Geotechnical Issues on Application of Highwall Mining System inIndonesia

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Abstract

Indonesia is the second largest coal exporter to Japan. Almost all the coal is produced from open cut mines. However, a great deal of coal is left in the highwalls of the mined-out pits. The use of highwall mining systems has increasingly come into play in the US and Australia, when overburden depth exceeds economical recovery in open cut mine. However, the stability of the highwalls is always a major safety concern in such mining. This paper describes the characteristics of the highwall mining system and discusses the appropriate highwall mining system for use in Indonesia.

Keywords: Highwall Mining System, Indonesia, Pillar Design, Slope Stability, Coal Recovery.

1. Introduction

Indonesia produces over 400 Mt of clean coal and is the second largest coal exporter to Japan, accounting for about 32 Mt of coal annually. Over 99% of the coal produced in Indonesia comes from surface mines. More open cut mines will be developed and more coal will be mined in order to fill the great demand both in Indonesia and the rest of the world.

In open cut mines in Indonesia, there are many sites where mining operations have developed long highwalls which have been abandoned due to the current economics. Mining operations have been transferred to lower stripping ratio blocks of coal or overlying seams. In some cases, coal lies buried beneath spoil heaps or is covered with mud and water. It is estimated that there is a great deal of coal beneath abandoned and working highwalls. Considering these situations, it seems to be worth introducing highwall mining systems into Indonesian open cut mines.

Final highwalls of open cut mines can form the starting point for other mining methods, such as highwall or underground mining. In its basic application, highwall mining is a technique utilized after an open cut portion of a reserve has been mined, sometimes prior to the introduction of underground mining (Seib, 1993). In this system, the coal seam is mined by remotely operated equipment, such as an auger machine or a modified continuous miner incorporated into a highwall mining system. Major issues of highwall mining systems are less coal recovery due to leaving coal as the pillars and the instability of openings and highwalls due to the pillar and roof failures.

This paper describes the characteristics of the highwall mining system and discusses the appropriate highwall mining system for Indonesia.

2. Highwall Mining Systems

Many coal seams that are presently uneconomical or technically unsuitable for conventional surface mining techniques can be recovered using highwallmining systems. Final highwalls of open cut coal mines can form the starting point for other mining methods, such as highwall or underground mining. In its basic application, highwall mining is a technique utilized after the open cut portion of a reserve has been mined, sometimes prior to the introduction of underground mining (Seib, 1993).

In these mining systems, a continuous miner or an auger machine is primarily used to extract coal from the highwalls.Recently other systems such as Bucyrus Highwall Miners (formerly Superior Highwall Miners) and American Highwall Systems have been introduced in the US (Highwall systems, 2006).

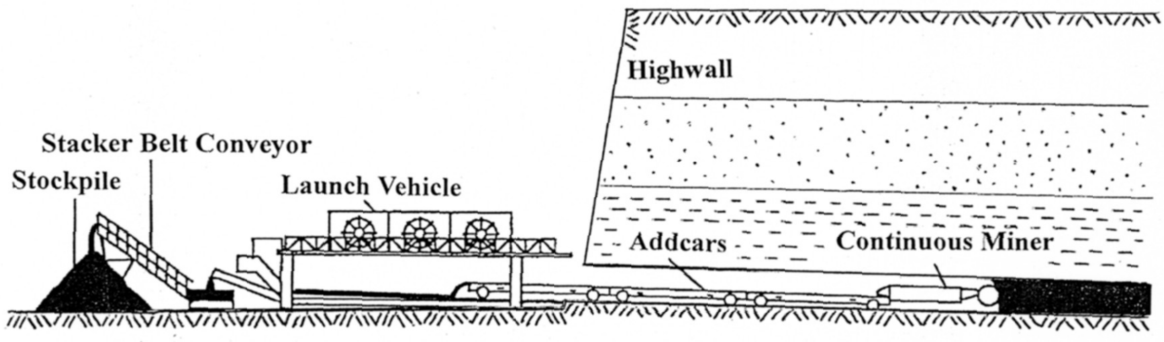

Fig.1. Addcar system.

Fig.2. Archveyor system.

The continuous miner system is called a continuous highwall mining (CHM) system and is categorized into two types: one is an Addcar system and the other is an Archveyor system. The former consists of a continuous miner, addcars (belt conveyor cars), a launch vehicle, a stacker conveyor and a loader as shown in Fig.1. The latter consists of a continuous miner, archveyor chain conveyor that conveys coal and trams the machine system itself, and a loadout vehicle as shown in Fig.2.

The CHM system can excavate rectangular holes over 350 m long, and the size of the hole depends on the specifications of the continuous miner. Fully automated control of the system is achieved with the aid of advanced navigation technology, including a roof and floor passive gamma detector system, inclinometers, a ring laser gyroscope and programmable logic controller (PLC).

The auger system, as shown in Fig.3, is very simple and can excavate holes over 100 m long and 0.5 m in diameter or greater into the coal seams in highwalls, depending on the application methods. This system is more maneuverable than the CHM system and can be applied when shorter lengths of highwall are presented. It is also suited to recovering open cut end walls and major pillars of coal remaining after the CHM operation (Matsui, et al., 2008).

One of the first true “highwall mining systems” to be demonstrated, the Metec miner system, was introduced in 1981 and featured in a number of trade exhibitions during the 1980s. As a successor of the Metec miner, the Bucyrus (formerly Superior) highwall mining and American highwall systems are now attracting significant attention in the US. This system consists of a continuous miner, double auger flights, a stacker conveyor and a front-end loader basically as shown in Fig.4. This system can excavate rectangular holes of over 300 m long, has maneuverability along the bench which is important for the higher productivity, and the machine is equipped with four crawlers allowing for rapid positioning from hole to hole.

Highwall mining systems have been used extensively in the US and Australia due to their safe and economical mining method. In Indonesia, only the auger system has been used at a few mines (Furukawa, et al., 2009).

Fig.3. Auger system.

Fig.4. Metec miner system.

3. Application of Auger Mining System in Indonesia

Highwall mining systems have improved mining operations due to their safety and productivity. However, the application is restricted by coal seam conditions such as the dip, thickness, roll, split of the seam, existence of faulting and folding, etc. It is difficult or almost impossible to apply the system into steeper dipping coal seams, over 15 degrees. Therefore, another type of system was developed, aimed at coal seams in the 16-25 degrees dip range. A high-powered auger machine, for use in seam dips of up to 23 degrees, was developed and introduced at a coal mine in Australia(Matsui, et al., 2003). There are currently no mining methods available for mining seams in this dip range beyond their final economic highwall. Using an effective dip mining method with basic highwall mining system is an alternative for steep coal seams as shown in Fig.5.

Considering Indonesian coal seam conditions, only the auger mining system has been tried at a few open cut coal mines as shown in Fig. 6. According to their experience, dipping and rolling coal seam conditions always controlled its performance. The non-navigated system sometimes made the augering hole penetrate into previous adjacent holes, leading to a stoppage of augering.

Practical experience shows that a face of a 6 m-thick seam would be mined by two augering lifts using 1.9 m diameter auger according to the original mining plan. However, the actual mining was quite different from the plan due to the coal seam conditions. As there were many dips, rolls and thickness changes in the seam, a single lift augering had to be used in the center of the seam. Therefore, the coal recovery was much less than had been planned.

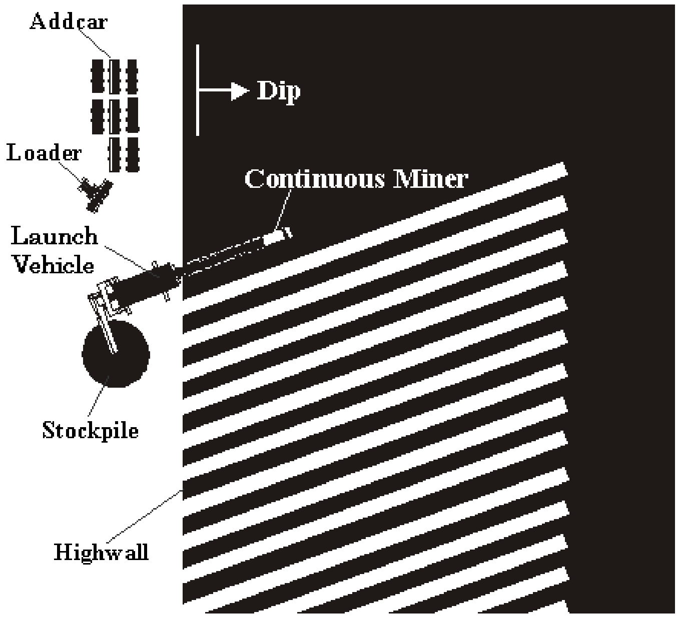

Fig. 5. Effective dip mining method.

Fig. 6. Auger mining system in Indonesia.

Indonesian coal measure rocks are generally very weak (Anwar, et al., 2003). Moreover, some coal measures rocks such as shale, mudstone, and siltstone show an excessive slaking behavior leading to a severe deterioration of their mechanical properties. The weak immediate roof tends to fall easily and the continuous miner also tends to sink into the softened floor or slip on the floor. The rectangular geometry of the continuous miner highwall systems openings shows some instability.

These problems make both the mining operations and the controlling systems of the CHM systems difficult or virtually impossible. Hence, it seems that an auger mining system is a more suitable highwall mining system for Indonesian geological conditions than others. Therefore, in order to discuss a suitable auger mining design in Indonesia, a series of laboratory tests and numerical analysis were conducted.

4. Stability of Openings/Pillars in Auger vs. CMH Mining Systems

4.1 Laboratory test

The formula for evaluating pillar strength for CHM (rectangular shape openings) has already been developed (Mark, C., et al., 1995). However, that for the auger mining system has not been done yet. Therefore, in order to evaluate pillar strength of the auger mining system (circular shape openings) and develop its suitable design criteria in Indonesia, the laboratory tests using a test model, were conducted.

Fig.7 shows the specimen used in this research. The dimension of this specimen was 200 mm in thick, 200 mm long and 150 mm high. The specimen consists of gypsum, cement and water (weight ration; gypsum : cement : water = 1:1:1). The shapes of openings were a circle with a diameter of 50 mm and/or a square 50 mm on a side. Four different pillar widths, 25 mm, 50 mm, 75 mm and 100 mm, were evaluated. These specimens were stored under dry conditions for three days and then a loading test was conducted.

Fig.8 shows the relationship between the pillar strength index and ratio of pillar width/opening width for circular and square openings. Here, the pillar strength was defined as the following equation in order to eliminate the variation of material strength;

$$\text{Pillar Strength Index} = \frac{\text{Failure Load}}{\text{Cross section of pillar} \times \text{UCS of material}} \quad (1)$$

It can be seen from this figure that the pillarstrength index increases with increasing pillar width for both shapes of openings. The pillar strength for circular shape openings is about 1.2-1.3 times stronger.

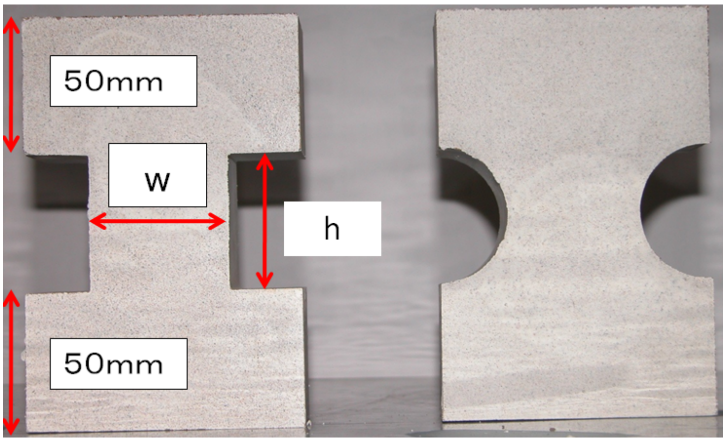

Fig. 7. Specimens for laboratory tests (left; square openings, right; circular openings).

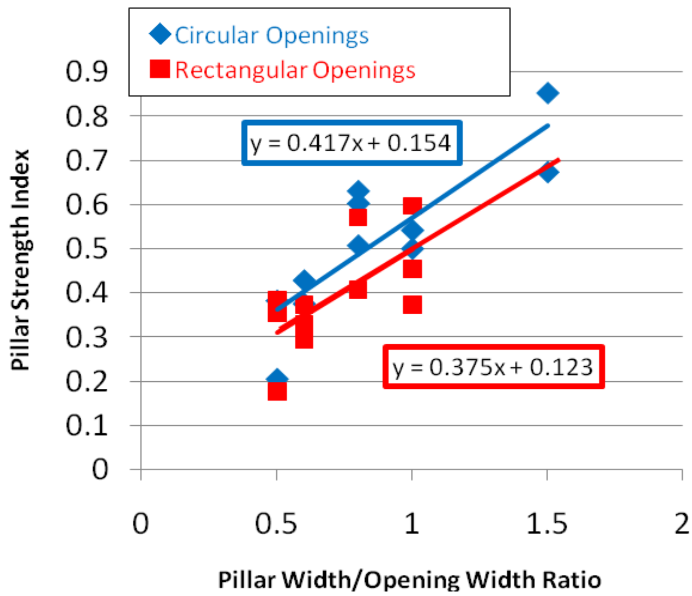

Fig. 8. Relationship between pillar strength and pillar width.

than that of the rectangular shape. From this result, the stability of pillars in the auger mining system may be estimated or evaluated based on the empirical formula for CHM that had been developed. However, in order to evaluate shape effect quantitatively, more detailed study have to be conducted under different geological conditions, in-situ stress conditions, etc.

4.2 Numerical analysis

In order to discuss the stability of pillars and mine openings in the auger mining system, finite element modeling was also applied in this research. Non-linear analysis was also performed using the two-dimensional FEM cord 'Phase^2' (Rocscience, 2006). For simplicity, a two dimensional model was used in this analysis as shown in Fig.9. The coal seam thickness is 3 m. The immediate roof and floor are siltstone being 4 m thick and 3 m thick, respectively. The initial vertical stress (P_v) was assumed to be the depth pressure ($P_v = \gamma$ h: γ = unit weight of overburden and h = cover depth or highwall height) and the initial horizontal stress (P_h) was variable. Five circular openings with a diameter of 3 m or square openings 3 m on a side were excavated one after the other in the coal seam. The pillar width (W_p) between the two openings was assumed to be 3 m and 1.5 m wide.

The following well-known Hoek& Brown criterion was employed as a failure criterion:

$$\frac{\sigma_1}{\sigma_C} = \frac{\sigma_3}{\sigma_C} + \left(m\frac{\sigma_3}{\sigma_C} + s\right)^{\frac{1}{2}} \quad (2)$$

whereσ_1 = major principal stress at peak strength, σ_3 = minor principal stress, m and s = constants that depend on the properties of the rock and the extent to which it had been broken before being subjected to the failure stresses, and σ_C = uniaxial compressive strength of the intact rock material. The mechanical properties and parameters of the coal and rocks are listed in Table 1.

Figs.10-12 show the results of the numerical analysis. From these figures, it can be seen clearly that the stability of openings/pillars in the auger mining system is higher than that in CHM. Fig.10 shows the failure development around the openings at different depths. With increasing the depth, the failure zones developaround the openings and in the pillars. Fig.11 also shows the failure development around the openings under the different initial stresses. The failure conditions depend on the stress conditions.

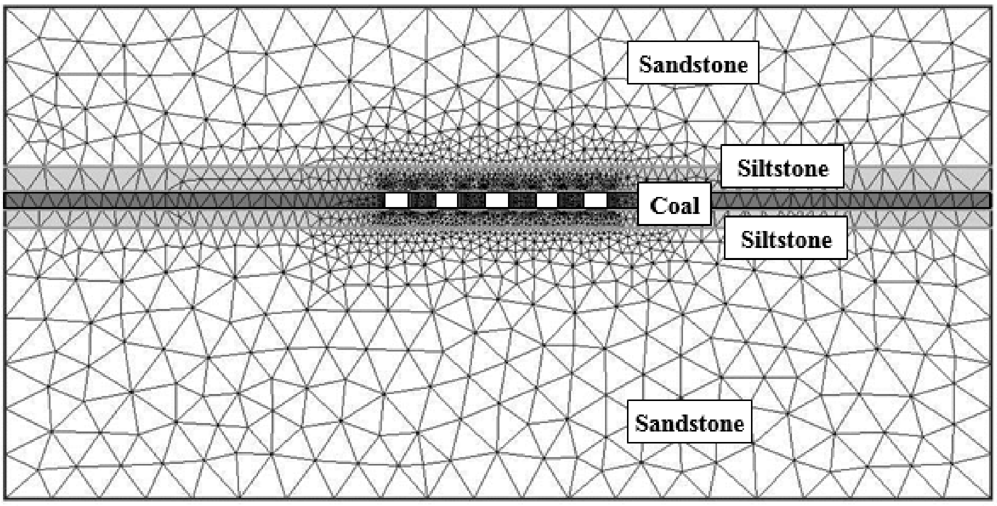

Fig. 9Two-dimensional finite element model.

Table 1. Mechanical properties of rocks used in this analysis.

	Young's modulus (MPa)	Poisson's ratio	Uniaxial compressive strength (MPa)	m	s	Unit weight (MN/m^3)
Sandstone	5,700	0.28	26.6	7.5	0.1	0.0243
Siltstone	4,650	0.27	20.9	2.0	0.02	0.0247
Coal	1,530	0.30	11.9	2.08	0.07	0.0134

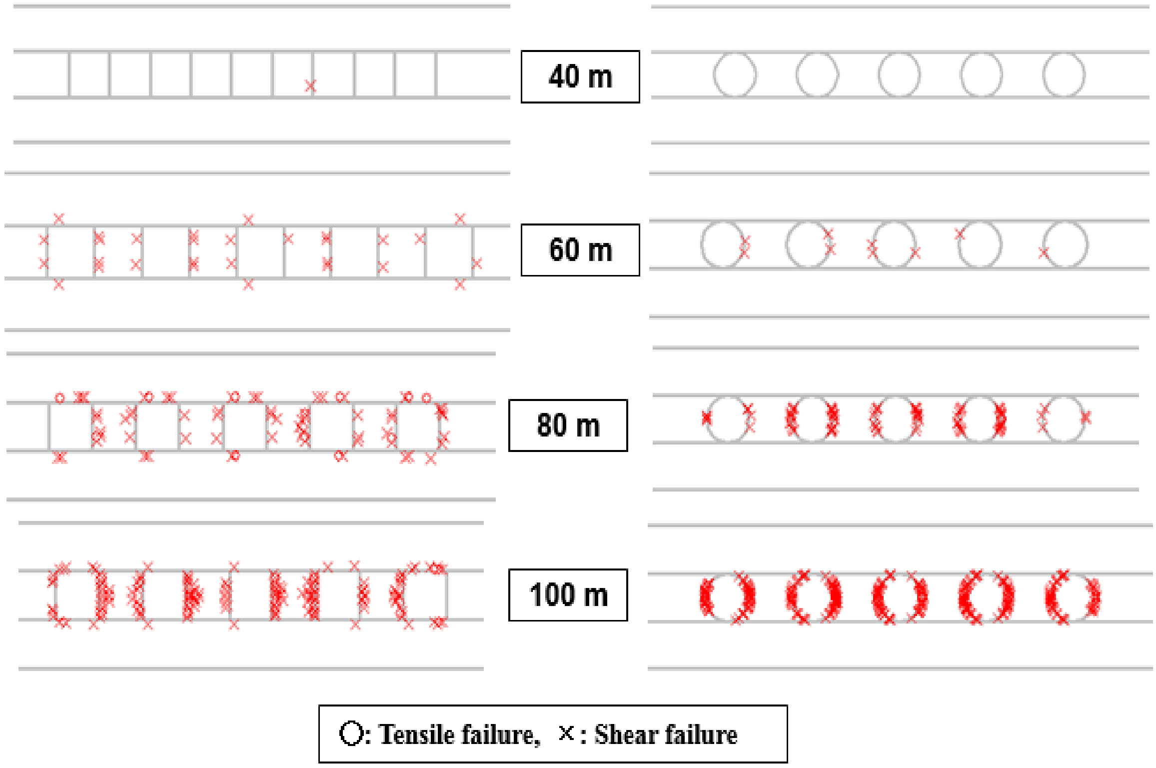

Fig. 10. Failure development around the openings at different depths
(left; square opening, right; circular opening, σ_H/σ_Z=0.75, width of opening : width of pillar = 1:1).

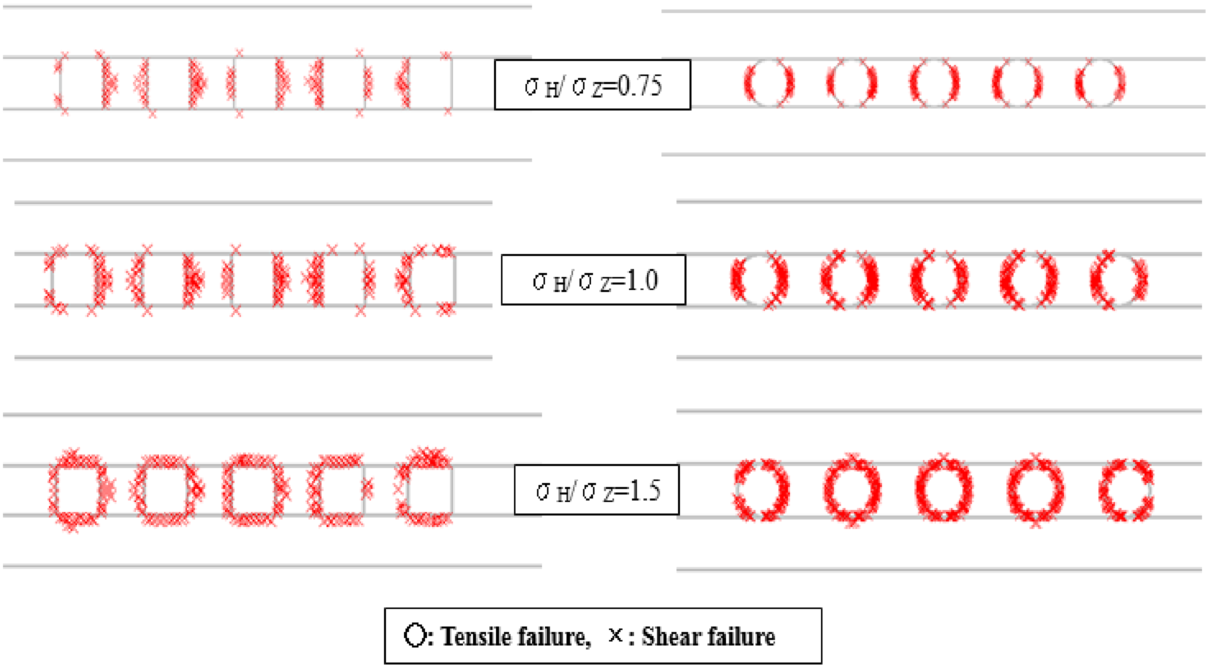

Fig. 11. Failure development around the openings under the different initial stress
(left; square opening, right; circular opening, depth=100 m, width of opening : width of pillar = 1:1).

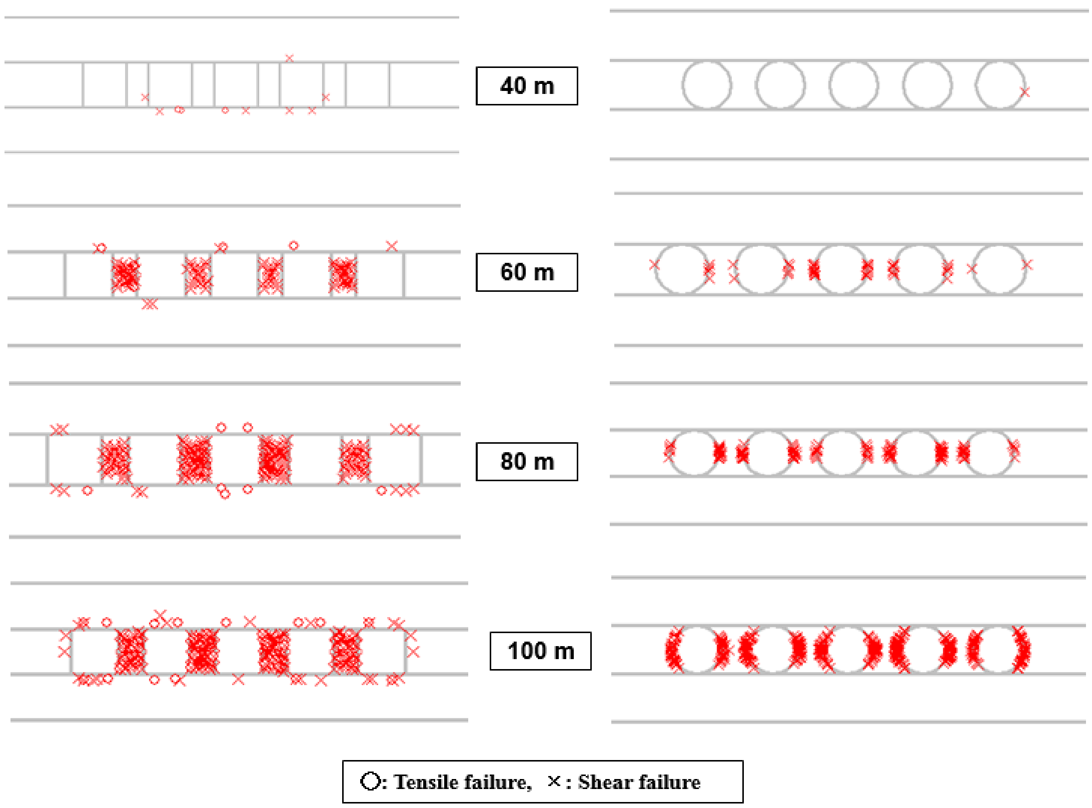

Fig. 12. Failure development around the openings with narrow pillars
(left; square opening, right; circular opening, σ_H/σ_Z=0.75, width of opening : width of pillar = 2:1).

Under high horizontal stress conditions, the roof and floor of the openings tend to induce shear failure easily. On the other hand, under small horizontal stress conditions, tensile failure is dominant in the roof and floor.Fig.12 shows the failure development around the openings with narrow pillars. Compared with Fig.10, the narrow pillar, the openings show less stability and the pillars fail much more severely in square openings. This situation will lead to unstable work conditions, and sometimes the cutting machine is caught in the opening being impossible to withdraw. On the other hand, in circular openings, no obvious and/or large failure can be recognized, at a depth of 100 m.

It can be concluded that the stability of pillars and mine openings in auger mining systems is much higher than that in CHM and an auger mining system is suitable for Indonesian geological conditions, such as weak/poor strata conditions. However, this mining system has to be improved to cope with steeper coal seams and water problems at the face in order to increase the extraction ratio and maintain the highwall stability.

5. Application of Punch Mining System in Indonesia

Conventional highwall mining systems extract coal with an auger machine or continuous miner. However, less coal recovery is a problem in these systems, because many coal pillars have to be left in order to maintain the highwall/mined openings stability and the mined length is limited by the inherent characteristics of the systems. Considering these issues, the introduction of underground mining systems is also an alternative. The punch mining system is not a new concept (Robertson et al., 1988 and Michell, 1999). The first punch mining system using an Archveyor system was proposed and tried in the US as shown in Fig.13. However, this mining system has to leave a lot of coal as pillars and is not cost effective in poor strata conditions. Bad roof and severe stress conditions make the mining itself impossible.

Board-and pillar punch or longwall punch mining system may be applicable under poor strata conditions. In punch longwall mining as shown in Fig.14, gateroads are driven into the seam directly from the open cut highwall. The longwall panel thus formed is retreated back to within several tens of meters of the highwall. This system has been used at Beltana Mine in Australia.

The introduction of this longwall punch mining system to Indonesian open cut mines will increase the coal recovery and also help the Indonesian coal mining industry understand and master underground

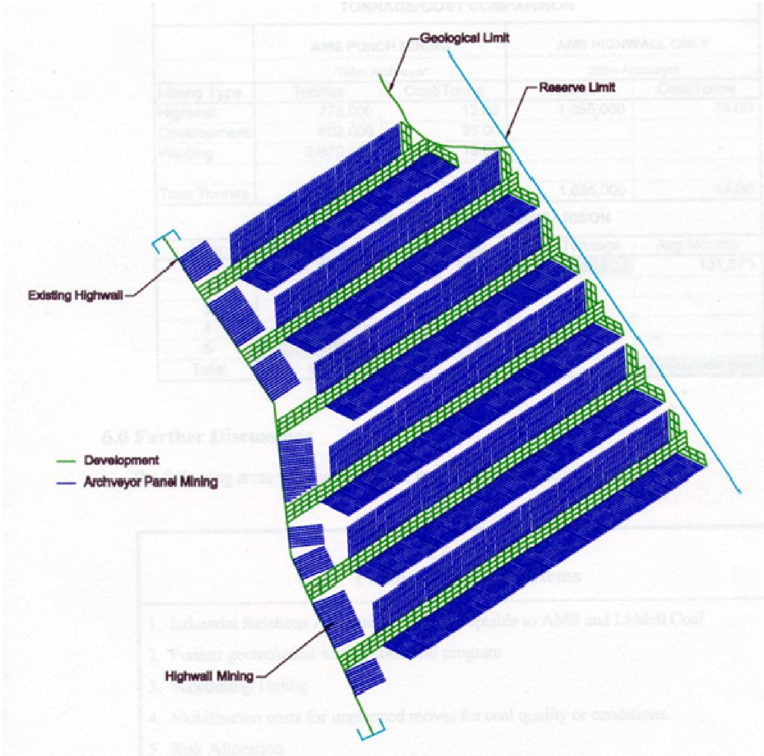

Fig. 13. Archveyor punch mining system.

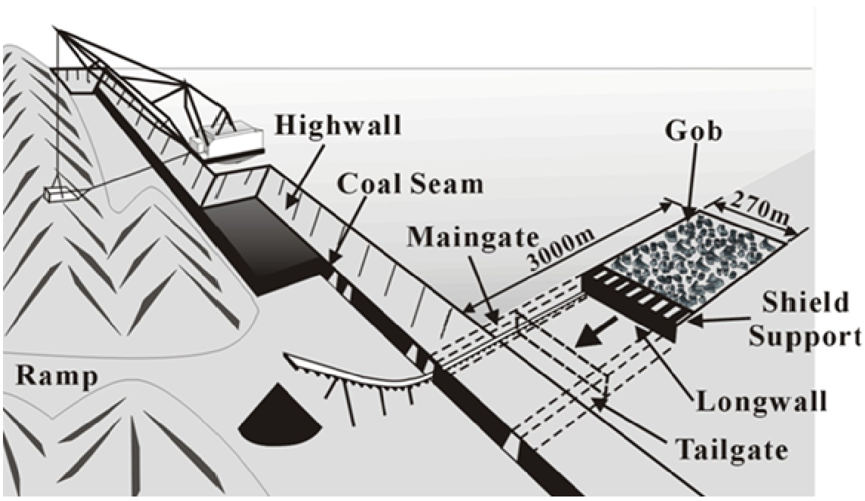

Fig. 14. Longwall punch mining.

mining technology before starting a full-scale underground mining program. However, the high capitalcost and geological conditions make the introduction of this system to Indonesia difficult or impossible. Instead of this system, the board-and-pillar punch mining system is an alternative as shown in Fig.15. The characteristics of this mining system are as follows:

- Drilling and blasting, continuous or roadheaderdrivage.
- Pillar recovery using hydraulic prop and cap system which has been used in Indonesian coal mines for many years.
- Flexible mining under poor geological conditions.
- Higher productivity.
- Lower capital cost compared to the longwall system.

Considering above factors, the punch board-and-pillar system also seems to be an effective mining system for the conditions of Indonesian coal mines. Shortwall and/or longwall using prop and cap are also used.

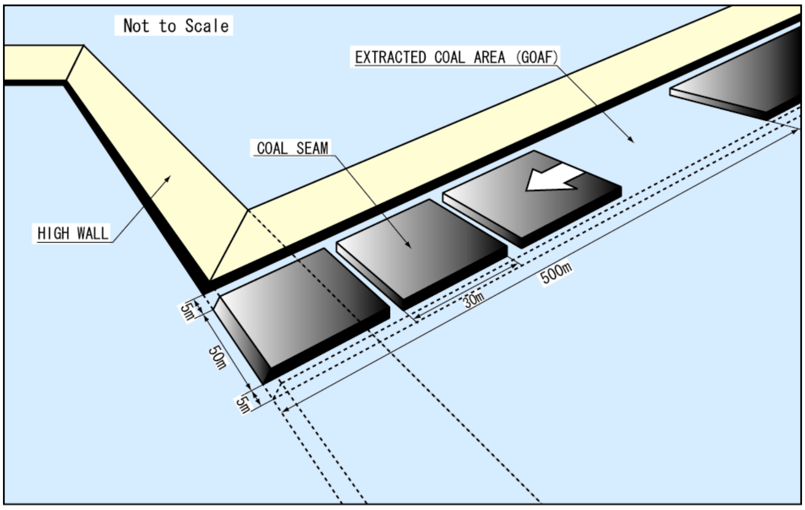

Fig. 15Board-and-pillar punch mining.

6. Conclusions

Highwall mining systems can sometimes be the final mining method used in open cut mines, or it can serve as a means of transition, with low capital cost, from surface mining to underground mining. From the results of a series of laboratory tests and numerical analyses, it can be concluded that the auger mining system is a suitable highwall mining system for Indonesian coal mines. However, this mining system has to be improved to cope with steeper coal seams and water problems at the face in order to increase the extraction ratio and maintain the highwall stability.

Considering the condition of Indonesian coal mines, the punch board-and-pillar highwall mining system using traditional underground mining methods can also be a suitable and effective mining system in Indonesia.

More research, including development of new technology, has to be conducted in order to develop an effective mining system in Indonesia.

References

Anwar, H. Z., Shimada, H., Ichinose M., and Matsui, K., 1999. Slaking-durability of the improvement of coal mine shales behavior, *Proceedings of Regional Symposium on Sedimentary Rock Engineering*, Taipei, Taiwan, 45-50.

Furukawa, H., Matsui, K., Sasaoka, T., and Shimada, H., 2009. Application of a punch mining system to Indonesian coal mines, *Proceedings of the 2nd International Symposium of Novel Carbon Resources Science, Earth Resource Science and Technology*, Bandung, Indonesia, pp.III-1-III9.

Highwall systems, 2006, Coal Magazine, 2006. September/October, 7-12.

Mark, C., Chase, F.E., and Campoli, A. A., 1995, "Analysis of retreat mining pillar stability", *Proceedings of 14th Conference on Ground Control in Mining*, Morgantown, WV, U.S.A., 49-59.

Matsui, K., Yabuki, A., Shimada, H., Sasaoka, T., Ueda, T., and Yuasa, T., 2003. A practical trial to increase the coal recovery in highwall auger mining in Australia, *Proceedings of 12th International Symposium on Mine Planning and Equipment Selection*, Kalgoorlie, Australia, pp.205-208.

Matsui, K., Sasaoka, T., Shimada, H., Ueda, T., Kramadibrata S., and Sulistianto, B., 2008. Highwall Mining Systems at Surface Coal Mines in Indonesia, *Coal International*, Vol. 256, No. 3, 28-31.

Michell, G., 1999. Benefits of longwall punch mining, T*he 2nd Annual LongwallMining Summit*, Queensland, Australia, 8

Robertson, B. N., O'Regan, G. and McKew, M., 1988. Longwall punch mining from open cut highwalls, *The 21st Century Higher Production Coal Mining Systems-their Implications*, Wollongong, NSW, Australia

Rocscience Inc., 2005. Application of the Finite Element Method to Slope Stability, http://www.grow.arizona.edu/GrowGetResource.php?url=http://www.rocscience.com/library/pdf/SlopeStabilityUsingPhase2.pdf&resourceid=1595.

Seib, W.T., 1993. Australian Coal Mining Practice, A.J. Hargraves& C.H. Martin (eds.), *The Australian Institute of Mining Metallurgy*, 238-242.