Handbook to best practices for mine shafts protection

Project Deliverable D4

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The MISSTER Project: This project addresses issues raised by mine shafts in terms of safety both during and after mining operations. The project aims are to:

- enhance the understanding of potential hazards that may affect mine shafts;
- optimise safety conditions for operating shafts and enhance safety conditions of land surface near active and abandoned shafts;
- develop tools to assess the likelihood of shaft deterioration and optimise closure methods.

More information about MISSTER may be found at www.misster.eu

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1. INTRODUCTION AND PURPOSE OF THE HANDBOOK

In Europe, mining situation is different depending on country and it is possible to find areas where shafts are all abandoned or in contrary still active. In these two cases, the most important point is to ensure their long term stability and avoid all possible failure caused by the shaft itself or due to an old closure treatment.

For abandoned mine shafts, some problems linked to deterioration of the sealing structure at the shaft head, or movement of backfilling material in the shaft have been observed. It is also common to find mine shaft opened even decades after mining activity. With time, it is also possible that mine shafts be localisable only thanks to mining map and not at surface.

So, there is a large range of situations (untreated, treated, localized, non localized...) or levels of risk (ground movement risk or physical injury risk), caused by the hazardous nature of the former works, for people in the vicinity of shafts or events which may occur (earth movements, gas emissions, others).

The techniques for closing mine working have evolved and improved thanks to feed-back on their relevancy, dimensions and durability. This handbook to good practices presents the most frequently used techniques and their implementation conditions in terms of risk situations and contexts.

This handbook is intended for local or regional players in the post-mining area and for mine operator. It identifies all criteria which may influence the choice of a method for enhancing mine works safety, and recommends the best adapted techniques, in the light of these criteria, with practical presentation of the data in the form of information sheets.

Some topics, developed in the different Work Packages of MISSTER project are introduced in this report. Indeed, these outputs contribute to improve the management of risks due to the presence of mine shaft.

For more details about these specific topics, it is possible to refer to the various deliverables of MISSTER project.

2. REMINDER OF RISKS DUE TO PRESENCE OF SHAFT

2.1 Risk of physical injury

The presence of shafts, insufficiently blocked, or in steeply sloping landscapes or still concealing infrastructure is problematic. If they are marked in the countryside, accessible or known locally, shafts inevitably arouse the curiosity of certain people. Others may be in the locality carrying out their daily activities.

The dangers linked to these structures due to their existence regardless of any events which may occur causing other hazards or accidents can be grouped into the so-called “risk of physical injury” category.

The main risks are given in Table 1 below. They are recurrent (many structures in France are insufficiently sealed-off or left open) and problematic (an accident may incur various forms of liability: the administration, the operator...).

Table 1 – Main risks of physical injury linked to presence of shaft

Fall into the shaft
Drowning after falling into the shaft
Persons falling from surface infrastructure still in place (staircase, landing, floor, etc)
Falling stones, blocks, bricks, wooden beams, metal girders, glass if there is shoring or ancillary buildings in the immediate proximity of the shaft
Injuries (cuts, fractures) caused by presence of abandoned scrap metal, residual voids linked to the presence of infrastructure or shallow technical service tunnels
Explosions and burning if methane is released by the shaft or accumulates in the cellars of buildings or technical service tunnels at shallow depths

2.2 Risks linked to events occurring or manifested in or on the edges of the works

The risks linked to shafts derive from the crossing of the hazard and issues. The hazard event is the possibility that a potential event will occur at certain intensity. The issues are the people, goods and activities above or adjacent to the shafts.

The main risks are linked to ground movements above or close to the works, and the emission on the surface of gas through the works which act as a conduit. Other risks can be identified and are described briefly below.

2.2.1 Ground movements which may affect the structures

2.2.1.1 Collapse

Contrary to the phenomenon of subsidence, collapse occurs when the surface drops discontinuously over time (rapid sudden event) and/or space (formation of fractures, tears, craters etc.).

Collapse is characterised by rapid movement caused by gravity which is vertical and may be significant. It can cause major consequences for the risk factors: the damage, even the demolition of infrastructure or buildings, physical injury or loss of human life.

Collapses induced by the presence of mine shaft can occur according to different scenarios:

- Collapse of the shaft filling material: it is a rough and dynamic remobilisation of the filling material which propagates down abruptly and rushes into the old working, generating a collapse of the surface if no structure or protection was installed at the head of the shaft. Collapse of the shaft filling material occurs generally after a slow degradation of the conditions of the filling material, in particular during mine water rising within the shaft column after exploitation. These progressive modifications end in the establishment of a limit balance and the intervention of an aggravating factor can be enough to activate the dynamic mobilisation of the column. Some collapses of the shaft filling material result from the formation of a void within the column during the dumping of filling material. These voids can result from the blocking of materials within the shaft column.
- Failure of the shaft head: Many shafts were closed by old techniques presenting no guarantee of sustainability. Some old mine shafts were closed by a single on-surface or near-surface wooden platform, eventually completed by filling material on the shaft head but leaving the whole column empty. Some structures, such as more recent concrete slabs, can break when they are subjected to excessive loads (motor vehicle transit, building…), or when surface ground materials on which they rest fail.
- Failure of the shaft lining: The most frequent failures of the shaft lining result from a decrease of its strength or from an increase of the pressure of surrounding rock. When the strength of the lining is exceeded, the lining (bricks, stone blocks, concrete, cast iron and steel) deforms and eventually breaks. It may collapse in the shaft with part of the surrounding ground. The decrease of the mechanical properties of a lining material with time is an inevitable phenomenon resulting from the progressive ageing of the

constituent materials. Shaft backfilling operations made without sufficient precautions may also damage lining. Stones or blocks dumped from the surface opening are subjected to free-falls of several hundreds of meters and can sometimes damage sections of the lining. Also, closure structures badly or insufficiently designed may sometimes induce high stresses on the shaft lining.

- Failure of deep closure structure: Galleries or mine works with connecting shafts may have been closed before the shaft was backfilled in order to avoid spreading of the backfilling material in the galleries. Structures generally consist of walls in hollow blocks, metal dams or concrete plugs. For old mine shafts, galleries may have been closed with remaining items but without particular design. Because of various causes, for example concrete segregation or poor lining design, a failure of this deep closure structure can occur allowing the filling material to spread into the galleries, resulting in a collapse of the shaft.
- Failure due to water effect and/or particular geologic formation: When an inflow of water occurs in a shaft, either by the rise of water levels, or by infiltration, this can become a triggering factor of the shaft lining failure, by increasing pressure on the lining. The additional water within the column of the shaft adds weight and may reduce fill strength due to pore pressure generation, thereby disturbing the equilibrium state within the column and generating failure. The presence of particular geological formations, such as soluble horizons (gypsum / salt) or soil seams lacking cohesion which are subject to flow (sand for example) may also induce the creation of voids behind the lining. This void may destabilise the lining of the shaft and induce its collapse.

Some examples of these different kinds of incidents are developed in the Deliverable D1 of MISSTER Project.

3.2.1.2 Compaction

Compaction includes a smooth lowering of the surface (tens to hundreds of centimetres), caused by remobilisation or consolidation of backfill material.

Many shafts were fully back-filled without the head being blocked by a cap or a capping slab. Differential compaction of the column of backfill results in slow and gradual remobilisation of the surface land. The latter may, if sufficiently extensive, affect some workings in the impact zone.

There are various causes of compaction:

- Overload on the surface above caused by the movement of heavy vehicles or construction of structures for which the foundations are supported in the shaft back-fill impact zone;
- Certain forms of vibration caused by blasting in mines near the opening, or by very heavy road traffic;
- Loss of stability caused by the effects of water. The last factor is important for shafts: changes in the water level in the backfill cause changes in the equilibrium of the material. The process is generally gradual and may cause slow and gradual subsidence of the surface, resulting in compaction of the loose material in the shaft. The backfill of reduced mechanical strength may gradually spread into uncapped service areas causing weakening at the top of the column of material in the shaft.

The most damaging consequences are damage to buildings and infrastructure on the surrounding land surface. The differential compaction values that may be achieved have a direct impact on the damage level.

2.2.2 Risks linked to the presence of gas

The presence of toxic or flammable gas (carbon monoxide and dioxide, methane, hydrogen sulphide, radon etc.) may be caused by:

- A concentration of gas in enclosed formations which is released into the cavities caused by mining;
- Breakdown or degradation of materials or products abandoned in the works.

This gas can migrate to the surface through the overburden or by preferential flows through mining structures reaching surface (shafts adits).

Emissions at the surface may occur during works, but also during flooding after the end of works, the gas migrating towards the surface by a piston effect.

Risk of gas emissions results essentially from:

- Conveying of gas dissolved in deep water in contact with old working, which can be released on the surface by the shaft column or the tunnel;
- The connecting of old works with surface (sudden loosening of shafts, construction of structures affecting these works);
- The breakdown or deterioration of structures, equipment or products which have remained or been placed in the tunnel or the shaft.

These gases can migrate to the surface according to different phenomena:

- Natural thermal draft, linked to the difference in temperature of the gas, but also due to the differential altitude of the linked mine openings;
- Variation in outside atmospheric pressure: according to Marriott's law, gas expand as the external pressure falls, conversely if the external pressure rises, air enters the abandoned mine shafts;
- Rising water: under its effect, the gases are driven by piston effect upwards, through the access openings. The level of the underground aquifer may vary depending on the seasons or precipitation (variations of water table) and cause slow or sudden rising of gas.

Four main types of risk have been identified:

- The risk of fire, since mine gas may contain methane which, in certain proportions forms a flammable/explosive mixture with air;
- The risk of suffocation, since mine gas may sometimes be poor in oxygen, and its accumulation in non or poorly ventilated locations may cause risks ;
- The risk of poisoning, given the presence of toxic gasses (CO_2, CO, H_2S, which are stored or tipped compounds etc.);
- The risk of inhaling radioactive elements (radon).

3. PREREQUISITES NECESSARY FOR APPROPRIATE TREATMENT OF SHAFT

3.1 Recall of treatment objectives

The primary objective of works to render shafts safe is to propose satisfactory solutions for the following hazards:

- Prevention of falls into abandoned shafts or adits;
- Prevention of any human intrusion;
- Prevention of risks linked to subsidence which may cause damage to existing structures in the impact zone;
- Prevention of risk of collapse of the surface land;
- Monitoring of atmospheric gas discharges;
- Offering long-term guarantees of stability and durability;
- Preserving the fauna and notably, protected species.

Every shaft has specific characteristics and is in a specific environment; hence the treatment objectives will vary from one to another. To identify the various risks and determine the various safety objectives, it is essential to carry out a detailed study of each case. To facilitate compilation of the parameters essential for the choice of the most appropriate technology, an overview of the main criteria is given below.

3.2 The parameters to be collected

The procedures to keep shaft safe consist of:

- Inspection of the site and research with documentary analysis
- Inventory and identification of the different risks;
- Identification of an order of priority for dealing with the existing risks;
- Technical investigations to collect all available information on the site likely to assist in choice of one or more treatment techniques;
- Implementation, after approval of the project design-sizing, of the most appropriate treatment as selected ;
- Surveillance and maintenance

The most difficult phase is analysing the parameters collected to identify the technique best adapted to the site. This requires covering all the risks incurred at an acceptable cost. All the parameters which must be collected are given below.

3.2.1 Precise details of position of the mine shafts

This very important parameter is one of the first to be obtained. The mine shafts may be clearly visible in the field, and so unambiguously identifiable. The location may also be pinpointed according to more or less specific evidence in the site, with an uncertain positioning, frequently of one to several metres. If the works are identified on the mining map, but are not observed or assumed in the site, the positioning uncertainty is correlated with that of the plan and the latest overlay on the ordnance survey map. This uncertainty is frequently of the order of ten to several tens of metres; treatment in this case cannot be considered without actions for specifying the position of the shaft (compulsory disclosure of documents, investigation with local people, geophysical techniques, surface excavation, surveys etc.).

Mine shaft detection using geophysical methods essentially depends on the physical parameters (often heterogeneous and diverse) of the shafts in relation to the surrounding rock.

The non-intrusive methods included are: seismic refraction, surface wave seismic, ground penetrating radar (high-frequency electromagnetic methods), low-frequency far field electromagnetic methods (VLF), low-frequency near field electromagnetic methods (Slingram), direct current earth resistivity, microgravimetry and thermal infrared. Non-intrusive geophysical methods may be used outside of urban areas and enable a large expanse of terrain to be investigated.

Intrusive geophysical methods allow to overcome surface disruptors and to prospect beneath houses. The main intrusive methods are mono-frequency (electromagnetic) drilling tomography, radar tomography, radar reflectivity, seismic drilling tomography, electrical methods.

In order to be efficient and best define the area to investigate, the mine shaft detection phase using geophysical methods must always be preceded by preliminary reconnaissance operations: investigation phase (collect of information in archives) and surface indication search phase (topographical anomalies, remnants, etc.) This data will enable to choose the most appropriate method and the gridding required for executing the measuring points to be defined.

The geological and climatic conditions, urbanisation, etc. are some factors that influence and limit the application of the geophysical methods for detecting old shafts. None of the geophysical procedures described above are able to give an unequivocal location in urban areas or in areas disturbed by human activity. Certain methods provide indications to verify by sounding or shovel trenching. In all cases, the use of a geophysical method must be considered as a stage in mine shaft reconnaissance methodology.

Details about the different methods, cited above, are given in the Deliverable 2.1 of MISSTER project. For each method the principle of operation, the measured data, the expected results, the typical areas of application, and the limitations are discussed. Seismic Surveying Trials and identification of areas for improvement and progress about Earth Resistivity Surveying are also itemised.

3.2.2 Ease of access to the site

The first inspection visit allows determining/confirming the position of the openings to be treated and the ease of access to the site.

When direct access to the mine-works is possible using existing infrastructure or by construction of a low-cost track, all treatment methods may be considered.

Conversely, if the mine works are located in a totally isolated area, with difficult access and no adjacent road suitable for use by heavy vehicles (mountainous zones), the range of feasible methods may be considerably reduced.

This is also the case when abandoned shafts are located in infrastructure or buildings, or when the surface is encumbered, restricting the circulation of engine and materials storage.

3.2.3 Nature and extent of local issues, future use of the land

The evaluation of the issues is fundamental for identifying the risks. It must be established if shafts are located in or close to an urban zone, a building, a road of which the traffic levels must be assessed, infrastructure, a frequently-used path, etc. For potentially dangerous abandoned works, it is also essential to assess accessibility, local information, whether mineralogical or speleological, details of use as a habitat for fauna, visual attractiveness, potential harm to farm livestock etc.

3.2.4 Geometric characteristics of the shaft to be treated

The type and dimensions of the opening to be treated govern the choice of treatment method. The size, shape, depth of shafts determines the quantity of material necessary for backfilling and design-sizing other safety techniques.

When the former openings are not visible, this data may be found in the archives.

When a shaft is opened, it is possible to inspect it using suitable probe. Three probes have been developed and tested in MISSTER project. These probes have different characteristics which do not allow them to be used in the same context and conditions. Dimensions of probes, reachable depth, video quality, gas sensors are not similar...

Those different characteristic are detailed in the following table. More information is available in Deliverables 2.2 and 2.3.

Table 1: comparison between probes developed in MISSTER project

Parameter	Probe 1 (DMT)	Probe 2 (GIG)	Probe 3 (INERIS)
Weight of probe	100 kg	100 kg	~ 5 kg
Total weight (probe, winches, car...)	~ 14 100 kg	~ 3 300 kg	150 kg
Dimensions of probe	2520 x 380 x 340 mm	1000 x 320 x 320 mm (main unit) and 320 x 320 x 320 mm	540 x 100 mm
Diameter of shaft (min → max)	1 m → ~150 m	3 m → 12 m	0.1 m → 12 m
Maximum reachable depth	2600 m	1200 m	140 m
Explosive atmosphere (ATEX)	No	Yes	No
Underwater research	No	No	Yes (1 to 14 bar)
Video recording	Limited	Very good	Very good
Geometry – laser scanning	Excellent	Limited	Good
Additional sensors	CH_4, O, Temp	CH_4, O, CO	None

3.2.5 Condition of mine works

Subject to respect of all safety conditions, the state of the opening must be evaluated, notably and first of all if it is unsecured and potentially dangerous. If possible, the nature, thickness and condition of the shaft lining and its contact with solid material must be investigated. The presence of zones which have collapsed, been backfilled or blocked off using barriers must also be recorded.

An examination of the shafts will allow establishing the safety conditions and an opinion on the justification for the treatment techniques.

For a shaft, if access is not possible, video cameras and laser or sonar techniques may be used to detect and inspect the walls.

3.2.6 Connections with other mine-works, presence of voids or infrastructure

The full backfilling technique requires to establish the number, size and extent of connections with other openings (shafts, tunnels) and of the main service area at the lowest level. It is advantageous to establish which former works are already totally backfilled or have collapsed, and those which are cut off from the mine-works by existing barriers and those which remain open.

Knowledge of voids located at a shallow depth close to the works (abandoned infrastructure or tunnel, underground worksite) is important, irrespective of the method of treatment selected.

Gathering knowledge on the presence and nature of former infrastructure and pipes close to the mine-works is important in the case of treatment techniques which affect the perimeter of the opening. The presence of cavities or ducts must absolutely be assessed when there is a risk of escape of mine gas, which can migrate into the voids.

3.2.7 Geology

The choice of the protection method implemented largely depends on the geology of the surrounding strata. A study of the nature, the condition and the mechanical characteristics of soils and rocks located in the impact zone of the mine-works should be conducted to verify any problem of stability of the shafts, and the anchoring conditions for certain techniques.

It is appropriate to consult all geological cross-sections/profiles of the strata crossed by the works as well as all studies of their geo-mechanical properties. If this data is not available, recourse can be made to any adjacent outcrops, and if necessary, test drilling.

An important aspect of many techniques is determining the nature and thickness of the mobile land surface (soil, backfill) in the case of a collapse, to evaluate the stability and durability required from the treatment, and to assess the extent of the works.

When a shaft has been abandoned and backfilled and compaction above the backfill is observed, taking cores from the backfill may in some risk situations be advisable to assess its compaction and stability; however, ensure that the drilling plant and operatives are safe, particularly regarding the risk of sudden decoring of the backfill.

3.2.8 Hydrogeology

The presence of water in the strata causes technical complications: reduction of mechanical properties of strata, communications between aquifers, water pollution, possibility of flooding etc.

The depth and thickness of water tables and the water levels close to the shafts to be treated should be assessed or surveyed to verify whether they will have any impact on the technique or the type of materials to be used.

The potential presence of pollution vectors in the abandoned works (waste, acid mine water) should be assessed to evaluate the effects of water on the closing-off works.

The choice of the method of treatment depends on the conclusions as to the hydro-geological status. If the water table is liable to rise or change significantly over the seasons and inundate the proposed safety structures, it will be necessary to use an appropriate material for the particular water chemistry. The need to render an outlet totally impermeable to water can be considered in some cases, thus limiting the potential protective techniques (cap, tightening, impermeable barrier, etc.).

3.2.9 Degradation

An important aspect to consider for the evaluation of shafts long-term stability is the possible degradation of the materials (shaft lining, capping, plug...).

One of the points that has become clear from the works developed in MISSTER project, is that no matter what material is used for shaft lining or treatment object, it will eventually degrade, especially for saturated shafts in presence of acidic mine water exists. The real uncertainty is how quickly the shaft lining material degrades, depending on the specific conditions and characteristics of the shaft.

A lot of tests have been performed in MISSTER project to evaluate the influence of weather and time on brickwork, stonework, mortars, concrete....

These results are developed in the Deliverable D3.2 of MISSTER project. Taking into account the degradation of all material, plugs and lining cappings are maybe not the best solution for the long-term stability of a shaft. In the same way that lining materials degrade, it is also safe to assume that all structural plugs and cappings will degrade and eventually fail. The option to backfill the entire shaft is the safest solution, when the backfilling is made in the rules of art (presence of deep closure structure, monitoring quantities...). The degradation of backfill material may lead to some long-term subsidence, which will be less significant, that potential failure from “plugged” or “capped” shafts.

However, the choice of treatment is not only derived from the long-term stability of the shaft, but also from other parameters such as cost, difficulty of implementation, accessibility to underground works, presence of protected species...

3.2.10Potential presence of mine gas

The potential presence of mine gas in the mine-works influences the type of treatment and may sometimes justify installation of ancillary systems intended to control gas. The maximum flow rate and composition of the gas must be assessed or evaluated in order to decide on the type of sealing technique or to define a safety exclusion zone, to assess the need for installation of specific systems (vents, ventilation system etc.), or even a monitoring system.

3.2.11 Need or wish to preserve access to underground mine-works

Before proposing safety measures, it should be decided whether it is necessary or if locally there is a wish to preserve access to old mine-works because:

- The need for access to carry out supervisory or strengthening works, or to manage interventions;
- The use of mining voids as habitats for protected fauna;

Taking into account the excess costs generated, problems of maintenance and safety, permanent sealing-off of the openings appears preferable. If access is required, the used techniques should limit the risks and render them acceptable. As a preliminary, the respective responsibilities of the owner and the operator of the works, the Mayor and the State should be clearly established.

3.2.12 Preservation of fauna, flora and the environment

When the abandoned mine-works are used as a permanent or temporary habitat for protected species (European Directive 92/43/CEE), the type of closure selected must allow for movement of fauna, by preserving the existing access and conditions (temperature and ventilation).

There are various type of concrete grill or walls with gaps to allow the passage of desired animals while prohibiting the entry of people. This type of system somehow increases the cost and requires regular maintenance.

The liability of each of the parties must be precisely established.

3.2.13 Costs

Costs should include not only the safety works but also upkeep and maintenance. The treatment costs may vary significantly from one site to another, depending on the location, the equipment and the materials to be used and the various complications, notably the need to maintain possible access or to preserve the environment.

4. GOOD PRACTICES FOR PROTECTING ABANDONED SHAFT

4.1 Principle

The information sheets presented in the next chapter are intended to set out the techniques that can be used in situations where there is a varying degree of risk of physical injury or of “ground movements”, and with a view to raising awareness to the post-treatment residual risks.

These information sheets briefly describe:

- the contexts and risk situations in which a technique can be used
- the most important design-sizing criteria for the required site conditions
- the prerequisites as well as the complexities which may significantly increase the costs of the works.

The purpose of these information sheets is to provide a better understanding of use of the techniques and to assist in choosing the most well adapted. The decision-making power is that of the owner, who may be called on to consider criteria other than the purely technical ones referred to here.

An explanation for the various items in the sheets is given below.

Treatment technique: generic name for a method or technique which could incorporate several variants.

Equivalence table: at the top of the sheet, a table allows rapidly reviewing the appropriateness of the technique for the risk situation encountered, the ease/simplicity of its implementation and the cost. These scores assume the process has been performed according to professional standards and the principles set out in the sheet. The scoring system is as follows:

★★★	very suitable technique
★★	Technique appropriate but other techniques may be more appropriate or modifications/adaptations may be necessary
★	Technique poorly adapted or to be reviewed
Θ	Technique unsuitable for this criterion
⌁	Technique to be prohibited for this situation

Table 2: Scoring of criteria in the correspondence table

Thus, for example, a score ★★★ for an economic criterion denotes that a technique is economically advantageous.

Risk situation: a table rapidly displaying the appropriateness of the technique for one or more risk situations encountered, a focus on physical injury and risks linked to ground movements (the term “ground movements risk” is used for ease of reading). This section presents the issues present close to the works, and the situation/degree of risk which in consequence justifies or favours use of the technique.

Required site conditions: describes the main conditions at the site, notably, access to the shaft allowing use of the technique.

Treatment principle: a brief description of the principle of the technique. The design-sizing criteria are described on the back of the sheet.

Maintenance/Monitoring: briefly describes maintenance, surveillance and repairs necessary for durability of the protection.

Post-treatment residual risks: indicates the risks which subsist or may subsist after treatment, or which are not treated by the considered technique. This heading frequently includes the risk of emissions of mine gas, for which some techniques are inoperative, or others requiring adaptations, structures or supplementary works.

Protected species: indicates whether the technique is appropriate given the presence and wish to preserve protected species, notably bats and crawling animals.

Pre-requisites: indicates the main pre-requisites necessary for the choice and design-sizing of the technique, these aspects having been detailed in Chapter 4.

Design-sizing: a heading which tackles the important points and criteria relative to the choice of a precise technique, the constituent material and the design-sizing of the structure.

Most frequent complexity criteria: lists the main constraints which may require prior or supplementary works with a modification of the overall cost of the technique.

4.2 Good practice sheets for safety of shaft

Treatment technique

Fencing

Risk of physical injury	Risk of “ground movements”	Risk of “gas emissions”	Economy	Ease/Simplicity
★★[1]	Θ /★★	Θ/★★	★★★	★★★

Risk situation (Risk diagnosis)

Physical injury risk:

The works are visible and present an established or latent risk of physical injury (non-durable treatment). Access is difficult (far from paths and communication routes). It may be known locally

“ground Movements” risk

The works present a residual “ground movement” risk. The challenges are agricultural activity (cultivation, livestock) or forestry

All risks: **Provisional safety structure pending more appropriate treatment**

Source : DREAL

Site conditions required:	The works are accessible to agricultural/forestry type machinery to bring in equipment

Principle of treatment:	All forms of fencing, very frequently erected as temporary measure so the works can be surveyed and to prevent access to the immediate vicinity. Many types of fencing exist depending on the period of use, and the level of maintenance desired. The fencing must take into account the risk of physical injury, but also the possibility of collapse (or gas emissions) occurring, causing accidents or the possibility of frequent vandalism.

Maintenance/Monitoring	Maintenance necessary depending on the quality of the fence (annual or multiannual)

Residual risks after treatment:	“Ground movement risks” and “mine gas emission risks” (if fencing area is incorrectly dimensioned)

Protected species:	Technique adapted to preservation of certain protected species if the works are not sealed-off.

Pre-requisites

- Accessibility of site. Preliminary visual inspection, gas measurements
- Study seeking to define the fencing area according to criteria of hazards and random events (ground movements, gas)

[1] ★★★: Technique highly adapted for the criterion
★★: Technique adapted but other techniques may be more appropriate, or it requires modifications/adaptations
★: Technique not particularly adapted for this criterion or to be investigated
Θ: Technique not adapted for this criterion
ϟ: Technique to be prohibited for this risk situation

Technical aspects

Design-sizing
Security fence This technique is frequently used when an accident or an event occurs, requiring the rapid deployment of provisional safety measures. A fence can be erected quickly pending implementation of other safety techniques. The same does not apply if the fence is to endure for a certain time or in certain cases where the risks are limited. The security fence must be assessed considering: • The zone around the mine workings, which may be the source of risks of physical injury (abandoned infrastructure, tunnels, pipes, other voids etc.); • The perimeter of the area subject to sudden ground movements (failure of shaft mine head, decoring of backfill, failure of the roof at the entrance to a tunnel). The perimeter area includes the impact zone of the event, and also, the margin of uncertainty as to the true location of the mine-works (frequently of a few metres according to indices in the field); • The perimeter area subject to mine gas emissions. Hence this technique is not very suitable when the abandoned mine-works are not apparent in the field and the uncertainty as to its location extends to tens of metres. It becomes more appropriate when shaft has been identified and their exact location is known: a global perimeter area can then be imposed with restrictions on ground use. **Nature of fence:** It would be pointless to list the possibilities. The objectives to be achieved are to prevent intrusion by persons and to limit intrusion by animals and avoid vandalism. Permanent fencing combined with limited maintenance requires the use of solid grids, of minimum height 2 metres, not flexible (“welded mesh” or “rigid” types), treated against corrosion. The posts must be solid (concrete, treated steel), anchored in the ground (for example 50cm), located a maximum of 3 metres apart, strengthened by corner posts. To avoid animals tunnelling, the grill should be sunk into the earth to the same depth as the posts. Use of the plot of land or requirements for subsequent surveys of the mine-works may require installation of a gate. These structures may be weak points, so it is recommended that the hinges and frames are as robust and dissuasive as possible. Whatever technique is used, this fence will not prevent the intrusion of those determined to gain access to the enclosure. A warning panel should be displayed on the fence setting out the risks incurred. These panels should be fixed firmly to grill/post on all sides of the enclosed area.

Most frequently-encountered complexity criteria (excluding accessibility to the mine-works)
• Demolition of any superstructure preventing erection of the fence • Land is very steeply sloping or broken-up • Vegetation to be removed • Several works requiring fencing off a large area • Presence of rocks making it difficult to hammer in posts

Treatment technique

Backfill

Risk of physical injury	Risk of “ground movements”	Risk of “gas emissions”	Economy	Ease/Simplicity
★★★[2]	★★★	★	★/★★	★★

Risk Situation (Risk diagnostic)	
Physical injury risk: The shaft presents an established risk of physical injury and the risk of falls must be eliminated	 Source : CdF
“Ground movement” risk: 1/Absence of local challenges 2/Reduced local challenges (path little used, agricultural activity constrained by the presence of the mine-works)	

Site conditions required:	Empty shaft, accessible or close to useable tracks, manageable adjacent area, availability of back-fill material

Principle of treatment:	Backfill consists in strengthening the entire shaft lining by absorbing some of the horizontal thrust of the surrounding land. It allows sealing off the mine head, and if appropriately performed, significantly reduces the risk of collapse. Monitoring process and stations strengthening should be controlled during this treatment

Maintenance/Monitoring	Monitoring level of back-fill for several years, or during the water submersion period

Residual risks after treatment:	“Ground movements” risk: compaction “Mine gas” emissions risk

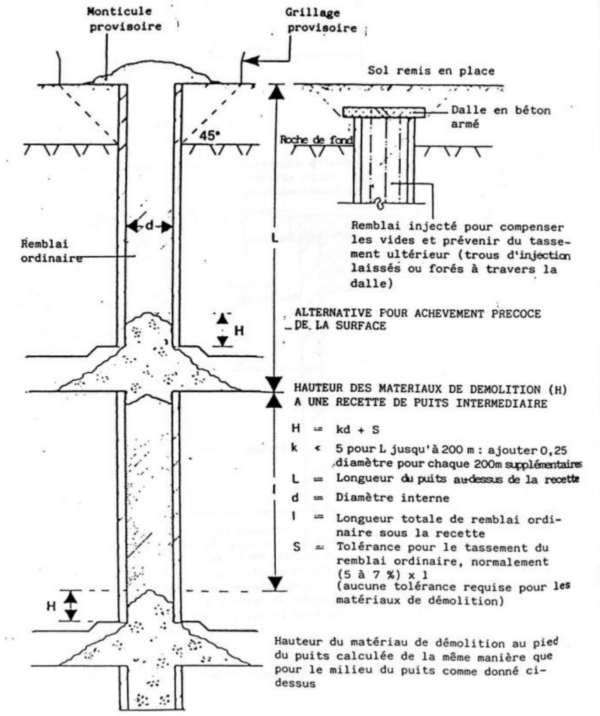
Protected species:	Technique not appropriate to preserve protected species roosting in the shaft (certain bats)

Pre-requisites
• Preliminary visual inspection • History of back-fill/problems with works (if the shaft was previously back-filled) • Underground connections to the shaft, assessment of potential gas emissions • Gas measurements, Piezometric measurements

[2] ★★★: Technique highly adapted for the criterion
★★: Technique adapted but other techniques may be more appropriate, or it requires modifications/adaptations
★: Technique not particularly adapted for this criterion or to be investigated
ϴ: Technique not adapted for this criterion
⊬: Technique to be prohibited for this risk situation

Technical aspects

Design-sizing



Principle of controlled back-filling of a mine shaft (National Coal Board, 1982).

Controlled back-fill of the shaft is recommended.

Materials to be preferred:

- grainy mineral material of grain size between 20 and 120 mm and grain median D_M = 100 mm, free of undersize particles,
- compression strength of at least 30 MPa,
- insoluble and non-flammable,
- without toxic compounds,
- no risk of leaching harmful and hazardous elements,
- meeting requirements of acceptable level of radioactivity.

The above requirements ensure creating a safe, water permeable backfill column. They can be met by using such rocks as: granite, gneiss, basalt or dolomite. There is also a possibility to use a grainy material of different qualities (i.e. of low strength parameters and different grain size distribution), such as waste materials from coal or steel processing. Using them is economical, yet it requires additional tests (Deliverable 3.1 of MISSTER project).

Techniques and controls

Shafts closure is most often conducted by filling it with a grainy material fed into the shaft with a conveyor or directly from a lorry.
It is essential to back-fill the first metres from the base of the shaft using coarse materials to guarantee a stable base for the superimposed back-fill, and avoid fine material flowing into the former works. All levels of the shaft with connections should be back-filled using coarse materials. These sections should start below the floor of the service area and block off the opening to the latter and continue up to an adequate height above the top of the service area. The same material is appropriate for filling water submerged shafts. The use of concrete may be appropriate in certain cases (reduction of voids, increased strength, capping block at the top to avoid any surface compaction).
During the back-filling operations, the alignment of back-filling conditions, the quantities of material deposited and the pre-defined quantities must be regularly verified by measuring the height of the back-fill. For water-submerged shafts, the water displaced by the back-fill may rise up and special precautions should be adopted for its removal (pumping) as the back-fill rises up the shaft.

Most frequently-encountered complexity criteria (excluding accessibility to the mine-works)

- Stability of the mine-head in the presence of heavy plant: safety distance, system for spreading loads
- Disassembly of equipment blocking the shaft (avoid residual voids in the works)
- Use of anti-explosion systems if there is gas
- Effect of falling materials if water is present;
- Adaptation of materials if shaft is deep and there are many service areas (see above)

Treatment technique

Renewing backfill

Risk of physical injury	Risk of “ground movements”	Risk of “gas emissions”	Economy	Ease/Simplicity
★★[3]	★	★	★★★	★★★

Risk Situation (Risk diagnostic)	
Physical injury risk: The works are visible and present an established or latent risk of physical injury (non-durable treatment). Access is difficult (far from pathways and communication routes). It may be known locally	
“Ground movement” risk: The structure presents a “ground movement” risk”. The challenges are agricultural activity (cultivation, livestock) or forestry	
All risks: provisional back-up renewal of back-fill pending more appropriate treatment	Source : INERIS

Site conditions required:	Structure is accessible to agricultural/forestry vehicles allowing transporting the back-fill

Principle of treatment:	Deposit of supplementary backfill in a previously filled shaft, acting as spare material in the event of compaction, sliding or sudden decoring of material in the shaft

Maintenance/Monitoring	Maintenance to be scheduled depending on recurring movements of the land (in the order of every few years)

Residual risks after treatment:	“Ground movement” risk and “mine gas emission” risk. Risk of physical injury, probable presence of old shaft infrastructure in the perimeter area

Protected species:	Technique not appropriate to preserve protected species

Pre-requisites
• Accessibility of site. • Preliminary visual inspection, gas measurements

[3] ★★★: Technique highly adapted for the criterion
★★: Technique adapted but other techniques may be more appropriate, or it requires modifications/adaptations
★: Technique not particularly adapted for this criterion or to be investigated
Θ: Technique not adapted for this criterion
⚡: Technique to be prohibited for this risk situation

Technical aspects

Design-sizing
This technique is sometimes used when an "accident" or an event occurs, requiring the rapid deployment of temporary safety measures. The method is to build a heap of backfill above a small volume shaft (for example diameter not exceeding 3 metres, internal depth less than 100 metres, limited number of service areas) previously backfilled, so that in the event of ground movements, a proportion of the backfill will fill the void formed. The materials to be preferred are land-fill of graded grain size, with a proportion of fine materials which can migrate in the event of movement in the shaft. The materials must be inert and non-flammable. The volume of the backfill cone must be adapted to that of the shaft; the slope of the heap of back-fill must be adjusted and its diameter must exceed that of the shaft. For example, a minimum of three times the diameter of the opening. This technique is not appropriate when the works have not been identified with certainty in the field.

Most frequently-encountered complexity criteria (excluding accessibility to the mine-works)
• Demolition of any superstructure preventing construction of the heap of material • Vegetation requiring extensive clearing • Several works requiring a large perimeter fence

Treatment technique

Capping Slab

Risk of physical injury	Risk of “ground movements”	Risk of “gas emissions”	Economy	Ease/Simplicity
★★★[4]	★★	★	★★	★★

Risk Situation (Risk diagnostic)	
Physical injury risk: The shaft presents an established risk of physical injury and the risk of falls must be eliminated	 Source : DREAL
“Ground movement” risk: An “ground movement” risk is established and there are significant challenges in the proximity of the anticipated instability perimeter of the shaft (e.g. dwelling, occupied building)	

Site conditions required:	Shaft accessible to vehicles Resistant land or support structure located at shallow depth (e.g. less than 5 metres)

Principle of treatment:	Installation of reinforced concrete after clearing the top section and surrounding of the shaft. Stability of the capping slab is guaranteed through support on the surrounding land/former infrastructure which maintains it by reaction, and the bending/tensile strength of the reinforcing bars.

Maintenance/Monitoring	Possible repair if the capping slab is incorrectly dimensioned and affected by ground movements. Possible maintenance of gas vents

Residual risks after treatment:	“Mine gas emission” risk. “Ground movement” risks (collapse if residual void under the capping slab)

Protected species:	Technique not appropriate to preserve protected species

Pre-requisites
Preliminary visual inspection. Condition of back-fill of works. Gas measurements, Piezometric measurements Geological and geotechnical profile of the edges of the shaft (studies already performed or specific survey) drilling pressiometric cores) to establish depth of the firm land. Documentary search: cross section or plan of the mine-head, nearby infrastructure, technical or shallow tunnels, assessment of potential gas emissions

[4]★★★: Technique highly adapted for the criterion
★★: Technique adapted but other techniques may be more appropriate, or it requires modifications/adaptations
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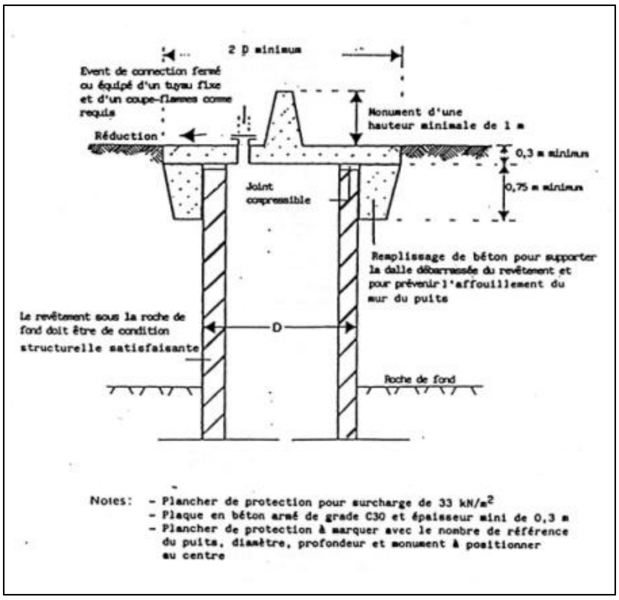
ʘ: Technique not adapted for this criterion
⌿: Technique to be prohibited for this risk situation

Technical aspects

Design-sizing

The capping slab is design-sized so that its own weight, that of the overload on the surface and any effects of decoring if the shaft is back-filled are taken up by the supports on the edge, and the bending/tensile strength of the constituent concrete.



Example of outline diagram of a surface slab of the light or heavy duty type and of underground slabs installed at the top of a rocky outcrop (according to the National Coal Board)

For design-sizing, the ratio between thickness of the concrete and the greatest dimension (length) of the slab must be taken into account. The thickness must take into account inclusion of the reinforcement bars (frequently welded trellis) enabling the slab to withstand bending/tensile force. The coating and diameter of the reinforcing must comply with the calculation rules for reinforced concrete (former BAEL rules, Eurocode 2). The compression strength of the concrete is not a fundamental value: however, for its resistance over time classes superior or equal to C25/30 (standard EN 206-1) should be preferred. It is also strongly recommended taking account of the environmental attack (notably, when the water level is close to the capping slab) for the cement dosage.

The widths and lengths of the capping slab must take into account ground movements which may occur subsequently: breakage of lining, sudden decoring of back-fill for a recently filled shaft. If the structure is intended to be durable, account must be taken of the margin of impact of a cave-in, according to the anticipated instability mechanism. Unless back-filling was performed according to professional standards in the shaft (see corresponding sheet), it is recommended that the capping slab should overhang the extrados of the shaft by a generous margin, depending on the margin of impact. Particular care should be paid to the external supports of the capping slab to avoid it becoming loose. If the quality criteria are not followed, it is probable that the repair or even complete replacement will be necessary given ground movements in or around the shaft.
The calculation of stress must take account of surface effects, both permanent (notably suction in the case of sudden decoring of the shaft back-fill) and ad hoc (notably anticipated loading caused by passage of vehicles/plant).

On occasion, a manhole is required to check the level of the back-fill (previously filled shaft) or to take gas measurements (where there is potential for emission at the surface). A vent may prove necessary for works where gas emissions are probable.

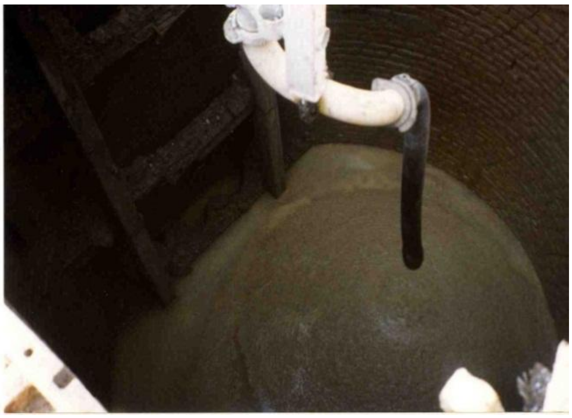
Most frequently-encountered complexity criteria (excluding accessibility to the mine-works)

- Controlled back-fill if the shaft is empty
- Blocking of pipes running alongside the shaft (potential gas emissions)
- Support blocks on the edges of the capping slab (unstable land)
- Installation of a decompression vent if residual risk of mine gas emissions

Treatment technique

Self-supporting plug

Risk of physical injury	Risk of “ground movements”	Risk of “gas emissions”	Economy	Ease/Simplicity
★★★[5]	★★★	★★	★	★★

Risk Situation (Risk diagnostic)	
“Ground movement” risk: An “ground movement” risk is established in the presence of major challenges above or in the immediate vicinity of the shaft (e.g. dwelling, occupied building, road with traffic)	 Source : CdF
Physical injury risk: The shaft presents an established risk of physical injury and the risk of falls must be eliminated	

Site conditions required:	Shaft accessible to vehicles Resistant land at shallow depth (e.g. less than 20 metres)

Principle of treatment:	Installation of concrete to a determined depth of the shaft. The geometrical irregularities of the shaft lining guarantees the cap withstands shearing stress

Maintenance/Monitoring	No maintenance (possibly gas vents)

Residual risks after treatment:	“Mine gas emission” risk

Protected species:	Technique not adapted to the preservation of protected species

Pre-requisites
Preliminary visual inspection. Condition of back-fill of works. Gas measurements, Piezometric measurements Geological and geotechnical profile of the edges of the shaft (studies already performed or specific survey) (drilling pressiometric cores) to establish depth of the firm land. Documentary search: cross section or plan of the mine-head, nearby infrastructure, technical or shallow tunnels, assessment of potential gas emissions

[5] ★★★: Technique highly adapted for the criterion
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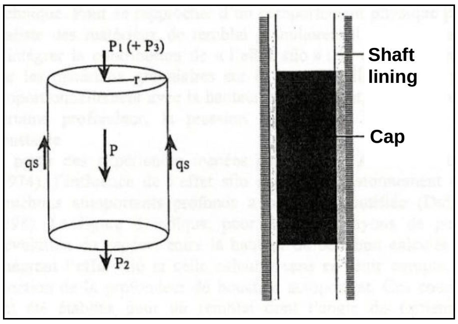
Θ: Technique not adapted for this criterion
ϟ: Technique to be prohibited for this risk situation

Technical aspects

Design-sizing



Principle of self-supporting cap with friction (shears strength) on the shaft lining

The concept of this method is to realise the cap in a rocky horizon where the constraints are taken up by the land and not by the lining. Self-support is guaranteed by resistance to shearing of the concrete on the shaft lining, which normally presents many irregularities. Satisfactory operation and durability of the cap are guaranteed if the structure is supported around the entire internal periphery of the shaft lining for optimum distribution of stress on the intrados generated by its weight. The quality of the lining, its interfacing with the land and the mechanical quality of the latter are also important aspects for retention of the cap over time.
The cap is design-sized so that the shearing resistance at the cap/shaft contact point exceeds the weight of the cap, the weight of any back-fill above the cap, and suction in the event of sudden decoring of back-fill or surface overload. A safety factor of 3 must be taken into account for resistant and moving forces. The height of the cap cannot be less than twice the diameter of the shaft.
Preferably the concrete cap should be constructed in two phases:

- Installation of a pre-cap design-sized to support casting the column of concrete;
- Once the pre-cap is sufficiently strong (20 MPa in compression), a second casting is made as defined by the principles and hypothetical calculations used to design-size the cap.

The choice of material used to constitute the cap affects its design-sizing depending on the shearing resistance of the lining/cap interface (which depends on the nature of the binder and the condition of the lining). The compression strength of the concrete is not a fundamental value: however, for its resistance over time classes superior or equal to C25/30 (standard EN 206-1) should be preferred. It is also strongly recommended taking account of the environmental attack when calculating the quantity of cement (Standard EN P18-201, CCTG booklet 65, standard P18-011). Insertion by pipe is to be preferred for shallow caps to avoid segregation.

The choice of back-fill material above the cap also has a major influence on the design-sizing of the latter. Landfill of varied grain size (see “back-fill” information sheet) or lean concrete can be used.

<u>*Constructive techniques:*</u>
1/ Installation of a pre-cap design-sized to support casting the column of concrete. 2/ Once the pre-cap is sufficiently strong (20 MPa in compression), a second casting is made as defined by the principles and hypothetical calculations used to design-size the cap. 3/ Insertion by pipe is to be preferred for shallow caps to avoid segregation.

Most frequently encountered complexity criteria (excluding accessibility to the mine shaft)

- Removal of back-fill if the shaft has been filled. Controlled back-filling, insertion of a packer or overhead planking/coffering if the shaft is empty
- Blocking of pipes running alongside the shaft (potential gas emissions)
- Use of special concrete or pumping if the shaft is submerged with water
- Special measures (pumping discharge points) if the presence of water renders this necessary (mine-works emerging for a shaft at a low topographical point)
- Installation of lockable access point at the top to monitor the level of back-fill, water or to measure gas if necessary
- Installation of a decompression vent if there is a residual risk of mine gas emissions

Treatment technique

Anchored plug/Closure

Risk of physical injury	Risk of “ground movements”	Risk of “gas emissions”	Economy	Ease/Simplicity
★★★[6]	★★★	★★	★	★

Risk Situation (Diagnostic of risk)	
Physical injury risk: The shaft presents an established risk of physical injury and risk of falls must be eliminated.	**No illustration**
“Ground movement” risk: An “ground movement” risk is established in the presence of major challenges above or in the immediate vicinity of the shaft (e.g. dwelling, occupied building, road with traffic)	

Site conditions required:	Shaft accessible to vehicles Presence of tunnels or excess widths at shallow depths in the shaft, allowing for anchoring Land suitable for the depth of anchoring

Principle of treatment:	The stability of closure is assured using anchor points (supported in the tunnels or service areas). The closure system is dimensioned to support the weight of the overlying back-fill

Maintenance/Monitoring	No maintenance

Residual risks after treatment:	“Mine gas emission” risk

Protected species:	Technique not adapted to the preservation of protected species

Pre-requisites
• Preliminary visual inspection. Condition of back-fill of works. Gas measurements, Piezometric measurements • Geological and geotechnical profile of the edges of the shaft (studies already performed or specific survey) (drilling pressiometric cores) to establish depth of the firm land. • Documentary search: cross section or plan of the mine-head, nearby infrastructure, technical or shallow tunnels, assessment of potential gas emissions

[6] ★★★: Technique highly adapted for the criterion
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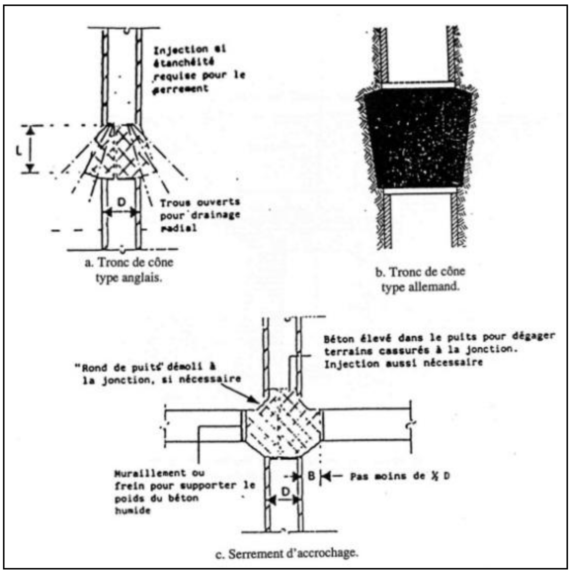
Technical elements

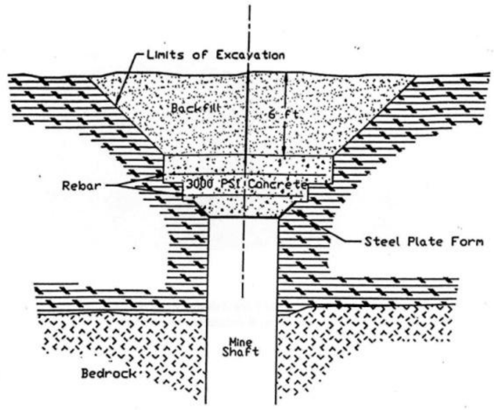
Design-sizing

Different forms of closures
Retention of the cap, the overlaying back-fill, surface overloads and any decoring is guaranteed and withstood by the structure being supported in the tunnels, conduits or service areas, or by using excess widths in the wall. Closure may be achieved according to two principles: • Anchoring to the service area: constitution of barriers to limit the flow of concrete to a predefined length; • Anchoring to the shaft wall: this technique requires extracting the shaft lining to the desired level, temporary consolidation (injection of concrete, grill, bolts) at the ring of lining located above the location of the future anchored cap. The last operation allows supporting the lining, of which the base must be excavated. Then the enclosing rock is hollowed out to house the anchored cap. The compression strength of the concrete is not a fundamental value: however, for its resistance over time classes superior or equal to C25/30 (standard EN 206-1) should be preferred. It is also strongly recommended taking account of the environmental attack when calculating the quantity of cement (Standard EN P18-201, CCTG booklet 65, standard P18-011). The choice of back-fill material above the cap also has a major influence on the design-sizing of the latter. Landfill of varied grain size (see "back-fill" information sheet) or lean concrete can be used The choice of infill material above the plug also has a major impact on its design sizing. Graduated

Most frequently-encountered complexity criteria (excluding accessibility to the mine-works)
• Removal of backfill if the shaft has been filled. Controlled backfilling, insertion of a packer or overhead planking/coffering if the shaft is empty. Blocking/coffering of tunnels, pipes or service areas running alongside the shaft (potential gas emissions) • Use of special concrete or pumping if the shaft is submerged with water • Work in the shaft: complexity/constraints of safety increase dramatically with depth • Special measures (pumping discharge points) if the presence of water renders this necessary (mine-works emerging for a shaft at a low topographical point) • If gas present in the shaft during works, use of plant fitted with anti-explosion systems and detection equipment for personnel • Installation of a decompression vent if there is a residual risk of mine gas emissions

Treatment technique

Surface cap

Risk of physical injury	Risk of “ground movements”	Risk of “gas emissions”	Economy	Ease/Simplicity
★★★[7]	★★★	★	★★	★★

Risk Situation (Diagnostic of risk) “Ground movement” risk	
An “ground movement” risk is established in the presence of major challenges above or in the immediate vicinity of the shaft (e.g. dwelling, occupied building, road with traffic)	 *Source National Coal Board, 1982*
Physical injury risk: The shaft presents an established risk of physical injury and risk of falls must be eliminated.	

Site conditions required:	Shaft accessible to vehicles Resistant land at shallow depth (e.g. less than 5 m)

Principle of treatment:	Concreting after clearing the top of the shaft filling. Stability of the cap is assured by the supporting land by reaction. It prevents accidental falls and any “ground movement” risks if correctly design-sized.

Maintenance/Monitoring	No maintenance (except vents for gas if necessary)

Residual risks after treatment:	“Mine gas emission” risk

Protected species:	Technique not adapted to the preservation of protected species

Pre-requisites

- Preliminary visual inspection. Condition of back-fill of works. Gas measurements, Piezometric measurements
- Geological and geotechnical profile of the edges of the shaft (studies already performed or specific survey) (drilling pressiometric cores) to establish depth of the firm land.
- Documentary search: cross section or plan of the mine-head, nearby infrastructure, technical or shallow tunnels, assessment of potential gas emissions

[7] ★★★: Technique highly adapted for the criterion
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Θ: Technique not adapted for this criterion
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Technical aspects

Design-sizing
The surface cap, frequently known as the “champagne cork” is design-sized so that its support on the sound solid material enables it to bear its own weight, that of surface overloads and any effects of sudden decoring if the shaft is back-filled. These supports must be design-sized taking into account the reaction capacities of the supporting solid ground. In particular, the support surface must be sufficiently wide enough to avoid phenomena of stress concentration (or “corners”) which are likely to cause failure of the supporting firm land. The installation of a surface cap requires clearing the land at the mine head, down to the depth of the firm ground over an adequate diameter. There may be variants of this type of structure, notably when the infrastructure around the mine head is concreted to a guaranteed strength. The concept of distributing support over the firm ground, whether natural (rock) or artificial, avoiding stress concentration, must be the basic principle of design-sizing. The choice of back-fill material above the cap also has a major influence on the design-sizing of the latter. Landfill of varied grain size (see “back-fill” information solution) or thin concrete can be used. The choice of infill material above the plug also has a major impact on its design sizing.

Most frequently-encountered complexity criteria (excluding accessibility to the mine-works)
• Removal of back-fill if the shaft has been filled. Controlled back-filling, insertion of a packer or overhead planking/coffering if the shaft is empty • Blocking of pipes running alongside the shaft (potential gas emissions) • Pumping if the shaft is submerged with water • Special measures (pumping discharge points) if the presence of water renders this necessary (mine-works emerging for a shaft at a low topographical point) • If gas present in the shaft during works, use of plant fitted with anti-explosion systems and detection equipment for personnel • Installation of a decompression vent if there is a residual risk of mine gas emissions

Treatment technique

Injection/inclusion techniques

Risk of physical injury	Risk of “ground movements”	Risk of “gas emissions”	Economy	Ease/Simplicity
★★★[8]	★★★	★ / ★★	★	★/★★

Risk Situation (Diagnostic of risk)
“Ground movement” risk: An “ground movement” risk is established in the presence of major challenges above or in the immediate vicinity of the shaft (e.g. dwelling, occupied building, road with traffic)
Physical injury risk: The shaft presents an established risk of physical injury and risk of falls must be eliminated.

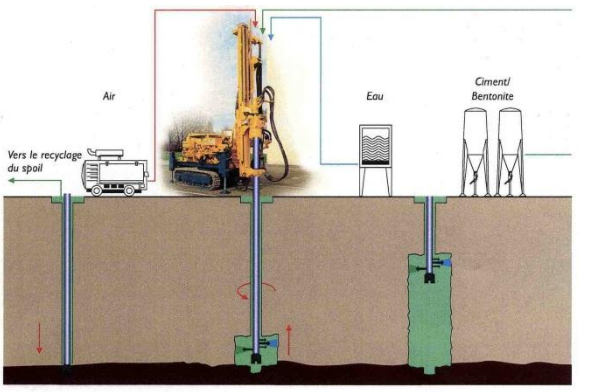

Diagram of jet grouting (keller website) to spoil recycling

Site conditions required:	Shaft accessible to vehicles Available space around the works for material and plant
Principle of treatment:	Injection of grout, mortar, concrete etc., according to various procedures to reinforce the back-fill in the shaft and/or the surrounding land.
Maintenance/Monitoring	No maintenance (except vents for gas if necessary)
Residual risks after treatment:	“Mine gas emission” risk
Protected species:	-

Pre-requisites

- Visual inspection of surroundings and encumbrances around the shaft. Condition of back-fill of works. Gas measurements, Piezometric measurements.
- Geological and geotechnical profile of the edges of the shaft (studies already performed or specific survey) (drilling pressiometric cores) to establish depth of the firm land. Nature of shaft back-fill in the event of treatment therein.
- Documentary search: nature of backfill, cross section or plan of the mine-head, nearby infrastructure, technical or shallow tunnels, assessment of potential gas emissions

[8] Technique highly adapted for the criterion
★★: Technique adapted but other techniques may be more appropriate, or it requires modifications/adaptations
★: Technique not particularly adapted for this criterion or to be investigated
Θ: Technique not adapted for this criterion
⊘: Technique to be prohibited for this risk situation

Technical aspects

Design-sizing
This sheet groups together all the technical measures for drilling with a view to including or combining with the ground, more resistant materials to reinforce (i.e. render the ground more consistent and strong). Ground means either the back-fill in the shaft or the back-fill and soil around the latter. These techniques are generally proposed in the following situations: • If the load-bearing rock is located at considerable depth, traditional "cap" solutions and anchoring in solid ground become technically or economically unfeasible. With reinforcement/improvement, resistant ground is created around the shaft, limiting or preventing extension of any collapse at the mine head. The back-fill in the shaft may also be consolidated to create a structure an equivalent to a cap; • When the shaft is not accessible because it is located under buildings or other superstructure preventing insertion of a traditional cap. By inclined drilling, a consolidated block is created in the shaft, ensuring it is lodged in a solid mass on the extrados of the works. There are many injection methods, and many possible material compositions, with variable operating pressures according to whether it is wished to include material in the land, or replace the latter. The main existing techniques are **solid injection** (grout, mortar) to densify the ground at various depths, **ballasted columns** which incorporate granular alluvial/clay soil which can be bound by grout or cement, **jet-grouting** which pumped in at high pressure, (20 to 40 MPa) replaces the original soil by grout. Land-strengthening companies have frequently created their own processes, which are fairly similar to these techniques. It is also possible to insert **ridged inclusions** (of the tie-bolt type) to anchor a cap injected in the rock on the extrados of the shaft. *Treatment around the shaft* The important points concerning the choice of technique are the depth of the soil to be treated, the perimeter around the shaft to be treated (depending on the potential impact margin for hazards linked to failure of the mine-head), and the grain size of the soils (distribution of gravel, sand, alluvium, clay). This finial parameter in fact orients the choice of technique, the density of injection points and the operating pressure. If the sound bedrock is below 30 metres efficaciousness of this technique is difficult to prove. *Treatment in the shaft* The method is to create a structure inside the shaft which can withstand coring of the back-fill, either by friction (same principle as self-supporting cap) or by anchoring and shear resistance in the ground on the extrados of the shaft lining. The important points concerning the choice of technique are depth of the shaft to be treated, the grain size of back-fill present in the shaft, the nature of the lining (if this is to be drilled, to install tie-bolts), the maximum slope of test drills given the space available on the surface. The use of these sometimes innovative techniques requires a detailed project design study.

Most frequently-encountered complexity criteria (excluding accessibility to the mine-works)
• Controlled back-filling, insertion of a packer or overhead planking/coffering if the shaft is empty • Encumbrances and presence of infrastructure/buildings on and around the shaft • Blocking of pipes running alongside the shaft (potential gas emissions) • Use of special concrete if shaft or surrounding land is submerged in water • Insertion of a decompression vent if there is a residual risk of mine gas emission

Treatment technique

Vent

Risk of physical injury	Risk of “ground movements”	Risk of “gas emissions”	Economy	Ease/Simplicity
Θ [9]	Θ	★★★	★★	★★

Risk Situation (Diagnostic of risk)	
Physical injury risk: Risk of asphyxia, ignition or explosion, if access to the opening is possible. Exposure to ionising radiation	 *Source INERIS*
“Ground movement” risk: Not applicable	

Site conditions required:	The works have been treated and are accessible to site plant. A nacelle may be necessary to access the flame arrester at the mine head

Principle of treatment:	This technique, ancillary to protecting old mine works with a risk of physical injury or of ground movements, intends to control surface emissions of mine gas according to the anticipated flow-rate and composition.

Maintenance/Monitoring	Maintenance required every 6 months

Residual risks after treatment:	“Ground movement” risk, if the structure was not protected against this risk

Protected species:	Technique not adapted to the preservation of protected species

Pre-requisites

Measurements of gas (flow rate, composition) at various periods to assess the pertinence of use of this technique in mining areas where mine gas hazards are uncertain.

Subsequently, a study is frequently necessary to estimate the safety radius around the vent, to take into account the risk of explosion, ignition, asphyxia, poisoning and exposure to ionising radiation.

Accessibility to the shaft or mine head. Verification of configuration of the site and the possibilities of installing a safety vent, positioning the top at a sufficient height, and accessing the various vent components for upkeep and maintenance.

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[9] ★★★ : Technique highly adapted for the criterion
★★: Technique adapted but other techniques may be more appropriate, or it requires modifications/adaptations
★: Technique not particularly adapted for this criterion or to be investigated
Θ: Technique not adapted for this criterion
⌁: Technique to be prohibited for this risk situation

Technical aspects

Design-sizing
Given the following constraints, notably linked to maintenance and upkeep of the vent, before committing to this technique it must be established whether it is pertinent, given the potential “gas emission” risk. A study should be prepared to define the flow rate and composition of the gas since this will have a direct influence on the nature and characteristics of the vent, and the required safety radius. The design-sizing of the vent (a diameter which may vary from 50 to 150 mm, a height which may vary from 3 metres to some 10 metres) will depend on the anticipated gas flow rate from the works, according to the volumes of mining voids, height of the pump outlets, flow rate of the gas and its composition. The flow rate will be higher during periods of low atmospheric pressure for so-called former “closed” mines (base-surface links principally composed of blocked shafts/tunnels). The design-sizing must take into account the potential chemical effects of gas which may be present (methane, gas low in oxygen, carbon dioxide, hydrogen sulphide, nitrogen oxide, radon etc.): • Accidental ignition of fire-damp (creation of a torch-type fire is possible if the outgoing foul air incorporates flammable gases in certain proportions, either directly on leaving the vent or following their dilution in air and contact with a source of ignition), the thermal effects linked to an unconfined gas explosion; the role of the wind must be taken into account for orientation and length of the smoke plume; • Poisoning or asphyxia (gas more or less toxic); • Corrosion of the structure; • Accidental risks (ignition, explosion, intoxication, asphyxia etc.) but also chronic risks (exposure to ionising radiation linked to the presence of radon). Sufficient distancing of dwellings or adequate height to ensure dilution of gasses must be ensured, depending on the configuration. The vent is made of several components: non-return valve, flame arrester, device for gas measurement (content and flow rate), ¼ turn valve to close the outlet at the base for maintenance and upkeep. One vent which operates successfully (in the case of a closed system, and while the mining voids represent an adequate volume) presenting differential pressure variations opposite to variations in barometric pressure. The construction of a fence with an access door may be necessary if significant flow rate of foul gas in anticipated and if the height of the flame requires extending the safety radius, to protect from risks of ignition, explosion, intoxication, asphyxia and exposure to ionising radiation.

Complexity criteria
Encumbrances at the site requiring special provisions Some shaft vents may be remote from the works being treated (lack of space on the surface, etc), and the pipe linking the shaft and the vent is then underground. The route of the pipe must be traced and mapped from its start (mine head in general) up to the vent in the same way as traditional pipes (DICT). Prefer pipes and equipment with the least possible loss of load (a non-return valve prevents entry of atmospheric air but requires over-pressuring up-stream to allow the gas to exit) Increased frequency of surveillance and maintenance in sensitive areas: verification of satisfactory functioning of the vent (soiling, oxidation of ferrous components etc.) non-degradation, access and integrity of the fence and information provided

Treatment technique

Geo-synthetics

Risk of physical injury	Risk of “ground movements”	Risk of “gas emissions”	Economy	Ease/Simplicity
★★[10]	★★	Θ	★★	★★

Risk Situation (Diagnostic of risk)	
Physical injury risk: The shaft may present a residual risk of physical injury. However this technique is not recommended for open shafts.	
“Ground movement” risk: A “ground movement” risk is established given the presence of a shallow shaft improperly filled. The challenges are low traffic roads, services, footpath	

Site conditions required:	Shaft back-filled, accessible to site plant, level land which can be compacted

Principle of treatment:	This occasionally used technique consists in installing over a surface which largely extends beyond the shaft, a flat geo-composite structure (geotextile, geo-grill, geo-membrane) which reduces the intensity of collapse or compaction of the shaft back-fill to render it acceptable and non-hazardous This technique reduces the consequence of ground movements without treating the cause. Moreover, there is little feedback on its use.

Maintenance/Monitoring	Tests under the norm EN 13251 Visual follow-up of the slope (for example, twice per year) Re-working of earthworks/replacement of geo-composites for example, every five years)

Residual risks after treatment:	Ground movement” risk: compaction. “Mine gas emission” risk

Protected species:	Not applicable

Pre-requisites
Knowledge of diameter, depth and state of back-fill in the shaft, assessing the intensity (depth, diameter) of remobilisation of back-fill

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Technical aspects

Design-sizing
Geo-synthetics can be classified in three major categories: • Geo-grills, which have a discontinuous flat structure, of which the varied mesh is adapted to the terrain. These structures, generally made in steel or PEHD, are selected depending on their shearing resistance and tensile strength. • Geo-textiles, woven or non-woven, have a continuous flat structure. Of varied chemical composition, their main purpose is to filter, drain or resist puncture by equipment. Tensile strength is not their main function but the denser types can cope with some slopes and the tensile stress generated. They are frequently used in association with a geo-grill or a geo-membrane. • Geo-membranes also have a continuous flat structure, but their role is to limit insofar as possible, the passage of liquids. They are used to render the works impermeable. Excluding specific use, geo-membranes are not immediately adapted to treating the surface of mine-works. The Comité Français des Géosynthétiques (http://www.cfg.asso.fr) has published many guides facilitating the choice of geo-synthetics depending on the desired purpose: drainage, filtering, anti-puncture, resistance to tensile load, impermeability. The manufacturer of the geotextile will have to accomplish what is specified regarding to the marked CE (Directive 89/106/CEE).The characteristics of the material will have to allow it to be resistant (without suffering tear when putting the overburden over it). For these purposes, the material will have these characteristics: • The longitudinal tensile strength won't be inferior to 21.1 KN/m • The transversal tensile strength won't be inferior to 24.8 KN/m. • The longitudinal elongation in minimum breakage will be of 60%. • The transversal elongation in minimum breakage will be of 60%. • The minimum elastic indentation will be of 3930 N. • The maximum dynamic perforation will be of 10 mm. • The minimum permeability perpendicular to the plane will be of 31 l/m2/s. With regard to treating mine shafts, it is important first to identify the anticipated impact on the surface of remobilising the back-fill in a shaft, extending the affected zone and the maximum tensile stress this may generate. A specific study, possibly with the support of modelling is deemed extremely important for the choice of the correct category of geo-synthetic to use. *Constructive techniques*: 1/ The geo-synthetics will be extended over a flat surface, previously shaped and free of cutting and sharping elements. The overlaps between layers won't be inferior to 50 cm, excepting that the joints between them are made by sawing or welding, in which case the overlap could be reduced to 30 cm. 2/ The pouring of the upper layer, generally of granular material, will be made very carefully in order not to damage the geosynthetic, not allowing the circulation of trucks over the textile. The first layer to extend, of thickness of 40 cm, will not content elements of superior size of 200 mm. 3/ The surface in which the geosynthetic will be extended will be clean and free of elements that can harm the geosynthetic. 4/ The extension of the upper layer will be in that way so that the machinery for the extension and compactation will never circulate over the surface of the geosynthetic. 5/ The first layer of material will be at least of 40 cm and the maximum size of the arid won't be bigger of 200 mm. 6/ It has to be adherent enough to the surface in order to absorb the impacts from the environment. 7/ The way of placing the net and its size is very important because it will determine the capacity of the solution.

Complexity criteria
• Clearing land around the mine head: increased difficulty depending on the geological nature of the land and its relief • Safety of earth moving plant at the edge of the shaft

4.3 Best constructive solution to avoid failure

In the previous paragraphs, the methods of shaft treatment and the different types of shaft failure were presented and detailed. In the Table 2, the main constructive solution to avoid failure and risk scenarios are proposed.

Table 2: Best constructive solution depending failure or risk type

Failure / risk type	**Constructive solution**
Collapse of shaft filling material	→ insure of the robustness of the deep closure structure → clean the shaft before the filling → choose suitable filling materials → control the filling of the shaft to avoid the creation of void
Failure of shaft head	→ insure the robustness of the existing cap → for opened shaft, establish a capping well dimensioned able to resist especially to water pressure and/or surface overload → reinforce the surrounding land by injection
Failure of shaft lining	→ for opened shaft, check by inspection the state of degradation of the lining and reinforce the lining in case of degradation → use backfilling method when possible → reinforce the surrounding land by injection
Failure of deep closure structure	→ design closure structure according to the applied loads → clean the shaft before the filling
Failure due to water effect and/or particular geologic formation	→ design capping taking into account possible water effect → use filling material appropriate to mining water → reinforce lining or soil to avoid water infiltration
Risk of subsidence	→ use appropriate filling material → control the filling of the shaft to avoid the creation of void
Risk of gas release	→ establishment of event → control of gas concentration

5.CONCLUSION

This handbook is a state of the art of all the treatment techniques known for mine shafts. No technique should be dismissed. The choice of treatment depends on several criteria such as geology context, urban context, cost....

However, among all the methods presented in this handbook, three of them are the most commonly used and have, repeatedly, demonstrated their effectiveness:

- Backfill, preferred when strata crossed by the shaft are not consistent, deconsolidated and when forces transmitted by a cap are not sufficient to insure shaft long-term stability;
- Anchored cap / surface cap, favored when strata are consistent and resistant to absorb the stresses transmitted by the cap;
- Self-supporting cap, privileged when the surface strata are healthy and consistent over a sufficient height, the condition of the masonry is also satisfactory, the establishment of a self cap is relevant because it generates low costs of implementing and if this technique do not require access to the shaft interior.