What Is a pile?

- A pile is a prefabricated element, made of concrete, steel or timber. It is generally long and slender.
- A pile is installed by hammering it into the ground using a pile driving hammer.
- Piling can be designed to support modest compressive and lateral loads. They generally cannot support as much load as a drilled shaft, so are often grouped under footings when heavy loads need to be supported.

<table>
<thead>
<tr>
<th>Size</th>
<th>Maximum Length</th>
<th>Abutments and Trestle Bents</th>
<th>Footings (per Pile)</th>
</tr>
</thead>
<tbody>
<tr>
<td>16 in.</td>
<td>85 ft.</td>
<td>75 ton</td>
<td>125 tons</td>
</tr>
<tr>
<td>18 in.</td>
<td>95 ft.</td>
<td>90 tons</td>
<td>175 tons</td>
</tr>
<tr>
<td>20 in.</td>
<td>105 ft.</td>
<td>110 tons</td>
<td>225 tons</td>
</tr>
<tr>
<td>24 in.</td>
<td>125 ft.</td>
<td>140 tons</td>
<td>300 tons</td>
</tr>
</tbody>
</table>

<TxDOT Geotechnical Manual>
Standard Spec Items

- ITEM 404 – Driving Piling
- ITEM 405 – Foundation Test Load

Relevant items
- Item 406 - Timber Piling
- Item 407 – Steel Piling
- Item 409 – Prestressed Concrete Piling
Piling Basics

- Piling are most often used along the Gulf Coast or in East Texas.
- Piling are well suited for softer soils, but not for hard soils or rock.
- Piling typically gain most of their load capacity from skin friction.
- End bearing can be significant if pile is tipped in packed sand or rock.
Pile Driving Issues

- Driving system approval.
- Hard driving conditions.
- Soft driving conditions.
Pile Driving System

- **Leads** – Used to hold piling and hammer, and keep them aligned with each other.
- **Power Hammer** – Uses air pressure or diesel to lift and drop heavy ram.
- **Helmet** – Connects the hammer to the top of the pile.
- **Cushion(s)** – Absorb some energy to prevent damage to pile and hammer.
Pile Driving System
Pile Driving Hammer System

- Impact Block
- Striker Plate
- Hammer Cushion
- Helmet
- Pile Cushion
- Pile
Pile Cushion

- Item 404.2 (B) Protection of Pile Heads

“Pay special attention to the condition of the cushioning material. Do not drive more than 3 piles with one cushion block. Change cushioning more frequently if necessary to prevent damage.”
Pile Driving System

- Must be sized appropriately based on pile type, weight and required resistance.
- Item 404 “Driving Pilling,” Table 1 provides reasonable guidelines for sizing hammers based in pile weight and required resistance.
- Requirements of Table 1 work well for “typical” soils and pile loads.
# Pile Driving System

## Table 1

<table>
<thead>
<tr>
<th>Piling Type</th>
<th>Hammer Type</th>
<th>Ram Weight (lb.)</th>
<th>Maximum Ram Stroke (ft.)</th>
<th>Minimum Hammer Energy (ft.-lb.)&lt;sup&gt;1&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timber</td>
<td>Air, Hydraulic</td>
<td>2,000 min.</td>
<td>5</td>
<td>330R</td>
</tr>
<tr>
<td></td>
<td>Diesel</td>
<td>2,000 min.</td>
<td>10</td>
<td>330R</td>
</tr>
<tr>
<td>Steel</td>
<td>Air, Hydraulic</td>
<td>3,000 min.</td>
<td>5</td>
<td>Larger of 250R or 2-1/2 Wp</td>
</tr>
<tr>
<td></td>
<td>Diesel</td>
<td>2,000 min.</td>
<td>10</td>
<td>Larger of 250R or 2-1/2 Wp</td>
</tr>
<tr>
<td>Concrete</td>
<td>Air, Hydraulic</td>
<td>3,000 min., but not less than 1/4 Wp</td>
<td>5</td>
<td>250R, but not less than 1 ft.-lb. per lb. of pile weight</td>
</tr>
<tr>
<td></td>
<td>Diesel</td>
<td>2,700 min., but not less than 1/4 Wp</td>
<td>8&lt;sup&gt;2&lt;/sup&gt;</td>
<td>250R, but not less than 1 ft.-lb. per lb. of pile weight</td>
</tr>
</tbody>
</table>

1. R = Design load in tons. Wp = Weight of pile in pounds based on plan length.  
2. Diesel hammers with less ram weight or greater ram stroke are permitted if a wave equation analysis indicates that the combination of ram weight, stroke, and cushioning will not overstress the piling.
Pile Driving System

- Large, heavily loaded piling require large hammers to achieve necessary penetration.
- Large hammers can create high compressive stresses during hard driving.
- Large hammers can create high **tensile** stresses during easy driving.
- More sophisticated evaluation of the pile driving system should be considered.
Wave Equation Analysis

- Computer analysis that looks at the specifics of the driving system, soil profile, etc. and predicts the stresses in the pile during driving.
- Requires additional information about the hammer cushion, helmet, specific hammer model, pile cushion, etc.

**GENERAL NOTES:**

- Designed according to AASHTO LRFD Bridge Specifications, 5th Edition (2010).
- Class "C" concrete strength shall be $f'_c = 3,600$ psi.
- All Cap reinforcing shall be Grade 60.
- See Footing Detail Sheet and Foundation Detail Standard Sheet, FD(MOD), for foundation details and notes.

Calculated Foundation Loads:

- Bents 2-8 = 70 Tons / Pile

Target Capacity = 2 x Foundation Load
Cracked Piling

- Most common cause is soft soil!!
- Striking a concrete pile a full blow with a heavy hammer requires that the pile have good resistance at the tip.
- If the tip is resting in soft soil or within a pilot hole, its momentum will cause it to “pull away” from the rest of the pile.
- The result is horizontal cracking of the pile.
Horizontal Cracking

- Caused by tension forces in the piling.
- Can be very difficult to see in early stages.
- Look for puffs of gray “smoke”.
- If caught early, repair may be simple epoxy injection.
- If caught too late, pile may need to be broken back or rejected.
Pile Driving Description

- Initial driving of the main pier piles resulted in horizontal cracking.
- Inspector caught the problem early and stopped additional driving.
- Main piers supported by 35, 20” sq. piling.
- Pile loading – 220 tons/pile.
- Soil profile was 25’ of soft bay deposits over stiff clay.
- Bridge Division performed wave equation analysis.
- Contractor hired a specialty firm to monitor pile driving and measure stresses directly.
## Soil Boring in Main Channel

### TEST HOLE #9
STA 18+90.00
EL = 3.90'

<table>
<thead>
<tr>
<th>Layer</th>
<th>Depth</th>
<th>Material Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>CLAY, sandy</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>CLAY, gray silty</td>
</tr>
<tr>
<td>9</td>
<td>11</td>
<td>CLAY, gray sandy silty, with sea shells</td>
</tr>
<tr>
<td>40</td>
<td>25</td>
<td>CLAY, brown sandy clay, with sea shells</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>CLAY, yellow</td>
</tr>
<tr>
<td>50</td>
<td>50(4.5)</td>
<td>CLAY, reddish brown</td>
</tr>
<tr>
<td>50(3)</td>
<td>50(2.25)</td>
<td>CLAY, brown sandy clay with sea shells</td>
</tr>
<tr>
<td>19(6)</td>
<td>21</td>
<td>CLAY, reddish brown</td>
</tr>
<tr>
<td>36(6)</td>
<td>29(6)</td>
<td>CLAY, packed brown silty, sandy clay</td>
</tr>
<tr>
<td>29(6)</td>
<td>38(6)</td>
<td>CLAY, it gray with yellow streaks</td>
</tr>
<tr>
<td>50(2.5)</td>
<td>50(4.75)</td>
<td>CLAY, packed brown silty, sandy clay</td>
</tr>
<tr>
<td>25(6)</td>
<td>28(6)</td>
<td>CLAY, reddish brown</td>
</tr>
<tr>
<td>B/H</td>
<td>-96.10</td>
<td></td>
</tr>
</tbody>
</table>

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**Bridge Division Presentations Webinar**

July 16, 2014
Tight Horizontal Crack
Worse Horizontal Crack
Badly Cracked and Spalling

02/13/2007
Evaluating Cracked Piling

- Perform wave equation analysis to model driving system and predict tensile loads in the piling.
- Use the program to evaluate changes to hammer stroke, cushion thickness and material, etc.
- Field instrumentation may also be used to directly measure acceleration and stresses during pile driving using Pile Driving Analyzer (PDA).
Solution for Pile Driving in Soft Soil

- Solution may require several things:
  - Use lower fuel setting (smaller stroke) for initial driving.
  - Use a smaller hammer for initial driving.
  - Use thicker pile cushions.
  - Don’t reuse pile cushions.
  - Don’t use soaked/saturated pile cushions.
Hard Driving in Stiff Clay or Dense Sand

Steel H piling damaged by hard driving condition.

Concrete Piling damaged by hard driving condition.

- If damage to the pile is apparent, stop driving and contact Bridge Division.

Hard Driving

- As piling is being driven, driving becomes very difficult well above plan grade.
- Can occur for several reasons:
  - Pile hammer is too small.
  - Pile is too long.
  - Soil has a hard layer near the surface.
  - Soil is too hard overall for advancement of pilling.
- A driving system that is too small can make it impossible to advance a pile.
- Concrete piling are heavy and take considerable energy to install.
- Item 404, Table 1 “Size of Driving Equipment” gives minimum and maximum requirements for hammers.

<table>
<thead>
<tr>
<th>Piling Type</th>
<th>Hammer Type</th>
<th>Ram Weight (lb.)</th>
<th>Maximum Ram Stroke (ft.)</th>
<th>Minimum Hammer Energy (ft.-lb.)¹</th>
</tr>
</thead>
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<tr>
<td>Timber</td>
<td>Air, Hydraulic</td>
<td>2,000 min.</td>
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<tr>
<td></td>
<td>Air, Hydraulic</td>
<td>3,000 min., but not less than 1/4 Wp</td>
<td>5</td>
<td>250R, but not less than 1 ft.-lb. per lb. of pile weight</td>
</tr>
</tbody>
</table>

¹ R = Design load in tons. Wp = Weight of pile in pounds based on plan length.
² Diesel hammers with less ram weight or greater ram stroke are permitted if a wave equation analysis indicates that the combination of ram weight, stroke, and cushioning will not overstress the piling.
If hammer doesn’t meet the Table 1 requirements

- Instruct the contractor to get a larger (or smaller) hammer.
- Paragraph 404.2 and Note 2 under Table 1 allows hammers that don’t meet the requirements if a “Wave Equation Analysis” is performed indicating that the hammer will work.
If soil has a hard layer near the surface

- Pilot Holes
- Jetting
Pilot Holes are like pre-drilling a piece of wood before hammering in a nail.

A pilot hole can make pile installation easier, but can also ruin the pile capacity (No Skin Friction).

Maximum hole diameter permitted will be approximately 4 in. less than the diagonal of square piling.

Don’t allow a contractor to drill a deep pilot hole simply to allow him to get piling is faster.

If the piling drive well without a deep pilot hole, don’t drill one.

Do allow a contractor to drill a deep pilot hole if driving to plan depth is difficult or impossible.
Jetting

- Using a water at high pressure and volume to “predrill” a hole for piling.
- Similar in effect to pilot hole.
- Very effective in sands, sometimes too effective.
- Hard to control the size of holes.
- Can be used to get a “stalled” pile going again or to remove a stuck pile.
- Not nearly a common as pilot holes.
If ground is too soft

- As piling approaches finished grade, resistance is not reaching the required design load.

- Can occur for two reasons...
  - Pile is too short.
  - Soil has re-molded during pile driving and lost strength.
Pile Resistance

- Driving Formula (Item 404)

- Single-acting Power Hammers:
  - \( P = \frac{2 WH}{(s + 0.1)} \)
  - \( P \) = Calculated Resistance (lbs.) (Allowable)
  - \( W \) = Weight of Ram (lbs.)
  - \( H \) = Height of Ram Fall (ft.)
  - \( s \) = Average Penetration for last 20 blows (inches per blow)

- Compare with Foundation Load (Built-in SF into Driving Formula)

GENERAL NOTES:

- Designed according to AASHTO LRFD Bridge Specifications, 5th Edition (2010).
- Class "C" concrete strength shall be \( f'c = 3,600 \) psi.
- All Cap reinforcing shall be Grade 60.
- See Footing Detail Sheet and Foundation Detail Standard Sheet, FD(MOD), for foundation details and notes.
- Calculated Foundation Loads:
  - Bents 2-8 = 70 Tons / Pile
Calculate Dynamic Resistance

- As pile nears finished grade, begin tracking hammer stroke and pile set.
- Hammer stroke is most often estimated visually by watching the height of the ram using jump stick or saximeter. Nearest half-foot is typical.
Calculate Dynamic Resistance

- If pile is moving well, set is easiest to measure by counting total blows for the final foot.
- 48 blows for the final foot equals a set of .25 inches. 12”/48 blows = .25 inches/blow.
- If pile is moving slowly, count total blows for final inch. 20 blows per inch = .05 inches/blow. 1”/20 blows = .05 inches/blow
Calculate Dynamic Resistance

- Ram Weight = 2200 lbs
- "Stroke" = 6.5 feet
- "set" = 5 blows per inch = .2 inches per blow

\[ P = \frac{2(2200)(6.5)}{(.2+.1)} = 95,333 \text{ lbs.} \]
\[ P = 47.7 \text{ tons} \]
Calculate Dynamic Resistance

- If driving resistance is low, we often let the pile “rest” anywhere from a few hours to 7 days. This allows disturbed soil around the pile to ‘set-up’. When we get back on to the piling, the resistance often increases 50 - 200%.
- Common practice is to stop driving the pile a foot or two above grade, then wait.
- Waiting time can vary from a few hours to 7 days. Overnight is most common.
- Begin driving the pile again after allowing the soil to “set up.” Carefully note the pile penetration on an inch-by-inch basis.
Why Inch-by-Inch?

- Some soils will begin to remold and lose strength after just a few inches of driving.
- The “best” indicator of true pile capacity is in the first inch or so of a re-drive.
- Waiting to measure set until the end of the re-drive may put you right back where you started.
Set-up factor (K factor)

Set-up Factor (Total Capacity)

![Graph showing set-up factor (K) over time (hr) for different sizes (24" SQ. and 54" CYL). The average K is 1.8.](image)

- **K** (set-up factor)
- **Time (hr)**
- **24" SQ.**
- **54" CYL.**
Set-up factor (K factor)

Set-up Factor (Skin Friction)

- 24" SQ.
- 54" CYL.

Avg. K = 2.8

Time (hr)

[Graph showing data points and a trend line with average K factor value]
Pile Resistance

- If you leave a pile a day or two and get good bearing, great.
- If you find yourself having to leave all piling for days, give us a call.
- Get us involved early so that we can review the design and offer assistance.
Pile Load Test

- Static Load Test
- Dynamic Load Test
- Statnamic Load Test
Static Load Test
Dynamic Load Test (PDA) and CAPWAP
Statnamic Load Test
Questions?

- Contact BRG, Geotechnical Branch;
  
  Marcus Galvan – 512-416-2224  
  John Delphia – 512-416-2359  
  Dina Dewane – 512-416-2550  
  Marie Fisk – 512-416-2285  
  Ryan Eaves – 512-416-2558  
  Todd McBride – 512-416-2217  
  Sean Yoon – 512-416-2492