Bored Piling in Bridge Construction: An experience of Kathmandu-Terai Fast Track (Expressway) Road Project

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Abstract

This paper describes the pile construction works in the Kathmandu-Terai Fast Track (Expressway) road project in Nepal. Bored pile works in the project included three methods: manual hole drilling, rotary drilling, and percussion hammer, depending on the geological condition, availability of the working area, soil types, and availability of the equipment. On the one hand, the manual hole excavation method is a simple technology that requires less working area and is very suitable in steep mountainous areas, which need a smaller working platform. On the other hand, it takes a long time to complete a hole and needs a sufficient diameter of the pile for the working people. The impact drilling method is suitable in silty soil and is the most cost-effective technology for pile boring. However, it is time-consuming compared to the rotary drilling method and not suitable for rocky soil. The rotary drilling method is suitable for every type of soil and the fastest method of pile boring, but it may face different types of problems when special care is not taken regarding equipment and soil properties. The article has compared the productivity of each methodology and the problems faced, such as hole collapse, discontinuity in pile concreting, and upliftment of the rebar. Solutions to these problems are also provided in this article.

Keywords: Bentonite, Bored pile, Manual hole drilling method, Rotary drilling method, Percussion hammer drilling method, Hole collapse

Introduction

Kathmandu-Terai Fast Track Road Project (KTFT) is the first expressway in Nepal, featuring double-lane dual carriageway standards, and comply with the Asian Highway Standards for primary class roads, with minor modifications. The designed expressway consists of a four-lane road with medians in the center. The design speed of the road project is 100 to 120 km/hr. in plain/rolling terai, and, 60 to 80 km/hr. in hill/mountainous terai, the maximum grade is 5%, and the minimum grade is 0.5% within the expressway alignment. The expressway project, spanning 70.977 km, includes 89 bridges with a total length of 12.885 km (as per revised DPR). The construction of the KTFT project is being carried out by the Nepali Army under the Ministry of Defense (KTFT, 2023). The construction area is divided into eleven packages. The KTFT Projects has Rigid-frame bridges, precast I-Girders, continuous prestressed box girders, cantilever prestressed box girders, and an extra dose bridge. All KTFT Project Bridges have a bored concrete pile foundation. The project has a pile depth of up to 76 m and a pile diameter of 1 m, 1.2m, 1.5 m, 1.8m, 2.0m, and 2.5 m.

The project passes through different complicated topographical and geological conditions including steep slope mountains to flat terai and having silty soil, mudstone, sand stone, and quartzite. Depending upon topography and soil types, the hole excavation in the project has been done with three different methods namely: Manual Hole Excavation, Drilling with a Rotary Machine, and Drilling with a Percussion Hammer.

Manual Hole Excavation (MHE) method

Manual hole excavation (MHE) mainly relies on manual excavation of the pile body in layers, and reinforced concrete arm guards are constructed

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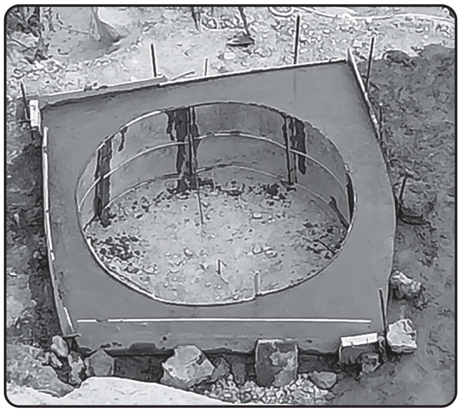

Figure 1: Orifice Guard Construction

Figure 2: Mucking in manual hole excavation

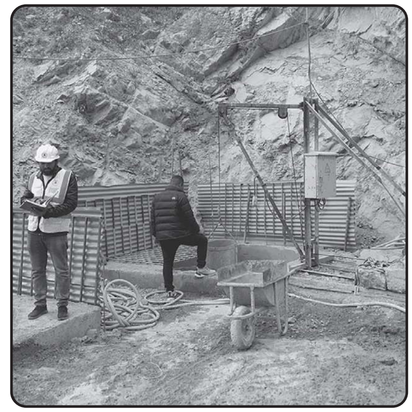

Figure 3: Mucking and Lifting Tools

Source: Field Survey

after each layer of excavation up to the design hole bottom elevation. The pictures during manual hole excavation of the piles are given below in Figure 1, Figure 2, and Figure 3.

The construction steps for Manual Hole Excavation of the pile are as follows.

1. Construction preparation and site leveling.
2. Survey and setting out.
3. Orifice Guard Construction.
4. Excavation of the first layer of the soil.
5. Installation of rebar and formwork for foundation pit arm protection.
6. Pouring arm protection concrete.
7. Excavation of the new layer of the soil under the protection concrete.
8. Measurement of pile hole size and Plane position.
9. Repeat the step until the hole excavation is as per the design.

Different excavation methods were adopted for manual hole-digging pile excavation according to different soil and lithology. The project is located in a rocky area. Picks were used for excavation at the top of the hole to excavate boulder-mixed soil and fragmented rocks. The shallow hole blasting method was used for excavation in hard rock. The blast hole depth was prepared to be 0.5m in hard rock stratum and 0.8m in soft rock stratum, with the dosage being less than one-third of the blast hole depth. The soil was loaded into a bucket, lifted with a simple electric lifting frame, and then transported to the spoil ground with a trolley. Mechanical ventilation was adopted in the process of hole excavation. Ventilation with a ventilator for 15 minutes after blasting construction was given and the air in the hole is detected by an air detector. If the oxygen level is normal, the operators go down to the hole for construction. When the construction operators was working at the bottom of the hole, the air content at the bottom of the hole is checked in every two hours.

Drilling With Rotary Machine

Drilling with Rotary machine is the fastest method of the hole excavation of the pile and suitable for each type of soil. The construction steps in this pile boring method are given below.

1. Preparation of the platform
2. Surveying and setting out
3. Casing Installation
4. Drilling Machine in place
5. Drilling
6. Measurement of pile hole size and plane position
7. Cleaning the hole

Different type of drill bits equipment is used in drilling by rotary drilling rig machine such as Rock Augur, Rock Bucket, Core Barrel, Roller Bit Tools depending upon soil types. Larisch (2015) proposed different types of drilling as per the rock strength as shown in the Figure 4.

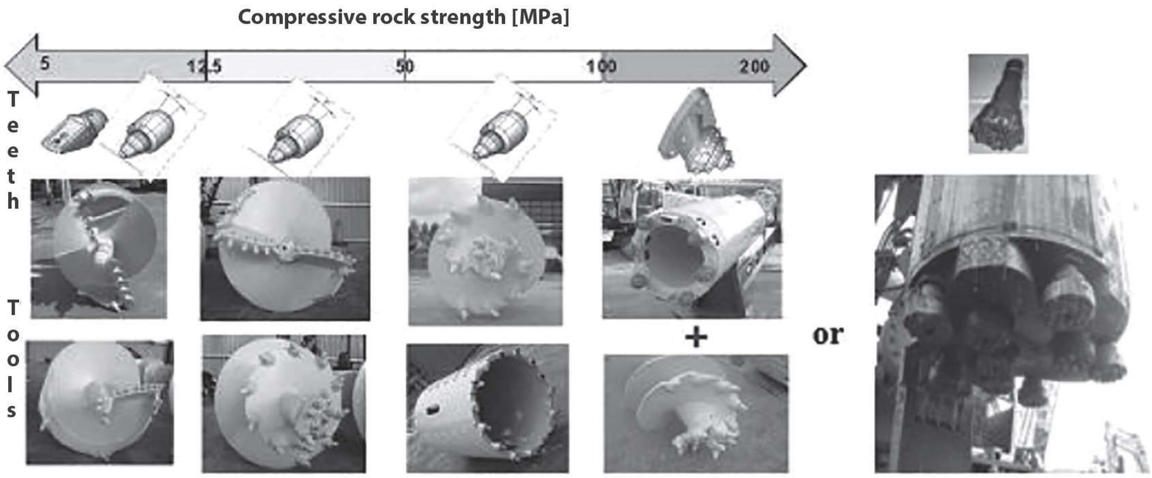

Figure 4: Different types of Drilling bits

The construction process is given below in Figure 5, Figure 6 and Figure 7.

Figure 5: drilling machine in place

Figure 6: Survey and Setting Out

Figure 7: Dry hole boring

Source: Field Survey

Drilling with Percussion Hammer (Impact Drilling Method)

The operator lifts the hammer with the impact device or winch, repeatedly hits on top and down, splits the earth and rock, and partially squeezes them into the hole wall during percussion drilling. Through the mud suspension drilling slag, the hammer can impact the new soil layer at the bottom of the hole every time. To clean the sludge, the mud pump is employed. The mud plays the role of suspending the drilling slags and protecting the hole- wall. The construction steps in this method are as follows.

a. Construction preparation and site levelling
b. Resurvey and setting out
c. Installation of percussion drilling machine
d. Percussion drilling
e. Checking the hole
f. Hole Cleaning

The site photos during drilling with percussion hammer are given below in the Figure 8, 9, & 10.

Application of Bentonite/Mud

During rotary drilling, bentonite was utilized to stabilize the sides of boreholes. The drilling team used suitable mud to stabilize the hole during impact drilling. The thixotropic property of bentonite/ mud suspension permits the material to have the consistency of a fluid during excavation. When undisturbed, it forms a jelly, which, when agitated, becomes fluid again. With granular soil, bentonite suspensions penetrate the sides under positive

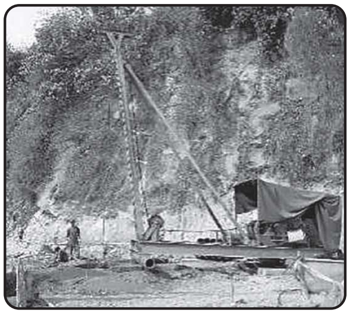

Figure 8: Impact Boring

Figure 9: Several Percussion machine for boring

Figure 10: Mud tank and Impact boring

Source: Field Survey

pressure and, after a while, form a jelly. During pile construction, the properties of the bentonite, such as density, viscosity, pH values, and sand content, were checked. Construction work continued only when the test parameters of the bentonite/mud were within permissible limits.

Manufacture and installation of Steel Reinforcement Cage

Manufacture of the cage was done using the template in the fabrication yards. At every 2m spacing, master rings were fixed. After that, the main bar was fixed outside the master ring by binding wire and welding. Then, helical binding was done with binding wire around the main bar and master rings. The two-rebar cage was joined vertically by an approved coupler or overlapping. A lifting holder was fabricated at the top of the cage so to lift the cage for installation. The lifting holders were fabricated with 28mm bar of 300×300mm size. They were welded securely so that the lifting device could easily lift and install the cage. The shackle was fixed on the lifting hook of a 25mm wire rope and lifted by a crane with a capacity of 25/40 tons. Suspension bars were set at the top of the steel cage according to the elevation of the bore top, and then the lifting point was fastened. Care was taken for the steel cage not to be deformed during the lifting process so that the steel cage became a natural lead-straight state after lifting.

Concrete pouring

The design strength grade of all the pile concrete was M40. Concrete was poured into a lined hole using the manual hole excavation method via a catheter pipe, with compaction achieved using a vibrator. The concrete pouring height of 1.5 m was maintained in this case. Concrete was poured underwater using the tremie method. The slump value, temperature, and air content were measured, and the concrete was poured only if the parameters were within the limit. Concrete shall not be segregated at any depth. During concrete pouring, the previously laid bentonite mixed water is removed as the concrete rises. Concrete was poured at an average rate of 20m3 per hour. Control the arrangement of the plug to ensure front sealing and smooth plugging. The top of the protective cylinder takes precautions to prevent concrete and other sundries from falling from the hole and affecting the quality of the bottom seal. During the pouring process, control the speed, ensure continuity, and control the buried depth of the catheter by concrete about 2-6m. To ensure the concrete quality of the pile head, an over-pouring of 0.5 to 1 m is maintained. Concrete shall be poured above the specified cut-off level of the pile.

A total of 1,596 nos. the concrete pile construction was completed in this project with different pile boring methods from September 2022, to April 2024 as summarized below in Table 1.

During construction through different types of soil, the project encountered challenges such as hole collapse, bucket breakage at the bottom of the hole, upliftment of the cage, etc. This article focuses on comparing three methods of hole formation and addressing the challenges encountered during pile construction in the project.

Table 1: Pile Construction with different Method in KTFT

Pile. dia., m	1.0	1.2	1.5	1.8	2.0	2.5	Total, Nos.
Manual hole Excavation Method	0	0	14	0	49	46	109
Percussion Hammer Drilling Method	0	0	120	0	0	0	120
Rotary Drilling Method	216	717	416	18	0	0	1367

Source: Field Survey

Literature on Pile Hole Boring Method and Their Selection

Different pile boring method are used for pile hole drilling for the bored pile construction. Different pile boring methods have different benefit and disadvantages. The cost of pile and its construction method depends upon the pile selection methodology listed out three main factors that govern the pile selection which are the site condition, types of pile and pile driving equipment(Aqilah & Rahim, 2008). Bhutale & Ladhe (2020) explained Direct Mud Circulation Method with tyred mounted rig machine and hydraulic rig machine, Reverse Circulation Mud methods and dry boring and recommended to use hydraulic rig machine for better efficiency, speedy construction and quality control. Zhou et al. (2021) studied bearing capacity of different hole forming method piles namely manual digging piles (MDP), rotary drilling piles (RDP) and impact drilling pile (IDP) in Wique-Dinbian Expressway. The construction process in these three methods is summarized below in the figure 11.

The authors concluded that pile foundation should be constructed with Impact drilling method and post-grouting in the loess area to achieve the large bearing capacity. Wu et al. (2020) studied the technology of rotary excavation and hole formation in areas with thick high groundwater and high ground water

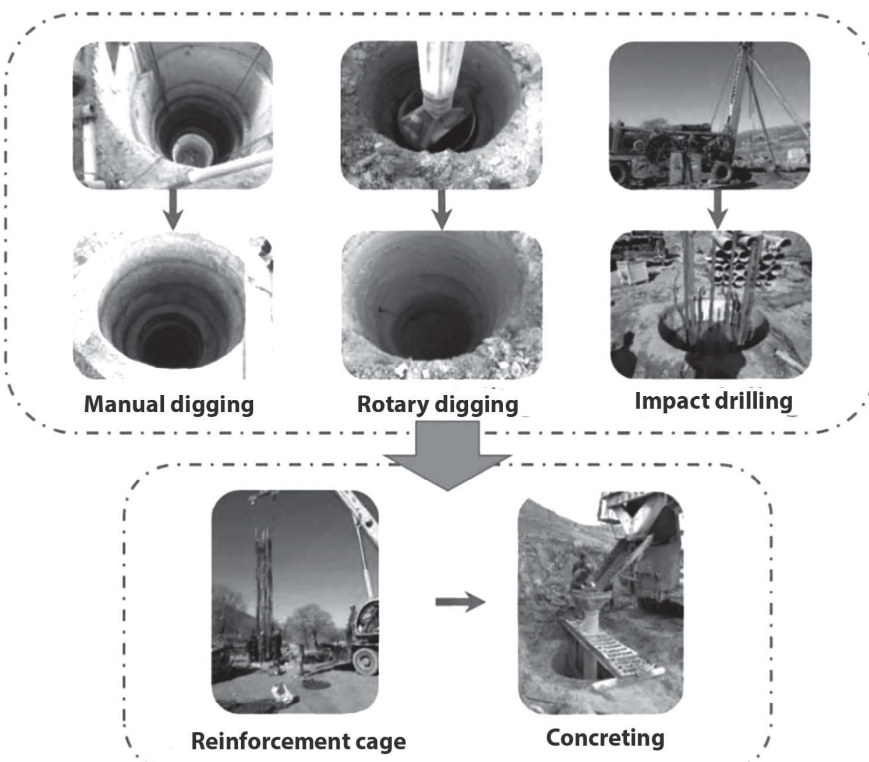

Figure 11: Construction Process of bored pile

and recommended the drilling speed should be controlled at 0.3~0.5m/min in sand layer and coarse round gravel soil layer, and 0.5~0.8m/min in silt and silty clay soil layers in order to prevent the problems of hole collapse and deviation. The pile hole wall is prone to instability in the unstable soil layers, and the stability of hole wall could be improved by increasing the gravity of mud slurry (Long et al., 2023). The bearings of behaviors of bored pile are affected by the construction technology (Xing et al., 2019). So, it should be considered in mind while selecting the pile construction technology. Construction of the bored pile under coarse soil whether or with drilling fluid encounters different uncertainties(Mata et al., 2021) and the contractor should be prepared for the uncertainties. Many problems have appeared in the construction of bored piles in any methods, such as casing sinking, unstable hole formation, concrete segregation, broken piles, and many more (Nan et al., 2023). So, quality control must be performed in every stage of the construction such hole formation, rebar cage fabrication and installation and concreting. Polymer can be used as a support fluid as it has less cost, less environment effect and the pile bearing capacity is higher as compared to bentonite(Hasan & Al-Saidi, 2024). Still, bentonite is preferred as study of the polymer is very few.

Productivity of the Different Hole Drilling Method

So, basically, this study's data is from working on the site from Sep 2022 to Apr 2024 on the KTFT projects. Manual hole excavation method, rotary drilling methods, and percussion hammer method were applied in the pile boring and their productivity is presented below.

Productivity of the Manual Hole Excavation Methods

Manual hole digging is generally done in a hilly rocky area or having a small working area where equipment cannot be mobilized. A group of three-four labors are mobilized in this method. One person will lift the muck and supply rebar from the top. The other three people collect the muck and fill the bucket. M20 concrete was prepared by manual mixing for concreting the orifice. Generally, it takes 12 to 14 hours to complete the excavation and lining of 1 m. depth of pile hole having a diameter of 1.5m to 2.5m. One cycle of the pile hole construction at a one-meter depth is completed within a day. The productivity depends upon the skill of the labors and the depth of the pile hole. In KTFT hole excavation was done upto 37m. The time required to complete 1 m. depth of the pile hole is given below in the Table 2.

Table 2: Average time required for 1m depth of pile.

S. N	Activities	Required Time, hours
1	Drilling and Blasting	4
2	Mucking	4
3	Rebar and form work Installation	2
4	Concreting	2

Source: Field Survey

Productivity of the Rotary drilling machine

Rotary Drilling machine worked either morning or night to manage the concreting time on day time. Pile Boring upto 76m depth was done by this method. Average productivity of Sany SR215 rotary machine silty stone and sandstone for 1.2m dia. pile 4.18 m/hour. Details of the productivity is given in Table 3.

Average Productivity of the Sany SR285 in silty sand and mudstone with and pile dia 1.5 m to 1.8 m rotary machine was 5.99 m/hour in siltstone and mudstone layer., while the rotary machine work continuously. While the rotary works at night time and the operator takes rest at least 4-5 hours the productivity of the machine is 1.32 m/hour. The details are given in Table 4.

Table 3: Productivity of Sany SR 215 Rotary Drilling Machine

S.No	Pile Id:	Soil Type	Required Duration	Pile depth	Boring depth m per hour
1	A1-P6	Siltysand, siltstone	5.50	17.77	3.23
2	A1-P2	Siltysand, siltstone	4.50	18.11	4.02
3	A1-P3	Siltysand, siltstone	4.50	17.73	3.94
4	A1-P8	Siltysand, siltstone	3.50	17.67	5.05
5	A1-P4	Siltysand, siltstone	3.00	17.37	5.79
6	A1-P7	Siltysand, siltstone	4.50	17.71	3.94
7	A1-P1	Siltysand, siltstone	5.33	17.57	3.30
Average Boring Depth (m/hour)				4.18	

Source: Field Survey

Table 4: Productivity of Sany SR285 pile boring machine

S.No	Pile No.	Soil Type, layer (m)	Duration, hour	Boring depth, m	m/hour
1	P2-1	Siltstone, mudstone	5.5	34.139	6.21
2	P4-1	siltysand, siltstone	5.75	33.157	5.77
		Average (Daytime)			5.99
3	P2-1	sandstone, siltstone	15:00	34.143	1.45
4	P2-2	Sandstone, siltstone	15:00	29.944	1.27
5	P1-1	Sandstone, siltstone	12:30	30.935	1.32
6	A1-1	Siltstone, mudstone	12:25	27.161	1.15
7	A1-2	Siltstone, mudstone	8:30	27.540	1.18
8	P4-2	Silt/sand, siltstone	8:15	33.146	1.42
9	P5-2	siltstone, sandstone	7:00	28.972	1.24
10	A1-3	Siltstone, mudstone	9:20	36.398	1.56
11	A1-4	Siltstone, mudstone	9:20	36.43	1.56
12	A2-2	siltstone, sandstone	9:20	25.60	1.09
		Average (Night time)			1.32
		Day and Night average			3.66

Source: Field Survey

The boring time in the rocky takes a longer time. Per day production of Sany SR285 I2.95 m perday. An average 4.09 days was required to bore a pile with 1.5m dia.. The details are given below in the Table 5.

Table 5: Productivity of Snay SR285 in hard rock

Foundation Nos	Total Nos. of pile	Total days required	Days per Nos. of pile	Pile depth of one pile, m	Per day boring rate per m
F1	16	49	3.06	45	14.69
F2	16	77	4.81	50	10.39
F3	16	97	6.06	50	8.25
F4	16	39	2.44	45	18.46
Average		**4.09**		**12.95**	

Source: Field Survey

3.3. Productivity of the percussion drilling machine

Percussion drilling machine was run automatically for 24 hours. Some Percussion machine was run by electricity and other one was by diesel. Average boring rate in silty sand and mudstone soil was only 3.27 m per day. Up to 50 m depth of pile boring was done by this method in KTFT. The details are given below in the Table 6.

Issues encountered during the Pile Hole Boring and Solution

Case 1 Pile concreting incomplete due to trapping the tremie pipe inside the hole.

The contractor was concreting in a pile with a length of 54 m. The bottom tremie pipe got stuck in a steel cage when 3 m was remaining in concrete and the concrete wasn't going into the pile. After this incident, the on-site personnel took too long to process, which resulted in a prolonged concrete pouring time and the top concrete began to gain initial setting. The concreting work was stopped without completing the remaining 3 m height. After this incident, the onsite personnel were instructed to ensure the tremie pipe was always at the center and control the arrival time of the concrete tanker to avoid excessive waiting time and concrete pouring during daytime as far as possible. The earthmoving equipment shall be handled carefully so that other pile areas shall not be disturbed. The construction of the remaining pile was done by the excavation up to the level of the suitable concrete level. The poor concrete was chipped and epoxy was used to bond new and old concrete and concreting was done with formwork and using vibrator. After sufficient curing and backfilling was done by the same excavated materials with compaction of layer by layer.

The same case happened when the concreting was completed 20m only and remained depth is 34 m. The 20 m pile was broken with percussion hammer in a period of a month and the concreting was re done from the bottom.

Case 2 Hole Collapse

The pile depth was 45 m according to the design drawing. The depth required to bore from the Casing top-level/ working level was 48.806 m. The boring depth was checked by using a measuring chain which was found 49.5m. After cleaning the drilling hole bottom, the rebar cage was started to be installed. After completion of the rebar cage installation, the tremie pipe was lowered. According to the bored depth, the tremie pipe length would be 49m. While lowering the tremie pipe, it touched the bottom level of the bored hole before the required depth. The hole depth was remeasured and was found 47.1m. So, it was predicted, that there might have been collapse of the borehole wall inside during rebar cage or tremie pipe installation. The total depth of collapse sediment was found (49.5-47.1) = 2.4m. The concrete pouring was stopped for the pile quality, and the rebar cage was pulled out using a 2 nos. 200ton hydraulic jack. The rebar cage was unusable and a new rebar cage was installed after reboring and cleaning the hole.

Case 3 Breakup and fall down of the drilling bucket

The design pile depth of a bored pile was 45m. The required depth to bore from the Casing top-level/ working level was 50.845m. While the hole drilling depth was completed at about 43m, the rig machine drilling bucket broke up and fell in to the pile hole,

Table 6: Daily Pile records of Percussion drilling machine

S. No	Pile No.	Soil Type, layer (m)	Duration, days	Boring depth, m	m/day	m/ hour
1	1	Silty sand (4.5), mudstone (9.0),	9	21.9	2.43	0.10
2	3	Sandstone (4.5), mudstone (7.5m).	10	37.5	3.75	0.16
3	7	Sandstone (4.5), mudstone (4.5) and siltstone (10)	10	36.2	3.62	0.15
Average Output				**31.87**	**3.27**	**0.14**

Source: Field Survey

after that the contractor tried to take the bucket out using the hook many times but failed. The contractor has completed 13 piles, and 3 piles were remaining. For the solution, the design of the pile capacity was rechecked and the length of 2 piles was increased to 5m. The broken drilling bucket was left at the bottom and filled with higher-than-M40 mortar. Two 50 m and one 36 m pile were built.

Case 4. Upliftment of the rebar

The contractor was in the process of pouring concrete into a pile, which had a depth of 37.5 meters. During the concreting process, as a truck containing 10 cubic meters of concrete was poured into the hole, the rebar cage was lifted 2.8 m, leading to the suspension of concrete work. Attempts were made to pull the rebar cage, but these were unsuccessful. The concrete work was resumed after some time for that pile, taking into consideration the revised pile depth of 37.5 – 2.8 = 34.7 meters.

For the solution, the pile capacity of the remaining of the group pile was revised. The length of the remaining 2 piles was increased to 2.5m each (37.5m+2.5m=40m) one pile remains 34.70m. To ensure the pile capacity, the pile capacity based on the adjusted pile length was computed and compared with the original design capacity of the piles. The results are presented in Table 7 below.

Selection of Hole Boring Method for a Pile in KTFT Project

Hole Boring method depends upon topographical, location, availability of the working area, availability of the equipment, speed of the work required, environmental criteria. The selection criteria of the hole boring method are summarized below on the table based on the above-mentioned discussion.

Table 7: Pile capacity calculation

Compare	Pile No.	Pile Length (m)	Qall (one pile) kN	Design Demand (kN)	Nos.	Total (kN)	Pile Capacity (kN)
Original	1 to 4	37.5	11709		4	46836	46,836
Revised	1	34.7	10970	8437	1	10970	47,495
	2	40	12408	10108	1	12408	
	3	40	12408	10056	1	12408	
	4	37.5	11709	8415	1	11709	

Source: Field Survey

Table 8

S. No.	Criteria	Manual Hole Digging (MHD)	Rotary Drilling Method	Impact Drilling Method
1	Steep terai	✓	✕	✕
2	Small Working Area	✓	✕	✕
3	Hard Rock Soil	✓	✓	✕
4	Silty Soil	✓	✓	✓
5	Less Expensive	✕	✕	✓
6	Faster Construction	✕	✓	✕
7	Stable Hole	✓	✕	✕
8	Lees Concrete Consumption	✓	✕	✕
9	Pile dia, <1.5m	✕	✓	✓

Source: Field Survey

Conclusion and Recommendation

The Bored pile can be done in any type of soil and topography. A rotary drilling machine is the best choice for the fastest construction of piles in any type of soil, but numerous problems may occur if experienced personnel are not available and great care is not taken on site. In the mountainous topography, where it is difficult to prepare a working platform and access road, the manual hole excavation method for pile boring is a suitable alternative. Percussion Impact hammer is also an inexpensive method for silty and sandy soil. It needs less working space and is cheaper than compared to the rotary drilling method, but it is time-consuming. Hence, rotary drilling machines are suitable for projects with experienced personnel and suitable working conditions. A manual excavation method is recommended in a small working area and percussion impact hammers for soft soil and budget constraints.

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