Introduction – Chapter 1

Dr. Mohammad S. El-Mashaleh

The construction industry

- The Jordanian construction industry is a major contributor to the economical growth of the country
- It accounts for about 6% of the gross national product
- Employs 6.4% of the labor force

Types of Contractors

- Two types:
- General contractors (prime)
- Specialty contractors (subcontractors)

- The employer enter into a contract with the general contractor
- General contractors “subcontract” portions of the project to subcontractors

Construction industry sectors

- What do we mean by sectors?
- **US sectors**

(1) Buildings (vertical construction)
- Residential
- Commercial

(2) Industrial
- Industrial facilities
- Utilities construction

(3) Heavy and highway (horizontal construction)
- Highways
- Airports
- Railroads
- Bridges
- Dams

- What about the Jordanian sectors?
- **Jordanian sectors**

(1) Buildings (ابنية)

(2) Highway and bridges (طرق وجسور)

(3) Water and sewage (مياه وصرف صحي)

(4) Electromechanical (كهروميكانيك)

Classification of contractors

- Are contractors in Jordan classified?
- Who is classifying them?
- What is the purpose of classification?

- Two purposes:

(1) To limit bidding on projects to contractors of particular type and classification

(2) To limit the size of projects that are undertaken by a contractor at any point in time

- Contractors are classified based on:
- Capital
- Owned equipment
- Personnel experience
- Personnel level of education
- Other

The construction industry and other industries

- Compared to other industries, we say that construction is unique
- Why?

- Construction is unique because:

(1) Very competitive

(2) Low profit margins

(3) Sensitive to the economical conditions locally and internationally

(4) Remote sites

(5) Changing conditions

(6) Seasonal demand

(7) Many parties involved

(8) Every project is different

Phases of a project

- A project is in a continual state of change as it progresses from its start, as needed by the owner, through design development and finally, construction

Owner's Need for Project

↓

Request for Engineering Study

↓

Conceptual Configurations and Alternatives for Technical Feasibility.
Development of Cost and Schedule for each Alternative

↓

Review by owner.
Economic analysis: rate of return, payback period, capital recovery, or benefit/cost ratio

Review by owner.
Economic analysis: rate of return, payback period, capital recovery, or benefit/cost ratio

↓ Owner Request for Further Study of Project ←

↓ Owner Abandons Project

↓

Owner Authorizes Project

↓

Final Design of Project
Detailed drawings, written specifications, and preparation of contract documents

Final Design of Project: detailed drawings, written specifications, and preparation of contract documents

↓

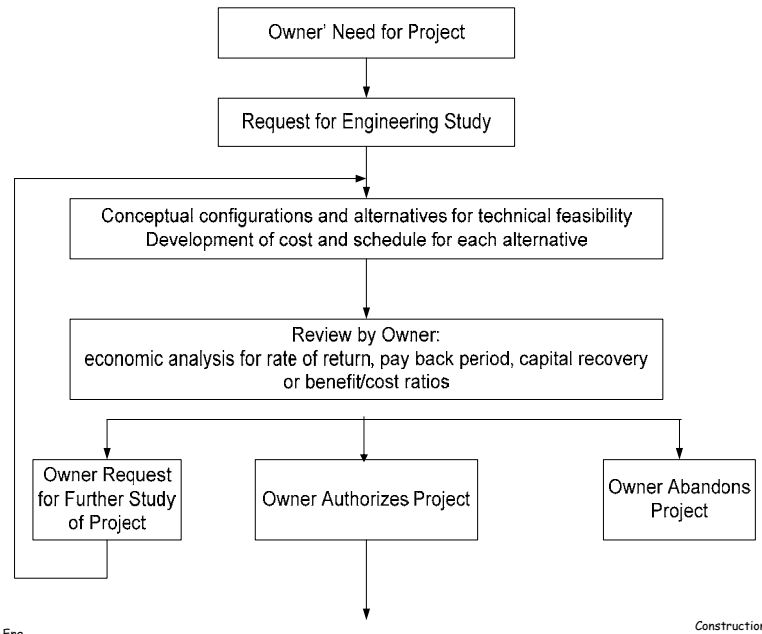
Procurement of bulk materials, special equipment, construction contracts

↓

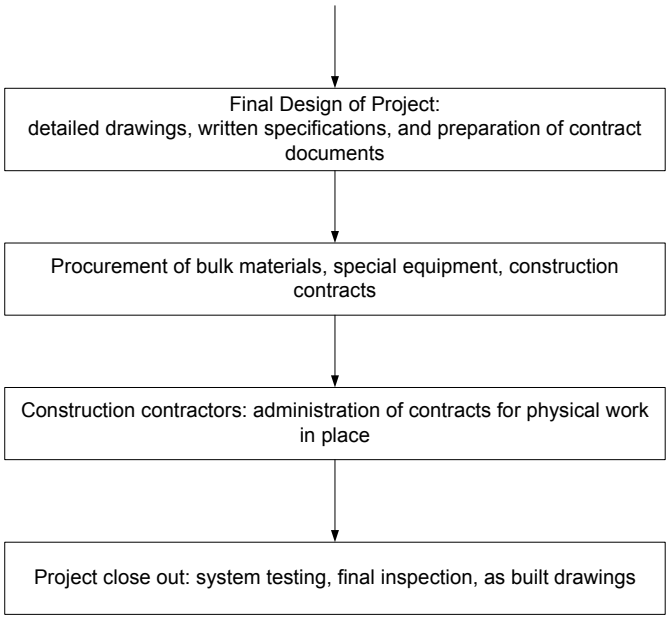
Construction contractors: administration of contracts for physical work in place

↓

Project close out: system testing, final inspection, as-built drawings



Source: Oberlender (2000)



Source: Oberlender (2000)

Project delivery approaches

- What are these?
- **Four** major approaches:

(1) Traditional (design-bid-build)

(2) Construction Management (CM)

- Design/Build (D/B)
- Build-Operate-Transfer (BOT)
- These will be covered in detail in your contracts and specifications class

Codes and regulations

- Construction projects must comply with certain codes and regulations
- Imposed by whom?
- Governmental bodies, municipalities, other agencies

- Examples:

- Building codes
- Zoning regulations
- Environmental regulations
- Others

Construction management

- The term refers to the act of managing the construction process

- The construction manager is responsible for managing the 5 basic resources of construction

- These are Money, Manpower, Machine, Material, and Time
- Often referred to as 4M&T

- Oberlender (2000) defines project management as:

- The art and science of coordinating people, equipment, materials, money, and schedules to complete a specified project on time and within approved cost

Scope of construction management services

- Includes:
- Contract administration

- Quantity takeoff and cost estimating

- Planning and scheduling

- Project controls
- Productivity improvement
- Other

Good construction management practices

- Improve the chances of project success
- How is success measured in construction projects?
- Ahead/on schedule
- Under/on budget

- Meets the owner's requirements
- Zero accidents
- Other

Safety and health

- Construction has a poor safety record when compared with other industries

- Safety research has shown that the following construction operations experience the highest rate of accidents

(1) Concrete construction: construction of formwork, placing concrete into formwork, and failure of formwork during construction

(2) The erection of prefabricated trusses, pre-cast concrete elements, and structural steel

(3) The construction and operation of temporary facilities (i.e., scaffolding)

(4) Working from elevated positions resulting in falls

(5) Construction equipment operations

New construction trends

- Recent trends in construction:
- Increasing international competition (globalization)
- Rapid changes in technology
- Wide availability of information on the web

- Increasing speed and ease of communication (collaboration tools)
- Increased governmental regulations (safety, environmental protection, etc)

Reasons for construction company failure

- Schleifer (1990) suggests 10 elements:

(1) Increase in project size

(2) Unfamiliarity with new geographic area

(3) Moving into new types of construction

(4) Changes of key personnel

(5) Lack of managerial maturity in expanding organizations

(6) Poor accounting systems

(7) Failure to evaluate project profitability

(8) Lack of equipment cost controls

(9) Poor billing procedures

(10) Transition to or problems with computerized accounting

Chapter 2: Earthmoving Materials and Operations

Part (1)

Dr. Mohammad S. El-Mashaleh

The Earthmoving process

- Earthmoving is the process of moving soil or rock from one location to another and processing it so that it meets construction requirements of location, elevation, density, moisture content, and so on

- What are the activities involved in the earthmoving process?
- Excavating, loading, hauling, placing, compacting, grading, and finishing

Equipment selection

- What factors do you think affect equipment selection?

(1) Ability of the equipment to perform the required work

(2) Maximizing return on investment (i.e., least cost/m^3)

(3) Possible future use

(4) Impact on other construction equipment and operations

(5) The character of the site and its boundaries (i.e., leveled, sloppy, suitability of access routes, site obstructions, etc.)

Production of earthmoving equipment

Production = Volume per cycle
× Cycles per hour
× Job efficiency factor

Example 1

- Assume that we have a 10m^3 truck
- It takes 10 minutes to move soil from one location to another
- How do you fit these numbers into the equation?

Table 2-1

Table 2–1 Job efficiency factors for earthmoving operations

	Management Conditions*			
Job 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

*Management conditions include:
Skill, training, and motivation of workers.
Selection, operation, and maintenance of equipment.
Planning, job layout, supervision, and coordination of work.
**Job conditions are the physical conditions of a job that affect the production rate (not including the type of material involved). They include:
Topography and work dimensions.
Surface and weather conditions.
Specification requirements for work methods or sequence.

Example 2

Soil volume change characteristics

- 3 soil states / conditions:
- Bank
- Loose
- Compacted

(1) Bank (in place)

- Material in its natural state before disturbance
- Unit volume is Bank Cubic Meter (BCM)

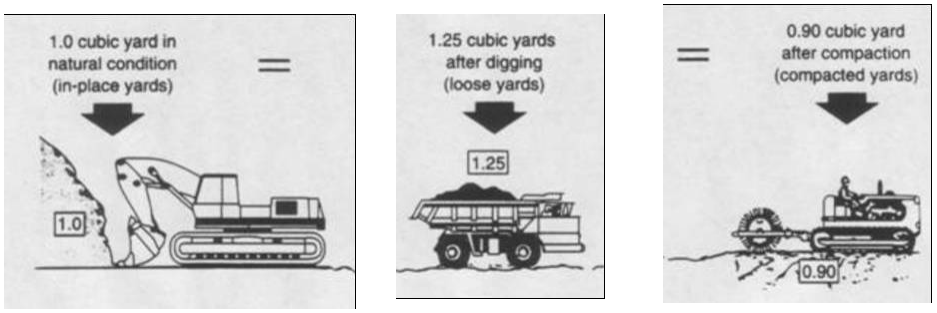
(2) Loose

- Material that has been excavated or loaded
- Unit volume is Loose Cubic Meter (LCM)

(3) Compacted

- Material after compaction
- Unit volume is Compacted Cubic Meter (CCM)

Bank – Loose - Compacted



Source: Nunnally (2006)

Swell

- When excavated, soil volume increases, why?
- Because soil grains are loosened and air fills the void spaces

$$Swell(\%) = \left(\frac{\text{Weight of soil in bank condition}}{\text{Weight of soil in loose condition}} - 1 \right) \times 100\%$$

Example 3

- What does that mean?

Shrinkage

- When the soil is compacted, some of the air is forced out of the soil's void spaces
- As a result, the soil will occupy less volume than it did under either the bank or loose condition

$$Shrinkage = \left[1 - \frac{\text{Weight of soil in bank condition}}{\text{Weight of soil in compacted condition}}\right] \times 100\%$$

Example 4

- What does that mean?

Table 2-5

Table 2–5 Typical soil weight and volume change characteristics*

	Unit Weight [lb/cu yd (kg/m³)]			Swell	Shrinkage	Load	Shrinkage
	Loose	*Bank*	*Compacted*	(%)	(%)	Factor	Factor
Clay	2310 (1370)	3000 (1780)	3750 (2225)	30	20	0.77	0.80
Common earth	2480 (1471)	3100 (1839)	3450 (2047)	25	10	0.80	0.90
Rock (blasted)	3060 (1815)	4600 (2729)	3550 (2106)	50	–30**	0.67	1.30**
Sand and gravel	2860 (1697)	3200 (1899)	3650 (2166)	12	12	0.89	0.88

*Exact values vary with grain size distribution, moisture, compaction, and other factors. Tests are required to determine exact values for a specific soil.
**Compacted rock is less dense than is in-place rock.

Load factor

- Used to convert loose volume to bank volume

$$\text{Load factor} = \frac{\text{Weight in loose unit volume}}{\text{Weight in bank unit volume}}$$

$$\text{Load factor} = \frac{1}{1 + \text{Swell}}$$

Shrinkage factor

- Converts bank volume to compacted volume

$$\text{Shrinkage factor} = \frac{\text{Weight in bank volume}}{\text{Weight in compacted volume}}$$

$$\text{Shrinkage factor} = 1 - \text{Shrinkage}$$

Example 5

Example 6

Earthmoving Materials and Operations

Chapter 2 – Part (2)

Dr. Mohammad S. El-Mashaleh

Spoil banks

- When planning and estimating earthwork, it is necessary to determine the size of the pile of material that will be created by the material removed from the excavation
- This pile is called “spoil bank”

- Spoil banks' cross section might take one of two forms:

(1)Triangular

(2)Conical (when material is dumped from a fixed position)

- To determine spoil banks dimensions, we need first to convert the volume of excavation from **Bank** conditions (BCM) to **Loose** conditions (LCM)

(1) Triangular spoil banks

$$\text{Volume} = \text{Section area} \times \text{Length}$$

$$B = \sqrt{\frac{4V}{L \times \tan R}}$$

$$H = \frac{B \times \tan R}{2}$$

B = Base Width (m)

H = Pile Height (m)

L = Pile Length (m)

V = Pile Volume (m^3)

R = Angle of Repose (deg)

(2) Conical spoil banks

$$\text{Volume} = \left(\frac{1}{3}\right) \times \text{Base area} \times \text{Height}$$

$$D = \left(\frac{7.64V}{\tan R}\right)^{\frac{1}{3}} \qquad H = \frac{D}{2} \times \tan R$$

$$\text{D} = \text{Diameter of the pile base (m)}$$

Angle of repose

- The angle that the sides of a spoil bank or pile naturally form with the horizontal when the excavated soil is dumped onto the pile
- It represents the equilibrium position of the soil
- Values of angle of repose vary depending on soil's physical characteristics and moisture content

Table 2–6 Typical values of angle of repose of excavated soil

Material	Angle of Repose (deg)
Clay	35
Common earth, dry	32
Common earth, moist	37
Gravel	35
Sand, dry	25
Sand, moist	37

Example 7

- Find the base width and height of a triangular spoil bank containing 100 BCM given the following:

- Pile length is 10 m
- Soil's angle of repose is 25
- Soil's swell is 12%

Example 8

- Find the base diameter and height of a conical spoil pile that will contain 100 BCM of excavation if the soil's angle of repose is 35 and its swell is 25%

Estimating earthwork volume

- When planning or estimating an earthmoving project, it is necessary to estimate the volume of material to be excavated or placed as fill
- Procedures for estimating earthwork volume can be broken into 3 categories

- These categories are:

(1) <u>Pit excavations</u>

- For small and relatively deep excavations
- Such as those required for basements and foundations

(2) <u>Trench excavations</u>

- For utility lines

(3) <u>Large excavations</u>

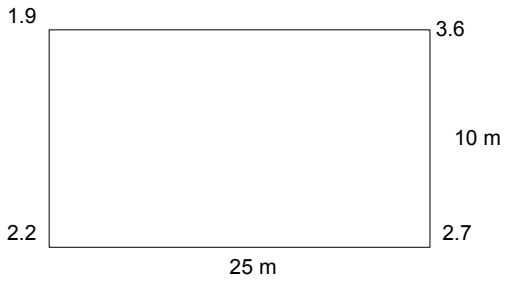
(1) Pit excavations

$$\text{Volume} = \text{Horizontal area} \times \text{Average depth}$$

- To perform the calculations, first we need to divide the horizontal area into a set of rectangles, triangles, or circular segments
- After the area of each segment is calculated, the total area is found as the sum of the segment areas

- For simple rectangular shapes, the average depth can be taken as the average of the four corner depths
- For more complex areas, we can measure the depth at additional points along the perimeter of the excavation and average all depths

Example 9



- Estimate the volume of excavation required (bank measure) for the basement shown above. Values shown at each corner are depths of excavation

(2) Trench excavations

- The volume of excavation required for a trench can be calculated as the product of the trench cross-sectional area and the linear distance along the trench line
- When trench sides are sloped and vary in width and/or depth, cross sections should be taken at frequent linear intervals and the volumes between locations computed

- These volumes are then added to find total trench volume

$$\text{Volume} = \text{Cross sectional area} \times \text{Length}$$

Example 10

- Find the volume (bank measure) of excavation required for the following trench

- Width = 1.2 m
- Depth = 0.65 m
- Length = 220 m

(3) Large areas

- To determine the earthwork volume involved in large or complex areas:

(1) Divide the area into a grid indicating the depth of excavation at each grid intersection

(2) Assign the depth at each corner or segment intersection a weight according to its location

(3) Find the average depth

(4) Multiply average depth by the horizontal area to find volume of excavation

Chapter 3: Excavating and Lifting

Part (1)
Introduction

Dr. Mohammad S. El-Mashaleh

Excavating and lifting

- An excavator is a power-driven digging machine
- 3 Major types of excavators:

(1) Hydraulic excavators
- Example: backhoe

(2) Cable operated crane-shovel family

- Examples: shovels, draglines, and clamshells

(3) Dozers, loaders, and scrapers

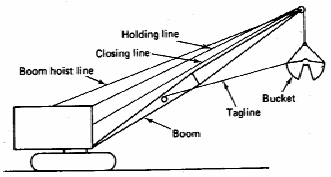
- These will be covered in subsequent chapters

(1) Hydraulic excavators

Figure 3–1 Hydraulic excavator. (Courtesy of Volvo Construction Equipment North America, Inc.)

Cable operated crane-shovel family

Figure 3–12 Components of a clamshell.



Advantages of hydraulic excavators over cable operated machines

1. Faster cycle time
2. Higher bucket penetrating force
3. More precise digging
4. Easier operator control

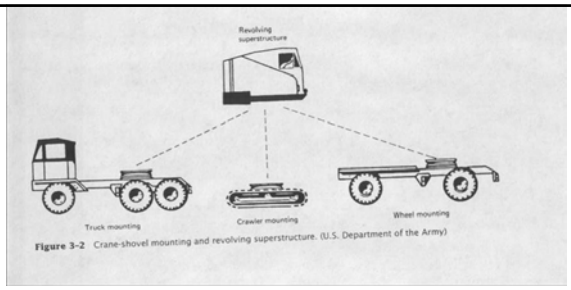


Figure 3-2 Crane-shovel mounting and revolving superstructure. (U.S. Department of the Army)

- Excavators and crane shovels consist of 3 major assemblies

1. A carrier or mounting (i.e., crawler, truck, wheels)
2. Revolving superstructure contains the power and control units
3. Front-end assembly

The crawler mounting

- Provides excellent on-site mobility
- Its low ground pressure enables it to operate in areas of low trafficability
- Widely used for drainage and trenching work as well as for rock excavation

Truck and wheel mounting

- Provide greater on-site mobility between job sites
- Less stable than crawler mountings and require better surfaces over which to operate

Excavator production

$$\text{Production} = \text{Volume per cycle} \times \text{Cycles per hr} \times \text{E}$$

Bucket loads

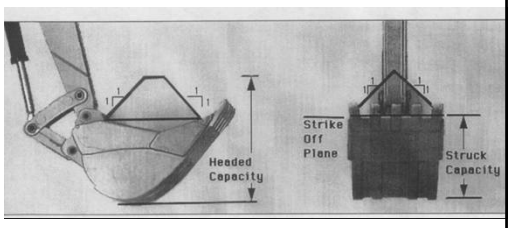
- We need to know the volume of material actually contained in one bucket load:

(1) Plate line capacity

(2) Struck capacity

(3) Water line capacity

(4) Heaped volume



(1) Plate line capacity

- Bucket volume contained within the bucket when following the outline of the bucket sides

(2) Struck capacity

- Bucket capacity when the load is struck off flush with the bucket sides; no allowance for bucket teeth

(3) Water line capacity

- Assumes a level of material flush with the lowest edge of the bucket
- Material level corresponds to the water level that would result if the bucket were filled with water

(4) Heaped volume

- The maximum volume that can be placed in the bucket without spillage based on a specified angle of repose for the material in the bucket

Table 3–2 Bucket fill factors for excavators

Material	Bucket Fill Factor
Common earth, loam	0.80–1.10
Sand and gravel	0.90–1.00
Hard clay	0.65–0.95
Wet clay	0.50–0.90
Rock, well-blasted	0.70–0.90
Rock, poorly blasted	0.40–0.70

- Bucket fill factors were developed to make it easier for us to estimate the volume of material in one bucket load

- The most accurate estimate of bucket load is obtained by multiplying the heaped bucket volume (loose measure) by the bucket fill factor

Chapter 3: Excavating and Lifting

Part (2)
Hydraulic Excavators

Dr. Mohammad S. El-Mashaleh

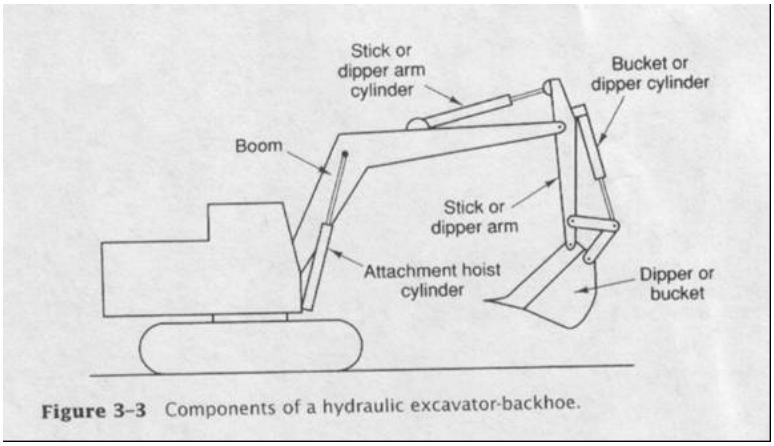


Figure 3–3 Components of a hydraulic excavator-backhoe.

Characteristics of hydraulic excavators (backhoes)

(1) Primarily designed to excavate below grade

(2) Has positive digging action

(3) Has precise lateral control

Use of backhoes

- Widely used for trenching work:

(1) Excavating trenches

(2) Laying pipe bedding

(3) Placing pipes

(4) Backfilling trenches

Measure of production

- The best measure is the length of trench excavated per unit of time
- Therefore, the dipper width should be chosen which matches the required trench width as closely as possible

Mini excavators

- Advantages of these small machines include:

(1) Compact size

(2) Hydraulic power

(3) Light weight

(4) Maneuverability

(5) Versatility

(6) Ability to operate with full 360-degree swing

(7) Low ground pressure

Estimating production

Production (LCM/h) = C x S x V x B x E

Where

C=cycles/h

S= swing-depth factor

V= heaped bucket volume (LCM)

B= bucket fill factor

E= job efficiency

- **Finding "C"**
- Table below is based on manufacturing data

Table 3–3 Standard cycles per hour for hydraulic excavators

Type of Material	Machine Size: Wheel Tractor	Small Excavator: 1 yd (0.76 m^3) or Less	Medium Excavator: $1\frac{1}{4}$–$2\frac{1}{4}$ yd (0.94–1.72 m^3)	Large Excavator: Over $2\frac{1}{2}$ yd (1.72 m^3)
Soft (sand, gravel, loam)	170	250	200	150
Average (common earth, soft clay)	135	200	160	120
Hard (tough clay, rock)	110	160	130	100

Source: Nunnally (2006)

- **Finding "S"**
- "S" depends on:

1. Depth of cut as a % of maximum
2. Angle of swing: angle between digging and dumping positions

Table 3–4 Swing-depth factor for backhoes

Depth of Cut (% of Maximum)	Angle of Swing (deg): 45	60	75	90	120	180
30	1.33	1.26	1.21	1.15	1.08	0.95
50	1.28	1.21	1.16	1.10	1.03	0.91
70	1.16	1.10	1.05	1.00	0.94	0.83
90	1.04	1.00	0.95	0.90	0.85	0.75

Source: Nunnally (2006)

Manufacturers publish maximum depth of cut for each machine, bucket size, and material

Table 3–4 Swing-depth factor for backhoes

Depth of Cut (% of Maximum)	Angle of Swing (deg)					
	45	60	75	90	120	180
30	1.33	1.26	1.21	1.15	1.08	0.95
50	1.28	1.21	1.16	1.10	1.03	0.91
70	1.16	1.10	1.05	1.00	0.94	0.83
90	1.04	1.00	0.95	0.90	0.85	0.75

What is the relationship between angle and production?

- **Adjustment factor for trench production**

Table 3–5 Adjustment factor for trench production

Type of Material	Adjustment Factor
Loose (sand, gravel, loam)	0.60–0.70
Average (common earth)	0.90–0.95
Firm (firm plastic soils)	0.95–1.00

Increasing? Why?

- In trenching work, a fall-in factor should be applied to excavator production to account for the work required to clean out material that falls back into the trench from the trench walls
- Production should be multiplied by the adjustment factor

Example 1

- Given the following information for a hydraulic excavator, find the expected production in LCM/h
- Heaped bucket capacity is 1.5 m^3. The material is tough clay with a bucket fill factor of 0.75. Job efficiency is 45 min/hr. Average depth of cut is 3.5 m. Maximum depth of cut is 5 m and average swing is 60°

Example 2

- Estimate the hourly production (LCM) for a hydraulic excavator that is digging a trench in common earth
- Heaped buck size is 2.0 m^3
- Bucket fill factor is 0.9
- Maximum digging depth is 10 m and the average is 3.0 m
- Average swing angle is 45°
- Job efficiency is 50 min/h

Job management

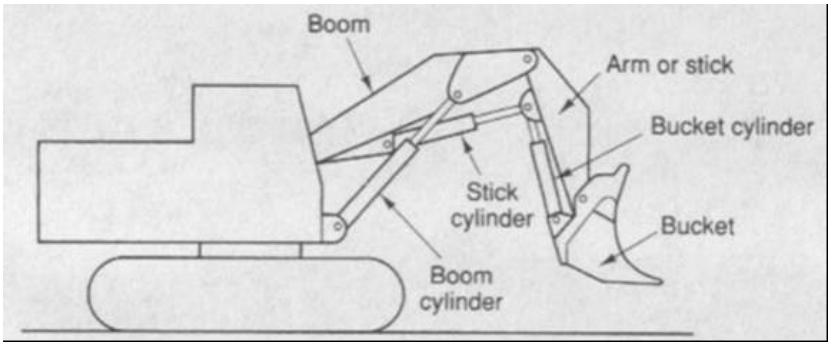
- In selecting the proper excavator for a project, consideration must be given to:
- Maximum depth
- Working radius
- Dumping height required

Chapter 3: Excavating and Lifting

Part (3) - Shovels

Dr. Mohammad S. El-Mashaleh

Shovels



- Shovels are mostly used for:
- Hard digging above track level
- Loading haul units
- The ability of the shovel to form its own roadway as it advances is a major advantage

- Shovels are capable of developing high breakout force with their buckets
- However, the material being excavated should be such that it will stand as a vertical bank (i.e., a wall of material that stands perpendicular to the ground)
- We call such a wall: digging face

Front-dump and bottom-dump shovels

(1) <u>Front-dump</u>

- Lighter
- Has a production advantage
- Costs less
- Requires less maintenance

(2) <u>Bottom-dump</u>

- Provides greater reach and dump clearance
- Produces less spillage

Shovel selection

- Two major considerations:

(1) Cost per cubic meter

(2) Job conditions under which the shovel will operate

(1) Cost per cubic meter

- In estimating the cost per cubic meter, one should consider the following factors:

1. The size of the job. A job that involves large quantity of material may justify the higher cost of a larger shovel

2. The cost of transporting the machine. A large shovel will involve more cost than a smaller one

3. The combined cost of drilling, blasting, and excavating. For a large shovel, these costs may be less than for a small shovel, as a large machine will handle more massive rocks than a small one. Large shovel may permit savings in drilling and blasting

(2) Job conditions under which the shovel will operate

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

1. If the material is hard to excavate, the bucket of the large shovel that has higher digging pressure will handle the material more easily

2. If the blasted rock is to be excavated, the large-size bucket will handle larger individual pieces

3. The size of available hauling units should be considered in selecting the size of a shovel
   - Small hauling units/ small shovel; vice versa
   - The haul unit capacity should be approximately five times excavator bucket size

Estimating Shovel Production

Production (LCM/h) = C x S x V x B x E

C: cycles per hour

S: swing factor (depends on angle between digging and dumping)

V: volume

B: bucket fill factor

E: job efficiency

Production (LCM/h) = C x S x V x B x E

Table 3–6 Standard cycles per hour for hydraulic shovels

Material	Machine Size: Small Under 5 yd (3.8 m³) Bottom Dump	Small Front Dump	Medium 5–10 yd (3.8–7.6 m³) Bottom Dump	Medium Front Dump	Large Over 10 yd (7.6 m³) Bottom Dump	Large Front Dump
Soft (sand, gravel, coal)	190	170	180	160	150	135
Average (common earth, soft clay, well-blasted rock)	170	150	160	145	145	130
Hard (tough clay, poorly blasted rock)	150	135	140	130	135	125

Adjustment for Swing Angle	Angle of Swing (deg)					
	45	60	75	90	120	180
Adjustment factor	1.16	1.10	1.05	1.00	0.94	0.83

Source: Nunnally (2006)

Example 3

- Find the expected production in LCM/h of a 5 m^3 hydraulic shovel equipped with a bottom-dump bucket. The material is gravel with a bucket fill factor of 0.95. The average angle of swing is 120° and job efficiency is 0.75.

Job management

- Two major factors control shovel production:

(1) Swing angle between digging and dumping. This angle should be kept to a minimum

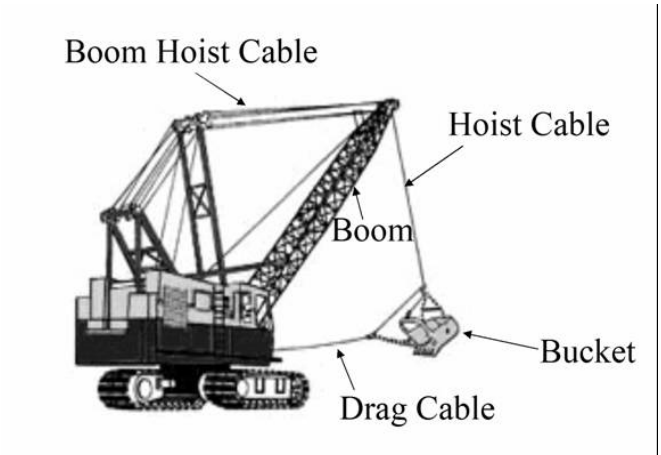
(2) Lost time during the production cycle. Haul units must be positioned to minimize the time lost as units enter and leave the loading position

Chapter 3: Excavating and Lifting

Part (4) - Draglines

Dr. Mohammad S. El-Mashaleh

Draglines



- The dragline works by dragging the bucket towards the machine
- Very versatile machine that has the longest reach for digging and dumping of any member of the crane shovel family (major advantage)
- Very advantageous when excavating material from pit or canal containing water

Dragline digging

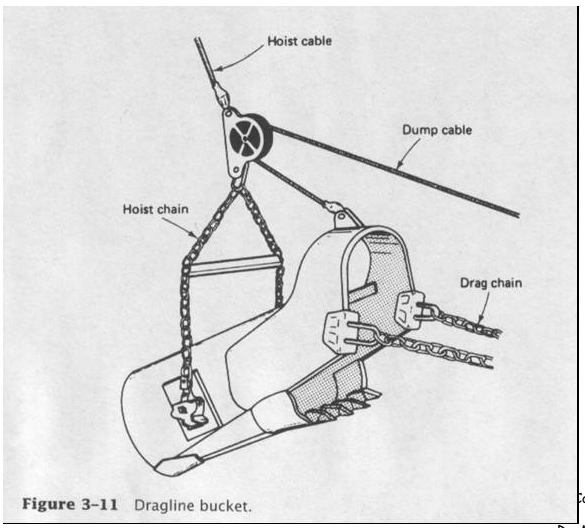


Figure 3–11 Dragline bucket.

- Bucket teeth and weight produce digging action as the drag cable pulls the bucket across the ground surface
- Digging is controlled by the position at which the drag chain is attached to the bucket
- The higher the point of attachment, the greater the angle at which the bucket enters the soil

Dragline vs. shovel

- The dragline does not have the +ve digging action or lateral control of the shovel
- The bucket may move sideways during hard digging

- More spillage must be expected in loading operations, than would occur with the shovel
- The size of haul units used for dragline loading should be greater than those used with a similar size shovel

Bucket size considerations

- The maximum bucket size of the dragline depends on:

(1) Machine power
(2) Boom length
(3) Material weight

- Why do we care about max bucket size?

Job management

- Trial operations may be necessary to select the following for maximum production:

- Boom length
- Boom angle
- Bucket size and weight

- Maximum production is obtained with minimum swing angle

- The lightest bucket capable of satisfactory digging should be used because it:

- Increases allowable bucket size

- Reduces cycle time

Production estimating

- Production Tables developed by the Construction Industry Manufacturers Association (CIMA)

Expected production =

Ideal output × Swing-depth factor × Efficiency

Ideal dragline output

Table 3-7 Ideal dragline output—short boom [BCY/h (Bm³/h)]*

	Bucket Size [cu yd (m³)]										
Type of Material	*¾ (0.57)*	*1 (0.75)*	*1¼ (0.94)*	*1½ (1.13)*	*1¾ (1.32)*	*2 (1.53)*	*2½ (1.87)*	*3 (2.29)*	*3½ (2.62)*	*4 (3.06)*	*5 (3.82)*
Light moist clay or loam	130 (99)	160 (122)	195 (149)	220 (168)	245 (187)	265 (203)	305 (233)	350 (268)	390 (298)	465 (356)	540 (413)
Sand and gravel	125 (96)	155 (119)	185 (141)	210 (161)	235 (180)	255 (195)	295 (226)	340 (260)	380 (291)	455 (348)	530 (405)
Common earth	105 (80)	135 (103)	165 (126)	190 (145)	210 (161)	230 (176)	265 (203)	305 (233)	340 (260)	375 (287)	445 (340)
Tough clay	90 (69)	110 (84)	135 (103)	160 (122)	180 (138)	195 (149)	230 (176)	270 (206)	305 (233)	340 (260)	410 (313)
Wet, sticky clay	55 (42)	75 (57)	95 (73)	110 (84)	130 (99)	145 (111)	175 (134)	210 (161)	240 (183)	270 (206)	330 (252)

*Based on PCSA data.

- Depends on type of material and bucket size

Source: Nunnally (2006)

Optimum depth of cut

Table 3-8 Optimum depth of cut for draglines [ft (m)]*

Type of Material	Bucket Size [cu yd (m^3)]										
	¾ (0.57)	1 (0.75)	1¼ (0.94)	1½ (1.13)	1¾ (1.32)	2 (1.53)	2½ (1.87)	3 (2.29)	3½ (2.62)	4 (3.06)	5 (3.82)
Light moist clay, loam, sand, and gravel	6.0 (1.8)	6.6 (2.0)	7.0 (2.1)	7.4 (2.2)	7.7 (2.3)	8.0 (2.4)	8.5 (2.6)	9.0 (2.7)	9.5 (2.9)	10.0 (3.0)	11.0 (3.3)
Common earth	7.4 (2.3)	8.0 (2.4)	8.5 (2.6)	9.0 (2.7)	9.5 (2.9)	9.9 (3.0)	10.5 (3.2)	11.0 (3.3)	11.5 (3.5)	12.0 (3.7)	13.0 (4.0)
Wet, sticky clay	8.7 (2.7)	9.3 (2.8)	10.0 (3.0)	10.7 (3.2)	11.3 (3.4)	11.8 (3.6)	12.3 (3.7)	12.8 (3.9)	13.3 (4.1)	13.8 (4.2)	14.3 (4.4)

*Based on PCSA data.

Source: Nunnally (2006)

Swing-depth factor

Depth of Cut (% of Optimum)	Angle of Swing (deg)							
	30	45	60	75	90	120	150	180
20	1.06	0.99	0.94	0.90	0.87	0.81	0.75	0.70
40	1.17	1.08	1.02	0.97	0.93	0.85	0.78	0.72
60	1.25	1.13	1.06	1.01	0.97	0.88	0.80	0.74
80	1.29	1.17	1.09	1.04	0.99	0.90	0.82	0.76
100	1.32	1.19	1.11	1.05	1.00	0.91	0.83	0.77
120	1.29	1.17	1.09	1.03	0.98	0.90	0.82	0.76
140	1.25	1.14	1.06	1.00	0.96	0.88	0.81	0.75
160	1.20	1.10	1.02	0.97	0.93	0.85	0.79	0.73
180	1.15	1.05	0.98	0.94	0.90	0.82	0.76	0.71
200	1.10	1.00	0.94	0.90	0.87	0.79	0.73	0.69

*Based on PCSA data.

Source: Nunnally (2006)

Example 4

- Determine the expected dragline production based on the following information:
- Dragline size = 1.13 m^3
- Swing angle = 150°
- Average depth of cut = 3.2 m
- Material = wet clay
- Job efficiency = 45 min/h

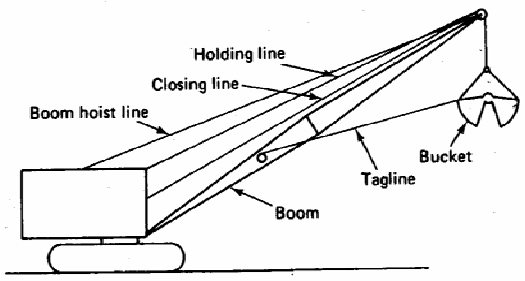
Chapter 3: Excavating and Lifting

Part (5) – Clamshells

Dr. Mohammad S. El-Mashaleh

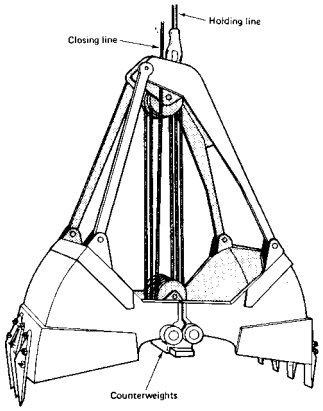
Clamshells

Figure 3–12 Components of a clamshell.



Clamshell excavation

- The clamshell is capable of excavating to great depths
- However, it lacks: the positive digging action and precise lateral control of the shovel and the backhoe



Commonly used for

- Excavating vertical shafts and footings
- Moving bulk material

Clamshell's bucket

- Bucket penetration depends on bucket weight assisted by the bucket teeth
- **Bucket weights:**

(1) Heavy buckets are suitable for digging medium soils

(2) Medium buckets are used for general purpose work

(3) Light buckets are used for handling bulk materials such as sand and gravel

Orange peel bucket

- Utilized for:
- Underwater excavation
- Rock placement
- Excavating piers and shafts

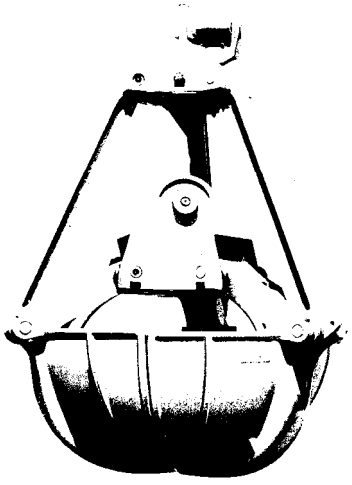


Figure 3–14 Orange peel bucket. (Courtesy of ESCO Corporation)

Production estimating

- No standard production tables
- Use:

$$\text{Production} = \text{Volume per cycle} \times \text{Cycles per hr} \times \text{E}$$

Example 5

- Estimate production in LCM/h for a clamshell excavating common earth
- Heaped bucket capacity is 1.5 m^3
- Bucket fill factor is 0.9
- Cycle time is 1 minute
- Job efficiency = 45 min/h

Example 6

- Estimate the time required to load 700 m^3 of poorly blasted rook into trucks using a clamshell that has:

- Heaped bucket capacity of 2.0 m^3
- Estimated cycle time is 45 sec
- Job efficiency is 50min/hr

Table 3–2 Bucket fill factors for excavators

Material	Bucket Fill Factor
Common earth, loam	0.80–1.10
Sand and gravel	0.90–1.00
Hard clay	0.65–0.95
Wet clay	0.50–0.90
Rock, well-blasted	0.70–0.90
Rock, poorly blasted	0.40–0.70

Job management

- Since the machine load includes the weight of the bucket as well as its load:
- The use of the lightest bucket capable of digging the material will enable a larger bucket to be used and will usually increase production

- Tests may be necessary to determine the size of bucket that yields maximum production in a particular situation
- Cycle time is reduced by organizing the job so that the dumping radius is the same as the digging radius

Chapter 3: Excavating and Lifting

Part (6) – Trenching and Trenchless Technology

Dr. Mohammad S. El-Mashaleh

Trenching and Trenchless Technology

- There is an increasing need for methods of installing utility systems below the ground with minimum open excavation
- Some methods available for achieving this goal include:
- Specialized trenching machines
- Trenchless technology

Trenching machines

Figure 3–16 Chain trencher. (Courtesy of Vermeer Manufacturing Co.)

- Chain trenchers
- Dig (0.35-0.9) m wide trenches with a depth up to 3.1 m

- Ladder trenchers
- Up to 3.1 m wide and 7.6 m deep

- Bucket wheel trenchers
- Up to 1.5 m wide and 2.7 m deep

Trenchless technology

- **3 principal categories:**

(1) Pipe jacking

(2) Horizontal earth boring

(3) Micro-tunneling

(1) Pipe jacking

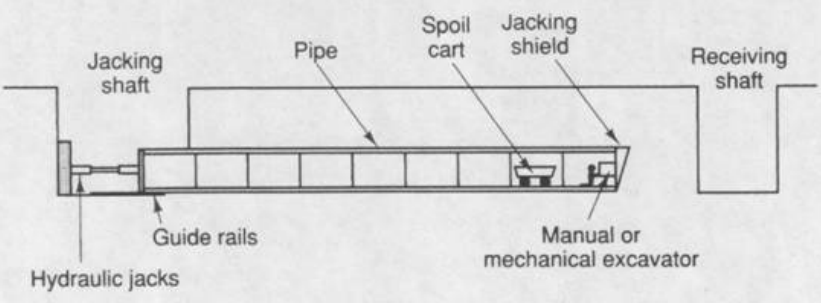


Figure 3–18 Installing a utility line by pipe jacking.

1. The process involves forcing pipe horizontally through the soil

2. Working from a vertical shaft, a section of pipe is carefully aligned and advanced through the soil by hydraulic jacks braced against the shaft sides

3. As the pipe advances, spoil is removed through the inside of the pipe

4. After the pipe section has advanced far enough, the hydraulic rams are retracted and another section of pipe is placed into position for installation

5. The process often requires workers to enter the pipe during the pipe jacking operation

(2) Horizontal earth boring

- Generally, a horizontal hole is created mechanically or hydraulically with the pipe to be installed serving as the casing for the hole
- The technology utilizes lasers and television cameras for hole alignment and boring control

- Detectors are used to locate the drill head and ensure that the desired alignment and depth are being maintained
- Figure below shows the use of a pneumatic piercing tool to create a borehole for a utility line

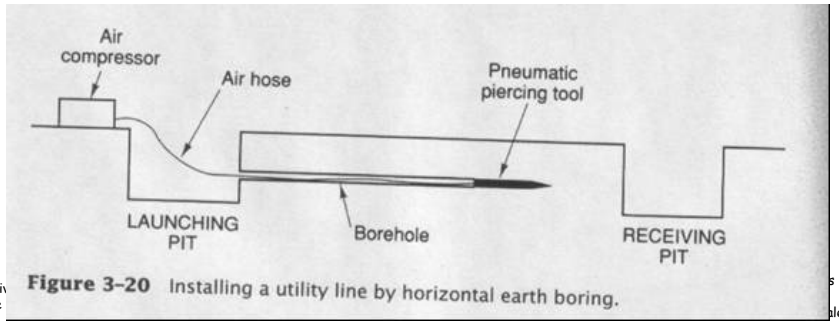


Figure 3–20 Installing a utility line by horizontal earth boring.

- After the bore has been completed, several methods are available to place pipe into the borehole:

1. The pipe is pulled through the bore using the tool's air hose or steel cable pulled by the air hose
2. Using the piercing tool to push the pipe through the borehole
3. Using a pipe pulling adapter attached to the piercing tool to advance the pipe at the same time as the piercing tool advances the bore

(3) Micro-tunneling or utility tunneling

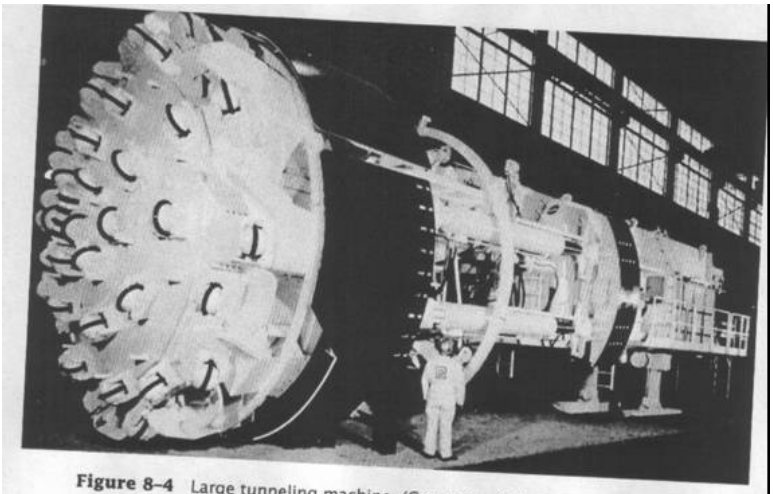


Figure 8–4 Large tunneling machine. (Courtesy of The Robbins Company)

- Tunneling machines or mechanical moles equipped with multiple cutter heads and capable of excavating to full tunnel diameter have come into an increasing use
- The one shown in previous slide can drill a hole of 5.8 m diameter

Repair and rehabilitation

- The repair and rehabilitation of existing pipelines without excavation is another form of trenchless technology
- A number of methods exist
- Bursting the existing pipe while inserting a new pipe is one of common methods

- Pipe bursting uses a high-powered hydraulic or pneumatic piercing tool equipped with a special bursting head to shatter the existing pipe and enlarge the opening by the piercing head

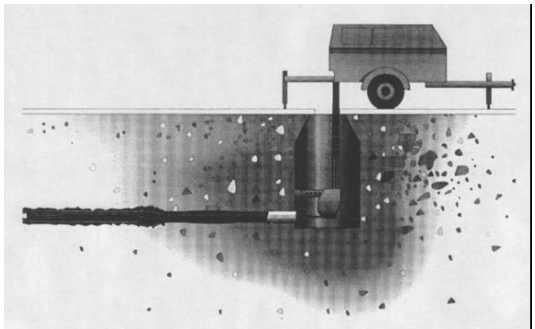


Figure 3–21 Schematic of pipe bursting. (Courtesy of Vermeer Manufacturing Co.)

Chapter 4: Loading and Hauling

Part (1) – Estimating Equipment Travel Time

Dr. Mohammad S. El-Mashaleh

Estimating equipment travel time

- In calculating the time required for a haul unit to make one complete cycle, we consider 2 components:

(1) Fixed time
(2) Variable time

Cycle time = Fixed time + Variable time

- **Fixed time:**
- Spot time
- Load time
- Maneuver time
- Dump time

- **Variable time:**
- Travel time to unloading site and return

Travel time

- Depends on:

(1) Vehicle's weight and power

(2) Condition of the haul road

(3) Grades encountered

(4) Altitude above sea level

Travel time considerations

Resistance to movement

- To determine the maximum speed of a vehicle in a specific situation, it is necessary to determine the total resistance to movement of the vehicle
- The resistance that a vehicle encounters in traveling over a surface is made up of two components

- These components are:

(1) Rolling resistance

(2) Grade resistance

Total Resistance =

Rolling Resistance + Grade Resistance

(1) Rolling resistance

- Results from:
- Friction or the flexing of the driving mechanism (tire flexing)
- Force required to shear through or ride over the supporting surface

- This resistance varies considerably with the type and condition of the surface over which a machine moves
- Soft earth offers a higher resistance than hard-surfaced roads as concrete pavement

Rolling Resistance Comparison

Narrow-tread, high pressure tire
Versus
Broad-tread, low pressure tire

(1) On a hard surfaced road

(2) On a soft surfaced road (the tire tends to sink into the earth)

(1) On a hard surfaced road

- A narrow-tread, high pressure tire gives lower rolling resistance than a broad-tread, low pressure tire
- Why?

- This is the result of the small area of contact between the tire and the road surface

(2) On a soft surface (the tire tends to sink into the earth)

- A broad-tread, low-pressure tire will offer a lower rolling resistance than a narrow-tread, high-pressure tire
- Why?

- The reason for this condition is that the narrow tire sinks into the earth more deeply than the broad tire and thus is always having to climb out of a deeper hole that is equivalent to climbing a steeper grade

Rolling resistance units

- Rolling resistance is expressed as:

(1) Kg of resistance per ton of vehicle weight

(2) or as an equivalent grade resistance

- For example, if a loaded truck that has a gross weight equal to 20 tons is moving over a level road whose rolling resistance is 100 kg/ton

- The tractive effort required to keep the truck moving at a uniform speed will be 2000 kg

Rolling resistance measurement

- The rolling resistance of a haul road can be determined by towing a truck (or other vehicle) whose gross weight is known along a level section of the haul road at a uniform speed
- The tow cable should be equipped with a device that will enable determination of the average tension in the cable

- This tension is the total rolling resistance of the gross weight of the truck
- It has been found that the rolling resistance factor increases about 15 kg/ton for each 2.5 cm of tire penetration
- It has been found that the rolling resistance is 20 kg/ton for:
- Rubber tired vehicle
- Equipped with conventional tires
- Moving over hard, smooth surface

Rolling resistance formula

- Use the following equation for estimating rolling resistance factors

$$\text{Rolling Resistance Factor (kg/ton)} = 20 + (6 \times \text{cm penetration})$$

  - Rolling resistance in kg may be found by multiplying the rolling resistance factor by the vehicle's weight in tons

Table 4–1 Typical values of rolling resistance factor

Type of Surface	Rolling Resistance Factor	
	lb/ton	*kg/t*
Concrete or asphalt	40 (30)*	20 (15)
Firm, smooth, flexing slightly under load	64 (52)	32 (26)
Rutted dirt roadway, 1–2 in. penetration	100	50
Soft, rutted dirt, 3–4 in. penetration	150	75
Loose sand or gravel	200	100
Soft, muddy, deeply rutted	300–400	150–200

*Values in parentheses are for radial tires.

Rolling resistance of crawler tractors

- Crawler tractors may be thought of as traveling over a road created by their own tracks
- Therefore, crawler tractors are usually considered to have no rolling resistance when calculating vehicle resistance and performance

- Actually, the rolling resistance of crawler tractors does vary somewhat between different surfaces
- However, the standard method for rating crawler tractor power (horse power) measures the power actually produced when operating on a standard surface
- Thus the rolling resistance of the tractor over the standard surface has already been subtracted from the tractor's performance

- When a crawler tractor tows a wheeled vehicle, the rolling resistance of the towed vehicle must be considered in calculating the total resistance of the combination

Recall that

Total Resistance =

Grade Resistance + Rolling Resistance

We are done with Rolling Resistance, lets move to Grade Resistance

(2) Grade resistance

- Represents the component of vehicle weight which acts parallel to an inclined surface

- When a vehicle is traveling:
- Up, grade resistance is +ve
- Down, grade resistance is –ve

Grade resistance (kg/ton) = 10 × grade (%)

Total resistance =

Grade resistance + Rolling resistance

↓ 10 × grade (%)

↓ 20 + 6 × penetration

Effective grade

Effective grade (%) =

Grade (%) + Rolling resistance factor (kg/ton) / 10

↑

To convert rolling resistance to an equivalent grade (%)

Example 1

Example 2

Chapter 4: Loading and Hauling

Part (2) – Estimating Equipment Travel Time

Dr. Mohammad S. El-Mashaleh

Effect of altitude

- All internal combustion engines lose power as their elevation above sea level increases
- Power generated by engine decreases approximately 3% for each 305m increase in altitude above the maximum altitude at which full rated power is delivered

- Manufacturers use a "**Derating Factor**" to express percentage of reduction in rated vehicle power at various altitudes
- If manufacturer's table is not available use:

  Derating factor (%) = (Altitude – 915) / 102

Where altitude is in meters

- Therefore:
  Rated power available = 1 – derating factor

Effect of traction

- The power used to move a vehicle and its load is expressed as (available power):
- **Rimpull** for wheel vehicles
- **Drawbar** for crawler vehicles

- The available power of the machine can be converted into tractive effort only if sufficient traction can be developed between the driving wheels or tracks and the haul surface

- If there is insufficient traction, the full available power of the engine can not be used as the wheels or tracks will slip on the surface

- Traction depends on:

(1)the coefficient of traction

(2)the weight on the drivers

Maximum usable pull =
Coefficient of traction x weight on drivers

Weight on drivers = total vehicle weight

Coefficient of traction

- The coefficient of traction can be defined as the factor by which the total weight on the drive wheels or tracks should be multiplied to determine the maximum possible tractive force between the wheels or tracks and the surface just before slipping

Table 4–2 Typical values of coefficient of traction

Type of Surface	Rubber Tires	Tracks
Concrete, dry	0.90	0.45
Concrete, wet	0.80	0.45
Earth or clay loam, dry	0.60	0.90
Earth or clay loam, wet	0.45	0.70
Gravel, loose	0.35	0.50
Quarry pit	0.65	0.55
Sand, dry, loose	0.25	0.30
Sand, wet	0.40	0.50
Snow, packed	0.20	0.25
Ice	0.10	0.15

* Substitute maximum altitude for rated performance, if known.

Example 4

Performance curves

- Used to find out the maximum speed that a vehicle can maintain
- Y-axis: **Rimpull** or **Drawbar** pull
- X-axis: maximum vehicle speed

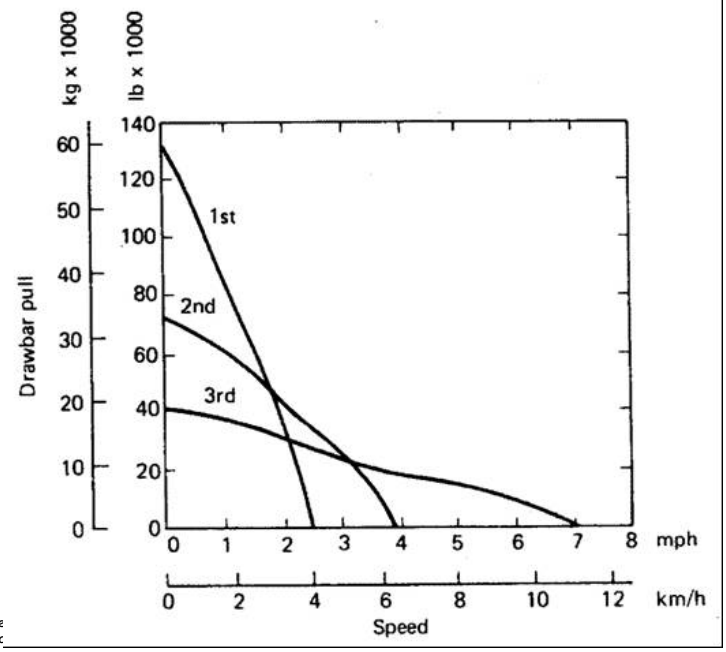


Figure 4–1 Typical crawler tractor performance curve.

Example 5

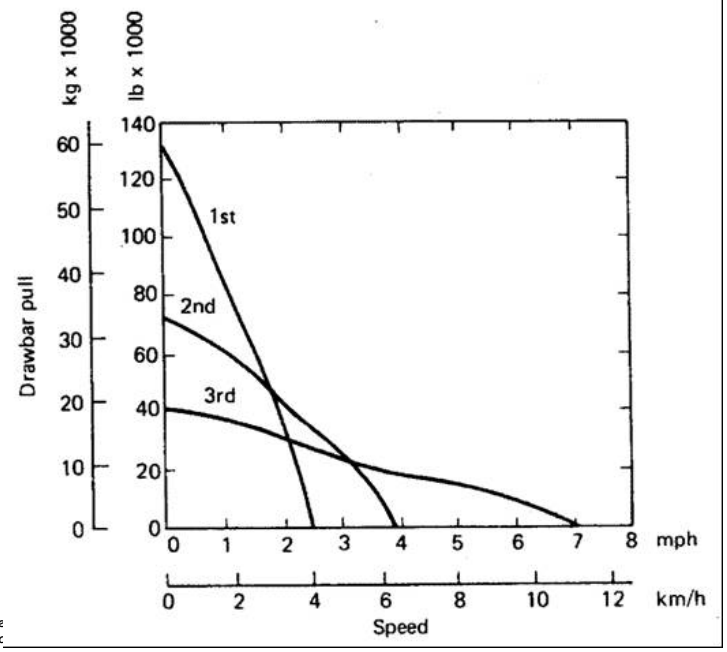


Figure 4–1 Typical crawler tractor performance curve.

- More complicated performance curve

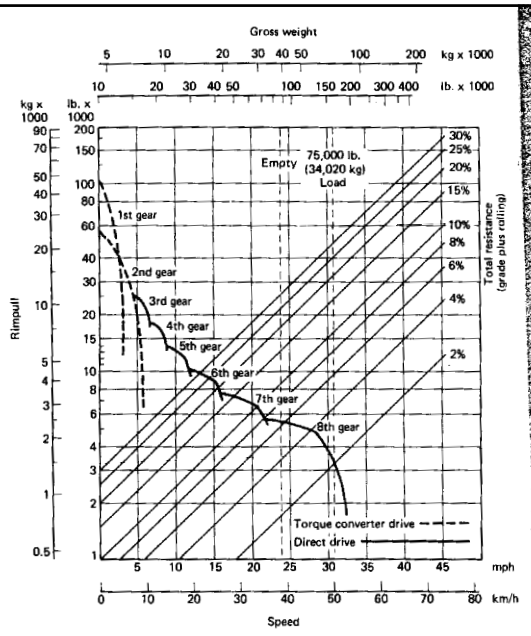


Figure 4–2 Wheel scraper performance curve. (Courtesy of Caterpillar Inc.)

- **<u>Adjusting for altitude</u>**
- Divide the required pull by (1-derating factor)
- Go horizontally to gears then vertically to speed

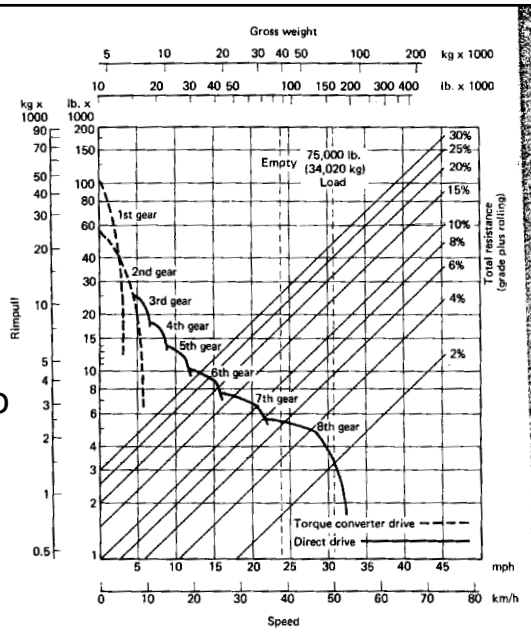


Figure 4–2 Wheel scraper performance curve. (Courtesy of Caterpillar Inc.)

Example 6

Travel time curves

- Manufacturers usually provide travel time curves for both loaded and empty conditions
- Figures 4-4 and 4-5 are examples
- Given distance and effective grade, we find travel time in minutes
- Note that we can not use these graphs in the case of negative grade

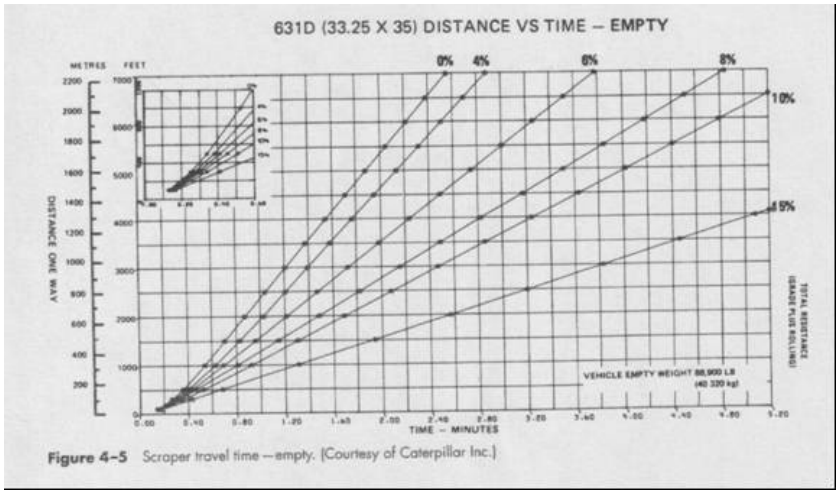


Figure 4–5 Scraper travel time – empty. (Courtesy of Caterpillar Inc.)

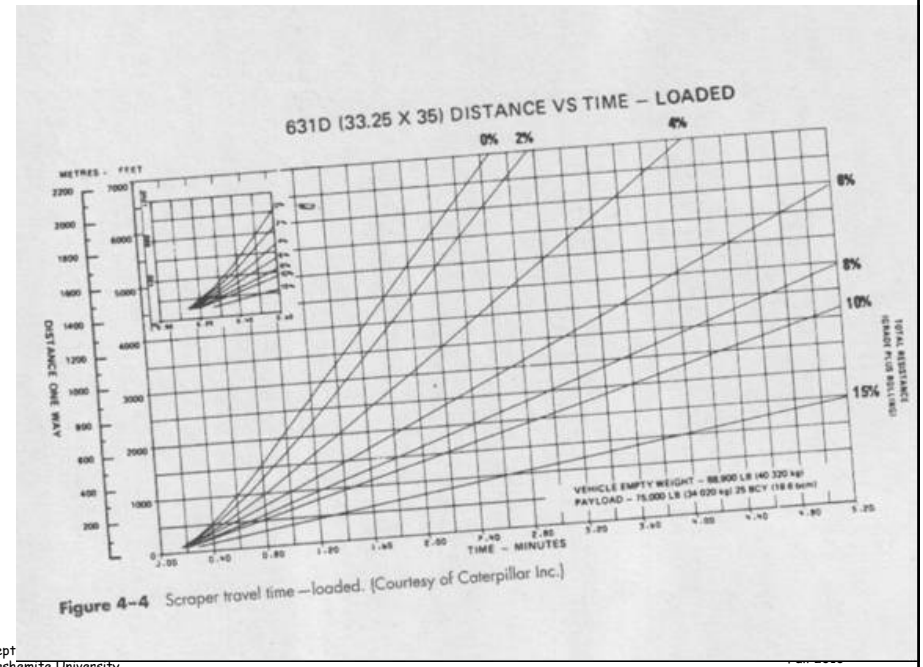


Figure 4–4 Scraper travel time—loaded. (Courtesy of Caterpillar Inc.)

Adjusting travel time curves for altitude

- Multiply obtained time by:

(1+derating factor)

Example 7

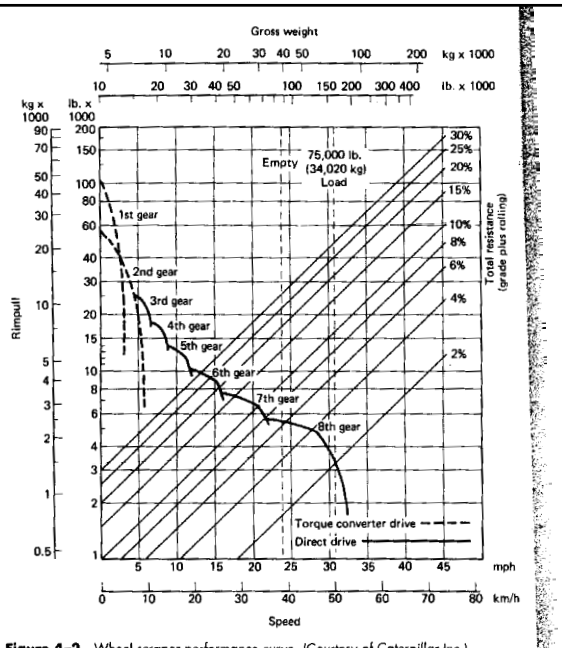


Figure 4–2 Wheel scraper performance curve. (Courtesy of Caterpillar Inc.)

Example 8

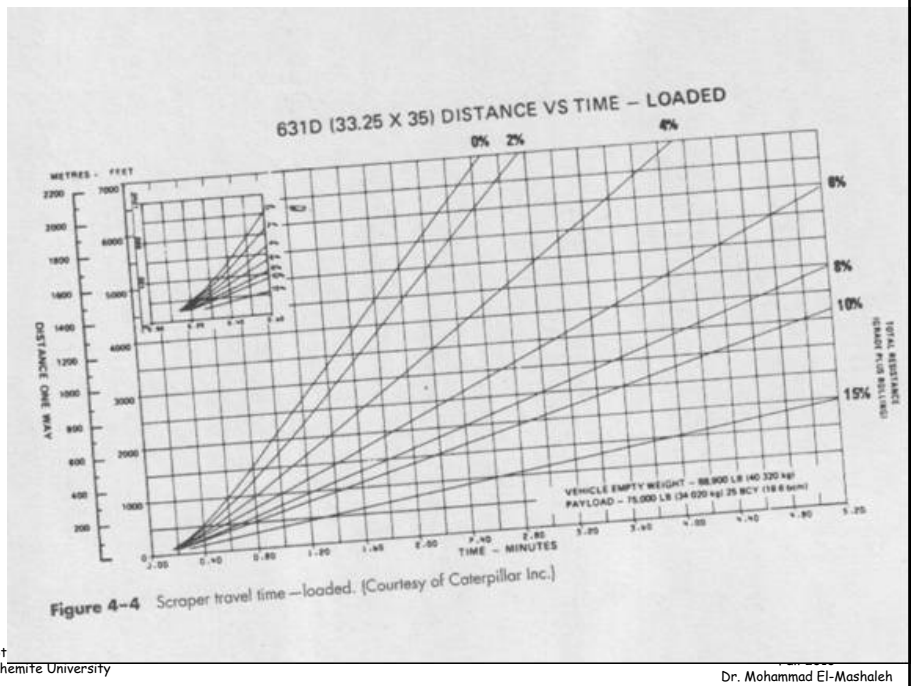


Figure 4–4 Scraper travel time—loaded. (Courtesy of Caterpillar Inc.)

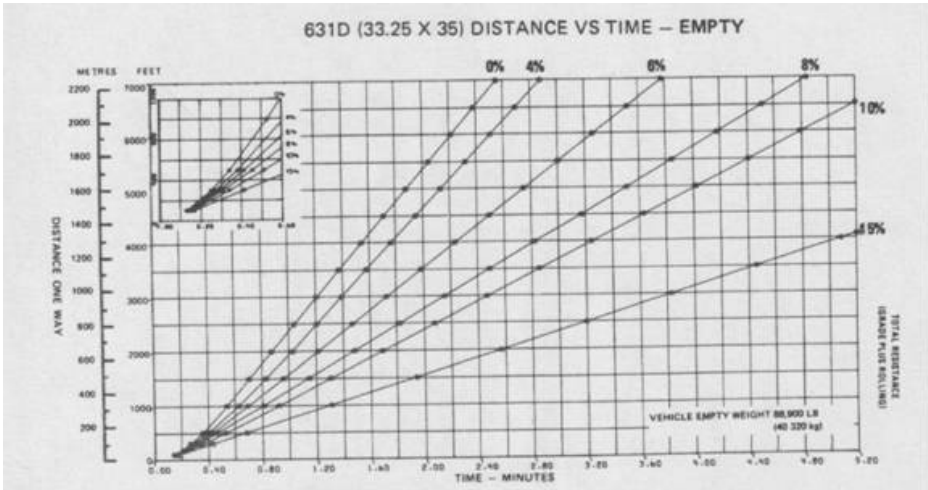


Figure 4–5 Scraper travel time—empty. (Courtesy of Caterpillar Inc.)

Chapter 4: Loading and Hauling

Part (3) – Tractors and Dozers

Dr. Mohammad S. El-Mashaleh

Dozer (Bulldozer)

- A dozer is a tractor equipped with a front-mounted earthmoving blade

Dozer method of operation

- A dozer moves earth by lowering the blade and cutting until a full blade load of material is obtained
- Then pushing the material across the ground surface to the required location
- The material is unloaded by pushing it over a cliff or into a hopper (truck)

Dozer's most common uses

1. Clearing land
2. Moving and excavating earth for short distances (<100 m)
3. Pushing scrappers during loading
4. Spreading fill material

Crawler dozers Vs. Wheel dozers

- Crawler dozers have excellent traction and low ground pressure
- Well suited for rough terrain and areas of low traficability
- Can operate on steeper side slopes and climb greater grades than can wheel dozers

Wheel dozers

- While the wheel tractor dozing is limited somewhat by its lower traction and high ground pressure, its high ground pressure makes it an effective soil compacter
- Wheel dozers operate at higher speed than do crawler dozers
- Wheel dozers are capable also of operating on paved roads without damaging the surface

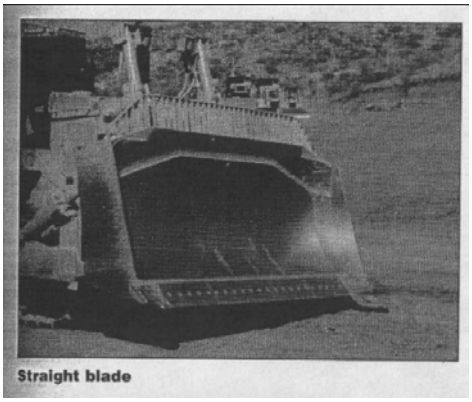
Dozer blades

- Four types

1. Straight blade
2. Universal blade
3. Angle blade
4. Cushion blade

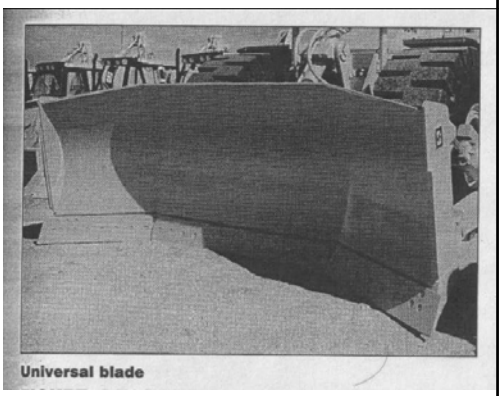
(1) Straight blade

- Used primarily for excavation work
- Considered the most versatile dozer blade
- Its smaller size gives it good penetrating and load pushing ability


Straight blade

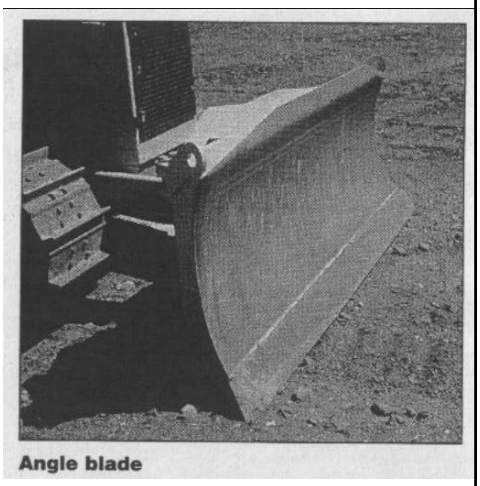
(2) Universal blade

- Efficient for moving big loads over distances
- However, its low horsepower per foot of cutting edge and per cubic yard limit its ability to penetrate hard soils or to move heavy materials


Universal blade

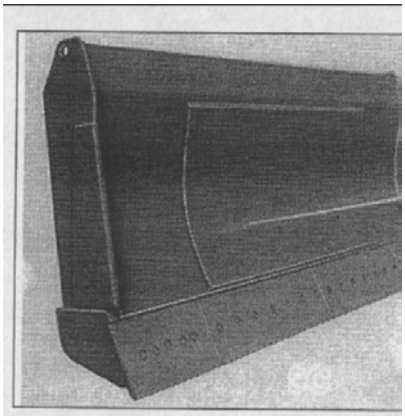
(3) Angle blade

- The ability to angle approximately 25 degrees to either side makes them very effective in sidehill cutting and backfilling
- They may also be used for rough grading and for moving material laterally

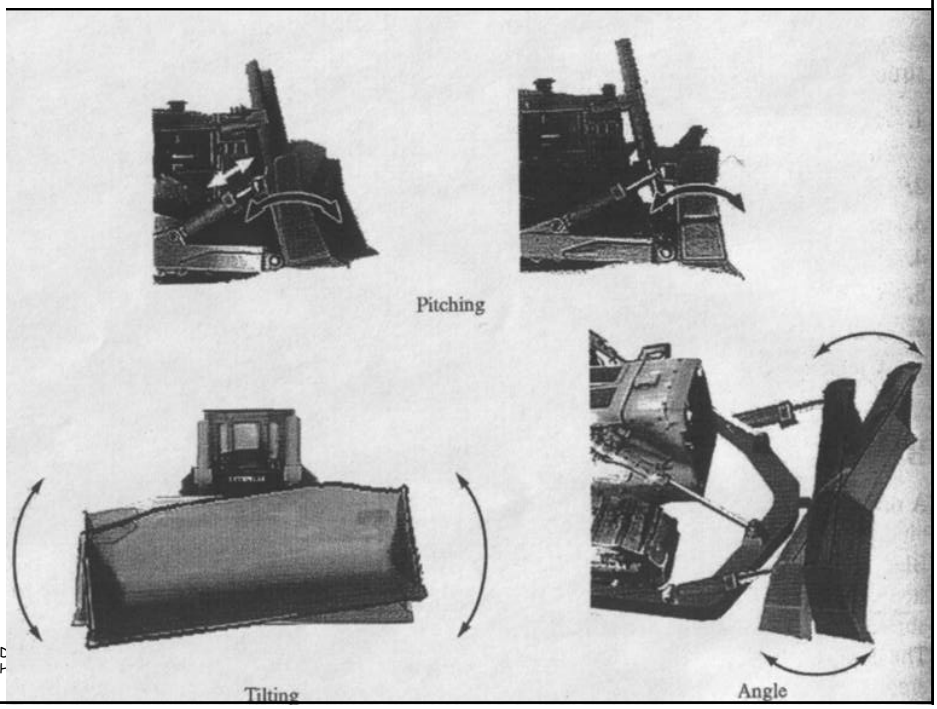

Angle blade

(4) Cushion blade

- Reinforced and equipped with shock absorbers to enable it to push-load scrapers
- May also be used for cleanup of the loading or dumping areas and for general dozing when not push-loading scrapers



Cushion blade



Indicators of dozer's performance

- **<u>Two indicators:</u>**

(1) Horsepower per foot of cutting edge (hp/ft)

(2) Horsepower per loose cubic yard (hp/lcy)

(1) Horsepower per foot of cutting edge (hp/ft)

- Provides an indication of the ability of the blade to penetrate and obtain a load
- The higher this ratio, the more aggressive the blade

(2) Horsepower per loose cubic yard (hp/lcy)

- Provides an indication of the blade's ability to push material once the blade is loaded
- A higher ratio means that the dozer can push a load at a greater speed

Estimating dozer production

$$\text{Production} = \text{Volume per cycle} \times \text{Cycles per hr} \times \text{E}$$

- To apply the above equation, we need:

(1) An estimate of average blade load

(2) Dozer cycle time

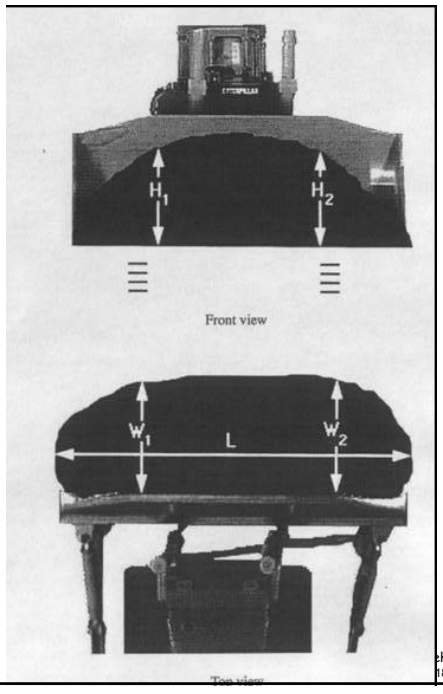
(1) Estimating average blade load

- **<u>Three methods are available:</u>**

1. Use the blade manufacturer's rating blade capacity
2. Base estimate on previous experience with similar conditions (materials, equipment, and job conditions)
3. Measure blade loads obtained in field tests

- Method 3 – measuring blade loads obtained in field tests:

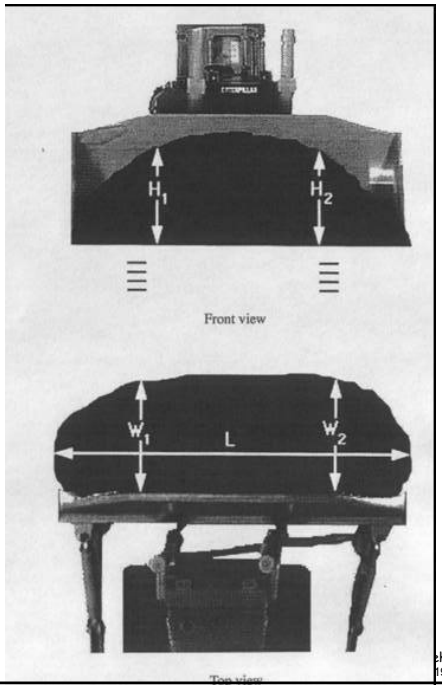
1. Obtain a full blade load, carry onto a level surface, and lift the blade while pulling slightly forward so that an evenly shaped pile is formed



2. Obtain the width of the pile (W) perpendicular to the blade

3. Obtain the height of the pile (H)

4. Obtain the length of the pile (L) parallel to the blade



5. Calculate blade volume as follows:

Blade load (LCM) = 0.375 x H (m) x W (m) x L (m)

(2) Estimating dozer cycle time

Cycle time = Fixed time + Variable time

- **Fixed time:**
- Maneuver
- Change gears
- Start loading
- Dump

- **Variable time:**
- Time required to doze and return

Since the haul distance is relatively short, a dozer usually returns in reverse gear

Table 4–4 Typical dozer fixed cycle times

Operating Conditions	Time (min)
Power-shift transmission	0.05
Direct-drive transmission	0.10
Hard digging	0.15

Table 4–5 Typical dozer operating speeds

Operating Conditions	Speeds
Dozing	
Hard materials, haul 100 ft (30 m) or less	1.5 mi/h (2.4 km/h)
Hard materials, haul over 100 ft (30 m)	2.0 mi/h (3.2 km/h)
Loose materials, haul 100 ft (30 m) or less	2.0 mi/h (3.2 km/h)
Loose materials, haul over 100 ft (30 m)	2.5 mi/h (4.0 km/h)
Return	
100 ft (30 m) or less	Maximum reverse speed in second range (power shift) or reverse speed in gear used for dozing (direct drive)
Over 100 ft (30 m)	Maximum reverse speed in third range (power shift) or highest reverse speed (direct drive)

Example 9

Example 10

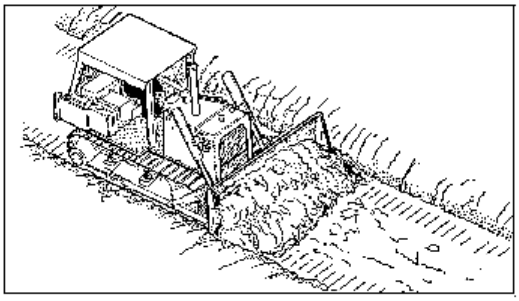
Job management

- Techniques used to increase dozer production include:
- Downhill dozing
- Slot dozing
- Blade-to-blade (side-by-side) dozing

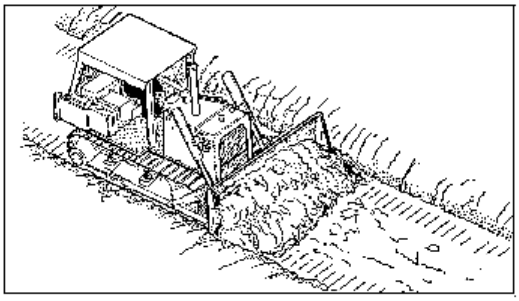
Downhill dozing

- Allows increased blade load or reduced cycle time by taking advantage of the force of gravity
- Not necessary for the dozer to actually travel downhill on each pass to take advantage of the production increase that results from downhill dozing
- It is efficient to pile up several blade loads and then push them to the bottom of the hill in one pass

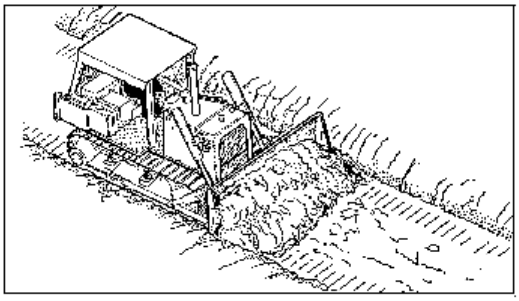
Slot dozing



- Utilizes spillage from the initial dozer passes to form ridges on each side of the dozer's cut area

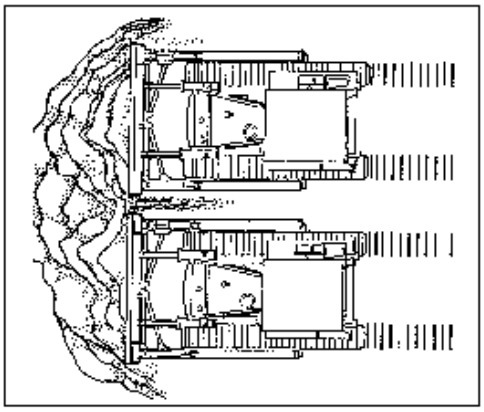


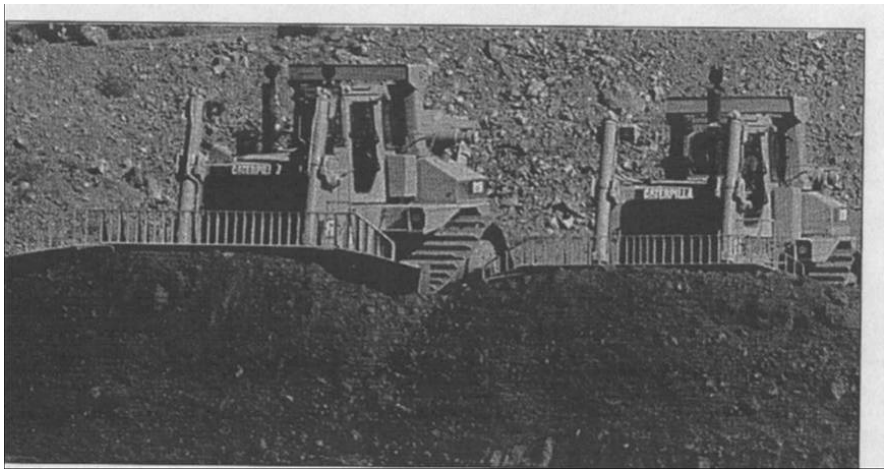
- A slot or trench is created which greatly increases the load that the blade can carry to the dump area
- The technique may be applied to large cut areas by leaving narrow uncut sections between slots

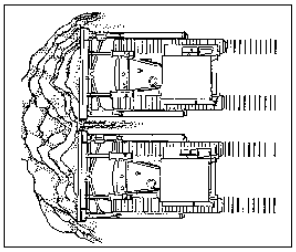


- The uncut sections are later dozed out near the end of the excavation process
- Slot dozing may increase dozer production up to 50% under favorable conditions

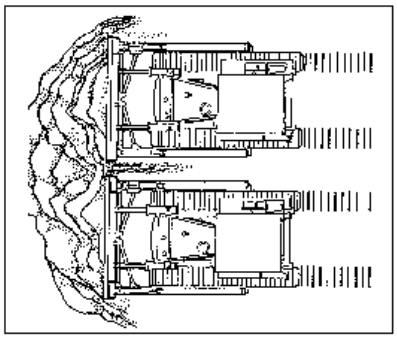
Blade-to-blade (side-by-side) dozing







- Two or more dozers operated in parallel with their blades almost touching
- This enables the blade load to be increased considerably
- Usually not efficient for dozing distances that are less than 15 m since the increased blade load is offset by the extra maneuvering time required



- Mechanically coupled side-by-side dozers equipped with a single blade are available and more efficient than using blade-to-blade dozing

Chapter 4: Loading and Hauling

Part (4) – Loaders

Dr. Mohammad S. El-Mashaleh

Loaders

Loaders most commonly used for

1. Excavating soft to medium-hard material
2. Loading haul units
3. Stockpiling material
4. Backfilling
5. Moving concrete and other construction materials

Wheel loaders

- Excellent job mobility
- Over the road movement between jobs at speeds of 40km/h and higher
- While their ground pressure is relatively low and may be varied by the use of different-size tires and by changing inflation pressures, they do not have all-terrain capability of track loaders

Track loaders

- Can overcome steeper grades and side slopes compared to wheel loaders
- Their low ground pressure and high tractive effort enable them to operate in the lowest traficability soils
- Because of their low speed, their production is less than that of a wheel loader over longer haul distances

Estimating loader production

$$\text{Production} = \text{Volume per cycle} \times \text{Cycles per hr} \times \text{E}$$

Loader bucket capacity is rated in heaped (loose) volume

As a result, bucket capacity should be adjusted by a bucket fill factor

Cycle time = **Basic** cycle time + Variable time

- **Basic cycle time:**
- Loading
- Dumping
- Making reversals of direction
- Traveling a minimum distance

- **Variable time:**
- Time required to haul and return

Loader basic cycle time

Front and rear axles are designed to provide greater maneuverability

Table 4–6 Basic loader cycle time

Loading Conditions	Basic Cycle Time (min)	
	Articulated Wheel Loader	*Track Loader*
Loose materials	0.35	0.30
Average material	0.50	0.35
Hard materials	0.65	0.45

Travel time curve

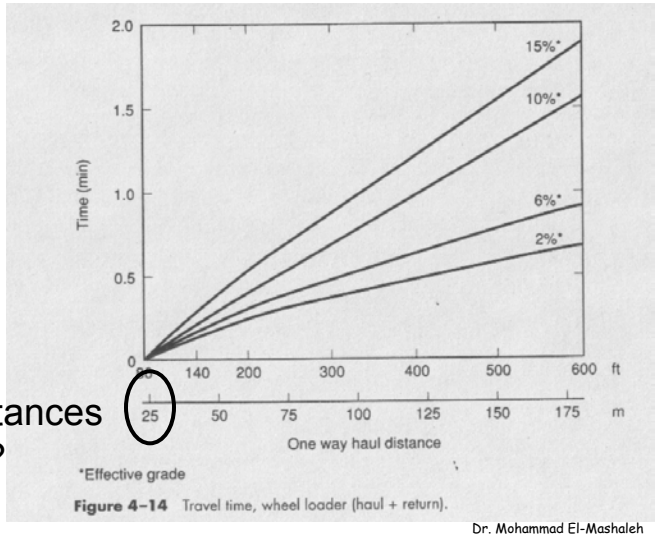


Figure 4–14 Travel time, wheel loader (haul + return).

What about distances that are <25 m?

- Studies show that there is little variation in basic cycle time for wheel loaders up to a distance of 25m between loading and dumping distance
- Therefore, travel time should not be added until one-way distance exceeds this distance

Example 11

Chapter 4: Loading and Hauling

Part (5) – Scrapers

Dr. Mohammad S. El-Mashaleh

Scrapers

Scraper uses

- Scrapers are capable of excavating, loading, hauling, and dumping material over medium to long haul distances
- Only the elevating scraper are capable of achieving high efficiency in loading without the assistance of a pusher tractor or another scraper

- The scraper excavates by lowering the front edge of its bowl into the soil
- The bowl front edge is equipped with replaceable cutting blades

Estimating scraper production

$$\text{Production} = \text{Volume per cycle} \times \text{Cycles per hr} \times \text{E}$$

Cycle time = Fixed time + Variable time

- **Fixed time:**
- Spot time
- Load time
- Maneuver
- Dump time

- **Variable time:**
- Haul time
- Return time

Table 4-7: typical values of fixed cycle time for scrapers

Time required for a unit to position itself in the cut and begin loading, including any waiting for a pusher

Table 4–7 Scraper fixed time (min)

Conditions	Spot Time: Single Pusher	Spot Time: Tandem Pusher
Favorable	0.2	0.1
Average	0.3	0.2
Unfavorable	0.5	0.5

Conditions	Load Time: Single Pusher (Pusher loaded)	Load Time: Tandem Pusher (Pusher loaded)	Load Time: Elevating Scraper (Self-loaded)	Load Time: Auger (Self-loaded)	Load Time: Push-Pull* (Self-loaded)
Favorable	0.5	0.4	0.8	0.7	0.7
Average	0.6	0.5	1.0	0.9	1.0
Unfavorable	1.0	0.9	1.5	1.3	1.4

Conditions	Maneuver and Dump Time: Single Engine	Maneuver and Dump Time: Twin Engine
Favorable	0.3	0.3
Average	0.7	0.6
Unfavorable	1.0	0.9

*Per pair of scrapers.

- Variable cycle time (travel time) includes:
- Haul time
- Return time

- Estimated by travel-time curves

- It is necessary to break a haul route up into sections having similar total resistance values

- The total travel time is found as the sum of the section travel times

- In determining the payload per scraper cycle, it is necessary to check both the rated weight payload and the heaped volume capacity

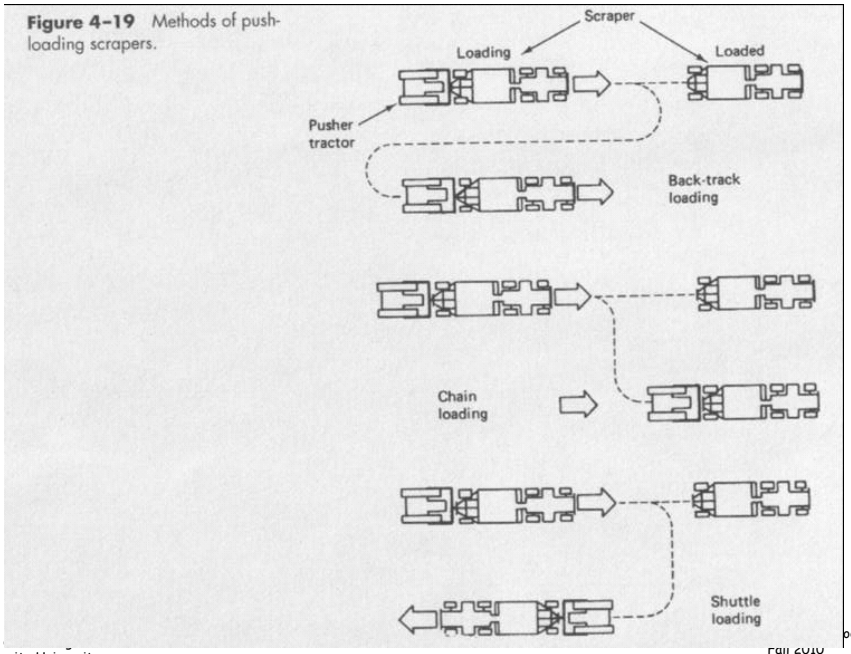
- The volume corresponding to the lesser of these two values will govern

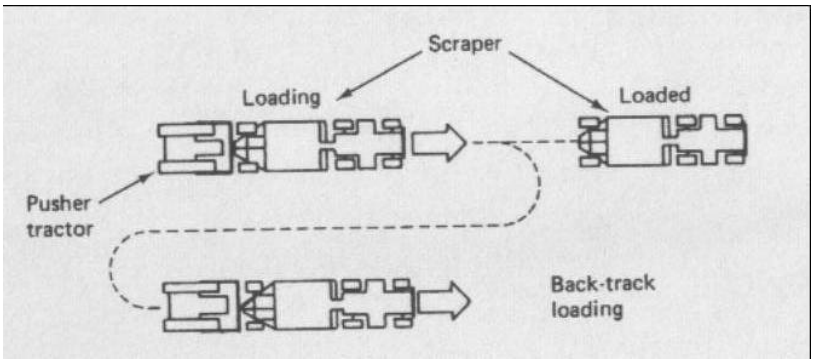
Example 12

Push-Loading

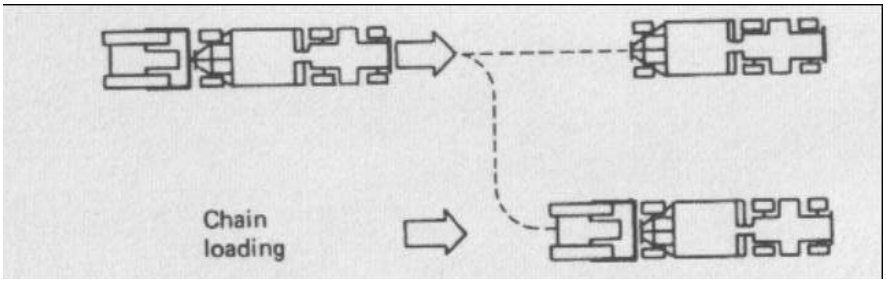
- Some scrapers require the assistance of pusher tractors to obtain maximum production

- 3 basic loading methods
- Back-track
- Chain
- Shuttle

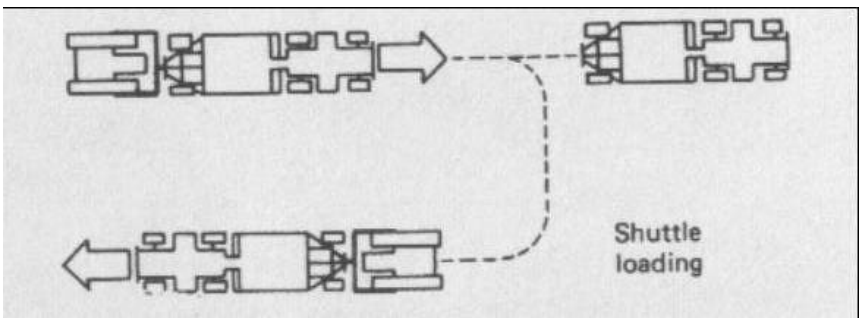




- Back-track loading
- Offers the advantage of always being able to load in the direction of the haul
- The slowest of the three methods because of the additional pusher travel time



- Chain loading
- Suitable when the excavation is conducted in a long cut



- Shuttle loading
- Infrequent use
- Pusher can serve scrapers hauling in opposite directions

Pusher cycle time

- Pusher cycle time consists of:

(1) Maneuver time: while the pusher moves into position and engages the scraper

(2) Load time

(3) Boost time: the pusher assists in accelerating the scraper out of the cut

(4) Return time

Calculating the number of pushers required

- The number of scrapers that can be handled by one pusher without a scraper having to wait for a pusher

$$\text{Number of scrapers served} = \frac{\text{Scraper cycle time}}{\text{pusher cycle time}}$$

$$\text{Number of pushers required} = \frac{\text{Number of scrapers}}{\text{Number served by one pusher}}$$

$$\text{Production} = \frac{\text{Number of pushers}}{\text{Required number}} \times \text{Number of scrapers} \times \text{Production per scraper}$$

Table 4–8 Typical pusher cycle time (min)

Loading Method	Single Pusher	Tandem Pusher
Back-track	1.5	1.4
Chain or shuttle	1.0	0.9

Example 13

Example 14

Techniques for maximizing scraper production

1. Use downhill loading whenever possible to reduce the required pusher power and load time
2. Use rippers to loosen hard soils before attempting to load
3. Have pushers give scrapers an adequate boost to accelerate units out of cut

4. Keep the cut in good condition by providing adequate drainage to improve traficability
5. Maintain the haul road in the best possible condition (use a grader)
6. Make the haul road wide enough to permit high speed hauling without danger

Chapter 5: Compacting and Finishing

Dr. Mohammad S. El-Mashaleh

Compaction

- What does the process of compaction involve?
- Compaction is the process of increasing the density of a soil by mechanically forcing the soil particles closer together, primarily by expelling air from the void spaces in the soil

- The increased density obtained by soil compaction improves the construction characteristics of the soil in several ways:

1. Increased strength
2. Reduced compressibility
3. Reduced permeability

- The amount of compaction that can be achieved with a given soil depends on:

1. The soil's physical and chemical characteristics (grain size, cohesiveness, etc.)
2. Soil's initial density
3. Soil's moisture content

4. Compaction method employed
5. The amount of compactive effort
6. Thickness of the soil layer being compacted

Compaction forces

- **Four** basic compaction forces

(1) Static weight

(2) Manipulation (kneading): most effective in plastic soils

(3) Impact

(4) Vibration

- Note that most compactors combine more than one force

Impact and vibration forces

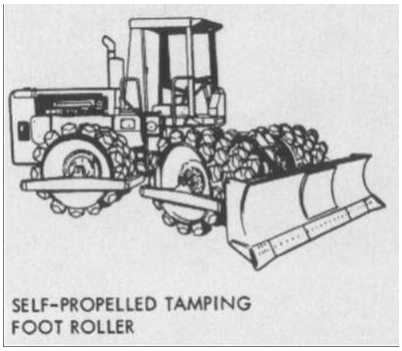
- Both produce similar forces, however, they use different frequencies
- **Impact** uses lower frequency (10 cycles per second (Hz)) that is more suitable for cohesive soils
- **Vibration** uses higher frequency (> 80 cycles per second) that is more suitable for cohesiveless soils like sand and gravel

Compaction equipment

- There are several types

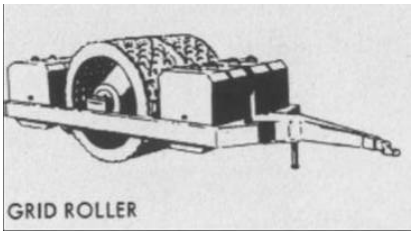
(1) Tamping foot rollers

- Uses a drum that is equipped with a number of protruding feet to achieve compaction
- These rollers come with a variety of foot shapes and sizes and include the classic sheepsfoot roller
- Achieve compaction through static weight and manipulation


SELF-PROPELLED TAMPING FOOT ROLLER

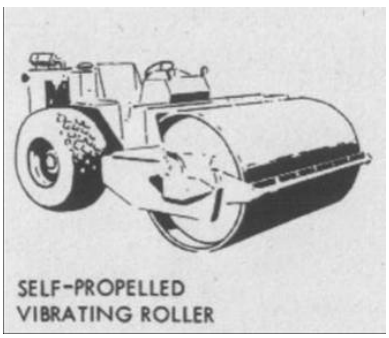
(2) Grid or mesh rollers

- Their compactive effort is due to static weight and impact
- Most effective in compacting gravel and sand
- Able to crush and compact soft rock



(3) Vibratory compactors

- Many vibratory compactors permit varying the vibration frequency to obtain the most effective compaction
- Compactive forces are principally vibration and static weight

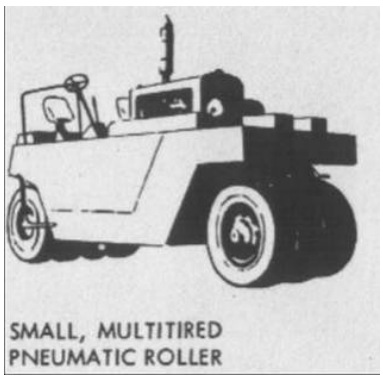


(4) Steel wheel or smooth steel drum rollers

- Widely used for compacting granular bases, asphaltic bases, and bituminous pavements
- Compaction achieved through static weight

(5) Rubber-tired or pneumatic rollers

- Well suited for compacting thick soil layers to high density
- Least suited for compacting sand and gravel



Material	Steel wheel	Pneumatic	Vibratory	Tamping foot	Grid
Rock	●	○	●	●	●
Gravel, clean or silty	●	◓	●	●	●
Gravel, clayey	●	◓	◓	●	◓
Sand, clean or silty	○	○	●	○	◓
Sand, clayey silt	○	◓	◓	●	○
Clay, sandy or silty	○	●	◓	●	○
Clay, heavy	○	●	◓	●	○

● Recommended
◓ Acceptable
○ Marginal

FIGURE 5–10 Compaction equipment selection guide.

Compaction production

Production (CCM/h) = 10 x W x S x L x E / P

Where:

W = width compacted per pass (m)

S = compactor speed (km/h)

L = compacted layer thickness (cm)

E = job efficiency

P = number of passes

Example 1

Grading and finishing

- Grading is the process of bringing earthwork to the desired shape and elevation (grade)
- Finishing is simply smoothing and shaping slopes
- The grader is usually the equipment used for grading and finishing

- Graders are used for stripping, grading, finishing, backfilling, mixing and spreading soil, and maintaining haul roads

Estimating grader production

$$\text{Time (h)} = \left[\sum \frac{\text{Number of passes} \times \text{section length (km)}}{\text{Average speed for section (km/h)}} \right] \times \frac{1}{\text{Efficiency}}$$

Typical grader operating speed

Table 5–6 Typical grader operating speed

Operation	Speed	
	mi/h	*km/h*
Bank sloping	2.5	4.0
Ditching	2.5–4.0	4.0–6.4
Finishing	4.0–9.0	6.5–14.5
Grading and road maintenance	4.2–6.0	6.4–9.7
Mixing	9.0–20.0	14.5–32.2
Snow removal	12.0–20.0	19.3–32.3
Spreading	6.0–9.0	9.7–14.5

Example 2

Concrete Formwork

Dr. Mohammad S. El-Mashaleh

What is formwork?

- Formwork is a temporary structure that supports its own weight and that of the freshly placed concrete as well as construction live loads including materials, equipment, and workmen

Formwork development

- Formwork development has paralleled the growth of concrete construction
- In the past, lumber was the only material used for formwork
- Nowadays, there is an increasing use of other materials: plywood, metal, plastics, and other materials

- Form designers and builders must be up-to-date on advancing technology in other material fields in order to develop creative innovations required to maintain quality and economy in formwork design
- Formerly, formwork was built in place and used only once

- The trend today is toward:

(1) Increasing prefabrication

(2) Assembly in large units

(3) Erecting by mechanical means (cranes)

(4) Continuing reuse of forms

Factors to consider

- The form builder is concerned with more than simply making forms the right size
- The form builder has 3 basic objectives in mind:
- Quality, safety, and economy

Quality

- To design and build forms accurately so that the desired size, shape, position, and finish of the cast concrete is in accordance with specifications

Safety

- The formwork is capable of supporting all dead and live loads without collapse or danger to workmen and to concrete structure

Economy

- To build efficiently, saving time and money for both the contractor and the owner
- Economy is a major concern since formwork costs range (35-60%) of the cost of concrete structure
- The Architect/Engineer can reduce formwork cost by keeping the requirements of formwork economy in mind when he is designing the structure

- To expedite the job and cut costs, form designer need to pay special attention to:

(1) Selection of materials and equipment

(2) Planning fabrication and erection procedures

(3) Scheduling reuse of forms

Formwork and concrete quality

- Accurate construction of forms is necessary to maintain the required size, shape, and alignment of slabs, beams, and other concrete structural elements

- To ensure the quality of the finished concrete, forms:

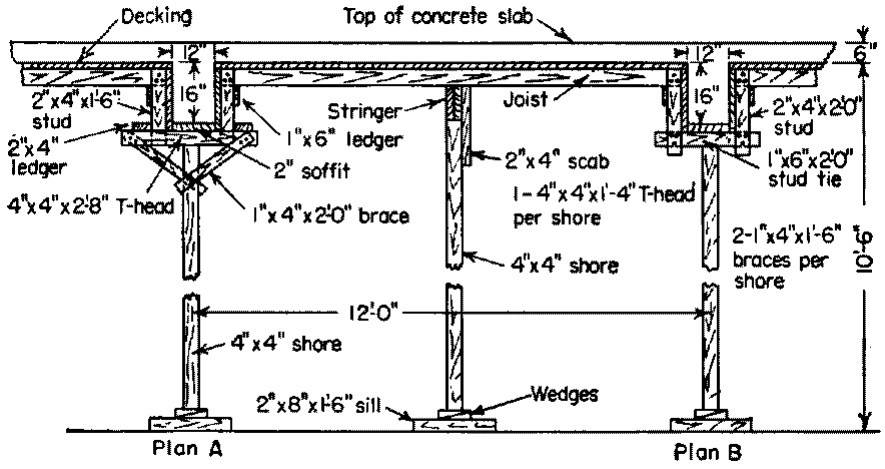
1. Must be built to correct dimensions
2. Must be rigid under the construction loads to maintain the designed shape of the concrete
3. Stable and strong enough to maintain large members in alignment
4. Substantially constructed so they can withstand handling and reuse without losing their dimensional integrity

6 major causes of formwork failures

1. Improper stripping and shore removal
2. Inadequate bracing
3. Vibration

4. Unstable soil under mudsills, shoring not exactly perpendicular
5. Inadequate control of concrete placement
6. Lack of attention to formwork details

Shores



Vibration

- Forms sometimes collapse when their supporting shores or jacks are displaced as a result of vibration
- This might be caused as a result of passing traffic or the movement of men and equipment on the formwork
- Or as a result of vibrating concrete to consolidate it

Unstable soil under mudsills, shoring not exactly perpendicular

- Formwork should be adequately braced and constructed so that all loads are carried to solid ground through vertical members
- The shores must be set exactly perpendicular and the ground must be able to carry the load without settling

- Site drainage must be adequate to prevent a washout of soil supporting the mudsills

Inadequate control of concrete placement

- Failure to regulate properly the rate and order of placing concrete on horizontal surfaces may produce unbalanced loadings and consequent failures of formwork

Lack of attention to formwork details

- Even when the basic formwork design is sound, small differences in assembly details may cause local weaknesses or overstress leading to form failure
- This may be as simple as insufficient nailing, or failure to tighten the locking devices on metal shoring

How can the A/E reduce forms costs?

(1) Study the formwork of the building as a whole

(2) Keep beam widths, beam depths, slab thicknesses, column sizes, and story heights constant for several floors, or all floors if possible

- Why?

- So forms can be reused from floor to floor. Vary strength if necessary by varying the amount of reinforcing steel

(3) Where column sizes must be changed, reduce one dimension at a time, and continue the same size for several floors

(4) To simplify formwork intersections, make joists and beams the same depth if possible over an entire floor

(5) Plan dimensions with sizes of commercially available materials in mind

- Why
- So that standard widths of lumber or plywood can be used as much as possible

Key areas of cost reduction

(1) Planning for maximum reuse

(2) Economical form construction

(3) Efficient setting and stripping practices

(1) Planning for maximum reuse

- Minimum investment in forms is achieved by constructing the least number of forms required for a smooth work flow and then reusing these forms as often as necessary until the job is completed

- The amount of work involved in reusing a form may depend on whether it has to be disassembled for stripping and reuse
- In some cases, the whole form can be removed
- More often, the form must be taken apart and moved section by section

- This may be required by the shape of the concrete structure which makes it impossible either to loosen the form or to withdraw it without taking it apart
- Or it may be that the weight of the whole form is beyond the capacity of the handling equipment
- A minimum number of different forms is established by the number of different shapes, sizes, and combinations of concrete members in the structure

- Where the same size, shape, or combination is repeated there is an opportunity for reuse
- However, note that placing schedule, stripping time, and other factors related to a specific job make it sometimes impractical to take advantage of all theoretical opportunities to reuse forms

- For example
- If the same size column appears 100 times in a building , theoretically all these columns could be cast by reusing one form 100 times
- However, this would not permit a smooth work flow and would extend the construction over an unreasonably long time
- In most cases, it is necessary to make a detailed study of work flow and construction sequence to decide on a practical number of reuses that will result in a fast, smooth, efficient job with lowest overall cost

(2) Economical form construction

- In evaluating different schemes to get maximum reuse of forms and an efficient construction sequence, the contractor must make an estimate of form construction cost for each plan
- Different choices need to be considered: building the forms, buying, or renting them

- When non-reusable forms are to be built in the position on the job, the contractor plans to use inexpensive materials that are easy to transport, handle, and shape in the field
- Reusable forms must be more durable, made of strong materials that can withstand continuing usage and usually must have added features that make them easy to handle and to assemble

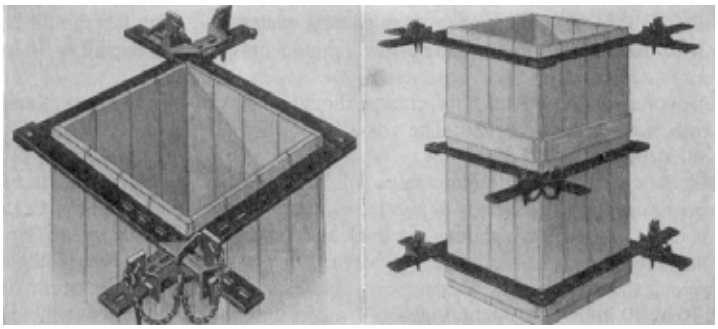
- In considering the type of materials to be used in construction of the forms, the contractor will keep in mind materials on hand and compare with the economics of purchasing or renting new materials

(3) Efficient setting and stripping practices

- The cost of setting forms in place and subsequently removing them from the concrete is an important factor
- The full benefit of a plan for reuse of forms can only be realized if the forms can be stripped and re-erected without too much lost time and if the form is not wrecked in the process

- Because of that, hardware details may have an important effect on erection and stripping costs
- For example, formwork can be assembled with metal clamps or special wedge pin connections that are secure, yet easy to assemble and disassemble
- Handles or a wood strip nailed to the form give workers a means of grasping the form side so they can pull it away from the concrete and thus eliminate or minimize the need for excessive force to loosen it

Metal clamps



Construction Safety

Chapter 19

Dr. Mohammad S. El-Mashaleh

Safety record in construction

- The US construction industry employs 4.8% of the US work force
- Accidents in the industry accounted for:
- 19.4% of work place fatalities, and
- 12.3% of the occupational injuries and illnesses

Source: Fredericks et al. (2002)

Safety record in the Middle East

- In Jordan, construction labor accounts for 7.1% of the labor force
- Accidents in the construction industry make up 10.5% of incidents

- In UAE, accidents in the construction industry represent 39.7% of all accidents (2001 report published by the UAE Ministry of Labor and Social Affairs)

Causes of construction worker fatalities in the US

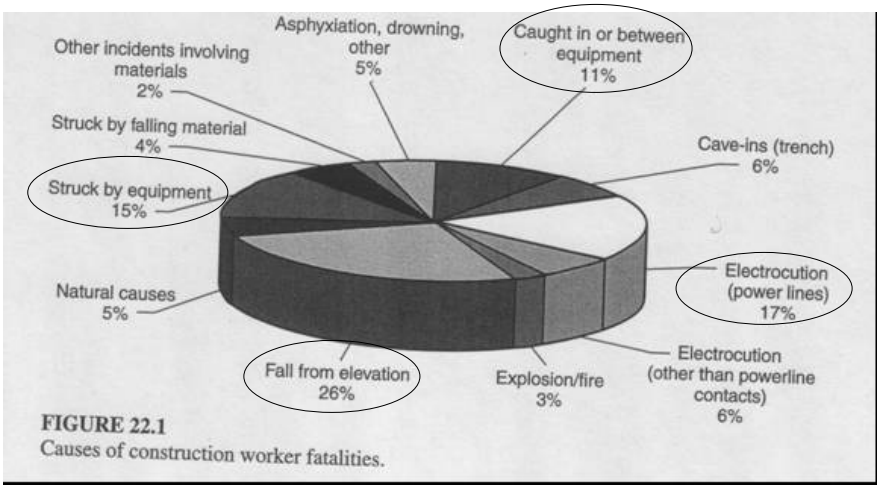


FIGURE 22.1
Causes of construction worker fatalities.

Source: Nunnally (2006)

Financial consequences for safety

- Poor safety record results in:
  - Increased worker's compensation insurance premiums
  - Increased public liability
  - Increased costs due to lost project time
- A construction firm can lose its competitive edge because of the increased insurance premiums as a result of poor safety

Occupational Safety and Health Administration (OSHA)

- The concern over the frequency and extent of industrial accidents and health hazards led to the passage of Occupational Safety and Health Act of 1970
- The essence of OSHA Act is that every worker should be provided with a safe place to work

- Each employer shall:

1. Furnish to each of his employees employment and a place of employment which are free from recognized hazards that are causing or likely to cause death or serious physical harm to his employees
2. Comply with occupational safety and health standards

- Virtually, every business is affected by OSHA regulations (not construction only)

- OSHA is responsible for developing and enforcing safety regulations:
  - Developing standards
  - Inspecting workplaces to enforce compliance
  - Performing short-term training and education
  - Developing injury and illness statistics

- To do that, OSHA has produced a comprehensive set of:
  - Safety and health regulations
  - Inspection procedures
  - Record keeping requirements where employers are required to keep records of all work related deaths, injuries, and illnesses

- 1926.20 Subpart C: General Safety & Health Provisions

(a) Contractor requirements: (a) (1) Section 107:

"….no contractor or subcontractor for any part of the contract work shall require any laborer or mechanic employed in the performance of the contract to work in surroundings or under working conditions which are unsanitary, hazardous, or dangerous to his health or safety"

(b) Accident prevention responsibilities

(b) (1) "It shall be the responsibility of the employer to initiate and maintain such programs as may be necessary to comply with this part"

(b) (2) "Such programs shall provide for frequent and regular inspections of the job sites, materials, and equipment to be made by competent persons designated by the employers"

- The previous OSHA quotes reflect two elements in a working definition of "construction safety"
- A person will not be required to work in surroundings or conditions which are unsafe dangerous to health
- Employers are responsible for initiating and maintaining a safety/health program that complies with standards

- 1926.16 Rules of Construction – Subpart B General Interpretations
- (a) ".. .In no case shall the prime contractor be relieved of overall responsibility for compliance with the requirements of this part for all work to be performed under the contract."
- (b) "By contracting for full performance of a contract the prime contractor assumes all obligations prescribed as employer obligations under the standards contained in this part, whether or not he subcontracts any part of the work"

(c) "... subcontractor of any stage ... also assumes responsibility for complying with the standards in this part with respect to that part. Thus, the prime contractor assumes the entire responsibility under the contract and the subcontractor assumes responsibility with respect to his portion of the work. With respect to subcontracted work, the prime contractor and any subcontractor or subcontractors shall be deemed to have joint responsibility"

(d) Where joint responsibility exists, both the prime contractor and his subcontractor or subcontractors, regardless of tier, shall be considered subject to the enforcement provisions of the Act.

OSHA inspections

- OSHA makes inspections of work sites to check the level of compliance with regulations
- Inspections can be made under 3 criteria:
  - Random or scheduled inspections
  - Reports of major accidents
  - Employee complaints
- Inspections are made by OSHA compliance officers

OSHA fines and penalties

- There are established penalties for violations of OSHA regulations
- Not all violations bring fines, but all unsafe conditions must be corrected
- The correction of unsafe conditions must occur within a designated period

- Failure to correct a violation will probably result in additional fine
- If the unsafe condition is serious, the fine may be quite high, up to $ 7000 for each day it remains uncorrected
- If a situation is considered one of “imminent danger”, it must be corrected immediately, with a shutdown of the operation until the correction has occurred

- “Imminent danger” is a situation that could reasonably be expected to cause death or serious physical harm
- After an OSHA inspection, the employer is notified with any violations and the corresponding penalty
- The employer has 15 days to contest any of the allegations or penalties

- In recent years, OSHA has become more aggressive in posing penalties for non compliance
- Fines of more than $1 million have been imposed against some employers!

Table 19–1 Maximum penalties under OSHA

Administrative Proceedings

Violation	*Maximum Penalty*
Willful or repeated	$70,000/violation
Routine or serious	7,000/violation
Failing to correct cited violation	7,000/day
Failing to post citation near the place where violation exists	7,000/violation

Criminal Proceedings

Violation	*Maximum Fine*	*Maximum Imprisonment*
Killing, assaulting, or resisting OSHA officials	$10,000	Life
Willful violation resulting in death of employee, first conviction	10,000	6 months
Willful violation resulting in death of employee, second conviction	20,000	1 year
Falsifying required records	10,000	6 months
Unauthorized advanced notice		

Source: Nunnally (2006)

Voluntary Protection Program (VPP)

- OSHA initiated the VPP program to increase its effectiveness in reducing worker injuries
- The program is designed to recognize outstanding achievement of firms that have successfully incorporated comprehensive safety and health programs in their overall management system

- Firms can be designated as: Star, Merit, or Demonstration
- The VPP designation is granted when a firm has established a cooperative relationships with its employees and OSHA
- The benefits of the program have shown that participants regularly experience injury rates that are 60% - 80% below the industry average

- Employers who participate in this program are not scheduled for OSHA programmed inspections

Management responsibility

- Under OSHA requirements, only management may be penalized for safety violations
- So, employees are not penalized for violating OSHA requirements; management is held responsible

- As such, OSHA recommended an Employer's Safety & Health Program:
  - Management Commitment & Leadership
  - Assignment of Responsibility
  - Identification & Control of Hazards
  - Training & Education
  - Record Keeping & Hazard Analysis
  - First Aid & Medical Assistance

Safety performance measures

- OSHA recordable incidence rate
- Experience Modification Rating (EMR)

OSHA recordable incidence rate

- Employers are required to record and report the following information:
- Number of fatalities
- Number of injuries and illnesses involving lost workdays

- Number of injuries and illnesses involving restricted workdays
- Number of days away from work
- Number of days of restricted work activity
- Number of injuries and illnesses without lost workdays

- OSHA incidence rate is calculated as follows:

Incidence rate
= No. of incidents * 200,000 hours / No. of hours worked

- The number of incidents in the formula is the total of the numbers of fatalities, injuries and illnesses involving lost and restricted workdays, and injuries and illness without lost workdays

- The 200,000 hours in the formula represents the equivalent of 100 employees working 40 hours per week, 50 weeks per year, and is the standard base of incidence rates

OSHA recordable incidence rate average

- The US construction industry average for the recordable incidence rate has declined from 12.2 in 1993 to 7.9 in 2001 (Mitropolous et al., 2005)

Experience Modification Rating (EMR)

- EMRs are established by independent rating bureaus (basically insurance companies)
- These companies gather safety information about contractors
  - Accidents, safety programs, top management commitment, etc.

- Based on these gathered information, they calculate an EMR for each contractor
- EMR dictates the contractor's premium of the workers' compensation insurance
  - Higher EMR values mean that the contractor pays more money to buy insurance for his workers
  - Similar to buying insurance for your car

- EMR values range between 0.5 and 2.0
- An EMR of 1.0 means an employer has an average safety record
- An EMR of 1.2 means that a contractor pays 20% more for workers' compensation insurance than a similar company with an EMR of 1.0
- An EMR of less than 1.0 indicates that the contractor is experiencing fewer losses than other comparable companies

How can a construction firm lose its competitive edge because of safety?

Safety programs

- All construction firms need a carefully planned and directed safety program to:
  - Minimize accidents
  - Ensure compliance with safety regulations
- No safety program will be successful without the support of top management

- Constructors working on the field need to be convinced that safety is as important as production

Elements of comprehensive safety programs

1. A formal safety training program for all new employees

2. Formal supervisory safety training program for all supervisors

3. A program of regular site visits by safety personnel to review and control job hazards

4. An established procedure for the emergency evacuation of injured workers

5. Provisions for maintaining safety records and reporting accidents in compliance with OSHA requirements

Safety procedures

- Most serious construction accidents involve:

1. Construction equipment operations

2. Trench and embankment failure

3. Falls from elevated positions

4. Collapse of temporary structures and formwork

5. Failures of structures under construction

- Therefore, special management attention should be devoted to the safety of these activities

- Good housekeeping on a project site is a safety measure and an indicator of good project supervision

- Used formwork and other material lying around a work area increase the likelihood of accidents

Safety guidelines for equipment operations

- Utilize guides or signal persons when the operator's visibility is limited or when there is danger to nearby workers
- Backup alarms must be used when equipment operates in reverse

- Use care when operating equipment on side slopes to prevent overturning
- Do not allow workers to ride on equipment unless proper seating is provided
- Exercise extreme caution and comply with safety regulations when operating near high-voltage lines
- Make sure that machines are equipped with required safety features and that operators use safety belts

- Do not exceed safe load limits when operating cranes (considering operating radius and boom position)
- Park equipment with the brake set, blade or bowl grounded, and ignition key removed at the end of work
- When hauling heavy or oversized loads on highways, make sure that loads are properly secured and covered if necessary
- Slow-moving and oversized vehicles must use required markings and signals to warn other traffic

Safety guidelines for excavations

- The side of excavations must be properly shored or sloped to the angle of repose to prevent cave-ins
- Banks over 1.5 meters must be shored, cut back to a stable slope, or otherwise protected (OSHA regulations)

- Protective systems (sloping, shoring, or shielding) for excavations over 6.1 m deep must be designed by a registered professional engineer (OSHA regulations)
- Ensure that workers are not allowed under loads being handled by excavators or hoists
- Watch out for buried lines when excavating

- Avoid the operation of equipment near the top edge of an excavation because this increases the chance of slope failure. The storage of materials near the top edge of an excavation, vibration, and the presence of water also increase the chance of slope failure
- If workers are required to enter the excavation, no spoil or other material may be stored within 0.6 m of the edge of the excavation

Safety guidelines for structures

- Properly guard all openings above ground level
- Provide guard rails, safety lines, safety belts, and/or safety net for workers on scaffolds or steel work

- Ensure that temporary structures are properly designed and constructed
- Special caution should be exercised in high-rise concrete construction
- Forms must be of adequate strength and properly braced

- Rate of pour must be maintained at or below design limits
- Shoring must be adequately braced and not removed until the concrete has developed the required strength

Environmental health in construction

- Major environmental health problems encountered in construction:
- Noise
- Dust
- Radiation
- Toxic materials
- Heat and cold

Noise

- Permissible noise levels are a function of length of exposure and range from 90 decibels for 8-h exposure to 140 decibels for impact noise
- Personal ear protection must be provided when satisfactory noise level cannot be attained by engineering control

- Increasing use of cab enclosures on construction equipment to protect equipment operators from equipment noise:
- Improved operator environment
- Safety hazard as it is difficult for workers to communicate with the equipment operator
- Increased attention must be given to the use of backup alarms, hand signals to avoid accidents

Dust

- Safety hazard due to loss of visibility
- Responsible for a number of lung diseases
- Silica dust and asbestos are particularly dangerous
- Asbestos dust has been found to be a cancer- producing agent

Toxic materials

- The most frequent hazard consists of buried utility lines and underground gases
- The air in the work area should be tested whenever an oxygen deficiency or toxic gas is likely to be encountered

- Emergency rescue equipment such as breathing equipment should be provided whenever adverse atmospheric (breathing) conditions may be encountered

Radiation

- Ionizing radiation is produced by X-ray equipment and radioactive material:
- X-raying welds
- Measuring soil density
- Performing nondestructive materials testing

- Nonionizing radiation is produced by laser equipment, and electronic microwave equipment
- Laser equipment is widely used for surveying and for alignment of pipelines, tunnels, and structural members

Heat

- Human body acclimate (accustom itself to new climate or environment) itself to high temperature conditions within a period of 7-10 days
- Serious heat illness may result when workers are not properly acclimated
- Ranges from fatal heat stroke to minor heat fatigue

- Heat cramp result when the body's salt level drops too low
- Use of mechanical equipment to reduce physical labor requirements
- Scheduling hot work for cooler part of the day
- Use of sun shields

- Providing cool rest areas
- Providing water and salt supply easily accessible to workers
- Use of proper hot weather clothing

Labor Productivity Improvement Techniques

Dr. Mohammad S. El-Mashaleh

Labor productivity improvement techniques

- These include:

(I) Activity sampling

(II) Crew balance charts

(I) Activity Sampling

Activity sampling

- Three approaches to activity sampling:

(1) Field ratings
(2) Productivity ratings
(3) 5-minute ratings

Source: Oglesby et al. (1989)

(1) Field ratings

- Field ratings are based on taking observations of labor
- Observations are recorded based on two settings only:
- Working
- Not working

- In other words, the observations indicate:
- Number of labor who is engaged in useful work
- Number of labor who is not engaged in a useful activity

Basic operating rules for simple field ratings

1. All those to be covered by the survey should be observed

2. At least 75% of the personnel must be in the sample to get dependable results

3. The rating should be taken at the first instant of observation. The observer should not bias the result by speculating about whether or not the subject was or will be active a moment before or after observation

4. To record normal activity for a project or crew, counts should not begin until at least ½ hour after workers start (or return to) work or closer than ½ hour until quitting time (lunch or end of day)

5. No counts should be discarded

Examples on "working"?

- To qualify as working, personnel should be engaged in such activities as:

1. Carrying material or holding or supporting material

2. Participating in active physical work, including:
   a. Measuring; laying out; reading blueprints; filling-in time cards; writing orders; giving instructions
   b. Supporting a ladder
   c. Operating a machine or piece of equipment, but only while actively engaged

3. Discussing the work, provided it can positively determined that such is the case

Examples on “not working”?

- Activities such as the following would be listed as not working:

1. Waiting for another to finish work, such as laborers waiting for their wheelbarrows to be loaded

2. Talking while not actively working

3. Attending self-operating machines, unless engaged in a useful task

Rules on “working” and “not working”

- Note that previous rules are not absolute
- Management should adjust them to provide the desired information

Calculating field rating

- The result of the count will then be the total number of employees observed and the total number classified as working

- The percentage working is the number working divided by the total observed

$$\text{Field rating} = \frac{\text{Number of labor classified as working}}{\text{Total number of labor observed}} \times 100\%$$

- To cover foreman and personal time (i.e., restrooms), 10 points are sometimes added to the percentage as computed to find an adjusted field-rating index

$$\text{Adjusted field rating} = [\frac{\text{Number of labor classified as working}}{\text{Total number of labor observed}} \times 100\%] + 10\%$$

  - If this overall index is less than 60%, job activity is often considered unsatisfactory

- For specialized crews, satisfactory performance might be considerably higher than the 60% figure
- Painters for example, probably would develop a higher percentage while causal labor doing cleanup might show considerably lower ratings

Example 1

- A sample report on a field rating might be as follows:
- Number of workers on job site = 132
- Number of workers observed = 122

- Number of workers classified as working = 59
- Based on the previous information, calculate the field rating and the adjusted field rating

(2) Productivity ratings

- These ratings define the individual activities that workers do and classify them into 3 categories:
- **Category 1**: effective work

- **Category 2**:essential contributory work
- **Category 3**:not useful work or idle (ineffective work)

Category 1: effective work

- Work is effective only when it directly adds to the completed product
- The definition of “completed product” or “end product” is easily determined on most projects

Examples on “completed product”

- A cubic meter of excavation
- A linear meter of pipe in place
- An electrical fixture installed in place

Examples on effective work

- Painting a wall
- Placing bricks
- Attaching a valve to a pipe
- Nailing boards on a wall
- Hauling material from an excavation

- Examples on effective work that is carried out away from the work station:
- Mixing mortar for bricks
- Cutting boards before nailing them

Category 2: essential contributory work

- Work not directly adding to but (through associated processes) essential to finishing the unit

Examples

- Building a scaffold to serve as a work platform
- Measuring a piece of pipe or placing it in a machine for cutting
- Returning an empty truck to be filled

Category 3: ineffective work

- Not useful or idle (ineffective work)

Examples

- Walking empty-handed
- Taking a coffee break
- Waiting for a truck
- Correcting an error
- Going back to the shop for a tool or a part

Productivity ratings for several construction trades developed by a large construction firm

Trade or craft	Percent of total time in category		
	Effective	Contributory	Not useful
Bricklayer	42	33	25
Carpenter	29	38	33
Cement finisher	37	41	22
Electrician	28	35	37
Insulator	45	28	27

Source: Oglesby et al. (1989)

Trade or craft	Percent of total time in category		
	Effective	Contributory	Not useful
Ironworker	31	36	33
Laborer	44	26	30
Painter	46	26	28
Pipe fitter	27	36	37
Average	36	33	31

- Note the differences in ratings among craftsmen whose tasks are repetitive such as bricklayers or painters compared to carpenters and pipe fitters

Labor utilization factors

- The principal goal of any work improvement scheme is to increase the number of employees engaged in the effective work category
- Based on this, we can calculate labor utilization factors

Calculating labor utilization factor

$$\text{Labor utilization factor} = \frac{\text{effective work} + \frac{1}{4}\,\text{essential contributory}}{\text{Total observed}}$$

$$\text{Total observed} = \text{effective} + \text{essential contributory} + \text{ineffective}$$

Example 2

- Based on the information below, calculate labor utilization factor

	Effective	Essential contributory	Ineffective
Skilled	35	10	15
unskilled	20	25	15
Sum	55	35	30

Interpretation of labor utilization factors

- Considered judgment as well as experience must be used in interpreting any labor utilization factor
- Acceptable values vary with the type of work or trade

- Clearly, a painter does more effective work and less contributory work than does a plumber
- Also, a labor crew doing cleanup around a project would rate low in effective work since very little of its time is spent directly adding to a finished product

- Labor utilization factors examples (Oglesby et al., 1989):
- Crew of laborers: 40% - 50%
- Electricians and pipe fitters: 30%- 40%
- Painters: 45% - 55%

- For a particular kind of work or a mixed crew, the factor would be different
- However, once a backlog of past observations had developed an accepted base, current samplings could be relied on to give a fairly accurate picture of management effectiveness
- These results could be used to make comparisons among projects or crews or to detect changes on a single project

- With good tools and a job to do, most workers will apply themselves if properly instructed and supervised
- Under most circumstances, labor utilization factors and any other form of activity sampling offer a numerical measure of the quality of foremen, superintendents, and managers, not that of the workers

(3) The 5-minute rating technique

- This is a quick method of activity sampling
- Less exact compared to field rating method
- Yet, still considered an effective method for making a general work evaluation

- Called so because of the rule that no crew should be observed for less than 5 minutes
- As a rule of thumb, the minimum observation time (in minutes) should be equal to the number of men in the crew

- Consequently, 12 men should be observed for at least 12 minutes
- To increase the reliability of the results, multiples of 5-minute ratings are utilized

Purposes of 5-mintue rating

1. Create awareness on the part of management of delays in a job
2. Measure the effectiveness of a crew
3. Indicate where more thorough, detailed observations or planning could result in savings

Example 3

- The tables in the next 2 slides show an activity that involves:
- hoisting pre-cast concrete wall panels into place by a crane
- and having a crew that is landing and fastening them into place

Source: Oglesby et al. (1989)

5-minute rating example

Time	Iron worker (1)	Iron worker (2)	Carpenter (3)	Carpenter (4)	Carpenter (5)	Welder (6)
10:13	√					
10:14	√	√	√	√	√	
10:15	√	√	√	√	√	
10:16		√	√	√	√	
10:17		√		√	√	

Start	Iron worker (1)	Iron worker (2)	Carpenter (3)	Carpenter (4)	Carpenter (5)	Welder (6)
10:18			√	√	√	
10:19			√	√	√	
10:20			√	√	√	
10:21	√	√	√			
10:22	√	√	√			
10:23						√
10:24						√
10:25						√
Sum	**5**	**6**	**8**	**7**	**7**	**3**

- Note that it is arbitrary to use 1-minute intervals
- Rather than work on a minute-by-minute basis, the observer can wait until a specific task is completed and then rate the workers as to whether the majority of their time was working or not
- Note that for studies lasting several hours, the time blocks can be 5-minute block of time

(II) Crew Balance Charts

Crew balance charts

- Used to depict the way all the individuals in a group use their time in carrying out a specific task at a particular work site
- The crew balance chart has vertical bars representing each person or machine element

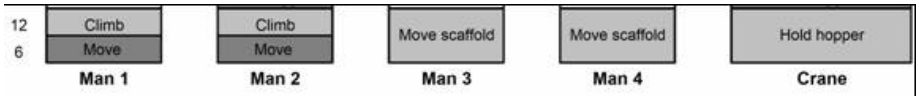
- Each bar is subdivided to show the times devoted to each of the various types and sequences of activities that make up the entire cycle, including idle time
- Since each element of time for the crew and equipment being observed is plotted to the same time scale, the interrelationship of the various elements of the activity can be seen by comparing them along any horizontal line on the chart

- The crew balance chart allows to compare interrelationships among the tasks assigned to the various members of the crew and equipment and to appraise the amount of nonproductive or non-effective time of each

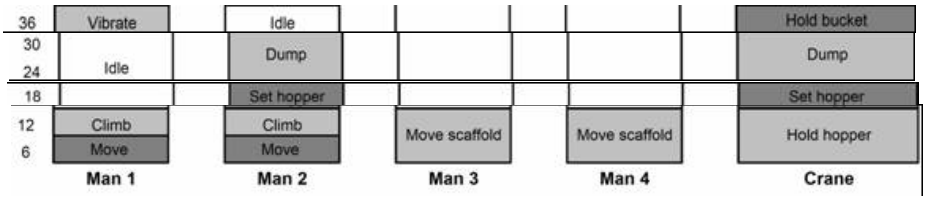
Example 4

- A crew of four workers and a crane are engaged in placing concrete in column forms
- The concrete is supplied by a crane and bucket

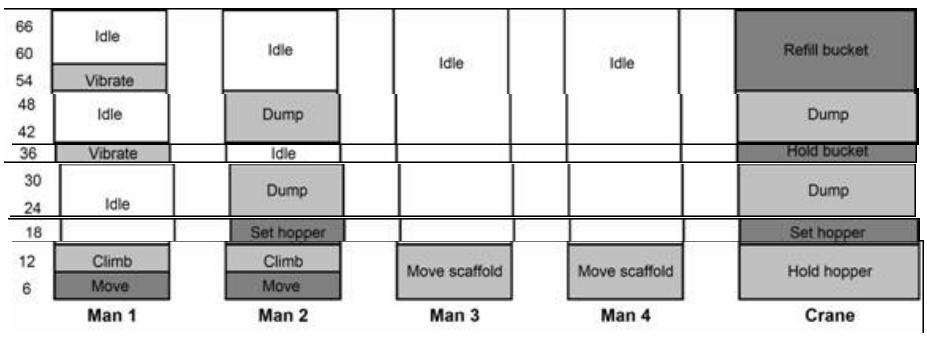
- A funnel-shaped wooden hopper is used to direct the concrete from the bucket into the top of the form
- Every column is filled concrete 3 times: dump concrete, then vibrate, and so on



- Note that Man3 and Man4 move the scaffold from one column to the next as concrete placement was completed

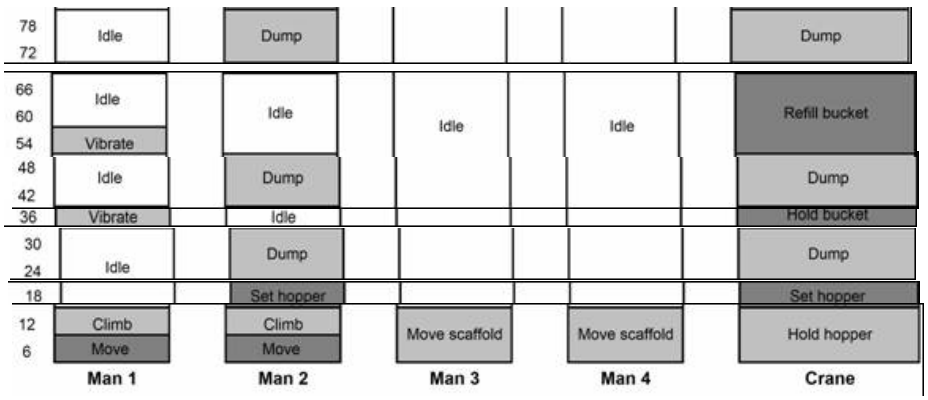


- Man2 helps the crane to set the hopper
- Man2 helps the crane in dumping concrete
- Man1 vibrates the concrete, while the crane is holding the bucket

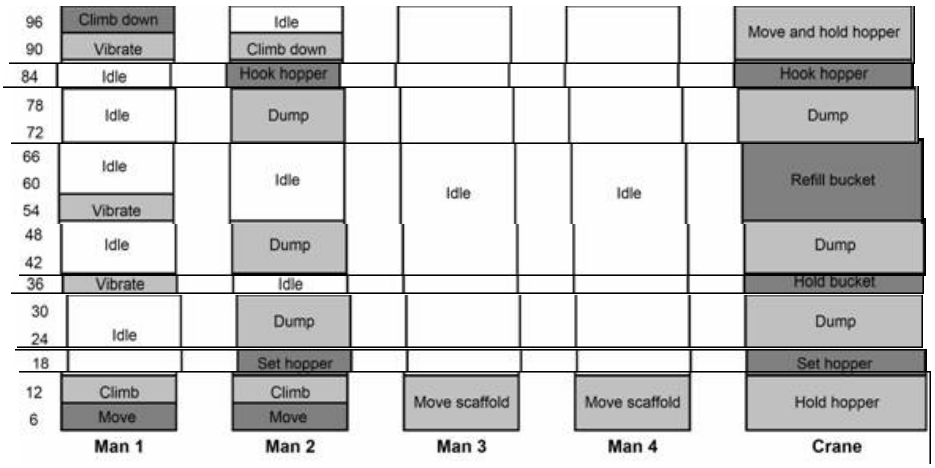


- Man2 helps the crane to dump one more time

- Man1 then vibrates concrete. At the same time, the crane refills the bucket



- The crane dumps concrete with the help of Man2 for the third time

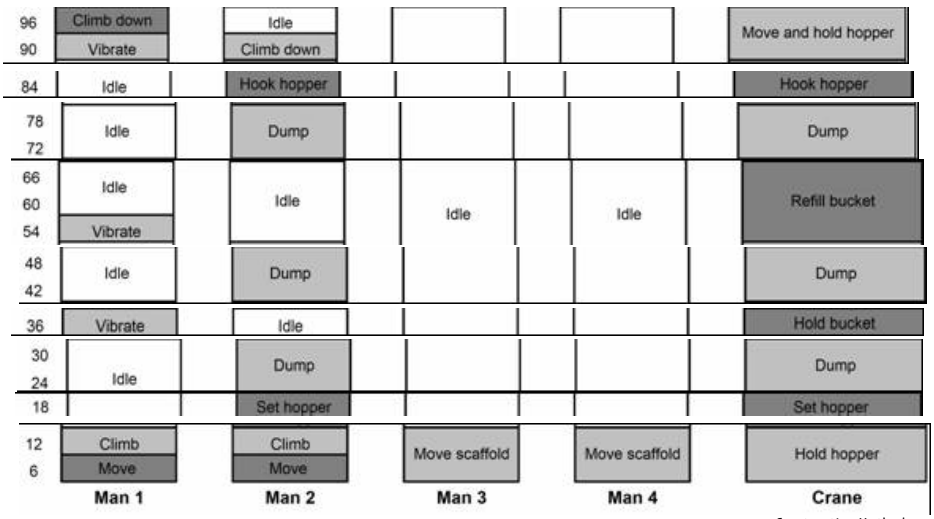


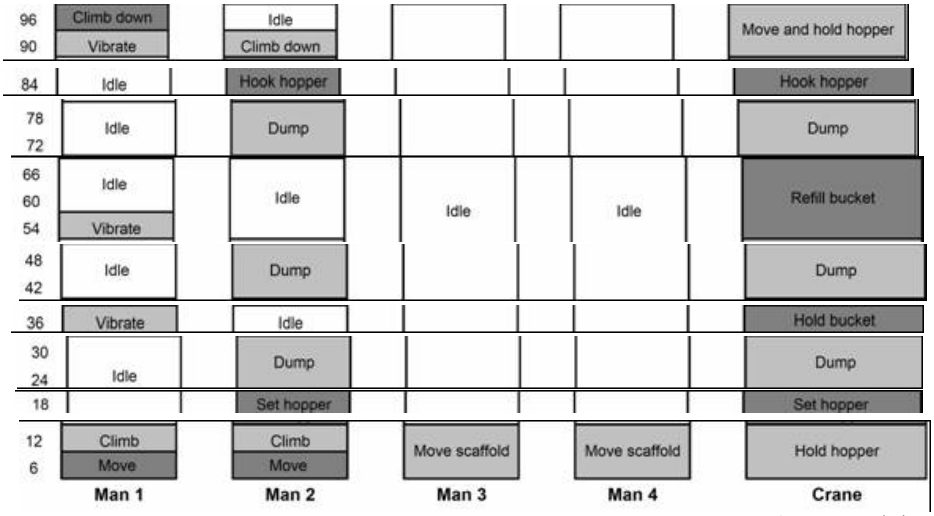
- Man 2 then hooks the hopper to the crane
- Man1 then vibrates the concrete, while Man2 climbs down

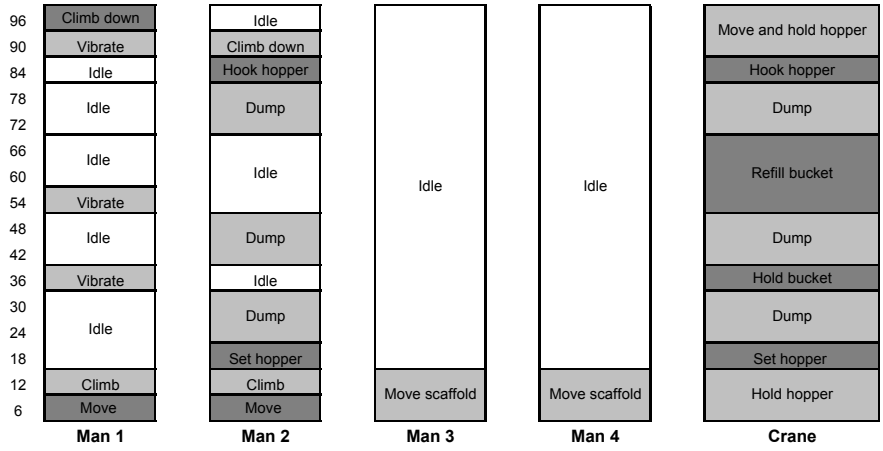
- The activity goes like this:
- Man3 and Man4 move scaffold
- Man1 and Man2 move to the next column, both men then climb the scaffold
- The crane holds the hopper then sets the hopper

- The crane dumps concrete, Man2 helps the crane to dump, while Man1 is idle
- Man1 vibrates concrete, while Man2 is idle
- The crane dumps concrete again with the help of Man2
- Man1 vibrates the concrete

- During this time, the crane refills the bucket with concrete
- The crane dumps concrete with the help of Man2
- Man1 then vibrates the concrete
- During this time, Man2 hooks the hopper to the crane




96
90
84
78
72
66
60
54
48
42
36
30
24
18
12
6
Climb down
Vibrate
Idle
Hook hopper
Idle
Vibrate
Idle
Climb
Move
Idle
Climb down
Hook hopper
Dump
Idle
Dump
Idle
Climb
Move
Move and hold hopper
Hook hopper
Dump
Refill bucket
Dump
Hold bucket
Dump
Set hopper
Hold hopper
Man 1
Man 2
Man 3
Man 4
Crane


96
90
84
78
72
66
60
54
48
42
36
30
24
18
12
6
Climb down
Vibrate
Idle
Idle
Vibrate
Idle
Vibrate
Idle
Climb
Move
Idle
Climb down
Hook hopper
Dump
Idle
Dump
Idle
Dump
Set hopper
Climb
Move
Idle
Move scaffold
Idle
Move scaffold
Move and hold hopper
Hook hopper
Dump
Refill bucket
Dump
Hold bucket
Dump
Set hopper
Hold hopper
Man 1
Man 2
Man 3
Man 4
Crane