IN-SITU-CAST BORED PILES CONSTRUCTION PRACTICES IN SRI LANKA – A REVIEW

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ABSTRACT

Piles are considered as a ground improvement technique as well as a type of deep foundation that can be applied for heavy structural loads dealing with weak soil conditions. Mainly piles are divided into two categories: in-situ-cast bored piles and driven piles. When coming to the in-situ-cast piles, they are having lengthy construction process that should be monitored through a well-organized quality controlling system. Design procedure is depended on the borehole test data, load test data or empirical calculations. But provided designs are not always adopted successfully in the practice due to problems arising related to unknown and unpredictable site conditions experiencing in piling process, during main three steps (1) excavation, (2) cleaning and (3) concreting. This paper will discuss a few of those problems related to the Sri Lankan context and adopted solutions for the same problematic situations in in local industry as well as in other countries. Solutions have been critically analysed for realizing expected skin friction resistance and toe resistance, finally contribute to the ultimate pile bearing capacity. For example, local geotechnical engineers are not reliable on the skin friction developed along the pile walls due to the doubt about efficiency of removing thick membrane made by drilling fluid used during excavation. Further, Capacity evaluation methods such as Dynamic Tests using Pile Dynamic Analyzer (PDA) and Maintained (static) Load Tests which are generally conducted to validate designs, modify specifications and rectify defects are effectively used to assure the quality of the end product. In addition, safety factors used in foundation designs are to be modified based on the experimental investigations and past experiences and could be specific for considered area. However, there are many internal and external factors, for instance, sudden changes in ground condition due to severe wet weather conditions are directly affected to the pile integrity but may not be changed or avoided. They make bored pile construction a real challenge in foundation engineering.

Keywords: bored piles, pile cleaning, bearing capacity, load test, safety factors

Introduction

Fulfilling the necessity of suitable land spaces for development activities in most of the countries is not always satisfied as the distributed nature of weak and weathered soil depositions such as clay and peat. Not only, though excellent soil conditions are available, difficulties of dealing with heavy structural loads are avoided by enhancing soil properties. Experiences in Sri Lankan construction industry are not much varied with current economic expansion requisites. Therefore, many ground improvement techniques are in practice to avoid inconveniences related to low bearing capacity which results full and partial settlements of both building and road structures. Piles are one of the techniques and become essential and important task under most construction projects to transfer heavy loads satisfactorily to the earth.

Simply piles are divided into two categories in more generalized form as, driven piles and bored piles and both are playing major roles in local construction industry. Driven piles are a kind of prefabricated structural elements and called as displacement piles, because while driving through the ground, surrounding soil particles displace creating a shear resistance along the shaft at soil-pile interface. It supports a gradual load transmission to the ground. Non-displacement piles or bored and cast piles are constructed in place by excavating a hole to a desired depth and filling a dense material like concrete, sand or rock particles. According to the definition given by Federal Highway Administration (FHWA) bored and cast piles are "cast-in-place deep foundation element constructed in a drilled hole that is stabilized to allow controlled placement of reinforcement and concrete" (FHWA 2010). This paper will discuss construction practices of bored and cast in-situ piles worldwide that already have been adapted to the local system and further improvements.

Many foundation engineering practices are emphasised on using in-situ cast bored piles for the cost effectiveness of constructions (Mullins & Winters 2014). Because costs for handling and transportation related to prefabricated piles are not incorporated with bored piles while advanced technology implements construction quality. As well as bored piles even with lengths exceeded 30– 40 times of the diameter range, provide excellent support to lateral loads, axial loads and bending movements when comparing driven piles (Mullins et al. 2014). Most important that bored piles have capability of dealing with wide range of subsurface conditions successfully, even with cohesive soils (FHWA 2010).

Pile Designing Criteria

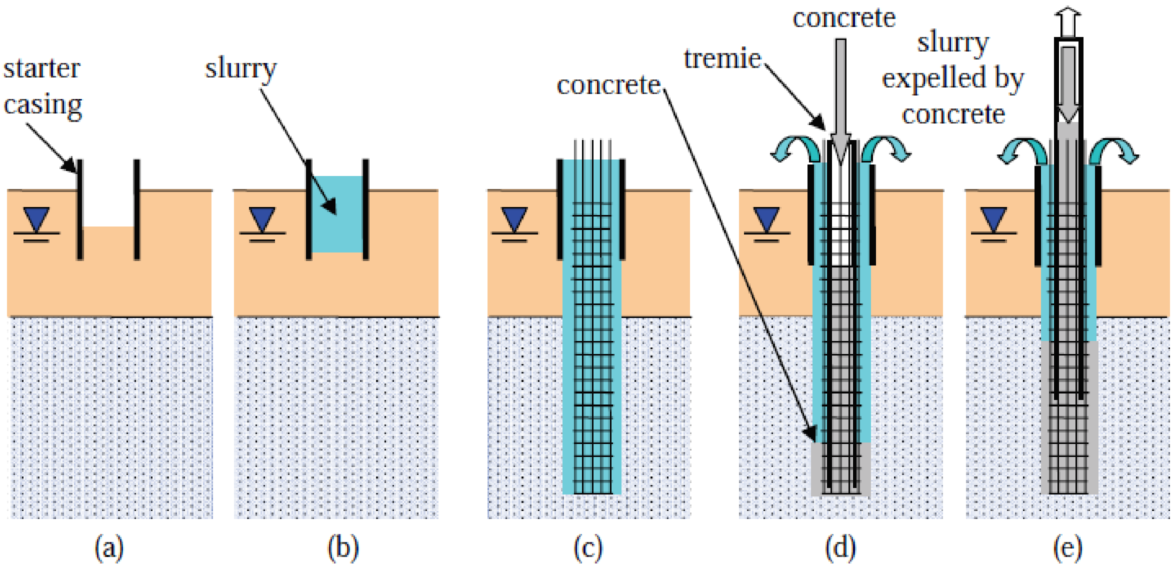
Pile designing procedure is not discussed in-detail in this paper. However, according to Euro Standards pile design is recommended to be done using data obtained from (1) bore hole test at the preliminary site investigations, (2) empirical or analytical calculations demonstrated by static load test results (3) dynamic load test results demonstrated by static load test results or (4) static load test results demonstrated by calculations or other experiences (Frank, 2008).

In common practice preliminary investigations such as Standard Penetration Test (SPT) and Cone Penetration Test (CPT) which are given an average measurement of surrounding soil profile are applied to perform empirical correlations introduced and modified time to time (Thounaojam & Sultana, 2015).

Construction Procedure

General pile construction procedure adapted in Sri Lanka can be briefly explained into three steps as borehole excavation, cleaning and concreting. Initially, soil boring (flight auger and boring bucket) and rock drilling (rock drilling bucket and core barrel) are done up to the desired depth. In some occasions, a 6m steel casing is used to support borehole edge and heavily disturbed topmost soil layers (Clayton & Militisky, 1983). However it incorporates more works in piling process to provide mechanical vibratory devices to drive steel casing into the hole. Rarely steel casings are used for total length of exaction, for instance, in loosen soils, but it is always not economical. (Thilakasiri, 2006) Therefore a drilling fluid is used as more economical approach to ensure the hole integrity instead of continuing steel casing along the wall. Betonite slurry is the most popular mineral slurry and pumped into the hole progressively to avoid earthen wall collapsing beneath the steel casing, reduce heat generation of rock drilling and finally as a pile cleaning agent. (Lam C. et al. 2014) In general for placing concrete, a treime pipe is used to reach concrete easily to the pile bottom. Figure 1 illustrates bored pile construction procedure.

Figure 1 – Bored pile construction (a) place steel casing (b) pump slurry (c) finish excavation, cleaning hole and placing Reinforcement cage (d) placing concrete (e) remove tremie pipe.

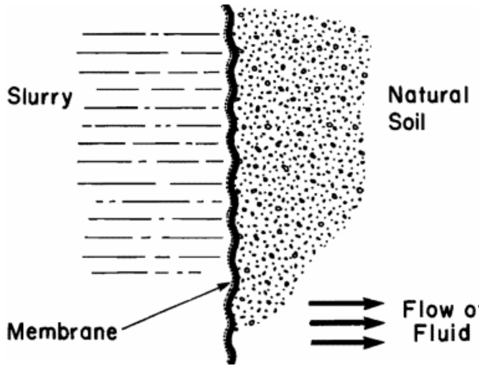


Source: Federal Highway Administration (2010)

Enhance Pile Capacity

Usually, ultimate capacity of a pile is contributed by negative skin friction resistance and toe resistance. When soils interacting with concrete surface, shear force is induced along the shaft with negative friction. Piles supported only with this negative friction are called as floating piles which are terminated before hard rock. Even in end bearing piles a considerable amount of load resistance is given by the shear force. Therefore, skin friction plays an important role in bored piles but there are many doubts on ultimate shear strength developed in surrounding earth wall at the end of this hidden process. During construction, Betonite slurry is established pile wall integrity by creating a thick continuous membrane on the earthen wall, called as 'filter cake' (Thilakasiri 2006, FHWA 2010, Lam C. et al. 2014) (see figure 2). Although there is a doubt whether this layer is removed, according to researches by FHWA (2010) and Mullins et al. (2014) skin resistance at the pile-soil interface would not be affected due to application of Betonite slurry. Because However, Clayton and Milititsky (1983) have been proposed that as the concrete placing begins at the bottom there is at least a chance to remove the continuous slurry film. But the efficiency of the process depends on the yield stresses of both materials (Clayton et al. 1983).Further, Fleming and Sliwinski (1977) have suggested that only a few amount of slurry will be remained as it is penetrated into the irregularities on the wall. Therefore it can be assumed that while concreting, the uplifting force created due to the density difference of two materials, concrete level will increase with displaced Betonite slurry.

Figure 2 – 'Filtercake' formation along the earthen wall (Tucker & Reese, 1984).



However, Sri Lankan geotechnical engineers do not rely only on the skin friction when bored pile designing due to possible post effects which would have due to remaining Betonite slurry on walls (Thilakasiri 2006). Because of the doubt about difficulties in removing drilling fluid penetrated into nearby soil due to long term exposure would be disturbed in developing skin friction. With reference to the UK standards by Institution of Civil Engineers in 2007, concreting should be commenced within 12 hours of starting the excavation. (Lam C. et al. 2014) It reveals importance of reduction of exposure time for drilling fluid. But in the USA the exposure time is specified as the duration of undisturbed drilling fluid in the hole should be less than 4hours. (Lam C. et al. 2014) An experimental study by O'Neill and Hassan (1994) has been proposed that when increasing exposure time and viscosity of slurry the thickness of filter cake formation is tend to be increased (Federal Piling Specialist, 2006). Further, Lam C. et al. also have experimentally shown that the effect of polymer based drilling fluids on the shear resistance is negligible during the lifetime. In local construction industry, according to the findings related to local experiences presented by Thilakasiri (2006), the maximum exposure time could be extended up to 36hours of excavation. As well as under favourable subsurface conditions the contribution of skin friction could be considered and should be taken into account in designing when the hard rock strata is found at deep level.

Bored piles are most preferable and effective with cohessionless soils such as sand that perform soil-pile interaction to a higher degree while weak soft soil reactions support to develop positive friction. Therefore if contractors are not followed a Quality Control and Quality Assurance (QA/QC) system strictly, final products would be ended up with loss of structural integrity due to various defects such as necking, bulging, and settlements.
When concrete level risen up, all flushed contaminants from the bottom can be clogged at the middle of pile creating necking, due to dense reinforcement case (Mullins et al. 2014). It can be avoided with highly workable concrete facilitating to a continuous flow through reinforcement. In addition to that collapsing unstabilized, unsupportive weak earthen wall beneath the steel casing even with drilling fluid can be collected at the bottom of the bored hole before concreting is caused bulging and unclear bottom resulting low bearing capacity. Full length cased method is rarely practiced in Sri Lanka to deal with such difficult soil profiles (Thilakasiri 2006).

To improve the base capacity, piles are terminated at a strong soil layer consisting with hard rock or dense sand. In general practice the length into hard rock is called as sockting length. Adequacy of hard rock reveals simply by visual observations of drilled samples to avoid pile terminations at weathered or weak stratum before the hard rock. But the reliable length of drilling should be decided according to the existing site conditions even would not be compatible with provided designs because of floating rocks (boulders), site specific depth variations of acceptable bed rock strata and adequate rock quality (FHWA 2010).
Bottom cleaning process of pile in wet construction method is achieved by circulating a drilling fluid at least 15 minutes (Gandhi, 1990) immediately prior to concreting, to remove remained soil in pile toe. The effectiveness depends on the rate of application (Mullins et al. 2014), properties of drilling fluid including density, viscosity, pH and sand content (Thasnanipan et al. 1998) and nature of flow (turbulent flow, a rate without affecting side walls is much efficient and effective). If loosened particles accumulation is allowed at the bottom, the resultant toe resistance would be partially mobilized or even have to neglect total contribution of end bearing capacity.

As described previously hidden cavities inside the borehole can be recognized during concreting by comparing actual volume with placed volume. Excessive additional volumes are susceptible to bulging effect. Locally pile concreting is done by pouring highly workable concrete through a trieme pipe to avoid contamination and segregation (Mullins et al. 2014). Usually slump range is from 150mm up to 230mm and FHWA has recommended 150 mm to 225 mm.
Further, rainy weathers are badly affected on the quality of piles as increasing groundwater table, water accumulation on the site, changes in subsoil conditions etc. (Thasnanipan et al. 1998). Though they are difficult to avoid in such situations, adverse effects can be minimized to some extend by implementing additional safety precautions on working conditions and those precautions may be unique for a site with available site conditions.

Capacity Evaluation
Capacity evaluation methods are performed in compliance specifications (evaluate QA/QC system), continuous improvement of construction practices and validate provided designs (Clayton & Militisky 1983), using either empirical or theoretical methods or

both. However, pile load tests are one of the prominent examinations of actual pile behaviour as a group or individually when (1) contractor is not well-experienced, (2) experience unpredictable sub soil profiles with extensive and sudden variations, (3) lack of pervious experiences in the same ground condition, (4) available theories or experiences are not enough to confidence on heavy load applications, (5) strong deviations of predicted pile behaviour than known through investigations or experiences (Frank 2008).

Dynamic load tests using Pile Dynamic Analyzer (PDA) is widely applied in prediction pile bearing capacity currently, as an economical, easy and quick testing method. Maintained (static) Load Test though requires relatively costly, complex test arrangements it can evaluate higher actual working loads up to 30MN. In general cost of load tests can be up to 10% of piling cost for a project, so a limited number of tests are conducted for small project (Federal Piling Specialist, 2006). Table 1 indicates number of tests and type of test required for pile groups under various ground conditions based on risk level according to the UK practices.

Usually for large pile groups, pilot tests are necessary to conduct to certify estimated pile capacity. Although conducting of pilot test is costly than working pile testing, it is beneficial as a group to carry out preliminary load tests prior to commence constructions since doing rectifications is difficult if down drags are not identified earlier. Finally, random verification is sufficient to make sure performance of total pile group. Solitary experience was in Thailand with 400 piles, diameters up to 1500mm and depth up to a 60m below the ground surface is a good example of taking advantage of preliminary capacity evaluation methods in the context of both cost reduction and reliable mobilization of designed capacity (Thasnanipan et al. 1998).

Table 1 – Pile testing criteria according to risk level

Piling conditions	Risk level	Pile test
Predictable ground conditions. No previous experiences. New piling technique or very limited relevant experience.	High	Both preliminary and working pile tests essential. 1 preliminary pile test per 250 piles. 1 working pile test per 100 piles.
Consistent ground conditions. No previous pile test data. Limited experience of piling in similar ground.	Medium	Pile tests essential. Either preliminary and/or working pile tests can be used. 1 preliminary pile test per 500 piles. 1 working pile test per 100 piles.
Consistent ground conditions. Previous pile test data is available. Extensive experience of piling in similar ground.	Low	Pile tests not essential. If using pile tests either preliminary and/or working tests can be used. 1 preliminary pile test per 500 piles. 1 working pile test per 100 piles.

Source: Handbook on Pile Load Testing, Federation of Piling Specialists

Discussion

Pile construction procedure is always affected by various internal factors (material characteristics, construction procedure etc.) and external factors (weather conditions, unpredictable soil profile, ground water table etc.) which should be controlled to reach required design capacity. Sufficient experiments have been done widely on frequently used materials such as concrete, drilling fluids and reinforcement on different perspectives. (Mullins et al, 2014)In addition to that various studies have been done on modifications for existing specifications to relevant site conditions and for clarifying doubts of material interactions based on accomplishing of pile bearing capacity (Clayton et al., 1983; FHWA, 2010; Mullins et al, 2014; Lam et al, 2014). According to the literature there are several factors affected on the ultimate pile bearing capacity and some cases are seriously considered in the foundation designing to eliminate possible capacity reductions. For instance, skin shear resistance decreases due to changes of soil behaviour by long term exposure of Bentonite slurry in the hole and disturbance of surrounding soil by mechanical vibration during excavation. (Clayton, 1983; Thilakasiri 2006) Therefore, the contribution of skin friction to total capacity is questionable and do not consider unless the hard stratum far below and costly to reach.

Though some external factors like rainy weather conditions cannot be avoided and difficult to provided ideal solutions for impacts, they can be minimized to a satisfactory level by strictly following quality control and assurance methods. Generally when expose to sever wet weather conditions soil properties may change considerably (Thasnanipan et al. 1998) with rising ground water table and seepage currents. According to the Clayton et al. in 1983 the tendency of earthen walls failure is a function of shear stress applied to the wall and seepage forces. The water flow into the bored hole can be resulted low integrity of piles as the concreting is not much effective in wet weather conditions. Because of washing away concrete on pile surface, reduce concrete strength due to increasing water cement ratio, and increase the possibility of mixing Betonite to concrete.
However, all construction activities should be verified under proper capacity evaluation methods for cost and safety considerations of outcomes. In order to capacity prediction these kind of load tests could not justify for same results everywhere even for same soil conditions and construction process. Fearenside & Cooke in 1978 had illustrated the degree of variability of load tests results for piles constructed under the same conditions in the close proximity. Further they proposed that the variation

could be shown as 20% in common and could be increased up to 60% maxima. (Clayton et al., 1983) Because of that to optimize safety factors used in foundation designs with respect to the existing site conditions whether they may compatible with initially collected data or with considerable deviations, both load testing methods and past experiences are important. Such experimental safety factors reductions lead pile construction towards more reliable and cost effective designs.

Conclusion

Expected serviceability of bored and cast-in-sit piles can be realised through an efficient quality control and assurance process which develops with regular in-situ experiments and pervious experiences and researches in the literature. Also a number of construction practices are available in different standards and specifications in different countries. Though all these techniques could not be adapted as a whole even for a single issue, adjustments could be done according to the local environment, before introducing to Sri Lankan construction industry.

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