Methods and applications of coal seam destress - A comprehensive literature review

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Abstract: **Coal mine and other type of mine workings continue to face the challenges, as mining activities are extending to deeper subsurface, the ever increasing stress conditions mostly ground stress is anticipated to result in much coal bumps, floor heave, roadway stability, roof failure, cutter failure and coalbursts/rockbursts etc, due to high overburden pressures associated with the extraction of brittle, low strength coal seams. Destress applications has been applied for almost a century to control these challenges or remove the stresses from the coal seam. The main goals of destress applications are the softening of competent rock layers, the reduction of strain energy storage, and rock mass stress release, which together contribute to minimizing rockburst occurrence and risk. This paper presents a comprehensive literature review of methods and applications of coal seam destress such as hydraulic fracturing techniques, destress blasting and drilling and discuss distribution of destress application in the past 100 years around the world. Almost every country use destressing methods for mining operations where high stress conditions have been an issue but there are some countries such as China, Australia, Canada, South Africa and United states they used mostly because of their adverse geomechanical and geological conditions and deep mining conditions. The paper discusses the main destress applications, methods and the evaluation of its effectiveness as a measure to overcome the challenges of high ground stresses causing different problems. Based on data collected from literature review both surface and underground coal mines and other types of mines, the work presented herein uses destress applications to show the coal seam destress associated with various parameters and geomechanical conditions.**

Keywords**: Destress; Method; Application; Coal seam;**

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1. Introduction:

Ground stress represents an inherent stress state within the crust rock within the natural environment. It is also known as rock initial stress or as the original rock stress. Ground movements and instabilities can be caused by changes in total stress (such as loading due to foundations or unloading due to excavations), but they can also be caused by changes in pore pressures (slopes can fail after rainfall increases the pore pressures). When a load is applied to soil, it is carried by the solid grains and the water in the pores. The stress acting at a point below the ground surface is due to the weight of everything that lies above, including soil, water, and surface loading. Ground stress thus increases with depth and with unit weight. Due to this ground stress there are many problems, risk and issues induced in mining, to solve these problem destress applications is needed which we discuss in this paper.

Underground excavation initiates a process of re-equilibrium, which leads to the generation of stresses around the excavation in a manner that free surfaces become planes for principal stresses and experience a bi-axial state of stress condition. The excavation boundaries may experience damage effects due to stresses and these effects for coal mines can be dislocation of rock reinforcement, interbed crossover of laminated roof rock mass, cutter failure, floor heave and/or rockburst/coal bump (Petr Konicek, 2011). To solve these problems destress application is widely used in both coal and other types of mines from almost a century.

Destressing is conceived as a blast fracturing techniques to stress relieve potential rock-bursts prone zones. It was first developed and widely used on the Witwatersrand gold reef in South Africa in the 1950's (Roux, 1957). The concept of destressing resulted from the observation that the zone of highly fractured rock immediately surrounding deep underground openings seemed to offer some shielding to both the occurance of and damage from rock bursting. It was then postulated that if this naturally fractured zone could be extended by blast fracturing ahead of the face, both the occurance and effects of rock bursting should be reduced. Figure 1 shows a sketch of this original concept of destressing.

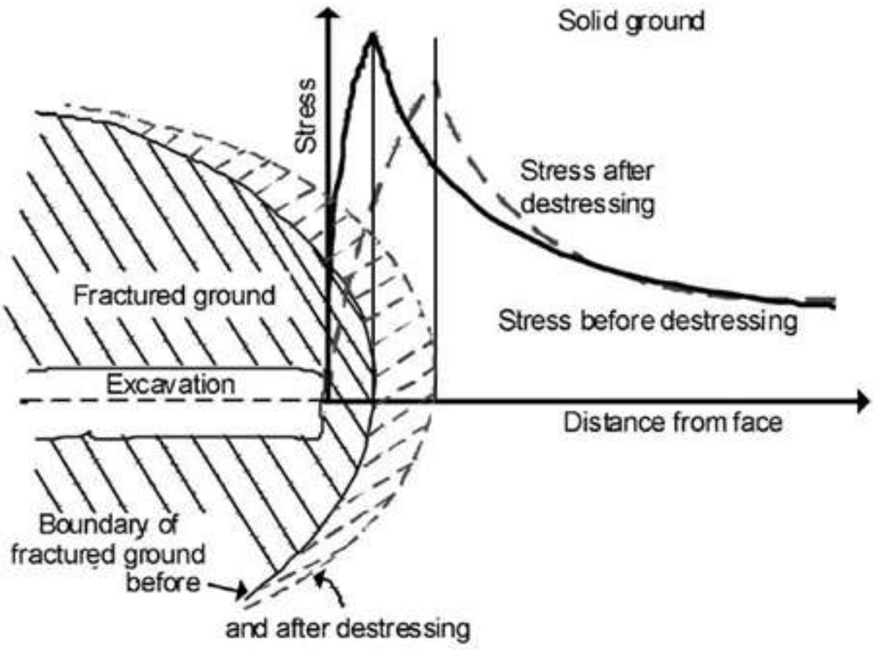

Figure 1 Concepts of destressing (Roux, 1957)

2. Purpose of destress

The purpose of destress is to fracture a volume of rock in suspected high stress or rock-burst zone. This fracturing reduces the load carrying ability of which results in a stress decrease in the fractured zone. There are following purpose of destress which are given below.

2.1 For controlling strata stability

Destress application is mostly used to control the strata stability. The term "strata control" generally refers to controlling the strata to maintain stability around the mine openings underground where operations are or will be taking place.
Mining-induced stress change and related rockmass relaxation can drastically influence the stability of underground openings. One of the consequences is that a decrease in stress may reduce the critical excavation span (Kaiser PK, 1997). Stability problems have been caused by:

1. Variability in rock mass strength due to the depositional environment of the seam and development of finely laminated rock strata

2. In-situ anisotropic horizontal stresses exceeding bedding plane strength of coal measure rocks, contributing to time-dependent delamination failure

3. Time dependent failure in the mine floor, reducing pillar effectiveness and resulting in a chain-type reaction

Roadway stability is an outstanding challenge in deep mining which is caused by stresses. A significant problem is the excessive deformation which makes the normal support system very difficult to be effective. Stress change not only influences the demand on the rock support, it also changes the support capacity of frictional support components such as plain cable bolts. The bond strength of such cable bolts decreases as the stress decrease reduces the confinement and thus the strength of the steel/grout interface.

Therefore, for stability assessments as well as for support design, it is important to understand the factors leading to detrimental stress changes. So, destress application is mostly used to control the strata stability.

2.2 For controlling dynamic hazards (coal and gas outburst and coal/rockburst)

Destress application mostly used for controlling dynamic hazards such as coal and gas outbursts and coal/rockbursts.

Excavation induced stresses are unavoidable part of mining and consequent damaging effects of the stresses can be manifested in many forms. The most challenging task for the engineers around the world is containing damaging effects of violent failure of rock mass termed as rock burst or coalbursts as the timing of rock bursts occurrences cannot be predicted despite of the advances made with the science and engineering of mining.

Various methods have been evolved over a century to contain damaging effects of rock bursts and coal bursts as shown in Figure 2. The evolution of these methods started with development of pillar less mining methods as it was soon realized that pillar formation is a major cause for violent failure of rock mass. Efforts were made to further increase the load bearing capacity of the rock mass with the use of rock reinforcement measures once it was realized that the formation of pillars is unavoidable and rock bursts do occur with pillar less mining too.

The damaging effects of rock bursts grew more with the enhancing rock mass load carrying capacity using higher capacity supports and rock reinforcement measures as larger volume involved in the violent failure.

Destress blasting proved to be the only proactive measure which can successfully contain damaging effects of rock bursts and coalbursts if applied in correct place, manner and timing. The success rate of destress blasting can be much higher if the correct manner of its application is learnt and it is made an integral part of routine mining cycle as the objective of destress blasting is to create a safety barrier between the excavation boundary and the high stress zones. Various terminologies used over time for destress blasting and these include concussion blasting, volley firing, shake blasting, Camouflet blasting and precondition blasting, to name a few.

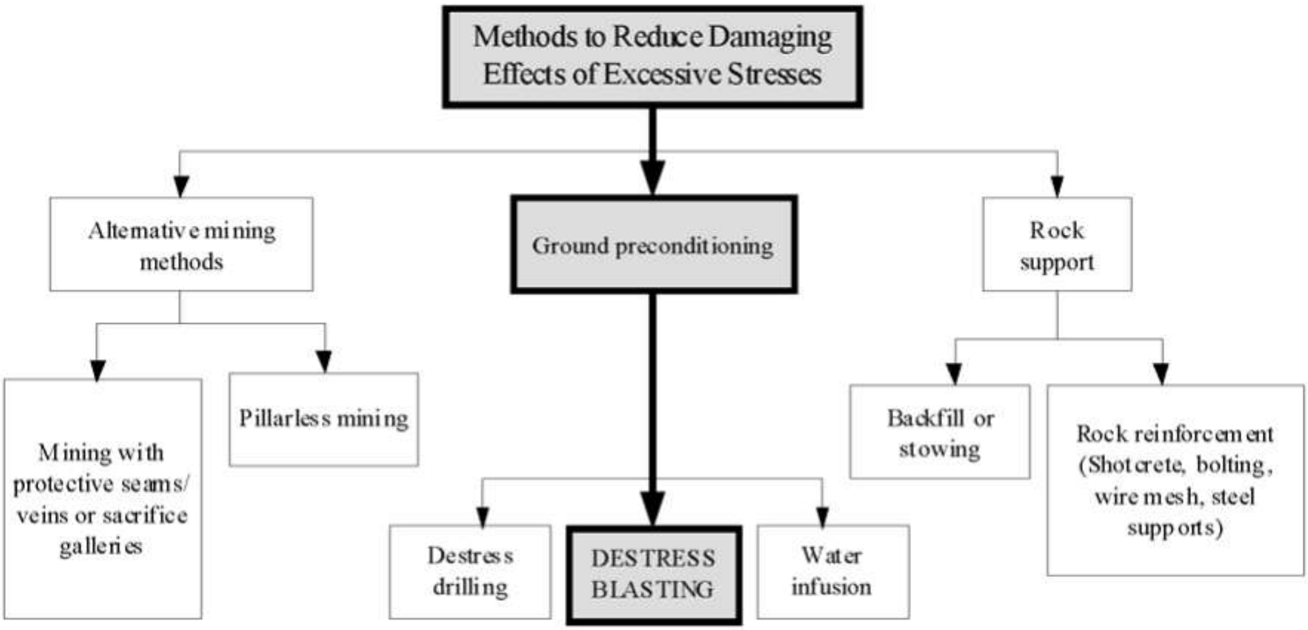

Fig 2 Methods to contain damaging effects of strain bursting (Mitri H. , 2000)

2.3 For increasing coal seam permeability and improving coal seam gas drainage

Gas disasters have been a major factor threatening the safe and efficient production of mines during coal mining (S. N. Zhou, 1990). Pre drainage of coal seam gas is a method to control gas disasters, but coal seams in a lot of mines have low permeability, high ground stress, and difficulty in gas drainage (C. Zhai, 2008).

At present, almost all Chinese and European underground coal mines require the gas drainage to reduce coal seam gas concentrations below a certain level. Many collieries will encounter the areas ahead of mining where it is extremely difficult to drain gas from the coal due to low permeability. With difficult drainage areas, the collieries may face significant production delay and different problems while intensive drilling has to be carried out to reduce the gas concentrations to acceptable levels.

The advances in mining equipment technology over the last twenty years have led to a significant increase in coal mine production, resulting in increased coal mine gas emission during the coal extraction process. High gas emissions, if not effectively managed, may exceed the diluting capability of the mine’s ventilation system, potentially exceeding the statutory limit, resulting in gas related production delay.

To avoid such delays and to solve different problems, the mine management may choose to use alternative techniques in order to increase the efficiency of gas drainage and coal seam permeability. So the different destress techniques or destress methods is chosen for increasing coal seam permeability and improving the efficiency of gas drainage in coal seams that are difficult to drain.

3. Destress methods

Destressing technique is a method to form a destressed zone in the surrounding rock mass of working face and a stress bearing zone ahead of working face. It has an obvious effect on controlling the stress concentration of surrounding rock mass and preventing rockburst in the surrounding rock mass of the stope by the principle of stress transfer (Evariste Murwanashyaka, 2019).

To better understand destressing as a means of underground excavation that initiates a process of re-equilibrium, which leads to the generation of stresses around the excavation in a manner that free surfaces become planes for principal stresses and experience a bi-axial state of stress condition. The excavation boundaries may experience damage effects due to stresses and these effects for coal mines can be dislocation of rock reinforcement, interbed crossover of laminated roof rock mass, cutter failure, floor heave and/or rockburst/coal bump etc.

Excess of the stress level in comparison to the strength and the rate at which the excess is attained during the re-equilibrium process is manifested into the different damaging effects. To control these problems which are generated by ground stress a number of destressing techniques or methods are described.

3.1 Destress by hydraulic fracturing

3.1.1 General description

Hydraulic fracturing is also called hydrofracking. It involves the injection of water into strata at high pressure to induce fracturing. Hydrofracking can be used to create fractures in the coal, to prevent it from being able to store sufficient elastic strain energy to burst. For example, 10 m long holes at 5 m spacing are drilled into the face and injected with water at 40 MPa for 20 minutes. A decrease in water pressure of 10 MPa or more can be indicative of adequate destressing. This method is suggested by (Brauner, 1994) to be the most economical destressing technique.

3.1.2 Mechanism of destress by hydraulic fracturing

Fracturing rocks at great depth frequently becomes suppressed by pressure due to the weight of the overlying rock strata and the cementation of the formation. This suppression process is particularly significant in "tensile" (Mode 1) fractures which require the walls of the fracture to move against this pressure.

Fracturing occurs when effective stress is overcome by the pressure of fluids within the rock. The minimum principal stress becomes tensile and exceeds the tensile strength of the material(Fjaer, 2008).Fractures formed in this way are generally oriented in a plane perpendicular to the minimum principal stress, and for this reason, hydraulic fractures in well bores can be used to determine the orientation of stresses. In natural examples, such as dikes or vein-filled fractures, the orientations can be used to infer past states of stress (Zoback, 2007).

Rock, fracture and fluid mechanics are critical elements in the understanding and engineering design of hydraulic fracture treatments. Rock mechanical properties dictate the stress and stress distribution at depth and elastic properties control the created fracture geometry. Contrast between the properties of adjoining layers controls the vertical fracture height migration.

During recent decades, hydraulic fracturing has been widely used for the stimulation of petroleum and geothermal reservoirs, remediation of soil and groundwater aquifers, injection of wastes, and measurement of in-situ stresses. Mechanism of Hydraulic fracturing contains different steps or it happens in small sections called stages which we discussed below:

Step 1 – Perforating the Casing. First, a perforating gun is lowered into a targeted position within the horizontal portion of the well. Then, an electrical current is sent down the well to set off a small explosive charge. This shoots tiny holes through the well casing and out a short, controlled distance into the shale formation. The holes created by the “perf” gun serve two purposes: they provide access for the fracturing fluid to enter the formation and subsequently allow natural gas to enter the wellbore.

Step 2 – Shale Fracturing. The fracturing of a well creates a complex network of cracks in the shale formation. This is achieved by pumping water, sand and a small amount of additives down the wellbore under high pressure. After these cracks are created the sand will remain in the formation propping open the shale to create a pathway for the gas to enter the wellbore and flow up the well.

Step 3 – Repeat in Stages. During each stage experts will monitor, adjust and record all of the stage parameters to ensure worker and public safety and to maximize the natural gas production from the shale. After each stage is completed, a plug will be set and new perforations created to direct the frac fluid to the next stage. By segmenting the well in stages, a greater amount of gas is produced from the lateral length of the well.

Step 4 – Safe Frac Fluid Removal. After hydraulic fracturing is completed, all of the plugs placed between frac stages are drilled out to remove the restrictions in the wellbore. The completed well is then opened up to safely remove the fracturing fluid so that natural gas can be harvested. The frac fluid that is recovered from each well is treated and reused in future frac jobs through Cabot’s closed-loop water recycling system.

Step 5 – Flaring. Toward the end of the frac fluid removal process, gas will start to travel up the well along with the fluid. Since the amount of gas increases as the water decreases, a flare is set up to make sure the gas is safely burned.

Step 6 – Harvesting the Natural Gas. After safely removing the fracturing fluid from the formation, the sand will remain in the shale to provide a pathway for the gas to flow into the wellbore and to the surface. Once at the surface, the gas will be processed and delivered to nearly 70 million homes and businesses across the country.

3.1.3 Advantages and disadvantages of destress by hydraulic fracturing

These fracking pros and cons examine the issue to see if there is a balance that can be found between the energy resources necessary for our current lifestyle and our requirement to protect the environment (Regoli, 2019).

1) Advantages

There are different advantages of fracking which are given below:

1. Improved control of fracture geometry

Hydraulic fracturing has the advantages of improved control of the fracture geometry by means of directional fracturing and it is generally less destructive. Hydraulic fracturing experiments are commonly conducted in mining industry especially in hard rock mines (PetrKonicek, 2011).

2. Eliminate rockbursts

Hydraulic fracturing can also be utilized to precondition competent rock mass under high stresses in order to eliminate the potential of rockburst induced by mining operation (Board, 1992).

3. Fracking is environmental friendly

As opposed to the hazardous gases coming from the burning of fossil fuels, fracking/hydraulic fracturing is more environment-friendly. When workers create a borehole into the ground to release the oil or gas located there, a protective lining is placed in the shaft as it continues to dig into the earth. This process prevents the water tables from being negatively impacted while the energy resources are extracted from the well.

4. Fracking removes natural gas and crude oil from ground

Fracking is a process of hydraulic fracturing which helps to remove natural gas and crude oil from under the ground. Workers inject liquids at high pressures into subterranean rocks, holes they have bored, and similar access points the force open any existing fissures that exist. This process then makes it possible to extract the fossil fuels that are useful in multiple ways.

5. Fracking utilizes a stable extraction process

Although some fracking activities have led to minor earthquakes in the Great Plains and the Midwest in the United States, these outcomes are more of the exception than the rule. Thousands of wells, boreholes, and access points are created each year that take advantage of hydraulic fracturing technologies without triggering such an event. The extraction process is stable, and ongoing research into the few events that do occur looks to minimize this issue for population centers even further.

6. Fracking does not create permanent damage

Every borehole, well, or access point that is created through the fracking process is a targeted operation. Rigs will go to where the highest potential of success happens to be. Scouting work helps to identify which geographic regions are the most likely to contain natural gas and crude oil that this extraction process can access. Once the resources are tapped, then the drilling operations will cease.

2) Disadvantages

There are different disadvantages of fracking which are given below:

1. Modeling is challenging

Modeling these systems is a challenging procedure as the involved processes take place on different scales of space and also require adequate multidisciplinary knowledge.

2. Fracking reduces the chance for disrupters to create innovative new methods

When we rely on hydraulic fracturing activities as a way to generate the energy we require, then it limits our attention in the research and development of newer, potentially better technologies.

3. Fracking appears clean because tracking mechanisms are not always accurate

The greenhouse gas emissions that come from hydraulic fracturing are not always accurately tracked. Monitoring activities are sometimes not even present when workers are in the middle of their work.

4. Fracking offers unknown consequences for the future

Assuming that the air quality improvements do occur over time as we transition from traditional coal to fracking and clean coal processing, we still do not know what the long-term consequences of hydraulic fracturing will be. Although this process has been known for several decades, it only started to become popular in the 1970s and 1980s as a method of energy extraction.

5. Fracking can leak high levels of methane during the extraction process

We cannot ignore the impact that methane has on the environment. It is one of the most potent and harmful pollutants that comes from the fracking process. Cornell University found that the number of leaks that are in the typical fracking process, from start to finish, are high enough that they wash out the advantages that we generate when switching from traditional coal to natural gas.

6. Fracking does create earthquakes

The number of earthquakes registered in the United States since the late 1960s has risen from 21 to over 1,000 per year. Many of the new quakes appear to be artificially generated based on the data collected by the USGS. With some coming close to 6.0 in strength, we must question if fracking is a contributing factor to this event.

Above fracking pros and cons take a realistic look at this industry to see what the advantages or disadvantages may be. The bottom line here is that we can see there are potential short-term gains to find, but this activity could also have devastating long-term consequences that we do not entirely understand. Until we know more about hydraulic fracturing, a cautious approach to this industry seems to be a reasonable position to take.

3.2 Destress by drilling

3.2.1 General description

The drilling method is a method for measuring residual stresses, in a material. It is one of the commonly used methods for mitigating rock bursts and creating safe areas, especially in coal mining.

The destress drilling method allows generation of a local self-developing high yielding relief zone. This zone prevents from accumulation of elastic energy in the adjacent rock mass. An important feature of this method is that after completion of the first stage of failure, the method works as a loop system: if stresses increase, for instance, on approach of stope front, the process of failure in rock mass between the holes activates. Under high initial stresses, failure of the destress hole walls begins immediately during the drilling. The circular cross-section of the holes becomes ellipsoid and, accordingly, the rock mass block in-between the holes narrows. Simultaneously, the radius of the ellipse curvature decreases in the hole failure zone, which results in reduction of the high stress area in the failure zone.

To better understand the influences of drilling on the destress effect is beneficial for rock burst mitigation. With the worldwide economic and social development, the shallow mineral resources are gradually depleted, and the depth of mining is deeper and deeper. So, rock burst has become one of the serious dynamic disasters in deep exploitation, to solve or mitigate these problems destress by drilling is being widely used in mining.

3.2.2 Mechanism of destress by drilling

As one of the widely used methods for mitigating hazards, the destress drilling method is that drilling boreholes with large-diameters in the stress or possible stress concentration areas in coal seams. When drilling boreholes in the stress concentration area, X-shape areas of plastic deformation will form around these holes (Q. H. Zhu, 2009). If the density of drilling boreholes is high enough, these plastic areas will be connected each other and thus a larger destressed area will form, leading to the transfer of high stress concentration area into the deep coal wall, as shown in Figure 3. Generally speaking, the destress drilling method mainly functions through stopping the formation or mitigating the stress concentration of high stress concentration areas (J. H. Liu, 2014). When it is used for premeditating stress concentration, its prevention mechanism of rock bursts is changing the mechanical parameters of coal/rock and decreasing its ability of strain energy accumulation; when it is used for preventing rock bursts, its prevention mechanism is dissipating the accumulated strain energy and increasing the resistant force.

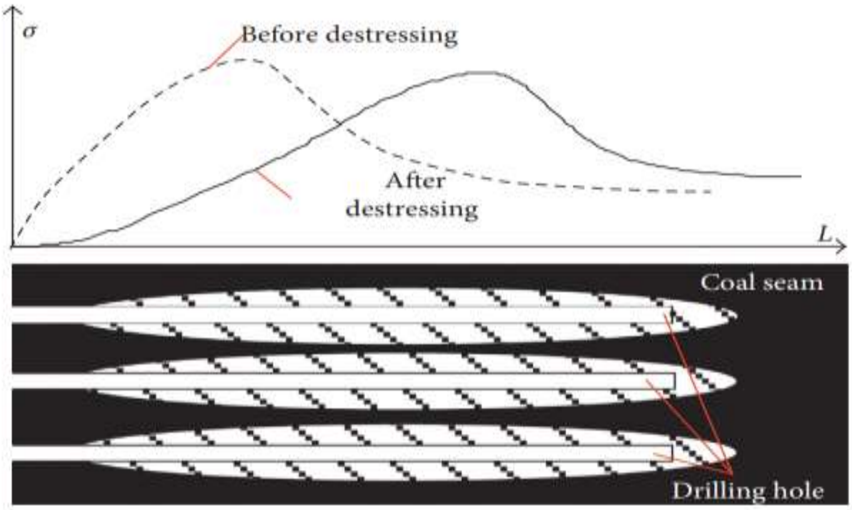

Figure 3 Sketch of destress drilling in coal seam (Tong-bin Zhao, 2018)

(C. Y. Jia, 2017) researched the destress mechanism of large diameter drilling by laboratory and numerical studies; (J. K. Li, 2009), and (E. B. Yi, 2011) numerically researched the diameter, space, and length of the drilling hole on the destress effect. Regarding the theoretical and field researches, (S. T. Zhu, 2015)proposed an energy dissipation index method for determining drilling parameters, and (X. X. Song, 2014) researched the collaborative control of destress drilling and roadway support.

Above researches mainly focus on the destress mechanism and on the destress effect by comparing parameters, but the drilling arrangement also has an essential influence on the destress effect of the drilling method.

The drilling arrangement mainly influences the bearing capacity of coal models. The uniaxial compressive strength increases nonlinearly with the increase of the drilling diameter, number of drilling holes in one row, or number of drilling rows. Among the three factors, the influencing degree in order from strong to weak is the drilling diameter, number of drilling holes in one row, and number of drilling rows. Compared with intact specimens, their decreasing percentages of uniaxial compressive strength are 0.78–25.31%, 4.84–16.78%, and 0.78–9.59%, respectively. However, the elastic modulus remains stable as increasing the number of these defects. This phenomenon might be caused by that materials are homogeneous and defects could only decrease the structural bearing capacity in simulating process (Tong-bin Zhao, 2018).

For specimens with different drilling diameters, shear failure accompanied with splitting failure is the main failure mode, but for specimens with different numbers of drilling holes in one row, splitting failure accompanied with shear failure is the main failure mode. However, it might be splitting or shear failure for specimens with different numbers of drilling rows.

The influencing mechanism of drilling diameter or number of drilling holes in one row on the prevention mechanism of the destress drilling method is to decrease the energy accumulation ability of coal without affecting the consumed energy of coal failure, as shown in Figure 4(a).However, the number of drilling rows influences not only the energy accumulation ability, but also the consumed energy of coal failure, as shown in Figure 4(b).As increasing the number of drilling rows, if the coal failure consumes lesser energy than before, the bursting energy index might increase, and vice versa.

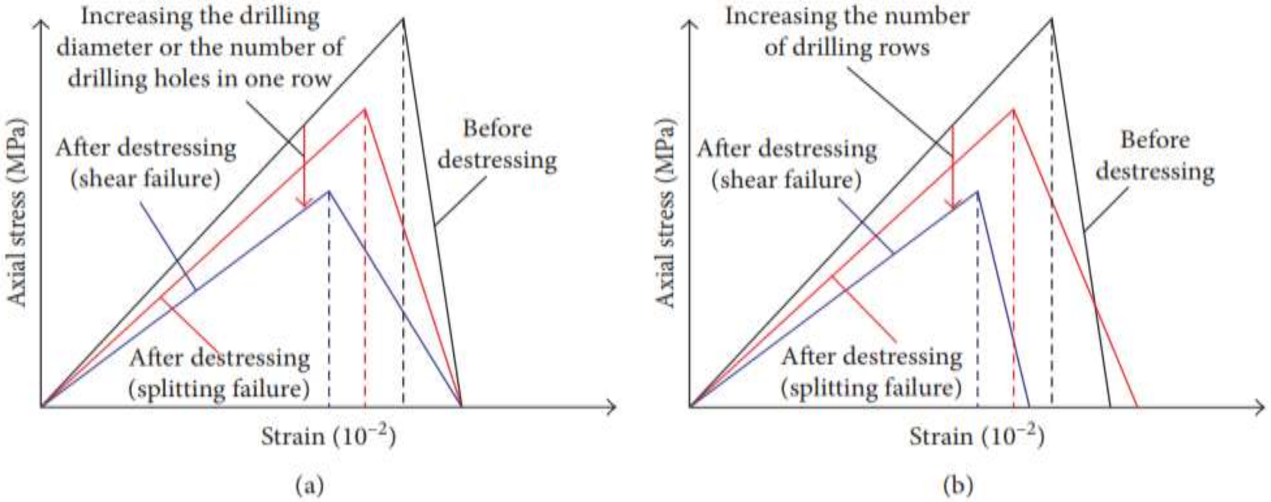

Figure 4 Sketch of the influencing mechanism of drilling arrangement on the prevention mechanism of destress drilling method. (a) Different drilling diameters and numbers of drilling holes in one row. (b) Different numbers of drilling rows (Tong-bin Zhao, 2018)

3.2.3 Advantages and disadvantages of destress by drilling

1) Advantages

There are different advantages of drilling which are given below:

1. Coalbursts prevention

It is a very successful method of coalburst prevention which has been used in Germany and Russia. The holes burst and fines are removed during drilling until the stress has reduced below bursting levels. It has to be repeated every 5 m or so of advance (Baltz, 2010) and (Calleja J, 2016).

2. Effective in soil conditions

Throughout Africa, Asia and South America there are 4 manual drilling principles used; sludging, jetting, and percussion and hand augering that proved to be very effective for well drilling in certain soil conditions. These methods have the advantage that they are cheap (wells can be up to 4 times cheaper compared to mechanized drilling of same depth and quality), easy to transport and are relatively easy to learn. Furthermore most parts, if not all, can be sourced and fabricated locally. Yet, as these methods are performed by hand, they are labour intensive and require more time for drilling a well.

3. Low cost

These drilling techniques become slightly more expensive but the manual labour will significantly decrease, which will speed up the process. The relief organizations confirmed that these drilling techniques could form an addition to their hardware. In addition, small enterprises that are locally based can be hired for such services and can be easily contracted compared to large companies with large machines.

2) Disadvantages

There are different disadvantages of drilling which are given below:

1. Slow process method

It is a slow process effective method for low productivity mining; Reducing the stress in the area where rock burst may occur; Transferring the high stress to away from the roadway and stope; Reducing the strain energy of surrounding rock; Reducing the mechanical parameters of rock mass, especially the elastic modulus (Evariste Murwanashyaka, 2019).

2. Poor ground conditions

Poor ground conditions during development. An assessment of ground conditions in relation to construction projects typically includes geology, hydrology, hydrogeology and soil conditions of a site and surrounding, along with the contaminated land. A site investigation report will highlight any findings that may affect the construction of the works and identify any health and safety concerns.

3. Increasing production rates

High level and uncontrolled dilution may ultimately defeat the purpose of increasing production rates addition to its direct impact on short term income of a mine; dilution causes significant changes in other factors that on the long term reduce the overall value of the project.

3.3 Destress by blasting

3.3.1 General description

Destress blasting of stiff, massive overburden strata over the longwall block is an important coalburst control technique which has been used successfully in the Czech Republic since the 1990s and internationally.
Destress blasting is a commonly practiced ground control technique in many underground mines. It is considered a mine safety tool because it is used to control seismic events that could lead to rockburst. It is practiced in both metal and coal mines albeit in different ways (Mitri H. S., 2018).

3.3.2 Mechanism of destress by blasting

Destress blasting can be defined as any attempt involving the usage of confined explosive charges (i.e., without free faces) to reduce the ground stresses in a particular region, and in which the blasted material is left in place. In the ‘‘preconditioning’’ sense, it is the process of using confined explosive charges in order to damage the rock mass, for the purpose of softening its behavior, reducing its capacity to carry high stresses and, hence, reducing the potential for it to undergo violent failure.Note that pre-conditioning has a connotation of eventually mining through the destressed area—as a result, a degree of restraint is required and such blasts typically do not involve very large amounts of explosive energy. Within the context of the large-scale choked destress blasts in mine pillars discussed in this paper, large amounts of explosive energy are used, resulting in major damage being caused in the targeted area, as well as in a significant quantity of material being dislodged—this ejection results in some convergence of the walls, and, in turn, in a local destressing effect. These particular blasts cause extensive damage, and there is generally no attempt to re-establish access near or through them (Patrick Andrieuxa, 2008).
A comparison of pre and post destress data from monitoring instrumentation indicated that the blasting did fracture the rock in the planned zone and did result in an immediate stress decrease and softening of rock, in the preconditioning zone with normal mining.

Because of the encouraging results of this initial test of preconditioning, an expanded test is now being carried out at Hecla's star mine that will precondition three stopes on the 7900 level all the way up to the 7700 level. Besides the improvement in rock bursts control, preconditioning is carried out during stope development, hence taking the destressing out of the production cycle which should result in higher productivity.

Although destress blasting is successfully practiced in various mines in the world, there is very little theoretical background on what actually happens to the stress, displacement and energy during the blast. There is a general consensus that destressing softens the rock and reduces its effective elastic modulus. There are conflicting views on the importance of reducing stress and the stored strain energy within the destressed rock.

Conditions of stress and strain, before and after destressing, were investigated by (Crouch, 1974).He postulated subcritical, critical and supercritical degrees of destressing as illustrated in Figure 5.

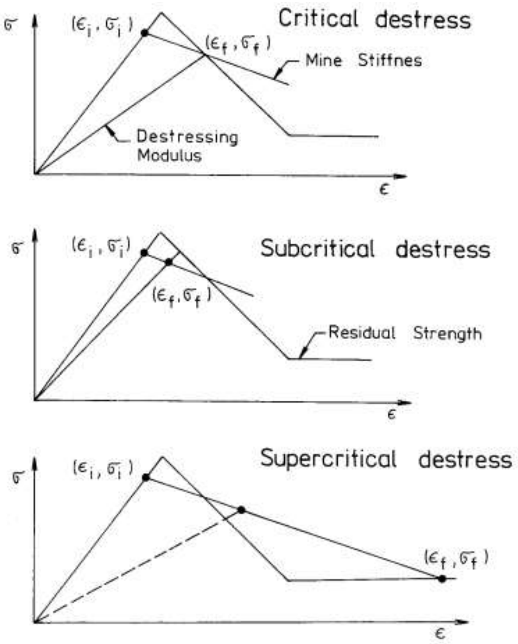

Figure 5 Different degrees of destressing (Vladimir, 1997)

After destressing the final equilibrium stress-strain position is dependent on the intersection of the destress modulus line with the slope of the local mine stiffness. If its intersection lies within the stress strain envelope (i.e., subcritical) the destress blast will ineffective. However, if the intersection lies outside the envelope (i.e., super-critical) excess energy will be released and eventually an equilibrium is achieved along the residual strength curve.

From it follows that destressing is most effective when the pillar is near its point of failure and the excess energy released in a destress blast, or a rockburst is derived from the change in potential energy of the rock mass, not the stored strain energy in the pillar.

(Vladimir, 1997) studies have looked at the before and after effects of destressing, and not what happens during the blast itself. When an explosive is detonated in a borehole, a reassure or shock wave radiates outwards producing radial fractures around the hole.

Expanding gases open and extend these fractures and physically displace (i.e., throw) the rock fragments. In a destress blast the explosive is confined and a free face is normally some distance away. Under these conditions the shock wave is the major source of rock fragmentation and most of the gases are probably vented through the borehole collar. Generally, the seismic energy in the shock wave is 5÷10% of the total chemical energy in the explosive.

3.3.3 Advantages and disadvantages of destress by blasting

1) Advantages

There are different advantages of destress by blasting which are given below:

1. Control hazards

Destress blasting is one of the active methods of rockburst control. The effect of destress blasting is manifested in two ways: (i) it relieves stress in the fore field of the longwall face due to failure of the coal seam immediately ahead of the face and thus moves the surcharge zone further ahead of the face (preconditioning); and (ii) it influences the mechanical properties of adjacent rocks (softening the rock, reducing its effective elastic modulus, etc.). Due to these measures the high stress concentrations in coal seams (or accompanying rocks) can be reduced.

2. Higher productivity

Besides the improvement in rock-burst control, preconditioning is carried out during stope development, hence taking the destressing out of the production cycle which should result in higher productivity. With the increase of production rates at greater mining depths in recent years, the importance of destress blasting is growing as a mine safety tool.

3. Protective barrier

Destress blasting in coal seams or immediate roof and floor rock mass has been adopted to manage cutter roof failure, floor heave and rockburst/coal bump. The objective has been to shift excessive induced stresses to the interior rock mass and to provide a protective barrier surrounding the excavation

2) Disadvantages

There are different disadvantages of destress by blasting which are given below:

1. Take too much time

Time is critical as destressing too soon can result in a subsequent on shift burst, and waiting too long increases the exposure time to on shift bursting. Maximum waiting time after destress blasting in adjacent rocks depends on the dilution of blast-induced fumes in the mine and registered seismic activity. Waiting time is from 45 to 60 minutes. Destress blasting in adjacent rocks of hard coal seams is not the most commonly used system of coal rockburst prevention.

2. Critical parameters

The stiffness, strength and brittleness of the rock mass are critical parameters, which largely control how much of a shattering effect the blasting energy will have.

3. Higher confinement

The confinement of the explosive charges also has a large effect on the amount of useful work they will provide. Higher confinement means a longer delay before the detonation gases reach a free face and vent to atmospheric pressure, during which they exploit and extend cracks inside the rock mass as they expand from the blast holes.

4. Hazardous

Subsequent mining using horizontal breast rounds could be hazardous if any misfires occur during destressing. The destress holes even on a 1.5m spacing may not be loaded heavily enough to accomplish complete destressing.

4. Destress applications in different countries

According to literature review, there are more than 600 cases about destress applications in coal mines and other types of mines collected, Figure 6 shows distribution of destress application in the past 100 years.

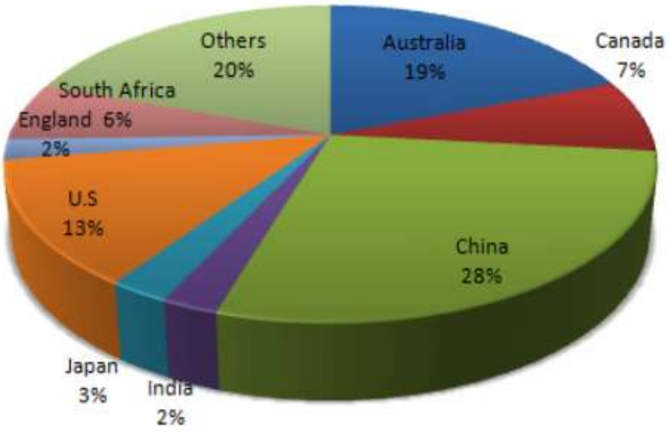

Figure 6 Destress applications around world

Preconditioning or "destressing" techniques have been applied in mining operations where high-stress conditions have been an issue. The techniques were used primarily to reduce or mitigate the risk associated with violent/catastrophic failure of the rock mass, thereby achieving more-stable mining conditions and resulting in safer mining operations. Nowadays, the caving industry has used preconditioning techniques in order to improve cave initiation and propagation to reach suitable draw rates; as well as reduce the risks of rock bursts and air blasts (Brown E, 2007).

According to data collected, around the world almost every country use destressing techniques for mining operations where high stress conditions have been an issue but there are some countries such as China, Australia, Canada, South Africa and United states they used mostly because of their adverse geomechanical and geological conditions and deep mining conditions. So we explain destressing techniques in these country one by one which are given below.

4.1 Destress application in China

According to data collected, China is one of the countries, which involved a large number of destress application in the world, due to adverse geomechanical and geological conditions and deep mining condition.

With the growth of mining depth, the stress, gas pressure and gas content of the coal seam increase significantly. The dynamic disasters accidents such as rock burst and coal and gas outburst increase accordingly (Jiang JY, 2011).These become a difficult problem to be solved in the mining conditions Theoretical research and mining practice indicated that destress techniques can effectively prevent and control these problems.

Table 1 shows the types of destress techniques used and time, it indicated that destress blasting technique and room and pillar mining method is the most frequently used in China, and destress application is mainly concentrated between 1995 and 2010.

Table 1 Destress techniques used from 1500-recent in China

De stress techniques	Years
Blasting/Room and pillar mining method	1500-1995
Blasting/Hydraulic Fracturing	1996-2004
Blasting/truck shovel	2005-2007
Blasting	2008-2010
Conventional mining/Blasting	2011-2018

4.2 Destress application in Australia

According to data collected, Australia is one of the countries, which involved a large number of destress application in the world, due to more disadvantageous geological and mining conditions. Mining depth, geological dislocations and mining remnants are factors which affect the rockburst hazard during underground mining to the greatest extent in Australia.
Table 2 shows the types of destress techniques used and time, it indicated that Drilling, Truck shovel, Front caving , Open pit , Pit dug, Conventional mining techniques is the most frequently used in Australia, and destress application is mainly concentrated between 1901 and 2000.

Table 2 Destress techniques used from 1500-recent in Australia

Destress techniques	Years
Drillings, Blasting	1500-1600
Bronze Hammer stones, Drilling	1601-1700
Drilling, Placer mining, Conventional mining techniques	1701-1800
Open cast, Destress, Pacer mining methods etc	1801-1900
Drilling, Truck shovel , Front caving , Open pit , Pit dug, Conventional mining techniques	1901-2000
Drilling, Blasting, Tragline, Shovel, Open pit, Conventional, Destress methods etc	2001-2018

4.3 Destress application in South Africa

In South Africa they used a combination of conventional drift and bench and low-profile mining methods for mining due to more disadvantageous geological and mining conditions. From the literature review, the objective of preconditioning using many different techniques such as Conventional drilling, leaching, dewatering, truck shovel method, block caving, pillar mining, leaching and blasting etc.

The first systematic experiments with destress blasting are however reported from South Africa and it was conceived that the purpose of destress blasting is to create a zone of fractured rock mass surrounding the excavation (Mani Ram Saharan, 2011).
Table 3 shows the types of destress techniques used and time, it indicated that Conventional, Drillings, Blasting, Shovel, Pillar mining , Leaching techniques are the most frequently used in South Africa, and destress application is mainly concentrated between 2011 and 2018.

Table 3 Destress techniques used from 1700-recent in South Africa

Destress techniques	Years
Conventional Drilling	1700-1800
Digging/Open pit techniques/Front caving/Block cavings methods,	1801-1900
Drilling/Blasting/truck shovel etc	1901-2000
Drilling/Blasting/shovel techniques	2001-2010
Conventional/Drilling/Blasting/Shovel/Pillar mining/Leaching etc	2011-2018

4.4 Destress application in U.S

According to data collected, U.S is one of the countries, which involved a fine number of destress application in the world, due to more disadvantageous geological and mining conditions.

Table 4 shows the types of destress techniques used and time, it indicated that placer mining, Destress, open pit mine techniques are the most frequently used in U.S, and destress application is mainly concentrated between 2008 and 2018.

Table 4 Destress techniques used from 1750-recent in U.S

Destress techniques	Years
Placer mining techniques, Drilling	1750-1800
Open pit techniques, Placer mining methods, Hydraulic mining	1801-1850
Destressing, Placer mining, Drilling , Hydraulic mining	1851-1900
Truck shovel, Quartz hard rock mining, Dredging, Blasting, Drilling, Leaching	1901-2000
Open pit , Conventional mining , Blasting, Destressing, Leaching	2001-2018

4.5 Destress application in Canada

According to data collected, Destress blasting is commonly used in Canada to minimize the occurance of rockbursts in mines. And also involved in the large number of destress application in the world, due to adverse geomechanical and geological conditions and deep mining condition.

In Canada destressing is commonly conceived as a blast fracturing technique to relieve stress in a potential rockburst zone. The fracturing reduces the load carrying ability of the rock which results in a stress reduction in the destressed zone. The purpose of destressing is as follows (Singh, 1987):

1) Push the pressure front further ahead, presumably away from the mining area.
2) Reduce the stress and stored strain energy.
3) Change the failure mode from brittle elastic to elastoplastic or plastic.
4) Allow the gradual yield of the fractured zone rather than sudden and violent failure.
5) Propagate minor bursts.
6) Distribute stress more evenly and over a large area than prior to destressing.

Table 5 shows the types of destress techniques used and time, it indicated that destress blasting and hydraulic fracturing technique is the most frequently used in Canada, and destress application is mainly concentrated after 1900.

Table 5 Destress techniques used from 1900-recent in Canada

Destress techniques	Years
Conventional techniques, Open cut, Blasting, Shovel, Surface mining techniques	1900-1950
Drilling, Shovel , Leaching , Blasting	1951-1970
Drilling, Leaching, Blastings, Room and pillar techniques	1971-2000
Room and pillar, Blasting, Shovel and truck etc	2001-2010
Flotation, Drilling , Blasting, leaching, Conventional mining techniques	2011-2018

5. Destress application in different geological and geomechanical conditions

Coal seams are extracted from past to recent based on geological and geomechanical conditions. Mining depth, geological dislocations and mining remnants are factors which affect the coalburst hazard during underground mining to the greatest extent. At the beginning of the 21st century, as the demand of more energy, the shallow resources are decreasing and the intensity of mining and infrastructural project are increasing. Domestic and foreign mines have successively entered the state of deep resource exploitation. With the increasing of mining depth, nonlinear dynamic mechanical phenomena and geological disasters, for instances, landslides, rockburst, gas outburst, rock nonlinear rheology, and water outburst, etc., occur with high frequency (Manchao Hea, 2018).

Destressing was conceived as a blast fracturing technique to stress relieves potential rock burst zones. It was first developed and widely used in Witwatersrand gold reef in South Africa in 1950's. After the success in South Africa it was tried in most other burst-prone mining districts around the world where high stress mining conditions, adverse geological and geomechanical conditions occurs.

5.1 Theoretical relation between coal seam stress and depth

The depth of mineral resources like coal continuously increases due to the exhaustion of shallow resources, and the characteristic of high ground stress in deep ground inevitably affects coal mining operation.

A common approach for determining the in-situ stress field is to assume that the pre-mining principal stresses are vertical and horizontal. Then, the vertical stress component can be estimated by the weight of the overburden, with $\sigma_v=0.025\text{-}0.027h$ (*h* is depth), even this assumption is not always true.

The word ‘depth’ in geomechanics seems to be used synonymously with ‘stress’ with the implication that the greater the depth, the higher the stress and vice versa. In particular, the limiting boundaries between these two extremes are typical different, for example, what is implied in coal (or soft rock) mining and hard rock mining (Suorineni, 2017).

Depth significantly affects both coal recoverability and underground mining conditions. With increasing depth, a number of logistical and geotechnical concerns including access and haul distances, roof and floor stability (increased rock pressures), temperature, groundwater issues and high stress conditions become increasingly problematic. The current depth limit to underground coal mining is usually considered to be between 914 and 1,219 m) (Fettweis, 1979).

(Cartwright, 1997) Explained about the relationships between horizontal stress and depth, within data base of UK stress measurements, there was a better correlation between stress and modulus than between stress and depth. Cartwright proposed that the two factors might be combined into a single equation:

$$S_H = B_0 + B_1\left[\left(\frac{v}{1+v}\right)(Depthh)\right] + B_2(Modulus) \qquad (1)$$

where $B_0$is a constant with units of *MPa*, $B_1$is a constant with units *MPa/m*, *v* is Poisson’s ratio, and dimensionless constant called the “tectonic strain factor” or TSF. Regression analysis provided the following values for the constants.

$$B_0 = -4.0\ MPa$$
$$B_1 = 0.009\ MPa/m$$
$$B_2 = 0.78^{*}10^{-3}$$

Cartwright’s analysis indicated that the modulus was more important than the depth for predicting the maximum horizontal stress.

The following are the assumptions from the different authors concern the relationship between stress and depth:

The depth at least as important as the modulus in predicting the horizontal stress, though both factors together should be better still.

The depth gradient should be somewhere between 1.0-1.6 times the vertical stress for coalfields located in stable, a-seismic mid-plate areas, like those in the eastern US, the UK, Germany, or central Queensland.

The depth gradient should be higher in a seismically active compressive regime like the one found in the Sydney Basin, and it should be lower an active extension regime like the one found in the western US coalfields.

The depth was as important as the modulus in predicting the horizontal stress in the coal mine data set, and it was a much better predictor in the non-coal data set. When both factors were combined, the accuracy of the predictions improved significantly.

There are number of investigators have been able to establish empirical relationships that hold on a regional or sub-continental basis. For example, showed that 40 measurements of horizontal stresses in the Fennoscandian block fitted the relationship (HOEK, 1978).

$$\sigma_1 + \sigma_2 = (18.73 \pm 0.10) + h(0.097 \pm 0.003) \qquad (2)$$

where σ_1 and σ_2 are the horizontal principal stresses in *MPa* and *h* is the depth of the measuring point in meters. (Hast, 1958) Found that data from a number of other parts of the world fell on a line having the same slope as that given by Eq.2but with a different intercept at $h=0$.

(Kropotkin K, 1972) found that Eq.2 fitted data from a number of localities in the U.S.S.R. and other countries, but suggested that such a relationship does not hold in sedimentary cover and fissured rocks. (Hast, 1958) claimed that relationships of the form of Eq.2had been found to apply for all competent rock. He also suggested that Eq.2 could be re-written as

$$\sigma_1 + \sigma_2 = 18.63 + h(MPa) \qquad (3)$$

(Herget, 1973) found that a number of sets of data from disparate localities in which horizontal stresses were greater than the vertical stresses could be represented by the equations

$$\sigma_{hav} = (8.16 \pm 0.54) + h(0.042 \pm 0.002) \qquad (4)$$

$$\sigma_v = (1.88 \pm 1.23) + h(0.026 \pm 0.003) \qquad (5)$$

where $\sigma_{hav}$and σ_v are the average horizontal and vertical stresses in *MPa* and *h* is the depth in meters.

More recently, (Haimson, 1978)found that a number of in-situ stress determinations made in the U.S.A. using the hydrofracturing technique, could be fitted by the relationships

$$\sigma_{hav} = 4.90 \pm 0.20\ h \qquad (6)$$

$$\sigma_v = 0.025\ h \qquad (7)$$

(Worotnicki G, 1976) found that the horizontal stresses at a number of sites in Australia were lower than those reported by (Hast, 1958), (Kropotkin K, 1972) and (Herget, 1973) being represented by

$$\sigma_{hav} = 7.26 + h\ (0.0215 \pm 0.0028)$$

At shallow depths, this may be associated with the fact that these stress values are often close to the limit of the measuring accuracy of the measuring techniques used. On the other hand, the possibility that high vertical stresses may exist cannot be discounted, particularly where some unusual geological or topographic feature may have influenced the entire stress field.
In Chinese collieries, the magnitude of the vertical stress σ_v is equivalent to the weight of the overburden. Vertical stress of outburst mining area could be represented by the Eq.9 and horizontal stress of outburst mining area by Eq.10.

$$\sigma_v = 0.02648h - 0.703 \qquad (9)$$

$$\sigma_{hmax} = 6.64 + 0.03h \qquad (10)$$

The major horizontal principal stress is increased with depth gradually. The increasing gradient in 400 to 550 m depth range is higher than under 550 m depth range.
(Brown, 1978) collected 116 in situ measurement data in the world, and found that the vertical stress could be represented by the relationship:

$$\sigma_v = 0.027h\ (MPa) \qquad (11)$$

Statistics showed that, in many mining areas of China such as Jiaozuo, Handan, Fengfeng, Kailuan and Luan, in situ stress were lower comparatively (Peng, 2002). The major horizontal principal stress could be described by the relationship:

$$\sigma_{hmax} = 0.02h + 4 \qquad (12)$$

The minor horizontal principal stress is not like the major horizontal principal stress and vertical stress. Relation between minor horizontal principal stress and depth is fitted as:

$$\sigma_{hmin} = 0.81 + 0.016h \qquad (13)$$

The correction coefficient is 0.684. With the depth increasing, its decentralization is obvious.
The relationship between average horizontal principal stress and depth from statistics (Zeng, 1990) was described by:

$$\sigma_{AV} = \frac{(\sigma_{hmax} + \sigma_{hmin})}{2} = 0.72 + 0.041h \qquad (14)$$

Average horizontal principal stress versus depth in outburst area could be written as a liner relationship:

$$\sigma_{AV} = \frac{(\sigma_{hmax} + \sigma_{hmin})}{2} = 2.9703 + 0.0287h \qquad (15)$$

The correlation coefficient is 0.960. It shows that the relationship between average horizontal stress and depth is very close. Upper the 180 m depth, the results of Eq.13 is larger than Eq.14. Under the 180 m depth, the latter is little than the former. At 800 m depth, the difference of them is *7.5MPa*. Eq.13 is fit to the upper depth.
The above equations show the relationship between depth and stress. The relationship between average horizontal stress and depth is very close and the horizontal stress is more remarkable in outburst area than others However, during the past 20 years such a pattern has been recorded at shallow depths by so many investigators in so many different locations and geological environments that it may now be considered to be the rule rather than the exception.

5.2 Destress application associating with coal seam depth

The most successful and widely accepted method of destressing is destress blasting with respect to coal seam depth. Destress blasting in coal seams or immediate roof and floor rock mass has been adopted to manage cutter roof failure, floor heave and rockburst/coal bump. The objective has been to shift excessive induced stresses to the interior rock mass and to provide a protective barrier surrounding the excavation.

Mostly destress coal blasting is used to alleviate rockbursts problems in Chinese, Australia, USA, South Africa and Canada collieries. Length of boreholes used for destress blasting depends on size of protective area which is created ahead of a face and this is a function of thickness of coal seam, size of pillars, mining depth and locked-in stresses in immediate roof rocks.

In Chinese collieries, mostly destress occurs due to pressure relief and permeability enhancement and they used destress blasting technique to control high stress conditions. The objective of destress blasting is to reduce the critical stress conditions and induce reduction in modulus values so that the rock mass shall not carry critical stress level.

In North American mines destressing is more widely practiced and apparently more successful. Destressing of sill pillars is done on a regular basis in the mines in the Coeur d`Alene district of northern Idaho. Normally, destressing takes place when the sill pillars have been reduced to 10-12m thickness and are highly stressed. Another concept is rock preconditioning where drilling and blasting is done before stoping takes place, and hence the rock is under its lowest stress condition. It has been reported that preconditioning significantly reduced seismic activity during mining (Blake W. , 1982).

In Canadian mines destressing is normally practiced in sill pillars in thin, steeply-dipping orebodies (Cook, 1983). Other applications of destressing techniques are in development openings including shafts and access openings.

In South Africa, mining is continuing beyond 4 km below surface at the Mponeng Gold Mine of AngloGold Ashanti. In general, underground mining in hard rock's takes place at greater depths compared to coal. This difference originates from the genesis of the two materials and their competency/strength as well as the strength of their host rocks.

Table 6 provides an intuitive ranking of depth. It is also intended to reflect the fact that what might be great depth in coal mining.

Table 6 Depth ranking/description based on literature review

Category	Depth	Ranking Description
1	<500 m	Very shallow
2	500-1000 m	Shallow
3	1000-1500 m	Intermediate/moderate
4	1500-3000 m	Deep
5	3000-4000 m	Ultra deep
6	>4000 m	Mega-depth

Maximum depth of coal mining in this range is 1000-1500 m. For coal 1,500 m may be mega-depth. Stress measurement problems start from deep depth. And to encounter these stress problem they used destress applications in both open pit and underground mines.

Table 7 Statistics of typical depth and destress techniques

Category	Mining	Typical depth	Destress techniques
1	Shallow	<1000 m	Development destressing/Shafts
2	Deep	1000-2250 m	Destress blasting/Drilling
3	Great	>2250 m	Pillar destressing

Statistics showed those mines or collieries which have less than 1000m depth which we refer as shallow depth and above than 1000m called deep or great depth in above Table 7.

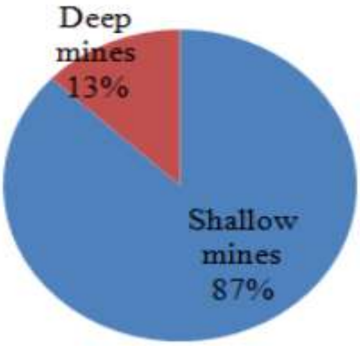

Figure 7 Collieries around world

Above Figure 7 show that according to statistics there are *87%* collieries which depth is less than 1000 m which we called shallow depth mines and remaining *13%* has depth more than *1000 m* from the surface called deep mines present around the world.

For shallow depth collieries, the most successful and commonly accepted application of destressing is development headings-drifts, raises and shafts. In zones of high stress and brittle rock the driving of these openings is commonly accompanied by popping and spalling rock, occasional bumping and small bursting, and usually excessive break. The problem is the high stress concentrations resulting from the sharp corner geometry at the heading face. The drilling and blasting of long holes ahead of the face almost always control this problem.

Great depth collieries or deep mines are characterized by high in situ stress, high temperature, and high water pressure. Compared with shallow resource extraction, deep mining may be associated with disasters such as rockbursts, large-scale caving, and large inrush of mixed coal, gas, and water. So they used different applications of destressing like pillar destressing, destress blasting, room and pillar and hydraulic fracture mining techniques to overcome these problems and mostly they used pillar destressing and destress blasting to prevent the rockbursts and outbursts around the world in deep mines or at great depth, but pillar destressing has been very successful in controlling rockbursting when done properly.

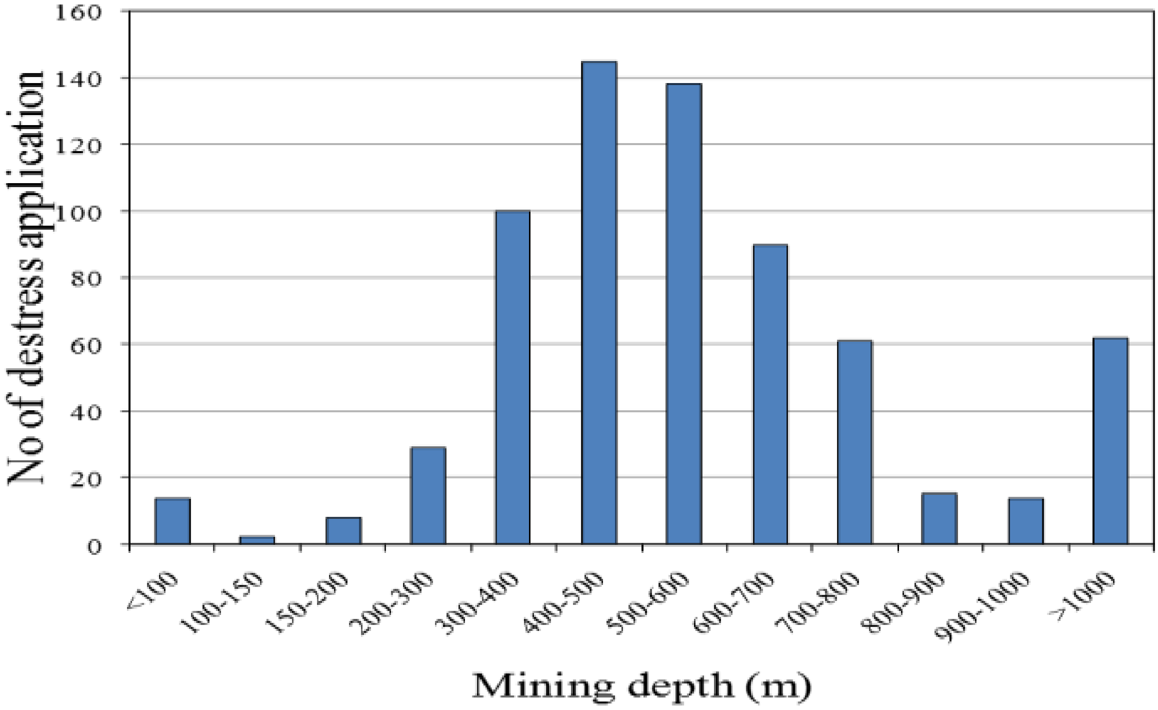

Figure 8 Destress distribution associating with mining depth

Above Figure 8 shows a graph of number of destress application verse with the growth of mining depth. These become a problem to be solved in the mining of deep coal seam. Theoretical research and mining practice indicated that destress techniques can effectively prevent and control the coal and gas outburst and other dynamic disasters in open pit and underground mining.

5.3 Theoretical relation between coal seam stress and coal/rock strength

The relationship of coal seam strength and coal seam stress were estimated using the equations proposed by (Mawdesley, 2001) as follows:

$$S = 0.27\sigma_c h^{-0.36} + \left(\frac{H}{250} + 1\right)\left(\frac{W}{h} - 1\right) MPa \qquad (16)$$

$$P = 0.25H\frac{(W+B)^2}{W^2}(MPa) \qquad (17)$$

Comparing Eq.16 and Eq.17and we get a new Eq.18 from that we can easily find the relationship of coal seam stress and strength.

$$S_p = \sigma_1[0.64 + 0.36\frac{W}{h} \qquad (18)$$

where S_p is strength in *MPa*, σ_1 is stress in *MPa* or in *psi*, *W* is width and h is height of the coal seam.
Vertical stress is derived by assuming that it originates from the weight of the overburden strata, and it is calculated from the densityp and thickness h of overlying rock mass or strata and gravity *g*:

$$S_v = phg \qquad (19)$$

The uniaxial approach assumes that (equal) horizontal stresses are generated by the vertical stress and the elastic properties of the overlying rocks.

$$S(Hor\ h) = \frac{v}{1-v} \qquad (20)$$

where *v* is the Poison's ratio.

5.4 De -stress application associating with coal seam strength of rock/coal

Reducing the stress in particular mine structure destress applications also results in modifying the rock/coal strength and material properties of the structure so that's its mode of failure is changed. Rock bursting is almost exclusively associated with rocks that behave in a brittle elastic manner and which have the potential to fail violently when their strength is exceeded. The most successful and widely accepted method of destressing is hydraulic fracture, pillar destressing, destress blasting and preconditioning with respect to coal seam strength.

On the other hand, rocks that will yield under pressure seldom fail violently. Thus, by fracturing a solid rocks mass by blasting, one attempts to modify its material properties so that's its mode of failure are changed from brittle elastic to plastic. The destressing should then blast fracture the rock-burst zone so that only is the stress in this zone reduced but yielding also occurs. Furthermore, continued loading of this zone will be displayed by continued yielding.

Destress blasting of development headings is a construction technique in deep tunnels, whereby explosives are used to fracture the rock in such a way that strain energy is dissipated from the rock mass, with minimal deformation. This is intended to reduce the frequency and severity of violent stress driven face or floor instability. Effective destressing relies on a shear mechanism of rock mass failure (Toper, 1997).

The outcome of destress blast is clearly influenced by the state of the rock mass at the time of its detonation. The response of the rock mass to destress blast is controlled by its mechanical properties, its degree of fracturing and the stress regime it is subjected to. In particular, the stiffness, strength and brittleness of the rock mass are critical parameters, which largely control how much of a shattering effect the blasting energy will have. The degree of fracturing of the rock mass affects its overall mechanical properties (including stiffness, strength and brittleness at the large scale), and influences the behavior and effects of explosive charges detonated in it (Patrick Andrieuxa, 2008).

Table 8 Statistics of strength of rock/coal and destress techniques

Category	Strength of rock/coal (MPa)	Destress techniques
1	<35 MPa	Drilling/Destress blasting
2	35-100 MPa	Hydraulic fracturing/Development destressing
3	>100 MPa	Preconditioning/Hydraulic fracturing

Table 8 shows the statistics view of destress applications/techniques with respect to rock/coal strength.
Destress blasting is one of the oldest stress relief measures used in underground coal mines. It is believed that the objective of destress blasting is to shift the zones of stress concentration to interior rock mass and to provide a protective barrier surrounding the excavation (PetrKonicek, 2011). Destress blasting is to release stored strain energy and to induce a reduction in modulus values so that the rock mass shall not carry critical stress level (Sedlak, 1997).
Hydraulic fracturing is a commonly used measure for reducing excessive stresses to mitigate rock burst potential. In contrast to destress blasting, hydraulic fracturing has the advantages of improved control of the fracture geometry by means of directional fracturing and it is generally less destructive. Hydraulic fracturing experiments are commonly conducted in mining industry especially in hard rock mines (PetrKonicek, 2011). Hydraulic fracturing can also be utilized to precondition competent rock mass under high stresses in order to eliminate the potential of rockburst induced by mining operation (Board, 1992).
International Society for Rock Mechanics (ISRM) raised the definition of soft rock in 1981: *"the International Society for Rock Mechanics (ISRM) describes rock with an UCS (uniaxial/compressive strength) in the range of 0.25 MPa to 25 MPa as 'extremely weak' 'to weak' "* (ISRM, 1981).

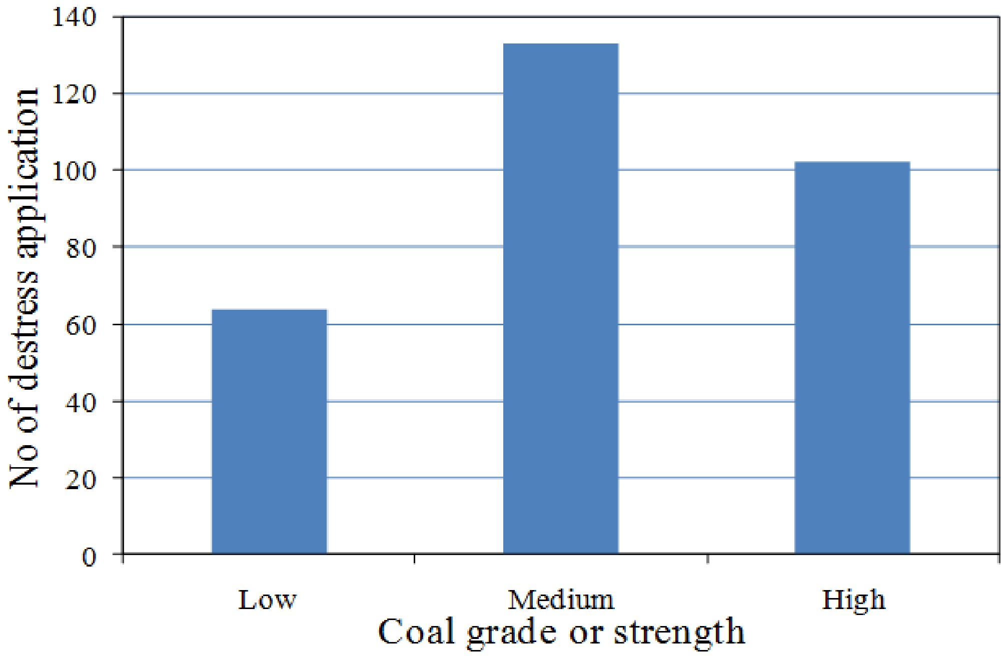

Figure 9 Destress distribution associating with coal grade/strength

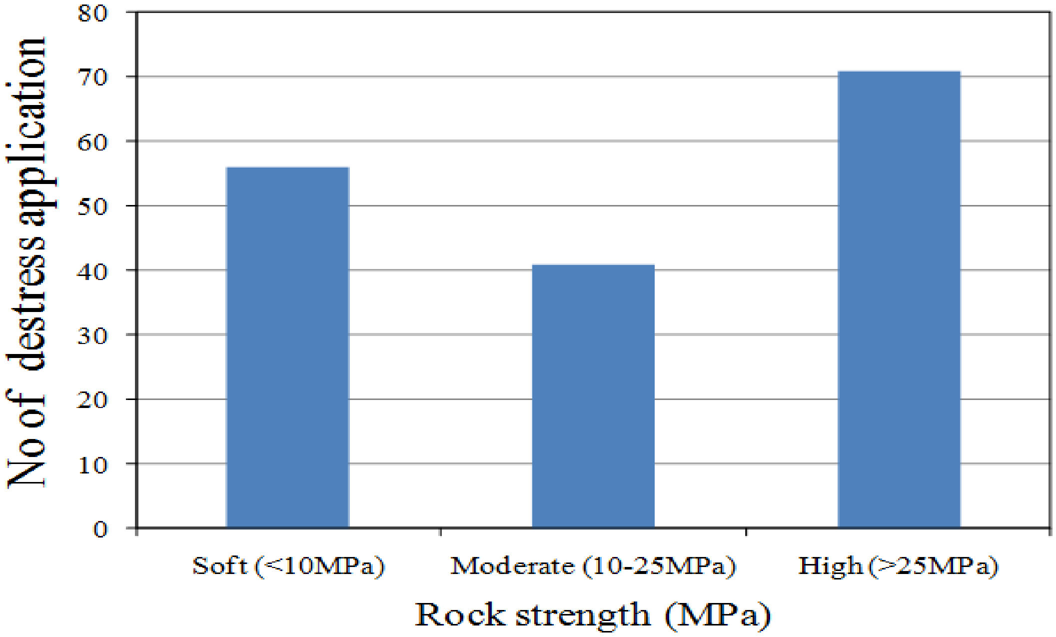

Figure 10 Destress distribution associating with rock strength

In soft rock collieries, rockbursts, landslides and other disasters basically have a close relation with large deformation of layered rocks. Rockbursts arise due to large squeezing deformations in soft and weak rocks called strainburst. So they used different applications of destressing to overcome these problems but mostly used destress drilling or destress blasting with respect to its geometry or structure.

In hard rocks, the concept is to prefecture or preconditioning a stope or zone of solid rock prior to mining so that the high stresses that usually results from mining are relieved by the yielding of the preconditioning zone. So preconditioning destress blasting is being used mostly in solid or hard rock's collieries.

6. Destress applications associated with different mining methods

6.1 Underground mining techniques

Underground mining refers to various underground mining techniques used to excavate hard minerals, usually those containing metals (De la Vergne, 2003) such as ore containing gold, silver, iron, copper, zinc, nickel, tin and lead but also involves using the same techniques for excavating ores of gems such as diamonds.

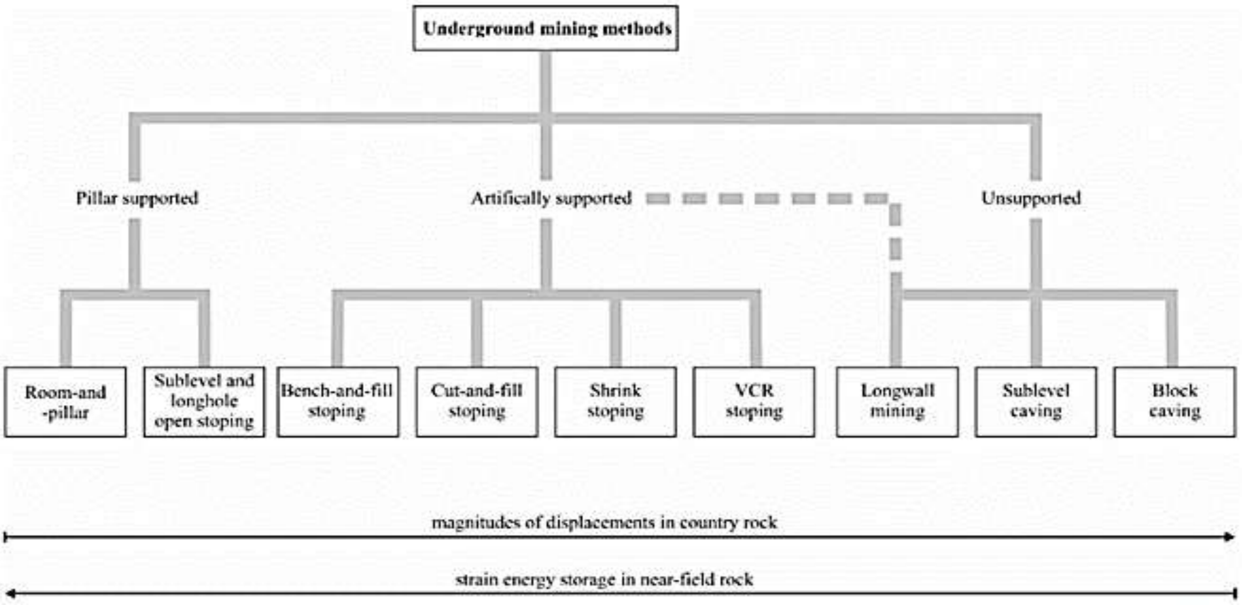

Figure 11 Underground mining methods/techniques(Okubo S, 2005)

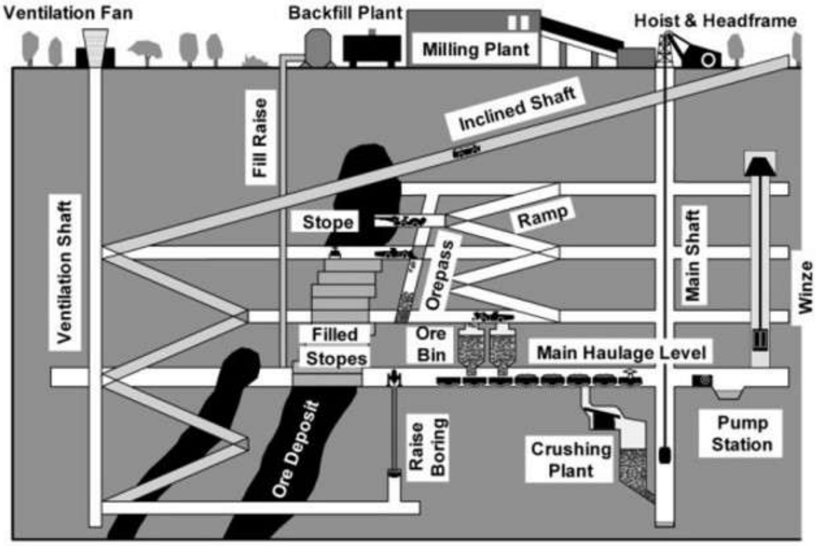

Figure 12 Example layout of underground mine(Okubo S, 2005)

6.1.1 Underground mining techniques associated with destress applications

When any ore body lies a considerable distance below the surface, the amount of waste that has to be removed in order to uncover the ore through surface mining becomes prohibitive, and underground techniques must be considered.

The mining methods or techniques used over the life of the mine have been mechanized cut and fill, open stoping, backfilling, longwall mining, room and pillar mining techniques. As the extraction ratio increased the operation became more and more susceptible to stress related problems, including rockbursts and outbursts which have caused large tonnages of reserves to be written off or put into a delayed mining category. To deal with these problems they used different types of destress application but with respect to underground mining methods mostly they used shown in Table 9.

Table 9 Statistics of underground mining techniques and destress application

Serial Num	Underground mining techniques	Purpose of destress	Destress applications
1	Longwall mining/Caving mining techniques	Heavy rockbursts	Preconditioning blasting
2	Room and pillar mining methods/Blast mining	Violent failure of rockmass	Destress blasting

Above Table 9 shows statistics view of destress applications with respect to underground mining techniques or methods.

Preconditioning has been successfully used in vein mines employing overhand cut-and-fill method(Blake W. , 1972).

Room and pillar destressing has been tried in most mining districts with rock-bursts problems but has probably been most successful in the Coeur d'Alenes. Here, the narrow steeply dipping silver or zinc veins are mined by an overhand horizontal cut and fill method or technique which results is the creation of rock burst prone pillar(Wilson, 1980). So according to this statement we can say that pillar destressing is suitable for those mines that used cut and fill mining techniques for mining.

Destress blasting is regarded as one of two ground preconditioning techniques that are used to stress relieve burst prone rock with respect to mining methods. Ground preconditioning technique that is well recognized today for the control of rockburst in underground mines (Mitri H. , 2000).

6.2 Open cut mining techniques

Open cut mining refers to various open cut; open pit and open cast mining techniques of extracting rock or minerals from the earth by their removal from an open pit or borrow.

Open-pit mines are characteristically engorged until either the mineral resource is exhausted, or a mounting ratio of overburden to ore makes more mining uneconomic. When this occurs, the exhausted mines are at times converted to landfills for disposal of solid wastes. Nevertheless, some form of water control is normally required to keep the mine pit from becoming a lake.

Open cut mines are dug on benches, which portray vertical levels of the hole. These benches are normally on four meter to sixty meter intervals, relying on the size of the machinery that is being utilized. A lot of quarries do not use benches, as they are normally shallow.

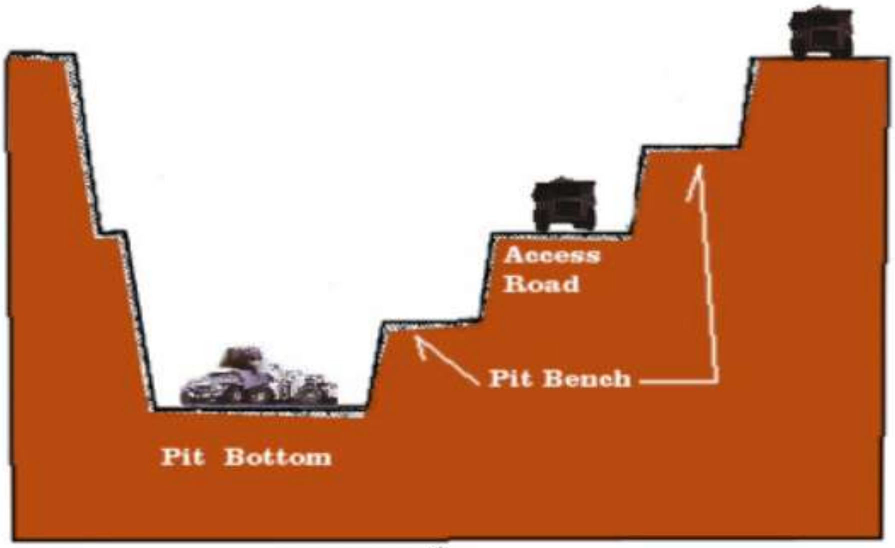

Figure 13 Illustration of a open pit surface mine

Figure 14 Magma copper's open pit mine on Arizona

6.2.1 Open cut mining techniques associated with destress applications

Open pit mines techniques can be used in coal mining, and they are used extensively in "hard rock" mining for ores such as metal ores, copper, gold, iron, aluminum, and many minerals.

In a open pit coal mine, the pit bottom would be the bottom mined coal seam elevation, since it is usually feasible to extract multiple seams when surface mining coal. In a hard rock mine, the bottom of the pit would be the lowest level (elevation) that mining would be conducted on the ore being mined. And in hard rock mining the main concept is prefacture the rocks before excavation or mining so we need application of destress, for hard rock mining or open mining methods the most useful application used is preconditioning destress blasting which helps to prefacture the rock before mining.

Table 10 Statistics of surface mining techniques and destress application

Serial Num	Surface mining techniques	Purpose of destress	Destress applications
1	Strip mining	Rockbursts	Destress blastings
2	Open pit /Open cut/Open shaft	Cutter failure and floor heave	Destress blasting, Preconditioning blasting/Drilling
3	Quarrying	Mine safety	Blastings
4	Conventional mining	Fracture the rock	Hydraulic fracture/Waterjet/Blastings

Above Table 10 shows statistics view of destress applications with respect to surface/open cut mining techniques or methods.

7. Destress applications associated with production

Production is the process of removing the valuable minerals from their surrounding rock, not an easy task. Rock is first mined and removed from the ground, then crushed, sometimes ground to a fine flour size, and then put through chemical or non-chemical processes to separate the valuable minerals from the waste minerals. The latter are stored permanently at the mine site, while the valuable minerals are sold in the marketplace. Mining production can support from tens to hundreds to thousands of jobs and can last from a few years to many decades. Some mines have even surpassed 100 years and as a result deliver opportunities and benefits for several generations.

The production phase includes extraction, milling and processing of raw materials, such as coal, metals, industrial minerals and aggregate. The length of time a mine is in production depends on the amount and quality of the mineral or metal in the deposit and profitability of the operation.

Coal is mined commercially in over 50 countries. Over 7,036 Mt/yr of hard coal was produced in 2007, a substantial increase over the previous 25 years. In 2006, the world production of brown coal (lignite) was slightly over 1,000 Mt, with Germany the world's largest brown coal producer at 194.4 Mt and China second at 100.6 Mt. Coal productions has grown fastest in Asia, while Europe has declined. Since 2013, the world coal production is decreasing, -6% in 2016.

Most coal production is used in the country of origin, with around 16 percent of hard coal production being exported. The People's Republic of China is the largest producer of coal in the world, while the United States contains the world's largest 'recoverable' coal reserves (followed by Pakistan, Russia, China, and India). China and the United States are also among the largest coal consumers. Other important coal producing countries include Australia, India, South Africa, and Russia.

Coal reserves are available in almost every country worldwide, with recoverable reserves in around 70 countries. At current production levels, proven coal reserves are estimated to last 147 years. However, production levels are by no means level, and are in fact increasing and some estimates are that peak coal could arrive in many countries such as China and America by around 2030.

7.1 Effects of destress on production

The most widely accepted destress application associated with production is preconditioning blast. Because of the encouraging results of preconditioning carried out at Hecla's star mine that will precondition three stopes on the 7900 level all the way up to the 7700 level. Besides the improvement in rock-burst control, preconditioning is carried out during stope development, hence taking the destressing out of the production cycle which should result in higher productivity.

In a Figure 15 shows a graph of production of minerals associating with destress applications. Coal is valued for its energy content, and, since the 1880s, has been widely used to generate electricity. Steel and cement industries use coal as a fuel for extraction of iron from iron ore and for cement production. China is the biggest coal producer in the world, and is also the world's largest coal consumer, with coal accounting for approximately 70 % of China's total energy consumption (Tingkan LU, 2015).

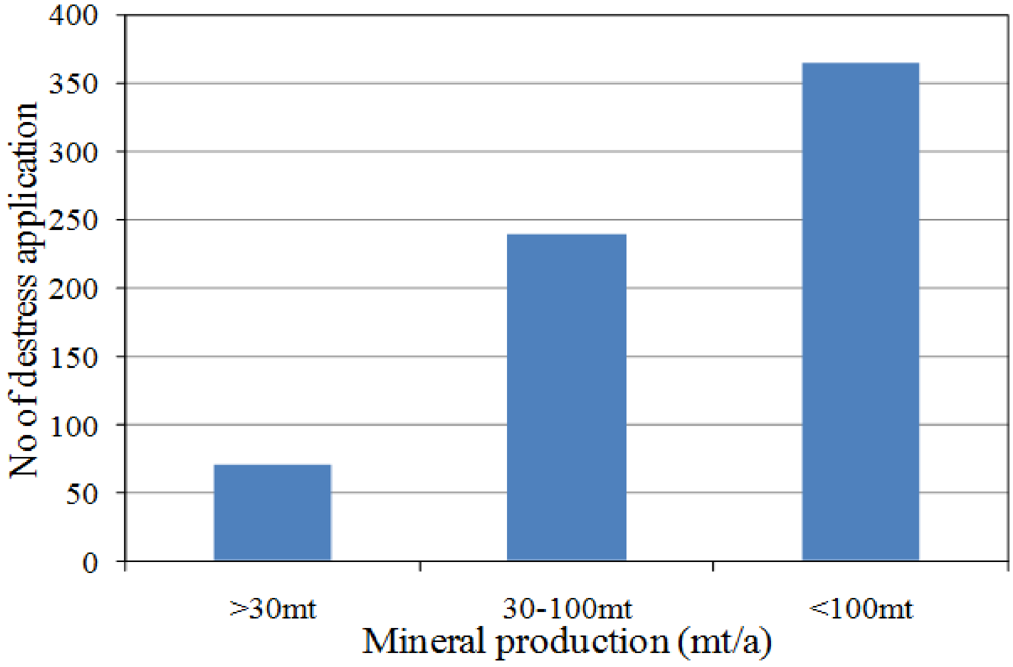

Figure 15 Destress distribution associating with mineral production around world

8. Conclusion and summary

Destress application is one of the essential methods to control the stress related problems in mines through the principle of stress transfer. From this review:

Destressing like mining, should be thought of in terms of stress engineering since it results in the transferring or shifting of stress from one area to another. Successful destressing requires more than the drilling and blasting of a few holes where deemed necessary. The destressing must be designed to fracture the rock in the burst-prone area so that the critical high stress is reduced and transferred to the adjacent rock without causing further problems.

Despite the factors which contribute to the increase of ground stress, it can be seen that all definitions of destress methods given by different researchers focus on ground stress control as the major triggering factor of problems in both underground and surface mines.

These applications were applied in different countries such as South Africa, Canada, USA, China, Australia ,on so on. From the view point of mechanism of coal seam destress by different method, it can be seen that, the high stresses concentration in surrounding rock mass of the underground mine working face are decreased after the application of destress.

It is substantiated that destress methods and application is the best reliable proactive means to control the threats of different problems which is caused by ground stress if reasonably employed in real place, manner and timing. The results of these method can be very good if the proper way of its application is mastered. Therefore, these methods can be considered to be a very important and necessary part of regular mining cycle as the objective of destress is to create a safety barrier between the excavation boundary and the high stress zones.

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