# Lecture 4:
# Bridge Design

# Truss Bridge Analysis

- Each student is required to design a bridge:
  - Load
  - Geometry
  - Forces in members
  - Weight of the bridge
  - Performance value (PV)

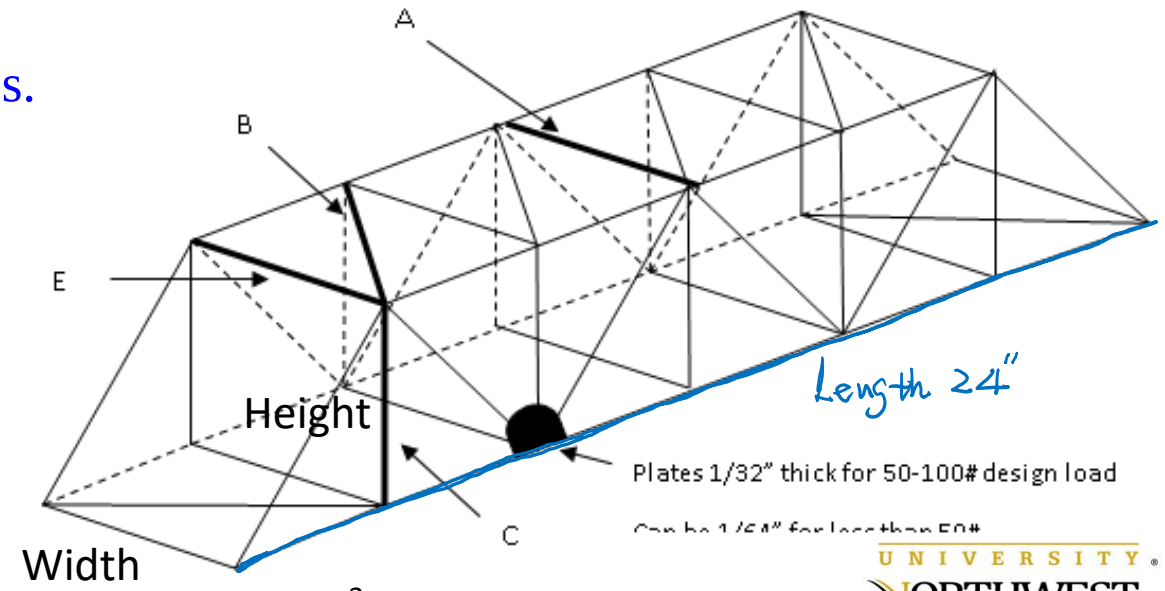
# Design a Basswood Bridge

**Design Parameters**

(a) Truss type bridge consists of 1) two parallel truss structures for the sides of the bridge and 2) necessary cross members to hold the sides in place.

(b) Top and bottom chords of the truss structures are to be parallel.

- Length (bottom chord) of the bridge must be 24 inches.
- Width must be 4 inches.
- Height must be ≥4 inches.



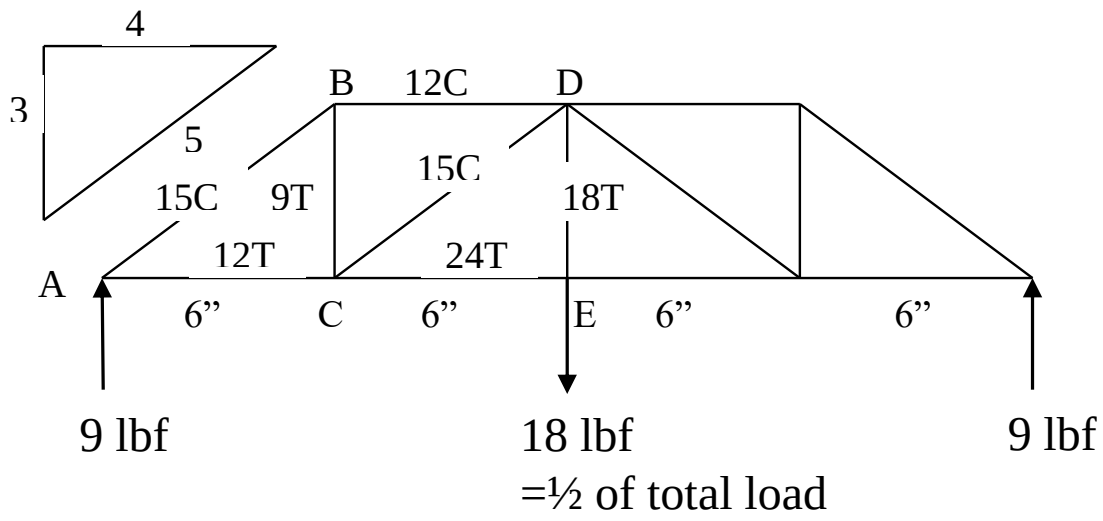
# Design Steps

## 1. Assume a Design Total Load

- 36 - 100lbf: e.g. 36lbf (minimum)

(This limits are from the testing machine.)

e.g.



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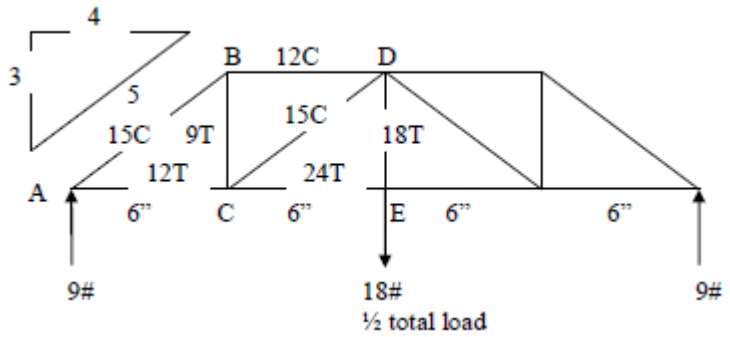
# 2. Choose a Truss Design and Bridge geometry

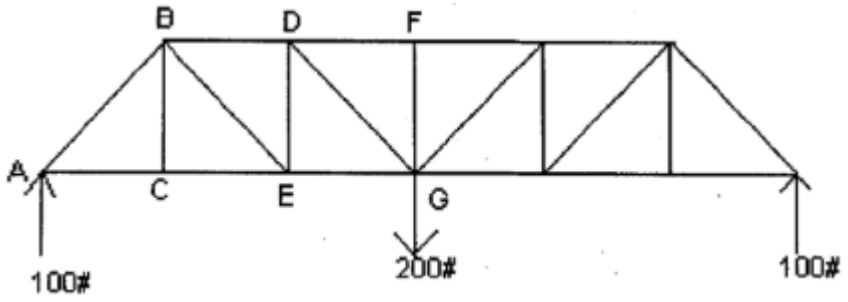
## a) Truss Design

1



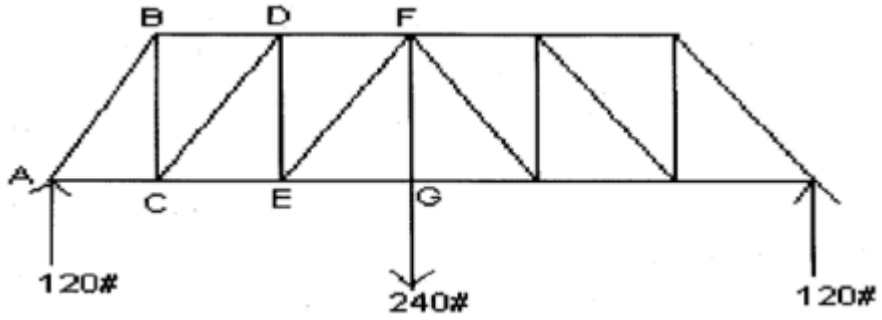

Slides Example

2




HW 3 Q1

3




HW 3 Q2



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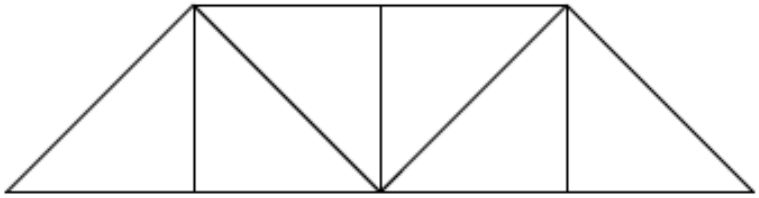
4



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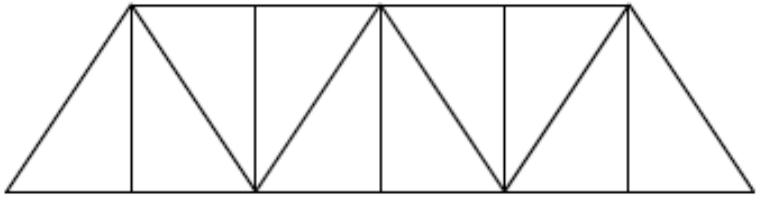

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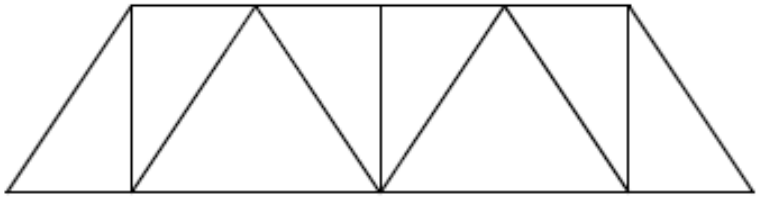
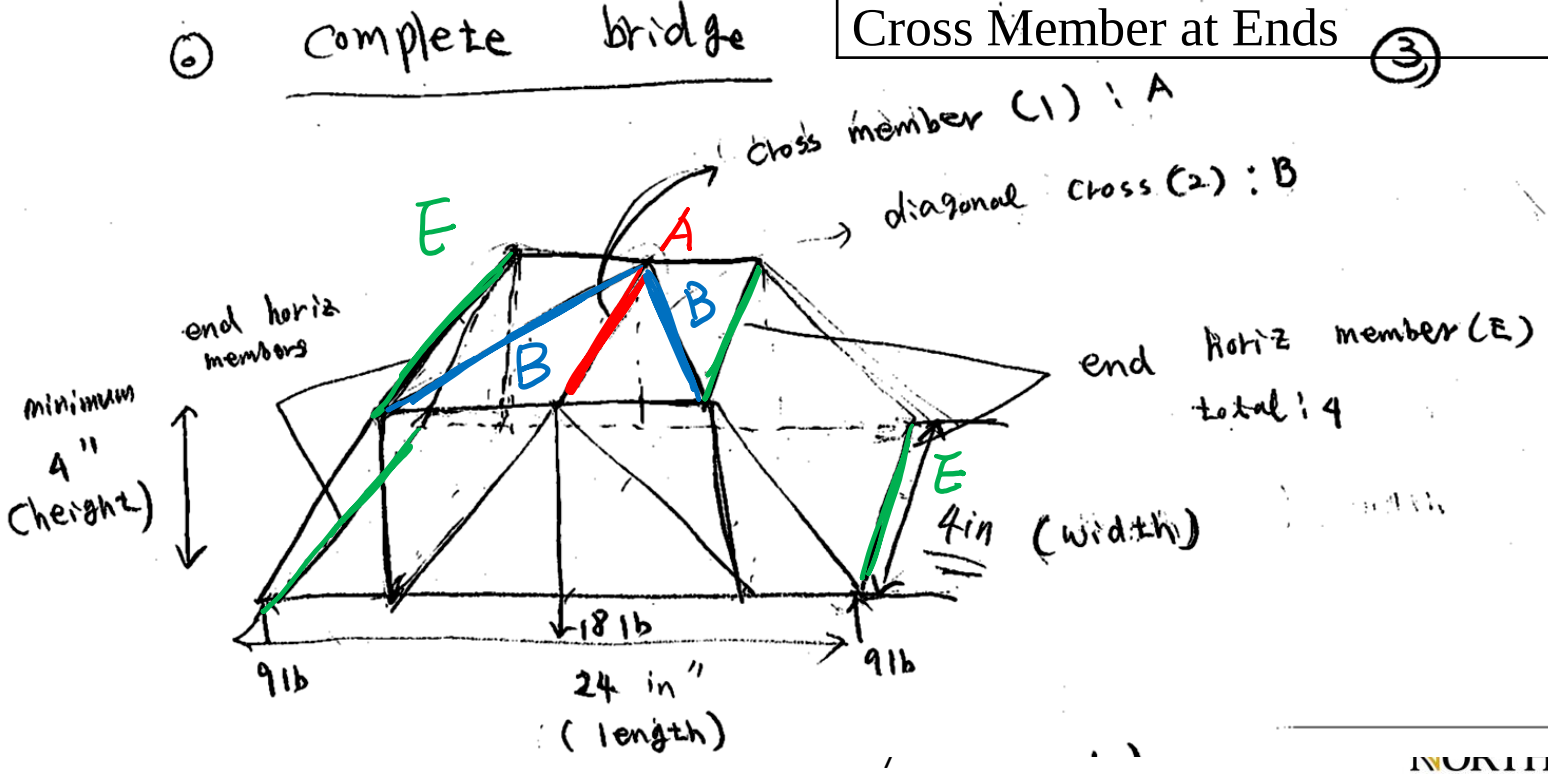


- Length (bottom chord) of the bridge must be 24 inches.
- Width must be 4 inches.
- Height must be ≥4 inches.

## b) Cross members at top and bottom surface

1. For top surface, cross members A, B and E are required.
   - Orientation of B will not affect PV.
2. For bridge floor, only cross members E is required;
   - A and B are optional (recommend to add two A and two B at least)

| | |
|---|---|
| Regular Cross Member | (A) |
| Diagonal Cross Member | (B) |
| Cross Member at Ends | (E) |



## 3. Calculate the length of members

### a) Truss members

Method 1 (Options 1, 2 and 3): calculate height
Method 2 (Options 4, 5 and 6): set height

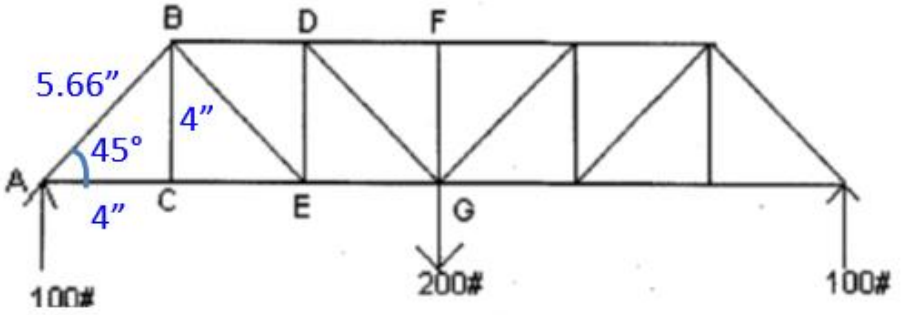
# Method 1 (Options 1, 2 and 3): calculate height

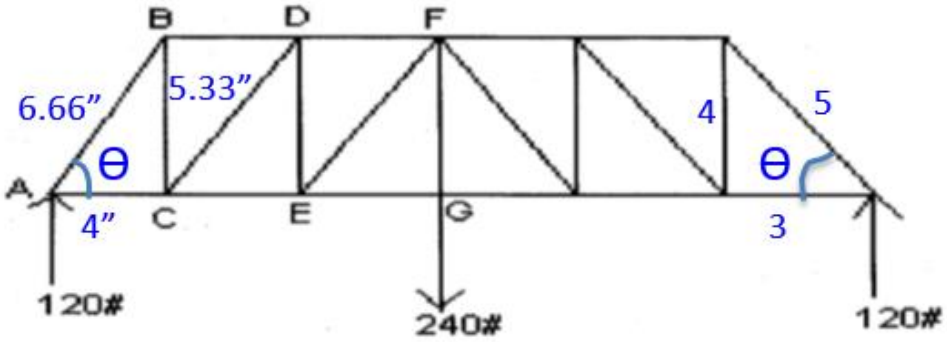
- From the given angle/trigonometry:

Step 1: Set the length of the lower chord as 24”.

Step 2: Calculate the base side of each triangle.

Step 3: Use trigonometry to find the height of the triangles and the length of the diagonals.




HW 3 Q1: Angle is 45°

1. 24” and 6 triangles
2. 24”/ 6 = 4”
3. BC = 4”· tan(45°) = 4”
   $AB^2 = 4”^2+4”^2 \rightarrow AB = 5.66”$

HW 3 Q2: 3, 4, 5 triangle

1. 24” and 6 triangles
2. 24”/ 6 = 4”
3. BC = 4”· tan(Θ) = 4”·4/3= 5.33”

$AB^2 = 4”^2+5.33”^2 \rightarrow AB = 6.66”$



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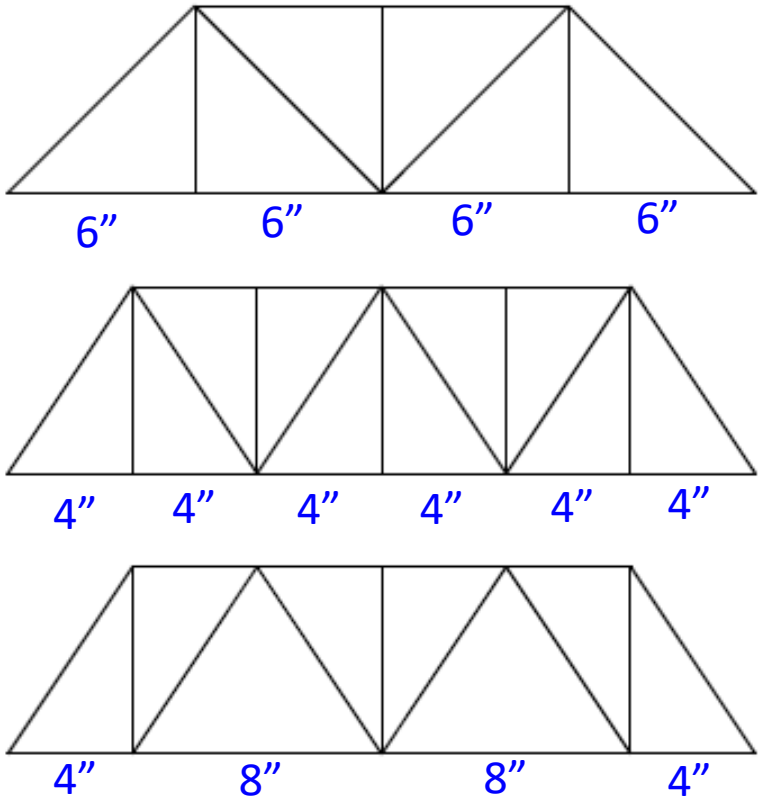
# Method 2 (Options 4, 5 and 6): set height

Step 1: Set the length of the lower chord as 24”.

Step 2: Calculate the base side of each triangle.

Step 3: Set a height ≥4 inches.

Step 4: Find length of diagonals.




Here are the base sides for each triangle in the 3 of the options listed.

Next would be to set a height ≥4 inches.

e.g. for option 4, height = 4”

$AB^2 = 6”^2 + 5”^2 \rightarrow \quad AB = 7.81”$



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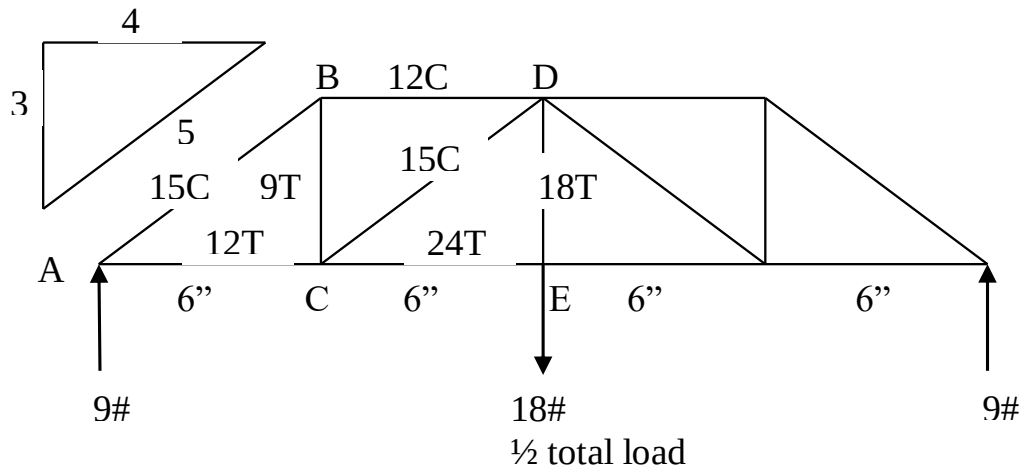
Results table:

e.g. Option 1




| Member | Length (inch) |
|---|---|
| AB | 6/4 x 5 = 7.5 |
| BC | 6/4 x 3 =4.5 |
| AC | 6 |
| BD | 6 |
| CE | 6 |
| DE | 4.5 |
| CD | 7.5 |



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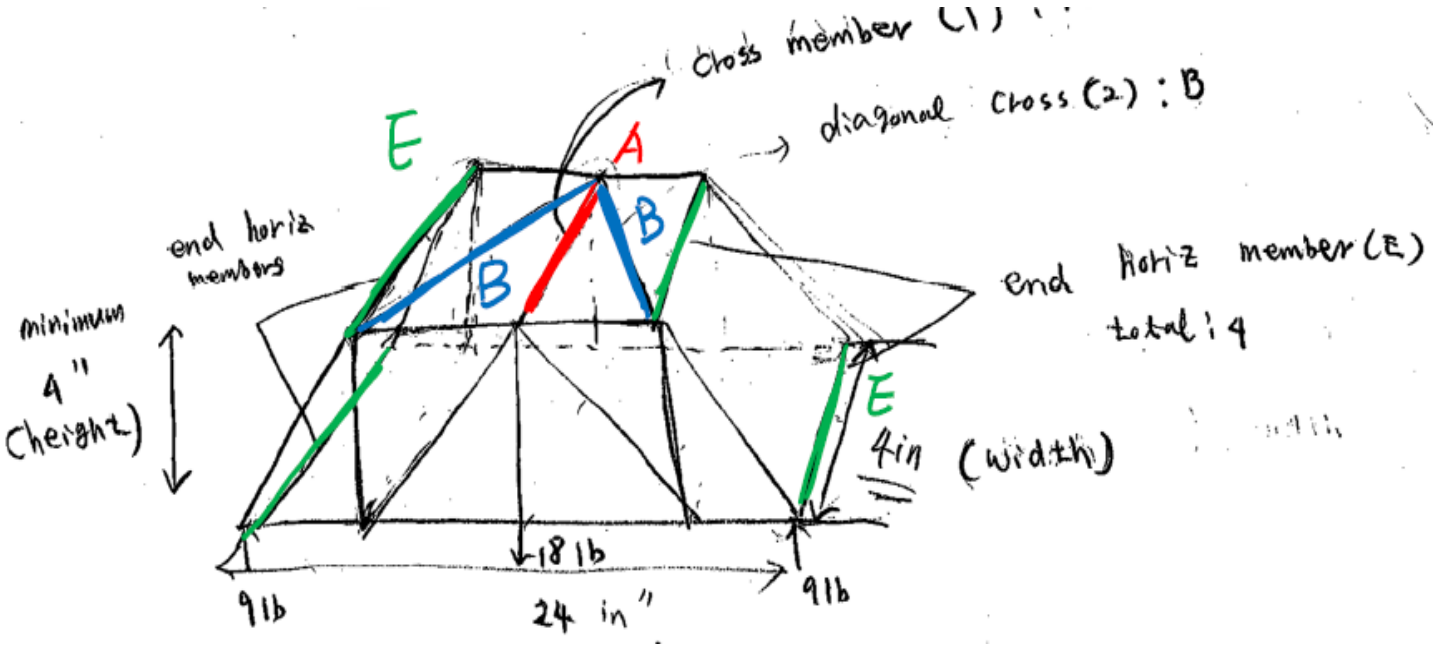
## 3. Calculate the length of members

### b) Cross members

- E and A members length is fixed to be 4” (Width of the bridge).
- The length of B members can be calculated with trigonometry.

- Make a Results table for cross members too.



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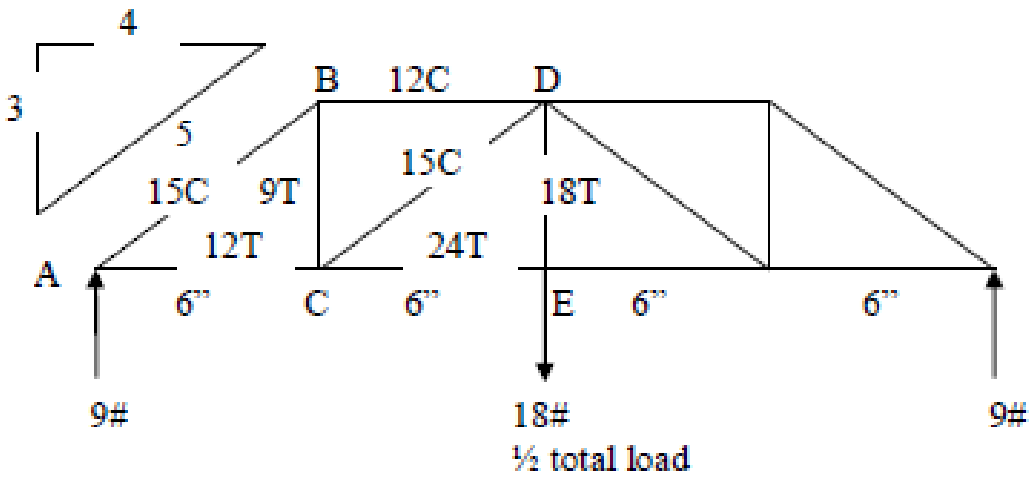
# 4. Calculate Forces in members of the Truss




e.g. Total Load = 36 lbf

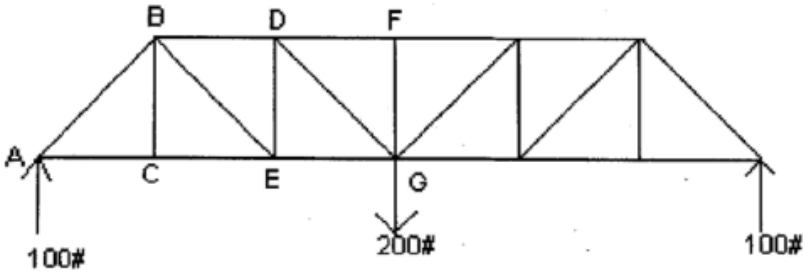
- Center of truss → 18 lbf
- Each pillar → 9 lbf

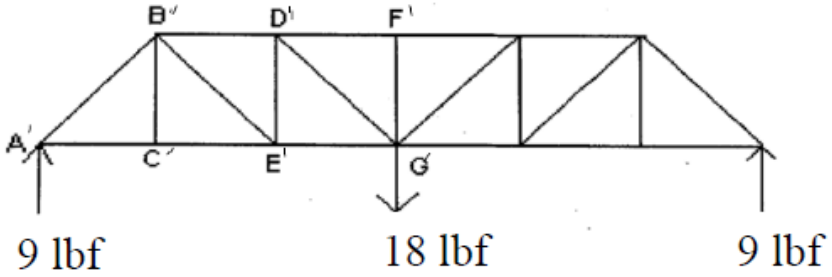
1. Take the total load assumed in 1st step.
2. Half of that load will be supported by each truss, and is placed in the center of the truss.
3. The ends of the Bridge are the Pillars, and each end must bear the half of the load (a quarter of the total load).
4. The forces in each member can be calculated joint by joint (as in HW 3), or in options 2 and 3, using a load ratio.

# Using Load Ratio to find the forces in members

**e.g. HW3 Q1**

Load ratio=$Force\ ratio = \frac{100}{9} = \frac{F_{AB}(HW)}{F'_{AB}(Design)} = 11.1 \rightarrow F'_{AB} = \frac{F_{AB}(HW)}{11.1}$




$F_{AB} = 141.42$ (C)
$F_{AC} = 100$ (T)
$F_{CE} = 100$ (T)
$F_{BC} = 0$
$F_{BE} = 141.42$ (T)
$F_{BD} = 200$ (C)
$F_{DE} = 100$ (C)
$F_{EG} = 200$ (T)
$F_{DG} = 141.42$ (T)
$F_{DF} = 300\ N$ (C)

$\div 11.1$ →

$F'_{AB} = \frac{141.42}{11.1} = 12.7$ lbf (C)
$F'_{AC} = \frac{100}{11.1} = 9$ lbf (T)
$F'_{CE} = \frac{100}{11.1} = 9$ lbf (T)
$F'_{BC} = 0$
$F'_{BE} = \frac{141.42}{11.1} = 12.7$ lbf (T)
$F'_{BD} = \frac{200}{11.1} = 18.02$ lbf (C)
$F'_{DE} = \frac{100}{11.1} = 9$ lbf (C)
$F'_{EG} = \frac{200}{11.1} = 18.02$ lbf (T)
$F'_{DG} = \frac{141.42}{11.1} = 12.7$ lbf (T)
$F'_{DF} = \frac{300}{11.1} = 27.03$ lbf (C)

Load ratio can be used in bridges that have same angles (same geometry, different scale), than others already solved.



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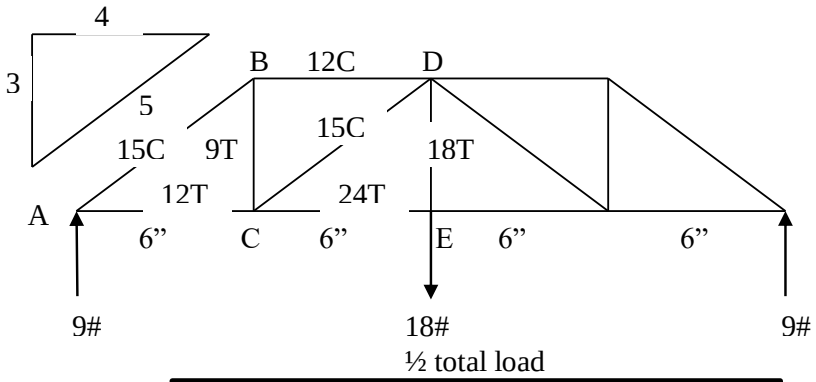
# 5. Determine Stick Size for each member:

## a) Tension

| Available basswood size (side: inch) | Permissible maximum tension loads (lbf) |
|---|---|
| 3/32 | 20 |
| 1/8 | 35 |
| 5/32 | 54 |
| 3/16 | 80 |
| 1/4 | 140 |




Choose the stick size based on the *Permissible maximum tension loads* which should be higher than the calculated force.

| Member | Force (lbf) | Length (in) | Size (in) |
|---|---|---|---|
| AB | 15C | 7.5 | |
| BC | 9T | 4.5 | 3/32 |
| AC | 12T | 6 | 3/32 →1/8 |
| BD | 12C | 6 | |
| CE | 24T | 6 | 1/8 |
| DE | 18T | 4.5 | 3/32 |
| CD | 15C | 7.5 | |

**Important!!: In the construction, the upper chord and lower chord must be one single stick, so the stick size is the bigger of all the members of the chord and constant!!**



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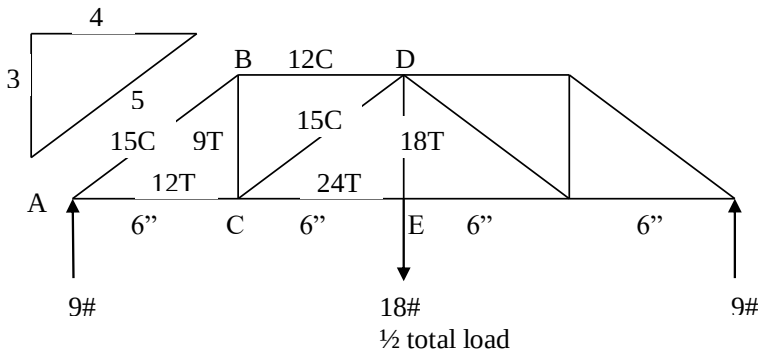
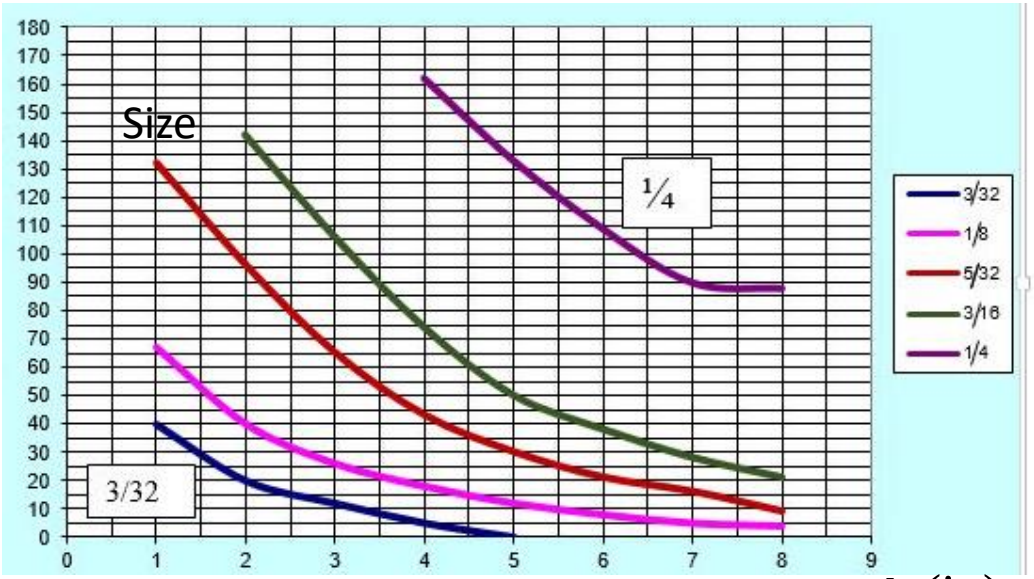
# 5. Determine Stick Size for each member:

## b) Compression




Permissible maximum compression loads (lbf)




| Member | Force (lbf) | Length (in) | Size (in) |
|---|---|---|---|
| AB | 15C | 7.5 | |
| BC | 9T | 4.5 | |
| AC | 12T | 6 | |
| BD | 12C | 6 | |
| CE | 24T | 6 | |
| DE | 18T | 4.5 | |
| CD | 15C | 7.5 | |

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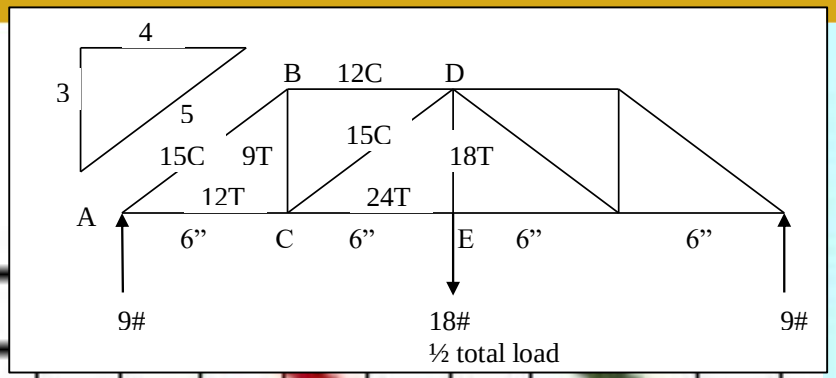
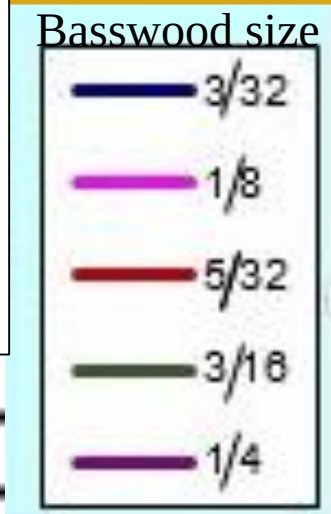
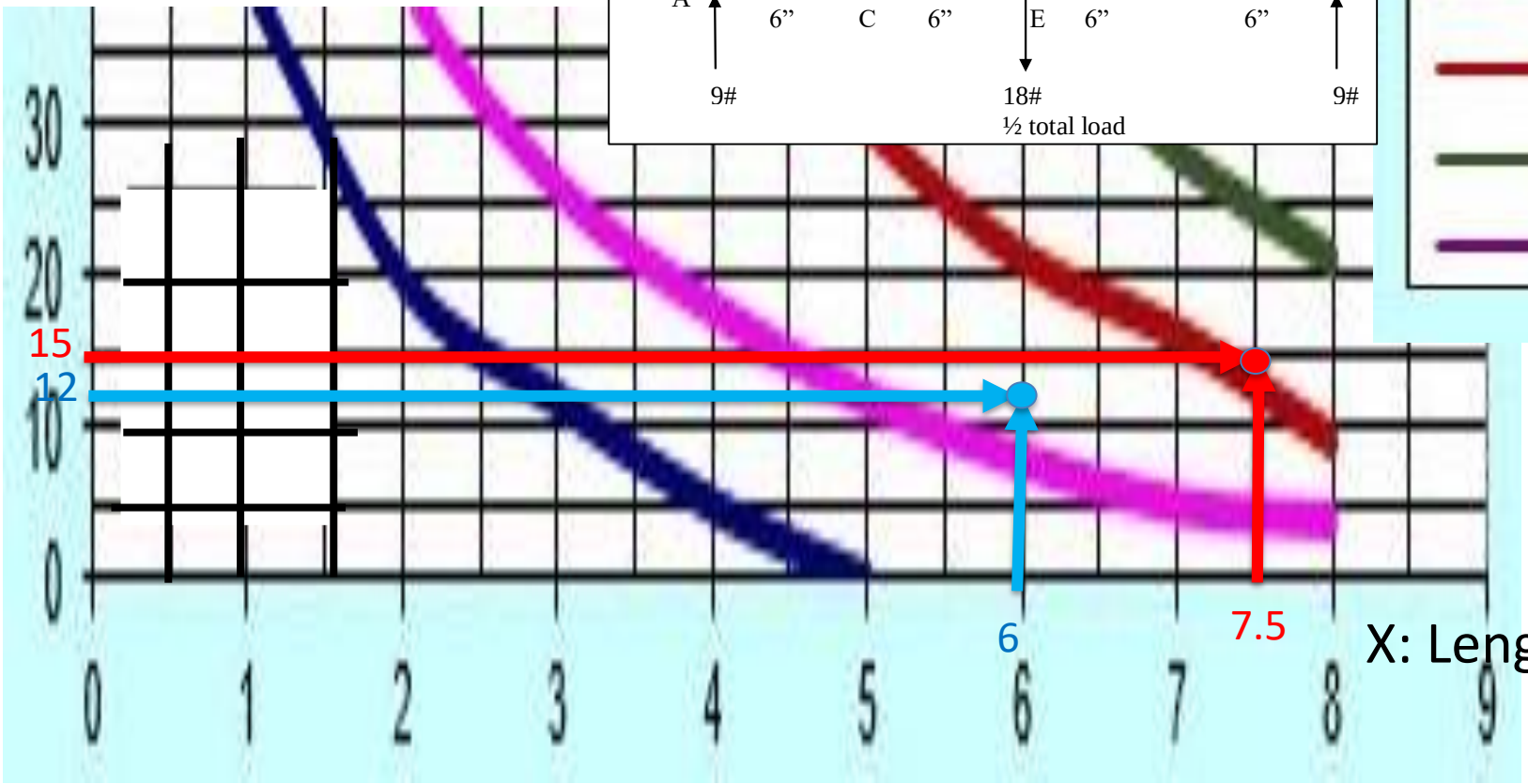
Permissible maximum compression loads (lbf)




Choose the stick size based on the *Permissible maximum compression loads* which should be higher than the calculated force.

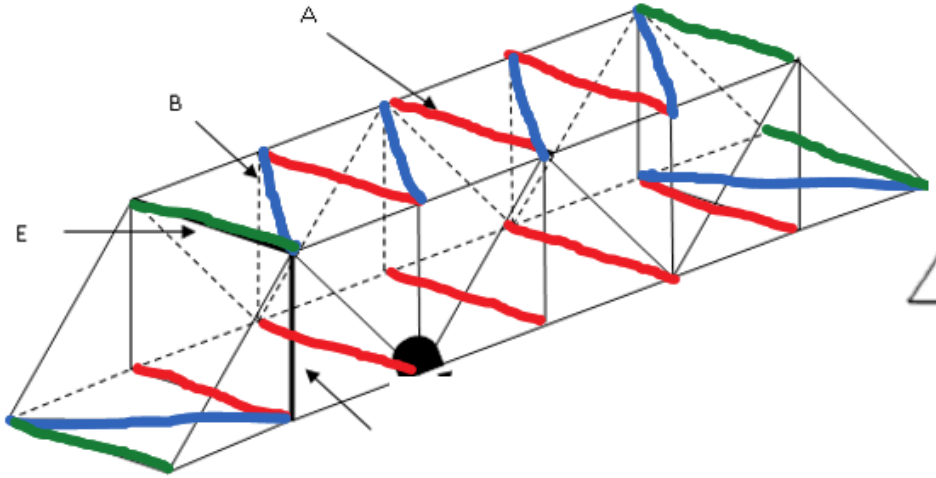
| Member | Force (lbf) | Length (in) | Size (in) |
|---|---|---|---|
| AB | 15C | 7.5 | 3/16 |
| BD | 12C | 6 | 5/32 |
| CD | 15C | 7.5 | 3/16 |

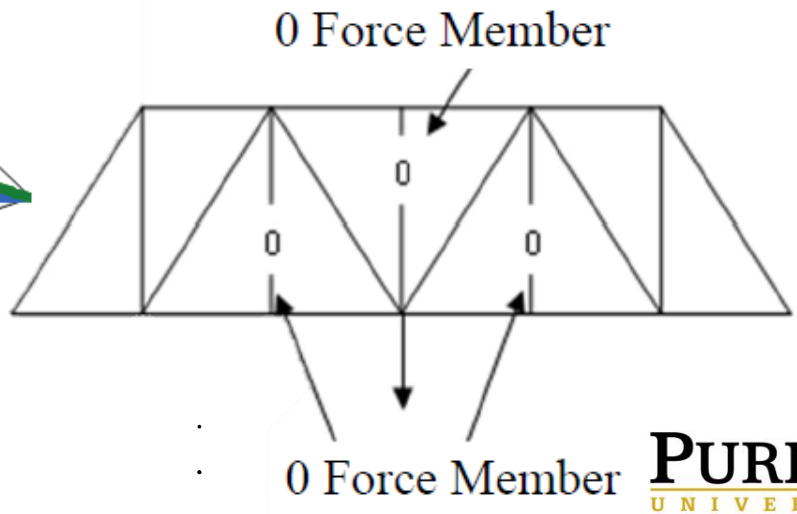
# 5. Determine Stick Size for each member:

## c) Cross and zero load members

Sizing of Cross and Zero Load Members

| | | Design Total Load Range (lbf) | | |
|---|---|---|---|---|
| | | 0-45 | 46-69 | 70-100 |
| Regular Cross Member | (A) | 3/32 | 1/8 | 5/32 |
| Diagonal Cross Member | (B) | 3/32 | 3/32 | 1/8 |
| End Cross Member | (E) | 1/8 | 5/32 | 3/16 |
| | | | | |
| 0 Force Member (with compression) | (C) | 1/8 | 1/8 | 5/32 |
| 0 Force Member (with tension) | (D) | Can be omitted | | |



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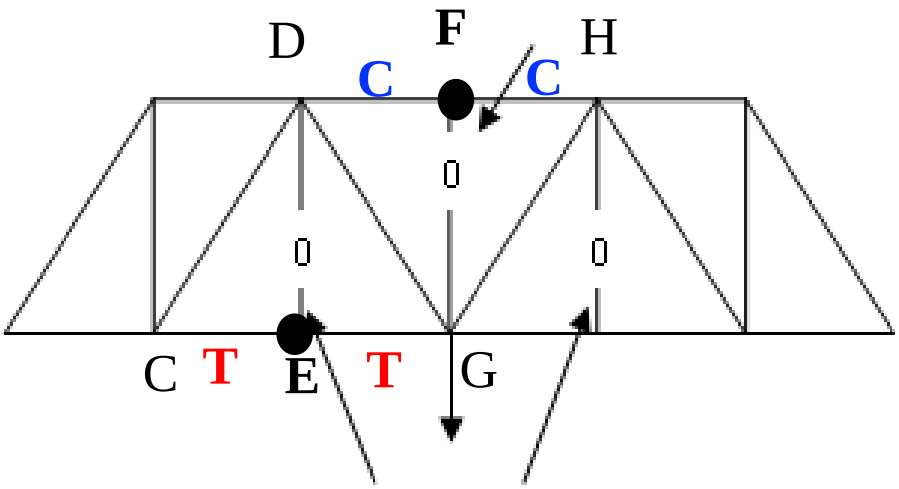
# Zero Force Members: Tension / Compression




These 2 zero force members can be omitted

**FBD of Joint F:**

- FG is Zero Force Member (with compression): the other members DF, FH around F are in compression

**- FG cannot be removed** to avoid buckling

Table I: Sizing of Cross and Zero Load Members

| | Design Total Load Range (lb) | | |
|---|---|---|---|
| | 0-45 | 46-69 | 70-100 |
| Zero Force Member (with compression) | 1/8 | 1/8 | 5/32 |

**FBD of Joint E:**

- DE is Zero Force Member (with tension): the other members CE, EG around E are in tension

**- DE can be removed**



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## 6. Calculate the Weight of the Bridge:

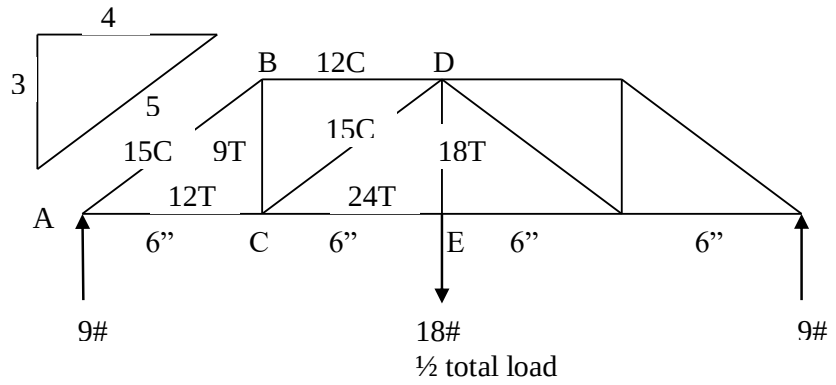
a) Truss
b) Cross Members
c) Joint Plates + Glue

$2 \cdot a + b$ = Wood weight

c = 15 – 20 % of Wood weight

**Total Bridge weight = $(2 \cdot a + b) \cdot 1.15$**

# 6.a) Calculate the Weight of 1 Truss




| Available bass wood size (in) | Density: weight per unit length (g/in) |
|---|---|
| 3/32 | 0.06 |
| 1/8 | 0.11 |
| 5/32 | 0.17 |
| 3/16 | 0.24 |
| 1/4 | 0.43 |

| Member | Force | Length (inch) | Size | Weight (g) |
|---|---|---|---|---|
| AB | 15C | 7.5 | 3/16 | Density * Length (.24)(7.5) = 1.80 |
| BC | 9T | 4.5 | 3/32 | (.06)(4.5) = 0.27 |
| AC | 12T | 6 | 1/8 | (.11)(6) = 0.66 |
| BD | 12C | 6 | 5/32 | (.17)(6) = 1.02 |
| CE | 24T | 6 | 1/8 | (.11)(6) = 0.66 |
| DE | 18T | 4.5 | 3/32 | (.06)(4.5) = 0.27 |
| CD | 15C | 7.5 | 3/16 | (.24)(7.5) = 1.80 |

**For 36lbf total load,**

**mass = (1.80 + 0.27 + 0.66 + 1.02 + 0.66 + 1.80 + 0.27 ) × 2 - .27 = 12.69 g**

**= (AB + BC + AC + BD + CE + CD +DE) × 2 - DE**



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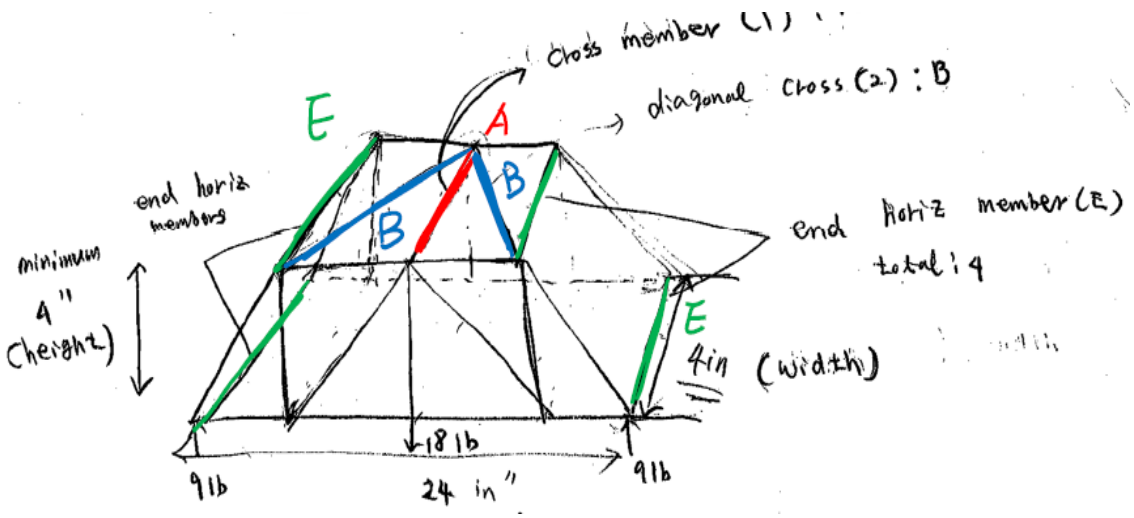
# 6.b) Calculate Weight of Cross and Zero Load Members

| Available bass wood size (in) | Density: weight per unit length (g/in) |
|---|---|
| 3/32 | 0.06 |
| 1/8 | 0.11 |
| 5/32 | 0.17 |
| 3/16 | 0.24 |
| 1/4 | 0.43 |




e.g. Load 36 lbf

| Type Member | Length | Size | Weight (g) | #Members | Total (g) |
|---|---|---|---|---|---|
| Regular Cross Member A | (Table 3.b) 4" | (Table 5.c) 3/32 | Density * Length 0.06*4" = 0.24g | Count them 1 | Weight * #members 0.240 g |
| Diagonal Cross Member B | 7.21" | 3/32 | 0.433 | 2 | 0.866 g |
| End Cross Member E | 4" | 1/8 | 0.44 | 4 | 1.760 g |

**Total Cross Member Weight = 2.866 g**



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# Total Bridge weight

For 36lbf total load,

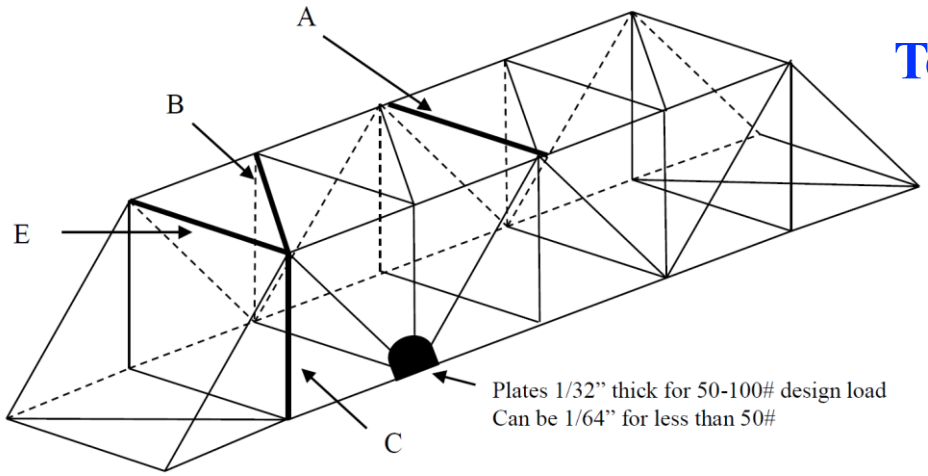
- 2 Trusses = 12.69 × 2 = 25.38 g
- Cross and zero members=2.866 g

**Total Bridge Weight**

= 2 Trusses + Cross and zero members + plates&glue
= 25.38 + 2.866 + plates&glue
= 28.246 + plates&glue
= 28.246 + 4.237
= 32.5 g

*plates&glue =~15-20% of wood members wt*

- *~4.237g (15% of 28.246g)*




**Total Bridge weight = (2 · a + b) · 1.15**

**TBW = (2 · 12.69 g + 2.866 g) · 1.15**

**TBW = 32.5 g**



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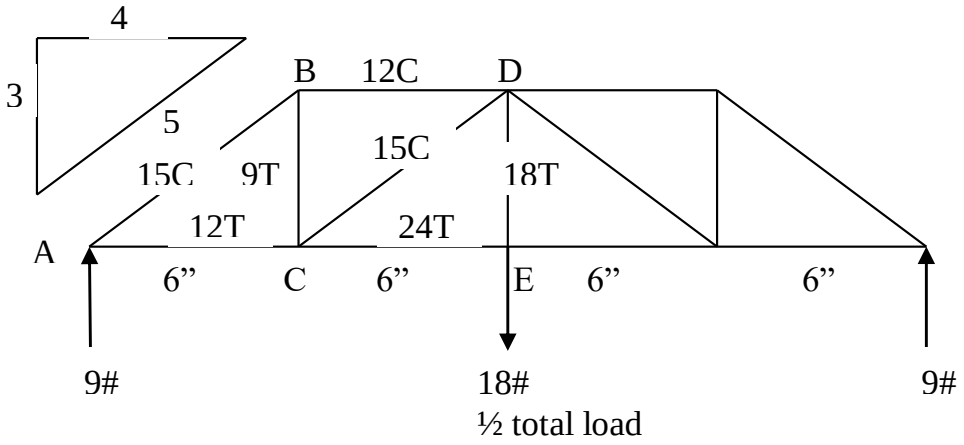
# 7. Calculate performance value (PV)

PV=L/W

- L is the design load (lbf) and W is the weight of the bridge (g)

E.g. For 36lbf total load,

PV = 36 lbf /32.5 g = 1.11 lbf/g




PV: higher →bridge: stronger

PV ≥1 means your bridge is strong.



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