Determination Of Zipline Tightening Weight Travell Distance

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Abstract: *This paper shows the determination of tightening weight travelling distance for the zipline. A rope for a zipline can be fixed at both ends, or it can be fixed at one end and tightened with a weight at the other. A both-sided anchorage is simpler to perform, but there is a problem with large changes in the rope force due to temperature differences and due to the movement of the load on it. With a rope that is fixed at one end and tightened with a weight at the other end, there are no such problems, because the force in the rope is always the same, but care must be taken to ensure sufficient travel of the tightening weight. The required travel of the weight is affected by temperature changes, ice buildup and snow, but also by the movement of passengers on the rope itself. Formulas based on which the weight movement is calculated are derived in the paper.*

Keywords*: ZIPLINE, CABLE, WIRE ROPE, TIGHTENING, ANCHORAGE*

1. Introduction

In this paper, the atmospheric effects on the zipline rope, which is tensioned by weight, will be analyzed. The paper will use data for a specific zipline, the construction of which was planned on Fruška Gora in Serbia, [1]. The span of the zipline is 1467 m, while the height difference between the stations is 99 m. A rope with a diameter of 16 mm with a weight of 1,09 kg/m was used, while a counterweight with a mass of 6400 kg was foreseen.

2. Impact of rider's descent

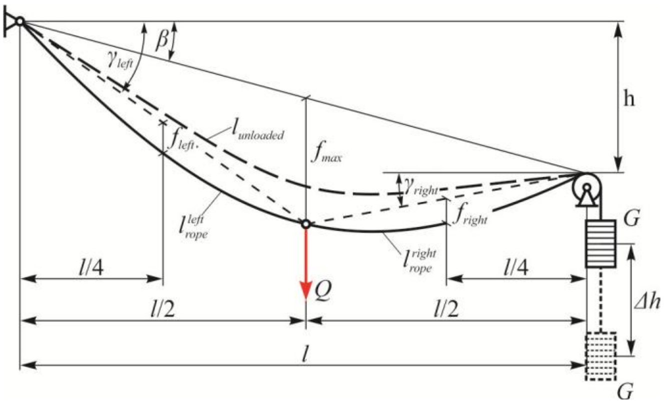

Fig. 1 *Determination of the counterweight displacement*

Based on Figure 1, it is possible to determine the counterweight travel distance (Δh) during the descent of the rider down the zipline rope as the difference between the length of the rope in the field when the rider is in the field and the length of the unloaded rope. The maximal value of the rope length in the field is obtained when the passenger is in the middle of the span. In that case, based on Figure 1, and [2-4] it follows that the lengths of the segments on the left $\left(l^{left}_{rope}\right)$ and right $\left(l^{right}_{rope}\right)$ sides of the load are:

$$l^{left}_{rope} = \frac{l}{2\cdot\cos\gamma_{left}} + \frac{16}{3}\cdot\frac{f^2_{left}}{l}\cdot\cos^3\gamma_{left} = $$

$$= \frac{1467}{2\cdot\cos 8,07^o} + \frac{16}{3}\cdot\frac{11,57^2}{1467}\cdot\cos^3 8,07^o = 741,31 \text{ m}$$

$$l^{right}_{rope} = \frac{l}{2\cdot\cos\gamma_{right}} + \frac{16}{3}\cdot\frac{f^2_{right}}{l}\cdot\cos^3\gamma_{right} = $$

$$= \frac{1467}{2\cdot\cos 0,39^o} + \frac{16}{3}\cdot\frac{11,45^2}{1467}\cdot\cos^3 0,39^o = 734,00 \text{ m}$$

where:

$$\gamma_{left} = arctg\frac{2\cdot f_{\max} + h}{l} = arctg\frac{2\cdot 54,52+99}{1467} = 8,07^o$$

$$\gamma_{right} = arctg\frac{2\cdot f_{\max} - h}{l} = arctg\frac{2\cdot 54,52-99}{1467} = 0,39^o$$

$$f_{left} = \frac{q\cdot\left(\frac{l}{2}\right)^2}{8\cdot H\cdot\cos\gamma_{left}} = \frac{1,09\cdot\left(\frac{1467}{2}\right)^2}{8\cdot 6400\cdot\cos 8,07^o} = 11,57 \text{ m}$$

$$f_{right} = \frac{q\cdot\left(\frac{l}{2}\right)^2}{8\cdot H\cdot\cos\gamma_{right}} = \frac{1,09\cdot\left(\frac{1467}{2}\right)^2}{8\cdot 6400\cdot\cos 0,39^o} = 11,45 \text{ m}$$

$$f_{\max} = \frac{l^2}{8H}\cdot\left(\frac{q}{\cos\beta} + 2\frac{Q}{l}\right) = \frac{1467^2}{8\cdot 6400}\cdot\left(\frac{1,09}{\cos 3,86^o} + 2\cdot\frac{150}{1467}\right) = 54,52 \text{ m}$$

while the length of the unloaded rope is:

$$l_{unloaded} = \frac{l}{\cos\beta} + \frac{8}{3}\cdot\frac{f^2_{unloaded}}{l}\cdot\cos^3\beta = $$

$$= \frac{1467}{\cos 3,86^o} + \frac{8}{3}\cdot\frac{45,92^2}{1467}\cdot\cos^3 3,86^o = 1474,14 \text{ m}$$

where the maximal deflection of unloaded rope is:

$$f_{unloaded} = \frac{l^2}{8H}\cdot\frac{q}{\cos\beta} = \frac{1467^2}{8\cdot 6400}\cdot\frac{1,09}{\cos 3,86^o} = 45,92 \text{ m}$$

where:

$$\beta = \text{arctg}\frac{h}{l} = \text{arctg}\frac{99}{1467} = 3,86^o \text{ – inclination angle}$$

$$H \approx G = 6400 \text{ kg} \text{ – horizontal force}$$

The weight displacement when lowering the trolley with a passenger with a total mass of 150 kg is then:

$$\Delta h = l^{left}_{rope} + l^{right}_{rope} - l_{unloaded} = 741,31 + 734,00 - 1474,14 = 1,17 \text{ m}$$

3. Ice buildup impact

According to [5, 6] the ice load is calculated based on:

$$q_{ice} = 0,18\cdot\sqrt{d_{rope}\,[\text{mm}]}\left[\frac{\text{daN}}{\text{m}}\right]$$

For the rope with a diameter of 16 mm, follows:

$$q_{ice} = 0,18\cdot\sqrt{16} = 0,72\ \frac{\text{daN}}{\text{m}} \approx 0,72\ \frac{\text{kg}}{\text{m}}$$

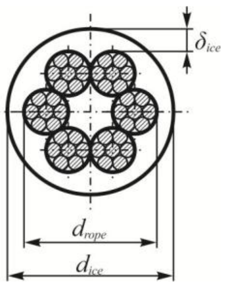

Fig. 2 *Frozen rope*

Knowing that the specific density of ice is 920 kg/m^3, it can be calculated that this weight of ice occurs at an ice thickness of around 9,5 mm, so the diameter of the frozen rope is:

$$d_{ice} = d_{rope} + 2 \cdot \delta_{ice} = 16 + 2 \cdot 9{,}5 = 35 \text{ mm}$$

The deflection of frozen rope is then:

$$f_{ice} = \frac{(q + q_{ice}) \cdot l^2}{8 \cdot H \cdot \cos\beta} = \frac{(1{,}09 + 0{,}72) \cdot 1467^2}{8 \cdot 6400 \cdot \cos 3{,}86^\circ} = 76{,}25 \text{ m}$$

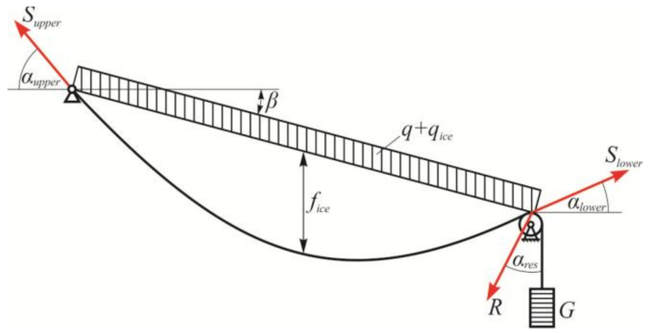

Fig. 3 *Rope loaded with ice*

If it is assumed that there are no losses on the redirection pulley, the resultant load on the lower support is:

$$R = 2 \cdot G \cdot \cos\alpha_{res} = 2 \cdot 6400 \cdot \cos 41{,}005^\circ = 9659{,}5 \text{ kg}$$

that is $S_{lower} = G$, where the angle of the resultant to the vertical is:

$$\alpha_{res} = \frac{90 - \alpha_B}{2} = \frac{90^\circ - 7{,}99^\circ}{2} = 41{,}005^\circ$$

while the tangent angle of the rope in the lower support is determined according to the:

$$tg\alpha_{lower} = tg\beta - \frac{(q + q_{ice}) \cdot l}{2 \cdot H \cdot \cos\beta} = tg3{,}8^\circ - \frac{(1{,}09 + 0{,}72) \cdot 1467}{2 \cdot 6400 \cdot \cos 3{,}86^\circ} = -0{,}140$$

$$\alpha_{lower} = arctg(-0{,}140) = -7{,}99^\circ$$

From there the rope force at the upper support can be obtained from:

$$S_A = S_B + h \cdot (q + q_l) = 6400 + 99 \cdot (1{,}09 + 0{,}72) = 6579 \text{ kg}$$

The tangent angle of the rope on the upper support is determined according to:

$$tg\alpha_{upper} = tg\beta + \frac{(q + q_{ice}) \cdot l}{2 \cdot H \cdot \cos\beta} = tg3{,}8^\circ + \frac{(1{,}09 + 0{,}72) \cdot 1467}{2 \cdot 6400 \cdot \cos 3{,}86^\circ} = 0{,}275$$

$$\alpha_{upper} = arctg(0{,}275) = 15{,}40^\circ$$

The length of the frozen rope is then:

$$l_{frozen} = \frac{l}{\cos\beta} + \frac{8}{3} \cdot \frac{f_{ice}^2}{l} \cdot \cos^3\beta = \frac{1467}{\cos 3{,}86^\circ} + \frac{8}{3} \cdot \frac{76{,}25^2}{1467} \cdot \cos^3 3{,}86^\circ = 1480{,}83 \text{ m}$$

4. Wind impact

Wind pressure is according to the [5, 6] calculated by the following expression:

$$p_{wind} = \frac{w^2 \ [\text{m/s}]}{16} \left[\frac{\text{daN}}{\text{m}^2}\right]$$

where the w represents the maximal wind velocity at the location where the zipline is built.

For:

$$w = 64 \ \frac{\text{km}}{\text{h}} = 17{,}8 \ \frac{\text{m}}{\text{s}}$$

follows:

$$p_{wind} = \frac{w^2}{16} = \frac{17{,}8^2}{16} = 19{,}8 \ \frac{\text{daN}}{\text{m}^2}$$

The load of the rope per length unit is then:

$$q_{wind} = p_{wind} \cdot d_{rope} = 19{,}8 \cdot 0{,}016 = 0{,}32 \ \frac{\text{daN}}{\text{m}} \approx 0{,}32 \ \frac{\text{kg}}{\text{m}}$$

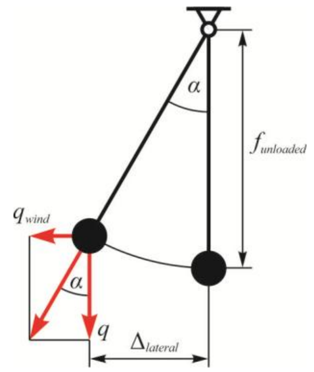

Fig. 4 *Lateral deflection of the rope*

The angle of rotation of the plane of the rope due to the action of the wind is

$$\alpha = arctg\left(\frac{q_{wind}}{q}\right) = arctg\left(\frac{0{,}32}{1{,}09}\right) = 16{,}4^\circ$$

Knowing that the maximal rope deflection amounts to 45,92 m, it follows that the lateral deflection is:

$$\Delta_{lateral} = f_{unloaded} \cdot \sin\alpha = 45{,}92 \cdot \sin 16{,}4^\circ = 12{,}96 \text{ m}$$

5. Temperature impact

According to regulations, ropes must be calculated for the minimum working temperature of -20°C and maximal working temperature of +40°C.

If it is assumed that the temperature during installation was 25°C, then the temperature differences for the calculation amounts to $\Delta t_1 = 25 - (-20) = 45^0 \text{ C}$ and $\Delta t_2 = 40 - 25 = 15^0 \text{ C}$.

According to the previous and assuming that at the temperature of -40° C the rope is completely frozen, the maximal displacement of the tightening weight is:

$$\Delta h = l_{frozen} - l_{unloaded} + \alpha_t \cdot \Delta t_1 \cdot l_{frozen} + \alpha_t \cdot \Delta t_2 \cdot l_{unloaded} =$$
$$= 1480{,}33 - 1474{,}14 + \left(45 \cdot 1480{,}33 + 15 \cdot 1474{,}14\right) \cdot 12 \cdot 10^{-6}$$
$$\Delta h = 7{,}76 \text{ m}$$

where α_t represents linear thermal expansion coefficients for steel:

$$\alpha_t(\text{steel}) = 11 \div 13 \cdot 10^{-6} \left[\frac{1}{{}^{\circ}C}\right] \Rightarrow \alpha_t = 12 \cdot 10^{-6} \ \frac{1}{{}^{\circ}C}$$

6. Conclusion

The zipline rope can be fixed with both-sided anchorage or by anchoring one end and tensioning with a counterweight at the other.

The both-sided anchored rope represents a statically indeterminated system. This case is easy to realize, so it is often applied for ziplines with short spans.

The case of rope that is anchored at one end and tensioned with counterweight at the other, is generally more favourable because the rope forces aren't changing much, there is no significant impact of the temperature and elasticity of the rope, but the solution requires more space on the pillar and the system is more expensive.

This paper gives an example of determining the change of rope length for a case of tensioning with a counterweight.

The maximum length of the weight displacement should be predicted for the case of the largest differences in rope lengths in the field. The maximum rope length in the field would occur when the rope is loaded with ice. The smallest rope length in the field occurs when the rope is unloaded. The influence of temperature should be added to this difference, as well as the difference due to riders descent.

7. References

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