Site Supervision of Installation of Bored piles

by
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Scope of presentation

1. Introduction
2. Role & responsibility of pile supervisor
3. Pre-construction issues
4. Construction inspection for bored pile installation process:
   • 4.1 General
   • 4.2 Boring operation
   • 4.3 Drilled shaft stabilization & base cleaning
   • 4.4 Reinforcement cage placement
   • 4.5 Concreting
   • 4.6 Post installation testing
5. Works specifications
6. Miscellaneous issues
7. Q & A/case histories
8. Concluding remarks
The Gist of issues to be discussed*

1. What are the role & responsibility of bored pile supervisors (CRE/RE/IOWS)?
2. In order to discharge the responsibility well, what are the basic info & knowledge that a qualified bored pile supervisor should learn & acquire?
3. What are the indispensable CP/standards for bored pile supervisors to refer?
4. What are the 3 basic bored pile construction methods? What are the basic construction process of bored pile installation? How construction process can affect performance?
5. What are the critical info sought from GI report for bored pile construction? Why a comprehensive GI report is required for proper planning of bored pile construction plan & preparation of method statement?
6. For boring operation, what are the factors that should be considered when interpreting "suitable boring rig & drill tools" for a bored pile project?
7. For drilled shaft stabilization, what are the common methods? Applications & limitations of each method? QC requirements for bentonite & polymer slurry? Is polymer slurry more expensive than bentonite slurry?
8. For base cleaning, what are the common methods? Applications & limitations of each method? How to check/test effectiveness of base cleaning as required by Specs?
9. For reinforcement cage placement, what are the important construction requirements?
10. What are the important quality & QC requirements of concrete for bored pile construction? What are the common defective concreting practice?
11. For post installation testing, what are the common test methods to validate/check structural integrity & capacity? When MTL>4000T, what are the problems & risks for MLT using kentledge (concrete blocks)? Bidirectional load test (O-cell/C-cell/T-cell) is reported to be safer, faster & cheaper, but can it be considered SLT? What are the basic requirements of PDA tests on bored pile? Test standards?
Typical Construction Process/sequence of Bored Pile Installation.

a. **Boring** by auger or bucket (suitable/adequate capacity/torque/tools for pile size, depth & soil/rock type?). **Drilled shaft stabilization? Criteria of terminating pile depth?**
b. **Reinforcement cage** is inserted into the drilled hole after boring is completed. WCGW?
c. **Tremie concreting** after base cleaning. WCGW?
d. **Removal of casing?**

What, how & why of these vital issues of bored pile installation?

1. **Introduction**

   - This presentation discusses: role & responsibility of bored pile supervisors; how to carry out supervision of bored pile installation according to BS EN 1536 plus their respective significance & effects on bored pile performance; case histories plus some recent research findings, etc.
   - For most geotechnical works including piling works, D & C are inseparable. Why?
   - The performance (durability, structural integrity & capacity) of bored piles can be significantly influenced by every process of construction with particular reference to **boring operation, drilled shaft stabilization, base cleansing, reinforcement placement & concreting**. The important construction requirements for these 5 important bored pile installation processes & the principles involved are the main focus of this presentation.
   - Bored piles are **very construction sensitive foundations** & require more thorough & stringent supervision than driven piles. Why? The conditions, integrity & capacity of driven prefabricated piles can be readily checked, inspected & monitored with blow counts of the hammer & subsequent testing, etc., but integrity & capacity of bored pile cannot be readily inspected & checked as it is being constructed.
   - In order to ensure the design is comprehensive & complied with the requirements stipulated by CP & local bylaws, design audit should be carried out especially those designs classified as GC3. Similarly, to ensure the construction is carried out properly in good engineering practice & according to the design drgs & specification, **proper supervision by properly qualified personnel is necessary as per CP requirements (EC7/BS 8004).**
The most important responsibility of supervisors is to inspect (look closely & critically) to ensure conformity to CP, Specs & drawings. To discharge this responsibility, the supervisors have to be well-versed with CP, Spec, drawings & construction requirements of boring processes.

### Bored Pile Installation

#### Role & Responsibility of Supervisors

- To represent the Project Owners & take care of their interests to ensure piles are properly installed.
- To inspect with due care, diligence & skill so as to ensure conformity to CP, Specs & drawings.
- To record the as-built conditions with due care, diligence & skill for record purpose & to serve as a basis for pile test selection.
- To report any non-conformity & abnormalities to designer & Client for necessary action.

#### Boring Processes & Construction Requirements

- Proper construction method (dry/wet/cased)
- Proper boring operation (boring rig & drill tools)
- Proper drilled shaft stabilization method (water/bentonite or polymer slurry/casing)
- Proper base cleaning method (cleanout bucket/air-lifting/down-the-hole pumping)
- Proper Reinforcement cage fabrication & placement

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**Important workshop/course details/contents covered in this presentation are as follows:**

<table>
<thead>
<tr>
<th>Course Content</th>
<th>Site supervision of Installation of Bored Piles</th>
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<tr>
<td>Objective</td>
<td>To prepare the site supervision of bored piling works to inspect, monitor and document/record the bored pile installation processes/operations ensuring safety, serviceability and durability of the pile foundation as per requirements of Code of Practice and the Contract Documents.</td>
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<tr>
<td>Course Content:</td>
<td>1. Will familiarize the pile supervisor with the relevant bored pile terminology, materials, equipment (bore rig &amp; tools) and process details pertaining to bored pile installation;</td>
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<td>2. Will provide the bored pile supervisor with the necessary knowledge, information and understanding of bored pile construction drawings/plans, Standard JKR Specifications (Section 10: Piling), etc.;</td>
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<td>3. Will explain &amp; describe the bored pile supervisor's role and responsibility for site supervision of bored piling works from step one of the pile installation plan to the final step of pile installation testing &amp; acceptance.</td>
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<td>4. The course includes a review of the boring rig &amp; drill tools used for bored pile installation and the construction requirements;</td>
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<td>5. Will explain all the important bored pile installation processes/sequences &amp; methods of installation; all necessary scope of inspection &amp; QC tests on materials, workmanship and acceptance tests/measurements for structural integrity and performance of bored piles, etc.</td>
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Duration of Course: One day
Important Reference Materials

- Workshop Notes by NCA- can be downloaded from www.egeo.com.my
- JKR Standard Specification for Road Works-Section 10:Piling (JKR/SPJ/2010-810)
- The main references used/referred to prepare this course/workshop note are as follows:
  - BS 8004:1986. CP for Foundations

Q & A*

- If you have any question or doubt, please interrupt & ask.
- The dumbest question is the question not asked.
- The question is always “what is the most cost-effective & practical solution to suit the specific site & subsoil conditions” and the answer is always required an understanding of engineering principles involved & detail ground info especially the critical ones.
Why proper GI is indispensable for D & C of bored piles?

For design
• Must know subsurface materials
• Must know subsurface conditions/engineering properties
• Must know capacity to support loads

For construction
• Subsurface materials dictate choice of boring rigs & drill tools
• Subsurface conditions dictate construction method
• Identify potential construction problems

What are the critical ground info sought for D & C of bored piles?
What are the complex & simple subsoil conditions?
Unknown subsoil conditions can give “surprises” & be detrimental to construction & performance of bored piles especially to the unwary Contractors & supervisors. Refer Cl 5 of BS EN 1536.

2. Role & Responsibility of Supervisor
• Basic & main job of supervisor is to inspect, to record & to report. To inspect is aimed to ensure conformity to specs & drgs or no defective construction. To record is aimed to establish as-built conditions with necessary details (BS EN 1536, Cl 10) for record purpose & to serve as a basis for pile selection for tests. To report if there is non-conformity or abnormalities.
• Purpose of supervision: Only sound piles complied with design drgs & specs are installed or to achieve zero defect construction.
• To inspect means to look or view closely & critically to ensure no defective construction. How to inspect with due care, diligence & skill? Required what basic skill & knowledge? The main scope of this presentation is to share with you “how to inspect & how to identify defective construction with whys”. To achieve these, you have to learn the common construction methods, construction process & their respective construction requirements plus principles involved.
• Bored pile supervisor (especially the novice) may be difficult or unable to see/feel what is happening underground while in pile driving, hammer blows can give some degree of indications.feels or comforts about the pile capacity.
Role & Responsibility of Supervision*

a) Parties involved in conventional construction contract:

- **Project Owner/client**: specifies the needs of the project & provides the project fund. Project owner also appoints project manager, Consultants & Contractors.
- **Project Manager appointed by the Client**: plans, manages & administers the project on behalf of the project owner; coordinates all the parties involved in the project to ensure successful implementation (planning, design & construction, budget/finance controls, etc.)
- **Project Consultants appointed by the Client**: prepare design drawings, specifications, BQ & Contract documents. Foundation works/piling are usually supervised by C & S Consultant who prepares the design of the foundation/piling works.
- **Contractors appointed by the Client**: carry out the construction works as per contract requirements & in accordance to drawings, specifications & BQ, etc. Usually piling works are carried out by a specialist sub-contractor.

b) Role & Responsibility

- Basic role of pile construction supervisors is to take care of Project owner’s interest & to perform supervision aimed to ensure piling works are carried out by the Contractor according to design drawings & specifications.
- The pile supervisors are responsible for:
  1. The conformity of piling works with design drawings & specifications;
  2. The validity of design assumptions through adequate scope of design validation;
  3. The inspection & monitoring of all piling processes & keeping of all necessary records to establish as-built conditions; and
  4. Keeping the Project owner and/or designer informed of any variations or deviations & abnormality from the expected situations or conditions of the site or any case of non-conformity.

- Generally and typically, five direct parties involved in a conventional construction of civil engineering and building project contract implementation are:
  - **The Client/Project owner** (specifies the needs of the project, provides project site & fund).
  - **The Project Manager** (appointed by the Client to manage and administer the project on behalf of the project owner & coordinates all parties involved in the project construction works. Has the authority to enforce the provisions of the Contract).
  - **The Consultants** (appointed by the Client/Project manager to prepare the design drawings & works specifications (std & addendum Spec) to meet the requirements of Codes of practice, BQ & other info for the contract document for the project & supervise the technical construction), and
  - **The Contractor** (charged/entrusted by the Client to carry out the construction works with necessary resources as designed and specified by the design Consultants through a contract with the Client). For design & build contract, the lead contractor engages a consultant and works together.
  - **The Supervisors** (IOW, ARE, RE/CRE), appointed/entrusted by the Client/Project manager to supervise the works. Has the authority to inspect (to look closely & critically), accept/reject or suspend the works, based on the conditions of contract.
Role of supervisor*

- Pile construction supervisors are appointed by the project owner/project manager to serve as representative of the Client/Project manager to take care of their interest and to perform site supervision aimed to ensure piling works are carried out by the Contractor according to the agreed/signed Contract documents including Conditions of Contract, BQ, design drawings and works specification.
- The supervisor (CRE/RE/IOW) should serve as the eyes and ears of the Client/designer, and as the recorder (to make accurate & unbiased observations; document events comprehensively & consistently; perform duty promptly, ethically & professionally with due care, diligence & skill) and as the reporter (to keep diary up-to-date & keep the RE/CRE/Project manager informed promptly, especially when there is deviation) for the job entrusted.
- **REMEMBER YOUR RESPONSIBILITY:** as a pile supervisor, always remember who you represent; use commonsense; don’t delay or interfere with the Contractor’s operation unnecessarily. Remember your main goal at site is to ensure the piling works are constructed & completed according to the drawings and specifications soonest possible. If you observe potential non-conformance, notify the Contractor early to avoid the undesirable situations from occurring.

Responsibility of supervisor

In order to discharge the responsibility of supervisor, he/she SHALL be a suitably qualified and experienced person, who shall be responsible for:

a) **The conformity of piling works with design drawings & specifications.** This means in compliance with good engineering practice and all the requirements stipulated by CP (relevant BS EN/BS 8004/EC7), specific design drawings & specifications. To discharge this responsibility, the supervisor has to be well-versed with the relevant terminology of piling works, all important processes/sequence of piling works and their relevant scope of inspection/QC tests on material, workmanship & performance tests plus their acceptance criteria. An experienced pile supervisor is always aware of the common defective constructions and how to mitigate them properly with the cooperation from the Contractor.

b) **Checking the validity of design assumptions**

c) The inspection & monitoring of all important piling processes/sequences and keeping of all necessary records to establish as-built conditions; and to

d) **Report & keep the Clients/Project manager and/or designer informed of any variations or deviations from the expected situations or conditions of the site or any cases of non-conformity.**
• **Important duties** for piling supervisors or RE/IOWs are as follows;

  • To check that all the piling works processes at site are carried out according to the specifications and drawings by identifying any faulty materials, defective workmanship, non-conformity work process, etc. (important processes for bored pile installation: setting up, boring operation, drilled shaft stabilization, base cleaning, reinforcement placement, concreting & post installation testing).
  • To check that the Piling Contractor provides adequate safety precautionary measures during the course of all the piling processes;
  • To check that the Contractor follows the approved works program and method statements;
  • To keep vigilance on any visual signs of pile distress on Site and in the surrounding buildings/structures and any apparent signs of abnormal or unforeseen ground conditions.
  • To report to designer/Client on faulty materials, defective workmanship, non-conformity works process, site problems, site safety, visual signs of distress, possible abnormal or unforeseen ground conditions, progress, quality of workmanship and adequacy of Contractor’s resources for the Works;
  • To make site measurements, sampling and testing of materials for the piling works;
  • To monitor the piling works of all his subordinates, if any;
  • To record and ensure that all site measurements, site diaries on site field works, record drawings, in-situ QC testing and other records are properly maintained and kept up-to-date;
  • To ensure consistent supervision, site safety and measurement standard across sites under his supervision.
  • To prepare and submit weekly/monthly progress reports and any other returns as required by designer/superior;
  • To check and verify bills of quantities submitted by the Contractor;
  • To check that the Quality Procedures are followed by all concerned subordinates;
  • To check the as-built drawings/records prepared by the Contractor; and
  • To check the overtime duties of all his subordinates, if any.

• **What is meant by proper & quality supervision of piling works? Significance of quality supervision?**

  • Proper supervision of piling works means piling works is supervised by adequate numbers of adequately qualified personnel with due care, diligence and skill to ensure conformity to design & specification. Qualified personnel for supervision of piling works required by BS 8004 (Clause 11.4)? What is meant by “with due care, diligence & skill”?
  • What are the role, objectives & scope of site supervision of piling works with particular reference to bored pile installation?
  • Site supervision of piling work is aimed to ensure the piling works are properly executed according to the requirements of contract document. Site supervision comprises of contract administration & technical supervision plus necessary project management.
  • The focus of this workshop is on technical supervision, which is aimed to ensure the piling works (bored pile) are properly carried out using proper machines, quality materials & proper procedure to suit site/subsoil conditions and to meet the requirements shown in drgs & spec/BS EN 1536 or as instructed by the Engineer. How to achieve the aims of technical supervision is the aim of this presentation.
  • What are the main scope/types/processes of construction activities for bored pile? What are their respective construction requirements of good engineering practice/CP for bored pile installation according to BS EN 1536?
  • This presentation will discuss the **SKILL** (technical know-how, training, knowledge & experience) required to discharge the main responsibility of site supervisors (RE & clerk of works). **Care & diligence** are matters of attitude of mind and are beyond the discussion within this presentation.
Site Supervision Planning

• The statement “All bored pile construction SHALL comply with all the requirements stipulated by BS EN 1536:2000.” shall be included in bored pile design drawing & Spec. Why?

• Important info for planning site supervision of bored pile installation: GI/SI report (Subsoil & WT conditions, Soil types especially unstable & water bearing granular soils with artesian pressure, Potential obstruction, etc.). GDR (pile details/geometry, numbers, size & depth of bored piles, criteria of termination, construction controls, etc.), Site conditions & dilapidation survey of nearby buildings/structures/utilities/services, Contract documents (drgs, BQ, Spec, etc.). Work program, Method statement, etc.

• Construction controls/checklist: GI/SI adequate? Potential problems of obstruction, unstable & collapsible strata, artesian pressure. QC system (types & frequency of tests, measurement, inspection, etc.) for materials (concrete mix & additives, rebars, coupler, spacer, etc.) & workmanship plus format of recording of works (daily activity, boring, shaft stabilization reinf cage, concreting, testing, etc.)

• Refer BS EN 1536 for details for supervision & monitoring of setting out, boring operation, stabilizing fluid, reinforcement, concreting & post construction testing plus the recording.

*Level 1 is inspection as and when required. Level 2, 3 & 4 are inspection monthly, fortnightly and weekly respectively. Level 5 is full-time inspection during site working hours. T1 and T2 are a certificate/diploma holder with minimum relevant working experience of 2 years and a higher certificate/higher diploma holder with minimum relevant working experience of 3 years respectively. T3 is a higher certificate or higher diploma holder with minimum relevant working experience of 5 years or a degree holder with minimum 2 years of working experience. T4 is a degree holder with minimum 4 years of relevant working experience or a registered professional engineer. T5 is a registered professional engineer with minimum 5 years of relevant working experience. (Technical Memo for Supervision Plan, Section 39A, Building Ordinance. 2009, HK)
Quality Assurance & Construction Controls


- Studies of foundation projects indicate that only 15% of damage or quality problems could not be anticipated & the remainder were avoidable. The same ratio is approximately valid for pile foundations. The main reasons for faulty quality are as follows:
  a. 40% errors in design & planning (designer’s responsibility) - mainly due to inadequate & unreliable SI/GI.
  b. 40% poor workmanship (responsibility of Contractor & supervisor)
  c. 10% material deficiencies (responsibility of Contractor & supervisor)
  d. 10% other deficiencies (responsibility of Contractor & supervisor)

- How to reduce deficiencies & damage during pile installation? QMS/ISO 9000
- For better control & supervision, construction procedures should be planned & construction sequences/processes and responsibilities be clearly defined.
- Drilling records, as required by C1 10 of BS EN 1536, are part of the quality assurance. Why?
- An essential element of quality assurance of piles is integrity testing of properly selected piles. Frequency & criteria of selection of piles for integrity testing for driven concrete RC/spun piles & bored piles? 1% to 2% (SS CP4:2003)

Principles of testing: Testing is not everything until and unless the result can be representative for the untested ones on the safe side. Selection criteria: How to meet this requirement when select piles for integrity and capacity tests? Why proper detail recording is an important part of QA system?
- One test is worth of a thousand of expert opinions?

Site Supervision of Bored Piles

- For bored pile installation, what are the essential construction processes & their respective construction requirements according to BS EN 1536? Supervisors should learn these thoroughly at their finger tips including the principles, significance & effects of the construction requirements to bored pile performance.
- Knowledge or skill can be acquired and enhanced through asking, reading, listening, working/practical experience, etc.
- What is a bored pile? Bored piles are formed in the ground by excavation/boring in circular shape of 0.3m to 3m to transfer loads from the superstructure into the ground through friction & end bearing. Also called as Drilled shafts, Drilled piers, Caissons, etc.
- What are the general applications, advantages & limitations for bored piles?
- Scope & process/sequence of works for bored pile installation?
- Site hazards & construction risks for bored pile installation. Identification & assessment.
- What are the main problems (uncertainties & risks) of bored pile installation in various typical subsoil conditions? Objectives & scope of supervision?
- What are the common mitigations vs. WCGW at site problems related to boring operation, shaft stabilization, base cleansing, reinforcement placement and concreting?
- What are the basic qualification & training required for site supervisors for bored pile installation?

Site supervisor’s “tools/resources” checklist*

All supervisors shall be equipped readily with the following tools/resources:


2. **Daily Essentials**: Helmet, boots, pencil & ballpen, 5-m tape, 30m (or longer) tape, life/reflective safety jacket, camera, weighted 30m tape, plumb bob, etc.

3. **Blank Forms**: approved Bored pile excavation log, Rock socket construction log, Bored pile inspection record log Concrete placement log, Concrete depth-volume form/graph, integrity test, PDA & load test record forms, etc.

4. **Critical & important info?**

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3. Pre-installation Planning*

a) **Site supervisors shall** carry out site inspection & desk study of GI report & GDR, etc., to familiarize the project & scope of works. Setting up. Dilapidation survey? Read BS EN 1536:2000 & Specs & need to become familiar & understand all the construction processes & construction requirements for bored pile installation.

b) **Bored pile installation plan**

- **Method statement** (MS) for bored pile installation shall be prepared by qualified construction engineer/manager & checked & approved by the RE before commencement of works. MS shall include 3M (specific materials, machine & manpower with specific details), sequence of works, output of works & QC including types, frequency & acceptance criteria of tests/measurements or observations, etc. Remedy if below par?

- Supervisor should discuss with the Contractor about the criteria of terminating the boring, especially when not clearly specified in drgs. Suitable boring rigs & drill tools shall be used. Construction method (dry/wet/cased) for collapsible strata such as water bearing granular strata, artesian pressure zone, very soft & loose soils to prevent collapse of drilled shaft. Collapsible drilled shaft should be properly stabilized by casing and/or mineral/polymer slurry, etc. Strict QC on the density, pH value, sand content & quality of drilling fluid shall be observed & checked, if used. Why?

- Discuss with the Contractor about construction methods & process such as rock socket construction method, reinforcement cage placement, base cleaning & concreting to ensure meeting the Spec. Risk or uncertainty in irregular & erratic bedrock and karstic limestone formation shall be adequately considered with necessary mutually agreed mitigations.

- Adequate scope of design validation & QC/QA scheme shall be as specified & agreed to check & verify the important critical design assumptions & performance criteria (capacity, settlement & structural integrity).
Some Comments & Advice to RE/CRE*

1. CRE/RE should be well-versed with BS EN 1536:2000.
2. CRE & RE have to remember that their main job is to supervise & inspect to ensure that the piling works are properly executed according to the drgs & specs. This means the RE & CRE have to know the specific requirements of the particular piling work process & be able to identify defective pile construction & unacceptable materials that are not in compliance with the specs & Drgs.
3. Nowadays, in order to achieve more cost & time saving, the pile designers and/or pile Contractors are more inclined to adopt marginal pile design & fast/cheap construction process (low quality 3M & poor workmanship). This means the piles constructed may not have the usual contingencies for unforeseen eventualities & unexpected treacherous subsoil conditions. This will put the responsibility of CRE & RE to be more stringent, demanding and challenging.
4. Inspection is as good as the knowledge, experience & qualification of the CRE & RE.
5. For bored piles, the CRE & RE must learn & understand the bored pile installation process (including the principles involved) with particular reference to boring operation, drilled shaft stabilization, base cleaning, placement of reinforcement cage & concreting so as to be able to identify defective material & defective construction that will affect bored pile structural integrity & capacity.
6. Most of the piling problems can be mitigated/averted, if a competent CRE/RE uses systematic inspection procedures coupled with due cooperation from the pile Contractor.
7. The CRE/RE must be more than just “look see look see at site” or just a “bored pile recorder”. The CRE/RE should be the “eyes & ears” of Client/designer/project owner. Timely observations, suggestions & correction advice can ultimately assure the success of the piling works. The earlier a problem or abnormality is detected & reported, the earlier a solution or correction in procedures can be made & hence, a potentially negative situation can be limited to manageable one. If the same problem is left unattended, the nos of piles affected will increase, as do the cost & time of remediation & the potential for claims/disputes or project delays. Thus, prompt detection & reporting of any problem by CRE/RE is very critical to keep the project on schedule & within budget.

Some more advice for RE & CRE*

1. CRE/RE must learn & must have the skill/knowledge to identify the various types/designs of boring rigs & drill tools being used by the Contractor.
2. CRE/RE should always REMEMBER that it is NOT CRE/RE’s responsibility to direct the Contractor’s works or techniques.
3. However, CRE/RE must make reliable & accurate but unbiased records & notes as to the boring rig & drill tools on site and being used.
4. If the Contractor only has soil augers on site and rock needs to be bored & penetrated, it is important to have this info noted, as the Contractor may say the material cannot be penetrated and was misrepresented or harder than indicated. May not really be so if they had the proper rock auger or rock boring tools.
5. The accurate, unbiased observations and documentation can serve to alleviate problems or disputes or claims that might arise.
6. The bored pile designer knows the project by heart as he/she have lived it for probably a few years or at least several months. The Contractor knows each detail of construction as he/she has gone through the Specs & Drgs with finger tip details during the tender process & site visit. The CRE & RE is most probably sent to site at the last moment, so it is imperative that CRE/RE should be familiar with the project (drgs, specs & site conditions) soonest possible so that the Method Statement can be checked & approved fast.
7. CRE/RE’s whole purpose of being sent to site is to verify that the bored piles are constructed in accordance with Specs & drags. Hence, the Specs, in reality, outline the responsibility of CRE/RE.
Responsibility of supervisor for important construction processes of bored pile installation. What are expected from the supervisor? What are the responsibility for each construction process?

**CONTRACTOR SET UP**
- Test Slurry
- Describe Soils & Rock
- Prepare Soil & Rock Excavation Logs
- Verify Shaft Depth
- Perform Shaft Inspection
- Prepare Shaft Inspection Log
- Verify hole cleanliness
- Document casing use, type, length

**BORING OPERATION**
- Shaft stabilization & base cleaning

**REINFORCEMENT PLACEMENT**
- Verify proper steel size, length, etc.
- Verify proper ties
- Verify proper spacers and intervals
- Verify Instrumentation protection

**CONCRETING**
- Test concrete
- Monitor concrete volumes
- Prepare Concrete Placement Log
- Check Const. Tolerances

**POST INSTALLATION TESTING**
- Verify pay quantities
- Verify integrity testing
- Complete required forms
- Verify Load Tests

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**INSTALLATION PLAN**

Contractor prepares Drilled Shaft Installation Plan

- Submits to Engineer, for Approval
- Review
- Changes
- Acceptance
- Engineer accepts Plan
- No changes may be made without the Engineers approval

Changes to Contractor within 14 days of receipt

Contractor resubmits to Engineer

Review
3.1 Pre-Installation Planning- cont.*

In brief, supervisors should discuss with the Contractor before construction & understand the following main scope & construction processes for bored pile installation & supervision:

- **Pre-construction** (method statement, dilapidation survey, site inspection & check/peruse documents: SI report, GDR, Contract document, etc.) Purposes?? Aimed to understand the site & subsoil conditions, scope & nature of works involved.
- **Setting up** (workmanship, pile spacing, tolerances of position, etc.)
- **Boring operation** (types of rigs & drill tools to suit site/subsoil conditions, workmanship, principles involved, response from soil/rock, common shortfalls, etc.)
- **Bored shaft stabilization** (types/methods & applications/limitations, QC for material quality & properties, principles involved, common inadequacies, etc.)
- **Criteria of termination of boring** (design criteria, technical basis, subsoil conditions, workmanship for depth & size measurement, shortfalls, etc.)
- **Base cleansing** (types/methods & applications/limitations, workmanship & quality assurance? Principles involved, common inadequacies & shortfalls, etc.)
- **Reinforcement placement** (material quality, workmanship for cover, spacing & stiffness of reinf cage. Clear openings between rebars? Handling & placement, common defects, etc.)
- **Concreting** (concrete properties/qualities, method of placement & integrity controls, volume check for overbreak, common defects, etc.)
- **QC on materials & workmanship** (concrete mix, types & frequency of QC tests, reinf, centralizers, couplers, etc.) & format & details of recording
- **Post installation Testing/design validation** (types/methods of testing & checking for structural integrity & performance/capacity/settlement, etc.)

3.2 Pre-construction Preparations

- Site inspection to familiarize the surrounding site conditions & identify mobility & potential construction problems, effects of bored pile installation to adjacent buildings/structures/utilities, etc. Understand the scope & nature of works involved.
- **GI/SI report** (Subsoil & WT conditions, Soil types, Potential obstruction, etc.) to identify boring obstruction & potential hole collapse, etc. Critical info? Any unstable/collapsible strata & artesian pressure?
- **GDR** (pile details/geometry, Numbers, size & depth of bored piles, criteria of termination, construction controls, etc.),
- **Site conditions & dilapidation survey of nearby buildings/structures/utilities/services** (if any), etc.
- **Contract documents** (drgs, BQ, Specs, etc.).
- **Work program,**
- **Method statement,** etc.
Classification of Construction Methods for Bored Piles

1. **Dry method**: for low water table or stiff clayey soils (low permeability soils) where the drilled shaft is stable & ingress of water into the borehole is negligible (<300mm/4hrs). Fast, simple & low cost excavation/boring. Sometimes, casing can be installed till bedrock & excavation/boring carried out in dry condition if the ingress of water is negligible or can be controlled especially when bedrock is shallow bedrock (say <20m) & the subsoil has low permeability (K<10⁻⁴m/s). Trial shafts/bores should be carried out to validate it.

2. **Wet/slurry method**: if dry method is not possible &/or ingress of water is excessive &/or drilled shaft not stable & required drilled shaft stabilization using drilling fluid (water or bentonite/polymer slurry). Water as a stabilizing fluid is only suitable for stiff or hard cohesive subsoil. If the maintenance of a pile hole is likely to be difficult, a trial bore of relevant dimensions should be carried out (CI 5.1.4, BS EN 1536). Bentonite slurry is generally effective to control inflow of groundwater/soil for water bearing granular soil (PI<20%) with some artesian pressure (casing is also needed if high artesian pressure is anticipated). Polymer is generally more effective for silty sand and sandy silt.

3. **Cased method**: drilled shaft unstable with slumping/caving/ squeezing problems or encountered cavities or very soft strata. Drilling fluid is also used to avoid base heave. Casing can be permanent or temporary. Usually at least some short temporary casing of few meters are used for all methods to serve as guide casing (centering) for boring, to prevent shaft collapse near the top soil & also as safety measure for workers from falling into the borehole.

4. Bored pile Construction Requirements

- **BS EN 1536:2000** has spelt out the details of requirements for good construction practice to ensure good performance of bored piles covering materials/products requirements and works/construction requirements (boring, shaft stabilization, base cleansing, placement of reinforcement cage & concreting, post installation testing). Requirements for quality supervision & records, etc., are also included.
- Technical requirements & QC tests for Materials & Products for bored Piles (raw materials for concrete mix & grout, concrete insitu, grout, stabilizing fluid & reinforcement bars, couplers, stiffeners, spacers, etc.).
- GI & design related considerations & requirements for workmanship (construction tolerance & alignment, excavation/boring, reinforcement, concreting, etc.).
- Works Execution & construction requirements/controls for excavation/boring, fixing & placement of reinforcement cage, concreting, etc.
- Requirements for supervisions (bored pile construction & testing)
- Requirements for records. Purpose?
- Common terminology about bored piles? Refer BS EN 1536:2000
- Bored pile construction method: dry, wet & cased construction. Applications?
- Important bored pile installation processes: setting up, boring operation, shaft stabilization, base cleansing, reinforcement cage placement, concreting & post installation testing. Construction requirements for each construction process? Role & scope of inspection by supervisor?
<table>
<thead>
<tr>
<th>Construction Activity</th>
<th>Scope of inspection/monitoring</th>
<th>Acceptance Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1 Pre-construction</strong></td>
<td>Site inspection, desk study, SI report, GDR. Check method statement. Coordination &amp; communication meeting among supervisors &amp; contractors to resolve issues. <strong>Trial shaft?</strong></td>
<td>Installation effects on nearby structures or utilities. Acceptable mitigations? Method statement OK? Dilapidation survey? Purposes?</td>
</tr>
<tr>
<td><strong>2 Setting up</strong></td>
<td>Tolerance of pile position &amp; alignment. Ground conditions When &amp; frequency of checks?</td>
<td>Setting up by qualified personnel? Ground stable for the machine? Acceptance criteria?</td>
</tr>
<tr>
<td><strong>4 Drilled shaft stabilization</strong></td>
<td>Check SI report &amp; types/methods of stabilizing: casing or water or bentonite/biodegradable polymer slurry or combination? Frequency &amp; acceptance criteria of QC tests required?</td>
<td>Casing for squeezing strata, bentonite or polymer for normal silty/sandy subsoil, water for stiff/hard clay, Casing plus bentonite for sandy soil with seepage flow or with artesian pressure. Desander?</td>
</tr>
<tr>
<td><strong>5 Rebar Placement</strong></td>
<td>See next slide</td>
<td></td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>5. Reinforcement Cage Placement</th>
<th>Check number &amp; size of rebars, clear bar spacing &amp; cover. Stiffness of rebar cage? Quality of coupler s &amp; centralizers? Rebar spacing (&gt;5 times aggregate size)? Check bar position &amp; cover after placement.</th>
<th>Refer Specs for material &amp; quality/strength requirements &amp; acceptance criteria? Principles involved?</th>
</tr>
</thead>
<tbody>
<tr>
<td>6. Concreting</td>
<td>Check concrete mix quality requirements? Check requirements for tremie pipe &amp; concreting methods &amp; controls. Check levels of concrete &amp; volume used, etc. Check for shaft overbreak/overpour?</td>
<td>Cohesive &amp; consistent mix, adequate slump (&gt;100mm) for full concreting period. Cube strength. No segregation/bleeding/leaching, intermixing/contamination. Refer Spec for acceptance criteria?</td>
</tr>
<tr>
<td>8. Miscellaneous (base grouting, etc.)</td>
<td>Check grout mix &amp; pressure plus volume of grout consumed at intended strata. QC &amp; design validation (method &amp; frequency, etc.)</td>
<td>Refer Specs for acceptance criteria? Principles involved?</td>
</tr>
</tbody>
</table>
### Checklist for Bored pile Installation

<table>
<thead>
<tr>
<th>Contractor &amp; Equipment Arrive on Site</th>
<th>YES</th>
<th>NO</th>
<th>NA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Has the contractor submitted bored pile installation Method Statement including specific 3M, sequence of works &amp; QC, etc., to show compliance with the specification and design drawings?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1A. Can the proposed drill rig &amp; tools in the method statement complete the boring operation for each bored pile as designed within 6 hrs.? Any test bore or trial shaft?</td>
<td></td>
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<tr>
<td>2. Has the Bored Pile Installation Method Statement been checked &amp; approved?</td>
<td></td>
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<tr>
<td>3. Does the Contractor have an approved concrete mix design that can meet the requirements specified?</td>
<td></td>
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</tr>
<tr>
<td>4. Has the contractor run the required Trail Mix and slump loss test for the concrete mix design up to 4hrs or up to maximum estimated concreting time for each bored pile?</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>5. If concreting is estimated to take more than 2 hours, has the Contractor performed a satisfactory slump loss test for the extended time period?</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>6. If the Contractor proposed a blended bentonite or polymer slurry, do they have an approved Slurry Management Plan/method statement to meet all the QC requirements (pH value, density, sand content &amp; viscosity) specified?</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>7. Is the Contractor’s technician qualified to log, to describe subsoil strata &amp; to take soil/rock samples of the bored hole (shaft excavation) in accordance with BS 5930:1999?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Has the Contractor carried out dilapidation survey to meet the safety &amp; protection requirements for the nearby structures/utilities as specified?</td>
<td></td>
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</tr>
<tr>
<td>9. Has the site clearing &amp; platform preparation been completed and ready for Bored pile installation?</td>
<td></td>
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</tr>
<tr>
<td>10. Does the Contractor have all the equipment and tools proposed in the method statement and mobilized to the site for inspection?</td>
<td></td>
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<tr>
<td>11. If casing is to be used, is it the right size &amp; stiffness in accordance with the specification or method statement?</td>
<td>YES</td>
<td>No/NA</td>
<td></td>
</tr>
<tr>
<td>12. Does the Contractor have the proper equipment &amp; facilities to mix &amp; test the quality for the proposed &amp; approved slurry?</td>
<td>YES</td>
<td>No/NA</td>
<td></td>
</tr>
<tr>
<td>13. Is a desander required for the recycled slurry?</td>
<td>YES</td>
<td>No/NA</td>
<td></td>
</tr>
<tr>
<td>14. If a desander is required, does the Contractor have it on site and operational?</td>
<td>YES</td>
<td>No/NA</td>
<td></td>
</tr>
<tr>
<td>15. Does the Contractor’s tremie pipe meet the requirements specified with respect to size, surface conditions, water-tightness, etc.?</td>
<td>YES</td>
<td>No/NA</td>
<td></td>
</tr>
<tr>
<td>16. Do you have all the required bored pile/drilled shaft forms (for logging the subsoil strata, rock socket construction, base cleanliness, concreting log &amp; volume consumption/depth, etc.) that need to be filled out during the bored pile installation?</td>
<td>YES</td>
<td>No/NA</td>
<td></td>
</tr>
<tr>
<td>16A. Are all the forms include all the important details to be filled as per requirements of BS EN 1536:2000?</td>
<td>YES</td>
<td>No/NA</td>
<td></td>
</tr>
<tr>
<td>17. Do you understand &amp; familiarize with all of the necessary forms to record bored pile installation (if not contact the CRE/designer for assistance)?</td>
<td>YES</td>
<td>No/NA</td>
<td></td>
</tr>
<tr>
<td><strong>Trial/test shaft</strong></td>
<td></td>
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<tr>
<td>18. Is the trial/test shaft positioned away from the production shafts or as suggested by CRE/RE or as specified in the contract documents?</td>
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<tr>
<td>19. Has the Contractor performed a successful test hole/trial shaft in accordance with the approved method statement?</td>
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<tr>
<td>20. Can the Contractor complete the boring of a bore hole within 6 hours?</td>
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<tr>
<td>21. Is the proposed construction method of rock socket suitable?</td>
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<tr>
<td>22. Has the Contractor revised the technique and equipment to (and the revision approved) to successfully construct a shaft?</td>
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</tbody>
</table>
### Shaft Excavation & Cleaning

<table>
<thead>
<tr>
<th>Question</th>
<th>YES</th>
<th>NO</th>
<th>NA</th>
</tr>
</thead>
<tbody>
<tr>
<td>23. Is the shaft being constructed in the correct location and within the tolerances specified?</td>
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<tr>
<td>24. Does the Contractor have a benchmark so the shaft can be constructed and inspected to the proper elevations?</td>
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<tr>
<td>25. If core holes are required, has the Contractor taken them in accordance with the specification?</td>
<td></td>
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<tr>
<td>26. If a core hole was performed, was the Rock Core form completed and did the Contractor maintain a log as specified?</td>
<td></td>
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<tr>
<td>27. If the Contractor is using slurry, can they perform tests and report results in accordance with the practice/specification?</td>
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<tr>
<td>28. Is the slurry level being properly maintained in accordance with the practice/specification?</td>
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<tr>
<td>29. Are the proper number and types of tests being performed on the slurry in accordance with the practice/specification?</td>
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<tr>
<td>30. Are you logging the Soil and Rock Excavation forms?</td>
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<tr>
<td>31. If permanent casing is being used, does it meet the specification?</td>
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<tr>
<td>32. If temporary casing is being used, does it meet the specification?</td>
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<tr>
<td>33. Is the Contractor maintaining an excavation log in accordance with the specification?</td>
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<tr>
<td>34. Is the shaft within the allowable vertical alignment tolerances as specified?</td>
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<tr>
<td>35. Is the shaft of proper depth after checking?</td>
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<tr>
<td>36. Does the shaft excavation time meet the specified time limit (&lt; 6hrs)?</td>
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<tr>
<td>37. Does the shaft bottom (cleanliness conditions) meet the requirements in accordance with the practice/specification?</td>
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<tr>
<td>38. Did you complete the Shaft Inspection form?</td>
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</tbody>
</table>

### Reinforcement Cage Placement

<table>
<thead>
<tr>
<th>Question</th>
<th>YES</th>
<th>NO</th>
<th>NA</th>
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</thead>
<tbody>
<tr>
<td>40. Is the rebar the correct sizes and configured in accordance with the project design drawings?</td>
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<tr>
<td>41. Is the rebar properly tied to ensure rigidity and stiffness as required without excessive deformation during handling?</td>
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<tr>
<td>42. Does the Contractor have fixed the proper and adequate spacers for the reinforcement cage to ensure the reinforcement cage is centralized in the hole?</td>
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<tr>
<td>42A. Does the Contractor have an approved method for centering &amp; supporting the reinforcement cage configuration?</td>
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<tr>
<td>43. If the reinforcement cage was spliced/coupled, was it done in accordance with the specification?</td>
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<tr>
<td>44. Is the reinforcement cage secured from settling and from floating (during concrete placement the cage sometimes rises with the placement of the concrete)?</td>
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<tr>
<td>45. Is the top of the steel cage at the proper elevation in accordance with the specification?</td>
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</tbody>
</table>

### Concreting Operations

<table>
<thead>
<tr>
<th>Question</th>
<th>YES</th>
<th>NO</th>
<th>NA</th>
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</thead>
<tbody>
<tr>
<td>46. Prior to concrete placement, has the slurry been tested in accordance with the specification to check quality?</td>
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<tr>
<td>47. If required, was the temporary casing removed in accordance with the specification?</td>
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<tr>
<td>48. Was the discharge end of the tremie pipe maintained in the concrete mass with proper concrete head above it?</td>
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<tr>
<td>49. If free-fall placement (dry shaft construction only), was concrete place in accordance with the specification?</td>
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<tr>
<td>50. Did concrete placement complete within the specified time limit as approved in the method statement/specification?</td>
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<tr>
<td>51. Are you filling out the Concrete Placement and Depth/Volume forms?</td>
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<tr>
<td>52. When placing concrete, did the Contractor overflow the shaft until good concrete flowed out?</td>
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<tr>
<td>53. Were concrete acceptance tests performed as required?</td>
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</tbody>
</table>
### Post Installation Testing

<table>
<thead>
<tr>
<th>Question</th>
<th>YES</th>
<th>NO</th>
<th>NA</th>
</tr>
</thead>
<tbody>
<tr>
<td>54. If shaft is constructed in open water, is the shaft protected for seven days or until the concrete reaches a minimum compressive strength of 20 MPa in accordance with the specification/method statement?</td>
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<tr>
<td>55. Is all casing removed to the proper elevation in accordance with the specification/method statement?</td>
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<tr>
<td>56. If required, has the Contractor complied with the specification related to Non-destructive Evaluation?</td>
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<tr>
<td>57. Is the shaft constructed within the acceptable construction tolerances?</td>
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<tr>
<td>58. Has the bored pile bore Log been completed?</td>
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<tr>
<td>59. Have you documented the pay items?</td>
<td></td>
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</tbody>
</table>

**Notes/Comments**

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### 4.1 General

- There are many types/designs of boring **rigs & drill tools** to suit various types of subsoil conditions & sizes/capacities of bored piles. Refer Catalogues from manufacturers (USA, Europe, etc.) about their drilling capacity (torque, crowd, Kelly/depth capacity, weight, etc.)

- Common drill tools (local make available):
  - Augers (0.45-3m): single cut for soil/rock; double cut for soil/rock & progressive flight for rock.
  - Buckets (0.45-3m): single or double cut for soil/rock or cleaning. Manual or auto opening
  - Core barrel: (0.45-3m): Tungsten bits, roller bits, cutter head, etc.
  - Double wall casing (0.6m -2m)
  - Tremie pipe (0.1-0.3m)

- Bored pile supervisor should learn to identify & recognize various common types of drill rigs & drill tools plus their uses & applications.

- **What should be the criteria for suitable drill rig & tools for a project?** Complete boring within 6hrs, clean base (FHWA Publication IF-99-025) minimum 50% of the base has < 0.5” or 12.5mm of sediment & maximum depth of sediment or debris is 1.5” or 38mm. Proper construction method & handling of slurry?
Important Terminology about bored piling rig & tools

**Kelly Bar** is the rod running through the turn table that drill tools can be attached to. Usually telescoping Table or turn table is connected to power unit to turn the Kelly Bar.

**Power Unit** provides the power to turn the table & Kelly Bar.

**Drill Tool** refers to soil/rock auger/bucket, cleanout bucket, core barrel, etc., that go down the bore hole.

There are many types/designs of boring rigs: mechanical, hydraulic & reverse circulation drill rig, etc. Crane/truck/track/crawler/carrier mounted. Their capacity is mainly indicated by the torque capacity (50 to 600 kN.m), depth capacity (Kelly bar) & weight. Most drill rigs are made in USA, Europe & China, etc.

Applications & limitations of drilling tools for specific subsoil conditions?

[Images of various drill tools and boring rigs]
Bored pile supervisor should learn to identify & recognize various types of drill rigs, drill tools & drill bits, etc., their applications & limitations. Proper tools are required to be deployed to carry out the works to achieve the purpose & to meet the design requirements to have high fsu & fbu plus structural integrity.

Functions, applications & limitations of soil/rock augers & buckets? Note the differences in design of the drill teeth.
Functions, applications & limitations of various types/designs of augers & buckets?

There are many types/designs of boring rigs & drilling tools to suit various subsoil conditions & to meet various construction requirements. Capacity of boring machine: bHP, torque, crowd, etc. Methods of drilled shaft stabilization: temporary/permanent casing, bentonite/mineral slurry, dry/liquid polymer? Types of drilling tools: soil/rock augers, soil/rock buckets, core barrels & bits, cleanout bucket, casing twister, etc. Method of rock socket construction? Base Cleansing methods?
When rock is encountered, borehole can be advanced by core barrel, rock bits, rock augers or combination, depending on rock conditions.

Observe & note the differences between the cleanout bucket and drilling/excavation bucket. Cleanout bucket usually is smaller than the drilling bucket. Why? Base also can be cleansed by air-lifting or down-the-hole pumping methods.
Three common construction methods: **Dry, wet & cased.** Applications of each method? When dry construction (easiest & simplest) is possible?

**Dry Method of Construction**
- **STEP 1:** Drill and Pile<br> - Bentonite Slurry
- **STEP 2:** Casing Placement (Free Fall)
- **STEP 3:** Concrete

**Bentonite Slurry**
- Hydrostatic Pressure
- Bentonite Filter Cake Formed by Clogging and Bridging
- Bentonite Particles
- Soil Grains

**Wet Method of Construction**
- **STEP 1:** Drill and Pile
- **STEP 2:** Removable Casing Placement
- **STEP 3:** Concrete Placement with Slurry

**Cased Method of Construction**
- **STEP 1:** Drill and Pile
- **STEP 2:** Removable Casing Placement
- **STEP 3:** Concrete Placement with Casing

**Dry Method for Bored Pile Installation.**

**Cheapest, most simple & fast excavation method without slurry.**

When is possible & applicable? Case histories?

- At least one test/trial shaft shall be done to confirm applicability.
- Side & base stable without caving, sloughing or swelling over 4 hrs. period after completion of excavation & water accumulation is <300mm/4 hrs. **Trial shaft.** Water & loose material can be removed before concreting (FHWA-IF-99-025). Less than 75mm water at base & <12mm loose material at base will not seriously affect performance. Concreting free fall >20m not allowed usually some tremie pipe or chute is required. Slump >150mm, max aggregate 20mm. **Dry method is usually possible under what subsoil conditions?**

**Dry Construction Method**

**NO (EN) TO USE**
- Inplace shafts will lead to the hole-walls from collapsing.
- Water table is below the 9m elevation.

**PROCESSES**
- Set temporary casing
- **Drill** the shaft excavation
- **Clean** the shaft excavation
- **Position**: the venturing stage
- **Place** the venturing stage

**Dry construction is also possible by installation of casing till bedrock if inflow of groundwater is negligible or can be controlled especially when bedrock depth is shallow, say <20m.**

In case encountered with unforeseen unstable strata, what to do??
When Dry Method for Bored Pile Installation is possible? FHWA requirements? Stability of drilled shaft & ingress of groundwater?
Dry method requires no casing & stabilizing fluid. Stiff cohesive subsoil/rock & no caving/sloughing/swelling strata &/ or WT below shaft tip. No base heave. Inflow water < 300mm/4 hr. Should be confirmed by a trial shaft/bore.

Why wet method is the most common & challenging method?
Wet method or slurry method can be by static process or circulation process. Pros & cons?
When permanent casing is required?

Wet Construction or Slurry-method
(Dry Method: <300mm of water per 4 hrs.; sides & bottom remain stable without caving/sloughing/swelling (4hr wait); loose material & water can be satisfactorily removed). Wet method: >75mm of water per hr.; sides & bottom not stable & require to be stabilized by casing/water/slurry of bentonite or polymer.

Slurry can be mixture of water & polymer or bentonite or other clays. Attapulgite & Sepiolite are typically used in saltwater environment. Must be hydrated & mixed by high speed colloidal mixer. It takes about 24 hrs. to hydrate.
Two Possible wet construction methods

Applicable for what type of subsoil conditions?

Collapsible strata such as water bearing granular soil especially with artesian pressure/very soft

Differences between wet static method & wet circulation method. Static method removes cutting to the surface by drill tools while the cuttings & sand is circulated to the surface through bentonite (usually not polymer, why?) by vacuum pump in direct or reverse circulation method.
Two possible construction methods using casing

In unstable boreholes, the casing should be maintained in advance of boring (CI 8.1.3.8, BS EN 1536)

Dry construction is possible by installation of casing ahead of boring till bedrock if inflow of groundwater is negligible or can be controlled especially when bedrock depth is not deep, say <20m.

Problems of cavity in water bearing granular soil if casing is not installed ahead of boring
When temporary casing & permanent casing method are required?

**Cased Method of Construction**

- When permanent casing is required?
  - Casing method is for very soft & sandy strata with artesian pressure, etc. Should be installed before boring. Telescoping casing when too deep. Some casing say 3m to 6m is usually installed with about 0.6m above ground level in dry & wet method as guide length, for safety purpose & to prevent material from drop in, etc. Methods to install casing? Pros & cons?
4.2 Boring Operation*

Important issues that site supervisors (CRE/RE) should know & understand the basis /principles about boring operation for a specific project are:

• What are the critical ground info sought for planning of boring operation? What are the common difficult/complex/treacherous subsoil conditions for boring operation? What are the common simple/easy subsoil conditions?
• What are meant by suitable/appropriate boring rigs & drill tools for the specific site & subsoil conditions? Check Specs & BS EN 1536.
• What are the acceptable construction tolerances in setting up, pile diameter, plan position & verticality of piles? Check Specs & BS EN 1536.
• What are the boring termination criteria? What is meant by rock socket & its definition/description (BS 5930:2015)? Check GDR & designer.
• What are details about boring operation that should be recorded? Check Specs & BS EN 1536. Purposes of detail records?
• What are the possible risks of excessive ground movement that may endanger workers, adjacent structures & completed piles, etc.? What are the precautions & mitigations required? Check Specs, GI report/GDR/ designer.
• What are the typical defective boring operation?
• What are the important construction requirements of boring operation? Complete boring within <6hrs (why?) or <12 hrs (rock socket), clean base (FHWA Publication IF-99-025): minimum 50% of the base has < 0.5” or 12.5mm of sediments & maximum depth of sediment or debris is 1.5” or 38mm). Complete one pile within 24 hrs./same working day (BS EN 1536). Base cleaning requirements?

4.2a Boring Operation or shaft excavation*

• Critical ground info sought for planning boring operation, shaft stabilization, etc. are: any collapsible/unstable strata (water bearing granular soils/soft strata, artesian pressure, cavities, boulder/hard obstructions, etc.). What are the most difficult/ complex/ treacherous subsoil conditions for boring operation? Easy/simple ones? Why?
• Borehole can be advanced by using many types of drill rigs & tools depending mainly on subsoil conditions (properties & groundwater level & pressure) and design size/depth/ capacity of bored pile. There are many types of drill rigs (bHP, torque & crowd/weight) & drill tools/ equipment plus drilled shaft stabilization methods to suit various site & subsoil conditions for a particular bored pile size/depth.
• Important requirements are boring process shall be as fast as possible (typically should be less than 6 hrs. for small piles & <12 hrs. for rock coring or large pile size >2m diameter). Normally drill rig with high torque capacity (>300 kN.m) can drill faster, deeper & bigger. Drill rig with low torque capacity (<100 kN.m) may have difficulty or slow for rock coring to construct rock socket, especially large diameter (>1.2m) rock socket in fresh hard rock.
• Normally the choice of construction method (wet/dry/cased) & selection of appropriate boring rig & drill tool is the responsibility of the Contractor unless otherwise specified by the designer. However, the Contractor’s proposed construction method & selected rig & tools shall have adequate capacity & power to achieve the specified construction requirements specified with particular reference to time, dimension tolerances, drilled shaft stability & cleanliness.
• Where bored piles are constructed in ground which is likely to deteriorate with time and it is not possible to finish the pile by the end of the working day, a depth equivalent to at least twice the shaft diameter but not less than 1.5m shall be bored the following working day immediately before concrete placement (BS EN 1536 Clause 8.1.1.8).
• During boring, if the ground differs significantly from the design such as presence of unstable strata, high artesian pressure, excessive ground loss or significant loss of drilling fluid, underground piping or unforeseen impenetrable obstruction prior to reach its designed founding level, the designer shall be informed immediately of further action required to continue the work. Refer BS EN 1536.
• The use of explosives for removing obstructions or for socketing piles into bedrock shall not be allowed as it may result in damage to adjacent piles or structures.
• The construction sequence of piles shall be chosen so as to avoid damage to neighboring piles. The minimum allowable distance shall be not less than 3 pile diameter away from any pile concreted less than 24 hrs.
Bored pile supervisor should learn & recognize **various types of boring rigs n tools** plus their applications & limitations.

- The capacity of a rotary drilling rig is often expressed in terms of the maximum torque that can be delivered to the drilling tools and the "crowd" or downward force that can be applied. Other factors can have great impact on the efficiency of the rig in making an excavation, particularly the type and details of the drilling tools, but the torque and crowd are important factors affecting the drilling rate.

- Torque and crowd are transmitted from the drilling rig to the drilling tool by means of a drive shaft of steel, known as the Kelly bar, or simply the "Kelly."

- The drilling tool is mounted on the bottom of the Kelly, which are usually either round or square in cross section, and may be composed of a simple single piece (up to about 20m long) or may telescope using multiple inner sections to extend the depth to which the Kelly can reach. The square Kelly bars often require a worker to insert a pin to lock the outer bar to the inner telescoping Kelly piece, whereas the round Kellers often include an internal locking mechanism. In some rigs the weight of the Kelly and the tool provides the crowd. In others, hydraulic or mechanical devices are positioned to add additional downward force during drilling.

- The site supervisor should have some knowledge to identify boring rig & drill tools used by the Contractor.

- Though the selection of construction methods & choice of appropriate boring rig & drill tools is normally the Contractor’s responsibility, the site supervisor has to check the boring rig & tools used can meet the specified requirements with reference to speed/time and quality (dimensional tolerance and cleanliness), etc. Supervisor also has to make accurate record as to the boring rig & tools on site and being used.

- If the Contractor only has soil augers on site but rock needs to be bored & penetrated, it is important to have this info noted, as the Contractor may say the material cannot be penetrated & was misrepresented or harder than indicated. May not be really so if they have the right tools/bits.

- The supervisor’s accurate, unbiased observation and documentation can help alleviate problems or questions that might arise.

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**Boring operation-cont.**

a) As a bored pile supervisor, he/she should learn:

- The boring termination criteria. Should be specified in Construction drg by designer or Method statement by the Contractor.

- How to log & record boring operation required by BS EN 1536 (CI 10). Strata description as per BS 5930:2015. Details to be logged, purpose, etc.

- How to check pile position & alignment. Techniques & acceptable limits.

- How to determine bored depth?

- How to distinguish/identify soil & rock subsoil? How to determine rock socket depth in bored hole? ASTM (1967), RPM @ max power & down thrust, use of rock drill tool, rock description BS 5930:2015, etc.

- How to assess base cleanliness as required by Specs? Techniques & acceptable limits.
What shall be the pile position tolerance? Practical & technical considerations?

Table – Positional Tolerances of Installed Piles

<table>
<thead>
<tr>
<th>Description</th>
<th>Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deviation from specified position in plan, measured at cut-off level</td>
<td>Land piles: 75 mm (100mm for diam &lt;1m, 150mm for diam &gt;1.5m) 150 mm Marine piles</td>
</tr>
<tr>
<td>Deviation from vertical</td>
<td>1 in 75 (1 in 50) 1 in 25</td>
</tr>
<tr>
<td>Deviation of raking piles from specified batter</td>
<td>1 in 25 (1 in 25) 25 mm</td>
</tr>
</tbody>
</table>

Notes: Table taken from General Specification for Civil Engineering Works Hong Kong Government, 1992. The bracket values are for bored piles according to BS EN 1536.

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Effect of Smear on Load-settlement Behaviour of Bored pile in rock Sockel (Hassan & O'Neill, 1997)

![Graph showing the effect of smear on load-settlement behaviour of bored piles in rock](image)
Cl. 8.3.1.1 of BS EN 1536: The interval between completion of excavation & commencement of concrete placement is required to be kept as short as possible.

Important Issues that Site Supervisor should know during Boring Operation (BS EN 1536)

1. What are the critical subsoil info that site supervisor should find out, if any?
2. During boring, if it is observed to have uncontrolled inflow of water and/or soil into the bore (Cl. 8.1.1.1), what to do? What is happening? Consequences?
3. In case of unfavourable strata when compared with the design bearing layer (Cl. 8.1.1.3) or ground conditions differ from those stipulated in the design (CL 8.1.1.6), what to do?
4. In case of slope surface of bedrock (Cl.8.1.1.4), what to do?
5. Where piles are constructed in ground which is likely to deteriorate with time & it is not possible to finish the pile by the end of the working day (Cl 8.1.1.8), what to do?
6. If a pile bore encounters an impenetrable obstruction prior reaching the founding level (Cl 8.1.1.9), what to do? Can use explosive &/or chiseling?
7. Disturbed soil, debris or any other material that could affect pile performance shall be removed from the base prior to concreting (Cl 8.1.1.12). How?
8. Why the info about WT & artesian conditions plus soil type are crucial for boring planning?
9. What are the effective mitigations vs. unstable strata (Cl 8.1.3.9, caving in & base heave/boiling)?
10. In case of sudden outflow of stabilizing fluid from the bore (Cl 8.1.4.8), what to do?
11. What are the desired properties of bentonite & polymer slurry (CL 8.1.4.1)? Consequence when the limits are exceeded?
12. What is meant by “piston” effect of drilling tool (Cl 8.1.4.9) during boring? Consequences?
13. What are purposes of lead-in tube or guide wall casing (Cl 8.1.14)?
4.3 Drilled Shaft stabilization & Base Cleaning*

Important issues that site supervisors (CRE/RE) should know & understand the basis/principles about drilled shaft stabilization & base cleaning for a specific project are:

1. What are the critical ground info sought for planning of drilled shaft stabilization? What are the common difficult/complex/treacherous subsoil conditions for shaft stabilization? What are the common simple/easy subsoil conditions?
2. When a hole is excavated in the ground, there will be a stress relief resulting in drilled shaft instability, especially below WT with artesian pressure. What are the engineering principles involved?
3. What are the common methods of drilled shaft stabilization? Factors influencing the selection? Principles, QC, applications & limitations of each method?
4. What are the common defects in drilled shaft stabilization? How the defects can affect the structural integrity & capacity of bored piles?
5. What are the common methods of base cleaning? Factors influencing the selection? Principles, QC, applications & limitations of each method?

4.3 Drilled shaft Stabilization & base cleansing-Cont.

a) When a bore hole is excavated, there will be some stress relief in the subsoil resulting in some movement of the surrounding ground and drilled shaft collapse (inflow of water and/or soil into the bore) especially in water bearing sandy subsoil or when there is artesian pressure. Proper drilled shaft stabilization is very important:
   - to reduce zone of stress relief (that will reduce f<sub>u</sub>);
   - to reduce disturbance to or instability of the bearing stratum or the surrounding ground, especially loose granular and soft cohesive ground,
   - to reduce unstable cavities outside the pile
   - to avoid/reduce overbreak or formation of irregular cavities.

b) Usual practice is to use temporary casing for the top few meters as guide length and then use water as drilling fluid if the subsoil is mainly stiff cohesive soil without very soft layers and absent of collapsible water bearing sand/gravel layers. Temporary casing shall be cylindrical and without significant longitudinal or diametrical distortion and also shall be strong enough to take handling stress and ground pressure. For unstable/caving subsoils (uniform non-cohesive soils (d<sub>50</sub>/d<sub>10</sub>&lt;1.5) below groundwater table or loose non-cohesive soils with relative density &lt;0.3 or sensitive clays or soft clay with Cu&lt;15 kPa) especially water bearing sand/gravel with some artesian pressure, bentonite slurry or casing or both is necessary to suppress “boiling” and borehole collapse. In built-up areas or more environment sensitive areas or designed to have high friction, liquid or solid polymer is used instead of bentonite. At all time during boring and concrete placement the level of stabilizing fluid (water/bentonite/polymer slurry) shall be maintained (at least 1m above the groundwater level). For deep very soft substrata, temporary or permanent casing has to be used to prevent necking problem. Casing exceeding 12m deep is difficult and/or problematic to install & extract, unless double/triple casings are used. Nowadays, most bored pile designers specify polymer to replace bentonite for drilled shaft stabilization because bentonite slurry has been reported to have about 15% to 40% reduction in f<sub>u</sub>, in addition to environment problems, especially when poor quality bentonite is used and proper control and tests on sand content, density and pH value of the bentonite slurry are not carried out.
### Supervision of Boring & Shaft Stabilization - cont.

- Favourable soil conditions for boring: Stiff cohesive soils or stiff clay with PI>30%. Why? Unfavourable to $f_{su}$?
- Unfavourable soil conditions: water bearing sandy soil. Why? Worst is with hydraulic gradient or artesian pressure. Why?
- How about boring problems in very soft clay? Very hard rock?
- What are the factors that influence bored shaft overbreak? Mitigations?
- How to ensure base of bored pile is free from soft material or debris? How to assess & verify at site?
- How structural integrity of bored pile can be influenced by concrete quality, concreting practice, reinforcement cage, boring & bored shaft stabilization method? What are the methods to assess structural integrity of completed bored piles?
- What are the common bored shaft stabilization methods? Factors influencing selection of bored shaft stabilization method? Principles, QC, applications & limitations of each method?

### What to record for boring operation?

**BORED PILE INSTALLATION LOG**

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Date/time</th>
<th>Elevation/RL</th>
<th>Soil/rock strata description &amp; observations</th>
</tr>
</thead>
</table>

**Casing information**

- ID: 
- Top Elev: 
- OD: 
- Bot Elev: 
- Length: 
- Type: 

**Elevation/RL**

- GL: 
- WL: 
- Cut off L: 

**Dimensions**

- Soil auger dia: 
- Rock Auger dia: 
- Drill bucket dia: 
- Cleanout bucket dia: 

**Drill Fluid**

- Type: 
- Theoretical vol: 
- Actual vol: 
- Test results: 
- Overbreak: 

**Concrete & Reinforcement**

- Theoretical vol: 
- Actual vol: 
- Overbreak: 
- Reinforcement: 

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1. Project Name: 
2. Contractor: 
3. Logged by: 
4. Inspected by: 

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• The position of bored pile should be checked before boring & after boring is completed. How in practice?
• How to check whether the position of bored is within the permissible tolerance? Permissible Plumbness/verticality of drilled shaft?
• The verticality of drilled shaft should be checked periodically as the shaft is progressed to ensure verticality is within the tolerable limit, especially the first few piles for each boring rig.

**Important QC tests for bentonite slurry (BS EN 1536) to ensure performance are as follows:**

<table>
<thead>
<tr>
<th>QC Tests</th>
<th>Fresh</th>
<th>At Time of ready for re-use</th>
<th>Before concreting</th>
<th>Test method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>&lt;1.10 g/cc</td>
<td>-</td>
<td>&lt;1.15 g/cc</td>
<td>Mud balance (API 13B-Sec 1)</td>
</tr>
<tr>
<td>Viscosity</td>
<td>Marsh value: 32 to 50 sec</td>
<td>32 to 60 sec</td>
<td>32 to 50 sec</td>
<td>Marsh Funnel (946cc) (API 13B-Sec 2)</td>
</tr>
<tr>
<td>Fluid loss</td>
<td>&lt;30 cm³</td>
<td>&lt;50 cm³</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>pH value</td>
<td>7 to 11</td>
<td>7 to 12</td>
<td>-</td>
<td>pH Paper/meter</td>
</tr>
<tr>
<td>Sand contents</td>
<td>-</td>
<td>-</td>
<td>&lt;4%</td>
<td>Sand screen set (API 13B-Sec 4)</td>
</tr>
</tbody>
</table>

(The slurry shall not stand for > 4hrs without agitation. Why?)

Level of bentonite slurry in bored hole should be at least 1.2m above the piezometric pressure level (or 1.8m if polymer slurry).

4 sets of tests for the first 8 hrs, & if the results are OK, 1 set of tests every 4 hrs. Sampling & testing should be just prior to concreting for near the base & at 3m intervals of the slurry column. For polymer slurry, the acceptable results may vary according to supplier specification. Polymer slurry & water requirements?
### Quality requirements for Polymer slurry

<table>
<thead>
<tr>
<th>Property (units)</th>
<th>At Time of Slurry Introduction</th>
<th>In Hole at Time of Concreting</th>
<th>Test Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (kg/m³)</td>
<td>995 to 1018</td>
<td>1000 to 1018</td>
<td>Mud Balance (API 13B- Sec 1)</td>
</tr>
<tr>
<td>Viscosity (min)</td>
<td>45 sec/0.95L</td>
<td>45/0.95L</td>
<td>Marsh Funnel (API 13B- Sec 2)</td>
</tr>
<tr>
<td>pH value</td>
<td>8-10</td>
<td>8-10</td>
<td>pH Paper pH Meter (API 13B- Sec 6)</td>
</tr>
<tr>
<td>Sand content (% by volume)</td>
<td>&lt;1%</td>
<td>&lt;1%</td>
<td>Sand Screen Set (API 13B- Sec 4)</td>
</tr>
</tbody>
</table>

### Importance of Drilled shaft stabilization*

- What is meant by defective drilled shaft stabilization? Works spec requirements? Common malpractice & shortfalls?
- What are the common methods for drilled shaft stabilization? Applications/pros & limitations/cons? QC tests & acceptance criteria? Principles involved?
- When can the Contractor use water as drilling fluid?
- What are the common base cleansing methods? JKR Specs? What are the acceptance criteria? How to assess & verify at site?
- Applications & limitations of water, bentonite & polymer slurry as drilled shaft stabilization methods? Important QC tests & acceptance criteria? Principles?
- Methods to install temporary/permanent casing? Common mishandling/management of casing? Consequences?
- Bentonite slurry must be hydrated for several hrs. & mixed by high speed mixer (shearing) until its viscosity is stabilized. When need desander to remove silt & sand contents before reuse. Why?
- There are many types of polymers; solid or liquid; semi-synthetic or totally synthetic slurry. Require less conditioning before reuse; can be disposed of inexpensively. Need longer time to let suspended cuttings (especially silt) to settle out before base cleaning and concreting. Not effective to control “boiling” due to low density.
Comparison

Functions of slurry: To stabilize open borehole; to retard shaft loosening/stress relief & to facilitate removal of cuttings in air lifting method, etc.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Bentonite Slurry</th>
<th>Polymer Slurry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Best application</td>
<td>Cohesionless soils, some artesian pressure</td>
<td>Clayey &amp; silty &amp; argillaceous rocks</td>
</tr>
<tr>
<td>Mixability</td>
<td>Difficult; must hydrated for several hrs. &amp; mixed with high speed colloidal mixer</td>
<td>Easy</td>
</tr>
<tr>
<td>Mix water sensitivity</td>
<td>Salt water sensitive</td>
<td>Generally OK</td>
</tr>
<tr>
<td>Caking ability</td>
<td>Best</td>
<td>OK</td>
</tr>
<tr>
<td>Suspension ability</td>
<td>Best</td>
<td>OK. Silt takes long time to settle</td>
</tr>
</tbody>
</table>

When Permanent Casing is Required?
Sloughing / caving strata such as very soft soil, cavities, etc.

**QC for slurry? Principles?**

**Mineral Slurry Films in Pores of Open-Pored Formation** (Modified after Fleming and Shadzinski, 1977)

**Effective Pressure** = \( \gamma_s - \gamma_w \cdot \frac{z_L}{z_F} \)

\( \gamma_s \) is the weight of slurry, \( \gamma_w \) is the weight of water.

---

**How Biodegradable Polymer helps to stabilize Drilled Shaft?**

**Application & limitation?**

**Slurry Flow into Formation**

\( z_p = z_w \)

Unit weight of slurry = \( \gamma_s + \gamma_w \)

Unit weight of water = \( \gamma_w \)

\( z_p > 1.5m \)
### Slurry Spec for Rock-socketed bored piles (after Holden, 1984)

<table>
<thead>
<tr>
<th>Bentonite property</th>
<th>Drilling slurry supplied to borehole</th>
<th>Drilling slurry properties in socket during interruptions in drilling</th>
<th>Drilling slurry properties during concreting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bentonite type</td>
<td>sodium montmorillonite</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bentonite dosage: Weight / weight of water, in per cent</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specific gravity (Density in g/cc)</td>
<td>1.03 min 1.08 max</td>
<td>1.03 min 1.08 max</td>
<td>1.03 min 1.20 max</td>
</tr>
<tr>
<td>Sand content (per cent by volume by API method)</td>
<td>0 min 2 max</td>
<td>0 min 2 max</td>
<td>0 min 10 max</td>
</tr>
<tr>
<td>Cake thickness (mm) (filter press test)</td>
<td>1 max</td>
<td>1 max</td>
<td></td>
</tr>
<tr>
<td>pH (field check)</td>
<td>8 min 11 max</td>
<td>8 min 11 max</td>
<td></td>
</tr>
<tr>
<td>Plastic viscosity (PV) from viscometer (centipoise)</td>
<td>4 min 10 max</td>
<td>4 min 10 max</td>
<td>4 min 20 max</td>
</tr>
<tr>
<td>Yield point (YP) from viscometer (Pa)</td>
<td>14 max</td>
<td>7.5 min 14 max</td>
<td>20 max</td>
</tr>
<tr>
<td>10-min gel strength from viscometer (Pa)</td>
<td>2 min 10 max</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marsh funnel viscosity (sec/quart or sec/0.945 L)</td>
<td>30 min 40 max</td>
<td>30 min 40 max</td>
<td>50 - 120</td>
</tr>
<tr>
<td>Fluid loss (ml / 30min.) (filter press test)</td>
<td>10 max</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head of bentonite slurry</td>
<td>1.0 m above piezometric surface</td>
<td>1.0 m above piezometric surface - min 1.5 m above piezometric surface - max</td>
<td>1.0 m above piezometric surface - min</td>
</tr>
</tbody>
</table>

### Range of properties of various fresh-water slurries at time of concreting consistent with maintenance of angle of friction in sand of 0.67° in Lab tests (after Majano et al, 1994)

<table>
<thead>
<tr>
<th>Property</th>
<th>Bentonite</th>
<th>Attapulgite</th>
<th>Emulsified PHPA (&quot;Vinyl&quot;)</th>
<th>Dry PHPA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity (Density in g/cc)</td>
<td>1.06 min 1.18 max</td>
<td>1.04 min 1.25 max</td>
<td>0.995 min 1.01 max 0.995 min 1.01 max</td>
<td>50 - 120</td>
</tr>
<tr>
<td>Marsh funnel viscosity (sec/quart or sec/0.945 L)</td>
<td>32 - 50</td>
<td>28 - 40</td>
<td>33 - 45</td>
<td>50 - 120</td>
</tr>
<tr>
<td>Yield point (Pa) (lb/100 ft²)</td>
<td>0.5 to 3.8 1 to 8</td>
<td>1.4 to 6.2 3 to 13</td>
<td>1.4 to 5.7 3 to 12 1.4 to 5.7 3 to 12</td>
<td>50 - 120</td>
</tr>
<tr>
<td>pH</td>
<td>8 - 10</td>
<td>8 - 11</td>
<td>8 - 11.6</td>
<td>8 - 11.7</td>
</tr>
<tr>
<td>Sand content, API method (per cent by volume)</td>
<td>0 to 8</td>
<td>0 to 14</td>
<td>0 to 1</td>
<td>0 to 1</td>
</tr>
</tbody>
</table>
### Quality requirements for Polymer slurry

<table>
<thead>
<tr>
<th>Property (units)</th>
<th>At Time of Slurry Introduction</th>
<th>In Hole at Time of Concreting</th>
<th>Test Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>995 to 1018 kg/m³</td>
<td>1000 to 1018 kg/m³</td>
<td>Mud Balance (API 13B- Sec 1)</td>
</tr>
<tr>
<td>Viscosity (min)</td>
<td>45 sec/0.95L</td>
<td>45/0.95L</td>
<td>Marsh Funnel (API 13B- Sec 2)</td>
</tr>
<tr>
<td>pH value</td>
<td>8-10</td>
<td>8-10</td>
<td>pH Paper pH Meter (API 13B- Sec 6)</td>
</tr>
<tr>
<td>Sand content (% by volume)</td>
<td>&lt;1%</td>
<td>&lt;1%</td>
<td>Sand Screen Set (API 13B- Sec 4)</td>
</tr>
</tbody>
</table>

**Type of ground:**
- Recommended Viscosity (MFV), Usually about 0.5kg to 2kg per m³ of water.
- Clay, Silt, Shale 32 – 35
- Fine to coarse sand 35 – 40
- Coarse to pea gravel 40 – 50
- Gravel to cobbles 50 – 70

**Important QC tests for bentonite slurry (Clause 6.52 of BS EN 1536) to ensure performance are as follows:**

<table>
<thead>
<tr>
<th>QC Tests</th>
<th>Fresh</th>
<th>At Time of ready for reuse</th>
<th>Before concreting</th>
<th>Test method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>&lt;1.10 g/cc</td>
<td>&lt;1100 kg/m³</td>
<td>-</td>
<td>Mud density balance (API 13B- Sec 1)</td>
</tr>
<tr>
<td>Viscosity (Marsh value)</td>
<td>32 to 50 sec</td>
<td>32 to 50 sec</td>
<td>32 to 50 sec</td>
<td>Marsh Funnel (API 13B- Sec 2)</td>
</tr>
<tr>
<td>Fluid loss</td>
<td>&lt;30 cm³</td>
<td>&lt;50 cm³</td>
<td>-</td>
<td>pH Paper/ meter (API 13B- Sec 6)</td>
</tr>
<tr>
<td>pH value</td>
<td>7 to 11</td>
<td>7 to 12</td>
<td>-</td>
<td>Sand screen set (API 13B- Sec 4)</td>
</tr>
</tbody>
</table>
Formation of Bentonite filter cake in response to different pressure head (after Wates & Knight, 1975)

Concreting through heavily-contaminated slurry (M O’Neill, 1999)
Factors causing weakened base of bored piles.
Drilled shaft not properly stabilized; base not properly cleansed; long lapse of time between base cleaning & concreting, poor concreting practice, etc. Case histories? Mitigations?

Placing Casing into mineral slurry with excessive solid contents
(M O’Neill, 1999)
Pulling casing too fast with insufficient head of fresh concrete  
(M. O’Neill, 1999)

Problems due to casing not installed ahead of boring in unstable strata.

Base Cleansing

- Collapsed materials or debris accumulated at the base of a bored pile may lead to intermixing and inclusions in the concrete or a layer of soft material at the base of the pile.
- Alternatively, foreign materials could be deposited accidentally into the pile. It will be prudent to ensure that a sufficient projection of the temporary casing is left above ground level and that empty bores are properly covered.
- The final cleaning of the pile base may be done with the use of a cleanout bucket followed by air-lifting or down-the-hole pumping.
- The use of a skirted airlift in which debris would be drawn in over a larger area may be more effective (Fleming et al, 1985). On some occasions, the reverse-circulation drill has been used for this purpose. Opinions differ as to the effectiveness and potential disturbance between the use of an airlift pipe and the reverse circulation flush, particularly in weathered rocks which may be susceptible to disturbance or damage of the bonding inherent in the grain structure. If base cleaning is not done properly, potential problems including plastering of the filter cake and presence of large pieces of debris at the pile base may occur.
- Even if the base is free from significant debris, the soil below the base may be disturbed and loosened as a result of digging, stress relief or airlifting.
- Special techniques may be adopted to consolidate and compact the loosened soil. These include pressure grouting with the use of a stone fill pack (Tomlinson, 1994) or Tube a-Manchette (Sherwood & Mitchell, 1989). In addition, shaft-grouting may be carried out to enhance the shaft stiffness and capacity (Morrison et al, 1987). However, Mojabi & Duffin (1991) reported that no significant gain in shaft resistance was achieved by shaft-grouting in sandstone and mudstone. Experience with such construction expedients is limited in Hong Kong.
Base Cleansing-cont

- What is meant by defective base cleansing? How to detect base that is not clean? Works spec requirements? Common malpractice & shortfalls?
- Collapsed materials or debris accumulated at the base of a bored pile may lead to intermixing and inclusions in the concrete or a layer of soft material at the base of the pile.
- Alternatively, foreign materials could be deposited accidentally into the pile. It will be prudent to ensure that a sufficient projection of the temporary casing is left above ground level and that empty bores are properly covered.
- The final cleaning of the pile base may be done with the use of a cleanout bucket followed by air-lifting.
- The use of a skirted airlift in which debris would be drawn in over a larger area may be more effective (Fleming et al, 1985). On some occasions, the reverse-circulation drill has been used for this purpose. Opinions differ as to the effectiveness and potential disturbance between the use of an airlift pipe and the reverse circulation flush, particularly in weathered rocks which may be susceptible to disturbance or damage of the bonding inherent in the grain structure. If base cleaning is not done properly, potential problems including plastering of the filter cake and presence of large pieces of debris at the pile base may occur.
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Base cleansing can be by cleanout /bailing bucket plus air lifting or down-the-hole pumping

AIR LIFT - An air lift is a device that uses air pressure to suck water and soil particles from the shaft bottom. An air line is run to the bottom of a pipe called an air lift pipe. Inside the bottom of the air lift pipe the air is discharged upward causing the water in the pipe to flow upward, discharging out of the top of the pipe. As water flows upward it draws in more water at the bottom of the pipe creating a suction. This pulls the finer material up with the water, cleaning the bottom. Pros & cons of this method of base cleansing?
4.4 Reinforcement cage Placement

a) Generally, main longitudinal reinforcement, $A_s = 0.5\%$ to 0.25\% (BS EN 1536, Cl 7.6.2.2) or more if designed as tension pile or large lateral is anticipated. The minimum main reinforcement shall be 4 bars (ribbed bars) of at least 12mm and the spacing between bars or bundles shall be 100mm to maximum 400mm and evenly spaced. Actual $A_s$ required depends on tension or lateral loads or moment on pile due to ground movement, etc.

b) Lateral helical or transverse reinforcement should be at least 6mm or one quarter of the maximum diameter of the main longitudinal bars at 100mm to maximum 300mm spacing.

c) BS EN 1536 also recommends that minimum concrete cover to reinforcement should be minimum 75mm when the bored piles are constructed without a (full) casing, etc. The concrete cover may be reduced to 40mm to the external face of a permanent casing or lining where used.

d) Cover to reinforcement usually is about 75mm in dry holes, non-aggressive subsoil & grade of concrete $>35$ is used. For wet holes cover should be 75mm to 125mm or moderate aggressive subsoil in dry holes. For aggressive subsoil in wet holes, special treatment by specialist is required. How to verify the cover at site?

e) AASHTO (2007) recommends that normally $A_s$ should be 1\% to 2\% (mainly for bridges, retaining walls and for slope stabilization), but may be 3\% in high seismic zones or high lateral load sites (soft ground/unstable slope).

f) For piles to be selected for PDA tests, full length reinforcement is required. Force induced on pile head by hammer is preferred $>2Qd$ by hammer weight as heavy as possible (1\% to 2\% of $2Qd$) & drop height as low as possible (<2m). The induced dynamic compressive stress ($f_c$) & tensile stress ($f_t$) should be checked by WEAP or Broms method to ensure they are within the permissible limits.

---

**Supervision of Reinforcement Cage Placement**

- What are the purposes of reinforcement cage for bored piles?
- Requirements of minimum amount of reinforcement (bar size & spacing) as per BS EN 1536?
- Requirements of clear spacing of longitudinal rebars and transverse bars? Requirements of reinforcement cage?
- What are the good construction practice for fabrication and placement of reinforcement cage for bored piles?
- What should be the cover to the main reinforcement bars in aggressive & non-aggressive ground? How to ensure the required cover is achieved at site to ensure the correct central position in the hole? Min 3 spacers per level at about 3m vertical intervals.
- What are the common defective construction for fabrication & placement of reinforcement cage? Not adequately tied by wires which become dusty & broken after left too long at site. Inadequate stiff due to too small rebars. Too clouded with net spacing less than 100mm holes at lapping without using proper couplers. Rebars contaminated with oil and soil. Effects & consequences of these defects? Mitigations?
- Effects of sonic logging pipes (3 to 5 nos of steel pipes of about 40mm diameter) to reinforcement?
Spacers should be durable materials such as plastic rings or at least grade 35 concrete rings. At least 3 spacers per level spaced at <3m vertically. Quality requirements for spacers?

How to ensure the reinforc cage is concentric within the casing with the necessary cover? Pile position?
Improper assembly & handling of rebar cage. How these can affect bored pile performance?

Unless otherwise specified by design to cater for ground movement/tension/bending, etc., the minimum amount of longitudinal reinforcement as recommended by BS EN 1536 shall be as in the following Table:

- Too much steel can do more harm than good. Why?? Opening or spacing between rebars should be as big as possible but not more than 400mm. Why?
- AASHTO (2007) recommends that normally $A_s$ should be 1% to 2% (mainly for bridges, retaining walls and for slope stabilization), but may be 3% in high seismic zones or high lateral load sites (soft ground/unstable slope).
- For bored piles subject to compression, the minimum main reinforcement bar shall be 0.5% of the pile cross-section area & shall be not less than 10m long below the cut-off level (SS CP4:2003). Why?

<table>
<thead>
<tr>
<th>Nominal pile cross section, $A_c$</th>
<th>Minimum area of longitudinal reinforcement, $A_s$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_c&lt;0.5m^2$ (or pile diameter, D&gt;0.8m)</td>
<td>$A_s&gt;0.5%A_c$</td>
</tr>
</tbody>
</table>
• Practical minimum $A_s$ is normally 0.5% for bored piles in stable ground with negligible bending and tension. Only deformed rebar with $f_y \geq 410$ MPa should be used if bentonite/clay/polymer slurry is used to stabilize drilled shafts. Rebars should be bundled if necessary to ensure clear net holes of more than 100mm x 200mm to enable concrete to flow out the reinforcement cage or spacing of rebars (main & transvers) should be 10 to 20 times the maximum aggregate size. Cover for reinforcement recommended by AASHTO for $W/C=0.4$ to 0.5 concrete for bored piles of 1m, 1m to 1.5m & >1.5m should be respectively 75mm, 100mm and 150mm. If $W/C>0.5$, the cover should be increased by 20%. This is because higher $W/C$ will result in higher concrete permeability & more shrinkage.

• Joints/couplers in reinforcement bars shall be such that the full strength of each bar is effective across the joint. Reinforcing bars shall not be welded at or near bends, but spot welding is permissible (BS EN 1536).

• The reinforcement cages shall be such that the cages can be lifted and installed without permanent distortion and that all bars remain in the correct position.

• To ensure the concentric position of the reinforcement cage and the necessary concrete cover, proper spacers/centralizers shall be arranged symmetrically around the cage with at least 3 spacers at each level and level intervals of not more than 3m. Spacers shall be designed and manufactured using durable material (plastic or at least grade 35 concrete).

• The reinforcement shall be installed and placed in the borehole as soon as possible after the cleaning of the pile bore. The installation of the reinforcement has to provide for its alignment with the pile axis and maintain the correct concrete cover over its full length. During concrete placement, the reinforcement level shall be maintained to provide the specified projection above the final cut-off level with 0.15m accuracy.
4.5. Concreting

a) Just before concreting, how the borehole & base shall be cleansed as specified?

b) What should be the desired properties for concrete mix for bored piles?

c) Usually grade 35 to 45 concrete is specified. Minimum cement content required is 325 kg/m³ & 400 kg/m³ for dry holes & tremie concreting respectively. Allowable compressive stress $f_{ca}=0.25f_{cu}$, but $f_{ca}$ usually discounted about 20% for uncertainty in tremie concreting (CP for Foundations (2004), HK). Other concrete properties specified: W/C=0.4 to 0.5 with slump 150mm to 250mm & with superplasticizer. For large & long bored piles or concreting taking more than 2hrs to complete, retarder admixture may be needed to ensure slump of the concrete near the base remains more than 100mm at the end of concreting. Why?

d) Criteria of cleanliness of base; 50% of base <12mm sediments and max depth of sediments< 38mm (SCDOT). How to check?

e) Concreting ASAP after reinforcement placement n base cleansing. Concreting shall be completed within 2hrs unless? Tremie pipe of 150mm to 250mm should be used and min embedment of tremie pipe in fresh concrete > 3m or mini 2m above hydrostatic pressure. Concrete flow should be positive & continuous. Tremie pipe should be smooth, clean, watertight and with ample strength. Why?

f) What are the common defective concreting for bored piles related to tremie pipe? Consequence?

g) What are the usual methods to assess and determine defective or poor quality concrete? How to check & control defective shaft (overbreak, contamination, etc) from concreting?
4.5 Concreting- cont.

- What is meant by zero defect construction of concrete placement? Works spec requirements? Common malpractice & shortfalls? Mitigations?
- Usually grade 35 to 45 concrete is specified. Minimum cement content required is 325 kg/m³ & 450 kg/m³ for dry holes & submerged/tremie concreting respectively. Other requirements and characteristics of concrete mix for bored piles that should be designed and specified or indicated on design drawings are as follows:
  - Excellent workability (slump>150mm to 250mm); Self weight compaction;
  - Resistance to segregation, bleeding & leaching; Controlled setting; Good durability

Concrete shall appear:
- To be homogeneous & have a high resistance against segregation;
- To be of high plasticity and good cohesiveness;
- To have good flowability;
- To have the ability to self-compact; and
- To be sufficiently workable for the duration of the placement procedure, including the removal of any temporary casings.

What are the required/desired quality of concrete mix for bored piles to achieve good performance? Types of QC tests? Defective mix: bleeding, non-cohesive, segregation. Common causes for the defects?

Base grouting in rock socket may not increase fsu & f_{bu} if the fractures/joints are infilled with sand/clay. Grouting can increase fsu & f_{bu} in gravelly & sandy subsoils.

For large & long bored piles or concreting taking more than 1.5 hours to complete, retarder admixture should be used to ensure slump of the concrete near the base remains more than 100mm at the end of concreting. Why this is very important? How to check the concrete is suitable with high quality for tremie concreting?

- Consistency ranges for fresh concrete in different conditions (BS EN 1536) are as follows:

<table>
<thead>
<tr>
<th>Flow diameter range, mm</th>
<th>Slump range, mm</th>
<th>Typical conditions of use (example)</th>
</tr>
</thead>
<tbody>
<tr>
<td>460&lt;D&lt;510</td>
<td>130&lt;H&lt;180</td>
<td>Concrete placed in dry hole conditions</td>
</tr>
<tr>
<td>530&lt;D&lt;600</td>
<td>H&gt;160</td>
<td>Placed by pumping or placed in submerged conditions under water by tremie pipe</td>
</tr>
<tr>
<td>570&lt;D&lt;630</td>
<td>H&gt;180</td>
<td>Concrete placed by tremie pipe in submerged conditions under a stabilizing fluid</td>
</tr>
</tbody>
</table>

Note: The measured slump (H) or flow diameter (D) is to be rounded off to the nearest 10mm.
• Concreting should be carried out immediately after the base is cleansed. Concreting should be continuous and uninterrupted. Records/measurements of consumption of concrete per unit depth (in 1m to 3m intervals) should be taken and plotted with depth/location of temporary casing & toe of tremie pipe plus the theoretical concrete volume to check localized cavities or overbreak.

• When the final casting level is well below the working platform, the fresh concrete should be protected against contamination from above by concreting above the cut-off level (at least 0.5m), by backfilling the empty bore with suitable material or by maintaining a stabilizing fluid inside the empty bore until the concrete has set. Case histories?

• The tremie pipe shall be water tight at all its joints and smooth to allow free flow of concrete. The internal diameter of tremie pipe should at least 150mm or 6 times the max aggregate size (whichever is the bigger), but the OD (with joints) not to exceed 0.6 times the inner width of reinforcement cage or 0.35 of the inner diameter of casing (Cl 8.3.3). The tremie pipe shall extend to the bottom of the pile at the commencement of the concreting. A bung or plug of suitable material, to prevent mixing of concrete with any fluid in the tremie pipe, shall be inserted into the pipe before commencement of concrete placement.

• As the first batch, a cement enriched mix or a charge of cement mortar may be used to lubricate the tremie pipe. To allow the first concrete to leave the tremie pipe, the pipe shall be lifted slightly, not exceeding a value equal to the inner diameter of the tremie pipe. Placement shall then proceed quickly to fill the entire base of the pile so that no concrete which may have segregated at the beginning of the discharge is trapped. During subsequent placement the tremie pipe shall be withdrawn progressively as the concrete rises in the bore. The tremie pipe shall at all times remain immersed in unset and workable concrete (min 1.5m or >2.5m for pile diameter D>1.2m) which has previously been placed and shall not be withdrawn from the concrete until the completion of the concreting process. Tremie pipe shall not be extracted too quickly as the resulting suction can lead to pile imperfections.

• Concrete shall be placed uninterrupted & continuously until concrete at the top of shaft is free of water, soil & debris, & uncontaminated concrete extends to the top of shaft elevation.

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**How f_{cu} is mobilized in sand & clay?**

*Importance of lateral pressure of fresh concrete on the wall of bored pile; how it can be affected by rebar spacing & slump. FHWA (2010) research findings.*
Ultimate friction, \( f_{su} = K_s N \)

Local published values

1. Toh CT (1989) reported that \( K_s \) varied from 5 for \( N < 20 \) & as low as 1.5 for \( N > 200 \)

2. Tan YC (1998) reported that \( K_s = 2.6 \) but \( f_{su} \) limited to 200 kPa

3. Neoh CA (1998) suggested allowable \( f_s \) for limestone bedrock, \( f_{sa} = 300 \) kPa for \( RQD < 50\% \), \( f_{sa} = 600 \) kPa for \( RQD = 50-70\% \) & \( f_{sa} = 1000 \) kPa for \( RQD > 70\% \)

4. Chang & Broms (1991) suggested \( K_s = 2 \) with \( N < 150 \) only.

This graph (Brown, 2002) shows that bentonite slurry has lowest while liquid polymer slurry has high \( f_{su} \). How bentonite slurry can reduce \( f_{su} \)?
Definition of vertical & horizontal effective stress.

Unit friction, $f_{su} = u \times$ normal stress

Slump Loss with time relation (M O'Neill, 1999)

Why workability/slump of fresh concrete is important from beginning until completion of concreting?
Cl. 8.3.3 Concreting under submerged conditions: tremie pipe shall be clean, smooth & water-tight; ID >150mm or 8x max. aggregate size; OD<0.35x ID of casing or 0.6x ID of reinforcement cage. A bung or plug of suitable material, to prevent mixing & leaching of concrete with any fluid in the tremie pipe, SHALL be inserted into the pipe before commencement of the concrete placement. The tremie pipe should always be immersed into concrete >1.2m to 2.5m (for D>1.2m). The tremie pipe should not be pulled/extracted too quickly to result in suction that can lead to pile imperfection.

Cl. 8.3.3.12 of BS EN 1536: To allow the first concrete to leave the tremie pipe, the pipe SHALL be lifted slightly (< ID of tremie pipe). This is to mitigate the Problem of leached concrete due to excessive initial lifting (from LCPC, 1986).

For water bearing sandy strata, casing has to be in advance or ahead of boring, otherwise cavity may be formed if proper fluid stabilization is not provided.
**Good Concreting Practice:**

- ASAP after placement of reinforcement cage, concreting should be completed within 2 hrs. unless approved with retarder to ensure slump >100mm before completion of concreting.
- Tremie pipe should be smooth, clean & watertight with ID>6x max aggregate size or 150mm (min) & OD (with joints)<0.35x inner casing or 0.6x inner reinf. cage diameter.
- Concreting shall be continuous & uninterrupted. Concrete plug?
- Tremie pipe embedment>3m. Positive pressure.

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**Defective concreting**

How this can happen?

Cavities in bored piles; rebars dislocated; poor concrete quality, etc. These are common defects & risks for bored piles.

Need to be aware of the potential existence of the problems; need to understand how these can happen; factors that can contribute to these problems; how to verify, detect & assess these problems. If the problems are encountered, how to rectify?

How to prevent & detect necking? Factors that can cause such problems?

Possible consequences? How to assess & detect?

Remedy? Mitigations?

- Based on SI results to identify potential strata for bored shaft collapse
- Provide casing/polymer, etc.? Refer case histories.

- Good construction practice;
- Supervision by qualified engineer;
- Check by concrete consumed/m, inspection through excavation (<4m deep), sonic logging, PIT (LSIT, ASTM D5882) or coring, etc.

Remedies if detected?
* How this can happen?
* Possible causes?
* How to detect & identify?
* Remedy?
* Mitigations?

Problems & ricks of bored piles socketed in limestone bedrock
Common Defective concreting
Problems of concreting for large diameter & long bored piles. Why concreting shall be continuous & uninterrupted? Problems of concreting with more than 1.5hrs? Problems of using grade 40 concrete?
1. Importance of preparation/measurement of depth-volume of concrete for each bore pile?

2. How to determine concrete level in bored pile during concreting? Level of casing should be recorded each time the concrete level is determined.
Cl.8.3.1.14: It can be necessary to contain the fresh concrete in soft ground ($c_u < 15$ kPa) along a part or whole of the pile length by installation of sacrificial lining or permanent casing.

Cl.8.3.1.15: During concreting, the volume placed & the level of concrete inside the bore SHALL be checked & recorded (at least once after every pour or before or after a temporary casing is lifted).
4.6 Post installation Testing*

• Two types of post installation tests: INTEGRITY tests or non-destructive tests to evaluate the soundness or integrity of the constructed bored piles & LOAD tests to determine the load capacity of the bored piles.

• As the performance (structural integrity & capacity) of bored piles is very sensitive to construction, post installation testing to verify & validate the structural integrity conditions (3-5%) & capacity (1-2%) shall be properly planned & carried out. What are the common types of tests & test standards? Selection criteria of piles for tests? Test result interpretation? Requirements for preliminary & working pile tests? Local practice? CP requirements? EC7 & SS CP4:2003 recommendations??

• Any defective or faulty constructions, which invariably can happen, during any construction process of bored pile installation will result in defects in structural integrity, which can be checked & verified by tests such as cross-hole sonic logging (CSL) by ASTM D 6760, LI/SIT/hammer test/shock/impact/sonic echo (ASTM D5882), excavation (for shallow depth), coring, etc.

• Common types of load test for bored piles: SLT/MLT, Bidirectional load tests (O-cells or C-cells), PDA/HSDPT, statnamic load test, etc. Applications & limitations for each type of tests? Test standards? CP requirements? Maximum test load (MTL) for preliminary & working pile tests? Problems of MTL>4000T? Serious foundation problems for supports of kentledge. EC 7 & CP 4:2003 requirements?? Why? Case history of failure?

• Can Bidirectional load tests be considered SLT? Advantages of Bidirectional load tests (T-cells, O-cells & C-cells) for load tests of bored piles?

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### Classification of Pile Tests

- **Preliminary Pile Test (2.5 to 3 Qd)**
  - Design Validation
  - Static Tests
    - Compression
    - Tension
    - Lateral
  - Dynamic Tests
    - MLT, CRP, QMLT, O-cell, C-cell

- **Working Pile Test (2 to 1.5 Qd)**
  - Proof Tests
  - Static Tests
  - Dynamic Tests
    - PDA, Statnamic
  - Pile Shaft Integrity Tests
    - Sonic Impact Test, Sonic Logging Test

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- Qd=design working load
- MLT=maintained load test
- QMLT=quick MLT
- CRP=constant rate of penetration
- O-cell/C-cell=bidirectional load tests
Concrete Coring

Coring is not always definitive in ruling out defects. Defects can be missed by the coring tool.

Crosshole Sonic Log Test Results

Sample CSL Profile

- Profile name designated by the tube number in each pair, tubes are numbered clockwise from the top.
- Depth is from the top of concrete
- Distance is distance between tubes

Accuracy possible defect at 69 feet
- Increase in arrival time (vel)
- Decrease in velocity (speed)
- Reduced energy blocks out reflected waveform plot

Velocity Reduction, VRL (%)

<table>
<thead>
<tr>
<th>VRL</th>
<th>Signal Disturbance/Strength</th>
<th>Concrete Rating</th>
<th>Indicated Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-10</td>
<td>none/normal</td>
<td>Good (G)</td>
<td>Acceptable-quantity concrete</td>
</tr>
<tr>
<td>10-20</td>
<td>low-energy</td>
<td>Questionable (Q)</td>
<td>No core damage,</td>
</tr>
<tr>
<td>&gt;20</td>
<td>severe/tough</td>
<td>Poor/Defect (PD)</td>
<td>Internal damage,</td>
</tr>
</tbody>
</table>

No signal, No尤为

>60 severe/tough        energy reduction ≥ 12 dB Water (W)

Source: FHWA Drilled Shafts Manual NP-10-016

Sonic Echo Test

Accelerometer

Oscilloscope

Hammer

Oscilloscope Screen

Time (milliseconds)

Propellant & Load Cell

L = FRIE LENGTH C = WAVE VELOCITY IN CONCRETE (13.1 FT/MIllsec)

Start of blow

Reflection from base of drilled shaft

Load Cell

Test Socket

Reaction Socket

Statnamic Load Test

Laser

Movement

Detector
Pile Load Testing*

- Types of load test:
  a) SLT: CRP, MLT (ASTM D1143 for compression, D3689 for tension, D3966 for lateral).
  b) PDA/HSDPT (ASTM D4945-12).
  c) Bidirectional load tests (SS CP4:2003 recognizes it as SLT). Refer www.YJACKpiletest.com
  d) Statnamic load test

- Applications & limitations of these tests? Test standards?

- CP requirements: frequency of tests? Interpretation of results?

- How to select piles for tests? Basis? Results of testing are not everything unless the results can be representative for the untested ones on safe side. How?
  Comprehensive inspection & recording for drilling (pressure, rate/timing & observation of water return/cuttings, etc.) & grouting (pressure, vol consumed, etc.) are useful guides to select representative piles for tests.

- PDA shall be conducted & interpreted by Dfi/FQA accredited tester (Advanced Level). Compliance with proper standards (ASTM D4945-12) is important. Why?

- For piles to be selected for PDA tests, full length reinforcement is required. Force measured on pile head by hammer >2Qd by hammer impact with hammer weight as heavy as possible (1% to 2% of 2Qd) & drop height as low as possible (<2m). The induced dynamic compressive stress (fc) & tensile stress (ft) should be checked by WEAP or Broms method to ensure they are within the permissible limits. How?

- Reporting format/presentation & interpretation for results of pile tests?

- WCGW in pile tests? Case Histories?
Pile Testing

- Importance of scope of inspection & records for selection criteria of piles for tests? Design is not everything until and unless it is validated by testing, which is also not everything until & unless the result of testing can be representative for the untested ones.
- When instrumented test pile should be carried out? Purposes? How?
- How to identify/select bored piles that are likely have structural integrity problems (with particular reference to subsoil conditions, boring operation, bored shaft stabilization method, placement of reinforcement cage & concreting)? What are the good construction practice to mitigate these problems?
- What are the applicable/suitable pile load test methods for bored piles of small capacity (<300 T), medium capacity (300 to 1000T), large capacity (1000 T to 2000 T) & very large capacity (>2000 T)?
- What are the applications & limitations for SLT/MLT (ASTM D1143), Bidirectional load tests (CP 4, SS), Statnamic load Tests, LSIT/PIT (ASTM DS882-00) & HSDPT (ASTM D4945-12)? Test standards?
- What are the common defects & errors for pile load test methods such as SLT/MLT, Bidirectional load tests, Statnamic load Tests & HSDPT? The requirements of test standards commonly ignored Or not fully complied with?
- What are the common tricks & malpractice in pile tests for conventional contract with quantities remeasurable, direct nego design & build contract with fixed sum or quantities remeasureable? Mitigations?
- How to determine the ultimate load from load test results?
- What is the main uncertainty of load test results?

What is Bi-directional Testing?

A sacrificial jacking system is cast within the pile body. Upon application of load, the pile is separated at selected balance point into two sections and load is applied to both sections simultaneously and reacting against each other in two directions; upward against upper skin friction and downward against base end bearing and lower skin friction. BD testing do not require reaction beams, anchor piles or Kentledge.

**Singapore CP 4:2003 considers BD tests as SLT.**

For large load test (Qd>2000T or max test load>4000T), bidirectional load test is faster & cost saving is about 30% to 50% when compared with conventional MLT.

Refer website: [www.YJACKpiletests.com](http://www.YJACKpiletests.com) for more info & videos about bidirectional load tests.
Bi-directional testing of piles—a brief history

Tomer Cell (T-cell)
• Patented technology in Europe (1978)
• Less popular worldwide

Osterberg Cell (O-cell)
• Patented technology in USA (1989)
• Popular worldwide

Capsule Cell (C-cell)
• Upgraded from T-cell
• Patented technology in China (2007)
• Very popular in China due to several advantages

What is O-cell and C-cell?

O-cell
The loads are applied by using hydraulic jack units. Need thick MS plate due to high pressure.

C-cell
The loads are applied by using hydraulic capsule units. Need thin MS plate due to low pressure.
C-cell Setup Diagram

(C-cell supper press jacks should be placed at balance point)

- Reference Beam
- Data Acquisition System or SLPBT
- Dial Gauges or LVDTs
- Telltale for Pile Top
- Telltale for C-cell Top Movement
- Telltale for C-cell Bottom Movement
- Hydraulic Pump & Pressure Gauge

How to locate the balanced point?

C-cell Super Press Jacks

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Fig. 10: Methods to Determine Ultimate Capacity of Pile from Load Tests
**Loading Procedure & acceptance criteria (JKR practice)**

- 1st cycle to WL in 4 increments & unload it in 4 decrement.
- 2nd cycle to 2WL ($Q_m$) in 4 increments & unload it in 3 decrements. Increments of load not applied until rate of settlement < 0.05mm in 30 min. $Q_m$ shall be maintained for at least 6 hrs. $S_{res}$ taken (after removal of $Q_m$) till at least 1hr. (Section 10 of JKR Standard Spec for Road Works:2010)

**Acceptance criteria:**

- $S_{res} < D/120 + 4$ or 12.5mm, whichever is the lower.
- $S_{WL} < 12.5mm$
- $S_{2WL} < 38mm$ or 10% pile size, whichever is the lower value.
- Basis for the above loading sequence and interpretation of SLT results?
- **Max test load ($Q_m$) shall** be till $Qu$ or 2.5 to 3.0 times the design working load (WL) for preliminary load tests & 2 to 1.5 times for working load tests (SS CP4:2003). Basis?

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**Loading Procedure & acceptance criteria (HK practice)**

- 1st cycle to WL in 2 increments & unload it.
- 2nd cycle to 2WL ($Q_m$) in 4 increments & unload it. Increments of load not applied until rate of settlement or recovery < 0.05mm in 10 min. $Q_m$ shall be maintained for at least 72 hrs. $S_{res}$ taken (after removal of $Q_m$) <0.1mm in 15 min.
- Acceptance criteria: $S_m < Q_m L/A_p E_p + D/120 + 4$ & $S_{res} < D/120 + 4$ or $.25S_m$
- Basis for the above loading sequence and interpretation of results?
- In MLT, loads should be maintained constant at each of at least 6 stages for a specified duration and until displacement <0.1mm/20 minutes (BS EN 1536, Cl 9.3.2)
5. Works Specification

- Purposes & scope of standard works spec & addendum spec? Materials requirements (stabilizing fluid, casing, reinforcement, concrete cover & corrosion protection, centralizers, coupler/joint, concrete mix, etc)? Construction works requirements (boring, shaft stabilization, placement of reinforcement cage, concreting, grouting, etc)? Acceptable types of QC tests/design validation/performance testing & acceptance criteria? Types of works spec? End product or procedural or both?
- Design & construction controls?
- Construction/boring methods: acceptable types of boring rigs & drill tools to suit specific design, site & subsoil conditions, construction techniques (cased, uncased or stabilizing fluid or combination), Record details required? Types & frequency of QC?
- Reinforcement: construction & technical requirements? Types & frequency of QC tests/checks? Scope of inspection & records?
- Concreting: suitable concrete mix/types & required properties, Types & frequency of QC for concrete mix? Concreting method & QC tests/checks. Record details required?
- Post installation testing: acceptable types & methods of tests for structural integrity & performance/capacity conditions. Interpretation of results & acceptance criteria, etc.
5. Works Specification for Bored Pile Construction

- Generally, spec only tells us to do this & to do that based on researches & experiences of experts. A supervisor has to find out the basis & to understand why need to do this & to do that. E.g. Acceptance criteria for bentonite slurry & load tests, etc.
- Basic contents of spec for bored pile construction are:
  - Works description: the scope of works involved
  - General requirements for setting up tolerance, records, method statement, etc.
  - Material requirements & QC for concrete, reinforcement (coupler, spacer), permanent/temporary casing, bentonite & biodegradable polymer slurry, etc.
  - Boring operation. Requirements for machine & tools, workmanship for size /depth/verticality, records/logs of subsoil conditions, drilled shaft stabilization requirements, base cleaning & inspection, etc.
  - Construction requirements for placement of reinforcement & concreting
  - Requirements & acceptance criteria for post installation testing for integrity & capacity
  - Specifications, should not needlessly restrict contractors in their choice of bore rig, drill tools, equipment or construction method, but Contractor’s choice should meet workmanship & quality/performance requirements specified. To achieve a cost-effective project, the specifications must permit as much flexibility to the contractor as possible, within the constraints of the project and the existing site conditions. E.g.?

A supervisor has to be well-versed with the works specification & has the technical know-how to carry out the tests/measurements or at least know what is right & what is wrong.

- Construction Tolerances - The specification contains all the allowable shaft tolerances, such as location, verticality (plumbness), cutoff elevation, rebar stick up, and diameter. Failing to meet these tolerances will result in a rejected shaft.
- Drilling and Excavation Methods - The specification contains the allowable procedures for the different shaft drilling methods. They also provide the requirements of each procedure. The contractor must adhere to these requirements or once again the shaft could be rejected.
- Rebar, Concrete Placement, and Temporary Casing Removal - The specification contains the allowable procedures and requirements for the above operations. Again, the contractor must adhere to these requirements or risk rejection of the shaft.
- The specification also contains additional miscellaneous information on shaft requirements that the supervisor should become familiar with. A good working knowledge of the specification is essential in proper bored pile or drilled shaft construction monitoring.
Bored Pile Construction Disputes due to Spec

• Problems of only standard spec of bored pile construction is included in Contract document without addendum spec to suit the specific design requirements, site & subsoil conditions. Typical examples & case histories? Contractual implications & construction disputes of standard spec (without design input) such as “appropriate boring plant & tools shall be deployed”, “suitable bored shaft stabilization method shall be used”, “grade 40 concrete of high slump of more than 150mm shall be used”, “rock socket shall be constructed by approved method”, “bored hole shall be fully stabilized by temporary casing”, etc.
• Construction dispute about “All bored piles shall be 1m diameter & the bored hole including rock socket shall be nor less than 1m”
• Construction disputes related to property damages of nearby buildings
• Construction disputes related to boring, placement of reinforcement & concreting.
• Construction disputes related to method statement.
• Contractual implications when Contractor submits method statement during tender stage for Engineer’s design Tender.

6. Miscellaneous issues

• Should bored pile construction be completed within the same working day (<24hrs)? In case the Contractor takes more than one day to complete due low capacity of boring rig & poor quality of drill tools or machine breakdown, what should site supervisors do?
• Rock socket constructed is typically smaller than the ID of temporary casing by about 150mm, which is obviously smaller than the design rock socket diameter. Is it acceptable? Should it be compensated for frictional area by equivalent deeper socket?
• Can bored piles be constructed in rake say 1:5 (V) to take lateral loads? What are the construction requirements needed to be met when constructing raked bored piles?
• If end bearing of bored pile in rock socket (moderately weathered granite) is considered (f_{b_{ub}}=10,000 kPa), what are the precautions & tests that need to be carried out to validate the design?
• What are the problems & mitigations when constructing rock socket in inclined bedrock & pinnacled bedrock such as limestone?
6.1 Common defective construction for Bored piles?

No problem is a big problem. Why? Important to be aware & understand the construction problems (mainly due to unexpected subsoil conditions) & principles involved. Effective mitigations?

1. **Boring problems**: Old & low capacity of boring rigs &/or worn out or poor drill soil/rock augers/bucket that take >6hrs to complete boring. Contract/Spec/CP requirements? Contractor's contractual obligations? Consequences?

2. **Improper drilled shaft stabilization method & procedure** to take care the hole collapse problems in treacherous & collapsible strata have resulted in low f<sub>su</sub> & integrity problems. CP/Spec requirements? Contractor's contractual obligations? Consequences?

3. **Inadequate or poor base cleaning method** has resulted in low f<sub>bu</sub> and structural integrity problems. How to check? CP/Spec requirements? Contractor's contractual obligations?

4. **Reinforcement cage is not properly fabricated** resulting in excessive deformation & loosening of rebars, improper cover & localized small spacing (<100mm), etc. CP/Spec requirements? Contractor’s contractual obligations? Consequences?

5. **Poor concreting technique** such as pulling temporary casing without adequate fresh concrete head, etc., may result in integrity problems. CP/Spec requirements? Contractor's contractual obligations? Consequences?

6.2 BORED PILE INSTALLATION CHECKLIST

- **Role of R.E.**
  - Inspect & ensure conformity with Spec & drgs
  - Record all construction process & report any variation or non-conformity to the designer.
  - Technically well-versed with drawings, specs, BQ & design concepts, mitigations against WCGW at site, etc.

- **Pre-construction controls**
  - Check spec, installation procedure & scope of inspection & records.
  - Check & approve method statement
  - List of record items & what can go wrong list plus mitigations

- **Check construction quality/workmanship**
  - Inspection & QC tests for materials & products, boring operation, shaft stabilization, base cleaning, placement of reinforcement cage & concreting. Refer Spec for good practice & acceptance criteria?
  - Pile installation, termination & acceptance criteria. Basis?

- **Check performance criteria/quality**
  - Pile tests to check capacity, settlement & structural integrity
  - Test standard/spec/process, method & acceptance criteria
  - Interpret test results & make decisions

- **Prepare as-built drawings, report, etc.**
6.3: Comparison of Micropile & Bored pile

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<thead>
<tr>
<th></th>
<th>Micropiles</th>
<th>Bored Piles</th>
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<tbody>
<tr>
<td>Common sizes &amp; capacity</td>
<td>100mm to 300mm diameters with slenderness ratio up to 220. Axial capacity = 200 to 2500 kN. ( Q_{stru} = 0.4f_{cu} A_c + 0.47 f_{y} A_s )</td>
<td>600mm to 3m diameters with slenderness ratio &lt; 80. Usual axial capacity = 1000 kN – 65000 kN. ( Q_{stru} = 0.25f_{cu} A_c ) to 0.2fcuAc</td>
</tr>
<tr>
<td>Reinforcement</td>
<td>Steel pipe or rebar (single or bundle), ( f_y = 250 ) to 550 MPa. 2-8% steel.</td>
<td>Rebar cage. Usually 0.25 – 1% steel.</td>
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<tr>
<td>Drilling / boring</td>
<td>Small drilling machine to flush out cuttings or debris by compressed air or water with polymer or bentonite. Casing is required in collapsible strata. Classification of drilling: Single tube advancement by wash boring or rotary percussion, Rotary duplex, Rotary percussion concentric/eccentric duplex &amp; double head duplex.</td>
<td>Large boring machine (torque = 20 – 300 kN.m or more) using soil/rock auger or bucket to take out the cuttings/debris. Casing is required in collapsible strata or use bentonite or polymer slurry or water to stabilize drilled shaft. Boring machine capacity is classified according to BHP/torque, crowd &amp; WT, etc.</td>
</tr>
<tr>
<td>Grout / concrete</td>
<td>Cement grouting method : normal tremie gravity. Injection with grouting pressure of about 1 to 10MPa with packers or tube-a-Manchette/secondary/post grouting. Grout mixture: w/c &lt; 0.45 with admixture to ensure flow (&lt; 15 sec) &amp; bleeding &lt; 1% &amp; fcu &gt; 30Mpa. Sand can be added if size&gt;200mm.</td>
<td>Fresh cohesive concrete with w/c &lt; 0.5 with superplasticizer &amp; slump = 150 – 250 mm, cement content &gt; 400 kg/m³ for tremie concreting. Concreting shall be uninterrupted &amp; high slump property shall be maintained (&gt;100mm) before concreting is completed. Retarder may be needed if concreting is &gt;1.5hr.</td>
</tr>
<tr>
<td>Applications</td>
<td>For underpinning works to increase foundation capacity &amp; to arrest settlement of existing structures. As structural support for new structures in difficult constraint site &amp; erratic subsoil conditions. As dowels for creeping slopes/grounds, etc.</td>
<td>As structural foundation for large, heavily loaded structures or structures with large lateral loads. As foundations for site where vibration and/or high noise level are not allowed. Applicable to stabilize creeping slopes.</td>
</tr>
<tr>
<td>Limitations</td>
<td>Low lateral load resistance unless the ground is treated. Expensive generally.</td>
<td>Required large machine &amp; big space to operate. Difficult at site constraints.</td>
</tr>
</tbody>
</table>

6.4 Common Shortfalls/lackings/inadequacies in Bored Pile Design & Construction

1. Inadequate & unreliable SI to provide reasonably accurate subsoil profile, especially the bonding stratum with relevant strength parameters. Critical subsoil info such as accurate groundwater conditions & unstable strata especially artesian pressures are not determined. No chemical test results to assess subsoil aggressiveness.
2. Specific criteria of terminating boring & grouting not clearly stated on Drg.
4. Incomplete construction details for joint, spacer, and anchorage to the pile cap or load transfer details.
5. Criteria of selection of piles for tests not defined.
6. Inadequate scope of design validation for the bond strength adopted.
7. Inadequate supervision
8. Incomplete method statement,
9. Incomplete construction records
Some recent research findings about bored pile design & construction

- Related to **boring operation**. Why boring should be completed within 6hrs.? BS EN 1536 requirements? Puolos & Ken Fleming’s findings?
- Related to drilled shaft stabilization. Pros & cons of each method?
- Related to reinforcement placement. How spacing of rebars can influence fsu? FHWA (2010) findings & BS EN 1536 requirements?
- Related to insitu concrete placement.
- Related to pile testing

**7. Q & A** (Do you have a question in mind? I can’t help if you don’t ask. The dumbest question is the question not asked.)

1. What are the role & responsibility of site supervision for bored pile installation?
2. What is meant by proper site supervision of piling works?
3. What are the basic qualification & experiences required for RE to supervise bored pile installation?
4. What are the main pre-construction checks and inspection for bored pile installation?
5. What are the important construction sequential activities/processes for bored pile installation? What are the common problems of each construction sequential activity?
6. What are the 3 common bored pile construction methods? Applications & limitations of each method? What are the factors influencing the selection of bored pile construction method?
7. What are the common drilled shaft stabilization methods? Applications & limitations?
8. What are the 3 common base cleaning methods? Applications & limitations?
9. What are the common methods of rock socket construction in soft weathered rocks and hard moderately weathered rocks?
10. What are the important scope of inspection, measurements & testing of quality & workmanship for bored pile boring, bored shaft stabilization, placement of reinforcement cage & concreting? Scope & purposes of recording?
11. What are the important types of tests to assess the structural integrity of bored piles? Their application & limitations? What should be the basis/criteria of selection of piles for tests?
12. What are the important types of tests to assess the performance (pile capacity & settlement) of bored piles? Their application & limitations?
13. What are the common defective bored pile construction related to boring, bored shaft stabilization, placement of reinforcement cage & concreting? Mitigations?
14. What are the common shortfalls/lacking of Malaysian RE involved in bored pile construction?
7. Q & A-cont.

15. What are the technical requirements for boring machine & boring tools for boring in soil, IMG, soft rock & hard rock? Base cleaning tools?
16. What are meant by squeezing, necking & cave-in of bored shaft? Factors influencing these problems? Mitigations?
17. Bored piles can be designed to be terminated in soil, rock and/or in certain suitable penetration depth. What are the typical bored pile termination criteria for (a) Granite formation with abundant boulders, (b) Residual soils of sedimentary rocks with shallow bedrock (<20m) & with very hard soil at shallow depth or with bedrock at great depth (>60m), (c) Soft alluviums underlain by loose to very dense silty/clayey sand at about 30m deep?
18. What are the acceptable methods, their scope of inspection & acceptance criteria for rock socket construction? Pros & cons for each method for soft/weak bedrock rock (UCS<5 MPa), moderately strong bedrock (UCS=12 to 50 MPa) & strong bedrock (50 to 100 MPa)?
19. What are the important scope of inspection, QC tests, acceptance criteria & records for reinforcement cage placement & concreting?
20. What are the common tricks & malpractice in bored pile construction?

7. Case Histories

Case histories to be discussed are:

• Case history 1 about over-specification (full temporary casing shall be used to stabilize the bored shaft). Bentonite shall be used.
• Case history 2 about boring in rock. No proper specification/description about boring in rock is included in Contract document.
• Case history 3 about MLT failure & RE decision.
• Case history 4 about interpretation of MLT & HSDPT results.
• Case history 5 about base grouting.
• Case history 6 about malpractice & misinterpretation related to PDA/MLT.
Important checklist & problems for kentledge MLT of 2m diam bored pile with Qd=3500T?
MTL=3,200 m³=15mx15mx15m concrete blocks.
Coaxial loading & risk of collapse/toppling? Cost per test ton? Time required to arrange blocks? High bearing pressure from supports of kentledge (>700 kPa)?

Can PDA be carried out on large bored piles to check structural integrity & capacity?
According to ASTM D4945-12; planned, conducted & interpreted by DFI accredited test engineer with Advance/expert level certification. Forced on pile must >MTL (2Qd); Hammer weight >1-2%MTL but drop <2m.

2m Diam bored pile, Qd=3500T.
Proposed hammer=75T, drop 1.8m to 2.1m. CSX=24 Mpa, FMX=7900T
CAPWAP Analysis Results:
Qs=4250T, Qb=2500T,
MVT@Qd=12mm,
MVT@MTL=29mm
Common defective construction for Bored piles?

No problem is a big problem. Why? Because you may not be aware of the problems. Important to be aware & understand the construction problems (mainly due to unexpected subsoil conditions) & the underlying principles involved. Effective mitigations?

1. Boring problems: Old & low capacity of boring rigs &/or worn out or poor drill soil/rock augers/bucket that take long time (>12hrs.) to complete boring. Contract/Spec/CP/BS EN 1536 requirements? Contractor’s contractual obligations? Consequences?

2. Improper drilled shaft stabilization method & procedure to take care the hole collapse problems in treacherous & collapsible strata have resulted in low $f_{su}$ & integrity problems. No QC tests. CP/Specs requirements? Contractor’s contractual obligations? Consequences?

3. Inadequate or poor base cleaning method has resulted in low $f_{bu}$ and structural integrity problems. QC & how to check? CP/Specs requirements? Contractor’s contractual obligations?

4. Reinforcement cage is not properly fabricated resulting in excessive deformation & loosening of rebars, improper cover & localized small spacing (<100mm), etc. CP/Specs requirements? Contractor’s contractual obligations? Consequences?

5. Poor concreting technique such as pulling temporary casing without adequate fresh concrete head, etc., may result in integrity problems. CP/Spec requirements? Contractor’s contractual obligations? Consequences?

Summary of presentation

1. Performance (structural integrity/durability, serviceability & capacity) of bored piles is very sensitive by the method of construction. Due care, skill & diligence by pile supervisors shall be exercised in performing the construction supervision. Some examples illustrating this close relationship between construction techniques and bored pile performance include: poor bottom cleaning procedures that may considerably reduce the available base resistance; prolonged exposure of the drilled shaft excavation (>6hrs) to bentonite slurry that may greatly reduce the available friction resistance ($f_{su}$); and failure to maintain a stable shaft excavation that may result in voids or soil inclusions in the shaft concrete and that may compromise the structural integrity of the completed drilled shaft, etc.

2. Unlike driven piles, where the resistance to driving or blow count provides a means of assessing the load bearing resistance of each driven pile, the proper performance of bored piles relies heavily on the consistent and repeatable application of the bored pile installation procedures.

3. Accordingly, for bored pile installation specifications, emphasis must be given to:
   • Qualifications of the bored pile Contractor and key personnel assigned to bored pile construction,
   • Proper planning of the work through the preparation and review of method statement
   • The application of appropriate bored pile installation methods for the anticipated ground and groundwater & pressure conditions as revealed by proper GI,
   • Use of experienced and knowledgeable bored pile supervision personnel (Consultant & Contractor),
   • Thorough and detailed documentation of all bored pile installation details & activities,
   • Carry out trial shafts and test shafts to verify design assumptions, as well as to evaluate the Contractor’s proposed/selected means and methods of bored pile construction method including type of bore rigs & drill tools, details of shaft stabilization, base cleaning, etc.
   • Integrity testing to verify the required structural integrity, and
   • Clearly defined acceptance criteria and installation tolerances.
8. Concluding Remarks

- Almost all high-rise buildings and heavy structures in Klang Valley adopt bored piles (0.5m to 3m diam) as the foundations, mainly due to cost-effectiveness. Bored piles can be easily sized & constructed in various subsoil conditions to give large range of capacity. Bored piles exceeding 2m diameters with design capacity >35,000 kN are common especially when top-down construction for deep basement of high-rise buildings are required and adopted.
- Performance of bored piles with respect to capacity ($f_{su}$ & $f_{bu}$), settlement & structural integrity depends not only on design but also heavily on construction. In fact, defective construction related to boring, drilled shaft stabilization, base cleaning, placement of reinforcement & concreting can cause serious structural integrity inadequacies and capacity problems as have been illustrated by the presentation. Proper supervision aimed for zero defective construction is the mandatory requirement by CP, but commonly ignored/violated or not paid with due attention by the Client & the supervisors, who may not be aware of their responsibility.
- Bored piles may not be safe & reliable unless it is properly supervised to ensure compliance with CP, properly designed drawings & specs. Supervision is not everything until & unless the piles are properly selected for testing to validate the design. Testing is also not everything until & unless the test result can be representative for the untested ones, as has been explained.
- Effective mitigation against defective construction is quality supervision plus adequate scope of design validation. Quality supervision is aimed for zero defective construction.
- What can go wrong will go wrong unless effective mitigation is in place.