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The Effects of Operational Parameters on the Output Efficiency of the Bucket Wheel Excavator

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ABSTRACT: In this study, the effects of operational parameters, such as slewing speed, bench height, terrace height, block width, etc., on output efficiency are discussed and the interrelationships between these parameters are investigated. The main theme of the study is the definition of the optimum values of operational parameters for the C-frame-type BWE Sch (2300 /5) x 32, which is in operation in Kislakoy open cast mine, Elbistan. A model is presented by means of which the optimal operational parameters may be selected. Finally, total efficiencies were calculated for two generalized bench geometries in which the slope height varied according to the necessary place between the bench belt conveyor and the toe of the side bench.

1 INTRODUCTION

The effective output of a mining system is based on the degree of utilization of its production capacity. This is the quotient of the effective to the optimum capacity. The effective utilization of a Bucket Wheel Excavator (BWE) mining system is defined as the product of the output efficiency and the time factor. The output efficiency depends on the effective output of the BWE and on the operation downtime of the transport and dumping systems. The time factor of a BWE system is expressed as net operating time divided by the total calendar time. Rasper (1975) shows that the output efficiency of the system is the product of the individual efficiencies. This is referred to as the total efficiency.

1.1 *Symbols*

The following symbols are used in this paper:
T|E= efficiency of the BWE, (%)
TIT = efficiency of the transport system, (%)
Tio = efficiency of the dumping system, (%)
T\H = time factor, (%)
Qdf = effective output, (bank m^3/h)
Q(h = theoretical output, (bank m^3/h)
I = bucket capacity, (m^3)
s = bucket discharges per minute (1 /minute)
f = material swell factor, (f=l + swell)
V = volume of the excavating block, (bank m^3)
SUMT = total operating time, (s)
SSTS = time of slewing process, (s)
SSTV = adjustment time for slice advance, (s)
STSE = adjustment time for terrace advance, (s)
TBE = adjustment time for block advance, (s)
TNS = time required for switch-on, (s)
H_N = net operating time, (h)
He = total calendar time, (h)
Hs = slewing lime for one slice, (s)
H_A = adjustment time for one slice advance, (s)
HT = adjustment time for one terrace advance, (s)
HB = adjustment time for one block advance, (s)
Ns = number of slices,
NTS = total number of slices,
N_T = number of terraces,
NB = number of blocks,
NTB = total number of blocks,
LT = length of slice, (m)
L_A = length of block, (m)
L_B = length of bench, (m)
a = slew angle (degrees)
dMiN = min. slewing angle (degrees)
Tws = angle of working slope, (degrees)
CXMAX = max. slewing angle (degrees)
hi = height of terrace, (m)
hs = height of working slope, (m)
bo= width of slice at (a) angle, (m)
b_a = depth of slice at (a) angle, (m)
t_s = max. depth of slice, (m)
t_x = direction of travel,
to = depth of slice at (a) angle, (m)
to = depth of slice at (0°), (m)
V_B = slew speed at (a) angle, (m/s)
V_s = average slewing speed, (m/s)
W_B = width of block (m)

2 DEFINITION OF OUTPUT EFFICIENCY OF BWE

Georgen (1983) designates the effective output of the BWE as the effective output divided by the theoretical output.

$$\eta_{(total)} = \eta_E \eta_T \eta_D \quad (1)$$

$$\eta_E = Q_{eff} / Q_{th} \quad (2)$$

$$\eta_H = H_N / H_C \quad (3)$$

The theoretical and effective outputs of the BWE can be expressed as follows:

$$Q_{th} = I\, S\, 60 / f \quad (4)$$

$$Q_{eff} = V\, 3600 / SUMT \quad (5)$$

Total operating time can be defined as follows:

$$SUMT = SSTS + SSTV + STSE + TBE + TNS \quad (6)$$

$$SSTS = H_S N_S N_T N_B \quad (7)$$

$$H_S = L_T / V_S \quad (8)$$

A terrace is formed when the advancement of the BW is repeated several times in a horizontal direction only between the limiting angles, while the height of the wheel position remains unchanged. The width of this terrace is the block width. The length of terrace (L_A) in the highest cut of the BW is determined by the boom length of the BWE and the inclination of the working slope (Figure 1).

The depth of slice must not exceed the largest cutting depth of the buckets (Durst & Vogt, 1988). For normal operation, the depth of a slice in the travel direction of the machine at slewing angle a = 0, should not exceed 90% of max ts.

$$t_\alpha = t_0 \cos\alpha \quad (9)$$

The cut area of a terrace cut is sickle-shaped. It is formed by two circles of the new and old cuts separated in a horizontal plane by the distance to resulting from the advance of the BWE with a slew angle a of 0°. Slice depths decrease continually with increasing slewing angles, away from the excavator travel direction, and become zero at a slewing angle of 90° (Figure 2). By introduction of the "cosine <p control" in the slewing process, i.e., by increasing the slewing speed according to equation (10), by the reciprocal value of cos φ, higher efficiencies are obtained:

$$V_\alpha = Q_{th} / 60\, h_T\, t_\alpha \quad (10)$$

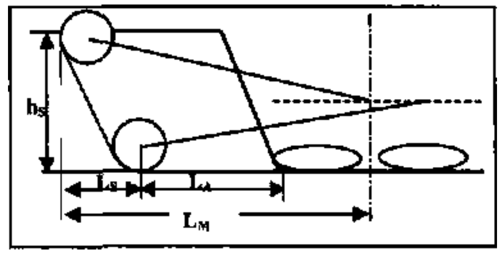

Figure 1. Length of terrace for face block excavation

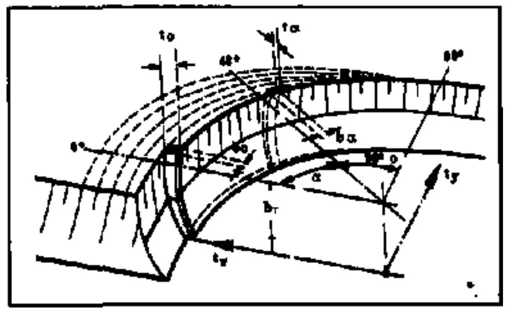

Figure 2. Reduction of slice depth with increasing slewing angle (Durst & Vogt, 1988)

The number of slices, number of terraces and number of blocks can be expressed as follows:

$$N_S = L_A / t_0 \quad (11)$$

$$L_A = L_M - L_S \quad (12)$$

$$N_T = h_S / h_T \quad (13)$$

$$N_B = L_B / L_A \quad (14)$$

The adjustment time for slice advance, adjustment time for terrace advance and adjustment time for block advance can be defined as follows:

$$SSTV = H_A N_{TS} \quad (15)$$

$$N_{TS} = N_S N_T N_B \quad (16)$$

$$STSE = H_T N_T \quad (17)$$

$$TBE = H_B N_{TB} \quad (18)$$

3 MODELLING OF OPERATING PROCESS

The parameters affecting the output efficiency of the BWE mining system can be divided into three categories. These are the material properties to be excavated and conveyed, the mechanical parameters of the mining equipment and the operational parameters. Panagiotou (1990) describes a mathematical digging model as the functions of geotechnical parameters of the ground to be dug (i.e., strength, fracture characteristics, etc.), the parameters of the excavated material (i.e., unit weight, swell factor, etc.), the operational parameters of the excavating equipment, the physical parameters of the excavating equipment (i.e., teeth and bucket geometry, available digging power, etc.) and the time during which changes in the excavation system take effect.

The purpose of the model created for mis study is to match the physical and operational characteristics of the excavating equipment to the mode of excavation (Figure 3), based on the appropnate equations governing the geometry of the excavation and the operation of the equipment. The model requires the following input parameters:

Bench height,
Bench length,
Block width,
Block length,
Angle of working slope,
Time required for switch-on.
Adjustment time for one block advance,
Adjustment time for one slice advance,
Adjustment time for one terrace advance,
Depth of shoe at (0°),
Number of terraces,
Height of terrace,
Number of blocks,
Slewing speed,
Slewing angle of BW boom İn horizontal direction,
Distance between bench belt conveyor and bottom of side slope,
Crawler width of BWE,
BW boom length.

3.1 *Application of the Model*

The model simulates the operation of the C frame BWE with a cordless-type boom, excavating according to the full block terrace cut method at the Kislakoy open cast mine, Elbistan, Turkey. The mine is equipped with six identical bucket wheel excavators of the type Sch Rs (2300/5) x 32.

A set of constraints that express limitations resulting from interaction of the BWE and pit geometry is incorporated in the model. The crawler widdi of the BWE determines the dimensions of the box cut and the shifting distance of the bench belt conveyor. The maximum height of the working slope is 32 m. The maximum depth of slice at (0°) is 1.15 m. The minimum distance between the bench belt conveyor and the bottom of the side slope is 15 m. Possible slewing speeds are between 5 and 30 m/min. The slewing speeds to obtain the rated output (3000 bank m^3/h) with respect to different terrace heights are given in Table 1. Other constraints direct the model to produce a logical design.

3.2 *Determination of Optimum Operational Parameters*

The effects of the different values of the block widths and terrace heights on the effective output of the BWE are investigated İn order to determine the optimum values of these parameters. The model shows that the effective output increases as the block width increases up to 58 m (Figure 4) and the terrace height increases up to 7 m (Figure 5). The first goal of the model proposed İs to maximize the total efficiency of the BWE. For this reason, it is applied to the first bench of Kislakoy open cast mine to determine the optimum values of operational parameters. The model is based on the following assumptions: (1) the overburden formations in the first bench of the mine are diggable by the BWE; (2) the bench heights are multiples of 7 m; (3) the block width is 58 m; (4) the angle of the working slope is fixed at 54°; and (5) the efficiency of the transport and dumping system are assumed to be fixed.

Because the optimum values of the bench heights are multiples of 7 m, two different bench models are created - the bench height of the first scenario is 21 m and the bench height of the second scenario is 28 m. The development distance of the bench in the excavating direction is chosen as 240 m. The load factor, time factor and total efficiency are calculated for each scenario. Figure 7 and Figure 8 show the excavating sequences of BWE operation for the first scenario. The input data and the simulation run results are presented in Table 2 and Table 3. The results for the scenarios of the bench models are compared in Table 4.

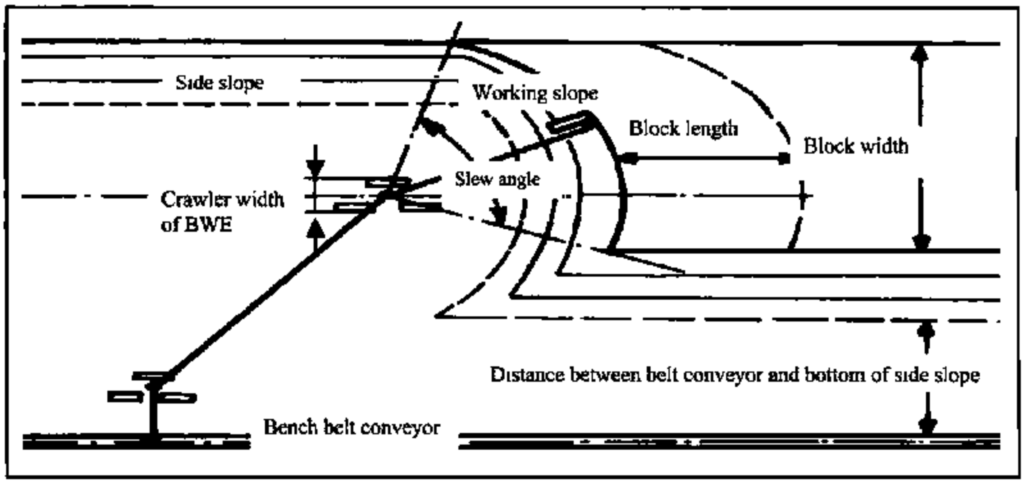

Figure 3. Physical and operational characteristics of the excavation.

Table 1 Slewing speeds to obtain rated output

Height of terrace (m)	Angle of slew (")								
	0	29	34	40	46	55	65	75	80
9	5 56	6.35	6.70	7 25	8 00	9 69	13.15	2147	63 74
8	6.25	7 15	7 54	8.16	900	10.90	14 79	24.15	7171
7	7.14	8.17	8.62	9.32	10.28	12.45	16.90	27.60	8196
6 125	8.16	9 33	9 85	10.66	M 75	14.23	19 32	31 54	93 66
6	8.33	9 53	10 05	10 88	12.00	14.53	19.72	32 20	95 61
5	10.00	11.43	12.06	13.05	14.40	17.43	23.66	38.64	114 74
4	12 50	14 29	15 08	16 32	17.99	21.79	29 58	48.30	143.42
3	16.67	19.06	20.10	21.76	23.99	29.06	39.44	64 40	191.23
2	25 00	28 58	30 16	32 64	35.99	43.59	59 16	96.59	286 84

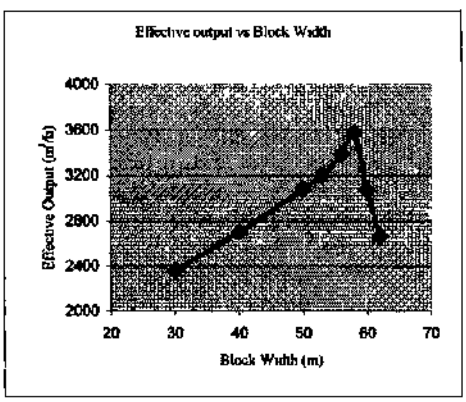

Figure 4. Effective output vs block width.

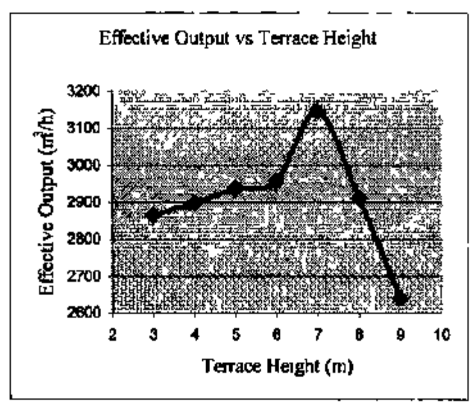

Figure 5 Effective output vs. terrace height.

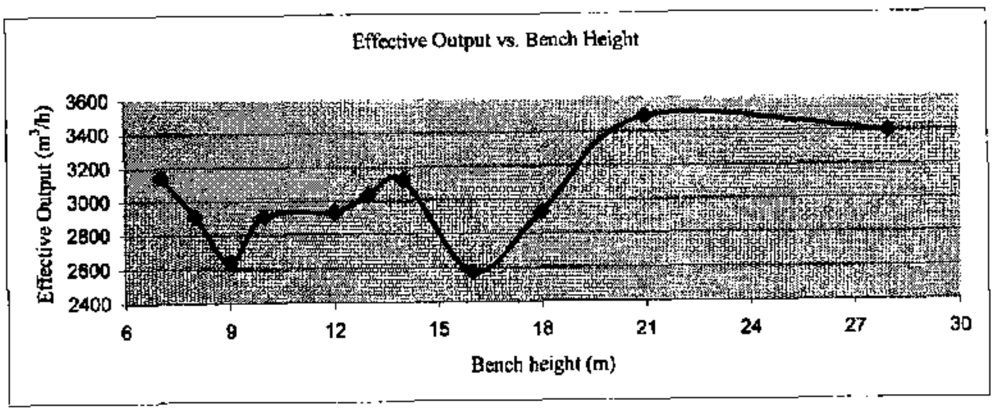

Figure 6. Effective output vs. bench height.

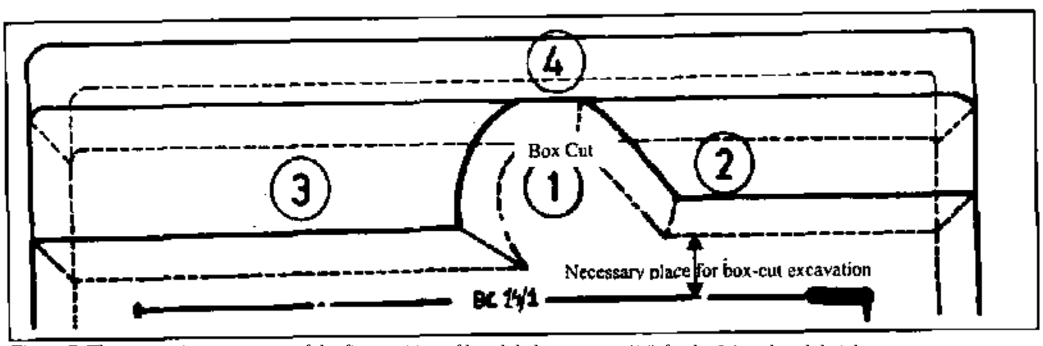

Figure 7. The excavation sequences of the first position of bench belt conveyor (14) for the 2 ! -m bench height.

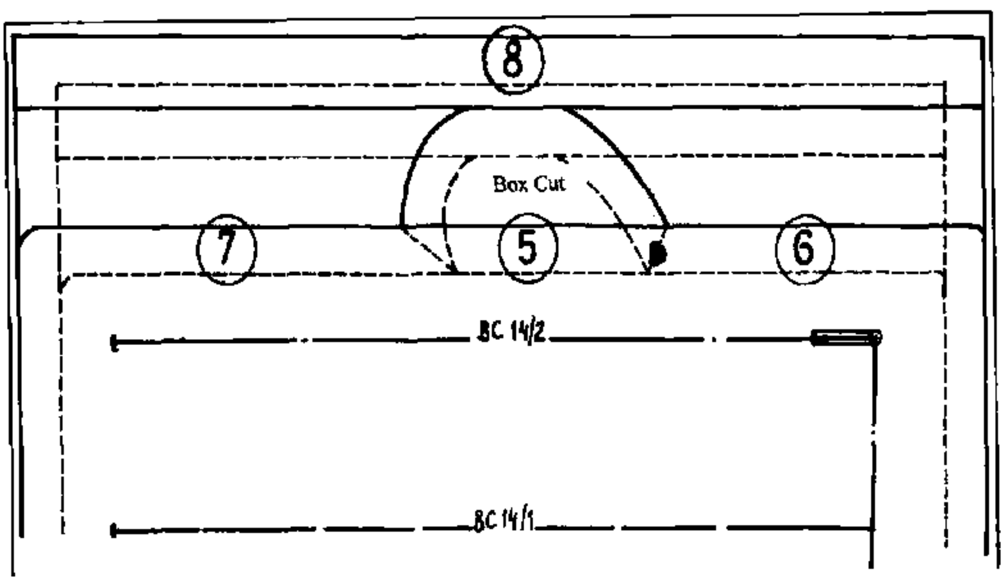

Figure 8. The excavation sequences of the second position of the bench belt conveyor for the 21-m bench height.

Table 2 Inpul data and the simulation run results for the 21-m bench height

Operation sequences	W_B (m)	V (m^1)	SUMT (h)	N_T	h_T (m)	$Q_{(}ff$ (bank mVh)	I F (%)
Block 1	48	88704	30 35	3	7	2923	0 78
Block 2	53	222600	64 73	3	7	3439	0 92
Block 3	58	389760	11701	3	7	3331	0 89
Block 4	34	428400	155 27	3	7	2759	0 74
BC Shifting for 80 m (32 h)							
Block 5	48	88704	30 35	3	7	2923	0 78
Block 6	50	227052	70 54	3	7	3219	0 86
Block 7	50	619920	225 12	3	7	2754	0 73
Block 8	30	110124	63 64	3	7	1730	0 46
BC Shifting for 80 m (32 h)							
Blockt	48	88704	30 35	3	7	2923	0 78
Block 2	50	222600	64 73	3	7	3439	0 92
Block 3	50	389760	11701	3	7	3331	0 89
Block 4	30	428400	155 27	3	7	2759	0 74
BC Shifting for 80 m (32 h)							
TOTAL		3221064	1124 37			2865	0 76

Table 3 Input data and the simulation run results for the 28-m bench height

Operation sequences	W_H (m)	V (m^3)	SUMT (h)	N_r	h_7 (m)	*QciT* (bank nrVh)	TIE (%)
Block 1	48	118272	39 82	4	7	2970	0 79
Block 2	53	296800	92 90	4	7	3195	0 85
Block 3	58	519680	170 68	4	7	3045	081
Block 4	23	79856	47 70	4	7	1647	045
BC Shifting for 60 m (32 h)							
Block 5	*48*	118272	39 82	4	7	2970	0 79
Block 6	53	227052	7107	4	7	3195	0 85
Block 7	58	599259	225 12	4	7	2662	071
BlockS	23	110124	63 64	4	7	1730	0 46
BC Shifting for 60 m (32 h)							
Block 1	48	345873	116 02	4	7	2981	0 80
Block 2	53	381901	116 68	4	7	3273	0 87
Block 3	58	417929	134 40	4	7	3110	0 83
Block 4	23	79856	47 74	4	7	1673	0 46
BC Shifting for 60 m (32 h)							
Block 1	48	118272	34 79		7	3400	091
Block 2	53	227052	69 62		7	3261	0 87
Block 3	58	619920	225 12		7	2754	0 73
Block 4	23	110124	63 64		7	1730	046
BC Shifting for 60 m (32 h)							
TOTAL		4370239	1558 76			2804	0 75

Table 4 Efficiency values of the first and second scenanos

	Excavation time 00	BC shifting time 00	He (h)	(%)		HT (%)
1 Scenario (bench height - 2 1 m)	1124 37	96	1220 37	0 76	0 92	0 70
2 Scenario (bench height - 28 m)	1558 76	128	1686 76	0 75	0 92	0 69

4 CONCLUSIONS

The main findings of this study are the following:

There are strict relationships between slice depth (to), slewing angle (a) and terrace height (hy). Digging capacity can be constant only if the slewing speed is increased continuously by the reciprocal value of cos a. Therefore, BWE operators should use the automatic cosine cp control process.

2. Possible slewing speed is limited to 30 m/min in view of the braking forces that occur when reversing direction. Therefore, the slewing angle should be limited up to 75° to obtain maximum digging capacity.

3. The terrace height should be selected so as to be as high as possible within the range of 6-8 m. Maximum digging capacity will be obtained if the terrace height is chosen as 7 m.

4. The block height should be chosen as a multiple of 7 m to obtain maximum BWE efficiency. The results obtained from the model indicate that block height is to be at least 21 m to ensure higher total efficiency of the BWE system.

5.-The necessary place between the bench belt conveyor and the toe of the side bench to begin the box cut after each belt conveyor operation strictly affects the shifting distance of the bench belt conveyor. A distance of 30 m is enough between the bench belt conveyor and the toe of the side bench to begin the box cut up to a bench height of 24 m. If the bench height is greater than 24 m, the necessary place between the bench belt conveyor and the toe of the side bench to begin the box cut after each belt conveyor operation should be at least 40 m.

6. When the slope height is greater than 24 m, the bench conveyor shifting distance can be a maximum of 60 m. If a slope height between 14 m and 24 m is chosen, it is possible to obtain a bench conveyor shifting distance of 80 m.

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