Soil Mechanics – Brief Review

Presented by: Gary L. Seider, P.E.
BASIC ROCK TYPES

• Igneous Rock (e.g. granite, basalt)
  • Rock formed in place by cooling from magma
  • Generally very stiff/strong and often abrasive

• Sedimentary Rock (e.g. shale, sandstone, limestone)
  • Rock formed from sediments (weathered rock) transported to position, heavily consolidated, and possibly cemented
  • Widely varying properties

• Metamorphic Rock (e.g. slate, marble)
  • Rock formed by metamorphosis (high temperature and/or pressure) of parent rock to form rock of a different type
  • Variable properties
What is a “Soil”? 

• **Inorganic — Mineral**
  • Gravel, Sand, Silt, Clay are Soils
  • Must be formed from weathered or disintegrated rock

• **Mineral soil**
  • Sediments or other accumulation of mineral particles produced by the physical or chemical weathering of rock
  • Minerals are naturally occurring.
  • Minerals have a definite chemical composition.

• **Organic material**
  • Peat, Wood, humus are NOT Soils
  • Soil containing deposits derived from plant or animal matter; typically mixed with some mineral-based soil particles.
    • “Topsoil”
    • Peat
    • Other organic soils
BASIC SOIL TYPES

• Residual Soil
  • Soil formed in place by physical/chemical weathering of parent rock

• Transported Soil
  • Soil formed by transport and placement of soil particles by natural means (water, ice, wind)
    • Aeolian – deposited by wind
    • Alluvial – deposited by running water
    • Fluvial – river/stream deposition
    • Glacial – deposited by ice flow (glaciers)

• Fill
  • Soil formed by placement of soil particles by humans
    • Engineered fill – placed and compacted to standards
    • Random (Uncontrolled) fill

Characteristics of soil depend on how it was formed
Identification of Soil Layers

- “O” horizon: both fresh and decaying plant materials
- “A” horizon: mix of humus & minerals, usually black
- “B” horizon: mineral horizon – usually red or brown
- “C” horizon: mineral horizon – usually gravel, silt or clay
- “R” horizon: underlying rock
Soils Exist in Infinite Variety

Soil Properties Depend on Particle Size, Mineral Type, Water Content
Gravel

Rock Fragments

- 1/8” (3 mm) to 3” (76 mm) sizes
- Usually angular – large void spaces
- Granite, Limestone, trap rock, bank run, processed
- Can be loose to compact
Sand

Rock Fragments

- Usually angular - gritty feel
- Typically less than 1/8” (3 mm) in size
- If moist will form small clumps
- Falls apart if touched when dry
- Can be loose to very dense
Silt

Mineral Grains

• 1/16” or smaller
• Smooth to the touch
  • Weak when dry
  • Easily powdered
  • Shows fingerprints

• Fine grained
• Typically rounded
• Often stains hands
• Can Be Very Soft to Hard
Clays

Mineral Grains
• Smooth to the touch
  • Strong when dry
  • Difficult to crush
  • Shows fingerprints
  • Molds easily (pottery)

• Extremely small particles
  (0.003” [0.076 mm] and less)
• Almost no void space
• Can be very soft to hard
Organic Materials

• All decay (compress) over time – not good for anchoring or foundations.
• Most have an odor.
• Most are black in color.
• Most show roots, woody material, or bugs.

PEAT
Typically found in coastal areas
Usually thick deposits
SOIL PROPERTIES

• Classification
  • Weight-volume (density, water content, etc)
  • Gradation (particle size distribution)
• Index Properties
  • Atterberg limits
  • Penetration resistance
• Mineralogy

• Engineering Properties
  • Shear strength (ability to resist applied loads)
  • Hydraulic conductivity/permeability (ability to conduct water)
  • Compressibility (relates settlement to applied loads)
USCS Soil Classification

• Granular soils
  • Greater than 50% (by weight) retained by #200 Sieve
  • Classified primarily according to gradation and, to a lesser extent, on the -200 fraction
    • Sands - SP, SW, SM, SC
    • Gravels - GP, GW, GM, GC
  • Characteristics
    • Often difficult to sample
    • Behavior primarily related to density

• Fine-grained soils
  • Less than 50% (by weight) retained by #200 Sieve
  • Classified primarily according to Atterberg limits (plasticity)
    • Clays – CL, CH
    • Silts – ML, MH
  • Characteristics
    • Generally considered “cohesive” soils
    • Behavior primarily related to plasticity and drainage
# Soil Particle Sizes

<table>
<thead>
<tr>
<th>Fraction</th>
<th>Sieve Size</th>
<th>Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Boulders</strong></td>
<td>12” Plus</td>
<td>300 mm Plus</td>
</tr>
<tr>
<td><strong>Cobbles</strong></td>
<td>3” - 12”</td>
<td>75 - 300 mm</td>
</tr>
<tr>
<td><strong>Gravels</strong></td>
<td>Coarse: .75” - 3” No. 4 - .75”</td>
<td>19 - 75 mm 4.76 - 19 mm</td>
</tr>
<tr>
<td></td>
<td>Fine: No. 10 - No. 4 No. 40 - No. 10 No. 200 - No. 40</td>
<td>2 - 4.76 mm 0.42 - 2 mm 0.074 - 0.42 mm</td>
</tr>
<tr>
<td><strong>Sand</strong></td>
<td>Coarse: No. 10 - No. 4 No. 40 - No. 10 No. 200 - No. 40</td>
<td>2 - 4.76 mm 0.42 - 2 mm 0.074 - 0.42 mm</td>
</tr>
<tr>
<td></td>
<td>Medium: No. 10 - No. 4 No. 40 - No. 10 No. 200 - No. 40</td>
<td>2 - 4.76 mm 0.42 - 2 mm 0.074 - 0.42 mm</td>
</tr>
<tr>
<td></td>
<td>Fine: No. 10 - No. 4 No. 40 - No. 10 No. 200 - No. 40</td>
<td>2 - 4.76 mm 0.42 - 2 mm 0.074 - 0.42 mm</td>
</tr>
<tr>
<td><strong>Fines (silts and clays)</strong></td>
<td>Passing No. 200</td>
<td>0.074 mm</td>
</tr>
</tbody>
</table>

**Fines (silts and clays)**: Passing No. 200
Soil Phases and Weight-Volume Relations

- Moisture Content: \( \omega = \frac{W_w}{W_s} \)
- Degree of Saturation: \( S = \frac{V_w}{V_v} \)
- Void Ratio: \( e = \frac{V_v}{V_s} \)
- Porosity: \( n = \frac{V_v}{V_t} \)
- Dry Unit Weight (Dry Density): \( \gamma_d = \frac{W_s}{V_t} \)
- Total Unit Weight: \( \gamma_t = \frac{(W_s + W_w)}{V_t} \)
- Saturated Unit Weight: \( \gamma_s = \frac{(W_s + V_v \gamma_w)}{V_t} \)
Atterberg Limits

Affinity for Water (Clays)

Very Dry  |  Solid State  |  Shrinkage Limit  
           |               |                

Semisolid State  |  Plastic Limit  

Plastic State  |  Plasticity Index  

Liquid State  |  LL Limit  

Very Wet  

Increasing moisture content

**ATTERBERG LIMITS**

PL = Plastic Limit  LL = Liquid Limit  PI = LL-PL = Plasticity Index
SOIL STRENGTH

• Ability to Withstand Deformation (movement) Under Pressure or Force.

• Soil has Little or no Tensile Resistance

• Consists of Two Parts:
  • Friction Between Particles (Physical)
  • Cohesion (Chemical Bond)
Soil Shear Strength

\[ P = (\sigma_1 - \sigma_3)A \]

\[ \sigma_{cell} = \sigma_3 \]

\[ \tau \]

\[ \sigma \] (or \( \sigma_0 \))

Failure Envelope
SOIL SHEAR STRENGTH

Can Represent in Terms of Total or Effective Stresses

- In terms of total stresses (ignoring $u$)

$$s = c + \sigma \tan \phi$$

- In terms of effective stresses

$$s = \bar{c} + (\sigma - u) \tan \bar{\phi}$$
Consolidation Analogy

Spring - Soil Skeleton
Water - Pore Water in Soil

1 FT.

Valve

Saturated Clay Stratum in Nature

Pressure

Gauge

Spring

Analogy of Soil and a Spring
Consolidation Analogy

Load Causes Pressure Increase in Water

Force

Valve

1 FT.

Closed Valve

100

Excess Pressure

0
Consolidation Analogy

Open Valve

1 FT.

Force

Water Flows Outward Due to Excess Pressure - Spring Begins to Compress

95

0
Consolidation Analogy

Open Valve

Force

<1 FT.

Piston Lowers -- Load Gradually Transferred From Water to Spring as Pressure Drops
Consolidation Analogy

Excess Pressure Dissipated - Full Load Carried by Spring. Compression Stops

Equilibrium - Spring Compressed

0.6 FT.
Determination of Soil Strength Parameters

• Laboratory Testing
  • Unconfined compression tests (cohesive soils)
  • Triaxial tests
  • Direct shear tests

• In-situ (in-place) Testing
  • Standard penetration test (SPT)
  • Cone penetration test (CPT)
  • Test Pit

• Correlation with index properties
  • Least reliable, but cheapest
  • Often useful for preliminary design
Field Testing

• Test Holes
  • Backhoe
    • inexpensive
    • common

• Borings
  • expensive
  • specialized equipment
  • specialized training
Standard Penetration Test

- SPT “N-value” is number of blows of special hammer required to penetrate standard sampler 12 inches
  - 140-lb hammer
  - 30-inch drop
  - Penetrate total distance of 18-inches, measure the number of blows required for each 6-inch increment
  - Compute “N-value” by summing number of blows for last 12-inches of penetration
Drill Rig
Hollow Stem Auger

Drill Stem

Drop Hammer

6” Increment Marks
# Boring Log

**Project No.:** 04-630  
**Project:** Central Site Borings  
**Client:** A.B. Chance Company  
**Boring No.:** 1  
**Rig:** CME 56  
**Location:** NE Corner Pratt & Brick Sts.  
**Driller:** L. Gottman

## Subsurface Profile

<table>
<thead>
<tr>
<th>Depth (ft)</th>
<th>Description</th>
<th>Qd. (ft)</th>
<th>Qd. (ft)</th>
<th>D.P. Max.</th>
<th>Dr. Penetration Test</th>
<th>Standard Penetration Test</th>
<th>Blows/ft</th>
<th>Water Content %</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Ground Surface</td>
<td>Ground Surface</td>
<td>Ground Surface</td>
<td>Ground Surface</td>
<td>Ground Surface</td>
<td>Ground Surface</td>
<td>Ground Surface</td>
<td>Ground Surface</td>
</tr>
<tr>
<td>0.75</td>
<td>Mottled Reddish Brown, Medium, (CL)</td>
<td>1</td>
<td>SS</td>
<td>11</td>
<td>11</td>
<td>11</td>
<td>11</td>
<td>11</td>
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<tr>
<td>2.00</td>
<td>Mottled Yellow Brown, Grading to Clay (CL)</td>
<td>2</td>
<td>SS</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
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<tr>
<td>3.00</td>
<td>Mottled Yellow Brown, Grading to Clay (CL)</td>
<td>3</td>
<td>SS</td>
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<tr>
<td>7.75</td>
<td>Light Gray Mottled Yellow Brown Clay, Little Sand, Silt, (CH)</td>
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<td>SS</td>
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<td>10.5</td>
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<td>13.0</td>
<td>Yellow Brown Mottled Light Gray, Silt, (CH)</td>
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<tr>
<td>15.0</td>
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<td>7</td>
<td>SS</td>
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<td>11</td>
<td>11</td>
<td>11</td>
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<tr>
<td>20.0</td>
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<td>11</td>
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<tr>
<td>22.0</td>
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<tr>
<td>30.0</td>
<td>Very Silt, (CL)</td>
<td>10</td>
<td>SS</td>
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<tr>
<td>32.5</td>
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<td>11</td>
<td>SS</td>
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<tr>
<td>33.5</td>
<td>Light Gray Mottled Yellow Brown Clay, Sand</td>
<td>12</td>
<td>SS</td>
<td>14</td>
<td>14</td>
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</tbody>
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**Drill Method:** 3 1/4" HSA & SPT  
**Boring Started:** 7-97-2004  
**Boring Completed:** 7-97-2004  
**Groundwater Elev. During Drilling:** 22  
**Groundwater Elev. @ Comp.:** 22  
**Groundwater Elev. @ 65 Hrs.:** 22  
**Boring Location:**

---

**Logging By:** J. Sick  
**Hannibal Testing Laboratories, Inc.**  
4010 Pikes Gravel Road, P.O. Box 267  
Hannibal, Missouri 63401, (573) 221-7714  
Sheet 1 of 2
## Boring Log

**Project No.**: 04-629  
**Project**: Central Site Borings  
**Client**: A.R. Chance Company  
**Boring No.**: 1

### Subsurface Profile

<table>
<thead>
<tr>
<th>Depth (Ft)</th>
<th>Description</th>
<th>QL Density, P.C.</th>
<th>Depth/Ext.</th>
<th>Number</th>
<th>Blowout</th>
<th>Grt. T.F.</th>
<th>Standard Penetration Test Blowout</th>
<th>Water Content %</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Very Silt, (CH)</td>
<td>2.00</td>
<td></td>
<td>13</td>
<td>25</td>
<td>14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>Gray Mottled Yellow Brown, Very Silt, (CH)</td>
<td>2.75</td>
<td></td>
<td>14</td>
<td>50</td>
<td>12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>Yellow Brown Mottled Light Gray, Very Silt, (CL)</td>
<td>2.78</td>
<td></td>
<td>15</td>
<td>59</td>
<td>13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>Light Gray, Silt, (CH)</td>
<td>3.00</td>
<td></td>
<td>16</td>
<td>59</td>
<td>12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>45</td>
<td>Mottled Yellow Brown, Silt, (CH)</td>
<td>3.50</td>
<td></td>
<td>17</td>
<td>59</td>
<td>11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>45</td>
<td>Yellow Brown Mottled Light Gray, Silty Sandy Clay, Trace of Gravel, Very Silt, (CL)</td>
<td>4.00</td>
<td>49.5</td>
<td>19</td>
<td>59</td>
<td>17</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>Very Silt, Little Gravel, Silt 47 F., (CL)</td>
<td>3.50</td>
<td>49.5</td>
<td>19</td>
<td>60</td>
<td>23</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>Dense Gravel, Hard, (CL)</td>
<td>4.50</td>
<td>49.5</td>
<td>20</td>
<td>60</td>
<td>49</td>
<td></td>
<td>28 %</td>
</tr>
</tbody>
</table>

**Drill Method**: J, M & SPT  
**Boring Started**: 7-27-2004  
**Boring Completed**: 7-27-2004  
**Tested By**: R. Black  
**Logging By**: J. Black

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**Groundwater Elev. During Drilling**:  
**Groundwater Elev. @ Comp.**:  
**Groundwater Elev. @ 6 Hrs.**: -32.0  
**Boring Location**:  

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**Hubbell Testing Laboratories, Inc.**
4813 Paris GRAVEL ROAD, P.O. BOX 137  
HANNEBROOK, MISSOURI 63041 - (573) 221-2714  
Sheet 2 of 2
Test Pits

- Exposes soil layers
  - look
    - color changes
  - feel samples
    - gritty?
    - smooth?
  - Poke
    - hard?
    - easy?
Estimation of Soil Properties

The following slides, may be used to estimate soil strength parameters, but is not a substitute for actual borings and testing.

• Granular Soils
  • Most commonly related to SPT N-value

• Cohesive Soils
  • Most commonly related to Atterberg limits
# Relative Density vs. N-Values

<table>
<thead>
<tr>
<th>Relative Density</th>
<th>N-Values</th>
<th>Friction Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Loose</td>
<td>0 to 4</td>
<td>&lt;28°</td>
</tr>
<tr>
<td>Loose</td>
<td>4 to 9</td>
<td>28° to 30°</td>
</tr>
<tr>
<td>Medium Dense</td>
<td>10 to 29</td>
<td>31° to 35.5°</td>
</tr>
<tr>
<td>Dense</td>
<td>30 to 49</td>
<td>36° to 41°</td>
</tr>
<tr>
<td>Very Dense</td>
<td>50 to 80</td>
<td>41° to 50°</td>
</tr>
<tr>
<td>Extremely Dense</td>
<td>&gt;80</td>
<td>?</td>
</tr>
</tbody>
</table>
## Consistency of Cohesive (CLAY) Soils

<table>
<thead>
<tr>
<th>Consistency</th>
<th>Consolidation History</th>
<th>Blows/ft $N_{70}$</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Soft</td>
<td>Normally Consolidated</td>
<td>0-2</td>
<td>Runs through fingers when squeezed</td>
</tr>
<tr>
<td>Soft</td>
<td>Normally Consolidated</td>
<td>3-4</td>
<td>Very easy to form into a ball</td>
</tr>
<tr>
<td>Medium</td>
<td>Normally Consolidated</td>
<td>5-8</td>
<td>Can be formed into a ball</td>
</tr>
<tr>
<td>Stiff</td>
<td>NC to OCR 2-3</td>
<td>9-15</td>
<td>Can make thumbprint w/ strong pressure</td>
</tr>
<tr>
<td>Very Stiff</td>
<td>Over Consolidated</td>
<td>16-30</td>
<td>Can scratch with thumbnail</td>
</tr>
<tr>
<td>Hard</td>
<td>Highly Over Consolidated</td>
<td>&gt;30</td>
<td>Cannot be deformed by hand</td>
</tr>
</tbody>
</table>
# Anchor Application Information

## SOIL CLASSIFICATION DATA

<table>
<thead>
<tr>
<th>Class</th>
<th>Common Soil-Type Description</th>
<th>Geological Soil Classification</th>
<th>Probe Values in.-lb. (NM)</th>
<th>Typical Blow Count &quot;N&quot; per ASTM-D1586</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Sound hard rock, unweathered</td>
<td>Granite, Basalt, Massive Limestone</td>
<td>N.A.</td>
<td>N.A.</td>
</tr>
<tr>
<td>1</td>
<td>Very dense and/or cemented sands; coarse gravel and cobbles</td>
<td>Caliche, (Nitrate-bearing gravel/rock),</td>
<td>750 - 1600 (85 - 181)</td>
<td>60-100+</td>
</tr>
<tr>
<td>2</td>
<td>Dense fine sands; very hard silts and clays (may be preloaded)</td>
<td>Basal till; boulder clay; caliche; weathered laminated rock</td>
<td>600-750 (68 - 85)</td>
<td>45-60</td>
</tr>
<tr>
<td>3</td>
<td>Dense sands and gravel; hard silts and clays</td>
<td>Glacial till; weathered shales, schist, gneiss and siltstone</td>
<td>500 - 600</td>
<td>35-50</td>
</tr>
<tr>
<td>4</td>
<td>Medium dense sand and gravel; very stiff to hard silts and clays</td>
<td>Glacial till; hardpan; marls</td>
<td>400 - 500 (45 - 56)</td>
<td>24-40</td>
</tr>
<tr>
<td>5</td>
<td>Medium dense coarse sands and sandy gravels; stiff to very stiff silts and clays</td>
<td>Saprrolites, residual soils</td>
<td>300 - 400 (34 - 45)</td>
<td>14-25</td>
</tr>
<tr>
<td>6</td>
<td>Loose to medium dense fine to coarse sands to stiff clays and silts</td>
<td>Dense hydraulic fill; compacted fill; residual soils</td>
<td>200 - 300 (23 - 34)</td>
<td>7-14</td>
</tr>
<tr>
<td><strong>7</strong></td>
<td>Loose fine sands; Alluvium; loess; medium - stiff and varied clays; fill</td>
<td>Flood plain soils; lake clays; adobe; gumbo, fill</td>
<td>100 - 200 (11 - 23)</td>
<td>4-8</td>
</tr>
<tr>
<td><strong>8</strong></td>
<td>Peat, organic silts; inundated silts, fly ash; very loose sands, very soft to soft clays</td>
<td>Miscellaneous fill, swamp marsh</td>
<td>less than 100 (0 - 11)</td>
<td>0-5</td>
</tr>
</tbody>
</table>

Class 1 soils are difficult to probe consistently and the ASTM blow count may be of questionable value.

**It is advisable to install anchors deep enough, by the use of extensions, to penetrate a Class 5 or 6, underlying the Class 7 or 8 Soils.**
PISA® & Tough One® Holding Capacity

Soil Class vs. Holding Capacity

Note: Holding Capacities are based on average test data and are offered as an application guide only. These are ultimate values. They are the highest capacities that can be expected in a given soil class. Apply an appropriate safety factor against soil failure.
PISA® & Tough One® Holding Capacity

Note: Holding Capacities are based on average test data and are offered as an application guide only. These are ultimate values. They are the highest capacities that can be expected in a given soil class. Apply an appropriate safety factor against soil failure.

Soil Class vs. Holding Capacity

www.hubbellpowersystems.com
Soil Class vs. Holding Capacity

Note: Holding Capacities are based on average test data and are offered as an application guide only. These are ultimate values. They are the highest capacities that can be expected in a given soil class. Apply an appropriate safety factor against soil failure.
SQUARE-SHAFT “SS” SCREW ANCHORS

APPLICATION AND ORDERING INFORMATION

LEAD SECTIONS

<table>
<thead>
<tr>
<th>Catalog No.</th>
<th>Length</th>
<th>Helix Combinations</th>
<th>Std. Pkg./Pallet</th>
<th>Soil Anchor Holding Strengths - (lbs.) vs. Chance Soil Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>P012642-AE*</td>
<td>3 ft.</td>
<td>8&quot; - 10&quot;</td>
<td>1/20</td>
<td>Class 7: 19,000</td>
</tr>
<tr>
<td>P012642-EJ</td>
<td>3½ ft.</td>
<td>10&quot; - 12&quot;</td>
<td>1/20</td>
<td>21,000</td>
</tr>
<tr>
<td>P012642-AEJ*</td>
<td>5½ ft.</td>
<td>8&quot; - 10&quot; - 12&quot;</td>
<td>1/20</td>
<td>26,000</td>
</tr>
<tr>
<td>P012642-EJN*</td>
<td>7 ft.</td>
<td>10&quot; - 12&quot; - 14&quot;</td>
<td>1/20</td>
<td>29,000</td>
</tr>
<tr>
<td>P012642-AEJN</td>
<td>10½ ft.</td>
<td>8&quot; - 10&quot; - 12&quot; - 14&quot;</td>
<td>1/20</td>
<td>31,000</td>
</tr>
<tr>
<td>P012642-EJNS*</td>
<td>10½ ft.</td>
<td>10&quot; - 12&quot; - 14&quot; - 14&quot;</td>
<td>1/20</td>
<td>40,000</td>
</tr>
</tbody>
</table>

Note: Holding capacities are based on average test data and are offered as an application guide only. These are ultimate values. They are the highest capacities that can be expected in a given soil class. Apply an appropriate safety factor against soil failure.
HeliCAP(R) v2.0 Helical Capacity Design Software

• Microsoft® Windows® Bearing & Uplift Capacity Software

• Based on soil and anchor/pile inputs. The program returns theoretical capacities and installation torque.
Special Soil Problems

- Organic Soils – highly compressible
- Expansive Soils – shrink/swell potential
- Collapsible soils
- Sensitive soils
- Deep fills
- Seasonally Frozen Ground and Permafrost
Conclusion

- PDH Credit
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- Include
  - PDH in Subject
  - Topics for future Webinars
  - Feedback
- Questions