

SHAFTS – DEFINITIONS AND CLASSIFICATIONS

ITA - Working Group n° 23
Shaft Design and Construction

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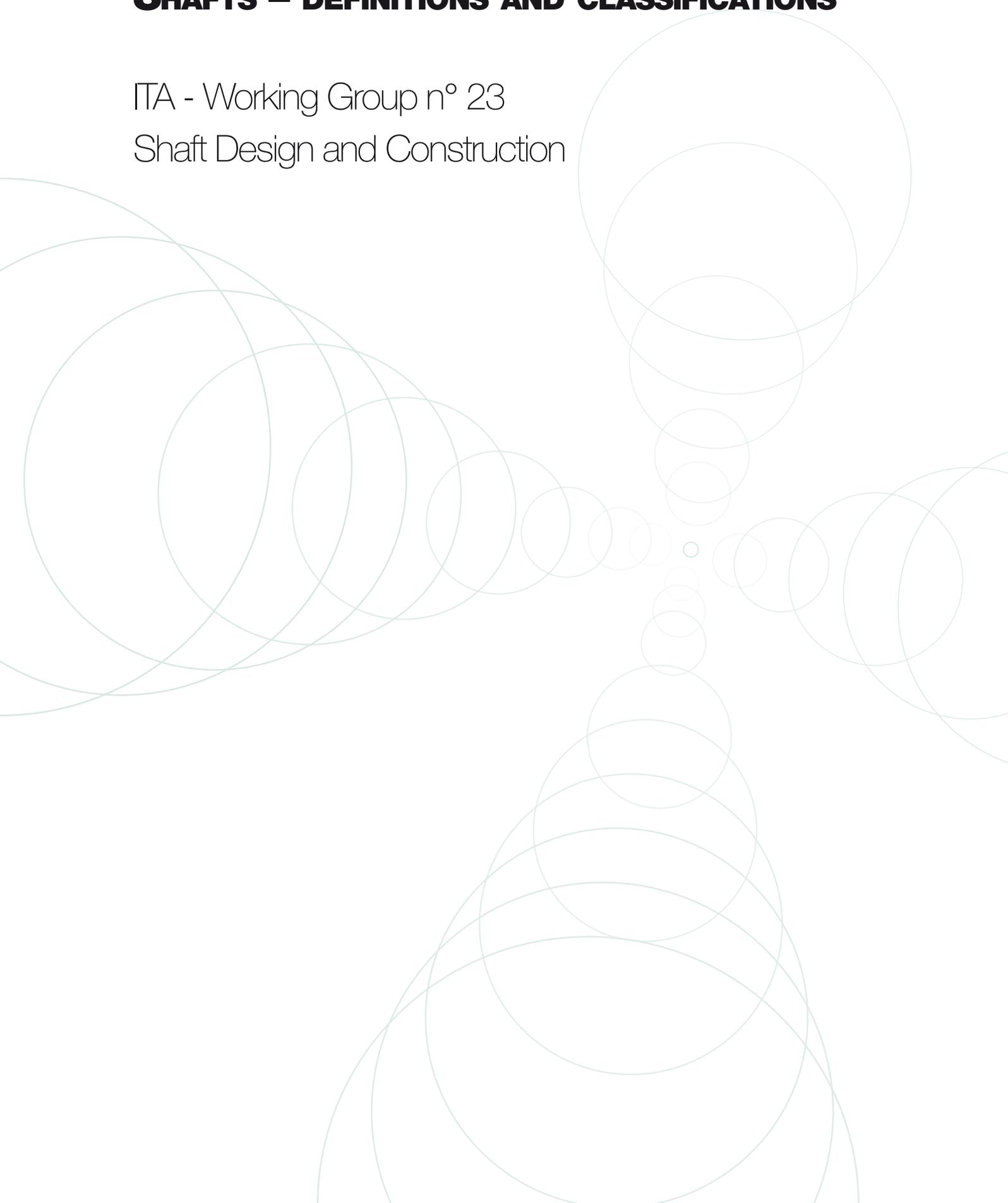
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SHAFTS – DEFINITIONS AND CLASSIFICATIONS

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Shaft Design and Construction



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The ITA general Assembly approved the proposal for establishing Working Group 23 on «Design and Construction of Shafts» in May 2019 at the World Tunnelling Congress in Naples.

Following the first WG 23 meeting in Naples, the need for defining common terms was raised and it was decided to prepare a document to explain and develop the correct terminology and nomenclature for shaft design and construction.

It was also discussed that suitable classifications for shafts based on their geometry, application, ground conditions, and construction methods was needed for a more uniform understanding of design and construction implications.

This document is prepared in response to the above mentioned needs and provides common definitions for relevant terms in addition to introducing different types of classification systems for shafts that can be implemented during design and construction of these structures.

The document contains contributions of various individuals. Work has been coordinated by Siamak Hashemi (Animateur of WG 23) and Jamal Rostami. Tarcisio Celestino was the Tutor of WG 23.

1 >> INTRODUCTION

Shafts and inclined openings are often integral parts of underground facilities and are the main means of access to the lower levels in mining operations. In tunneling projects, shafts are often used for launching the tunnel excavation and are usually on the critical path of the project schedule. Shafts provide access to mass transit and underground rail tunnels for passengers, an escape route, or other types of services such as utility corridors from surface to tunnel level. Shafts can provide ventilation for metros, railways, highways, and other mass transit tunnels. They may also be used as inlet and outlet structures for flood control tunnels and dams, as down-take and up-take shafts for water supply tunnels, or as drop shafts for wastewater tunnels.

The rate of shaft sinking is much lower than driving tunnels of the same size and has long remained stagnant. The past few decades have witnessed major advances in tunneling using various mechanized systems to increase the daily advance rates to the tune of several tens of meters per day, while in the shaft sinking operations 1-2 m per day is often the norm. There have been some movements in different operations where new and mechanized shaft construction methods have been applied, but the knowledge of shaft design and construction, including raises and inclines / declines, requires further engineering advancement in order to be able to face new challenges.

Obviously, different methods can be used to access the underground. Choosing the most suitable method includes consideration of the type of use. Each tunneling or mining project has its unique characteristics and hence each proposed shaft within a project will also have its own individual characteristics and conditions. Access to the subsurface via shafts could either be provided between surface and underground or between two different subsurface levels. In mining when the top of the excavation is the ground surface, it is referred to as a «shaft»; when connecting different levels in a mine and the top of the excavation is underground, it is called a «winze» or a «sub-shaft». When a

winze is worked upwards from a lower level it is usually called a «raise».

The project characteristics and conditions will dictate parameters for design and construction of the various elements, for example temporary or permanent ground support. Selecting the necessary support will typically be based on factors such as :

- Functional requirements
- Depth of shaft
- Size, shape, and geometry of shaft
- Geotechnical, hydrogeological, and environmental conditions
- Available working area
- Adjacent structures
- Direct or indirect loadings (such as traffic)
- Allocated budget
- Time and schedule
- Local regulations and codes

In mining, other access passageways include «adits» which are horizontal or near horizontal entrances. They are used for entering the subsurface, drainage of water, ventilation, exploration for mineral veins, or extraction of minerals at the lowest convenient level. In tunneling, the term «adit» refers to a short horizontal or near horizontal passage between a shaft and the main tunnel or a cross passage between two parallel tunnels. The term «drift» in mining is a more general term for horizontal or sub-horizontal passages that follow a mineral vein or seam. Unlike an adit, a drift does not need to break out to the surface. Adits can only be driven into a mine where the local topography permits. Most adits are designed to slope slightly upwards from the entrance so that water will flow freely out of the mine. Many use the term «tunnel» interchangeably with adit, drift, and of course tunnel, which is often used for a near horizontal opening that daylight on both ends.

Another type of passage is the «ramp» (or «drift») which is a passage driven downward from the surface connecting one level to another. The slope of ramps is determined

by different factors such as the capacity of vehicles and presence of curves and level intersections. Hence they are more attractive for connecting shallow subsurface levels. Ramps allow increased equipment mobility between levels compared to shafts which requires minimizing the size of equipment fleets and increasing utilization of equipment.

A «decline» is another type of passageway to underground space and sub-levels that can either be straight or spiraled (Bustillo Revuelta, 2018). It can also be a system of ramps and crosscuts (horizontal drives) that connects different points and sublevels (Brazil, et al, 2008).

Some of the terms and their definitions used in the industry in relation to shafts and other types of underground passageways are provided in Section 2.

2 >> DEFINITIONS

Construction of shafts is not new and has been used since thousands of years ago for mining activities (Evans, V., and Graham, C., 2020). However tools and methods have evolved and shafts are nowadays not only used for mining operations but also for civil engineering purposes such as providing access and ventilation for tunnels and other underground structures. The terms and definitions provided in this section include definitions used in either civil or mining engineering. It should be noted that some of these terms are used differently across the industries and even within each of these industries some terms may differ, for instance some terms used in coal mining are not being used in other types of mining operations. Several older terms are still in use whilst some terms have changed or been replaced, especially those related to newer technologies. Some terms are more common in some parts of the world whilst the same definition is applied to a different term in other countries. The main objective of this section is to define the most current terms used across the industries and refer to different versions where possible.

Adit : A horizontal or near horizontal passage driven from the ground surface into a ridge or mountain for the purpose of working, ventilating, or removing water from a mine.

Air lock : A casing at the top of a shaft that minimizes air leakage (also called shaft casing).

Air shaft : A shaft that is mainly used for ventilation (also called ventilation shaft).

Bearing set : A thickened portion at the bottom of the collar lining designed to carry loads from above by bearing on rock.

Blind shaft : A sublevel shaft, connected to the main shaft. An internal shaft or a winze (Pryor, 1963; Graham, 1996).

Blind boring : A method where the excavation of a raise is carried out upwards with no access to the upper level. Blind boring can be carried out with or without the use of a predrilled pilot hole (See «boxhole drilling»).

BorPak : a special self driven full-face machine mounted on a crawler track for blind boring which climbs up the raise as it bores using grippers (Rustan et. al., 2010; Tatiya, 2013).

Boxhole drilling : upward excavation of a raise where a pilot hole is drilled as a guide from the lower level and a reamer bit is then driven along the pilot hole to the upper level, also referred to as Upream Drilling, Blindhole Drilling, or Raise Drilling.

Bunton : a horizontal steel structure that supports the shaft guides and underground services. Buntons can be either constructed from standard rolled steel sections or specially formed aerodynamic shaped steel sections. Buntons are typically supported on the shaft lining or shaft wall.

Caisson sinking : A method of sinking a shaft in soils with high water table down to firm strata. The caisson comprises of the walls of the final structure which is gradually lowered (under its own weight, or jacked down) as the shaft is excavated inside the walls.

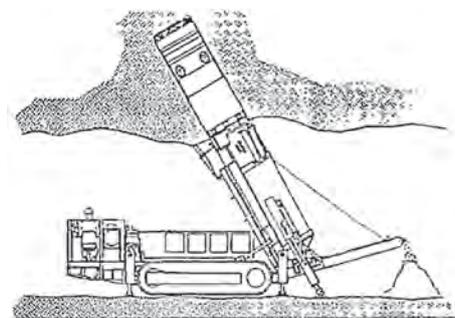


Figure 1 : Schematic Drawing of BorPak – Raise Boring Machine (Tatiya, 2013).



Figure 2 : Caisson sinking using jacks (Auld, 1997)

Decline : A sloping underground passage that provides access from the ground surface or from one level to another and is excavated at low angle with a dip less than 20 degrees (Bustillo Revuelta, 2018).

Downcast shaft : Intake air passage or ventilation shaft through which air enters a mine or tunnel (also known as fresh air ventilation shaft (FA) or fresh air vent raise).

Drops shaft (method) : A sinking system that uses a cutting shoe at the bottom of a shaft lining which is continually being augmented as the shoe descends whilst the material inside the lining is being excavated. Also known as caisson sinking, or sinking caisson. (U.S. Bureau of Mines, 1968; Smirnov and Bereznitskii, 1981).

Drop shaft : A shaft used in water conveyance tunnels or sewer systems to transfer flows from a higher elevation to a lower one.

Drift : A horizontal or inclined passage from the surface or underground in a mine.

Drilled shaft : also known as drilled piers, caissons, bored piles, or cast-in-drilled-hole piles, are a form of deep foundation system constructed by filling a cylindrical excavation with reinforced concrete to form the pile (FHWA, 2010). Diameters for most normal applications are between 1 to 3 meters, but drilled shafts with diameters up to 9 m have also been constructed (Smith et al., 2003).

Footwall : The block of rock that lies under an inclined vein or bedded deposit.

Foreshaft : The first section of a shaft constructed where the overburden thickness is extensive and consist of a substantial reinforced concrete structure that extends down to solid rock where the plant and services for the main shaft sinking are installed (Grieves, 1996).

Freezing method : A method of shaft sinking through water-bearing strata, especially when loose or unstable, where artificial cooling, such as refrigerated brine or liquid nitrogen (LN), is used to freeze the ground to strengthen

2 >> DEFINITIONS

the soil / unconsolidated materials and offer sealing to stop the flow of water, so that the shaft can be excavated and pre-supported by the frozen zone.

Guide : vertical steel formed sections or that of steel wire ropes use to guide the man/material conveyance or rock hoisting skip/conveyance up and down the shaft.

Headframe : The structural frame above a shaft, used to support the hoist or winch ropes and to house wire rope guiding systems and rock transferring systems. Also called winding tower, hoist frame, pit frame, poppet head, headgear or pit head. In mining application headframe is a permanent structure that facilitates operation of the shaft during its service life.

Hoist : A device used to raise or lower conveyances within a shaft.

Hornset : See “bearing set”.

Incline : An inclined surface connecting two levels, also referred to as a slope or ramp often at a slope angle that allows for operation of the vehicles or conveyors to be used during the service life of the incline. Typical max slope is around 15% for rubber tired vehicles and around 15-20 degrees for operation of the conveyor belts. (Synonymous with Decline).

Inclined shaft : A shaft sunk at an inclination from the vertical. Slope of inclined shafts are between vertical and a typical incline, defined earlier.

Intermediate shaft : The height of shaft excavated and supported below the coping section and above the station level. The intermediate shaft is usually excavated in rock.

Mechanical Raise Climbing : upward driving of the raise from lower level through the use of a platform that can climb a special rail mounted on the roof of the tunnel and turns on the side of the raise. This technique was introduced by Alimak Company (Tatiya, 2013) and hence sometimes called Alimak raise driving.

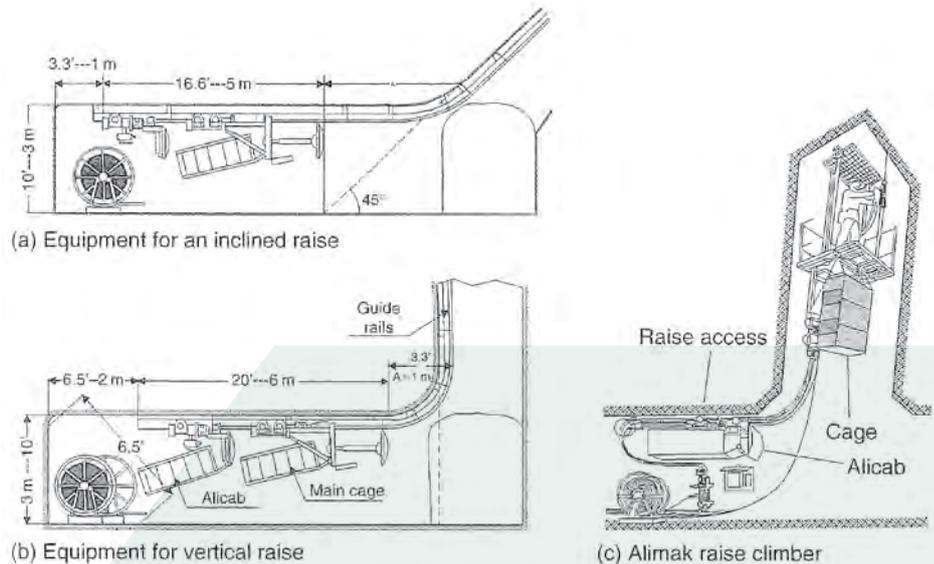


Figure 3 : Schematic drawing of the Alimak system (Tatiya, 2013).

Portal : The mouth of a tunnel, adit, ramp or decline is referred to as portal and constructed to provide protection from the immediate area above the portal entrance.

Ramp : An inclined access from the surface into the mine or between different elevations. Typical slopes are the same as inclines.

Raise borer : A machine used to excavate a circular shaft between two levels of the underground or between an underground level and the surface without the use of explosives.

Raise drilling : see “boxhole drilling”.

Raised shaft : A shaft driven upward from a lower level to connect with the level above, also called “raise”. This often refers to the conventional excavation by drill and blast.

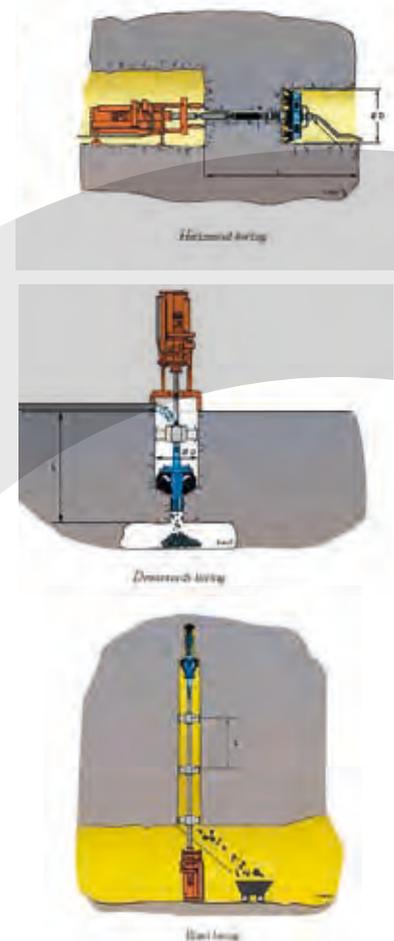
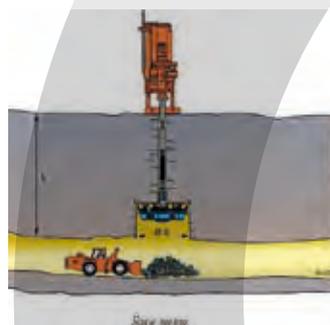


Figure 4 : Schematic drawing of Raise boring, horizontal boring, Raise drilling (or blind boring), Down reaming (Epiroc).

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Service shaft : A shaft employed solely for the hoisting of workers and materials to and from underground.

Shaft : A vertical or steeply inclined passage extending downward and cut through the ground at an angle greater than 20° to the horizontal. (USACE, 2014).

Shaft (shallow) : A shaft which can be constructed from the surface using Civil Engineering methods. The depth is limited by the safe winding limit for a crane (see also Section 3.3. Depth)

Shaft (deep) : A shaft which requires to be sunk using a headframe and sinking stage for construction (see also Section 3.3. Depth)

Shaft barrel : the part of the shaft that continues into the ground beneath the shaft collar.

Shaft collar : The uppermost section of a shaft that opens to the ground surface also called Bank or Deck. This section is designed to accommodate live loads during shaft sinking and the loads and duty of a permanent headframe or enclosed ventilation building. Initially it provides a rigid, fenced structure and often includes a concrete slab at the ground surface (Grieves, 1996). The dimensions of a collar such as depth, shape and thickness depend on shaft function, overburden characteristics and hydrological conditions, shaft construction methods, and loading conditions (Unrug, 1984).

Shaft collar pad : The concrete slab near the ground surface at the top of the shaft collar.

Shaft coping : The barrel of the shaft below the collar pad.

Shaft inset : The intersection point of a shaft and a horizontal tunnel; the entrance to an underground passage from a shaft; a landing, also called a shaft station.

Shaft lining : The temporary or permanent cover installed to support shaft walls. In the past steel, or bricks were used for this purpose. Nowadays, cast-in-place concrete

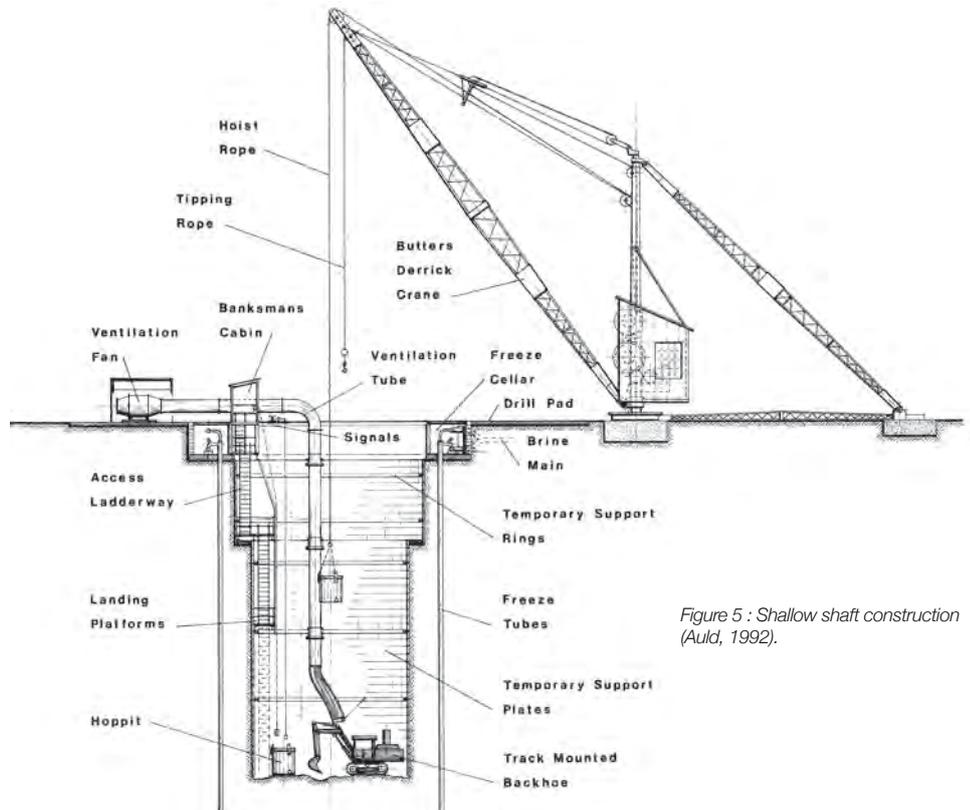


Figure 5 : Shallow shaft construction (Auld, 1992).

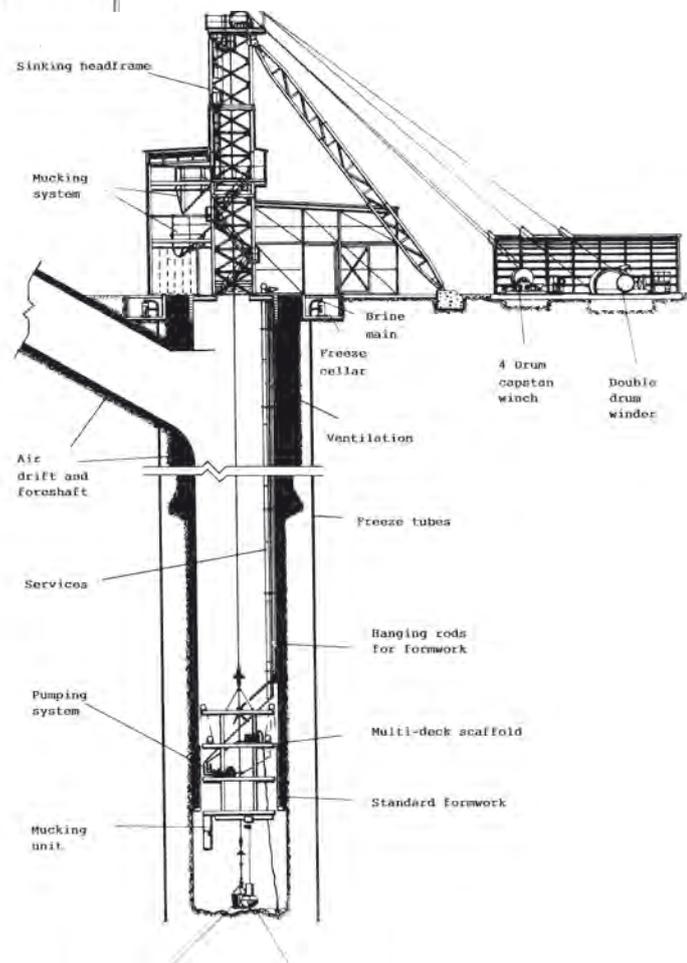


Figure 6 : Deep shaft construction (Auld 1992).

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or a precast concrete or spheroidal graphite (SG) cast iron segmental lining is generally favored as a permanent shaft support. Shaft lining is also used to support the permanent shaft steelwork (guides and buntons) and services to the underground workings.

Shaft lining inserts : Inserts are set into the concrete shaft lining to attach (fix) buntons and brackets used for the support of shaft services (utilities).

Shaft mucker : A machine used for removing the muck, which has been loosened at the bottom of a shaft.

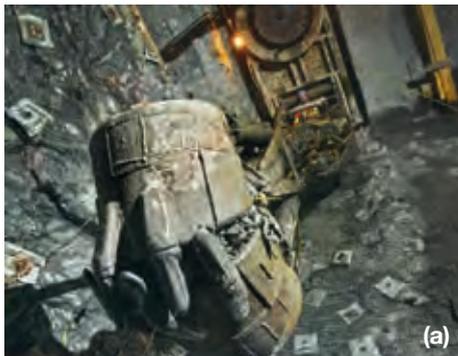


Figure 7 :
(a) Clam shell Grab Bucket Shaft mucker (Slack, 2020),
(b) Cactus Grab mucker (Niemann,2020).

Shaft rib : See “shaft wall”.

Shaft pillar : An area of a mine left unworked around the shaft to ensure stability.

Shaft services : permanent or temporary services installed in the shaft to service the

underground workings of the mine, like power cables, service water, pump columns, grout ranges and other cables for communications etc. Temporary services are used only during the shaft sinking phase of the shaft.

Shaft sinking : Excavating a shaft downwards. Also called shaft mining. (Nelson, 1965; Graham, 1996)

Shaft station : An enlarged area where the shaft barrel intersects a level that allows workforce, materials, and supplies to be loaded and unloaded.

Shaft survey : A survey to determine the alignment of a shaft. (Graham, 1996)

Shaft wall : The lining of a shaft that supports the surrounding ground; the side of a shaft forming its perimeter (the inside diameter).

Sheave : The grooved wheel of a pulley or block over which wire rope is passed.

Slope : See “decline”.

Sump : The bottom of a shaft that is used for collecting drainage water or spill material, usually excavated deeper than the station level.

Tubbing : A lining of metal around the shaft of a mine; A series of cast-iron segments bolted together into rings which are used to line a shaft in ground that cannot be controlled by other less costly methods. Tubbing must be installed bottom up and may be considered permanent due to high hydrostatic pressure at depth.

Tunnel : An excavation beneath the surface of the ground that intercepts the surface at two or more points, the longer axis of which is near horizontal.

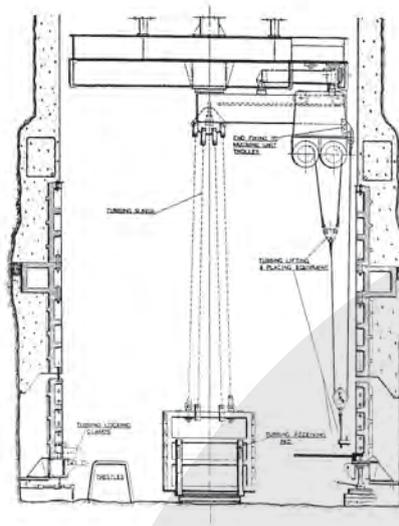


Figure 8 : Installation of cast iron tubbing (Auld, 1992)

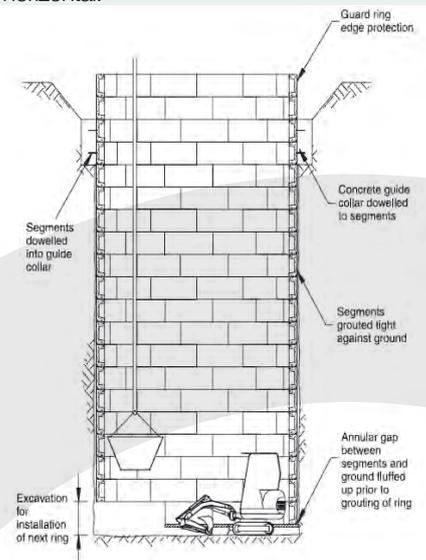


Figure 9 : Shaft construction using underpinning technique (BTS and ICE, 2004)

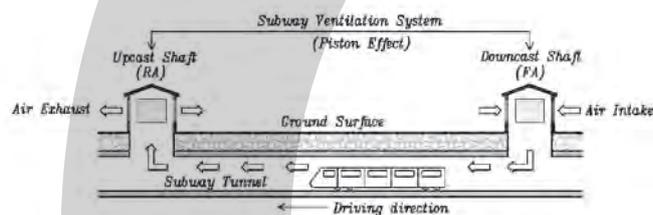


Figure 10 : Schematic diagram of Fresh Air (downcast) and Return Air (upcast) ventilation shafts in a subway tunnel.

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Underpinning : A technique used for construction of shafts if the ground is competent and can remain unsupported for the required depth and time for excavating and erecting a number of lining segments. Excavation starts at ground surface and continues until a complete ring of segments can be installed and the gap behind the lining is grouted.

Upcast shaft : Return air passage or return air (RA) ventilation shaft through which upward current of air leaves a mine or tunnel.

Water ring : A narrow chamber excavated and lined outside the shaft lining that usually follows the full circumference of the shaft. The shaft waterproofing is terminated in the top of the water ring, where the water is collected in a channel and directed to drain pipes leading into the mine groundwater collection system.

Winder : A hoist or winch.

Winding shaft : A shaft used for hoisting miners or materials, also called hoisting or service shaft.

Winze : A vertical or inclined underground opening driven downwards from an upper level. A «sub-shaft» or «internal shaft».

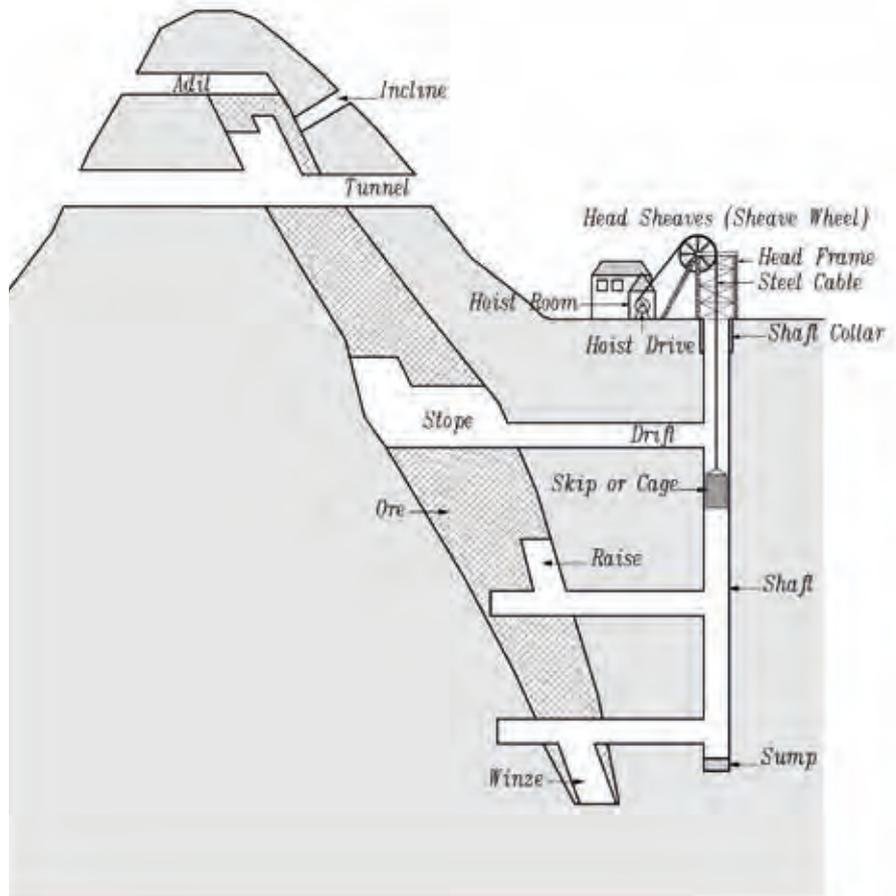


Figure 11 : Schematic diagram of a mine shaft

3 >> CLASSIFICATION OF SHAFTS

Shafts can be classified based on different features. Each feature can have different relevant categories. Once a shaft is classified correctly, suitable design and construction considerations can then apply. Some classification / aspects need to be considered in combination and they are not mutually exclusive, indeed any shaft could be a part of several classes (i.e. an elliptical mine shaft that goes through soil and rock using different ground support types). Ground conditions will determine several factors such as the size of the shafts or partial sinks, construction technique, support requirements etc. Hence a thorough ground investigation needs to be carried out at the site, and results need to be fully reviewed to determine how findings could affect the design and construction sequence.

3.1 SHAPE

Shafts may be constructed in different shapes, depending on project requirements. These include the following :

- (a) circular
- (b) elliptical
- (c) rectangular

For structural efficiency reasons the cross-section of shafts are generally circular or elliptical, although other geometries may also be used. Shafts must resist lateral pressures such as ground and water pressure during their construction and operation. Circular shafts rely on compression to carry the lateral loads and require less internal bracing and reinforcement. Rectangular shafts have historically been used for both shallow and deep mining operations but are used less frequently nowadays. They are used for launching and serving tunneling operations - for example TBM assembly and launch operations. Often larger rectangular shafts that are used to launch the tunneling operation for metro applications using cut and cover construction method are the metro stations. Many of the larger circular shafts used for launching TBMs for water and sewer applications are subsequently used as pump stations.



Figure 12 :
(a) rectangular service shaft of Tehran's Metro Line 7 at Sanaat Square (Mohammadi, 2020) and
(b) circular access shaft of Tehran's Metro line 6 at Valiasr Square (Mohammadi, 2020)

3.2 SIZE

Before designing a shaft, the minimum size of the shaft must be determined. This decision may depend on the type of construction or on the size of a structure located at the start or end of the shaft. The size of the shaft is determined by the volume of air required for ventilation, or depends on the size of equipment or material that will be fitted into or handled through the shaft, for instance where a lift needs to be accommodated or utilities installed. Often the rule of thumb for launching a TBM is to have the shaft with minimum diameter 2.5 to 3 times machine excavation diameter. For example, a typical single track metro line is often mined using a 6.5m diameter shield, and typical minimum shaft diameter for launching such machine is 16 to 20 m.

Irrespective of their shape, shafts can be classified into the following groups (adapted from Holl, Fairon, 1973) :

- a) Very Small, $< 20 \text{ m}^2$ ($\Phi \sim < 5 \text{ m}$)
- b) Small, $20\text{-}35 \text{ m}^2$ ($5 < \Phi < 6.5 \text{ m}$)
- c) Medium, $35\text{-}50 \text{ m}^2$ ($6.5 < \Phi < 8 \text{ m}$)
- d) Large $50\text{-}115 \text{ m}^2$ ($8 < \Phi < 12 \text{ m}$)
- e) Very large $> 115 \text{ m}^2$ ($\Phi > 12 \text{ m}$)

3.3 DEPTH

Classification based on depth is always difficult due to varying uses. Generally shafts used for mining projects tend to be much deeper compared to those used in civil engineering projects. Shafts used for the construction or as part of buildings, utilities, or urban transit have a rather shallow or moderate depth. But, regardless of the project purpose, various parameters such as earth pressure and hydrostatic pressure are affected by depth and need to be considered during design and construction of shafts.

Shaft linings can be classified in accordance with depth into two categories :

a) Shallow Civil Engineering shafts :

Shafts which can be constructed from the surface using Civil Engineering methods. According to the UK Approved Code of Practice on the mines (Shafts and Winding) regulations 1993, the depth is limited by the safe winding limit for a crane which is stated as 90m from the top of the crane jib. However, the depth could also be limited by various national, state, or local regulations for using Civil Engineering methods.

- Depth 70 m – 90 m

b) Deep shafts and mine shafts :

Shafts which require to be sunk using a headframe and sinking stage for construction

- Medium depth 90 – 300 m
- Deep 300 – 500 m
- Very deep $> 500 \text{ m}$

3 >> CLASSIFICATION OF SHAFTS

3.4 GEOLOGY

Subsurface conditions including rock and/or soil in addition to groundwater will dictate/ affect construction methods. The geologic classification is considered when selecting construction methods. Such classification describes the anticipated ground behavior during construction works and design considerations that would affect the excavation stability. A general classification based on geology and type of ground in which shafts are constructed includes the following :

- a) *Soft ground, Soil*
- b) *Mixed Ground*
- c) *Rock*

- Soft rock (unstable when excavated)
- Hard rock (self-standing when excavated)
- Rocks exhibiting time dependent deformation under load (creep) when excavated

For analysis purposes, however, more detailed classifications could be used. For instance, soils may be classified into the following types: Firm; Slow Ravelling; Fast Ravelling; Running; Flowing; Cohesive Running; Squeezing; and Slabbing (Meyers et al., 2014). A good source for soil classification could be the Unified Soil Classification system (USCS), which covers the above noted categories but is well adopted and accepted in general Geotechnical practices. Rock formations may be classified based on Rock Quality Designation (RQD) index (Deere, 1964, 1989), Rock Structure Rating (RSR) (Wickham, et al., 1974), Rock Mass Rating (RMR) (Bieniawski, 1989), Geological Strength Index (GSI) (Marinos and Hoek, 2000; Tsiambaos and Saroglou, 2010), or Q value (Barton, 1974, 2002). It would be ideal if a new rock mass classification can be developed, exclusively for shaft construction purposes since the existing rock mass classification systems were originally developed for tunneling applications and were adopted in other applications due to their common use.

3.5 GROUNDWATER (RELATIVE TO BOTTOM OF THE SHAFT)

The presence of water could potentially affect the ground behavior and stability. The construction of shafts can be classified based on the presence of water (relative to the bottom

of the shaft) into the following two groups :

- a) *Dry*
- b) *Wet or limited flow*
- c) *Under pressure*

Sinking a dry shaft means that limited to no water flows in, and Wet means that any water that flows into the excavation is pumped out to leave no significant standing or flowing water in the base of the shaft. In the areas that are less sensitive to lowering of the groundwater table, the ground ahead of the shaft can be drained, lowering the groundwater table using pumped wells. This is not applicable in areas that are sensitive to groundwater table movement since it can create differential settlements reaching as far as the cone of depression can reach.

When a shaft is sunk in wet conditions, water is allowed to flow in and the muck is excavated out of the base of the shaft underwater. This can be done by using a cactus grab or clam shell when water inflow is small and manageable by pumping. Alternatively the shaft can be excavated in submerged conditions using a mechanized system featuring reverse circulation to remove the excavated muck. Since in these methods, the shafts will be flooded, it is not possible to construct the lining simultaneously with shaft excavation. When a large amount of water is present, it may be managed and controlled by methods such as pre-excavation grouting, cover grouting, or freezing.

In certain applications water stops are implemented as part of the pre-excavation support of the ground. In these methods, typically used in soils, the lining is installed before sinking of the shaft (for instance the use of sheet piles, secant pile, slurry wall, jet grouting columns, etc.) or where the lining is sunk down with or ahead of the shaft and offers support of the ground and prevents movement of water towards the shaft. When applying these systems the water inflow in the bottom / face of the shaft should be considered and mitigated by various methods, including grouting. An alternative to these systems is the implementation of ground freezing that freezes water in place and creates a seal through the ice, while offering structural support to the ground.

3.6 INCLINATION

Based on the angle that shafts are excavated they can be classified as :

- a) *Vertical,*
- b) *Inclined*

However in case of inclined shafts the inclination should not be less than about 20 degrees to the horizontal (USACE, 2014). Some references may refer to different inclinations to differentiate between inclined shaft and other types of passageways such as an inclination of 15 degrees or over (Holl and Fairon, 1973) or a slope of at least 40 degrees (Lancaster-Jones, 1984). For the purpose of this document, passageways with an inclination of at least 35 to 40 degrees, which is above the common angle of repose of materials, should be considered as inclined shafts.

3.7 CONSTRUCTION METHODS

Depending on the shape, size, and depth of shafts and the ground conditions, different methods may be used for their construction. For instance, a segmental lining installed by underpinning or sinking caisson can be employed to form a circular shaft (David Chapman et al, 2010). Incremental excavation with shotcrete can also be applied to form a circular or elliptical lining. Incremental excavation supported by shotcrete, rock bolts, cable anchors, and steel sets or ribs may be utilized to construct shafts in both soil and rock, under proper conditions. Sheet piles, diaphragm walls, or bored piles may be used to construct a square or rectangular braced shaft. Shaft excavation methods can be listed as follows :

3.7.1. Methods used in Rock

- a) *Blind sinking by drill and blast;*
- b) *Alimak raising for rock excavation using drill and blast (conventional);*
- c) *Sequential Excavation Method (SEM) or New Austrian Tunneling Method (NATM, observational method);*
- d) *Blind shaft boring with a Shaft Boring Machine (SBM);*
- e) *Blind sinking with Shaft Drilling Machine (SDM);*

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- f) "V Mole" down reamer as blind shaft or with raise bore pilot;
- g) Raise boring (drilling a pilot down and reaming up);
- h) Herrenknecht's VSM and SBR cutting methods of blind sinking, as partial face machines;
- i) Horo-diam or raise/slash (a combination of raise boring followed by drill and blast or sloughing);
- j) Reverse circulation drilling.



Figure 13 : Shaft Jumbo (Slack, 2020).



Figure 14 : Vertical shaft sinking machine VSM9000 constructing an urban shaft in Naples, Italy (Herrenknecht, 2020).

3.7.2. Methods used in Soft ground

- a) Drilled Shafts using large size augers up to 9 m (Smith et al., 2003)
- b) Pre excavation support using sheet piles, slurry/diaphragm walls, jet grout columns, or bored piles
- c) Segmental lining installed by underpinning,

- with backhoe or excavator for mining the soft ground
- d) Cast in Place (CIP) Concrete poured behind formwork
- e) Sinking Caisson using Cast in Place or Segmental Lining
- f) Ground freezing.

3.7.3. Methods used in Mixed ground

Sequential Excavation Method (SEM) or New Austrian Tunneling Method (NATM, observational method)

3.8 MEANS OF CONSTRUCTION

- a) Blind shaft sunk downward,
- b) Blind raise moving upward with mucking at lower level
- c) Access to both ends and sinking down (down reaming with mucking in lower level)
- d) Access to both ends and mining up (with mucking in lower level).

3.9 SERVICE LIFE

Shafts can be classified into the following groups based on their service life :

- a) Temporary
- b) Permanent

When the shaft facilitates the construction of a tunnel or provides access to a short life mine area, it is a temporary structure and does not have a role in service life beyond its limited time purpose. Once the construction is completed, a temporary shaft is normally backfilled. In other cases, the shaft may become an integral part of a permanent structure (Jenny, 1996). Examples are service shafts, vent shafts, drop structures and risers in water conveyance, pump stations etc.

3.10 FINAL APPLICATION

The final application of shafts is important since it will affect the location of the shaft, which in turn is very important for construction planning. A shaft near vacant land allows the erection of temporary buildings. If located at the midpoint

of a tunnel, the shaft could provide access to both directions or reduce mucking distance. The final function of a shaft could also influence parameters such as size, depth, and shape due to project requirements, which will affect design considerations and construction method. As already mentioned, shafts may be part of temporary or permanent structures and have a proportional life span. Temporary shafts mostly facilitate tunnel construction or in some cases mine projects (for a short or long period). Permanent shafts can also be used during construction, even though they will become an integral part of the permanent structure and used for ventilation, manholes, pump stations, utility lines, etc. Permanent shafts require a suitable final lining to serve in their long-term roles. Such differences depend on the intended application and need to be considered during design and construction phases. Some of the applications of shafts are listed below :

a) Water and Sewer Applications

- Work / Launch shafts for water mains, Combined Sewer Overflow (CSO), Sanitary Sewer Overflow (SSO) and micro-tunneling.
- Distribution Chambers for water
- Drop Shafts (for CSO/SSO),
- Access shafts / Manholes
- Maintenance shafts
- Lifting shafts
- Ventilation shafts
- Risers for hydropower plants
- Penstocks/Intake shafts
- Others: Diffuser shafts, Storage, etc.

b) Transportation Applications

Work / Launch shafts for tunneling operation such as launch and receiving shafts for TBMs or pipe jacking and Micro-Tunnelling projects

- Metro Stations
- Access shafts / Manholes
- Maintenance shafts
- Ventilation and Utility shafts.

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Figure 15 : Micro tunnel work shaft of Tehran's Western Sewage Canal (Mohammadi, 2020).

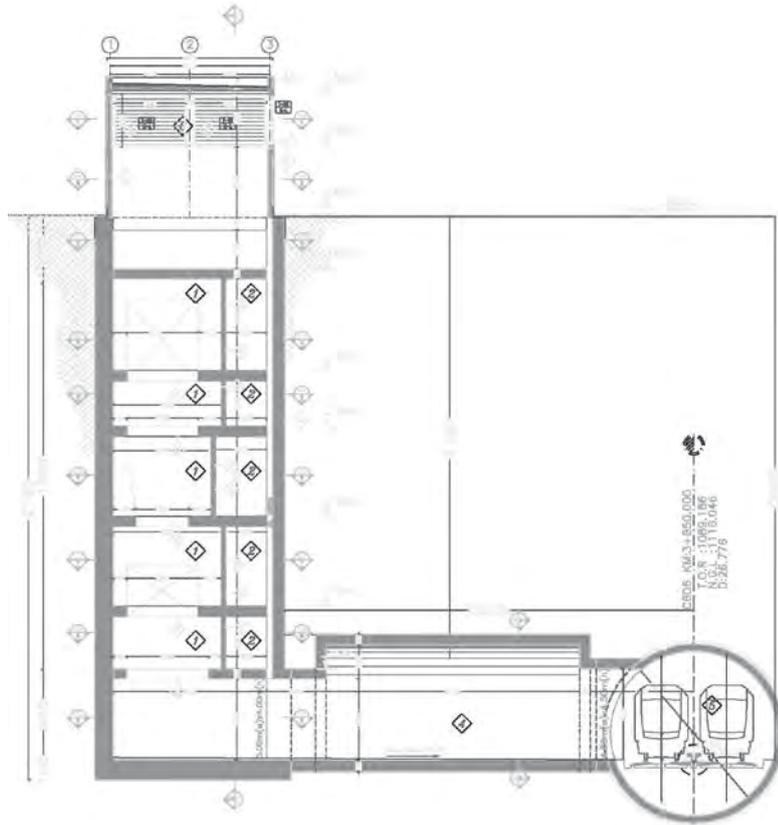


Figure 16 : Drawing of a ventilation shaft for Tehran's Metro Line 6 (TUSRC, 2015).

c) Mining Applications

- Main / hoisting shaft,
- Ventilation shaft,
- Utility shaft,
- Ore chute,
- Blast slot for stoping,
- Sublevel shafts or raises.

d) Miscellaneous Applications

- Parking Garages
- Storage
- Military / Defense (such as missile silos)
- Research and development (such as the Deep Underground Science and Engineering Laboratories - DUSEL)
- Shelters
- Geothermal heat / cold harnessing structures.



Figure 17 : Launch shaft for a Mixshield TBM at the Eurasia Tunnel on the Asian side of the Bosphorus, Istanbul (Herrenknecht, 2020).



Figure 18 : Receiving shaft of a Mixshield TBM in Düsseldorf for the Wehrhahn metro line (Herrenknecht, 2020).



Figure 19 : The 650 tons and 71.4 m high double headframe of the hoisting shaft of Germania Coal Mining Complex in Dortmund-Marten that currently stands at Bochum's German Mining Museum (Nawrot, 2013).

4 >> CONCLUSION

Terminology in different subjects plays an important role in the understanding of contexts. Using correct and common terms in their technical and scientific contexts helps the engineer to understand the message of relevant documents more easily. Hence, terms used in the design and construction of shafts in both civil and mining engineering are reviewed in this document to find a common ground.

The classification of shafts also enables engineers to communicate more efficiently through common understanding and language. This will help in the design process and making decisions for type of construction. For instance, the type of site investigation or data required for the design of shallow shafts may differ from deep shafts. The construction method of a shaft in a soil mass may differ from that in a rock mass. The presence of groundwater also affects the choice of construction method. The ground support in a temporary shaft may differ from a permanent shaft or even differ because of the shape of a shaft. Hence, classification of shafts will help engineers to reach a mutual understanding in regard to design and construction requirements.

It should be noted that this document is prepared as a guideline and not a basis for development of contract documents. As noted before, the terminology and application of the shafts vary between different regions and countries, and perhaps even different jurisdictions, hence the engineers should use the terminology and follow available codes that are pertinent to their project.

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