INTRODUCTION

Hydraulic power is the key to the utility of many excavators.
CHAPTER 8. EXCAVATORS

INTRODUCTION

Hydraulic front shovels are used predominantly for hard digging above track level and for loading haul units.

Hydraulic hoe excavators are used primarily to excavate below natural surface of the ground on which the machine rests.

INTRODUCTION

The loader is a versatile piece of equipment designed to excavate at or above wheel/track level.

Unlike a shovel or hoe, to position the bucket to dump, a loader must maneuver and travel with the load.

They come in various models.
CHAPTER 8. EXCAVATORS

HYDRAULIC EXCAVATORS

HOE

WHEEL & TRACK LOADERS
The hydraulic control of machine components provides

- Faster cycle times.
- Outstanding control of attachments.
- High overall efficiency.
- Smoothness and ease of operation.
- Positive control that offers greater accuracy and precision.

Machines which make use of hydraulic pressure to develop bucket penetration into materials are classified by the digging motion of the bucket.

The hydraulically controlled boom and stick, to which the bucket is attached, may be mounted on either a crawler or a wheel tractor base.

A downward arc excavator is classified as a "hoe." It develops excavation breakout force by pulling the bucket toward the machine and curling the bucket inward.
INTRODUCTION

- An upward motion unit is known as a "front shovel." A shovel develops breakout force by crowding material away from the machine.

- The downward swing of a hoe dictates usage for excavating below the running gear.

- The boom of a shovel swings upward to load; therefore, the machine requires a material face above the running gear to work against.

EXCAVATOR PRODUCTION

Steps for Estimating Production:

1. Obtain the heaped bucket load volume (in lcy) from the manufacturers’ data sheet.

2. Apply a bucket fill factor based on the type of machine and the class material being excavated.
Steps for Estimating Production (cont’d):

3. Estimate a peak cycle time. This is a function of machine type and job conditions to angle of swing, depth of height of cut, and in the case of loaders, travel distance.

4. Apply an efficiency factor.

5. Conform the production units to the desired volume or weight (lcy to bcy or tons).

6. Calculate the production rate.
**EXCAVATOR PRODUCTION**

**Production Formula:**

\[
\text{Production} = \frac{3,600 \times Q \times F \times (\text{AS:D}) \times E}{t} \left( \frac{60}{60 - \text{hr}} \right) \left( \frac{1}{\text{Vol. Correction}} \right)
\]

- **Q** = heaped bucket capacity (lcy)
- **F** = bucket fill factor
- **AS:D** = angle of swing and depth (height) of cut correction
- **t** = cycle time in seconds
- **E** = efficiency (min per hour)

**Production formula (cont’d)**

Volume correction for loose volume to bank volume, \( \frac{1}{1 + \text{swell factor}} \)

For loose volume to tons, \( \frac{\text{loose unit weight, lb}}{2,000 \text{ lb/ton}} \)
FRONT SHOVELS

Front shovels are used predominately for hard digging above track level, and loading haul units.

The loading of shot rock would be a typical application.
A shovel is capable of developing a high breakout force.
The material being excavated should be such that it will stand with a fairly vertical face.
Crawler-mounted shovels have very slow travel speeds, less than 3 mph.

The size of a dragline is indicated by the size of the bucket, expressed in cubic yards (cu yd).
Struck Capacity: Volume actually enclosed by the bucket for no allowance for bucket teeth.
CHAPTER 8. EXCAVATORS

**BUCKET SIZE**

EXCAVATORS can usually be equipped with several different size and type buckets.

**SIZE OF A FRONT SHOVEL**

*Heaped Capacity*: 1:1 angle of repose for evaluating heaped capacity. A 2:1 angle of repose is used by the Committee on European Construction Equipment (CECE).
**Fill Factor:** Rated heaped capacities represent a net section bucket volume; therefore, they must be corrected to average bucket load based on the material being handled. Fill factors are percentages which, when multiplied by rated heaped capacity, adjust the volume by accounting for how the specific material will load into the bucket (see the following table, Table 5, or Table 8.1 of Textbook).

### Table 1. Fill Factors for Front Shovel Buckets (Caterpillar Inc.)

<table>
<thead>
<tr>
<th>Material</th>
<th>Fill Factor (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bank clay, earth</td>
<td>100 to 110</td>
</tr>
<tr>
<td>Rock-earth mixture</td>
<td>105 to 115</td>
</tr>
<tr>
<td>Rock-poorly blasted</td>
<td>85 to 100</td>
</tr>
<tr>
<td>Rock-well blasted</td>
<td>100 to 110</td>
</tr>
<tr>
<td>Shale; sandstone-standing bank</td>
<td>85 to 100</td>
</tr>
</tbody>
</table>

* Percent of heaped bucket capacity
**CHAPTER 8. EXCAVATORS**

### SHOVEL PRODUCTION

**Typical cycle element times under average conditions, for 3 to 5-cu-yd shovels, will be**

- **Load bucket**: 7-9 sec
- **Swing with load**: 4-6 sec
- **Dump load**: 2-4 sec
- **Return swing**: 4-5 sec

**Actual production of a shovel is affected by the following factors:**

- Class of material
- Height of cut
- Angle of swing
- Size of hauling units
- Operator skill
- Physical condition of the shovel

*Production efficiency ranges from 30 to 45 min per hour*
EFFECT OF THE HEIGHT OF CUT AND SWING ANGLE ON SHOVEL PRODUCTION

The Power Crane and Shovel Association (PCSA) has published findings on the optimum height of cut based on data from studies of cable operated shovels as shown in Table 2 (Table 8.2 of Textbook)

Table 2. Factors for Height of Cut and Angle of Swing Effect on Shovel Production

<table>
<thead>
<tr>
<th>Percent Optimum Depth (%)</th>
<th>Angle of Swing (degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>45</td>
</tr>
<tr>
<td>40</td>
<td>0.93</td>
</tr>
<tr>
<td>60</td>
<td>1.10</td>
</tr>
<tr>
<td>80</td>
<td>1.22</td>
</tr>
<tr>
<td>100</td>
<td>1.26</td>
</tr>
<tr>
<td>120</td>
<td>1.20</td>
</tr>
<tr>
<td>140</td>
<td>1.12</td>
</tr>
<tr>
<td>160</td>
<td>1.03</td>
</tr>
</tbody>
</table>
SWING ANGLE?

swing angle of 30-60°

90°

30°

60°

EFFECT OF THE HEIGHT OF CUT AND SWING ANGLE ON SHOVEL PRODUCTION

The percent of optimum height of cut, in the table, is obtained by dividing the actual height of cut by the optimum height for the given material and bucket, and then multiplying the result by 100.
EFFECT OF THE HEIGHT OF CUT AND SWING ANGLE ON SHOVEL PRODUCTION

The optimum height of cut ranges from 30 to 50% of the maximum digging height:
- 30% for easy to load materials (i.e., loam sand, gravel)
- 40% for common earth
- 50% for poorly blasted rock, or sticky clay

The ideal production of a shovel is based on operating at a 90° swing and optimum height of cut.

The ideal production should be multiplied by the proper correction factor in order to correct the production for any given height and swing angle.

Table 2, or Table 8.2) can be used for this purpose.
**Example 1**

A 5-cu-yd shovel having a maximum digging height of 34 ft is being used to load poorly blasted rock. The face being worked is 12 ft high and the haul units can be positioned so that the swing angle is only 60°. What is the adjusted ideal production if the ideal cycle time is 21 sec.

**Example 1 (cont’d)**

Optimum height = 0.50 X 34 = 17 ft  
Fill factor from Table 5, 85 to 100%, use 90%  

\[
\text{Ideal Production} = \frac{60}{21} \times 5 \times 0.9 = 12.86 \text{ lcy/min} = 771 \text{ lcy/hr}
\]

\[
\text{Percent Optimum Height} = \frac{12}{17} = 0.71
\]

Height-swing Factor = 1.08 (from Table 2, by interpolation)

The Adjusted Ideal Production = 771 (1.08) = 833 lcy per hour
Example 2

A 3-cu-yd shovel, having a maximum digging height of 30 ft, will be used on a highway project to excavate well-blasted rock. The average face height is expected to be 22 ft. Most of the cut will require a 140° swing of the shovel in order to load the haul units. Determine the estimated production in cubic yards bank measure.

Example 2 (cont’d)

Optimum height = 0.50 X 30 = 15 ft
Fill Factor from Table 1, (100 to 110%), use 100%
Cycle Time = Load + Swing Loaded + Dump + Swing empty

\[
= 9 + 4 + 4 + 4 = 21 \text{ sec} = 0.35 \text{ min}
\]

Ideal Production = \[
\frac{60}{0.35} \times 3 \times 1.0 = 514 \frac{\text{cy}}{\text{hr}}
\]

Percent Optimum Height = \[
\frac{22}{15} = 1.47 = 147\%
\]
Example 2 (cont’d)

Table 1. Fill Factors for Front Shovel Buckets (Caterpillar Inc.)

<table>
<thead>
<tr>
<th>Material</th>
<th>Fill Factor (%)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bank clay; earth</td>
<td>100 to 110</td>
</tr>
<tr>
<td>Rock-earth mixture</td>
<td>105 to 115</td>
</tr>
<tr>
<td>Rock-poorly blasted</td>
<td>85 to 100</td>
</tr>
<tr>
<td>Rock-well blasted</td>
<td>100 to 110</td>
</tr>
<tr>
<td>Shale; sandstone-standing bank</td>
<td>85 to 100</td>
</tr>
</tbody>
</table>

* Percent of heaped bucket capacity

Example 2 (cont’d)

Height-swing Factor = 0.73 (from Table 2, by interpolation)

The Adjusted Ideal Production = 514 (0.73) = 375 lcy per hour

Percent swell, Table 4-3 (Textbook): Well-blasted Rock = 60%

Production (bcy) = \( \frac{375}{1.6} = 234 \) bcy/hr

If an efficiency of 45 min per hour is used, then

Production = (45/60) X 234 = 175.5 bcy/hr
Example 2 (cont’d)

Table 2. Factors for Height of Cut and Angle of Swing Effect on Shovel Production

<table>
<thead>
<tr>
<th>Percent Optimum Depth (%)</th>
<th>Angle of Swing (degrees)</th>
<th>45</th>
<th>60</th>
<th>75</th>
<th>90</th>
<th>120</th>
<th>150</th>
<th>180</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td></td>
<td>0.93</td>
<td>0.89</td>
<td>0.85</td>
<td>0.80</td>
<td>0.72</td>
<td>0.65</td>
<td>0.59</td>
</tr>
<tr>
<td>60</td>
<td></td>
<td>1.10</td>
<td>1.03</td>
<td>0.96</td>
<td>0.91</td>
<td>0.81</td>
<td>0.73</td>
<td>0.66</td>
</tr>
<tr>
<td>80</td>
<td></td>
<td>1.22</td>
<td>1.12</td>
<td>1.04</td>
<td>0.98</td>
<td>0.86</td>
<td>0.77</td>
<td>0.69</td>
</tr>
<tr>
<td>100</td>
<td></td>
<td>1.26</td>
<td>1.16</td>
<td>1.07</td>
<td>1.00</td>
<td>0.88</td>
<td>0.79</td>
<td>0.71</td>
</tr>
<tr>
<td>120</td>
<td></td>
<td>1.20</td>
<td>1.11</td>
<td>1.03</td>
<td>0.97</td>
<td>0.86</td>
<td>0.77</td>
<td>0.70</td>
</tr>
<tr>
<td>140</td>
<td></td>
<td>1.12</td>
<td>1.04</td>
<td>0.97</td>
<td>0.91</td>
<td>0.81</td>
<td>0.73</td>
<td>0.66</td>
</tr>
<tr>
<td>160</td>
<td></td>
<td>1.03</td>
<td>0.96</td>
<td>0.90</td>
<td>0.85</td>
<td>0.75</td>
<td>0.67</td>
<td>0.62</td>
</tr>
</tbody>
</table>

Example 2 (cont’d)

Table 3. Bank and Loose weight and swell factor

<table>
<thead>
<tr>
<th>Material</th>
<th>Bank weight</th>
<th>Loose weight</th>
<th>Percent swell</th>
<th>Swell factor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>lb/cu yd</td>
<td>kg/m³</td>
<td>lb/cu yd</td>
<td>kg/m³</td>
</tr>
<tr>
<td>Clay, dry</td>
<td>2,700</td>
<td>1,600</td>
<td>2,000</td>
<td>1,185</td>
</tr>
<tr>
<td>Clay, wet</td>
<td>3,000</td>
<td>1,780</td>
<td>2,200</td>
<td>1,305</td>
</tr>
<tr>
<td>Earth, dry</td>
<td>2,800</td>
<td>1,660</td>
<td>2,240</td>
<td>1,325</td>
</tr>
<tr>
<td>Earth, wet</td>
<td>3,200</td>
<td>1,895</td>
<td>2,580</td>
<td>1,528</td>
</tr>
<tr>
<td>Earth and gravel</td>
<td>3,200</td>
<td>1,895</td>
<td>2,600</td>
<td>1,575</td>
</tr>
<tr>
<td>Gravel, dry</td>
<td>2,800</td>
<td>1,660</td>
<td>2,490</td>
<td>1,475</td>
</tr>
<tr>
<td>Gravel, wet</td>
<td>3,400</td>
<td>2,020</td>
<td>2,980</td>
<td>1,765</td>
</tr>
<tr>
<td>Limestone</td>
<td>4,400</td>
<td>2,610</td>
<td>2,750</td>
<td>1,630</td>
</tr>
<tr>
<td>Rock, well blasted</td>
<td>4,200</td>
<td>2,490</td>
<td>2,640</td>
<td>1,565</td>
</tr>
<tr>
<td>Sand, dry</td>
<td>2,600</td>
<td>1,542</td>
<td>2,260</td>
<td>1,340</td>
</tr>
<tr>
<td>Sand, wet</td>
<td>2,700</td>
<td>1,600</td>
<td>2,360</td>
<td>1,400</td>
</tr>
<tr>
<td>Shale</td>
<td>3,500</td>
<td>2,075</td>
<td>2,480</td>
<td>1,470</td>
</tr>
</tbody>
</table>
HOES

Hoes are used primarily to excavate below the natural surface of the ground on which the machine rests.

A hoe is sometimes referred to by other names, such as backhoe or back shovel.
HOES

Hoes are adapted to excavating trenches and pits for basements, and the smaller machines can handle general grading work.

In storm drain and utility work the hoe can perform the trench excavation and handle the pipe, eliminating a second machine.
HOE BUCKETS

There are special buckets for everything from light sand to hard rock digging.

HYDRAULIC HOES

Bucket penetration (break out force) is developed by the hydraulic cylinders of the boom stick and bucket.
HYDRAULIC HOES

The hoe can be track or wheel mounted.

MULIPURPOSE TOOL

A crane for carefully lifting heavy loads into position.
HYDRAULIC HOES

- These machines offer precision and efficiency.
- The average (first owner) life is about seven years.

PRODUCTION ESTIMATING

STEP 1: Bucket size (LCY)

Many different size buckets will fit the same machine. Interested in heaped capacity.

- Heaped capacity ratings for hoe buckets assume a 1:1 material angle of repose.
STEP 2: Material type

STEP 3: Fill factor, Table 8.4

HEAPED CAPACITY is a net section 1:1 slope volume. It must be adjusted based on the characteristics of the material being handled.

Table 3. Fill Factors for Hydraulic Hoe Buckets (Caterpillar Inc.)

<table>
<thead>
<tr>
<th>Material</th>
<th>Fill Factor (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moist loam/sandy clay</td>
<td>100 to 110</td>
</tr>
<tr>
<td>Sand and gravel</td>
<td>95 to 110</td>
</tr>
<tr>
<td>Rock – poorly blasted</td>
<td>40 to 40</td>
</tr>
<tr>
<td>Rock – well blasted</td>
<td>60 to 75</td>
</tr>
<tr>
<td>Hard, tough clay</td>
<td>80 - 90</td>
</tr>
</tbody>
</table>

* Percent of heaped bucket capacity

\[
\text{BUCKET VOL. (LCY)} = \frac{\text{HEAPED CAPACITY}}{\text{Fill Factor}}
\]
STEP 4: Cycle time, (load, swing load, dump and swing empty).

Typical excavation cycle times based on machine size are given in Table 8.5.

Swing is influenced by job conditions such as obstructions and clearances.

The Table 8.5 cycle times must be increased when loads are dumped into haul units.
CYCLE TIME

Small machines swing faster than large ones.

SWING ANGLE?

Table 8.5 cycle times are based on a swing angle of 30-60°
PRODUCTION ESTIMATING

STEP 5: Check depth of cut

Typical cycle times are for depth of cut between 40-60% of maximum digging depth.

Check manufacturer's data. Table 8.3 gives typical information based on hoe size.

DEPTH OF CUT

STEP 5: Manufacturer's data.

C. Maximum dig depth
D. Dig depth, level bottom
CHAPTER 8. EXCAVATORS

PRODUCTION ESTIMATING

STEP 6: Check loading height

Does the selected hoe have the reach capability to load the haul unit. **Table 8.3**

---

PRODUCTION ESTIMATING

STEP 7: Efficiency factor

The three primary conditions that control the efficiency of excavator loading operations are:

- Bunching
- Operator efficiency
- Equipment availability
PRODUCTION ESTIMATING

STEP 7: Efficiency Factor

- Bunching: In actual operation cycle times are never constant. When loading haul units they will sometimes bunch. The impact of bunching is a function of the number of haul units.

- Operator efficiency: How good is the operator.

- Equipment availability: Are the haul units in good condition and repair? They will be available x% of the time.
STEP 8: CALCULATION

Step 1 \times Step 3 \times \frac{Step 7}{Step 4} = \text{LCY} / \text{hr}

Bucket size
\times \text{Fill Factor}
\times \frac{\text{Efficiency}}{\text{cycle time}} = \text{LCY} / \text{hr}

PRODUCTION ESTIMATING

STEP 9: Convert Production to BCY, CCY or TONS as required.

Table 4.3
CHAPTER 8. EXCAVATORS

PRODUCTION ESTIMATING

Production Formula:

\[
\text{Production} = \frac{3,600 \text{ sec} \times Q \times F}{t} \left( \frac{E}{60 - \text{min hr}} \right) \left( \frac{1}{\text{Vol. Correction}} \right)
\]  

(2)

\[Q = \text{heaped bucket capacity (lcy)}\]

\[F = \text{bucket fill factor}\]

\[t = \text{cycle time in seconds}\]

\[E = \text{efficiency (min per hour)}\]

Production formula (cont’d)

Volume correction for loose volume to bank volume, \(\frac{1}{1 + \text{swell factor}}\)

For loose volume to tons, \(\frac{\text{loose unit weight, lb}}{2,000 \text{ lb/ton}}\)
**PRODUCTION ESTIMATING**

- Optimum depth of cut for a hoe depends on the type of material being excavated and bucket size.

- **As a rule**, the optimum depth of cut is usually in the range of 30 to 60% of the machine’s maximum digging depth.

---

**Example 3**

A crawler hoe having a 3½-cy bucket is being considered for use on a project to excavate very hard clay from a borrow pit. The clay will be loaded into trucks having a loading height of 9 ft 9 in. Soil-boring information indicates that
Example 3 (cont’d)

below 8 ft, the material changes to an unacceptable silt material. What is the estimated production of the hoe in cubic yards bank measure, if the efficiency factor is equal to a 50-min hour?

Example 3 (cont’d)

Step 1:

Size of bucket = 3½ cy

Step 2:

Bucket fill factor, Table 3 (Table 8.4 Text) gives 80 to 90%.
Use average: \( \frac{80 + 90}{2} = 85\% \)
Example 3 (cont’d)

Step 3:

- Typical cycle element times:
- Optimum depth of cut is 30 to 60% of maximum digging depth (see slide 60)
- From Table 8.3 (Text), for 3½-cu hoe, maximum digging depth is 23 to 27 ft.

\[
\frac{8}{23} \times 100 = 34\% \geq 30\% \text{ OK} \quad \frac{8}{27} \times 100 = 30\% \geq 30\% \text{ OK}
\]

Example 3 (cont’d)

- The cycle times from Table 8.5 (Text), for 3½-cu hoe would be 22.

Step 4:

- Efficiency factor or 50-min hour

Step 5:

- Hard clay, swell factor = 35% from the following table (Table 4.3 Text)
Example 3 (cont’d)

Step 6:

Probable Production: using Eq. 2,

\[
\text{Production} = \frac{3,600 \text{ sec} \times Q \times F}{t} \left( \frac{E}{60 \text{ min hr}} \right) \left( \frac{1}{\text{Vol. Correction}} \right)
\]

\[
\text{Production} = \frac{3,600 \times 3.5 \times 0.85}{t} \left( \frac{50}{60} \right) \left( \frac{1}{1.035} \right) = 300 \text{ bcy/hr}
\]

Check maximum loading height to ensure the hoe can service the trucks. From Table 8.3 (Text), 21 to 22 ft:

9 ft 9 in = 9.75 ft < 21 OK
Loaders are used extensively in construction work to handle and transport bulk material, such as earth and rock, to load trucks, to excavate earth, and to charge aggregate bins at asphalt and concrete plants.

There are basically two types of loaders:

- The crawler-tractor-mounted type, and
- The wheel-tractor-mounted type.
The term "trenching machine" applies to the wheel- and ladder type machines.

These machines are satisfactory for digging utility trenches for water, gas, and oil pipelines; shoulder drains on highways; drainage ditches; and sewers where the job and soil conditions are such that they may be used.
TRENCHING MACHINES

They provide relatively fast digging, with positive depths and widths of trenches, reducing expensive finishing.

These machines are capable of digging any type of soil but are generally not suitable for rock.

They are available in various sizes for digging trenches of varying depths and widths.

They are usually crawler-mounted to increase their stability and to distribute the weight over a great area.