# Green Roof Structural Design

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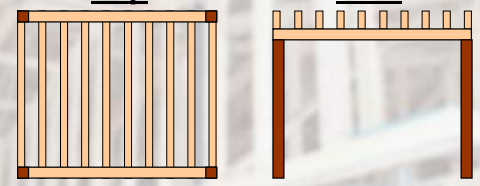
## General Approach

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

## Structure Components


## Structure Components

**Top** **Side**



Rafters
Girders / Beams
Columns

## 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 Grades

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

## Lumber Dimensions

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

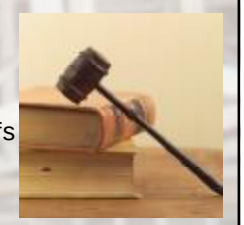
| Size Range | Adjustment |
|---|---|
| < 6 inches | - ½ inch |
| ≥ 8 inches | - ¾ inch |

## 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

| Material | Load |
|---|---|
| Conventional Roof | 7-10 psf |
| Drainage Layer (saturated) | 2-3 psf |
| Soil Media (saturated) | Next Slide |
| Plants | 1-2 psf |

## Green Roof Soils

| Media | Saturated Density lb/ft³ |
|---|---|
| Expanded Clay / Slate | 60 – 95 lb/ft³ |
| Stalite Extensive Mix [1] | 91 lb/ft³ |
| Erth Foods Extensive Mix [2] | 82 lb/ft³ |

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 $_{(lb/ft^3)}$ * (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

| Thickness | Typical Span Rating |
|---|---|
| 1/2" | 32/16 |
| 5/8" | 42/20 |
| 3/4" | 48/24 |

## 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

LL = 20 psf DL = 30 psf

| Size | Spacing | S.S. | No. 1 | No. 2 |
|---|---|---|---|---|
| 2 x 6 | 12 | 15-10 | 12-9 | 11-1 |
| | 16 | 13-9 | 11-1 | X |
| | 19.2 | 12-6 | 10-1 | X |
| | 24 | 11-3 | 9-0 | X |

## Failure is Not an Option

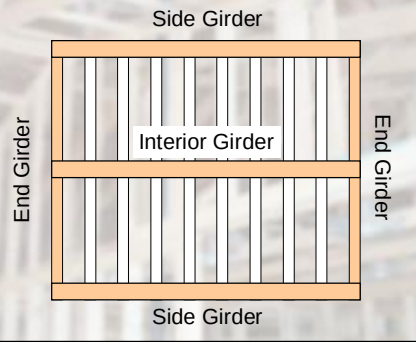
## Cost Considerations

- **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

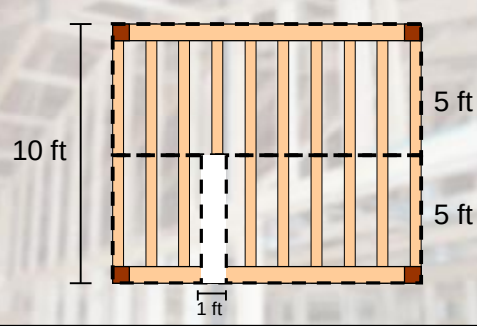
## Girder Locations



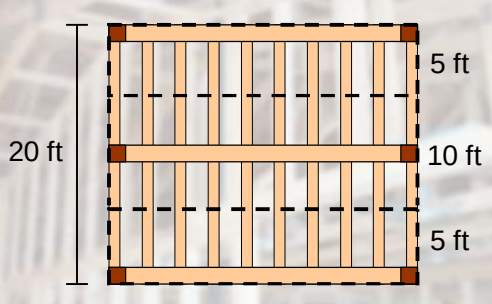
## Tributary Area

- Determine area that is contributing load to a structural member
- Generally spans half the distance to the next similar structural member

## Tributary Area




## Tributary Area



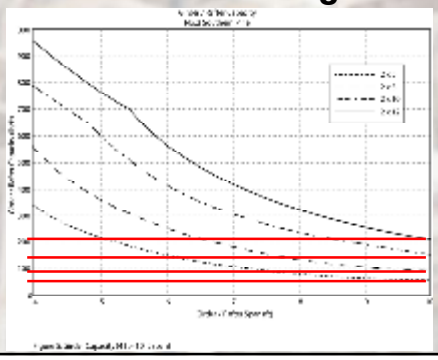

## Girder Loading

- **Girder Load = TA x (DL + LL)**
  - **Girder Load (lb/ft)**
  - **TA: Tributary Area ($ft^2/ft$)**
  - **DL: Dead Load (psf)**
  - **LL: Live Load ($lb/ft^2$)**

## Girder Example

- Live Load = 20 psf
- Dead Load = 30 psf
- Span = 10 ft
- Tributary Area = 10 $ft^2/ft$
- Load = 10 $ft^2/ft$ * (20 psf + 30 psf) = 500 lb/ft

## Girder Sizing



## Girder Example

| Size | Allowable Load | # Needed |
|---|---|---|
| 2x6 | 50 lb/ft | 500 lb/ft / 50 lb/ft = 10 |
| 2x8 | 95 lb/ft | 500 / 95 = 5.26 = 6 |
| 2x10 | 150 lb/ft | 500 / 150 = 3.33 = 4 |
| 2x12 | 210 lb/ft | 500 / 210 = 2.38 = 3 |

## 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

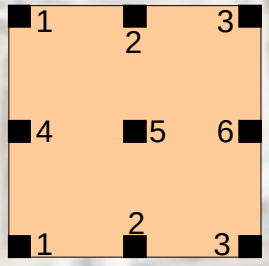
## What if I can't find a large enough girder?

- Laminated Veneer Lumber
- Steel Columns

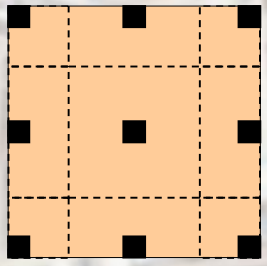
## Column Loading

- 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)

## Which Column Carries the Most Weight?



## 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 = ½ 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 of cost effective to make changes to the structure

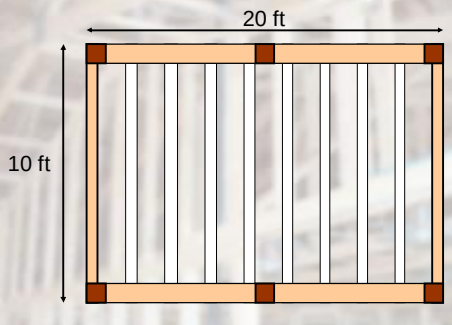
## Design Example

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

**LL = 20 psf DL = 50 psf**

| Size | Spacing | S.S. | No. 1 | No. 2 |
|---|---|---|---|---|
| 2 x 6 | 12 | 13-5 | 10-9 | 9-5 |
| | 16 | 11-7 | 9-4 | 8-1 |
| | 19.2 | 10-7 | 8-6 | 7-5 |
| | 24 | 9-6 | 7-7 | 6-8 |

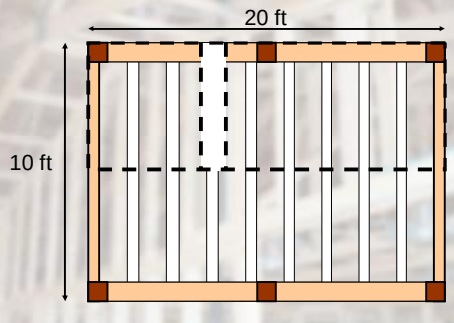
## Sizing Rafters

**LL = 20 psf DL = 50 psf**

| Size | Spacing | S.S. | No. 1 | No. 2 |
|---|---|---|---|---|
| 2 x 8 | 12 | 16-9 | 13-7 | 12-1 |
| | 16 | 14-6 | 11-9 | 10-6 |
| | 19.2 | 13-3 | 10-9 | 9-7 |
| | 24 | 11-10 | 9-7 | 8-7 |

## Girder Sizing

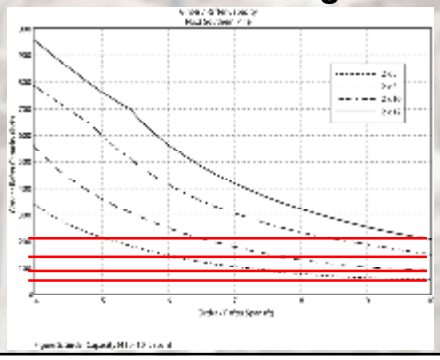
## Tributary Area



## Girder Sizing

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

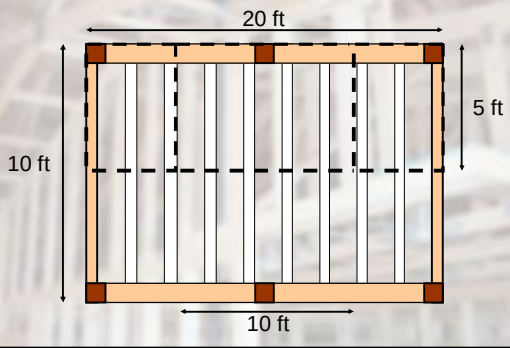
## Girder Sizing



## Girder Example

| Size | Allowable Load | # Needed |
|---|---|---|
| 2x6 | 50 lb/ft | 327 lb/ft / 50 lb/ft = 6.54 = 7 |
| 2x8 | 95 lb/ft | 327 / 95 = 3.44 = 4 |
| 2x10 | 150 lb/ft | 327 / 150 = 2.18 = 3 |
| 2x12 | 210 lb/ft | 327 / 210 = 1.56 = 2 |

## Tributary Area




## Column Loading

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

## Column Loading

| Effective Length | 4x4 | 4x6 | 4x8 | 4x10 |
|---|---|---|---|---|
| 9 ft. | 5720 | 8970 | 11780 | 14980 |

## Footer Sizing

- Column Load = 3270 lb
- Footer Area = 3270 lb / 2000 lb/ft² = 1.64 ft²
- Footer Dimensions = 1.28 ft x 1.28 ft
- Footer Depth = 1.28 ft / 2 = 0.64 ft

## Questions?

## Resources

- National Design Specification for Wood Construction: American Forest & Paper Association
- 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

•Water Weight (psf) = Porosity * 62.4

•Example:

Porosity = 35%

Water Weight = 0.35 * 62.4 = 22 psf

## Lumber Weight

- Southern Pine = 37.3 lb/ft³
- Spruce Pine = 28.6 lb/ft³
- ⅜" plywood = 1.1 psf
- ½" plywood = 1.5 psf