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Technical recommendations in effect

BOOK N. 18
(May 2001)

Recommendations for the design and construction of double monocable aerial ropeways with regard to their specific features

This Recommendation is not mandatory but provides guidance to the profession. Its application would be desirable in all countries, however, without prejudice to national standards as well as requirements specified by public authorities.

International Organisation for Transportation by Rope

O.I.T.A.F.

**Recommendations for the design and construction
of double monocable aerial ropeways with regard to
their specific features**

Book 18

Work Committee No. 1

May 2001

RECOMMENDATIONS FOR THE DESIGN AND CONSTRUCTION OF DOUBLE MONOCABLE AERIAL ROPEWAYS WITH REGARD TO THEIR SPECIFIC FEATURES

The below recommendations contain technical requirements which are based on the specific features of double monocable aerial ropeways. They are based on previous double monocable aerial ropeway executions and on the experience gained from their operation. In the event of changed design characteristics, the recommendations shall be adhered to so as to achieve at least the same level of safety. Interaction of the parallel running ropes loaded with carriers during operation will cause a transposition of loads and geometrical changes, such as changes in the rope shape or in the structural clearance.

Contents:

1. Scope
2. Wind loads during operation
3. Rope line and length of rope spans
4. Lateral clearance
5. Track gauge
6. Safety distance behind station conveyors
7. Tension to shear ratio
8. Additional loads caused by restricted transverse sway
9. Synchronism of ropes
10. Annex

1. Scope

- 1.1 The recommendations contained in this text are for ropeways intended for the transportation of passengers, the carriers of which are attached to, suspended from, and continuously moved by two parallel running haulage ropes or one haulage rope which forms a double loop.
- 1.2 The recommendations contained in this text apply both for ropeways where the gauge of the parallel running ropes is wider than the carrier width (e.g. Funitel system) and for ropeways where it is narrower.

2. Wind loads during operation

The magnitude of the wind load (dynamic pressure) based on which proof of the load case 'in operation' is to be furnished, shall be selected in accordance with the wind speed at which the ropeway shall still be operable according to the design provisions. The minimum dynamic pressure is 0.25 kN/m^2 . Since double monicable aerial ropeways can be operated at higher wind speeds than monicable aerial ropeways, it is advisable to assume a dynamic pressure of at least 0.4 kN/m^2 .

3. Rope line and length of rope spans

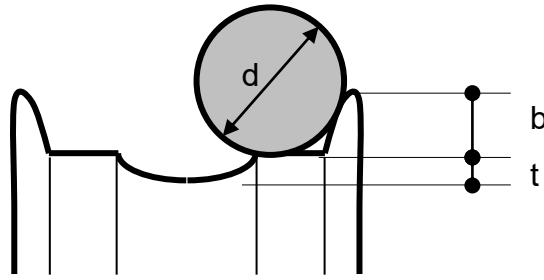
In addition to the conditions to be taken into consideration for ropeways in general (e.g. tower loads, local stress on the haulage rope), particular attention is to be paid to the effects of the double guidance of the rope on double monicable aerial ropeways on load transposition and geometry.

Due to the wind stability of the carriers additional proof is required for long rope spans. Additional requirements must therefore be met for the load case 'in operation' which are specified under items 3.1, 3.2 and 3.3. The magnitude of the wind load (dynamic pressure), on which the proof of the load case 'in operation' is based, shall be assumed in accordance with the provisions of item 2. A reduction of the wind load as indicated for the proof of the track gauge (see item 5) shall not be made.

3.1 Design measures on the rollers

With new roller liners, the quotient of projection (b) of the flange beyond the liner and groove depth (t) in the liner must be at least 2.0.

On support rollers the projection (b) of the flange beyond the liner must be at least $1/4$ of the rope diameter (d).



3.2 Minimum roller loads

The minimum roller load may not be less than 1.0 kN.

If the minimum roller load is not achieved, safe guidance of the rope must be ensured by means of suitable design measures.

When determining the minimum roller load, a change in the load of the rope on the rollers caused by lateral winds must not be considered while taking into account the torsion resistance of the track.

3.3 Lateral lead-on¹ angle

The safety against the rope leaving the liner groove must be determined for the first roller on the leading end of a tower. The safety against the rope leaving the liner groove is defined as the quotient of the lead-on angle at which the rope will leave the groove (permissible lateral lead-on angle, determined on the basis of the actual conditions and the design on the roller such as roller shape, rope diameter, etc.) and the calculated lateral lead-on angle.

For the load case 'in operation' under the effects of lateral wind, it must be at least 1.0 according to item 2.

If the quotient is less than 1, devices must be provided which will prevent the rope from leaving the liner groove or detect that the rope is leaving the liner groove and consequently cause a shut-down of the ropeway before the rope derails completely.

3.3.1 Calculatory determination of the lateral lead-on angle

The size of the lateral lead-on angle at empty rope and with a rope span loaded with single loads is to be calculated in accordance with the annex (item 10).

If the lateral lead-on angle is calculated for the empty rope, the dynamic pressure can be reduced in accordance with the provisions of item 5. If the lateral lead-on angle is calculated by means of the single loads located within the rope span, a reduction of the dynamic pressure is not permissible.

¹ Translator's note: O.I.T.A.F. News 1/2000 refers to the lateral lead-on angle as 'winding angle'.

3.3.2 Permissible lateral lead-on angle

Proof is required for the size of the permissible lateral lead-on angle.

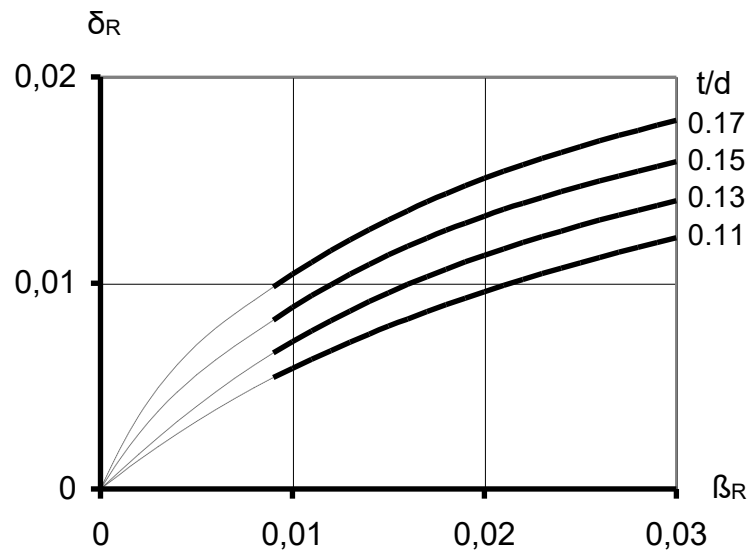
While taking into account the other, usually secondary, influences (see dissertation Piskoty) the below diagram can be used for support and compression roller batteries, provided the following requirements are met:

$$R/d \leq 0.7$$

$$\text{friction coefficient between rope and roller liner} \leq 0.30$$

$$\text{distance between rollers} \leq 14d$$

$$\text{number of rollers} \geq 4$$



(from G. Piskoty, dissertation July 1995)

t groove depth

d rope diameter

δ_R .. permissible lateral lead-on angle

β_R .. vertical deflection angle per roller

R ... groove radius

4. Lateral clearance

4.1 Lateral clearances in the rope span

The lateral clearances must be investigated for the load cases 'in operation' and 'out of operation' considering the influence of a laterally acting horizontal dynamic pressure. Account shall be taken of :

In operation:

- Transverse displacement of ropes
- Transverse displacement of carriers
- Transverse swaying of carriers

Out of operation:

Transverse displacement of ropes

When determining the lateral clearances, the dynamic pressure can be reduced in accordance with the provisions of item 5.

4.1.1 Horizontal² transverse displacement

For the determination of the transverse displacement of the ropes caused by the effects of wind, an evenly distributed dynamic pressure acting horizontally and over the entire length of the span shall be assumed for both the load case 'in operation' and 'out of operation'.

4.1.2 Horizontal transverse displacement caused by wind acting on the carriers

The transverse displacement of carriers due to wind action shall be calculated using single loads. For detailed explanations refer to the annex (item 10).

4.1.3 Transverse swaying of carriers

Transverse swaying in the rope span shall be assumed to be 0.35 rad. This principle can be abandoned if transverse swaying is determined taking into account the resistance of the track formed by the parallel running ropes and the influence of additional carriers in the rope span.

The influence of the other carriers in the rope span must be taken into consideration assuming a static balance (all carriers stationary in transverse sway position). If no explicit proof is furnished, the influence of several carriers in the rope span can also be defined by approximation by defining the transverse sway for one individual carrier and multiplying the result with 1.2.

For detailed explanations refer to the annex (item 10).

4.2 Lateral structural clearance at tower crossings

Due to the restricted transverse swaying of carriers on the towers no lateral deviations caused by wind action are to be considered. The definition of the structural clearance of a carrier on the tower is therefore by means of design

² Translator's note: Does 'horizontal' actually refer to a strictly horizontal displacement or is the word merely used to emphasise the 'transverse' movement (in which case the word 'horizontal' could probably be dropped)?

and geometrical provisions. The following must be taken into account when defining the structural clearance of the carrier:

- design-permitted transverse swaying or movement of a spring suspended carrier
- an inclination of the carrier in relation to the hanger, caused by failure of dampening elements in the suspension devices of the grip carriage on the carrier.

The clearance must be ensured even for longitudinal swaying of the carriers of 0.35 rad. An overlap of transverse and longitudinal swaying can be ignored.

The distance of carrier components to fixed components of the tower (tower shaft, working platforms, etc.) must at least be an additional 30 cm.

In addition, the carrier must be able to pass over the tower without touching any tower structures even if the rope derails into the rope catching device on one side.

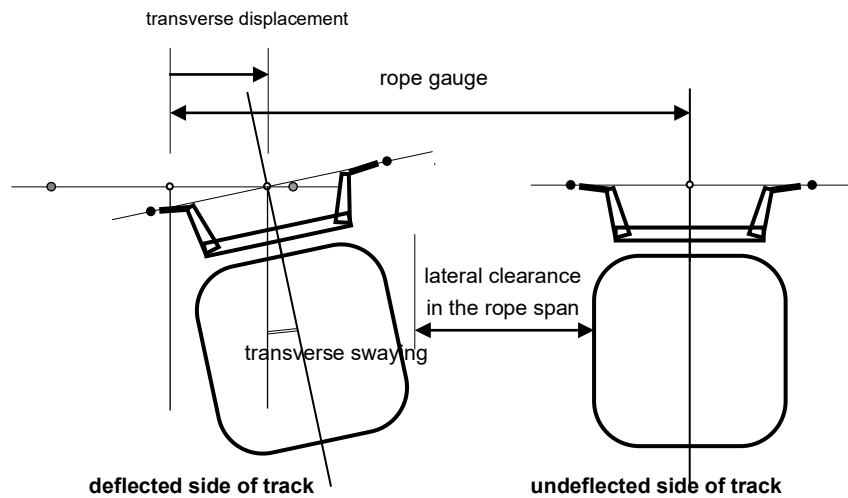
5. Track gauge

The load case 'in operation' shall be considered when determining the track gauge. The structural clearance shall be defined in accordance with item 4, whereas the magnitude of the dynamic pressure shall be assumed in accordance with the wind speed at which operation of the ropeway shall be possible.

For proof of a sufficient rope gauge the transverse swaying of the carrier shall be assumed to be 0.20 rad. This figure can be ignored if the transverse swaying is determined as described under item 4.1.3.

For detailed explanations refer to the annex (item 10).

In this case, the minimum transverse swaying to be assumed shall be 0.15 rad. With regard to the ropes, no lateral movement due to wind action is to be assumed on one side of the track ; on the other side of the track, a lateral deviation due to wind action is to be assumed.



To define the transverse movement of the ropes caused by wind action for inclined rope span lengths of more than 400 m, a dynamic pressure q_F acting on the entire rope span length can be assumed, which is to be calculated from the notional span length L_F as follows:

$$q_F = q (L_F/L)^2$$

The notional span length L_F is calculated from the inclined span length L (in meters) with the following equation:

$$L_F = 240 + 0.4 L$$

q dynamic pressure

L inclined rope span length (m)

6. Safety distance behind station conveyors:

If behind the grip closing line no measures are taken which would prevent a carrier where the grip has not closed correctly on the rope from leaving the station, a safety distance of at least 1.2 times the stopping distance must be provided. The maximum permissible mean rope inclination at the carrier position is 0.10 rad over the entire length of the safety distance.

No safety distance is required if

- the carriers are equipped with at least four grips, whereas at least two grips must be attached to each haulage rope, and

- the carriers are clamped to the rope by at least two independent mechanical devices, and
- the relative position of the ropes and the grips is mechanically forced in every possible fault scenario, and
- the sliding resistance of two grips on the rope is bigger than 1.5 times the pulling force along the rope of a fully loaded carrier while taking into account the operationally permissible influences on the grip force (change in rope diameter, wear in the grip mouth).

7. Tension to shear ratio

The tension to shear ratio as the quotient from the rope tension force and the normal force acting on the rope may not fall below the value of 15.0 for a single grip device and 11.0 for a double grip device. For a double grip device, the central distance between the individual grips must be at least 1.0 m, otherwise the grip devices shall be regarded as one single normal force.

8. Additional loads caused by restricted transverse sway

The track formed by the two ropes limits the free transverse swaying of carriers in the event of lateral winds. The force couple formed by the resistance of the track, must be taken into consideration when dimensioning the carriers (grips, grip carriage) and rope supports (rollers, roller batteries, tower support structures). The wind load determined for the load case 'in operation' shall be assumed as the lateral wind load.

Due to the restricted transverse swaying in lateral winds, the additional load

$$Z = \frac{W \cdot h}{e}$$

shall be considered when dimensioning carrier and rope support components.

W	laterally and horizontally acting wind force on a carrier (N)
h	distance of wind force to centre of rotation of the ropes (m)
e	distance between ropes (m)

In addition to the additional load Z, the influence of the carriers located in the adjacent rope spans must be considered when dimensioning the rope support components. Detailed explanations are contained in the annex (item 10).

9. Synchronism of ropes

Rope guidance of the ropes which are moving in the same direction shall be such that external loads acting on the ropes (e.g. friction, dynamic forces) will as far as possible act with the same magnitude and in the same direction.

Technical measures shall be applied to ensure or monitor synchronism of the ropes. If a deviation in the synchronism is detected, the ropeway must be shut down. The tolerance beyond which a deviation in the synchronism will trigger a response from the monitoring device, must be considered during dimensioning (inclination of carrier, consideration of an additional load introduced into the grips in direction of the rope).

10. Annex

Explanation re. item 3.3.1

The largest lateral lead-on angle on a tower is reached when a carrier is immediately in front of the tower.

The tangent component of the lateral lead-on angle according to the wind load on the carriers on a rope ($\tan \alpha_E$) can be calculated with the following equation:

$$\tan \alpha_E = \frac{W \cdot n}{2L \cdot S_m} \cdot \left(L - \frac{a}{2} \cdot (n-1) \right)$$

W	lateral wind load on each individual carrier (N)
L	inclined rope span length (m)
S _m	average rope tension force in the rope span under consideration (N)
a	distance between carriers (m)
n	number of carriers in the rope span

The tangent component of the lateral lead-on angle according to the wind load on the individual rope ($\tan \alpha_s$) can be calculated with the following equation:

$$\tan \alpha_s = \frac{w \cdot L}{2S_m}$$

w	evenly distributed horizontal wind load (N/m)
L	inclined rope span length (m)
S_m	average rope tension force in the rope span under consideration (N)

The lateral lead-on angle is determined by adding up the two tangent components.

Explanation re. item 4.1.2

The horizontal deflection f_x at the respective rope position³ can be calculated with the following equation:

$$f_x = \frac{W}{S_m} \cdot \left[\frac{x}{L} \cdot \left(n \cdot (L - b) - \frac{a \cdot n}{2} \cdot (n - 1) - \frac{a \cdot y}{2} \cdot (y + 1) \right) \right]$$

$$n = 1 + \text{int} \frac{x}{a} + \text{int} \frac{L - x}{a}$$

$$b = x - a \cdot \text{int} \frac{x}{a}$$

$$y = \text{int} \frac{x}{a}$$

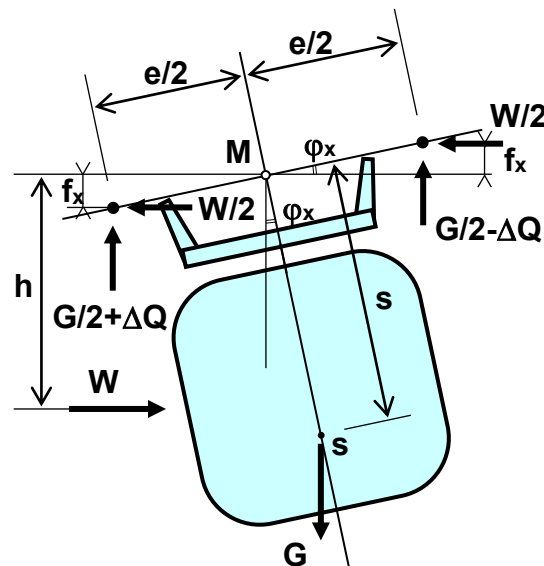
W	lateral wind load on each individual carrier (N)
S_m	average rope tension force in the rope span per rope (N)
x	inclined distance of the rope position under consideration from tower i (m)
L	inclined rope span length (m)
b	distance (measured on the rope) between first carrier in the rope span and tower i (m)
n	number of carriers in the rope span
a	distance between carriers (m)
y	number of carriers between tower i and rope position x

³ Translator's note: The term 'rope position' (Seilpunkt/Seilort) could perhaps be replaced by 'position of the grip on the rope', which might better define the meaning. It was not used in this translation because of the more general term 'Seilpunkt/Seilort' used in the German original.

Explanation re. item 4.1.3

Transverse swaying of the carriers is dependent on the installation-specific conditions in the rope span (rope tension force, length of rope span, number of carriers in the rope span, distance between carriers, distance between the ropes, carrier mass, etc.). Due to the moving resistance of the track formed by the two parallel running ropes, the extent of the inclination φ_x of a carrier at rope position x can be calculated with the following equation:

$$\sin \varphi_x = W \cdot h \cdot \left(\frac{2x \cdot (l - x)}{S_m \cdot l \cdot \cos \gamma \cdot e^2 + 2G \cdot s \cdot x \cdot (l - x)} \right)$$



$\sin \varphi_x$	sine component of transverse swaying
W	laterally and horizontally acting wind force on one carrier (N)
h	distance of wind force to centre of rotation of the ropes (m)
x	horizontal distance from rope position to tower (m)
l	horizontal rope span length (m)
S_m	average rope tension force in the rope span (N)
γ	angle of chord inclination of the rope span
e	distance between ropes (m)
G	weight of the empty carrier (N)
s	distance from centre of gravity of the empty carrier to the centre of rotation of the ropes

Explanation re. item 8

The consideration of several carriers in a rope span is by means of the moving resistance of the track.

$$\psi = \frac{1}{1 + \frac{2G \cdot s \cdot x \cdot (l - x)}{S_m \cdot l \cdot \cos \gamma \cdot e^2}}$$

G	weight of the empty carrier (N)
s	distance from centre of gravity of the empty carrier to the centre of rotation of the ropes (m)
x	horizontal distance of rope position to tower (m)
l	horizontal rope span length (m)
S _m	average rope tension force in the rope span (N)
γ	angle of chord inclination of the rope span
e	distance between ropes (m)

The vertical load ΔQ on the rope caused by the individual carriers distributed in the rope span is dependent on the carrier position and calculated with the following equation:

$$\Delta Q = \psi \cdot \frac{W \cdot h}{e}$$

W	laterally and horizontally acting wind force on one carrier (N)
h	distance of wind force to centre of rotation of the ropes (m)
e	distance between ropes (m)