Micropile Lateral Load Testing in the Charleston, SC Area

A special thanks to:
Micropiles are being used more frequently in the Charleston, SC area

• Limited space or overhead
• Noise or vibration considerations
• Rehabilitation of an existing older structures
• Additions to existing structures in close quarters
• Underpinning
• Upgrading of foundation support due to seismic and wind load requirements
Purpose of Presentation

1. Provide a limited understanding of the lateral design factors and the use of cased and uncased sections.

2. Provide 5 case histories in Charleston, SC that indicate the lateral loads possible using both cased and uncased upper micropile sections.

3. Provide a starting point for the economical use of micropiles to resist lateral loads

4. Continue load testing and design processes to increase case history data base.
Geotechnical Test Methods

The following test methods have been used to verify & refine Micropile Design with Load Testing

- ASTM D-1143 (Axial Compression)
- ASTM D-3680 (Axial Tensile)
- ASTM D-3966 (Lateral Loading)
Background for Design Methods

• Specifications that govern design may include the current International Building Code

SECTION 1808
PIER AND PILE FOUNDATIONS

1808.1 Definitions. The following words and terms shall, for the purposes of this section, have the meanings shown herein.

FLEXURAL LENGTH. Flexural length is the length of the pile from the first point of zero lateral deflection to the underside of the pile cap or grade beam.

MICROPILES. Micropiles are 12-inch-diameter (305 mm) or less bored, grouted-in-place piles incorporating steel pipe (casing) and/or steel reinforcement.
Background for Design Methods

- Performance based on local conditions

- Cost & Anticipated installation difficulties

- Differences in LPILE design analysis vs. test modeling
FHWA-NHI-05-039 (Micropile Design and Construction) has become widely used as a more specific requirement in addition to IBC requirements.

- It is specific to micropile design and construction
- It recognizes four micropile construction types.

A newer Type E exists that is incorporates a hollow bar with a bit to self drill the hole. This is the type used for tests.
Micropile Equipment Information

- The typically used micropile in the Charleston, SC area are comprised of TITAN Injection Bore (IBO) 40/20 steel rods
- The TITAN IBO steel rods are comprised of StE460 micro-alloy construction steel
- Bit size x factor = hole size. Common factors in Charleston soils is 1.1 to 1.4

Rod sizes up to 40/16 have a left hand thread

Rod sizes larger than 40/16 have a right hand thread
### Titan Micropile Reinforcing Size

![Titan Micropile Reinforcing Size Diagram](image)

**Left Hand (shown), Sizes 30/16-52/26**

**Right Hand, Sizes 73/63 - 103/78-51**

**Left Hand, on Bar R32/20**

<table>
<thead>
<tr>
<th>Rod Size</th>
<th>Area (mm²)</th>
<th>Ultimate G.U.T.S (kN)</th>
<th>Yield (kN)</th>
<th>Load Capacity (kN)</th>
<th>Design¹ (70% G.U.T.S) (kN)</th>
<th>Design² (80% G.U.T.S) (kN)</th>
<th>Outside Effective Ø (in)</th>
<th>Diameter Nominal Ø (in)</th>
<th>Weight (lbs./ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30/16 L.H. THREAD</td>
<td>382</td>
<td>220</td>
<td>180</td>
<td>49.5</td>
<td>40.5</td>
<td>39.6</td>
<td>176</td>
<td>154</td>
<td>34.6</td>
</tr>
<tr>
<td>30/14 L.H. THREAD</td>
<td>395</td>
<td>260</td>
<td>220</td>
<td>58.5</td>
<td>49.5</td>
<td>48.6</td>
<td>182</td>
<td>156</td>
<td>40.9</td>
</tr>
<tr>
<td>32/20 L.H. THREAD</td>
<td>389</td>
<td>291</td>
<td>244</td>
<td>65.4</td>
<td>54.9</td>
<td>52.3</td>
<td>182</td>
<td>156</td>
<td>45.8</td>
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<tr>
<td>30/11 L.H. THREAD</td>
<td>446</td>
<td>320</td>
<td>260</td>
<td>72.0</td>
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<td>58</td>
<td>204</td>
<td>175</td>
<td>50.4</td>
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<tr>
<td>40/20 L.H. THREAD</td>
<td>726</td>
<td>539</td>
<td>430</td>
<td>121.2</td>
<td>96.7</td>
<td>95.6</td>
<td>323</td>
<td>287</td>
<td>84.8</td>
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<td>40/16 L.H. THREAD</td>
<td>879</td>
<td>690</td>
<td>525</td>
<td>148.4</td>
<td>118.1</td>
<td>118.9</td>
<td>425</td>
<td>377</td>
<td>103.9</td>
</tr>
<tr>
<td>52/26 L.H. THREAD</td>
<td>1337</td>
<td>929</td>
<td>730</td>
<td>208.9</td>
<td>164.2</td>
<td>160.1</td>
<td>650</td>
<td>557</td>
<td>146.2</td>
</tr>
<tr>
<td>73/56 L.H. THREAD</td>
<td>1414</td>
<td>1194</td>
<td>78.5</td>
<td>268.5</td>
<td>176.5</td>
<td>174.3</td>
<td>770</td>
<td>616</td>
<td>161.1</td>
</tr>
<tr>
<td>73/53 L.H. THREAD</td>
<td>1631</td>
<td>1160</td>
<td>970</td>
<td>280.9</td>
<td>218.1</td>
<td>208.7</td>
<td>812</td>
<td>696</td>
<td>182.6</td>
</tr>
<tr>
<td>73/45 L.H. THREAD</td>
<td>1868</td>
<td>1390</td>
<td>1180</td>
<td>366.5</td>
<td>265.3</td>
<td>263.1</td>
<td>978</td>
<td>812</td>
<td>256.6</td>
</tr>
<tr>
<td>73/35 L.H. THREAD</td>
<td>2280</td>
<td>1630</td>
<td>1180</td>
<td>865.5</td>
<td>618.4</td>
<td>618.1</td>
<td>1345</td>
<td>1140</td>
<td>302.5</td>
</tr>
<tr>
<td>103/78 L.H. THREAD</td>
<td>3146</td>
<td>2282</td>
<td>1800</td>
<td>1532</td>
<td>1204</td>
<td>1200</td>
<td>1780</td>
<td>1597</td>
<td>359.2</td>
</tr>
<tr>
<td>103/51 L.H. THREAD</td>
<td>3853</td>
<td>2750</td>
<td>1800</td>
<td>2048</td>
<td>1680</td>
<td>1678</td>
<td>2242</td>
<td>1906</td>
<td>400.3</td>
</tr>
<tr>
<td>127/111 L.H. THREAD</td>
<td>5501</td>
<td>3460</td>
<td>2700</td>
<td>3132</td>
<td>2518</td>
<td>2518</td>
<td>3592</td>
<td>3079</td>
<td>544.6</td>
</tr>
<tr>
<td>130/60 L.H. THREAD</td>
<td>9540</td>
<td>7940</td>
<td>5250</td>
<td>359.7</td>
<td>2400</td>
<td>2400</td>
<td>4046</td>
<td>3778</td>
<td>406.8</td>
</tr>
</tbody>
</table>

**Note:** Subject to change without notice.

**Shear Force**

Allowable shear force is determined by the formula:

\[
Q_{allow} = \frac{Yield}{1.75 \times 3}
\]

**Certified to ISO 9001**

**TITAN 127/111:** Allowable bending moment = 23.9 kNm (737.5 lbsft)
Method of Installation

MicroPile Installation

- Use appropriate rotary drilling technique which is normally wet wash drilling, driven casing or other acceptable means.
- Mix sufficient flushing grout (W/C=0.70) and pump into holding tank.
- Start pumping to assure that grout will exit drill bit.
- Start rotary drilling while pumping grout continuously out of the holding tank.
- When final depth is reached, change to W/C ratio of 0.44 and recirculate until the flushing grout replaced.
- Based on the measured grout volumes (number of bags of cement and water per bag) taken during installation, the average pile diameter and cross-sectional can be back calculated.
Method of Installation

- The contractor normally uses a neat cement grout w/ a minimum of 28 day unconfined compressive strength of 5000 psi.

- The grout plant equipment is a ChemGrout CG600 Pneumatic Plant or similar used for both mixing and pumping the mixture.
Method of Installation

• The grout is injected from the lowest point of the hollow steel reinforcing bar into the drilled hole. The mixer and pump are monitored continually to control the quality and quantity of the grout.

• When the grouting is completed, the hollow bar remains in the hole and is filled with high strength grout.

• Normally after grouting the grout compressive strength can exceed 5000 psi after 3-5 days. At that time the pile can be load tested based on structural strength.
Installation Equipment

Casagrande C-4 XP, Casagrande S.P.A
Installation Equipment

PD 1011HD
Grout Mixer,
PennDrill
Manufacturing
Installation Equipment

TEJ model WD 50

Skid Steer tracked loader with hydraulic drill mounted as attachment
Micropile Case Histories

Our 5 detailed case histories include...
Load Test Overview

The following table summarizes specific information about each of the five test locations.
### Case Study Summary

<table>
<thead>
<tr>
<th>Project Name</th>
<th>Micropile Information</th>
<th>Surface Soil Conditions</th>
<th>Design Loads</th>
<th>Test Results</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bar Size</td>
<td>Diameter (in.)</td>
<td>Length (ft.)</td>
<td>Cased/Uncased</td>
</tr>
<tr>
<td>1 MUSC HVAC Pad</td>
<td>40/20</td>
<td>8.6</td>
<td>85</td>
<td>Cased (7.625” x 14’)</td>
</tr>
<tr>
<td>2 Galliard Auditorium Renovations</td>
<td>40/20</td>
<td>8</td>
<td>53</td>
<td>Uncased</td>
</tr>
<tr>
<td>3 Citadel Mechanical Pad</td>
<td>40/20</td>
<td>8.6</td>
<td>60</td>
<td>Uncased</td>
</tr>
<tr>
<td>4 Roper Cardiac Center</td>
<td>40/20</td>
<td>9.5</td>
<td>75</td>
<td>Uncased</td>
</tr>
<tr>
<td>5 Morris Square</td>
<td>40/20</td>
<td>8.6</td>
<td>31.25</td>
<td>Uncased</td>
</tr>
</tbody>
</table>
Geotechnical Design Methods

- Compression and Tensile Capacity
  - LCPC Method - Laboratoire Central Ponts et Chaussees
  - Alpha
    - Composite LCPC/Alpha
  - Beta
  - Local Cooper Marl Design Method
    - Composite

- Safety Factors used range from 2.0 to 3.0 depending on data quality and QC/QA
Geotechnical Design Methods

Lateral Capacity – Initially determined using generalized soils information, structural loads or deflection ranges and the LPILE software.
Case History Locations 1-5
Case History 1: MUSC HVAC Pad
Case History 1: MUSC HVAC Pad

MUSC Mechanical Pad
Medical University of South Carolina (Charleston, South Carolina)

Date: May 7, 2012
Estimated Water Depth: 10 ft
Rig/Operator: BR

Latitude: 32.7862
Longitude: -79.9477
Elevation: 15.0

Total Depth: 82.3 ft
Termination Criteria: Target Depth
Cone Size: 10 cm²

Cone Penetration Test

Sleeve Friction
Pore Pressure
Undrained Shear Strength
Equivalent (N180)

Depth (ft)
Tip Resistance: $q_t$
Sleeve Friction: $f_s$
Pore Pressure: $u_p$
Undrained Shear Strength: $s_u$

SBT Fr Normalized

Clays-Clay to Silty Clay
Clays-Clay to Silty Clay
Clays-Clay to Silty Clay
Clays-Clay to Silty Clay
Sands-Clean Sand to Silty Sand
Clays-Clay to Silty Clay
Clays-Clay to Silty Clay
Clays-Clay to Silty Clay
Clays-Clay to Silty Clay

Elev (ft)
Case History 1: MUSC HVAC Pad

Pertinent Pile Information

- Cased (diameter: $7\frac{5}{8}$ inches, length: 14 ft.)
- Pile length – 85 feet
- Titan IBO 40/20
- Pile Diameter - ~ 8.6 inches
- Design Axial Capacity – 60 kips
- Available Capacity – 120 kips
- Design Lateral Capacity – 7.5 kips
- Available Lateral Capacity – 45 kips
Load Testing
Case History 1:
MUSC HVAC Pad - Site Plan
Case History 1: MUSC HVAC Pad - Axial Load Test

MUSC - Mechanical Pad
Terracon Project No.: EN125033
Axial Static Load Test (SLT) for Test Pile 1 (TP1)
7 5/8 inch O.D. Casing by 85 ft Total Length Micropile


Required Ultimate Bearing 120 Kips (FS = 2.0)
Case History 1: MUSC HVAC Pad - Lateral Load Test

Exhibit A-5. Load vs. Deflection.
Case History 1:
MUSC HVAC Pad - LPILE Results

40/20 Micropile (Cased to 14 ft) - LPILE Analysis Results
Free Head Conditions - Seismic
Case I - 2.5 kip Lateral Load
Case II - 5.0 kip Lateral Load
Case History 2:
Gaillard Center
Case History 2: Gaillard Center

CPT LOG NO. C1

PROJECT: Gaillard Renovations
CLIENT: Palmetto Guntle Construction Co., Inc.
SITE: Calhoun St.
Charleston, South Carolina

BORING LOCATION:
Elevation: +/- 13.5 ft
Latitude: 32.78731
Longitude: -79.953032

Depth (ft) | Tip Resistance $q_t$ (psf) | Sleeve Friction $q_s$ (psf) | Pore Pressure $u_s$ (psf) | Friction Ratio $f$ (%) | SBT Fr Normalized (MA = 1, 1990)
---|---|---|---|---|---
0 | 80 | 1.2 | -1.2 | 1.2 |
5 | 160 | 2.4 | 3.6 | 2.4 |
10 | 240 | 3.6 | 4.8 | 3.6 |
15 | 320 | 4.8 | 4.8 | 4.8 |

Notes:
3 ft S of NE Bldg Corner / 24 ft off Wall

WATER LEVEL OBSERVATION
9.5 ft measured water depth

Test Completed: 11/28/2012
Driller/Log: JB/Pagani TG73-200
Project No.: EN120040

Exhibit
Case History 2: Gaillard Center

Pertinent Pile Information

- Uncased
- Pile length – 53 feet
- Titan IBO 40/20
- Pile Diameter - ~ 8 inches
- Design Axial Capacity – 80 kips
- Available Capacity – 157 kips
- Design Lateral Capacity – 7.6 kips
- Available Lateral Capacity – 24 kips
Case History 2: Gaillard Center - Site Plan
Case History 2: Axial Compression Load Test – Gaillard Center

Gaillard Reconstruction Project
Terracon Project No.: EN125091
Axial Compression Static Load Test for Test Pile 1 (TP1)
8 inch O.D. by 53 ft Total Length Micropile

Exhibit B-1. Axial Compression Load vs. Deflection for Test Pile 1.
Case History 2: Lateral Load Test - Gaillard Center

Gaillard Reconstruction Project
Terracon Project No.: EN125091
Lateral Load Test for Test Pile 3 (TP3)
8 inch O.D. by 53 ft Total Length Micropile

Case History 2: Gaillard Center – Theoretical LPILE Results

40/20 Micropile (uncased) - LPILE Analysis Results
7.6 kip Lateral Load (under seismic conditions)
Case I - Free Head Conditions
Case II - Fixed Head Conditions
Case History 2: Gaillard Center – Modified LPile Results

40/20 Micropile (uncased) - LPILE Analysis
Lateral Load Test Comparison - Modified p-y
Case I - 8 kips Shear
Case II - 16 kips Shear
Case History 3: Citadel Mechanical Pad

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Case History 3: Citadel Mechanical Pad

Cone Penetration Test

Total Depth: 60.3 ft
Termination Criteria: Target Depth
Cone Size: 1.75

Depth (ft)
Tip Resistance $q_t$ (tsf)
Sleeve Friction $f_s$ (tsf)
Pore Pressure $u_s - u_d$ (tsf)
Friction Ratio $R_f$ (%)
Equivalent N$_{eq}$

Values and descriptions for each layer are shown in the diagram.
Case History 3: Citadel Mechanical Pad

Pertinent Pile Information

- Uncased
- Pile length – 60 feet
- Titan IBO 40/20
- Pile Diameter - ~ 8.6 inches
- Design Axial Capacity – 22 kips
- Available Capacity – 50 kips
- Design Lateral Capacity – 2 kips
- Available Lateral Capacity – 10 kips
Case History 3:
Citadel Mechanical Pad - Site Plan
Case History 3: Citadel Mechanical Pad-Axial Load Test

The Citadel - Coward Hall Refrigeration Replacement
Terraccon Project No.: EN125034
Axial Static Load Test (SLT) for Test Pile 1 (TP1)
7.5 inch O.D. by 60 ft Total Length Micropile

Required Ultimate Bearing
44 Kips (FS = 2.0)
Case History 3: Citadel Mechanical Pad - Lateral Load Test

The Citadel - Coward Hall Refrigeration Replacement
Terracon Project No.: EN125034
Lateral Load Test (LLT) for Test Pile 2 (TP2)
7.5 inch O.D. by 60 ft Total Length Micropile

Exhibit A-5. Load vs. Deflection.
Case History 3: Citadel Mechanical Pad – LPile Results

8” Micro-Pile w/ 40-20 Titan IBO - LPILE Analysis Results
Fixed Head Conditions - Static
Case I - 1” Deflection
Case II - 1/2” Deflection
Case III - 1/4” Deflection
Case History 4: Roper Cardiac Center Entrance
Case History 4: Roper Cardiac Center Entrance
Case History 4:
Roper Cardiac Center Entrance

Pertinent Pile Information

- Uncased
- Pile length – 75 feet
- Titan IBO 40/20
- Pile Diameter - ~ 7.9 inches
- Design Axial Capacity – 61 kips
- Available Capacity – 120 kips
- Design Lateral Capacity – 4 kips
- Available Lateral Capacity – 45 kips
Case History 4:
Roper Cardiac Center Entrance -- Axial Load Test

EXHIBIT A - 4

Roper- St. Francis Cardiac Renovation
Micropile Axial Load Test
East Loading Dock
WPC Project # EN111022
Case History 4:
Roper Cardiac Center Entrance – Lateral Load Test

ROPER ST FRANCIS CARDIAC RENOVATIONS
LATERAL MICROPILE LOAD TEST
EAST LOADING DOCK
WPC PROJECT # 111022

LOAD, Pounds

LATIAL DEFLECTION, Inches
Case History 5: Morris Square
Case History 5: Morris Square
Pertinent Pile Information

- Uncased
- Pile length – 31.25 feet
- Titan IBO 40/20
- Pile Diameter - ~ 8.6 inches
- Design Axial Capacity – 15 kips
- Available Capacity – 50 kips
- Design Lateral Capacity – 7.6 kips
- Available Lateral Capacity – 11.5 kips
Static Load Test - Morris Square

TP4 Static Load Test (TP4 SLT)
Morris Square Charleston, SC
WPC Project Number: CHS3-03-103

Pile Properties:
- 150mm Cutting Head Diameter
- Titan IBO 40/20 Micro-Pile
- Total Length: 31.25 ft

Design Allowable Load = 15 tons
Design Ultimate Load = 30 tons (FS = 2)
Failure Load (Davisson's Criteria) = 51 tons

ASTM D1143 Quick Test Method (Section 5.6)
Test Date: 4/17/06

Figure A. TP4 Static Load Test Results
Lateral Load Test - Morris Square

TP4 Lateral Load Test (TP4 LLLT)
Morris Square Charleston, SC
WPC Project Number: CHS3-03-103

Pile Properties:
- 150mm Cutting Head Diameter
- Titan IBO 40/20 Micro-Pile
- Total Length: 31.25ft

Failure Load (1 Inch Deflection) = 11.5 kips
ASTM D3966 Standard Test Method
For Piles Under Lateral Loads
Test Date: 5/26/06

Figure B. TP4 Lateral Load Test Results
Initial Geotechnical Conclusions

- Lateral load test results varied from $xx.x$ for uncased to $xx.x$ for case
- Test results indicate...
  - a higher capacity than normally assumed
  - significant increase in lateral capacity when using properly designed casings
- Lateral loads of 8-10 kips do not require the use of casings
Initial Conclusions of Testing

- Successful use of modified P-Y parameter curves for site specific design
- Installation method is extremely important for Coastal SC
  - Steady grout pressure
  - Proper centering of drill rod
  - Over sizing hole based of soil type, depth, rotation speed and cuttings removal
- Can be used in close quarters
These initial case histories provide a basis for:

Structural Design of Uncased Micropiles
Federal Highway Administration
Micropile Design and Construction

Considers Only Cased Piles
Federal Highway Administration
Micropile Design and Construction

The effective length factor, K, depends on the rotational restraint at the ends of the micropile and the means available to resist lateral movements. This value is typically assumed equal to 1.0 for micropile design.

The assumption that the entire axial load is carried by the steel casing is conservative. Richards and Rothbauer (2004) proposed a combined stress check that can account for the contribution of the grout inside the casing to compression capacity. This method assumes that buckling potential is negligible. The Richards and Rothbauer combined stress check can be written as:

\[
\frac{P_L}{P_L_{\text{allow}}} + \frac{M_{\text{max}}}{M_{\text{allow}}} \leq 1.0 \quad \text{(Eq. 5-6)}
\]

where

- \( P_L \) – maximum axial compression load;
- \( P_L_{\text{allow}} \) – determined from Eq. 5-1;
- \( M_{\text{max}} \) – maximum bending moment in the micropile; and
- \( M_{\text{allow}} = P_L(0.55 P_L_{\text{allow}}) + 8 \).

More advanced methods which consider composite action between the steel casing and the grout inside the casing in carrying these axial loads could be used, but are beyond the scope of this manual.

5.7 STEP 6: STRUCTURAL DESIGN OF MICROPILE UNCASED LENGTH

The allowable compression load for the uncased length of a micropile is given as:

\[
P_{\text{allow, uncased}} = 0.47 f_y f_c A_{\text{uncased}} + 0.47 f_{c,\text{grout}} A_{\text{grout}} \quad \text{(Eq. 5-7)}
\]

For the uncased portion of the pile, the reinforcing bar yield stress used in the calculations in compression is assumed to not exceed 600 MPa (87 ksi) (i.e., to prevent grout crushing at an assumed strain of 0.003 unless data is provided demonstrating that the confined grout can sustain higher strain levels without crushing).

The allowable tension load for the uncased length of a micropile is given as:

\[
P_{\text{allow, uncased}} = 0.55 f_y f_c A_{\text{uncased}} \quad \text{(Eq. 5-8)}
\]
1810.8.1 Construction. Micropiles shall consist of a grouted section reinforced with steel pipe or steel reinforcing. Micropiles shall develop their load-carrying capacity through a bond zone in soil, bedrock or a combination of soil and bedrock. The full length of the micropile shall contain either a steel pipe or steel reinforcement.
1810.8.4.1 Seismic reinforcement. ...
Where a structure is assigned to Seismic Design Category D, E or F, the pile shall be considered as an alternative system. In accordance with Section 104.11, the alternative pile system design, supporting documentation and test data shall be submitted to the building official for review and approval.
2006 International Building Code

1810.8.4.1 Seismic reinforcement. ...
Where a structure is assigned to Seismic Design Category D, E or F, the pile shall be considered as an alternative system. In accordance with Section 104.11, the alternative pile system design, supporting documentation and test data shall be submitted to the building official for review and approval.
There are no direct references to Micropiles in ACI 318
So... We know that

- Design as Alternative System with Testing
- Compression and Tension- No Problem!

**But**

Lateral forces induce flexural stresses What about **Bending**?
Technical Treatises and Research Papers on Bending of Circular Concrete Sections with Center Reinforcement:

ZERO!
10.2.6 — The relationship between concrete compressive stress distribution and concrete strain shall be assumed to be rectangular, trapezoidal, parabolic, or any other shape that results in prediction of strength in substantial agreement with results of comprehensive tests.
Actual vs. Whitney Stress Block

\[ c = 0.72 \ \frac{f'_c}{c} \ \text{lb/in}^2 \]

\[ c = 0.85 \ \frac{f'_c}{a} \ \text{lb/in}^2 \]

\[ T = A_s f_s \]

**Fig. 2.11** Actual and equivalent rectangular stress distributions at ultimate load (for \( f'_c \) less than 4000 psi).
\( a = \beta_1 c \)

10.2.7.3 — For \( fc' \) between 2500 and 4000 psi, \( \beta_1 \) shall be taken as 0.85. For \( fc' \) above 4000 psi, \( \beta_1 \) shall be reduced linearly at a rate of 0.05 for each 1000 psi of strength in excess of 4000 psi, but \( \beta_1 \) shall not be taken less than 0.65.
So... Back to Basic Reinforced Concrete Design

2 Failure Modes: Compression- Concrete Crushes And Tension- Steel Yields
Basic Reinforced Concrete Design

2 Failure Modes:
Compression- Catastrophic!
And
Tension- More Desirable
Basic Reinforced Concrete Design

Designs where Compression Failures occur are considered **Over-Reinforced**

Designs where Tension Failures occur are considered **Under-Reinforced**
Basic Reinforced Concrete Design

Balanced Failures when the concrete crushes at the same loading as the reinforcing yields
QUESTIONS?