Description

- This seminar intends to familiarize students with typical materials and how they are considered in building construction.
- The course covers material characteristics of:
  - wood
  - steel
  - concrete
  - masonry
  - soils

About me

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About you

- Plan review engineers
- Plans examiners
- Design engineers
- Architects
- Inspectors
- Building officials

Objectives

- Upon completion, participants will be better able to:
  - Identify the typical materials used in building design and construction.
  - Describe specific design characteristics of each building material.
  - Determine what potential issues exist for a given soil at the construction site.

Typical construction materials
Why worry?

- Building failures drive concern over building materials

Advantages

- Relatively inexpensive and fast construction
- Many contractors have experience
- Readily available material
- Lightweight materials require only human power
Solid Sawn Lumber

- National Design Specification for Wood Construction
  - 2015 edition
  - Contains design values for engineered design of solid sawn lumber and fasteners – gravity loads

Solid Sawn Lumber

- Special Design Provisions for Wind and Seismic
  - 2015 edition
  - Contains design values for engineered design diaphragms, shear walls and their connecting elements – lateral loads

Solid Sawn Lumber

- Wood Frame Construction Manual
  - 2015 edition
  - Contains
    - Design values for engineered design
    - Prescriptive tables for conventional construction
    - 1-2 story buildings only
Solid Sawn Lumber

- Design and Construction of Log Structures
  - 2012 edition
  - Contains design values for engineered design of log buildings

Species

The most common species in the US are:

<table>
<thead>
<tr>
<th>Common Species</th>
<th>Harvest Locations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Douglas Fir – Larch (DFL) or (DF)</td>
<td>Northwestern US and Western Canada</td>
</tr>
<tr>
<td>Southern Pine (SP)</td>
<td>Southeastern US</td>
</tr>
<tr>
<td>Spruce-Pine-Fir (SPF)</td>
<td>Throughout the US and Canada</td>
</tr>
</tbody>
</table>
Grading

- Most lumber is visually graded and given a grade mark after inspection that lists:
  - Grading agency.
  - Mill at which the lumber was graded.
  - Species mark.
  - Grade designation.
  - Moisture content.

Grade Stamps

Machine Rated Lumber

<table>
<thead>
<tr>
<th>MSR Grade Stamp</th>
<th>MEL Grade Stamp</th>
</tr>
</thead>
<tbody>
<tr>
<td>TP: 2400F 2.0E 000 KD-19 SYP</td>
<td>TP: KD-19 SYP M-23</td>
</tr>
<tr>
<td>2400lb 1.8E 1800ft</td>
<td>2400lb 1.8E 1800ft</td>
</tr>
</tbody>
</table>

Lumber Specification

<table>
<thead>
<tr>
<th>Visually Grade Lumber</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Select Structural</td>
<td></td>
</tr>
<tr>
<td>No. 1 and Btr</td>
<td></td>
</tr>
<tr>
<td>No. 1</td>
<td></td>
</tr>
<tr>
<td>No. 2</td>
<td></td>
</tr>
<tr>
<td>No. 3</td>
<td></td>
</tr>
<tr>
<td>Stud</td>
<td></td>
</tr>
<tr>
<td>Construction</td>
<td></td>
</tr>
<tr>
<td>Standard</td>
<td></td>
</tr>
<tr>
<td>Utility</td>
<td></td>
</tr>
</tbody>
</table>
Lumber Specification

Mechanically Graded Lumber

MSR – Machine Stress Rated

- 1650f – 1.5E
- 1800f – 1.6E
- 1950f – 1.7E
- 2100f – 1.8E
- 2250f – 1.9E
- 2400f – 2.0E

End-jointed Lumber

Approved end-jointed lumber is permitted to be used interchangeably with solid-sawn members of the same species and grade.
### End-jointed Lumber

- End-jointed lumber used in an assembly required to have a fire resistance rating shall have the designation “Heat Resistant Adhesive” or “HRA” included in its grade mark.

![End-jointed Lumber Diagram]

### Preservative-treated wood

#### 2303.1.9

- Lumber, timber, plywood, piles and poles
- AWPA Standard U1 and M4
- Preservatives shall be listed in Section 4 of AWPA U1
- Quality mark (stamp or label) stating:
  1. Treating manufacturer
  2. Type of preservative used
  3. Min. preservative retention
  4. Accredited inspection agency
  5. End use
  6. AWPA standard

![Preservative-treated wood Diagram]

### Fire-retardant-treated wood

#### 2303.2

Wood product which, when impregnated with chemicals which meets minimum requirements ASTM E 84 or UL 723

- Listed flame spread index of 25 or less
- No evidence of significant progressive combustion during 20 minute period
- Flame front does not progress more than 10.5 feet

![Fire-retardant-treated wood Diagram]
Fire-retardant-treated Wood

Quality mark (stamp or label) stating:
1. Treating manufacturer
2. Fire-retardant treatment
3. Species of wood treated
4. Flame spread index
5. Smoke-developed index
6. Method of drying
Engineered Lumber

Glued lumber – basic solid sawn shape

- Structural Composite Lumber
  - Laminated Strand Lumber (LSL)
  - Laminated Veneer Lumber (LVL)
  - Oriented Strand Lumber (OSL)
  - Parallel Strand Lumber (PSL)
- Structural Glue-laminated Timber

Engineered Lumber

- Manufacturers maintain documents for design, specifying and installation of their products
  - Boise Cascade
  - Pinkwood
  - Louisiana Pacific
  - Rosboro
  - Weyerhaeuser
  - Georgia Pacific
Engineered Lumber

- Prefabricated Wood I-joist
- Engineered Wood Rim Board
- Cross-laminated Timber
- Trusses

Definitions 2302

Panel Products

- Wood Structural Panel
- Oriented strand board (OSB)
- Plywood
- Fiberboard
Fasteners

Joist Hangers, Nails and Staples

- Joist Hangers - ASTM D 7147
- Nails - ASTM D 1667
- Staples - ASTM D 1667
Nails

- Nailed connections are used when the loads to be transmitted are relatively small.
- Bolts are used for joints with larger loads.
- Nails are identified by their pennyweight, and recently, by diameter.

Screws

- Lag and wood screws are also used to connect structural members.
- They:
  - Can transfer larger individual loads than nails
  - Have better withdrawal strength than nails
  - Have deeper penetration into multiple wood members due to a longer length
**Screws**

- Lag screws and wood screws should have pilots holes drilled.
  - Lag Screw: the diameter of the pilot hole should be equal to the diameter of the screw shaft.
  - Wood Screw: the diameter of the pilot hole should be 90% of the diameter of the wood screw shaft (slightly smaller than the shaft).

**Bolts**

- Used to connect wood members when the transmitted load is large
- Used in wood to wood connections and wood to steel connections
- Located so loads are applied laterally through the bolt
- Connections are checked for bolt strength and wood-bearing strength

**Hangers and Plates**

- Connect wood members together
- Can increase bearing area, bearing capacity, connection capacity, and installation speed
- Frequently used to connect the joists within the floor diaphragm
- Have evaluation reports published by ICC-ES
Truss Plates

- Truss plates are used to connect wood 2x4 or 2x6 members together

Yield Mechanisms

Failure due to wood crushing of side or main member, or both at once.

Yield Mechanisms

Failure due to nail bending rather than wood crushing.
**Light-frame wood construction**

- Generally light-frame construction
- Used in nearly all 1- to 4-story residential construction
- Smaller 1- and 2-story commercial buildings
- Religious buildings
- 'Green' structures

Cheapest and quickest solution for construction – but light-frame construction has little natural fire-resistance compared to other materials.

**Heavy-timber construction**

- Decreasing use for decades due to lack of large diameter solid-sawn lumber
- Increasing in the last two decades as engineered lumber becomes more available on the market
- Largest growing segment of wood market

**Deterioration Issues**

- Wood exposed to moisture and then dried allows mold and mildew to form
- Wood can also be attacked by pests
- Wood kept underwater does not rot
- Fires will char the exterior layer of wood
Useful Resources


Wood-framed Shear Wall Construction, 2nd ed. – Written by Thor Matteson, 2009, ICC

Steel – Structural

Advantages

- Iconic structures with large spans
- Skyscrapers possible
- Materials may be readily available
- Flexible buildings
Steel manufacturing

ASTM Standards
- A 992 (W-shapes)
- A 36 (M, S, C, L-shapes)
- A 500, grade B (HSS)
- A 572 (HP-shapes)

Types of Steel
- Structural steel is categorized according to its chemical composition:
  - Carbon-manganese steels
    - Most common
    - Material includes iron, carbon, and manganese.
    - Normally called mild structural steels or carbon steels.
    - Strength and ductility are high
      Example: ASTM A 36

- High-strength, low-alloy steels
  - Newer product
  - Chemical elements added to improve the strength
  - Example: ASTM A 572

- High-strength tempered and quenched alloy steels
  - General structural purposes
  - Example: ASTM A 514
Types of Steel

- Steel contains primarily iron, with less than 2% carbon. The addition of carbon produces materials with high strength and low ductility.
- Typical steel sections
  - beams
  - channels
  - flats (plates)
  - angles

- Tension pulls the two ends of a steel element apart.

- Compression squishes a steel member.
Efficiency of shape

Why the holes?
- Some areas of a steel member resist loads more than other areas.
- A W-shape primarily resists loads in compression.
  - flanges - high load
  - web - smaller load

Open-web trusses

Efficiency of shape

What an odd shape
- Sometimes, welding plates to a member is easier than creating an unusual shape to resist loads concentrated in one location.

Built-up member

Steel – Testing during fabrication
### Testing
- Metallurgy
  - Hardness
  - Impact
  - Wear
  - Machinability
  - Hardenability

- Tension
- Compression
- Shear
- Ductility
- Fatigue
- Corrosion

### Quality Assurance
- QA or special inspection
  - Nondestructive testing
    - UT, RT, MT
    - Eddy current - conductivity
  - Destructive testing
    - Coupons
Fab shop drawings

- Steel fabricators take an engineer’s design drawings and make the elements required
- Shop drawings are for the fab shop to actually make the required parts

Numbering Systems = Location & Labeling
What about when it goes wrong?

- 14 spans, most steel girder, 1 steel truss spanned the water
- A design flaw - undersized gusset plates - was assumed to be the cause of the collapse,
- Gusset plates ripped along a line of rivets

I-35 Minnesota bridge

Photo credit: FEMA

What about when it goes wrong?

- Design of hangar rod connection changed from suspension of 1 deck to 2 decks
- Fab shop changed drawings
- Steel, glass and concrete walkway

Hyatt Regency suspended deck

Steel – Welding & Bolting
Welding Standard

- American Welding Society (AWS) welding standard for structural steel
- AWS D1.1-2010 edition

Welding Quality Assurance = Special Inspection

- A third-party inspection of the welds is required
- Visual inspection, inspection of welding process, and nondestructive testing (NDT) are done

Bolting Standard

- Specification for Structural Joints with High-strength Bolts
- 2014 edition
- Published by the Research Council on Structural Connections (RCSC)
Bolt and Washer Types

- Direct Tension or Load Indicating Washers
- Tension control or ‘twist-off’ bolts

Connections

- Snug tight – joint requires components to be touching with washer and bolt head in contact with steel
- Pretensioned joints – joint requires tensioning but may move or slip
- Slip critical joints – joint may not move in connection - used for high-risk connections

Bolting Quality Assurance = Special Inspection

- A special inspection is required for all high-strength connections
Structural Steel

- Typically used in very tall buildings – high-rise and skyscrapers
- Used in buildings requiring a very long span – hangars, warehouses
- Strong, but light-weight for the strength

Steel - Deterioration

Rust

Water
- Steel will oxidize when in contact with water. The oxidation of iron leaves iron-oxide or ‘rust’.

Salts
- Salts break down when in water into component ions. Those ions increase the oxidation of steel creating more rust.
Fatigue

- Steel will fatigue over time if vibrated.
- Bridges and industrial equipment typically have vibratory issues, not buildings.
- Amusement park rides and the buildings built around them can have problems.

Steel – Cold-formed

Advantages

- Relatively inexpensive
- Relatively fast construction
- Lightweight materials require only human power
Typical Buildings

- Floor and roof trusses common in masonry, tilt-up and light-frame construction
- Create light-weight, inexpensive floors and roofs
- Flat or peaked forms

Typical Construction

Assemblies
Steel Trusses

Light-frame construction
- Entire structure built with cold-formed steel studs, beams and trusses
- Used frequently in nursing homes (fire resistance) and strip malls

Cold-formed Steel - Fasteners
Fasteners

- Steel fasteners bolt cold-formed steel studs, joists and channels together
- Welding is atypical although shear tabs are welded to CFS diaphragms

Light-frame cold-formed steel

- Quick, easy construction
- Relatively inexpensive
- Used for 1-story buildings in strip malls, 1- to 3-story nursing homes
- Areas with severe termite infestations

Useful Resources

www.cfsei.org/design-guides
Concrete

Advantages

- Large spans
- Skyscrapers possible
- Readily available materials
- Good fire and moisture resistance
Typical Buildings

Typical Construction

Concrete

Styles:
- Reinforced
- Prestressed
- Prefabricated panels
Concrete Standard

- Building Code Requirements for Structural Concrete
- 2014 edition
- Contains design values and equations for engineered design of all structural concrete components and assemblies

The Concrete Mix

- PORTLAND CEMENT – The Cementing Ingredient *
- WATER – The Hydration and Workability Ingredient
- AGGREGATE – The Filler Ingredient
- ADMIXTURE – The “Modifier” Ingredient

*Heartbeat of the concrete mix
Durable Concrete

Mix
- Proper selection of cement
- Maximum water-cement ratio
- Minimum strength
- Adequate air content
- Limiting chloride content

Construction
- Adequate cover of reinforcement
- Adequate consolidation
- Sufficient moist curing

Types of Portland Cement

ASTM C 150
- I – Normal (85 to 90% of all cements)
- II – Moderate sulfate resistance
  - C₃A limited to 8%
- III – High early strength
  - Ground finer/reacts faster
- IV – Low heat of hydration
  - Currently not available
- V – High sulfate resistance
  - C₃A limited to 5%

C₃A is tricalcium aluminate or 3 CaO•Al₂O₃

Sulfate Attack
- Use low w/c
- Use sulfate resistant cement (Type II or IV)
Aggregates for Concrete

Fine Aggregate
- Sand and/or crushed stone
- < 0.2 in.
- FA content usually 35% to 45% of total aggregates

Coarse Aggregate
- Gravel and crushed stone
- ≥ 0.2 in.
- Typically between ⅜ and 1½ in.

Grading of Aggregate

- **Grading**: Particle-size distribution of an aggregate as determined by a sieve analysis using wire mesh sieves with square openings ASTM C33.
- **Fine aggregate**: 7 standard sieves with openings from No. 100 to ⅛ (0.375) in.
- **Coarse aggregate**: 13 standard sieves with openings from 0.046 in. to 4 in.

Range of Particle Sizes
Recycled-Concrete Aggregate

Maximum Size Aggregate

Admixtures

- Air-entraining admixtures
- Water-reducing admixtures
- Plasticizers
- Accelerating admixtures
- Retarding admixtures
- Hydration-control admixtures
- Corrosion inhibitors
- Shrinkage reducers
- ASR inhibitors
- Coloring admixtures
- Miscellaneous admixtures
Air-entrained concrete

- Air-entraining cement
- Air-entraining admixture
  - Lowers surface tension of water → enhances incorporation of bubbles
  - Impedes bubble coalescence
  - Anchors bubbles to cement and aggregate particles
  - Stabilizes bubbles

Advantages of Air-entrained Concrete

**Fresh Concrete**
- Improves workability
- Reduces segregation and bleeding
- Reduces required sand
- Reduces water

**Hardened Concrete**
- Increases freeze-thaw resistance (10 to 20x)
- Improves resistance to salt and sulfates
- Improves watertightness

Fibers

**Types of Fibers**
- Steel
- Glass
- Synthetic
- Natural
Reinforcement

---

CRSI Manual of Standard Practice

- Reinforcing basics
- Resources

---

<table>
<thead>
<tr>
<th>ASTM Standard Reinforcing Bars</th>
<th>Bar Size</th>
<th>Bar Diameter (inches)</th>
<th>Bar Area (sq. in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#3</td>
<td>0.375</td>
<td>0.11</td>
<td></td>
</tr>
<tr>
<td>#4</td>
<td>0.500</td>
<td>0.20</td>
<td></td>
</tr>
<tr>
<td>#5</td>
<td>0.625</td>
<td>0.31</td>
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<tr>
<td>#6</td>
<td>0.750</td>
<td>0.44</td>
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<td>#7</td>
<td>0.875</td>
<td>0.60</td>
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<td>#8</td>
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<tr>
<td>#9</td>
<td>1.128</td>
<td>1.00</td>
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<td>#10</td>
<td>1.270</td>
<td>1.27</td>
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<td>#11</td>
<td>1.410</td>
<td>1.56</td>
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<td>#14</td>
<td>1.693</td>
<td>2.25</td>
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</tr>
<tr>
<td>#18</td>
<td>2.257</td>
<td>4.00</td>
<td></td>
</tr>
</tbody>
</table>
Identifying Rebar

- Front of bar tag
  - ABC Steel
  - City, State
  - General Contractor
  - Job: Name
- Back of bar tag
  - Order No. XXX
  - No. of pcs: 36
  - Size: #6
  - Length: 15'-6"
  - Mark: RXXX
  - Grade: 40

Why Epoxy-Coated Reinforcement?

- Adds resistance to corrosion

Hot Weather Concreting

- Fogging
- Ice
Cold Weather Concreting

Cold Weather is:
- Average daily temperature < 40°F for three successive days.
- Stays < 50°F for more than one-half of any 24 hour period.

Insulating Blankets and Enclosures

- Wood
- Canvas
- Tarpaulins
- Polyethylene Film

Deterioration Issues

- Water will rust reinforcement which will expand cracking concrete
- Salt will accelerate rust formation cracking concrete and causing it to spall in only a few years
- Fires slowly destroy concrete surfaces, with very high heat (> 2000°F) concrete will chemically change to a powder and crumble
Useful Resources

www.iccsafe.org

- **Concrete Manual: Concrete Quality and Field Practices**
  - 2015 edition
  - Covers details of concrete design at plants and placing of concrete onsite

Useful Resource

www.concrete.org

- **ACI 318: Building Code Requirements for Structural Concrete**
  - 2014 edition
  - American Concrete Institute (ACI)
- **Concrete Repair Manual**
  - 4th edition
  - ACI and International Concrete Repair Institute (ICRI)
- **MNL-3 Guide to Assessment, Repair and Rehab of Existing Concrete Structures**
  - 2016 edition
  - Based on ACI 562-16
  - ACI and ICRI

Useful Resources

www.pci.org

- PCI Design Handbook
  - 8th edition
- PCI Concrete Construction Guide
  - 2nd edition

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Advantages

- Rapid construction
- Good fire and moisture resistance
- Good sound barrier

Masonry Standard

- Building Code and Specification for Masonry Structures
- 2013 edition
- Design values and equations for engineered design of masonry

The Masonry Society (TMS)
American Concrete Institute (ACI)
American Society of Civil Engineers (ASCE)
Masonry Standards Joint Committee (MSJC)

Building Code Requirements for Masonry Structures
(Code and Commentary)
(TMS 402-13/ACI 530-13/ASCE 5-13)

Specification for Masonry Structures
(Specifications and Commentaries)
(TMS 602-13/ACI 535.1-13/ASCE 6-13)

2015 International Building Code
Chapter 21
Construction +/-

Bricks and Blocks

Clay Brick
Reinforcement

- Reinforcing bar is identified by grade marks and numbers on the side of the rebar.
- Grade mark lines must be continued at least five deformation spaces.

Standard Hooks

- Standard hook 180° bend
- Standard hook 90° bend

Standard Hooks

- Stirrup and tie anchorage with 60° bend
- Stirrup and tie anchorage with 135° bend
Mortar

- Cementitious material that glues individual bricks or blocks together
- Masonry and mortar cements
- Mortar cement tested for bond flexibility – may be used in high seismic applications

Grout

- Cementitious material that fills in cells of CMU block
- Placed between wythes of masonry to bind rebar to brick or block
- Coarse (pea gravel and sand) and fine (sand only) grout

Joint Caulking

- Control Joint in a Wall
Deterioration Issues

- Repointing
- Erosion of brick
- Loss of mortar bond
- Moisture intrusion

Useful Resources

www.masonrysociety.org
## Unified Soil Classification System

Adopted by Corps of Engineers and Bureau of Reclamation, January, 1952, in collaboration with A. Casagrande, PhD.

### Coarse-grained soil classes

<table>
<thead>
<tr>
<th>Major Group</th>
<th>Designation</th>
<th>Letter Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>GL</td>
<td>Gray clay, gray clay loam, or gray silty clay loam</td>
<td>Y</td>
<td>Fine-grained clays, fine-grained silt, or fine-grained silty soil.</td>
</tr>
<tr>
<td>GP</td>
<td>Gray sand, gray sand loam, or gray silty sand</td>
<td>Y</td>
<td>Fine-grained sands, fine-grained silt, or fine-grained silty soil.</td>
</tr>
<tr>
<td>GM</td>
<td>Gray loam, or gray silty loam</td>
<td>Y</td>
<td>Fine-grained loams, fine-grained silt loams, fine-grained silty loams, or fine-grained silty clay loams.</td>
</tr>
<tr>
<td>GB</td>
<td>Gravelly sand, gravelly sand loam, or gravelly silty sand</td>
<td>Y</td>
<td>Fine-grained gravels, fine-grained silt gravels, or fine-grained silt silts.</td>
</tr>
</tbody>
</table>

*Note: The #4 sieve (¼ in. openings) is used to separate coarse-grained soils from finer-grained soils.*
Coarse-grained soils

Gravelly sands - SP

Coarse-grained soils

Clayey sands – SC

Fine-grained soil classes

ML: Impervious soils and very fine sands, rock flour, silt or clayey fine sands or clays with slight plasticity
CL: Silt loam, loam, or fine sandy loam; slightly plastic clays or clayey silts
ML: Clayey silts and silt loams with plasticity
DL: Coarse sands and organic soil classes of less plasticity
ML: Organic soils, peat, or peaty soils
ML: Clayey soils of high plasticity (boggy)
ML: Organic classes of medium to high plasticity; organic soils
PT: Peat, humus, swamps, soils with high organic contents
Fine-grained soils
Inorganic clays – CH

Soils
The good stuff:
- Site Class A – “East coast hard rock”
- Site Class B – “West coast hard rock”
- Site Class C – Stiff rocky soil
- Site Class D – Good stiff soil (not rock)
- Site Class E – Soft clay soils
- Site Class F – Organic or liquefiable soils

Hard Rock (East Coast) – Site Class A
Soft Rock (West coast) – Site Class B

Stiff Rocky Soil – Site Class C

Hard to tell whether it is solid rock or compacted soil. Sometimes brittle rock is placed in this category.

Stiff Soil – Site Class D
Liquefiable Soils – Site Class E or F

Liquefaction caused the sand boils pictured here in the Nisqually earthquake (Feb. 28, 2001).

Highly Organic Soils

Shallow Foundations

- No formal definition
- Generally, walls eight feet tall or less
- Concrete or masonry
Excavation

- Removal of soil to:
  - build foundation
  - improve bearing capacity below the foundation

Fill

- Addition of high quality soils to:
  - improve bearing capacity
  - flatten an area before construction

Deep Foundations

- Subdivided into main two categories:
  - Driven piles
  - Cast-in-place piers
- Material quality, pile length, angle, and load capacity all need to be observed and verified.
Driven Deep Foundations

- Driven foundation elements are typically steel cylinders or H-shapes pounded into the soil by a pile driver at the surface.

Testing

SPT – standard penetration test
CPT – core penetration test

Cast-In-Place Deep Foundation Elements

- Grout or concrete used during or after drilling to create a pier to increase soil bearing capacity
Data Collection

- Grout volume
- Plumbness

Helical Piles

- Screwed into soils like a wood screw.
- Geotechnical reports and manufacturer’s installation requirements help determine compliance with design requirements.

Useful Resources

- Soils, Earthwork and Foundations: A Practical Approach Based 2015 IRC and IBC
ICC preferred providers

- AWC
- ACI
- PCI
- TMS
- SSTC
- CRSI

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