**General Approach**

- Sketch general structural layout
- Determine roof loading
- Determine required lumber dimensions
- Transfer load down the structure

**Structure Components**

- Plywood
- Roofing Membrane
- Drainage Layer
- Filter Fabric
- Soil Media
- Plants
- Rafters
- Girders / Beams
- Columns
- Top
- Side

**Lumber Grades**

- Visually Graded (*Most Common*)
  - Select Structural (SS)
  - No. 1
  - No. 2
  - No. 3
- Machine Stress Rated (MSR)
- Machine Evaluated Lumber (MEL)

**Is all lumber the same?**

- Different types of wood perform differently under loads
- Important to design for the type of wood used in construction
- Today, we’ll focus on Southern Pine
Lumber Dimensions

- Nominal Dimensions ≠ Actual Dimensions
- Example:
  - 2” x 4” Lumber = 1.5” x 3.5”

<table>
<thead>
<tr>
<th>Size Range</th>
<th>Adjustment</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 6 inches</td>
<td>- 1/8 inch</td>
</tr>
<tr>
<td>≥ 8 inches</td>
<td>- 3/4 inch</td>
</tr>
</tbody>
</table>

Types of Loads

- Live Loads
  - Dynamic loading associated with roof usage
- Dead Loads
  - Static loading from structure and equipment
- Snow Loads
- Wind Loads
- Concentrated Loads

Importance of Building Codes

- Guidance and requirements for structure
- Vary between states
- May contain special provisions for green roofs

North Carolina Building Code

- Roof Gardens:
  - Intensive
  - 100 psf live load
- Landscaped Roofs:
  - Extensive
  - 20 psf live load

When is your roof most likely to fail?

During rainfall, when materials are saturated

Roof Loading

<table>
<thead>
<tr>
<th>Material</th>
<th>Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional Roof</td>
<td>7-10 psf</td>
</tr>
<tr>
<td>Drainage Layer (saturated)</td>
<td>2-3 psf</td>
</tr>
<tr>
<td>Soil Media (saturated)</td>
<td>Next Slide</td>
</tr>
<tr>
<td>Plants</td>
<td>1-2 psf</td>
</tr>
</tbody>
</table>
Green Roof Soils

<table>
<thead>
<tr>
<th>Media</th>
<th>Saturated Density lb/ft³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expanded Clay / Slate</td>
<td>60 – 95 lb/ft³</td>
</tr>
<tr>
<td>Stalite Extensive Mix ¹</td>
<td>91 lb/ft³</td>
</tr>
<tr>
<td>Erth Foods Extensive Mix ²</td>
<td>82 lb/ft³</td>
</tr>
</tbody>
</table>

¹ 55% Expanded Slate, 30% Root Zone Sand, 15% Compost
² 75% Expanded Clay, 10% River Sand, 5% Biosolid Compost

Green Roof Soils

- Soil Load = Soil Density * (Soil Depth/12)
  - Soil Load (psf)
  - Soil Density (lb/ft³)
  - Soil Depth (in)

Example:

91 lb/ft³ * (4 in / 12) = 30.4 psf

Now we know the live and dead roof load.

What's next?

Size the structural members

Plywood

- Span Rating: X / Y
  - X = maximum span for roof sheathing
  - Y = maximum span for subfloor

Subfloor span rating is recommended for green roofs

<table>
<thead>
<tr>
<th>Thickness</th>
<th>Typical Span Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2&quot;</td>
<td>32/16</td>
</tr>
<tr>
<td>5/8&quot;</td>
<td>42/20</td>
</tr>
<tr>
<td>3/4&quot;</td>
<td>48/24</td>
</tr>
</tbody>
</table>

Allowable Loads

- Need to prevent failure from:
  - Bending stress
  - Deflection

- One approach:
  - Apply adjustment factors to known allowable stresses

Span Tables

- Inputs:
  - Load
  - Joist Size
  - Joist Spacing

- Output:
  - Maximum span length
  - Factor of safety built into the tables
Span Table Example

DL = 20 psf  LL = 30 psf
Need to cover a span of 10 ft.

Span Tables

<table>
<thead>
<tr>
<th>Size</th>
<th>Spacing</th>
<th>S.S.</th>
<th>No. 1</th>
<th>No. 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 x 6</td>
<td>12</td>
<td>15-10</td>
<td>12-9</td>
<td>11-1</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>13-9</td>
<td>11-1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>19.2</td>
<td>12-6</td>
<td>10-1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>11-3</td>
<td>9-0</td>
<td></td>
</tr>
</tbody>
</table>

Failure is Not an Option

Cost Considerations

- Concerns:
  - High grade lumber (No. 2 most common)
  - Close rafter spacing (16" o.c. common)
  - Large lumber size

Sizing Girders

- Girders carry the load from the rafters
- May support different loads due to location
- Load is assumed to be uniform
- Load can be estimated using tributary area

Girder Locations
**Tributary Area**

- Determine area that is contributing load to a structural member

- Generally spans half the distance to the next similar structural member

**Girder Loading**

- Girder Load = TA x (DL + LL)

  - Girder Load (lb/ft)
  - TA: Tributary Area (ft²/ft)
  - DL: Dead Load (psf)
  - LL: Live Load (lb/ft²)

**Girder Example**

- Live Load = 20 psf
- Dead Load = 30 psf
- Span = 10 ft
- Tributary Area = 10 ft²/ft

- Load = 10 ft²/ft * (20 psf + 30 psf) = 500 lb/ft

**Girder Sizing**
### Girder Example

<table>
<thead>
<tr>
<th>Size</th>
<th>Allowable Load</th>
<th># Needed</th>
</tr>
</thead>
<tbody>
<tr>
<td>2x6</td>
<td>50 lb/ft</td>
<td>500 lb/ft / 50 lb/ft = 10</td>
</tr>
<tr>
<td>2x8</td>
<td>95 lb/ft</td>
<td>500 / 95 = 5.26 = 6</td>
</tr>
<tr>
<td>2x10</td>
<td>150 lb/ft</td>
<td>500 / 150 = 3.33 = 4</td>
</tr>
<tr>
<td>2x12</td>
<td>210 lb/ft</td>
<td>500 / 210 = 2.38 = 3</td>
</tr>
</tbody>
</table>

### Is a 4x6 girder the same as two 2x6s?

### End Girders
- Function similar to rafters
- May experience more stress due to construction and usage
- Typically double the rafter lumber

### What if I can't find a large enough girder?
- Laminated Veneer Lumber
- Steel Columns

### Column Loading
- Similar procedure to girder sizing
- Use tributary area to determine column load
- Column Load = TA x (LL + DL)
  - Column Load (lbs)
  - TA: Tributary Area (ft²)
  - LL: Live Load (psf)
  - DL: Dead Load (psf)
Tributary Area

Is it a good idea to specify different column dimensions for each tributary area?

Sizing Footers
- Typically constructed from concrete
- Typical soil load capacity = 2000 lb/ft²
- Footer Area (ft²) = Column Load / 2000 lb/ft²
- Footer Depth = 1/2 of width or length

Difficulties with Retrofits
- Need to obtain detailed structural plans
- Need to account for any changes since plans were produced
- Permission / liability concerns
- May not be practical or cost effective to make changes to the structure

Design Example
- Design a carport with a green roof on top
- Dimensions: 20 ft L x 10 ft W x 9 ft H
- Support 4" of Stellite Extensive Mix

General Procedure
1. Sketch structure layout
2. Determine roof loading
3. Determine rafter size and spacing
4. Determine required beam size
5. Determine required column size
6. Determine footer size
**Design Layout**

**Roof Loading**
- Live Load = 20 psf
- Dead Load:
  - Standard Roof: 10 psf
  - Drain Material: 3 psf
  - Saturated Media: 30.4 psf
  - Plants: 2 psf
  - Total: 45.4 psf

---

**Sizing Rafters**

<table>
<thead>
<tr>
<th>Size</th>
<th>Spacing</th>
<th>S.S.</th>
<th>No. 1</th>
<th>No. 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 x 6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>13-5</td>
<td>10-9</td>
<td>9-5</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>11-7</td>
<td>9-4</td>
<td>8-1</td>
<td></td>
</tr>
<tr>
<td>19.2</td>
<td>10-7</td>
<td>8-6</td>
<td>7-5</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>9-6</td>
<td>7-7</td>
<td>6-8</td>
<td></td>
</tr>
</tbody>
</table>

**Sizing Rafters**

<table>
<thead>
<tr>
<th>Size</th>
<th>Spacing</th>
<th>S.S.</th>
<th>No. 1</th>
<th>No. 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 x 8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>16-9</td>
<td>13-7</td>
<td>12-1</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>14-6</td>
<td>11-9</td>
<td>10-6</td>
<td></td>
</tr>
<tr>
<td>19.2</td>
<td>13-3</td>
<td>10-9</td>
<td>9-7</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>11-10</td>
<td>9-7</td>
<td>8-7</td>
<td></td>
</tr>
</tbody>
</table>

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**Girder Sizing**

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**Tributary Area**
**Girder Sizing**

- Tributary Area = 5 ft\(^2/\)ft
- Load = 5 ft\(^2/\)ft \(\times\) (20 psf + 45.4 psf) = 327 lb/ft
- Span = 10 ft

**Girder Example**

<table>
<thead>
<tr>
<th>Size</th>
<th>Allowable Load</th>
<th># Needed</th>
</tr>
</thead>
<tbody>
<tr>
<td>2x6</td>
<td>50 lb/ft</td>
<td>327 lb/ft / 50 lb/ft = 6.54 = 7</td>
</tr>
<tr>
<td>2x8</td>
<td>95 lb/ft</td>
<td>327 / 95 = 3.44 = 4</td>
</tr>
<tr>
<td>2x10</td>
<td>150 lb/ft</td>
<td>327 / 150 = 2.18 = 3</td>
</tr>
<tr>
<td>2x12</td>
<td>210 lb/ft</td>
<td>327 / 210 = 1.56 = 2</td>
</tr>
</tbody>
</table>

**Column Loading**

- Tributary Area = 5 ft \(\times\) 10 ft = 50 ft\(^2\)
- Load = 50 ft\(^2\) \(\times\) (20 psf + 45.4 psf) = 3270 lbs
- Effective Length = 9 ft

**Column Loading**

<table>
<thead>
<tr>
<th>Effective Length</th>
<th>4x4</th>
<th>4x6</th>
<th>4x8</th>
<th>4x10</th>
</tr>
</thead>
<tbody>
<tr>
<td>9 ft</td>
<td>5720</td>
<td>8970</td>
<td>11780</td>
<td>14980</td>
</tr>
</tbody>
</table>
**Footer Sizing**

- Column Load = 3270 lb
- Footer Area = \( \frac{3270 \text{ lb}}{2000 \text{ lb/ft}^2} = 1.64 \text{ ft}^2 \)
- Footer Dimensions = 1.28 ft x 1.28 ft
- Footer Depth = \( \frac{1.28 \text{ ft}}{2} = 0.64 \text{ ft} \)

**Resources**

- ASTM E 2397: Standard Practice for Determination of Dead Loads and Live Loads associated with Green Roof Systems

**Notes**

- Saturated 4” Stalite: 30.4 psf
- Sedum: 1-2 psf (already in live load)
- Drain Materials: 2-3 psf (saturated) (dead)
- Standard roof materials: 10 psf
- Total Dead Load typically 30-35 psf (just due to green roof)
- Soil bearing capacity: 2000 lb/ft²
- 35% porosity for green roof media
- Standard size is 4’ x 8’
- C-D-X: Used for structural sheathing where appearance is not important

**Lumber Weight**

- Southern Pine = 37.3 lb/ft³
- Spruce Pine = 28.6 lb/ft³
- 3/8” plywood = 1.1 psf
- 1/2” plywood = 1.5 psf