Chapter 6
Excavation Equipment

6. Introduction:

This chapter will deal with some types of equipment that are used to excavate earth and related materials and to lift Items frequently used in construction operations. The equipment includes the following:

– Power shovels (مجرفات آلية).
– Backhoes (جرافات).
– Cranes (رافعات).
– Trenching machines (آلات حفر الخنادق).
– Wheel-mounted belt loaders (احزمة رافعة مدولبة).

The first three machines belong to a group identified as the ***Power Crane and Shovel Association*** family. This association has supervised studies and tests which provided information related to the performance, operating conditions, production rates, economic life and cost of owning and operating such equipment.

The results of these studies have been published and are adopted as standards for such equipment. In this chapter we will study the Power Shovels.

6.1. Power Shovels:

Power shovels are used primarily to excavate earth and load it into trucks or tractor–pulled wagons or onto conveyer belts. They are capable of excavating all classes of earth, except solid rock, without prior loosening. They may be mounted on crawler trucks (crawler-mounted shovels), such shovels have very low travel speed but their wide treads give low soil pressures, which permit them to operate on soft ground. Fig. 6-1 illustrates a crawler-mounted shovel.
Power shovels may be mounted on rubber tired wheels.

Fig. 6-1 Illustrates a Crawler-Mounted Shovel

6.1.1. The Size of Power Shovels:

The size of a power shovel is indicated by the size of the dipper, expressed in cubic yards (cubic meters). In measuring the size of the dipper the earth is struck within the contour of the dipper, this is referred to as the ***struck volume***, as distinguished from the heaped volume which the dipper may pick up in loose soil. The bank-measure volume of a dipper will be less than the loose volume. If a 2cu-yd dipper, excavating a soil whose swell is 25%, is able to fill the dipper to its struck volume, the bank-measure volume will be:

$$(\textit{Bank Volume} = \frac{\textit{Loose Volume}}{1+swell} = \frac{2}{1.25} = 1.6\ cu-yd).$$

Power shovels are commonly available in sizes: 3/8, 1/2, 3/4, 1, 1.25, 1.5, 2 and 2.5cu-yd.

6.1.2. The Basic Parts and Operation of a Shovel:

The basic parts of a power shovel include:

1. Mounting (الحامل),
2. Cab (الحجرة).
3. Boom (ذراع التطويل).
4. Dipper stick (عصا المغرفة).
5. Dipper (المغرفة).
6. Hoist line (سلك الرفع).

These parts are illustrated in Fig. 6-2.

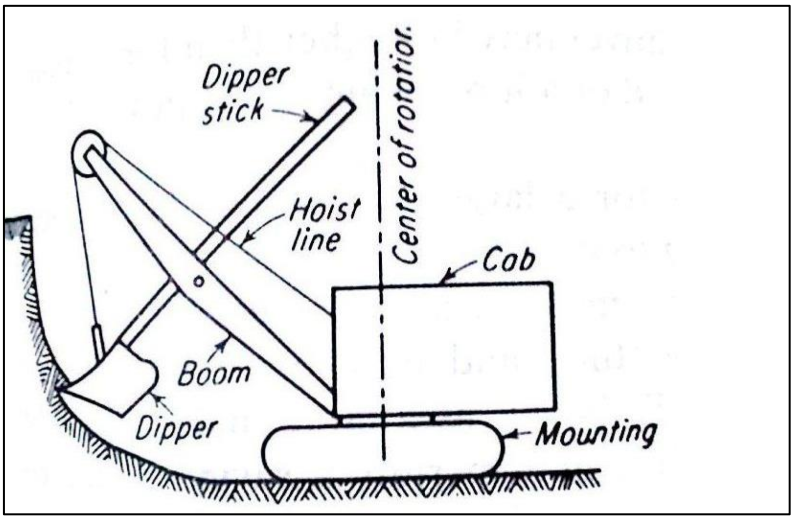

Fig. 6-2 Basic Parts of a Cable-Operated Power Shovel

With a shovel in the correct position (near the face of the earth to be excavated), the dipper is lowered to the floor of the pit, with the teeth pointing into the face.

A crowding force is applied through the shaft and at the same time tension is applied to the hoisting line to pull the dipper up the face of the pit.

If the depth of the face, referred to as ***the depth of cut***, is right the dipper will be filled as it reaches the top of the face. If the depth of the cut is too shallow, it will not be possible to fill the dipper completely without excessive crowding and hoisting tension. This subjects the equipment to excessive strain and reduces the output of the unit.

If the depth of the cut is greater than is required to fill the dipper, it will be necessary to reduce the depth of penetration of the dipper into the face if the full face is to be excavated or to start the excavation above the floor of the pit. The material left near the floor of the pit will be excavated after the upper portion of the face is removed.

6.1.3. Selecting the Type and Size of Power Shovels:

In selecting the type of shovels the prospective purchaser should consider the probable concentration of work to be performed. If there will be numerous small jobs in different locations, the mobility of the rubber-tired-mounted shovels will be a distinct advantage. If the work will be concentrated in large jobs, mobility will be of less importance and the crawler-mounted shovels will be more desirable. A crawler-mounted shovel usually is less expensive than the rubber-tired-mounted unit and can operate on ground surfaces which are not firm enough to support the latter type unit.

In selecting the size of a shovel, two primary factors should be considered:

1. The cost per cubic meter of material excavated
2. The job conditions under which the shovel will operate.

In estimating the cost per cubic meter, the following factors should be considered:-

1. The size of the job (larger job may justify the higher cost of a large shovel).
2. The cost of transporting a large shovel will be higher than for a small one.
3. The depreciation rate for a large shovel may be higher than for a small one, (especially if it is to be sold at the end of the job, because of the probable great difficulty of selling a large shovel).

4. The cost of downtime for repairs for a large shovel may be greater than for a small one (due to increased delays in obtaining parts for a large shovel, especially if the parts must be manufactured to order).
5. The combined cost of drilling, blasting and excavating rock for a large shovel may be less than for a small shovel, because a large shovel will handle bigger rock than a small one (this may permit a saving in the cost of drilling and blasting).
6. The cost of wages per cubic meter will be less for large shovels than for a small one.

The following job condition should be considered in selecting the size of a shovel:-

1. High lift (to deposit earth) from a basement or trench into trucks (at natural ground) will require a large shovel.
2. If blasted rock is to be excavated, large-size dipper will handle bigger rocks.
3. If the time for the completion of a project requires a high hourly output, a large shovel must be used.
4. The size of available hauling units should be considered in selecting the size of a shovel. If small hauling units (must be used), a small shovel is needed, whereas for large hauling units a large shovel is needed.
5. The weight limitation imposed by most countries for hauling on highways (may restrict the size of a shovel). Also, the clearance of bridges and under passes (may restrict the size).

6.1.4. Optimum Depth of Cut:

The optimum depth of a cut is the depth which produces the greatest output and at which the dipper comes up with a full load without undue-crowding. The optimum depth of cut varies with class of material (soil) and the size of dipper.

Values of optimum depths for various classes of soils and sizes of dippers are given in table (6-1).

Table (6-1) - Ideal Outputs of Cable-Operated Power Shovel, in Cubic meters Per 60-min hour, Bank Measure.

Class of material	Size shovel, cubic meter								
	0.3	0.4	0.6	0.8	1	1.2	1.4	1.6	2
Moist loam or high sand clay	1.1* 65**	1.4* 88**	1.6* 126**	1.8* 157**	2.0* 190**	2.1* 218**	2.2* 245**	2.4* 271**	2.6* 310**
Sand and gravel	1.1 61	1.4 84	1.6 118	1.8 153	2.0 178	2.1 206	2.2 229	2.4 252	2.6 298
Good common earth	1.4 54	1.7 73	2.1 103	2.4 134	2.6 160	2.8 183	2.9 206	3.1 229	3.4 268
Hard, tough clay	1.8 38	2.1 57	2.4 84	2.7 111	3.0 137	3.3 156	3.5 180	3.7 202	4.1 236
Well-blasted rock	— 30	— 46	— 72	— 95	— 118	— 137	— 156	— 175	— 210
Wet, sticky clay	1.8 19	2.1 30	2.4 53	2.7 73	3.0 91	3.3 110	3.5 125	3.7 141	4.0 175
Poorly blasted rock	— 11	— 19	— 38	— 57	— 73	— 88	— 107	— 122	— 149

* These values are the optimum depth of cut in meters.
** These values are the ideal outputs in cubic meters.
- Source: Power Crane and Shovel Association.

6.1.5. The Output of Power Shovels:

The output is affected by numerous factors such as the following:

1. Class of material.
2. Depth of cut.
3. Angle of swing.
4. Job condition.
5. Management condition.
6. Size of hauling units.
7. Skills of operator.
8. Physical condition of the shovel.

The output of a shovel should be expressed in cubic meters per hour (m^3/hr) based on bank-measure volume. (The capacity of a dipper is based on its struck volume. In excavating some classes of materials, it is possible for a dipper to pick up an amount which may exceed the struck volume. In order to obtain the bank-measure volume of a dipper the average loose volume should be divided by 1 plus the swell, expressed as a fraction).

$$Bank-Measure\ Volume\ of\ a\ Dipper = \frac{Loose\ Volume}{1+swell}$$

For example:-

If a $2m^3$-dipper, excavating material whose swell is 25%, will handle an average loose volume of $2.25m^3$, the bank-measure volume will be:

$$Bank-Measure\ Volume\ of\ a\ Dipper = \frac{2.25}{1+0.25} = 1.8m^3$$

If this shovel can make 2.5 cycles per min, the output will be:

$$Output = 2.5 \times 1.8 = 4.5m^3\ /\ min\ \ or\ 270m^3\ /\ hour$$

Table (6-1) gives the ideal outputs of power shovel (expressed in cubic meters **bank measures**) for various classes of materials based on digging at optimum depth with a 90^o swing and no delays.

6.1.5.1.The Effect of the Depth of Cut on the Output of a Power Shovel:

1) If the depth of the face is too shallow:-
   a) It will be difficult to fill the dipper in one pass up the face
   b) So the time per cycle will increase. When the operator make more than one pass to fill the dipper.
   c) Or he may carry a partly filled dipper to the hauling unit each cycle.
   d) In each case the output of the shovel will be reduced.

2) If the depth of the face is greater than the minimum required to fill the dipper.
   a) He may reduce the depth of penetration of the dipper into the face in order to fill the dipper in one full stroke. (This will increase the time for a cycle).
   b) He may be digging above the base of the face and then remove the lower portion later.
   c) He may run the dipper up the full to the face and let the excess earth spill down to the bottom of the face, to be picked up later.

So, any of the above procedures, will result in some lost time, based on the time required to fill the dipper when it is digging at optimum depth.
The percent of optimum depth of cut is obtained by dividing the actual depth of cut by the optimum depth for the given material and dipper, then multiplying the result by (100).

$$\% \ of \ optimum \ \ cut = \frac{Actual \ \ Depth}{Optimum \ \ Depth} \times 100$$

If the actual depth of cut is (1.8m) and the optimum depth is (3m), the percent of optimum depth of cut is

$$\% \ of \ optimum \ \ cut = \frac{1.8}{3} \times 100 = 60 \ \%$$

6.1.5.2.The Effect of the Angle of Swing on the Output of a Power Shovel:

The angle of swing is horizontal, expressed in degree, between the position of dipper when it is excavating and the position when it is discharging the load.
The total time in a cycle includes digging, swinging to the dumping position, dumping and returning to the digging position. If the angle of swing is increased the time for cycle will be increased and the output of the equipment will be decreased.
The conversion factor for depth of cut and angle of swing is illustrated in table (6-2).

Table (6-2) Conversion Factor for Depth of Cut and Angle of Swing

Angle of swing , deg.							Percent of Optimum Depth
180	150	120	90	75	60	45	
0.59	0.65	0.72	0.8	0.85	0.89	0.93	40
0.66	0.73	0.81	0.91	0.96	1.03	1.1	60
0.69	0.77	0.86	0.98	1.04	1.12	1.22	80
0.71	0.79	0.88	1.00	1.07	1.16	1.26	100
0.7	0.77	0.86	0.97	1.03	1.11	1.20	120
0.66	0.73	0.81	0.91	0.97	1.04	1.12	140
0.62	0.67	0.75	0.85	0.90	0.96	1.03	160

6.1.5.3.The Effect of the Job Conditions on the Output of a Power Shovel:

Every owner of a power shovel knows that no two excavation jobs are alike. There are certain conditions at every job over which the owner of the shovel has no control. Those conditions must be considered in estimating the probable output of a shovel.

Job conditions may be classified as excellent, good, fair and poor. There is no uniform standard which may be used as a guide in classifying a job. Each job planner must use his own judgment and experience, in deciding which condition best represents his job.

6.1.5.4. The Effect of the Management Conditions on the Output of a Power Shovel:

The attitude of the owner of a shovel in establishing the conditions under which a shovel is operated will affect the output of the shovel. While the owner may not be able to improve job conditions, he may take several steps to improve management conditions. Management conditions may be classified as excellent, good, fair and poor.

The effect of job and management conditions on the output of a power shovel is illustrated in table (6-3).

Table (6-3) Coefficient Related to Management and Job Conditions*

Job Conditions	Management Conditions			
	Excellent	Good	Fair	Poor
Excellent	0.84	0.81	0.76	0.70
Good	0.78	0.75	0.71	0.65
Fair	0.72	0.69	0.65	0.60
Poor	0.63	0.61	0.57	0.52

* Values are based on a 50-min per hour.

To calculate the Probable Output of a power shovel the ideal output obtained from table (6-1) must be multiplied by the $(D\text{-}A)_F$, $(J\text{-}M)_F$ and $(Time)_F$

$$\boldsymbol{Probable\ \ Output = Ideal\ Output \times \left(D_{cut}\ \&\ A_{swing}\right)_F \times \left(J\ \&\ M\right)_F \times \left(Time\right)_F}$$

Ex: 6-1:

A (1.6 m^3) power shovel is used to excavate a good common earth having an actual depth of (3.6m) and an angle of swing of (60^o). Calculate the Probable output of the power shovel in (m^3/hr bank volume).

Solution:-

From table (6-1), for (1.6m^3) power shovel, good common earth:

Ideal output= 229 m^3/hr, Optimum depth= 3.1m

$$\%\ of\ optimum\ \ cut = \frac{3.6}{3.1} \times 100 = 116.13\%$$

In table (6-2), there is no (116.13%) of optimum height for 60^o angle of swing; therefore, interpolation must be done:

$$\left(D_{cut}\ \text{-}\ A_{swing}\right)_F = F_1 + \left(F_2 - F_1\right)\left(\frac{D_R - D_1}{D_2 - D_1}\right)$$

From table (6-2), by interpolation for 116.13% between 100% and 120% of optimum height and 60^o angle of swing:

Optimum Depth %	Angle of Swing	Conversion Factor $\left(D_{cut}\ \&\ A_{swing}\right)_F$		$\left(D_{cut}\ \&\ A_{swing}\right)_F$
D_1=100	60^o	F_1=1.16	→	F_R =1.12
D_R=116.13	60^o	F_R		
D_2=120	60^o	F_2=1.11		

$$\left(D_{cut}\ \text{-}\ A_{swing}\right)_F = F_1 + \left(F_2 - F_1\right)\left(\frac{D_R - D_1}{D_2 - D_1}\right) = 1.16 + \left(1.11 - 1.16\right)\left(\frac{116.13 - 100}{120 - 100}\right)$$

$$\left(D_{cut}\ \text{-}\ A_{swing}\right)_F = 1.12$$

$$Probable\ \ Output = Ideal\ Output \times \left(D_{cut}\ \&\ A_{swing}\right)_F$$

$$Probable\ \ Output = 229 \times 1.12 = 256.5\ \ m^3\ /\ hr$$

The following example illustrates the use of the information given in tables (6-1) to (6-3):

Ex:6-2:

A (0.8 m^3) power shovel is used to excavate a hard, tough clay earth having an actual depth of (2.25m) and an angle of swing of (75^o). Calculate the probable output of the power shovel in (m^3/hr bank-measure volume), noting that the working hour is 50 min, the job conditions are fair and management conditions are good.

Solution:-

From table (6-1) the ideal output will be 111m^3/hr, the optimum depth is 2.7m.

$$\% \text{ of optimum cut} = \frac{2.25}{2.7} \times 100 = 83.33\%$$

From table (6-2), by interpolation for 83.33% between 80% and 100% of optimum height and 60^o angle of swing:

Optimum Depth %	Angle of Swing	Conversion Factor $(D_{cut} \,\&\, A_{swing})_F$		$(D_{cut} \,\&\, A_{swing})_F$
D_1=80	75^o	F_1=1.04	→	F_R =1.045
D_R=83.33	75^o	F_R		
D_2=100	75^o	F_2=1.07		

$$(D_{cut} - A_{swing})_F = F_1 + (F_2 - F_1)\left(\frac{D_R - D_1}{D_2 - D_1}\right) = 1.04 + (1.07 - 1.04)\left(\frac{83.33 - 80}{100 - 80}\right)$$

$$(D_{cut} - A_{swing})_F = 1.045$$

From table (6-3), for fair job and good management conditions:

$$(J \,\&\, M)_F = 0.69$$

$$\text{Probable Output} = \text{Ideal Output} \times (D_{cut} \,\&\, A_{swing})_F \times (J \,\&\, M)_F \times (Time)_F$$

$$\text{Probable Output} = 111 \times 1.045 \times 0.69 \times \frac{50}{60} = 66.7 \ m^3 / hr$$