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REGIONAL ISSUES OF SUBSOIL USE: KUZBASS

Technological Significance of Internal Dumping in Open Pit Coal Mining in the Kemerovo Region

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Abstract—The article reports research findings in the area of open pit coal mining and substantiates alternative technologies based on new technological and organizational principles of open pit mining. Using the method of geometrical analysis of an open pit mine field and technological design of mining systems, stage-wise mining technologies have been developed for the case when mining front advance is changed. Such technologies ensure the improvement of a wide range of technical-and-economical and ecological performance of an open pit mine. The main flow charts of the mining sequences are interconnected with natural-technological groups of deposits, that influence cross-wise configuration of an open pit (ultimate contour) and structural characteristics (parameters) of working areas and generate geometrical type of an open pit field.

Keywords: Methodical attitudes, open pit mining, internal dumping, structural mining scheme, open pit field, open pit coal mines.

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The current open pit mine projects in the Kemerovo Region contain process solutions aimed to mitigate mining-induced damage. One of such solutions is internal dumping. In this method, an open pit mine field is divided into blocks, the first block is mined out down to project depth with external dumping, and overburden from the next blocks is piled in the mined-out void after previous block extraction [1]. This article offers improved structural flow charts of block mining sequence for any open pit mine field (group of deposit); at the initial stage (general level), the basic and supplementary approaches to construction of flow charts are considered. These are, first of all, solutions on physical layout (basic) and technology (supplementary). The basic and supplementary solutions in the aggregate generate indicators for the mining sequence flow charts.

The increased technology intensity and coal production (Fig. 1a) results in reduced area of farming in the Kemerovo Region (Fig. 1b), which is an issue of very high concern [2].

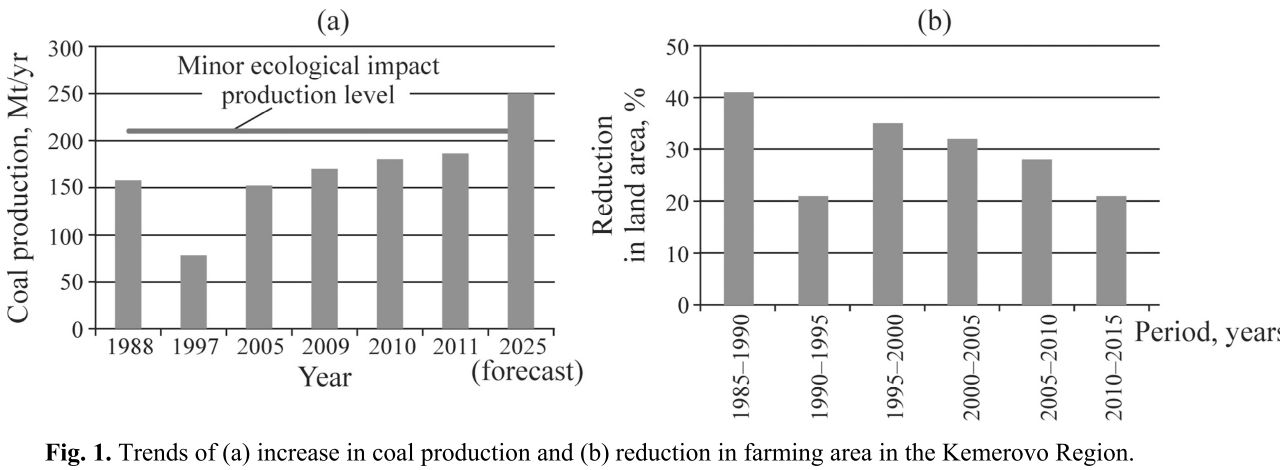

Fig. 1. Trends of (a) increase in coal production and (b) reduction in farming area in the Kemerovo Region.

Mining systems with internal dumping [3]

Open pit mine	Mining system	Dumping			Technology		
		Stage 1		Stage 2	Direct dumping	Truck-and-shovel	
		Within mine field	External	Internal		railway	motor
Bachatsky	One-way, section-wise increase in the rate of mining		+			+	+
Kedrovsky		+	+	+			+
Sartaki		+	+	+			+
Kiselevsky		+	+	+			+
Listvyansky		+	+	+			+
Talda		+	+	+	+		+
Kaltansky		+	+	+			+
Osinnikovsky	Sideways	+	+	+			+
Olzherassky		+	+	+			+
Talda Severnaya		+	+	+	+		+
Brazsky		+	+	+			+
Krasnobrodsky		+	+	+			+
Vakhrushevsky		+	+	+			+
Chernigovets		+	+	+	+		+

The widely used open pit mining methods aimed at deepening of the pit are suitable for deposits composed of a single bed, when completeness and quality of mineral extraction depend on planning of accessing and mining front advance for a single bed. Moreover, overburden, entirely or majority of it, is placed in mined-out void. When such methods are used at complex structure coal deposits, external dumping is required, which results in progressive withdrawal of lands. External dumps are as a rule arranged far from faces, and overburden handling calls for more motor vehicles and auxiliary equipment. This raises cost of coal and makes it uncompetitive in the market. Accordingly, the applied systems of mining may disagree with the natural and technological conditions, and better engineering solutions are wanted.

Ecological impact minimized using mining with internal dumping (see the table). Neglect of this in the nearest decade will result that open pit mines are limited by the own external dumps and cannot develop any more.

As an example, the application of strip mining method in Krasnobrodsky surface mine [4] (Fig. 2) is discussed below.

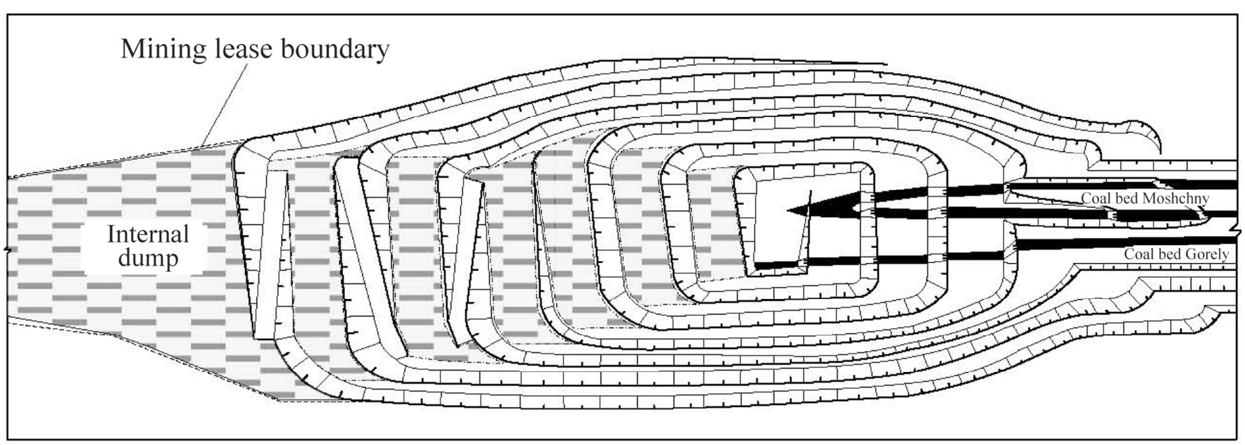

Fig. 2. Sideways mining with internal dumping, Krasnobrodsky open pit mine.

It has been found that transition to strip mining with direct dumping and reduction in cost of overburden removal enables 1.5 times higher ultimate stripping ratio. This method offers the following benefits:

—no need to construct and maintain displaceable ramps on a non-mining flank of the open pit as enlargement of the flank in this case is indispensably connected with additional overburden;

—overburden haulage distance is shorter from 7.3 to 1.5–2 km;

—variation in current stripping ratio is lower from 0.38 to 0.11 and, as a consequence, the required overburden removal output is lower by 24%;

—the excavation is 4–5 times smaller in area and, considering internal dumping, withdraws 8–10 times less land for external dump;

—as the working area is small, the length of non-mining flanks is shorter, which enhanced their slope stability by 5–8% and reduces volume of stripping by 15–18% at the same coal production;

—internal dump accommodates more amount of overburden, by 400 Mm^3;

—the period between the disturbance of the land and its rehabilitation is shorter and makes 7–9 years;

—cost per 1 t of produced coal is lower by 38%;

—mineable coal reserves are doubled.

The relevance of surface mining with differently directed fronts of coal extraction and internal dumping at complex structure deposits is highlighted in [5–13].

For Kuzbass mines, the author puts forward a modified interpretation of open pit mining sequence charts based on design-and-parameter-based customization of internal dumping [14]. Introduction of new solutions on physical laying-out will enable faster technological and ecological benefits of internal dumping at all stages of mining, owing to additional intermediate dumping.

At the present time, for customization of internal dumping modes in Kuzbass open pit mines, more representative grouping of bedded deposits has been implemented. In particular, bedded folded structures, including centroclinal folds and downfolds, are placed in a separate group. These groups of deposits (the first 6 groups are by type of deposits in Kuzbass) are:

1) steep deposits with mean number of beds, from 5–6 to 8–10, complex occurrence;

2) steep and inclined beds, plenty of beds, above 8–10, equally distributed beds in series, smooth relief;

3) inclined beds, mean number of beds, from 3–4 to 8–10, medium-concentrated series, mean range of dip α from 17–25 to 35–40°, even relief;

4) flat dipping beds, small number of beds, from 2 to 3–4, concentrated series, hillside, upper limit of the angle characteristics represented by the sum of average dips of beds and hillside incline—$\alpha+\omega=15-20°$;

5) flat dipping beds, small concentrated number of beds, moderate hillside, $\alpha+\omega=13-17°$;

6) flat dipping beds, small concentrated number of beds, even relief or gentle hillside, mid-range of the sum $\alpha+\omega=5-12°$);

7) flat dipping thick bed, even relief or gentle hillside, lower limit of the sum $\alpha+\omega=5-12°$, by the type of deposits in Kansk–Achinsk Basin;

8) flat dipping multibed deposits, diverse geological sections and series, bald mountainous relief and hillside, variable coal content of extraction areas, by the type of united series structure of geological sections in Krasnogorsky open pit mine field;

9) mid-size brachysyncline bounded and unbounded multibed (from 1 to 3–4 beds), one or two ends, variable coal content (by the type of Kedrovsko-Krokhalevskie structures in the north of Kuzbass, or by the type of Neryungri deposit in the Southern Yakutia);

10) large downfold-like medium- and multi-bed deposits with wide ends, variable coal content of stratigraphical groups of coal and extraction areas (by the type of Talda deposit).

The deposits from groups 1 to 7 differ in geometry, lateral dimension of open-pit field and in structural parameters of working areas, and structural designs for mining sequence charts are made in conjunction with these factors. The deposits from groups 8 to 10 differ in geometrical dimension and technological characteristics, which is also included in structural designs of sequence charts.

From this standpoint, deposits of groups 1 and 2 make an associate type of open-pit fields labeled by B—trapezoidal cross-section. Deposits from groups 3 to 7 make an associate type of open-pit fields labeled by A—triangular cross-section. Deposits from groups 8 to 10 make an associate type of open-pit fields labeled by V—complex shape cross-section and plan (and variable per extraction areas).

Open-pit fields are typified based on geometrical and mining factors, considering influence of open-pit type on the structural design of the open pit mining sequence chart.

Type 1 (B1)—trapezoidal open-pit field, two-side working area in hanging wall and footwall, the pit bottom is in the group of main beds, absence of non-mining flank (group 1 of deposits)—structural design of open pit mining sequence chart K1.

Type 2 (B2)—trapezoidal open-pit field, single-side working area in hanging wall, the pit bottom is the floor of the bottom bed in the series, non-mining flank is on the floor of the bottom bed; or two-side working area, the pit bottom is the floor of the group of main beds, temporary non-mining flank is on the floor of the group of main beds (group 2 of deposits)—structural design of the open pit mining sequence chart K2.

Type 3 (A3)—triangular open-pit field, deepening type, one-side working area in hanging wall, relatively narrow pit bottom in the series, non-mining flank, no internal dumping (group 3 of deposits)—structural design of the open pit mining sequence chart N1.

Type 4 (A2)—triangular open-pit field, pronounced hill–depth type, one-side working area in hanging wall (with the hill and depth subareas, inclined short non-mining flank, internal dumping (group 4 of deposits)—structural design of the open pit mining sequence chart P1.

Subtype 4-1 (A2)—triangular open-pit field, pronounced hill–deep-earth type, one-side working area in hanging wall (with the hill and depth subareas, inclined medium-length non-mining flank, internal dumping (group 5 of deposits)—structural design of the open pit mining sequence chart P2.

Type 5 (A^1)—triangular open-pit field, deep earth type, one-side working area in hanging wall (no division into subareas), ling inclined non-mining flank with an internal dump (group 6 of deposits)—structural design of the open pit mining sequence chart P3.

Subtype 5-1 ($A1^1$)—triangular open-pit field, deep earth type, one-side working area in hanging wall of single thick bed, long inclined non-mining flank with an internal dump (group 7 of deposits)—structural design of the open pit mining sequence chart $P3^1$.

Type 6 (V1)—linear-canted compound medium-long and extended open-pit fields, hill–deep earth type, variable geological sections and series per areas of extraction with one-side compound working area (different deep earth and hill subareas), compound geometry of benches—horizontal and inclined with non-mining flank with an internal dump (group 8 of deposits)—structural design of the open pit mining sequence chart O1.

Type 7 (V2)—curvilinear bounded or unbounded open-pit fields, one or two ends, alternate bloc-stagewise or sequential extraction, compound working area (archwise, segmented, sectored), mid-size brachysyncline deposit composed of small number of beds (group 9 of deposits)—structural design of the open pit mining sequence chart O2.

Type 8 (V3)—series of twin or triple (or more) open-pit fields, level-wise or swooping sequence of mining in end curvilinear areas, compound working areas (archwise, sectored or triangular), large downfold-wise deposit composed of many beds (group 10 of deposits)—structural design of the open pit mining sequence chart O3.

It is worthy to mention that deposits in groups 1 to 5 may contain special groups of deposits based on specific geometrical and technological (linear and volumetric) parameters. There are two sets of characteristics and parameters of working areas and two sets of individual sings and mining sequence charts. The first set (for short and medium-length deposits) characterizes conditions when due to the presence of zone with locally high coal content in open-pit field (e.g. due to increased thickness of beds), it is feasible to locate the first phase of mining with transition period—blocks A, B and C in this area (in this case, block A comprises blocks B and C). Accordingly, the second phase—with block C for lateral system of mining is designed for the full perimeter of the open-pit field, which is advantageous for the open pit mine efficiency. This makes mining sequence chart O4.

The second set is for very much extended, monoclynal or folded deposits, when after a certain development period of mining with two separate open-pit fields (at the flanks of the deposit) or with one twin open-pit field (at the center of the deposit), with functional blocks of the first phase (blocks A. B and C), further lateral extraction with two-side (two-front) mining from flanks to the center of from the center toward the flanks is ensured for higher efficient coal production this makes mining sequence charts O5 and $O5^1$.

The main charts of mine sequence are interrelated with natural and technological groups of deposits, that influence the shape and parameters of open-pit fields (ultimate limits) in cross-section, and govern structural parameters of working areas, thus forming a geometrical type of an open-pit field.

Based on the types and subtypes ofdeposits, the author proposes the modified typification of flexible technologies withj internal dumping (Figs. 3 and 4), with descripition of physial layouts and technological solutions below in ths article.

The technology of mining with continuous deepening consists in the following. At one of ends of a deposit, a limit size open pit mine is constructed from the current depth down to the project depth—open pit phase I. it key purpose is to create an initial reservoir to place overburden in it. Open pit phase I runs with formation of non-mining flanks at the end and sides of the open pit mining, and the highwall is arranged at the opposite end. After completion of open pit phase I, the rest of the reserves are extracted along the strike and overburden is placed in the prepared mined-out reservoir. Overburden haulage involves motor transport along bench terraces, and coal is transported to the surface, to storage and processing stations. Since open pit phase I can be carried out be levels (I–III), i.e. for long time), in order to minimize volume of overburden to be placed in external dumps, the open pit mine should have the smallest parameters, except for the depth. After completion of open pit phase I, transition to internal dumping is performed. The benefits of this approach as compared to conventional axial deepening of an open pit include reduction in land withdrawal as overburden is placed in mined-out void, shorter haulage distance for overburden; feasibility of extraction of all beds in the series on the side of hanging wall, reduction in coal loss. The shortcomings are the limited mining front and rigorous interconnection of face and dump zones.

The lateral mining technology with open pit phase I, although enhanced production efficiency as against conventional coal mining technology, also has some drawbacks. The worst is the requirement to construct open pit phase I down to the limit depth, which extends the transition to internal dumping and results in withdrawal of land to place external dumps. Furthermore, it becomes difficult to re-design open pit mine if its ultimate limits are changed.

The stage-wise deepening approach consists in the following. At one end of a coal deposit, a pit is constructed across the strike from the current depth to the depth equal to a bench height. Overburden is places in external dump. After the pit has been constructed, next overburden is placed in this pit.

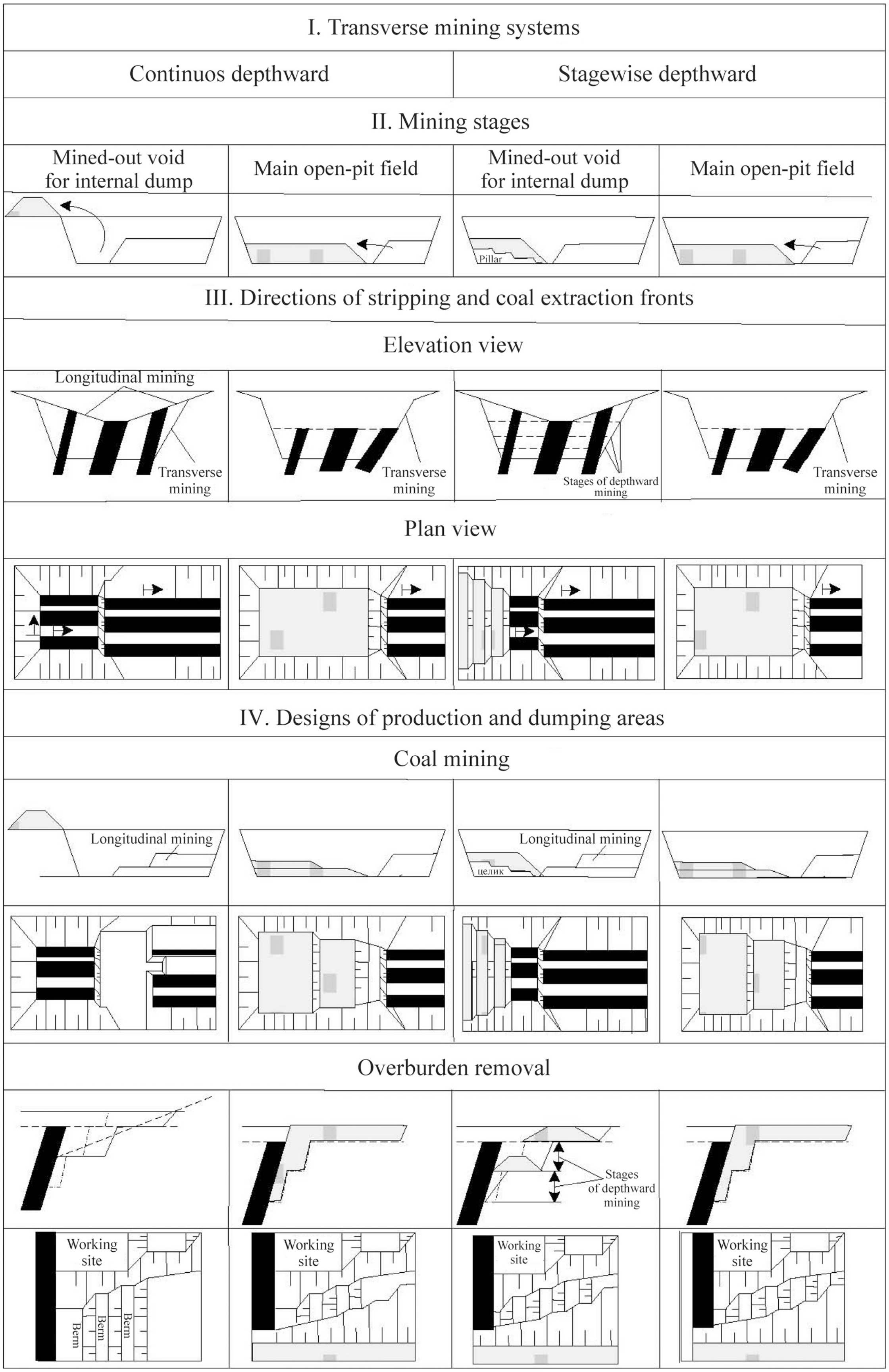

Fig. 3. Continuous deepening and stage-wise deepening approaches.

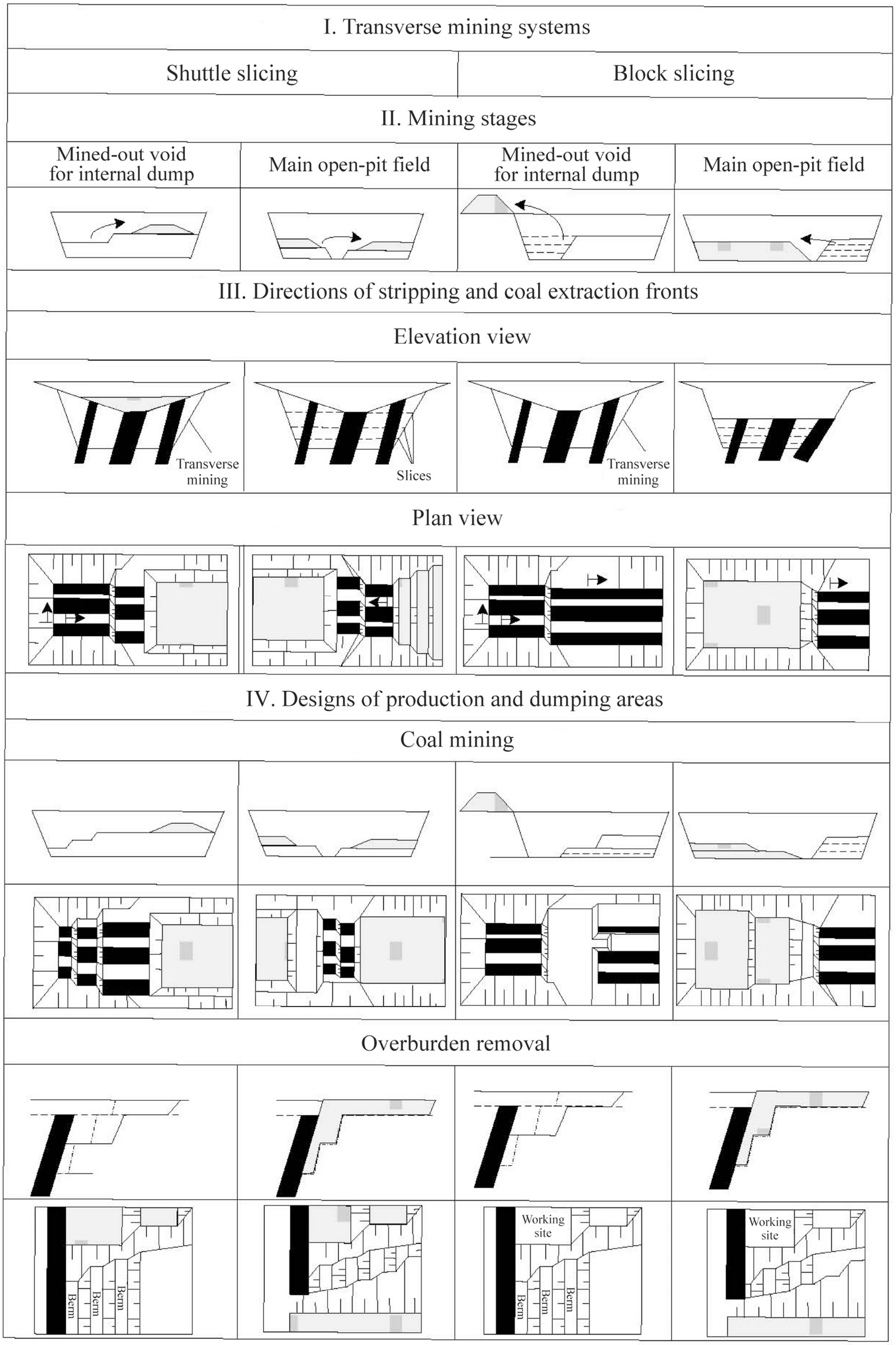

Fig. 4. Shuttle slicing and bock slicing systems of mining.

Further depthward benching depends on the storage capacity of the lower lying horizon. Downward benching proceeds down to the design depth. Then the working area becomes permanent, and overburden is dumped in the internal mined-out void. The downward benching angle range is 16–18°, which governs stability of the internal dump and time of reaching design pit depth to start mining with completely internal dumping. The application of this technology reduces volumes of external dumping and land withdrawal. Moreover, period of construction of open pit mine and transition to internal dumping technology is shortened. The lower lying horizon can be mined with truck-and-shovel technology. It becomes feasible to reclaim mined-out area subsequent to mining front advance, which mitigates ecological impact of open pit mining. An essential fault of the technology is putting a part of reserve in prolonged storage. The stagewise depthward benching can be used in inclined or steep coal series largely elongated along the strike.

A feature of block slicing is division of coal body into blocks, including the first turn pit and blocks extracted to accommodate internal dump. Initially, the first turn pit is excavated; its parameters are determined to be such that the pit can store overburden removed from the neighbor block. Parameters of the block are estimated in accordance with the following argumentation. It is assumed that one block is mined within one year. Production capacity of the open pit is maintained. Thickness of horizontal slice in the block is conditioned by the minimized loss and dilution. Slicing is implemented in the block sequentially, from top downward. Mining uses front shovels and back hoes on the side of hanging wall to reduce coal loss and dilution. Dumping is carried out by layers, horizontally or at angle of repose.

The benefits of the technology are convenient conditions for extraction of coal from all beds of series, overburden dumping in mined-out void and high movability of mining machines within a slice.

The disadvantages are unstable current stripping ratio within a year and large overburden volumes placed in external dumps. This technology can be uses in mining series of coal beds of complex structure and occurrence given the open pit limits are adequately determined.

The shuttle slicing technology means horizontal slicing sideways, with internal dumping. First, a cross slice is made to a depth determined based on transportation criterion after comparing effect of technologies using truck-and-shovel approach and direct dumping in overburden removal operation. Overburden is placed on the surface of the open-pit field. The mineable thickness of slicing reaches 100 m. The width of the slice depends on the capacity of mined-out void to accommodate removed overburden volume. The length of the slice bottom is assumed to be equal to the horizontal thickness of the series.

After the cross slice has been made at one of the coal body ends, the horizontal slicing is continued with a single high bench divided into subbenches. Overburden dumping is draglines. Coal extraction involves hydraulic excavators, overburden is removed toward mined-out void and is than re-handled to internal dump using draglines. Subbenching is performed from top downward, by cross slicing, with advanced extraction of coal using hydraulic backhoes.

After the first slice has been completed, and overburden is placed in mined-out area, it is possible to make the cross pit on the lower lying slice. The overburden is placed on the surface of internal dump of the first slice. The second slice mining is carried out with internal dumping in mined-out area on the same horizon. Overburden from the internal dump of the first horizon is removed to the internal dump of the same horizon of the internal dump of the lower lying layer. In this manner, the mining front advances in the opposite direction relative to the fist layer mining.

After the second slice has been completed, the third downward slicing is carried out if necessary, subject to all technical requirement of the previous slice mining, with advancing the mining front in the opposite direction. With such sequence of slicing, mining is carried out down to a horizon where the slice stripping ratio is equal to the limit stripping ratio.

A feature of the shuttle slicing is one production slice. The upper lying mined-out layers act as internal dumps cyclically re-excavated from one place to another in the course of extraction of lower lying coal.

The benefits of the technology are the absence of external dumps, which reduces land withdrawal, the use of direct dumping and, thus, coal production cost saving, and the internal dumping, which makes the length and cost of overburden haulage shorter.

The shortcoming of the technology is multiple re-handling, which increases current stripping ratio, and rigorous interconnection between subbench mining. A possible area of application of the shuttle slicing technology is extended beds with high coal content.

CONCLUSIONS

The studies into design and parameters of flexible technologies for operation open pit coal mines in Kuzbass, considering geological structure of coal deposits, enable reduction in coal loss and dilution in thin beds by coal mining on the side of hanging wall, which allows shorter distance for overburden dumping (by estimates, by 30–40% shorter), which cuts down overburden haulage cost; internal dumping, which contributes to higher performance of open pit mine; reclamation of disturbed land subsequent to mining front advance, which mitigated ecological impact of mining; minimized parameters of residual mining.

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