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Review

A short review on the surficial impacts of underground mining

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Subsidence in terrains is one of the most serious geological hazards because they can effect slopes and damage engineering structures, settlement areas, natural lakes, and allow infiltration of contaminant into the groundwater. Causes of underground mining activities such as subsidence, slope deformation, etc. are very important problems in most countries and these types of impacts are very well known in coal, metal and other types of mining. The main aim of this article is to provide technical documentation of environmental impacts related to underground mining, to discuss significant impacts on the environment and land-use during and/or after underground mining projects. Identification, measuring and mitigation of the effect of underground mining activities for practitioners is also aimed in this short review article. This short review article will also be important in order to better understand the nature and magnitude of displacements that can affect surface infrastructure.

Key words: Underground mining, subsidence, collapse, slope deformation, surface

INTRODUCTION

When the extraction coal, oil, shale and other minerals or geological materials by surface mining is impossible, underground mining methods are used. In underground mining, geological materials completely enclose the working environment. Underground mining is one of the most important mining activities in the world and it has been found as very large terrestrial areas in different parts of the world. Underground mining (soft rock) refers to a group of underground mining techniques used to extract coal, oil shale and other minerals or geological materials from rocks, and this technique also differs greatly from surface mining techniques. Shortwall, longwall, room and pillar, blast, etc. are the few methods in underground mining activity. Removal of the material by underground mining can create environmental problems and safety hazards.

Longwall mining (Figure 1) is a kind of underground mining where a long wall of material is mined in a single slice (typically 1 to 2 m thick). The longwall panel (the block of material that is being mined) is typically 3 to 4 km long and 250 to 400 m wide. However shortwall mining is similar to longwall mining. Panels in shortwall mining are 50 to 100 m wide and more than a half-kilometer long. As explained by Hustrulid and Bullock (2001), longwall mining applies to thin-bedded deposits of uniform thickness and large horizontal extend. Longwall mining applies to both hard and soft rock as the working area along the mining face can be artificially supported where the hanging wall tends to collapse. The longwall mining method extracts ore along a straight front having a large longitudinal extension.

Room-and-pillar (Figure 2) is designed for flat-bedded deposits of limited thickness such as copper, shale, coal, salt and potash, limestone, and dolomite. This method is used to recover the maximum amount of ore and miners aim to leave the smallest possible pillars. Classic room and pillar mining applies to flat deposits having moderate to thick beds and to inclined deposits with thicker beds. Mining the ore body creates large open stops where trackless machine can travel on the flat floor. Ore bodies with large vertical heights are mined in horizontal slices starting at the top and benching down in steps (Hustrulid and Bullock, 2001).

Blast mining is an older practice of mining that uses

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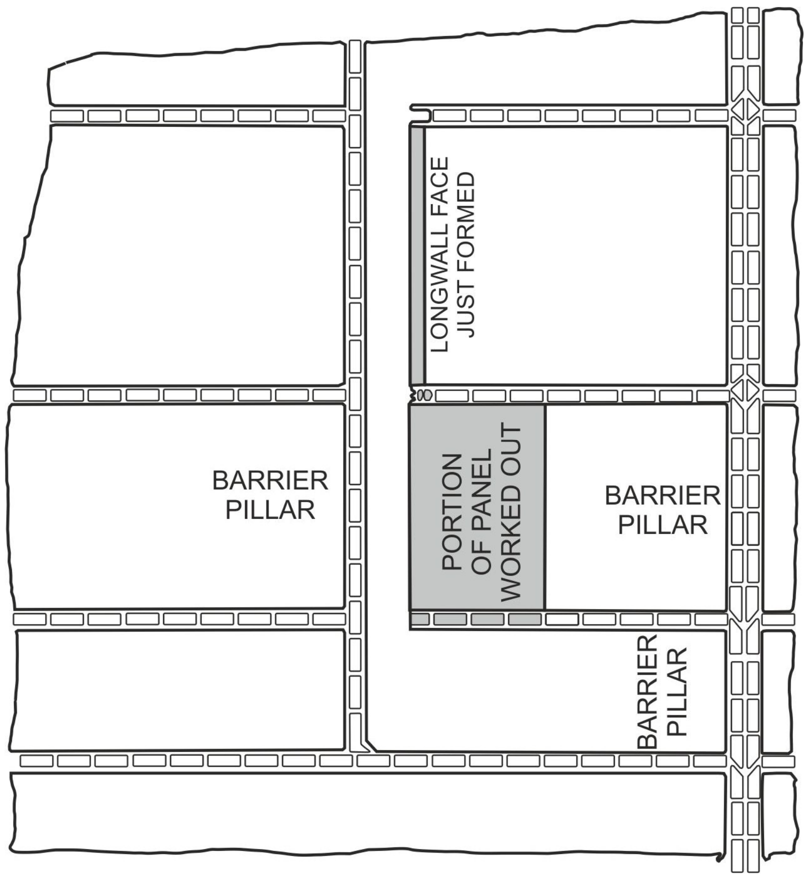

Figure 1. Longwall method in underground mining (Hamrin, 1980).

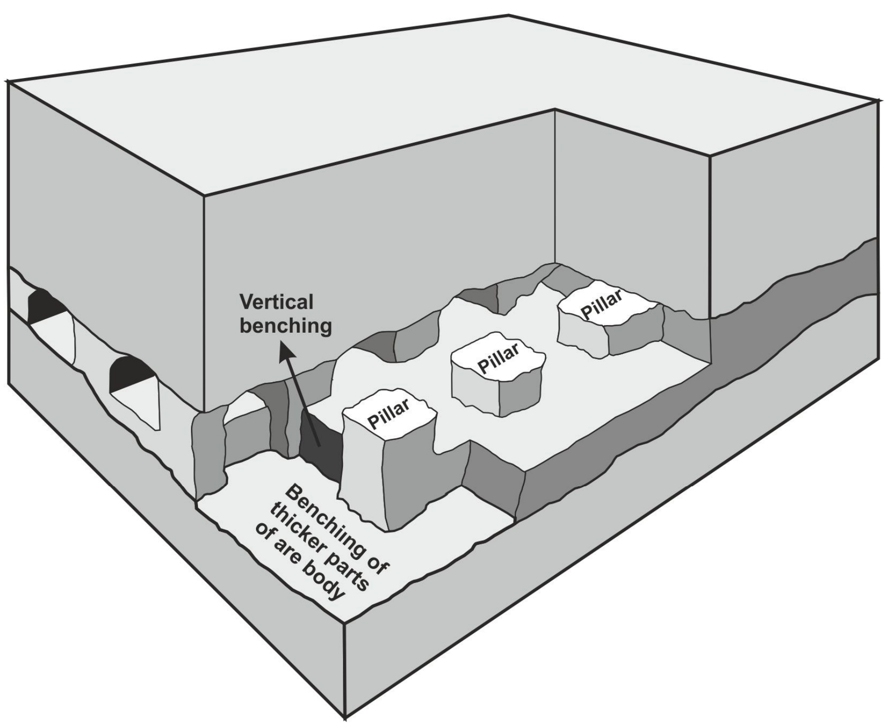

Figure 2. Room-and-pillar method in underground mining (Hamrin, 1980).

explosives such as dynamite to break up the coal seam, after which the coal is gathered and loaded onto shuttle cars or conveyors for removal to a central loading area. This process consists of a series of operations that begins with "cutting" the coal bed so that it will break easily when blasted with explosives. This type of mining accounts for less than 5% of total underground production in the U.S. today.

Surface subsidence and slope deformation due to underground mining activities is an old problem, and the increase in use of long wall mining and further housing development into the abandoned mine lands in the suburban areas further accelerated the public concerns about surface subsidence and slope deformation due to underground mining.

Subsidence or collapse can be defined as the vertical ground movement and have serious effects on buildings, services and communications. Sinking and/or lowering of a land surface, which may occur gradually or suddenly, affects areas from few square meters to square kilometers. Collapse, subsidence and difficult engineering conditions sourced from underground mining activities constitute very important problems in many countries in the world. Collapse and subsidence may occur in the course of time or suddenly and catastrophically. Planning and precautions in such hazardous areas is very important and has a priority. Remediation and construction of the special building is needed at a higher cost. So, legislation for very special construction regulations put the contractors or owners to a higher expense.

The aim of this article is to provide technical documentation of environmental impacts related to underground mining, to discuss significant impacts on the environment and land use during and/or after underground mining projects. This short review article will also be important in order to better understand the nature and magnitude of displacements that can affect surface infrastructure.

SURFACE IMPACT OF THE UNDERGROUND MINING METHODS

However, the main impacts of underground mining activities on the surface are subsidence and slope deformation. These activities have also other impacts on the groundwater and surface water, spring, lakes and rivers accompany.

Subsidence

Cavity collapse has led to extensive cracking and subsidence at the ground surface. Subsidence can be regarded as the vertical component of ground movement and have serious effects on buildings, services and communications. Subsidence as the sinking or lowering of the land surface may occur gradually, almost imperceptibly or it may occur quite suddenly. Cover collapse may affect areas as small as a few square meters or as large as 1000 of square kilometers. Subsidence in terrain is one of the most serious geological hazards because they can damage engineering structures, settlement areas, natural lakes and allow infiltration of contaminant into the groundwater.

Soliman (1998) defines subsidence as a natural and/or man-made phenomena which is associated with a variety of processes including compaction of natural sediments, ground water dewatering, wetting, melting of permafrost, liquefaction and crustal deformation, withdrawal of petroleum and geothermal fluids, and mining of coal, limestone, salt, sulfur and metallic ores. Subsidence has always been a consequence of underground mining to at least some extent, beginning when the first rock fell on top of a person working underground for the purpose of extracting a mineral resource (Blodgett and Kuipers, 2002).

Subsidence on the surface is generally a result of cavity creation. Blodgett and Kuipers (2002) also reported that another mining-related phenomenon is the withdrawal of water to facilitate underground mining. Water withdrawal also causes the formation of cavities (which were once filled with water) and, like cavities directly created by mining, may result in subsidence as the hydro-geological properties of the associated strata are changed.

As quoted from Betournay (2002), shallow stopes are defined as the underground metal mine openings closest to surface, usually within 30 m, situated at or very near overburden bodies of water or infrastructure. The natural tectonic ground stresses may not be sufficient to prevent gravity failures or in the case of intense regional mining activity, the rock mass may be destressed. When the rock mass is poorly jointed, and of high quality, extensive lateral stope dimensions, or very thin pillars can be stable in the short term.

Movements of the rock mass at the periphery of shallow stopes can be sudden and massive, piecewise and continuous, or gradual over long periods of time, and may not ever reach surface because of re-equilibration, lack of space for the failure material to enter (preventing the failure to continue) or changes in geology or stope configuration. When rock material has poor self-support capabilities, failure to surface by exceeding rock strength is possible. Rock mass instabilities fundamentally originate with geological discontinuities (joints and faults) and rock fabric (bedding, foliation, etc.).

However, surface impact from underground mining activity is very well known and reasonably well understood as a result of the effect of underground mining activities. Many hazards, undesired structural and environmental problems on the surface are being addressed in many countries. Many case studies are reported related to the impact of the underground mining activities such as Crane (1929), Allen (1934), Rice (1934), Hedley et al. (1979), Commission d' Enquete Mine Belmoral (1981), Robertson and Kirsten (1984), CANMET Contract (1984, 1985, 1986, 1987, 1988, 1990,1991), Betournay et al. (1987), Betournay and Labrie (1988), Whittaker and Reddish (1989), Charette and Betournay (1992), Charette and Hamel (1993), Wang et al. (1995), Betournay (1994, 1995), Betournay and Wang (1997), Perski and Jura (2003), Marschalko et al. (2008 a, b, c), Marschalko et al. (2009), Marschalko and Treslin (2009), and modified from Betournay (2002).

Slope deformation

A mining landslide refers to a mountain landslide that is caused by the deformation and destruction of the upper stratum (soil) under the influence of underground mining (Li, 2003; Song et al., 2003).

Tang (2009) reported that the formation of a mining landslide depends on three factors; sloping ground, underground mining and a weak intercalated bed (face) in the upper stratum. The topographic and geologic circumstance that has sensitive influence in a mining landslide mainly includes:

(a) A mountain with a steep gradient.
(b) A slope stacked with slack material.
(c) A layer with a weak intercalated bed.
(d) A geologic circumstance with an ancient slide.

The influence that is caused by underground mining mainly includes (Tang, 2009):

(a) Cracking caused by mining formed on the ground surface.
(b) Loss of the pedestal body of the mountain.
(c) Changes in the stress field, and geological and mechanical properties of the upper stratum.
(d) A change in the hydrologic circumstance of the upper stratum.

Mining activities (ground and/or underground) are one of the most important factors which affect and change the engineering geological conditions. Subsidence in the surface through underground mining area may cause settlement, slope movements, discontinuous deformations and changes in hydro-geological conditions. The slope deformations may be triggered by occurrence of a subsidence trough undermined area. Changes of gradient, state of stress in slope, physical and mechanical properties of the slope material, ground water levels, etc. causes the slope deformations.

The mining activities may cause a relative increase in the groundwater level (terrain surface depression) which usually causes saturation of the slope material, and stability of the slope is worsened. In certain cases the terrain depression can lead to the formation of undrained depressions (lakes or small lakes).

The least positive area of the subsidence trough is its slope, on which deformations caused by the rock movements into the centre of the mined out area show the most. The subsidence slope has a characteristic shape and its parts are generally labeled (from the slope crest) as convex portion, point of inflection and concave portion (Figure 3.). At the localization of the slope deformation in the point of the subsidence slope, two critical situations can appear in dependence on their mutual surface areas. If the landslide takes up a larger area than the subsidence slope, deformations characteristic for the convex portion, point of inflection as well as the concave portion of the subsidence slope will show. In the opposite case, the overall slope deformation is situated in one part of the subsidence slope (Marschalko et al., 2008; Marschalko and Treslin, 2009).

Subsidence occurrences due to underground mining and their development cause a negative impact on the stability conditions of surficial area as the slope movement. Direction and size of movement and the surface deformation caused by this movement can be clearly specified in case of this slope movement action. As stated by Marschalko and Treslin (2009), in cases of mutual action for the purposes of identification of a terrain deformation cause, it is necessary to separate the individual influences which can be achieved by the correlation of changes in the terrain deformation and the overall development of a subsidence trough with slope deformation movement measurements.

DISCUSSION

In both the underground and surface mining, if a void is excavated in a rock continuum, the load formerly applied on the rock in the opening will be transferred either to the rock surrounding the opening or to the supports (pillars) within the opening or both, and finally to the ground surface, hence resulting in a macroscopically non-uniform deformation of the surface in the horizontal or vertical direction. If the uneven deformation or subsidence (that is, differential subsidence on the top of the mined-out area) cannot be effectively controlled, then it will cause damage and even a disaster such as deformation or even cracking of buildings, particularly tall buildings. This means that the failure of a building is to a great extent controlled by the presence of differential subsidence rather than the absolute magnitude of subsidence (Li et al., 2006).

The underground mining process has a large negative influence on the environment of the whole undermined area. If after mining out of the seam, large depressions and reactivation of extensive slope deformations (blocks and landslides) on the surface occurs, several villages, highways and railways in endangered area may be affected (Malgot and Baliak, 2004).

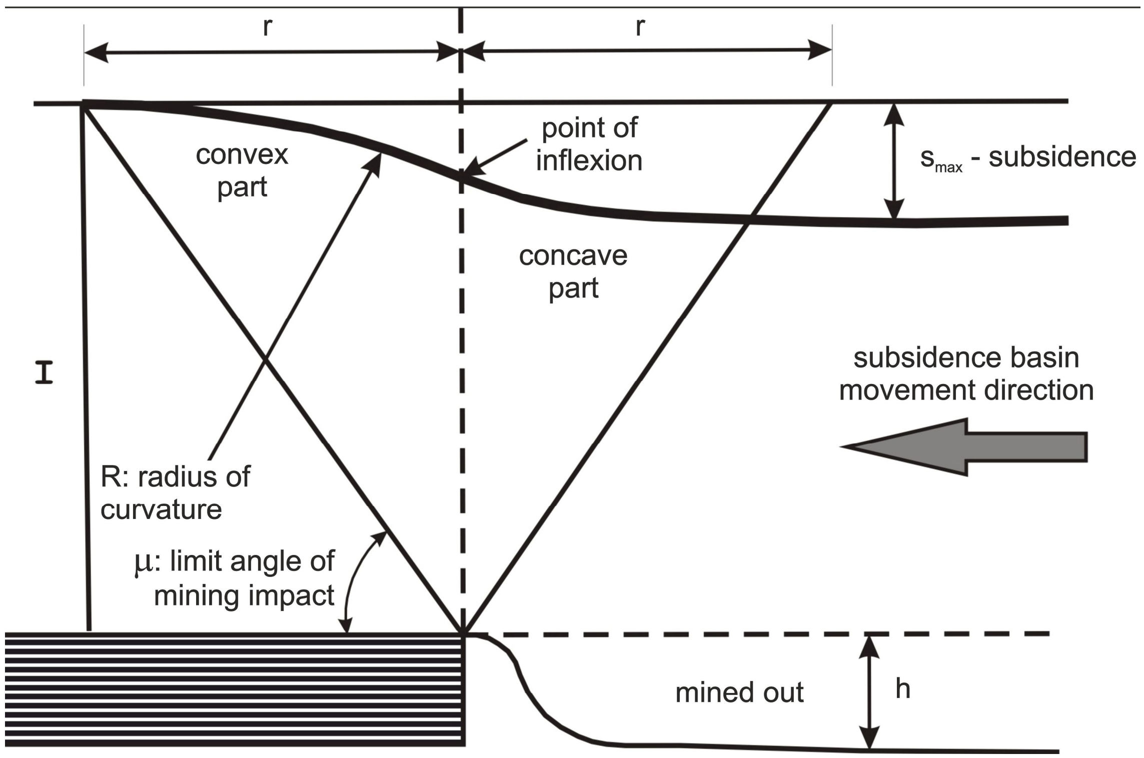

Figure 3. Schematic representation of influenced slope deformation by the subsidence (Marschalko et al., 2008; Marschalko and Treslin, 2009).

The displacement and deformations of rock mass due to underground mining has often resulted in major disasters throughout the world, frequently inflicting heavy losses of life and damage to property. And these disasters have motivated the development of rock mass mechanics. The prediction of displacement of rock mass and their surface effects is an important problem of the rock mass mechanics in the excavation activities especially the coal and metal mining in mountainous areas (Li et al., 2006).

Mine subsidence can be a problem with underground mining, whereby the ground level lowers as a result of material having been mined beneath. A thorough understanding of subsistence patterns in a particular region allows the effects of underground mining on the surface to be quantified. The mining industry uses a range of engineering techniques to design the layout and dimensions of its underground mine workings so that surface subsidence can be anticipated and controlled. This ensures the safe, maximum recovery of mine resource while providing protection to other land users.

When underground mining involves total extraction, it induces overburden strata movements. If not properly planned, it causes surface subsidence and affects surface environmental conditions. Total extraction usually refers to long wall mining, and bord and pillar mining with pillar extraction. Surface subsidence has long been a subject of intensive research for scientists all over the world and considerable achievements have been obtained. However, due to its difficulties and complicated nature, research into overburden movements has been thus far incomplete as compared to that of surface subsidence. Since surface subsidence is a manifestation of the results of overburden, movement must be fully understood in order to establish the mathematical prediction models of surface subsidence (Rao, 2004).

Underground mining raises a number of environmental challenges including subsidence, slope deformation, water pollution, etc. That's' why steps should be taken in modern mining operations to minimize impacts on all aspects of the environment. By carefully pre-planning projects, implementing subsidence and slope deformation control measures, monitoring the effects of mining and rehabilitating mined areas, the mine industry minimizes the impact of its activities on the neighboring community.

Presentation of engineering geological data in the form of a hazard map is a useful tool in urban planning. In order to avoid the problems related to the subsurface and thus save property and money, detailed geo-scientific data should be collected and used in urban development plans. The main topic providing the integrated information for urban development is engineering geology. Engineering geological maps contain information mainly on the physical - mechanical properties of soils, shallow groundwater levels, potential hazardous processes, etc. The systematized information provided by the engineering geological map is used for:

(a) Evaluation and planning of urban areas according to the engineering conditions.
(b) Elaboration of project planning documents for construction.
(c) Selection of the optimum range of engineering geological investigations in particular areas of construction.
(d) Selection of a suitable foundation type and construction design.
(e) Prognosis of changes of engineering geological conditions and prediction of hazardous geological phenomena.

In order to implement a control scheme for avoidance from severe collapse and destruction of properties and infrastructures, relative collapse hazard and/or susceptibility level should be first assessed (Yilmaz and Yavuzer, 2005; Yilmaz and Bagci, 2006; Yilmaz, 2008; Yilmaz, 2009).

Whenever a building on underground mining activity area is compulsorily constructed, the following attentions should be considered particularly:

(a) Implement detail geological, geophysical and borehole exploration before construction.
(b) Fill the cavities close to the foundation.
(c) Divert the surface flows away from the structure.

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