What is a drilled shaft?

A foundation system constructed by filling a cylindrical excavation with reinforced concrete
Typical Applications for Drilled Shafts

- Support heavy loads and minimize settlement
- Support uplift loads
- Support lateral loads
- Structures on swelling soils
- Residential foundation repair/underpinning
Structures Supported on Drilled Shafts

Petronas Towers, Kuala Lumpur

High rise tower in Chicago
Structures Supported on Drilled Shafts

Electrical Transmission Towers

Small drilled shafts used to retrofit a land slide

Bridge Foundations

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Potential Advantages

- Very high capacities with rock sockets
- Avoids vibration problems of pile driving
- Suitable for a wide variety of ground conditions
- Eliminates need for a pile cap
- Provides opportunity to examine excavated materials; soil or rock beneath tip can be probed or sampled
- Available in any dimensions; can be used as “shallow” foundations
- NDT/NDE provides tool for post-construction quality assurance
Examine Excavated Materials
Potential Disadvantages

- Lack of redundancy compared to pile group
- Quality is sensitive to construction procedures
- Construction may be difficult or more costly in difficult ground (e.g., groundwater problems, squeezing clay, cobbles, and boulders)
- Not suitable in very soft and soft clays
- Requires engineers to be familiar with constructability issues
“Do not design on paper what you have to wish into the ground” Karl Terzaghi

Engineers and contractors involved in drilled shaft design and construction must be familiar with the relationship between design and construction
Keys of Drilled Shaft Constructability

- Subsurface investigation
- Engineers’ knowledge and experience with construction procedures, equipment, and costs
- Field quality assurance/quality control
Site Investigation

- Soil Profile
- Groundwater conditions
- Borehole stability
- Presence of cobbles, boulders, weathered rock, their size and distribution
- Use of in situ tests that correlate with drilled shaft design parameters
Site Investigations

- Part of the contract documents.
- Provide opportunity for contractors bidding a job to visually inspect soil/rock samples.
- For larger projects, construct a full-size drilled shaft under actual site conditions.
- For large shafts, locate borings at every shaft location.
Engineering Knowledge & Experience

- Construction Methods
- Construction Equipment
- Steel & Concrete Placement
Construction Methods

Dry Method
Wet Method
Casing Methods
Dry Method

- Hole will not cave during construction
Slurry (Wet) Method

- Excavated hole is filled with slurry to prevent squeezing of the hole
Functions Of Slurry

- Maintain stability of the excavation
- Prevent suspended particles from settling to the bottom
- Allow clean displacement by concrete
- Allow easy pumping

Types of slurry
- Bentonite + water
- Synthetic polymer + water
Filter Cake

- Slurry penetrates pore space forming a low permeability filter cake

- Hydrostatic pressure balances earth pressure
Slurry Specifications

- Density
- Viscocity
- Sand Content
- pH

Slurry Design must balance 2 conflicting objectives
- Hole Stability (Dense & viscous)
- Easily displaced by concrete (Less Dense & viscous)

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Slurry specifications (ADSC 1989)

<table>
<thead>
<tr>
<th>Property</th>
<th>Range of Results at 20°C</th>
<th>Test Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (pcf)</td>
<td></td>
<td>mud balance</td>
</tr>
<tr>
<td>a. during excavation</td>
<td>65 to 85</td>
<td></td>
</tr>
<tr>
<td>b. before concreting</td>
<td>75 max</td>
<td></td>
</tr>
<tr>
<td>Viscosity, during excavation</td>
<td>30 to 50</td>
<td>Marsh funnel</td>
</tr>
<tr>
<td>Sand content before concreting</td>
<td></td>
<td>sand screen</td>
</tr>
<tr>
<td>a. shafts with design end bearing</td>
<td>4 max</td>
<td></td>
</tr>
<tr>
<td>b. no design end bearing</td>
<td>25 max</td>
<td></td>
</tr>
<tr>
<td>pH during excavation</td>
<td>8 to 12</td>
<td>paper test strips</td>
</tr>
</tbody>
</table>

1The density of the mud slurry shall not be less than what is needed to drill the shaft.
Mud Density Balance
Marsh Funnel

- Viscosity
- Time required for one quart of slurry to drain from funnel is measured
Thief Sampler

- Retrieve slurry from a desired depth
  - Lower cap lowered to desired depth
  - Slide tube to desired depth
  - Slide Top cap
  - Lift cable, thus sealing *Thief Sampler*
Casing Methods

- Caving soils (e.g. sand below GWT)
- Difficult ground water conditions
Casing Method I

a) Drilling

b) Placing casing

c) Balling slurry after casing is sealed
Casing Method II

CASING METHOD OF CONSTRUCTION

d) Advancing hole below casing
e) Belling tool
f) Extracting casing
Different Casing Installation Techniques

Own Weight

Twister or Hercules bar, fits in slots at top of casing allows drill rig to twist and push

Oscillators and rotators make it easier to push casing while excavating soil from inside

Vibratory Hammer
Oscillator Casing

Note Mechanical joints for precise fit

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Clam Shell used for excavation

- Clam Shell hammer grab tool is dropped in casing in an open position to take a “bite” of soil.
Hammer Grab

- Cutting teeth can penetrate soils with large boulders
Rotator Operates at 5-10 RPM
Rotator Hanging from Dead-man Anchor
Cleanout Bucket used to remove loose material from a dry hole
Air Lift

- Air lift is used to remove water or slurry from hole
Air Lift Construction

- Compressed air flows through air hose and up the air lift, creating enough suction to remove water or slurry.
Engineering Knowledge & Experience, Cont.

- Construction Methods
- Construction Equipment
- Steel & Concrete Placement
Basic elements of a drilled shaft rig

- Power Source (diesel engine)
- Rotary Table
- Kelly Bar
- Drilling Tool
Crawler Mounted Drill Rig

Max Depth = 80 ft
Max Shaft diameter = 6ft
Track Mounted Drill Rig
Truck Mounted Drill Rig

Max Depth = 80 ft
Max Shaft diameter = 6 ft
Four Axel Truck Mounted Drill Rig

Max Depth = 120 ft
Max Shaft diameter = 8ft
Max Torque = 100,000 ft-lb
Max Crows = 50,000 lb
Carrier Mounted
European Rig

- **SoilMec R312HD**
  - Max Depth = 150 ft
  - Max Shaft diameter = 5ft
  - Max Torque = 84,000 ft-lb
  - Max Crows = 25,000 lb
Soil Mec R-930
Max Depth = 250 ft
Max Shaft diameter = 8ft
Max Torque = 220,000 ft-lb
Max Crows = 60,000 lb
Slide shows casing being extracted while concrete is pumped in the hole.
Drill Rig fitted with a continuous flight auger
Crane mounted attachments are mounted on a suitable crane to make a drill rig
Specialty drill rig for low head room
Tools attached to Kelly Bar
Augers

- Most drilling is accomplished with an open helix auger
- Augers are matched to soil conditions
  - Knife blade for soft soil
  - Teeth for stiff soils
Augurs

36 inch Rock Auger with Shark Teeth for drilling in soft rock

8 Ft. diameter Augur with drag bit teeth
Augers, cont.

Rock Auger with drag bit teeth for Shale and soft sandstone. Stinger Keeps Auger Centered
Drilling in Rock

Cluster drill for very hard rock
Uses 5 rotary Percussion down hole hammers and bits

Rotary Core Barrel for medium rock
Belling Bucket

Blade is retracted for insertion into the hole
Churn Bit

Used to break through thin layers of rock

Bit rotates as it drops in the hole thus churning the rock

Slow but efficient

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Boulder Clam

For removing cobbles and boulder sized material from the excavation
Boulder Rooter

- Used to drill through boulders
Cleaning Buckets

Used to remove loose material from the bottom of the hole prior to concrete placement
Tool used for drilling & Cleaning

Note drag bit cutting teeth at the bottom and side cutting teeth
Case History
Route 52, San Diego, CA
Sub Surface Conditions

- Water bearing sand overlying bedrock
- Sloped bedrock may cause deflection of driven piles and drilling tools
- 7 ft diameter shafts from 25-65 ft deep
- 3 levels of casing used to control water in sand
Core barrels were selected for drilling

Drilling was done using crane mounted attachments

Roller cone bits Being welded
Note absence of joints and discontinuities in cored rock
Chisel used to break up rock
Intact core
ENGINEERING KNOWLEDGE AND EXPERIENCE (Cont)

- Construction Methods
- Construction Equipment
- Steel & Concrete Placement
Requirements for Concrete

- Adequate strength and stiffness
  - compression
  - shear stresses

- Properties of wet concrete and placement procedures result in complete filling of the excavation, without contamination, voids, necking, or any other defects
Mix Design

- Relative proportions of cement, water, fine and coarse aggregates, and admixtures

Objectives:
- constructability
- strength
- stiffness
- durability
Recommended Slump

- Dry method: 4-6 inches
- Casing: 5-7 inches
- Tremied or pumped: 7-9 inches

- Slump is an index test for concrete workability
- No need to vibrate concrete with these slumps!
High Slump, Poor Consistency
Plastic but Slump is too Low
Good Concrete for Drilled Shafts
How to achieve high slump without sacrificing strength, durability, and other desirable properties?

- higher sand contents
- rounded aggregates
- admixtures
  - Super plasticizers
  - Retardants
  - Water reducing agents
Observations When Temporary Casing is Pulled

- Level of groundwater outside of casing
- Level of concrete inside casing
- Movement of concrete level (up or down)
- Time of pour interruptions

- Maintain an adequate concrete head to offset pressure head of groundwater or slurry
Tremie Pipes

- Must be embedded in concrete, to prevent mixing of concrete & slurry
Requirements for Steel

- Yield strength, modulus, and area of steel are sufficient to resist tensile and shearing stresses
- Clear spacing between bars prevents interfere with concrete during placement
- Field handling of cage doesn’t cause excessive bending stresses
Rebar Cage

- Longitudinal bars equally spaced in a cylindrical arrangement
- Transverse reinforcing (spirals or hoops) attached to the longitudinal bars with ties or welds
- Other components: sizing hoops; placement guides; lifting loops; NDTE access tubes
Note Bundled longitudinal bars

On-site Construction of Large diameter cage
Placing the Reinforcing Cage

- Position
- Plumbness
  - spacers or centralizers
  - minimum cover
- Cage deformation
- Rebar spacing
  - to allow for flow of concrete
  - depends upon maximum aggregate size
- Position of access tubes for NDT
Centering the Cage in the Hole

Spacing wheels attached to stirrups
Polystyrene feet prevent the cage from settling into the soil.
Cages must be braced & supported
Remove internal bracing as cage is lowered in the hole

Worker using torch to remove bracing
Use hard back & multiple lift points to prevent excessive strain in reinforcing cage
Quality Assurance/Control

- Field inspection
- Post-construction integrity testing
  - Nondestructive testing & evaluation
  - Destructive testing (e.g., coring)
Available Resources
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