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Mining structures — Underground structures

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

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, therefore this document was developed in response to a desire for a unified global approach to the design of safe and reliable structures used in underground mines. The characteristics of ore bodies, such as their depth and shape, and the geotechnical parameters, 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 this document will facilitate improved safety and operational reliability.

There are many reasons, based on mining processes, mining equipment, technical, timing, and cost factors why certain structures can be constructed underground for a particular application rather than on surface, and these are carefully assessed at feasibility stage of any mining project. While this document is not meant to provide comments or recommendations regarding the advantages and disadvantages of using any type of structure underground, it covers specific design aspects that need be considered when using structures in underground mines. It is thus primarily intended to provide the technical information necessary to ensure good engineering of structures where their construction and use underground is the chosen solution.

The majority of the material in this document deals with the loads to be applied in the design of structures used in underground mines. Many of the loads and design considerations for underground structures are identical to the loads and design considerations for similar structures on surface. However, the underground context introduces some specific differences and challenges that must be addressed in order to achieve safe and cost-effective structures. This document deals with those issues and concepts that are specific to structures used in underground mines.

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.

Mining structures — Underground structures

1 Scope

This document specifies the design loads and the design procedures for the design of structures used in underground mines. It covers all steel and concrete structures used in underground mines, irrespective of the depth of the mine or the product being mined.

This document adopts a limit states design philosophy.

Typical underground structures covered by this document include, but are not limited to:

— box front structures at the bottom of rock passes;

— conveyor gantry and transfer structures;

— chairlift support structures;

— crusher support structures;

— fan support structures;

— fixed or retractable arresting structures for ramps (see ISO 19426-5);

— foundations for pumps, fans, winches and underground winders;

— high-pressure bulkheads;

— monorails;

— overhead crane gantries for workshops, pump stations and sub shaft winder chambers;

— settler structures;

— silo bulkhead structures;

— silo structures;

— structures supporting loose rock;

— tip structures, including dump structures;

— underground head frames;

— ventilation control doors and other ventilation structures;

— walls and floors for safety bays, refuge stations and sub-stations;

— water control doors;

— water retaining structures.

This document does not cover matters of operational safety or layout of the underground structures.

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 2394, *General principles on reliability for structures*

ISO 3010, *Bases for design of structures — Seismic actions on structures*

ISO 4354, *Wind actions on structures*

ISO 10721-1, *Steel structures — Part 1: Materials and design*

ISO 12122, *Timber structures — Determination of characteristic values*

ISO 19338, *Performance and assessment requirements for design standards on structural concrete*

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*

ISO 22111, *Bases for design of structures — General requirements*

EN 1997-1, *Eurocode 7: Geotechnical design – Part 1: General rules*

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 https://www.electropedia.org

3.1
arresting structure
structure installed in a ramp or inclined roadway to arrest the motion of a runaway vehicle, or installed in a roadway approaching a vertical or decline shaft to prevent vehicles inadvertently entering the shaft

Note 1 to entry: See emergency arresting dropset in ISO 19426-1.

3.2
bagcrete
required dry ingredients to prepare a specified strength of concrete, put into a bag with the cement in a smaller waterproof bag inside the larger bag and sealed

3.3 Bulkheads

3.3.1
high-pressure bulkhead
liquid-retaining structure constructed in underground excavations, primarily designed to prevent water or other liquid from entering a working area of a mine or to prevent compressed air from escaping, and where the pressure exceeds 70 m head of water

3.3.2
silo bulkhead
structure at the bottom of an underground silo that contains the weight of material in the silo

3.4
development
tunnel excavated through *ground* (3.7) to gain access and provide a ventilation airway to the orebody and infrastructure required to mine the orebody

3.5
dump structure

structure installed at the top of a rock pass to receive rock into the rock pass

Note 1 to entry: A dump structure is often constructed of concrete lined with steel plates, and can be equipped with a rock sizing mechanism.

3.6
floor

ground (3.7) across the bottom of an underground excavation

3.7
ground

surrounding rock

natural material (hard or soft) surrounding an excavation or underground workings in a mine

3.8
initial relaxation

strain in the *ground* (3.7) that occurs when an underground excavation is made due to reduction or redistribution of the ground stress at the excavation from some higher value to zero

3.9
injection

process of introducing *injection grout* (3.9.1) at pressure into the ground-mortar contact area or into fractured or fissured *ground* (3.7)

3.9.1
injection grout

mixture of cement and water, that can include chemicals, injected into the ground-bulkhead contact area and the surrounding *ground* (3.7) under pressure to meet the designed hydraulic gradient requirements around the bulkhead

Note 1 to entry: In the context of this document, this refers to bulkhead constructions.

3.10
intrusion

process of introducing *intrusion mortar* (3.10.1) into previously placed aggregate, such that the pressure at the mortar outlet pipe is no more than is just required to introduce the mortar over the full area of the placed aggregate

3.10.1
intrusion mortar

mix of fine aggregate, cement and water, that can include chemicals, intruded into the entire volume of the *high-pressure bulkhead* (3.3.1) once placement of the *plums* (3.11) and coarse aggregate has been completed

Note 1 to entry: In the context of this document, this refers to bulkhead constructions.

3.10.2
intrusion pipes

small bore pipes in the *high-pressure bulkhead* (3.3.1) structure, placed to facilitate an even placement of *intrusion mortar* (3.10.1) within previously placed aggregate and *plums* (3.11)

3.11
plum

cobble

piece of rock larger than standard aggregate, that can be added to concrete in specified circumstances

3.12
return airway

tunnel, or *development* (3.4), used to exhaust the air from the working areas of the mine

3.13

roof

hanging wall

back

ground (3.7) across the top of an underground excavation

3.14

deflector plate

shedder plate

plate placed over equipment and inclined in such manner as to deflect any spillage away from the equipment

3.15

side wall

ground (3.7) at the side of an underground excavation

3.16

slick line

pipe installed in a shaft or a borehole (normally during sinking) to convey wet concrete from the batch plant to the point of use

3.17

slinging

operation of suspending equipment or materials below a conveyance for transport in the mine shaft

3.18

tightening

high-pressure *injection* (3.9) of grout around the perimeter of the mortar *intrusion* (3.10) *high-pressure bulkhead* (3.3.1) in order to seal the interface between the bulkhead and the surrounding *ground* (3.7) and render the bulkhead watertight

3.18.1

tightening pipe

pipe of a suitable diameter in the *high-pressure bulkhead* (3.3.1) structure to allow re-drilling in the bulkhead structure to enable the sealing [*tightening* (3.18)] of the mortar-ground interface and surrounding *ground* (3.7) fractures

4 Symbols

a_n	seismic acceleration (m/s^2)
A_B	area of bearing between the high-pressure bulkhead and the surrounding ground (m^2)
A_H	surface area of the high-pressure bulkhead (m^2)
b_l	bearing strength of the surrounding ground (N/m^2)
B_l	bearing resistance of the interface between the high-pressure bulkhead and the surrounding ground (N/m^2)
d_i	deformation of the relevant structural component (m)
F	design load, or load effect (N, Nm)
F_H	additional permanent load due to water head (N)
F_R	factored parallel sided high-pressure bulkhead design strength (N)
F_U	ultimate parallel sided high-pressure bulkhead design load (N)

g	acceleration due to gravity (m/s^2)
G	permanent load or effect (N, Nm)
h_b	design height of the rock pass (m)
h_d	height through which the rock falls; to be taken as the depth of the rock pass (m)
H	maximum height of liquid above the centre of the high-pressure bulkhead (m)
i	hydraulic gradient
L	length of the high-pressure bulkhead (m)
m_r	mass of the largest rock (kg)
p_h	reference pressure (Pa)
q	water pressure (Pa)
q_n	additional hydraulic pressure due to seismic action (Pa)
R_D	relative density of the liquid
R_i	single rock impact load on the box front (N)
v_I	shear strength of the surrounding ground (N/m^2)
V_I	shear resistance of the interface between the high-pressure bulkhead and the surrounding ground (N)
Z_i	impact energy of the falling rock (J)
α_i	proportion of potential energy transferred into impact energy on the box front
γ	unit weight of water (N/m^3)
ρ_L	density of the liquid (kg/m^3)
ρ	density of the rock pass contents (kg/m^3)
φ_H	load factor for the additional permanent water head load
ϕ_H	resistance factor for the shear resistance between the high-pressure bulkhead and the surrounding ground

5 Materials

5.1 Underground storage

The owner of the mine shall specify the storage location and conditions for underground storage of construction materials, bearing in mind the adverse environment, the length of time for storage and possible rough handling.

Specific requirements for storage are made in 5.2 and 5.3, and further recommendations for underground storage are made in Annexes A, B and C.

5.2 Concrete

5.2.1 General

The materials used in the construction of concrete structures for underground mines structural concrete shall comply with ISO 19338. The design strength of the concrete to be used shall be specified on the structural drawings, using the common designation for “cylinder strength “or ”cube strength”.

5.2.2 Target strength

The target strength of the concrete to be used shall be defined in order to ensure that the specified design strength is achieved. Annex B provides guidance.

5.2.3 Plums

Plums can be used in high-pressure bulkheads, and can be used in other large structures with the approval of the design engineer.

Plums shall be brushed and washed to remove all contamination and fines immediately prior to placement.

Plums should consist of hard, intact rock. Any rock that is friable, fractured or subject to deterioration on contact with oxygen should not be used.

Plums should consist of sizes with a mass not exceeding what can be handled by one person.

5.2.4 Special recommendations for underground application

Annex B provides general guidance on the use of concrete underground.

Annex C provides guidance for high-pressure bulkheads constructed by mortar intrusion.

5.2.5 Water quality

Some water present in underground mines (e.g. hyper saline and containing sulphates and chlorides) can be very deleterious to concrete structures. Where water other than potable water is used, samples should be tested and the owner of the mine should provide the results to the designer of concrete structures.

5.2.6 Durability

The designer shall specify any specific concrete mix design criteria required to ensure the required durability of the completed concrete structure.

When a structure is constructed in any area containing exhaust air, or other contaminated air, the durability of the structure shall take this into account.

Annex B provides guidance.

5.3 Steel

5.3.1 General

The materials used in the construction of steel structures for underground mines shall be structural steel complying with ISO 10721-1. The material used shall be specified on the structural drawings.

5.3.2 Special requirements for underground application

5.3.2.1 Corrosion protection

The owner of the mine shall specify the corrosion protection of steel for underground use. Steel structures underground are susceptible to dust build-up or ore spillage on horizontal surfaces. Some ores, when oxidized and in the presence of moisture, create corrosive products. Mine water used for wash-down can also be corrosive in nature. Careful detailing of structures is required to minimise surface build up or pockets for water collection. This can be achieved by means of appropriately positioned deflector plates, coatings or drain holes.

5.3.2.2 Storage

Where it is necessary to store steel underground, the following precautions should be observed:

- the storage area should be well ventilated by clean air;
- the storage area should be dry, so that steel is not exposed to seepage from the roof or the side walls, or to drain water;
- stacked steel sections should be supported in such a manner that the weight of overlying steel does not damage underlying steel;
- stacked steel sections should not be nested in direct contact with underlying steel sections, but should be separated using a porous material.

Where it is not possible to achieve one or more of these precautions, specification of the corrosion protection should take this into account.

If any steel is stored underground for a period exceeding the period anticipated during design by more than three months, then that steel and corrosion protection shall be thoroughly inspected for deterioration prior to its installation. An inspection report shall be kept together with all construction documentation.

5.3.3 Durability

An adequate corrosion protection system shall be applied to all steelwork to provide the durability required. Where the life of the corrosion protection system is anticipated to be less than the life of the mine, an inspection and repair strategy should be recommended to the owner of the mine.

The owner of the mine shall provide the following information for the specific excavation to guide selection of the appropriate corrosion protection system:

- temperature range;
- humidity range;
- air quality and gas content of the air;
- chemical analysis of ground water;
- chemical analysis of mine water;
- rock properties and their propensity to produce corrosive substances when oxidized or in the presence of moisture.

5.3.4 Timber

The materials used in the construction of timber structures for underground mines shall be designed using characteristic strength as determined in ISO 12122. The material used shall be specified on the structural drawings.

6 Nominal loads

6.1 Operating loads

6.1.1 General loads

The general loads shall be those specified by ISO 22111.

6.1.2 Spillage loads

Due to the potential for dust or rock spillage build-up on underground structures, in combination with infrequent clean-up, consideration should be given to increasing the imposed spillage loads.

6.1.3 Air pressure loads

Structures underground are not subjected to wind loads. However, many underground excavations have ventilation air circulating and air blast loads caused by the mining method. There can be various causes of air pressure applied to underground structures in different locations.

a) Underground structures can be constructed in an air way.

   The air velocity loads shall be determined in accordance with ISO 4354, where the site wind speed shall be taken as equal to the nominal velocity of ventilation air past the structure.

   Where the velocity of ventilation air does not exceed 6 m/s, the loads due to air velocity are small and can be omitted.

   The velocity of ventilation air is constant, and structures in underground mines are typically not slender. Wind dynamic effects can thus be omitted, provided the risk assessment concludes that this is acceptable.

b) Walls or door structures can be used to separate ventilation zones or to separate intake and exhaust air ways.

   Where an underground structure separates ventilation zones or intake and exhaust air ways, the ventilation air flow causes differential pressures on the two sides of the structure. The nominal differential pressure can be treated as a static load on the structure, unless the risk assessment and/or a ventilation flow analysis shows that there is potential for a significant increase in pressure due to some unintended event, such as failure of a fan, unblocking of an ore pass or sudden blockage of an air way.

c) Structures subjected to air blast loads from mining methods shall be designed to resist such loads.

d) Walls or gates can be used to contain compressed air. Where any wall or gate contains accumulated compressed air, the pressure shall be taken as the maximum pressure in the compressed air system.

6.1.4 Thermal loads

Thermal loads shall be considered, unless specific provision is made to detail the structure in such a manner that expansion can take place freely.

The owner of the mine shall specify the temperature range to be considered.

6.1.5 Loads on box fronts

The loads on box fronts shall be taken as the most severe of a pressure (a), or a concentrated load (b). These two loads shall be assumed to act independently and not in combination in the following way.

a) If it can be shown that dry, granular rock conditions can exist in the rock pass, rational analyses may be used to assess the loads on box fronts. If not, the load applied to box fronts shall be based on reference pressure p_h , using the following formula:

$$p_h = \rho \cdot g \cdot h_b \tag{1}$$

where

ρ is the density of the rock pass contents, expressed in kilograms per cubic metre (kg/m^3);

g is the acceleration due to gravity, expressed in metres per square second (m/s^2);

h_b is the design height of the rock pass, expressed in metres (m).

The design height of the rock pass may be taken as the height of the rock pass for heights of up to 30 m, or equal to 30 m for rock passes of height in excess of 30 m. This 30 m limit is based on rock passes having a hydraulic radius of 2 m to 3 m.

This pressure shall be applied to all components of box fronts, including concrete in-fill areas, chutes and radial gates.

b) All main structural components of box fronts shall be designed to resist a single rock impact load on the box front, R_i, which shall be based on energy considerations. The impact energy Z_i shall be taken as:

$$Z_i = \alpha_i \cdot h_d \cdot g \cdot m_r \tag{2}$$

where

Z_i is the impact energy of the falling rock, expressed in joules (J);

α_i is the proportion of potential energy transferred into impact energy on the box front;

h_d is the height through which the rock falls; to be taken as the depth of the rock pass, expressed in metres (m);

g is the acceleration due to gravity, expressed in metres per square second (m/s^2);

m_r is the mass of the largest rock, expressed in kilograms (kg).

The proportion of potential energy transferred into impact energy on the box front, α_i , shall be based on a rational assessment of energy losses in the rock pass, or it may be taken as:

1) 0,8, when the rock pass is inclined at more than 70° to the horizontal;

2) 0,6, when the rock pass is inclined at less than 70° to the horizontal; and

3) 0,3, when there is a dogleg in the rock pass not more than 15 m above the box front.