

Dragline cycle time analysis

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Draglines operate in a cyclic nature. Excluding the infrequent walking, a dragline spends its major operational time by digging the dirt and paying it out on a spoil pile. Considering the fact that a dragline performs tens of thousands of cycles per year, it is evident that even a small reduction in a single cycle time would result in a significant increase in productivity. Thus, it is to the benefit of a mine that dragline cycles need to be critically analyzed and corrective measures be taken. Although there exist different opinions on what segments constitute a dragline cycle, in this study it is accepted that a dragline cycle is composed of the following phases: (i) Filling the bucket by dragging it towards the dragline; (ii) Swinging the loaded bucket along a predetermined arc; (iii) Paying out the dirt onto a spoil pile; (iv) Swinging the empty bucket back to excavation face; and (v) Positioning the bucket to re-load. The study is based on field investigation conducted on six draglines with different capacities and operating modes. Stopwatch study is performed. Influence of cut dimensions, nature of material excavated, mode of digging, type of bucket employed, swing angle, operators' judgements and condition of dragline on cycle time are analyzed. The results are presented by tabular data and illustrations.

Keywords: Cycle time, Dragline, Drag-dependency, Hoist-dependency, Swing-dependency

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Introduction

Demand of energy is continuously increasing. Coal, which is the most homogeneously spread raw material throughout the earth's crust, is one of the most sought after fossil fuels. A considerable portion of coal is produced by surface mining methods. The economics of scale extraction methods are highly mechanized and equipments with huge capacity are utilized.

Draglines have been abundantly used in coal mining for decades, either as stripper or as stripper and coal extractor. Draglines are the most expensive equipments possessing certain inherent advantages; hence they must be operated at the 24 h for highest productivity levels. A dragline can be said to have a simple routine of work, which is composed of digging and walking. Mine design team has little control on walking, which is a steady process. Almost all walking draglines take a step of approx. 2 m within a period of 0.75-1 min. The design of strip panels, equipped with a specific unit with one operator's room on the desired side or with two on both sides and the management's strategy in coal loading operation, largely affects the frequency and the length of long deadheading periods, when unit is unproductive. Digging is controllable, and a repetitive process, which mainly consists of filling, swinging the loaded bucket along a circular arc of predetermined length, dumping, swinging back, and repositioning the bucket for the next bite. Transition between successive components cannot be sharply distinguished and, therefore, there is no common agreement as to what components constitute a dragline cycle. In its simplest form, a typical cycle comprises of filling, swing to (full) and dumping, and swings back (empty) and positioning. A cycle, however, is described as composition of filling, swing to (full), dumping and swing back (empty) to the cut face¹⁻⁴. One of the approaches adds one more component, which is positioning of the bucket or preparation to drag⁵⁻⁷.

Methodology

Objectives

Main objectives of the study are: i) Determining components of a dragline cycle; ii) Analyzing bucket filling process and time spent during this process; iii) Establishing correlation between loaded swing angle and swing time; iv) Analyzing dumping process and the time spent during this process; v) Establishing the correlation

Table 1—Characteristics of draglines and panels on which they are deployed

Draglines	Bucket capacity (m ³)	Cut width (m)	Cut depth (m)	Mode of operation at the time of visit	Overburden characteristics
DL1	22.9	75	25	Bench preparation	Blasted marl and conglomerate
DL2	24.5	50	30	Bridge preparation	Rehandled marl
DL3	24.5	65	25	Bridge preparation	Unblasted limestone
DL4	25.2	60	12	Direct excavation	Blasted marl
DL5	49.7	88	32	Working on bridge	Rehandled marl
DL6	53.5	50	30	Direct casting	Unblasted clayey marl

between back swing angle and swing time; vi) Analyzing the differences between loaded swing and back swing processes; vii) Analyzing repositioning and time spent during this process; and viii) Introducing conditions that determine swing, hoist or drag dependent cycles.

The objectives were analyzed for key cutting, main cutting and chop cutting. By key cutting, the alignment and slope of the new highwall is secured and another free surface is created for excavating the main cut. The key cut, when completed, takes the shape of a trough, which is confined at the bottom to approx. the width of the bucket. The remaining material is dug and cast with the dragline located on main cut position, as close to the spoil piles as possible. Thus, the maximum horizontal reach of the dragline is utilized. In chop cutting, the working level of the dragline is lowered by a bench, which is cut one pit in advance of the working pit, below the natural surface.

Methodology Types

Out of nine dragline units operating at various surface mines in Turkey, six were visited to look into their characteristics and mode of operation (Table 1). At the time of visit, DL1 was positioned at the corner of a new panel and preparing a bench to work on. DL2 and DL3 were again sitting at the starting point of a new block and constructing a bridge for extended benching operation. DL4 was operating in direct casting mode on a fairly dipping coal seam. The machine spoiled all the material and the coal on the pad behind itself where a rope shovel was employed to load trucks. DL5 was practising rehandling on a bridge, at the end of a block. Finally, DL6 was operating in direct casting mode, spoiling the waste on a spoil pile, clear of the coal seam.

None of the dragline was equipped with a duty-cycle recording and data acquisition systems. For this reason, a precision stopwatch with 10 lap functions was used for recording dragline cycle components. Dragline swing angles were measured at a sensitivity level of 5°. The circle along which the dragline can make a full turn was divided into intervals of 5°. By recording the starting and finishing intervals, swing angles were determined (Fig. 1).

In order to analyze the influence of location of a particular digging point on the time spent for filling the bucket, another method was adopted. The cut was divided into regions on the basis of proximity to the point on which the dragline is located. Thus the planes (Fig. 2) were divided into three regions, horizontal (near, middle and far) and vertical (top, middle and bottom). When it is considered that dragline cuts are designed in the same manner, it can be safe to assume that the dimensions can be eliminated. For instance, under normal operating circumstances the farthest point a dragline can reach is the vertical projection of the boom sheave on the cut. Likewise the deepest point for a dragline is the one on which the limit of the hoist rope is reached.

Discrimination of Cycle Time Components

One of the main difficulties in recording a dragline's cycle time is discriminating successive components from each other. They really seem interconnected. For instance, swing to and dumping appear as two successive parts of a single operation as do swing back and repositioning. At the boundary of any two phases, all the operators used the drag and hoist levers and swing pedals more clearly and more sharply. Since a dragline's response to an operator's moves takes some seconds, the method developed during data gathering phase was the continual observation of the bucket.

Filling phase commenced when the bucket had started to drag in towards the dragline. The phase of swing started when the bucket cleared off the ground. Dumping phase began when the mouth of the bucket inclined

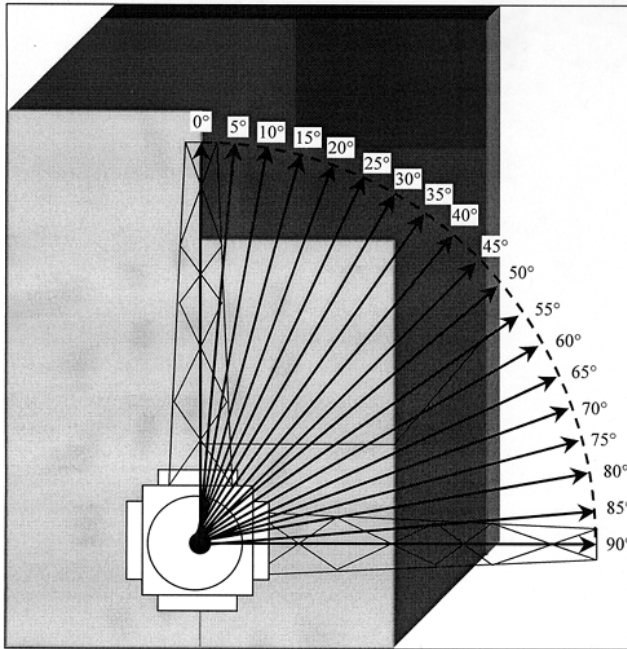


Fig. 1—The methodology of dividing the swing circle into 5° intervals

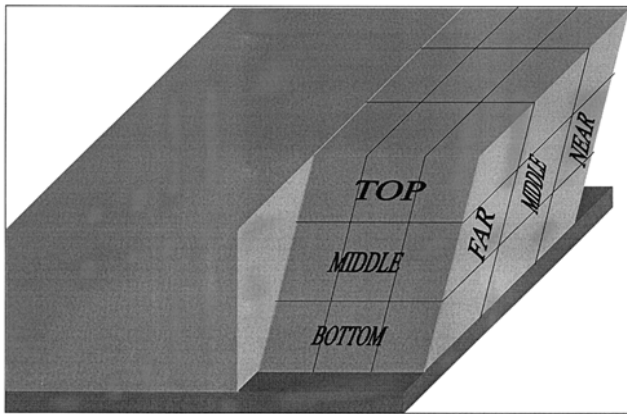


Fig. 2—Separation of the cut into horizontal and vertical regions

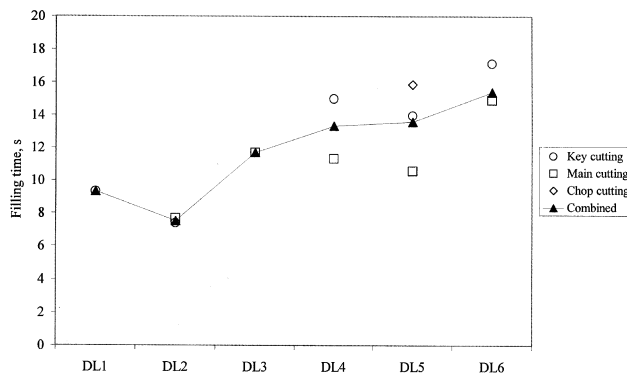


Fig. 3—Filling time as a function of bucket capacity for all operating modes

down and the material casted down. Swing back phase started when the bucket was relieved from momentary fixed suspension and accelerated towards cut face. Finally, transition to repositioning phase is discriminated by the conscious efforts of the operator in finding a suitable location for the bucket to position for the start of the next filling cycle. It must be noted that in this particular phase the boom can still be swinging back slowly.

Case Study

The aim of the present study was to discover the ways to reduce cycle time and, thus, to increase the productivity of the stripping draglines by some significant percentage. In this study, field observations were conducted at six dragline panels to analyze the components of cycle time.

Filling

There exists a positive correlation between bucket capacity and filling time. The larger the bucket, the greater becomes the time it takes to fill (Fig. 3).

The criterion employed for classifying draglines were the horizontal and vertical proximity of the point on which the bucket penetrates the cut face for filling. The cut was divided into blocks of 2-D pairs such as top-near or far-bottom. Data from key, main and chop cutting practices reveal that bucket filling time increases with the distance of penetration point (Figs 4-9). However, it should be noted here that DL5, though having a larger capacity, fills the bucket faster than DL4. This could be attributed to the fact that DL5 operated on rehandled material, which was easier to fill.

A similar behaviour was observed in main cutting practices. Filling time is positively correlated to the vertical (Fig. 7) and horizontal proximity (Fig. 8) of the bucket penetration point. Time spent at this operation increases with going away from the dragline.

Filling time has shown significant deviations, most of which are attributable to the following causes:

- Failing to fill the bucket at the first attempt due to which, it is released back and another attempt is made until the operator is satisfied with the filling.
- Drag rope limit is reached. Similar to above, while dragging in towards the dragline, drag limit switch interrupts the operation, as the bucket gets too close. In case the bucket is not full, the operator may decide to bypass the limit switch and continue to drag the bucket in slow and gentle manner.
- Hard bands of dirt, especially when unblasted, may significantly retard the filling process.

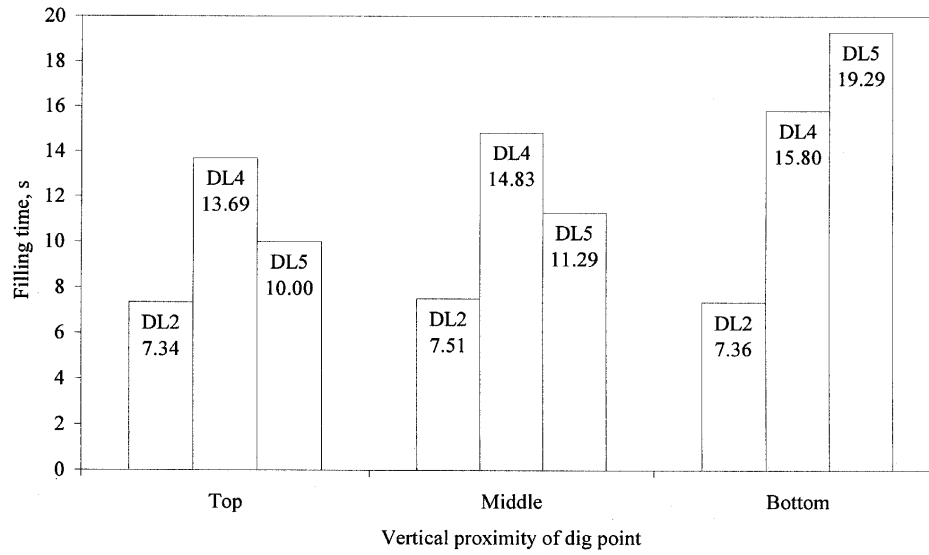


Fig. 4—Filling time as a function of depth of dig point for key cutting

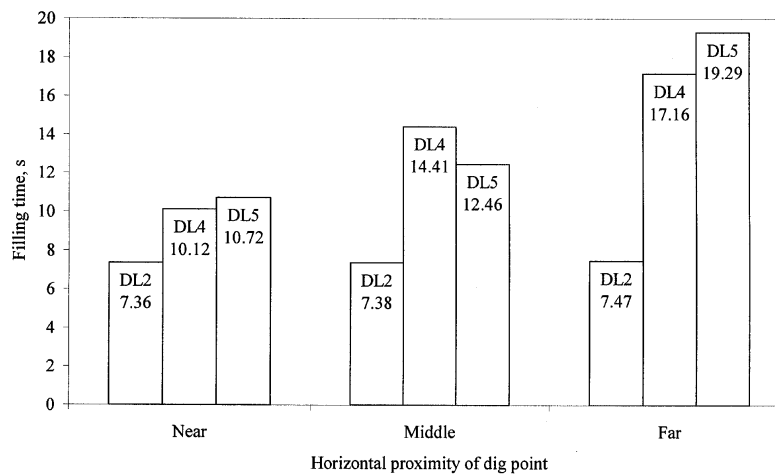


Fig. 5 — Filling time as a function of nearness of dig point for key cutting

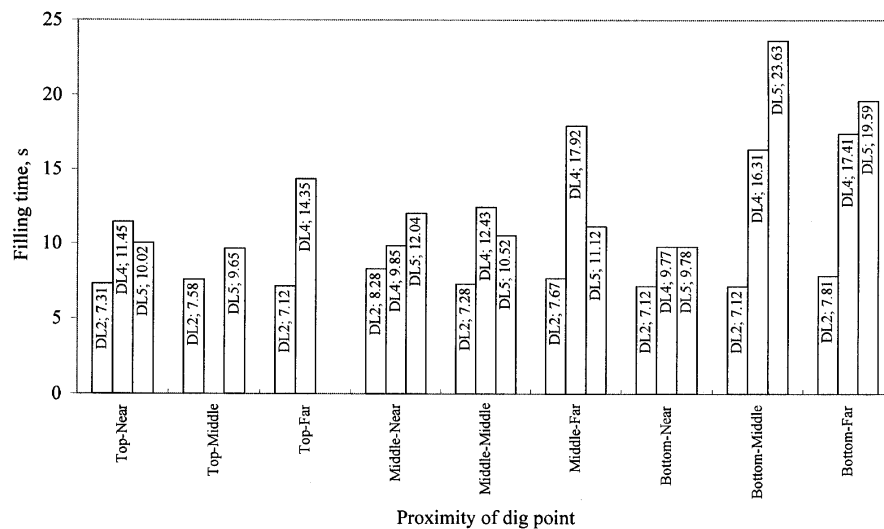


Fig. 6—Filling time as a function of 2-D proximity of dig point for key cutting

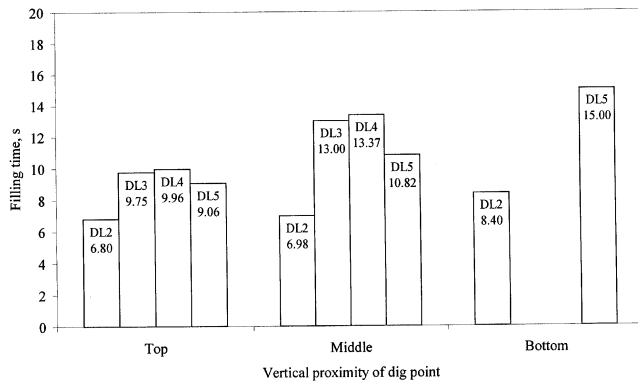


Fig. 7—Filling time as a function of depth of dig point for main cutting

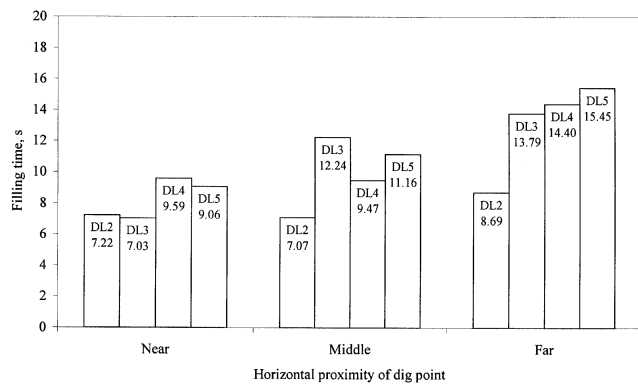


Fig. 8—Filling time as a function of nearness of dig point for main cutting

(d) Influence of environmental heat can by no means be overlooked. Operators normally tend to slow down the whole cycle, especially in the afternoon when the ambient temperature rises significantly.

(e) Digging near the cut walls increases the filling time. Operators try to shape the new highwall by careful and smooth movements of the bucket.

(f) Digging near the cut bottom on the top of the coal seam again increases the filling time. Operators work at the bottom with the intention of not diluting the coal with waste.

(g) In key cutting, when the operator is deep digging, the cycles tend to become hoist-dependent, which implies that the bucket is to be hoisted first to clear off the ground and then the boom starts swinging.

(h) The operator continues to drag the bucket towards the dragline even if bucket may have been filled at the start of the drag phase. Operator decides to lift the bucket at a specific point along the track on which the centre of gravity of the filled bucket would make it lean backwards.

(i) The operator drags the bucket along a curved, diagonal track rather than dragging along a straight route.

(j) Wet and sticky material resists proper filling of the bucket.

Swing To and Swing Back

The time spent during loaded and back swinging

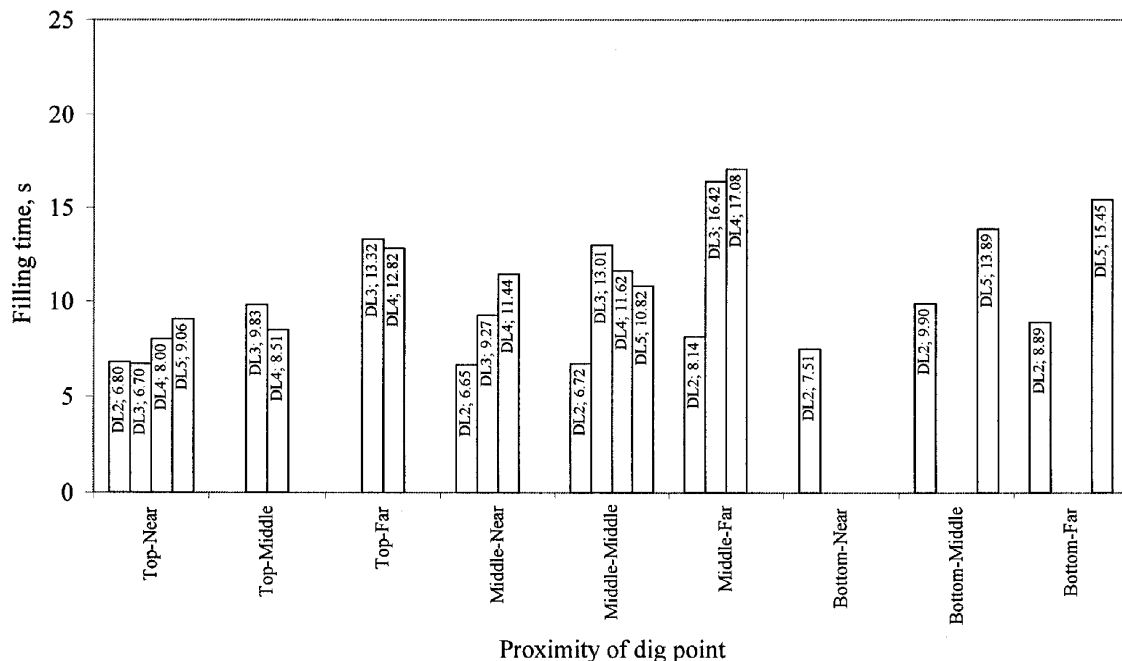


Fig. 9—Filling time as a function of 2-D proximity of dig point for main cutting

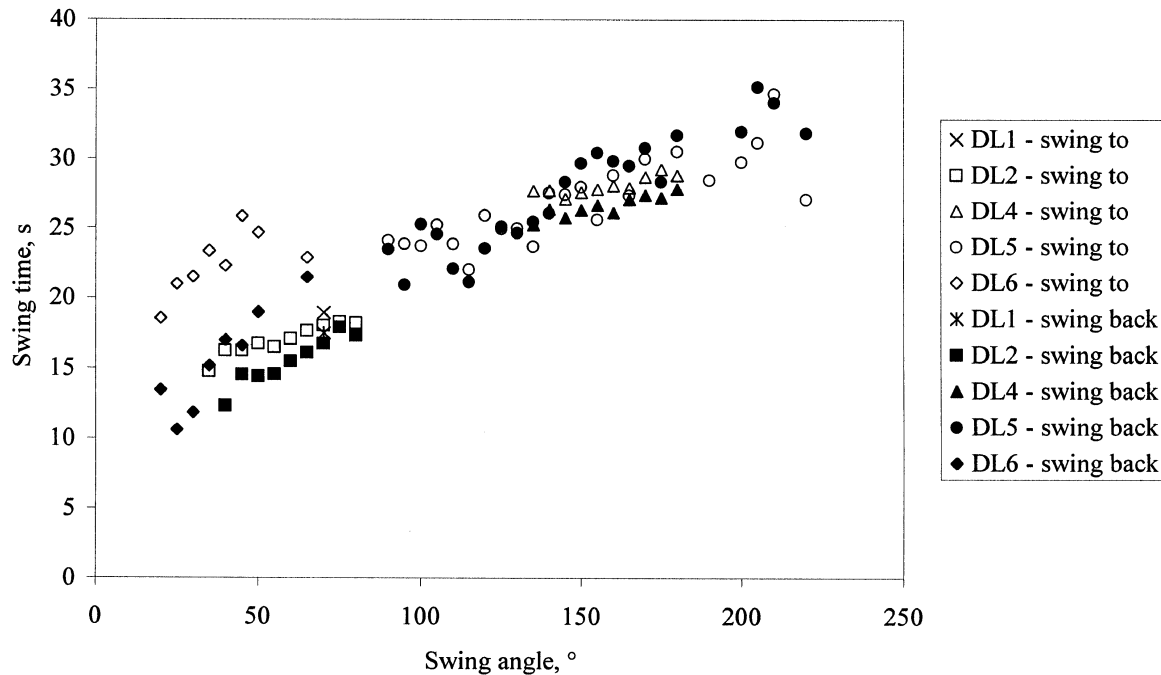


Fig. 10—Loaded and back swing times as a function of swing angle on key cutting

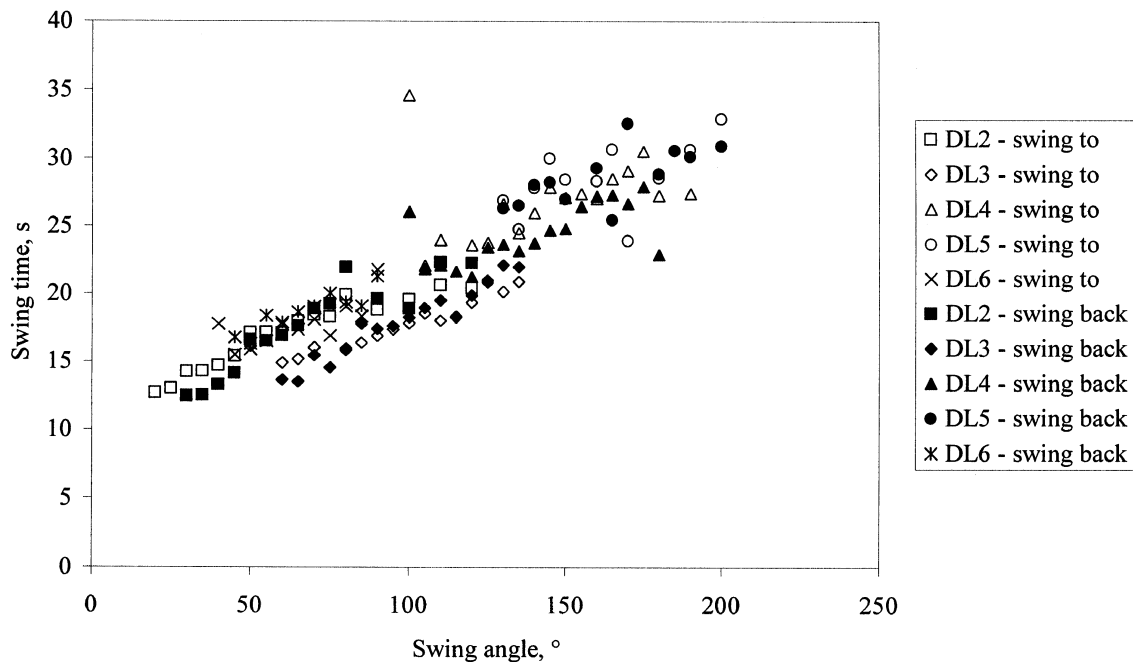


Fig. 11—Loaded and back swing times as a function of swing angle on chop cutting

phases were observed, recorded, averaged and grouped at 5° swing angle intervals for various modes of excavation. On all modes of excavation, there exists a strong positive correlation between swing angle and swing time for key cutting (Fig. 10), main cutting (Fig. 11) and chop cutting (Fig. 12). It can be observed that swing backward times are slightly less (~1-2 sec) than those of swing forward attributed to the less load carried by the boom when swinging backward.

To better visualise the case study, related data were normalised and swing time was plotted against swing angle for key cutting (Fig. 13), main cutting (Fig. 14) and chop cutting (Fig. 15). It can be observed that

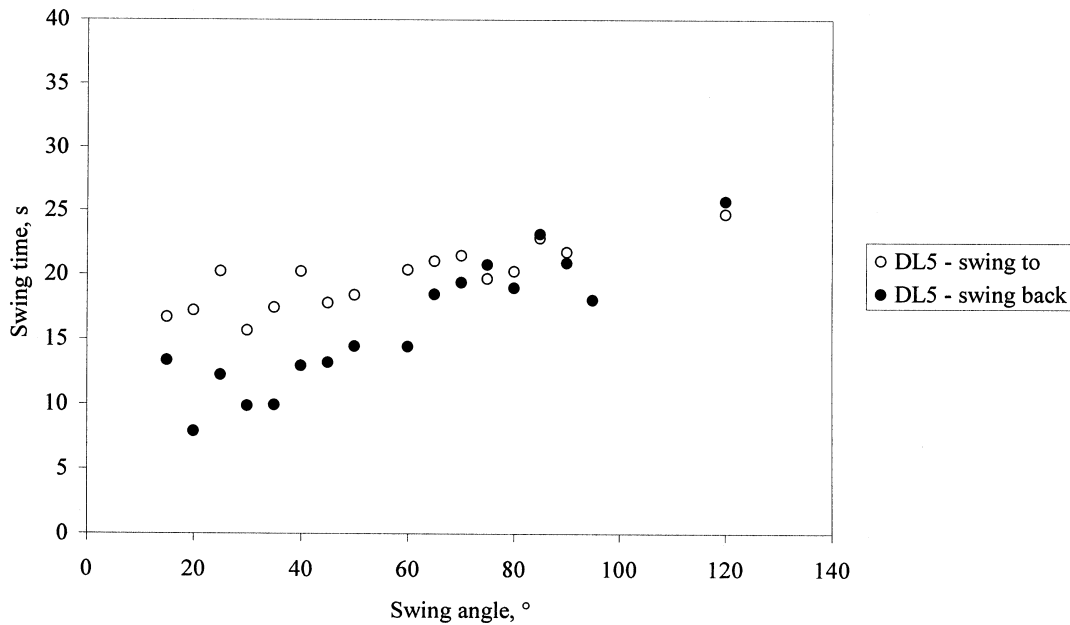


Fig. 12—Loaded and back swing times as a function of swing angle on main cutting

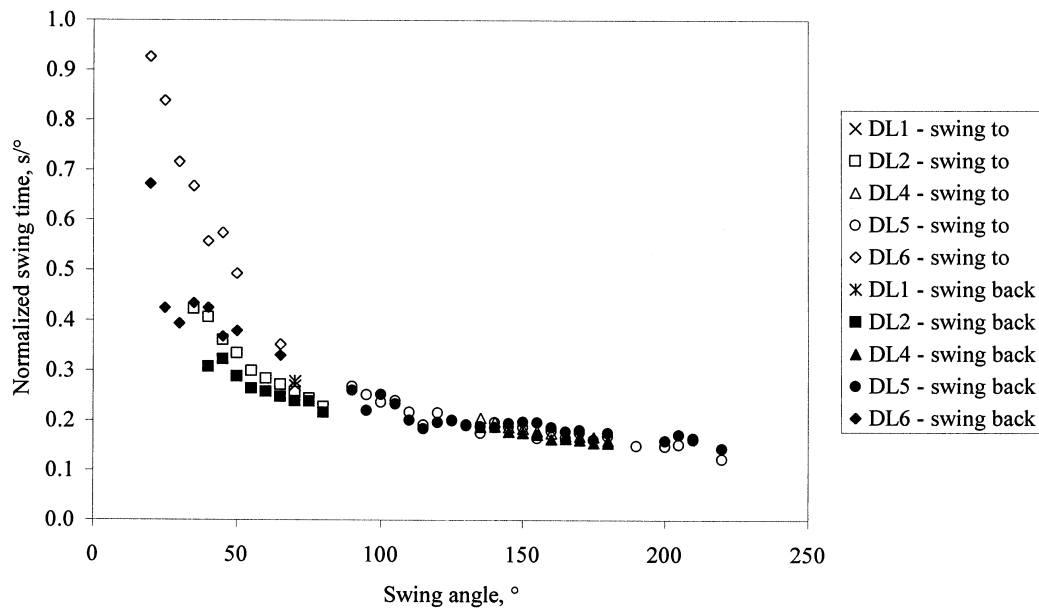


Fig. 13—Normalized loaded and back swing times as a function of swing angle on key cutting

normalised swing time approaches a constant value after nearly 50° of swing angle. Assuming that none of the operations was hoist-dependent and the angular acceleration of the boom is disregarded, this particular situation indicates that cycles with small swing angles are actually drag-dependent. Therefore, in the cycles with small swing angles, hoist and swing movements must actually have been retarded intentionally to allow for the drag payout move to coincide with them at the dump point. This, in turn, is corroborated with the result that cycles with small angles are not necessarily taking as short time as it would span. Thus, a better spoiling practice should avoid such experience.

Statistical analysis of the data (Figs 10-12) reveals that a line of regression (Figs 16, 17), which depicts the

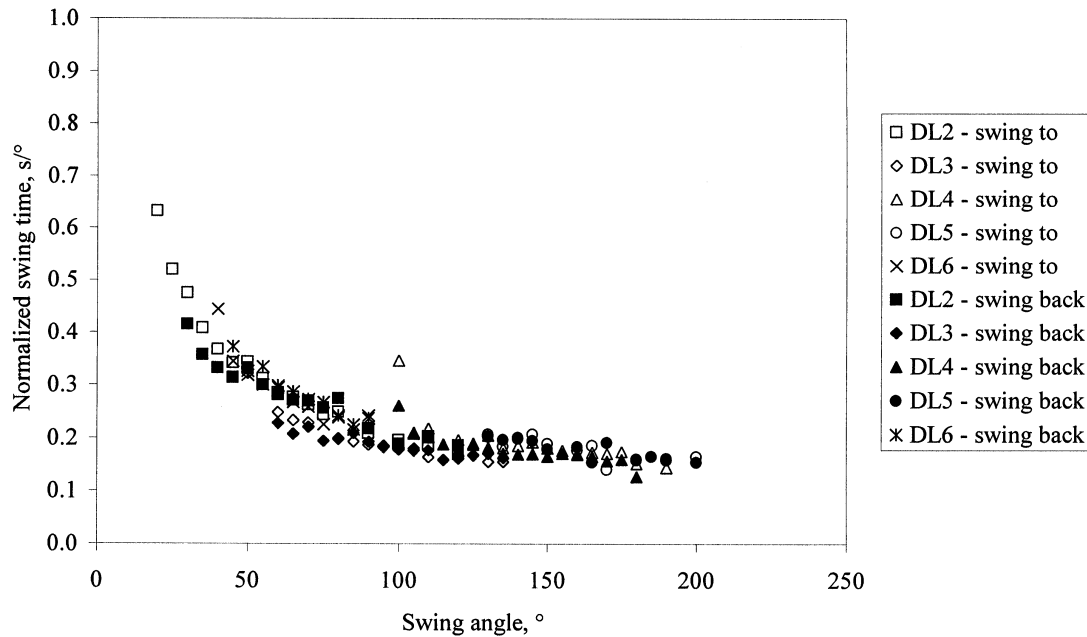


Fig. 14—Normalized loaded and back swing times as a function of swing angle on main cutting

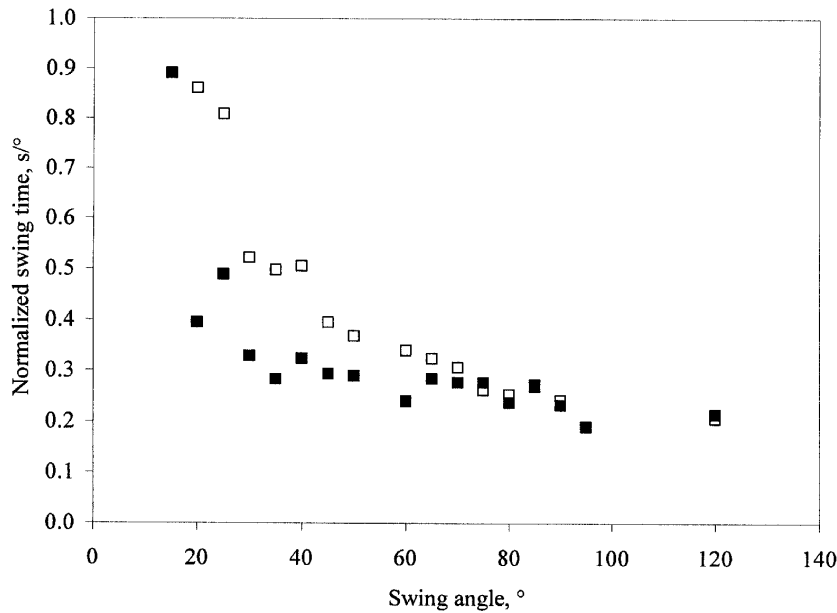


Fig. 15—Normalized loaded and back swing times as a function of swing angle on chop cutting

relationship of dependency between swing angle and swing time is not passing through the origin and if the data were to be extrapolated, it appears that for a 0° of swing approx. 10 to 13 sec are needed. This controversial situation can be attributed to the phenomenon of dependency among independent movements namely, swinging, hoisting, and paying out⁶.

To establish the relationship between swing angle and elapsed time in loaded and back swing phases separately, data were re-handled and statistically evaluated (Fig. 16). The data (Fig. 17) reveal an irrefutable relationship between swing angle and swing time. A regression equation is fitted with an acceptable degree of fit (Table 2).

Loaded and back swing times have also shown large deviations due to the following field observations: (a) In some cycles the swing back and drag payout processes were not properly synchronised. The operator starts

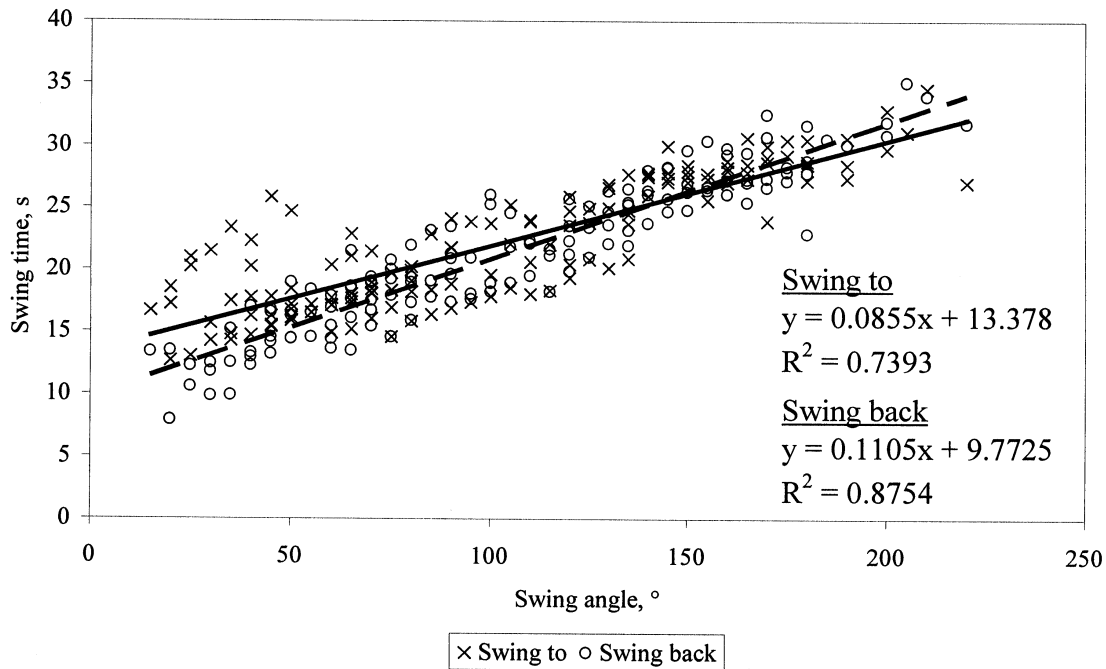


Fig. 16—Swing time as a function of swing angle on loaded and back swing cycles

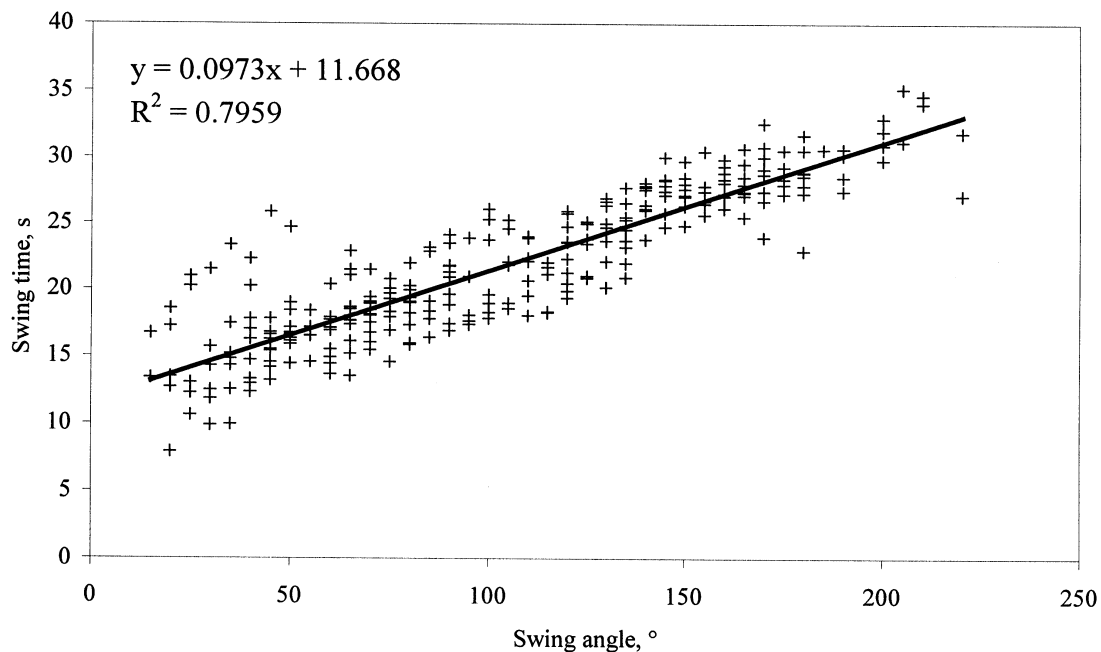


Fig. 17—Swing time as a function of swing angle for all modes of excavation

releasing the drag rope after the swing back is completed, thus adding a few seconds in the cycle time; and (b) In swing back phase, the bucket landed on an obstructed place, such as, the wall of the key cut.

Dumping

Larger buckets may require longer time to dump or the operator may speed up or retard the process. Dumping time (Fig. 18) seems to be within 3-5 sec for all modes of excavation, which is slightly less than those published previously^{2,4}.

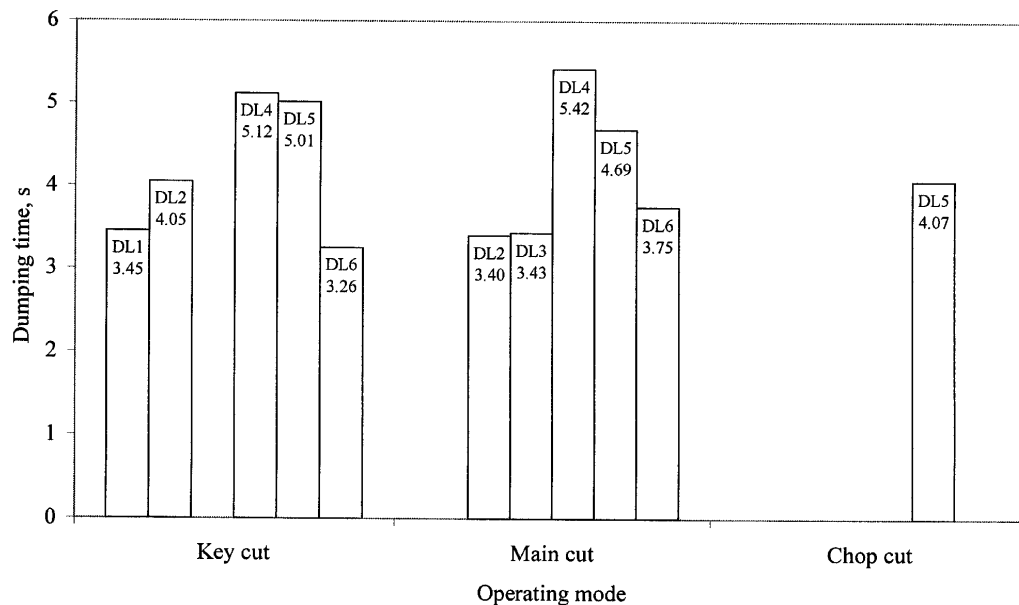


Fig. 18—Dumping time for all modes of excavation

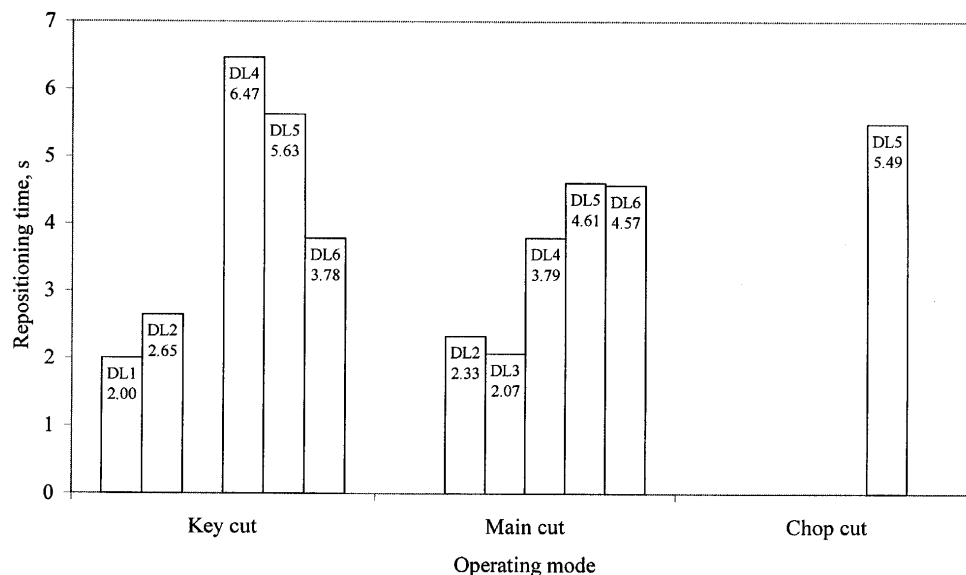


Fig. 19—Repositioning time for all modes of excavation

Table 2—Results of regression analyses on swing time

Operating mode	Regression equation	Degree of fit (R^2 , %)
	$y = \text{swing time, (s)}$ $x = \text{swing angle, (}^\circ\text{)}$	
Chop cutting – swing to	$y = 0.0708x + 15.727$	73.01
Chop cutting – swing back	$y = 0.1546x + 7.005$	83.18
Key cutting – swing to	$y = 0.0742x + 16.003$	74.46
Key cutting – swing back	$y = 0.1125x + 10.223$	91.98
Main cutting – swing to	$y = 0.1057x + 10.039$	85.30
Main cutting – swing back	$y = 0.1031x + 10.170$	82.58

Repositioning

Repositioning time (Fig. 19) for key cutting is longer by 1-2 sec, than other modes of excavation. A few operator related reasons attributed for repositioning times are summarised as: (a) The operator consciously seeks a proper point at the dig face to begin the filling phase rather than landing it at the point where the bucket was lifted in the previous cycle; (b) The dig face is obstructed or partly hidden to the operator such as at the foot of the

key cut, due to which, one operates the levers cautiously; and (c) The operator attempts to use the bucket as a pendulum to reach a specific point on the dig face, which is lying beyond the reach of the dragline.

Conclusions

Analysing dragline cycle time, it was observed that filling time is positively correlated to bucket capacity and the proximity of penetration point. A likely reason of prolonged times is the continual dragging of the bucket inwards even after it is full. Therefore, filling time could be reduced by equipping the dragline with systems, by which the bucket could be hoisted right after it is fully loaded. Filling time is greatly influenced with the fragmentation of the material excavated and the ease of digging. Proper bench blasting must be provided and high degree of material fragmentation be ensured. Besides, filling time can also be improved by maintaining the bucket in good condition. A proper angle of attack between the teeth of the bucket and the ground and sharp teeth are essential.

Swing times (both loaded and back) are positively correlated to swing angles. Since swing times may not be reduced, the dragline panel design may be so optimized that dragline swing angles are kept at a minimum. The dragline cycles are mostly swing-dependent. However, in the case of narrow and deep key cuts, cycles tended to be hoist-dependent. Further, when the swing angles were smaller than 50°, cycles became drag-dependent, which took longer than larger-swing-angle cycles due to longer payout processes. Such situation needs to be avoided. Dumping time and repositioning time fluctuate within a narrow time interval. As such they may be considered to be constants for various modes of operation (key cut, main cut and chop cut). Operator's experience plays a significant role in filling, dumping and repositioning phases.

Acknowledgments

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