SAG AND TENSION CALCULATIONS

The energized conductors of transmission lines must be placed to totally eliminate the possibility of injury to people. Overhead conductors, however, elongate with time, temperature, and tension, thereby changing their original positions after installation.

Despite the effects of weather and loading on a line, the conductors must remain at safe distances from buildings, objects, and people or vehicles passing beneath the line at all times.

Bare overhead transmission conductors are quite flexible and uniform in weight along their length. Because of these characteristics, they take the form of a **catenary** (Ehrenberg, 1935; Winkelmann, 1959) between support points.

The shape of the catenary changes with conductor temperature, ice and wind loading, and time.

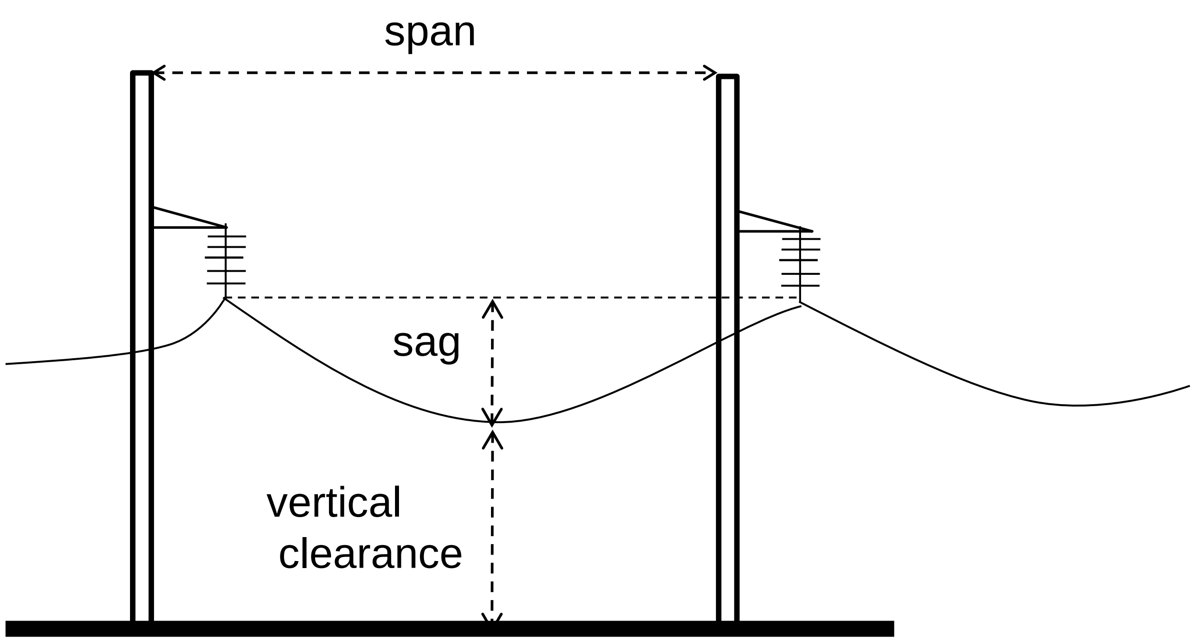
The behavior of the conductor catenary under all conditions must be known before the line is designed

- To ensure adequate vertical clearance under all weather and electrical loadings,
- To ensure that the breaking strength of the conductor is not exceeded

The behavior of the conductor is determined through calculations commonly referred to as ***sag-tension*** calculations.

	Vertical Clearances (m)					
Maximum System Voltage (kV)	0-1	1-17.5	36	72.5	170	420
Waterways without navigation on them	4.5	5	5	5	6	8.5
Meadow, field, pasture and smilar places suitable for passage of vehicles	5	6	6	6	7	9.5
Village and city roads available to the passage of vehicles	5.5	7	7	7	8	12
Intercity Highways	7	7	7	7	9	12
Trees	1.5	2.5	2.5	3	3	5
Open flat-roofed structures	2.5	3.5	3.5	4	5	8.7
Restricted slope-roofed structures	2	3	3	3.5	5	8.7
Electric lines	2	2	2	2	2.5	4.5
Oil and natural gas pipelines	9	9	9	9	9	9
Channels and waters with traffic	4.5	4.5	5	5	6	9
Telecomunication lines	1	2.5	2.5	2.5	3.5	4.5
Railways	7	7	7	7	8	10.5
Highways	14	14	14	14	14	14

Required Vertical Clearances as Per the National Regulation



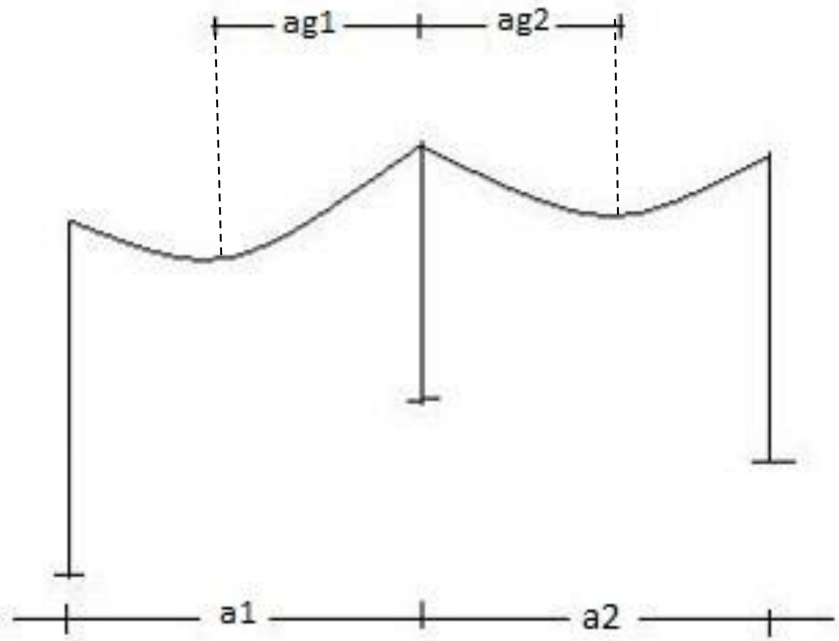
Span (a): is the horizontal distance between two supports.

$$a \leq 50m \quad short\ spans$$

$$a > 50m \quad \text{long spans}$$

In TEİAŞ transmission lines, span length is around 350-400m.
For strait crossings, the span is greater than 1000m.

Sag (f) : the difference between points of supports and the lowest point on the conductor



<u>Wind span (a_w)</u> :When looking at the transmission line profile view, the wind span is defined as half of the sum of adjacent spans. $a_w=(a_1+a_2)/2$

<u>Weight span (a_g)</u> : Weight span is defined as the distance from low point sag of one span to the low point sag of the next span. $a_g=(a_{g1}+a_{g2})$

The factors affecting the sag of a conductor strung between supports are:

1. Conductor load per unit length.
2. Span.
3. Temperature.
4. Conductor tension.

In order to determine the conductor load properly, the factors that need to be taken into account are:

1. Weight of conductor itself. (Provided by the manufacturer)
2. Weight of ice or snow clinging to wire.
3. Wind blowing against wire.

Ice and wind conductor loads

Climatic actions such as wind or ice play important roles in the sag and tension calculations.
When a conductor is covered with ice and/or is exposed to wind, the effective conductor weight per unit length increases.

IEC 60826 applies to the evaluation of climatic loads and rating of line strength.
In Europe, the standard **EN 50341-1** was established as a ***regional overhead electrical line standard*** consisting of general requirements and common specifications, for the individual CENELEC member countries.
CENELEC: European Comittee for Electrotechnical Standardization.Turkey is a member of CENELEC.
All the calculations carried out comply with the National Electrical Installation Regulations.

Ice loading

The formation of ice on overhead conductors may take several physical forms; glaze ice, rime ice or wet snow.
The impact of ice formation is usually considered in the design of line sections at high altitutes.

Factors affecting the ice load are

- Temperature (Ice is usually formed between -8 $^\circ$C and 2 $^\circ$C) .
- Humidity (> %90)
- Wind velocity and direction
- Altitude

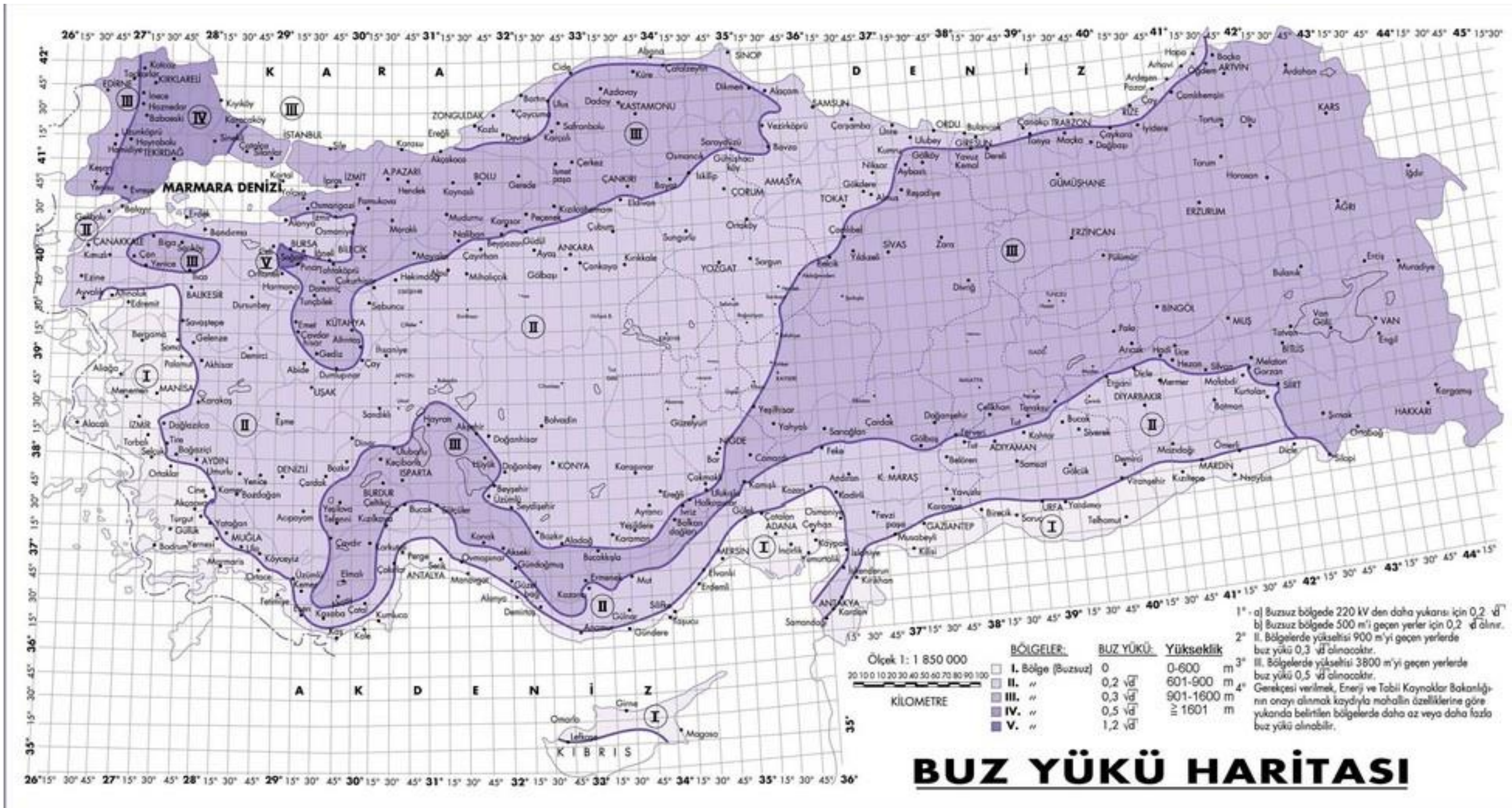
Ice loadings on overhead conductors influnce line design in a number ways:

- Ice loads determine the maximum vertical conductor loads that structures and foundations must withstand.
- In combination with simultaneous wind loads, ice loads also determine the maximum transverse loads on structures.

Ice loads on conductors

Density of ice load measured in Turkey takes a value between 0.4kg/dm^3 and 0.8kg/dm^3 . The calculation of ice loads on conductors is normally done with an assumed density of $\gamma_{ice} = 0.6\,\frac{\text{kg}}{dm^3}$.

According to National Regulations Turkey is divided into 5 regions considering ice loading.



Ice load per unit length of the conductor:

$$w_i = k\sqrt{d} \qquad kg/m$$

d : diameter of the conductor (mm)
k: constant defined according to the ice load regions

Ice loading regions in Turkey	k	Altitude (m)	Ambient temperature (ºC)	
			Min	Max
I	0	0-600	-10	50
II	0.2	601-900	-15	45
III	0.3	901-1600	-25	40
IV	0.5	≥1601	-30	40
V	1.2		-30	40

1st Region :

If the volage level of the transmission line is greater than 220kV, then

$w_i = 0.2\sqrt{d}$

If the altitude is greater than 500m , then $w_i = 0.2\sqrt{d}$

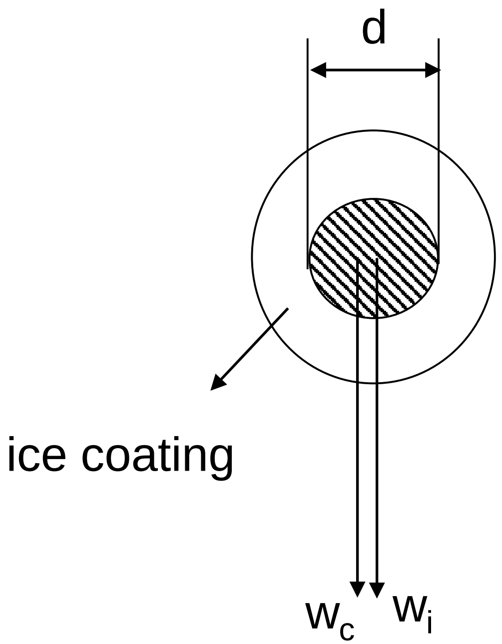
2nd Region:

If the altitude is greater than 900m, then $w_i = 0.3\sqrt{d}$

3rd Region:

If the altitude is greater than 3800m , then $w_i = 0.5\sqrt{d}$

The weight of ice acts vertically downwards *i.e.*, in the same direction as the weight of conductor.



d:diameter of the conductor (mm)
w_c: weight of the conductor per unit length (kg/m)
w_i : ice load per unit length (kg/m)

Total weight of the conductor per unit length (with ice load)

$$w_t = w_c + w_i$$

Ice load is assumed to be uniform, cylindirical and formed at -5°C.

De-icing of the power lines:

De-icing is important to ensure the smooth and safe operation of these power lines during winter or icy conditions. Here are a few common methods:

Mechanical Methods: This involves physically removing the ice or snow from the transmission lines. This can be done by using helicopters or drones equipped with de-icing equipment to fly along the lines and break the ice accumulations. Alternatively, specialized devices like steamers, brushes, or de-icing balls can be used to mechanically remove ice from the lines.

Electrical Methods: These methods involve using electrical currents to heat up the transmission lines and melt the ice. One common technique is called "conductor heating," where a controlled electrical current is passed through the conductors, generating heat that melts the ice. Another option is "hot air de-icing," which uses high-velocity hot air blown onto the lines.

Chemical Methods: Certain chemicals can be used to de-ice transmission lines. Anti-icing or de-icing chemicals like calcium magnesium acetate (CMA) or potassium acetate can be applied to the lines to prevent or remove ice accumulations. However, these methods may require environmental considerations due to chemical usage.

Wind loading

Wind loads on overhead conductors influence line design in a number ways:

- The maximum span between structures may be determined in moderate winds.
- The maximum transverse loads on structures are often determined by infrequent high wind-speed loadings.
- Permanent increase in conductor sag may be determined by wind loading in areas of light ice load.

Wind load per unit length of the conductor:

For a_w<200m

$$w_w = cpd10^{-3} \qquad kg/m$$

a_w: wind span (m)

d:diameter of the conductor (mm)

c: dynamic wind pressure coefficient
p: dynamic wind pressure (kg/m^2)

For a_w≥ 200m

$$w_w = k_1 cpd10^{-3} \qquad kg/m$$

$$k_1 = 0.6 + \frac{80}{a_w}$$

Dynamic wind pressure

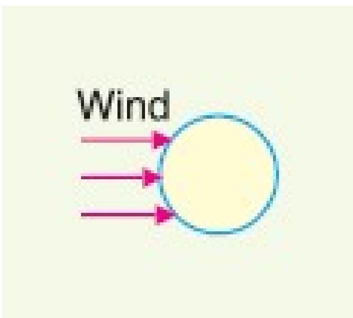
Altitude (m)	**Wind pressure on conductors (kg/m²)**
0-15	44
15-40	53
40-100	68
100-150	86
150-200	95

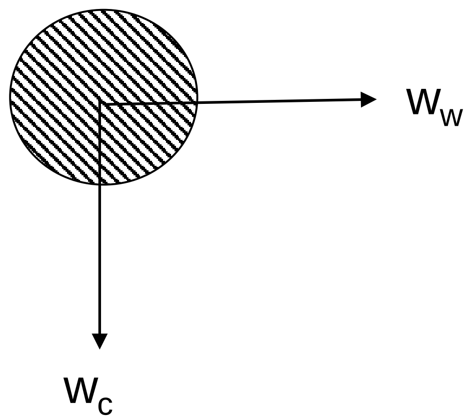
$$p \cong \frac{1}{16} v^2$$

p: dynamic wind pressure (kg/m^2)
v: wind velocity (m/s)

Conductor diameter (mm)	**c**
d ≤ 12.5	1.2
12.5<d ≤ 15.8	1.1
d >15.8	1.0

The force due to the wind is most effective acting horizontally *i.e.*, at right angle to the projected surface of the conductor usually at 5°C.



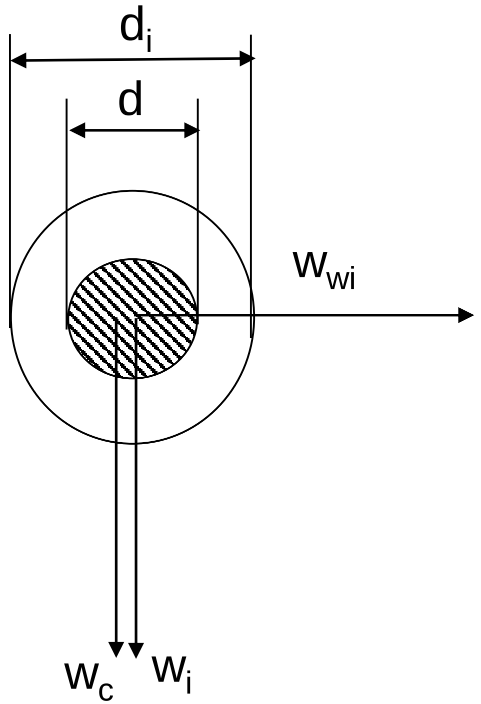


$$w_t = \sqrt{w_c^2 + w_w^2}$$

The total force on the conductor is the vector sum of horizontal and vertical forces

Combined Ice and Wind loading

The weight per unit length of the conductor under both ice and wind loading is given by the following equation:



$$w_t = \sqrt{(w_c + w_i)^2 + w_{wi}^2}$$

d:diameter of the conductor (mm)

d_i: diameter of the ice-loaded conductor (mm)

$$d_i = \sqrt{2122\, k\sqrt{d} + d^2}$$

Since wind acts on the ice loaded conductor, diameter of the ice loaded conductor is used when calculating the wind load in combined ice and wind loading.

$$w_{wi} = c p d_i 10^{-3} \qquad a_w < 200m$$

Excessive ice load coefficients ,which caused faults, observed in the past years in Turkey

(Enerji İletim Sistemleri Cilt-4, Selim Ay)

k (in the project)   k’ (oserved during the fault)

Transmission line	U (kV)	k	k’	k’/k
Tokat-Sivas	154	0.3	0.96	3.2
Yozgat-Çorum	154	0.3	2.57	8.57
Ferrokrom-Bingöl	154	0.3	0.8	2.67
Kartal-Adapazarı	154	0.2	1.2	6.0
Bozöyük-Söğüt	154	0.2	3.0	15
Paşalar-Adapazarı	154	0.2	1.88	9.4
Çorlu-Hadımköy	154	0.2	0.8	4.0
Babaeski-İkitelli	380	0.3	0.82	2.73
Keban-Ankara	380	0.3	2.9	9.67
Gökçekaya-Seyitömer	380	0.3	2.26	7.53

According to EKATY,

It is assumed that the conductors in ice load regions will experience normal ice loads at -5º C, while no ice load will be present at any other temperature.

When the transmission line passes through multiple ice load regions, the calculations for each section of the line will be performed using the parameters of the corresponding region. However, if the line section within a specific region is less than 10 km, calculations can be made based on the conditions of the larger line section.

In lines with voltages of 380 kV and above, it will be assumed that there is a normal ice load for each region at -5ºC, combined with a dynamic wind pressure of 20 kg/m^2.

It will be assumed that a normal wind load is present on the conductors at +5ºC, and no wind load exists at all other temperatures.