CHAPTER

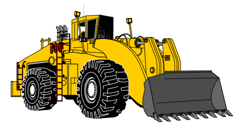
8

Construction Planning, Equipment, and Methods

Sixth Edition

EXCAVATORS

A. J. Clark School of Engineering •Department of Civil and Environmental Engineering



By

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ENCE 420 – Construction Equipment and Methods

Spring 2003

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INTRODUCTION

Hydraulic power is the key to the utility of many 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.

HYDRAULIC EXCAVATORS

WHEEL & TRACK LOADERS

INTRODUCTION

- 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.

INTRODUCTION

- 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.**

EXCAVATOR PRODUCTION

- Steps for Estimating Production (cont'd):
  3. Estimate a peak cycle time. This a function of machine type and job conditions to angle of swing, depth of height of cut, and in the the case of loaders, travel distance.

EXCAVATOR PRODUCTION

- Steps for Estimating Production (cont'd):
  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:

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

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)

EXCAVATOR PRODUCTION

- Production formula (cont'd)

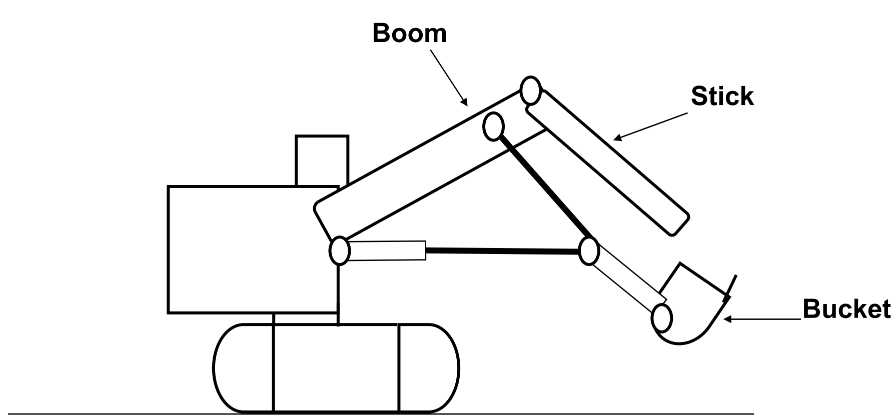
Volume correction for loose volume to bank volume, $\dfrac{1}{1 + \text{swell factor}}$

For loose volume to tons, $\dfrac{\text{loose unit weight, lb}}{2{,}000\ \text{lb/ton}}$

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.

FRONT SHOVELS



FRONT SHOVELS

- 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.

SIZE OF A FRONT SHOVEL

- 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.

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 angles of repose is used by the Committee on European Construction Equipment (CECE).

SIZE OF A FRONT SHOVEL

- ***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).

SIZE OF A FRONT SHOVEL

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

Material	Fill Factor* (%)
Bank clay; earth	100 to 110
Rock-earth mixture	105 to 115
Rock-poorly blasted	85 to 100
Rock-well blasted	100 to 110
Shale; sandstone-standing bank	85 to 100

* Percent of heaped bucket capacity

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

SHOVEL PRODUCTION

- 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

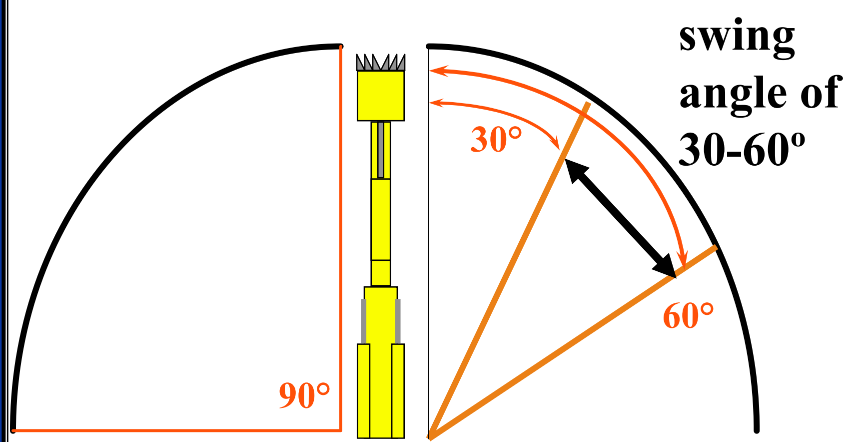
- The Power Crane and Shovel Association (PCSA) has published findings on the optimum height of cut based on data from studies of cable operated shovels as shown in Table 2 (Table 8.2 of Textbook)

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

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

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

SWING ANGLE?



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 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

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

- The ideal production of a shovel is based on operating at a 90^0 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 60^0. 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%

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

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

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 140^0 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 sec = 0.35 min

$$\text{Ideal Production} = \frac{60}{0.35} \times 3 \times 1.0 = 514 \frac{\text{lcy}}{\text{hr}}$$

$$\text{Percent Optimum Height} = \frac{22}{15} = 1.47 = 147\%$$

Example 2 (cont'd)

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

Material	Fill Factor* (%)
Bank clay; earth	100 to 110
Rock-earth mixture	105 to 115
Rock-poorly blasted	85 to 100
Rock-well blasted	100 to 110
Shale; sandstone-standing bank	85 to 100

* 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%

$$\text{Production (bcy)} = \frac{375}{1.6} = 234\,\frac{\text{bcy}}{\text{hr}}$$

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

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

Example 2 (cont'd)

Material	Bank weight		Loose weight		Percent swell	Swell factor
	lb/cu yd	kg/m³	lb/cu yd	kg/m³		
Clay,dry	2,700	1,600	2,000	1,185	35	0.74
Clay, wet	3,000	1,780	2,200	1,305	35	0.74
Earth, dry	2,800	1,660	2,240	1,325	25	0.80
Earth, wet	3,200	1,895	2,580	1,528	25	0.80
Earth and gravel	3,200	1,895	2,600	1,575	20	0.83
Gravel, dry	2,800	1,660	2,490	1,475	12	0.89
Gravel, wet	3,400	2,020	2,980	1,765	14	0.88
Limestone	4,400	2,610	2,750	1,630	60	0.63
Rock, well blasted	4,200	2,490	2,640	1,565	60	0.63
Sand, dry	2,600	1,542	2,260	1,340	15	0.87
Sand, wet	2,700	1,600	2,360	1,400	*15*	0.87
Shale	3,500	2,075	2,480	1,470	40	0.71

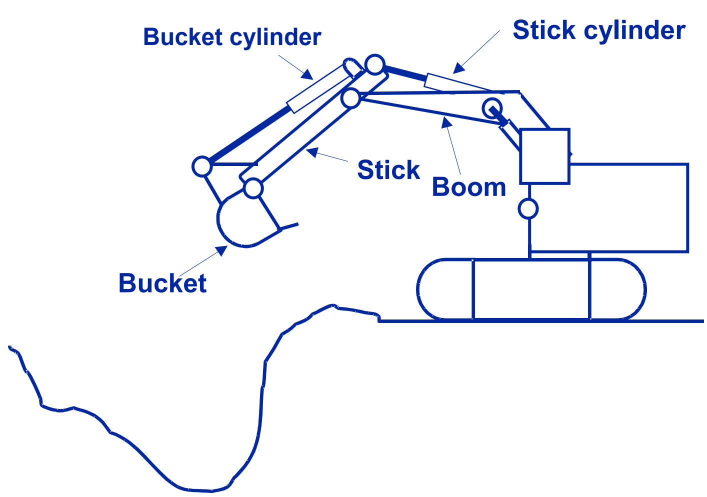
HOES

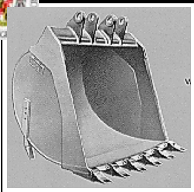
- Hoes are used primarily to excavate below the natural surface of the ground on which the machine rests.
- A hoe is sometimes referred to by other names, such as backhoe or back shovel.

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.

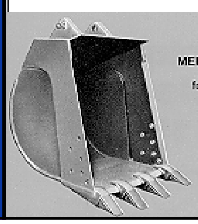
HOES

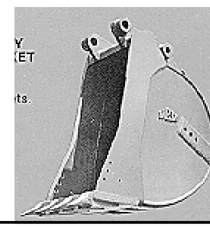




HOE BUCKETS

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





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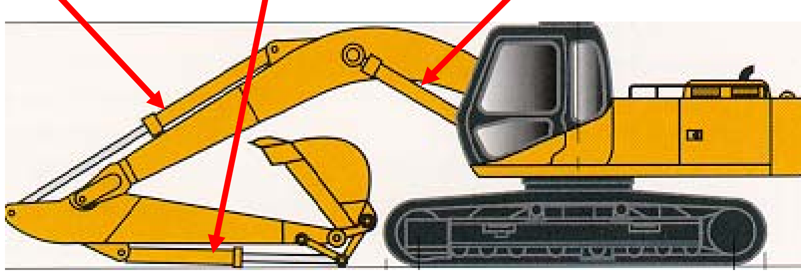
HYDRAULIC HOES

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.

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.**

PRODUCTION ESTIMATING

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.

PRODUCTION ESTIMATING

Table 8.4 of Text

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

Material	Fill Factor* (%)
Moist loam/sandy clay	100 to 110
Sand and gravel	95 to 110
Rock – poorly blasted	40 to 40
Rock – well blasted	60 to 75
Hard, tough clay	80 - 90

* Percent of heaped bucket capacity

BUCKET VOL.(LCY) =
HEAPED CAPACITY
X Fill Factor

PRODUCTION ESTIMATING

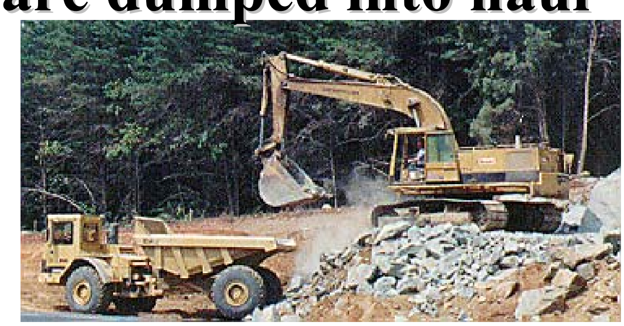
STEP 4: Cycle time, (load, swing load, dump and swing empty).

Typical excavation cycle times base on machine size are give in Table 8.5.

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

PRODUCTION ESTIMATING

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

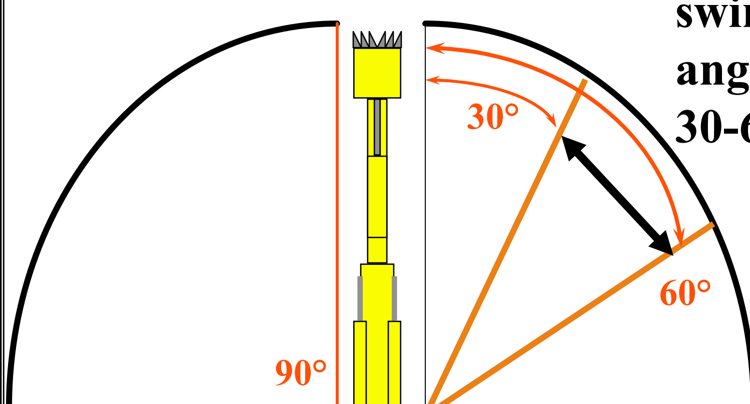


CYCLE TIME

Small machines swing faster than large ones.

SWING ANGLE?

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

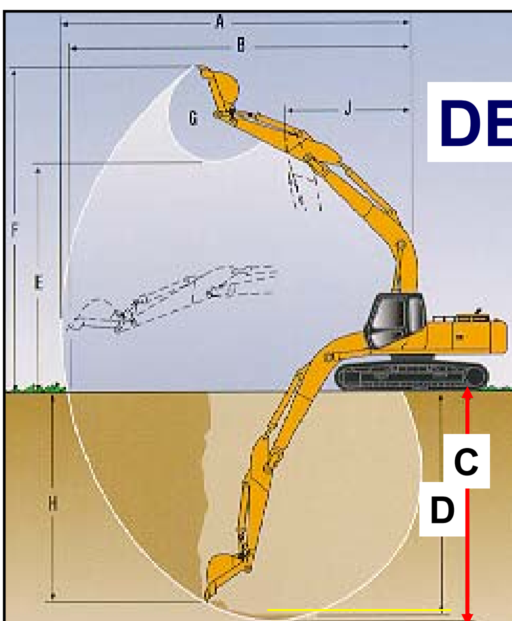


PRODUCTION ESTIMATING

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.

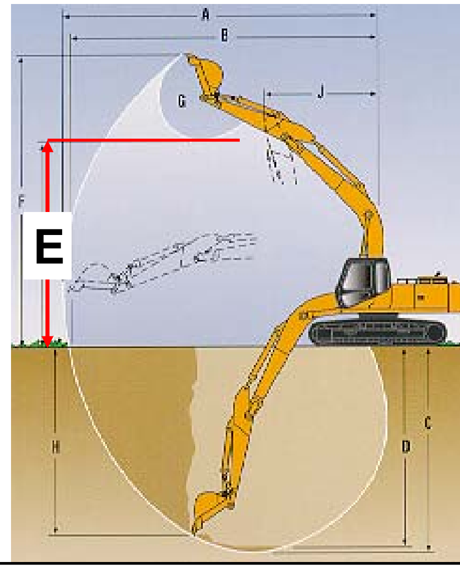
C. Maximum dig depth

D. Dig depth, level bottom

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.

PRODUCTION ESTIMATING

STEP 7: Efficiency factor

- 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

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

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

PRODUCTION ESTIMATING

STEP 9: Convert Production

to BCY,

CCY or

TONS as required.

Table 4.3

PRODUCTION ESTIMATING

- Production Formula:

$$\text{Production} = \frac{3{,}600\,\text{sec} \times Q \times F}{t}\left(\frac{E}{60-\text{min hr}}\right)\left(\frac{1}{\text{Vol. Correction}}\right) \qquad \textbf{(2)}$$

Q = heaped bucket capacity (lcy)
F = bucket fill factor
t = cycle time in seconds
E = efficiency (min per hour)

PRODUCTION ESTIMATING

- 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.

$$\frac{8}{23}\times 100 = 34\% \geq 30\% \text{ OK} \qquad \frac{8}{27}\times 100 = 30\% \geq 30\% \text{ OK}$$

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,

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

$$\text{Production} = \frac{3{,}600 \times 3.5 \times 0.85}{t}\left(\frac{50}{60}\right)\left(\frac{1}{1+0.35}\right) = 300\,\frac{\text{bcy}}{\text{hr}}$$

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

$$9\text{ ft }9\text{ in} = 9.75\text{ ft} < 21\ \text{OK}$$

Example 3 (cont'd)

Material	Bank weight lb/cu yd	Bank weight kg/m³	Loose weight lb/cu yd	Loose weight kg/m³	Percent swell	Swell factor
Clay,dry	2,700	1,600	2,000	1,185	35	0.74
Clay, wet	3,000	1,780	2,200	1,305	35	0.74
Earth, dry	2,800	1,660	2,240	1,325	25	0.80
Earth, wet	3,200	1,895	2,580	1,528	25	0.80
Earth and gravel	3,200	1,895	2,600	1,575	20	0.83
Gravel, dry	2,800	1,660	2,490	1,475	12	0.89
Gravel, wet	3,400	2,020	2,980	1,765	14	0.88
Limestone	4,400	2,610	2,750	1,630	60	0.63
Rock, well blasted	4,200	2,490	2,640	1,565	60	0.63
Sand, dry	2,600	1,542	2,260	1,340	15	0.87
Sand, wet	2,700	1,600	2,360	1,400	*15*	0.87
Shale	3,500	2,075	2,480	1,470	40	0.71

LOADERS

- 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.

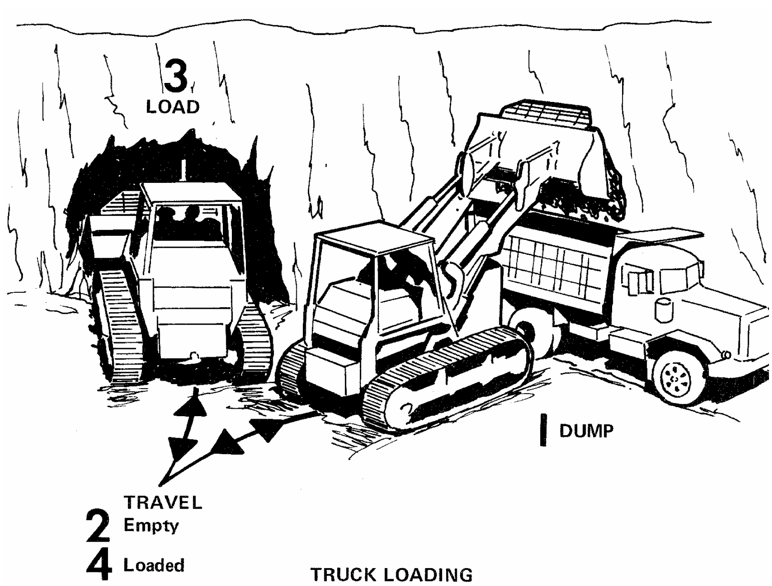
LOADERS

- There are basically two types of loaders:
  - ✓The crawler-tractor-mounted type, and
  - ✓The wheel-tractor-mounted type.

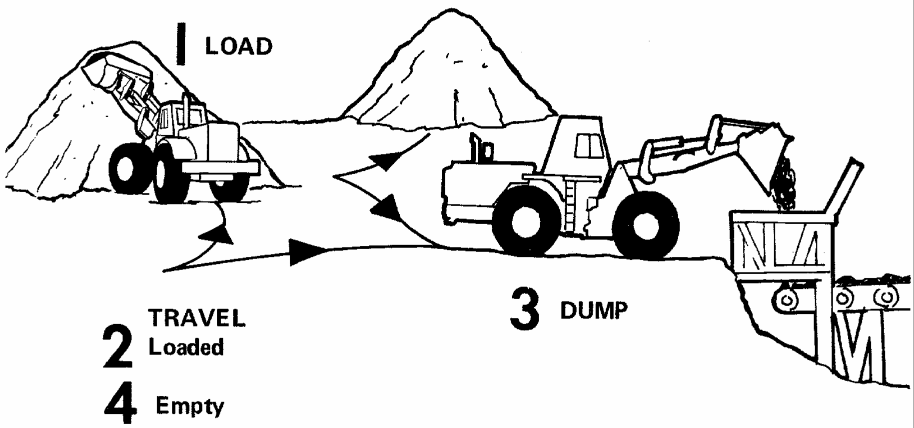
WHEEL & TRACK LOADERS

LOADERS PRODUCTION

LOADER PRODUCTION



LOADER PRODUCTION



TRENCHING MACHINES

- 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.

TRENCHING MACHINES

- 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.