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Mining structures — Underground structures

Structures minières — Structures souterraines

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

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*.

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 terminology 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:

$$p_h = \rho \cdot g \cdot h_b \quad (1)$$

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:

$$Z_i = \alpha_i \cdot h_d \cdot g \cdot m_r \quad (2)$$

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.

The impact load shall be calculated assuming plastic deformation of the structural components of the box front, but shall be taken as not less than 100 000 N, and need not be taken as more than the point load strength of the rock. The impact load is given, using the following formula:

$$R_i = \frac{Z_i}{d_i} \tag{3}$$

where

R_i is a single rock impact load on the box front, expressed in newtons (N);

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

d_i is the deformation of the relevant structural component, expressed in metres (m).

This load shall be taken as acting in a direction parallel to the axis of the ore pass.

The mass of the rock may be based on a rock size limited by the physical constraints of the rock handling system, but the rock size shall not be taken as less than 0,02 m^3.

The plastic deformation of the relevant structural component, d_i, shall be taken as being in the range from 2 % to 5 % of the span of the relevant structural component.

The structural members surrounding the chute and the door of the box front can be designed using plastic design methods. The columns and other main structural components shall be designed to remain elastic.

NOTE The main structural components include the columns, struts, beams and anchors, but exclude the chute and doors.

6.1.6 Loads on high-pressure bulkheads

6.1.6.1 Additional permanent loads

The additional permanent load due to the head of liquid behind the high-pressure bulkhead shall be based on the height of liquid, from the centre of the high-pressure bulkhead to the highest liquid surface level, multiplied by the relative density of the liquid and the cross-sectional area of the high-pressure bulkhead. Thus:

$$F_H = A_H \cdot \rho_L \cdot g \cdot H \tag{4}$$

where

A_H is the cross-sectional area of the high-pressure bulkhead (m^2);

ρ_L is the density of the liquid (kg/m^3);

g is the acceleration due to gravity (m/s^2);

H is the maximum height of liquid above the centre of the high-pressure bulkhead (m).

The relative density of the liquid shall be determined from site conditions.

The height of liquid, from the centre of the high-pressure bulkhead to the highest liquid surface level, shall be determined from site conditions.

6.1.6.2 Seismic load

The additional hydraulic load on high-pressure bulkheads due to seismic action, Q_n, can be taken as:

$$Q_n = A_H \cdot \frac{a_n}{g} \cdot \rho_L \cdot g \cdot H \quad (5)$$

where

A_H is the cross-sectional area of the high-pressure bulkhead (m^2);

a_n is the peak ground acceleration with a 10 % probability of being exceeded in a return period to be specified by the owner of the mine (m/s^2);

ρ_L is the density of the liquid (kg/m^3);

g is the acceleration due to gravity (m/s^2);

H is the maximum height of liquid above the centre of the high-pressure bulkhead (m).

6.1.7 Liquid pressure

The pressure due to a contained body of liquid shall be the hydrostatic pressure based on the depth of the liquid and the relative density.

6.1.8 Loads on pipe supports

The loads on pipe supports shall be as specified in ISO 19426-5.

6.2 Ground displacement loads

Structures constructed underground can be attached to one, or both, side walls and they are often founded on the floor and connected to the roof. Due to mining activities, the ground surrounding any mining excavation always experiences some amount of strain. Where any structure in an underground mine is attached to side walls or the roof, ground strain can induce loads into the structure. The risk assessment shall consider the severity and likelihood of consequences that can occur.

6.2.1 Initial relaxation

Initial relaxation in ground cannot be reversed, but it usually occurs before any structure can be constructed. The strain to which a structure in an underground mine is exposed can be taken as the nominal strain due to mining activities, less the initial relaxation.

6.2.2 Long-term ground displacement

Ground strain can occur over a long time period when the ground strains as mining progresses through the ore body. Long-term displacement of the ground surrounding the structure shall be determined from stress analysis of the ground at each progressive mining step.

Where this long-term displacement of the ground can induce loads in the structure, provision shall be made to:

— either design the structure to withstand these loads, or a portion of these loads;

— or ensure that the displacement is monitored and the structure is modified as necessary to be able to cater for these loads.

6.2.3 Sudden ground displacement

Ground strain can occur over a short time period when the ground slips along a fault or other discontinuity. The sudden displacement shall not be taken as less than 25 % of the maximum long-term displacement that can occur in any 12-month period.

Where this sudden displacement of the ground can induce loads in the structure, provision shall be made to:

— either design the structure to withstand these loads;

— or ensure that the structure can deform safely as the ground displaces.

6.3 Seismic loads

Where structures in underground mines are supported at the base only, seismic design shall comply with the requirements of ISO 3010. Underground structures are usually low structures with substantial members, so they typically have high fundamental frequencies, and in most cases seismic loads can thus be neglected.

Where structures in underground mines are supported at the base and on any other wall, i.e. one of the side walls or the roof, the structure is constrained to move together with the ground. Seismic design provisions can be ignored in this case, provided the risk assessment concludes that this is acceptable.

Where possible, structures should not be located in such a manner that they straddle any known geological fault, plane of weakness, or discontinuity.

6.4 Emergency loads

6.4.1 General

The risk assessment shall consider the likelihood and the consequences of each of the events in 6.4.2 to 6.4.7 and other possible events.

6.4.2 Explosion loads

The risk of explosion in proximity to any area where flammable gas, explosive substances or flammable materials can accumulate or any area where explosives are stored or transported shall be considered. Any structure closing a significant portion of an excavation where the risk assessment concludes that explosions can occur shall be designed to withstand the pressure that can be exerted.

The pressure to be used for design should be determined by an explosive's specialist.

When there is a blockage or hang-up in some part of ore handling systems, such as chutes, small explosive charges can be used as a method of last resort to clear such blockages. The explosion loads on components and supporting structures should be considered in their design in consultation with the owner of the mine.

6.4.3 Air blast loads

The risk of air blasts with air being forced under high pressure through an excavation containing any structure shall be considered. Examples of this are where block caving mining methods are used and the block caving area can collapse, or where rock in a rock pass or silo can hang up and then collapse. Any structure closing a significant portion of an excavation where the risk assessment concludes that air blasts can occur shall be designed to withstand the pressure that can be exerted.

The pressure to be used for design should be determined by a mining ventilation specialist.

6.4.4 Mud-rush loads

The risk of a mud rush in proximity to any rock pass or silo shall be considered. Any structure in an excavation where the risk assessment concludes that mud rushes can occur shall be designed to withstand the pressure that can be exerted.

The pressure to be used should be determined on the basis of mud flow velocity and height of build up against the relevant structure.

6.4.5 Vehicle impact loads

The risk of a vehicle impact on any structure shall be considered. Where a structure is located near a haulage or roadway where vehicles operate and where the risk assessment concludes that impact is possible, an arresting structure shall be provided, or the structure shall be designed to withstand the vehicle impact.

The load to be used should be determined on the basis of the velocities and masses of vehicles operating in the vicinity of the structure.

6.4.6 Ground or rock impact loads

The risk of a sudden drop of ground or rock supported on any structure shall be considered. Any structure supporting ground or rock and where the risk assessment concludes that sudden loosening of the ground or rock is possible shall be designed to withstand the ground or rock impact.

The load to be used should be determined on the basis of the behaviour of the ground or rock.

6.4.7 Emergency load on pipe supports

The emergency load on pipe supports should be as specified in ISO 19426-5.

7 Design procedure

7.1 Risk assessment

The owner of the mine shall coordinate and approve a design risk assessment for all underground structures. The outcome of the risk assessment shall be retained as part of the design documentation for the structure. The design risk assessment should follow the guidance given in IEC 31010, and should utilize one of the techniques described in IEC 31010.

The risk assessment shall include, but not be limited to, all items noted in Clause 6 of this document.

In addition, the design risk assessment should consider the following:

— potential for a lower level of quality control and quality assurance for any work done underground;

— limited access to perform inspection of assets during their operating life leading to possible unmanaged degradation;

— quality assurance of maintenance works during a shutdown can be difficult to execute well;

— temporary works;

— difficulty in replacing/repairing underground structures in an operating environment;

— other relevant aspects depending on the site conditions.

The above factors typically dictate generous allowances and a more conservative design approach than for similar surface structures.

When considering the design of a high-pressure bulkhead, the following additional factors should be considered:

— future mining activities;

— site investigation;

— application of the high-pressure bulkhead;

— required life of the high-pressure bulkhead;

— liquid quality on the wet side, short and long term;

— consequence of failure;

— stress corrosion;

— accessibility and maintenance after construction and mining activities have ceased;

— acceptable leakage/seepage;

— lifespan of service piping and valves.

7.2 Design procedure

The design of underground structures shall ensure safety as required by ISO 2394. The design can be done in a similar manner to design of surface structures.

7.3 Partial safety factors

In determining the relevant partial safety factors for design of underground structures, cognizance should be given to types of loads and possible modes of failure. The following should be considered:

a) loads induced by ground movement are not gravity loads, and can cause deformation of the structure, but possibly not sudden catastrophic failure;

b) where structures are connected to both the floor and the roof, or to the floor and the sidewalls, any weakness in a structural component can be compensated by load sharing to other structural components.

7.4 Provision for excavation variations

Depending on how excavations are made, the dimensions of excavations can differ widely from what is shown on drawings. This can lead to the requirement for structural components to be modified, usually by shortening or lengthening. Drawings shall clearly show what allowance has been made for such modifications, and at what extent of over-excavation or under-excavation a re-design shall be done.

The construction drawings shall include a note to the effect that “where excavation tolerances are not met, the design shall be referred to the engineer for review”.

Refer to 8.4 for further details.

7.5 Design of high-pressure bulkheads

7.5.1 Types of high-pressure bulkheads

High-pressure bulkheads are typically hitched bulkheads, tapered bulkheads or parallel-sided bulkheads as shown in Figure 1.

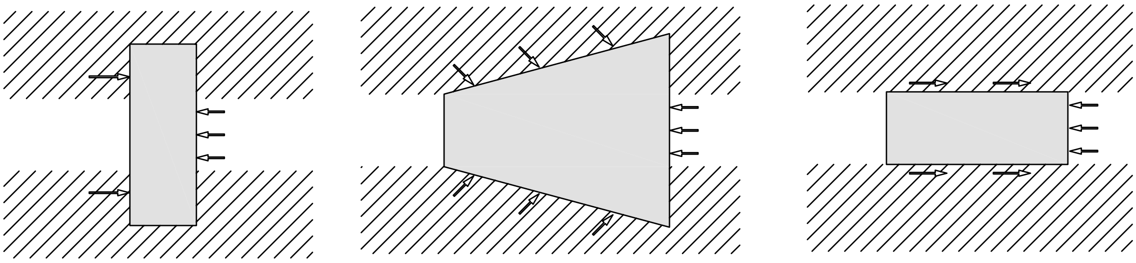

Figure 1 — Shapes of high-pressure bulkheads

Usually, the hitched high-pressure bulkhead is conventionally constructed of reinforced concrete, whereas the tapered and parallel-sided bulkheads are constructed using mortar intrusion into pre-placed aggregate. Reinforced concrete construction of hitched high-pressure bulkheads should be limited to high-pressure bulkheads containing not more than 70 m head of water pressure, whilst mortar intruded construction using tapered or parallel sided high-pressure bulkheads is associated with higher pressures. Annex C provides further guidance regarding parallel-sided mortar intruded high-pressure bulkheads.

7.5.2 Strength requirements

7.5.2.1 Bearing resistance

The bearing resistance of the interface between the high-pressure bulkhead and the surrounding ground shall be taken as:

$$B_I = A_B \cdot b_I \tag{6}$$

where

A_B is the area of bearing between the high-pressure bulkhead and the surrounding ground (m^2);

B_I is the bearing resistance of the interface between the high-pressure bulkhead and the surrounding ground.

The owner of the mine shall provide the bearing strength of the surrounding ground.

7.5.2.2 Shear resistance

The shear resistance of the interface between the high-pressure bulkhead and the surrounding ground shall be taken as:

$$V_I = L \cdot P \cdot v_I \tag{7}$$

where

L is the length of the high-pressure bulkhead (m);

P is the average perimeter of the interface between the high-pressure bulkhead and the surrounding ground (m);

v_I is shear strength of the surrounding ground (N/m^2).

The owner of the mine shall provide the shear strength of the surrounding ground.

Where the construction method is mortar intrusion, the length of the high-pressure bulkhead shall not be less than the longest diagonal of the high-pressure bulkhead cross section. Under this condition, secondary stresses in the high-pressure bulkhead due to bending and compression can be neglected.

7.5.3 Watertightness requirements

Watertightness is achieved by means of limiting the hydraulic gradient, i, and by injection of grout during construction.

$$i = \frac{H \cdot R_D}{L} \tag{8}$$

where

H is the maximum height of liquid above the centre of the high-pressure bulkhead (m);

L is the length of the high-pressure bulkhead (m);

R_D is the relative density of the liquid.

The owner of the mine should specify the maximum value of i, based on the permeability of the surrounding ground and on how much leakage is tolerable. Indicative values are provided in Annex C.

7.6 Design of underground head frames

The design of underground head frames shall comply with the requirements of ISO 19426-2 in addition to the requirements of this document.

8 Construction requirements

8.1 Transport and storage

All transport and storage of structural materials shall be planned and executed in such a manner so as to ensure the components do not suffer damage and materials do not deteriorate prior to completion of construction of the structure.

8.2 Anchoring into ground

Rock anchors can be used to reduce the mass of concrete in a foundation, to provide support to structures on the roof or side walls of an excavation, or to improve the shear strength of structural connections to the ground surrounding the excavation. When this design method is used, the designer should consider:

— the type of grout used for the anchoring of the anchor into the ground;

— the strength of the ground;

— known, or anticipated, fracturing of the ground due to geological factors, or following blasting of the excavation or drilling of the hole.

Similar rock anchors can be used for roof support and structural support. However, no rock anchor shall be used to simultaneously provide roof support and structural support, unless it is demonstrated that the anchor has sufficient strength to resist the sum of the roof support and structural support loads.

8.2.1 Chemical grouted anchors

The design of chemical grouted anchors shall comply with the requirements of EN 1997-1.

8.2.2 Cementitious grouted anchors

The design of cementitious grouted anchors shall comply with the requirements of EN 1997-1.

8.2.3 Mechanical anchors

The design of mechanical anchors shall comply with the requirements of EN 1997-1.

NOTE EN 1997-1 only defines the tensile strength of anchors and their shear connection to the ground.

8.2.4 Shear loads on rock anchors

When anchors are used that are anchored at their end and for only a part of their length, there is a free tendon length near the ground face and projecting outside the ground face. This free length of the tendon or anchor bolt has little bending strength, so anchors have very little transverse load carrying strength. This is not the case with fully grouted anchors.

Where anchors are used to pull brackets into secure contact with the ground face, it may be possible to use friction to resist loads parallel to the ground face.

The shear resistance transverse to the anchor shall be rationally evaluated on the basis of the bending strength of the anchor and any friction resistance that can be developed between the structure and the ground.

8.2.5 Intact ground

The owner of the mine shall provide the tensile strength of the intact ground.

8.2.6 Fractured ground

The owner of the mine shall provide the depth of the fractured ground.

8.2.7 Anchor tests

Grouted rock anchors should be tested in accordance with the requirements of ISO 22477-5.

8.2.8 Lifting or pulling from rock anchors

Specially designed lifting lugs, or pulleys for winch ropes, that are secured to the roof or side walls with rock bolts can be used. For any lifting or pulling that depends on attachment of lifting or pulling tackle to rock anchors installed in the roof or side walls, not less than three rock anchors should be used. In such instances, the lug or pulley should be proof tested by means of a pull test after installation. The magnitude of the proof load should be based on the design risk assessment, giving due consideration to possible impact during the lifting operation.

8.3 Bearing against ground

8.3.1 Intact ground

The owner of the mine shall provide the bearing strength of the intact ground.

8.3.2 Fractured ground

The owner of the mine shall provide the depth and bearing strength of the fractured ground.

8.4 Excavation tolerances

Where any structure is connected to an excavated surface, the owner of the mine shall specify the excavation tolerances. The following tolerances on the final, as-excavated, surface are recommended:

a) under excavation (i.e. projection inside the specified excavation dimensions): 0,00 m;

b) over excavation (i.e. outside the specified excavation dimensions): 0,25 m.

Where the specified tolerances are not met, the design of the structure shall be reviewed and modified if necessary.

8.5 Construction of high-pressure bulkheads

High-pressure bulkheads can be parallel-sided, tapered or keyed into the surrounding ground. High-pressure bulkheads can be constructed using conventional reinforced concrete construction, mortar intrusion grouting, or other methods.

The design engineer shall prepare a construction procedure.

Annex C provides guidance for the construction of parallel-sided bulkheads, using mortar intrusion.

Annex A
(informative)

Transportation, handling and storage

A.1 General

This annex provides guidance with respect to transportation and storage of materials used for underground structures.

A.2 Storage

All materials should be stored in a clean and dry place. If it is not possible to keep the floor dry, then all materials should be stored on a platform to keep them above any water on the floor.

No cement or concrete materials should be stored underground for longer than three months.

A.3 Lifting

It is often not possible to use mobile cranes for underground construction. It is thus recommended that a lifting plan be prepared for all underground construction work. The lifting plan should include, but not be limited to, the following.

a) A schedule of all significant masses to be lifted.

b) A schedule or drawing indicating the location at which all significant masses are to be lifted off their transport and into position in the structure. It is considered good practice to clearly mark the mass of large components or sub-assemblies directly on the component.

c) A statement of what method or equipment is to be used to lift all significant masses.

A significant mass is any mass that requires lifting tackle to be lifted, either off its transport, or into position in the structure.

No person should be allowed to enter the area below the mass being lifted, nor the area below the lifting rope.

It should be certified that any structural frame used for lifting should have been properly designed and constructed by persons authorized to do so.

A.4 Transport dimensions and weights

Design of assembled sub-modules is preferred to limit installation time underground.

The maximum dimensions and weights of individual structural components is limited by available means of access to the underground workings. The size and weight limits for such sub-assemblies should be specified by the owner of the mine, based on the hoisting capacity of the winder and the geometry of the shaft and underground workings.

Annex B
(informative)

Use of concrete underground

B.1 Target strength for underground concrete

B.1.1 Target strength of concrete

Target strength of concrete is determined from the design strength specified on the construction drawings and quality control expectations at the site of construction. If good quality control is expected, then the difference between the target strength and the design strength will be less. For example, where a 30 MPa design strength is specified, a target strength of 37 MPa to 38 MPa is often used for 'average' site conditions on surface as a starting point. The margin between the target strength and the design strength can be reduced as confidence is gained in the repeatability of the actual strengths obtained.

In the underground situation, the ability to control the quality of the concrete during the construction process reduces, and it becomes significantly more difficult to consistently produce the same result. Experience suggests that if a 30 MPa design strength is required, it is necessary to aim for a 45 MPa target strength. No fixed rules for the difference in quality control standards underground versus surface conditions have been established. Therefore, it is not possible to provide firm guidelines.

The requirements for any particular scenario can vary depending on the importance and safety critical nature of the structure, the design philosophy of the design engineer in applying the agreed design parameters, specific project constraints, the target strength of the concrete, and how the acceptance criteria are applied.

EXAMPLE 1 Winder foundation for a sub shaft

When winder foundation is being constructed, the following can apply:

— high importance, and safety critical, structure;
— large concrete pours in the underground context;
— comparatively high level of supervision, both from the constructor and the designer;
— reasonably high level of concrete skills;
— use of bagcrete, with the contents able to achieve a specified strength;
— concrete mixer of 200 to 400 litre capacity;
— pumping of concrete by a concrete blower;
— access to the site can be reasonable.

Recommended target strength is 1,4 multiplied by design strength.

EXAMPLE 2 Base for pumps

When pump foundation is being constructed, the following can apply:

— relatively small quantity of concrete required;
— construction personnel can be less experienced in use of concrete;
— concrete mixing conditions can be well below optimal;
— site can be located away from the shaft or be close to the shaft.

Recommended target strength is 1,5 to 1,6 multiplied by design strength.

EXAMPLE 3 Box fronts

When production box fronts are being constructed, the following can apply:

— safety critical structure;

- can be far away from the shaft;
- quantities of concrete tend to be small;
- personnel used often multi-skilled and or multi-tasked workers;
- personnel used are normally general underground construction crews who undertake all construction done underground, not only concrete works;
- method of mixing the concrete can vary from hand mixing on the floor to use of small concrete mixers.

Recommended target strength is 1,7 multiplied by design strength.

It is recommended that engineers with experience in concrete mix design, or professionals who have experience with the use of underground structural concrete, be approached to give advice in any particular situation.

B.2 Design of structural concrete

B.2.1 Introduction

The design of concrete structures follows the same principles as concrete structures on surface.

It is recommended that the design parameters used for design be agreed with the owner of the mine prior to design proceeding. This should include allowance for conservative design due to unknown factors commonly encountered in the underground environment.

B.3 Materials for concrete

B.3.1 Cement

Cement and cement extenders should comply with concrete and or cement specification. It is strongly recommended that where cement extenders are used they be supplied pre-mixed and not mixed at the underground site.

B.3.2 Concrete additives

Concrete additives used should comply with specification for concrete construction.

If concrete additives are to be used, it is recommended that dry additives be used. If possible, the dry concrete additives should be thoroughly mixed into the cement prior to taking underground.

When batching of concrete is done underground, the use of concrete additives should follow the recommendations provided by the concrete additives suppliers and concrete construction specifications.

B.3.3 Concrete aggregates

Aggregates for use in underground structural concrete should comply with concrete construction specifications.

When aggregate is crushed underground, it is sometimes decided to use a single aggregate rather than a coarse aggregate and a sand. Should this be the case, the concrete mix design should be designed taking this into account.

When aggregates are sourced from the mining operation, the aggregate should be tested as is normally the case. The content of the sulphides in the rock used to crush for aggregates should always be monitored carefully as sulphides can be present in higher volumes in rock that is associated with ore bodies. The explosives used in the mining operations can introduce contaminants and these can be trapped into the blasted rock, this is particularly the case for chlorides.

B.3.4 Water for concrete

B.3.4.1 Background

Potable water is commonly used for mixing structural concrete.

In the underground environment, potable water may not be available in sufficient quantities. Experience has shown that refrigeration water and ground water can sometimes be used to mix concrete. Neither of these water sources normally meet potable water standards, refrigeration water generally being high in nitrates, sulphides and other salts (to lower the freezing point of the water).

Any water used for concrete should be tested, unless potable water is used.

B.3.4.2 Use of water for underground concrete

For concrete used for floor levelling, or other non-structural concrete applications, the water used is generally not important. Exceptions to this include highly trafficked areas, such as station floor areas, haul roadways and heavy workshop floors. This is not of a structural concern, but longevity and the ability to provide a good wearing surface free of tripping hazards can be determining factors.

Structural concrete that must be in use for many years should have guidance provided in the concrete specifications applied. If potable water is not available, water quality tests should be undertaken to provide the required confidence that the available water is suitable. Another option is to use historical records of the performance of concrete structures if these are available.

In the case of production box fronts where the expected life of the structure can be relatively short, the use of non-potable water can be deemed acceptable.

B.4 Bagcrete

B.4.1 Background

Bagcrete is a term that has developed in some countries because of the use of bags to transport dry concrete ingredients underground. The use of this system was extended to include the correct ingredients to have a specified strength once water was added.

B.4.2 Bags used for bagcrete

Bags used for bagcrete should be sturdy.

The bag should have the following shown on the bag:

— grade of concrete;

— quantity of water to be added;

— suppliers name.

B.4.3 Cement for bagcrete

Cement for bagcrete should be contained inside the bag used to transport the bagcrete. The cement bag should be waterproof.

B.5 Curing of concrete

B.5.1 Background

Curing of concrete should follow generally accepted standards for concrete curing.

Curing of concrete is as important as on surface to ensure the intended parameters for hardened concrete is achieved.

B.5.2 Curing of concrete

Curing requirements of concrete underground vary depending on the depth of the underground mine.

Different mining depths create different environmental conditions. Shallow mines tend to have environmental/climatic conditions similar to surface, while deep mines create their own environmental/climatic conditions.

a) Shallow mines

In shallow mines, curing methods used on surface are appropriate.

b) Deep mines

Generally, the environmental conditions in deep mines are advantageous for the curing of concrete as the conditions necessary for people to work in are good for the curing of concrete.

Care should be taken when structural concrete work is done in return airways as the speed of the ventilation air and air temperature can be much higher, as it is not intended that people work in a return airway.

B.6 Durability

The owner of the mine should specify the functional and performance parameters for any particular structure. From this, the designer of the structure can specify the requirements to achieve the durability of the structure.

Adequate provision should be made for durability in the concrete detailing and mix design. Cover to steel reinforcing should be not less than that shown in Table B.1. The concrete mix design should give particular attention to mixing conditions, how the wet concrete is to be transported, and compaction methods.

Table B.1 — Recommended concrete cover to reinforcing

Situation	Dry, well ventilated area	Wet, poorly ventilated area
Against excavated ground face	75 mm	75 mm
Floor of an excavation	60 mm	75 mm
Walls and roof of an excavation	50 mm	50 mm

B.7 Testing requirements

B.7.1 Introduction

The testing requirements for all materials to be used to produce concrete should adhere to the requirements set out in the concrete construction specifications.

B.7.2 Cylinder and cube making and storage

Concrete cylinders/cubes should be made in the manner described in the concrete construction specifications.

Once made, the cylinders/cubes should be stored at the point of placement for 24 h. During this time, the cylinders/cubes should be covered and treated in the same manner as the concrete that has been poured.

After 24 h, the cylinders/cubes should be stored in water as specified in the concrete construction specifications. When transporting the cylinders/cubes to a bath for curing purposes, the time taken should be minimised.

B.7.3 Testing of concrete cylinders and cubes

Testing of concrete cylinders/cubes should be done as specified in the concrete construction specifications.

B.8 Tolerances

B.8.1 Introduction

Tolerances for underground construction work should be as stated in the concrete construction specifications.

B.8.2 Tolerances for cylinder and cube tests

If acceptance criteria similar to those usually given in the concrete construction specifications for surface concrete were to be applied to underground structural concrete works, almost all concrete poured underground would fail. Therefore, assessment of the tolerances for the test results for cylinders/cubes should have a pragmatic approach applied.

There is no literature to provide guidance on this matter. Rather, experience is used to decide what is acceptable.

One approach that has been used successfully is to use the design strength as the only criterion against which the cylinder/cube test results are evaluated. This methodology implies that a simple pass or fail criterion is applied.

B.9 Transportation of materials in the underground environment

B.9.1 Background

Transportation of materials on surface is easy and has minimal constraints when compared to concrete construction underground.

The context of where the structure is to be constructed, in the underground situation, is a major contributor to the structural designers when preparing their design and construction drawings.

Where decline access is common and mine depths shallower, or where concrete is mixed at a central location underground, it is common to transport concrete underground in agitator trucks. Where concrete is transported in mines with vertical shafts, it is common for it to be transported in buckets and/or dropped down slick lines.

B.9.2 Reinforcement

Access to the area of the mine where construction is to be done provides the parameters against which the criteria for detailing of reinforcement are set to enable transportation and fixing. The designer should consider, amongst other aspects, the following:

— the cross-sectional area of the shaft (vertical or decline) that is used to access the mine;

— the size of the cage/bogey transporting the reinforcement;

— the need to sling long materials under the cage (in the case of a vertical shaft);

— ensuring that the need to sling reinforcement is minimised, as time for slinging of materials is normally limited;

— ensuring that all reinforcement bars can be manhandled.

B.9.3 Formwork

The use of materials for formwork and scaffolding does not differ greatly from surface construction conditions, if at all.

B.9.4 Concrete materials

The use of bagcrete is described in B.4.

This method of transporting concrete materials underground has the advantage of ease of transport. Small bags can be placed into large bags and put on a pallet for ease of handling, both on surface and underground.

B.9.5 Water

The method of transporting water to the work site depends on the conditions in the mine concerned. Should the mine be an existing mine, the existing system to transport water can be utilised. Storage of water at the point of construction, if any, is often dependent on space availability.

If the piping for water is not installed into the construction area, alternative arrangements for the transportation of water are necessary.

B.9.6 Transport of mixed structural concrete

Where concrete is delivered underground, directly from a surface or underground batch plant, by means of a skip or agitator truck, consideration should be given to the expected transportation times from the batch plant to the construction site underground. Additives should be specified where appropriate.

Where concrete is delivered underground through a pipe or lined borehole, adequate provision shall be made at the lower end to absorb the energy and to remix the concrete, which can suffer from segregation of its components, prior to use.

B.10 Reinforcing in structural concrete

All aspects of reinforcing in structural concrete, including materials, bending, installation, and inspections by a competent person should comply with the same standards and procedures used for concrete construction on surface.

B.11 Shaft lining concrete

B.11.1 General

The design, transportation, placement and curing of concrete used in shaft linings is a specialist field with respect to the use of concrete. Recommendations arising from shaft lining experience are given in B.11.2 to B.11.7.

B.11.2 Design

The designer of the concrete lining system specifies the minimum required strength of the concrete.

The ruling criterion for the design strength requirement during the sinking of a shaft is often found to be the minimum strength necessary for the removal of the shaft formwork. This criterion is set by the sinking method used to excavate and line the shaft.

Using the example of a blind sink (the process of excavating a shaft from surface going down) where the shaft lining is to be constructed as soon as possible after excavation of the shaft, it can be necessary to remove the shaft formwork 8 h after placement of the concrete. To achieve this, a concrete strength of 5 MPa can be required 8 h after placement of the concrete. This criterion normally gives a higher 28-day strength than is normally required for design purposes.

When accelerator additives are used in concrete to assist with the high early strength requirements, this can lead to the phenomenon of loss of strength after 28 days. This requires consideration during the design of the concrete mix. It is recommended that the strength of the concrete be tested not less than 56 days prior to the mix design being finalised.

Where water is expected in the shaft, the use of anti-washout agents should be considered in the concrete mix design.

Experience shows that the slump of the concrete is such that there is complete collapse when performing a slump test. This is accepted practice. This arises because the water cement ratio is high, and the cement content can be as high as 700 kg to 800 kg of cement per cubic metre of concrete.

The use of self-compacting additives can be considered, as discussed further in B.11.5.

It is recommended that concrete mix designs be kept as simple as possible.

B.11.3 Batching and mixing of concrete

Batch plants for the mixing of concrete are normally erected as close as possible to the shaft collar to minimise the distance to the slick line or the bucket used to transport concrete down the shaft. This minimises the time required from time of mixing the concrete to it arriving at point of placement.

B.11.4 Transportation

Concrete is often transported down vertical shafts using slick lines. The concrete is pumped from the batch plant into a hopper that sits directly on top of the slick line. The slick line feeds the wet concrete into a kettle (a pot like receptacle) at the discharge point of the slick line. This kettle is intended to break the force of the concrete as it exits the slick line and to remix the concrete after its fall in from the slick line. The concrete is then transported to the shaft liner by means of an elephant hose or similar, the same as used on surface works.

It is normal to install at least 2, but preferably 3 slick lines down a shaft. This ensures a reasonable chance of availability of a slick line at all times during the sinking operations, thus it minimises the possibility of the shaft sinking operations being halted due to slick lines not being available.

Concrete can also be transported down a shaft by means of concrete buckets.

B.11.5 Placement of concrete

As the concrete normally has a very high slump, it behaves like a liquid rather than a plastic concrete seen in surface construction. This leads to the belief that the concrete, when placed, is self-levelling. To an extent this is true, but it is also dependent on the time since mixing occurred. After more time since the batching of the concrete, the setting process of the cement will have advanced more. This can lead to the concrete starting to behave more as a semi liquid rather than a liquid. When this occurs, the self-levelling ability is lost.

Self-compaction of the concrete is also believed to occur, particularly when the concrete is in a liquid state. Experience has shown that this is not always achieved. When self-compacting additives are included in the concrete mix design, it is recommended that compaction of the concrete, once placed, be undertaken using vibrators.

B.11.6 Curing of concrete

The duration of curing of the concrete in shaft lining can be expected to be limited. As the required design strength is usually achieved due to the high early strength requirement for formwork stripping, the lack of curing is not normally a concern.

In a blind sinking operation, the ambient temperature and velocity of the air vary quite significantly depending on the operation in progress at any particular time. Temperatures of up to 32 °C when personnel are in the shaft bottom area can be expected, along with air velocities that are relatively low.

Following blasting in the shaft, ventilation increases to the maximum possible to exhaust the blasting fumes. This increases the air velocities and the ambient air temperature.

If curing of the concrete is a concern, following formwork removal, a proprietary curing compound can be applied. However, the use of curing compounds in the shaft sinking environment has not been documented.

Thermal cracking can occur in concrete shaft linings. This is particularly the case if high performance concretes, and or high strength concretes, are used.

B.11.7 Testing of concrete

The concrete should be tested as specified in the specifications. It is expected that, as a minimum, this should include slump or flow characteristics of the concrete once batched, and strength tests.

The slump or flow characteristics of the concrete should be tested at the batch plant.

The samples for strength testing are normally taken at the point of discharge into the slick line. Further samples can be taken on the sinking stage after discharge into the point of placement. The samples made underground should be kept at the point of placement (on the stage is acceptable) for 24 h. Thereafter, they should be transferred to a curing bath.

Once the test cylinders or cubes have been crushed, the criteria given in the construction specifications should be used to assess the acceptability of the concrete.

If the results of the samples taken at the point of placement are found to be low, the samples taken at the point of entry to the slick line can be used for reference. Irrespective of the result of the reference samples however, the concrete that is in question should be tested for acceptability as per the construction specifications.

Annex C
(informative)

Design and construction of parallel sided high-pressure bulkheads by mortar intrusion

C.1 General

This annex provides background and additional recommendations for the design, construction and condition monitoring, including record-keeping, of parallel sided high-pressure bulkheads that are subject to high hydrostatic pressures and are constructed using the process of mortar intrusion into pre-placed coarse aggregate.

It is presumed in this annex that the parallel sided high-pressure bulkhead is constructed in a horizontal, or near-horizontal excavation. Where the parallel sided high-pressure bulkhead is constructed in a vertical or steeply inclined excavation, appropriate consideration should be given to changes that may have to be made.

NOTE Parallel sided high-pressure bulkheads are often the preferred option over others such as positive tapered or hitched excavations as no additional shaping has to be engineered or excavated.

In some countries, the use of conventionally designed structural concrete high-pressure bulkheads is preferred, whilst in other countries the use of the parallel sided high-pressure bulkheads is preferred. The decision regarding which to use often lies in the expected permeability of the surrounding (or host) ground into which the structure is constructed.

See Reference [9] for hitched high-pressure bulkheads.

C.2 Materials

C.2.1 General

The design engineer should approve all mortar and grout mixes. The use of any cement additives and extenders is acceptable, but should be approved by the design engineer.

C.2.2 Cementitious binder

The best results are likely to be achieved with cements having contents of 50 % ground granulated blast furnace slag or 50 % fly ash.

The 28-day unconfined compressive strength of the mortar should be at least 25 MPa.

C.2.3 Fine aggregate (sand)

Mortar sand should meet the requirements normally specified for concrete.

Fine aggregate should comprise uniform grained sand all of which passes a 1 180 µm screen and not more than 4 % passes a 75 µm screen.

C.2.4 Coarse plums aggregate

Plums should be rock that is categorised as very strong, durable rock, free from flaky elongated slabs, shale, schist and such like. Plums should be fairly round in shape and size, varying between a minimum of 75 mm and a maximum of 300 mm in diameter and not exceeding a mass that one person can handle.

C.2.5 Water

Potable water should be used. The use of non-potable water should only be used after extensive water quality testing to prove that the long-term durability of the mortar and or grout will not be affected.

C.2.6 Cement additives

For underground conditions, the added complications involved in introducing additional processes and/or material should be avoided. However, retarders and plasticizers may be employed to prolong final setting time and improve flow characteristics respectively, but only under the guidance of a competent person. In particular, the long-term durability should be considered.

Where additives are used, additional quality control measures should be put in place and controlled under strict supervision.

C.2.7 Bulkhead intrusion mortar

C.2.7.1 Sand/cement ratio

The sand/cement ratio used depends on the circumstances relating to any specific intrusion mortar operation. It is highly desirable that the water/cement ratio be maintained at 0,60 to 0,65. Therefore, to obtain optimum mortar viscosity to ensure a bleed capacity of the order of 3 % but not more than 5 %, the sand/cement ratio by mass can vary between 1,6 and1,0.

C.2.7.2 Strength

The 28-day intruded mortar strength should be at least 25 MPa.

C.2.8 Injection grout

Different mixes are used to suit specific conditions to achieve maximum penetration and thereby optimum sealing.

C.3 Design requirements

C.3.1 Load factors

As the ultimate load is applied slowly and its maximum value is exactly determinable, a fairly low load factor may be used. A load factor of not less than 1,1 is recommended where the water level used in design cannot be exceeded, such as where it is taken as the ground surface. Where the assumed water level is not accurately known, a load factor of not less than 1,3 is recommended. Where water bulkheads are designed for intermediate water levels, or for perched water tables, a higher load factor should be used.

C.3.2 Design procedures

C.3.2.1 Shear strength

The bearing strength and shear strength of the ground surrounding the high-pressure bulkhead varies depending on the type of ground, and its condition (i.e. whether it is weathered or fractured). The bearing strength and shear resistance of the ground surrounding the high-pressure bulkhead should be determined if unknown. Indicative values are shown in Table C.1.

Table C.1 — Indicative ultimate strength value for different ground types

Descriptor	Typical bearing strength (MPa)	Typical shear strength (MPa)	Typical ground types
Extremely strong	60	>10	Chert, fresh basalt, gneiss, granite, quartzite
Very strong	30	4 to 10	Basalt, gneiss, limestone, marble, sandstone
Strong	15	2 to 4	Limestone, marble, sandstone, schist, shale
Medium strong	5	>1	Claystone, coal, schist, shale, siltstone

C.3.2.2 Bulkhead length

a) Applied load

The load applied to a parallel sided high-pressure bulkhead is:

$$F_H = A_H \cdot \rho_L \cdot g \cdot H \qquad \text{(C.1)}$$

where

A_H is the cross-sectional area of the high-pressure bulkhead (m^2);

ρ_L is the density of the liquid (kg/m^3);

g is the acceleration due to gravity (m/s^2);

H is the maximum height of liquid above the centre of the high-pressure bulkhead (m).

Including the load factor, the ultimate parallel sided high-pressure bulkhead design load is:

$$F_U = \varphi_H \cdot A_H \cdot \rho_L \cdot g \cdot H \qquad \text{(C.2)}$$

where φ_H is the load factor for the additional permanent load.

Typical values of φ_H have been taken as 1,3 to 1,6.

b) Strength

The factored parallel sided high-pressure bulkhead design strength may be taken as:

$$F_R = L \cdot \phi_H \cdot P \cdot v_I \qquad \text{(C.3)}$$

where

L is the length of the high-pressure bulkhead (m);

ϕ_H is the resistance factor for the shear resistance between the high-pressure bulkhead and the surrounding ground;

P is the average perimeter of the interface between the high-pressure bulkhead and the surrounding ground (m);

v_I is the shear strength of the surrounding ground (N/m^2).

Typical values of ϕ_H have been taken as 0,1 to 0,15.

c) Watertightness

The hydraulic gradient across the parallel sided high-pressure bulkhead length may be taken as:

$$i = \frac{H \cdot R_D}{L} \quad (C.4)$$

where

H is the maximum height of liquid above the centre of the high-pressure bulkhead (m);

R_D is the relative density of the liquid;

i is the hydraulic gradient.

The hydraulic gradient to be used should be determined based on site conditions.

A hydraulic gradient not exceeding 50 has been applied successfully in very strong and reasonably intact ground.

Where pumping systems can deal with a reasonable amount of leakage, the actual hydraulic gradient adopted may not be very important. However, where only limited leakage can be tolerated, the following procedure is recommended:

i. permeability testing of the ground mass surrounding the high-pressure bulkhead should be carried out;

ii. injection grouting of the ground mass surrounding the high-pressure bulkhead location should be done if necessary to reduce the permeability;

iii. and/or a lower value of limiting hydraulic gradient should be adopted.

d) Parallel sided high-pressure bulkhead length

The length of the parallel sided high-pressure bulkhead may be taken as the greater of:

$$L \geq \frac{\varphi_H \cdot A_H \cdot \rho_L \cdot g \cdot H}{\phi_H \cdot P \cdot v_I} \quad (C.5)$$

based on strength, or:

$$L \geq \frac{H \cdot R_D}{i} \quad (C.6)$$

based on permeability.

C.4 Service and grout pipes

C.4.1 Cast-in service pipe and fastener materials

An assessment should be made of the potentially corrosive nature of water to be retained on the wet side of the plug and similarly on the dry side, with particular emphasis on the acidity level, and dissolved chlorine and sulphur compounds. The pipe and valve material chosen should show significant resistance to long-term corrosion in terms of the anticipated service. Corrosion allowances should be applied when calculating pipe wall thicknesses and fastener dimensions.

Seamless piping, without longitudinal welds, should be used unless the weld design and technique used has been demonstrated to have corrosion resistant properties at least equal to that of the parent metal.

Valves, pipe and any puddle flanges should be manufactured from material compatible with that of the pipes and having as far as possible the same electrode potential in the galvanic and electrochemical series.

Fastener and gasket materials should similarly be selected for corrosion resistance. Any potential for galvanic corrosion cells to develop between fasteners and piping should be mitigated by using impervious and chemically stable washers and coatings.

Gaskets to be used within the body of the plug should remain stable at the anticipated temperatures arising from the heat of hydration during construction and should withstand temperatures in excess of 90 °C. Spiral wound type designs have been proven by experience and should be used internally. Coupling designs with compatible metallic compression rings are preferred provided they are specified and have been proven through actual tests to seal effectively at 120 % above the nominal rated plug pressure.

All welding should be carried out by appropriately trained and experienced welders.

Austenitic stainless steels are preferred over ferritic stainless steels in view of their improved corrosion resistance that includes stress corrosion and weldability.

Allowance should be made for puddle flanges along the length of the service pipe to avoid a preferential flow path for water.

The manufacture of the service pipes and valves, watertight doors and other equipment should have a quality management system in place, such as ISO 9001. Proof testing should include pressure tests of individual valves, doors and other equipment, as well as the trial assembly with all components fitted.

C.4.2 Cast-in service pipes

C.4.2.1 Position of service pipes

The positioning of the service pipes should be determined with consideration being given to minimizing the risk of concrete shear failure between pipes, the practicalities of packing plums between the pipes and accessibility to control valves on the dry end of the high-pressure bulkhead. The spacing between pipes and walls, and between any two pipes, should be not less than twice the largest plum size.

C.4.2.2 Pipe support

Bending forces on the pipes emerging from the dry face, arising from valve static weight and actuation forces, should be included in pipe wall thickness stress calculations. Adequate support should be provided for long overhangs to minimize bending stresses.

C.4.2.3 Ergonomics

Valves should be positioned such that they can readily be installed and operated without interference. Particular care should be exercised in the positioning of hand wheels so that operators are not at risk of injury.

C.4.2.4 Collision damage protection

Dry side pipes and valves should be protected from possible impact by for example runaway trains and mechanized mining equipment.

C.4.2.5 Provision for grouting of the service pipes

The design should incorporate a method that allows grouting and plugging of the service pipes once the bulkhead is in service and subjected to hydraulic loading.

C.4.2.6 Valve configuration

Service pipes should be fitted with a double-valve system. The valve nearest to the bulkhead should be the isolating valve and the other valve should be the operating valve.

C.4.2.7 Service valves

Service valves should be designed for bi-directional flow and be manufactured from material compatible with that of the pipes and having as far as possible the same electrode potential in the galvanic and electrochemical series. An alternative galvanic corrosion protection system should be installed should this not be feasible in any particular application.

Valve actuators should be manufactured from materials that do not interfere with their function over the anticipated life of the installation. Similarly, any deterioration of actuating mechanism lubricants under the operating environment should not interfere with valve operation.

C.4.3 Mortar intrusion pipes

During the process of packing the plums and coarse aggregate in the bulkhead structure, ASTM-A106 Grade B seamless 25 mm diameter Schedule 40 sandblasted piping should be installed in successive layers commencing with the lower level pipes just above the floor of the bulkhead section.

C.4.4 Tightening injection pipes

In addition to the intrusion pipes, ASTM_A106 Grade B seamless 50 mm diameter Schedule 80 sandblasted pipes should be installed in the sequence as specified on the bulkhead design drawing to be used for injection of tightening grout. The ground to bulkhead interface area that is covered by one pipe should not exceed 3,5 m^2.

C.4.5 Design drawings

Detailed construction and assembly mechanical drawings for all pipes should be prepared and properly approved.

The drawings should include full specifications of standards used, weld procedure, materials, proof testing, fasteners, configuration and assembly procedures.

C.5 Bulkhead construction

C.5.1 Site selection and preparation

The selection of a site for a bulkhead requires a detailed assessment, on a local scale as well as a regional scale, of all the factors affecting the stability and water tightness of the proposed bulkhead site.

C.5.1.1 Ground engineering investigation

A ground engineering investigation for site preparation should consider at least the following items.

a) Site investigation

The importance of a thorough understanding of the geological setting and ground engineering domains cannot be over-emphasised. Site investigations should be carried out to verify existing geological, hydrogeological and ground engineering data. Potential bulkhead sites should be identified. Specific geotechnical drilling should be carried out in these areas.

The influence of the following geological conditions should be evaluated and predicted:

— structural such as geology features including faults, planes of weakness and discontinuities;

— in situ and induced stresses;

— groundwater;

— quality and durability of the ground and ground mass;

— ground mass hydrogeological conditions including permeability.

b) Geotechnical logging of borehole core

The borehole core should be suitable for geotechnical logging. If necessary, double or triple tube drilling should be considered. The orientation of the borehole core in relation to the jointing should be carefully considered. The core should be logged per geotechnical zone within which the core displays similar geotechnical characteristics, and within which the ground mass is expected to perform uniformly.

c) Mapping of exposed ground surfaces

To determine the potential for the formation of blocks and wedges, it is necessary to know the following parameters for each joint set:

— orientation (dip and dip direction);

— spacing (distribution);

— length;

— surface condition.

d) Quantification of ground strength parameters

Other ground parameters that need to be quantified are:

— drill core recovery (expressed as RQD);

— ground type;

— ground competence;

— weathering;

— hardness.

e) Laboratory ground testing

Specific laboratory testing should be carried out in order to quantify in situ ground properties more accurately. The testing programme should be designed based on the current level of knowledge and confidence in the available data, the anticipated risks and the potential failure modes and mechanisms. The durability of the different ground units including joint infilling, under the anticipated hydraulic gradient in-service conditions, should also be considered.

f) Estimation of in situ ground stress conditions

The field stresses (virgin stresses plus mining induced stresses) present in the ground mass forming the water barrier and at the proposed plug site should be assessed by considering the following steps:

— determine the in situ stresses in the ground,

— consider the database of in situ stress measurements, if any exists for the relevant mining area;

