International Journal of GEOMATE, Jan., 2017, Vol. 12, Issue 29, pp. 204 - 211
Geotec., Const. Mat. & Env., ISSN: 2186-2990, Japan; DOI: http://dx.doi.org/10.21660/2017.29.67564

OVERVIEW OF ROCK BURST RESEARCH IN CHINA AND ITS APPLICATION IN IVORY COAST

*****Kouame Arthur Joseph KOUAME[1], Fuxing Jiang[1], Sitao Zhu[1], Yu Feng1

[1] School of Civil and Environmental Engineering, University of Science and Technology Beijing, Beijing, PR China

*Correspondence: Received: 26 June 2016; Revised: 5 July 2016; Accepted: 8 July 2016

ABSTRACT: Rock bursts and mining-induced seismic events have serious socio-economic consequences for the Chinese mining industry, as its mines are extended to a specific depth. This paper mainly discusses deep mine hazards and rock burst problems in China. First, the definition of a 'rock burst' is given. The paper also introduces the current situation of deep mining and predicts its influences in Ivory Coast over the next ten years. Second, it explains the dynamic hazards arising from deep mining (the most dangerous hazard in deep mining in China).It then emphasizes that dynamic hazard control is a complex technology system that involve many techniques: evaluation, control, prevention and treatment. The burst technique system involves devices that are highly complex. Finally, the paper presents cases of controlled rock burst using the control technologies described, and considers their applications in Ivory Coast’s deep mining industry.

Keywords: Rock Burst, Deep Mining, Dynamic Hazard，Control Technology, Ivory Coast

1. INTRODUCTION

1.1 Definition of Rock Burst

A Rock burst is defined as a mining-induced seismic event that causes damage to openings in the rock. A rock burst will cause damage of varying severity. A more sophisticated definition of a rock burst is damage associated with a seismic event to an excavation, which occurs in a sudden or violent manner.

Spontaneous rock bursts occur when the stresses near the boundary of an excavation exceed the rock mass strength. Here, the failure proceeds in a violent manner. A combination of strength over time and loss of confinement can also lead to deterioration of the capacity of the rock mass. One or all of these conditions cause the strength of the rock mass to be exceeded by the stress upon it, leading to failure. As a result, loss of structural stability; a factor independent of the strength of the rock mass; can also cause a self-initiated rock burst, as can be demonstrated in the sudden buckling of column or slab of rock.

A rock burst is a spontaneous, violent fracture of a rock that can occur in deep mines. The digging of a mineshaft relieves neighboring rocks of tremendous pressure, which can literally cause the rock to explode as it attempts to re-establish equilibrium. Rock bursts are a serious hazard [1]. The magnitude of rock bursts basically depends on the size and depth of the excavation.

1.2 Rock Bump and Rock Burst

Rock bursts are the result of the fracturing of brittle rock, causing it to collapse rapidly with the violent expulsion of approximately 100 to 200 tons or more of rock. This release of energy reduces the potential energy of the rock around the excavation. (Another explanation is that the changes brought about by the mine's redistribution of stress triggers latent seismic events, deriving from the strain energy produced by its geological aspects). The likelihood of rock bursts occurring increases as the depth of a mine increases. The likelihood is also affected by the size of the excavation (the larger the riskier), becoming particularly likely if the excavation is ~180m or more in diameter [2]. Induced seismicity such as bad mining methods can also trigger rock bursts. Finally, rock bursts can be caused by the presence of faults, dykes, or joints.

1.3 Deep Mine Hazards

Currently more and more mines in China, especially gold, and diamond mines, have reached a depth exceeding 600 meters. These deep mines have lead to a variety of new problems arising from underground pressure, including more complex mining induced stress fields as well as new catastrophic dynamic phenomena (of which a rock burst is the most unpredictable and violent ([3]; [4]). Thus mining depth is directly related to hazards, especially for rock bursts.

Stress levels of gold mines increase with mine depth. Excavation and extraction work also cause stress redistribution and leads to stress concentration around tunnels (roadways and mine entries) and mining sites. In deep gold mines, when stress around an opening exceeds the strength of the surrounding rock (host rock, country rock, adjacent rock) beyond a certain extent, the rock will bump into the opening suddenly and violently. This is roughly how a rock burst occurs. The burst medium must be brittle and hard, not soft and flexible. When soft rock is under high stress it moves into the opening slowly, rather than bumping suddenly and violently.

1.4 Rock Burst in Ivory Coast

Ivory Coast is rich in ore and other resources, although mining represents only a small proportion of the country's economy: (about 2-3%). As in most African countries, gold is the primary focus of foreign investment, among various resources. In Ivory Coast nearly all of the prospecting and mining licenses are issued for gold.

The country has a broad commodity base with undeveloped iron ore, bauxite, nickel, and manganese and tantalite resources. Artisanal workings of gold and diamonds are widespread. Over the past 40 years, Ivory Coast has committed to developing its gold mining sector so as to increase its foreign exchange reserves. With more and more gold mines being exploited and extracted and mine depth increasing over time, the country has faced many difficulties including rock burst disasters, damage to natural landscape, environmental pollution, and so on. In the past ten years Ivory Coast has seen over 150 gold mines exceeding 600 meters in depth and a handful exceeding 1500 meters. Mine depth in 30% gold mines is expected increase dramatically—between 500 and 1200 meters—over the coming 10 years. With mine depth increasing, underground rock stability has become a major challenge. [7]

Just as China, Ivory Coast cherishes the great aspiration of contributing to construction of mining sector, however there are still many spaces that can be studied and improved in the future due to many dynamic disasters such as rock burst occurred every year in Ivory Coast, while China has achieved much progress in mining disaster after decades of development and ahead of that of Ivory Coast. So rich experience can draw lessons from China under the Chinese research outcome. As such, this paper will asses this challenge by analyzing cases of controlled rock bursts using control technologies described in the line with data from qualitative and quantitative research. Using this methodology, the results obtained will consider their applications in Ivory Coast's deep mining industry ([5], [6]).

2. DYNAMIC HAZARD IN DEEP MINES

2.1 Formation Mechanics of Rock Bursts

As mine depth increases, the challenge of rock bursts related to seismic events also increases. This is more likely to happened rock burst when the mining depth is over 600 meters. (See Fig.1) Seismic monitoring systems are installed in mines to monitor seismic events and better understand their causes. Data from the monitoring systems are used to study seismic events and their parameters.

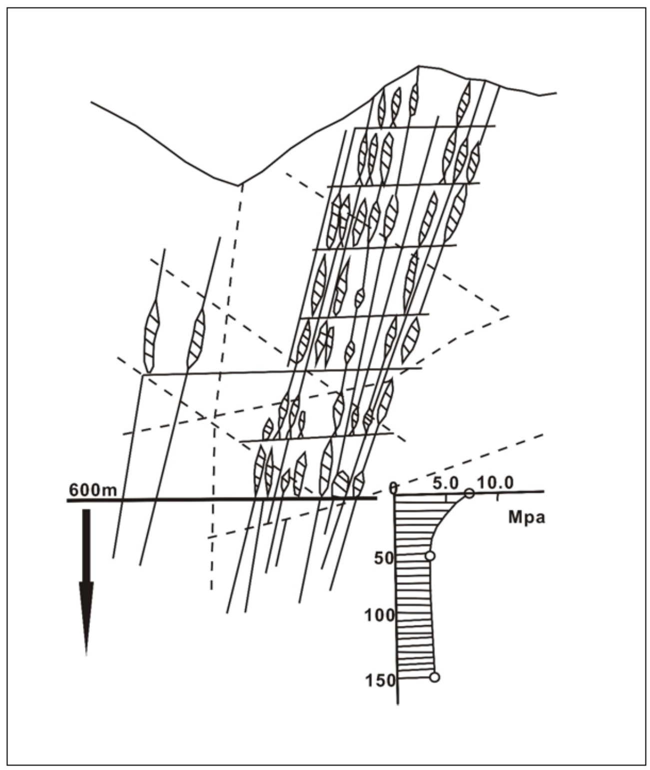

Fig.1 The stress diagram of rock burst region in deep mining

Take a coal mine for example: as the depth of the mine increases, so does the pressure on the hard rock. When the pressure exceeds the coal-rock junction resistance at a certain depth and area, the coal-rock junction resistance acting on the backplane is unable to take the pressure. A rock burst is likely to occur [8]. See Fig.2.

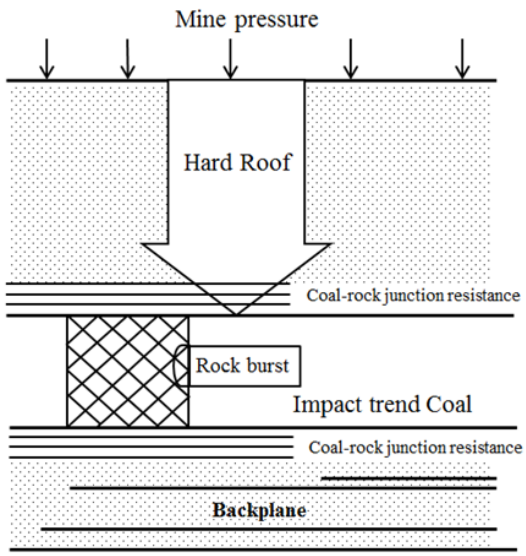

Fig. 2 A Rock burst mechanism in a coal mine

Generally, a rock burst occurs in hard rocks with fold structures. A rock burst is closely linked to fault and joint structures. When the tunnel face is parallel to a fault or joint strike, it is easy to initiate a rock burst. When the strength of a surrounding rock cannot bear the concentrated and excessive stress, buckling failure will occur.

In the evolutionary model, rock burst occurs in three stages: plate cracking vertically, flexion deformity, and finally rock burst damage. Surrounding rock stress can be determined using the following experimental formula (See Fig.3 and Fig.4.):

$$\sigma 1/\sigma c > 0.165 \sim 0.35$$
$$\sigma c/\sigma 1 > 6.06 \sim 2.86 \qquad (1)$$

σ1 stands for MPS: Maximum Principal Stress among rock natural stress,

σc stands for UCS: Uniaxial Compressive Strength among surrounding rock stress.

In this example, rock burst is likely to occur in the brittle rock.

2.2 Characteristics of Rock Burst Disaster

Rock burst disasters have the following basic characteristics:

2.2.1 Hysteresis Quality

A rock burst usually does not occur immediately after the excavation of rocks in deep mining, but several hours or even a long time later.

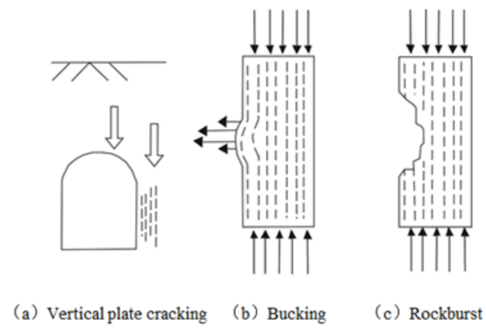

Fig. 3: evolutionary model of Rock burst

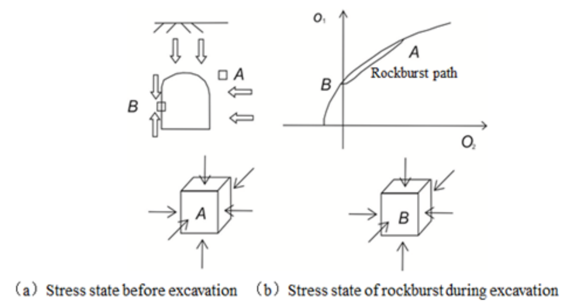

Fig. 4 Sketch map of rock burst stress

2.2.2 Continuity

Rock burst are not one-off events. Rock bursts will often happen again ten days or even longer after an initial rock burst.

2.2.3 Attenuating Property

Rock bursts, which occur at the beginning of excavation, are generally stronger than those, which occur later. Energy is redistributed over time and its release becomes less intense.

2.2.4 Sudden

Rock bursts reflect a sudden outburst of energy.

2.2.5 Violence

Rock bursts manifest in the ejection of rock and violent sound. They represent one of the most intense phenomena in underground excavation and the most catastrophic events in the deep mining.

2.2.6 Perniciousness

Rock bursts in general terms, negatively affect regular production, equipment and property, and personal safety.

2.3 Dynamic Hazard and Disaster in Deep Mines

As is well known, dynamic hazards lead to the most dangerous disasters in deep mining around the world. A rock burst is a geological disaster occurring in underground excavation. It affects the normal construction of engineering, causes damage to construction equipment and property and endangers people's safety and lives.

Rock bursts in deep mining have been a prominent issue in China over the past decades. Sometimes rocks expelled in bursts block underground tunnels and thus trap miners underground. For instance, the gas explosion on December 5th，2007 in Hongtong County, Shanxi Province, which caused the death of 105 miners, is an exceptional case of rock burst in China. Rock burst often leads to mine roof collapse, killing miners, destroying equipment and suspending mining production. Over the past 20 years almost 30 people every year have been killed or injured by rock burst in deep mining in China. Let's take a look at another example: Sanmenxia in Henan province of China where over ten miners were trapped in a coal mine after a "rock burst" due to an explosion after an earthquake according to official report from the state media. After the accident four miners died and over 50 miners were missing [9]. As for the accident reason，it is mainly caused by manmade factors and possibly by incorrect operation in charging process. In addition, the unstable geological structure with some broken belts, which often causes rock burtt in China, in that region is also matters. The decision to close many illegal mines in China has inspired the current government of Ivory Coast, which ruled to close more than 150 illegal gold mines sites in the northern and central parts of the country after several fatalities from a landslide in which five people, including children, died [10]. In Ivory Coast, rock bursts have killed roughly 20 miners each year [11]. Many of the lessons that have been learnt about rock bursts in deep mining must be treated as greatly important in both China and Ivory Coast.

3. ROCK BURST CONTROL TECHNOLOGY

The rising difficulties in deep mining will increase the likelihood of rock bursts occurring. So measures must be taken to prevent it in deep mining operation.

Dynamic hazard control is a complex technology system. It involves evaluating burst proneness (burst potential) before excavation and mining, the distress technique in evaluating burst risk zones, real time monitoring techniques and devices (including mining stress monitoring techniques and devices, micro-seismic monitoring techniques and devices, and the acoustic emission monitoring technique and device), roadway (entry and tunnel) support in burst risk zones, and management techniques in burst risk zones (for miners and mining equipment and materials).

3.1 Burst Proneness Assessment

Burst proneness assessment is a technique that can predict and judge how a burst will behave before it happens. It is useful theoretically and realistically to study the relationship between physical properties and rock burst potential, in order to predict and evaluate rock burst risk in correlative engineering. Deforming increases before the stress reaches the peak strength of rock, while it becomes weak over the peak strength. As such we can simplify the constitutive curve of rock as a bilinear line. It is at a linear elastic stage when the stress is less than peak strength, and a linear softening area when above peak strength—as seen in Fig. 5:

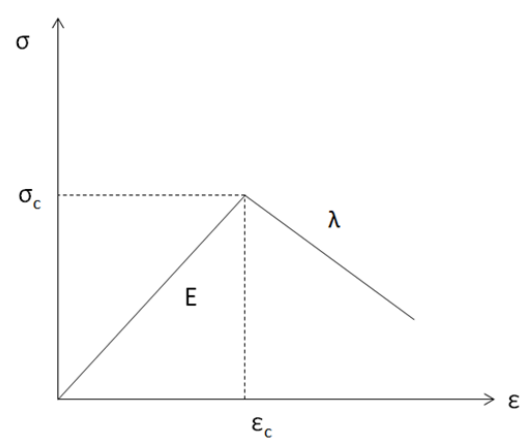

Fig. 5 Bilinear constitutive curve of rock

Where σc is the peak strength, εc is the strain corresponding to peak strength; E is the elastic modulus (the value of the slope of the line before peak point), λ is the softening modulus (the negative value of the slope of the line over peak point). When the strain exceeds the marginal value, then it predicts burst proneness. So it is necessary to manage and ensure the strain remains below a reasonable boundary when deep mining [12].

3.2 De-stress Techniques in Burst Risk Zones

When there is burst proneness in one or several regions, the consequences are potentially dangerous. So it is essential that various measures are taken to de-stress the overburdened area.

Usually an anchoring technique is adopted to reduce the strain on the rocks. As is well known, the rock-soil anchoring technique is a safe and economical method for the support and reinforcement of unstable rock-soil. Most deep mines in China have adopted the anchoring technique to distress overburdened areas in burst risk zones during the past ten years. Pre-stressed anchor technology is used to improve the stress condition for the safe performance of strain release and energy dissipation. Although the anchor technique is widely used in geotechnical engineering in China and other big mineral industries, the mechanism of anchorage is still not well-known. As such, the method does not always work well and blasting treatment for burst risk zones is thus essential in most deep mines.

For rocks in grave danger, a special blasting treatment is needed to eliminate the potential risks in burst risk zones. To implement a blasting, some special blasting parameters and technologies must be implemented, controlling the overlying pressure on the burst risk zone.

3.3 Rock Burst Monitoring Techniques

A rock burst is an invisible potential disaster in mining activities. As such it is critical that long-term supervision mechanisms are established in deep mines. Most mines in China were built in 1950~1960s, and most of them are or will soon become deep mines. So we must establish a long-term, real-time system to monitor potential rock bursts. As foundational work for mine earthquake forecast and control, monitoring and predicting play a key role in deep mining activities. This is not only good for making informed decisions and organizing relief quickly to reduce loss caused by the rock bursts; it also helps with the prediction of mine earthquakes.

Currently, some domestic monitoring techniques and acoustic emission monitoring techniques have been applied in monitoring activities. Some foreign equipment has also been introduced into China for rock burst disaster monitoring. Examples include the ISS micro-seismic monitoring system, the multi-channel micro-seismic monitoring system and the macro seismic and micro-seismic monitoring system [13]. All these monitoring systems use the principles of electrical signal transmission to monitor the mining stress and likelihood of rock burst in deep mining.

The micro-seismic monitoring and orientation system rock burst signal identification program is shown in flowchart Fig. 6, below. First, basic parameter setting is necessary. Each sub-station setting is needed to judge whether it will receive vibration signals. Next the vibration signal mine earthquake filter average is analyzed. If both of the above steps are workable, then a signal waveform data archiving mine earthquake alarm (sound or light) is available. If not, each step returns to the previous step [14].

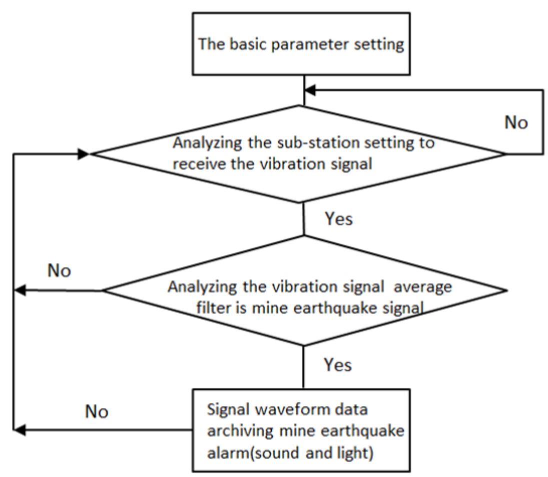

Fig.6 Flowchart of rock burst signal identification program

3.4 Roadway Support Technique in Burst Risk Zones

Roadway support is a practical and comparatively convenient and reliable method to prevent rock burst in most mining. Its main role is to reduce the overlying pressure on the roadway. There are three main support methods based on the support materials: namely bolting support, concrete and reinforced concrete support, and framed roadway support.

Bolting alone supports the use of an anchor. Anchor bolt support is widely used in tunneling, mining and underground opening supports as an economical, reliable, simple and convenient method. Which is well-known for its effectiveness in the support of joints containing rock mass.

Being an efficient and economical cavern-support technique, pre-stressed bolt support has been widely used in different underground projects.

The Concrete Support is a support bracket with precast concrete blocks or poured concrete masonry. The support of the reinforced concrete prefabricated reinforced concrete components or pouring reinforced concrete masonry bracket support. Both support retaining the mineshaft, transportation roadway and bottom whole car places support. According to the different materials the shed-like bracket can be divided into wooden supports and metal stents [15].

Framed roadway support, known as framed timber, is the most effective way to support the roadway in unstable coal seam with "weak-rock-coal-floor" many coal mines. It consists of one top beam and two leg pieces. The interaction between the roadway support, wall rock and dependency on each other, has a common loading effect. So the framed roadway support mainly used in those roadways that the wall rock is very broken and unstable [11].

3.5 Management Technique in Burst Zones

Good management is vital to any mining activities. Good management improves production and ensures the safety of the project. Modern mines should adopt modern management techniques such as SWOT (Strength, Weakness, Opportunity, Threats) analysis of management science.

Information management techniques and good project management are essential for preventing rock bursts. It is evident that ensuring production safety is a huge responsibility. There must be no compromise on production safety for the sake of profit. As such it is necessary to set strict rules and take effective measures to prevent rock bursts.

In fact, China has done a good job and had some limited success in this area in recent years. According to incomplete statistics, there were only two or three fatal accidents due to rock bursts in deep mining per year over the past eight years. This is due to China's strict implementation of safety production regulations over this period.

4. SOME MONITORING TECHNOLOGY AND EQUIPMENT TO PREVENT ROCK BURSTS

4.1 Cases of Rock burst in China and Ivory Coast

A rock burst is a typical mine disaster both in China and Ivory Coast. Nowadays，as mine depth increases, rocks bursts have become more and more common in both China and Ivory Coast, and are a serious threat to mine production and the safety of the property and lives of miners. In July 2015, two rock burst accidents happened in Shandong Province, China.

The first happened at the 3302 face of the track trough in Xingcun coal mine of Shandong Tianan Coal Mine Group Ltd., on Jul 26. Roughly, a 200-meter-deep tunnel deformation with a 0.2~1.5 meter backplane prominence occurred at the 3302 face of the tail entry. Parts of the devices in the trough shifted and the pre-support single props around 100 meters of the working face were bent or broken off. One miner was injured in the accident.

The second incident happened at the 1305 island mining face in the Zhaolou Coal Mine of Yankuang Group Ltd., on July 29th. A rock burst occurred when the extraction was just getting started, around 30 meters away from the tail entry. Five people were injured [16].

In Ivory Coast, rock burst is among the most common hazard in mining. In March this year a gold mine in Korhogo, northwest of Ivory Coast, a serious and violent mine tunnel roof collapse killed three miners and left five injured.

4.2 Burst Monitoring Technology in China

The burst monitoring technique systems and devices are very complex and often difficult to understand. To use them well requires spending a long time learning to understand them. Deep mining requires preparation. Presently, more and more advanced techniques and equipment for rock burst monitoring have come into use in China. As 30 percent of China’s mines have transferred into deep mines (more than 600 meters), the demand for rock burst monitoring technology is increasing. A large amount of monitoring technology and related equipment has been produced and put into service in mining activities. There are some well-known monitoring techniques invented by Chinese scientists and researchers. An example is the micro-seismic monitoring and orientation system implemented by the team of Professor Jiang Fuxing at USTB. It uses micro-seismic monitoring technology to monitor strata fracturing in underground coal mines. It mainly uses the principle of transmitting rock burst signals into straight data to a computer, for analysis by a researcher. The researcher can then evaluate burst proneness and likely locations.

Using this technique, researchers have successfully predicted several rocks bursts in deep gold and coal mines in North China. They were then able to control dynamic hazards in advance.

4.3 Comparison between China and Ivory Coast

Like China, Ivory Coast has a large mining industry with a number of rock burst disasters every year. There are approximately 400 gold mines in Ivory Coast and about 40 percent of them have transferred to deep mining more than 800 meters as it shown in Fig.7. As mines get deeper, more rock burst disasters are likely to occur. The following table compares figures and parameters relevant to rock burst in gold mines in China and Ivory Coast.

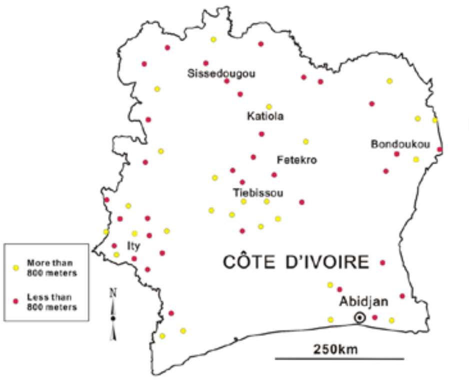

Fig.7 The distribution map of gold mines in depth in Ivory Coast.

Fig.8 The distribution map of gold mines in China

This table shows that both Ivory Coast and China face an increased risk of rock burst incidents due to more and more gold mines transferring to deep mining. Both countries should take measures and implement monitoring techniques to prevent rock burst, which could otherwise cause major mining disasters in the future. With the help of China's experience with monitoring techniques for rock burst, Ivory Coast can make use of advanced technology and equipment to prevent rock burst in deep mining in the future.

5. CONCLUSION

As unpredictable and invisible disasters occur in deep mines, the rock burst phenomenon in China and Ivory Coast is the subject of increasing amounts of research. To review the information presented in this study: a rock burst is a spontaneous, violent fracture of rock that can occur in deep mines.

Table 1 Comparison between China and Ivory Coast

Events	China	Ivory Coast
Number of Gold Deposits	Up to 1200 gold mines	Up to 300 gold mines
Mining Depth	30 percent of mines have transferred to deep mining (more than 600 meters)	40 percent of them have transferred to deep mining (more than 800 meters)
Rock burst Disasters	2-3 per year. 25 people injured and 10 killed due to rock burst disasters each year.	5-6 per year. 60 people injured and 25 killed due to rock burst each year.
Main Monitoring Methods	Micro-seismic Monitoring and Orientation System; Multi-Channel Micro-seismic Monitoring System	ISS Micro-seismic Monitoring System, Macro seismic and Micro-seismic Monitoring System

In deep gold mines, when stress around the opening exceeds the strength of the surrounding rock (host rock, country rock) beyond a certain extent, the rock will bump into the opening suddenly and violently. Responses to the risk of rock burst include monitoring techniques (such as burst proneness assessments, the distress technique and the rock burst monitoring technique), roadway support techniques and management techniques. The micro-seismic monitoring and orientation system implemented by the USTB's team has worked well in monitoring bursts. As such, we propose that Ivory Coast should introduce these advanced monitoring techniques to reduce the risks of rock burst in deep mining.

6. REFERENCES

[1] Campbell, C. (2009). Wikipedia: The Free Encyclopedia. http://en. Wikipedia.org/wiki, s. vv. Theatre, Performance, and Performance Studies TDR/The Drama Review, 53(4), 185-187.

[2] Marshak, Stephen. Earth: Portrait of a Planet &Company, 2001. ISBN 0-393-97423-5 (p. 463)

[3] He, H., Dou, L., Li, X., Qiao, Q., Chen, T., & Gong, S. (2011). Active velocity tomography for assessing rock burst hazards in a kilometer deep mine. Mining Science and Technology (China), 21(5), 673-676.

[4] Abousnina, R. M., Manalo, A., Shiau, J., & Lokuge, W. (2015). An overview on soil contaminated sand and its engineering applications. *International Journal of Geomate*, *10*(19), 1615-1622.

[5] Hagen, M. (2016). Induced earthquakes correlations with earth's crustal. *International Journal of Geomate*, *11*(23), 2228-2234.

[6] Moghal, A. A. B., Dafalla, M. A., Elkady, T. Y., & Al-Shamrani, M. A. (2015). Lime Leachability Studies on Stabilized Expansive Semi-Arid Soil. *International Journal of Geomate*, *9*(2), 1467-1471.

[7] Yin, P. (2014). Multiple surface cracks coalescence mechanism in granite (Doctoral dissertation, The Hong Kong Polytechnic University).

[8] Liu, J. P., Feng, X. T., Li, Y. H., & Sheng, Y. (2013). Studies on temporal and spatial variation of micro-seismic activities in a deep metal mine. International Journal of Rock Mechanics and Mining Sciences, 60, 171-179.

[9] BBC. (2011, November 4). China mine disaster: Dozens trapped by 'rock burst. Retrieved November 3o, 2011, from Business Human Right: http://business-humanrights.org/en/china-mine-disaster-dozens-trapped-by-rock-burst.

[10] Kouame, K. J. A., Feng, Y., Jiang, F., & Zhu, S. (2015). Evasion of Children in Ivory Coast Artisanal Mining Activities. Journal of Sustainable Development, 8(9), 24.

[11] Monroe, J., Wicander, R. & Hazlett, R. (2006). Physical geology: exploring the Earth. Cengage Learning.

[12] Torres, V. F. N., da Gama, C. D., e Silva, M. C., Neves, P. F., & Xie, Q. (2011). Comparative stability analyses of traditional and selective room-and-pillar mining techniques for sub-horizontal tungsten veins. International Journal of Minerals, Metallurgy, and Materials, 18(1), 1-8.

[13] Jiang, F. X., &Xun, L. (2002).Application of micro-seismic monitoring technology of strata fracturing in underground coal mine. Chinese Journal of Geotechnical Engineering-Chinese Edition, 24(2), 147-149.

[14] Mendecki AJ Seismic monitor in Mines [M]. London:Chapman and Hall,1997:179-184

[15] Tanglizhong.Zhangjun.etc.,(2015)The response characteristic research of mine micr-seismic activity on its mining rate based on quantitative seismology[J].Chinese Journal of Rock Mechanics and Engineering.31(7), 1349-1354.

[16] Qi, F. (2015, August 05). Accidents in two coal mines. Retrieved September 20, 2015, from tianjinwe.com: tianjinwe.com/rollnews/201508/t20150805_1703274.html