EEN-206: Power Transmission and Distribution

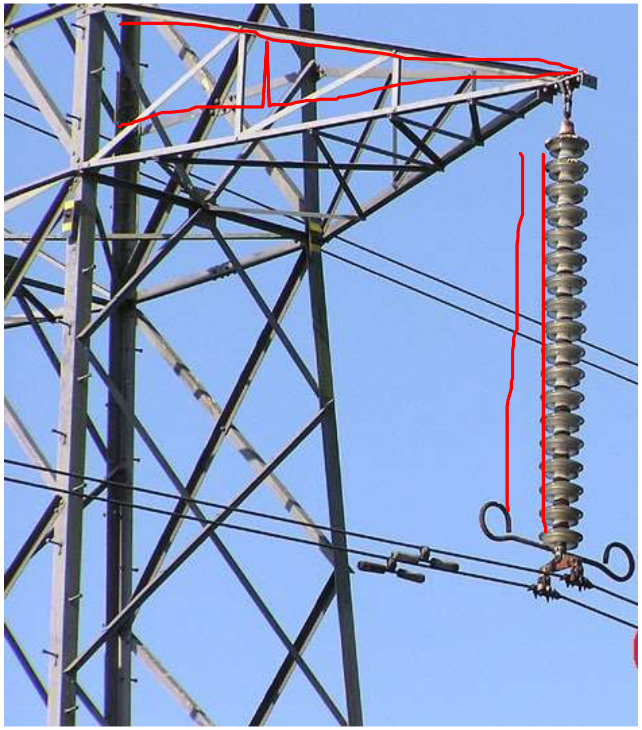
Lecture -06

Chapter 2: Overhead Transmission Lines

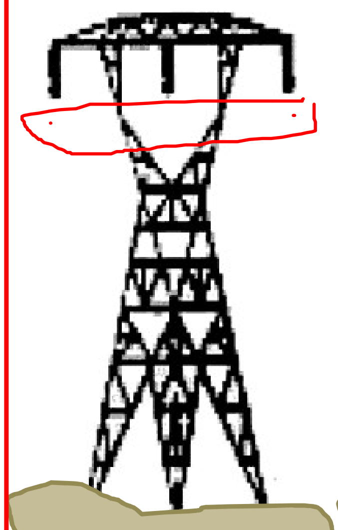
- **Mechanical Design**

Main Components of Overhead Line

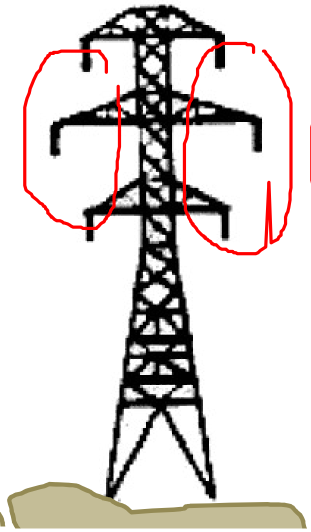
- Support Structure (Towers): Cost, voltage level, conductor size, conductor spacing (cross-arm length), etc.
  - Galvanized steel (for high voltage)
  - Wood, concrete, steel poles (for low voltage)
- Insulators: Voltage level
  - Porcelain
  - Glass
  - Polymer insulation
- Conductors: Thermal limit, weight, conductivity, mechanical strength, regulation, etc.



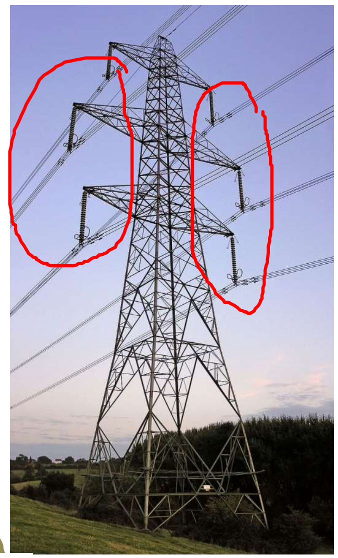
Tower Structures (High Voltage Transmission)



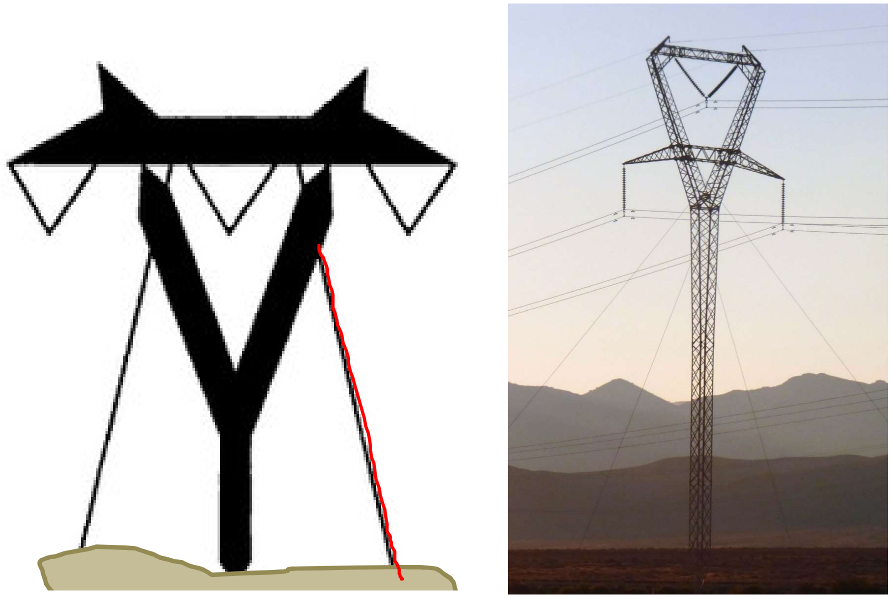
Single-Circuit



Double-Circuit



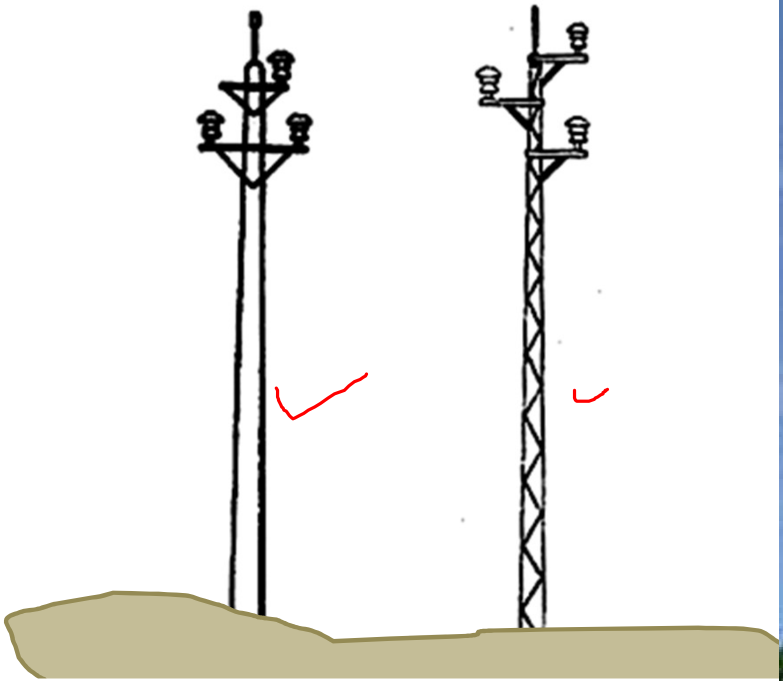
Self-supporting Towers



Guyed wire towers

- Galvanized steel (for high voltage)

Tower Structures (Low Voltage Distribution)



- Wood, concrete, steel poles (for low voltage)

Types of Conductor

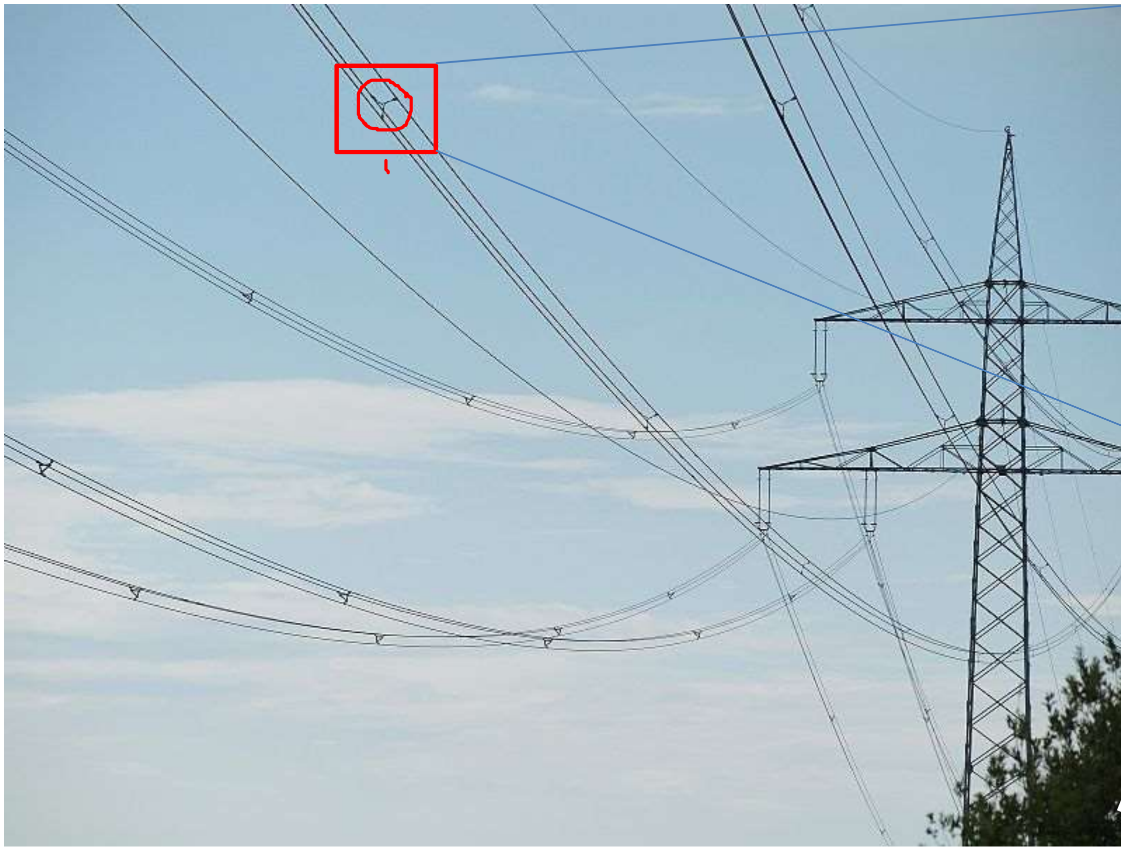
- Copper: Good conductor, durable, high scrap value, tensile strength, but cost is high.
- **Aluminum:**
  - **Cheaper,**
  - **lighter,**
  - **but less conductive (requires large cross section for same resistance)**
  - less tensile strength than copper
- Types of Aluminum conductors
  - AAC (All Aluminum Conductor)
  - AAAC (All Aluminum Alloy Conductor)
  - **ACSR (Aluminum Conductor Steel Reinforced)**
  - ACAR (Aluminum Conductor Alloy Reinforced)
  - Expanded ACSR

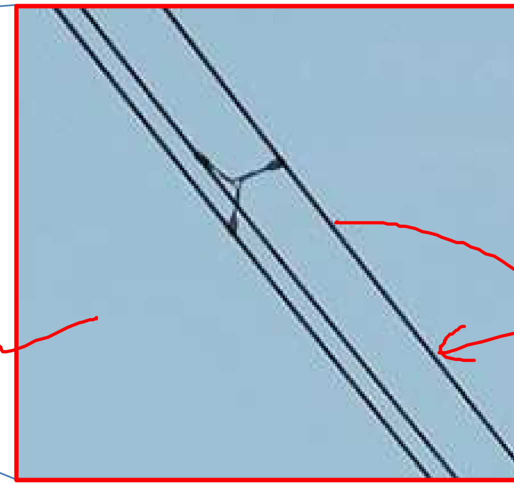
ACSR Conductor

ACSR Conductor Data Sheets

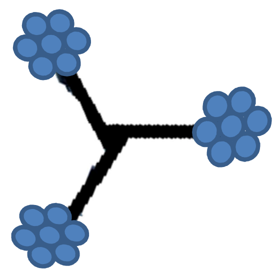
CODE NAME	NOMINAL ALUMINIUM AREA	EQUIVALENT COPPER AREA	CONDUCTOR CONSTRUCTION		APPROX. OVERALL DIAMETER	CALCULATED AREA	APPROX. WEIGHT	NOMINAL BREAKING LOAD	MAX. DC RESISTANCE AT 20°C	CURRENT RATING
			ALUMINIUM	STEEL						
	mm^2	mm^2	No./mm		mm	mm^2	kg/km	N	Ω/km	Amp
GOPHER	25	16.1	6/2.36	1/2.36	7.08	30.62	106	9600	1.093	77
WEASEL	30	19.4	6/2.59	1/2.59	7.77	36.88	128	11400	0.9077	84
FERRET	40	25.8	6/3.00	1/3.00	9.00	49.48	172	15200	0.6766	98
RABBIT	50	32.3	6/3.35	1/3.35	10.05	61.70	214	18400	0.5426	112
HORSE	70	45.2	12/2.59	7/2.79	13.95	116.2	538	61200	0.3936	148
DOG	100	64.5	6/4.72	7/1.57	14.15	118.5	394	32700	0.2733	153
WOLF	150	96.8	30/2.59	7/2.59	18.13	194.9	726	69200	0.1828	162
DINGO	150	97.9	18/3.35	1/3.35	16.75	167.5	506	35700	0.1815	179
LYNX	175	113.0	30/2.79	7/2.79	19.53	226.2	842	79800	0.1576	178
CARACAL	175	113.7	18/3.61	1/3.61	18.05	194.5	587	41000	0.1563	205
PANTHER	200	129	30/3.00	7/3.00	21.00	261.5	974	92200	0.1363	191
BISON	-	226	54/3.00	7/3.00	27.00	431.3	1444	120900	0.07571	208
JAGUAR	200	130	18/3.86	1/3.86	19.30	222.3	671	46600	0.13670	197
ZEBRA	400	258	54/3.18	7/3.18	28.62	484.5	1621	131900	0.06740	202

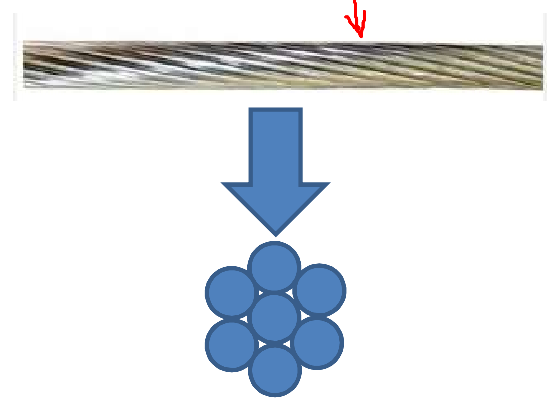
Bundled Conductors





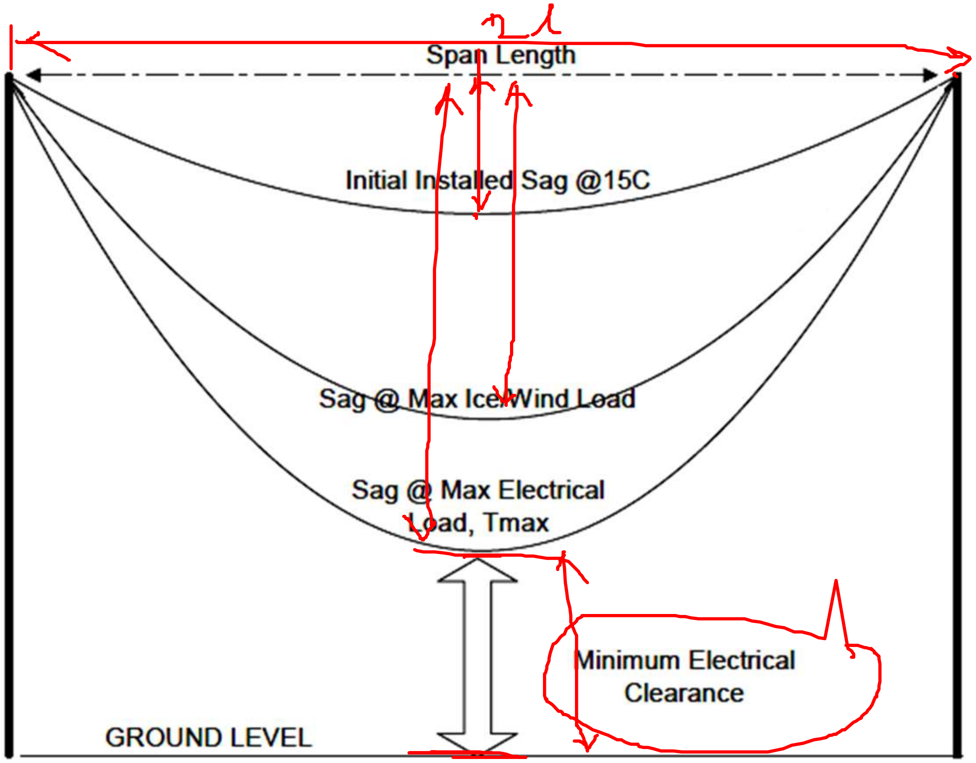
High





http://en.wikipedia.org/

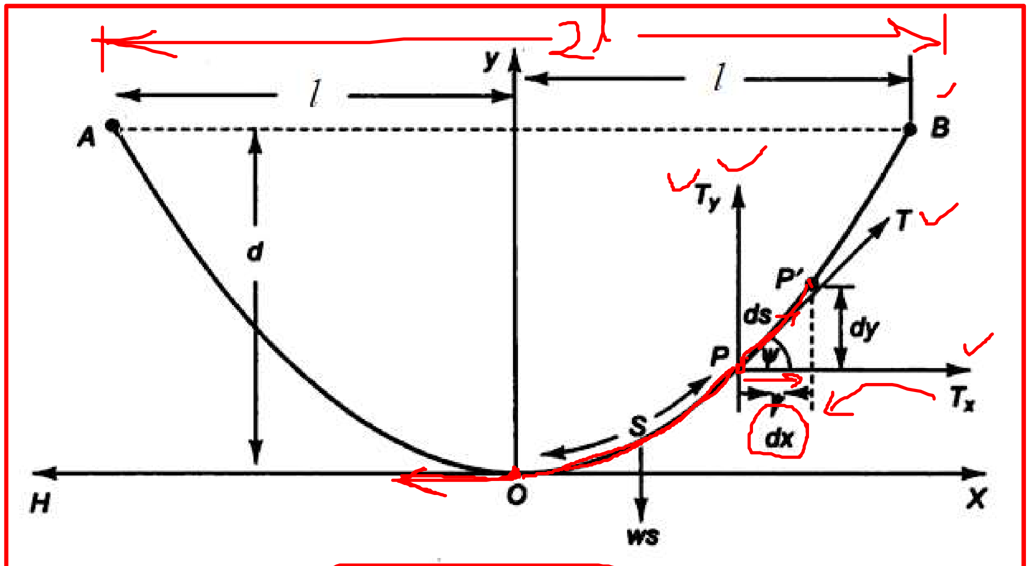
Sag and Tension:



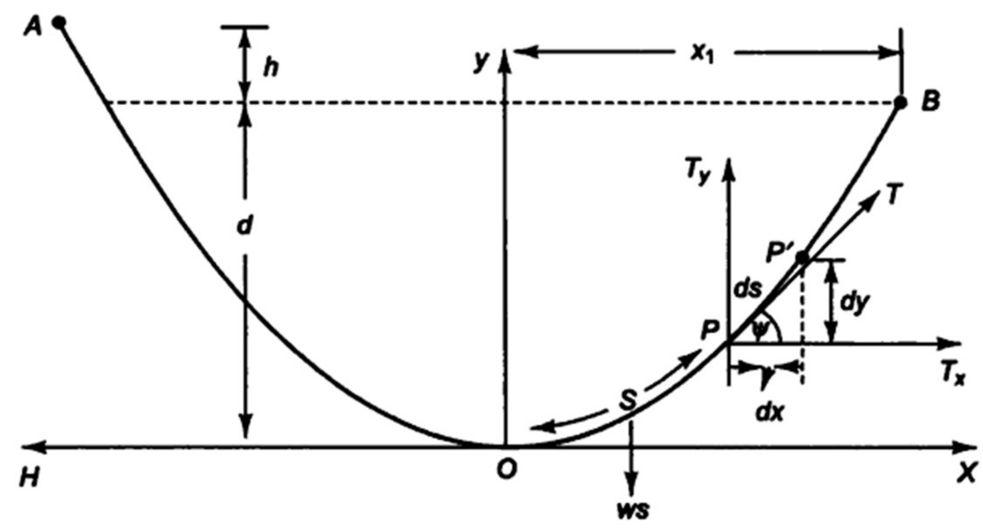
220 kV line: GC 7.0 m, SL 380, and CC 5.1 m
400 kV line: GC 8.8 m, SL 400, and CC 7.0 m

- **Sag (d)** is defined as vertical distance between the point where the line is joined to the tower to the lowest point on the line.
- Sag depends on the **tension (T)** with which conductors are pulled.
- **Span Length (SL)** is horizontal distance between two towers.
- Vertical distance between lowest point on line to the ground plane is called **ground clearance (GC)**.
- Values of sag and tension at **winter and summer condition** and at **various loading conditions** must be known.
- **Mechanical loadings**
  - Weight of conductor itself
  - Weight of ice or snow clinging to wire
  - Wind blowing against wire

Calculation of Sag and Tension



Towers at same height



Towers at different height

- w =weight per unit length
- H = tension at point O
- T = tension at point P
- $2l$ =Span length
- O is the lowest point on the wire

Calculation of Sag and Tension

$$H = T_x$$

$$T_y = ws$$

$$\tan\,\psi = dy/dx = T_y/T_x = ws/H$$

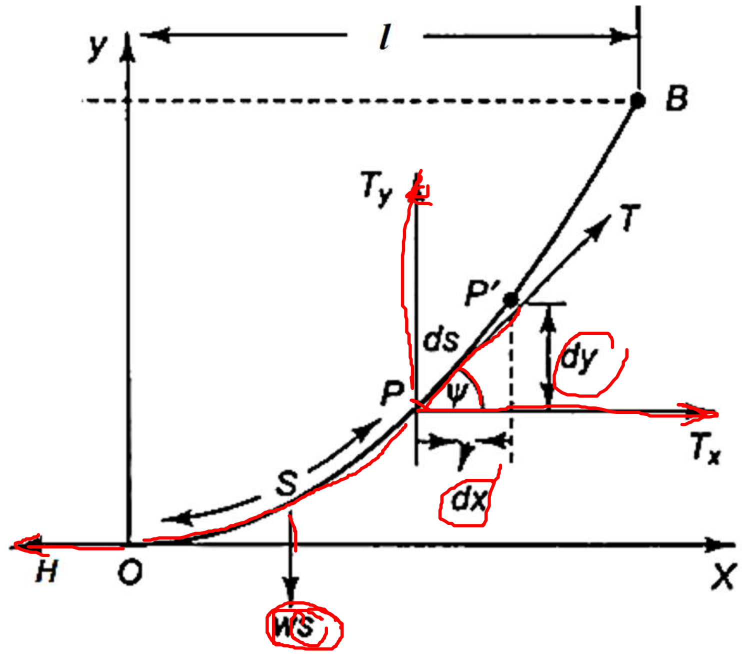
$$ds^2 = dx^2 + dy^2$$

$$\frac{ds^2}{dx^2} = 1 + \frac{dy^2}{dx^2}$$

$$\frac{ds}{dx} = \sqrt{1+(dy/dx)^2}$$

$$\frac{ds}{dx} = \sqrt{1+w^2s^2/H^2}$$

$$dx = \frac{ds}{\sqrt{1+w^2s^2/H^2}}$$



Calculation of Sag and Tension

$$dx = \frac{ds}{\sqrt{1 + w^2 s^2 / H^2}}$$

Integrating

$$\int dx = \int \frac{ds}{\sqrt{1 + w^2 s^2 / H^2}}$$

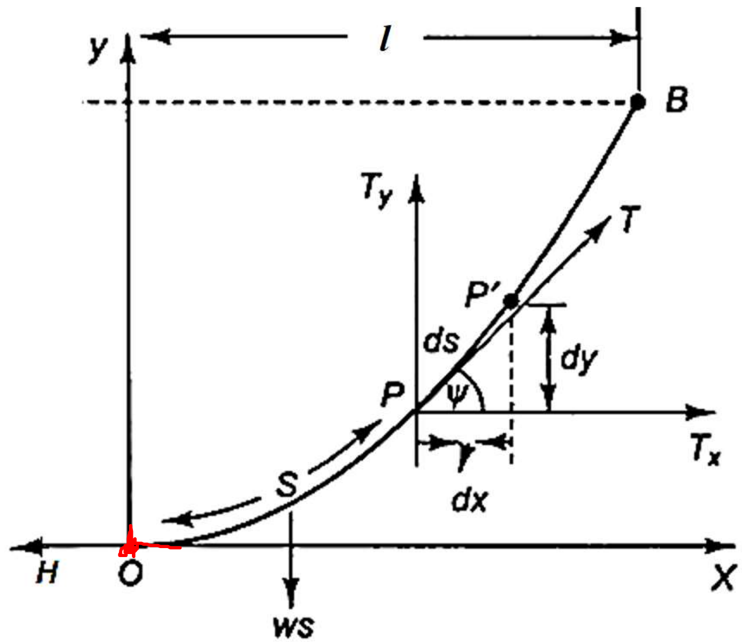
Thus

$$x + c_1 = \frac{H}{w} \sinh^{-1}\left(\frac{ws}{H}\right)$$

At x=0, s=0, therefore c_1=0

$$x = \frac{H}{w} \sinh^{-1}\left(\frac{ws}{H}\right)$$

$$\boxed{s = \frac{H}{w} \sinh \frac{wx}{H}}$$



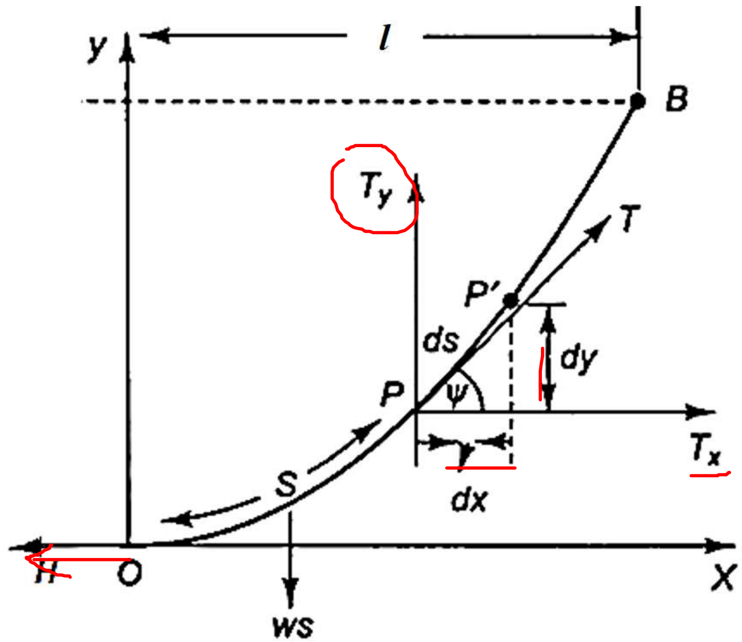
Calculation of Sag and Tension

$$s = \frac{H}{w} \sinh \frac{wx}{H}$$

$$\frac{ws}{H} = \sinh\left(\frac{wx}{H}\right)$$

Also $\quad \dfrac{dy}{dx} = \dfrac{ws}{H}$

$$\frac{dy}{dx} = \sinh\left(\frac{wx}{H}\right) \quad \Rightarrow \quad dy = \sinh \frac{wx}{H}\, dx$$



Calculation of Sag and Tension

$$dy = \sinh \frac{wx}{H}\, dx$$

Integrating

$$\int dy = \int \sinh \frac{wx}{H}\, dx$$

Thus $$y = \frac{H}{w} \cosh\left(\frac{wx}{H}\right) + c_2$$

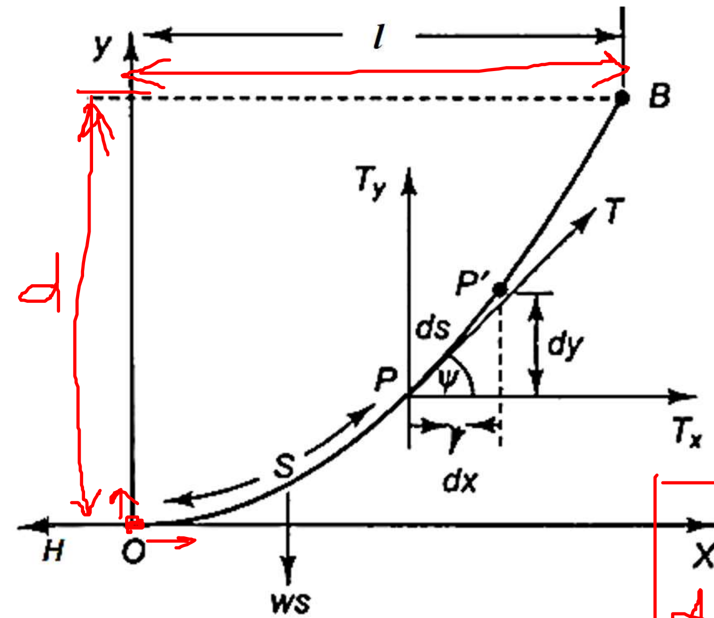
At x=0, y=0 therefore $$\boxed{c_2 = -\frac{H}{w}}$$

$$y = \frac{H}{w} \cosh\left(\frac{wx}{H}\right) - \frac{H}{w}$$

$$\boxed{y = \frac{H}{w}\left(\cosh \frac{wx}{H} - 1\right)}$$

$$\cosh x = 1 + \frac{x^2}{2!} + \frac{x^4}{4!} + \frac{x^6}{6!} + \cdots$$

$$y = \frac{H}{w}\left(1 + \frac{w^2x^2}{2H^2} - 1\right) = \frac{wx^2}{2H}$$



$$\boxed{d = \frac{wl^2}{2H}}$$

$$y = \frac{wx^2}{2H}$$

Calculation of Sag and Tension

For tension at point P,

$$T^2 = T_x^2 + T_y^2$$

$$= H^2 + w^2 s^2$$

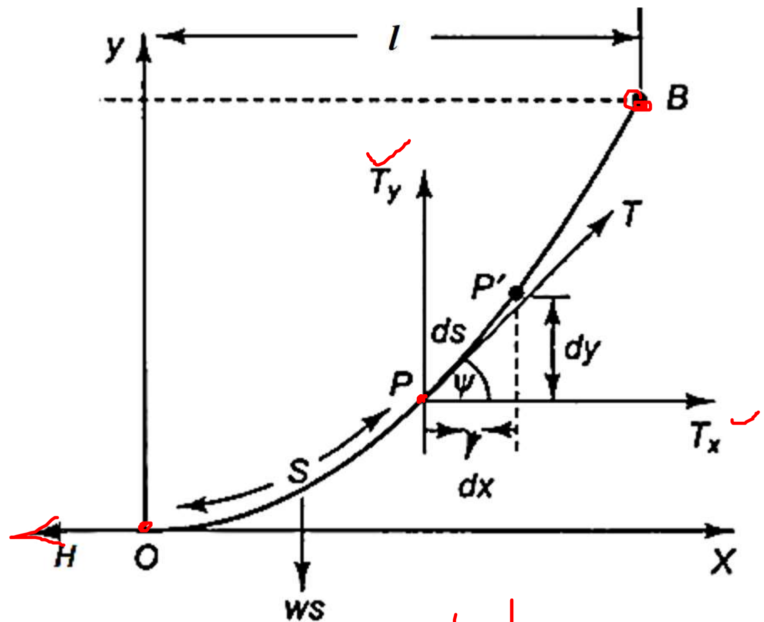
We know $\boxed{s = \frac{H}{w} \sinh \frac{wx}{H}}$

$$T^2 = H^2 + H^2 \sinh^2\left(\frac{wx}{H}\right)$$

$$= H^2\left(1 + \sinh^2\left(\frac{wx}{H}\right)\right)$$

$$\boxed{T^2 = H^2 \cosh^2\left(\frac{wx}{H}\right)}$$

$$\boxed{T = H \cosh \frac{wx}{H}}$$



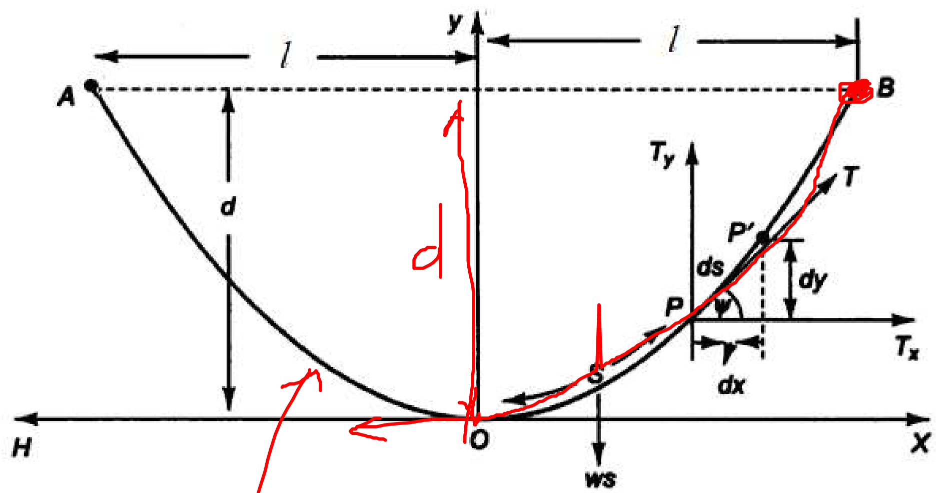
Support at Same Heights

If the towers at same height and span is *2l*, i.e. half span is *l*

$$s = \frac{H}{w}\sinh\frac{wx}{H} \;\Rightarrow\; S = \frac{H}{w}\sinh\left(\frac{wl}{H}\right)$$

$$y = \frac{H}{w}\left(\cosh\frac{wx}{H} - 1\right) \;\Rightarrow\; d = \frac{H}{w}\left(\cosh\frac{wl}{H} - 1\right)$$

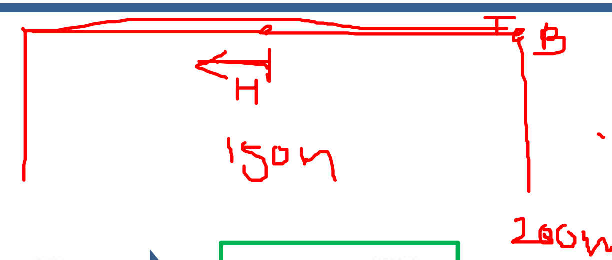
$$T = H\cosh\frac{wx}{H} \;\xrightarrow{T \text{ at Ends}}\; T = H\cosh\frac{wl}{H}$$



d

$\frac{1000N}{2} = 500$

Approximate Formulae for Sag and Tension



$$-T \quad H\cosh\frac{wl}{H} \Rightarrow \boxed{T \approx H\left(1+\frac{w^2l^2}{2H^2}\right)}$$

$$d=\frac{H}{w}\left(\cosh\frac{wl}{H}-1\right) \Rightarrow d \approx \frac{H}{w}\left(1+\frac{w^2l^2}{2H^2}-1\right) \Rightarrow \boxed{d \approx \frac{wl^2}{2H}}$$

Sag

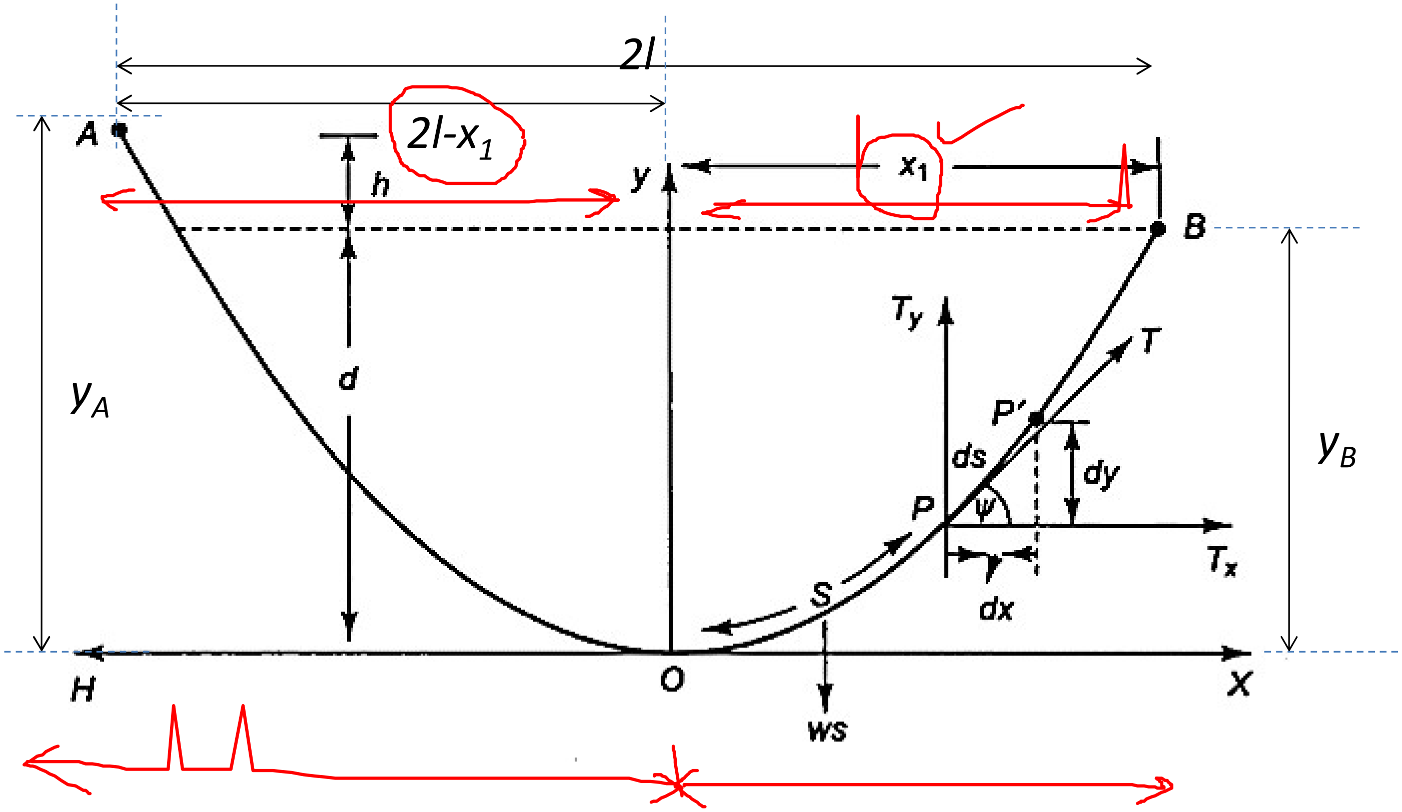
$$S=\frac{H}{w}\sinh\left(\frac{wl}{H}\right) \Rightarrow S \approx \frac{H}{w}\left(\frac{wl}{H}+\frac{w^3l^3}{6H^3}\right) \Rightarrow \boxed{S \approx l+\frac{w^2l^3}{6H^2}}$$

Short Spans

$$T \approx H \Rightarrow \boxed{d \approx \frac{wl^2}{2T}} \quad \text{and} \quad \boxed{S \approx l+\frac{w^2l^3}{6T^2}}$$

$$\sinh x = x+\frac{x^3}{3!}+\frac{x^5}{5!}+\frac{x^7}{7!}+\cdots \quad \text{and} \quad \cosh x = 1+\frac{x^2}{2!}+\frac{x^4}{4!}+\frac{x^6}{6!}+\cdots$$

Supports at Different Heights



Supports at Different Heights

$$y = \frac{H}{w}\left(\cosh\frac{wx}{H} - 1\right)$$

For tower B

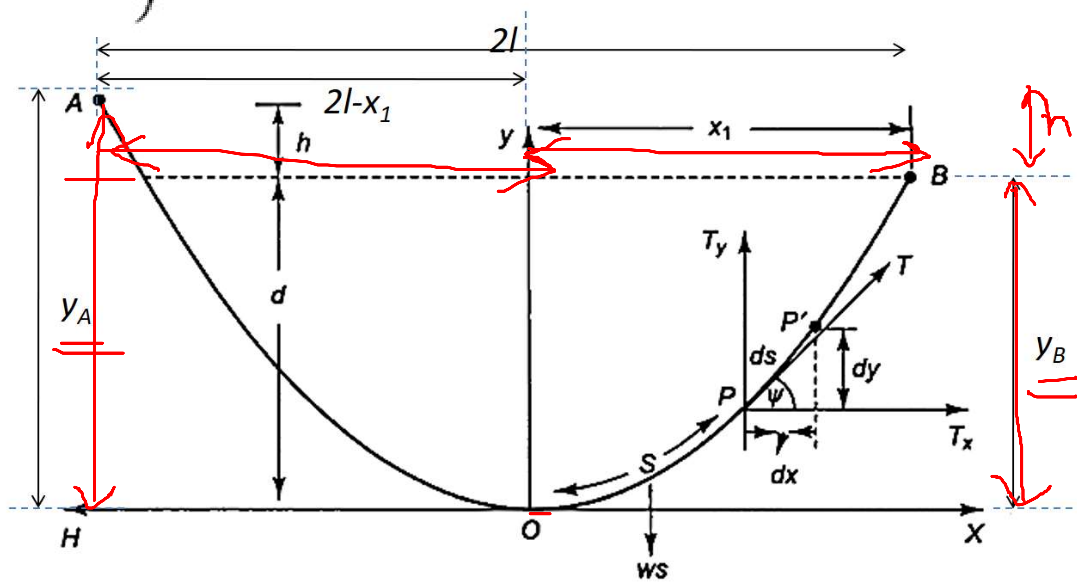
$$y_B = \frac{H}{w}\left(\cosh\frac{wx_1}{H} - 1\right)$$

For tower A

$$y_A = d + h = \frac{H}{w}\left(\cosh\frac{w(2l - x_1)}{H} - 1\right)$$

Therefore, difference in tower heights

$$h = \frac{H}{w}\left(\cosh\frac{w(2l - x_1)}{H} - \cosh\frac{wx_1}{H}\right)$$



Thank You