Geotechnological structure of a combined opencast and underground mining method in the condition of integrated development of coal deposits

B A Anfyorov and L V Kuznetsova
The Federal Research Centre of Coal and Coal Chemistry SB RAS, 10 Leningradskiy ave., Kemerovo, 650065, Russia
E-mail: lvk@icc.kemsc.ru

Abstract. A combined opencast-to-underground mining method is widely used for final extraction of border zone coal reserves and extracting areas with limited and non-technological reserves. The idea of the method is that coal is extracted by opencast method and continued by underground mining using highwall mining complex, mobile mining mechanical equipment, augers, mechanized complexes and water jetting facilities.

1. Introduction
Innovative direction of Russian economy development requires creation and further application of geo-technologies that meet and rival the international standards. One of the criteria for effective exploitation of interior part of the Earth is a completeness of commercial minerals extraction.

In 2019 in Russia 440.7 mln. tonnes of coal [1] were produced and 75 percent of them were done by opencast method. However, despite high effectiveness, comparing to the underground mining, large coal reserves are irretrievably lost:

• behind the projected open-pit outlies, in open-pit walls and on the open-pit bottom after reaching economically feasible critical overburden ratio [2];
• at the sections with limited reserves when the traditional opencast development is unfeasible due to significant capital and operation costs [3];
• at the sections with non-technologic reserves on the steep and steeply inclined seam of low capacity due to the lack of effective and safe technologies [4].

2. Final extraction of border zone reserves
For final extraction of border zone reserves, sections with limited or non-technological reserves a combined opencast to underground mining method is widely applied. The idea of the method is in developing the deposit firstly by the opencast method and then by underground mining method. Geotechnological structure of the combined opencast to underground mining method is presented in figure 1.

Final extraction of border zone coal is done from the bench of highwall using “Highwall mining system”. Its modification is Auger mining method (AM) [5-7]; highwall miner complex (Metec miner system; Continuous Highwall Mining – CHM) [8-12]; longwall punch mining using integrated mechanization equipment meant for underground mining (Longwall punch mining) [13]; pillar-and-
bord mining using mobile mining mechanical equipment (Room/Bord-and-pillar punch mining) [13]; water-jet mining – WJM [14].

Augering mining method (AM) is applied when extracting low coal seams by way of drilling the bore holes applying auger facility from the bench of the highwall leaving adequate pillars between the holes. This technology makes 4 percent of the total coal mining in the USA [5]. Closely-situated multiple low coal seams of central coal deposits of Appalachians and West Virginia make this method the most advantageous and sometimes the only one possible to apply for extracting the residual border zone coal reserves which are usually left after open casting.

Figure 1. Geo-technological structure of the combined opencast-to-underground mining method of coal seam development. Highwall mining system: LPM – Longwall punch mining; WJM – water jet mining; BPPM – Bord-and-pillar punch mining; AM – Auger mining; CHM – Highwall miner complex, the complex of deep seam excavation (Continuous Highwall Mining, Metec miner system).

In Russia in “Yun’yaginskey” open-pit (OAO “Vorkutaugol”) the extraction of coal out of the seam with the thickness varying from 0.6 m to 1 m with occurrence angle to 18 degrees down dip was fulfilled by drilling the boreholes to the depth of about 260 meters [6,7] The technology involves gross mining losses as it does not allow developing middle thickness and thick seams.

CHM system is applied for extracting coal seams with the thickness up to 4.5 meters from the open-pit highwall by means of making straight roadways (extraction chambers) and leaving adequate pillars between them. Two modifications of this technology are well-known and they are: Addcar system (the equipment package includes: continuous miner, mobile belt-type conveyor sections (auger flights), launch vehicle, stacker conveyor and a loader) and Archveyor system differs from the first
one by applying archveyor chain conveyor that transports the coals and provides delivering loadout machine on the face. Fully automated control of CHM system is achieved by means of advanced navigation technologies including roof and floor passive gamma detector system, inclinometer, a ring laser gyroscope and programmable logic controller [8]. In Russia this technology was not applied and did not get widespread use abroad due to the low reliability of the conveyor sections.

Longwall punch mining System was initially applied in Australia in 1990 for developing flat seams in longwall faces. Windways and belt entries were made from the highwall. In the depth of the highwall a mechanized longwall set of equipment is installed meant for underground extraction with retreating. The coal along the belt entry is delivered into the belt conveyor installed at the highwall and is transported further into the coal storage. The production reached 6 mln. tonnes per year [13].

Apart from this system the technology of Room/Board-and-pillar punch mining is applied in short stopes for extracting limited reserves (for example, protective pillars) by means of mobile mechanical equipment [2].

From the bench, down-dip, an in-seam working (slope) is done, firstly, starting from the soil of the seam to its roof under angle $\beta$ and continued further at the seam roof to the open-pit contour. The height of the working is considered with technical specification of the applied mechanical equipment (figure 2). At the open-pit contour this working is gradually rounded up at 90 degrees and then it is continued along the seam level bearing in the form of the drive at the length equal to 4 multiple length of the combined machine (figure 3). Both a slope part and a roadway are propped by development workings support.

![Figure 2](image)

**Figure 2.** The scheme of carrying out slope near a roof seam: 1 – a bench; 2 – a slope; 3 – a drive at an open-pit contours; $\alpha$ – a seam pitch (inclination); $\beta$ – an angle of an in-seam working pitch (inclination).

![Figure 3](image)

**Figure 3.** The scheme of final extraction of a thick seam of the first part of the range (view the plan): 1 – slope; 2 – combined machine; 3 – self-propelled wagon; 4 – drive; 5 – booster fan; 6 – ventilation tubbing; 7 – temporary storage; 8 – extraction chamber; 9 – diagonal stub heading.
The advantages of these two systems are in high productivity of a stope, that the do not require permanent stripping workings, complex transportation and ventilation systems. However, it requires adequate planning and designing of an enterprise that provides saving and supporting the surface infrastructure of the open-pit during all the underground mining works. These systems cannot be applied if the highwall rocks are hazardous (unstable).

Metec miner system technology being based on Superior Highwall Miners complex equipment which has started to be produced under Bucyrus Highwall Miners Brand (in the USA there are 65 operating complexes) since 2010 is widely used abroad [10]. Four SHM complexes No. 28, 29, 34, 56 were delivered in Russia and 3 out of them are used in operation under Highwall Miners complex brand [9].

The complex equipment consists of the launching set equipment, extracting machine of continuous operation, double-drum shearer conveyor, temporary coal storage conveyor and front-end loader. Highwall mining complex is installed on the open space formed as a result of extracting stripping soils along the highwall contour which is meant to be developed applying this system. Highwall mining complex allows excavating coal seams with 1.1 – 4.8 meter thickness (the depth of the seam development downwards – 300 meters) without presence of people in the stope areas [9].

In Kuzbass coal seams in the areas of surface operations of ZAO “Raspadskaya”, ZAO Razrez Kuprinsky”, JSC “Razrez Yuzhny” were excavated by this Highwall mining complex system [7, 9, 12].

As Russian and foreign practices show the main problem of Highwall mining complex technology is in large amounts of coal losses in pillars (to 60 percent) and during excavation of the seams with the thickness of more than 4.8 meters coal mining losses are even higher, high hazardous level of stopes due to pillar disintegration and roof caving. To improve the roof stability in a developed working is possible by building roof bolting (figure 4) [2].

Water (hydraulic) Jet Mining technology provides opening to surface (cross-cut) development from the bottom of the strip-pit. It is made at a slight pitch up for arranging gravity hydraulic transport of coal. It is applied to develop all suite formations occurring in border zones [14]. Along the seams meant for development from a cross-cut in both sides under a slight pitch up drives are made. On the cross-cut and drives soil a special gutters for gravity hydraulic transport of effluents are arranged. From the operational area of a bench down-dip a borehole is drilled towards the drive. A hydraulic mining giant and standing pipe are assembled. Coal destruction around the borehole is made by a water jet in a reverse order and the loose coal is transported along the gutters of a crosscut to the bottom of a strip-pit where it accumulates in special containers.
3. The development of limited reserve deposit sections

The development of deposit sections with limited reserves can be done by baring the coal seam directly from the daylight area using integrated mechanization complexes (Longwall punch mining), auger mining, Highwall miners complexes (Continuous Highwall mining).

For example if coal seam occurrence has a form of a closed-form “bowl” (brachycyncline) then application of traditional opencast or underground mining techniques are not reasonable due to significant capital and operation costs and negative impact on the environment. The preferred option is applying Bord-and-pillar punch mining technique directly from the daylight surface (figure 5) [3].

Baring the seam is done by constructing several operating platforms at the seam intercrops consequently in one direction starting from the northern part and continuing further to the western one. Preparation is done by making a slope starting from the operating platform to the hinge part. While deepening further coal is extracted in short faces by horizontal layers. All the works are done by one set of mobile equipment: a roadheader with selective cutting head and self-propelled wagon of 1GPKS and 10BC15 type. After developing the reserves the operating platforms are consequently reclaimed. Due to minimal stripping volumes a natural landscape is saved, land use intensity decreases significantly and the volumes of disturbed soils reclamation goes to minimal.
4. Developing non-technological reserves

The development of non-technological reserves can be done by stripping the seam from both the bench of the highwall and directly from the daylight surface using all above mentioned technologies. For example, while developing steeply inclined coal seams of medium (from 2.2 m) and high thickness striping is done by making an initial inclined cut from the surface. Preparation of a coal seam is done by inclined stone drifts and cross drifts. The underground mining is done by Bord-and-pillar punch mining (mobile mining mechanical equipment: roadheader of selective action of GPKS type, self-propelled wagon B15K) in layered extraction chambers. Stripping and preparation of single seams is done according to individual scheme and series of strata is done according to group scheme [4] (figure 6).

Figure 6. The scheme of stripping, preparation and development of steeply inclined coal seam:
1 – operating platform; 2 – outcropping; 3 – roadheader; 4 – self-propelled wagon; 5 – slope; 6 – slope collar; 7, 10, 11 – extraction chamber; 8 – belt-type conveyor; 9 – conveyor hopper; I, II, III – layer chamber

5. Conclusions

Thus for final extraction of border coal reserves of open-casts, sections with limited and non-technological reserves combined opencast-to-underground mining method (“Highwall mining system”), is widely used. The idea of the method is that coal is extracted by opencast method and continued by underground mining using Highwall mining complex, mobile mining mechanical equipment, augers, mechanized complexes and water jet facilities.

There are well-proven technologies for final extraction of border coal reserves of the open-cast. The most effective and widely used one is by Highwall miners complexes (“Highwall Miners”), that allowed developing seams with thickness from 1.1 to 4.8 m without presence of people in a stoping zone under the condition of stable enclosing rocks which allow long and significant roof exposure (to 1000 m²). Roof strata bolting can allow increasing the period of the working space support. To achieve it the extracting machine of the Highwall miners complex is to be equipping by remotely controlled roof-bolter. This upgrade will allow achieving safety and more complete coal extraction out of both the coal seams of medium thickness developed in one layer and of high coal one developed in multilayers. Opencast-to-underground mining development of sections with limited and non-technological reserves by Bord-and-pillar punch mining technique allows reducing coal losses in grounds and negative influence on the environment.
References

[1] Website of Public Company “TSEDU TEK” http://www.finanz.ru/novosti/aktsii/dobycha-uglya-v-rossii-v-2019-godu-uvelichilas-na-0-2-percent-do-440-7-mln-tonn-cdu-tek-1028790949

[2] Anfyorov B A and Kuznetsova L V 2019 *Kuzbass State Technical University Bulletin* 1 78–85

[3] Kuznetsova L V, Anfyorov B A and Patrakov Yu F 2018 *News of the Ural State Mining University* 1 62–7

[4] Anfyorov B A and Kuznetsova L V 2016 *News of the Ural State Mining University* 3 91–4

[5] Yi Luo. Highwall Mining: Design Methodology, Safety and Suitability / Report number: 2014-004, Affiliation: Department of Mining Engineering, West Virginia University https://www.researchgate.net/publication/266732695_Highwall_Mining_Design_Methodology_Safety_and_Suitability

[6] Caplan A V and Lapaev V N 2013 *Gornoye Delo* 1 https://mwork.su/gornie-zhurnali

[7] Grigoryan A A et al 2014 *Ratsionalnoye Osvoeniye Nedr* 4 23–7 https://roninfo.ru/about

[8] Sasaoka T, Karian T et al 2016 *Int. Journal of Coal Science & Technology* 3(3) 311–21

[9] Netsvetaev A G et al 2015 *Gornaya Promyshlennost’ (Russian Mining Industry)* 4(122) p 87

[10] Highwall Miners Extend Mine-able Reserves. Bucyrus http://www.sacea.org.za/docs/Highwall%20Mining%20Extend%20Mine-able%20Reserves%20-%20Fouche.pdf

[11] Grigoryan A A 2014 *Mining Informational and Analytical Bulletin* 8 40–4

[12] Netsvetaev A G, Grigoryan A A and Pruzhina D I 2014 *Ugol’* 11 73–7

[13] Nay Zar Lin 2014 *Mining System and Design for Development of Underground Coal Mine from Open-cut Highwall for Thick Coal Seam* Doctoral dissertation. (Kyushu University, Fukuoka, Japan), URL: https://catalog.lib.kyushu-u.ac.jp/opac_download_md/1441219/eng2331.pdf

[14] Anfyorov B A and Kuznetsova L V 2014 *Kuzbass State Technical University Bulletin* 5 54–7