Role of Geological Structures on Pot-hole Subsidence Development due to Underground Mining

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Abstract

Subsidence is defined as the readjustment of the earth's surface caused by natural or man-induced modification of the underlying litho structure. There are two types of subsidence namely trough and pot-hole subsidence. It occurs in two forms, Trough subsidence and Pot-hole subsidence. Trough subsidence usually occurs in great depth whereas pot-hole at shallow depth. In this paper, we have discussed the occurrence of pot-hole due to different geologic structures which are the most important factor in comparison to other causative factors. Also, discussed the different case studies in relation to these geological structures in details for the occurrence of pot-hole in underground mining.

1. Introduction:

Surface deformation is caused due to underground exploitation of minerals which occurs in two forms, Trough and Pot-hole subsidence. Trough subsidence usually occurs at great depth whereas Pot-hole at shallow depth. In pot-hole subsidence, geology is the most important parameter for their occurrence in comparison to other factors. The importance of geological structure in ground control particularly the nature of the overlying strata, faulting systems and fractures and breaks in the strata are identified as special factors. Faults, however, are regarded as having more serious effects than other features in producing displacements at the surface.

ICE (1977) suggests that variations in the types of strata between the extracted seam horizon and the surface do not affect the maximum amount of subsidence. This is most certainly not the case when considering the presence of massive sandstones overlying coal seams. The importance of certain rock types such as limestone, which may exhibit significant fracturing and intense differential displacements with the potential to cause serious damage at the surface in the form of pot-hole subsidence.

2. Geological Structures:

Geological structures are very important causative factors for the occurrence of pot-hole subsidence due to underground mining. These structures include fissures, faults, fractures, lithology, etc. A brief description to these structures is discussed below one by one.

***Keywords**: Underground Mining, Pot-hole Subsidence, Geological Discontinuity, Hydrogeology*

2.1 Fissures :

The fissures occur in brittle rocks and along lines of maximum tensile strain if it is sufficiently intense as to induce failure or cause opening of pre-existing lines of weakness within the rock structure at the surface and sub-surface. Fissures subjected to tensile strains are of particular importance to pot-hole subsidence. The term fissure is essentially by definition that of an opening initially resulting from some fracture process but being also subjected to widening due to erosion or weathering at some stage. Fissures are mainly of natural origin with occurrences linked with tectonic movements. They are encountered in surface bed rock conditions above mining areas and posing problems. Bed rocks are commonly covered with more recent deposits of soils, clay, sand etc. On exposure, bed rock exhibit marked weathering effects, particularly degradation of weaker rock types. Sandstones and limestones show significant localized weathering along major joint planes. The bed rock is subjected to surface denudation effects of successive period of glaciation. The joints between blocks have consequently been exposed to a wide range of weathering effects. The result has been creating fissure development mainly through natural process. Such effects obviously decrease in intensity with increasing depth below the surface, although subterranean water courses can give rise to widening of joints and formation of cavities at appreciable depths.

The thickness of cover of surface soils will be of special significance, since a thin layer can result in rapid occurrence of a fissure line at the surface owing to soil collapsing into a fissures system which may have been opened by subsidence. Movements will tend to concentrate along lines of least resistance, with strain effects being greatest at the vertical lines of fissures development. If fissures have been disturbed by mining activities, subsequent rainfall and downward percolation of surface waters can give rise to later fissure opening at the surface owing to the washing down action of fine materials into a deeper fissure system. Plugging of the fissure in allowing further surface soils washing down. This type of surface instability does not necessarily require pot-hole to trigger its occurrences. Some typical fissures observed in sandstone, limestone and mudstone/shale/coal are discussed below;

2.1.1 Fissures in sandstones:

Fissures development is mainly a near-surface development. Surface denudation and successive period of glaciation and weathering results in widening of joints in bedrock. Water courses and sub-surface drainage can result in localized widening of jointed structures. Figure 1 (a) shows a fissure in sandstone.

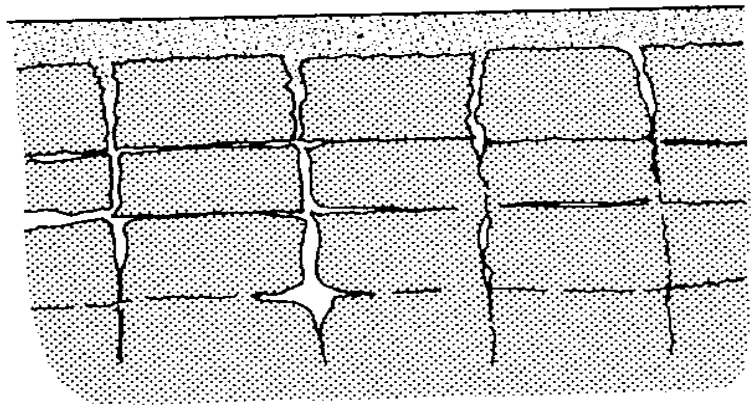

Figure 1 (a): Fissure development in sandstones

2.1.2 Fissure in limestones:

Limestones denudation cycles during glaciation and subsequent natural weathering are significantly prone to fissure development. Solubility of limestone results in additional widening of joints especially in connection with water courses; sub-surface erosional features are also generally present. Fissure development is more prominent within immediate bedrock. Fig. 1 (b) shows a fissure in limestones.

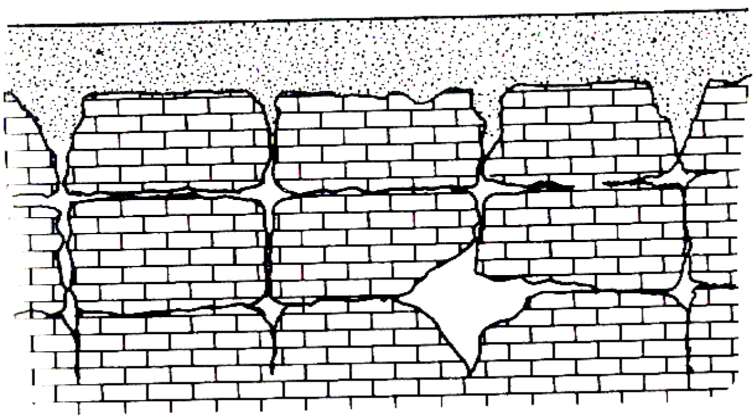

Figure 1 (b) Fissure development in Limestones

2.1.3 Fissure in mudstone/ shale/ coal measures:

Mudstones inhibit fissure development owing to slaking properties and general degradation behaviour. Fissures can occur if well-jointed sandstone exists at, or near, the surface. Significant degradation of bedrock occurs in near-surface situations. Fig. 1(c) shows a fissure in Mudstone/shales/Coal Measures.

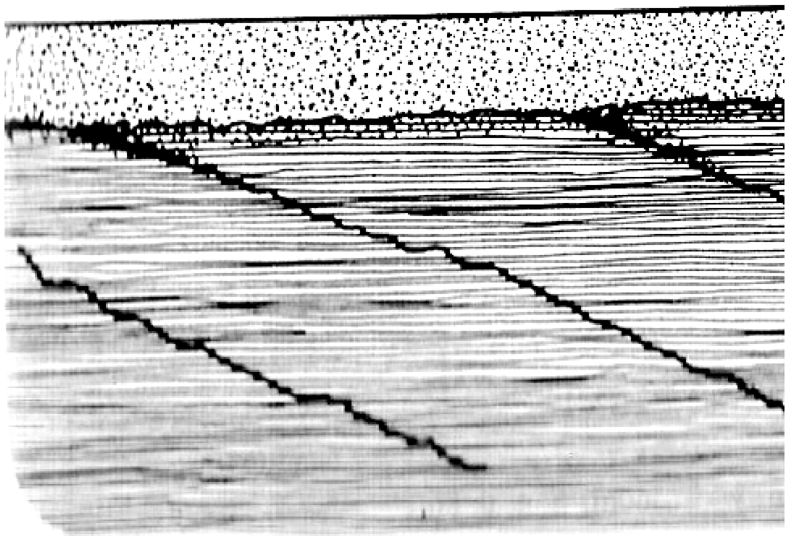

Figure 1(c) Fissure development in mudstone/ shale/ coal measures

King, Whittaker and Shadbolt (1974) reported that the behaviour of sandstones to mining subsidence effects tends to be mainly influenced by joint pattern and structures. Differential slipping between constituents block occurs as a result of lateral surface strain. Bunter sandstone sometimes fissures but their natural jointing patterns tend to predominate and such discontinuities prove difficult to detect owing to the presence of surface drift deposits. Magnesium Limestone exhibits brittle properties and variable bedding in addition to possessing well-developed systems of jointing, which have a regional trend. Limestone fissures may have been subjected to weathering effects and have widened and subsequently become in filled with clays and other loose materials. Consequently irregular behaviour is likely when affected by pot-hole tending to concentrate along fissure.

Some of the common observation for the occurrence of fissures is discussed below.

1. The fissures mainly occurred near the position of maximum tensile strain.
2. The surface fissure appeared at the time of mine working
3. Some of the fissures appeared as multiple stepped features
4. The fissures ran parallel to the edge of the mining extraction

2.1.4 Case study:

Due to fissures, which are intersected in the seam numbers, pot-hole are reported in Jamuna Kotma Area of SECL. Following case study is discussed to understand how fissures play a role for pot-hole development.

Details of the panel:

Name of Area:	Jammuna Kotma
Name of Colliery:	Bhadra Colliery
Name of Incline:	Narayan Incline
Seam	Upper Kotma (bottom)
Depth:	55m (Average)
Method of mining:	Bord & Pillar
Extraction Height:	2.8 m
Width of gallery	4.2 m
Working status:	Development

The extraction of the panel at shallow depth and presence of seasonal water appear to be responsible for this pot-hole subsidence as it occurred during rainy season. Due to percolation of water, weathering occurred and it results in widening of joints in bedrock. Also sub-surface drainage can result in localized widening of jointed structures as shown in Fig. 1(a). The presence of water in the overburden is expected to deteriorate the rock mass and reduce the strength and create conditions leading to pot-holing. When the pot-hole occurred, water with soil and sand sludge appeared in the working. The size and shape of pot-hole which occurred in Jamuna Kotma Area is as follows.

Details of the pot-hole:

Dimension	5 X 5 X 10 m
Width/Diameter	Length- 40 m/Width-12 to 20 m
Depth	15 m
Shape	Oval/ half circular

2.2 Faults:

The term 'fault' is fairly general and can be represented in several forms, but is essentially a well-defined break in the continuity of the rock formation. Faults can occur in any plane between the vertical and horizontal with accompanying displacements which may be of the order of millimeters or kilometers. The term may describe faults possessing a clean smooth shear plane or one containing a wide zone of fault gouge material. Depending upon the nature of the fault, it is to be expected therefore that they can have different effects on the development of subsidence profile.

King et al. (1974) have pointed out that the main influence of faults is that of giving rise to irregularities in mining subsidence with the potential for surface steps to occur, although these authors draw attention to the depth and dimensions of the extraction influencing the probability of such irregular behaviour becoming discernible in the first place.

Kratzsch (1983) on of his research demonstrated that a fault produces a marked localised subsidence profile irregularity. The study shows that a well-defined step in the subsidence profile occurs. There is a further important feature demonstrated, however, and that is there were high early movements observed along the position of the fault indicating its sensitivity to initial ground movements. Singh (2007) reported many pot-hole occurrences along fault plane at shallow depth in Jamuna and Kotma area of South Eastern Coalfields. Important types of faults are as given below:

2.2.1 Normal faults:

This type of fault mainly results from ground extension associated with tectonic movements. Normal faults are considered to occur under a state of high vertical stress and relatively low horizontal stress thereby creating a net increase in lateral movement. It is the most commonly encountered fault in coal bearing strata, particularly the carboniferous Coal Measures. Normal faults are most likely to move under the influence of pulled apart and hence friction plays a lesser role than in other fault types shown in Figure 2(a).

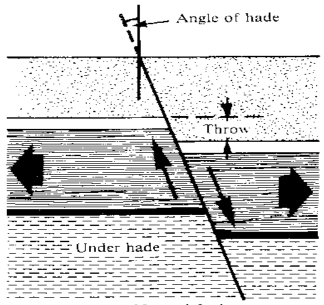

Figure 2 (a) Normal fault

2.2.2 Reverse Faults:

Reverse fault occur where the horizontal stress predominates over the vertical stress with lateral compression behaviour on the fault plane. Ground compression due to tectonic movements is the main cause of reverse faults as shown in Figure 2(b). The configuration of such fault encourages increased frictional effect across the two surfaces of the fault plane, and thus decreases its sensitivity to movements due to mining subsidence.

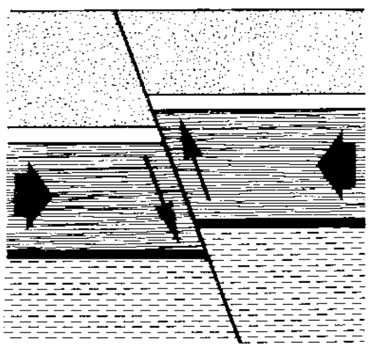

Figure 2(b) Reverse fault

2.2.3 Thrust and lag Faults:

These fault types are generally found in areas of severe folding and distortion of the strata. They frequently have high angles of hade.

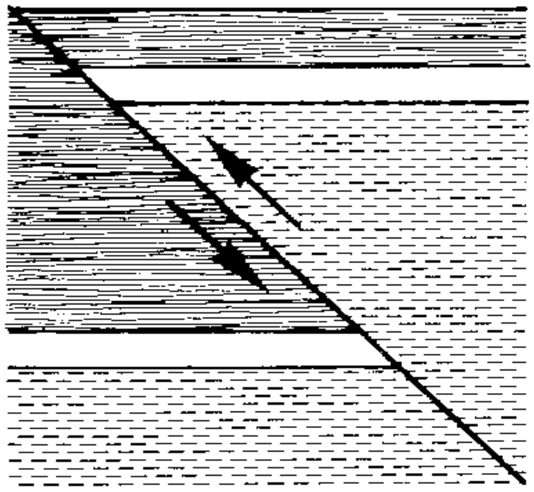

Figure 2(c) Thrust fault

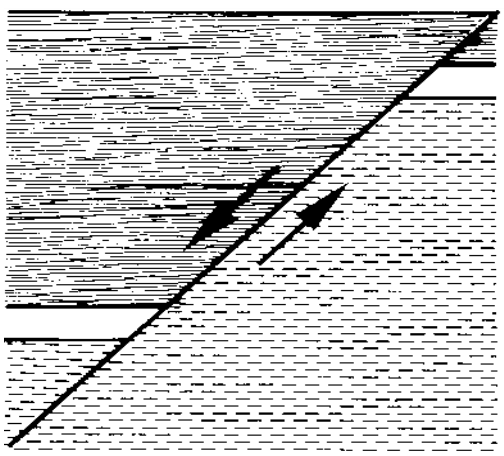

Figure 2 (d) Lag fault

2.2.4 **Strike Faults**:

This type of fault generally occurs when a block of strata is subjected to high horizontal shear forces. Movement is predominantly horizontal. It is less common in coalfield situations than other faults types. These faults can extend for hundreds of kilometers and frequently affect regional tectonic movements.

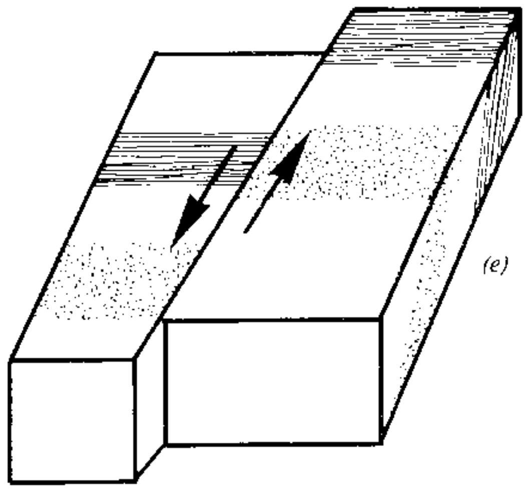

Fig. 2(e): Strike fault

2.2.5 Case Study:

In India, majority of pot-holes have occurred due to faults (Singh, 2007). Whenever an underground opening is created the strata immediately above the opening become de-stressed. The opening remains stable as long as the stresses do not exceed the tensile strength of the roof rock. Over a period of time, roof stability may be jeopardized by the change in the stresses and strength of the roof rock. A south eastern coalfield of Coal India Limited is the genuine example where number of pot-holes occurred due to faults. Following case study is discussed to understand how fault play a role for pot-hole subsidence.

Details of the panel:

Name of Area:	Jammuna Kotma
Name of Colliery:	Govinda Colliery
Name of the seam:	Middle Kotma
Depth:	31.8 m (Average)
Method of mining:	Bord & Pillar
Extraction Height:	2.8 m
Width of gallery	3.6 m
Working status:	Depillared

During extraction of the panel, pot-hole occurred 50 m away from the fault plane (Fig. 2 f). Extraction was carried out at shallow depth. Here above the roof, strata is formed by blocks bounded by joints and it fail by shearing along the planes of weakness when vertical stress exceed the shear resistance along the joints. Before occurrence of the pot-hole abnormally heavy water seepage was recorded through the fault plane along with eroded sand and soil before formation of pot-hole.

2.2.6 Details of the pot-hole:

Pothole Shape:	Ovoidal
Size of Pot-hole:	5.0 X 6.0 m
Depth of Pot-hole:	3.7 m
Remark:	Occurred 50 m away from the fault plane

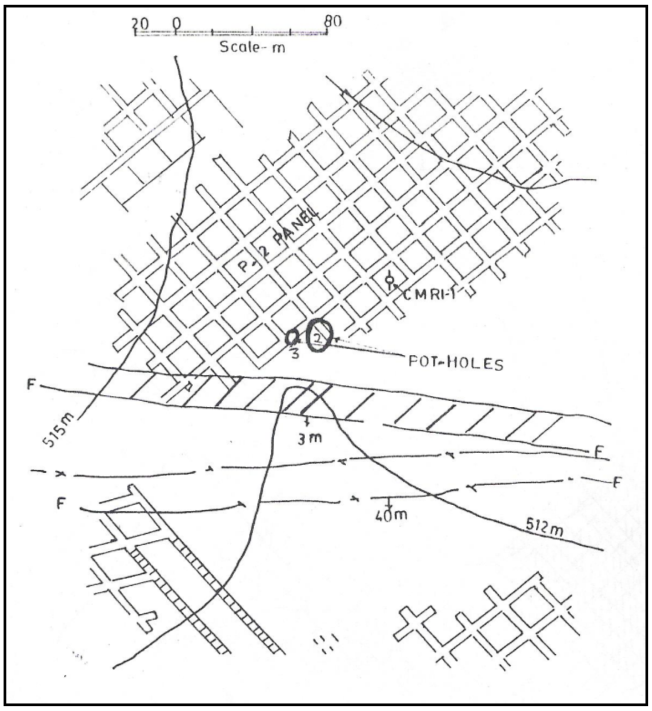

Figure 2(f) Part plan of Middle Kotma seam showing pot-hole at Govinda colliery

2.3 Fracture Developments in Rock Structures:

A comprehensive discussion on fracture developments in rocks has been given by Bles and Feuga (1986). Essentially, fractures in rocks can range from symmetrical sets of joints to tension controlled gashes (fractures). Folding curvature can produce both tension and shear fractures. Conjugate fractures appear to mainly result from different combinations of vertical and horizontal stress components and displacement along the resulting shear planes is a common feature.

a) Conjugate Fractures

In this fracture, stress in one direction of sufficient magnitude can cause shear failure. Major shear plane commonly encounters displacement with striation of failure plane and secondary shear plane as part of failure movement process. Fracture shown in Fig. 3(a) is an example of conjugate fractures.

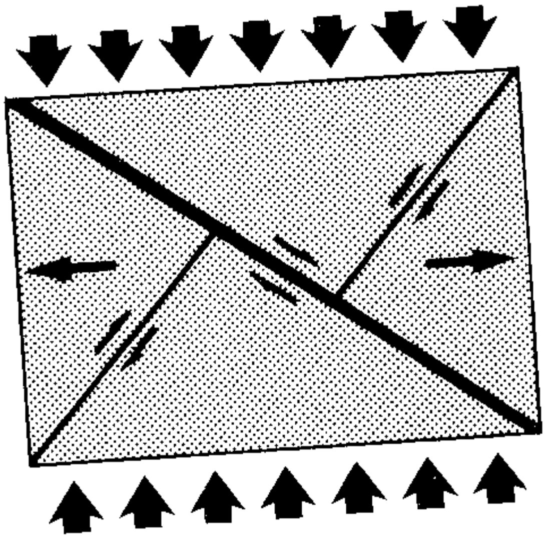

Fig. 3(a): Conjugate Fracture

b) Jointed Structure

Joints are frequently well-developed in one direction and often poorly developed in others. These fractures show no signs of movements. Joints appear to be related to other form of tectonic movement such as faults and folds. Typical pattern is shown in Figure 3(b).

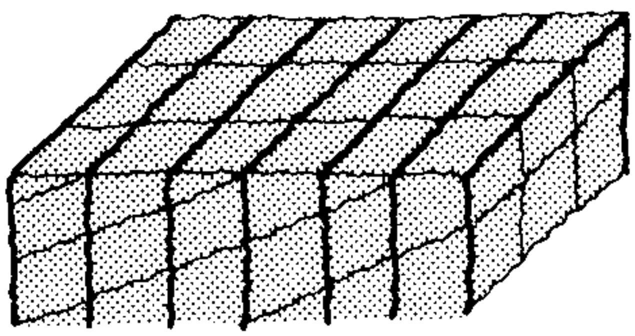

Figure 3(b) Jointed Structure

c) Tension Fracture

These types of fractures are formed under states of tensile stress and mostly deformation takes place under shear stress. Fracture shown in Figure 3(c) is an example of tension fractures.

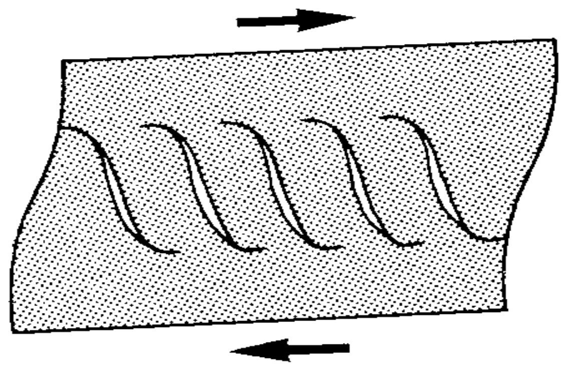

Figure 3(c) Tension Fracture

d) Tension and shear fractures

Due to the tectonic activity intensity and magnitude of fracture related to curvature of fold and are essentially directional controlled. Fractures shown in Figure 3(d) is an example of tension and shear fractures.

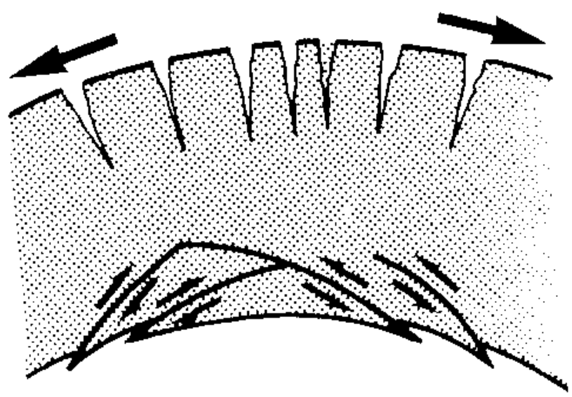

Figure 3 (d) Tension and Shear fractures

Rock type influences the nature of fracture development, particularly the size of constituent blocks formed between fractures, although the degrees of curvature of folding will also be a major factor influencing the intensity and distribution of the resulting fractures. Stress intensity and degree of constraint are major factors. Some naturally formed fractures such as tension gashes and fractures occurring on the tension surfaces of tectonically folded strata will be of the open variety.

2.4 Effect of Surface Rocks on Pot-Hole Subsidence:

The influence of near-surface rocks in relation to mining subsidence has been given by Shadbolt (1972). Sandstones, limestones, transitional siltstones and mudstones are the common rock types present at the surface, although they are frequently covered with varying thickness of drift deposits. Within these rock types, differing deformational behavioral features have been observed. Their geological histories have no doubt played a role here, particularly the varying ways they have reacted to the stresses from tectonic movements resulting in folding, faulting, jointing and localized stress variations. The rocks at the surface are also affected by weathering and erosion which is a causative factor for pot-hole subsidence.

a) Bed-rock behaviour

Shadbolt (1972) argued that in the majority of cases the near-surface rocks behave predictably when affected by mining subsidence.

According to Shadbolt some of the most severe damage is caused by

1. The ground fracturing under the action of tensile strain.
2. The strength of the rocks will play a role here as well as the factor of lithology, stress intensity, jointing patterns and extent of development of fault and their distribution.
3. The degree of weathering and erosion.
4. Fissures are usually a feature of brittle rocks but they can occur along the lines of maximum tensile strain if the strain is sufficiently severe as to exceed the natural strength of rock.
5. The pre-existence of natural jointing, fissures or faulting offer potential planes of weakness which can cause concentration of pot-hole subsidence.

b) Joint pattern effects

Joint patterns when subjected to tensile forces associated with a subsidence trough tend to exhibit a rotational effect as illustrated in Fig. 4. Joint opening is dependent to a large extent on the ground curvature occurring around the tensile strain regions of the subsidence profile. Compressive strain regions do not tend to be vulnerable to joint effects although some relative sliding in the vertical plane of joints sets is a possibility if the strain magnitudes are particularly high.

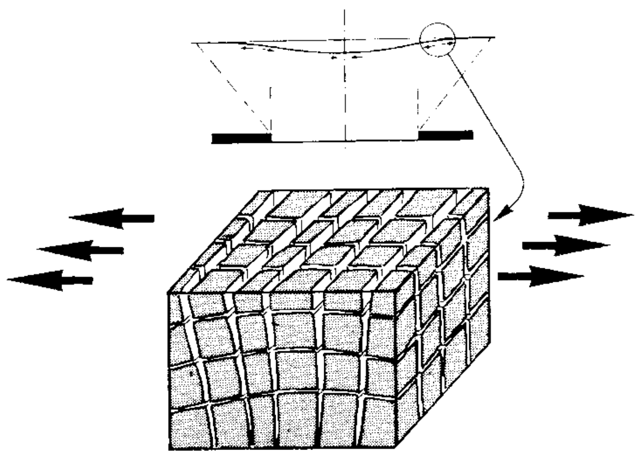

Figure 4 Joint pattern

Shadbolt, Whittaker and Forrester (1973), discussed the deformation characteristic. These characteristic have a major bearing on the geological setting.

i) Block shear failure

Due to near-surface underground extraction, this type of failure occurs occasionally as a pot-hole. Shear failure plays a significant role in the caving process of the roof beds. The shape of the block encourages freedom of movement in the vertical plane as shown in Fig. 5(a). Very shallow workings have experienced this type of pot-hole phenomenon, although it is fairly infrequent. The ground surface if suddenly lowered by this mechanism, which tends to give a much reduced width when compared to the extraction width causing the collapse. Such collapses tend to be time-dependent, and deterioration in strength of the cover rocks is a governing factor. Development of the major plane of shear failure can be of a progressive nature or may occur rapidly under some conditions.

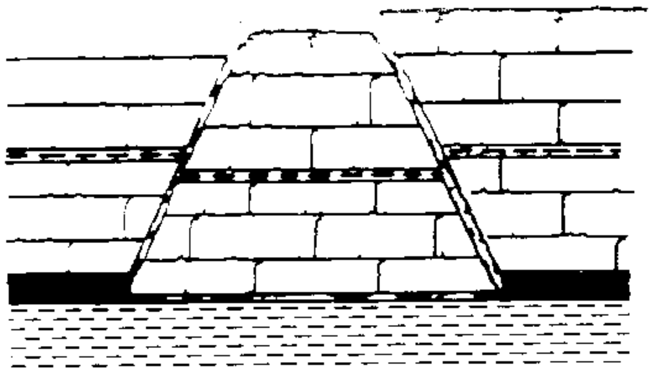

Figure 5(a) Block shear failure

ii) Shear block failure

It is generally seen in shallow conditions and can result in surface subsidence occurring as a result of the sliding of blocks of strata. Block tilting does not appear to be significant factor in these conditions. A stepped surface subsidence profile is common with this form of deformation process as shown in Fig. 5(b).

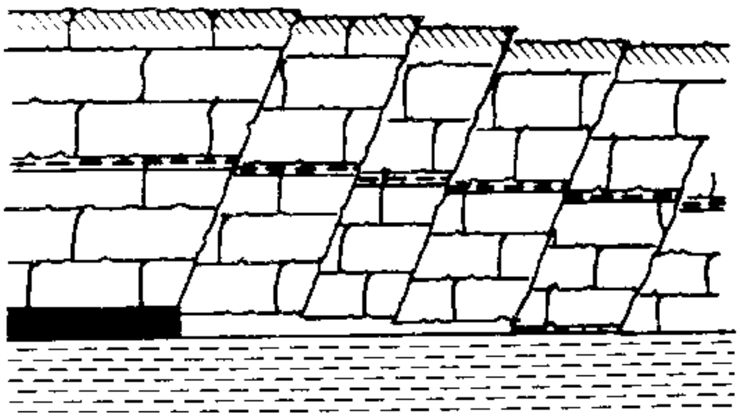

Figure 5(b) Shear block failure

iii) Surface crack development and bed deformation

The presence of a strong and competent bed occurring at the surface and is underlain by weaker and more flexible strata. This form of geological setting can encourage the formation of bed separation between the strong upper bed and the weaker underlying rock. Bed separation of this type tends to exhibit inconsistent development as it depends upon the overall integrity of the upper bed; the presence of natural weakness planes can play an important role in development (Whittaker and Reddish, 1989). Surface subsidence in the form of pot-hole, which is, at large, geologically controlled, is shown in Fig. 5(c).

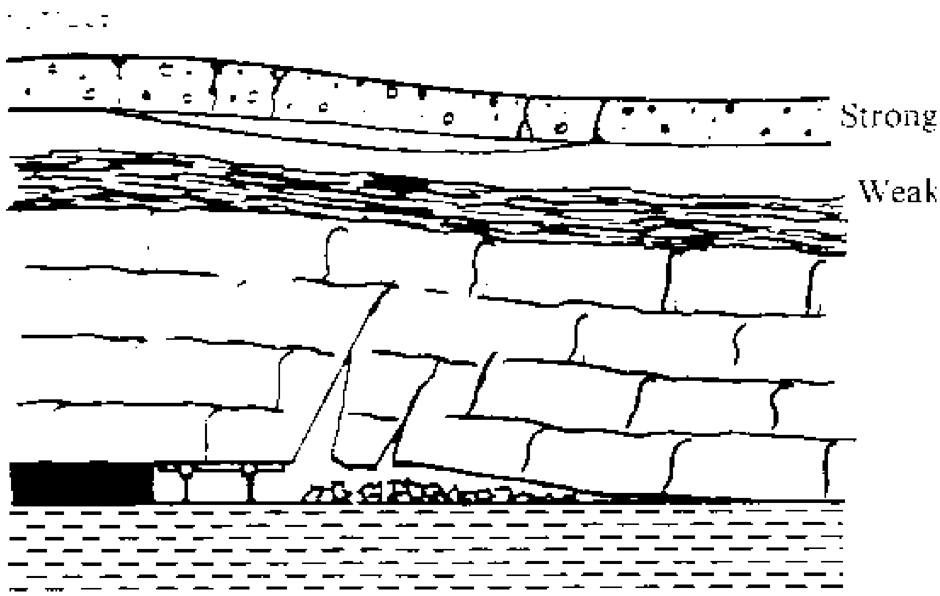

Figure 5(c) Surface crack development and bed separation

iv) Weathering Process

This involves the opening of fissures in the limestone capping of weaker rocks and clays, which is shown in Fig. 5(d). Valley bulging encourages the limestone fissures and joints to open. This is a natural process of weathering and can lead to appreciable localised subsidence effects particularly the opening of fissures which can results in instability of surface structures.

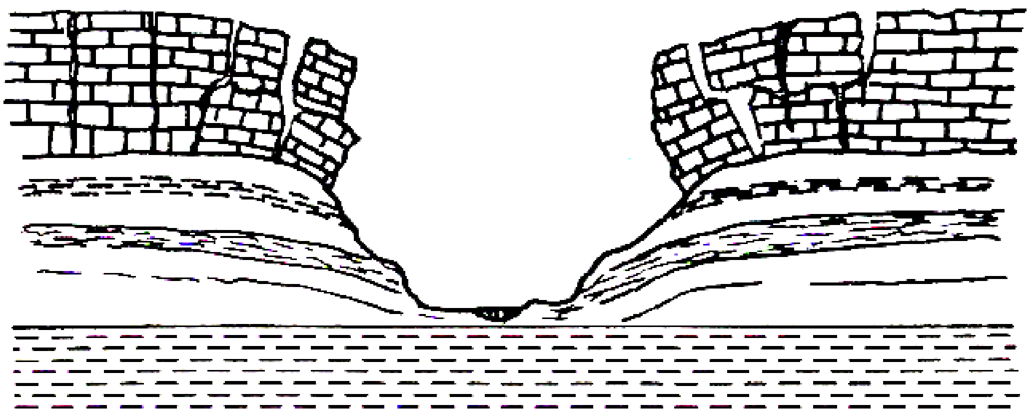

Figure 5(d) Valley bulging through fissures

c) Hydrogeology and its influence

Hydro-geological factors are of importance in pot-hole subsidence as the latter can alter drainage gradient and patterns in addition to ground water flow characteristics. Near-surface rocks which have been subjected to appreciable subsidence strains and have experienced opening of joints and fissures can result in increased or changed ground water flow behaviour. Localized erosion can occur with formation of cavities which may be of pot-hole potential at a later stage of development. Conversely, there may be a natural tendency for loose material to wash into such opened joints or fissures and result in a filling action or in some situations produce a localized dam effect to the water drainage pattern (Forrester and Whittaker, 1976).

2.5 Conclusions:

The types of geological conditions encountered above indicate that shallow mining operations strongly influence, the general character and magnitude of the resulting pot-hole. The presence of faults and naturally fissured rocks can appreciably influence the nature of the pot-hole. Strength and type of cover rock conditions can greatly influence the magnitude and limit of pot-hole subsidence. Hydrogeology also plays an important role in the pot-hole phenomenon in underground coal mining.

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