

CHAPTER 2 LITERATURE REVIEW

2.1 History of the dragline

The first dragline was invented by John W. Page in 1904 for excavating the Chicago Canal. His Company, Page Engineering, developed its first crude walking dragline in 1923. In the 1960s, he also invented an arch-less bucket design in 1935. Page Company upgraded its mechanism to an eccentric drive with its walking-type dragline. In 1988, Harnischfeger Corporation (P&H Mining Equipment) acquired Page Engineering Company. P&H Mining was established in 1884 by Alonzo Pawling and Henry Harnischfeger. The world's first gasoline engine-powered dragline was also manufactured by P&H in 1914 (Jones,2007). A typical walking-type dragline consists of major components, as shown in figure 2.1.

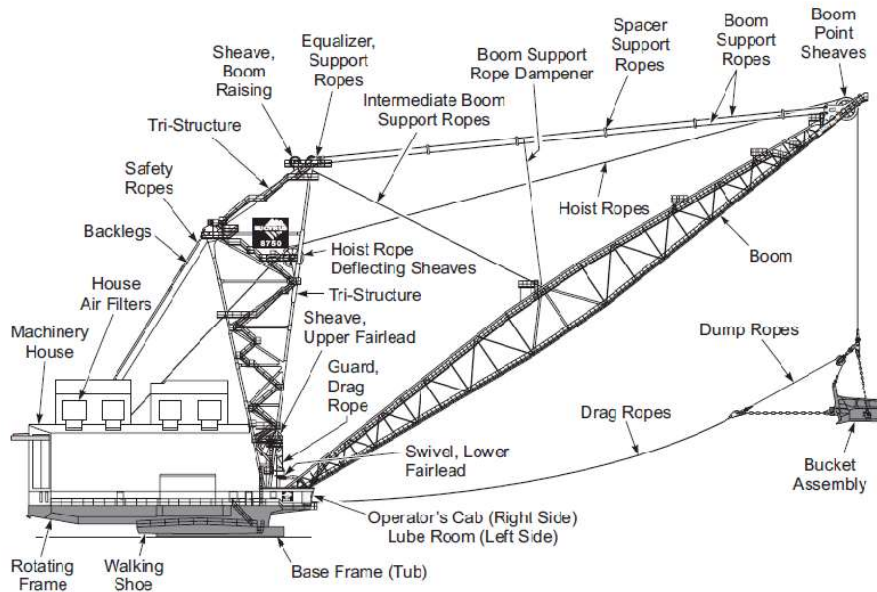


Figure 2.1 Schematic diagram of a typical dragline (Humphrey, 1990).

2.2 An introduction to dragline

The following reasons include some significant factors that contributed to the dragline being the preferred stripping tool. The dragline has greater flexibility in handling

overburden depths. The flexibility of the dragline in digging and placing material makes it more suitable to perform the functions required to meet today's reclamation standards Learmont (1975). The forces imposed on the machine structure during digging operations and the type of walking equipment which can be used result in reduced maintenance costs in dragline over a shovel of comparable size.

As compared to a stripping shovel, the depth of the overburden handling is limited by its range, while a large dragline can rehandle to negotiate peaks. According to Atkinson and Walton (1979), the coal is exposed by a walking dragline to directly cast the overburden across the pit and into the space left by the previous strip. Concurrently, reclamation is facilitated. Even the heaviest draglines may be used in soft or wet ground conditions because of the dragline walking mechanism's flexibility and low ground pressure.

Learmont (1989) compared pre-stripping in different types of material by a single dragline, two draglines, shovel-dumper, and bucket wheel excavator-conveyor in various depths of overburden. According to the cost projections, the walking dragline will always be efficient at removing significant amounts of overburden and will keep playing a significant part in the removal of overburden in the future.

The development of low-cost explosives like ANFO and metallized slurries has significantly decreased the cost of blasting, which has tended to favour the dragline because it requires better overburden fragmentation.

As a result of its deeper digging capacity, operational flexibility, and reduced operating costs, the walking dragline has emerged as the equipment of choice for stripping regular, gently dipping coal seams.

2.3 Classifications of dragline

Draglines can be grouped into three classes (Kennedy ,1990). These classes are based on-

- Truck-mounted or portable draglines.
- Crawler-mounted draglines: These types of draglines have a bucket capacity of less than 19 cubic meters, and it is generally diesel operated for mobility (Humphrey, 1990).
- Walking draglines: These are the most popular draglines. The dragline rests on a big circular tub and walks with a crankshaft mechanism.

2.4 Dragline applicability conditions in mining operations

The dragline finds applications when deep digging is required, and slope stability or other conditions make operation undesirable on the pit floor. The following mining conditions are best suited for a dragline operation.

- Mineral reserve should be enough to match with dragline working life (approximately 20 years).
- Overburden material should be blasted before handling by dragline.
- The inclination of the mineral or coal seam should not be more than 1 in 6.
- Coal seam(s) should be free from faults & other geological interruptions.
- The coal seam should be along the major strike length.
- The coal deposit on the hilly property is not suitable.

2.5 Dragline applications

A dragline excavator is used in surface mining and civil operations, wherever the excavated material needs to be transported only a relatively short distance, or a maximum of approximately 215 meters (Clarke et al., 1990). The two most common large dragline applications involve the strip mining of coal and phosphate (Tagieddin,1992). Draglines are used extensively in phosphate mining, where they not only dig and spoil the overburden but also excavate the phosphate (matrix), thereby eliminating the need for any other equipment in the pit (Ramani,2012). These direct material casting machines are also sometimes used as loaders (George et al.,1986). The machine is most useful as loader when the bottom of the pit is too deep for a hydraulic excavator and unsuitable for truck traffic. They can also be used for parting and thin seam removal. The smaller dragline units generally are applied to meet more shallow mining requirements and, in addition, are more frequently assigned to:

- Truck loading of the overburden or ore.
- Digging ponds and basins (Swenson et al., 2000).
- Surface levelling in the mine during reclamation stage (Measles and Bugosh,2007; Dudinskiy and Nechaev,2020; Krasavin et al.,1983).
- They can also remove partings in case of multiple coal seam mining.

2.6 Dragline advantages, disadvantages, and limitations

2.6.1 Advantages

The dragline has many benefits when compared to other mining machines. It is widely considered the best combination of productivity and versatility (Bandopadhyay and Ramani,1979; Hrebar,1990; Adams,1990). If the geologic and operating conditions allow its use, the dragline exhibits the following advantages-

- Because of the dragline's unique capability to dig below its level, rotate, and dump at substantial distances, it can eliminate often-costly vertical lift associated with secondary haulage like truck and other haulage systems.
- Draglines have the capability to dig and transport material that is blocky or contains boulders. It can also handle various types of material.
- Adverse weather conditions have little or no impact on the dragline operation because it is generally stationary while during its operation.
- Material excavation from outside the pit has advantages as it does not have to go into the pit when digging a pit, ditch, and canal containing water.
- Material handling with the dragline has the lowest cost per unit (Demirel,2007).
- Although a bucket wheel excavator can move a cubic meter of material at a low cost than a dragline, its applications are very restricted (Bertoldi,1977).
- The machine has low operator fatigue and a low bearing pressure; hence it can be placed close to edges (Humphrey, 1990).

2.6.2 Disadvantages

The most significant disadvantage of the machine is its high ownership cost, the primary investment. Hence the overall success of mine stripping depends primarily on the effective use of dragline (Chatterjee et al.,1977). The distance that the material can be transported is small; hence dozer as an auxiliary machine is generally needed in support. Poorly blasted or fragmented material can impact machine productivity to a great extent (Bertoldi,1977). The dragline has the following disadvantages.

- If the blasted rocks are of a large lump or poorly blasted, the bucket is filled insufficiently, efficiency is reduced, and the bucket and drag rope wear rapidly.

- Its bucket fill factor and output efficiency are less compared to the powered shovel.
- Dragline stripping cost is more compared to the powered shovel.
- The machine has lesser spotting ability.
- Max ramp slope for dragline walking is 10%, and maximum bench slope for dragline working is 2% (Sahu and Palei,2020).
- Rehandling of overburden reduces the rate of coal exposure and hence productivity.
- Additional bench preparation and levelling cost occurs during the preparation of the sitting position of the dragline.

2.6.3 Limitations

Dragline material dumping capabilities are limited by their boom height and boom length. Another limitation is the length of the drag and hoist ropes. These ropes limit the dragline digging depth (Wardeh and Frimpong,2020). A dragline is most efficient in digging material below its sitting level, it can dig above its sitting level, but it is not so efficient in loading piled-up material as compared to a rope shovel or front-end loader.

2.7 Dragline modes of operation

The dragline operational modes depend on the digging position and the technique to drag the bucket. There are three main operational modes in which the dragline bucket can be dragged (Mirabediny,1998).

- Normal underhand digging.
- Overhand digging or chop-down operation.

- Pull back operation from the spoil side.

2.7.1 Normal underhand digging

The extended bench, main cut, and key cut are removed in a conventional underhand digging mode. As shown in figure 2.2, the dragline generally operates from the highwall side and then excavated material from below the elevation of its pad.

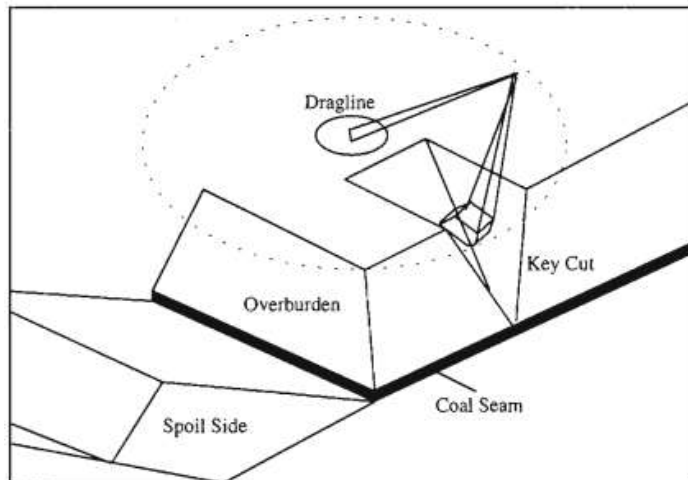


Figure 2.2: Dragline removing key cut material in its normal underhand mode (Mirabediny,1998).

2.7.2 Overhand digging or chop-down operation

The dragline excavates overburden material from a bench above its operating bench in the overhand chop-cutting mode, as shown in figure 2.3. To provide the bucket penetrating force in this condition, it is typically kept in a dump position, and the teeth are pushed into the material. The bucket is pushed downward and towards the dragline to finish the digging process and fill it.

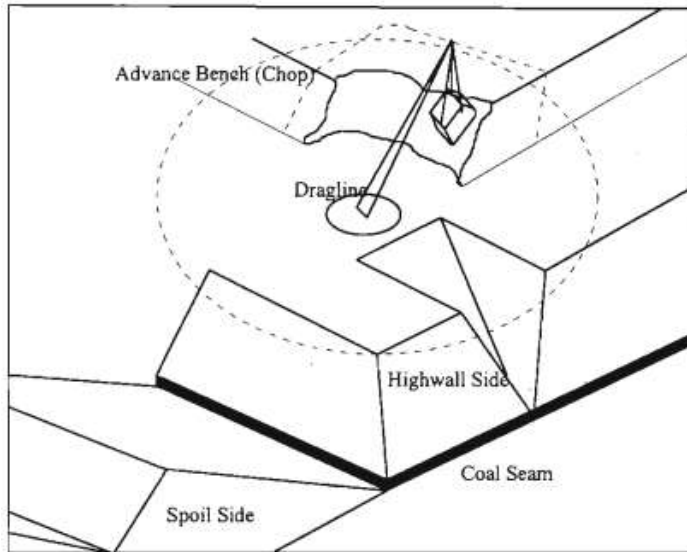


Figure 2.3: Dragline removing an advance bench material in an overhand chopping (Mirabediny,1998).

2.7.3 Pull-back operation from spoil side

Sometimes in multi-pass operations, the dragline does not have enough space to extract all the material from a standard bridge; pulling back from the spoil side is a frequent technique used to dig the material. As shown in figure 2.4, The dragline pad on the spoil side is constructed more closely to the spoil area and at a higher level than a typical bridge.

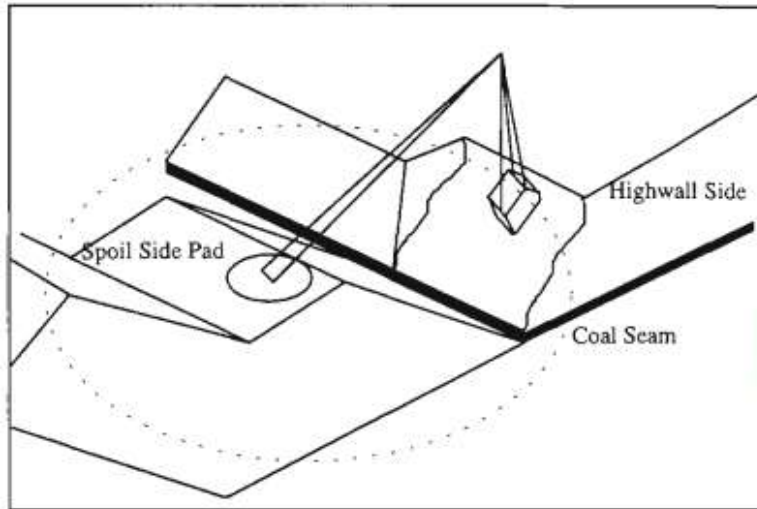


Figure 2.4: Material is being pulled back by a dragline by slicing against the highwall from a pad on the spoil side (Mirabediny,1998).

The sequencing of the operating modes accomplished by the dragline is called the digging or stripping method. The following section describes dragline stripping methods.

2.8 Dragline stripping methods

The selection of a particular stripping method depends on the number of coal seams, overburden or interburden thickness, dragline dump stability, blasting methods, coal thickness, and operator experience (Walton and Atkinson,1979; Baafi et al.,1995). There are around fifteen methods used worldwide (Michaud,1993), but in this paper, the most used methods are discussed. These can be categorized as below (Mirabediny,1998).

- Single-seam methods
- Tandem dragline methods
- Multi-seam methods

2.8.1 Single seam methods

2.8.1.1 Simple side casting method

Simple side casting is the primary method for a single-seam operation with shallow overburden depths. In this method, the dragline is sited on an immediate overburden bench above the coal, removes the overburden, and dumps in the de-coaled area of the previous cut (Mirabediny,1998). The width of the cut is usually less than 40 m, so re-handling of the overburden will be negligible, although some re-handling is needed around the coal access ramps. The method is suitable for a single thin coal seam. The basic operations of this method are shown in figure 2.5.

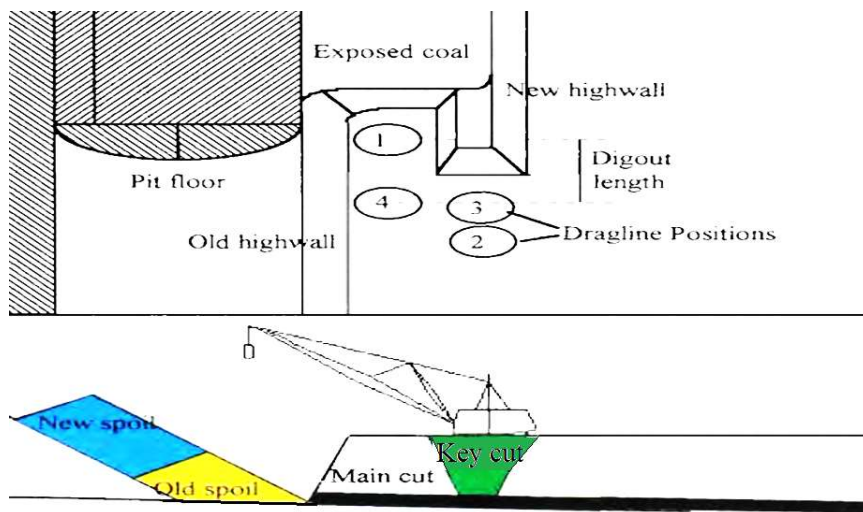


Figure 2.5: Plan and sectional view of simple side casting method (Mirabediny,1998).

2.8.1.2 Standard extended bench method

It gets more challenging for the dragline to side-cast all the overburden using a simple side-casting technique as the overburden thickness and pit width increase. Another method, the extended bench method, could fix this issue. Using the material left over from the initial key cut of the overburden face to widen the dragline bench on the highwall side (also known as the bridge) allows the dragline to increase the radius of its side-casting dumping greatly. The bridge overburden should always be handled twice; hence this method requires repeated overburden handling. Figure 2.6 describes the standard extended bench method.

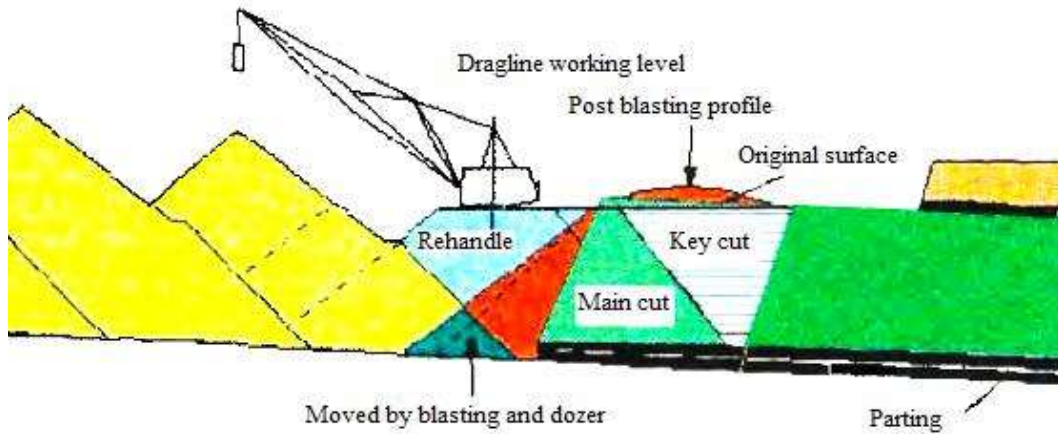


Figure 2.6: Cross-sectional view of a standard extended bench method combined with a cast blasting technique (Mirabediny,1998).

2.8.1.3 Split-bench (deep pre-strip method)

The maximum overburden depth that the dragline can dig may limit the dragline operating level for a deep operation. With increased overburden depth, the proportion of material that needs to be handled again also substantially rises. Using an advance bench ahead of the dragline main pass is one possible strategy for decreasing rehandle. This method, known as the split bench method, is frequently employed to remove heavy overburden that covers a single thick coal seam. The basic operation of this method is shown in figure 2.7.

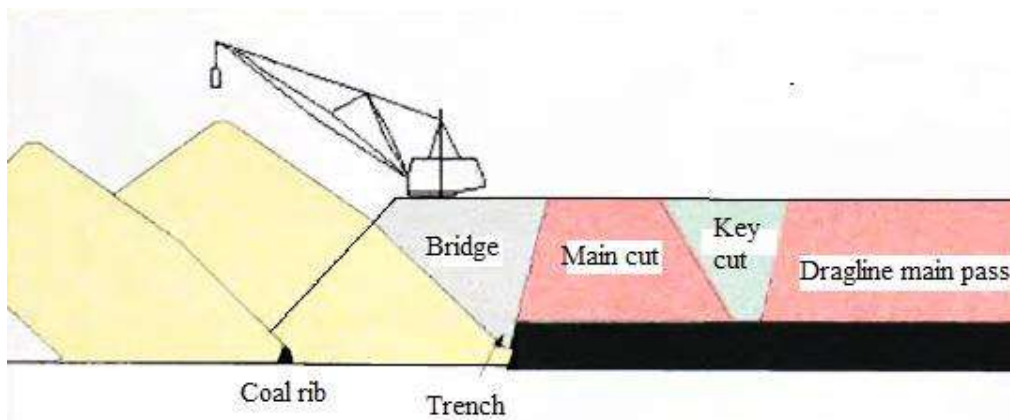


Figure 2.7: Cross-sectional view of the split bench dragline digging method (Mirabediny,1998).

2.8.1.4 Extended key cut method

As shown in figure 2.8, the extended key cut method is a two-pass procedure that uses a highwall extended key cut in the first pass and a lowwall pull-back operation in the second pass. This technique is related to cast blasting, just like the in-pit bench technique. In the first pass, the dragline bench is on the highwall side, and in the second pass, it is located on the lowwall side, about 10 to 15 meters below the pre-blasted surface.

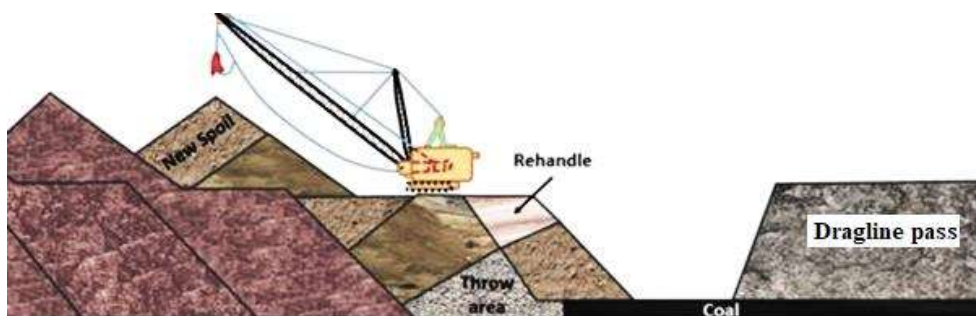


Figure 2.8: Cross-sectional view of extended key cut method (Akhundov and Demirel,2019).

2.8.2 Tandem dragline method

In tandem working, two or more draglines work in synchronism, in the same pit and on the same or different benches. One of the units is the leading (primary/ independent) dragline, and the other is the lagging (secondary/dependent) dragline. The leading dragline has no hindrance against advancing. It is termed independent because it moves freely and at its own pace on the allocated bench. The lagging dragline is set to work on the spoil side to remove some part of the overburden from the main stripping bench and rehandle some portion from earlier cast overburden to fully expose to the coal seam. It is dependent on leading dragline advancement, the so-called dependent dragline (Erdem and Celebi (1999).

The major work done for this study is to develop a computer program for planning of tandem dragline operation only. There are mainly two modes of operation practice in Indian opencast coal mines. These are horizontal tandem and vertical tandem.

2.8.2.1 Horizontal tandem operation

In the horizontal tandem operation (Figures 2.9 and 2.10), both the draglines are deployed in the same bench for a fast rate of advance and coal exposure (Chironis, 1986; Chaoji and Dey, 2000). The single or combined operating radius of the draglines determines the cut width of the strip. According to Rzhovsky (1987), maximising cut width offers advantages like reduction in relative time losses of standby and unproductive walking of draglines. Moreover, the cut width should be optimized to obtain a greater height of the stripping bench.

The leading dragline is deployed on the highwall side and provides a key cut (sitting on position Le D/L, P-I or axis no 1) towards the highwall, and after completing the key cut, the dragline is moved towards the de-coaled area (spoil dump side) to excavate the first cut, which is next to key cut (sitting on position Le D/L, P-II or axis no 2). After excavating these two cuts, the leading dragline is again moved to a new key cut position (to position Le D/L, P-III or axis no 1) to advance further. The dragline is ready for the next stripping cycle. The same sequence goes on in a zig-zag manner.

The lagging dragline is deployed on the spoil side (sitting on position La D/L, P-I or axis no 3) on the extended bench formed by the leading dragline after dumping overburden (which is levelled and graded using a dozer) by it from the key cut and first cut. The lagging dragline excavates the first dig (next to the first cut done by the leading dragline) in the remaining portion of the stripping bench. Besides excavating the first dig, the lagging dragline then also rehandles the spoil dumped by the leading dragline and dumps

it over the previous spoil to a greater height and distance to expose the coal seam fully. The leading dragline strip down the overburden and spoil overburden on the side into the decoaled area (space from which coal has been mined out previously) to form a level pad (extend the bench on spoil side) for deployment (seating position) of lagging dragline towards decoaled area.

Horizontal tandem operation is a combined method of simple side casting an extended bench. Both the draglines always operate below their own level. The combination of both the draglines working spoil the overburden to a greater distance and thus, extend the reach of the draglines (Chugh, 1980).

Figure 2.9 describes the plan of the mining system, stripping sequence, positions and travel axis of the draglines deployed in horizontal tandem operation.

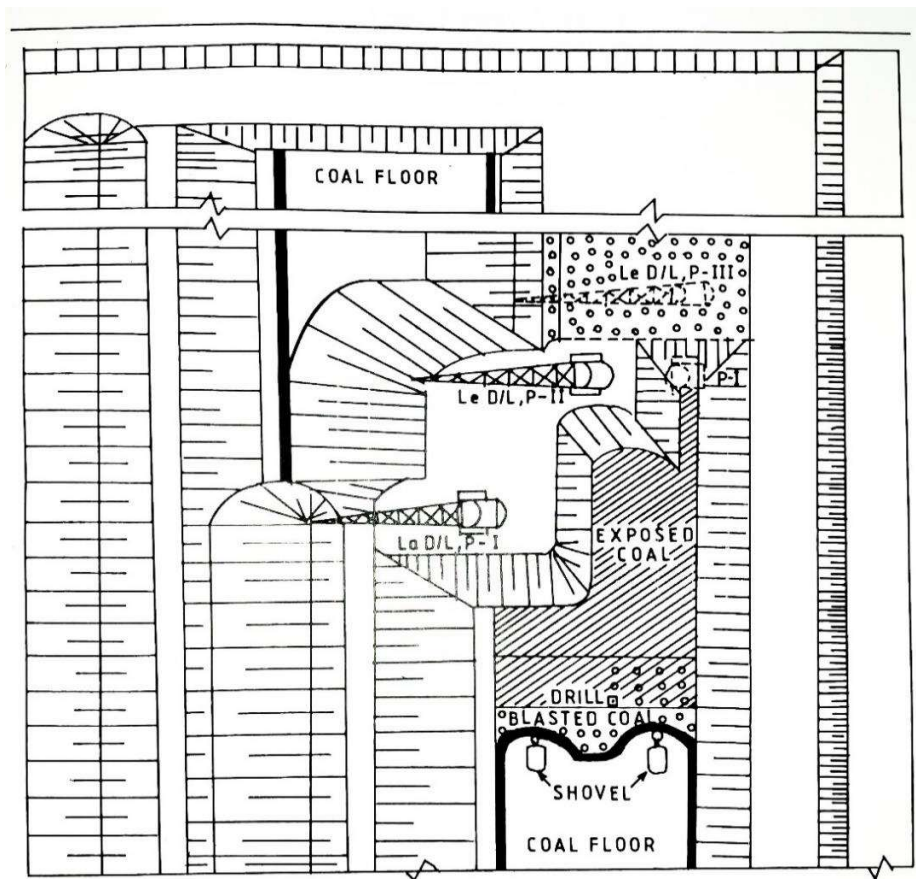


Figure 2.9: Plan of mining system in horizontal tandem.

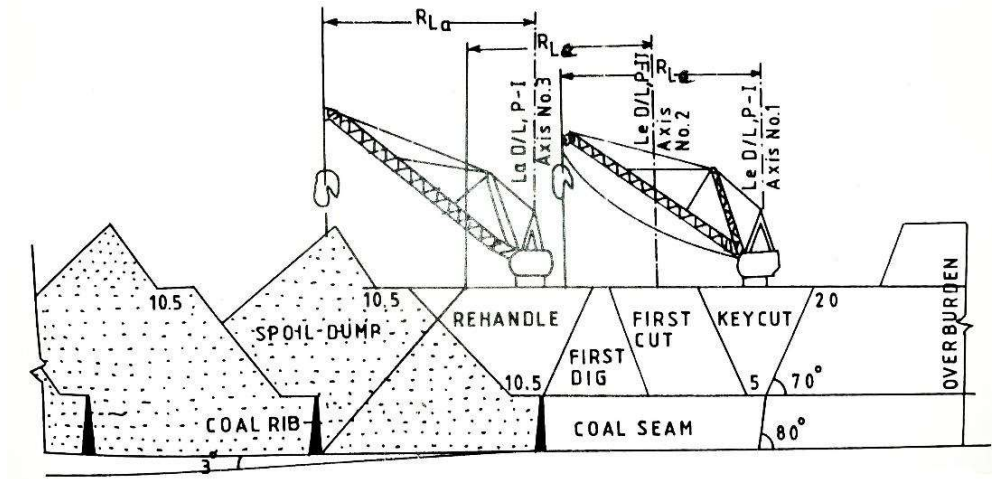


Figure 2.10: Cross-section showing draglines in horizontal tandem

Figure 2.10 describes draglines cuts sections, dump sections, seam inclination, positions and travel axis of the draglines deployed in horizontal tandem operation.



Figure 2.11: Two draglines working in horizontal tandem with key terms elaborated. (Modified from Mousa and Rai,2015)

Applicability of horizontal tandem operation

The horizontal tandem operation is suitable where the coal seam gradient is mild and the overburden layers are constant throughout. According to Rzhovsky, 1987 horizontal tandem operation is beneficial when a higher rate of coal production is required through wider cut width with two or three cuts and where additional spoil reach is required to take wider cut width.

Another condition which is suitable for horizontal tandem is that the dragline bench height should not exceed the digging depth of the dragline. It is also particularly suitable where there are highwall or spoil heap stability problems are present.

Advantages of horizontal tandem operation

The principal advantage of the horizontal tandem method is that wider cut excavation is possible. Wider cut widths will have several benefits like a high rate of coal exposure, rehandle percentage decreased for wider strips (as the cross-sectional area of strip cuts increases and rehandle cross-sectional area is almost the same for the same mining method), and a reduction in time losses on standby and unproductive moves (deadheading frequency) of dragline and excavators used in the coal extraction.

Another advantage is coal losses in the rib is reduced; hence more space is available for excavators used in coal extraction and hence safer condition near the coal rib side.

All the ancillary operations, such as drilling and blasting, and preparation of access roads to the highwall, can be supervised easily as all the heavy earth moving machine operations are going on the same bench, resulting in better utilisation of HEMM and thus better profitability for the mines. Mine and equipment scheduling is easier because each strip takes a longer time to complete. Marching of the dragline at the end of the cut is easier than in vertical tandem because the dragline will be sitting at a higher level.

Productivity is increased due to less swing angle and fewer problems due to dumping height.

Limitations of horizontal tandem operation

With an increase in cut width, there are some negative impacts associated with it. A wider cut width will result in a greater swing angle, which will reduce productivity. According to Rzhevsky (1987), specific consumption of explosives also increases with wider cut width. Smaller cut widths which are less than 60 m may not be

suitable for the horizontal tandem operation (Rai, Kishore, and Nath, 1999). However, this negative impact is minimized by its advantages, which were previously mentioned.

Another issue with horizontal tandem is that workload (cross-sectional areas of the cuts) should be distributed in proportion to the annual output capability of individual draglines for synchronisation (Erdem and Celebi, 1999). A horizontal distance of approximately 200 m should be maintained between two draglines for safety, which sometimes creates problems when strike length is lesser.

2.8.2.2 Vertical tandem operation

Where the coal seam lies at a depth that is beyond the capability of a single dragline, two draglines can be deployed in vertical tandem operation in the same pit. In vertical tandem operation (figure 2.12 and 2.13), the main overburden bench is worked in two vertical benches, i.e., the upper bench (top bench) and lower bench (main bench), in synchronism. One dragline deployed on the upper bench is called the leading (primary/independent) dragline, and another dragline on the lower bench is called the lagging (secondary/dependent) dragline. The upper bench is always kept ahead of the lower bench. The working of these two vertical lifts is tied up and has interference in

working. The overburden material of the upper bench is cast nearer to the decoaled highwall, which involves maximum rehandling.

In vertical tandem operation, the height of stripping benches increases, and the overburden rehandle volume decreases. Vertical tandem operation is a combined method of simple side casting, advanced benching, and extended bench. Both the draglines always operate below their levels. In this method of stripping, the leading dragline operates from the top of the upper bench, strips down to the upper bench, and side casts the spoil into the decoaled area to form a level pad (extend bench) for the lagging dragline. In this case, the leading dragline (on the upper bench) forms the bench for the lagging dragline on the lower bench, which first excavates the lower bench overburden with various cuts and then rehandles the dumped spoil into the decoaled area to a greater height and distance sitting on spoil side.

Figure 2.12 and 2.13 describes the stripping sequence of the draglines deployed in vertical tandem operations. The leading dragline on the upper bench seat at position Le-D/L, P-I, excavates the upper bench overburden and moves in the same dragline (Le-D/L, P-I) axis. Then the lagging dragline moves on the lower bench excavates the key cut from position La-D/L, P-I, axis no. 1, and side casts the spoil into the decoaled area. After completing the key cut, the lagging dragline marches towards the decoaled area to position La-D/L, P-II, axis no. 2, to excavate the first and second dig, respectively in the end cut position in order to expose the coal seam. After this, the lagging dragline marches towards the spoil side and sits on it position La-D/L, P-III, axis no. 3 to rehandle the spoils for a greater height and distance to expose the coal seam fully. Upon completion of rehandling, the dragline moves again to the key cut position and repeats the basic process again.

Figure 2.13 describes the dragline cuts sections, dump sections, seam inclination, positions and travel axis of the draglines deployed in vertical tandem operation.

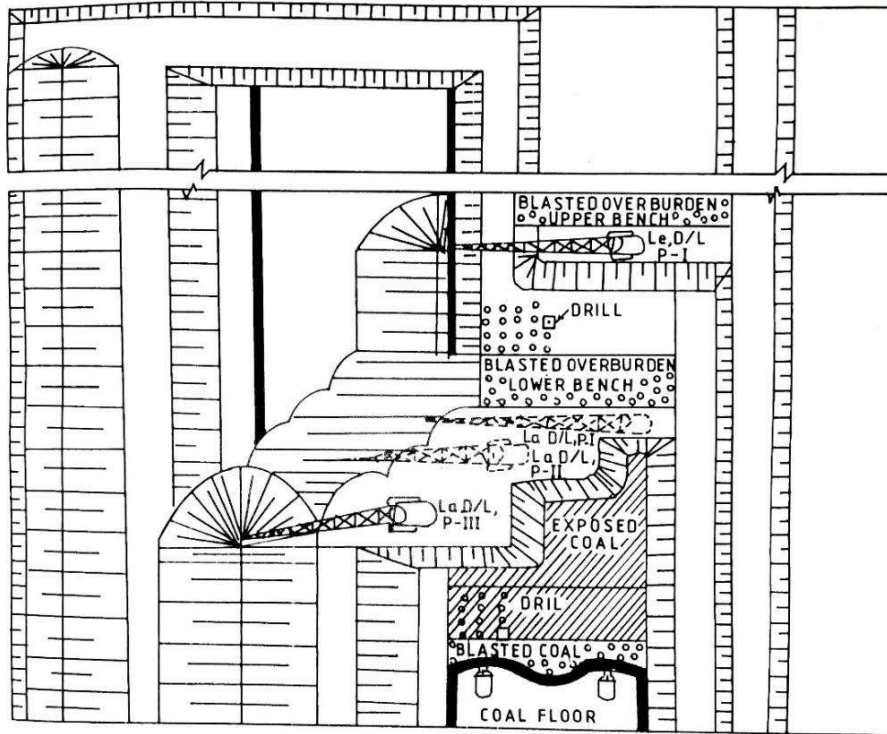


Figure 2.12: Plan of mining system in vertical tandem.

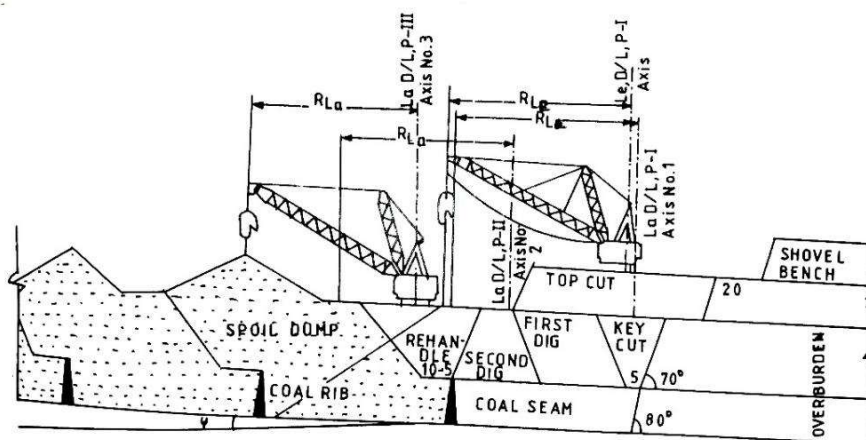


Figure 2.13: Cross-section showing draglines in vertical tandem.



Figure 2.14: Two draglines working in vertical tandem at Bina mine of NCL.

Different modes of vertical tandem

In the vertical tandem mode 1, the leading dragline is deployed on the upper bench for removal of the upper bench material (top cut) and comes back to the lower bench to excavate the key cut in the lower bench also. The lagging dragline deployed on the lower bench to excavate the first dig, second dig and rehandle parts of the material. Whereas in the vertical tandem mode 2, the leading dragline deployed on the upper bench only to excavate top cut and advances in the upper bench only. The second dragline (lagging) is deployed on the lower bench to excavate the key cut next to the key cut, i.e., first dig, second dig (as the cases prevail) and rehandle some parts of the material.

Applicability of vertical tandem operation

The tandem operation of the dragline in vertical may be considered where the rate of coal exposure needed is very high (Rzhevsky,1987; Rai, 1990), justified by increasing the height of the stripping bench. Another suitable condition is when the accommodation of material available is such that the dragline sitting at a lower bench height does not face any problem of required dumping height (Rai, 1990). The shovel capacity is not

matching with dragline capacity and is unable to provide sufficient working space for the dragline.

Advantages of vertical tandem operation

The main feature of the vertical tandem operation of draglines is its ability to do deep digging. This makes it possible to increase the height of the stripping bench Chaoji and Dey, 2000. Increasing bench height will raise the production capacity of the draglines, decreases rehandling, and increase the coal production rate. Other merits of vertical tandem operation include increases in operational flexibility.

Limitations of the vertical tandem operation

With the increase in the digging depth of the draglines beyond 40 m, problem is experienced by the dragline operators in filling the dragline bucket because of its non-visibility and floating tendency (Rai, Kishore and Nath, 2000). Also, in deep digging conditions, the hoist time of the bucket becomes critical by exceeding the loaded swing time (Johnson, 1974). This adversely affects the productivity of the dragline.

Another issue is that the existence of two or more large stripping units, together with the complexity of the stripping method, makes the sequencing of operations more difficult and thus challenging (Erdem and Celebi, 1998).

Comparison of single dragline and tandem dragline operation

The concept of tandem operation of draglines, especially on longer face lengths, has recently acquired immense popularity with the expansion of mines for higher-rated outputs in order to maximise the coal exposure and reduce the rehandling factor (Singh and Rai, 1998). This is due to issues with the extended bench method and the fact that the use of draglines operating singly does not produce coal at the needed rate.

Dragline operating in tandem has benefits in terms of decreased idle marching, greater coal recovery, decreased coal dilution, and improved quality control of coal. Additionally, there are safer working conditions close to the coal rib side and less loss of coal in the ribs (Lal, Agarwal and Rai, 1988).

Learmont (1989) conducted a thorough analysis of comparisons between a single dragline and a combination of two draglines operating in tandem, in various depths and cut widths of overburden, and he concluded that tandem dragline systems exhibit lower operating costs than single dragline systems. Greater dragline reach is required at deeper overburden depths, which raises investment costs per unit of capacity.

Similarly, when the cut width of the strip increases, a single dragline's reach is limited by its fixed boom length (Chironis, 1986). Hence, the cut width of the strip can be increased by using two draglines in horizontal tandem on the same bench. This will cause less frequent movements of draglines, will be economic, and, therefore, will increase the mineral capacity of the quarry (Rzhevsky, 1987).

Fishler (1987) found out that the operating radius necessary for the dragline is significantly decreased by using a tandem machine with an intermediate extended bench. In this view, tandem dragline operation may be more cost effective for most applications since it maximizes flexibility while lowering costs and hazards.

2.8.3 Multi-seam methods

The thicknesses of the overburden and interburdens affect the choice of a suitable digging method in multi-seam operations. The order of the different dragline positions and coal mining is more difficult in a multi-seam operation; these are usually critical to the overall performance of the strip mine operation. Multi-seam operation is completed using a combined different digging method. Waste removal often involves a mix of

highwall and lowwall dragline passes. Two common methods for a typical three seam operation are 1. single highwall and double lowwall, and 2. double highwall and single lowwall.

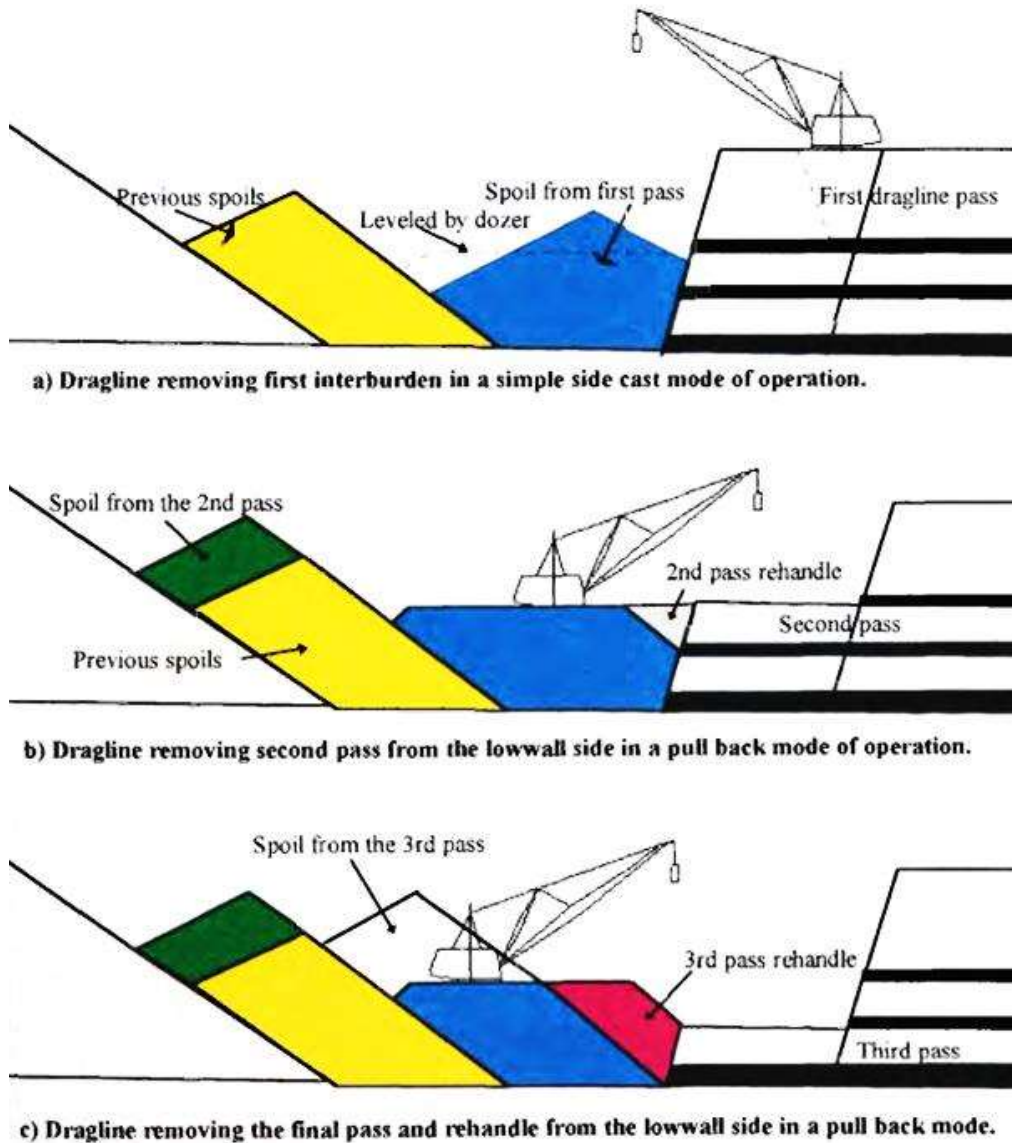


Figure 2.15: Three seam operation: Single highwall and double lowwall method. (Mirabediny,1998).