Objectives: Efficiency, Elegance, and Safety. ? define.

Our bridge seeks to safely accommodate the passage of pedestrians using as few resources as possible. In the context of it being constantly viewed and used by people on leisure, elegance is important to ensure the bridge positively impacts the user experience of crossing it. To accomplish these objectives, our bridge implements a single truss down the center of the deck, a gradually sloping top chord, slanted diagonal members, and the prevalence of the golden ratio. Objectives vague.

Single Truss

A single truss down the middle braced by wires hanging on the side reduces the number of members required in the truss and the number of obstructions to strollers, who are empowered to enjoy the view. A single truss is also more efficient than two trusses with smaller members in terms of cost to support the same load, as larger members have proportionally increasing radii of gyrations – measure of the square root of second moment of area to area. ok...

Sloping Top Chord

The sloping was designed so the compression in each of the top chord members and the tension in the diagonal members would be the same under uniform loading. This maximizes the efficiency of the top chord and diagonal members, as the chord must be constructed out of a HSS that accommodates the maximum compression in any member. This efficiency translates into a more elegant design requiring less steel, less dead load, and less cost.

Slanted Diagonal Members

Having one slanted member for each node instead of a vertical one and another diagonal one increases the efficiency of the bridge two-fold. Performance is not compromised under balanced loading. Under heavy point loading, having separate diagonal and vertical members would be more effective - meaning less compression in comparison in the top chord – but such situations would be highly unlikely under service for pedestrians. Additionally, having single diagonal members at each node puts each diagonal member and the bottom chord under tension, with only the top chord in compression. The diagonal members in most bridges are longer than the top members, and putting the compression of a system on shorter members make the bridge safer and more efficient as they are less likely to buckle.

Golden Ratio

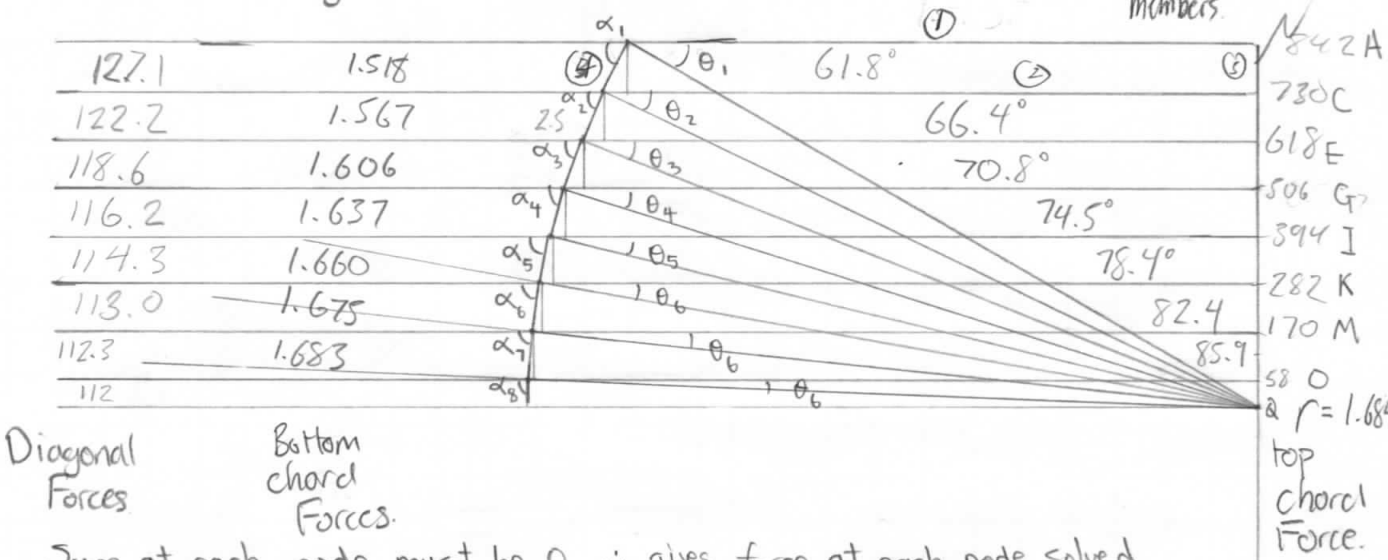
Acknowledging that the bridge's main purpose is to service pedestrians, aesthetics is a substantial concern. Employing the golden ratio (1.618) in our design makes the bridge more pleasing to look at, an important part of improving the user experience. The length of the large truss to the small ones is 67/41.5 = 1.614 while the ratio of sections is 16/10 = 1.600.

Our design's efficiency is reflected by our very competitive cost of $236,000 and dead load of $0.356kN/m^2$ and $0.537kN/m^2$, well below the assumed dead load of $0.7kN/m^2$. In recognition of the cost to elegance and construction cost of having numerous members, our entire bridge is made of only 33 diagonal members. Our design allows the minimization of maximum load in each of the chords and diagonal members, and should be chosen for its achievement of efficiency, elegance, and safety.

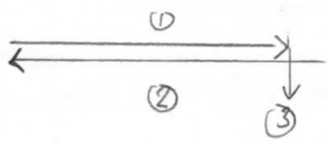
ok.

UNIVERSITY OF TORONTO
FACULTY OF APPLIED SCIENCE & ENGINEERING
NAME Cameron, Wilson, Johnson

consider the following force polygon. Good...
Each horizontal is the force in a bottom chord,
Each long diagonal is the force in the top chord.
Each small diagonal (that creates the "arc") is the force in the bridge's middle members.

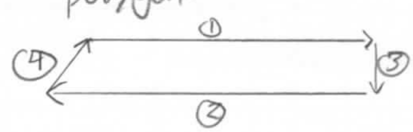


Sum at each node must be 0 ∴ gives force at each node solved
By taking parts of the diagram, we can use pythagorus to calculate the angles in our truss.
EG) by using segments ①, ② and ③, we can create the following:



=>

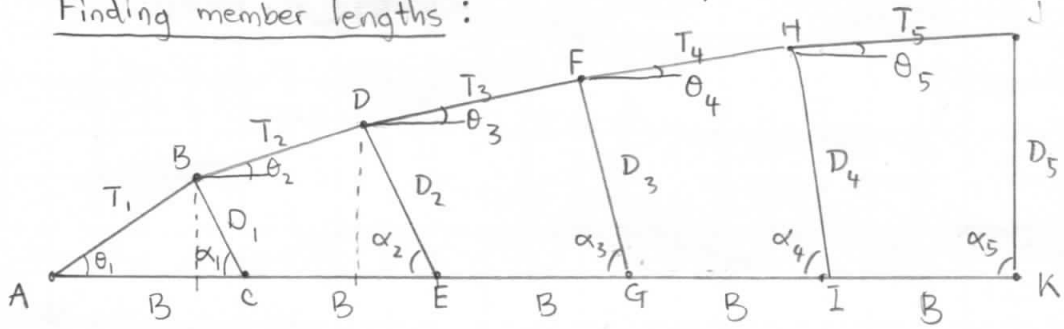
∴ ④ must counteract this, as it closes the force polygon.



Thus, we can calculate the shape of our truss.

show? How do you carry?

Finding member lengths:



angles are all known

$B = \frac{\text{length}}{\text{sections}}$

first values

sine law to find T_1

$$\frac{T_1}{\alpha_1} = \frac{B}{\pi - \alpha_1 - \theta_1} \qquad T_1 = \frac{B\alpha_1}{\pi - \alpha_1 - \theta_1}$$

$$T_1 \sin\theta_1 = D_1 \sin\alpha_1$$

$$D_1 = T_1 \frac{\sin\theta_1}{\sin\alpha_1}$$

values known

further values at point D

$$D_2 \sin\alpha_2 = T_1 \sin\theta_1 + T_2 \sin\theta_2 \qquad B = T_2 \cos\theta_2 + D_2 \cos\alpha_2 - D_1 \cos\alpha_1$$

$$D_2 = \frac{T_1 \sin\theta_1 + T_2 \sin\theta_2}{\sin\alpha_2} = D_2 = \frac{B + D_1 \cos\alpha_1 - T_2 \cos\theta_2}{\cos\alpha_2}$$

$$T_1 \sin\theta_1 \cos\alpha_2 + T_2 \sin\theta_2 \cos\alpha_2 = B \sin\alpha_2 + D_1 \sin\alpha_2 \cos\alpha_1 - T_2 \sin\alpha_2 \cos\theta_2$$

$$T_2 = \frac{B \sin\alpha_2 + D_1 (\sin\alpha_2 \cos\alpha_1 - \cos\alpha_2 \sin\alpha_1)}{\sin\theta_2 \cos\alpha_2 + \cos\theta_2 \sin\alpha_2}$$

$$T_2 = \frac{B \sin\alpha_2 + D_1 \sin(\alpha_2 - \alpha_1)}{\sin(\theta_2 + \alpha_2)}$$

for all top members

$$\boxed{T_n = \frac{B \sin\alpha_n + D_{n-1} \sin(\alpha_n - \alpha_{n-1})}{\sin(\theta_n + \alpha_n)} \qquad D_n = \frac{T_{n-1} \sin\theta_{n-1} + T_n \sin\theta_n}{\sin\alpha_n}}$$

iterative formula

…VERSITY OF TORONTO
…CULTY OF APPLIED SCIENCE & ENGINEERING

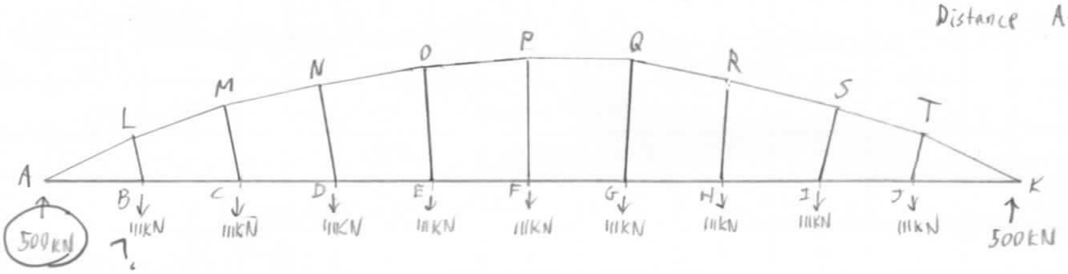
NAME: Cameron, Wilson, Johnson

COURSE NO.	COURSE NAME	2

Load

$(6.7\,kN/m^2)(4m)(4.15m)(9\,wires) = 1001\,kN$ $\qquad$ $1001kN/9 = 111kN$

Distance A–K = 41.5m



$\frac{wL}{2}$

The truss was designed so that all the members in the top chord have an equal compression load equal to 1001kN.

Forces in Bottom Chord: through geometric method as before

$AB = \sqrt{1.001^2 - 0.5^2} = 0.867MN$ $\quad$ $BC = \sqrt{1.001^2 - (0.5-0.111)^2} = 0.922MN$ $\quad$ $CD = \sqrt{1.001^2 - (0.5-0.222)^2} = 0.962MN$

$DE = \sqrt{1.001^2 - (0.5-0.333)^2} = 0.987MN$ $\quad$ $EF = 0.999MN$

Through symmetry, the loads in opposite members can be found

$FG = 0.999MN$ $\quad GH = 0.987MN$ $\quad HI = 0.962MN$ $\quad IJ = 0.922MN$ $\quad JK = 0.867MN$

Angles with horizontal:

$\angle AL = 90 - \left(\cos^{-1}\left(\frac{0.5}{1.001}\right)\right) = 30^\circ$ $\quad$ $\angle LM = 90 - \left(\cos^{-1}\left(\frac{0.5-0.111}{1.001}\right)\right) = 22.9^\circ$ $\quad$ $\angle MN = 90 - \left(\cos^{-1}\left(\frac{0.5-0.222}{1.001}\right)\right) = 16.1^\circ$

$\angle NO = 90 - \left(\cos^{-1}\left(\frac{0.5-0.333}{1.001}\right)\right) = 9.66^\circ$ $\quad$ $\angle OP = 90\left(\cos^{-1}\left(\frac{0.5-0.444}{1.001}\right)\right) = 3.25^\circ$

Through symmetry, the angles of opposite members can be found

$\angle PQ = -3.25^\circ$ $\quad \angle QR = -9.66^\circ$ $\quad \angle RS = -16.1^\circ$ $\quad \angle ST = -22.9^\circ$ $\quad \angle TK = -30^\circ$

Forces in Vertical Members:

$BL = \sqrt{(0.922-0.867)^2 + 0.111^2} = 0.1242MN$ $\quad$ $CM = \sqrt{(0.962-0.922)^2 + 0.111^2} = 0.1180MN$ $\quad$ $DN = \sqrt{(0.987-0.962)^2 + 0.111^2} = 0.1141MN$

$EO = \sqrt{(0.999-0.987)^2 + 0.111^2} = 0.1119MN$ $\quad$ $FP = \sqrt{0^2 + 0.1112^2} = 0.1112MN$

Through symmetry, the loads in opposite members can be found.

$GQ = 0.1119MN$ $\quad HR = 0.1141MN$ $\quad IS = 0.1180MN$ $\quad JT = 0.1242MN$

Angles of Vertical Members to horizontal:

$\angle BL = \tan^{-1}\left(\frac{0.111}{0.922-0.867}\right) = 63.6^\circ$ $\quad$ $\angle CM = \tan^{-1}\left(\frac{0.111}{0.962-0.922}\right) = 70.5^\circ$ $\quad$ $\angle DN = \tan^{-1}\left(\frac{0.111}{0.987-0.962}\right) = 77.1^\circ$

$\angle EO = \tan^{-1}\left(\frac{0.111}{0.999-0.987}\right) = 83.6^\circ$ $\quad$ $\angle FP = \tan^{-1}\left(\frac{0.111}{0}\right) = 90^\circ$

Through symmetry, the opposite members can be calculated.

$\angle GQ = 83.6^\circ$ $\quad \angle HR = 77.1^\circ$ $\quad \angle IS = 70.5^\circ$ $\quad \angle JT = 63.6^\circ$

UNIVERSITY OF TORONTO
FACULTY OF APPLIED SCIENCE & ENGINEERING

NAME Cameron, Wilson, Johnson

COURSE NO. | COURSE NAME | 2

Finding Lengths of the Members in the 41.5m Span Truss

$$\frac{\sin(180-30-58.6)}{4.15} = \frac{\sin(63.6)}{AL} = \frac{\sin(30)}{BL} \quad AL = 3.72m \quad BL = 2.08m$$

$$CM\sin(74.9) - (\sin(63.6))(2.08) = \sin(22.9)LM$$

$$\cos(22.9)LM + \cos(70.5)CM = 4.15 + \cos(55.9)2.08$$

$$LM = \frac{(4.15 - \cos 70.5\,CM + (\cos 63.6)2.08}{\cos 22.9}$$

$$\sin(70.5)CM - \sin(63.6)(2.08) = \tan(22.9)4.15 - \cos(70.5)\tan(22.9)CM + \cos(63.6)\tan(22.9)2.08$$

$$CM = 3.70m$$

$$LM = 4.17m$$

$$\sin(77.1)DN - (\sin(63.6))(3.70) = \sin(16.1)MN$$

$$\cos(16.1)MN + \cos(77.1)DN = 4.15 + \cos(70.5)(3.70)$$

$$MN = \frac{4.15 + \cos(70.5)3.70 - \cos(77.1)DN}{\cos(16.1)}$$

$$\sin(77.1)DN - (\sin(63.6))(3.70) = \tan(16.1)4.15 + \tan(16.1)\cos(70.5)(3.70) - \tan(16.1)\cos(77.1)DN$$

$$DN = 4.68m$$

$$MN = 4.52m$$

$$\sin(83.6)EO - (\sin(70.5))(4.68) = \sin(9.66)NO$$

$$\cos(9.66)NO + \cos(83.6)EO = 4.15 + \cos(77.1)(4.68)$$

$$NO = \frac{4.15 + \cos(77.1)4.68 - \cos(83.6)EO}{\cos(4.66)}$$

$$\sin(83.6)EO - \sin(70.5)4.68 = \tan(9.66)4.15 + \tan(9.66)\cos(77.1)4.68 - \tan(9.66)\cos(83.6)EO$$

$$EO = 5.23m$$

$$NO = 4.68m$$

$$FP - \sin(83.6)\,5.23 = \sin(3.25)\,OP$$

$$\cos(3.25)OP = 4.15 + \cos(83.6)5.23$$

$$OP = 4.74m$$

$$FP = 5.47m$$

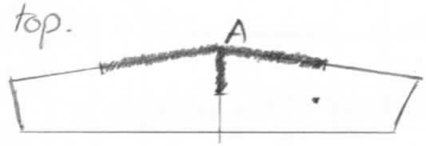
We can then use symmetry to find the lengths of all the opposite members

GQ = 5.23m HR = 4.68m IS = 3.70m JT = 2.08m

PQ = 4.74m QR = 4.68m RS = 4.52m ST = 4.17m TK = 3.72m

Wind Bracing in Center Section.

For the top chord, we will brace for the largest force at each node. Thus, we are concerned only with wind force at the top.



This is the area corresponding to the force at node A.

$\therefore$ Area $= \frac{1}{2}(4.78m)\cdot(0.254m)\cdot 2 + \frac{1}{2}(8.94m)(0.127m)$ $R = 0.02(1683) = 33.66kN$

$= 1.782m^2$

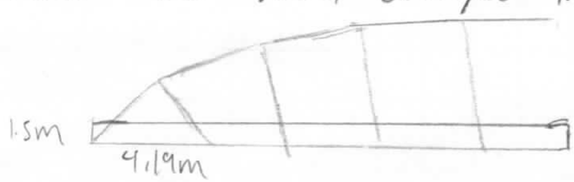
$\therefore F = 2KN/m^2 \cdot 1.782m^2 = 3.56KN$ $33.66 + 3.56 = 37.2KN$

Since we are bracing with wires, we can calculate their thickness.

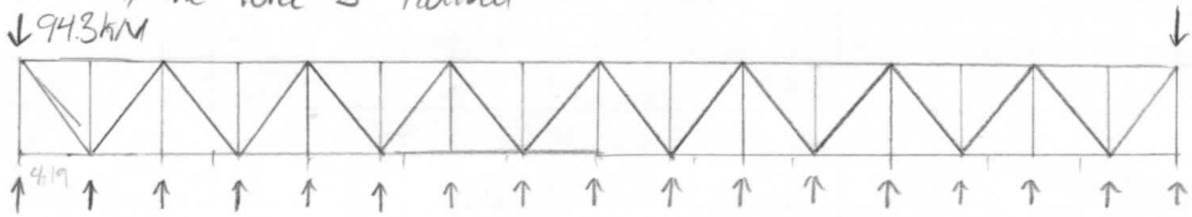
$\therefore \sigma_{yield} = \frac{2\cdot F}{A} = 350MPA = \frac{2(37200N)}{A}$

$\Rightarrow$ Area = 213 mm².

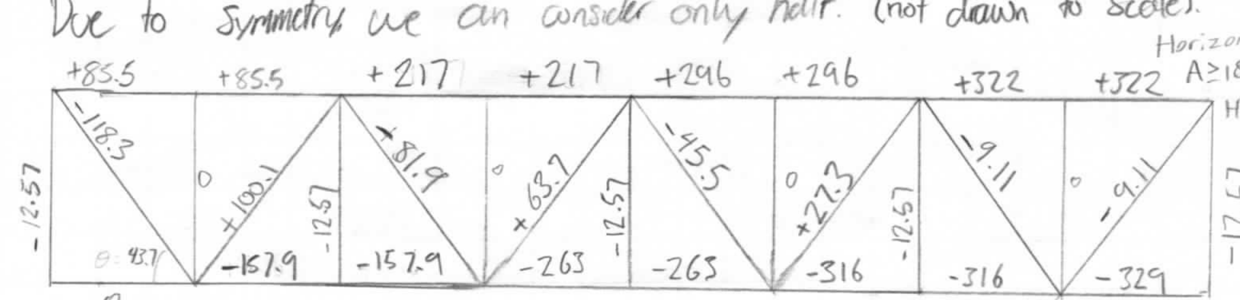
For the bottom chord, we will use a truss underneath the deck. Thus we must analyze the wind forces at each node



Due to the hand railing, (made of glass), each node except for the end ones have effective area of $1.5m \times 4.19m = 6.29m^2$, and thus an effective wind force of 12.57KN acting on it. At the ends, the force is halved



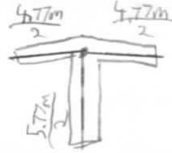
Due to symmetry we can consider only half. (not drawn to scale).



Diagonal members $A \geq 676\,mm^2$ $I \geq 3.16\times10^6$ so   HSS 102x102x6.4

Wind Bracing for Top Chord (41.5m Truss)

For the top cord we will brace for the largest force at each node. Thus, we are concerned only with the wind force at this join



$$Area = 2\left((4.77)(0.203) + \frac{(5.77)(0.089)}{2}\right) = 2.45KN$$
$$R = (0.02)(1001) + 2.45$$
$$= 22.47KN$$

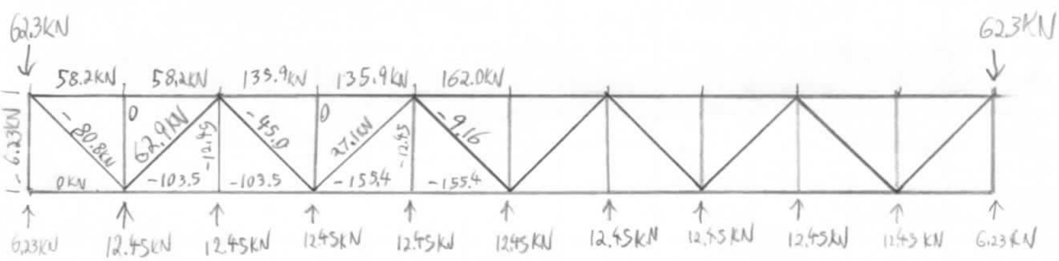
Since we are bracing with wires, we can calculate their thickness

$$\sigma_{yield} = \frac{2 \cdot F}{A} = 350MPa = \frac{2(22470)}{A}$$ ok

$$Area = 128.4mm^2$$

Wind Bracing for Bottom Chord:

Due to the glass hand railing, the surface area's for each node are $1.5 \times 4.15 = 6.225m^2$ and thus the windforce is $2 \times 6.225 = 12.45KN$ and at the ends is 6.225KN



The largest force in a diagonal member is -80.8KN

$$A \geq \frac{2 \times 80800N}{350} \qquad I \geq \frac{3 \times 80800 \times 5760^2}{200{,}000\,\pi^2}$$
$$A \geq 462mm^2 \qquad I \geq 4.08 \times 10^6$$

so we choose HSS $102 \times 102 \times 9.53$ for all these

diagonal wind bracing members

The largest horizontal force is -155.4KN

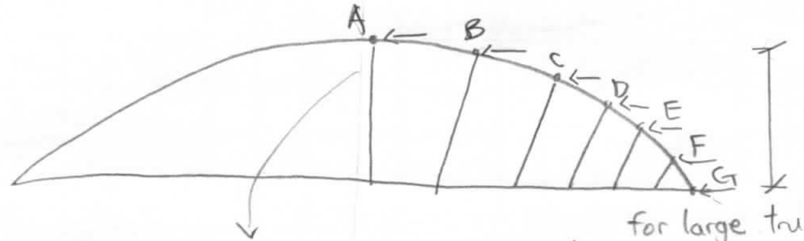
$$A \geq 888 \qquad I \geq 4.07 \times 10^6$$

so HSS $127 \times 127 \times 4.8$

NIVERSITY OF TORONTO
FACULTY OF APPLIED SCIENCE & ENGINEERING

NAME Cameron, Johnson, Wilson

COURSE NO. | COURSE NAME | 2



width · wind

$5m \cdot 0.254 m \cdot 2kN/m^2$

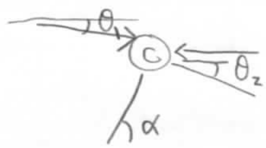
$= 2.54 kN$ → total frontal load

for large truss, 16 sections

nodes = sections / 2 = 8

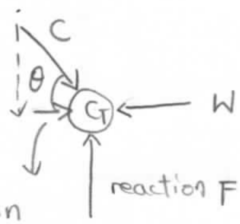
load at each node $= \frac{2.54}{8}$

$= 0.31754N$



determinate from the edge

know all θ and α



doesn't change top chord load!

bottom in

30° in this case

t or c depend on whether $C\sin\theta < W$

~1.6MN

<u>diag members</u> - worry about A and r only   normally in t

$L/r \le 200 \quad r \ge \frac{L}{(L/r)} = \frac{L}{200} = \frac{5773 \text{ mm}}{200} = 28.865$ for 41.5

in mm   maximum diag-len

44.69 for 67

$A \ge \frac{2 P_E}{350 MPa} = \frac{2(124.215 \cdot 1000)}{350} = 709.8 mm^2$ for 41.5

$725.2 mm^2$ for 67

choose $\boxed{89 \times 89 \times 4.8 \text{ for } 41.5}$ and $\boxed{127 \times 127 \times 4.8 \text{ for large}}$

<u>bot_members</u> - worry about A and r only   normally in t

$r \ge \frac{4150}{200} = 20.75$ for 41.5   20.95 for 67

$A \ge \frac{2 \cdot 999.434 \cdot 1000}{350} = 5711 mm^2$ for 41.5 $9614 mm^2$

choose $\boxed{254 \times 254 \times 6.4 \text{ for } 41.5}$ $\boxed{254 \times 254 \times 11 \text{ for } 67}$

<u>top members</u> - compression

$I \ge \frac{3 \cdot (1.001E6)(4740)^2}{\pi^2 E} = 34.2 E6 mm^4$ for 41.5 span $\frac{3 \cdot (1.681E6)(4777)^2}{\pi^2 E} = 58.3 E6 mm^4$

$A \ge$ $5720 mm^2$ $9619 mm^2$

choose $\boxed{203 \times 203 \times 8 \text{ mm for } 41.5\text{m span}}$ $\boxed{254 \times 254 \times 11 \text{ mm for } 67\text{m span}}$

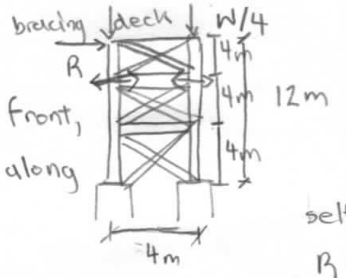
UNIVERSITY OF TORONTO
FACULTY OF APPLIED SCIENCE & ENGINEERING

NAME Cameron, Johnson, Wilson

COURSE NO. | COURSE NAME | 2

each column supports: $\left(\frac{41.5}{2}\right)(4)(6.7) + \left(\frac{67}{2}\right)(4)(6.7) = 1.454\text{ MN}$ vertically

half small truss   large +

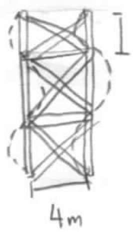


horizontal bracing: $94.3 + 62.3 = 156.6\text{kN}$

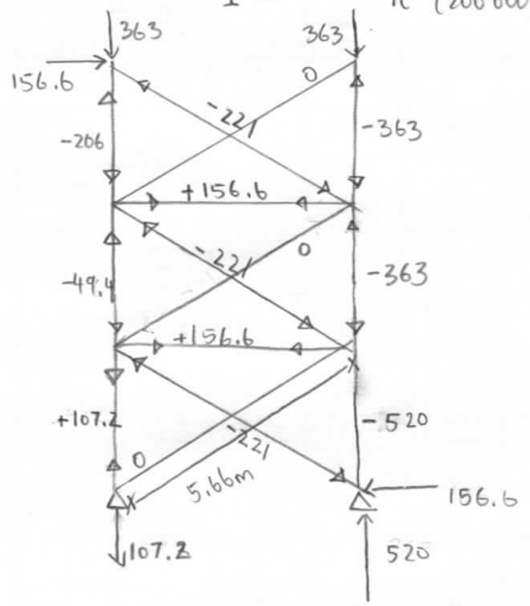
which direction?

self bracing for compression
$R = 0.02(363) = 7.26\text{kN}$

I required to withstand lateral buckling: FOS of 3



$$I \geq \frac{3 \cdot 520000\text{N} \cdot 4000^2}{\pi^2 (200\,000)} = 12.64\text{E}6\ \text{mm}^4$$



Diagonals

$$I \geq \frac{3(221000)(5657)^2}{\pi^2(200000)} = 10.75\text{E}6\ \text{mm}^4$$

$$A \geq \frac{2(221000)}{350} = 1263\text{mm}^4$$

$\boxed{\text{HSS: } 152 \times 152 \times 6.4\text{ mm}}$

Verticals

$I \geq 12.64\text{E}6$

$A \geq 2971\text{ mm}^2$

$\boxed{\text{HSS: } 152 \times 152 \times 8\text{ mm}}$

Horizontals

$A \geq 895\text{ mm}^2$

$r \geq \frac{4000}{200} = 20$ $\boxed{\text{HSS: } 64 \times 64 \times 4.8\text{ mm}}$

Use same configuration for all 4 sides.

Checking our Dead Load Guess of $0.7 kN/m^2$

41.5m span Trusses:

Top chord, Vertical members, Bottom chord, Wind Bracing

$(0.465)(43.64m) + (0.119)(38.11m) + (0.476)(41.5) + (10)(5.76)(0.252) = 59.1 kN$

$59.1 kN/(4m)(41.5m) = 0.356 kN/m^2$

67m Span Truss:

Top chord, Vertical members, Bottom chord

$(0.808)(70.2m) + (0.175)(94.98m) + (0.808)(67m) + (16)(5.79m)(0.178) = 144.0 kN$

$144.0 kN/(4m)(67m) = 0.537 kN/m^2$

Verified.

Cost

Mass of steel:

41.5m Span Trusses

$2(43.64)(47.5) + 2(38.11)(12.2) + 2(41.5)(48.5) + 4(41.5)(17.9) + 2(10+11)(25.7) = 9529 Kg$

67m Span Trusses

$(82.4)(70.2) + (17.9)(94.98) + (82.4)(67) + 2(67)(17.9) + (16+17)(18.2) = 16005 Kg$

8 columns

$(2)(4)(6)(28.3) + (2)(4)(2)(8.35) + (2)(4)(3)(34.8) = 2327 Kg$

Cost of Steel $= (\$4,000)(9.529 + 16.005 + 2.327) = \$111,400$

Cost of wooden deck $= (75)(4)(150) = \$45,000$

Cost of Footings $= 8(10,000) = \$80,000$

$\boxed{\Sigma Cost = \$236,000}$

ok.

Tabulate?

DATE	1 Time Log	PAGE
NAME		
COURSE NO.	COURSE NAME	2

Oct 18 4:00 - 5:00pm
- Everyone met for discussing team philosophy and general designs

Oct 19 5:00 - 6:00pm
- Johnson found method of solving efficient trusses and shares with team

Oct 19 6:00 - 8:00pm
- Everyone attempts to understand method, general design established

Oct 21 7:00 - 8:00pm
- Wilson solves a hypothetical design and establishes constraints on design

Oct 23 5:00 - 7:00pm
- Everyone met to share takeaways from individual calculations

Oct 26 4:00 - 7:00pm
- Everyone started calculations to solve for loads and angles
  - Wilson took on 67m span bridge
  - Cameron took on 41.5m span bridge
  - Johnson started excel document for allowable lengths of members

Oct 27 5:00 - 2:00pm
- Calculations by everyone started on geometry

Oct 28 5:00 - 4:00pm
- Everyone continued calculations
- Johnson wrote program to calculate loads and lengths of a variable truss
- Wilson continued on drawing and geometry of large truss
- Cameron continued on cost calculations

Cameron Buttazzoni

Johnson Zhong   Wilson Huang   Cameron Buttazzoni

Good.