, the bucket, and the dipstick. In order to use the backhoe, you must first park the tractor in a stable position using stabilizer legs. Then you can use the backhoe to dig up trenches, holes, small ponds, or similar applications.

3.9.5 The Boom

Located closest to the cab, the boom is the long piece of the backhoe arm attached to the tractor. The boom can lift, lower, or swing left and right. An operator controls the motion of the boom from the safety of the cabin.

3.9.6 Dipper arm

The other main part of a backhoe arm is the dipper arm. The dipper arm runs from the pivot to the bucket located at the end of the backhoe arm. The dipper arm stabilizes the weight of the materials inside the bucket.

3.9.7 Bucket

Located at the end of the backhoe arm, the bucket scoops and transports debris and other materials. When you want to scoop dirt into the bucket, you maneuver the bucket toward the dipstick. To empty the bucket, you move the bucket away from the dipstick.

3.10 PILE FOUNDATION

A pile foundation is defined as a series of columns constructed or inserted into the ground to transmit loads to a lower level of subsoil. A pile is a long cylinder made up of a strong material, such as concrete. Piles are pushed into the ground to act as a steady support for structures built on top of them. Piles transfer the loads from structures to hard strata, rocks, or soil with high bearing capacity. The piles support the structure by remaining solidly placed in the soil. As pile foundations are set in the soil, they are more tolerant to erosion and scour.

3.10.1 Types of piles based on shape and composition



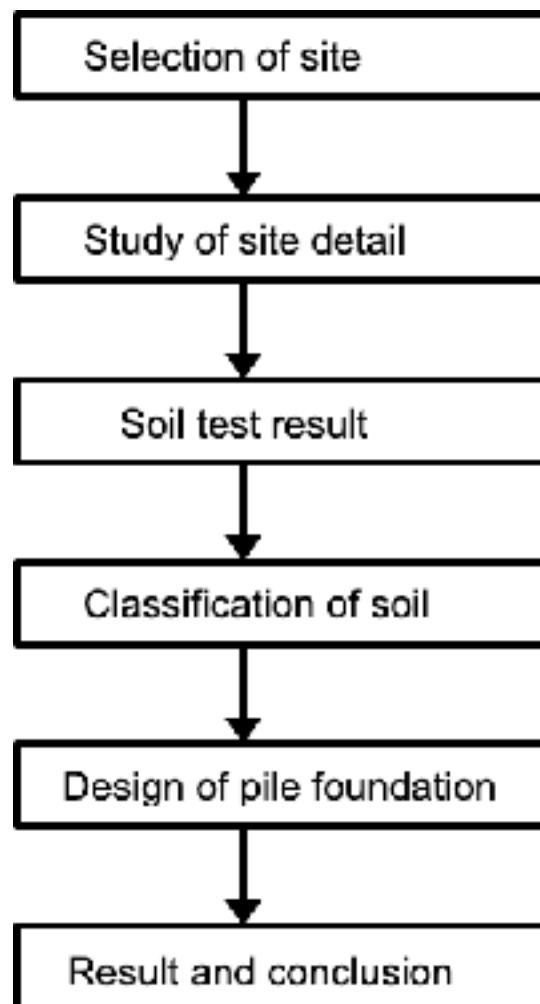
Figure 27 : Types of piles

3.10.2 Following are the situations when using a pile foundation can be used

1. When the groundwater table is high.
2. Heavy and non-uniform loads from superstructure are imposed.

3. Other types of foundations are costlier or not feasible.
4. When the soil at shallow depth is compressible.
5. When there is the possibility of scouring, due to its location near the river bed or seashore, etc.
6. When there is a canal or deep drainage systems near the structure.
7. When soil excavation is not possible up to the desired depth due to poor soil condition.
8. When it becomes impossible to keep the foundation trenches dry by pumping or by any other measure due to heavy inflow of seepage.

3.10.3 Flowchart of pile foundation process



3.10.4 Classifications of pile foundation

End Bearing Pile: In end bearing piles, the bottom end of the pile rests on a layer of especially strong soil or rock. The load of the building is transferred through the pile onto the strong layer. In a sense, this pile acts like a column. The key principle is that the bottom end rests on the surface which is the intersection of a weak and strong layer. The load therefore bypasses the weak layer and is safely transferred to the strong layer.

Friction Piles: Friction piles work on a different principle. The pile transfers the load of the building to the soil across the full height of the pile, by friction. In other words, the entire surface of the pile, which is cylindrical in shape, works to transfer the forces to the soil.

To visualise how this works, imagine you are pushing a solid metal rod of say 4mm diameter into a tub of frozen ice cream. Once you have pushed it in, it is strong enough to support some load. The greater the embedment depth in the ice cream, the more load it can support. This is very similar to how a friction pile works. In a friction pile, the amount of load a pile can support is directly proportional to its length.

Pile foundations are deep foundations. They are formed by long, slender, columnar elements typically made from steel or reinforced concrete, or sometimes timber. A foundation is described as 'piled' when its depth is more than three times its breadth. A pile is basically a long cylinder of a strong material that is pushed into the ground to act as a steady support for structures built on top of it.

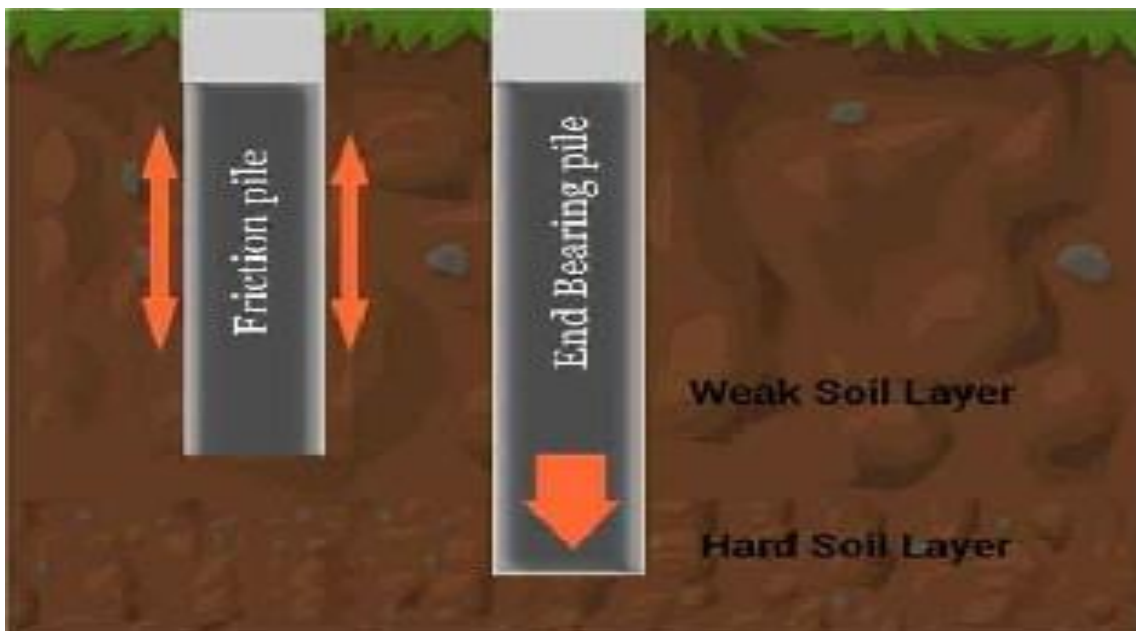


Figure 28 : Friction and End bearing piles

3.10.5 Classification of pile foundation based on the effect of soil:

Driven piles: Driven piles, also known as displacement piles, are a commonly-used form of building foundation that provide support for structures, transferring their load to layers of soil or rock that have sufficient bearing capacity and suitable settlement characteristics. They can also be used in applications such as embankments, retaining walls, bulkheads, anchorage structures and cofferdams.



Figure 29 : Driven Pile

Bored piles: Bored piles, also known as replacement piles, are a commonly-used form of building foundation that provide support for structures, transferring their load to layers of soil or rock that have sufficient bearing capacity and suitable settlement characteristics. Bored piles are piles where the removal of spoil forms a hole for a reinforced concrete pile which is poured in situ. The spoil is replaced by the pile, hence 'replacement' piles as opposed to displacement piles where soil is forced away by driving or screwing the pile. Bored piles are used primarily in cohesive subsoils for the formation of friction piles and when forming pile foundations close to existing buildings. They are popular in urban areas as there is minimal vibration, where headroom is limited, where there is no risk of heave, and if there is a need to vary the length of the piles.

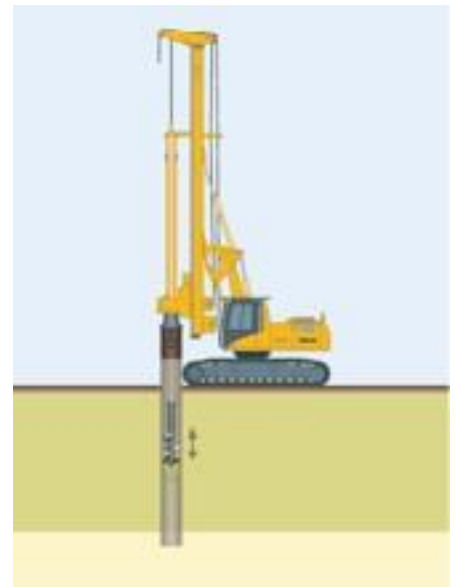


Figure 30 : Bored Pile

Screw pile: Screw pile foundations are a type of pile foundation with a helix near the pile toe so that the piles can be screwed into the ground. The process and concept is similar to screwing into wood. A screw pile may have more than one helix (also called a screw), depending on the usage and the ground conditions. Generally, more helices are specified if a higher load is required or softer ground is encountered.



Figure 31 : Screw piles

3.10.6 Classification based on Material of Piles Construction:

Timber piles: Timber piles are the oldest of all the contemporarily used piles. They are usually precast displacement piles installed with the driving method, or less commonly, the vibratory method. The natural convergence of pile shafts allows us to obtain a relatively high pile load capacity.

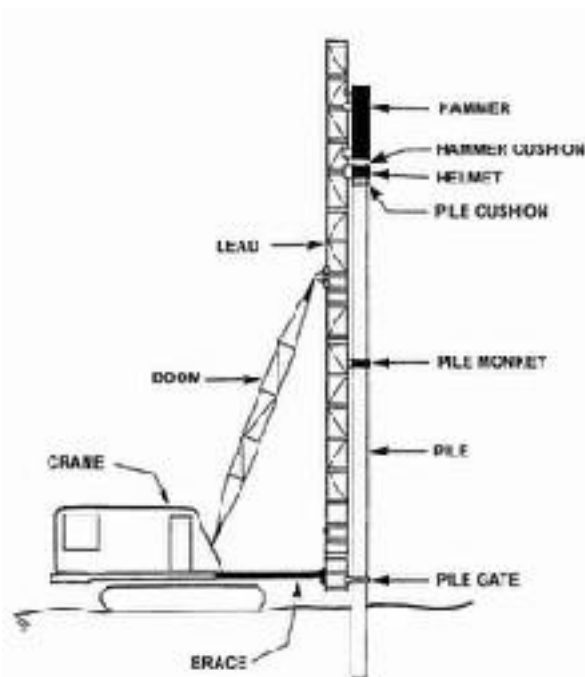
Steel piles: Driven steel piles are installed using impact or vibration hammers to a design depth or resistance. You can install the complete suite of driven piles from small diameter tube piles to large diameter steel caissons to support your project.

Concrete piles: Concrete piles are common structural foundation elements used to support offshore structures such as bridges, oil-rigs, and floating airports. The use of offshore structures is still a fairly new technique and there is still much research to be done in this field.



Figure 32 : Steel pile

3.11 COMPONENTS OF PILE DRIVING SYSTEM



The driving system consists of the following components

1. The lead, also called the set of leads, sometimes including a brace that allows for the adjustment of the lead angle.
2. The hammer cushion, which protects both the hammer and the pile from excessive stress. Hammer cushion materials are relatively soft compared to steel. Usually, a striker plate protects the cushion.
3. The helmet, which aligns the pile head and hammer. It is usually a steel casting.
4. The pile cushion. This is only needed on concrete piles, and usually consists of several layers of plywood.

Figure 33 : Components of pile driving machine

All components of the driving system have some effect on the performance of a hammer and/or how the hammer transfers its energy to a pile.

3.12 BASIC COMPONENTS OF AN EXTERNAL COMBUSTION HAMMER

The hammer is connected to a cable that is attached to a winch on the crane. The hammer is raised to the desired stroke. The winch has a clutch on it that then allows the operator to release the hammer, which falls by its own weight and strikes a pile cap and the pile. A hoist from the same crane, which supports the pile and the leads, usually lifts it. After lifting the ram to the desired stroke, it is dropped by either a tripping mechanism or by releasing the hoisting drum. In the former case, all the developed energy remains in the ram; in the latter case, some energy is needed to unwind the cable from the drum. The available energy per blow of a drop hammer is the product of the ram weight times the drop height. Standard ram weights range from 500 to 10,000 lbs (2.5 to 50 kN). Typical drop heights are approximately 4' (1.2 m). For a given hammer, varying the drop height can vary the energy per blow.

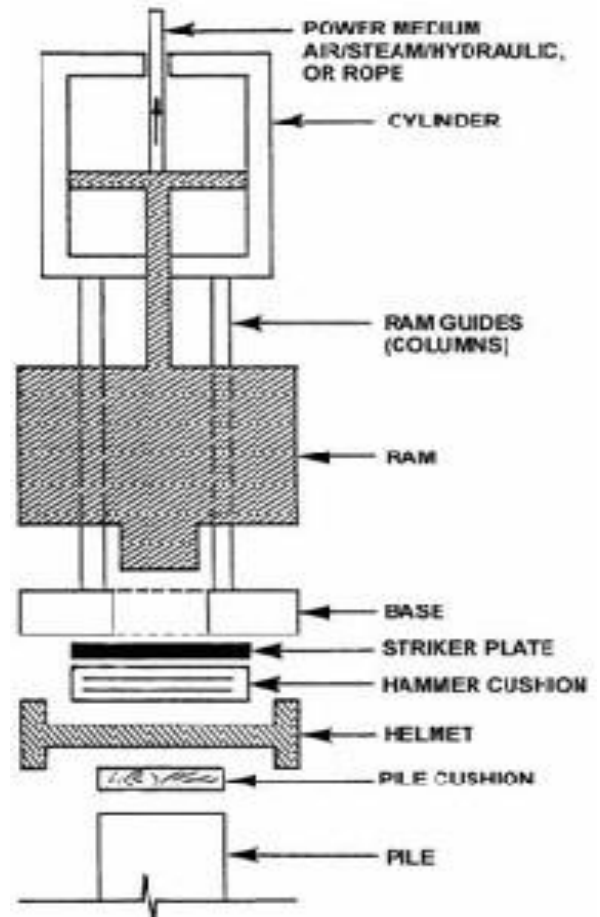


Figure 34 : Combustion Hammer

3.13 PRODUCTIVITY ANALYSIS FOR EQUIPMENTS

Productivity analysis is much like earned value analysis, in the sense that it compares the planned value with the actual value. Productivity analysis can provide a deeper understanding of the activity under consideration compared with the use of just bar charts. It makes it possible to devise a plan for an activity with respect to the manpower needed and cost consideration. Productivity analysis for any activity under consideration should go through three distinct stages: an analysis before the commencement, tracking and management when the activity is ongoing, and storage of information in a lessons learned database after the activity has been completed.

Equipment productivity is a key factor that enables contractors to make decisions regarding project scheduling, fleet selection, and project costs. In construction plan one should significantly concentrate on the type, number, and schedule of presence of the equipment at the project site.

To determine productivity of dozer

$$Q = q \times N \times E$$

$N = \frac{\text{cycle's total}}{\text{cycle's time}}$
(cycle/hour)

Q = productivity per hour (m^3 / h loose)

q = productivity per cycle (m^3) L.H2.a

E = efficiency factor

To determine how much time is need to complete the job

$$\text{Total time (hours)} = Q / (P \times N) \text{ where}$$

Q = quantity of material to be moved

P = hourly production rate per dozer

N = Number of Dozers

- **To determine the number of dozers required to complete project within specific time**

Total number of dozers = $Q / (P \times T)$ where Q = quantity of material to be moved

P = hourly production rate per dozer

T = maximum allowable duration in hours

3.13.1 Bulldozer

Bulldozers are considered one of the strongest and toughest heavy equipment used in the c heavy equipment used to move dirty along large open tracts of land. Bulldozers have a wide flat blade in front that can be operated using two hydraulic pistons allowing the blade to be moved in limited angles or depths. They are normally used to push piles of earth and for rough / fine grading depending on the size of the bulldozer. Its weight can be used to crush larger boulders among other action Construction industry. It is powerful and extremely.

3.13.2 Excavator

Excavators are large earth movement equipment that can be available over wheels or treads; this one is considered the standard in the industry. A traditional excavator usually has a long bucket arm attached to a pivoting cab that can rotate a full 30 degrees. The operator sits in the cab and from there he/she can be able to have visibility over the site. Excavators are used most of the times to dig dirt or to lift heavy pieces including prefab pieces, pipes and other smaller equipment.

The most common uses of an excavator are:

- Material handling
- Digging of trenches, holes and foundations
- Brush cutting with hydraulic attachments
- Rough grading
- Heavy lifting
- River dredging.

The production rate can also be found by the following equation :

$$q = ((3600\text{sec/hour} \times B \times E \times P) / C) \times \text{Volume Correction}$$

Volume Correction = for loose volume to bank volume = $1/(1+\text{swell factor})$

q = Volume of soil excavated and dumped in a truck by the excavator (CY/hr)

B = Bucket struck capacity (CY)

E = Bucket efficiency factor (from a table or given)

P = Productivity factor (from a table or given)

C = Cycle time for 90 degree angle and optimum depth.

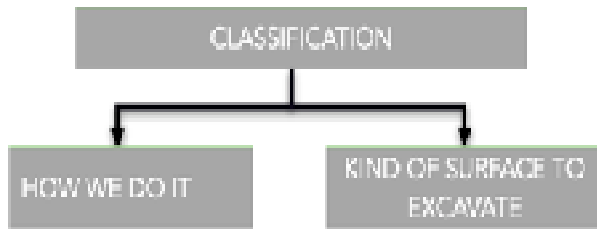
No.	Kind of Heavy Equipment	Time (Hours)
1.	Excavator	2089,86 hours
2.	Bulldozer	1287,73 hours
3.	Dump Truck	551,49 hours
	Time total	2089,86 hours
1.	Backhoe	1557,95 hours
2.	Loader	1277,52 hours
3.	Dump Truck	1277,52 hours
	Time total	2835,489 hours
	Time Deviation	745,62 hours

Table14 : Equipment time tabulation.

3.13.3 Excavation

Excavation is the process of forming a cavity by cutting, digging or scooping.

- **Cutting** is the usage of implement such as claws, manual tools, hands, heavy equipment to remove material from the earth surface.
- **Digging or scooping** is the combination two process 1. Breaking 2. Removal and relocation.



-Manual Excavation

Laborious, Expensive, slow, precise, small quantity or definitive work.

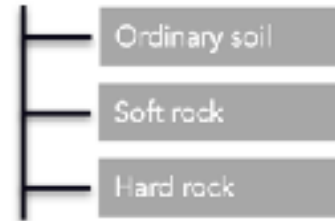
Tools used : Trowel, Pick axe, Hoe, Spade, Shovel.

Types of surfaces

- Mechanical excavation

Less labour, Fast, Not precise, Huge quantity

Machines used : Excavator, Earth mover, Dozer, Scraper, Grader, Drills, Breaker.



3.13.4 Example of bucket capacity calculation

If the capacity of each rotor bucket is 10 cubic feet, the wheel has only one bucket, the rotor rotates at a speed of 5 rotations per minute, and the filling factor and the soil loosening factor are one, the productivity of the excavator stands at:

$$Q = (60 \times q \times z \times n \times kf) / kl, \text{ here } q=10 \text{ cu.ft, } z=1, n=5 \text{ rotations per min, } kf=1$$

$$Q = (60 \times 10 \times 1 \times 5 \times 1) / 1$$

$$Q = 3,000 \text{ cubic feet per hour.}$$

kf stands for the filling factor of a bucket while **kl** represents the soil-loosening factor.

3.13.5 Calculation of bucket capacity

Formula for calculating excavator productivity is $Q = (60 \times q \times z \times n \times kf) / kl$.

where **Q** is the productivity of the excavator,

q is the capacity of each rotor bucket in cubic ft

z is the number of buckets on the wheel and

n is the speed of rotation of the rotor, measured in revolutions per minute.

kf stands for the filling factor of a bucket while **kl** represents the soil-loosening factor.

3.13.6 Comparison between different types of earth equipments

S.NO	COMPARISON FACTOR	POWER SHOVEL	BACK HOE	DRAGLINE	CLAMSHELL
1	EXCAVATION IN HARD SOIL OR ROCK	Good	Good	Not good	Poor
2	EXCAVATION IN WET SOIL OR MUD	Poor	Poor	Moderately good	Moderately good
3	DISTANCE BETWEEN FOOTING AND DIGGING	Small	Small	Long	Long
4	LOADING EFFICIENCY	Very good	Good	Moderately good	Precise but slow
5	FOOTING REQUIRED	Close to work	Close to pit	Fairly away from pit	Fairly away from pit
6	DIGGING LEVEL	Digs at or above footing level	Digs at or below footing level	Digs at or below footing level	Digs at or below footing level
7	CYCLE TIME	Short	Shortly more than power shovel	More than power shovel	More than the other equipment

Table15 : Earthing equipments comparison

S.NO	KIND OF WORK	EQUIPMENT REQUIRED
1	Clearing	Bull dozer, Backhoe, Loader etc
2	Excavating	Shovel (Backhoe, Dragline, Clamshell), Bulldozer, Ripper, Rock breaker.
3	Loading	Wheel loader, Track loader, Loading shovel (Front shovel)
4	Excavating / Loading	Power Shovel (Backhoe, Dragline, Clamshell), Bulldozer, Ripper, Rock breaker.
5	Excavating / Hauling	Bulldozer, Scraper, Loader etc
6	Hauling	Dump truck, Wagon, Conveyor etc
7	Spreading / Grading	Bulldozer, Wheel dozer, Motor grader
8	Compacting	Tire roller, steel roller, vibration roller, Tamping roller, Vibration compactor, etc
9	Trenching	Trencher, Backhoe, Excavator
10	Slant finishing	Motor grader

Table16 : Equipment requirement.

3.13.7 Equipment economics

The economics of any equipment associated with ownership and operation. Utilization is the working time duration and not calendar duration.

$$\text{EQUIPMENT COST} = \text{OWNING COST} + \text{OPERATING COST}$$

$$\text{DEPRECIATION COST} = \frac{\text{EQUIPMENT COST} - \text{SALVAGE VALUE}}{\text{ECONOMIC LIFE IN YEARS}}$$

Basis of costing: Hourly, Daily , Weekly, Miles and Fuel consumption.

Equipment owning cost - Equipment price, Taxes and Insurance, Cost of capitals, Depreciation cost.

Economic life of an Equipment - Excavator - 13,000 hrs, Dumper - 2.5 to 3L km

Equipment operating cost - Fuel costs, Maintenance costs, Operator's costs.

Fuel costs - Excavator formula

COST OF FUEL CONSUMED IN 1HR = COST PER LITRE X HOURLY FUEL CONSUMPTION

HOURLY FUEL CONSUMPTION = 0.15 X RATED HP X LOAD FACTOR

Fuel costs - Dumper formula

COST OF FUEL CONSUMED PER KM = COST PER LITRE X FUEL CONSUMPTION PER KM

FUEL CONSUMPTION PER KM = 0.15 X RATED HP X LOAD FACTOR

Equipment output capability

PLANNED OUTPUT = IDEAL OUTPUT X PERFORMANCE FACTOR X CORRECTION FACTOR

Where, **IDEAL OUTPUT = BUCKET OUTPUT/CYCLE X CYCLES/HOUR**

Correction factor depends upon the characteristic of equipment and site condition like swing factor, soil factor, rolling resistance and traction factor.

3.14 PILE EQUIPMENT

3.14.1 Pile types by functioning

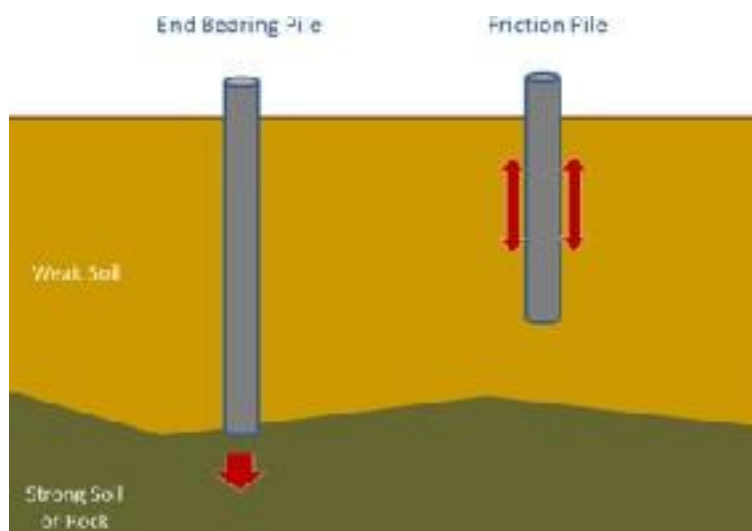


Figure 35 : Pile type - By function

3.14.2 Pile types by installation

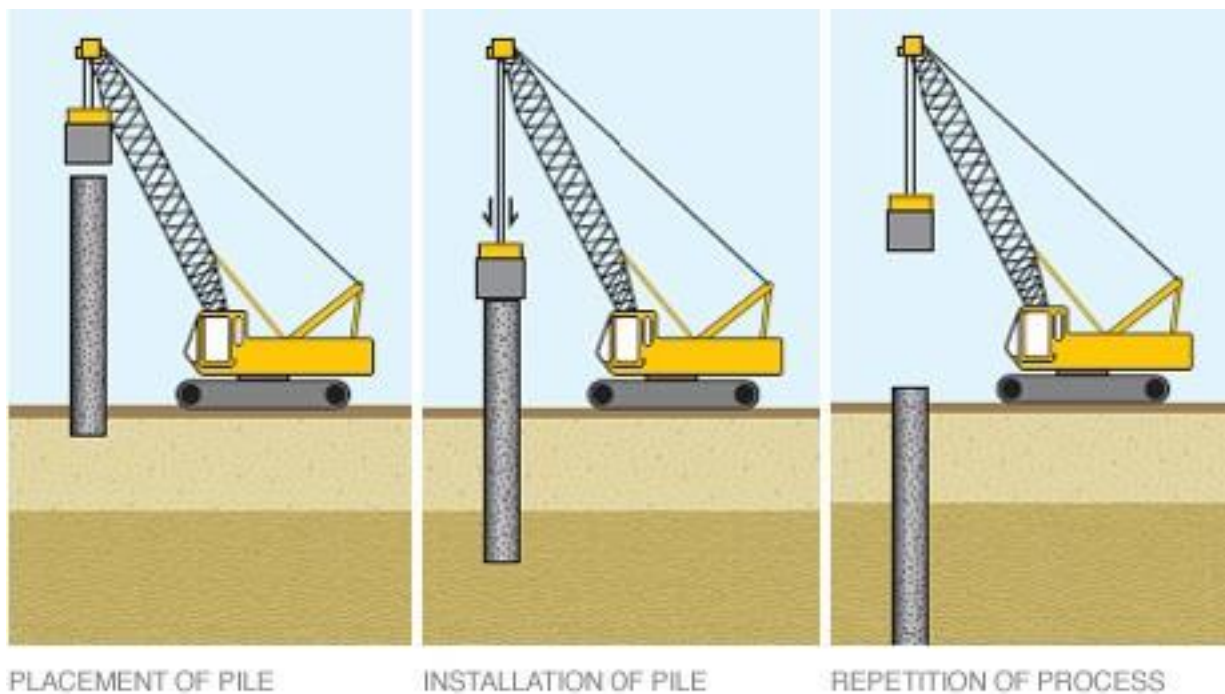


Figure 36 : Displacement pile / Driven pile

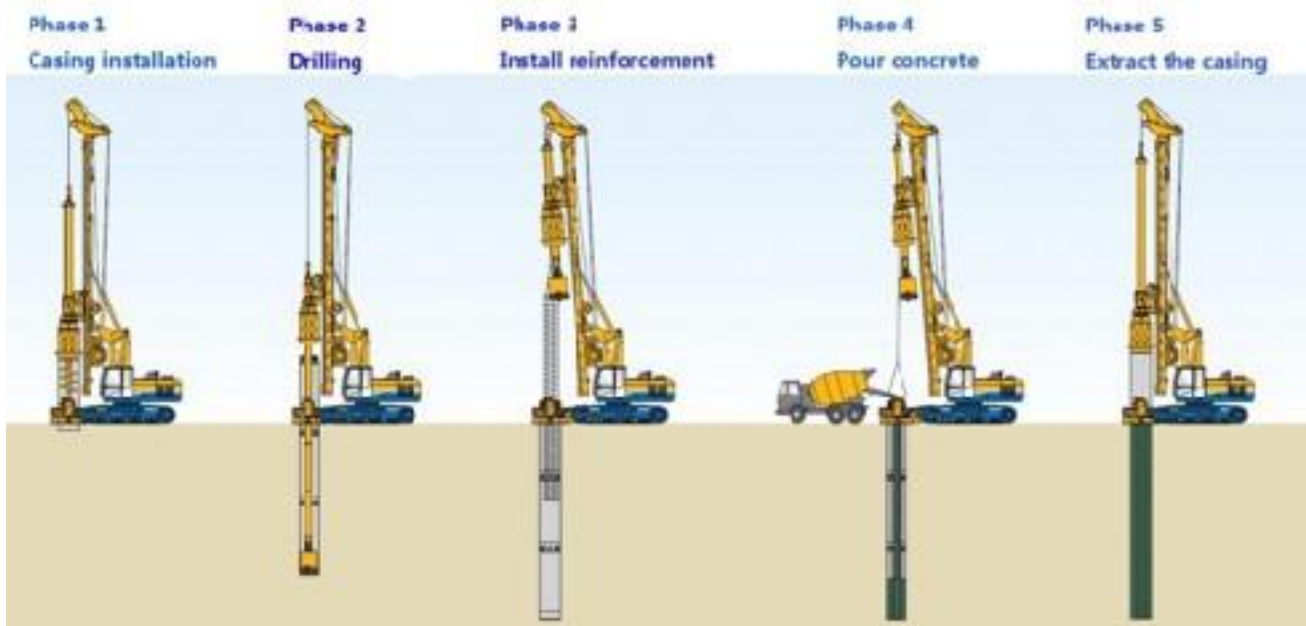
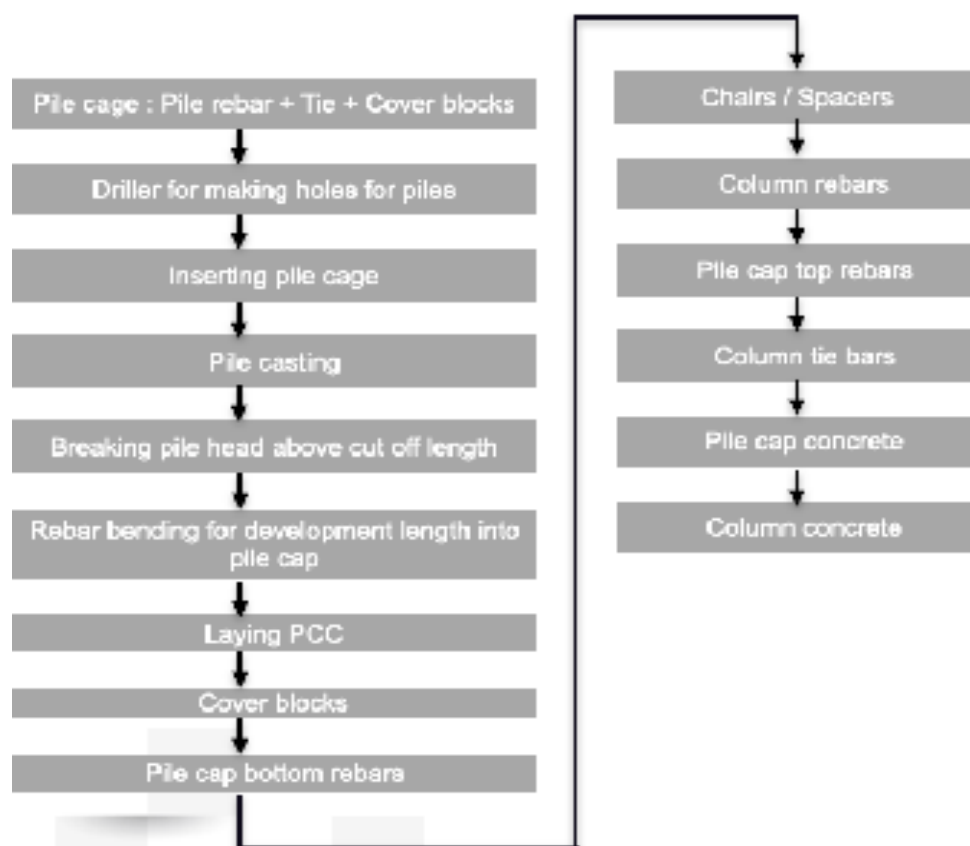


Figure 37 : Replacement pile / Bored pile

3.14.3 Pile construction methodology

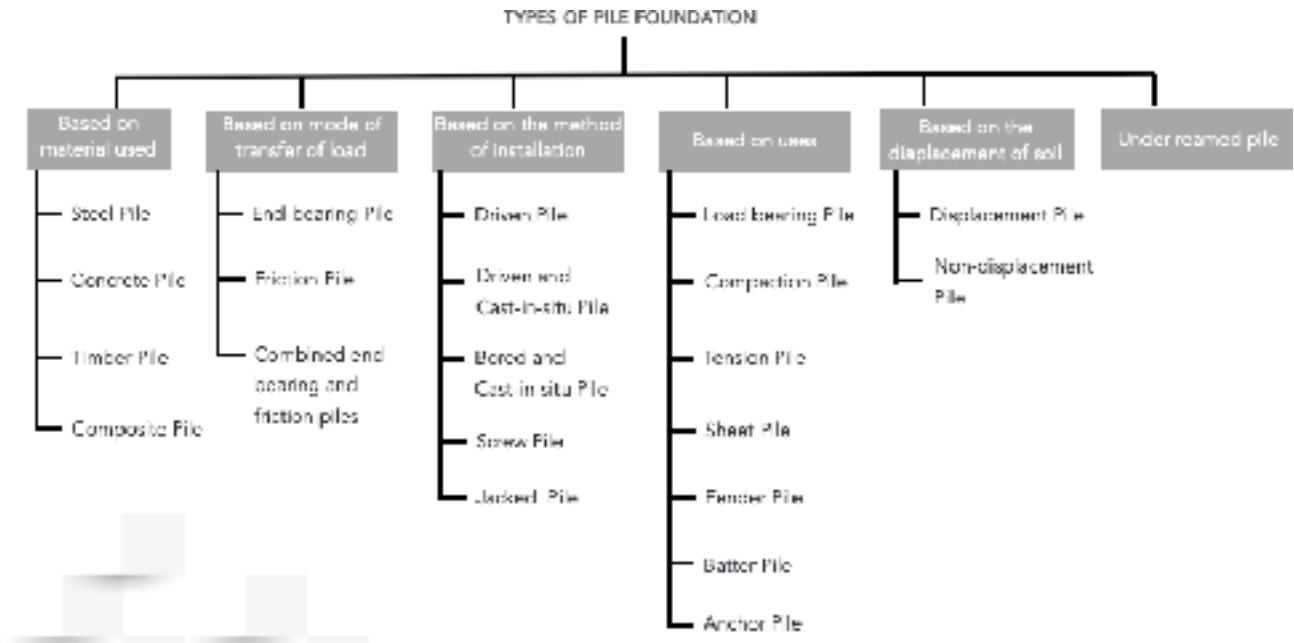


3.14.4 Comparison between different types of pile equipment

CRITERIA	PILING RIGS	ROTARY DRILLING RIG	HYDRAULIC IMPACT PILE HAMMER	VIBRATORY PILE HAMMER	PILING WINCHES
Usage	Drill in soil & clay, used in cast in situ	Sharp rotating drill to cut the subsurface	Drive steel tubes, sheet piles, precast concrete and timber piles.	Drive sheet piles, pipes or other elements into the soil	To hoist the object vertically in construction, port and mine
Features	360° camera rearview, Double-rotary interlocking kelly bars, crowd force.	Interlocking kelly bar, air-conditioning system in cabin, Kelly bar, tailored chassis	Easy to connect to different hydraulic systems, Drive caps, Double-acting hammers.	Hammer brake, Open-loop hydraulics, 360° rotating gears, internal clamp comes with check valve	Single, Double and Triple drum, Main shaft rotating. Available in 2.5 tone, 5 tone and 7.5 tonne capacity
Pictures					
Capacity	150 - 500 ft	500 - 1000 ft	-	10 - 50 ft	200 ft
Max speed	-	10 mph	-	2400 rpm	45 - 55 rpm

Table 17 : Pile equipment comparison

3.14.5 Types of pile foundation



3.14.6 Bored cast in situ pile

Based on the installation method the mostly adopted type is Bored cast in situ pile. For installation of the pile, the method is selected based on soil strata, site condition, availability of machinery and tools. For loose to medium dense soil strata commonly used method for construction of pile are DMC (direct mud circulation), RMD (reverse mud circulation), for the dry boarding.

Out of this DMC by means of tyre mounted rig machine (TMR) and dry boring by means of hydraulic rig machine is used. The comparison between TMR and hydraulic rig machine in terms of efficiency, fuel consumption, time, quality of work, and ease of work are done. It also helps to estimate the various stakeholders, difficulties and challenges in construction of bored in situ pile concrete pile.

Equipment for boring pile - Percussion type rigs / Rotary rigs

Methods adopted

Direct Mud circulation / Reverse mud circulation - To bring the cuttings out.

Bailers and Chisel method

- To avoid effect of suction
- Used in soft layers and loose sands.

Construction stages:

1. Drilling stage

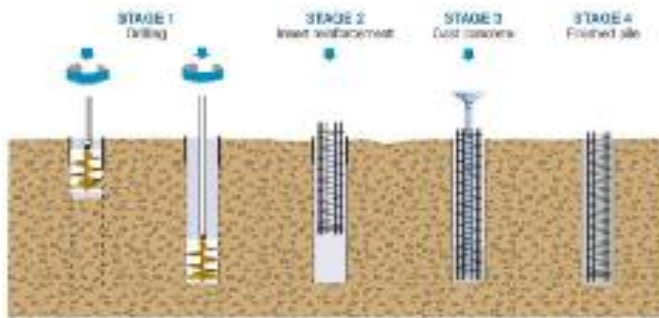


Figure 38 : Dry excavation

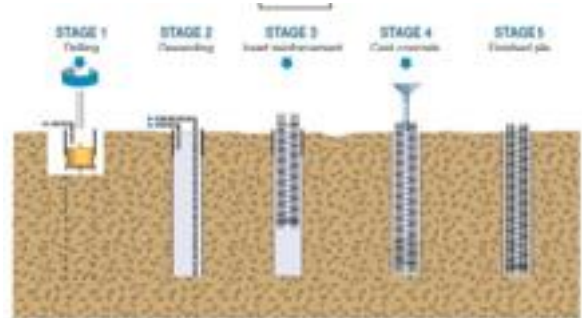
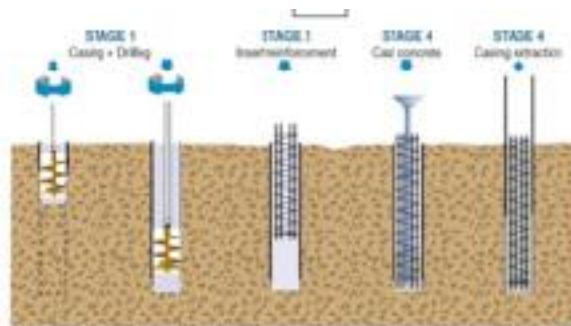


Figure 39 : Excavation with drilling fluids



Each method consist of different stages based on the stage different tools are used for the job.

Figure 40 : Casing drilling.

To create the cavity or hole in the soil strata of required diameter for the construction which is equal to pile diameter drilling is implemented with suitable method.

To stabilize the borehole, three methods can be used:

1. Dry pile construction.
2. Wet pile construction
3. Cased pile construction.

The next step is the construction of the pile: firstly, the reinforcing cage is lowered into the hole and then concrete is cast. In the method of using the casing for the soil stabilization two types are found. Temporary and permanent casing. Temporary is removed after casting and permanent is left inside the borehole after casting concrete.

S.NO	METHOD	DESCRIPTION	USAGE
1	Dry excavation	Drilling, removing loose material from bore hole, reinforcement cage and concreting	In stable soil
2	Excavation with drilling fluids	Special bentonite or polymer slurries are used to stabilise the borehole walls. These bentonite is produced in the site.	In Non stable bore hole
3	Excavation without drilling fluids	Temporary casings into the borehole driven using the rotary head of drilling rig /or a hydraulic vibratory hammer.	In Non stable bore hole
4	Excavation with casing support	Segmental casing is used as a temporary or permanent support. Installed and extracted by using a drilling rig or an oscillator.	Deeper unstable soil conditions
5	Casing drilling	Two type of casings are temporary and permanent casing	Soils with rocks or boulders

Table 18 : Type of drilling

Each of these methods have their own areas and applicability based of the soil strata and availability of drilling tools and machinery.

2. Cleaning of bottom Borehole

The main purpose of bottom cleaning is to remove the loose material at the bottom of the bore hole. In case of DMC (Direct Mud Circulation) the flushing should be done after lowering the cage by means of tremie pipe lowering in the borehole for concreting purpose.

3. Cage Lowering

The cage is lowered in the borehole by using suitable machine like Crane/ Hydra/Rig Machine. The reinforcement cage should be properly held in position by means of resting hooks while driving into the borehole. Before lowering the cage make sure that the proper cover block is attached as per cover given for the particular pile.

4. Tremie concreting

- The concrete should be coherent, rich in cement (not less than 400 kg/m³) and of slump between 150-180 mm;
- The tremie should have a hopper attached to its head by a water-tight connection;

- The tremie pipe should be large enough in relation to the size of the aggregate. For 25 mm down aggregate, the tremie pipe should have a diameter not less than 200 mm.
- A steel plate or a ball is placed at the bottom of the hopper and the hopper is filled with concrete. The first charge of concrete is sent down the tremie by removal of this plate or ball.
- The tremie pipe should always be kept full of concrete and should always remain at least one meter into the concrete in the bore hole.
- All tremie pipes should be cleaned before and after use;

Advantages of Bored Pile:

Piles of variable lengths can be extended through soft, compressible, or swelling soils into suitable bearing material.

Piles can be extended to depths below frost penetration and seasonal moisture variation.

Large excavations and subsequent backfill are minimized.

Less disruption to adjacent soil occurs. Vibration is relatively low, reducing disturbance of adjacent piles or structures.

For many design situations, bored piles offer higher capacities with potentially better economics than driven piles.

3.14.7 Pile cap

A reinforced concrete slab or block which interconnects a group of piles and acts as a medium to transmit the load from wall or column to the Piles is called a Pile Cap. The Pile cap should normally be rigid so as to distribute the forces equally on the piles of a group.

Parameters of pile cap

- Shape of pile cap.
- Depth of pile cap.
- Amount of steel to be provided.
- Arrangement of reinforcement.

Shape of pile cap

1. IS 2911 part1, sections 1 and 2 recommended a minimum spacing of two and half times the diameter of the pile for bored cast in situ piles.
2. The size of the pile cap is made 300 mm more than the outer- to outer distance of the exterior piles. (150 mm on either side).
3. Standard pile caps:

Spacing of pile (S) = F x hp, Where

hp = diameter of pile in mm.

F = Spacing factor= Centre to centre spacing / pile diameter.

Depth of pile cap

PILE DIAMETER (mm)	DEPTH OF PILE CAP (mm)
300	700
350	800
400	900
450	1000
500	1100
550	1200
600	1400
750	1800

Depth of pile cap is dependent on the following factors:

- Shear Capability of Pile Cap.
- Soil shrinkage and swelling.
- Frost attacks.
- Pile anchorage.
- Water table & soluble sulfates.

Table 19 : Pile depth

- Holding bolt assemblages for steel columns.

Because it is subjected to concentrated loads, the pile cap is usually deeper than the pad footing. This results in substantially stronger bending moments and shear forces.

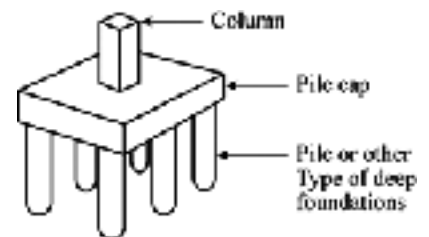
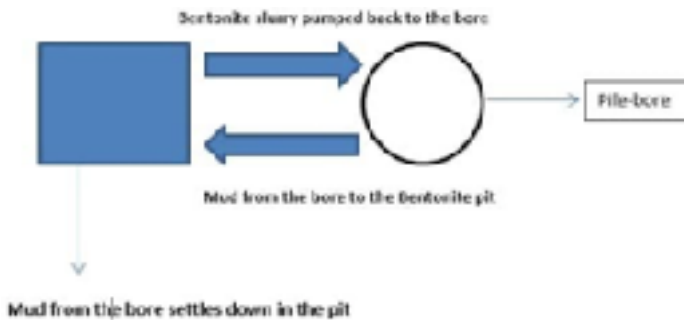


Figure 41: pile cap

3.14.8 Direct mud circulation method

The method is termed as Direct Mud Circulation because it involves the circulation of mud from the pile bore directly to the bentonite pit where the pump reuses the bentonite slurry leaving alone the settled mud. It is used for bored cast-in-situ piles. DMC is a fairly cheaper method to install piles.



Two stages to use the Bentonite suspension:

- First flushing: When the earth is being bored, bentonite suspension of specific gravity between 1.05 to 1.12 is to be maintained.
- Second flushing: When the bore has to be cleaned after the completion.

Figure 42 : Direct mud circulation method.

Process Of DMC Method to install Pile

- Set the tripod in position and start the winch machine.
- Make a bore hole for installing the casing. Install the casing in proper position.
- Apparatus - A tripod pulley, winch machine, wire rope, chisel, Drill pipes, Tremie pipes, a vertical pump and a pit where Bentonite powder is mixed with fresh water.
- Specific gravity of bentonite between 1.05 to 1.12 used during drilling and flushing.
- Now remove soil from casing.
- After inserting the casing insert the chisel inside the casing for drilling.
- Attach 'n' number of drill pipes with the chisel for drilling upto required depth of pile.
- Drilling continuous mud from bore keeps moving to the bore hole and directed to the bentonite pit.
- After completion of bore chisel is brought outside.
- Insert cage inside the bore and tremie pipes are inserted. Check depth before concreting.

- Attach the hopper to the tremie pipe hopper is top hung by wire rope.
- The joint between the hopper and the tremie pipe is closed with a steel plug.
- The hopper is then filled with concrete to its full capacity and steel plug is removed to allow the concrete to flow down the tremie pipes thereby replacing the bentonite solution.
- Concreting is done up to at least 1m above the cut-off levels to ensure good concrete for proper embedment into the pile cap.

3.14.9 Checklist for concreting

PROJECT NAME :		EVENT :		
DRAWING REFERENCE		DATE		
S NO	DESCRIPTION OF WORK	VERIFIED		REMARKS
CONCRETING		YES	NO	
1	Type of cement - OPC / PPC			
2	Mix ratio - As per structural drawing			
3	Ensure min cement content			
4	Slump value (150-180mm)			
5	Drop the first concrete for the min of 0.5 to 0.6 cum			
6	Ensure tremie always inside concrete (min 1.5m)			
7	Take specimen for testing min six (150mm cubes)			
8	Continue pouring till the fresh concrete coming out			
9	Remove the casing pipe with two side rope			
10	Compare actual and theoretical consumption			

Table 20 : Checklist for bored cast in situ concreting.

CHAPTER 4

LIVE CASE STUDY

4.1 IT COMMERCIAL PROJECT, OMR - CHENNAI

4.1.1 Project details

City - Chennai

Location - Old Mahabalipuram Road

Site area - 6.7 acres

Buildup area - 20,240 sq.m

Type of foundation - Bored Pile foundation

Structural consultants - ECPL

Stage - Ongoing project

Project duration - Dec 2020 till date

Type of project - IT and IES commercial

No.of storeys - Basement + 1 to 4 Stilt + Podium + 1 to 14 storeys + Terrace

No of units - Phase I, II, III

No of blocks - 3

Total No of piles - 1083 piles

Pile diameter - 600mm, 1000mm, 1200mm.

4.1.2 Equipment details

Type of Crane - Hammerhead Tower crane

Condition - Not fixed yet

Brand - Potain cranes

Pile driving machine - MAIT

Model no - HR 180

No of equipment - 2

Drilling rig - MAIT

Model no - BR 165

No of equipment - 1

Rotary drilling rig - SANY

Model no - SR 205

No of equipment - 1

Total No of Pile driving machine used - 4

Dump truck - 2



Figure 43 : Site picture.

Its an ongoing IT and IES commercial project in OMR, chennai. Based on soil examination report the foundation recommended is pile foundation. The clayey soil is identified. Hence, bored in-situ pile is selected and implemented. The project is in foundation construction stage now. The equipment for foundation used is analysed in detail further. The labour, material, fuel, maintenance is studied in detailed manner.

4.1.3 Pile layout - phase II block

- The pile foundation is adopted for this particular project due to the presence of Clayey soil.
- The total number of piles planned for this project is 1083 with diameter of 600mm, 1000mm and 1200mm.
- MAIT brand pile driving machine and SANY rotary drilling rig is employed in the site work.
- Number of pile driving machine employed are 4.
- Upto 5 piles are casted in the site per day with the usage of four equipments in the site.
- The average minimum labours required for employing one machine in the site is five.
- Labours are required for the work of casting, sample collection, supervision, signalling, quality checking, depth checking and for flushing (cleaning) work.
- Safety precautions to be considered before initiating the work. Dump truck is used to carryout the excavated soil from the bore hole.

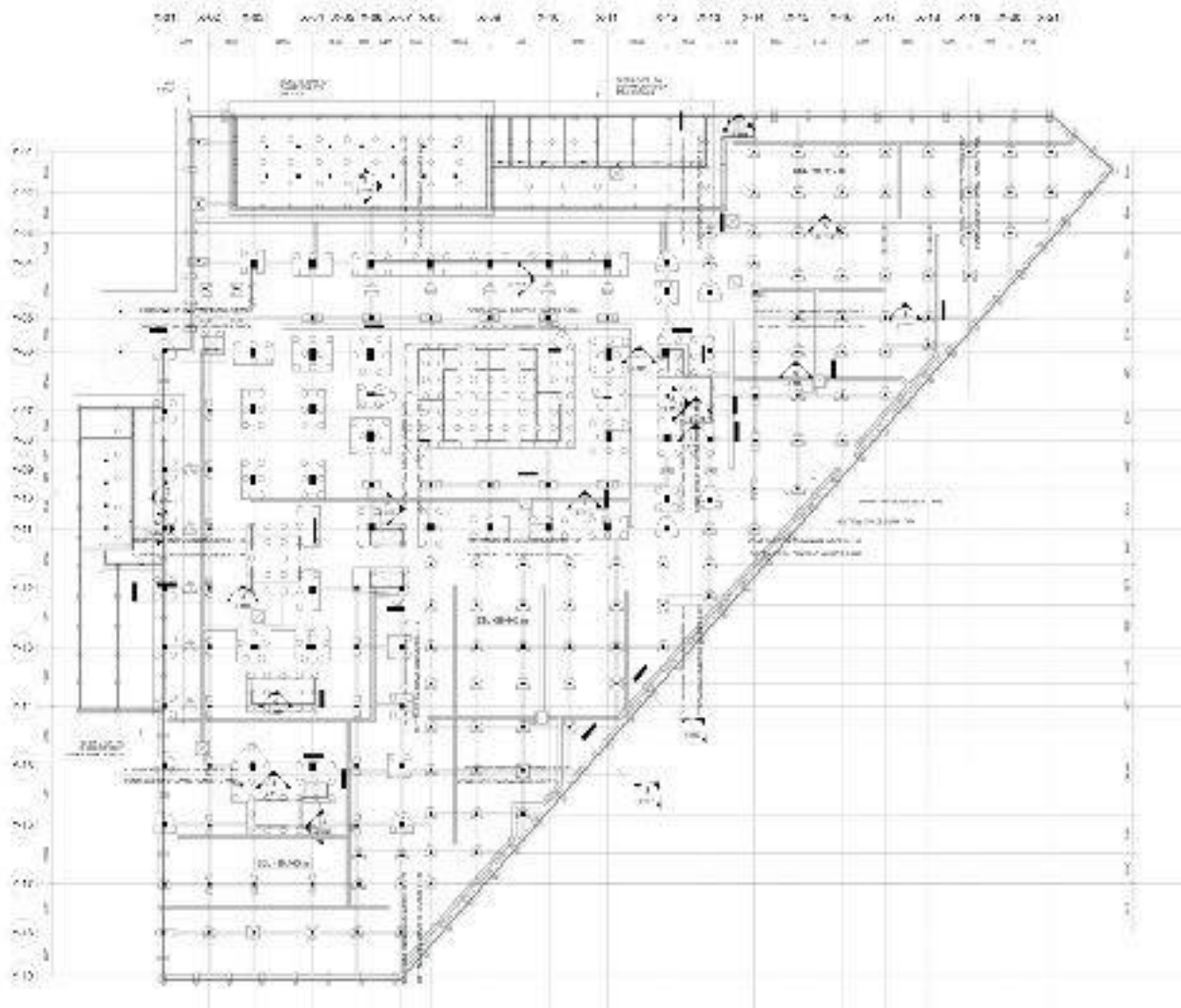


Figure 44 : Pile layout

4.1.3 Pile detailed drawing

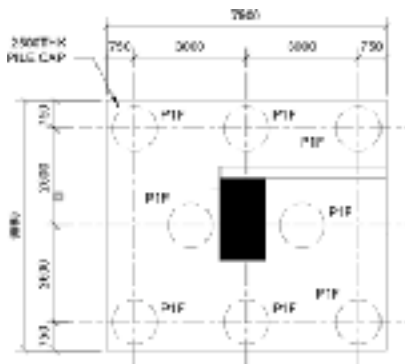


Figure 45 : PC 1A Details

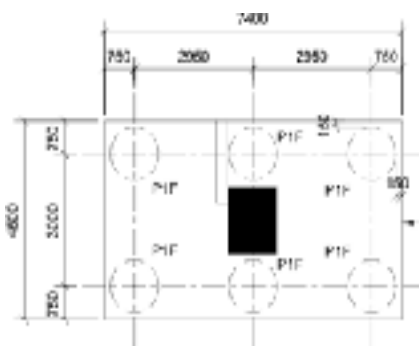


Figure 46 : PC 2A Details

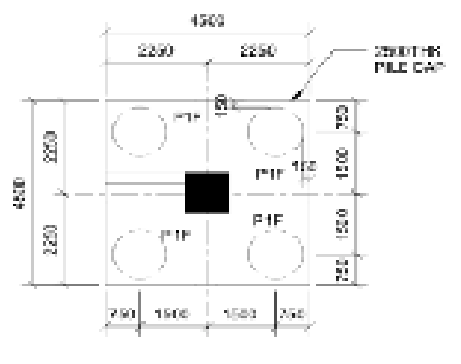
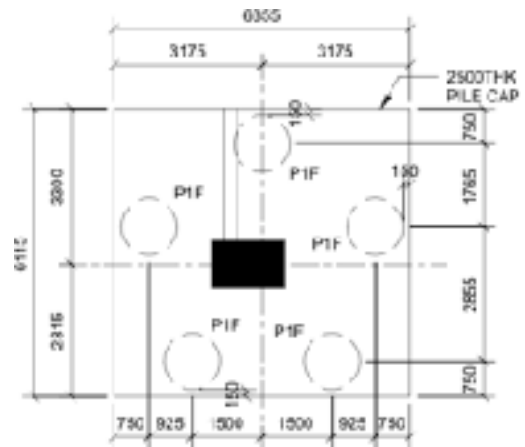
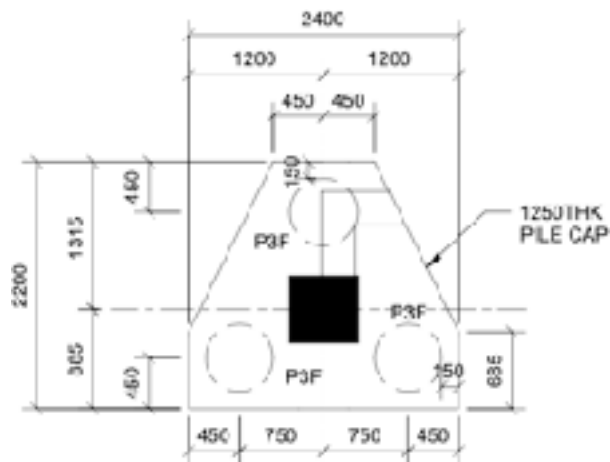
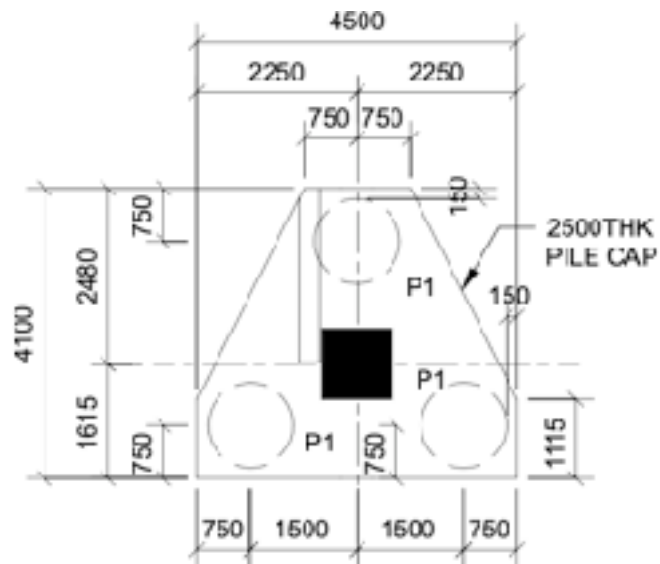
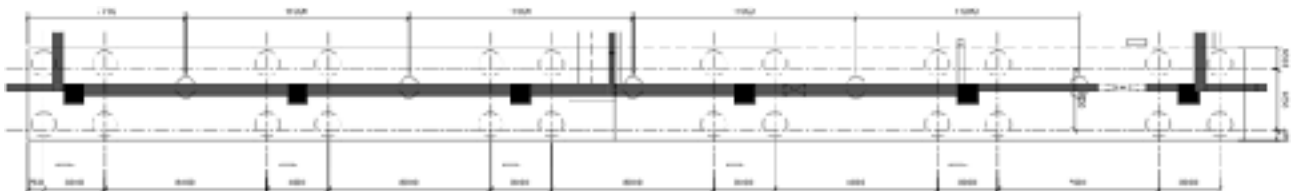
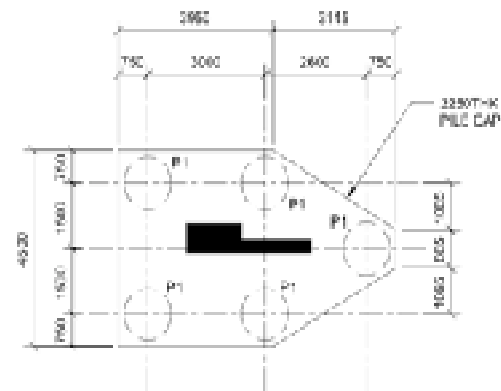
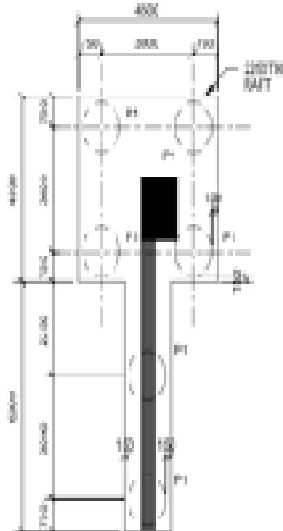
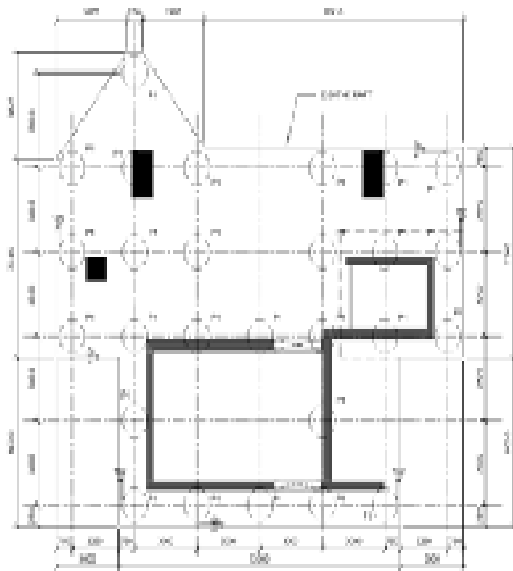
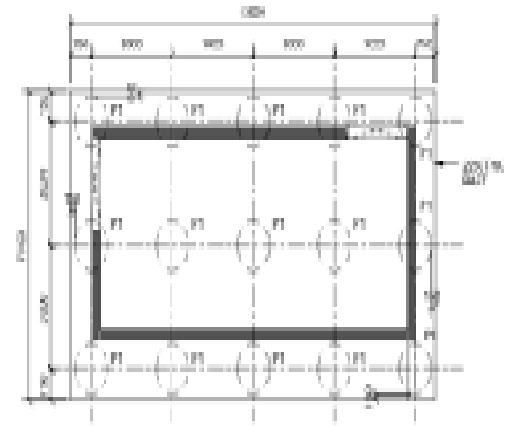
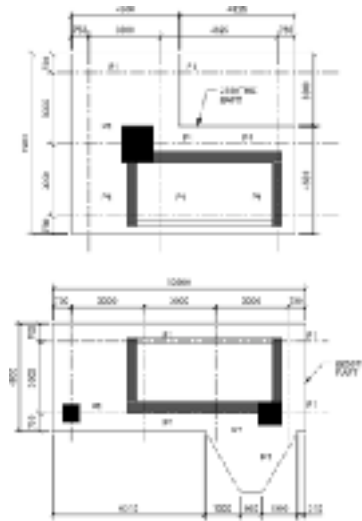
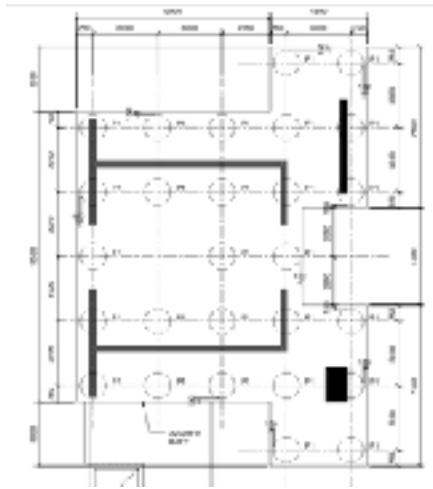


Figure 47 : PC 4A Details



The pile detailed drawing shows the distance between each pile and the distance between the column location and the piles below. The pile number varies for different size of the columns. The Detail drawing (sections and plans) shows the size, quantity and location of column, pile spacing, edge distance and pile cap thickness. The center to center distance of the pile is mentioned along with the overall dimension.



4.1.4 Pile layout sections

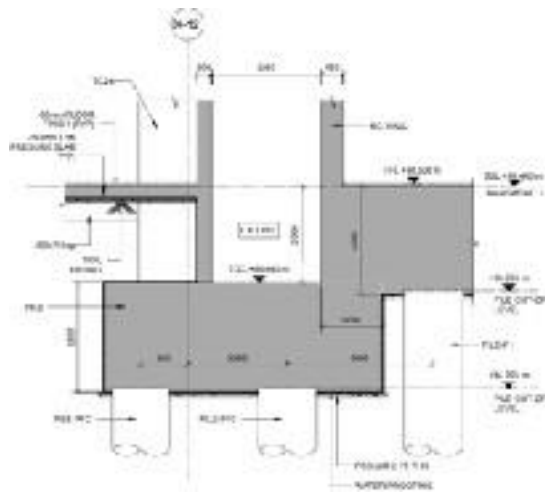


Figure 59 : Section 1

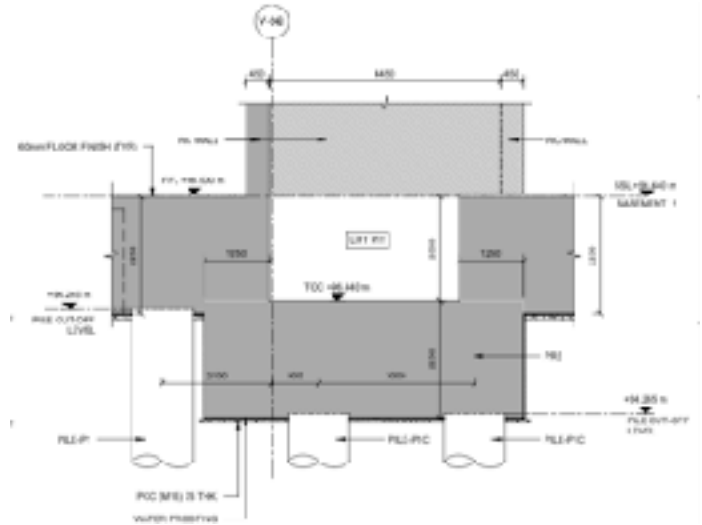


Figure 60 : Section 2

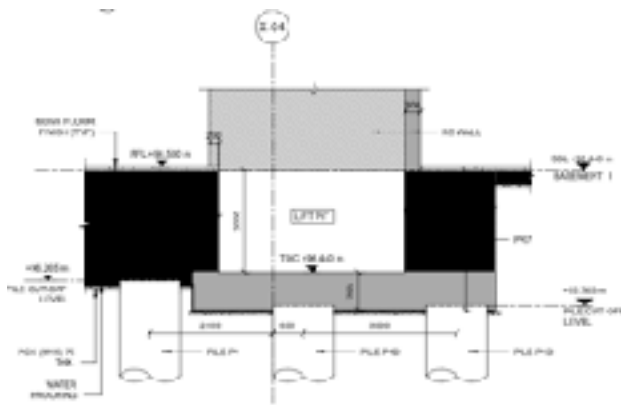


Figure 61 : Section 3

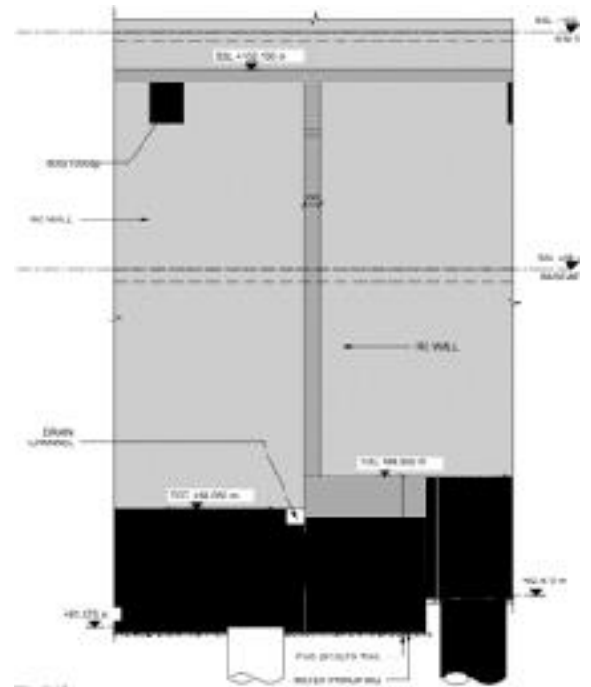


Figure 63 : Section 5

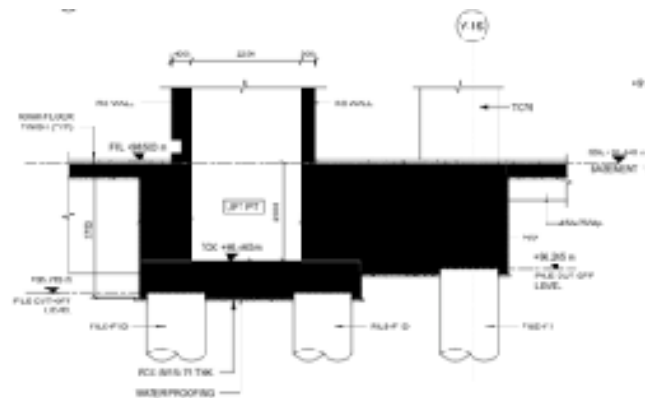


Figure 62 : Section 4

4.1.5 Flowchart for the excavation of bored pile process

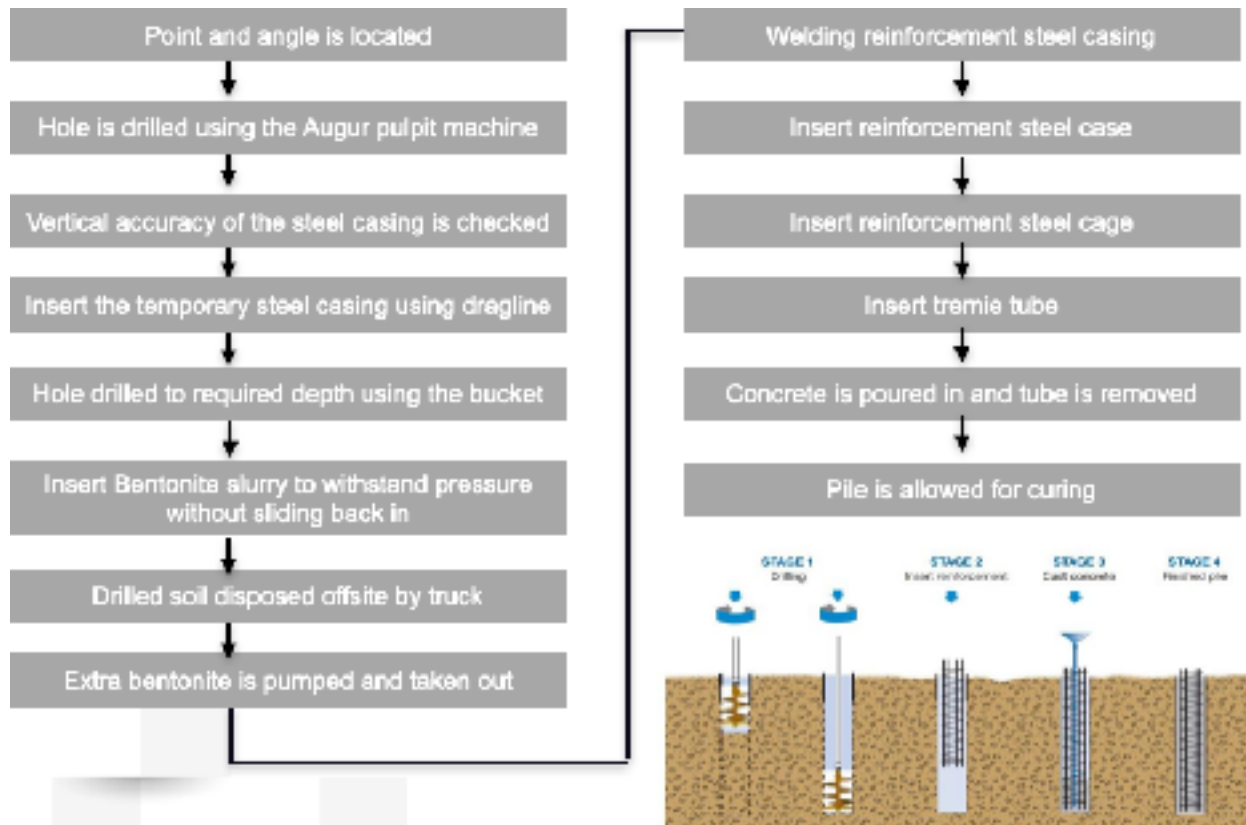


Figure 64 : Stages in bored pile construction

4.1.6 Procedure for construction of bored pile - Cast In situ

Prior to the commencement consider the following:

- Prepare construction program that involves main project milestones.
- Prepare and maintain all templates and quality check formats.

STEP 1 : Setting out pile points

- Mark set out points properly so as the points are clear and fix to avoid detrimental effect of other activities around the area.
- Use total Station or theodolite to set out pile position. Make sure to recheck these points before starting the piling activity. Establish temporary reference points (TR) for this purpose.



Figure 65 : Setting points

STEP 2 : Plan preparation for rig movement

- Prepare a layout that illustrate the expected path for rig movement based on the work program and the planned deployment of resources.
- The layout shall guarantee easy movement of all rigs without causing disturbances and problems to other rig operations.

STEP 3 : Boring process

- Position the rig over the established pile point.
- Diameter of the cutting tool shall not less than the required pile diameter by more than 75mm.
- After rig positioning, drive the casing into the ground. Drive steel casing to a minimum a depth of 1 m below the ground level to take lateral loads and movements.
- stabilize the borehole during boring process using bentonite or other suitable means.
- Consistency of the drilling mud shall be controlled throughout the boring as well as concreting operations. This measure used to stabilize the borehole as well as avoid concrete getting mixed up with the thicker suspension of the mud.
- Practiced great care to guarantee straight piles driven.
- It is recommended to carry out penetration tests to estimate 'N' value of the founding strata. In addition to take and maintain soil or rock samples from the founding strata, for future reference.
- It is also advisable to take soil samples from each intermediate soil strata at the depths specified in the soil test report.
- Finally, end the boring process upon reaching the designated boring depth. Check the borehole depth through measuring bailer pipe length after its removal from the borehole, and use sounding technique to recheck the borehole depth.



Figure 66 : Boring for pile



Figure 67 : Reinforcement cage

STEP 4 : Reinforcement placement

- Lower reinforcement cage into to the borehole vertically, without disturbing the sides of the hole.
- Equip the reinforcement cage with adequate stiffener bars to avoid sideways sway.
- weld stirrups, stiffeners and laps to prevent breakage.

STEP 5 : Bored cast in situ pile Concreting

- Concreting begins by lowering tremie pipes in to the borehole. Common tremie pipe diameter is around 200mm.
- Clean borehole bottom adequately before concrete pouring.
- Connect a hopper to the top of tremie pipe. After that, close the joint between hopper and tremie pipe with a steel plug before concrete first charge.
- Then, fill the hopper with concrete to its full capacity. Once filled, remove the steel plug to allow the concrete to flow down, and replace the bentonite slurry present in the pipe.
- Keep the bottom end of the tremie pipe embedded, at least 2m, within the laid concrete.
- To replace bentonite from bottom upwards and avoid mixing concrete with water or bentonite.
- Extend pile Concreting at least 60cm to 90cm above the cutoff level to ensure good concrete for proper embedment into pile cap.
- If the cutoff level is at ground level, then permit spill over of concrete till good concrete is visible.



Figure 68 : Concreting



Figure 69 : Pile riggers in the site

4.1.7 Equipment details - Mait HR 180

Model name	Category	Max torque (kNm)	Max Diameter (mm)	Max Depth (m)	Weight (ton)
HR 180	BORED PILES	233	1600	60	57 - 60

Figure 70 : MAIT HR 180 - Main specification.

Description:

The HR 180, has versatility, and it is easily adaptable to many different applications such as:

- Drilling with augers or buckets
- Execution of drilling casings directly with rotary and by casing oscillator
- Continuous Flight Auger (CFA)
- Diaphragm Walls
- Execution of Double Head drilling

The HR 180 is available in two versions: HR 180 CP – the standard version, is equipped with a Pull-down Cylinder which exerts it's force on the rotary, and is principally utilized for drilling large diameter bore holes. The rotary is able to work with a stroke of 5.100 m (17 ft) approx. The HR 180 CP uses a parallelogram system of articulation. HR 180 THD – available upon request, The THD system moves the rotary by utilizing the winch, allowing the rotary to be used along a larger stroke of the mast, 10 m (33 ft) approx. The THD version is particularly useful for driving and extracting casing tubes directly by the rotary, and without a doubt increasing your daily productivity. The HR 180 drilling rig base is already predisposed for all the various works listed above.



Figure 71 : Mait pile rigger



Figure 72 : Piling work

Technical data

Rotary		
Nominal Torque	233 kNm	171,900 lbf·ft
Rotary Nominal Pulldown	180 kN	40,500 lbf
Unloading Speed	150 rpm	
Stroke	9,300 mm (CP version) 10,000 (THD version)	30.7 ft (CP version) 32.8 ft (THD version)
Winches		
Main Winch Nominal Pullback	180 - 230* kN	40,500 - 51,750* lbf
Secondary Winch Nominal Pullback	60 kN	10,000 lbf
Engine		
Brand	CATERPILLAR	
Model	C9	
Power	242 kW @ 2,100 rpm	325 HP @ 2,100 rpm
Hydraulic System		
Hydraulic Oil Tank	800 liters	211 gal
Fuel Tank	430 liters	114 gal
Crawler		
Length	4,900 mm	16.1 ft
Width	3,000 - 4,300 mm	9.8 - 14.1 ft
Shoes	600 mm	2.6 ft
Weight		
Approx Weight	57 - 60 ton	120,000 - 132,500 lbs

Working characteristics

Works With Augers & Buckets		
Max Diameter (Without Lower Mast Extension)	2,000 mm	6.5 ft
Max Diameter (Without Casing)	2,000 mm	6.5 ft
Max Diameter (With Casing)	1,600 mm	5.2 ft
Depth	30 - 40 - 50 - 60 m	98.5 - 131 - 164 - 197 ft
Works With Casing Oscillator		
Max Diameter	1,600 mm	5.2 ft

Table 21 : Technical data of Mait Hr 180

4.1.8 Equipment details - Mait BR 165

Model name	Category	Max torque (kNm)	Max Diameter (mm)	Max Depth (m)	Weight (ton)
BR 165	BORED PILES	170	1,600	45 - 58 m	46.5

Figure 73 : MAIT BR 165 - Main specification

Description:

The BR 165 is a drilling rig suitable for medium to large diameter drilled shafts in any kind of soil by using a rotary system with kelly bar, augers and bucket. This model of hydraulic rig combine the high quality and reliability from MAIT experience with a design with renewed line. The cabin has been designed to offer maximum efficiency and comfort for the operator and equipped with air conditioning and heating system.



Figure 74 : MAIT BR 165

Working characteristics

Works With Augers & Buckets		
Max Diameter	1,600 mm	5.2 ft
Max Diameter (Without Lower Mast Extension)	1,800 mm	6 ft
Depth	30 - 40 - 48 m	98.5 - 131 - 157.5 ft
Works With Casing Oscillator		
Max Diameter	600 - 1,300 mm	2 - 4.3 ft

Table 22 : Technical data - Mait BR 165

4.1.9 Equipment details - Sany SR 155-C10



Figure 75 : Sany SR 155 - Main specification

Description:

Main performances	Unit	Parameter	Remark
Pile			
Max. drilling diameter	mm	1500	
Max. drilling depth	m	56/44	①
Rotary drive			
Rated output torque	kN · m	155	
Rotation Speed	rpm	5-35	
Crowd system			
Crowd force	kN	155	
Line pull	kN	160	
Stroke	mm	4200	
Main winch			
Lifting capacity	kN	160	
Wire rope diameter	mm	26	
Max. line speed	m/min	80	
Auxiliary winch			
Lifting capacity	kN	60	
Wire rope diameter	mm	14	
Max. line speed	m/min	75	
Mast inclination			
Forward/backward	°	5/90	
Lateral	°	±3	
Main Chassis			
Base engine	/	D06FR	Mitsubishi
Engine power	kW/rpm	147/2100	
Emission regulation	/	COM II	
Engine displacement	L	6.373	
Chassis length	mm	5975	
Extension width	mm	4100	
Track shoe width	mm	700	
Swing radius	mm	3715	
Overall machine			
Overall height	mm	10590	
Operating weight	t	48	
Transport width	mm	3140	
Transport height	mm	3265	

High efficiency and flexibility: Suitable for the construction of small and medium-sized soil layer boreholes. High main winch lifting speed and boreholes verticality, flexible operation, working efficiency higher than similar models of competitor by 15%.

Economical fuel saving: Using power optimization control technology, real-time adjustment of power distribution, quick response, high fuel efficiency, comprehensive energy saving by 10%

High reliability: The mast adopts box structure with strong resistance to torsion and fatigue; sixth generation kellybar adopting upgraded material and strengthened block ring, the overall strength increased by 25% with high drilling ability in strongly weathered rock layer.

Convenient transportation: The whole machine size is small, only 48T in weight, barrier free in city transportation and meet height limit.

Intelligent upgrade: 10-inch HD touch screen, fast response.

	Kelly bar	Weight(Kg)	Depth(m)	Option
Inter-locking kelly	Φ377×4×11	6100	40	
	Φ377×4×12	6600	44	
Friction kelly	Φ377×4×12	6100	44	Standard
	Φ377×5×12	5800	56	

Figure 76 : Friction kelly depth / interlocking kelly



Figure 77 : Horizontal transportation dimension

The SANY SR 155 pile rotary drilling rig is employed in the site.

Special chassis :Telescopic large widening chassis designed for rotary drilling rig, roller type large diameter slewing bearing to guarantee the high stability in deep borehole construction.

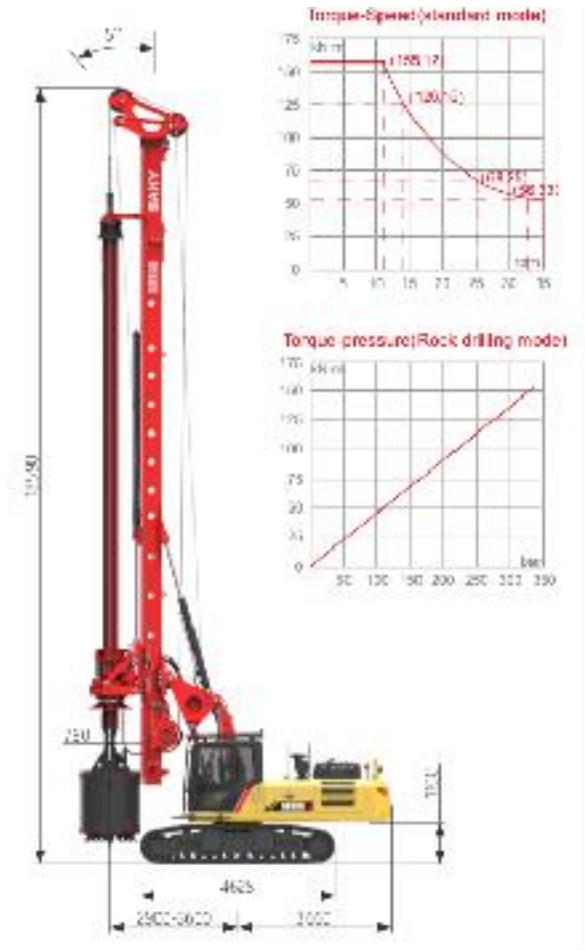


Figure 78 : Vertical transportation dimension

Economical : Imported large-displacement EFI engine with strong power, adopts power optimization control technology, adjusts power distribution in real time, fast response speed, higher fuel efficiency and more energy-saving.



Figure 79 : Equipment in the site



Figure 80 : Sany piling rig

4.1.10 Pile calculation

Total number of piles = 1083 (Retaining wall pile + column piles)

Expected duration to finish pile construction = 2 months (Avg 60 days)

One machine work = 5 pile per day

No of equipments used in the site (Pile drilling machine) = 4

Number of pile to be casted per day = No of piles / Duration

$$= 1083 / 60 = 18 \text{ nos.}$$

Number of Pile machines required = No of piles to be casted per day

$$\text{One machine work per day}$$

$$= 18 / 5 = 4 \text{ machines.}$$

Hence, The number of equipment in the site is satisfied.

If the time has to be reduced further and work to be finished as soon as possible number of equipments should be increased. The selection of equipment is important in considering the time and cost of the pile construction. The pile should be casted in odd and even number format to avoid the pile collapse once its casted. Minimum of 5 people required to operate a machine to cast the pile, upto 15 people can be employed for the job.

4.1.11 Concrete estimation for a pile

Quantity of cement = ratio of cement X total volume / total ratio sum of grade used

Total volume = volume of pile

Ratio of cement = ratio in grade of concrete used

Total ratio sum = sum of cement, sand, aggregate ratio

Quantity of sand = ratio of sand X total volume / sum of ratio

Quantity of aggregate = ratio of aggregate X total volume

For steel or reinforcement

- Bar bending schedule is made
- As per drawings we know main bar and distribution bar dia and spacing.

e.g = # 6 @8" = 6mm dia at 8" spacing = Main bar

= # 8 @10" = 8mm dia at 10" spacing = Distribution bar.

4.1.12 Weekly schedule fo pile construction

Planned schedule for week 1 - week 9 , Assumption vs Actual

WEEK	NO OF PILE TO BE CASTED (PLANNED)	NO OF PILE TO BE CASTED (ACTUAL)	EQUIPMENT USED (PLANNED)	EQUIPMENT USED ACTUALLY	WORKING HOURS 8 PER DAY	LABOUR NOS REQUIRED	LABOUR NOS ACTUAL
Week 1	120	120	Pile drilling machine 5 nos, Backhoe 2, Dump truck 2	Pile drilling machine 4 nos, Backhoe 2, Dump truck 1	48	15	14
Week 2	120	120	Pile drilling machine 5 nos, Backhoe 2, Dump truck 2	Pile drilling machine 4 nos, Backhoe 2, Dump truck 2	48	15	14
Week 3	120	108	Pile drilling machine 5 nos, Backhoe 2, Dump truck 2	Pile drilling machine 4 nos, Backhoe 1, Dump truck 1	48	15	12
Week 4	120	108	Pile drilling machine 5 nos, Backhoe 2, Dump truck 2	Pile drilling machine 4 nos, Backhoe 1, Dump truck 1	48	15	12
Week 5	120	108	Pile drilling machine 5 nos, Backhoe 2, Dump truck 2	Pile drilling machine 4 nos, Backhoe 1, Dump truck 1	48	15	12
Week 6	120	108	Pile drilling machine 5 nos, Backhoe 2, Dump truck 2	Pile drilling machine 4 nos, Backhoe 1, Dump truck 1	48	15	12
Week 7	121	108	Pile drilling machine 5 nos, Backhoe 2, Dump truck 2	Pile drilling machine 4 nos, Backhoe 1, Dump truck 1	48	15	12
Week 8	121	108	Pile drilling machine 5 nos, Backhoe 2, Dump truck 2	Pile drilling machine 4 nos, Backhoe 1, Dump truck 1	48	15	12
Week 9	121	108	Pile drilling machine 5 nos, Backhoe 2, Dump truck 2	Pile drilling machine 4 nos, Backhoe 1, Dump truck 1	48	15	12
Week 10	-	87	Pile drilling machine 5 nos, Backhoe 2, Dump truck 2	Pile drilling machine 4 nos, Backhoe 1, Dump truck 1	48	15	12
TOTAL	1083	1083			480	150	124

Table 23 : Weekly schedule

4.2 SATHYABAMA AUDITORIUM, SIST CAMPUS, CHENNAI

4.2.1 Project details

Project name - Sathyabama institute of science and technology Auditorium

City - Chennai

Location - OMR

Site area - 15060 Sq.m

Buildup area - 8690 sq.m

Type of foundation - Pile foundation

Type of Pile - Bored in situ pile

Pile diameter - 600 mm

Pile cap types - 4

Pile cap group - 6 pile group ,4 pile group, 8 pile group and 2 pile group

No of floors - 2 (with mezzanine floor)

Stage - Yet to start

Type of project - Auditorium construction

Total No of piles - 439.

4.2.2 Pile design consideration

Type of Pile : Bored Cast in situ

Pile Diameter : 600 mm

Spacing of piles : 2100 mm

Column Dimension B x D : 750 x 750 mm

Circular column dimension : 900mm dia

Depth of pile : 15.5 m

Pile type - Bored Cast in situ

Volume of single pile : 346 sq.ft or 9.75sq.m

Concrete Mix : M30 Grade

Central column load : 40 to 50 tons (approx)

Pile cut-off level : 1.5m from FGL

Factor of Safety : 2.5

Safe vertical capacity of single pile : 116 tonnes.

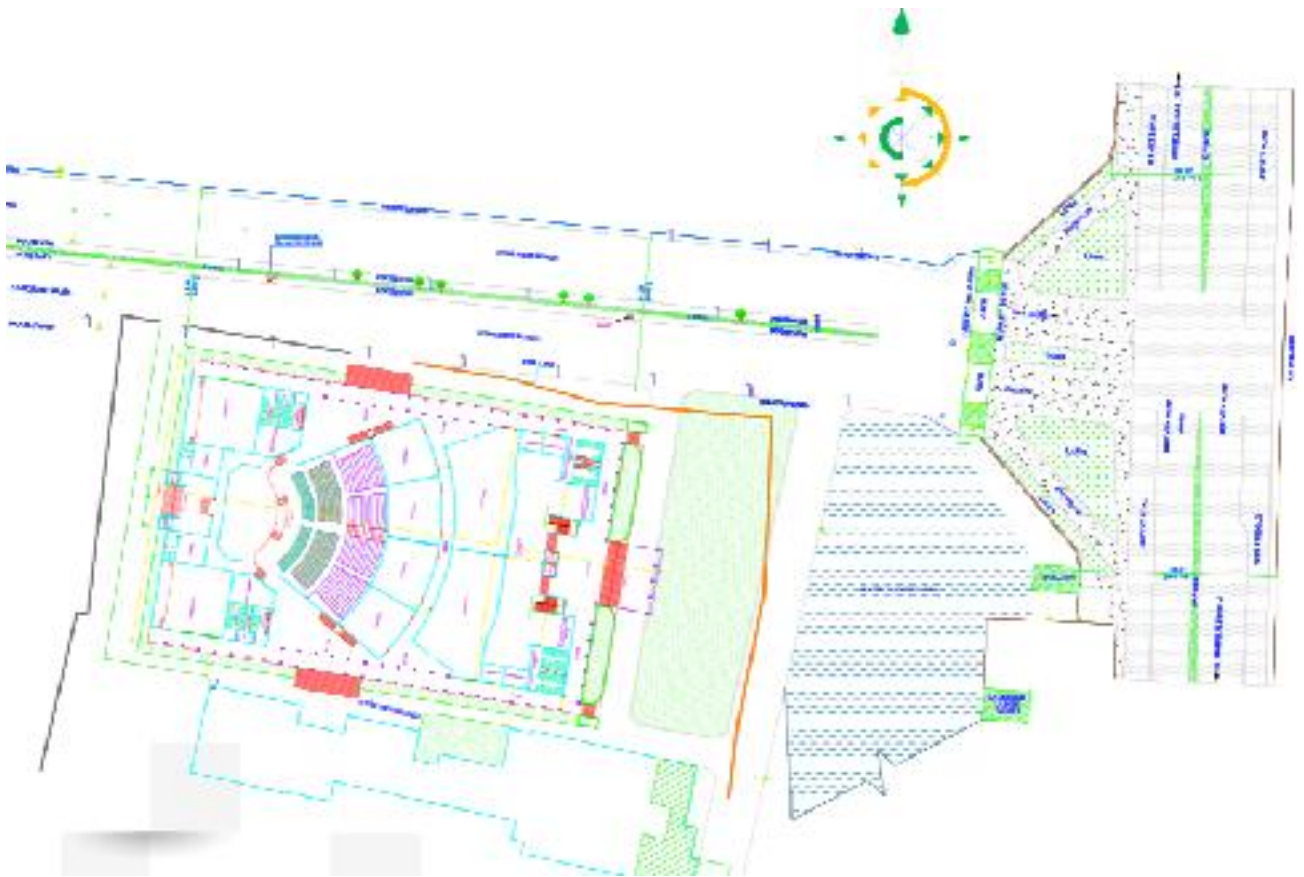


Figure 81: Site plan of the auditorium.

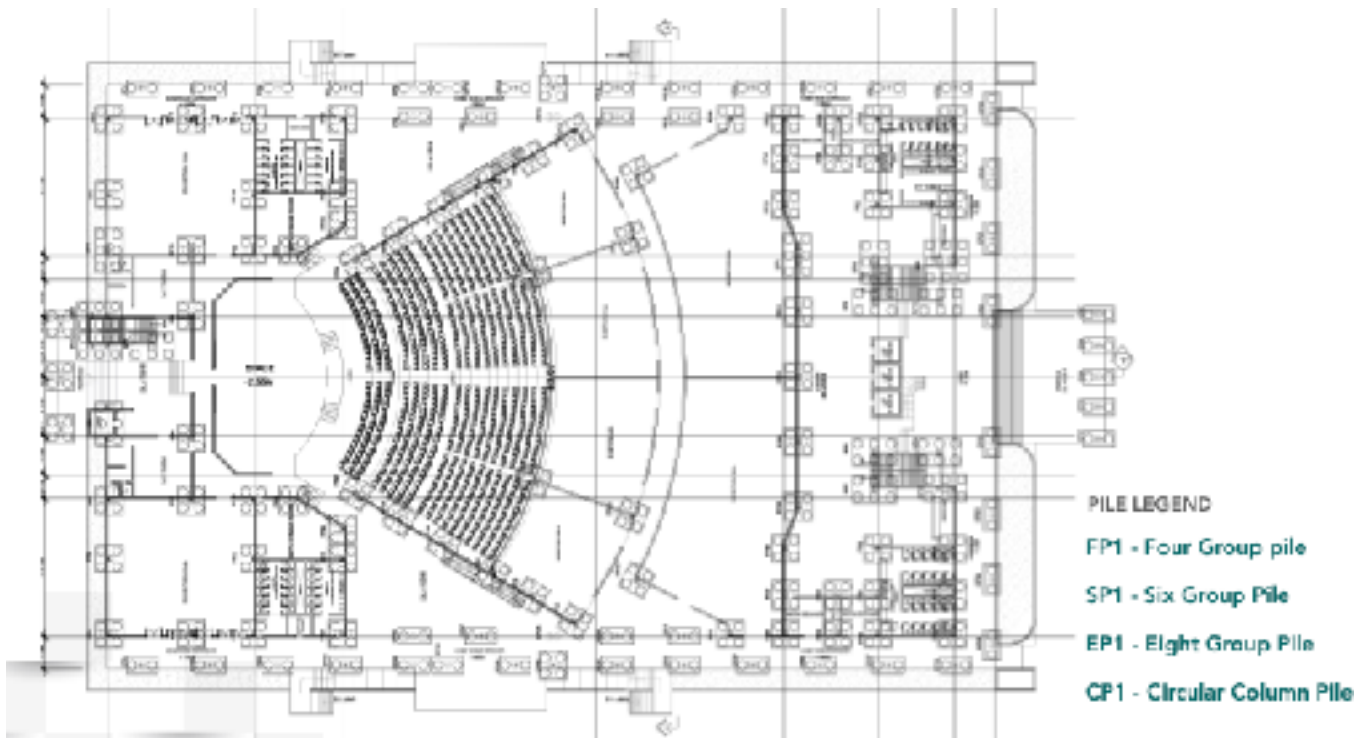


Figure 82 : Proposed pile layout.

4.2.3 M30 Concrete design mix

Stipulations for proportioning	
Grade designation	M30
Type of cement	OPC 53 grade
Maximum Nominal Size of Aggregate	20mm
Minimum Cement Content	320kg /cu.m
Maximum Cement Content	450kg/cu.m
Maximum Water Cement ratio	0.45
Workability	50 -75mm (slump)
Type of Aggregate	Crushed Angular Aggregate
Chemical Admixture Type	Superplasticizer Confirming to IS-9103
Exposure condition	Normal
Selection of Water Cement Ratio	
Maximum Water Cement ratio	0.45
Selection of Water Content	
Maximum water content (IS 10262- table 2)	186 lit
Estimated water content for 50-75mm slump	160 lit
Calculation of cement content	
Estimated W/C ratio	0.42
Cement content (160 / 0.42)	380 kg/cu.m
Mix proportions for one cu.m of concrete	
Mass of cement in kg/cu.m	380
Mass of water in kg/cu.m	160
Mass of Fine & coarse aggregate in kg/cu.m	711 and 1283
Mass of 20mm & 10mm in kg/cu.m	924 and 359
Mass of Admixture in kg/cu.m	1.90

Table 24 : M30 concrete design mix

4.2.4 Calculation of Volume of pile

Four group pile :

Volume of Pile

Diameter of pile - 600mm or 0.6m

Radius of pile - 300mm or 0.3m

Depth of pile - 15.5m No.of pile - 4

Concrete volume of pile = $\pi r^2 h$ ($\pi = 3.14$)

$$= 3.14 \times 0.3 \times 0.3 \times 15.5 \times 4$$

$$= 17.52 \text{ cu.m} / 4.38 \text{ cu.m for 1 pile}$$

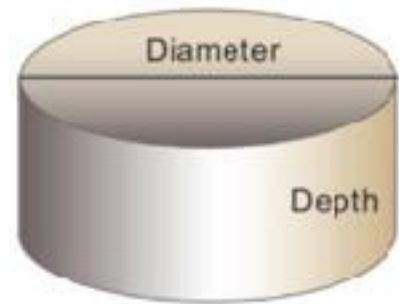


Figure 83 : Volume of the pile

Volume of Pile Cap

Length of pile cap - 3.5m or 3500 mm

Breadth of pilecap - 3.5m or 3500 mm

Depth of pile cap = 1.4m or 1400 mm

Volume of Pile cap = Length x Breadth x Height

$$= 3.5 \times 3.5 \times 1.4 = 17.15 \text{ cu.m}$$

Six group pile :

Volume of Pile

Diameter of pile - 600mm or 0.6m

Radius of pile - 300mm or 0.3m

Depth of pile - 15.5m No.of pile - 6

Concrete volume of pile = $\pi r^2 h$ ($\pi = 3.14$)

$$= 3.14 \times 0.3 \times 0.3 \times 15.5 \times 6$$

$$= 26.3 \text{ cu.m}$$

Volume of Pile Cap

Length of pile cap - 5.65m or 5650 mm

Breadth of pile cap - 3.6m or 3600 mm

Depth of pile cap = 1.4m or 1400 mm

Volume of Pile cap = $L \times B \times H = 5.65 \times 3.6 \times 1.4 = 28.3 \text{ cu.m.}$

Eight group pile :

Volume of Pile

Concrete volume of 6 pile = $\pi r^2 h$ ($\pi = 3.14$)

$$= 3.14 \times 0.3 \times 0.3 \times 15.5 \times 8$$

$$= 35 \text{ cu.m}$$

Volume of Pile Cap

Length of pile cap - 5.65m or 5650 mm

Breadth of pile cap - 5.75m or 5750 mm

Depth of pile cap = 1.4m or 1400 mm

Volume of Pile cap = Length x Breadth x Height

$$= 5.65 \times 5.75 \times 1.4$$

$$= 57 \text{ cu.m.}$$

Circular piles - Peripheral

Volume of 1 pile = $3.14 \times 0.3 \times 0.3 \times 15 = 4.23 \text{ cu.m}$

Volume of 54 pile = $4.23 \times 54 = 229 \text{ cu.m}$

Pile cap for 4 group = 17.15 cu.m

Pile cap for 2 group = 8.4 cu.m .

4.2.5 Field sampling

BH- No	Easting	Northing	R.L based on NGL	Investigated depth from NGL (m)
BH -1	415935.788	1423174.753	4.062	15.5
BH -2	415930.699	1423118.711	4.103	15
BH -3	415892.347	1423157.647	4.050	13
BH -4	415828.725	1423117.749	3.844	15.5
BH -5	415834.697	1423190.852	4.117	16.5

Table 25 : Sample collected in the field.

4.2.6 Soil profile

Based on visual identification of soil samples and test results (of both field and laboratory tests), the soil profile arrived. Subsoil is made-up of five distinctive layers there are

- (i) Soft to medium stiff CLAY up to -3.5m with SPT's N= 3-10
- (ii) Medium dense SAND -3.50 to -5.0m with SPT's= 11-30
- (iii) Stiff to very stiff CLAY-5.0m to -10.0m with SPT's N=14-24
- (iv) Medium Dense SAND -10.0m to -13.0m with SPT's N=17-30
- (v) Soft disintegrated Rock -13.0m -16.50m with SPT's N=>100.

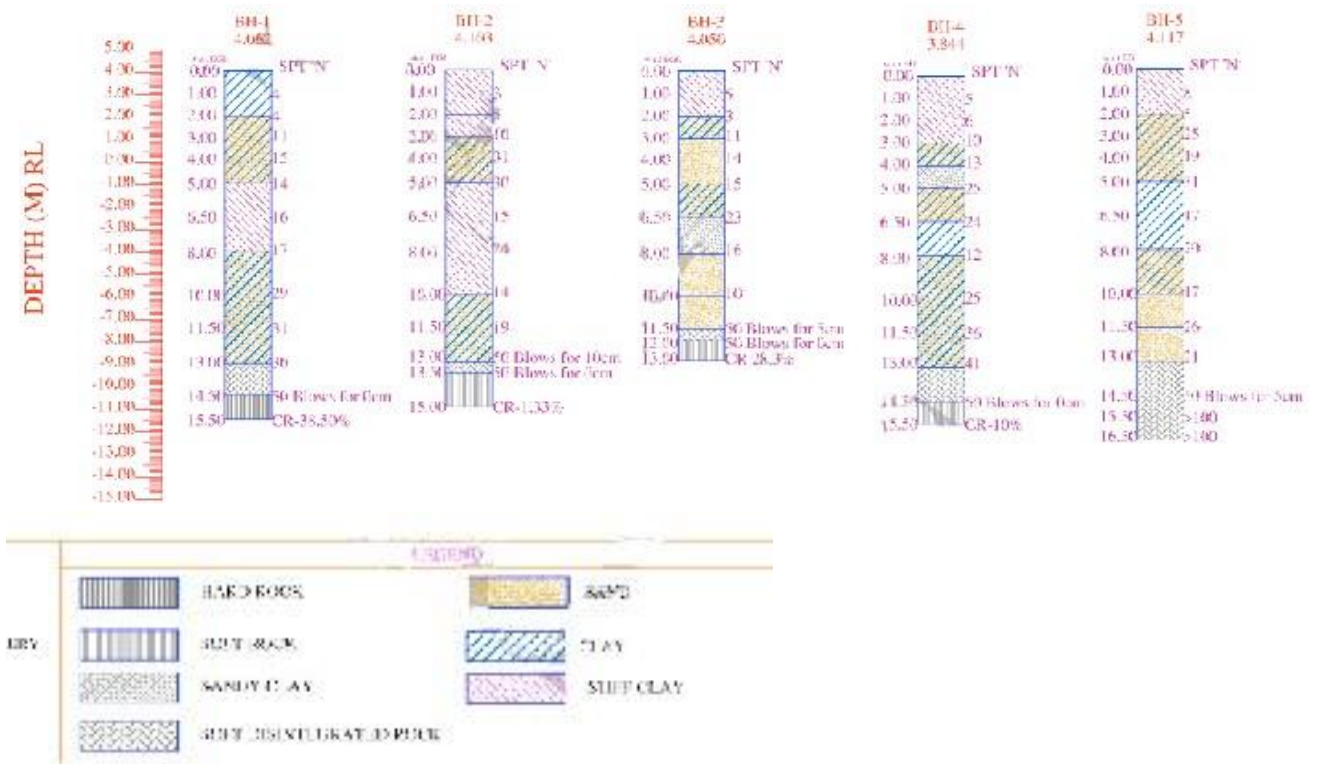


Figure 84 : Sub soil profile of the site.

LENGTH OF PILE (m) FROM FGL	PILE DIA (mm)	SAFE VERTICAL CAPACITY (Tonnes)	SAFE UPLIFT CAPACITY (Tonnes)	SAFE LATERAL CAPACITY WITH REGARD TO 5mm DEFLECTION	
				FREE HEAD (Tonnes)	FIXED HEAD (Tonnes)
15.5	450	73	32	1.3	3.3
15.5	500	85	42	1.4	3.7
15.5	600	113	51	1.7	4.4

Table 26 : Pile capacities.

4.2.7 Pile design considerations - Tabulated

TYPE OF PILE	PILE GROUP	PILE GROUP NUMBER	NO OF PILE IN EACH GROUP	TOTAL NO OF PILE IN ONE GROUP	COLUMN SIZE (mm)	NO OF COLUMNS	PILE DIAMETER	PILE DEPTH (m)	DEPTH OF PILE CAP (mm)	PILE CAP DIMENSION (mm)
Bored Cast in situ	E.Pile 1-5	5	4	20	750 X 750	5	600	15.3	1400	3500 X 3500
Bored Cast in situ	F.Pile 6-11	6	4	24	750 X 750	6	600	15.3	1400	3500 X 3500
Bored Cast in situ	F.Pile 12-17	6	4	24	750 X 750	6	600	15.3	1400	3500 X 3500
Bored Cast in situ	F.Pile 18-19	2	4	8	750 X 750	2	600	15.3	1400	3500 X 3500
Bored Cast in situ	F.Pile 20-27	8	4	32	750 X 750	8	600	15.3	1400	3500 X 3500
Bored Cast in situ	F.Pile 28-29	2	4	8	750 X 750	2	600	15.3	1400	3500 X 3500
Bored Cast in situ	F.Pile 30-31	2	4	8	750 X 750	2	600	15.3	1400	3500 X 3500
Bored Cast in situ	F.Pile 32-33	2	4	8	750 X 750	2	600	15.3	1400	3500 X 3500
Bored Cast in situ	F.Pile 34-37	4	4	16	750 X 750	4	600	15.3	1400	3500 X 3500
Bored Cast in situ	F.Pile 38-43	6	4	24	750 X 750	6	600	15.3	1400	3500 X 3500
Bored Cast in situ	F.Pile 44-45	2	4	8	750 X 750	2	600	15.3	1400	3500 X 3500
Bored Cast in situ	F.Pile 46-55	10	4	40	750 X 750	10	600	15.3	1400	3500 X 3500
Bored Cast in situ	F.Pile 56-59	4	4	16	750 X 750	4	600	15.3	1400	3500 X 3500
Bored Cast in situ	F.Pile 60-65	6	4	24	750 X 750	6	600	15.3	1400	3500 X 3500
Bored Cast in situ	F.Pile 66-71	6	4	24	750 X 750	6	600	15.3	1400	3500 X 3500
Bored Cast in situ	S.Pile 1-5	5	5	25	750 X 750	5	600	15.3	1400	3500 X 3500
Bored Cast in situ	S.Pile 7-13	7	5	35	750 X 750	7	600	15.3	1400	3500 X 3500
Bored Cast in situ	S.Pile 1	1	5	5	750 X 750	1	600	15.3	1400	3500 X 3500
Bored Cast in situ	C.Pile 1,3,13,14,44,45	7	4	28	900 Dia	14	600	15	1400	3500 X 3500
Bored Cast in situ	C.Pile 4,12,15,43,46-54	17	1	17	900 Dia	17	600	6	1400	4700 X 2100
TOTAL NUMBER OF PILES				439						

Table 27 : Pile details considered.

4.2.8 Equipments for pile construction

Bored Piles typically utilise a Drill Rig, Helper Crane, Spoil Handling (loader, skip pan, etc.), casing, slurry handling, cage erection template, concrete truck and concrete pump truck.

Selection criteria:

It is important to select an appropriate machine. The optimally selected pile machine guarantees fast and efficient performance of assumed tasks at a lower cost. The optimization can be realized on the basis of technical parameters of the machines and their rank. Hence few steps are followed.

1. Establish significance of particular criteria of a machine; its sum should equal to unity.
2. Establish minimum and maximum values for particular criteria

3. Calculate the range of values for particular criteria.
4. Transform the particular criteria into a normalized values.
5. Calculate values of measures being relative distances of particular criteria from the respective optimum values for successive machines.
6. Calculate the values of measuresl being relative distances of respective values in group of machines.
7. Calculated synthetic measures should be multiplied by established value for the respective criteria.

The obtained synthetic measures can be used for the evaluation and comparison of machines among themselves. The pile machines were pre-analyzed in view of their technical characteristics, without taking into account the economic aspects. When selecting a pile machine attention was mainly paid to the CCS pull up/down force and torque.

4.2.9 Pile machine calculation

Total no.of piles = 439 (pheripheral column piles + building column pile)

Expected duration to finish pile construction = 60 days (aproxy 2 months)

One machine work = 1.5 pile per day

Number of pile to be casted per day

= No of piles / Duration

= 439/60

= 7 nos of pile.

Number of Pile machines required

= No of piles to be casted per day / One machine work per day

= 10 /1.5 = 7 machines.

4.2.10 Material calculation for concrete

Requirement for 439 piles

Cement bags

Volume of 1 pile - 4.38 cu.m

Cement for 1 pile - 6307 kg

No of cement bags required for 1 pile - 126 bags

Cement bags for 439 piles - $126 \times 439 = 55,314$

Sand

Sand for 1 pile - 3867 kg / 86 cu.ft

Sand for 439 piles - $86 \times 439 = 37,754$ cu.ft

Aggregate

Aggregate quantity for 1 pile - 1066 kg / 25 cu.ft

Aggregate quantity for 439 piles = 25×439

= 10,975 cu.ft of aggregates.

4.2.11 Labour

- The pile should be casted in odd and even number format to avoid the pile collapse once its casted.
- Minimum of 4 or 5 people required to operate a machine to cast the pile, upto 15 people can be employed for the job.
- The market range of labour wages is 1000 rupees per day (private) and 450 to 800 /day.

4.2.12 Water requirement

The water is required to fill the whole depth of the pile to clean the mud.

Diameter of pile = 600mm or 0.6m

$$(5D^2/4) = 5 \times 0.6 \times 0.6/4 = 0.28\text{sq.m} = 4.38 \text{ cu.m}$$

1pile = 10,000 litres (approx)

Water is mixed with bentonite for the usage.

4.2.13 Steel cage

Pile cages are used to support weight loads and protect the earth from general or seismic movement that can collapse the structure. Once the pile cavity has been bored, reinforcing steel cages are lowered into the hole with spacer wheels maintaining clearance from the bored hole edges. The maximum weight of the reinforcement cage will be approximately 9 ton. Pile cage (1 cage = 10 to 16 rods).



Figure 85 : Steel cage

4.2.14 Piling work in the night time

- For work during the night time, the lighting of at least **100 lux intensity** shall be provided at the worksite.
- The lighting provided for the whole construction area is named as “Area lighting”. The separate **spot lighting** to be provided for the pile casting area.
- Usually concreting work is carried out in the night time due to cool environment where the concrete temperature plays a vital role. And low traffic during the night time makes it feasible to work.
- Drilling works are carried out during the day time.
- The construction power to be brought separately for the usage. Diesel generator can also be used if the power bill is found to be high.
- The labour accommodation is also considered for the electricity arrangement in the night time.
- The power consumption of the equipment. Its preferable to use the new equipment because old equipments utilizes more power and fuel.

4.2.15 Market overview of piling rig

The demand for foundation equipment in India, has been growing at the rate of 25-30 percent year on year basis. The market size of the foundation equipment is estimated to be INR 150-170 crores.

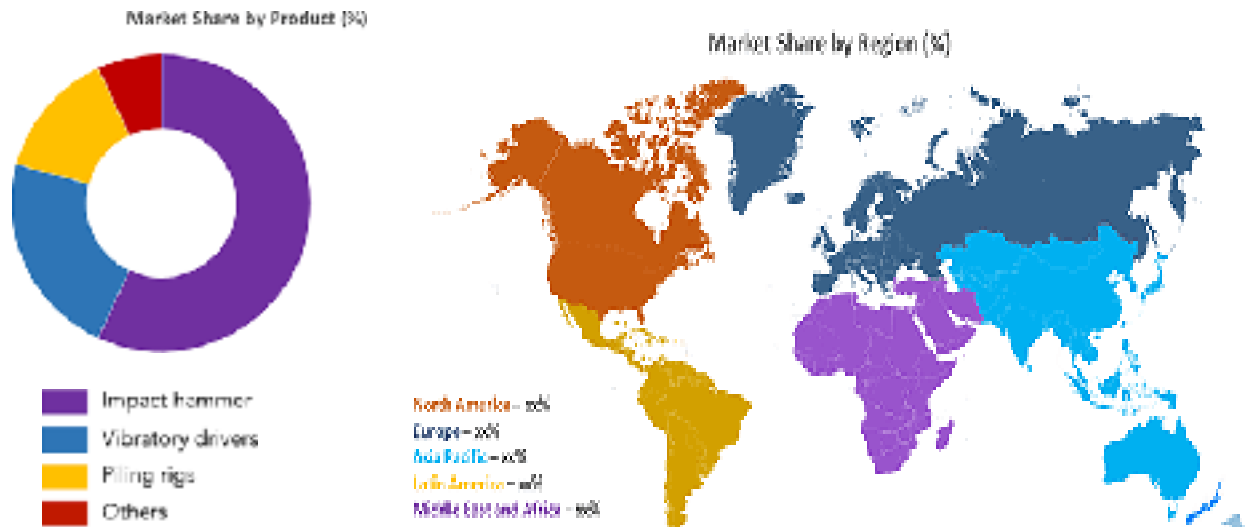


Figure 86 : Global Piling Machine Market.

The piling rings segment accounted for approximately 36% of the market share in 2021. Piling rings are used for different applications, such as foundation reinforcement, cast-in piles, and installing diaphragm walls among others. Piling rings can perform auger boring, drilled percussion, impact-driven, and rotary boring piling activities. Piling rings are utilized to dig within the earth's subsurface, making of the water wells, oil wells, or natural gas extraction wells, and to install sub-surface fabrications among others.

CHAPTER 5

ANALYSIS AND CONCLUSION

5.1 ANALYSIS OF PILING MACHINE

5.1.1 Piling rig cost analysis

Cost elements

- **Transportation cost:** the cost of transporting equipment to the proposed site from a predecessor site or elsewhere.

- **Consumables cost:** the cost of materials and chemical supplies that are consumed by operating the equipment such as fuel, oil and grease. These cost items can be applied to all equipments even considering the various consumption rates and types of consumables.
- **Labor cost:** refers to the cost of equipment drivers, operators, assistants, riggers and the rig captain. It includes daily rates, catering, motivation and bonus structure based on productivity metrics. The supervision and services staff are excluded as they will be included in other cost items.
- **Maintenance cost:** it the total cost of equipment regular maintenance during the project performance period by an authorized service center or retailer. It can be obtained using the time ratio of the performance period to the whole year.
- **Depreciation cost:** calculated as the decrease in equipment book value using straight line depreciation (SLD) method during the project performance period and can also be calculated using the time ratio of the performance period to the whole year.

5.1.2 Cost break down

A S.NO	COST ELEMENT	DIRECT COSTS COST ITEM	UNITS
1	RIG	Transportation	Lumpsum
		Fuel	Litre / day
		Oil	Litre / day
		Grease	Kg/ day
		Riggers	Working day
		Driver	Working day
		Rig captain	Working day
		Maintenance	Lumpsum
		Depreciation	Lumpsum
2	EXCAVATOR	Fuel	Litre / day
		Oil	Litre / day
		Grease	Kg/ day
		Driver	Working day
		Maintenance	Lumpsum
		Depreciation	Lumpsum
8	INDIRECT COSTS		
3	STAFFS	Project manager	Monthly salary
		Site engineer	Monthly salary
		Supervisor	Monthly salary

Table 28 : Cost breakdown

5.1.3 Pile sequencing

PILE GROUP	NO OF PILE TO BE CASTED	DAYS
FP1,3,5,7,9 - SP2,4,6,8,10	10	Day 1
FP2,4,6,8,10 - SP1,3,5,7,9	10	Day 2
FP11,13,15,17,19 - SP11,13 - CP1	10	Day 3
FP20,22,24,26,28 - SP 12, CP3, - - -	10	Day 4
FP21,23,25,27,29 - CP2,4,6,8,10	10	Day 5
FP30,32,34,36,38 - CP 12,14,16, 18,20	10	Day 6
FP39,41,43,45,47 - CP22,24,26, 28, 30	10	Day 7
FP48,50,52,54,56 - CP32,34,36, 38,40	10	Day 8
FP57,59,61,63,65 - CP42,44,46, 48,50	10	Day 9
FP56,68,70 - CP52,54 - EP1	10	Day 10
FP567,79,71 - CP51, 1,3	10	Day 11
FP1,3,5,7,9 - SP2,4,6,8,10	10	Day 12
FP2,4,6,8,10 - SP1,3,5,7,9	10	Day 13
FP11,13,15,17,19 - SP11,13 -CP1	10	Day 14
FP20,22,24,26,28 - SP 12, CP3, - - -	10	Day 15
FP21,23,25,27,29 - CP2,4,6,8,10	10	Day 16
FP30,32,34,36,38 - CP 12,14,16, 18,20	10	Day 17
FP39,41,43,45,47 - CP22,24,26, 28, 30	10	Day 18
FP48,50,52,54,56 - CP32,34,36, 38,40	10	Day 19
FP57,59,61,63,65 - CP42,44,46, 48,50	10	Day 20
FP56,68,70 - CP52,54 - EP1	10	Day 21
FP567,79,71 - CP51	10	Day 22
FP1,3,5,7,9 - SP2,4,6,8,10	10	Day 23
FP2,4,6,8,10 - SP1,3,5,7,9	10	Day 24
FP11,13,15,17,19 - SP11,13 -CP1	10	Day 25
FP20,22,24,26,28 - SP 12, CP3, - - -	10	Day 26
FP21,23,25,27,29 - CP2,4,6,8,10	10	Day 27
FP30,32,34,36,38 - CP 12,14,16, 18,20	10	Day 28
FP39,41,43,45,47 - CP22,24,26, 28, 30	10	Day 29
FP48,50,52,54,56 - CP32,34,36, 38,40	10	Day 30
FP57,59,61,63,65 - CP42,44,46, 48,50	10	Day 31
FP56,68,70 - CP52,54 - EP1	10	Day 32
FP567,79,71 - CP51,1,3	10	Day 33
FP1,3,5,7,9 - SP2,4,6,8,10	10	Day 34

PILE GROUP	NO OF PILE TO BE CASTED	DAYS
FP2,4,6,8,10 - SP1,3,5,7,9	10	Day 35
FP11,13,15,17,19 - SP11,13 -CP1	10	Day 36
FP20,22,24,26,28 - SP 12, CP3,	10	Day 37
FP21,23,25,27,29 - CP2,4,6,8,10	10	Day 38
FP30,32,34,36,38 - CP 12,14,16, 18,20	10	Day 39
FP39,41,43,45,47 - CP22,24,26, 28, 30	10	Day 40
FP48,50,52,54,56 - CP32,34,36, 38,40	10	Day 41
FP57,59,61,63,65 - CP42,44,46, 48,50	5	Day 42
FP566,68,70 - CP52,54 - EP1	5	Day 43
FP567,79,71 - CP51, EP1	5	Day 44
FP1,3,5,7,9 - SP2,4,6,8,10	9	Day 45
FP2,4,6,8,10 - SP1,3,5,7,9	8	Day 46
FP11,13,15,17,19 - SP11,13 -CP1	8	Day 47
FP20,22,24,26,28 - SP 12, CP3,	10	Day 48
FP21,23,25,27,29 - CP2,4,6,8,10	10	Day 49
FP30,32,34,36,38 - CP 12,14,16, 18,20	10	Day 50
FP39,41,43,45,47 - CP22,24,26, 28, 30	10	Day 51
FP48,50,52,54,56 - CP32,34,36, 38,40	10	Day 52
FP57,59,61,63,65 - CP42,44,46, 48,50	10	Day 53
FP566,68,70 - CP52,54 - EP1	10	Day 54
FP567,79,71 - CP51	10	Day 55
FP1,3,5,7,9 - SP2,4,6,8,10	10	Day 56
FP2,4,6,8,10 - SP1,3,5,7,9	10	Day 57
FP11,13,15,17,19 - SP11,13 -CP1	10	Day 58
FP20,22,24,26,28 - SP 12, CP3,	10	Day 59
FP21,23,25,27,29 - CP2,4,6,8,10	10	Day 60
FP30,32,34,36,38 - CP 12,14,16, 18,20	10	Day 61
FP39,41,43,45,47 - CP22,24,26, 28, 30	10	Day 62
FP48,50,52,54,56 - CP32,34,36, 38,40	10	Day 63
FP57,59,61,63,65 - CP42,44,46, 48,50	10	Day 64
FP566,68,70 - CP52,54 - EP1	10	Day 65
FP567,79,71 - CP51, EP1	10	Day 66
FP1,3,5,7,9 - SP2,4,6,8,10	10	Day 67
FP2,4,6,8,10 - SP1,3,5,7,9	10	Day 68

Table 29 : Pile sequencing

5.1.4 Weekly schedule for pile construction

Planned schedule for week 1 - week 9

WEEK	NO OF PILE TO BE CASTED / DAY (Planned)	TOTAL PILE CASTED IN ONE WEEK	EQUIPMENT TO BE USED (PLANNED)	WORKING HOURS	LABOUR NOS REQUIRED
Week 1	10	50	Pile rig machine 2 nos, Concrete truck 2, Dump truck 2	40	35
Week 2	10	50	Pile rig machine 2 nos, Concrete truck 2, Dump truck 2	40	35
Week 3	10	50	Pile rig machine 2 nos, Concrete truck 2, Dump truck 2	40	35
Week 4	10	50	Pile rig machine 2 nos, Concrete truck 2, Dump truck 2	40	35
Week 5	10	50	Pile rig machine 2 nos, Concrete truck 2, Dump truck 2	40	35
Week 6	10	39	Pile rig machine 2 nos, Concrete truck 2, Dump truck 2	32	35
Week 7	10	50	Pile rig machine 2 nos, Concrete truck 2, Dump truck 2	40	35
Week 8	10	50	Pile rig machine 2 nos, Backhoe 3, Concrete truck 2, Dump truck 3	40	35
Week 9	10	50	Pile rig machine 2 nos, Backhoe 3, Concrete truck 2, Dump truck 3	40	35
TOTAL NO OF PILES		439		352	

Table 30 : Weekly schedule

5.1.5 Analysis of pile rigging machines

S. N. O	PILE RIG MACHINE BRAND	USAGE	MODEL	COST UNIT (Approx)	MAXIMUM DEPTH (m)	MAXIMUM DIAMETER (mm)	ENGINE POWER (HP/ rpm)	OVERALL HEIGHT (m)	OPERATING WEIGHT (t)	TORQUE RANGE (kN.m)	MAIN WINCH PULLING FORCE (kN)	TRANSPORT WIDTH (mm)	TRANSPORT HEIGHT (mm)
1	SANY	Auger/Bucket drilling, casing oscillator, CFA and Diaphragm walls	SR155	68,00,000	44	1500	200/2100	18.5	48	155	160	3140	3265
			SR235	2,25,00,000	54	2000	344/2000	22.8	81	235	235	3540	3573
2	MAIT	Auger/Bucket drilling, casing oscillator, CFA and Diaphragm walls	HR180	1,20,00,000	60	1600	335/2100	-	60	233	100 - 230	3000	3000
			HR 200	2,27,62,000	82	3600	443/2100	-	73	260	240-260	4300	3600
3	ACE	Auger/Bucket drilling, casing oscillator, CFA	GA175	2,10,00,000	56	1500	220/2000	18.5	50.5	170	160	3980	4630
4	SCHWING Stecker	Bucket drilling	XR 150DII	70,00,000	56	1500	200/2100	19	49	150	160	2960	3140
5	CASA GRAND	Auger/Bucket drilling, casing oscillator, CFA and Diaphragm walls	B170	1,84,00,000	50	2000	260/2000	19.3	51	155	180	2500	3300
			B300	98,00,000	89	4200	535/2100	26.5	95	220	270	3000	3755
7	HITACHI	Hammer, Auger, Slant pile driving	SP110 K560	65,00,000	43	1200	177/2100	33	10	150	-	4670	3253
8	LIEBHERR	Auger/Hydraulic hammer, vibratory/rotary drilling	LRB 16	1,92,00,000	53	3250	533/1700	15.2	43.5	120	-	3050	3400
9	SOILMEC	Pile, CFA, Auger, DP	SR 40	1,25,00,000	69.7	3000	269/2000	17.8	40	185	165	2530	3394

Table 31 : Comparison of pile rigging machines

5.2 ANALYSIS OF EXCAVATOR

5.2.1 Excavation details of the project

EXCAVATOR		
Number of Excavator used	3	
Duration of work estimated	12 days	
Excavation depth	1 to 3m	
Type of soil	Clay, Stiff clay and sand	
Excavation per day	180 - 200 cu.m	
Bucket capacity (assumed)	1.2	
Time taken for 1 bucket excavation		
Digging time	6	sec
Scooping time	8	sec
Swinging time	10	sec
Loading	5	sec
Moving and positioning	5	sec
Total time	0.56	Min
Working hrs of excavator	8	hrs
Effective work of excavator	75%	
Effective work of excavator in min	36000%	Min
Production per day	190	cu.m

Table 32 : Excavator analysis

DUMPER		
Capacity of Dumper	5.00	Cu.m
Dumper Avg. Speed (Km/h)	30	km/hr
Leading distance(Two way travel)	1.00	km
Loading Time	10	min
Unloading Time	2	min
Travel Time	2	min
Position Time	2	min
Total Time/Dumper	16	min
Working hours for Dumper	8	hrs
Effective work of Dumper	75%	
Effective work of Dumper in "min"	36000%	min
No of trips required/Dumper	23	Nos
Productivity Per day per Dumper	115	Cu.m/day
Total dumper required/day (Practically)	3	Nos

Table 33 : Dumper analysis.

5.2.2 Equipment economics

Provide the right equipment at the right time and place, so the work can be accomplished at the lowest cost.

- Basis of costing
- Hourly
- Daily
- Weekly

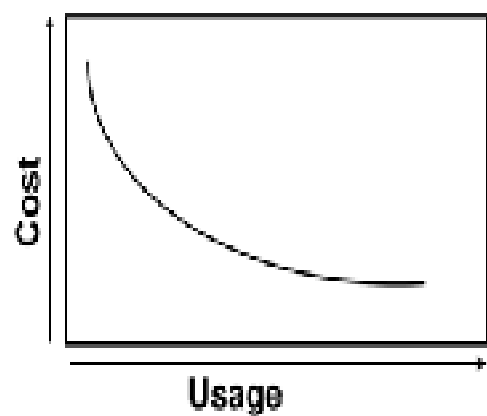


Figure 87 : Ownership cost



Figure 88 : New equipment

Figure 89 : 4 years later Rs. 90,00,000

- Miles and Fuel consumption

Rs.1,90,00,000

Ownership expense = 1,00,00,000. Include the cost of all attachments and delivery charges in initial machine cost.

Operating cost

Consumables - fuel, oil, grease & filters (FOG)

Repair

Maintenance

Tires or tracks

High wear items - cutting edges, teeth.

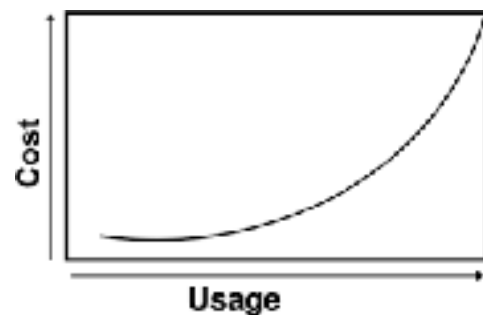


Figure 90 : Operating cost.

Cost of equipment

- Construction equipment can be purchased or rented.
- Purchased when used extensively Rented when used sparingly.
- When equipment is purchased, it is necessary to determine:
 - (a)ownership cost
 - (b) operating cost.
- Ownership costs include:
 - Initial cost,
 - Financing (investment) costs,

- Depreciation costs
- Taxes and insurance costs.
- The operating costs include:
 - Maintenance and repair costs, Storage costs
 - Fuel and lubrication costs.

Fuel costs

- Construction equipment require fuel for operating
- The fuel may be gasoline or diesel.
- The equipment is seldom used for **60 minutes per hour**.
- Most machines normally operate for **45 minutes per hour**.
- Moreover, the machine is not operated at its full capacity all the time.
- It may work at full power during heavy load conditions.
- At normal temperature and pressure;
 - Gasoline engine will consume approximately 0.06 gallons of fuel for each hp developed.
 - Diesel engine will consume approximately 0.04 gallons of fuel for each hp developed.

Calculation

$$\text{HOURLY FUEL CONSUMPTION} = 0.15 \times \text{RATED HP} \times \text{LOAD FACTOR}$$

$$\text{LOAD FACTOR} = \text{LOAD IN EXCAVATOR} / \text{LOAD CAPACITY} = 0.50$$

Fuel Consumption per hour = $0.15 \times 672 \times 0.50 = 50$ litres /hour

Fuel cost = Fuel rate X Fuel consumption per hour = $65 \times 50 = \text{Rs. } 3250$.

Labour cost

Operator cost = Rs. 800 per day & Rs. 100 per hour. (approx).

Maintenance cost

Equipment maintenance cost per month = Rs. 5600

Average maintenance cost per hour = Rs. 35

Road tax = Rs. 10,000 for 13,000 hours = 0.75 per hour (aproxy)

Insurance = 9.8% of value so that per year = 9800 / year

Insurance per hour = $9800 / (120 \times 12) = 6.80$ per hour.

Equipment operating cost

Equipment **owning cost** per hour = $6.80 + 0.75 + 35 + 100 = 142.5$ /hour

Equipment **operating cost** per hour = Fuel cost per hour + operator cost per hour
= $390 + 100 = 490$.

EQUIPMENT COST = OWNING COST + OPERATING COST
--

Equipment cost = $490 + 142.5 = 632.50$

Contractor margin = 10% of equipment owning cost = 63.2

So, the contractor can rent out excavator = Rs.700 (per hour)

Working hours = $8\text{hrs} \times 14\text{days} = 112$ hours.

5.2.3 Analysis of excavator

Number of Excavator planned to be employed in the site was 2 for the digging work after the completion of the pile cap work.

Selection criteria for Excavator

- Based on the soil - If the soil to be excavated is loose and marshy nulk excavation is involved.

- The appropriate model of equipment based on different characteristics such as payload of bucket and speed required.
- The number of equipment needed for the project to carry out the given quantity.
- The number of associated equipment required to support the main equipment.

Delay factors contributed by equipment

- Equipment breakdown and their idle time and lack of tools in market.
- Shortage of heavy equipment when necessary.
- Lack of skilled operator leading to low efficiency & productivity.
- Wrong kind of equipment selection and lack of advanced equipment.
- Complication in transporting to the site.

NATURE OF SOIL	DIGGING EFFORT	SOIL EFFORT
Loam, Sand gravel	Easy digging	1.0
Common earth	Medium digging	0.85
Stiff clay, Soft rock	Hard digging	0.67

Table 34 : Digging effort.

ANGLE OF SWING	15	40	75	90	120	150	180
FACTOR VALUE	1.20	1.16	1.07	1.0	0.83	0.79	0.71

Table 35 : Angle of swing bucket.

NATURE OF SOIL	BANK VOLUME	LOOSE VOLUME	COMPACTED VOLUME
Common Earth	1.00	1.25	0.90
Sand	1.00	1.12	0.95
Clay	1.00	1.27	0.90
Rock blasted	1.00	1.50	1.30

Table 36 : Nature of soil factor.

5.2.4 Daily inspection checklist

- Check to make sure there is enough coolant and Check engine oil and hydraulic oil levels
- Check for leaks in compartments and under machine
- Check track (see Undercarriage below for more detailed information)
- Check coolers to make sure they are free of debris and Drain water from fuel/water separator.
- Check dust ejector from air filter
- Make sure teeth are present on bucket and they are in good condition
- Check wear plates on bucket and Grease all pins and bushings daily
- Check controls and seat belt in cab and make sure they are operating properly
- Turn on machine and check controls, windshield wipers, seatbelt and air conditioning system
- Remove trash and debris from cab.

5.2.5 Maintenance process

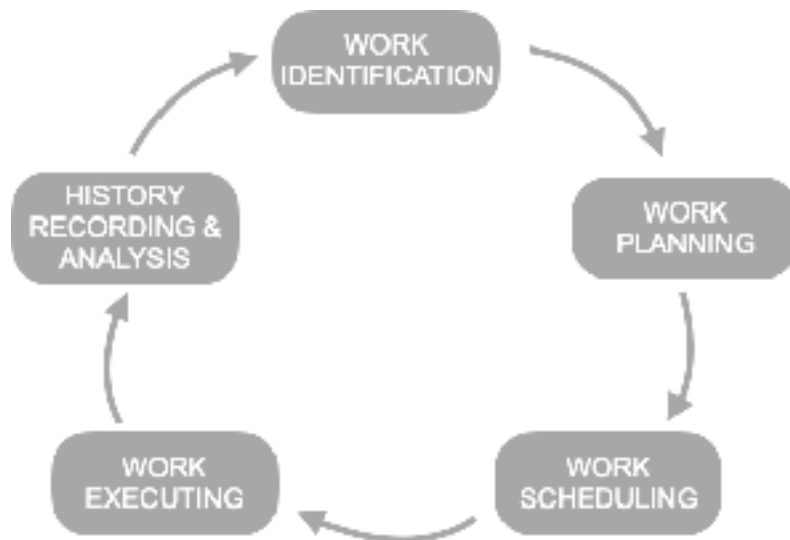
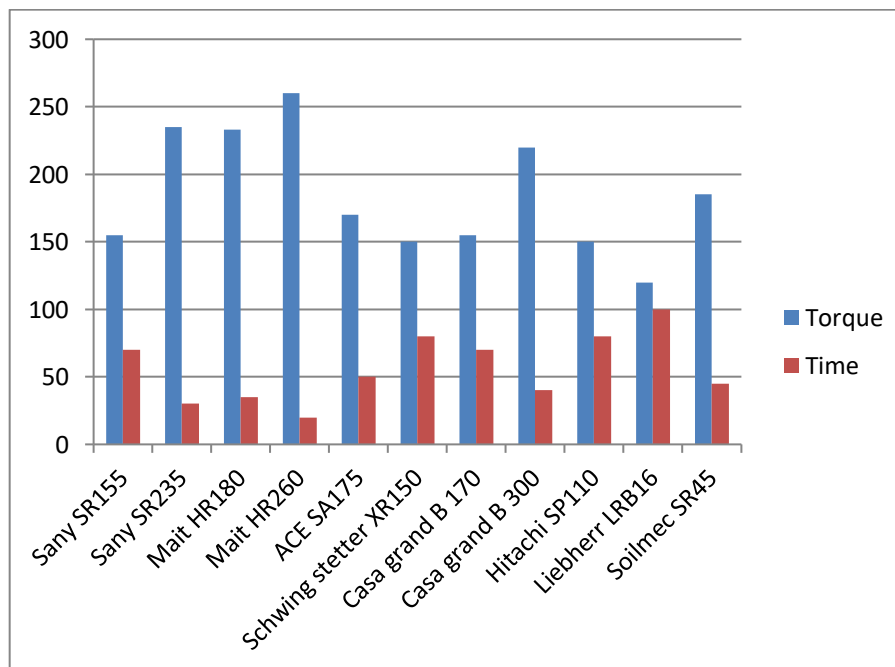


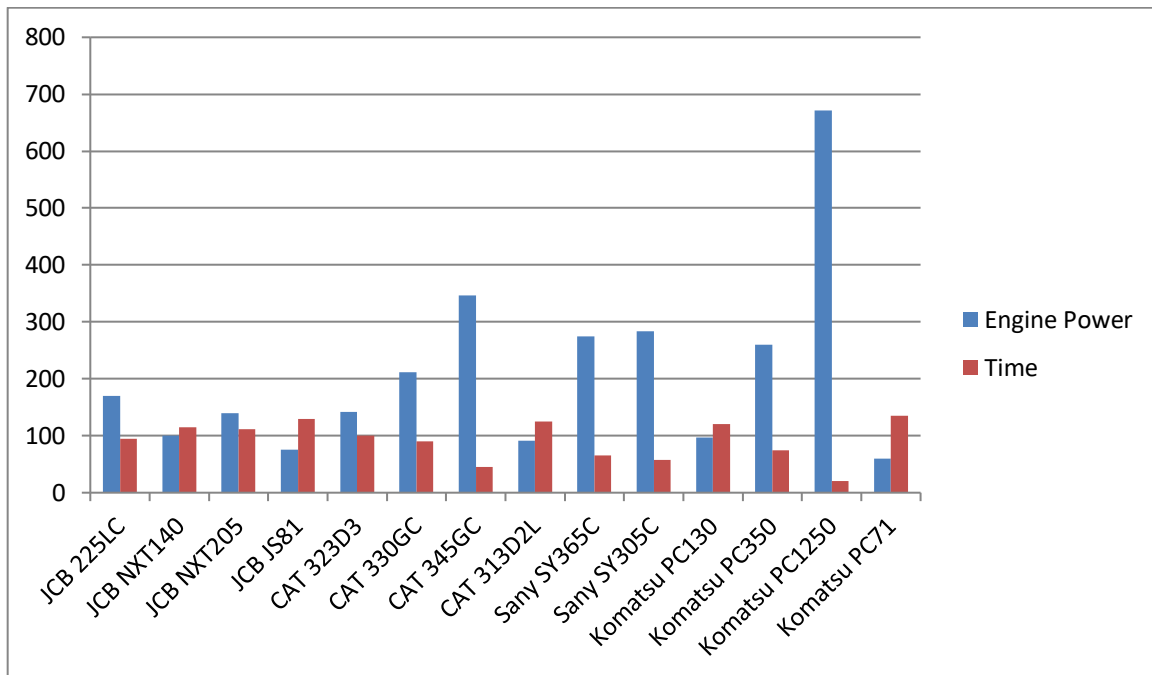
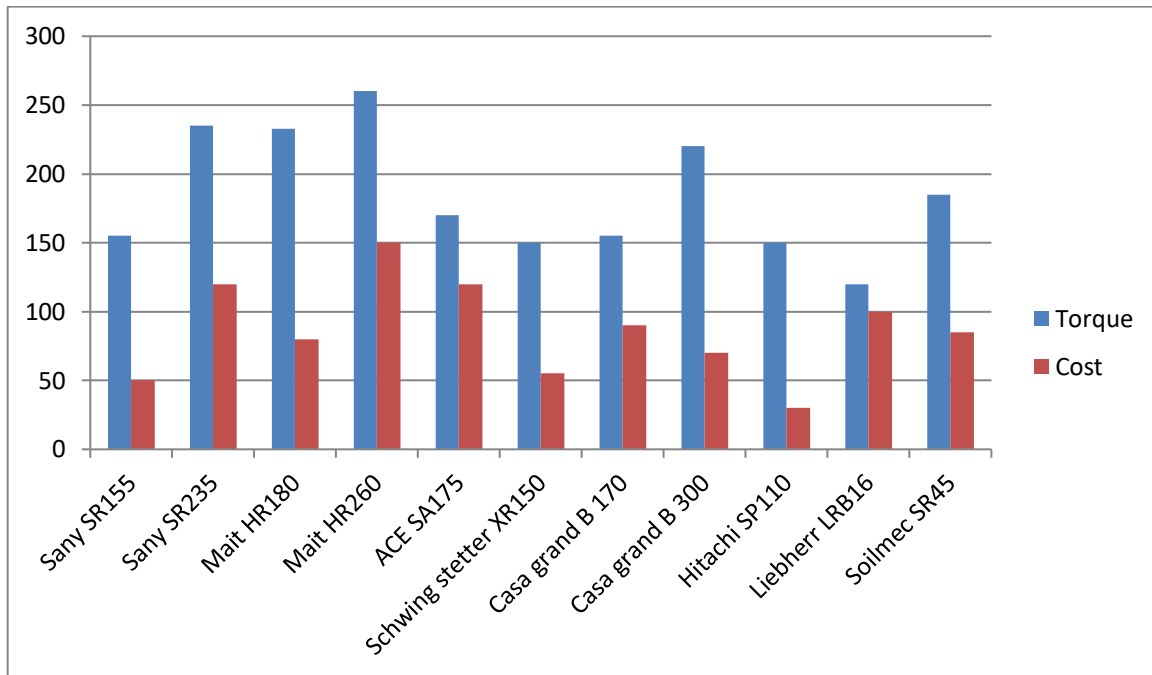
Figure 90 : Flowchart for the maintenance process.

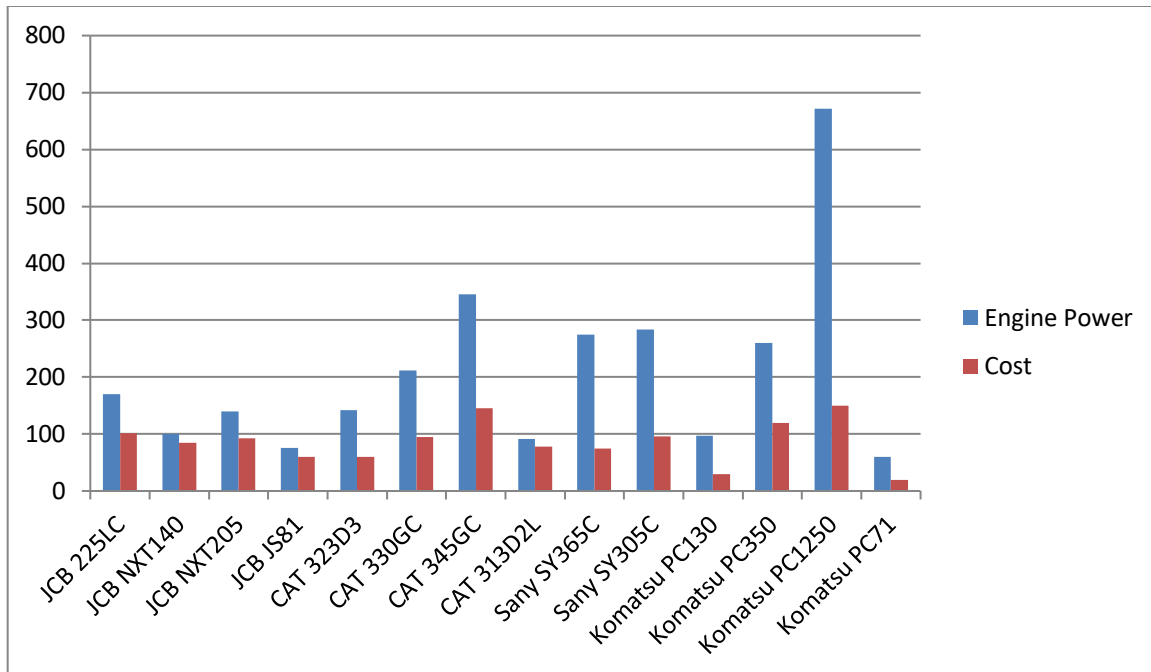
BRAND	MODEL	ENGINE POWER (HP)	BUCKET CAPACITY Cum	MAXIMUM LOAD (Kgs)	COST (Rs) (approx)	FUEL TANK (Litres)	HYDRAULIC TANK (L)
JCB	225LC	170	0.9 - 1.2	21,750	59,00,000	343	120
	NXT 140	100	0.63 - 0.72	14,320	46,00,000	253	73
	NXT 205	140	0.80 - 1.02	21,250	53,00,000	343	120
	JSB1	76	0.24 - 0.32	8050	30,00,000	164	55
CAT	323D3	142	1.20	22,800	30,00,000	410	139
	330GC	212	1.80	28,400	55,00,000	474	147
	345GC	346	3.00	42,200	60,00,000	600	196
SANY	313D2L	91	0.76	13,300	44,00,000	250	72
	SY365C	275	1.5	36,700	40,00,000	540	360
	SY305C LC	284	1.3 - 1.7	35,000	56,00,000	540	300
KOMATSU	PC130-11	97	0.34 - 0.78	13,000	13,00,000	250	69
	PC350 LC	280	1.4 - 2.3	35,200	90,00,000	605	188
	PC1250-8R	672	3.4 - 5.2	1,10,900	20,00,000	1360	670
	PC71	60	0.09 - 0.35	7050	11,00,000	130	57

Table 37 : Comparison study of Excavator.

5.3 Analysis on efficiency of the piling rig and excavator







The analysis is done for both selected piling rig and excavators based on the two important criteria which is time and cost. The torque is considered for the piling rig machine which is vital in efficiency increase. Likewise, the horse power (HP) is considered for the excavators which is vital for the efficient performance.

In the piling rig graph, MAIT HR 260 and SANY SR 235 consumes less time to complete the work, meanwhile their cost is high. In the excavator analysis graph, Komatsu PC 1250 and CAT 345 GC consumes less time since it has high horse power but their cost is high compared to other equipments. So equipments are chosen based on these to criteria.

5.4 Conclusion

- Because of outstanding advantages, piles are most widely applied for the construction purposes. Their principal aim is found in transmitting outer loads onto layers deposited at greater depths or improving the mechanical properties of soil. By providing incredible strength it brings possibility to build even in the soil with less bearing capacity.
- A number of companies produce specialist geotechnical equipment all over the world. Among them few are very experienced companies which have existed on the market for years and who have systematically improved their products as years pass by. Sany, Mait, Casagrande and Soilmec dominate in the production of pile machines. In the sameway, Komatsu, CAT, and JCB tops in the excavator production.
- The most suitable pile machine fit for performing large-diameter piles at great depth should be selected on the basis of the multi-criteria optimization. Knowing the scope of

work, one can establish the weight of particular parameters of pile machines on the basis of particular parameters of the machines, assess them and select the right one.

5.5 Recommendation

- The recommendation is based on the certain criterias such as time to drill the bore hole, the productivity range, soil type, capacity to drill efficiently and time consumed to finish the work. In the study of a pile machine for large diameter and long piles, the selection was based on the multi-criteria optimization. My recommendation based on my study is as follows.
- The cost is also the main factor to be considered, the new equipment with higher torque and horse power is costly and if its exceeding the budget its better to go for the medium range torque and horse power piling rig and excavator equipment. But in that case time can be the constraints, it consumes more time to finish up the targeted project foundation.
- The analysis of the results revealed that the best pile machine observed is **HR260 of MAIT**. It had the highest CCS pull up/down force and highest torque. Another machine is **SR235 of SANY** and has slightly lower parameters than MAIT HR 260 piling rig machine.

The excavator is employed in the site for scooping and dumping the mud exerted from the piling work. Based on the analysis result the best excavator found to be employed to obtain more efficiency is **PC 1250 8R of Komatsu** and another machine identified is **345GC of CAT** which has the highest engine power thus provides maximum efficiency to finish work sooner.