The New Library at the University of Virginia’s College at Wise

Macenzie Ceglar | Structural Option
Advisor: Heather Sustersic
April 14, 2014
Owner: University of Virginia
Architecture & Engineering: Cannon Design

Size: 68,000 GSF
Stories Above Grade: 6
Height: 102 FT
Cost: $43 Million

August 2012 – August 2015
UVA’s New Library

- Building Introduction
  - Statistics
    - Gravity System
    - Lateral System
  - Problem Statement & Solution
  - Two-way System
  - PT System
  - Lateral System
  - Cost and Schedule Analysis
  - System Comparison
  - Conclusion

Building Introduction

Unique Feature: Integration into 60 Hill Side

Image Courtesy of Cannon Design

Image from Construction Documents
UVA’s New Library

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Existing Gravity System

- Spread/Strip Footings
- Temporary-Leave-In-Place Retaining Wall System

- Composite Steel Floor Framing
  - 2” 18 ga. Metal Decking
  - 4 ½” NWC Topping
  - 3 ½” x ¾” Studs

- Wide Flange Members

- Typical Bay Size: 25’-4” x 25’-4”
UVA’s New Library

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Existing Lateral System

• Ordinary reinforced concrete shear walls
  • 12” thick
  • #5 rebar @ 18” EW EF
• Located near stairs and elevator shafts

Image from Construction Documents
**UVA’s New Library**

- Building Introduction
- **Problem Statement & Solution**
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**Problem Statement**

- Exiting structure well designed
- **Problem Scenario**
  - Redesign the structure in concrete

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**Proposed Solution**

- Redesign structural systems as a two-way concrete slab system
- Address deflections in longer span bays
- Investigate the possibility of a post-tensioned system
- Determine feasibility of a concrete system
- Consider cost and schedule impact
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Two-Way Concrete System
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**Floor Slab Design**

- Trial slab thickness: 10”
- Drop Panel Sizes:
  - L/6 in each direction
- Thickness: 1.25h = 12.5”
- Punching shear controlled design

<table>
<thead>
<tr>
<th>Column</th>
<th>X (FT)</th>
<th>Y (FT)</th>
<th>Thickness (IN)</th>
<th>Required an Increase in Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>3E</td>
<td>1.33</td>
<td>8.44</td>
<td>8.44</td>
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</tr>
<tr>
<td>3D</td>
<td>1.11</td>
<td>8.44</td>
<td>8.44</td>
<td>Yes</td>
</tr>
<tr>
<td>3C</td>
<td>1.33</td>
<td>8.44</td>
<td>8.44</td>
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<td>5.17</td>
<td>4.56</td>
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<td>6D</td>
<td>6.20</td>
<td>5.47</td>
<td>5.07</td>
<td>Yes</td>
</tr>
<tr>
<td>6C</td>
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<td>5.47</td>
<td>5.07</td>
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<tr>
<td>8B</td>
<td>13.67</td>
<td>1.33</td>
<td>12.67</td>
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• Building Introduction
• Problem Statement & Solution
• **Two-way System**
  • Floor Slab Design
  • Deflection Checks
  • Final Slab Design
  • Column Design
• PT System
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Trial Floor Slab Designs

- Drop Panels Only
- Shear Studrails
- Drop Panels & Edge Beams
- Shear Studrails & Edge Beams
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Deflections

- Maximum Allowable Deflection: L/480

<table>
<thead>
<tr>
<th>Span</th>
<th>Length (FT)</th>
<th>Deflection</th>
<th>L/480</th>
<th>Pass/Fail</th>
</tr>
</thead>
<tbody>
<tr>
<td>5D-6D</td>
<td>31</td>
<td>1.33</td>
<td>0.775</td>
<td>Fail</td>
</tr>
<tr>
<td>6D-7D</td>
<td>27.33</td>
<td>1.02</td>
<td>0.683</td>
<td>Fail</td>
</tr>
<tr>
<td>5E-6D</td>
<td>40</td>
<td>1.43</td>
<td>1.0</td>
<td>Fail</td>
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<td>6E-7D</td>
<td>37.33</td>
<td>1.24</td>
<td>0.933</td>
<td>Fail</td>
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<tr>
<td>5C-6D</td>
<td>40</td>
<td>1.33</td>
<td>1.0</td>
<td>Fail</td>
</tr>
</tbody>
</table>
UVA’s New Library

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Deflections

- Trial Design Solutions:
  - Weighted Average
  - Compression Reinforcement
  - Drop Panels
  - Shallow Beams

<table>
<thead>
<tr>
<th>Span</th>
<th>Length (FT)</th>
<th>Deflection</th>
<th>L/480</th>
<th>Pass/Fail</th>
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<td>0.709</td>
<td>0.775</td>
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<td>6D - 7D</td>
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<td>6E - 7D</td>
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<td>0.817</td>
<td>0.933</td>
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<td>5C - 6D</td>
<td>40</td>
<td>0.827</td>
<td>1.0</td>
<td>Pass</td>
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</table>
UVA’s New Library

- Building Introduction
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**Two-way System**
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---

Final Floor Slab Design

- Slab thickness: 10”
- Drop Panel: 7’ x 7’ x 6”
- Shallow Beam: 7’ x 14”
- Additional edge beams and interior beams
- Program output verified by hand
## UVA’s New Library

- Building Introduction
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### Two-way System
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### PT System

### Lateral System

### Cost and Schedule Analysis

### System Comparison

### Conclusion

---

### Slab Reinforcement

#### Typical Slab Reinforcing Schedule

<table>
<thead>
<tr>
<th>Slab Thickness</th>
<th>Top Mat</th>
<th>Bottom Mat</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>E-W</td>
<td>N-S</td>
</tr>
<tr>
<td>0'-10&quot;</td>
<td>#5 @ 16&quot;</td>
<td>#5 @ 16&quot;</td>
</tr>
</tbody>
</table>

---

![Diagram of slab reinforcement](image_url)
UVA’s New Library

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**Column Redesign**

- Typical:
  - 24” X 24”
  - (8) # 8 Long. Bars
  - #3 Ties

- Non-Typical Columns:
  - 6D
  - 6C
  - 7C

Image from Construction Documents
Column Redesign

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<table>
<thead>
<tr>
<th>Level</th>
<th>$P_n$ (k)</th>
<th>$\phi P_n/Pu$</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>185</td>
<td>6.5</td>
</tr>
<tr>
<td>5</td>
<td>495</td>
<td>2.4</td>
</tr>
<tr>
<td>4</td>
<td>803</td>
<td>1.5</td>
</tr>
<tr>
<td>3</td>
<td>1112</td>
<td>1.08</td>
</tr>
<tr>
<td>2</td>
<td>1420</td>
<td>1.24</td>
</tr>
<tr>
<td>1</td>
<td>1730</td>
<td>1.02</td>
</tr>
</tbody>
</table>

- 24” x 24”
- (8) #8 Bars
- 28” x 28”
- (16) #8 Bars

Image from Construction Documents
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Post-Tensioned Concrete System
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  • Number of Tendons
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Unfavorable Factors

• Unfavorable Arrangement of Shear Walls and Location of Foundation Walls

Solution: Pour Strips and Slip Joints
UVA’s New Library

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Initial Number of Tendons

• Based on minimum precompression stress = 125 psi
• 27 kips/tendon after all stress losses

Distributed Direction:

\[
\frac{(125 \text{ psi})(12/1')(8')}{12000 \text{ lb/ft}} = 4.5 \text{ ft}
\]

Banded Direction:

\[
\begin{align*}
A &= (24.33')(12/1')(8') = 2429 \text{ in}^2 \\
P &= (125 \text{ psi})(2429 \text{ in}^2) = 304 \text{ kips} \\
\text{Tendons} &= \frac{304 \text{ kips}}{27 \text{ kips/tendon}} = 11 \text{ Tendons}
\end{align*}
\]

- **ACI318-11 18.12.4**: Maximum tendon spacing of: \(\frac{5}{8} \times \text{Slab Thickness}\)
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Adjusting Number of Tendons

• Maximum tensile stress = $6\sqrt{f'c} = 424.3$ psi
• Max precompression stress = 350 psi
• Span D5-D6 and D6-D7:
  • Maximum number of tendons = 32
  • Required number of tendons = 34

FAIL

Required number of tendons: 26
Deflections

- Maximum Allowable Deflection: L/480
- Class U system → Deflections calculated using uncracked section properties.

\[
2(\text{Self Dead}) + 2(\text{Balance}) + 3(\text{Other Dead}) + 1.6(\text{Live})
\]

<table>
<thead>
<tr>
<th>Span</th>
<th>Length (FT)</th>
<th>Deflection</th>
<th>L/480</th>
<th>Pass/Fail</th>
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<tbody>
<tr>
<td>5D - 6D</td>
<td>31</td>
<td>0.578</td>
<td>0.620</td>
<td>Pass</td>
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</table>
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Shear Force Comparison

Max Shear due to Soil Loads: 2294 K

Comparison of Shear Forces

<table>
<thead>
<tr>
<th></th>
<th>Shear Capacity (k)</th>
<th>Force (k)</th>
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<tbody>
<tr>
<td>Original Loads</td>
<td>4752</td>
<td>3071</td>
</tr>
<tr>
<td>New Loads</td>
<td>4934</td>
<td>3908</td>
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<tr>
<td>Percent Increase</td>
<td>3.8%</td>
<td>27.3%</td>
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</tbody>
</table>

Drift Comparison

Max Allowable Building Deflection: 3.1”
Max Allowable Story Drift: 3.2”

Comparison of Maximum Drifts

<table>
<thead>
<tr>
<th></th>
<th>Max Building Deflections (in) (Wind Case 4 +M Same Direction)</th>
<th>Max Story Drift (Y-Direction +M)</th>
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<tbody>
<tr>
<td>Original Loads</td>
<td>2.16</td>
<td>2.81</td>
</tr>
<tr>
<td>New Loads</td>
<td>2.72</td>
<td>3.18</td>
</tr>
<tr>
<td>Percent Increase</td>
<td>25.9%</td>
<td>13.2%</td>
</tr>
</tbody>
</table>
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Cost and Schedule Analysis
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Steel System Cost

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  - Schedule Analysis
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- Conclusion

<table>
<thead>
<tr>
<th>Item</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fiber Reinforcement</td>
<td>28,317</td>
</tr>
<tr>
<td>Normal Weight Fill</td>
<td>144,125</td>
</tr>
<tr>
<td>Finish Elevated Slab</td>
<td>67,830</td>
</tr>
<tr>
<td>Cure and Protect Slab</td>
<td>10,755</td>
</tr>
<tr>
<td>Wide Flange Steel Column</td>
<td>208,893</td>
</tr>
<tr>
<td>Structural Floor Framing</td>
<td>742,673</td>
</tr>
<tr>
<td>Metal Floor Deck</td>
<td>178,797</td>
</tr>
<tr>
<td>Spray Fire Proofing</td>
<td>102,629</td>
</tr>
<tr>
<td><strong>Total Cost</strong></td>
<td><strong>$1,484,019</strong></td>
</tr>
</tbody>
</table>

- Structure ~ 3% of total project cost

Concrete System Cost

<table>
<thead>
<tr>
<th>Item</th>
<th>Amount</th>
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</thead>
<tbody>
<tr>
<td>Formwork</td>
<td>553,622</td>
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<tr>
<td>Structural Concrete</td>
<td>273,961</td>
</tr>
<tr>
<td>Finishing</td>
<td>42,883</td>
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<tr>
<td>Placement</td>
<td>51,167</td>
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<tr>
<td>Reinforcement</td>
<td>23,115</td>
</tr>
<tr>
<td><strong>Total Cost</strong></td>
<td><strong>$1,268,000</strong></td>
</tr>
</tbody>
</table>

- Reuse of formwork
- +$8 for accelerated slab concrete mix
- +$2/Month for rented column forms
15% Project Cost Savings

<table>
<thead>
<tr>
<th>Total System Cost</th>
<th>Steel</th>
<th>Concrete</th>
</tr>
</thead>
<tbody>
<tr>
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<td>$1,484,019</td>
<td>$1,268,000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Per Square Foot Cost</th>
<th>Steel</th>
<th>Concrete</th>
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<tbody>
<tr>
<td></td>
<td>$24.50</td>
<td>$21.00</td>
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</table>
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Steel System Schedule

- Construction length: 119 days
- March 3rd, 2014 – August 15th, 2014

Concrete System Schedule

- Construction length: 112 days
- March 3rd, 2014 – April 5th, 2014

Image Courtesy of Cannon Design
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Schedule Comparison

7 Day Project Duration Decrease

<table>
<thead>
<tr>
<th>Material</th>
<th>Total System Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>119 Days</td>
</tr>
<tr>
<td>Concrete</td>
<td>112 Days</td>
</tr>
</tbody>
</table>
UVA’s New Library

System Comparison

- **Construction Type**
  - Steel: 1B
  - Concrete: 1B
  - No Change

- **Floor Depth**
  - Member | Steel | Concrete |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Slab/Floor (in)</td>
<td>6.5</td>
<td>10</td>
</tr>
<tr>
<td>Interior Beam (in)</td>
<td>16</td>
<td>-</td>
</tr>
<tr>
<td>Interior Girder (in)</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>Maximum Edge Beam (in)</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Total Decrease</td>
<td>6.5 in – 12.5 in</td>
<td></td>
</tr>
</tbody>
</table>

- **Cost**
  - Steel: $1.5 Million
  - Concrete: $1.2 Million
  - 15% Savings

- **Construction Time**
  - Steel: 119 Days
  - Concrete: 112 Days
  - 7 Day Decrease

- **Special Consideration:**
  - Concrete Construction Crew
UVA’s New Library

Conclusions

Proposed Goals

• Redesign structural systems as a two-way concrete slab system
• Address deflections in longer span bays
• Investigate the feasibility of a post-tensioned system
• Determine feasibility of a concrete system
  • Consider cost and schedule impact

27% Cost Savings + 7 Day Schedule Decrease
Acknowledgements

A Special Thanks to:

- Cannon Design | Rachel Chicchi
- SK&A Engineers | Walid Choueiri & Hakan Onel
- AE Faculty | Professor Heather Sustersic
- My Family, Fiancé, and Friends
- Jesus Christ
Appendix Slides

Verification of Output
Balancing Tendons
Two-way Deflections
PT Deflections
Edge Deflections
Water Path
Waterproof Membranes
Drainage Calculations

Calculation of Water Path
### Verification of Output

#### UVA’s New Library

<table>
<thead>
<tr>
<th>Percent Different in Total Design Moments</th>
<th>Hand Calculations/SP Stab</th>
<th>RAM Concept</th>
<th>% Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Moment in Span A-B</td>
<td>650.13</td>
<td>712.75</td>
<td>9%</td>
</tr>
<tr>
<td>Total Moment in Span B-C</td>
<td>806.82</td>
<td>777.11</td>
<td>4%</td>
</tr>
<tr>
<td>Total Moment in Both Spans</td>
<td>1456.95</td>
<td>1489.86</td>
<td>2%</td>
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#### Percent Differences in Total Design Moments

<table>
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<th>Joint</th>
<th>Moment (Hand)</th>
<th>Moment (RAM)</th>
<th>% Difference</th>
</tr>
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<tbody>
<tr>
<td>Joint A</td>
<td>650.13</td>
<td>712.75</td>
<td>9%</td>
</tr>
<tr>
<td>Joint B</td>
<td>806.82</td>
<td>777.11</td>
<td>4%</td>
</tr>
<tr>
<td>Joint C</td>
<td>1456.95</td>
<td>1489.86</td>
<td>2%</td>
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</tbody>
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**Return to Appendix Index**
### Verification of Output

#### UVA’s New Library

<table>
<thead>
<tr>
<th></th>
<th>RAM Concept</th>
<th>Hand Calculations</th>
<th>% Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max Shear Demand</td>
<td>143.1 K</td>
<td>143.1 K</td>
<td>0%</td>
</tr>
<tr>
<td>Max Capacity</td>
<td>302.6 K</td>
<td>278.4 K</td>
<td>8%</td>
</tr>
</tbody>
</table>

#### Shear Stud Rail Design

<table>
<thead>
<tr>
<th></th>
<th>RAM Concept</th>
<th>Decon STDesign</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stud Rails per Column</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Studs per Stud Rail</td>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td>Stud Spacing</td>
<td>3.75 in</td>
<td>3.75</td>
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#### One-Way Shear

<table>
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<tr>
<th></th>
<th>RAM Concept</th>
<th>Hand Calculations</th>
<th>% Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max Shear Demand</td>
<td>143.1 K</td>
<td>143.1 K</td>
<td>0%</td>
</tr>
<tr>
<td>Max Capacity</td>
<td>302.6 K</td>
<td>278.4 K</td>
<td>8%</td>
</tr>
</tbody>
</table>

#### Two-Way Shear

<table>
<thead>
<tr>
<th></th>
<th>RAM Concept</th>
<th>Hand Calculations</th>
<th>% Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max Shear Demand</td>
<td>284.6 K</td>
<td>280 K</td>
<td>1.6%</td>
</tr>
<tr>
<td>Max Capacity</td>
<td>189.7 K</td>
<td>189.9 K</td>
<td>0.1%</td>
</tr>
</tbody>
</table>

Return to Appendix Index
Balancing the Tendons

• Balancing Load = weight of design strip
• Lower Limit = 50% of design strip weight
• Upper Limit = 125% of design strip weight
Two-way System Deflections

- **ECR in RAM Concept:**
  - Default ECR = 3.35 (ACI209)
  - To account for cracking RAM Concept uses a conservative approach:
    - New ECR = ECR \times \left( \frac{M_{\text{service}}}{M_{\text{crack}}} \right)

- **Initial ECR Adjustment:**
  - ACI318-11
    - Initial factor = 1
    - Long term factor = 2 (5 + Years w/ no compression reinforcement)
  - Adjusted ECR = 3
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Two-way System Deflections

• Trial 1: Weighted Average

\[ \frac{\text{Live Load}}{\text{Live Load} + \text{Dead Load}} (1.6) + \frac{\text{Dead Load}}{\text{Live Load} + \text{Dead Load}} (\text{ECR}) \]

\[ = \frac{80}{80+141.5} (1.6) + \frac{141.5}{80+141.5} (3) = 2.5 \]

<table>
<thead>
<tr>
<th>Span</th>
<th>Length (FT)</th>
<th>Deflection</th>
<th>L/?</th>
<th>Pass/Fail</th>
</tr>
</thead>
<tbody>
<tr>
<td>5D - 6D</td>
<td>31</td>
<td>1.27</td>
<td>0.775</td>
<td>Fail</td>
</tr>
</tbody>
</table>

• Trial 2: Compression Reinforcement

- Compression reinforcement changes the long term deflection factor
- Based on trial runs in RAM Concept an ECR < 1 from compression reinforcement would be required → Unrealistic!
# Two-way System Deflections

**Trial 3: Drop Panel**
- First size: 6’ x 6’ x 6”

<table>
<thead>
<tr>
<th>Span</th>
<th>Length (FT)</th>
<th>Deflection</th>
<th>L/480</th>
<th>Pass/Fail</th>
</tr>
</thead>
<tbody>
<tr>
<td>5D - 6D</td>
<td>31</td>
<td>1.0</td>
<td>0.775</td>
<td>Fail</td>
</tr>
<tr>
<td>6D - 7D</td>
<td>27.33</td>
<td>0.669</td>
<td>0.683</td>
<td>Pass</td>
</tr>
<tr>
<td>5E - 6D</td>
<td>40</td>
<td>1.07</td>
<td>1.0</td>
<td>Fail</td>
</tr>
<tr>
<td>6E - 7D</td>
<td>37.33</td>
<td>0.971</td>
<td>0.933</td>
<td>Fail</td>
</tr>
<tr>
<td>5C - 6D</td>
<td>40</td>
<td>1.04</td>
<td>1.0</td>
<td>Fail</td>
</tr>
</tbody>
</table>

**Second size: 7’ x 7’ x 6”**

<table>
<thead>
<tr>
<th>Span</th>
<th>Length (FT)</th>
<th>Deflection</th>
<th>L/480</th>
<th>Pass/Fail</th>
</tr>
</thead>
<tbody>
<tr>
<td>5D - 6D</td>
<td>31</td>
<td>0.955</td>
<td>0.775</td>
<td>Fail</td>
</tr>
<tr>
<td>6D - 7D</td>
<td>27.33</td>
<td>0.592</td>
<td>0.683</td>
<td>Pass</td>
</tr>
<tr>
<td>5E - 6D</td>
<td>40</td>
<td>1.03</td>
<td>1.0</td>
<td>Fail</td>
</tr>
<tr>
<td>6E - 7D</td>
<td>37.33</td>
<td>0.92</td>
<td>0.933</td>
<td>Pass</td>
</tr>
<tr>
<td>5C - 6D</td>
<td>40</td>
<td>0.986</td>
<td>1.0</td>
<td>Pass</td>
</tr>
</tbody>
</table>
### Two-way System Deflections

- **Trial 4: Larger Drop Panel or Shallow Beam**
  - **Drop Panel:** 8’ x 8’ x 6’

<table>
<thead>
<tr>
<th>Span</th>
<th>Length (FT)</th>
<th>Deflection</th>
<th>L/480</th>
<th>Pass/Fail</th>
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<tbody>
<tr>
<td>5D - 6D</td>
<td>31</td>
<td>0.943</td>
<td>0.775</td>
<td>Fail</td>
</tr>
<tr>
<td>6D - 7D</td>
<td>27.33</td>
<td>0.614</td>
<td>0.683</td>
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<tr>
<td>5E - 6D</td>
<td>40</td>
<td>1.02</td>
<td>1.0</td>
<td>Fail</td>
</tr>
<tr>
<td>6E - 7D</td>
<td>37.33</td>
<td>0.943</td>
<td>0.933</td>
<td>Fail</td>
</tr>
<tr>
<td>5C - 6D</td>
<td>40</td>
<td>0.974</td>
<td>1.0</td>
<td>Pass</td>
</tr>
</tbody>
</table>

- **Shallow Beam:** 7’ x 7’ x 4’

<table>
<thead>
<tr>
<th>Span</th>
<th>Length (FT)</th>
<th>Deflection</th>
<th>L/480</th>
<th>Pass/Fail</th>
</tr>
</thead>
<tbody>
<tr>
<td>5D - 6D</td>
<td>31</td>
<td>0.709</td>
<td>0.775</td>
<td>Pass</td>
</tr>
<tr>
<td>6D - 7D</td>
<td>27.33</td>
<td>0.511</td>
<td>0.683</td>
<td>Pass</td>
</tr>
<tr>
<td>5E - 6D</td>
<td>40</td>
<td>0.875</td>
<td>1.0</td>
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</tr>
<tr>
<td>6E - 7D</td>
<td>37.33</td>
<td>0.817</td>
<td>0.933</td>
<td>Pass</td>
</tr>
<tr>
<td>5C - 6D</td>
<td>40</td>
<td>0.827</td>
<td>1.0</td>
<td>Pass</td>
</tr>
</tbody>
</table>
PT System Deflections

- ACI318-11 Section 9.5.2.5:
  - Long term deflection factor of 5 or more years = 2
- Sustained loads = DL + SW + portion of LL
- 30% sustained LL for commercial building occupancies of office and residential
- SW DL not counted in instantaneous deflections due to these deflections happening prior to the attachment of non-structural elements

Total Deflection

= Service instantaneous + Long term
=(SID + LL) + 2(SW DL + SID + 0.3LL)
= 2(SW DL) + 3(SID) + 1.6(LL)

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## Edge Deflections: Two-way

<table>
<thead>
<tr>
<th>Span</th>
<th>Span Length (FT)</th>
<th>Initial Deflections (in)</th>
<th>Final Deflections (in)</th>
<th>Sustained Deflections (in)</th>
<th>L/600 (in)</th>
<th>Pass/Fail</th>
</tr>
</thead>
<tbody>
<tr>
<td>3C-3D</td>
<td>25.33</td>
<td>0.018</td>
<td>0.19</td>
<td>0.17</td>
<td>0.51</td>
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<tr>
<td>3D-4E</td>
<td>25.33</td>
<td>0.026</td>
<td>0.31</td>
<td>0.27</td>
<td>0.51</td>
<td>Pass</td>
</tr>
<tr>
<td>4E-5F</td>
<td>25.33</td>
<td>0.059</td>
<td>0.51</td>
<td>0.49</td>
<td>0.51</td>
<td>Pass</td>
</tr>
<tr>
<td>5F-6G</td>
<td>31</td>
<td>0.044</td>
<td>0.59</td>
<td>0.48</td>
<td>0.62</td>
<td>Pass</td>
</tr>
<tr>
<td>6G-7H</td>
<td>27.33</td>
<td>0.030</td>
<td>0.35</td>
<td>0.33</td>
<td>0.55</td>
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</tr>
<tr>
<td>7H-8I</td>
<td>25.33</td>
<td>0.060</td>
<td>0.38</td>
<td>0.33</td>
<td>0.55</td>
<td>Pass</td>
</tr>
<tr>
<td>8I-9J</td>
<td>25.33</td>
<td>0.000</td>
<td>0.03</td>
<td>0.03</td>
<td>0.47</td>
<td>Pass</td>
</tr>
<tr>
<td>9J-10K</td>
<td>25.33</td>
<td>0.000</td>
<td>0.03</td>
<td>0.03</td>
<td>0.47</td>
<td>Pass</td>
</tr>
<tr>
<td>10K-11L</td>
<td>25.33</td>
<td>0.000</td>
<td>0.03</td>
<td>0.03</td>
<td>0.47</td>
<td>Pass</td>
</tr>
<tr>
<td>11L-12M</td>
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<td>0.03</td>
<td>0.03</td>
<td>0.47</td>
<td>Pass</td>
</tr>
<tr>
<td>12M-13N</td>
<td>25.33</td>
<td>0.000</td>
<td>0.03</td>
<td>0.03</td>
<td>0.47</td>
<td>Pass</td>
</tr>
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</table>

## Edge Deflections: PT

<table>
<thead>
<tr>
<th>Span</th>
<th>Span Length (FT)</th>
<th>Deflections (in)</th>
<th>L/600 (in)</th>
<th>Pass/Fail</th>
</tr>
</thead>
<tbody>
<tr>
<td>3C-3D</td>
<td>25.33</td>
<td>0.14</td>
<td>0.51</td>
<td>Pass</td>
</tr>
<tr>
<td>3D-4E</td>
<td>25.33</td>
<td>0.13</td>
<td>0.51</td>
<td>Pass</td>
</tr>
<tr>
<td>4E-5F</td>
<td>25.33</td>
<td>0.31</td>
<td>0.51</td>
<td>Pass</td>
</tr>
<tr>
<td>5F-6G</td>
<td>31</td>
<td>0.32</td>
<td>0.52</td>
<td>Pass</td>
</tr>
<tr>
<td>6G-7H</td>
<td>27.33</td>
<td>0.21</td>
<td>0.55</td>
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</tr>
<tr>
<td>7H-8I</td>
<td>25.33</td>
<td>0.21</td>
<td>0.55</td>
<td>Pass</td>
</tr>
<tr>
<td>8I-9J</td>
<td>25.33</td>
<td>0.33</td>
<td>0.51</td>
<td>Pass</td>
</tr>
<tr>
<td>9J-10K</td>
<td>25.33</td>
<td>0.33</td>
<td>0.51</td>
<td>Pass</td>
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<tr>
<td>10K-11L</td>
<td>25.33</td>
<td>0.33</td>
<td>0.51</td>
<td>Pass</td>
</tr>
<tr>
<td>11L-12M</td>
<td>25.33</td>
<td>0.33</td>
<td>0.51</td>
<td>Pass</td>
</tr>
<tr>
<td>12M-13N</td>
<td>25.33</td>
<td>0.33</td>
<td>0.51</td>
<td>Pass</td>
</tr>
<tr>
<td>13N-14O</td>
<td>25.33</td>
<td>0.33</td>
<td>0.51</td>
<td>Pass</td>
</tr>
</tbody>
</table>

### Appendix Index

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Water Path

1. Top Soil
2. Compacting Clay
   - 10” – 12” Thick
   - Thins out to top soil 12’-20’ from building
3. Backfill
   - recommended by geotechnical engineer
   - full gradation soil with minimal fines
4. Protection Board
   - 1/2” thick
   - plastic & geotextile material
5. Waterproofing Membrane
6. VADOT 57 Stone

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UVA’s New Library

**Waterproofing Membranes**

- **Foundation Wall:** Bituthane System 4000
  - Thickness: 1/16\(^{th}\)
  - Excellent adhesion to the wall through the use of the System 4000 Surface Conditioner
    - Water based, latex surface treatment
    - High tack finish to the treated substrate
    - Formulated to bind site dust and concrete efflorescence
  - Reduces inventory and handling costs by packaging the conditioner and membrane together

- **Basement Slab:** Bituthane System 4000
  - Thickness: ½”
  - Installed between the mud slab and floor slab
  - Forms a permanent seal against ground water
  - High tensile strength to provide resistance against the stress of ground settlement

[Return to Appendix Index]
Drainage Calculations

- At the time of boring all holes were dry
- 48-72 hours later all holes showed water levels
- All holes were 3 ¼” in diameter

<table>
<thead>
<tr>
<th>Boring Number</th>
<th>Location</th>
<th>Top of Footing</th>
<th>Bottom of Footing</th>
<th>Elevation of Water Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-1</td>
<td>Outside of building footprint - West side</td>
<td>-</td>
<td>-</td>
<td>2484.0</td>
</tr>
<tr>
<td>B-2</td>
<td>Outside of building footprint - West side</td>
<td>-</td>
<td>-</td>
<td>2463.5</td>
</tr>
<tr>
<td>B-3</td>
<td>Outside of building footprint - North-west side</td>
<td>2476.5</td>
<td>2474.83</td>
<td>2471.6</td>
</tr>
<tr>
<td>B-4</td>
<td>Inside of building footprint</td>
<td>2476.5</td>
<td>2474.83</td>
<td>2474.4</td>
</tr>
<tr>
<td>B-5</td>
<td>Inside of building footprint</td>
<td>2476.5</td>
<td>2474.83</td>
<td>-</td>
</tr>
<tr>
<td>B-6</td>
<td>Inside of building footprint</td>
<td>2474</td>
<td>2472.33</td>
<td>2494.3</td>
</tr>
<tr>
<td>B-7</td>
<td>Outside of building footprint - East side</td>
<td>2476.5</td>
<td>2474.25</td>
<td>2503.0</td>
</tr>
<tr>
<td>B-8</td>
<td>Outside of building footprint - East side</td>
<td>2476.5</td>
<td>2474.25</td>
<td>2511.0</td>
</tr>
</tbody>
</table>
### Flow Rate of Ground Water

<table>
<thead>
<tr>
<th>Boring Number</th>
<th>Depth (FT)</th>
<th>Area of Bore Hole (FT²)</th>
<th>Depth * Area (FT³)</th>
<th>Number of Hours</th>
<th>Flow Rate (FT/HR)</th>
<th>Flow Rate (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-6</td>
<td>22</td>
<td>8.29</td>
<td>182.4</td>
<td>48</td>
<td>4</td>
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<tr>
<td>B-7</td>
<td>46</td>
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<td>381.4</td>
<td>72</td>
<td>5</td>
<td>0.6604</td>
</tr>
<tr>
<td>B-8</td>
<td>59</td>
<td>8.29</td>
<td>489.2</td>
<td>72</td>
<td>7</td>
<td>0.8470</td>
</tr>
</tbody>
</table>
Drainage Calculations

• Average rainfall rates Bristol, VA = 0.028 gpm/SF

• Tributary Area:
  • 10’ away from structure (half the distance to the surrounding storm drain)
  • 2870 SF

• Total rainfall per pipe = 40.2 gpm
Drainage Pipe Design

• Using Perforated PVC Drainage Pipe:
  • 4” pipe at the base of the foundation walls
  • (2) 4” pipe beneath the slab-on-grade