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Structures for mine shafts —

Part 7: Rope guides

Structures de puits de mine —

Partie 7: Guides-câbles

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 82, *Mining*.

A list of all parts in the ISO 19426 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Many mining companies, and many of the engineering companies that provide designs for mines, operate globally so ISO 19426 was developed in response to a desire for a unified global approach to the safe and robust design of structures for mine shafts. The characteristics of ore bodies, such as their depth and shape, vary in different areas so different design approaches have been developed and proven with use over time in different countries. Bringing these approaches together in ISO 19426 will facilitate improved safety and operational reliability.

The majority of the material in ISO 19426 deals with the loads to be applied in the design of structures for mine shafts. Some principles for structural design are given, but for the most part it is assumed that local standards will be used for the structural design.

Structures for mine shafts —

Part 7:
Rope guides

1 Scope

This document specifies the design loads and the design procedures for the design of rope guides and rubbing ropes used for guiding conveyances and preventing collisions in vertical mine shafts for permanent operations. It covers personnel and material hoisting, as well as rock hoisting installations. There are no fundamental limitations placed on the size of conveyances, the hoisting speeds, shaft layout configurations, or the shaft depth.

This document can be applicable to shaft sinking operations when kibbles run on the stage ropes.

There are many reasons, based on technical, timing, and cost factors, why rope guides are selected or not for a particular application, following careful assessment at feasibility stage of any project where rope guides are considered. This document provides some comments regarding the advantages and disadvantages of using rope guides compared to rigid guides, and specific design aspects for consideration when using rope guides. However, it is primarily intended to provide the technical information required to ensure good engineering of shafts where rope guided hoisting is the chosen solution.

This document does not cover matters of operational safety.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 19426-1, *Structures for mine shafts — Part 1: Vocabulary*

ISO 19426-2, *Structures for mine shafts — Part 2: Headframe structures*

ISO 19426-5, *Structures for mine shafts — Part 5: Shaft system structures*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 19426-1 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org

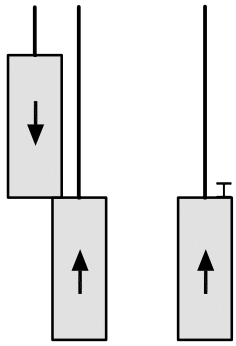
3.1
cheeseweight
stack of weights, usually steel castings, suspended from the bottom of a rope guide forming a dead weight tensioning system

3.2
direct collision
event in which a conveyance strikes another conveyance or some other surface that is essentially transverse to the direction of travel of the conveyance

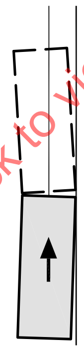
Note 1 to entry: See Figure 1 a).

3.3
oblique collision
event in which a conveyance strikes a shaft side wall or some other surface that is oriented essentially parallel with the direction of travel of the conveyance

Note 1 to entry: See Figure 1 b).



a) Direct collision



b) Oblique collision

Figure 1 — Schematic of possible collision types

3.4
design clearance
static clearance
nominal distance between different conveyances, or between conveyances and fixed objects, in the shaft, as shown on the design drawings

3.5
design location
intended location of elements of the rope guided hoisting installation, as shown on the design drawings

3.6
displacement multiplier
factor by which the predicted conveyance lateral displacement is multiplied to make statistical allowance for inaccuracies in simulation and aerodynamic coefficients and construction tolerances

3.7
dynamic clearance
minimum distance between different conveyances, or between conveyances and fixed objects, in the shaft during hoisting in the shaft, which is equal to the *design clearance* (3.4) less the maximum *dynamic displacement* (3.8)

3.8
dynamic displacement
lateral displacement of conveyances while travelling in the shaft

3.9
design dynamic displacement
lateral *dynamic displacement* (3.8) of conveyances while travelling in the shaft multiplied by the *displacement multiplier* (3.6), which makes provision for simulation uncertainties and construction inaccuracies

3.10
reduced dynamic clearance
minimum distance between different conveyances, or between conveyances and fixed objects, in the shaft during hoisting in the shaft, which is equal to the *design clearance* (3.4) less the *design dynamic displacement* (3.9)

3.11
entry point
position at which a conveyance enters fixed guides at the top and bottom ends of the hoisting cycle, and at any intermediate stations

3.12
guide block
guide bush
guide slipper
attachment of a conveyance to the rope guides

Note 1 to entry: The guide block is usually made in two halves to bolt around the rope guide, and it has a guide block liner forming the rubbing surface on the rope guide.

3.13
intermediate loading station
loading station between bank level or a tipping station at the top of the shaft and a loading station at the bottom of the shaft, or any loading station located more than 100 m below the top anchor point of the rope guides or more than 100 m above the bottom anchor point of the rope guides

3.15
rope guide shoe
mounting to secure the *guide block* (3.12) through which the rope guide passes to the conveyance

3.16
rubbing block
fixed guide slippers
contact point between a conveyance and the fixed guides at top and bottom of winding cycle, which can run within or outside the fixed guide

Note 1 to entry: Where the fixed guides are located close to the rope guides, the rubbing block can also serve the purpose of the rope guide shoe.

3.17
rubbing rope
rope located between conveyances running on rope guides, intended to deflect conveyances away from each other, thereby reducing the severity of a possible collision

3.18
vertical shaft cylinder
maximum circular cylinder, clear of any obstructions, that fits within the excavated mine shaft and constructed infrastructure

3.19
winder emergency braking
winder trip-out
braking of the winder under emergency conditions, such as loss of electrical power, detection of over-tension or under-tension on the hoist ropes, or accident to shaft signal

4 Symbols

a	Conveyance acceleration, m/s^2
A_C	Area of the relevant side of a conveyance, m^2
A_R	Cross sectional steel area of a single head rope, m^2
A_1, A_2	Area of specified portions of a shaft cross-section, m^2
b	Thickness of skip stiffeners, m
B_E	Distance between the conveyance centre of gravity and the geometrical centre of the set of rope guides, guiding that conveyance, m
B_X, B_Z	Plan dimensions of a conveyance, m
C_{BX}, C_{BZ}	Basic aerodynamic lateral force coefficient in appropriate direction, taken as 0,018
C_L	Aerodynamic force coefficient
C_{LX}, C_{LZ}	Aerodynamic lateral force coefficient in appropriate direction
C_{LP}	Conveyance passing buffeting force coefficient
C_Q	Torque factor applied to head ropes
C_T	Coefficient of thermal expansion of the rope guide, °C^{-1}
d_S	Shaft diameter, m
d_R	Rope diameter, m (note that this is usually given in mm in hoist rope catalogues)
D_A	Lateral conveyance displacement due to steady state aerodynamic force, m
D_B	Lateral conveyance displacement due to buffeting forces, m
D_C	Lateral conveyance displacement due to Coriolis force, m
D_{EB}	Lateral conveyance displacement at the bottom of the conveyance due to conveyance eccentricity with respect to the head rope attachment point, m
D_{EC}	Lateral conveyance displacement at the centre of gravity of the conveyance due to conveyance eccentricity with respect to the head rope attachment point, m
D_{ET}	Lateral conveyance displacement at the top of the conveyance due to conveyance eccentricity with respect to the head rope attachment point, m
D_G	General lateral displacement of the centre of gravity of a conveyance in a shaft, m

D'_G	General lateral displacement of the geometric centre of the set of rope guides guiding one conveyance in a shaft, m
D_I	Amplitude of initial rope guide motion prior to hoisting of a conveyance, m
D_M	Nominal design movement allowance between a conveyance and other objects in a shaft, m
D_N	Nominal design clearance between a conveyance and other objects in a shaft, m
D_O	Minimum dynamic clearance, m
D_P	Total combined lateral displacement of a conveyance, m
D_R	Lateral conveyance displacement due to initial rope guide motion, m
D_X	Recommended tolerance allowance, m
D_Y	Lateral displacement due to yaw rotation of the conveyance in the shaft, m
E_S	Elastic modulus of the head rope or the rope guide, Pa
F_A	Steady state aerodynamic force acting on a conveyance, N
F_C	Coriolis force acting on a conveyance, N
F_P	Peak force during buffeting of a conveyance, N
F_X	General lateral force applied to a conveyance, N
F_Y	General moment applied about the centre of gravity of a conveyance, Nm
g	Acceleration due to gravity, m/s^2
h_1	Body height of a conveyance, m
h_2	Ventilation opening height on a cage, m
H	Overall height of a conveyance, m
H_C	Height from the conveyance centre of gravity to the top of the conveyance, m
I_C	Mass moment of inertia of a conveyance about the vertical centroidal axis, kgm^2
K_H	Lateral stiffness at conveyance elevation, of a single head rope, N/m
K_L	Lateral stiffness at conveyance elevation, of the set of ropes attached to one conveyance, N/m (this includes the rope guides, the head ropes, and where applicable the tail ropes)
K_R	Lateral stiffness at conveyance elevation, of a single rope guide, N/m
K_T	Lateral stiffness at conveyance elevation, of a single tail rope, N/m
K_θ	Rotational stiffness at conveyance elevation, of the set of ropes attached to one conveyance, Nm/rad
L	Overall length of the rope guides, m
L_H	Head rope length between the conveyance and the sheave, m
L_T	Tail rope length between the conveyance and the bottom sheave, m

L_1 Rope guide length between the top of a conveyance and the top anchor point, m

L_2 Rope guide length between the bottom of a conveyance and the bottom anchor point, m

m_C Conveyance mass, including mass of rope attachments and payload, kg

m_H Mass per unit length of a single head rope, kg/m

m_P Payload mass, kg

m_R Mass per unit length of a single rope guide, kg/m

m_T Mass per unit length of a single tail rope, kg/m

M_O Overturning moment due to eccentric loading, Nm

n An integer greater than 1

n_H Number of head ropes for a single conveyance

n_R Number of rope guides guiding a single conveyance

n_T Number of tail ropes for a single conveyance

Q Rope torque applied to a conveyance, Nm

Q_i Rope torque from rope i applied to a conveyance, Nm

r_t Ratio of acceleration time to natural period

R Ratio of first force peak to second force peak used for buffeting as two conveyances pass each other, taken as 1,5

R_B Blockage ratio for two conveyances in a shaft

R_G Gap ratio between conveyances in a shaft

R_D, R_W Distance and width ratios for air inflow and outflow buffeting

R_S Shape factor for air inflow and outflow buffeting

S_A Conveyance size factor

S_{PX}, S_{PZ} Sidewall proximity factors

S_{SX}, S_{SZ} Conveyance shape factors in X- and Z-directions

t Time, s

t_P Time taken for two conveyances to pass each other in a shaft, s

T Tension in a rope, N

T_{BOT} Rope guide tension at the bottom anchor point, N

T_H Head rope tension at a conveyance, N

T'_H Increased head rope tension at a conveyance, N

T_L Rope guide tension at conveyance elevation in the shaft, N

T_M Rope guide tension at mid-depth of the shaft, N

T_T Tail rope tension at a conveyance, N

T_{TOP} Rope guide tension at the top anchor point, N

U_i Horizontal dimensions of the air inflow or outflow duct, m

v_D Horizontal component of airflow velocity in a station or side duct, m/s

v_H Hoisting speed of a conveyance, m/s

v_R Velocity of a conveyance relative to ventilation airflow speed, m/s

W Total eccentric payload applied to a conveyance, N

w Width of the skip stiffener, m

x_C, z_C Horizontal distances between the conveyance centre of gravity and the geometric centre of the shaft, m

x_{HC}, z_{HC} Horizontal distance between the conveyance centre of gravity and the centre of hoist rope attachment, m

x_{Hi}, z_{Hi} Horizontal distance between the conveyance centre of gravity and the centre of hoist rope number *i*, m

x_P, z_P Horizontal distance between the payload centre of gravity and the centre of hoist rope attachment, m

x_{Ri}, z_{Ri} Horizontal distance between the conveyance centre of gravity and the centre of rope guide number *i*, m

x_{TC}, z_{TC} Horizontal distance between the conveyance centre of gravity and the centre of tail rope attachment, m

x_{Ti}, z_{Ti} Horizontal distance between the conveyance centre of gravity and the centre of tail rope number *i*, m

Y_i Vertical dimensions of the air inflow or outflow duct, m

α A dynamic magnification factor

α_T Winder emergency braking magnification factor for torque and eccentricity

β Tilt angle of a conveyance subjected to an eccentric payload, rad

β_1, β_2 Angles of the top or bottom of a skip, rad

Δ_C Change in ambient temperature, °C

Δ_T Change in rope guide tension, N

θ General yaw rotation of the conveyance in the shaft, rad

ρ Air density, kg/m^3

γ_R Displacement multiplier

ϕ Latitude of the mine shaft site, positive north and south of the equator, deg

ϕ_A Angle of the air inflow or outflow duct, rad

ω_E Radial rotation velocity of the earth, 7,27x10^{-5} rad/s

ω_R Fundamental radial frequency of oscillation of the rope guides, rad/s

ω_{RC} Fundamental radial frequency of oscillation of the rope guides with the conveyance, rad/s

ω_{RCY} Fundamental radial frequency of yaw rotation of the rope guides with the conveyance, rad/s

ω_{VT} Fundamental natural frequency of vertical motion of the conveyance suspended from the head ropes, rad/s

5 Materials

The materials used for rope guides and rubbing ropes shall be materials having guaranteed mechanical properties. It is most common to use high strength steel wire ropes complying with EN 12385-6 and EN 12385-7.

6 Disturbing actions

6.1 Coriolis force

The Coriolis force always acts in a westerly direction for an ascending conveyance, and in an easterly direction for a descending conveyance. The Coriolis force acts on all the moving masses, that is the mass of the conveyance and the head and tail ropes.

The Coriolis force results from the rotation of the earth and masses moving in a vertical direction. The Coriolis force F_C is defined as:

$$F_c = 2mv_h\omega_E\cos\phi \tag{1}$$

where m can be taken as:

$$m = m_c + n_H m_H \frac{L_H}{3} + n_T m_T \frac{L_T}{3} \tag{2}$$

where

L_H is the head rope length between the conveyance and the sheave, m;

L_T is the tail rope length below the conveyance, m;

m_C is the conveyance mass, including mass of rope attachments and payload, kg;

m_H is the hoist rope unit mass, kg/m;

m_T is the tail rope unit mass, kg/m;

n_H is the number of hoist ropes;

n_T is the number of tail ropes;

v_H is the hoisting speed of conveyance, m/s;

ω_E is the radial rotation velocity of the earth, 7,27x10^{-5} rad/s;

ϕ is the latitude of the mine shaft site, positive whether north or south of the equator.

6.2 Aerodynamic loads

6.2.1 Steady state

The steady state aerodynamic force acting on a conveyance F_A is defined as:

$$F_A = \frac{1}{2} C_L \rho v_R^2 A_C \quad (3)$$

where

C_L is the aerodynamic lateral coefficient, but not less than 0,02;

ρ is the air density, which may be approximated using the values in Table 1, kg/m^3;

v_R is the conveyance velocity relative to the ventilation airflow, m/s;

A_C is the area of the relevant side of the conveyance, m^2.

Values of C_L should be obtained from an appropriate level of accuracy of computational fluid dynamics analysis. However, for preliminary design only, the values may be obtained from Annex C. When C_L exceeds 0,02 it shall be taken to act in a specific direction arising from the aerodynamic flow around the conveyance. When C_L is taken as 0,02 it shall be taken to act in either direction.

Note that different values of F_A act on a conveyance in each of the two horizontal directions.

6.2.2 Buffeting

6.2.2.1 Buffeting force when two conveyances pass each other

The amplitude and time variation of the buffeting force when two conveyances pass each other in the shaft should be obtained from computational fluid dynamics analysis.

The amplitude of the buffeting force F_P is defined as:

$$F_P = \frac{1}{2} C_{LP} \rho v_H^2 A_C \quad (4)$$

where

C_{LP} is the buffeting force coefficient (see Annex C);

ρ is the air density, which may be approximated using the values in Table 1, kg/m^3;

v_H is the relative passing speed, m/s;

A_C is the area of the relevant side of the conveyance, m^2.

Values of C_{LP} should be obtained from an appropriate level of accuracy of computational fluid dynamics analysis. However, for preliminary design only, the values may be obtained from Annex C.

The time variation of this buffeting force should be obtained from computational fluid dynamics analysis. However, for preliminary design only, the time variation may be obtained from Annex C.

6.2.2.2 Buffeting in the wake of a leading conveyance

The amplitude and time variation of the buffeting force on a conveyance following closely behind another conveyance, and travelling in the same direction in the shaft, should be obtained from computational fluid dynamics analysis.

When winders are controlled in such a manner as to ensure that conveyances cannot travel closer than five conveyance lengths behind another conveyance, this action can be neglected.

6.2.2.3 Buffeting force when conveyance passes inflow or outflow of air

The amplitude and time variation of the buffeting force induced when a conveyance passes an area of air inflow or air outflow in the shaft should be obtained from an appropriate level of accuracy of computational fluid dynamics analysis.

The amplitude of the buffeting force F_P is defined as:

$$F_P = \frac{1}{2} C_{LP} \rho v_D^2 A_C \quad (5)$$

where

C_{LP} is the buffeting force coefficient (see Annex C);

ρ is the air density, which may be approximated using the values in Table 1, kg/m^3;

v_D is the horizontal component of airflow velocity in the station or side duct, m/s;

A_C is the area of the relevant side of the conveyance, m^2.

The time variation of this buffeting force may be taken as described in Annex C.

6.2.3 Air density

The air density may be assumed to be constant throughout the depth of the shaft. The air density should be taken as the average of the air density at the top of the shaft and the air density at the bottom of the shaft, taking account of the ventilation pressure, altitude above sea level, the ambient air temperature and the humidity. The air density may be obtained from Table 1.

Table 1 — Values of dry air density ρ

Altitude above sea level m	Air density, ρ kg/m^3		
	0 °C	20 °C	40 °C
-1 000	1,44	1,34	1,26
0	1,30	1,21	1,13
1 000	1,16	1,07	1,01
2 000	1,01	0,94	0,88
When air is saturated, such as in an upcast shaft, the density should be increased by 25 %.			

6.3 Rope torque

6.3.1 Head rope torque

The rope torque applied to a conveyance, Q, by any one head rope is defined as:

$$Q = C_Q d_R T_H \quad (6)$$

where

C_Q is the rope torque factor;

d_R is the rope diameter, m;

T_H is the head rope tension at the conveyance, N.

6.3.2 Tail rope torque

The rope torque applied to a conveyance, Q, by any one tail rope shall be determined on the basis of the method of attachment of the tail rope to the conveyance. Where steel wire ropes are used and the attachment of the tail rope to the conveyance is fixed, the torque shall be taken as:

$$Q = C_Q d_R T_T \tag{7}$$

where T_T is the tail rope tension at the conveyance, N.

In other cases, the torque may be neglected.

6.3.3 Torque applied by multiple ropes

The torque applied to a conveyance by multiple head or tail ropes shall be determined on a rational basis, taking account of the handing of the ropes, the variability of the rope tension, and the variability of the rope torque factor. The values given in Table 2, based on the method recommended in Annex D, may be used.

Table 2 — Recommended torque values

Number of head ropes	Recommended torque
1	$Q=C_Q d_R T$
2	$Q=\pm 0{,}3 C_Q d_R T$
3	$Q=1{,}3 C_Q d_R T$
2n	$Q=\pm 0{,}5 C_Q d_R T$
2n+1	$Q=1{,}5 C_Q d_R T$
n is an integer greater than or equal to 2.	

6.4 Eccentric conveyance loading

The overturning moment due to eccentric loading of the conveyance payload shall be taken into account. The overturning moment due to payload eccentricity M_O is defined as:

$$M_O = m_P x_P \tag{8}$$

where

m_P is the payload mass, kg;

x_P is the horizontal distance between payload centre of gravity and centre of hoist rope attachment, m.

If the payload is persons, or rock in a skip, the eccentric loading may be taken as zero.

If the payload is centred in the conveyance by some means, the eccentric loading may be taken as zero.

6.5 Winder emergency braking

The rope torque and the eccentric conveyance loading actions shall be increased during winder emergency braking by the dynamic magnification factor for torque and eccentric conveyance loading, α_T:

$$\alpha_T = 1 \pm \frac{2a}{g} \tag{9}$$

where

a is the braking deceleration, m/s^2;

g is gravity acceleration, m/s^2.

The increased head rope tension T'_{H} is defined as:

$$T'_{\mathrm{H}} = \alpha_T T_{\mathrm{H}} \tag{10}$$

where

T_{H} is the head rope tension, N;

α_T is the dynamic magnification factor for torque and eccentric conveyance loading.

Whether the rope torque and the eccentric conveyance loading actions under winder emergency braking conditions need to be combined with other actions shall be assessed on a rational basis. Factors to consider include:

— the number of winders in the shaft;

— how the winders are interlocked;

— direction of conveyance travel and air flow.

6.6 Thermal actions on headframe

Consideration should be given to the possibility of lateral movement of the rope guide anchorages due to deformation of the headframe due to thermal effects.

6.7 Wind load on conveyances

Where the headframe has open sides, a conveyance in the headgear can be subjected to wind loads. Under these conditions, wind loading shall be applied, but need not be combined with any other actions.

7 Restoring forces

7.1 Rope guide tension

The information contained in Annex E can be used for preliminary guidance.

The tension in rope guides should be continuously monitored by means of load cells. Where the tension is not monitored, the design tension should be reduced by 15 %.

7.2 Rope guide stiffness

7.2.1 Stiffness of rope guides

The lateral stiffness at the conveyance elevation K_R of a single rope guide shall be determined on a rational basis.

The lateral stiffness at the conveyance elevation K_R of a single rope guide may be taken as:

$$K_R = \frac{T_L}{L_1} + \frac{T_L}{L_2} = \frac{T_L L}{L_1 L_2} \tag{11}$$

where

T_L is the tension at the conveyance elevation on a single rope guide, N;

L_1 is the rope guide length between the top of the conveyance and the top anchor point, m;

L_2 is the rope guide length between the bottom of the conveyance and the bottom anchor point, m;

L is the overall length of the rope guides, m.

These variables are illustrated in Annex E.

7.2.2 Stiffness of head and tail ropes

The lateral stiffness at the conveyance elevation K_H of a single head rope or K_T of a single tail rope guide shall be determined on a rational basis.

The lateral stiffnesses of the individual head and tail ropes, K_H and K_T respectively, may be taken as:

$$K_H = \frac{T_H}{L_H} \tag{12}$$

$$K_T = \frac{T_T}{L_T} \tag{13}$$

where

T_H is the tension at the conveyance of a single head rope, N;

T_T is the tension at the conveyance of a single tail rope, N;

L_H is the head rope length between the top of the conveyance and the sheave, m;

L_T is the tail length between the bottom of the conveyance and the bottom sheave, m.

Where the tail ropes hang freely at the bottom of the shaft, the tail rope stiffness may be taken as zero.

The lateral stiffness at the conveyance elevation K_L of the set of ropes attached to a conveyance (i.e. the rope guides guiding the conveyance, the head ropes and the tail ropes where appropriate) can be taken as the sum of the individual rope stiffnesses:

$$K_L = \sum_1^{n_R} K_R + \sum_1^{n_H} K_H + \sum_1^{n_T} K_T \tag{14}$$

where

n_H is the number of head ropes;

n_R is the number of rope guides;

n_T is the number of tail ropes.

The rotational stiffness at the conveyance elevation K_θ of the set of ropes attached to a conveyance and with the layout shown in Figure 2 can be taken as the sum of the individual rope stiffnesses multiplied by the square of their distances from the conveyance centre:

$$K_\theta = \sum_{1}^{n_R} K_{Ri}\left(x_{Ri}^2 + z_{Ri}^2\right) + \sum_{1}^{n_H} K_{Hi}\left(x_{Hi}^2 + z_{Hi}^2\right) + \sum_{1}^{n_T} K_{Ti}\left(x_{Ti}^2 + z_{Ti}^2\right) \quad (15)$$

where

x_{Ci} are the X dimensions from conveyance centre of gravity to head ropes, m;

z_{Hi} are the Z dimensions from conveyance centre of gravity to head ropes, m;

x_{Ri} are the X dimensions from conveyance centre of gravity to rope guides, m;

z_{Ri} are the Z dimensions from conveyance centre of gravity to rope guides, m;

x_{Ti} are the X dimensions from conveyance centre of gravity to tail ropes, m;

z_{Ti} are the Z dimensions from conveyance centre of gravity to tail ropes, m.

NOTE In many cases the contribution to rotational stiffness of the head and tail ropes can be ignored because of their geometrical location.

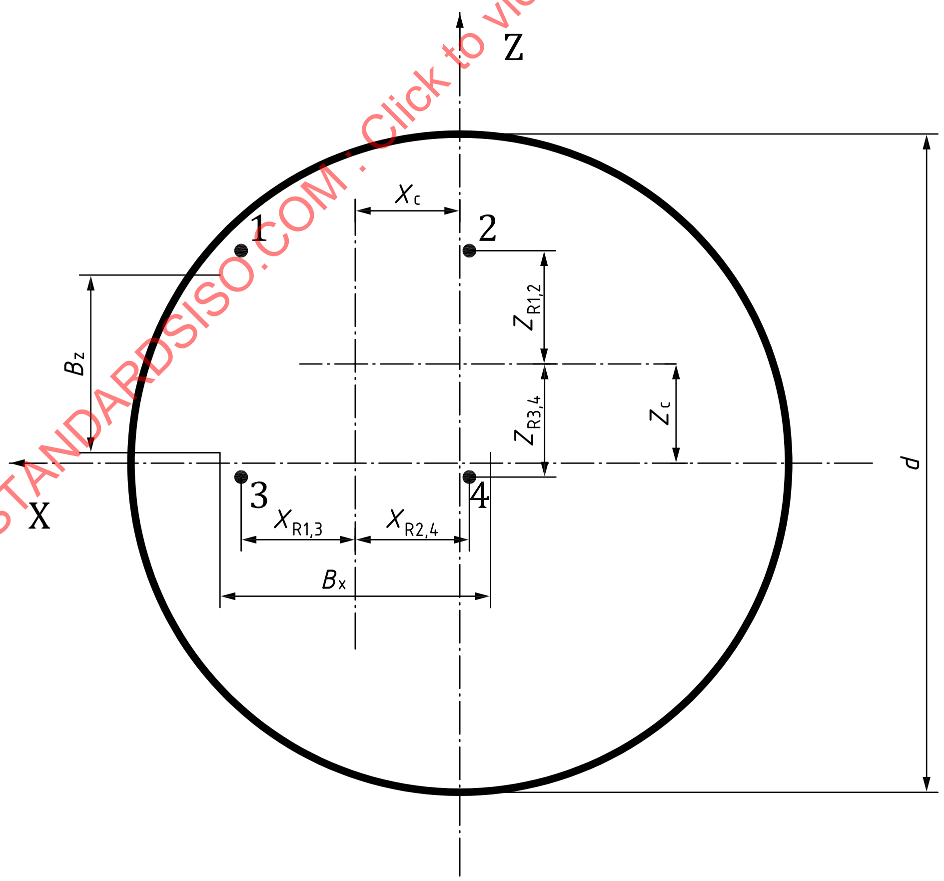


Figure 2 — Typical shaft cross section geometry

8 Conveyance trajectory

8.1 Simulation of conveyance behaviour

The conveyance trajectory during hoisting in the shaft is a dynamic response to the dynamic actions applied during operation.

The conveyance trajectory shall be obtained by simulation of this dynamic behaviour. Provided the shaft and conveyance layout fall within the scope described in Annex B, the formulae provided in Annex F can be used to provide maximum values of conveyance operating displacements for preliminary design only.

8.2 Combination of actions

The various actions acting on conveyances shall be combined in a rational manner, giving due consideration to the duration, likelihood of simultaneous occurrence and location of the actions and conveyance operating behaviour. The rational combinations of actions to be used shall be based on the risk assessment and shall be approved by the owner of the mine prior to final design.

The combinations recommended in Annex A should be used.

9 Design procedure

9.1 Function of rope guides

The primary function of rope guides is to provide adequate lateral and rotational restraint for the conveyances as they travel through the shaft, in order to keep the conveyances within their hoisting compartments and thus to prevent collisions.

9.2 Risk assessment

A risk assessment shall be performed for all rope guide installations. The outcome of the risk assessment shall be retained as part of the design documentation for the life of the shaft.

The risk assessment shall include, but shall not be limited to, consideration of all disturbing actions noted in Clause 6.

9.3 General design procedure

To achieve the function of rope guides, a suitable combination of the following mine shaft parameters shall be selected:

a) shaft layout and clearances;

b) rope guide construction, diameter, and tensile grade;

c) number and plan configuration of rope guides;

d) rope guide tension and tensioning method.

The design procedure shall then include:

— calculation of disturbing actions;

— use of these actions to calculate the conveyance trajectory as it is hoisted in the shaft;

— comparison of the conveyance trajectory with shaft clearances, to confirm that safe hoisting is assured.

9.4 Simple design procedure

9.4.1 Limits on parameters

The simple design procedure described in this clause may be used, provided all of the following criteria are met:

a) the shaft depth does not exceed 1 000 m;

b) the shaft does not contain more than two conveyances, operating on one winder;

c) the winding speed does not exceed 15 m/s;

d) the sum of the conveyance self-mass and payload does not exceed 25 000 kg;

e) there are no intermediate loading stations;

f) rubbing ropes are not used;

g) four rope guides are used for each conveyance;

h) the ventilation air flow velocity shall be not more than 10 m/s.

9.4.2 Design requirements

The simple design procedure shall provide a shaft where:

a) the minimum design clearance between the conveyance and the vertical shaft cylinder shall be not less than 0,400 m;

b) the minimum design clearance between the two conveyances shall be not less than 0,600 m;

c) the tension in each of the rope guides shall be not less than the greater of 10 000 N per 100 m depth of the shaft, or 30 000 N.

9.5 Comprehensive design procedure

The comprehensive design procedure shall include the following:

a) all relevant disturbing actions shall be evaluated;

b) the trajectory of each conveyance operating in the shaft shall be calculated;

c) the dynamic clearance between each conveyance and the vertical shaft cylinder shall be calculated;

d) the dynamic clearance between all conveyances shall be calculated at any location in the shaft where they may pass each other;

e) the minimum dynamic clearances throughout the shaft shall be calculated for each conveyance operating in the shaft;

f) the dynamic clearances shall exceed the minimum design clearances (see 10.1);

g) the reduced dynamic clearances shall exceed the minimum reduced dynamic clearances (see 10.3);

h) where the outcome required in f) and g) above is not achieved, the design parameters shall be adjusted, and the above design procedure shall be repeated.

10 Minimum clearances

10.1 Design clearances

The design clearances shall not be less than those given in Table 3.

Table 3 — Minimum design clearances

Clearance to vertical shaft cylinder	Clearance to other conveyance	Clearance when conveyance is entering or in fixed guides
0,300 m	0,500 m with no rubbing ropes 0,350 m with rubbing ropes	0,050 m

10.2 Dynamic displacement envelope

The dynamic displacements of any conveyance shall be taken as the maximum displacements within a displacement envelope determined as follows.

a) When calculating the clearance to a fixed object in the shaft, the displacement envelope shall include displacements of the conveyance from 5 m above the object to 5 m below the object, whilst the conveyance is either ascending or descending.

b) When calculating the clearance to the shaft wall, the displacement envelope shall include displacements of the conveyance throughout the entire hoisting depth of the shaft, whilst the conveyance is either ascending or descending.

c) When calculating the clearance to the other conveyance on the same winder, the displacement envelope shall include displacements of the conveyance from 10 m above the design passing elevation to 10 m below the design passing elevation, whilst the conveyance is either ascending or descending and the other conveyance is descending or ascending, respectively.

d) When calculating the clearance to another conveyance on a different winder, the displacement envelope shall include displacements of the conveyance in any portion of the shaft where the conveyances may pass each other, giving due cognizance to the winder control systems. Where the winder controls do not constrain when any winder starts, it shall be assumed that the conveyances can pass at any location throughout the depth of the shaft, so the displacement envelope shall include displacements of the conveyance throughout the entire hoisting depth of the shaft, whilst the conveyance is either ascending or descending.

10.3 Reduced dynamic clearances

The dynamic displacements shall be multiplied by a displacement multiplier to obtain the design dynamic displacements. The displacement multiplier shall be determined from the risk assessment but shall not be less than 1,5 for oblique collisions, nor less than 2,0 for direct collisions. Recommended values are presented in Annex A.

The reduced dynamic clearances shall be determined by subtracting the relevant design dynamic displacements from the design clearances.

The minimum acceptable values of reduced dynamic clearances shall be determined from the risk assessment but shall not be less than those given in Table 4.

Table 4 — Minimum reduced dynamic clearances

Clearance to vertical shaft cylinder	Clearance to other conveyance	Clearance when conveyance is entering or in fixed guides
0,150 m	0,250 m with no rubbing ropes. 0,150 m with rubbing ropes.	0,020 m

10.4 Use of rubbing ropes

Where rubbing ropes are used between any two conveyances in a shaft, a collision between those two conveyances may be treated as an oblique collision.

11 Construction and installation tolerances

11.1 Shaft vertical cylinder diameter

The shaft vertical cylinder shall have a diameter not less than that specified on the design drawings.

11.2 Tolerance of associated structures

All anchoring points for rope guides and rubbing ropes shall not deviate by more than ± 0,020 m from the position shown on design drawings.

All fixed structures associated with the hoisting installation, including fixed guides, platforms and screens, shall not deviate by more than ± 0,010 m from the position shown on the design drawings.

11.3 Tolerance on rope guide tension

The tension on installed rope guides shall not be less than the value shown on the drawings.

11.4 Commissioning

11.4.1 Commissioning procedure

A written commissioning procedure shall be prepared. The commissioning procedure shall be approved by the owner of the mine, prior to final commissioning of the shaft.

11.4.2 Components of the commissioning procedure

The hoisting system performance (primarily the conveyance trajectory and clearances in the shaft) shall be confirmed by means of the following.

Tensioning of rope guides

Load cells should be provided to demonstrate the correct rope guide tension.

Survey of rope guide and guide block positions

The actual, as built, positions of the rope guides at the top and bottom of the shaft, and the actual positions of the guide blocks on the conveyances, shall be accurately surveyed.

Survey of the shaft barrel

The shaft shall be surveyed during commissioning of the shaft, to confirm that the intended vertical shaft cylinder has been achieved. The tolerances for shaft alignment are set by the designer.

Measurement of static conveyance position

The static position of each conveyance shall be measured at bank level, mid-shaft level, and shaft bottom, with the shaft airflow velocity as close to zero as possible. These locations shall be within the tolerances specified in the design.

Trial runs of the conveyance through the shaft

Trial runs of all conveyances shall be made. It is recommended that trial runs start at low hoisting speed, not exceeding 2 m/s, and then at hoisting speeds incrementally increased up to full hoisting speed.

During trial runs, and where the reduced dynamic clearances are less than 0,300 m to shaft side walls or less than 0,500 m to other conveyances, the actual clearances shall be measured by suitable means. Where measurements are obtained, measured dynamic clearances greater than 75 % of those required by Clause 10 may be accepted.

12 Other design considerations

12.1 General

The practical aspects listed in this clause shall be considered in the design of rope guide hoisting installations.

12.2 Loading and unloading of conveyances

Conveyances supported on rope guides cannot be safely loaded and unloaded because the rope guides are too flexible to provide adequate restraint for the conveyances. Some means of ensuring good restraint to conveyances at loading and unloading stations shall thus be provided.

Common means of ensuring good restraint are the use of fixed guides or hydraulically activated retractable platforms at stations.

12.3 Accessing intermediate levels

Where access is required to any intermediate stations, conveyances shall be held in position by some means, as described in 12.2.

Where fixed guides are the chosen means of securing the conveyance, the conveyance shall pass the station at very low speed.

12.4 Number of rope guides

Wherever possible, four rope guides should be used. However, for small low speed installations, two rope guides may be used. Where only two rope guides are used, this shall be justified in the risk assessment because the loss of tension in one rope can lead to a collision.

12.5 Rope guide positions

Rope guides provide the same restraint against lateral motion of the conveyance irrespective of how they are placed relative to the conveyance. However, the rotational restraint offered against twisting of the conveyance can be maximised by placing the rope guides as far apart as possible. It is thus recommended that rope guides be placed as far apart as possible within the geometrical constraints of the shaft.

12.6 Rope guide construction

Either a half-locked coil (HLC) or a full locked coil (FLC) are the recommended constructions for rope guides because the smooth outer surface and larger diameter of the outer wires provides greater wear tolerance than other constructions and any broken wires are held within the rope.

12.7 Rope guide tension and factor of safety

In order to provide the highest possible restraint to conveyances for any selected rope guide size, it is recommended that the tension be maximized within the constraint of the specified factor of safety.

12.8 Rope guide attachments

All rope guide attachments should provide spherical seatings to facilitate rotation of the rope.

The attachment of rope guides and rubbing ropes to anchorages is usually by means of wedge type glands.

The attachment of rope guides and rubbing ropes to cheeseweights is typically by means of one of:

— wedge type glands;

— wedge type long loop capels;

— sockets.

All rope guide attachments shall be designed in such a way as to minimize any damage to the rope. In particular, clamp surfaces in contact with rope guides shall be radiused.

12.9 Shafts with more than one winder

Where rope guides are used in any shaft having more than one winder, the winders should be interlocked to ensure that both winders cannot start simultaneously so that the conveyances cannot all pass at mid-shaft, and one conveyance cannot travel in the wake of another conveyance.

12.10 Design life

The design life of rope guides is usually determined by corrosion and/or wear of the ropes.

Provision should be made for lifting or lowering of rope guides at regular intervals to move the entry points into attachments and thus avoid continuous corrosion, fretting and fatigue of the ropes at these points.

Provision should be made for turning of rope guides at regular intervals to avoid continuous wear on one side of the ropes.

12.11 Rope guide tensioning

12.11.1 Gravity tensioning devices

Gravity tensioning devices can simply be a series of slabs (usually circular) of material (usually cast iron or steel) suspended from the lower end of the rope guide. The rope guide passes through a duct or sleeve fixed to a grid of steelwork to ensure that it is properly located in its correct position in the horizontal plane, and it is then attached to a rod passing through the slab weights.

The headframe anchor structure shall be designed in accordance with ISO 19426-2 to resist the rope guide tension.

12.11.2 Hydraulic tensioning devices

A hydraulic tensioning device may be used (usually in the headgear) to tension the rope guides, which are then clamped to the anchor structure.

The headframe anchor structure shall be designed in accordance with ISO 19426-2 to resist the rope guide tension.

The shaft bottom anchor structure shall be designed in accordance with ISO 19426-5 to resist the rope guide tension.

13 Assessment of existing installations

13.1 General

Assessment of existing rope guided hoisting installations can be required for various purposes, such as:

— confirming safe performance;

— informing decisions regarding upgrades;

— investigating accidents or near hits.

Assessment of an existing installation should include both of the following elements.

a) Design calculations and simulation as described in this document.

b) Measurement of the trajectory of the conveyances, unless previous measurements are available. When assessing measurements, it should be borne in mind that each measurement represents the outcome of just one specific set of conditions, and not the general performance of the installation.

13.2 Application of measurements

Measurements may be used to confirm the performance of a rope guided hoisting installation.

Measurements may be used to permit a reduction in the dynamic clearances specified in this document, provided that the following is met.

a) The risk assessment shows this to be acceptable.

b) The sets of conditions under which measurements are to be made shall be specifically listed following risk assessment, and a minimum of three measurement runs shall be recorded for each set of conditions. Measurements shall be made under at least the following sets of conditions, where relevant:

  — full cage ascending and descending;

  — empty cage ascending and descending;

  — counterweight ascending and descending;

  — full skip ascending;

  — empty skip ascending and descending.

c) Dynamic clearances shall not be reduced on the basis of measurements to less than 75 % of those required by Clause 10 of this document.

13.3 Upgrades or modifications

Any upgrade or modification shall be treated as a new design and dealt with in compliance with this document.

14 Inspection and maintenance

14.1 Deterioration mechanisms

14.1.1 General

Rope guides and rubbing ropes can be subjected to the deterioration mechanisms listed in 14.1.2 to 14.1.5. All of these deterioration mechanisms shall be investigated during inspections and shall be addressed by maintenance.

14.1.2 Wear

Wear of rope guides can occur due to the rubbing blocks on the conveyances running along the rope guides. Due to the directional nature of loads applied to the conveyances, the wear often occurs only on one side of the rope guide.

14.1.3 Corrosion

Rope guides and rubbing ropes can be subjected to corrosion.

14.1.4 Mechanical damage

Rope guides and rubbing ropes can be subjected to mechanical damage caused by objects falling down the mine shaft, or due to accidents.

14.1.5 Broken wires

Rope guides and rubbing ropes can have broken wires due to fatigue, wear, corrosion or mechanical damage.

14.2 Inspections

14.2.1 General

Inspections of rope guides and rubbing ropes should be as specified by SANS 10293.

14.2.2 Inspection intervals

The interval between inspections shall be determined by risk assessment of the particular shaft, giving consideration to aspects including:

— hoisting schedule in the shaft;

— aggressiveness of the shaft environment.

14.2.3 Visual inspection

The full length of all rope guides and rubbing ropes, and all rope attachments, shall be visually inspected at determined intervals.

14.2.4 Non-destructive inspection

The full length of all rope guides and rubbing ropes shall be thoroughly tested using appropriate non-destructive testing (NDT) procedures at determined intervals. Where rope guides and rubbing ropes are subjected to corrosive conditions, NDT inspection intervals should not exceed 6 months.

14.3 Maintenance actions

14.3.1 Maintenance intervals

The intervals between maintenance actions shall be determined by risk assessment of the particular shaft, giving consideration to aspects including:

— hoisting schedule in the shaft;

— aggressiveness of the shaft environment;

— experience with maintenance in the shaft.

14.3.2 Lubrication

The entire length of all rope guides and rubbing ropes shall be lubricated at determined intervals.

All glands, or other anchoring devices, shall be thoroughly cleaned and visually inspected for wear, corrosion, or any other damage at determined intervals.

14.3.3 Rope turning and rope lifting

All rope guides shall be lifted or lowered at determined intervals, which should not exceed five years.

All rope guides shall be turned through an angle of 90° at determined intervals, which should not exceed five years.

14.3.4 Equalisation of hoist rope tensions

Where multiple hoist ropes are used, hoist rope tension can be automatically equalized by mechanical means, such as the use of rocker plates.

Where this is not done, provision shall be made for measurement of the hoist rope tensions and adjustment of the attachments or hoist rope lengths in order to equalize the hoist rope tensions. Hoist rope tensions shall be measured at determined intervals, which should not exceed 3 months for the first 12 months after installation of new ropes, and 6 months thereafter. If the tension in any hoist rope differs by more than 10 % from the nominal average hoist rope tension, then appropriate adjustments shall be made to equalize the tensions.

14.4 Rope guide discard criteria

Rope discard criteria should be specified for all rope guides and rubbing ropes. The criteria should be agreed between the owner of the mine and the rope supplier.

All rope guide installations should have provision made in their design for replacement of rope guides and rubbing ropes.

Rope discard criteria should be as specified by SANS 10293.

14.5 Rope guide attachments

All rope guide and rubbing rope attachments shall be maintained at determined intervals. Maintenance should include clearing spillage and oiling to prevent failure or lock-up due to corrosion.

Annex A
(informative)

Load combinations and displacement multipliers

A.1 General

This annex provides guidance with respect to combinations of actions (see 8.2) and displacement multipliers which comply with the requirements of 10.3.

The recommendations made in this annex are based on typical safety margins and load combination requirements in structural design standards.

A.2 Operating combinations

When performing a simulation of the conveyance dynamic displacements, the combinations of actions in Table A.1 can be used.

When calculating the maximum values of the conveyance dynamic displacements, the combinations of actions in Table A.2 can be used.

Table A.1 — Recommended combination of actions for simulation of dynamic displacements

Specific action		Combinations of actions			
a)	Coriolis force	1,0	1,0	1,0	1,0
b)	Aerodynamic steady state load	1,0	1,0	1,0	1,0
c)	Aerodynamic buffeting load – conveyances passing	1,0	1,0	1,0	1,0
d)	Aerodynamic buffeting load – air inflow or outflow	1,0	1,0	1,0	1,0
e)	Rope torque	1,0	-1,0	1,0	-1,0
f)	Eccentric load in conveyance	1,0	1,0	-1,0	-1,0

Table A.2 — Recommended combination of actions using maximum values of dynamic displacements

Specific action		Combinations of actions							
a)	Coriolis force	1,0	1,0						
b)	Aerodynamic steady state load	1,0	1,0						
c)	Aerodynamic buffeting load – conveyances passing	1,0	1,0						
d)	Aerodynamic buffeting load – air inflow or outflow (within middle half of shaft depth)	1,0	1,0						
e)	Aerodynamic buffeting load – air inflow or outflow (outside middle half of shaft depth)			1,0	1,0				
f)	Rope torque	1,0	-1,0	1,0	-1,0	1,0	-1,0	1,0	-1,0
g)	Eccentric load in conveyance					1,0	1,0	-1,0	-1,0

A.3 Displacement multipliers

The displacement multipliers γ_R shown in Table A.3 can be used.

Table A.3 — Recommended displacement multipliers γ_R

	Shafts with personnel conveyances	Shafts with only rock and equipment conveyances
Direct collision	2,5	2,0
Oblique collision	2,0	1,5

Annex B
(informative)

Introduction to Annexes B to F, and basic parameters

B.1 Calibration

Calibration of the information in this document only considers shafts within the normal scope of rope guided hoisting as pertaining in the underground mining industry prior to the year 2005. Typically, this means that conveyances with payloads up to 35 000 kg, travelling at hoisting speeds of up to 18 m/s, in shafts not more than about 1800 m deep, and where the ventilation speed does not exceed 12 m/s, are considered. Limits are thus placed on the scope within which this document can be used, based on the limits of current experience rather than on any fundamental technical limitations. It is intended that this document be used where friction winders or drum winders are specified.

B.2 Scope and use of Annexes B to F

This Clause defines the specific parameters and scope of the most common shaft layouts and conveyance geometry for which the formulae given in Annexes B to F are valid. It should be noted that there are no specific technical reasons why other shaft layouts or conveyance geometry cannot be used, and the additional computer analyses required are described in this document. The aim is to simplify the design procedure for the most common shaft layouts and conveyance geometry, whilst still providing design guidelines for other shaft layouts and conveyance geometry. Where this specific scope is not met, the design procedure should follow a rational method, including use of computational fluid dynamics methods to determine the aerodynamic factors and simulation of the conveyance trajectory through the shaft to determine the dynamic displacements.

The following notes define the general shaft configurations, shown in Figure B.1, for which the formulae in Annexes B to F have been specifically developed.

a) Circular shafts without any brattice wall, because no computational fluid dynamics analysis has been done with a brattice wall. Where a brattice wall is used, only the aerodynamic forces change, and it is likely that the changes are small. The shaft compartment layouts shown in Figure B.1 are included.

i. A shaft layout with one winder, having one compartment located in each half of the shaft.

ii. A shaft layout with two winders, with a total of four compartments. One compartment is located in each quadrant of the shaft.

iii. A shaft layout with one personnel and materials winder and one rock winder, having a total of four compartments. The two skip compartments are next to each other on one side of the shaft, and the cage and counterweight compartments are on the other side of the shaft.

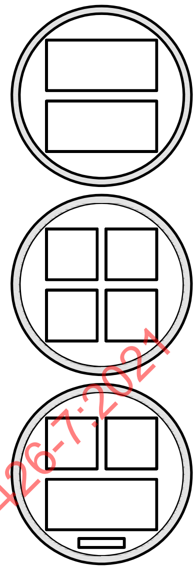


Figure B.1 — Shaft configurations included in the scope of Annexes B to F

b) The formulae given in this document are valid where the rope guide configuration is doubly symmetrical about each conveyance, whether two or four rope guides are used per conveyance. The rope guides should be located at, or near, the extremities of the conveyance, as shown in Figure B.2.

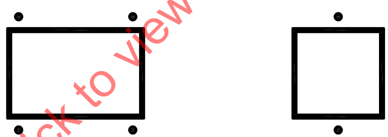


Figure B.2 — Typical rope guide arrangements

Where the rope guide arrangement is unsymmetrical about one axis (either 4 rope guides placed unsymmetrically about the centre of gravity which is fairly common with skips, or 3 rope guides), the only change to the formulae provided in this document arises because there is coupling between the lateral and rotational forces and displacements. Where this lack of symmetry exists, the coupling of the forces may be dealt with by calculating the displacement D_G, and the rotation θ, from:

$$F_X = D'_G K_L \tag{B.1}$$

$$D'_G = \frac{F_X}{K_L} \tag{B.2}$$

$$F_Y - F_X B_E = \theta K_\theta \tag{B.3}$$

$$\theta = \frac{F_Y - F_X B_E}{K_\theta} \tag{B.4}$$

$$D_G = D'_G - \theta B_E = \frac{F_X}{K_L} - \frac{F_Y - F_X B_E}{K_\theta} B_E \tag{B.5}$$

The formulae given in this document can be adapted accordingly, where the symbols used are as defined in Figure B.3 and:

B_E is the distance between the conveyance centre of gravity and the geometric centre of the set of rope guides guiding that conveyance, m;

D_G is the lateral displacement of the centre of gravity of the conveyance, m;

D'_G is the lateral displacement of the geometric centre of the set of rope guides guiding that conveyance, m;

F_X is the general lateral force applied to a conveyance, N;

F_Y is the general moment applied about the centre of gravity of a conveyance, Nm;

K_L is the lateral stiffness at the conveyance elevation of the set of ropes guiding the conveyance, N/m;

K_θ is the rotational stiffness at the conveyance elevation of the set of ropes guiding the conveyance, Nm/rad;

θ is the general yaw rotation of the conveyance in the shaft, rad.

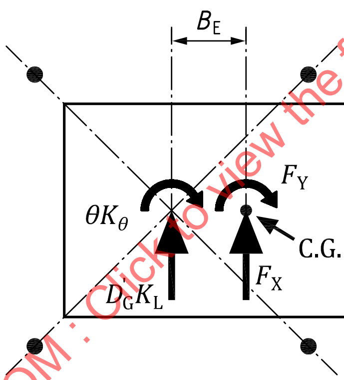


Figure B.3 — Unsymmetrical four rope guide arrangement

c) All conveyances in the shaft run on rope guides, so there are no fixed guides or buntons throughout most of the length of the shaft. Fixed guides are only used at the top and bottom extremities of the shaft where conveyances are loaded and unloaded. There are no intermediate stations.

d) The following notes define the general conveyance geometry for which the formulae in Annexes B to F can be used.

i. Conveyances covered are either skips or cages that can be represented by the geometry shown in Figure B.4.

ii. Conveyances have a body height h_1 of at least twice the maximum horizontal dimension. Shorter skips show evidence of unstable airflow patterns, so it is not possible to specify aerodynamic forces that are constant with time, and it is presumed that cages show similar instability.

iii. Conveyances are in fixed bridles and separate or multi-purpose bridles.

iv. The ratio of the conveyance plan dimensions, B_X/B_Z, is less than 0,8 because this is the limit of the computational fluid dynamics analyses that have been done.

v. Cages with any number of decks are included within the scope of this document, provided they comply with the length requirement in item b).

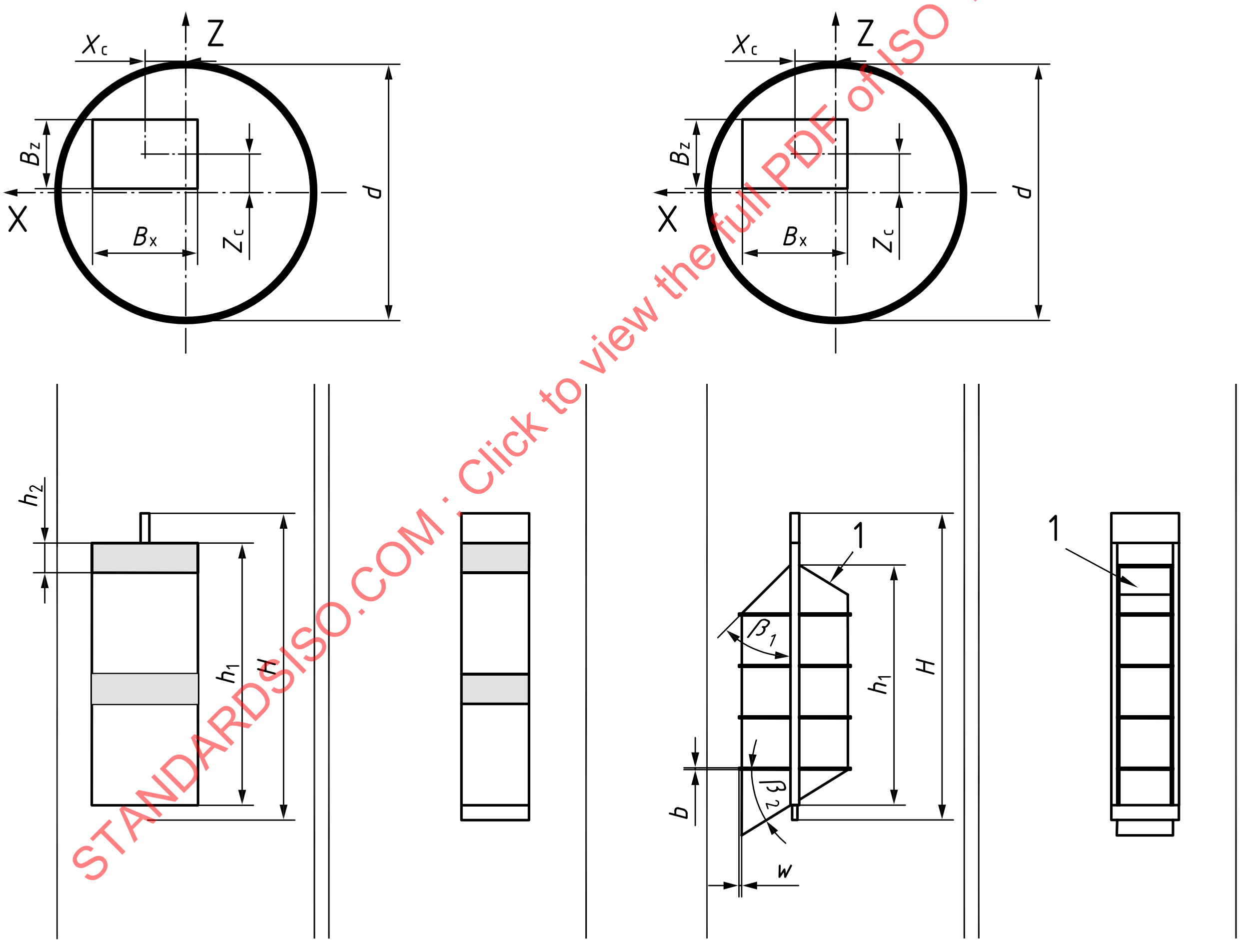
vi. Skip/cage combinations are not covered by this document. They are not considered to be commonly used conveyances, so no computational fluid dynamics analyses have been done for them. They can however be assessed using the computational fluid dynamics mesh generator as described in Clause B.4.

vii. Shaft layouts with, or without, rubbing ropes may be designed using the formulae given in Annexes B to F.

Buffeting as two conveyances pass each other has only been studied for two similar conveyances, travelling at the same hoisting speed, i.e. the two conveyances on a single winder.

The formulae in the guidelines have been developed for shafts where the hoisting speed of the conveyances is up to 18 m/s, and where the ventilation airflow speed does not exceed 12 m/s.

Annexes B to F do not make any reference to any shaft services, such as pump columns, compressed air lines, cables, or others. This is deliberate, as the services are not considered as part of the hoisting installation. It is however important to bear in mind that all specified and design clearances are to the shaft wall, or to any services attached to the walls.



a) Cage

b) Skip

Key

1 skip open at back

Figure B.4 — Typical conveyance geometry covered by this document

B.3 Basic shaft parameters

B.3.1 Nominal shaft geometry

The sign convention used in this document takes the vertical direction as *Y*, positive in the upwards direction. *X* is the out-of-plane direction (i.e. the direction parallel to the tipping direction for skips and the loading direction for cages), and *Z* is the in-plane direction (i.e. the direction perpendicular to the tipping direction for skips and the loading direction for cages).

The main parameters required to define the shaft vertical (long) section geometry are:

— the overall length of the rope guides between top and bottom anchor points;

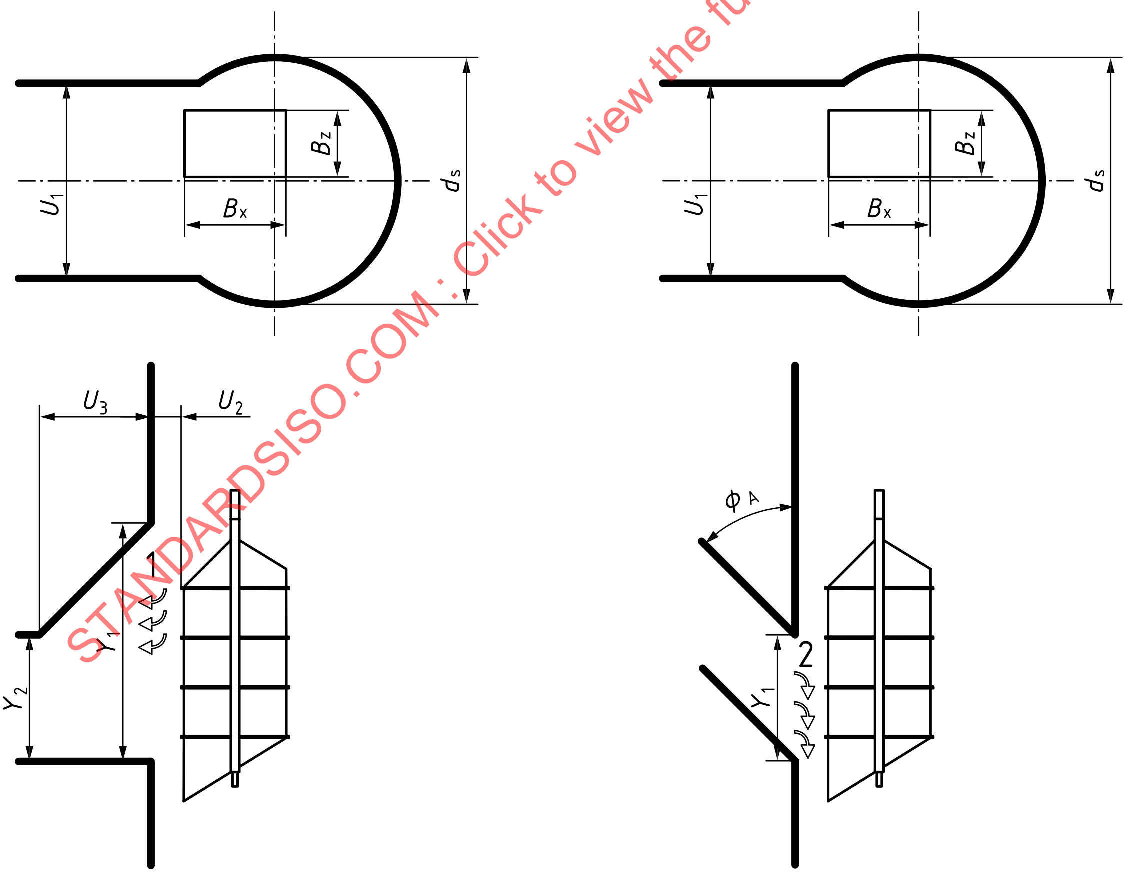
— the distance of the ends of the fixed guides from the rope guide anchor points;

— the elevation of top and bottom hoisting levels and any intermediate levels;

— the elevation of any air in-flow or out-flow levels.

B.3.2 Airflow characteristics

Almost all shafts that are equipped for hoisting are also used for ventilation. The direction and speed of airflow in the shaft, as well as locations at which air enters or leaves the shaft, are important parameters when considering the behaviour of rope guided conveyances. Figure B.5 shows the parameters necessary to define air inflow or outflow locations in shafts.



a) Air outflow   b) Air inflow

Key

1 partial airflow out of shaft 2 partial airflow into shaft

Figure B.5 — Air inflow and outflow locations

B.3.3 Shaft wall misalignments

The extent of misalignments of the shaft side walls needs to be assessed in some way, as this can have a major influence on the clearances from conveyances to the walls in the completed shaft hoisting installation. It is of crucial importance to safe operation of a rope guided hoisting installation that the shaft barrel be carefully surveyed prior to commissioning of the shaft. The usual assumption that surveying of the shuttering prior to placement of concrete gives an accurately constructed shaft should not be accepted.

<u>"Blind sink" (drill and blast) shafts</u>

Typical misalignments in concrete lined shafts are of the order of ± 0,050 m, although localised bulges of up to 0,300 m have been known to occur. This can happen where shuttering is not properly secured during pouring of the concrete, when the shuttering is too lightly stiffened, or when concrete is not properly distributed around the shaft side walls during pouring. Typical misalignments in unlined shafts, or shafts with a thin sprayed lining, can be much greater. Misalignments in excess of 0,250 m are not uncommon. This suggests that lining of shafts for rope guided hoisting installations should be considered good practice, particularly where clearances are tight.

<u>Raise-bored shafts</u>

The walls in raise-bored shafts are generally reasonably smooth, so little is gained by lining them, unless ground support is required. The shaft diameter is also determined by the raise-bore head, so it is accurate. However, the misalignment of raise-bored shafts can be much more than in blind sunk shafts, because the alignment accuracy of raise-bored shafts is determined by the accuracy of alignment of the pilot hole. There is one known case where this deviation was as much as 1,500 m from the nominal vertical.

<u>General</u>

In determining what shaft wall misalignments should be incorporated in the design, cognisance should also be taken of the shaft sinking contract. In South African practice, it is most common for the shaft diameter shown on drawings to be taken as the nominal diameter. The shaft sinking contractor sets shuttering at this nominal diameter, so that misalignment can be inside or outside this diameter. In Australian and Canadian practice, it is quite common for drawings to specify a minimum clear shaft barrel diameter. The shaft sinking contractor then sets shuttering on a larger diameter, so that all shaft wall misalignment is outside the clear shaft barrel, and design clearances are thus not reduced by deviations of the shaft wall.

A final consideration with respect to possible shaft wall misalignment is the possibility of rock movement due to mining activities. This generally occurs where the shaft passes through the reef horizon, and in deep shafts. It is unlikely to be significant in shallow shafts, or where the shaft is sunk outside a vertical or steeply dipping ore body. Ground movements are also likely to occur towards the bottom of shafts, unless there are several reef horizons or zones of poor ground above the reef. In most cases, ground movement leading to shaft wall misalignment is not a significant problem, but it should be considered.

B.4 Basic rope parameters

B.4.1 Head and tail rope parameters

The parameters required for the head and tail ropes are:

— the number of ropes;

— the mass of the ropes;

— the rope construction, lay direction handing, and diameter;

— the torque factors;

— the location of the ropes;

— the method of attachment of the ropes to the conveyance.

B.4.2 Rope guide and rubbing rope parameters

The parameters required for the rope guides are:

— the number and location of rope guides;

— the mass of the ropes;

— the rope construction and diameter;

— the tension to be applied to the rope guides;

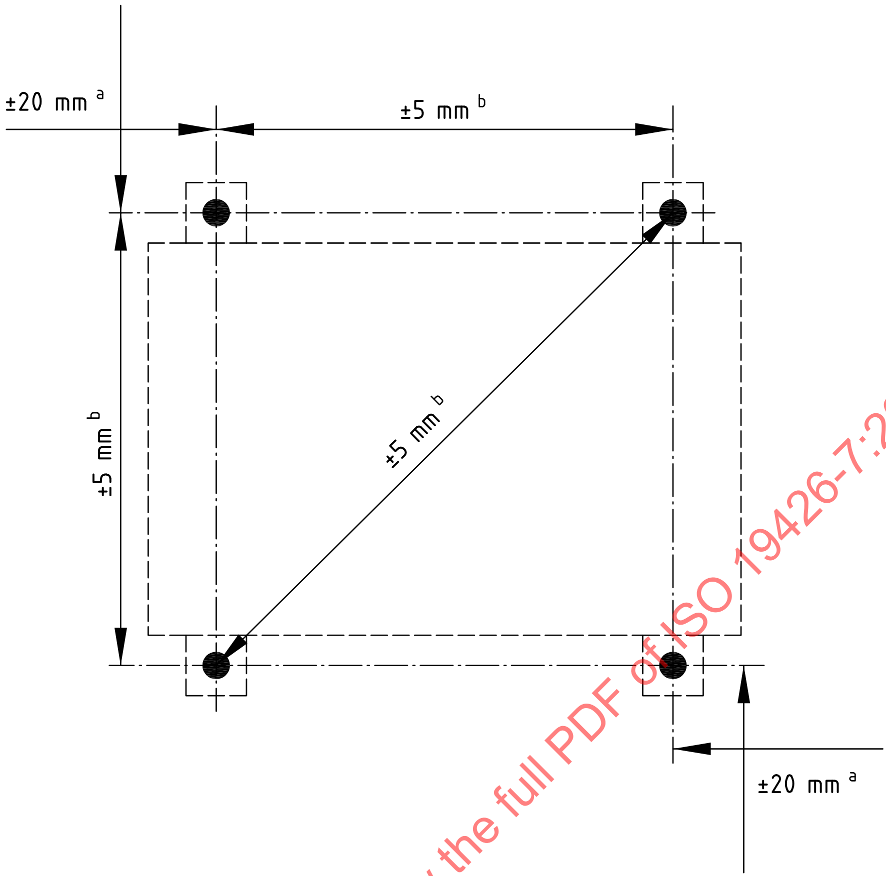
— the method of applying the tension to the rope guides.

B.4.3 Rope guide and fixed guide installation accuracy

The location of rope guides is dictated by the location of the top and bottom anchor points. In order to ensure acceptable installation accuracy for rope guides, their anchor points should thus be positioned with acceptable accuracy. The actual location of the anchor points should not deviate from the design location by more than the following, shown in Figure B.6.

— The location of all anchor points at the top and the bottom of the shaft should not deviate by more than 0,020 m in either horizontal direction from the design location.

— Within the group of rope guides for any one conveyance, the dimensions between the anchor points should not deviate by more than 0,005 m from the design dimensions.



Key

a Location.

b Dimension.

Figure B.6 — Rope guide anchor point installation accuracy

The installation accuracy for fixed guides should be specified as ± 0,005 m in both horizontal directions.

The installation accuracy in the vertical direction has less importance in relation to the rope guides, or the behaviour of conveyances on the rope guides. However, there is at least one known case of excessive rope wear that was attributed to this. The overall vertical installation accuracy of rope guides should be within 1/1 000 of the shaft depth, with a maximum error of 1 000 m.

B.5 Basic winder and conveyance parameters

B.5.1 General parameters

The general parameters of the winder are the following:

— hoisting speed;

— the number of winders and conveyances;

— the geometric layout of conveyances in the shaft.

B.5.2 Cage and counterweight parameters

The basic geometric parameters for cages and counterweights are shown in Figure B.4. In addition, the following parameters are required:

— the self-weight;

— the payload of personnel and of material.

B.5.3 Skip parameters

The basic geometric parameters for skips are shown in Figure B.4. In addition, the following parameters are required:

— the self-weight;

— the rock payload.

The number of stiffeners is not important. A range of computational fluid dynamics analyses with different numbers of stiffeners was done, and this showed that the difference between four stiffeners and more than this was negligible.

In the development of Annexes B to F, only skips without an angled cover plate between the top of the skip and the bridle were considered. This can have some effect on the aerodynamic coefficients, but this effect is not expected to be large.

Annex C
(informative)

Preliminary aerodynamic coefficients

C.1 General

Numerous computational fluid dynamics analyses have been performed to establish the aerodynamic coefficients for specific cases. Certain changes were found to have negligible influence on the aerodynamic lateral coefficients. These were the following.

— Scale effects did not change the aerodynamic coefficients at all.

— There was no significant difference between the aerodynamic coefficients on full or empty skips. The empty skip appeared to form a block of dead air inside the body, so the airflow characteristics around the skip were similar to that of a full skip.

— The assumption that the aerodynamic forces are proportional to the relative air velocity squared appeared approximately correct. A 50 % increase in the relative air velocity led to a 5 % reduction in horizontal aerodynamic coefficients. It is thus assumed that relative air velocity has a negligible influence on the aerodynamic coefficients.

— The stiffener size did not appear to have a very significant influence on the lateral aerodynamic forces, except where the stiffeners protruded close to the shaft side walls. Where the clearance between the conveyance and the side walls is less than about three or four times the stiffener size, the aerodynamic suction towards the wall appears to reduce significantly, probably because the additional turbulence generated slows down the relative air velocity. No provision for stiffener size has thus been made in the following procedure for calculating the horizontal aerodynamic coefficients, as it is considered to be unlikely that stiffeners of this size are practical.

The procedure for deriving the aerodynamic coefficients, as described in Clause C.2, is an empirical procedure developed from the results of these analyses. The aerodynamic lateral coefficient is defined as a basic value, modified as required by various factors, based on the conveyance and shaft geometry.

C.2 Steady state lateral coefficient C_{LX} and C_{LZ}

The computational fluid dynamics analyses that have been carried out show that the horizontal aerodynamic coefficients on the conveyances are determined by numerous factors, several of which interact with each other. The procedure proposed below is an empirical one, based on a study of the computational fluid dynamics values and their variations.

The most important four factors are the shape of the conveyance, the size of the conveyance relative to the size of the shaft, the proximity of the conveyance to the shaft sidewalls, and the presence of any axes of symmetry. These four factors are used, with a basic coefficient of 0,018, to define the horizontal aerodynamic coefficients.

$$C_{LX} = C_{BX} S_{SX} S_{A} S_{PX} \geq 0{,}02 \quad \text{(C.1)}$$

$$C_{LZ} = C_{BZ} S_{SZ} S_{A} S_{PZ} \geq 0{,}02 \quad \text{(C.2)}$$

$$C_{BX} = C_{BX} = 0{,}018 \quad \text{(C.3)}$$

where

C_{BX} and C_{BZ} are the basic aerodynamic lateral force coefficients;

S_{SX} and S_{SZ} are the conveyance shape factors;

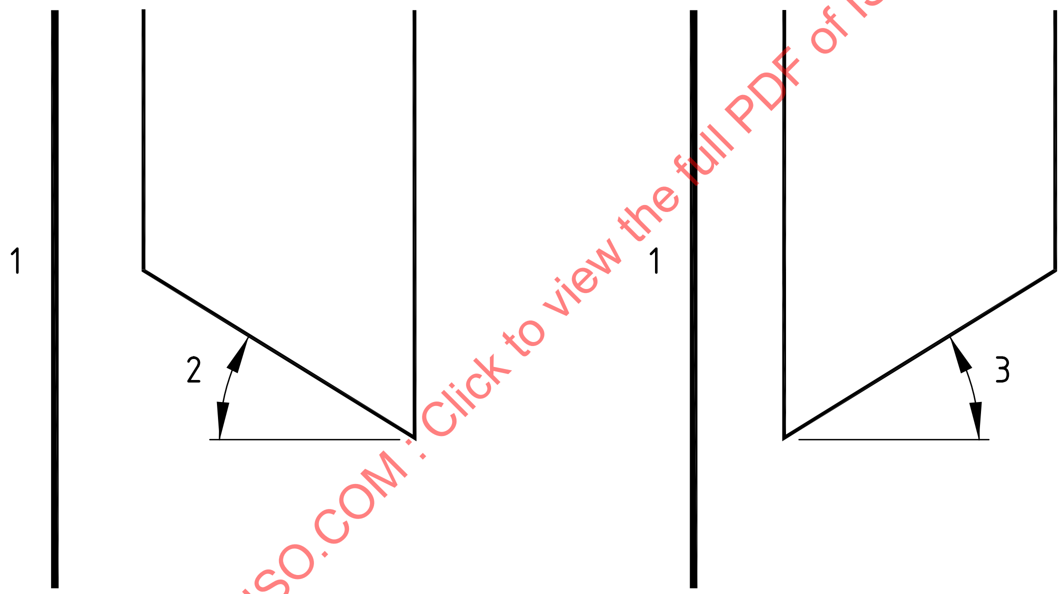
S_A is the conveyance size factor;

S_{PX} and S_{PZ} are the sidewall proximity factors.

Conveyance shape factors S_{SX} and S_{SZ}

The shape of the conveyance is defined primarily by two parameters. The first parameter of importance is the angle of the base of the conveyance. It is assumed that generally the top of conveyances is more or less horizontal, but that the angle of the bottom of skips varies. The angle is defined as shown in Figure C.1.

The second parameter of importance is the ratio of the height of the body of the conveyance to the width of the body (h_1/B_X or h_1/B_Z). The computational fluid dynamics analyses all considered conveyances that were almost square in plan, having B_X to B_Z ratios between 0,8 and 1,0. Where the ratio is less than 0,8, the steady state aerodynamic coefficients should be obtained from computational fluid dynamics analyses.



Key

1 shaft sidewall

2 positive angle

3 negative angle

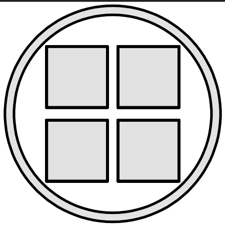
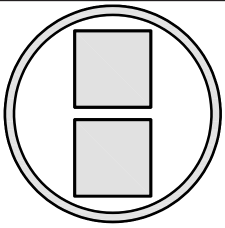
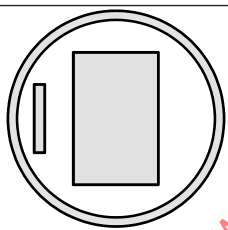
Figure C.1 — Angle of bottom of conveyance

The values of the conveyance shape factor depend on the direction of travel, and they differ for the *X*- and *Z*-directions. The curves in Figures C.3 and C.4 give the appropriate values for conveyance travel in the up (ascending) and down (descending) directions, respectively.

Conveyance size factor S_A

The size of the conveyance relative to the size of the shaft is an important factor because this defines the extent to which a single conveyance in the shaft constricts the ventilation airflow. The base case is a shaft where there are two winders and four winding compartments. In this case, the size factor is defined as S_A = 1,00. Where a shaft has one winder with two similar conveyances occupying the available shaft area, the size factor is S_A = 1,08. Where a single conveyance occupies the shaft, the size factor may be taken as S_A = 1,25. These values are shown in Table C.1. Engineering judgement should be used to interpolate between these values.

Table C.1 — Conveyance size factors for drag coefficient

Conveyance and shaft area geometry	S_A
	1,00
	1,08
	1,25

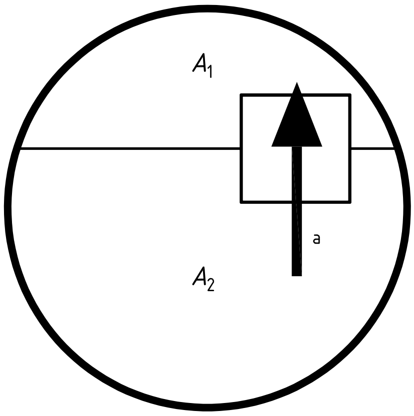
Sidewall proximity factor S_{PX} and S_{PZ}

Air is funnelled between the conveyance and the sidewall of the shaft, usually forming a zone of high velocity and thus low pressure air. The conveyance thus experiences an aerodynamic force acting towards the side wall. The magnitude of this force is strongly dependent on the distance between the conveyance and the sidewall. An empirical formula to define the magnitude of the wall proximity magnifier is:

$$S_{PX} = \sqrt{\frac{A_2}{A_1} - 1} \geq 1{,}0 \qquad (C.4)$$

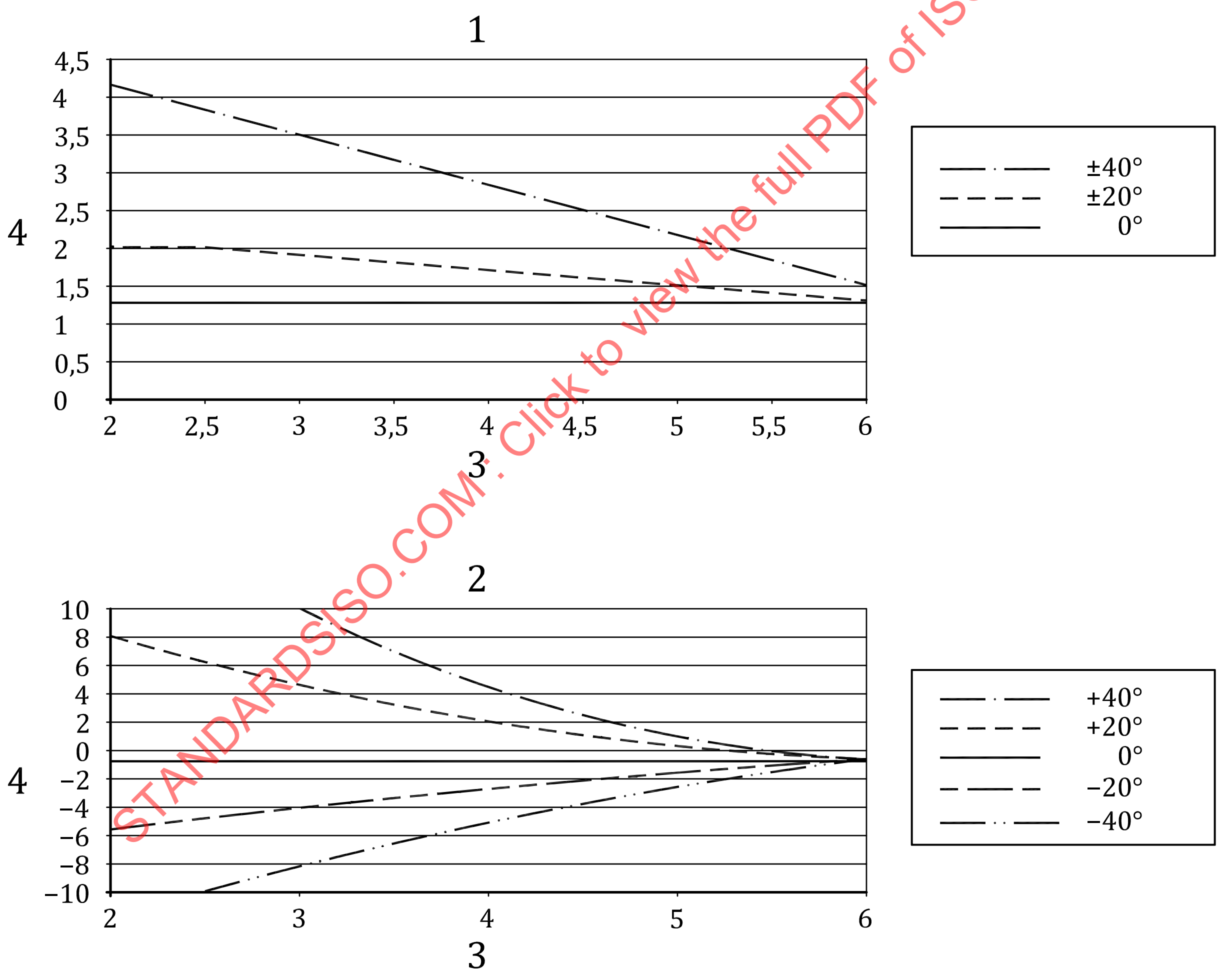
$$S_{PZ} = \sqrt{\frac{A_2}{A_1} - 1} \geq 1{,}0 \qquad (C.5)$$

where A_1 and A_2 are the relevant specified portions of the shaft cross-sectional area as shown in Figure C.2. This ratio should be calculated separately for sidewall proximity factors in the *X*- and *Z*-directions. The areas should be calculated based on the force towards the closer wall, so the area ratio is always greater than 1,0.



[a] Force direction.

Figure C.2 — Definition of A_1 and A_2



Key

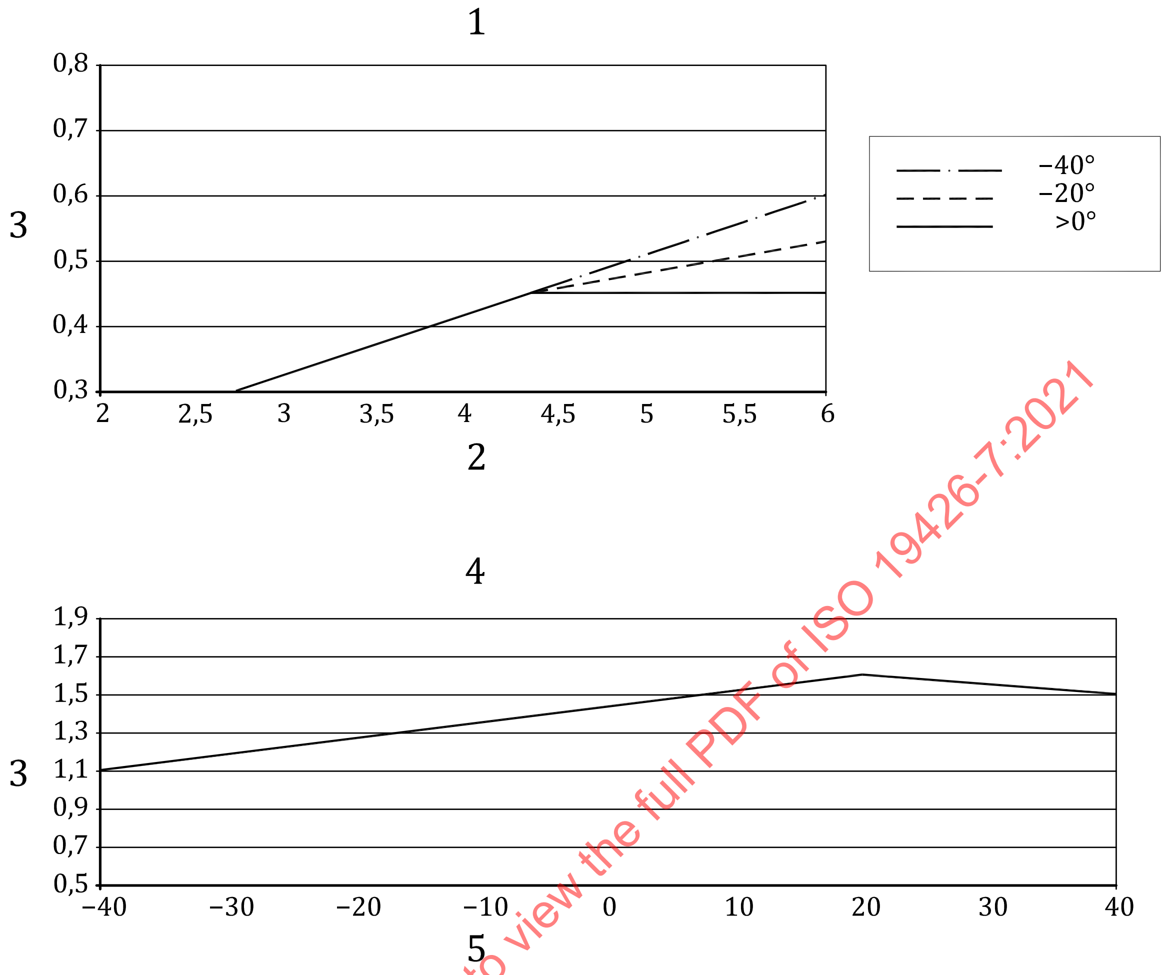
1 shape factors (*x* up)

2 shape factors (*x* down)

3 height/width ratio

4 shape factor

Figure C.3 — Conveyance shape factors for aerodynamic lateral coefficients, S_{SX} (*X*-direction)



Key

1 shape factors (*z* up)
2 height/width ratio
3 shape factor
4 shape factors (*z* down)
5 bottom angle (degrees)

Figure C.4 — Conveyance shape factors for aerodynamic lateral coefficients, S_{SZ} (*Z*-direction)

Minimum value of aerodynamic coefficient

There are uncertainties in regard to the aerodynamic coefficients. It would thus be inadvisable to use too small a value, even if the above procedure suggests a very small value. The value of C_{LX} and C_{LZ} should never be taken as less than 0,02 for a positive value, or greater than -0,02 for a negative value. Where either of C_{LX} and C_{LZ} does fall between 0,02 and -0,02, it is uncertain in which direction the aerodynamic force actually acts, so that the implications of C_{LX} or C_{LZ} = 0,02 and C_{LX} or C_{LZ} = -0,02 should be investigated.

C.3 Buffeting

C.3.1 General

There are two aerodynamic buffeting forces that can be applied to conveyances. The first is the buffeting effect as two conveyances pass each other in the shaft, and the second is the buffeting that occurs as a conveyance passes a ventilation side opening, where air is being blown into the shaft, or extracted from the shaft.

C.3.2 Buffeting force when two conveyances pass each other

The buffeting between two conveyances has only been analysed using computational fluid dynamics analysis for two nominally identical conveyances, with the same hoisting speed. Engineering judgement is required to assess the buffeting forces on different conveyances.

Force in the *Z*-direction (away from other conveyance)

In deriving the force away from the other conveyance (*Z*-direction – see Figure C.5) two ratios are defined. The first is the blockage ratio for two conveyances in a shaft R_B. The blockage ratio is defined as the ratio of the plan area of the two conveyances, to the shaft cross-sectional area, i.e.:

$$R_B = \frac{2B_X B_Z}{\frac{\pi d_S^2}{4}} \quad \text{(C.6)}$$

where d_S is the shaft diameter, m.

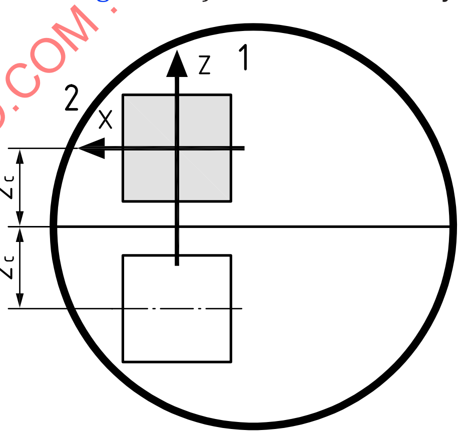
The second ratio is the gap ratio between two conveyances in a shaft R_G. The gap ratio is defined as the ratio of the gap between two conveyances in a shaft, to the width of one conveyance. The gap ratio is:

$$R_G = \frac{2z_C - B_X}{B_X} = \frac{2z_C}{B_X} - 1 \quad \text{(C.7)}$$

Where a shaft has two or more winders operating, there is always the possibility of buffeting between conveyances on different winders as they pass each other. This possibility should be dealt with as described above, but making appropriate substitutions of the *X*-direction and *x* values for the *Z*-direction and *z* values in this section.

Force in the *X*-direction (perpendicular to other conveyance)

The forces in the *X*-direction (shown in Figure C.5) are small, and may thus be neglected.



Key

1 Z-direction buffeting force

2 X-direction buffeting force negligible

Figure C.5 — Direction of buffeting force

Conveyance passing buffeting force coefficient

The conveyance passing buffeting force coefficient is given empirically by:

$$C_{LP} = 0{,}39(1{,}33 - R_G)(0{,}15 + R_B) \quad (C.8)$$

Conveyance passing buffeting force time variation

The force applied to the conveyance during buffeting, as two conveyances pass each other in the shaft, can be approximated by a sine wave form. The first and second peaks of force on the conveyance travelling in the direction opposite to the ventilation airflow, and the first peak of force on the conveyance travelling in the same direction as the ventilation airflow, are of similar magnitude. The second peak of the force on the conveyance travelling in the same direction as the ventilation airflow is approximately 1,5 times greater than the other force peaks. The assumed buffeting force as two conveyances pass each other is shown schematically in Figure C.6 a).

a) Two conveyances passing each other

(Force on conveyance travelling in opposite direction to airflow)

b) Conveyance passing air inflow or outflow

Figure C.6 — Assumed buffeting forces applied to conveyances

The conveyance passing buffeting force is approximately sinusoidal in form, with a period of approximately 1,25 times the time taken for two conveyances to pass each other in the shaft, t_P.

$$t_P = \frac{H}{v_H} \quad (C.9)$$

where

H is the height of the conveyance, m;

v_H is the conveyance hoisting velocity, m/s.

Based on computational fluid dynamics analysis, the conveyance passing buffeting force is approximately given by:

conveyance travelling in opposite direction to airflow:

$$F_P(t) = F_P \sin\left(\frac{2\pi t}{1{,}25 t_P}\right) \text{ for } t \geq 0 \text{ and } < 1{,}25 t_P \quad (C.10)$$

conveyance travelling in same direction as airflow:

$$F_P(t)=F_P \sin\left(\frac{2\pi t}{1{,}25t_P}\right) \text{ for } t \geq 0 \text{ and } < 0{,}625t_P \quad \text{(C.11)}$$

$$F_P(t)=RF_P \sin\left(\frac{2\pi t}{1{,}25t_P}\right) \text{ for } t \geq 0{,}625t_P \text{ and } < 1{,}25t_P \quad \text{(C.12)}$$

where

t is the time, s;

t_P is the time taken for two conveyances to pass each other in a shaft, s;

R is the ratio of the second force peak to the first force peak, taken as 1,5.

The direction of the buffeting force on the shaded conveyance is initially in the positive X-direction as shown in Figure C.6, and then it becomes negative.

C.3.3 Conveyance passing inflow or outflow of air

The airflow buffeting coefficient C_{LP} is determined primarily by the width ratio for air inflow and outflow buffeting R_W, the distance ratio for air inflow and outflow buffeting R_D, and the shape of the passage through which air entered or left the shaft.

$$R_W = \frac{B_X}{U_1} \quad \text{(C.13)}$$

$$R_D = \frac{d - U_1}{d_S} \quad \text{(C.14)}$$

where

U and U_2 are horizontal dimensions as shown in Figure C.7, m;

d_S is the shaft diameter, m.

The other variables are as previously defined.

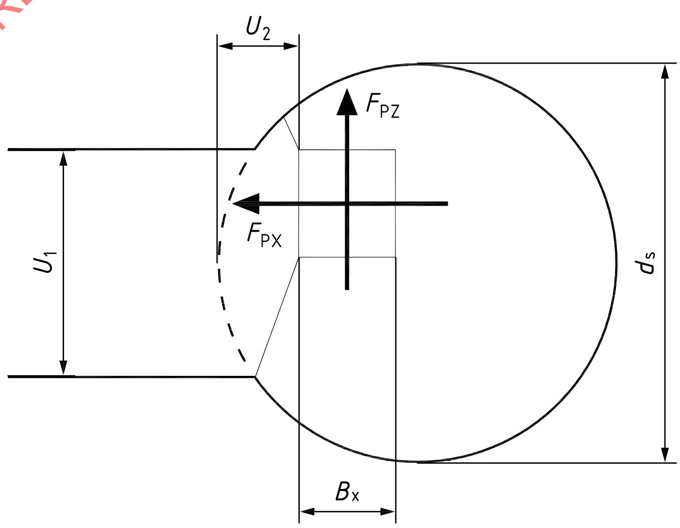


Figure C.7 — Variables for R_D

