A model for extended bench casting in dipping coal seam

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This paper deals with extended bench casting with draglines in surface coalmines. A computer model, developed for panel design, covers three fundamental operating modes: i) level casting for flat-lying coal seam; ii) downhill casting; and iii) uphill casting for inclined coal seam conditions. Influence of pit width on critical pit dimensions such as cut length, dragline reach on key cut and main cut positions, swing angles on key cut and main cut positions and rehandle percentage is critically studied. The model is equipped with a device to determine total number of points within a cut on which dragline is placed. With another module, walking pattern of dragline between adjacent cuts is decided. The model indicates that coal seam inclination significantly influences dragline productivity. All things being equal, the uphill operation mode demands larger dragline dimensions. Extended bench construction in uphill casting is easier and faster as less material is required. Besides, dragline operates on a safe bench. As coal seam gets inclined, a large dragline may switch from extended benching in downhill mode to direct casting owing to the room available for spoil piles increases with coal seam inclination. However, a small dragline would likely fail to operate in downhill mode as the size of the extended bench would expand faster than the waste available in the cut. Besides, dragline would not be adversely affected by failures occurring in spoil piles. It has been observed that in extended benching practice with an inclined coal seam downhill casting should be considered first.

Keywords: Dragline, Extended benching, Pit geometry

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Introduction

Extending dragline-operating ranges beyond original design figures is indirectly achieved by moving dragline on a bench out to the edge of old highwall. Essence of the procedure followed for bridge construction is leading some key cut spoil in a way to lean against old highwall. Finally, part of the bridge is re-handled to clear spoil away from the highwall. Basic operating principles of the technique in flat-lying coal seam conditions are discussed1-3. Erdem et al6 derived patterns for bench extension. Duran7 investigated dragline panel design for extended benching in inclined coal seam conditions. Rai et al8 used balancing diagrams for horizontal tandem dragline operations. This study presents design and development of a model for extended bench casting in dipping coal seam.

Developed Model

A computer model is developed to analyze the influence of pit width and coal seam dip angle on the productivity of a dragline deployed in extended benching mode based on a hierarchical structure (Fig. 1). First consideration is setting of coal seam, either flat or dipping. While flat coal seams are handled by level-spoiling rationale, there exists two spoilage alternatives for dipping coal seams: i) strike line method of downhill spoiling; and ii) uphill spoiling. Thus computer model (Fig. 2) covers three operating modes: i) level operation on flat-lying seam, ii) downhill spoiling on dipping seam; and iii) uphill spoiling on dipping seam. Pit width, particularly in moderate-to-deep overburden condition, significantly affects dragline productivity and thus, overburden removal cost. Therefore, extended bench casting model is designed to allow several pit width values and pit configurations depending on dragline dimensions to carry out sensitivity analyses on crucial pit dimensions.

When dragline is positioned on bridge, a minimum cut length (Lmin; 1.75×tub diam) of dragline would be adequate for operational safety. In the model, cut length is so designed that dragline can reach foot of key cut (Lkey). In case of a small dragline or thick overburden, a dragline may fail to do so (Lmin>Lkey). Then...
Extended Bench Model

Inclined coal seam
Downhill casting

Flat coal seam
Level casting

Inclined coal seam
Uphill casting

Optimum pit width
Optimum bench extension
Optimum cut length
Optimum number of sitting points

Fig. 1 — Extended bench model

Fig. 2 — Flow chart of the computer model
key cut is excavated in two slices with dragline using two positions.

To determine the number of sitting positions, first point on the new highwall line (⊙) and the last point on which the dragline sits closest to the spoil pile (⊙) are fixed. Number of intermediary positions is a function of width of span dragline covers from a particular position (Figs 3a & b). While a large dragline can have as few as two positions (⊙ and ) a small one can use several positions (⊙, ⊙, ⊙, …., and ⊙). The dragline’s walk from last position on bridge to first position on adjacent cut is modeled. To minimize time spent, dragline is desired to walk straight along the line connecting positions ⊙ and ⊙ (Path I, Fig. 4). However, depending on cut length, dragline may approach too close to the old high wall. In such cases an alternative path is chosen (Path II, Fig. 4).

Testing the Model

Parametric studies are done with the data representing characteristics of the virtual surface coal mine (Table 1). Arbitrarily seven draglines ranging from small to large in dimensions and capacity were selected (Table 2). The extended bench model is executed for coal seam dip angle (CDA) of 0-16 degrees with 1-degree increments (Table 3).
Table 2 — Basic dimensions of draglines entered in model run

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<tr>
<th>Dragline</th>
<th>Operating radius m</th>
<th>Dumping height m</th>
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<th>Maximum allowable load kg</th>
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Operational Radius Required ($R_{key}$) and Available ($D_{key}$) at Key Cut Position

$R_{key}$ is directly proportional to level pit width (LPW) and independent from CDA (Fig. 5a). $D_{key}$ is independent from LPW and CDA. Larger the dragline, larger is $D_{key}$ and $R_{key}$.

Operational Radius Required ($R_{main}$) and Available ($D_{main}$) at Main Cut Position

For level and uphill modes, $R_{main}$ is directly proportional to LPW (Fig. 5b). This relationship also works for downhill spoiling at shallow CDAs (<14 degrees). At steeper plunges, however, $R_{main}$ is inversely proportional to LPW. Marginal increase in $R_{main}$ in uphill mode is greater than that in downhill mode, which offers a spacious room for spoil piles.

$R_{main}$ is directly proportional to CDA for uphill casting and inversely proportional for downhill casting. Larger the dragline, larger is $R_{main}$. For level and downhill modes, $D_{main}$ is independent from LPW. For uphill mode, on the other side, it slightly decreases from $W_{min}$ to $W_{max}$. Both for downhill and uphill spoiling modes, $D_{main}$ is inversely proportional to CDA. Larger the dragline, larger is $D_{main}$.

Rehandle Percentage ($P_{reh}$)

$P_{reh}$ is inversely proportional to LPW (Fig. 6). $P_{reh}$ is inversely proportional to CDA for downhill casting and directly proportional for uphill casting. Larger the dragline, lesser is $P_{reh}$.

Cut Length ($L_{cut}$)

$L_{cut}$ is inversely proportional to LPW (Fig. 7). For downhill casting, $L_{cut}$ is directly proportional to CDA (up to 10 degrees) but becomes inversely proportional for larger CDAs. For uphill casting, $L_{cut}$ is always inversely proportional to CDA. Larger the dragline, larger is $L_{cut}$.

Swing Angle at Key Cut Position ($\beta_{key}$)

$\beta_{key}$ is inversely proportional to LPW (Fig. 8a). For downhill casting, $\beta_{key}$ is directly proportional to CDA (up to 10 degrees) but becomes inversely proportional for larger CDAs. For uphill casting, $\beta_{key}$ is always inversely proportional to CDA. Larger the dragline, larger is $\beta_{key}$.

Swing Angle at Key Cut Position ($\beta_{main}$)

$\beta_{main}$ is inversely proportional to LPW (Fig. 8b). $\beta_{main}$ is inversely proportional to CDA. Larger the dragline, larger is $\beta_{main}$.

Results and Discussion

For level and downhill casting, as pit widens dragline operating radius required at key cut and main cut positions increase. However, available operating radius for both positions remains constant throughout pit width interval as dragline dimensions are independent from those of the pit. For uphill casting, as pit widens dragline operating radius required at key cut and main cut positions increase. While available operating radius for key cut position remains constant, that of the main cut position decreases from the shortest pit toward the largest pit.

As wider pits are employed, larger extensions are to be made to the working bench in towards the empty pit, and percent rehandle decreases because amount of material in the pit increases more rapidly than that in the extended bench. As pit widens, $L_{cut}$ decreases. The dragline sitting on initial position must be capable to reach the foot of key cut. As enlargement of the pit entails a comparative enlargement in key cut, wider pits imply longer reaches which are resulted in shorter cut lengths.

$L_{min}$ is independent from pit width. This dimension is determined from experience as 1.75 times the tub diam where a safety margin of ¾ times the tub diam is allowed.
Table 3 — Model run showing pit width intervals and rejection indicators

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1. Length of the extended bench is larger than the cut itself. The particular dragline is a small capacity one.
2. Cut with respect to key cut position cannot be formed due to insufficient dragline reach.
3. Dragline cannot satisfy the required minimum cut length constraint.
4. Extended bench width is negative. Dragline can switch to direct casting.
5. Extended bench cannot be constructed due to insufficient amount of material in key cut.
at the cut face. For a given pit width, number of sitting positions within a cut is inversely proportional to the size of dragline. Thus, while larger draglines can excavate whole cut from a few positions, small draglines employ considerably more positions for digging. Also, number of sitting positions is directly proportional to LPW. While for small draglines, $L_{cut}$ is dictated by $L_{min}$, for larger ones it is determined by that as measured from $L_{key}$. Thus, in case of $L_{cut} = L_{min}$ key cut is excavated from two positions (Fig. 3b) and distances between sitting positions are different. When $L_{cut} = L_{key}$, key cut is excavated from one position (Fig. 3a) and the dragline is positioned with equal distance intervals.

To ensure a safe journey, smaller draglines walk from the last position on extended bench to the first position on next cut on a segmented route while larger ones walk there along a straight path (Fig. 4). This is because smaller draglines are assigned a minimum cut length ($L_{key} < L_{min}$) while larger ones a longer cut length...
For optimum use of this method, pit width must be kept at the maximum.

**Comparative Results for Downhill and Uphill Casting**

Small draglines can be operated in downhill casting mode but not in uphill mode, which entails the waste to be cast further and higher. Longer bench extension requirements and greater rehandle percentages are experienced in uphill casting than in downhill mode. More sitting positions are required in uphill casting than in downhill mode. As CDA increases, larger draglines in downhill casting may switch from extended benching
to direct side casting because available room for spoil piles increases with coal seam pitch. As CDA increases, smaller draglines in downhill casting may fail to operate in extended benching, because of no enough material in the cut to construct downhill-extended bench.

Uphill casting mode requires higher dumping radius and digging depth capability and offers smaller spoil room. Therefore, shorter pits should be selected. Smaller draglines generally fail to operate in uphill casting, as they cannot satisfy above requirements. Downhill casting offers a more flexible operating environment than uphill casting on a dimensional basis. Any particular dragline can operate on higher coal seam inclinations in downhill mode than on uphill mode. So, at highly dipping coal seams, downhill casting seems to be the only method to be switched to. Uphill casting should be preferred as
the dragline bench would mostly be on the safer side of the pit. Downhill casting should be preferred as spoil pile instability would not influence the operations.

Conclusions

This study presents a computer model developed to analyze the influence of coal seam inclination on dragline panel design in extended bench casting. Response of critical dimensions like cut length, required operating radius at key cut and main cut positions, rehandle percentage, required digging depth and dumping height at key cut and main cut positions and swing angles at key cut and main cut positions to changes in pit width and coal seam inclination are investigated. Emphasis is placed on dragline positioning within the pit and determining the proper walking pattern within adjacent cuts.

Nomenclature

- $A_{cut}$: Cut cross-sectional area (plan view), $m^2$
- $A_{bridge}$: Bridge cross-sectional area, $m^2$
- $A_{key}$: Key cut cross-sectional area (swelled), $m^2$
- $A_{rehab}$: Cross-sectional area of bridge to be rehandled, $m^2$
- $A_{spoil}$: Spoil pile cross-sectional area, $m^2$
- $B_{bridge}$: Boolean indicator showing whether bridge extends across pit to old spoil piles
- $B_{cut}$: Boolean indicator showing whether dragline reaches key cut foot
- $d_1$: Distance between dragline’s first and second sitting positions on bench, m
- $d_2$: Distance between dragline’s second and third sitting positions on bench, m
- $d_3$: Distance between dragline’s third and fourth sitting positions on bench, m
- $d_{h}$: Length of horizontal projection of cut face, m
- $d_{setback}$: Safety distance as measured from the crest of highwall, m
- $d_n$: Distance between dragline’s nth and (n-1)th sitting positions on bench, m
- $D_{key}$: Available operating radius at key cut position, m
- $D_{main}$: Available operating radius at main cut position, m
- $D_{ext}$: Benchmark design pattern (1, 2, 3 or 4)
- $F_{overburden}$: Swell factor of overburden material, per cent
- $H_{coal}$: Coal seam thickness, m
- $H_{dig}$: Dragline digging depth, m
- $H_{dump}$: Dragline dumping height, m
- $H_{setback}$: Required digging depth, m
- $H_{dump}$: Required dumping height, m
- $H_{sp}$: Spoil pile height, m
- $H_{overbur}$: Depth of overburden left for dragline stripping, m
- $i$: Coal seam dip angle, degrees
- $L_{cut}$: Cut length, m
- $L_{key}$: Cut length as measured from key cut position, m
- $L_{max}$: Maximum length of cut, m
- $L_{min}$: Minimum length of cut, m
- $L_{setback}$: Setback distance as measured from crest of cut face, m
- $P_{reh}$: Rehandle percentage, per cent
- $R_{key}$: Required operating radius at key cut position, m
- $R_{main}$: Required operating radius at main cut position, m
- $R_{o}$: Dragline operating radius, m
- $walktype$: Dragline walking pattern between cuts (diagonal or rectangular)
- $W_{max}$: Widest pit on which dragline could operate, m
- $W_{min}$: Narrowest pit on which dragline could operate, m
- $\beta_{key}$: Average swing angle at key cut position, degrees
- $\beta_{max}$: Maximum swing angle at key cut position, degrees
- $\beta_{min}$: Minimum swing angle at key cut position, degrees
- $\beta_{main}$: Average swing angle at main cut position, degrees
- $\beta_{min}$: Minimum swing angle at main cut position, degrees
- $\beta_{max}$: Maximum swing angle at main cut position, degrees
- $\Phi_{b}$: Coal seam bench angle, degrees
- $\Phi_{h}$: Highwall angle, degrees
- $\Phi_{tub}$: Dragline tub diameter, m
- $\Theta$: Angle of repose of spoil pile, degrees

References

2. Bucyrus-Erie, Surface Mining Supervisory Training Program (Bucyrus-Erie Company, South Milwaukee, USA) 1977, 1-112.