Construction Methods – 110401542

1. Earthmoving Materials and Operations

Dr. Mohammad Almashaqbeh
Department of Civil Engineering
Hashemite University

1

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
- Activities involved in this process include:
- Excavating, loading, hauling, placing (dumping and spreading), compacting, grading, and finishing

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Equipment Selection

- Factors that should be considered in selecting equipment for a project:

1. Ability of the equipment to perform the required work, including all factors associated with the specific physical task
2. Maximizing the profit or return on the investment produced by the equipment

   Profit is maximized when:

   The lowest cost per unit of production is achieved

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3. Possible future use of the equipment
4. Equipment availability and the availability of parts and maintenance
5. The effect of equipment downtime on other construction equipment and operations

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Production of Earthmoving Equipment

- Production = Volume per cycle × Cycles per hour × Job efficiency factor
  - Volume per cycle: Average volume of material moved per equipment cycle
  - Cycles per hour: Number of cycles actually achieved (or expected to be achieved) per hour
  - Job efficiency factor: Number of working minutes per hour divided by 60
- Cost per unit of production = Equipment cost per hour / Equipment production per hour

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Table 2–1 Job efficiency factors for earthmoving operations (From TM 5-331B, U.S. Department of the Army)

	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.

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Example

- Estimate the production of a loader that needs 15 minutes to load a truck. Assume each load is 2 m^3 and good job and management conditions

- Production = Volume per cycle × Cycles per hour × Job efficiency factor
- Production = 2 m^3 x (60/15) x 0.75 = 6 m^3 /hr

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Soil Volume-Change Characteristics

- Three principal conditions or states in which earthmoving material may exist:

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)

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Swell

- An increase in the volume of soil when it is excavated because the soil grains are loosened during excavation and air fills the void spaces created

$$\text{Swell}\,(\%) = \left(\frac{\text{Weight/bank volume}}{\text{Weight/loose volume}} - 1\right) \times 100$$

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Example

- Find the swell of a soil that weighs 2300 kg/m^3 in its natural state and 2000 kg/m^3 after excavation. What does your answer mean?

$$\text{Swell} = (\frac{2300}{2000} - 1) \text{ x } 100 = 15\%$$

- 1 BCM will expand to 1.15 LCM after excavation

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Shrinkage

- When the soil is compacted, some of the air is forced out of the soil's void spaces

$$\text{Shrinkage (\%)} = \left(1 - \frac{\text{Weight/bank volume}}{\text{Weight/compacted volume}}\right) \times 100$$

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Example

- Find the shrinkage of a soil that weighs 1500 kg/m^3 in its natural state and 2000 kg/m^3 after compaction. What does your answer mean?

$$\text{Shrinkage} = (1 - \frac{1500}{2000}) \times 100 = 25\%$$

- 1 BCM will shrink to 0.75 CCM after compaction

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Load Factor

- Used to convert loose volume to bank volume

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

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

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Shrinkage Factor

- Converts bank volume to compacted volume

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

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

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Example

- A soil weighs 1163 kg/LCM, 1661 kg/BCM, and 2077 kg/CCM
- Find the load factor and shrinkage factor for the soil
- How many Bank Cubic Meters (BCM) and Compacted Cubic Meters (CCM) are contained in 593,300 LCM of this soil

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

Load factor = $\frac{1163}{1661}$ = 0.7

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

Shrinkage factor = $\frac{1661}{2077}$ = 0.8

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- Bank volume = 593,300 x 0.70 = 415,310 BCM
- Compacted volume = 415,310 × 0.8 = 332,248 CCM

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

	Unit Weight [lb/cu yd (kg/m^3)]			Swell (%)	Shrinkage (%)	Load Factor	Shrinkage Factor
	Loose	*Bank*	*Compacted*				
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.

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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
- If the pile of material is long in relation to its width, it is referred to as a spoil bank
- Spoil banks are characterized by a triangular cross section
- If the material is dumped from a fixed position, a spoil pile is created which has a conical shape

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- To determine spoil banks dimensions, we need to convert the volume of excavation from Bank conditions (BCM) to Loose conditions (LCM)
- Angle of repose: Is 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
- Angle of repose represents the equilibrium position of the soil. The value of this angle depends on soil's physical characteristics and moisture content

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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

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Department of Civil Engineering
Hashemite University

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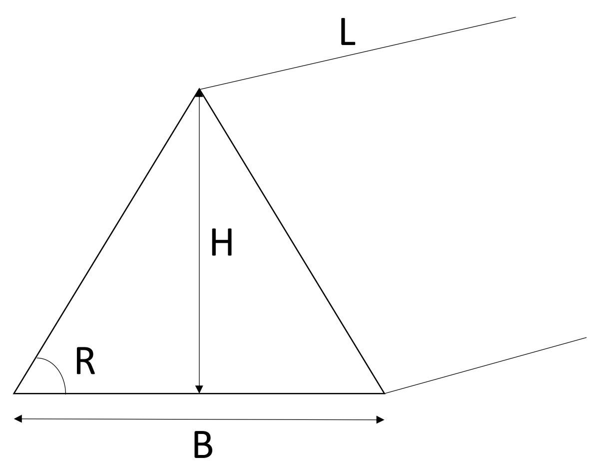
Triangular Spoil Bank

- B = Base width (m)
- H = Pile height (m)
- L = Pile length (m)
- R = Angle of repose (deg)



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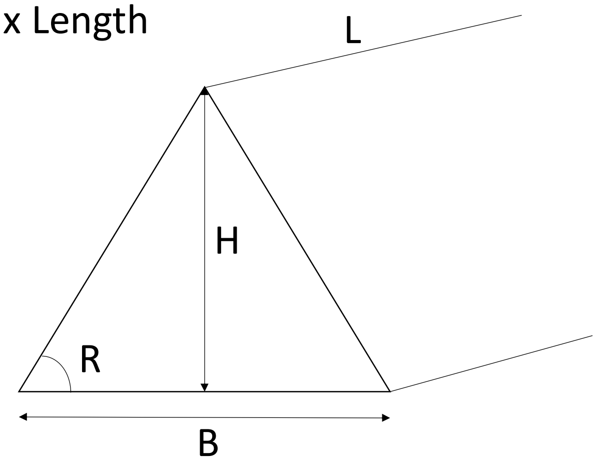
Triangular Spoil Bank

- Volume (m^3) = Section area x Length
- $V = (\frac{1}{2} \times B \times H) \times L$
- $\tan R = \frac{H}{B/2}$
- $H = \frac{B \times \tan R}{2}$
- $B = (\frac{4V}{L \times \tan R})^{\frac{1}{2}}$



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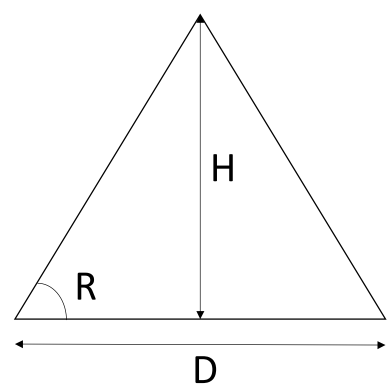
Conical Spoil Pile

- D = Diameter of the pile base (m)



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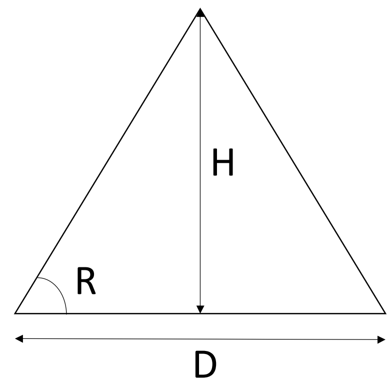
Conical Spoil Pile

- V = ($\frac{1}{3}$ x Base area x Height)
- V = $\frac{1}{3}$ x $\frac{\pi D^2}{4}$ x H
- tan R = $\frac{\text{H}}{\text{D}/2}$
- H= $\frac{\text{D x tan R}}{2}$
- D = $\left(\frac{7.64\text{V}}{\tan \text{R}}\right)^{\frac{1}{3}}$



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Example

- Find the base width and height of a triangular spoil bank containing 76.5 BCM if the pile length is 9.14 m, the soil's angle of repose is 37°, and its swell is 25%

6

Example

- Find the base width and height of a triangular spoil bank containing 76.5 BCM if the pile length is 9.14 m, the soil's angle of repose is 37°, and its swell is 25%

- Loose volume = 76.5 × 1.25 = 95.6 m^3
- Base width = $[(4 \times 95.6) \div (9.14 \times \tan 37)]^{1/2}$ = 7.45 m
- Height = (7.45 / 2) × tan 37 = 2.8 m

7

Example

- Find the base diameter and height of a conical spoil pile that will contain 76.5 BCM of excavation if the soil's angle of repose is 32 and its swell is 12%

8

Example

- Find the base diameter and height of a conical spoil pile that will contain 76.5 BCM of excavation if the soil's angle of repose is 32 and its swell is 12%

- Loose volume = 76.5 × 1.12 = 85.7 m^3
- Base diameter = $[\ (7.64 \times 85.7) \div \tan 32\ ]^{1/3}$ = 10.16 m
- H = (10.16/2) × tan 32 = 3.17 m

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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
- The procedures to be followed can be divided into three principal categories:

1. Pit excavations (small, relatively deep excavations such as those needed for basements and foundations)
2. Trench excavations for utility lines
3. Excavating or grading relatively large areas

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Pit Excavations

Volume = Horizontal area x 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

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- 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

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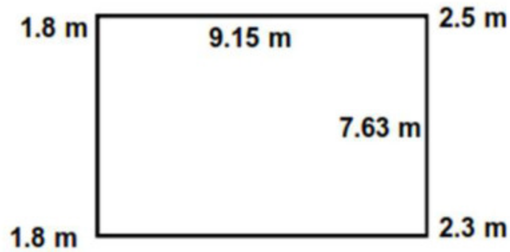
Example

- Estimate the volume of excavation required (bank measure) for the basement shown below



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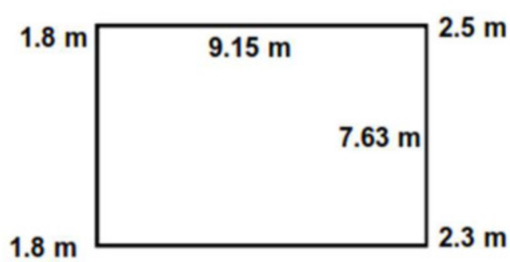
Example



- Volume = Horizontal area × Average depth

= (9.15 × 7.63) × [(1.8 + 2.5 + 2.3 + 1.8) / 4] =146.6 BCM

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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

Volume = Cross-sectional area x Length

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Example

- Find the volume (bank measure) of excavation required for a trench 0.92 m wide, 1.83 m deep and 152 m long

16

Example

- Find the volume (bank measure) of excavation required for a trench 0.92 m wide, 1.83 m deep and 152 m long

Volume = Cross-sectional area × Length

$$= (0.92 \times 1.83) \times 152 = 255 \text{ BCM}$$

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Large Areas

- To estimate 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: Interior points (intersection of four segments) are assigned a weight of four, exterior points at the intersection of two segments are assigned a weight of two, and corner points are assigned a weight of one

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3. Find the average depth

$$\text{Average depth} = \frac{\text{Sum of products of depth} \times \text{Weight}}{\text{Sum of weights}}$$

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

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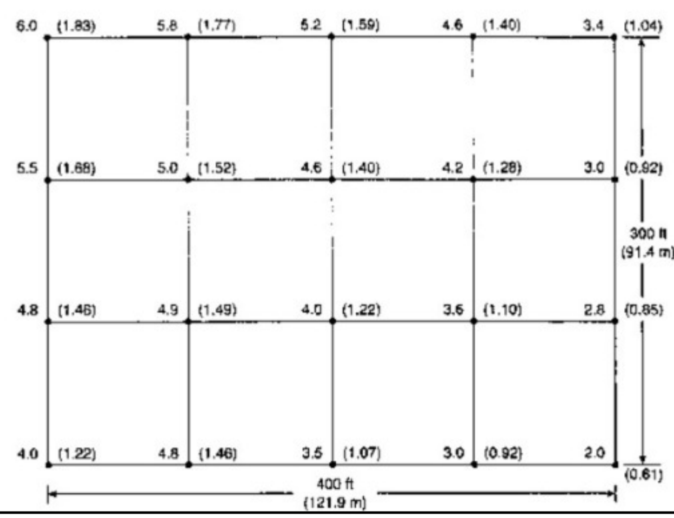
Example

Find the volume of excavation required for the area shown below



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- Corner points: 1.83 + 1.04 + 0.61 + 1.22 = 4.7 m
- Border points : 1.77 + 1.59 + 1.4 + 0.92 + 0.85 + 0.92 + 1.07 + 1.46 + 1.46 + 1.68 = 13.12
- Interior points : 1.52 + 1.4 + 1.28 + 1.1 + 1.22 + 1.49 = 8.01

$$\text{Average depth} = \frac{\text{Sum of products of depth} \times \text{Weight}}{\text{Sum of weights}}$$

- Average depth = $\dfrac{4.7 \times 1 + 13.12 \times 2 + 8.01 \times 4}{4 + 10 \times 2 + 6 \times 4}$ = 1.31 m

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- Average depth = $\dfrac{4.7 \times 1 + 13.12 \times 2 + 8.01 \times 4}{4 + 10 \times 2 + 6 \times 4}$ = 1.31 m

- Volume = (91.4 × 121.9) × 1.31 = 14,596 BCM

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Construction Use of the Mass Diagram

- A mass diagram is a continuous curve representing the accumulated volume of earthwork plotted against the linear profile of a roadway or airfield
- Mass diagrams are prepared by highway and airfield designers to assist in selecting an alignment which minimizes the earthwork required to construct the facility while meeting established limits of roadway grade and curvature

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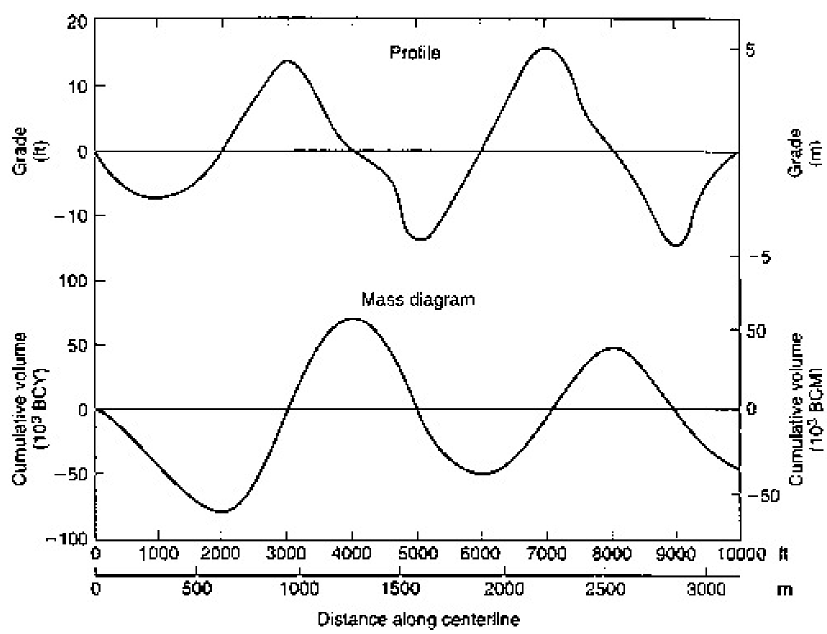

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- Characteristics of a mass diagram:

1. The vertical coordinate of the mass diagram corresponding to any location on the roadway profile represents the cumulative earthwork volume from the origin to that point
2. Within a cut, the curve rises from left to right
3. Within a fill, the curve falls from left to right
4. A peak on the curve represents a point where the earthwork changes from cut to fill

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5. A valley (low point) on the curve represents a point where the earthwork changes from fill to cut
6. When a horizontal line intersects the curve at two or more points, the accumulated volumes at these points are equal. Thus, such a line represents a balance line on the diagram

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Using the Mass Diagram

- Some of the information which a mass diagram can provide:

1. The length and direction of haul within a balanced section
2. The average length of haul for a balanced section
3. The location and amount of borrow (material hauled in from a borrow pit) and waste (material hauled away to a waste area) for the project

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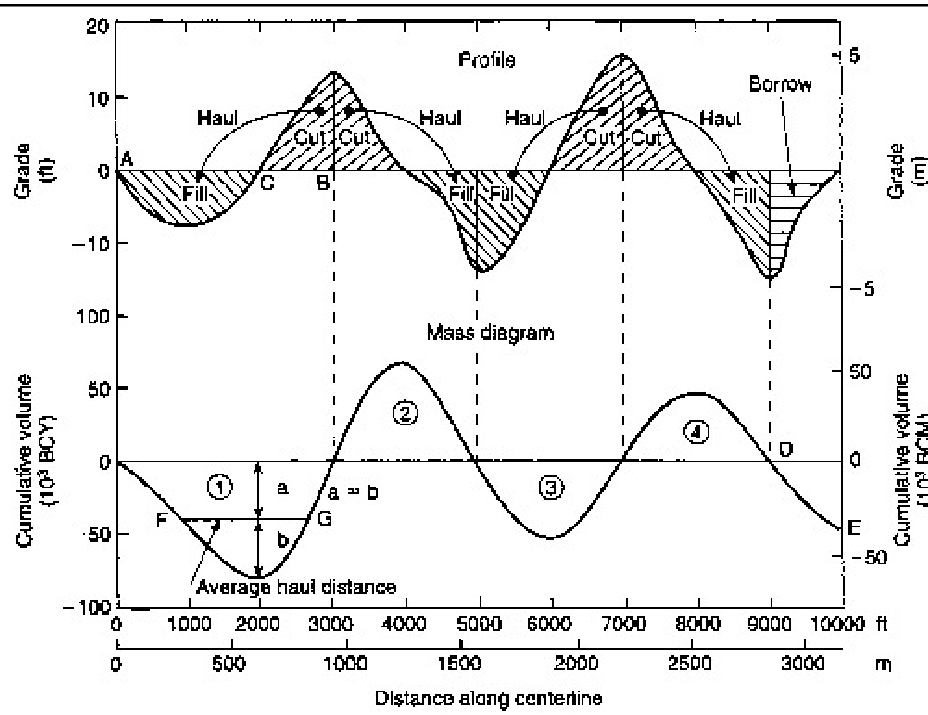

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- The following explanation of methods for obtaining this information from a mass diagram:

1. For a balanced section (section 1 on the figure), project the end points of the section up to the profile (points A and B). These points identify the limits of the balanced section
2. Locate point C on the profile corresponding to the lowest point of the mass diagram within section 1. This is the point at which the excavation changes from fill to cut. The areas of cut and fill can now be identified on the profile

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3. The direction of haul within a balanced section is always from cut to fill
4. Repeat this process for sections 2, 3, and 4
5. Since the mass diagram has a negative value from point D to the end, the ordinate at point E (- 38,230 BCM) represents the volume of material which must be brought in from a borrow pit to complete the roadway embankment

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6. The approximate average haul distance within a balanced section can be taken as the length of a horizontal line located midway between the balance line for the section and the peak or valley of the curve for the section. Thus, the length of the line F–G represents the average haul distance for section 1, which is 549 m

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3. Excavating and Lifting

Dr. Mohammad Almashaqbeh
Department of Civil Engineering
Hashemite University

1

- An excavator is a power-driven digging machine
- Three 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

2

Dragline

Hydraulic excavator

3

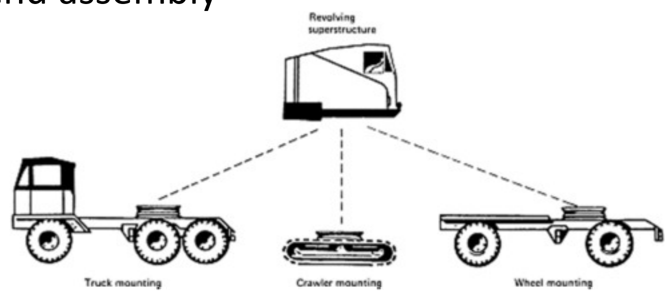
- Advantages of hydraulic excavators over cable operated machines:

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

4

- Excavators and crane shovels consist of three major assemblies:

1. A carrier or mounting
2. A revolving superstructure containing the power and control units (also called the revolving deck or turntable)
3. A front-end assembly



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Crawler mountings:

- 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 mountings:

- Provides greater mobility between job sites
- Less stable than crawler mountings
- Requires better surfaces over which to operate

6

Truck mountings:

- Use modified truck chassis as a carrier
- Separate stations for operating the carrier and the revolving superstructure
- Capable of highway travel of 80 km/h or more

Wheel mountings:

- Single operator's station to control both the carrier and the revolving superstructure
- Highway travel is limited to 48 km/h or less

7

Excavator Production

Production = Volume per cycle x cycles per hr x E

- 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

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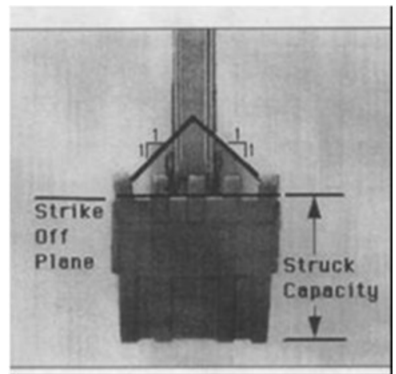
1. Plate line capacity
    - Bucket volume contained within the bucket when following the outline of the bucket sides
2. Struck capacity
    - Bucket capacity when the load is struck off flush with the bucket sides; no allowance for bucket teeth



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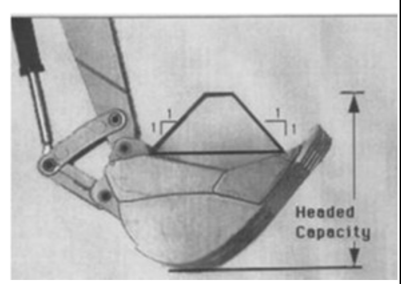
3. Water line capacity
    - Assumes a level of material flush with the lowest edge of the bucket
    - Material level corresponds to the water level that would result if the bucket were filled with water
4. Heaped volume
    - The maximum volume that can be placed in the bucket without spillage based on a specified angle of repose for the material in the bucket



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- A better estimate of the volume of material in one bucket load will be obtained if the nominal bucket volume is multiplied by a bucket fill factor or bucket efficiency factor
- Bucket fill factors were developed to make it easier for us to estimate the volume of material in one bucket load

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

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4. Excavating and Lifting

Dr. Mohammad Almashaqbeh
Department of Civil Engineering
Hashemite University

1

Hydraulic Excavators

- The original and most common form of hydraulically powered excavator is the hydraulic excavator equipped with a hoe front end. This machine is also called a backhoe.
- Primarily designed to excavate below grade
- Positive digging action
- Precise lateral control
- It digs by pulling the bucket back toward the machine

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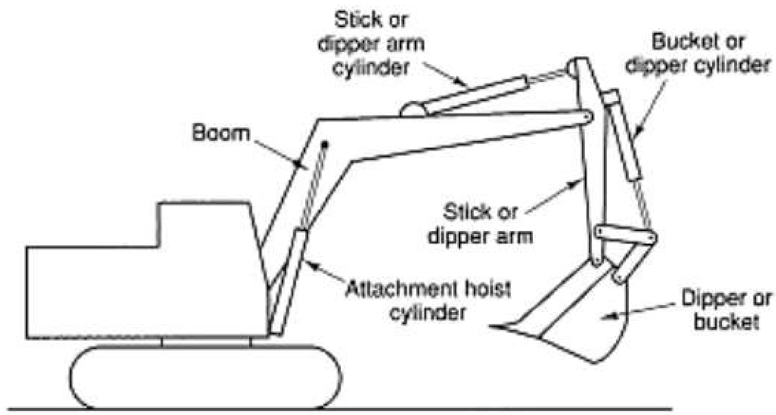

Figure 3–3 Components of a hydraulic excavator-backhoe.

3

- Widely used for trenching work:
  1. Excavating trenches
  2. Laying pipe bedding
  3. Placing pipes
  4. Backfilling trenches
- The best measure of production in trench excavation 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

4

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

5

Production Estimating

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

6

Finding "Cycles per hour"

- Prepared from manufacturing data
- "C" depends on:
  - Type of material
  - Machine size

Table 3–3 Standard cycles per hour for hydraulic excavators

Type of Material	Wheel Tractor	Machine Size: Small Excavator: 1 yd (0.76 m^3) or Less	Medium Excavator: 1¼–2¼ yd (0.94–1.72 m^3)	Large Excavator: Over 2¼ 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

7

Finding "Swing-depth factor"

- "S" depends on:
  - Depth of cut as a % of maximum
  - 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

8

- Depth of cut as a percentage of maximum: Manufacturers publish maximum depth of cut for each machine, bucket size, and material
- Angle of swing: Angle between digging and dumping positions. The smaller the angle, the higher the production

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

9

Adjustment factor for trench production

- 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

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

10

Example

- Find the expected production in LCM/h of a small hydraulic excavator. Heaped bucket capacity is 0.63 m^3. The material is common earth and soft clay with a bucket fill factor of 0.95. Job efficiency is 47 min/hr. Average depth of cut is 4.6 m. Maximum depth of cut is 9.2 m and average swing is 75°.

11

Example

- Find the expected production in LCM/h of a small hydraulic excavator. Heaped bucket capacity is 0.63 m^3. The material is common earth and soft clay with a bucket fill factor of 0.95. Job efficiency is 47 min/hr. Average depth of cut is 4.6 m. Maximum depth of cut is 9.2 m and average swing is 75°.

- Production (LCM/h) = C x S x V x B x E
- = 200 x 1.16 x 0.63 x 0.95 x (47/60)
- = 108.8 LCM/h

12

Job Management

- In selecting the proper excavator for a project, consideration must be given to:
  1. Maximum depth
  2. Working radius
  3. Dumping height required
  4. Adequate clearance for the carrier, superstructure, and boom during operation
- When lifting pipe into place do not exceed load given in the manufacturer's safe capacity for the situation

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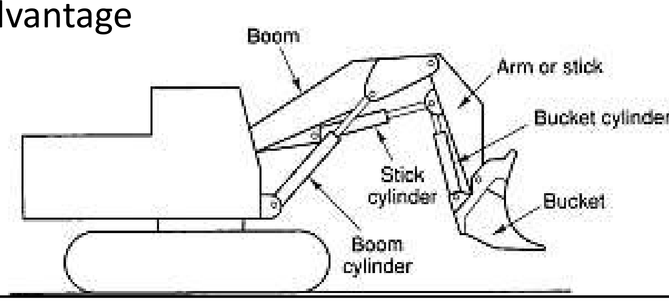
5. Excavating and Lifting

Dr. Mohammad Almashaqbeh
Department of Civil Engineering
Hashemite University

1

Shovels

- Also called a front shovel or hydraulic excavator-front shovel
- The shovel is mostly used for:
  1. Hard digging above track level
  2. Loading haul units
- The ability of the shovel to form its own roadway as it advances is a major advantage



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- 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
- Digging face is easily formed when digging a bank or hillside
- When the material to be excavated is located below ground level, the shovel must dig a ramp down into the material until a digging face of suitable height is created (ramping down)

3

Front-dump and bottom-dump shovels

Front-dump:

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

Bottom-dump

- Provides greater reach and dump clearance
- Produces less spillage

4

Shovel selection

- Two main factors should be considered:
  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:

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

5

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

6

2. Job conditions under which the shovel will operate

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

- If the material is hard to excavate, the bucket of the large shovel that has higher digging pressure will handle the material more easily
- If the blasted rock is to be excavated, the large-size bucket will handle larger individual pieces
- 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

7

Production Estimating

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

- C: Cycles per hour
- S: Swing factor
- V: Volume
- B: Bucket fill factor
- E: Job efficiency

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Table 3–6 Standard cycles per hour for hydraulic shovels

	Machine Size					
	Small *Under 5 yd (3.8 m^3)*		*Medium* *5–10 yd (3.8–7.6 m^3)*		*Large* *Over 10 yd (7.6 m^3)*	
Material	**Bottom Dump**	**Front Dump**	**Bottom Dump**	**Front Dump**	**Bottom Dump**	**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

9

Example

- Find the expected production in LCM/h of a 4 m^3 hydraulic shovel equipped with a front-dump bucket. The material is tough clay. The average angle of swing is 60° and job efficiency is 0.75.

10

Example

- Find the expected production in LCM/h of a 4 m^3 hydraulic shovel equipped with a front-dump bucket. The material is tough clay. The average angle of swing is 60° and job efficiency is 0.75.

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

= 130 x 1.1 x 4 x 0.8 x 0.75

= 343.2 LCM/h

11

Job Management

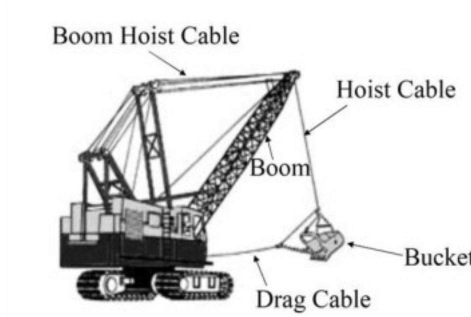
Two major factors control shovel production:

- Swing angle between digging and dumping. This angle should be kept to a minimum
- Lost time during the production cycle. Haul units must be positioned to minimize the time lost as units enter and leave the loading position

12

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
- Very advantageous when excavating material from pit or canal containing water



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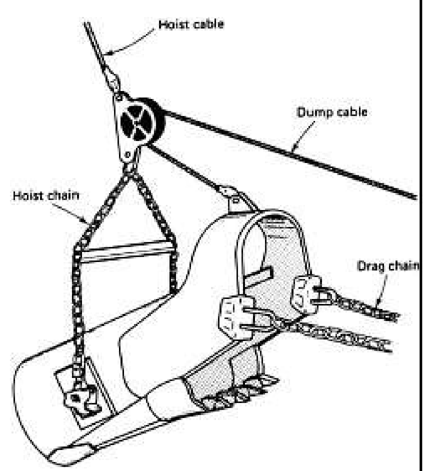
- Bucket teeth and weight produce digging action as the drag cable pulls the bucket across the ground surface
- Digging is controlled by the position at which the drag chain is attached to the bucket
- The higher the point of attachment, the greater the angle at which the bucket enters the soil



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- The dragline does not have the positive 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
- The maximum bucket size of the dragline depends on:
    - Machine power
    - Boom length
    - Material weight

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Production Estimating

- Production Tables developed by the Construction Industry Manufacturers Association (CIMA)
- Expected production = Ideal output × Swing-depth factor × Efficiency
- Ideal dragline output: Depends on type of material and bucket size

Table 3-7 Ideal dragline output—short boom [BCY/h (BCM/h)]*. (This is a modification of data published in *Technical Bulletin No. 4*, Power Crane and Shovel Association, Bureau of CIMA, 1968.)

	Bucket Size [cu yd (m³)]										
Type of Material	***$\frac{3}{4}$ (0.57)***	***1 (0.75)***	***$1\frac{1}{4}$ (0.94)***	***$1\frac{1}{2}$ (1.13)***	***$1\frac{3}{4}$ (1.32)***	***2 (1.53)***	***$2\frac{1}{2}$ (1.87)***	***3 (2.29)***	***$3\frac{1}{2}$ (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 100% efficiency, 90° swing, optimum depth of cut, material loaded into haul units at grade level.

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• Optimum depth of cut

Table 3–8 Optimum depth of cut for short boom. (This is a modification of data published in *Technical Bulletin No. 4*, Power Crane and Shovel Association, Bureau of CIMA, 1968.)

	Bucket Size [cu yd (m^3)]										
Type of Material	*$\frac{3}{4}$ (0.57)*	*1 (0.75)*	*$1\frac{1}{4}$ (0.94)*	*$1\frac{1}{2}$ (1.13)*	*$1\frac{3}{4}$ (1.32)*	*2 (1.53)*	*$2\frac{1}{2}$ (1.87)*	*3 (2.29)*	*$3\frac{1}{2}$ (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)

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• Swing-depth factor

Table 3–9 Swing-depth factor for draglines. (This is a modification of data published in *Technical Bulletin No. 4*, Power Crane and Shovel Association, Bureau of CIMA, 1968.)

Depth of Cut	Angle of Swing (deg)							
(% of Optimum)	*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

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Example

- A 1.53 m^3 dragline is being used to excavate a canal in common earth. The average swing angle is 70°, the average depth of cut is 2.7 m, and job efficiency is 50 min/h. Estimate the dragline's hourly production in loose measure

19

Example

- A 1.53 m^3 dragline is being used to excavate a canal in common earth. The average swing angle is 70°, the average depth of cut is 2.7 m, and job efficiency is 50 min/h. Estimate the dragline's hourly production in loose measure

Ideal output = 176 BCM/h

Optimum depth of cut = 3.0 m

Depth of cut (% of optimum) = 2.7/3 = 0.9

Swing-depth factor = 1.063

Expected production = Ideal output × Swing-depth factor × Efficiency

= 176 × 1.063 × (50/60) × 1.25 = 194.88 LCM/h

20

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

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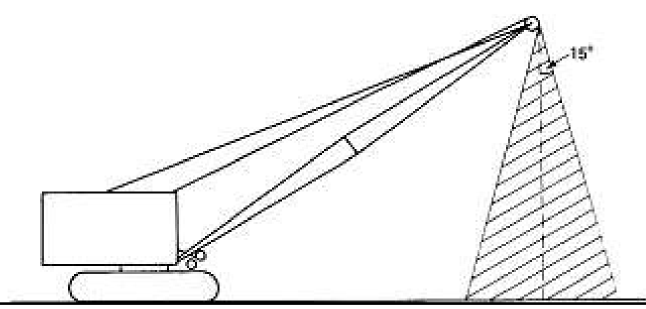
- It has been found that the most efficient digging area is located within 15° forward and back of a vertical line through the boom point
- Deep cuts should be excavated in layers whose thickness is as close to the optimum depth of cut as possible



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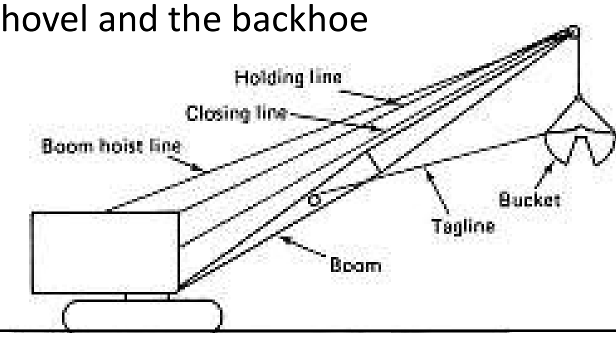
Clamshells

- Clamshell: A Crane-shovel equipped with a crane boom and clamshell bucket
- The clamshell is capable of excavating to great depths
- Clamshell lacks the positive digging action and precise lateral control of the shovel and the backhoe



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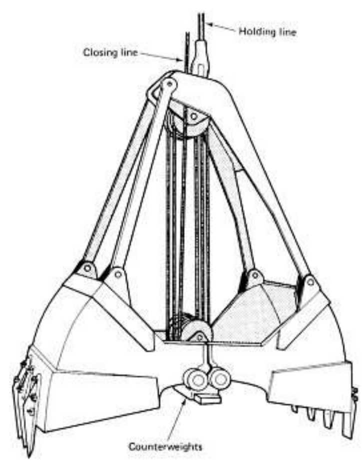
- Commonly used for

1. Excavating vertical shafts and footings
2. Unloading bulk materials from rail cars and ships
3. Moving bulk material from stock piles to bins, hoppers, or haul units

- Bucket halves are forced together or opened by the action of the closing line against the sheaves
- When the closing line is released, the counterweight cause the bucket halves to open as the bucket is holding line



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- Bucket penetration depends on bucket weight assisted by the bucket teeth
- Bucket weights
  - Heavy buckets are suitable for digging medium soils
  - Medium buckets are used for general purpose work
  - Light buckets are used for handling bulk materials such as sand and gravel

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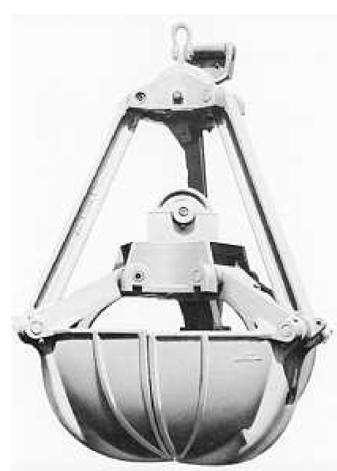
Orange Peel Bucket

Utilized for:

1. Underwater excavation
2. Rock placement
3. Excavating piers and shafts
4. Similar to Clamshell in operation



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Production Estimating

- No standard production tables
- Production = volume per cycle × cycles per hour × E

Example

- Estimate the production in LCM/h for a medium-weight clamshell excavating loose earth. Heaped bucket capacity is 0.75 m^3. The soil is common earth with bucket fill factor of 0.95. Estimated cycle time is 40 seconds. Job efficiency is estimated at 50 min/h.

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Construction Methods – 110401542

6. Excavating and Lifting

Dr. Mohammad Almashaqbeh
Department of Civil Engineering
Hashemite University

Production Estimating

- No standard production tables
- Production = volume per cycle × cycles per hour × E

Example

- Estimate the production in LCM/h for a medium-weight clamshell excavating loose earth. Heaped bucket capacity is 0.75 m^3. The soil is common earth with bucket fill factor of 0.95. Estimated cycle time is 40 seconds. Job efficiency is estimated at 50 min/h.

- Estimate the production in LCM/h for a medium-weight clamshell excavating loose earth. Heaped bucket capacity is 0.75 m^3. The soil is common earth with bucket fill factor of 0.95. Estimated cycle time is 40 seconds. Job efficiency is estimated at 50 min/h.

Production = volume per cycle × cycles per hour × E

= (0.75 × 0.95) × (3600/40) × (50/60)

= 53.44 LCM/h

3

Example

- Estimate the time required to load 306 m^3 of gravel into trucks using a clamshell having a heaped bucket capacity of 0.75 m^3. Estimated cycle time is 25 sec. Job efficiency is estimated to be 80%

4

Example

- Estimate the time required to load 306 m^3 of gravel into trucks using a clamshell having a heaped bucket capacity of 0.75 m^3. Estimated cycle time is 25 sec. Job efficiency is estimated to be 80%

Production = volume per cycle × cycles per hour × E

= (0.75 × 0.95)× (3600/25) × (0.8)

= 82.08 LCM/h

Estimated time = 306 / 82.08 = 3.73 hrs

5

Job Management

- Since the machine load includes the weight of the bucket as well as its load, 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 can be reduced by:
  - Organizing the job so that dumping radius is the same as digging radius
  - Keep the machine level to avoid swinging uphill or downhill

6

Trenching and Trenchless Technology

- There is a growing demand for methods of installing utility systems below the ground with minimum open excavation
- Available methods for achieving this goal include:
  - Specialized trenching machines
  - Trenchless technology (Trenchless excavation)

7

Trenching Machines

- 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

8

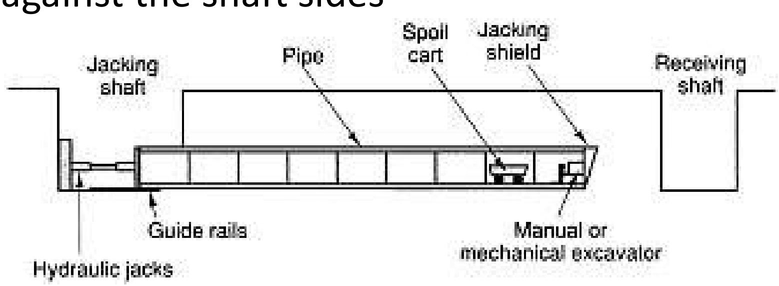
Trenchless technology

- Three principal categories:
  - Pipe jacking
  - Horizontal earth boring
  - Microtunneling

9

Pipe Jacking

- The process involves forcing pipe horizontally through the soil
- 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



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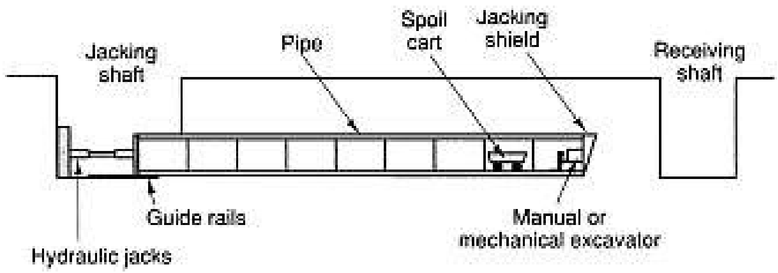
- As the pipe advances, spoil is removed through the inside of the pipe
- After the pipe section has advanced far enough, the hydraulic rams are retracted and another section of pipe is placed into position for installation
- The process often requires workers to enter the pipe during the pipe jacking operation



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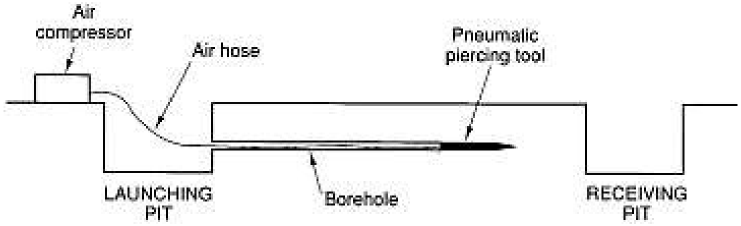
Horizontal Earth Boring

- 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



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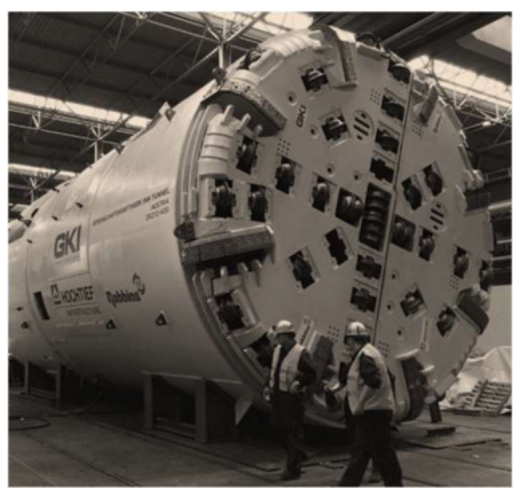
- Detectors are used to locate the drill head and ensure that the desired alignment and depth are being maintained
- After the bore has been completed, several methods are available to place pipe into the borehole:
  1. The pipe is pulled through the bore using the tool's air hose or steel cable pulled 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

13

Microtunneling (Utility Tunneling)

- Tunneling machines or mechanical moles equipped with multiple cutter heads and capable of excavating to full tunnel diameter have come into an increasing use



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Repair and Rehabilitation of Pipelines

- The repair and rehabilitation of existing pipelines without excavation is another form of trenchless technology
- A number of methods exist

1. Relining of the existing pipeline:
    - Pulling a new plastic pipe into the existing pipe (Smaller section)
    - Inserting a liner into the existing pipe

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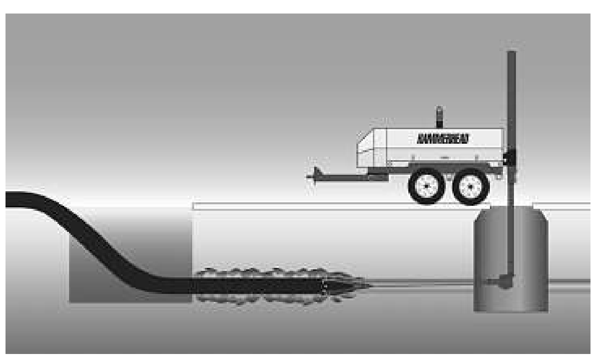
2. Bursting the existing pipe while inserting a new pipe:
    - Uses a high-powered hydraulic or pneumatic piercing tool equipped with a special bursting head to shatter the existing pipe and enlarge the opening by the piercing head



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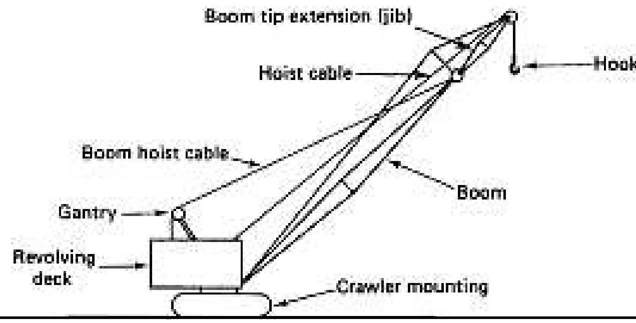
Cranes

- Primarily used for lifting, lowering, and transporting loads
- Move loads horizontally by swinging or traveling
- Most mobile cranes consist of:
  - Carrier
  - Superstructure equipped with a boom and a hook



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- Major factor controlling load that may be safely lifted by a crane is its operating radius
- Safety regulations limit maximum crane load to a percentage of the tipping load
- Tipping load: load that will cause the crane to begin to tip
- Crane manufacturers provide charts giving the safe load capacity of the machine under various conditions

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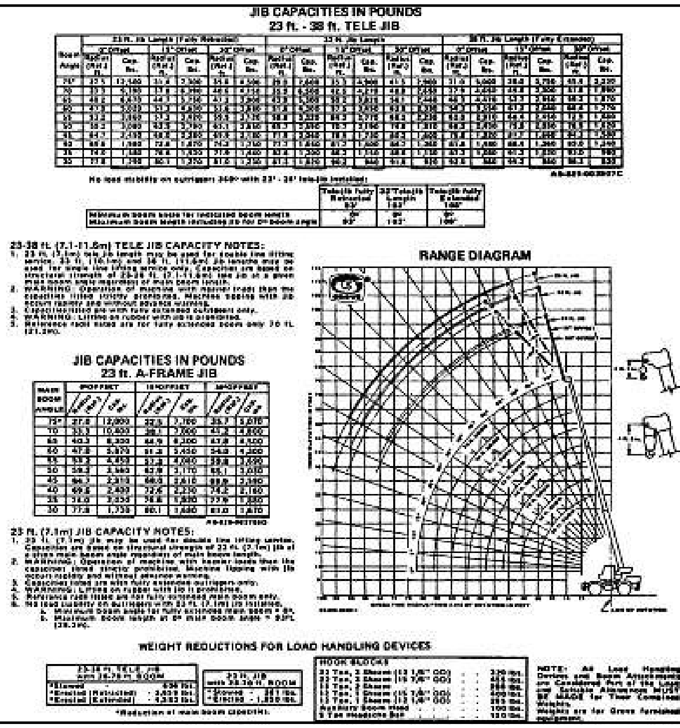

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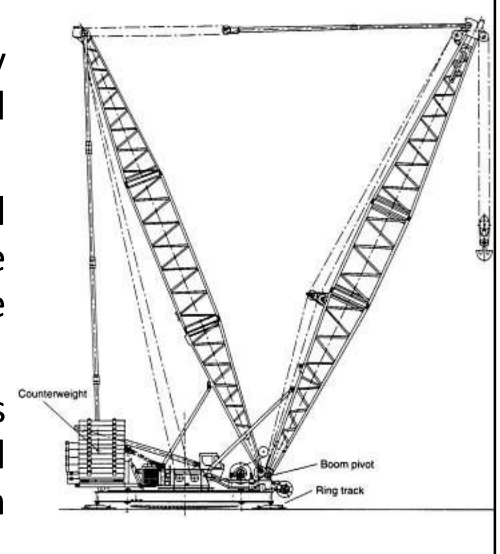
Heavy Lift Cranes

- Cranes intended for lifting very heavy loads are usually crawler-mounted lattice boom model
- To lift even heavier loads, several loads can be used together or the crane can be modified to allow the use of extra counterweight
- When a modified counterweight is used, some method must be provided to support the counterweight when there is no load on the hook



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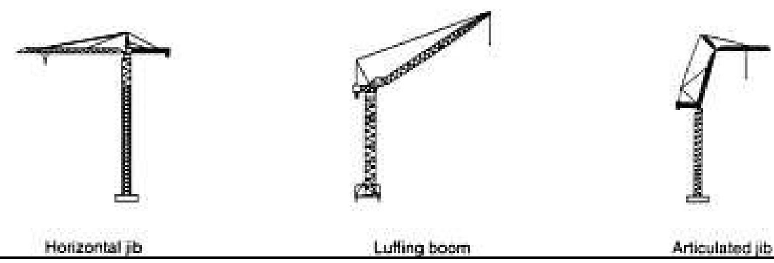
Tower Cranes

- Tower cranes are widely used in building construction because of their wide operating radius and almost unlimited height capacity
- Major types of tower cranes:
  - Horizontal jib cranes
  - Luffing boom cranes
  - Articulated jib cranes



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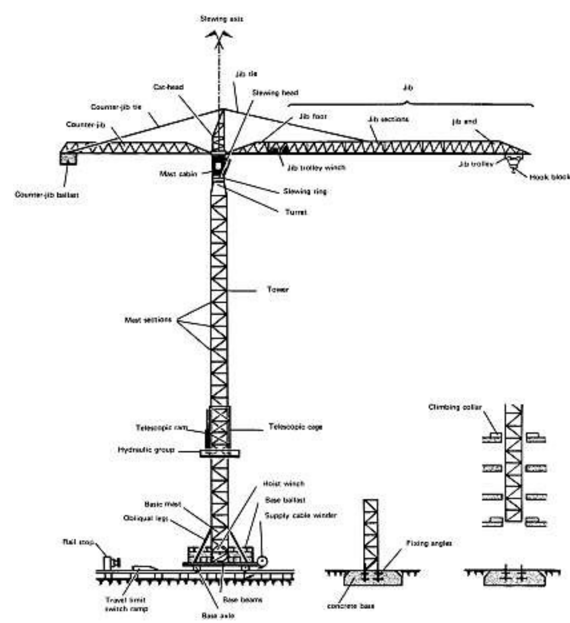
- The majority of tower cranes are of the horizontal jib type
- Luffing boom models have the ability to operate in areas of restricted horizontal clearance not suitable for horizontal jib cranes with their fixed jibs
- Articulated jib cranes are able to reposition their hinged jibs to convert excess hook reach into added hook height



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Job Management

Suggestions for safe crane operations:

1. Carefully set outriggers on firm support
2. The crane base must be level. Safe crane capacity is reduced as much as 50% when the crane is out of level by 3° and operating with a long boom at minimum radius
3. Use a communication system or hand signals when the crane operator can not see the load at all times. Make sure that all workers involved in the operation know the hand signals to be used

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4. Provide restraining lines when there is any danger caused by swinging loads
5. Ensure that crane operators are well trained and know the capability of their machines
6. Check safe-lifting-capacity charts for the entire range of planned swing before starting a left. Use a load indicator if possible

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Construction Methods – 110401542

7. Loading and Hauling

Dr. Mohammad Almashaqbeh
Department of Civil Engineering
Hashemite University

1

Estimating Equipment Travel Time

- In calculating the time required for a haul unit to make one complete cycle, it is customary to break the cycle down into fixed and variable components

Cycle time = Fixed time + Variable time

- Fixed time includes:
  - Spot time (moving the unit into position to begin loading)
  - Load time
  - Maneuver time
  - Dump time
- Fixed time can usually be closely estimated for a particular type of operation

2

- Variable time: Represents the travel time required for a unit to haul material to the unloading site and return
- Variable (travel) time depends on:
  - Vehicle's weight and power
  - The condition of the haul road
  - The grades encountered
  - Altitude above sea level

Resistance to Movement

- The total resistance to movement of the vehicle affects the maximum speed of a vehicle in a specific situation
- The resistance that a vehicle encounters in traveling over a surface is made up of two components
  - Rolling resistance
  - Grade resistance

  Total resistance = Rolling resistance + Grade resistance
- Resistance is expressed in: kg/ton (Resistance factor)

Rolling Resistance

- Rolling resistance results primarily from tire flexing and penetration of the travel 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

5

- On a hard surfaced road:
  - A narrow-tread, high pressure tire gives lower rolling resistance than a broad-tread, low pressure tire
  - This is the result of the small area of contact between the tire and the road surface
- 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
  - 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

6

Rolling Resistance Units

- Rolling resistance is expressed as kg of resistance per ton of vehicle weight 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 2,000 kg

Rolling Resistance Measurement

- One can determine the rolling resistance of a haul road 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
- Use the following equation for estimating rolling resistance factors:

Rolling resistance factor (kg/ton) = 20 + (6 × cm penetration)

9

- 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.

10

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

11

- 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

12

Grade Resistance

Total resistance = Grade resistance + Rolling resistance

- Grade resistance: Represents the component of vehicle weight which acts parallel to an inclined surface
- When a vehicle is traveling:
  - Upgrade resistance is positive
  - Downgrade resistance is negative

13

Grade resistance = vehicle weight x sine of the angle between road surface and horizontal

- Approximately:

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

Grade resistance (kg) = vehicle weight (ton) × grade resistance factor (kg/ton)

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- Total resistance = Grade resistance + Rolling resistance
  - Grade resistance =10 × grade (%)
  - Rolling resistance = 20 + 6 × penetration

- Effective grade: A simpler method for expressing total resistance is to state it as a grade (%), which would have a grade resistance equivalent to the total resistance actually encountered
- Effective grade (%) = Grade (%) + Rolling resistance factor (kg/ton) / 10

15

Example

- A wheel tractor scraper weighting 91 tons is being operated on a haul road with a tire penetration of 5 cm. What is the total resistance (kg) and effective grade when: (a) the scraper is ascending a slope of 5%; and (b) the scraper is descending a slope of 5%

16

Example

- A wheel tractor scraper weighting 91 tons is being operated on a haul road with a tire penetration of 5 cm. What is the total resistance (kg) and effective grade when: (a) the scraper is ascending a slope of 5%; and (b) the scraper is descending a slope of 5%?

Rolling resistance factor (kg/ton)

= 20 + 6 × penetration (cm)

= 20 + 6 × 5 = 50 kg/ton

Rolling resistance (kg) = 50 kg/ton X 91 ton = 4,550 Kg

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(a) ascending 5% slope:

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

= 10 × 5(%) = 50 kg/ton

Grade resistance (kg) = 50 kg/ton X 91 ton = 4,550 Kg

Total resistance = Rolling resistance + Grade resistance

= 4,550 kg + 4,550 kg = 9,100 kg

Effective grade = Grade (%) + Rolling resistance (kg/ton) /10

= 5 + 50/10 = 10%

18

(b) descending 5% slope:
Rolling resistance factor = 50 kg/ton
Rolling resistance = 4,550 kg
Grade resistance factor = - 50 kg/ton
Grade resistance = - 4,550 kg
Total resistance = 0 kg
Effective grade = Grade (%) + rolling resistance /10
= - 5 + 50/10 = 0%

19

Example

- A crawler tractor weighting 36 tons is towing a rubber-tired scraper weighting 45.5 tons up a grade of 4%. What is the total resistance (kg) of the combination if the rolling resistance factor is 50 kg/ton?

20

- A crawler tractor weighting 36 tons is towing a rubber-tired scraper weighting 45.5 tons up a grade of 4%. What is the total resistance (kg) of the combination if the rolling resistance factor is 50 kg/ton?

Rolling resistance factor = 50 kg/ton

Grade resistance factor = 10 × 4 (%) = 40 kg/ton

Total resistance (kg)= Rolling resistance of scraper + Grade resistance for both = 50 × 45.5 + 40 × (45.5+36)

= 2,275 + 3,260

= 5,535 kg

Construction Methods – 110401542

8. Loading and Hauling

Dr. Mohammad Almashaqbeh
Department of Civil Engineering
Hashemite University

1

Effect of Altitude

- All internal combustion engines lose power as their elevation above sea level increases because of the decreased density of air at higher elevations
- Power generated by engine decreases approximately 3% for each 305m increase in altitude above the maximum altitude at which full rated power is delivered
- Derating factor: Index used by manufacturers to express percentage of reduction in rated vehicle power at various altitudes

2

- If manufacturer's table is not available use:

$$\text{Derating factor (\%)} = (\text{Altitude} - 915) / 102$$

- Where altitude is in meters
- Therefore: Rated power available (%) = 1 – derating factor

3

Effect of Traction

- The power available to move a vehicle and its load is expressed as (power):
- Rimpull for wheel vehicles
- Drawbar pull for crawler vehicles
- Rimpull: The pull available at the rim of the driving wheels under rated conditions
- Drawbar pull: The power available at the hitch of crawler tractor operating under standard conditions

4

- The maximum traction that can be developed between the driving wheels or tracks and the road surface limits the usable power of the vehicle
- 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

5

- Traction depends on:
  - The coefficient of traction
  - The weight on the drivers
- Weight on drivers = total vehicle weight (for crawler tractors and all-wheel-drive rubber-tired equipment)
- Maximum usable pull = Coefficient of traction x Weight on drivers

6

- Coefficient of traction: 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

7

Example

- A four-wheel-drive tractor weighs 23,000 kg and produces a maximum rimpull of 20,000 kg at sea level. The tractor is being operated at an altitude of 2,850 m on dry earth. A pull of 12,000 kg is required to move the tractor and its load. Can the tractor perform under these conditions?

8

- Derating factor = (Altitude – 915) / 102

 = (2,850 – 915) / 102 = 18.97

- Rated power available = 1 – derating factor

= 1 – 0.19 = 0.81

- Maximum available power (rimpull) = 0.81 x 20,000 = 16,200 kg
- Maximum usable pull = Coefficient of traction x weight on drivers

= 0.6 x 23,000 = 13,800 kg

- Since the maximum pull as limited by traction is more than the required pull, the tractor can perform under these conditions

9

Construction Methods – 110401542

9. Loading and Hauling

Dr. Mohammad Almashaqbeh
Department of Civil Engineering
Hashemite University

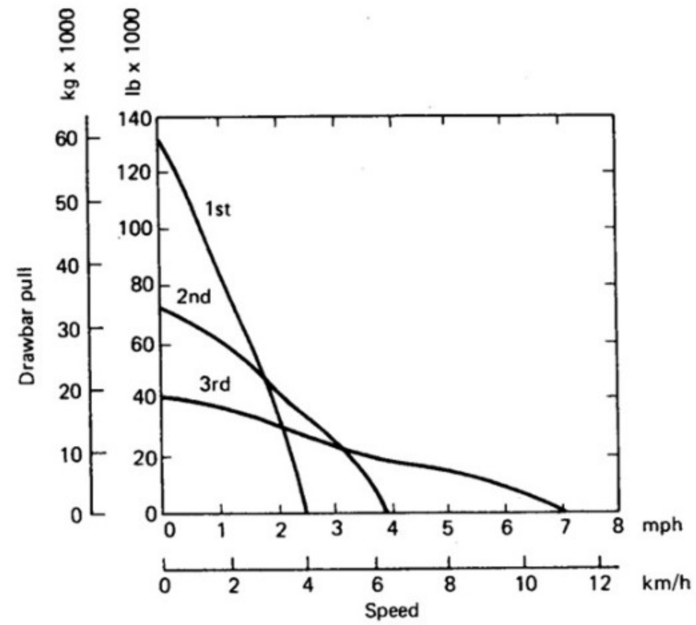
1

Performance Curves

- Manufacturers usually present the speed versus pull characteristics of their equipment in the form of performance charts
- A performance chart indicates the maximum speed that a vehicle can maintain under rated conditions while overcoming a specified total resistance
- Y-axis: Rimpull or drawbar pull
- X-axis: Maximum vehicle speed

2

Figure 4–1 Typical crawler tractor performance curve.



3

Example

- Use the performance curve (Figure 4-1) to determine the maximum speed of the tractor when the required pull is 10,000 kg

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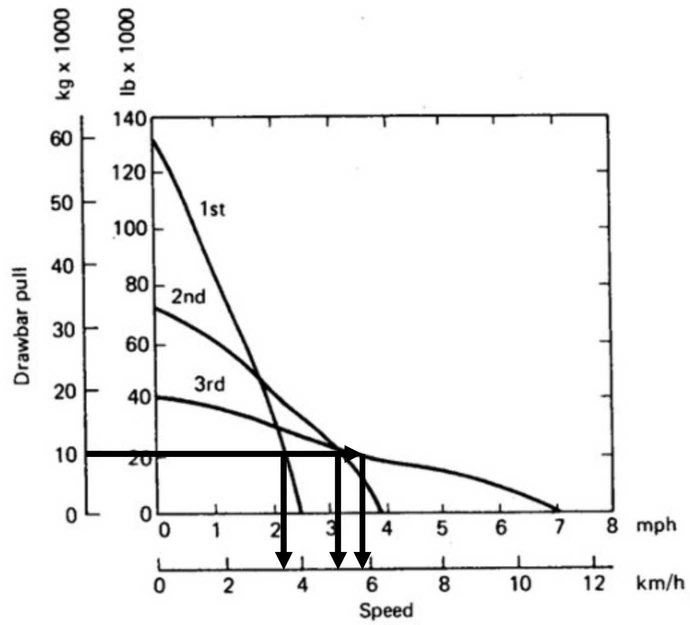
Figure 4–1 Typical crawler tractor performance curve.

- The maximum possible speed is 5.7 km/h in third gear



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- A more complex performance curve of the type frequently used by manufacturers of tractor-scrapers, trucks, and wagons
- In addition to curves of speed versus pull, this type of chart provides a graphical method for calculating the required pull (total resistance)
- To use this type of curve, enter the top scale at the actual weight of the vehicle (empty or loaded as applicable)

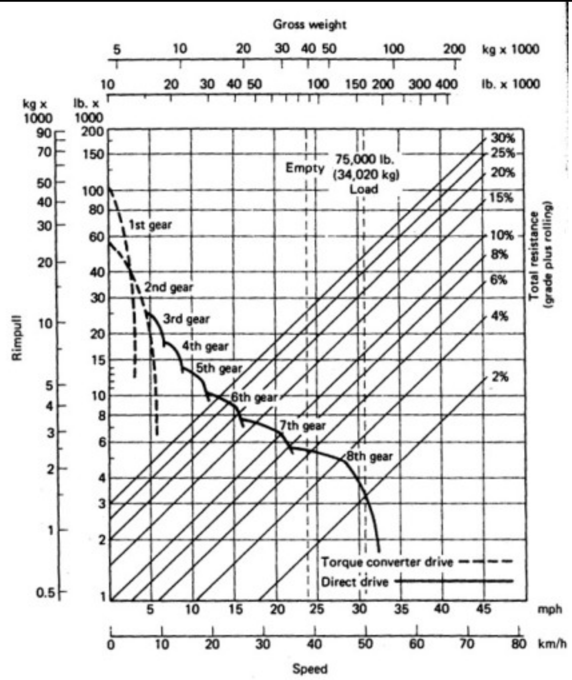

Figure 4–2 Wheel scraper performance curve. (Courtesy of Caterpillar Inc.)

6

- Drop vertically until you intersect the diagonal line corresponding to the percent total resistance (or effective grade), interpolating as necessary
- From this point move horizontally until you intersect one or more performance curves
- From the point of intersection, drop vertically to find the maximum vehicle speed
- When adjusting for altitude:
- Divide the required pull by (1-derating factor)
- Go horizontally to gears then vertically to speed

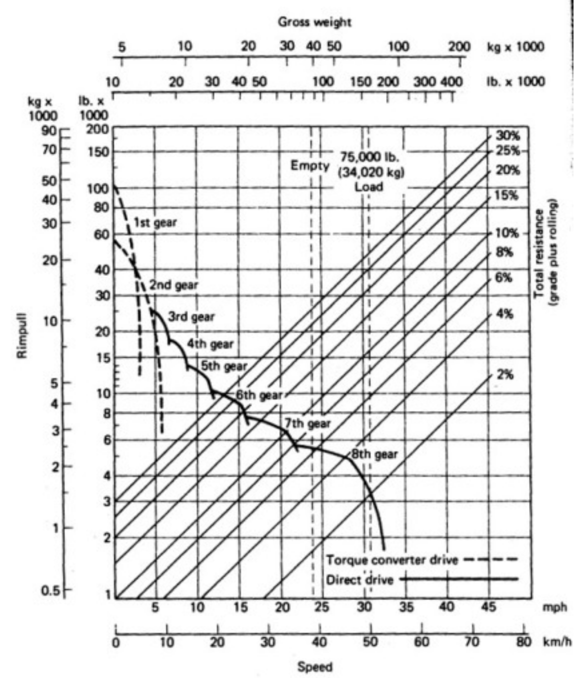

Figure 4-2 Wheel scraper performance curve. (Courtesy of Caterpillar Inc.)

7

Example

- Use the performance curve (Figure 4-2) to determine the maximum speed of the vehicle if its gross weight is 68,000 kg, the total resistance is 10%, and the altitude derating factor is 25%

8

- Start on the top scale with a weight of 68,000 kg, drop vertically to intersect the 10% total grade line, and move horizontally to find a required pull of 6,800 kg on the left scale
- Divide 6,800 kg by 0.75 to obtain an adjusted required pull of 9,080 kg
- Enter the left scale at 9,080 kg and move horizontally to intersect the first, second, and third gear curves
- Drop vertically from the point of intersection with the third gear curve to find a maximum speed of 10 km/h

9

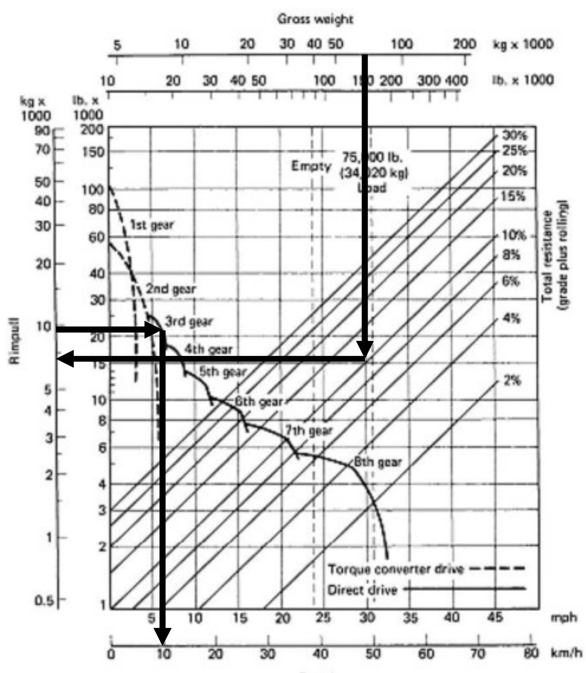

Figure 4-2 Wheel scraper performance curve. (Courtesy of Caterpillar Inc.)

10

Retarder Curves

- A retarder chart indicates the maximum speed at which a vehicle can descend a slope when the total resistance is negative without using breaks
- Retarder charts derive their name from the vehicle retarder which is a hydraulic device used for controlling vehicle speed on a downgrade
- The retarder curve is read in a manner similar to the performance curve. However, in this case the vertical scale represents negative total resistance

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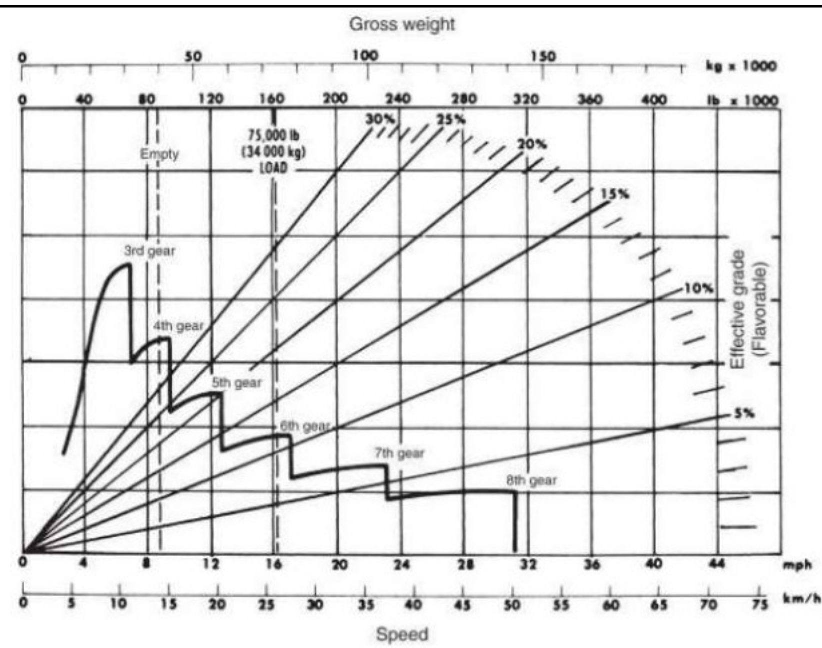

FIGURE 4-3. Wheel scraper retarder curve. (Reprinted Courtesy of Caterpillar Inc.)

12

Estimating Travel Time

- The maximum speed that a vehicle can maintain over a section of the haul route cannot be used for calculating travel time over the section, because it does not include vehicle acceleration and deceleration
- One method for accounting for acceleration and deceleration is to multiply the maximum vehicle speed by an average speed factor from Table 4–3 to obtain an average vehicle speed for the section

13

Table 4–3 Average speed factors

Length of Haul Section *ft*	Length of Haul Section *m*	Starting from 0 or Coming to a Stop	Increasing Maximum Speed from Previous Section	Decreasing Maximum Speed from Previous Section
150	46	0.42	0.72	1.60
200	61	0.51	0.76	1.51
300	92	0.57	0.80	1.39
400	122	0.63	0.82	1.33
500	153	0.65	0.84	1.29
700	214	0.70	0.86	1.24
1000	305	0.74	0.89	1.19
2000	610	0.86	0.93	1.12
3000	915	0.90	0.95	1.08
4000	1220	0.93	0.96	1.05
5000	1525	0.95	0.97	1.04

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- Travel time for the section is then found by dividing the section length by the average vehicle speed
- When a section of the haul route involves both starting from rest and coming to a stop, the average speed factor from the first column of Table 4–3 should be applied twice (i.e., use the square of the table value) for that section
- A second method for estimating travel time over a section of haul route is to use the travel time curves provided by some manufacturers

15

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
- To adjust for altitude, we multiply the obtained time by (1+derating factor)

16

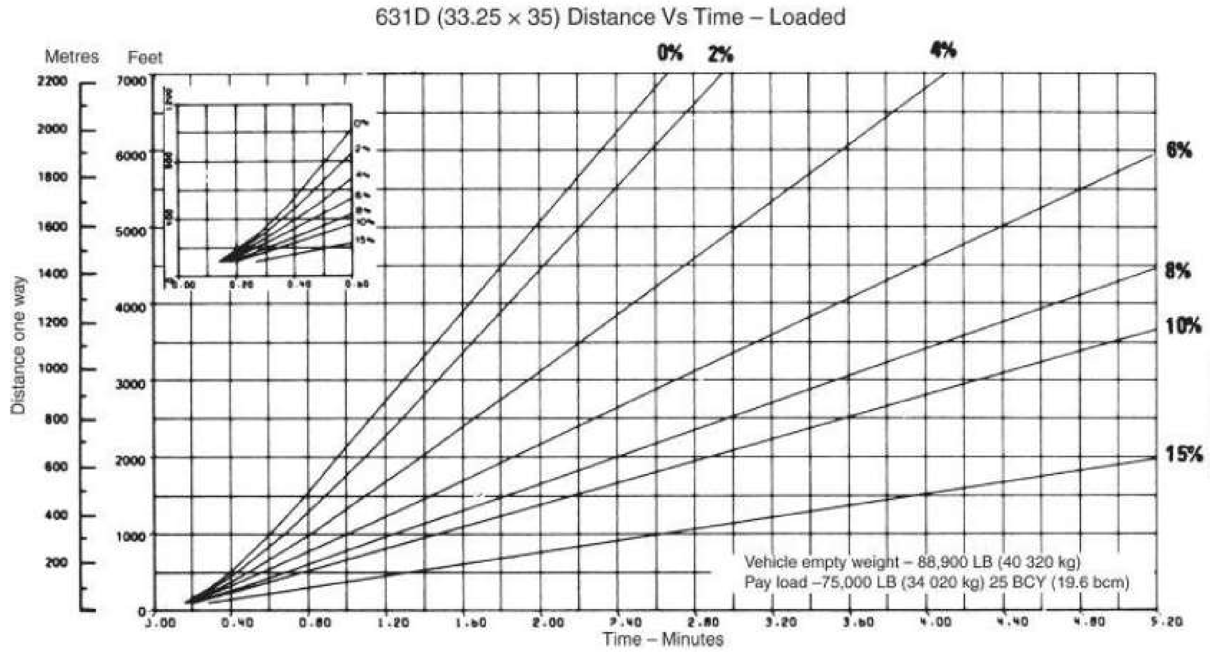

FIGURE 4-4. Scraper travel time—loaded. (Reprinted Courtesy of Caterpillar Inc.)

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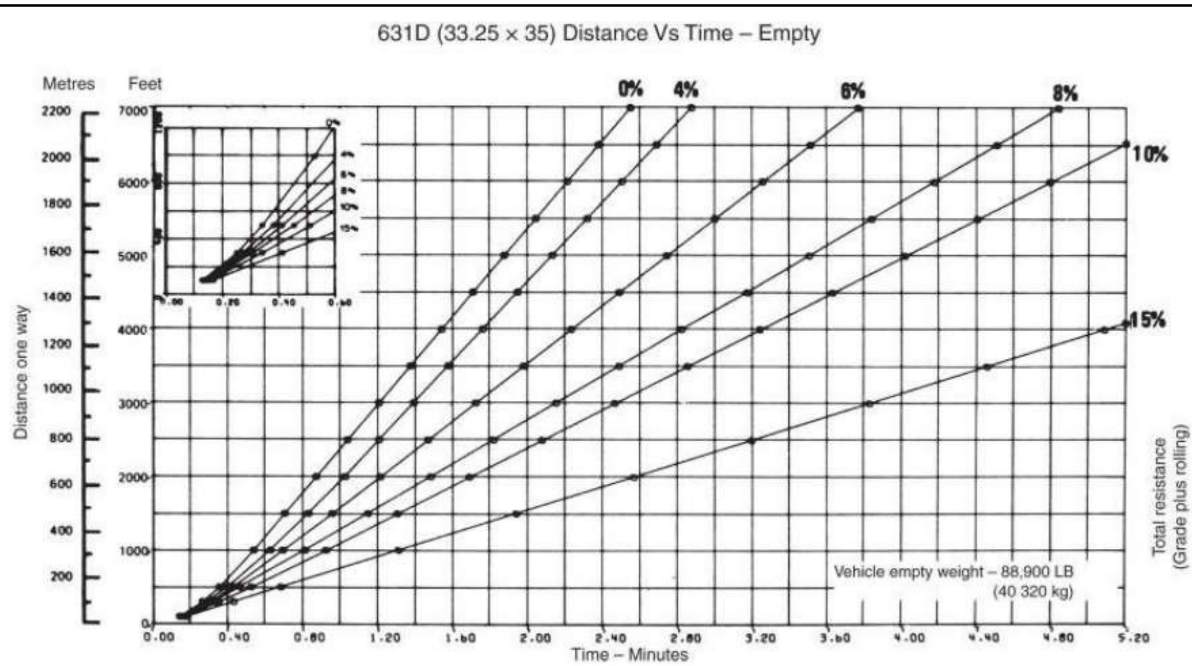

FIGURE 4-5. Scraper travel time—empty. (Reprinted Courtesy of Caterpillar Inc.)

18

Example

- The tractor-scraper whose travel time curves are shown in Figures 4-4 and 4-5 hauls its rated payload 1,600 m up a 2% grade from the cut to the fill and returns empty over the same route. The rolling resistance factor for the haul road is 40kg/ton. Estimate the scraper travel time.

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- Effective grade when loaded = 2% + 40/10 = 6%
- Haul time = 4.4 min
- Effective grade when empty = -2% + 40/10 = 2%
- Return time = 2 min
- Travel time = 6.4 min

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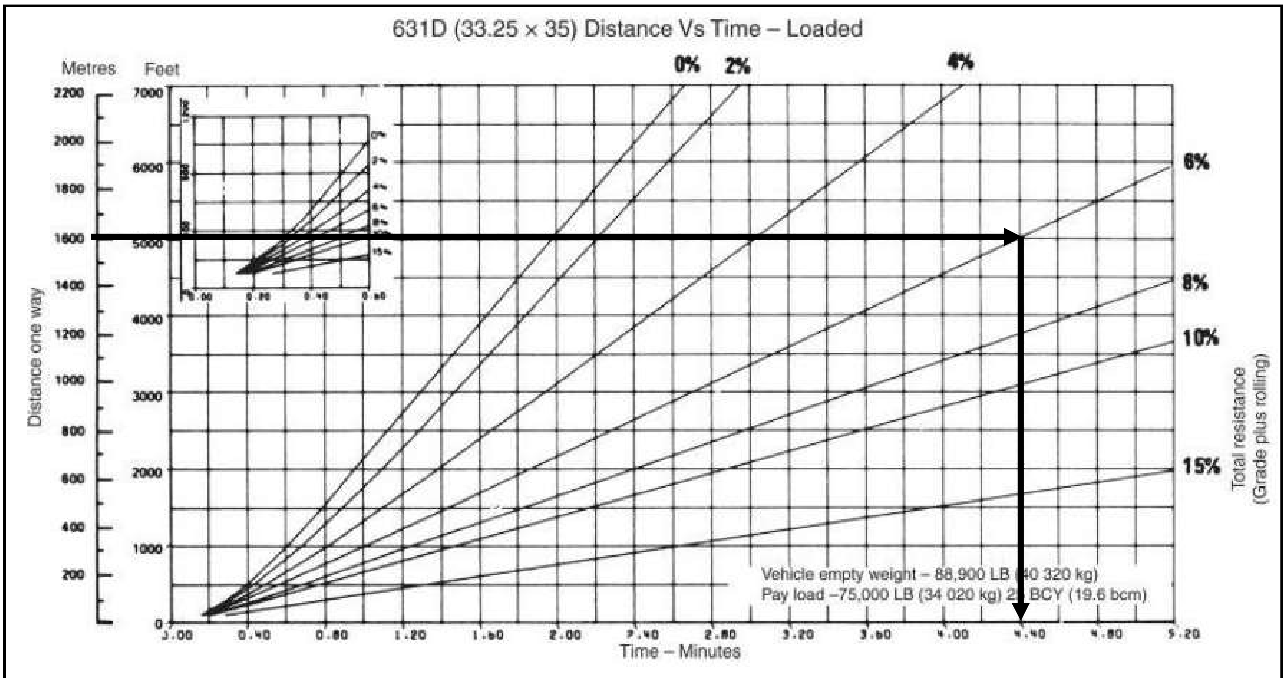

FIGURE 4-4. Scraper travel time—loaded. (Reprinted Courtesy of Caterpillar Inc.)

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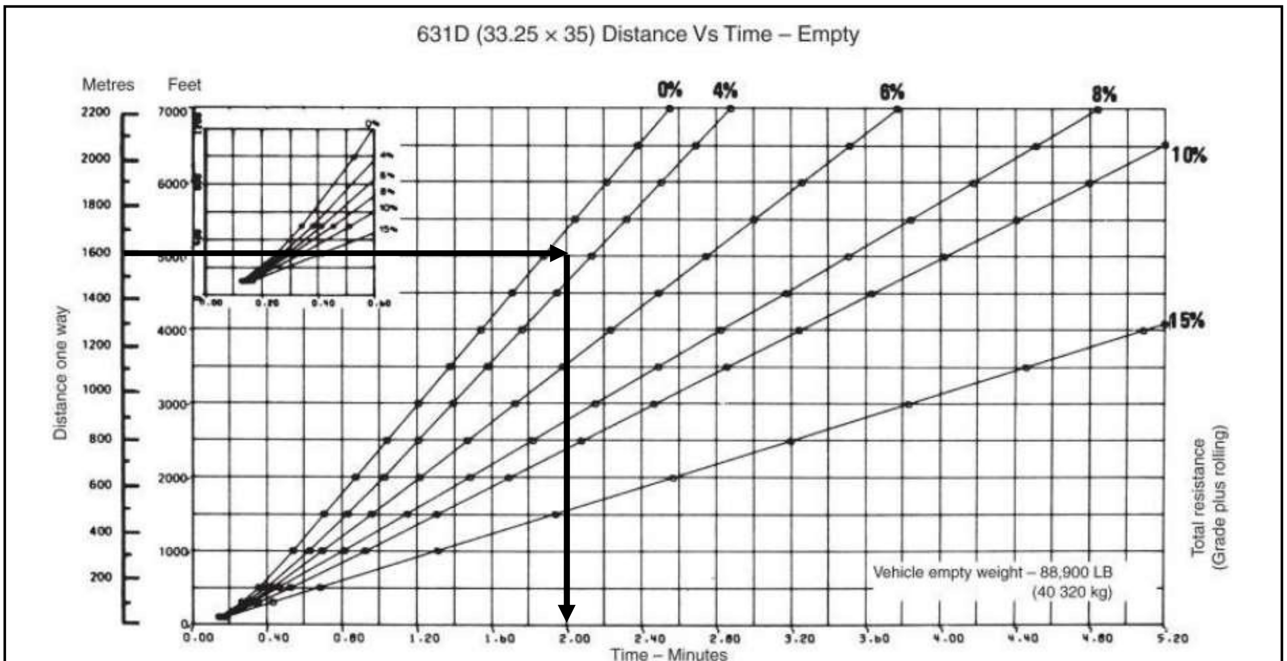

FIGURE 4-5. Scraper travel time—empty. (Reprinted Courtesy of Caterpillar Inc.)

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Construction Methods – 110401542

10. Loading and Hauling

Dr. Mohammad Almashaqbeh
Department of Civil Engineering
Hashemite University

1

Dozer (Bulldozer)

- Dozer (Bulldozer): A tractor equipped with a front-mounted earthmoving blade

2

- 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) or by raising the blade to form a spoil pile

3

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

4

Crawler Dozers Vs. Wheel Dozers

- Crawler dozers have excellent traction and low ground pressure (typically 41 to 62 kPa)
- Well suited for rough terrain and areas of low trafficability
- Can operate on steeper side slopes and climb greater grades than can wheel dozers

5

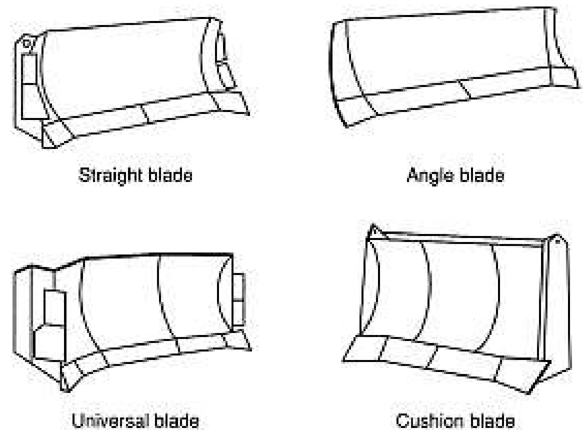
Wheel Dozers

- While the wheel (rubber-tired) tractor dozing is limited somewhat by its lower traction and high ground pressure (172 to 241 kPa), 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

6

Dozer Blades

- A number of types of dozer blades are available:
  - Straight blade
  - Universal blade
  - Angle blade
  - Cushion blade



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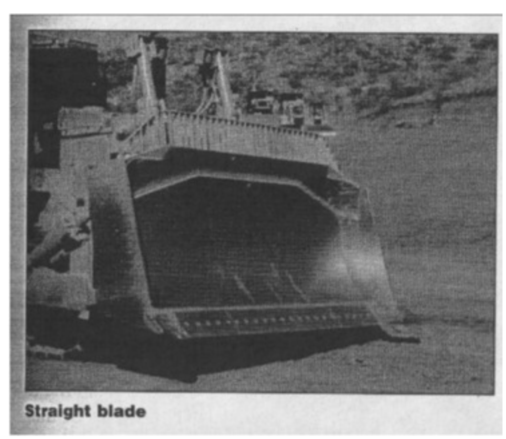
- Straight blade:
  - The most versatile dozer blade
  - Used primarily for excavation work
  - Its smaller size gives it good penetrating and load pushing ability



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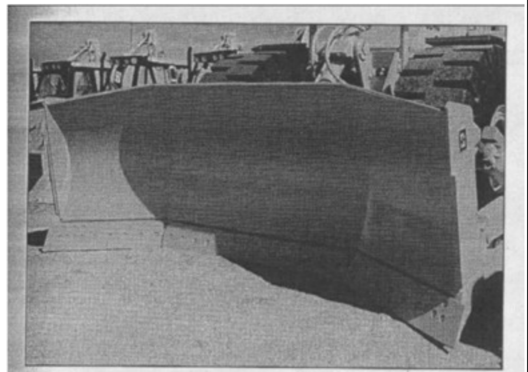
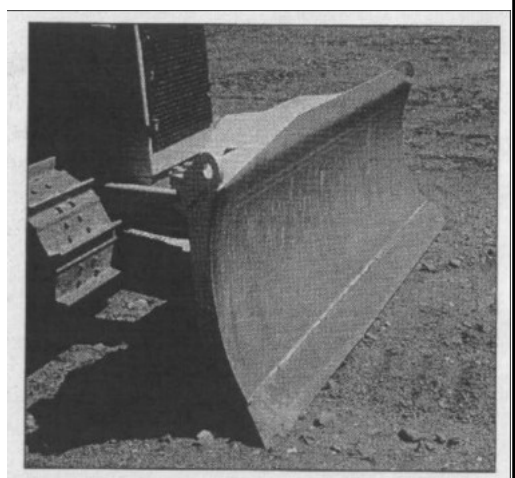
- Universal blade:
  - The wings enable it to push a large volume of material over long distances
  - However, its low horsepower per foot of cutting edge and per cubic yard limit its ability to penetrate hard soils or to move heavy materials


Universal blade

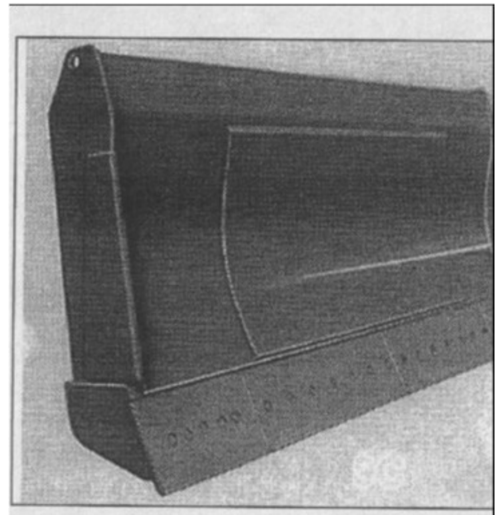
9

- Angle blade:
  - The ability to angle approximately 25 degrees to either side makes it very effective in sidehill cutting and backfilling
  - May also be used for rough grading and for moving material laterally


Angle blade

10

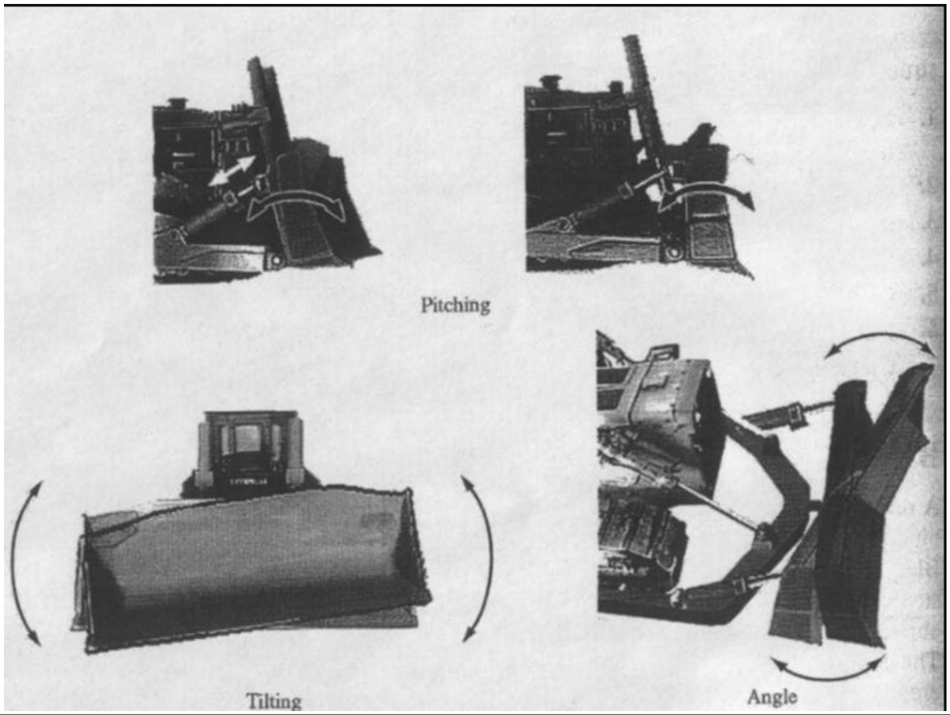
- Cushion blade:
  - Reinforced and equipped with shock absorbers to enable it to push-load scrapers
  - May also be used for cleanup of the loading or dumping areas and for general dozing when not push-loading scrapers


Cushion blade

11

- Three types of adjustments to dozer blades:
  1. Pitching
     - Pitching forward: reduces blade penetration and causes the loose material to roll in front of the blade
     - Pitching backward: increases penetration
  2. Tilting: useful for breaking up crusty soil
  3. Angling: helpful when moving material laterally
- All blades may be tilted except cushion blade
- Only the angle blade can be angled

12



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Indicators of Dozer Performance

- Two indicators of potential dozer performance (Based on the ratio of tractor power to blade size):

1. Horsepower per foot of cutting edge (hp/ft)
   - Provides an indication of the ability of the blade to penetrate hard soils
   - 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

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Estimating Dozer Production

Production = Volume per cycle x Cycle per hour

- To apply the above equation, we need:
  - An estimate of average blade load
  - Dozer cycle time
- There are 3 methods for estimating average blade load:
  1. Use the blade manufacturer's capacity rating
  2. Base estimate on previous experience under similar conditions (materials, equipment, and job conditions)
  3. Actual measurement of several typical loads obtained in field tests

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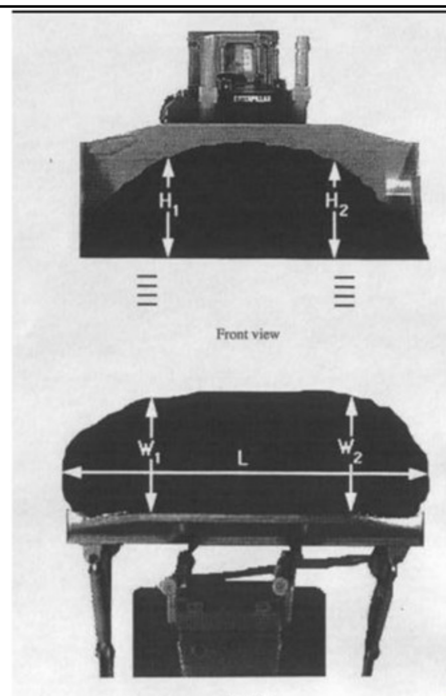
- Measuring Blade Loads Obtained in Field Tests:
- Obtain a full blade load, carry onto a level surface, and lift the blade while pulling slightly forward so that an evenly shaped pile is formed
- Obtain the width of the pile (W) perpendicular to the blade and in line with the inside of each track or wheel (average the two measurements)



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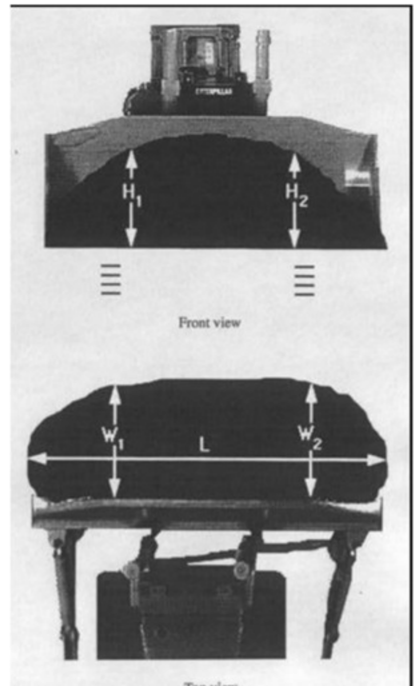
- Obtain the height of the pile (H) in a similar manner
- Obtain the length of the pile (L) parallel to the blade
- Calculate blade volume:

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



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Dozer Cycle Time

Cycle Time = Fixed Time + Variable Time

- Fixed cycle time:
  - Maneuver, change gears, start loading, and dump
- Variable cycle time
  - Time required to doze and return
- Since the haul distance is relatively short, a dozer usually returns in reverse gear

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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)

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Example

- A power-shift crawler tractor has a rated blade capacity of 5.8 LCM. The dozer is excavating loose common earth and pushing it a distance of 72 m. Maximum reverse speed in third range is 9 km/h. Estimate the production of the dozer if job efficiency is 45 min/h.

20

- Fixed time = 0.05 min (Table 4-4)
- Variable time:

Dozing speed = 4 km/h (Table 4-5)

Dozing time = Distance / Speed

= (72 m / 4 km/h) x (60/1000)

= 1.08 minutes

Return time = (72 m / 9 km/h) x (60/1000)

= 0.48 minutes

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- Total cycle time = 0.05 + 1.08 + 0.48 = 1.61 minutes

- Production = Volume per cycle x Cycle per hour x E

= 5.8 LCM x (60 / 1.61) x (45 / 60)

= 162.11 LCM/h

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Example

- A power-shift crawler tractor has a rated blade capacity of 4.3 LCM. The dozer is excavating tough clay and pushing it a distance of 25 m. Maximum reverse speeds are: first range, 3.7 km/h; second range, 6.2 km/hr; third range, 11.5 km/hr. Estimate the production of the dozer if job efficiency is 50 min/h.

23

- Fixed time = 0.05 min (Table 4-4)
- Variable time:

Dozing speed = 2.4 km/h (Table 4-5)

Dozing time = Distance / Speed

= (25 m / 2.4 km/h) x (60/1000)

= 0.63 minutes

Return time = (25 m / 6.2 km/h) x (60/1000)

= 0.24 minutes

24

- Total cycle time = 0.05 + 0.63 + 0.24 = 0.92 minutes

- Production = Volume per cycle x Cycle per hour x E

= 4.3 LCM x (60 / 0.92) x (50 / 60)

= 233.70 LCM/h

25

Job Management

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

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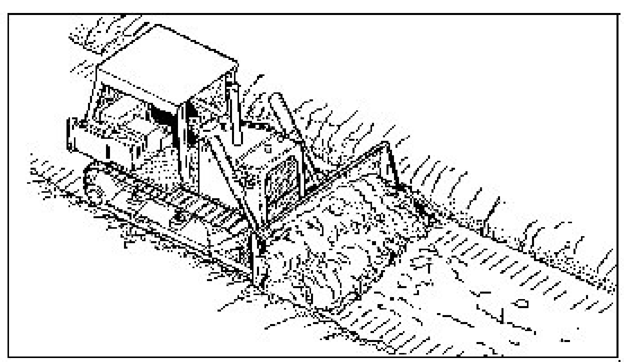
Downhill Dozing

- 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

27

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



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- 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

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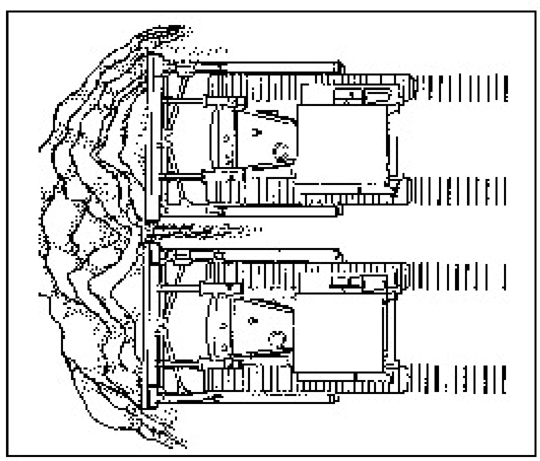
Blade-to-Blade (Side-by-Side) Dozing

- Two or more dozers operated in parallel with their blades almost touching
- This enables the blade load to be increased considerably



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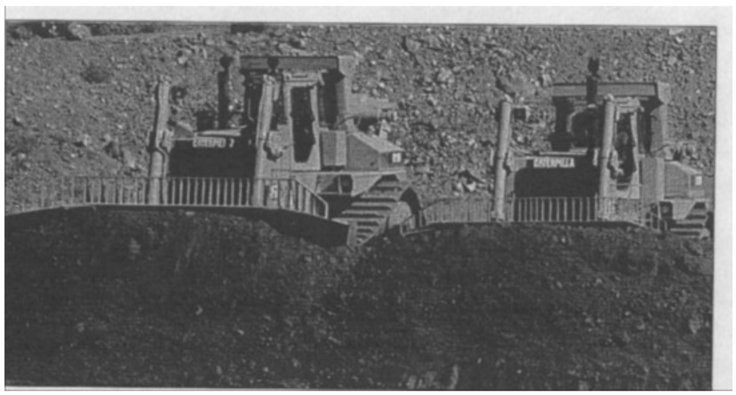
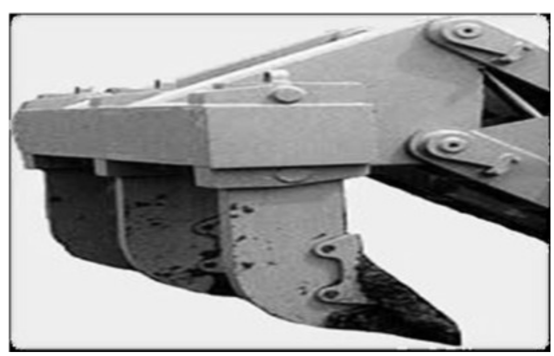
- Usually not efficient for dozing distances that are less than 15 m since the increased blade load is offset by the extra maneuvering time required
- Mechanically coupled side-by-side dozers equipped with a single blade are available and more efficient than using blade-to-blade dozing



31

Ripper

- The ripper is the long claw-like device on the back of the bulldozer
- Rippers can come as a single shank/giant ripper) or in groups of two or more (multi shank rippers)
- Usually, a single shank is preferred for heavy ripping



32

- Ripping rock breaks the ground surface rock or pavement into small rubble easy to handle and transport, which can then be removed so grading can take place

33

- Either rubber-tired or crawler tractors may be equipped with attachments other than dozer blades and rippers
- These include:
  - Rakes (used for gathering up brush and small fallen trees)
  - Plows
  - Scarifiers (used to break up hard surfaces)

34

Construction Methods – 110401542

11. Loading and Hauling

Dr. Mohammad Almashaqbeh
Department of Civil Engineering
Hashemite University

Loaders

- A tractor equipped with a front-end bucket is called a loader, front-end loader, or bucket loader
- Both wheel loaders and track loaders are available

- Most modern wheel loaders are articulated:
  - They are hinged between the front and rear axles to provide greater maneuverability

Articulated wheel loader with articulated hauler

3

- Loaders most commonly used for:
  - Excavating soft to medium-hard material
  - Loading haul units
  - Stockpiling material
  - Backfilling
  - Moving concrete and other construction materials

4

- Track Loaders:
  - Capable of overcoming steeper grades and side slopes than are wheel loaders
  - Their low ground pressure and high tractive effort enable them to operate in low-trafficability soils
  - Because of their low speed, their production is less than that of a wheel loader over longer haul distances

5

- Wheel Loaders:
  - Possess excellent job mobility
  - Capable of over-the-road movement between jobs at speeds of 40 km/h or higher
  - Their ground pressure is relatively low and may be varied by the use of different-size tires and by changing inflation pressures
  - Do not have the all-terrain capability of track loaders

6

- Attachments available for the loader include augers, backhoes, crane booms, dozer and snow blades, and forklifts in addition to the conventional loader bucket
- Some models of wheel loader are designed as a combination backhoe and loader (backhoe loader)

7

- Tool Carriers:
  - Similar to wheel loaders
  - More versatile because they are equipped with quick coupling devices to accommodate a wide range of attachments or tools
  - Some of the many attachments available include buckets, forks, blades, material handling arms, rotary brooms, asphalt cutters, hooks, augers, and hydraulic hammers

8

- Skid-Steer Loaders:
  - Small wheel loaders having rigid axles
  - Steer by braking the wheels or tracks on one side of the machine while applying power to the other side
  - Weigh less than 4,536 kg
  - Lift capacities of 272 to 2,858 kg
  - While rubber-tired machines predominate, track machines are also available for operating in muddy or loose soils and on steep slopes

Skid-steer loader with backhoe attachment

9

- Skid-steer are popular because of their small size, high productivity, and versatility
- Like the tool carrier, they can accommodate a number of attachments in addition to the basic loader bucket
- Some of the many available attachments include: augers, brooms, forks, and hammers

Compact track loader

10

- Material Handlers:
  - Cranes and wheel loaders are often used to move materials around a construction site
  - However, specialized machines called material handlers or rough-terrain forklifts have been developed for this purpose
  - Available material handlers have maximum lift greater than 18 m

11

Estimating Loader Production

Production = Volume per cycle x Cycles per hour

- Basic cycle time includes time required for:
  - Loading
  - Dumping
  - Making reversals of direction
  - Traveling a minimum distance
- Loader bucket capacity is rated in heaped (loose) volume. Bucket capacity should be adjusted by a bucket fill factor to obtain the best estimate of actual bucket volume

12

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

13

- Use manufacturers' performance curves to estimate travel time whenever possible
- Studies have shown little variation in basic cycle time for wheel loaders up to a distance of 25 m between loading and dumping distance
- Therefore, travel time should not be added until one-way distance exceeds this distance

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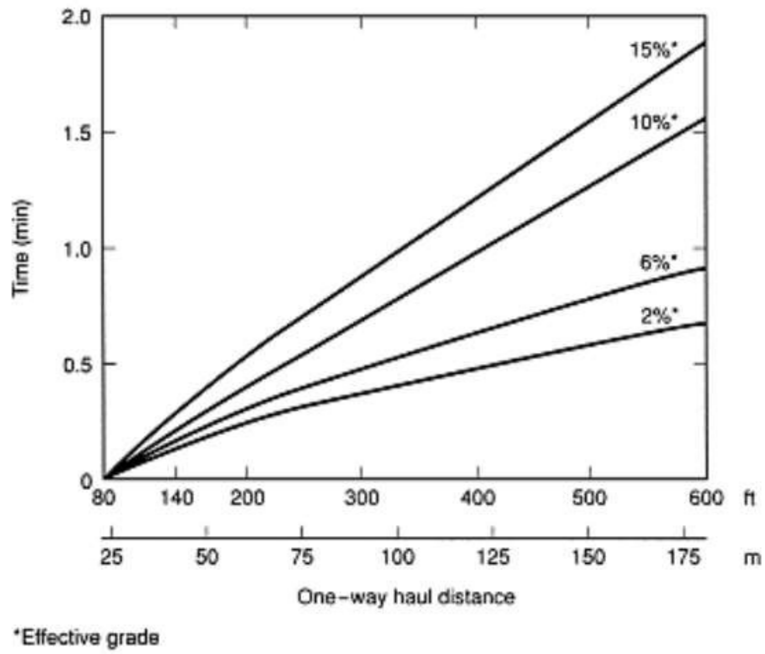


Figure 4–15 Travel time, wheel loader (haul + return).

15

Example

- Estimate the hourly production in loose volume (LCM) of a 3.4 m^3 wheel loader excavating hard materials from a pit and moving it to a stockpile. The average haul distance is 75 m, the effective grade is 6%, the bucket fill factor is 0.85, and job efficiency is 50 min/h.

16

- Basic cycle time = 0.65 min (Table 4-6)
- Travel time = 0.4 min (Fig 4-15)
- Cycle time = 1.05 min

- Production = 3.4 x 0.85 x (60/1.05) x (50/60)

= 137.62 LCM/h

17

Example

- Estimate the hourly production in loose volume (LCM) of a 4.2 m^3 wheel loader excavating sand and gravel (average material) from a pit and moving it to a stockpile. The average one-way haul distance is 115 m, the effective grade is 10%, the bucket fill factor is 1, and job efficiency is 53 min/h.

18

- Basic cycle time = 0.5 min (Table 4-6)
- Travel time = 0.9 min (Fig 4-15)
- Cycle time = 1.4 min

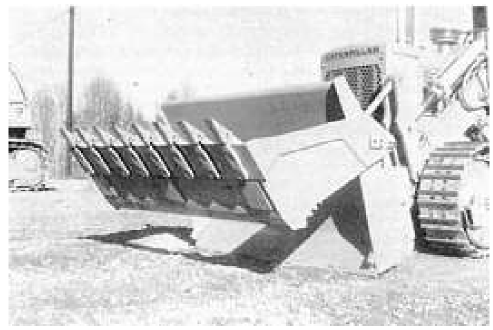
- Production = 4.2 x 1 x (60/1.4) x (53/60)

= 159 LCM/h

Job Management

- Because of tipping load limitations, the weight of the material being handled may limit the size of the bucket that may be used on a loader
- In selection of a loader, consideration must also be given to the clearances required during loading and dumping
- Optimum positioning of the loader and haul units will minimize loading, maneuver, and dump times
- Blasting or ripping hard materials before attempting to load them will often increase loader production in such materials

- Multisegment buckets, also called 4-in-1 buckets and multipurpose buckets, are capable of performing as a clamshell, dozer, or scraper, as well as a conventional loader
- Such buckets are often more effective than are conventional buckets in handling wet, sticky materials



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Construction Methods – 110401542

12. Loading and Hauling

Dr. Mohammad Almashaqbeh
Department of Civil Engineering
Hashemite University

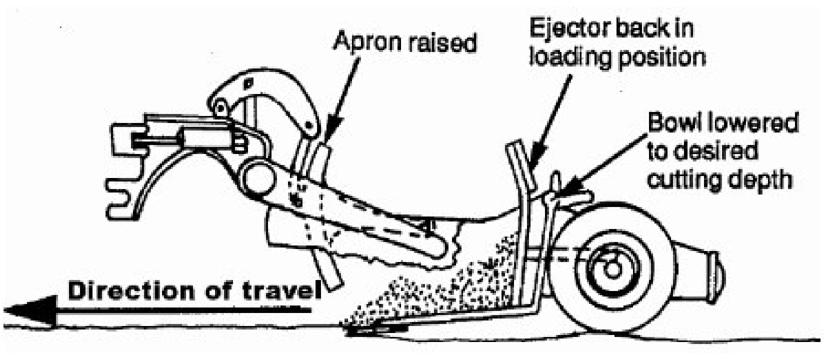
1

Scrapers

- Scrapers are capable of excavating, loading, hauling, and dumping material over medium to long haul distances
- The scraper excavates by lowering the front edge of its bowl into the soil

2

- The bowl front edge is equipped with replaceable cutting blades, which may be straight, curved, or extended at the center
- Straight blades are preferred for finish work



3

- Principal types include single engine, overhung (two-axle) scrapers, three-axle scrapers, twin-engine all-wheel-drive scrapers, elevating scrapers, auger scrapers, push-pull or twin-hitch scrapers, and pull-scrapers
- Only the elevating scraper and the Auger scraper are capable of achieving high efficiency in loading without the assistance of a pusher tractor or another scraper

4

- Two-axle or overhung scrapers utilize a tractor having only one axle
- Such an arrangement has a lower rolling resistance and greater maneuverability than does a three-axle scraper that is pulled by a conventional four-wheel tractor
- However, the additional stability of the three-axle scraper permits higher operating speeds on long, relatively flat haul roads

5

- All-wheel-drive scrapers, as the name implies, utilize drive wheels on both the tractor and the scraper
- Normally, such units are equipped with twin engines
- The additional power and drive wheels give these units greater tractive effort than that of conventional scrapers

6

- Elevating scrapers utilize a ladder-type elevator to assist in cutting and lifting material into the scraper bowl
- Elevating scrapers are not designed to be push loaded and may be damaged by pushing

7

- Push-pull or twin-hitch scrapers are all-wheel-drive
- scrapers equipped with coupling devices that enable two scrapers to assist each other in loading

8

- Pull-scrapers utilize one or more scraper pans towed by a tractor
- One of the earliest types of scraper
- When towed by a tractor having high-flotation tires, these units can operate under adverse soil conditions and are capable of loading without pusher assistance in sandy and sandy-clay soils

9

- Such a combination has a lower initial price and lower operating cost than does a conventional scraper but can be even more productive on medium hauls in suitable soils
- Pull-scrapers can also be connected in tandem

10

Estimating Scraper Production

Estimated production = Volume per cycle x Cycle per hour x E

Cycle time = Fixed cycle time + Variable cycle time

- Fixed cycle time: Spot time, load time, maneuver time, and dump time
- Variable cycle time: Haul time, and return time
- Spot time: The time required for a unit to position itself in the cut and begin loading, including any waiting for a pusher

11

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*	*Tandem Pusher*	*Elevating Scraper*	*Auger*	*Push-Pull**
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*	*Twin Engine*
Favorable	0.3	0.3
Average	0.7	0.6
Unfavorable	1.0	0.9

*Per pair of scrapers.

12

- Variable cycle time (travel time) includes:
  - Haul time
  - Return time
- Estimated by:
  - Travel-time curves
  - Average speed method with performance curve
- 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

13

- 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

14

Example

- Estimate the production of a single engine two-axle tractor scraper whose travel-time curves are shown in Figures 4–4 and 4–5 based on the following information
- Scraper type: single-engine
- Operating conditions: average single pusher
- Material: sandy clay: 1898 kg/BCM; 1571kg/LCM
- Rolling resistance: 50kg/t

15

- Scraper capacity:
  - Rated payload= 34,020 kg
  - Heaped volume= 24 LCM
- Altitude derating factor = 4%
- Job efficiency = 50 min/h
- Haul route:
  - Section 1. Level loading area
  - Section 2. Down a 4% grade, 610 m
  - Section 3. level dumping area
  - Section 4. up a 4% grade, 610 m
  - Section 5. level turnaround, 183 m

16

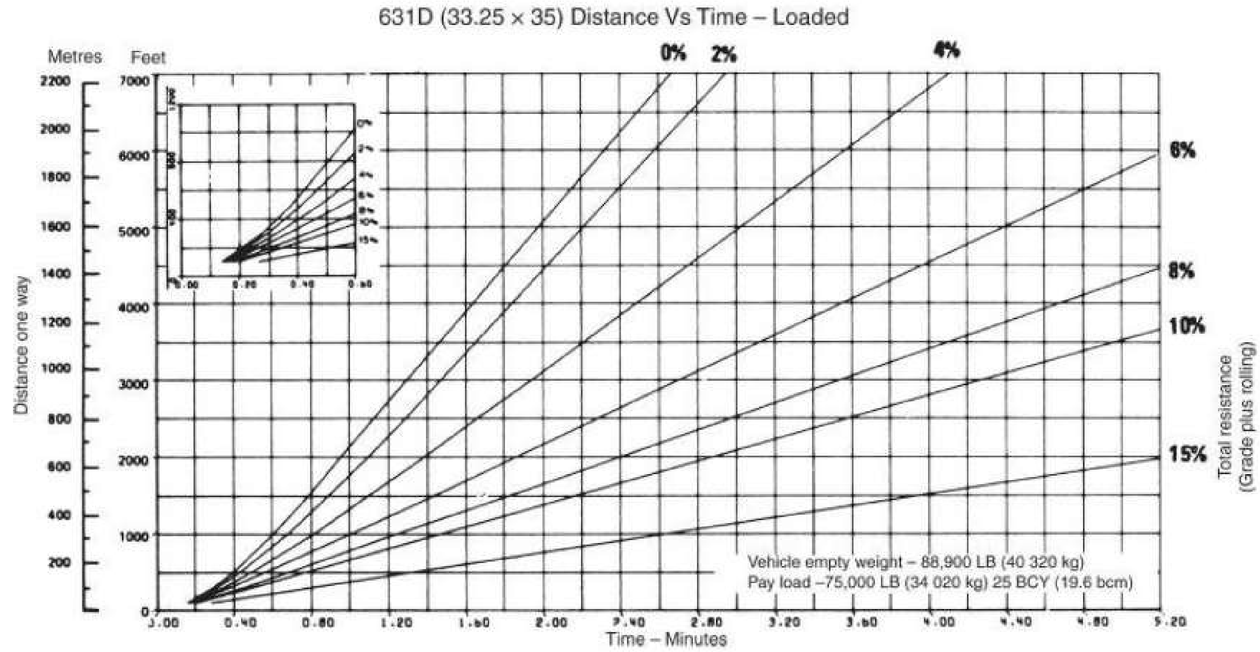


FIGURE 4-4. Scraper travel time—loaded. (Reprinted Courtesy of Caterpillar Inc.)

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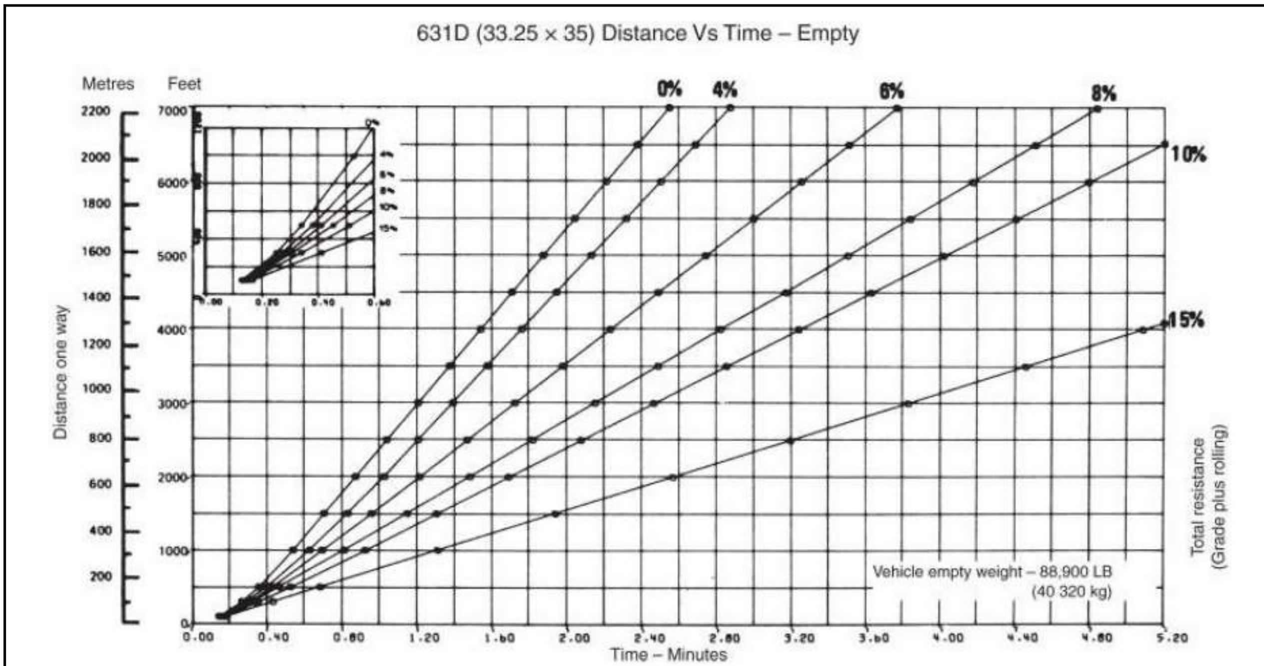

FIGURE 4-5. Scraper travel time—empty. (Reprinted Courtesy of Caterpillar Inc.)

18

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	Tandem Pusher	Elevating Scraper	Auger	Push-Pull*
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	Twin Engine
Favorable	0.3	0.3
Average	0.7	0.6
Unfavorable	1.0	0.9

*Per pair of scrapers.

19

- Check load

  Weight of heaped capacity = 24 LCM x 1571 kg/LCM

  = 37,794 kg > rated payload = 34,020 kg

  Therefore, maximum capacity = 34,020 kg/ (1571 kg/LCM) = 21.7 LCM

  OR, in bank measure = 34,020 kg / (1898 kg/BCM) = 17.9 BCM/load
- Calculate effective grade
  - Haul = -4% + 50/10 = 1%
  - Return = 4% + 50/10 = 9%
  - Turnaround = 0 + 50/10 = 5%

20

- Find cycle time
  - Travel time
    - Section 2 (haul, 610m, 1% grade): 1 min (Fig 4-4)
    - Section 4 (return, 610m, 9% grade): 1.6 min (Fig 4-5)
    - Section 5 (turnaround, 183m, 5% grade): 0.45 min (Fig 4-5)
    - Travel time = 1.04 [1 + 1.6 + 0.45] = 3.2 min
  - Fixed time
    - Spot time = 0.3 min Table (4-7)
    - Load time = 0.6 min Table (4-7)
    - Maneuver and dump time = 0.7min Table (4-7)
    - Fixed time = 0.3 + 0.6 + 0.7 = 1.6 min
  - Total cycle time = 3.2 + 1.6 = 4.8 min

21

- Estimated production

  = Volume per cycle x Cycle per hour x E

  = 17.9 BCM x (50/4.8)

  = 186.5 BCM/h

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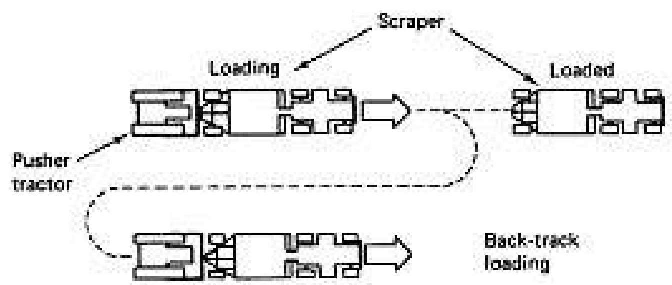
13. Loading and Hauling

Dr. Mohammad Almashaqbeh
Department of Civil Engineering
Hashemite University

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
  - Most commonly used since it permits all scrapers to load in the same general area
  - 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



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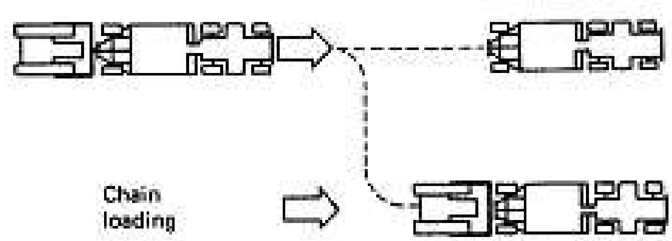
- Chain loading
  - Suitable when the excavation is conducted in a long cut



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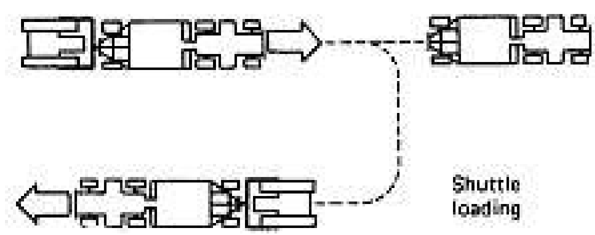
- Shuttle loading
  - Requires two separate fill areas for efficient operations
  - Infrequent use
  - Pusher can serve scrapers hauling in opposite directions



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- Pusher cycle time consists of
  - Maneuver time: while the pusher moves into position and engages the scraper
  - Load time
  - Boost time: the pusher assists in accelerating the scraper out of the cut
  - Return time

6

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

Number of scrapers served = scraper cycle time / pusher cycle time

- The number of pushers required to fully service a given scraper fleet

Number of pushers required = number of scrapers / number served by one pusher

7

- When the number of pushers actually used is less than the required number to fully serve the scraper fleet, expected production is reduced

Production = (No. of pushers / required No.) x No. of scrapers x 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

8

Example

- The estimated cycle time for a wheel scraper is 5.2 min. Calculate the number of pushers required to serve a fleet of 12 scrapers using single pusher. Determine the results for both back track and chain loading methods

9

- Back track loading

  Pusher cycle time = 1.5 min

  No. of scrapers served = 5.2/1.5 = 3.47 scrapers

  No. of required pushers =

  No. of scrapers / No. of scrapers served by one pusher

  = 12 / 3.47 = 3.46 pushers = 4 pushers

10

- Chain loading

  Pusher cycle time = 1 min

  No. of scrapers served = 5.2/1 = 5.2 scrapers

  No. of required pushers =

  No. of scrapers / No. of scrapers served by one pusher

  = 12 / 5.2 = 2.31 pushers = 3 pushers

11

Example

- Find the expected production of the previous example if only 2 pushers are available and the chain loading method is used. Expected production of a single scraper assuming adequate pusher support is 165 BCM/h

12

Production = (No. of pushers / required No.) x No. of scrapers x Production per scraper

= (2/2.31) x 12 x 165 BCM = 1,714.29 BCM/h

13

Push-Pull Loading

- In push-pull or twin-hitch scraper loading, two all-wheel-drive scrapers assist each other to load without the use of pusher tractors
- The scrapers are equipped with special push blocks and coupling devices

14

- The sequence of loading operations is as follows
  1. The first scraper to arrive in the cut starts to self-load
  2. The second scraper arrives, makes contact, couples, and pushes the front scraper to assist it in loading
  3. When the front scraper is loaded, the operator raises its bowl. The second scraper then begins to load with the front scraper pulling to assist in loading
  4. The two scrapers uncouple and separate for the haul to the fill

15

- This method offers the loading advantages of self-loading scrapers while retaining the hauling advantages of standard scrapers
- No pusher tractor or its operator is required
- There is no problem of pusher-scraper mismatch
- No lost time due to pusher downtime

16

- However, scrapers must operate in pairs so that if one scraper breaks down, its partner must be diverted to a different operation
- Conditions favoring push-pull operations include long, straight hauls with relatively easy to load materials
- An adequate number of spreading and compacting units must be available at the fill, since two scrapers dump almost simultaneously

17

Job Management

- Techniques for maximizing scraper production
  - Use downhill loading whenever possible to reduce the required pusher power and load time
  - Use chain or shuttle loading methods if possible
  - Use rippers to loosen hard soils before attempting to load
  - Have pushers give scrapers an adequate boost to accelerate units out of cut
  - Keep the cut in good condition by providing adequate drainage to improve trafficability

18

- Maintain the haul road in the best possible condition. Full-time use of a motor grader on the haul road will usually pay off in increased scraper production
- Make the haul road wide enough to permit high speed hauling without danger
- Keep the fill surface smooth and compacted to minimize scraper time in the fill
- Boost scrapers on the fill if spreading time is excessive

Construction Methods – 110401542

14. Loading and Hauling

Dr. Mohammad Almashaqbeh
Department of Civil Engineering
Hashemite University

1

Optimum Load Time

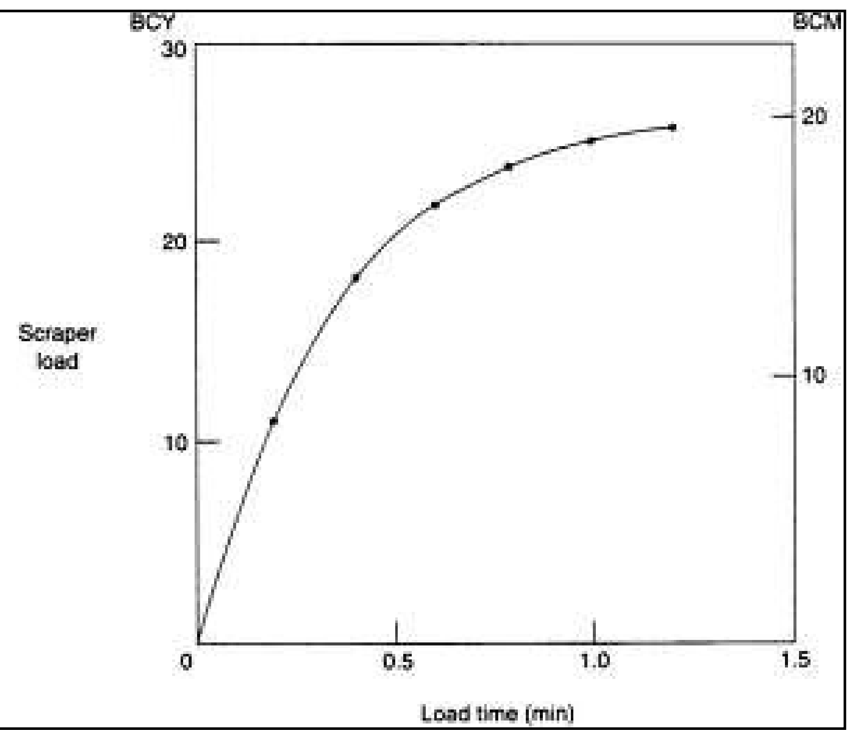
- In field studies performed by Caterpillar Inc., it was found that the scraper loading time which yielded maximum scraper production in a given situation was usually less than the loading time required to obtain the maximum scraper load
- Caterpillar called the loading time which yielded maximum production the optimum load time

2

- To determine the optimum load time, it is first necessary to plot the volume of scraper load versus loading time
- To do this, the scraper must be loaded for controlled periods of time and weighed each time after loading
- The load weight is then converted into scraper volume and plotted as a load growth curve
- The slope of the load growth curve at any loading time corresponds to the rate of loading at that time

3

Load Growth Curve



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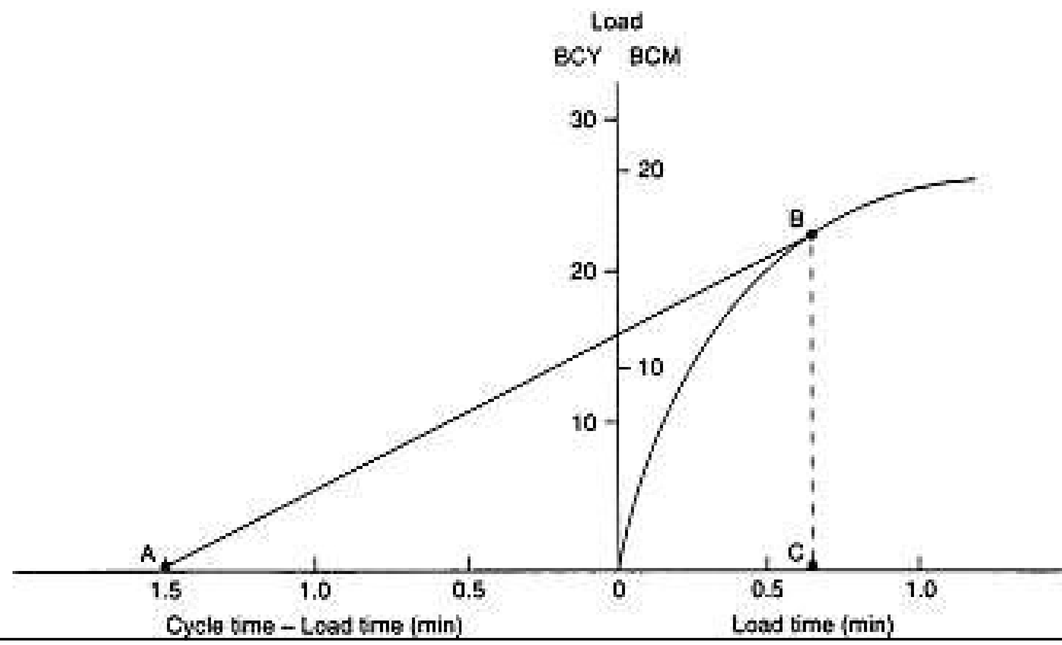
Graphical Method for Determining the Optimum Load Time



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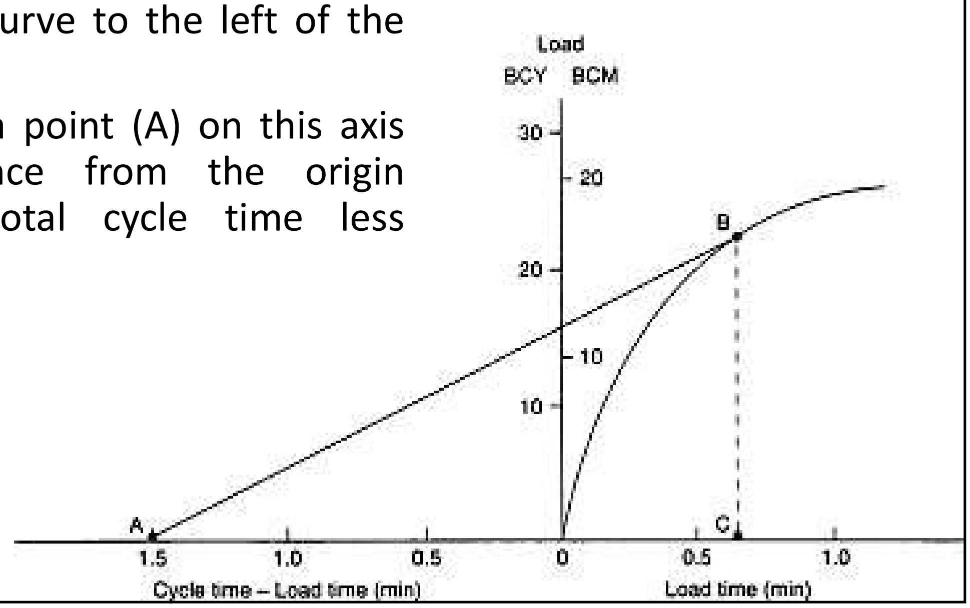
- First, extend the horizontal axis of the load growth curve to the left of the origin
- Next, Locate a point (A) on this axis whose distance from the origin represents “total cycle time less loading time.”



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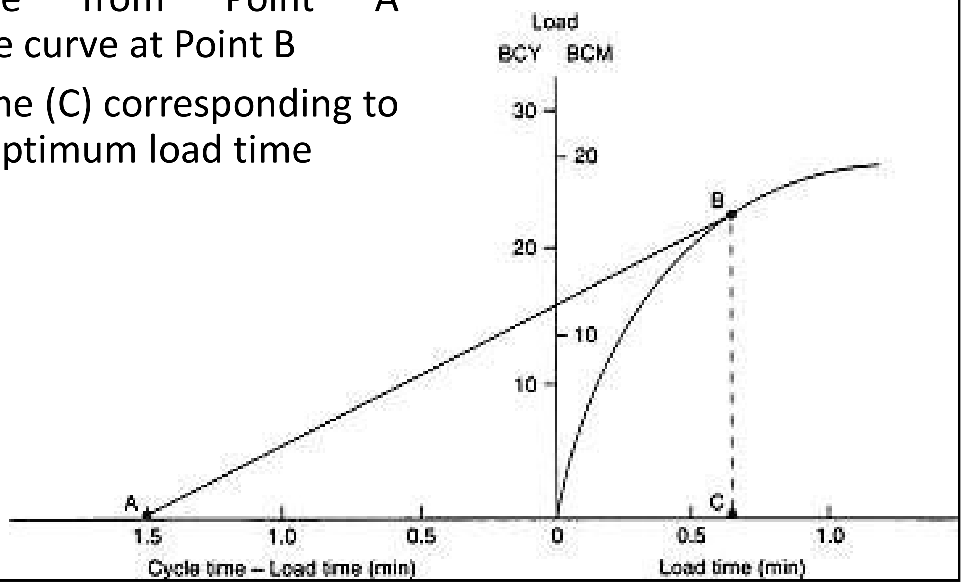
• Finally, draw a tangent to the load growth curve from Point A intersecting the curve at Point B

• The loading time (C) corresponding to Point B is the optimum load time



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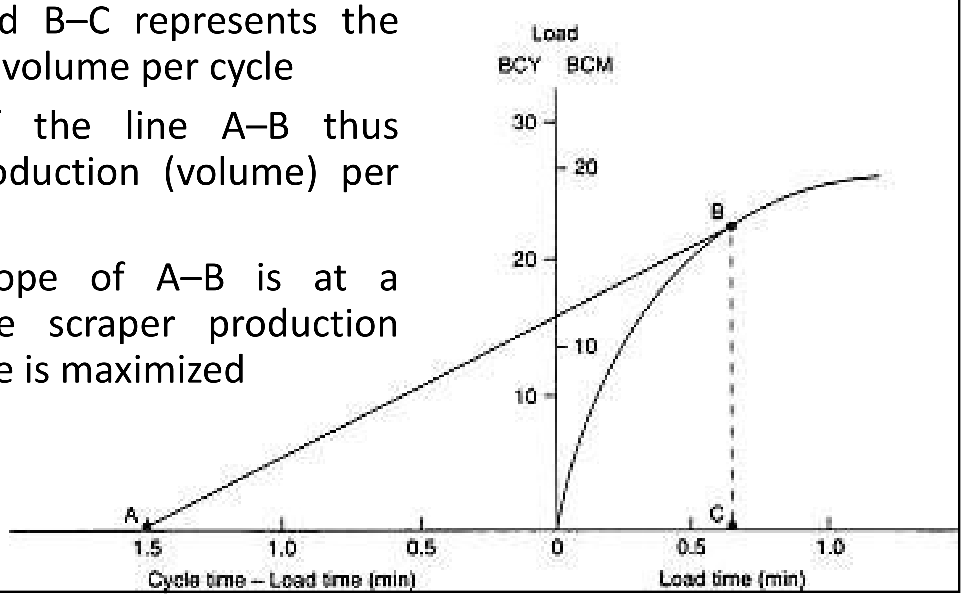
• To prove this, realize that the distance A–C represents total scraper cycle time and B–C represents the corresponding volume per cycle

• The slope of the line A–B thus represents production (volume) per unit of time

• When the slope of A–B is at a maximum, the scraper production per unit of time is maximized



8

Trucks and Wagons

- Because hauling (or the transportation of excavation) is a major earthmoving activity, there are many different types of hauling equipment available to the constructor
- In addition to the dozer, loader, and scraper already described, hauling equipment includes trucks, wagons, conveyor belts, and trains
- Trucks and wagons are still the most common forms of construction hauling equipment

9

- There are a wide variety of types and sizes of dump truck available
- Trucks used for hauling on public highways are limited by transportation regulations in their maximum width, gross weight, and axle load

10

- Wagons are earthmoving trailers pulled by tractors or truck-tractors
- Although wagons are independent pieces of equipment, some are especially designed to work with a particular make and model of tractor

11

Determining the Number of Haul Units Needed

- Truck or Wagon cycle time
  - Fixed: spot, load, maneuver, and dump
  - Variable: haul and return

Table 4–9 Spot, maneuver, and dump time for trucks and wagons (min)

Conditions	Bottom Dump	Rear Dump
Favorable	1.1	0.5
Average	1.6	1.1
Unfavorable	2.0	2.5

12

- Load time =

  Haul unit capacity / Loader production at 100% efficiency
- The reason for using an excavator loading rate based on 100% excavator efficiency that excavators have been found to operate at or near 100% efficiency when actually loading
- Thus, the use of the 100% efficiency loading rate is intended to ensure that an adequate number of trucks is provided so that the excavator will not have to wait for a truck
- Either bank or loose measure may be used, but the same unit must be used in both numerator and denominator

13

- Load time =

  Number of bucket loads x Excavator cycle time
- The number of trucks theoretically required to keep a loader fully occupied and thus obtain the full production of the loader may be calculated as follows:
- Number of haulers required (N) =

  Haul unit cycle time / Load time

14

- Although this method gives reasonable values for field use, it should be recognized that some instances of the loader waiting for haul units will occur in the field when this method is used
- This is due to the fact that some variance in loader and hauler cycle time will occur in the real-world situation
- More realistic results may be obtained by the use of computer simulation techniques or the mathematical technique known as queueing theory

15

- If more than the theoretically required number of trucks is supplied, no increase in system production will occur, because system output is limited to excavator output
- If less than the required number of trucks is supplied, system output will be reduced, because the excavator will at times have to wait for a haul unit
- The expected production in this situation may be calculated as follows:
- Expected production =

  (Actual number of units / N) x Excavator production

16

Example

- Given the following information on a shovel/truck operation, a) Calculate the number of trucks theoretically required and the production of this combination; b) Calculate the expected production if three trucks are removed from the fleet
- Shovel production at 100% = 302 BCM/h
- Job efficiency = 0.8
- Truck capacity = 17.4 BCM
- Truck cycle time (excluding loading) = 0.6 h

17

A) Loading time = 17.4 / 302 = 0.058 h

Truck cycle time = 0.6 + 0.058 = 0.658 h

Number of trucks = 0.658/0.058 = 11.34 trucks = 12

Production = 302 BCM/h x 0.8 = 241.6 BCM/h

18

B) Production = (9/11.34) x 302 x 0.8 = 191.75 BCM/h

19

Job Management

- An important consideration in the selection of excavator/haul unit combinations is the effect of the size of the target that the haul unit presents to the excavator operator
- If the target is too small, excessive spillage will result and excavator cycle time will be increased
- Empirical studies found that haul unit capacity should be 3-5 times excavator bucket capacity
- Clamshells and draglines require even larger sizes (5-10 times excavator bucket capacity)
- A major source of inefficiency is the time lost in spotting haul units for loading

20

- Techniques for maximizing haul unit production
  - Do not overload haul units. Overloading results in excessive repair and maintenance
  - Maintain haul roads in good condition to reduce travel time and minimize equipment wear
  - Develop an efficient traffic pattern for loading, hauling, and dumping
  - Roads must be wide enough to permit safe travel at maximum speeds
  - Provide standby units (20% of fleet size) to replace units that break down

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15. Compacting and Finishing

Dr. Mohammad Almashaqbeh
Department of Civil Engineering
Hashemite University

1

The Compaction Process

- Compaction is the process of increasing the density of a soil by mechanically forcing the soil particles closer together, thereby expelling air from the void spaces in the soil
- Compaction should not be confused with consolidation
- Consolidation is an increase in soil density of a cohesive soil resulting from the expulsion of water from the soil's void spaces
- Consolidation may require months or years to complete, whereas compaction is accomplished in a matter of hours

2

- Compaction has been employed for centuries to improve the engineering properties of soil including:
  - Increased bearing strength
  - Reduced compressibility
  - Improved volume-change characteristics
  - Reduced permeability

3

- Equipment and methods employed for compaction in building construction are usually somewhat different from those employed in heavy and highway construction
- Some of the building construction characteristics producing these differences include:
  - Limited differential settlement that can be tolerated by a building foundation
  - Necessity for working in confined areas close to structures
  - Smaller quantity of earthwork involved

4

- The degree of compaction that may be achieved in a particular soil depends on:
    - The soil's physical and chemical properties (grain size, cohesiveness, etc.)
    - Soil's initial density
    - Soil's moisture content
    - The compaction method employed
    - The amount of compactive effort
    - The thickness of the soil layer being compacted

5

- The four basic compaction forces are:
    - Static weight (pressure)
    - Manipulation (kneading)
    - Impact
    - Vibration
- All compactors utilize static weight to achieve compaction
- Most compactors combine static weight with one or more of the other compaction forces. For example, a plate vibrator combines static weight with vibration

6

- Manipulation of soil under pressure to produce compaction is most effective in plastic soils
- The forces involved in impact and vibration are similar except for their frequency
- Impact or tamping involves blows delivered at low frequencies, usually about 10 cycles per second, and is most effective in cohesive soils
- Vibration involves higher frequencies, which may extend to 80 cycles per second or more
- Vibration is particularly effective in compaction of cohesionless soils such as sand and gravel

7

Optimum Moisture Content

- Optimum moisture content: The moisture content at which maximum dry density is achieved under a specific compaction effort
- Although soil moisture content is only one of the six factors influencing compaction results, it is a very important one
- A standard laboratory test called a Proctor test has been developed to evaluate a soil's moisture-density relationship under a specified compaction effort

8

- Two Proctor tests which have been standardized by the American Society for Testing and Materials (ASTM) and the American Association of State Highway and Transportation Officials (AASHTO)
  - The Standard Proctor Test (ASTM D698, AASHTO T-99)
  - The Modified Proctor Test (ASTM D1557, AASHTO T-180)
- Since the modified test was developed for use where high design loads are involved (such as airport runways), the compactive effort for the modified test is more than four times as great as for the standard test

9

Table 5–1 Characteristics of Proctor compaction tests

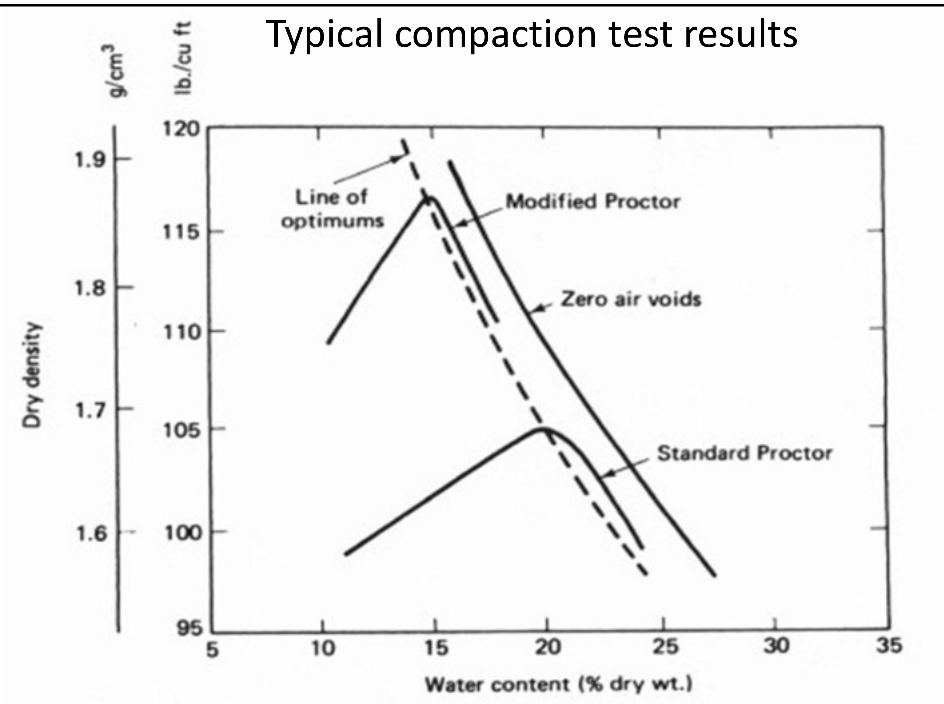
Test Details	Standard	Modified
Diameter of mold		
in.	4	4
mm	102	102
Height of sample		
in.	5 cut to 4.59	5 cut to 4.59
mm	127 cut to 117	127 cut to 117
Number of layers	3	5
Blows per layer	25	25
Weight of hammer		
lb	5.5	10
kg	2.5	4.5
Diameter of hammer		
in.	2	2
mm	51	51
Height of hammer drop		
in.	12	18
mm	305	457
Volume of sample		
cu ft	$\frac{1}{30}$	$\frac{1}{30}$
l	0.94	0.94
Compactive effort		
ft-lb/cu ft	12,400	56,200
kJ/m^3	592	2693

10

- To determine the maximum density of a soil using Proctor test procedures:
  - Compaction tests are performed over a range of soil moisture contents
  - The results are then plotted as dry density versus moisture content
  - The peak of each curve represents the maximum density obtained under the compactive effort supplied by the test

11

Typical compaction test results

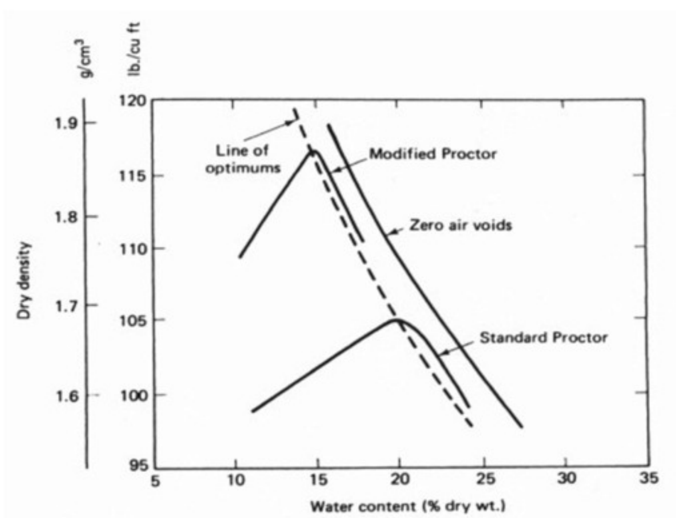


12

- Zero air voids curve represents the density at which all air voids have been eliminated; that is, all void spaces are completely filled with water
- It represents the maximum possible soil density for any specified water content
- Actual density will always be somewhat less than the zero air voids density because it is virtually impossible to remove all air from the soil's void spaces

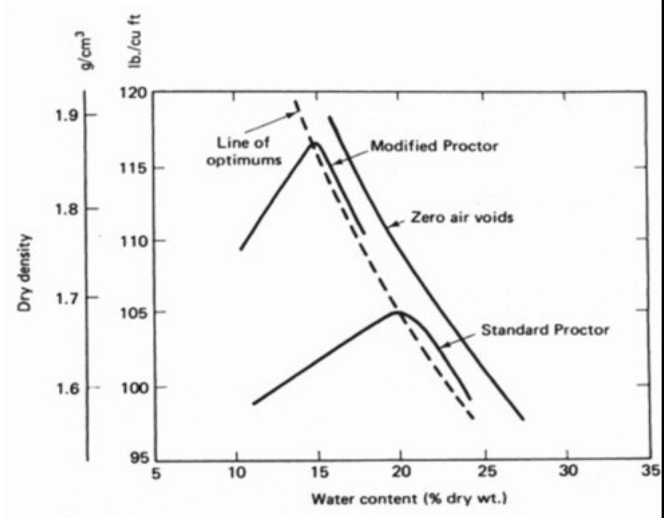
13

- For the Standard Proctor Test the optimum moisture content for this soil is about 20% of the soil's dry weight
- The optimum moisture content for the modified test is only about 15%
- This relationship is typical for most soils
- A soil's optimum moisture content decreases as the compactive effort is increased



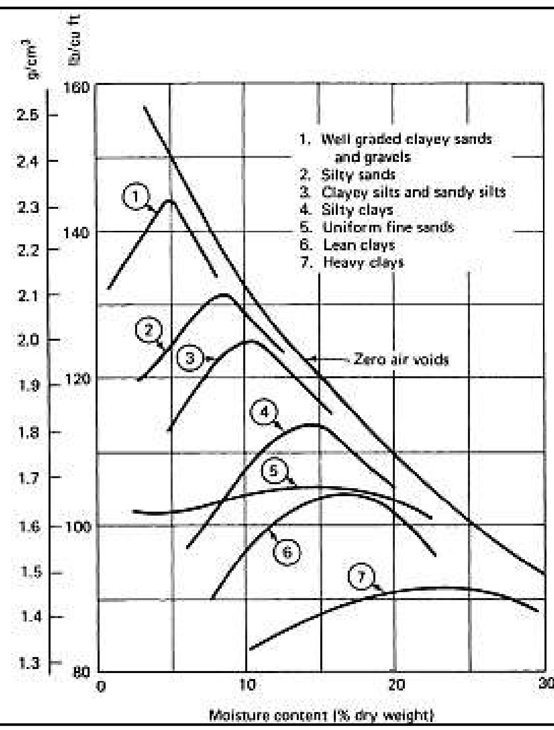
14

- Suppose that specifications require a density of 1.6 g/cm³ for this soil and that the compactive effort being used is equal to that of the Standard Proctor Test
- It can be seen that the required density may be achieved at any moisture content between 13% and 24%
- However, a density 1.68 g/cm³ can only be achieved at a moisture content of 20%



15

- The effect of soil type on compaction test results (Modified Proctor Test)
- Most soils display a similar characteristic shape
- Flat curve obtained when compacting uniform fine sands (curve 5)
- The compaction curve for heavy clays (curve 7) is intermediate between that of uniform fine sands and those of the more typical soils



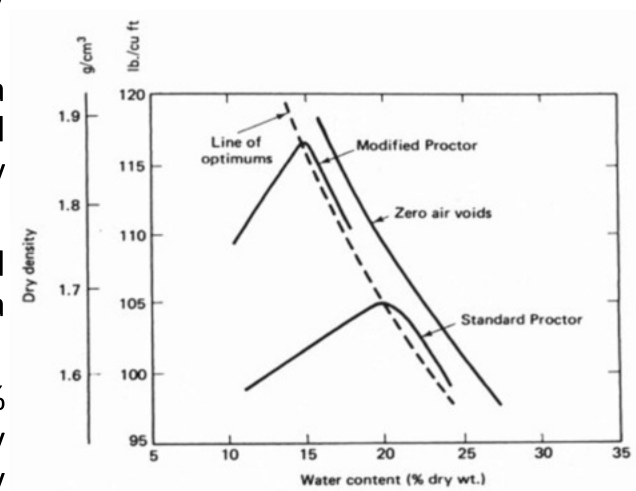
16

Compaction Specifications

- Compaction specifications are intended to ensure that the compacted material provides:
  - The required engineering properties (minimum dry density to be achieved)
  - A satisfactory level of uniformity (A maximum variation of density between adjacent areas)
- To ensure that the required engineering properties are provided, it is customary to prescribe the characteristics of the material to be used and a minimum dry density to be achieved
- If the natural site material is to be compacted, only a minimum density requirement is needed

17

- The Proctor test is widely used for expressing the minimum density requirement
- The specification will state that a certain percentage of Standard Proctor or Modified Proctor density must be obtained
- For this soil, 100% of Standard Proctor density corresponds to a dry density of (1.68 g/cm^3)
- A specification requirement for 95% of Standard Proctor density corresponds to a minimum dry density of (1.60 g/cm^3)



18

- Typical density requirements range from 90% of Standard Proctor to 100% of Modified Proctor
- For example, 95% of Standard Proctor is often specified for embankments, dams, and backfills
- A requirement of 90% of Modified Proctor might be used for the support of floor slabs
- For the support of structures and for pavement base courses where high wheel loads are expected, requirements of 95 to 100% of Modified Proctor are commonly used

19

- It is important that uniform compaction be obtained
- A lack of uniformity in compaction may result in:
    - Differential settlement of structures
    - A bump or depression in pavements
- Uniformity is commonly controlled by specifying a maximum variation of density between adjacent areas

20

Measuring Field Density

- To verify the adequacy of compaction, the density (soil or asphalt) actually obtained in the field must be measured and compared with the specified density
- The methods available for performing in-place density tests include:
  - Traditional methods (liquid tests and sand tests)
  - Nuclear density gauges
  - Nonnuclear density gauges
  - Equipment-mounted compaction measurement systems

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- All of the traditional test methods involve:
  - Removing a material sample
  - Measuring the volume of the hole produced
  - Determining the dry weight of the material removed
- Compacted density is then found as the dry weight of material removed divided by the volume of the hole
- Liquid tests measure the volume of material removed by measuring the volume of liquid required to fill the hole
- Sand tests involve filling both the hole and an inverted funnel placed over the hole with a uniform fine sand

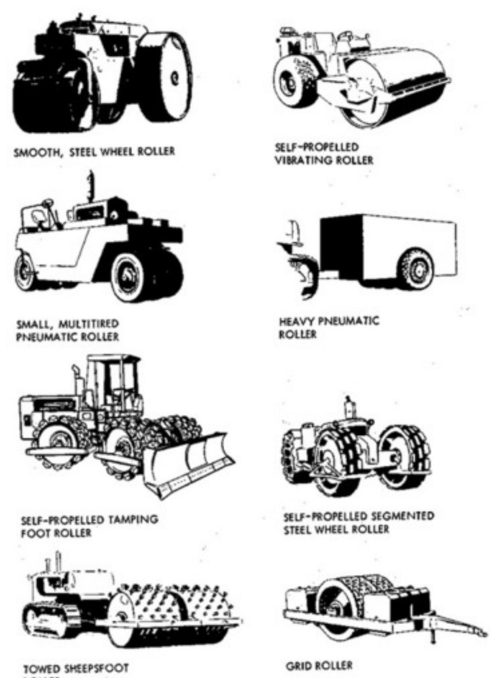
22

- Nuclear density devices measure the amount of radioactivity from a calibrated source that is reflected back from the compacted material to determine both material density and moisture content
- Nonnuclear density gauges that measure asphalt density, temperature, and moisture content are also available
- Equipment mounted compaction measurement and control systems provide rapid measurement of compaction results. Some systems control the energy being delivered by the compactor to avoid over or under compaction of the material

23

Compaction Equipment

- Principal types of compaction equipment:
  - Tamping Foot Rollers
  - Grid or Mesh Rollers
  - Vibratory Compactors
  - Smooth Steel Drum Rollers
  - Pneumatic Rollers
  - Segmented Pad Rollers
  - Tampers or Rammers



24

Construction Methods – 110401542

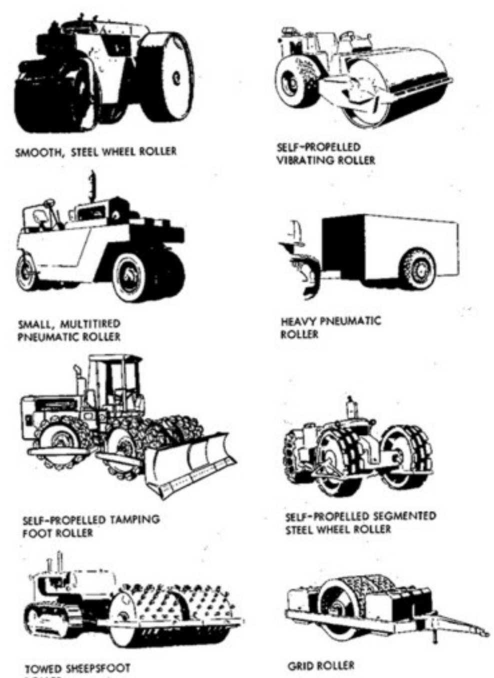
16. Compacting and Finishing

Dr. Mohammad Almashaqbeh
Department of Civil Engineering
Hashemite University

1

Compaction Equipment

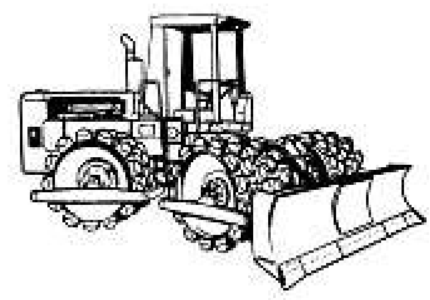
- Principal types of compaction equipment:
  - Tamping Foot Rollers
  - Grid or Mesh Rollers
  - Vibratory Compactors
  - Smooth Steel Drum Rollers
  - Pneumatic Rollers
  - Segmented Pad Rollers
  - Tampers or Rammers



2

Tamping Foot Rollers

- Tamping foot rollers utilize a compaction drum equipped with a number of protruding feet
- Available in a variety of foot sizes and shapes, including the sheepsfoot roller
- During initial compaction, roller feet penetrate the loose material and sink to the lower portion of the lifts



SELF-PROPELLED TAMPING FOOT ROLLER

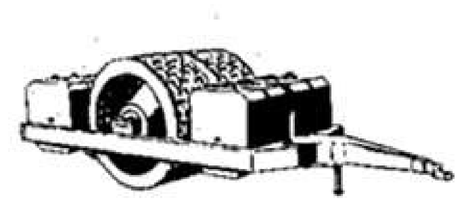
3

- As compaction proceeds, the roller rises to the surface or “walks out” of the soil
- All tamping foot rollers utilize static weight and manipulation to achieve compaction
- They are most effective on cohesive soils

4

Grid or Mesh Rollers

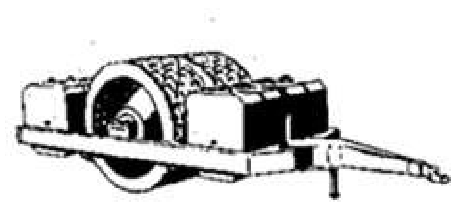
- Utilize a compactor drum made up of a heavy steel mesh
- They can operate at high speed without scattering the material being compacted
- Compaction is due to static weight and impact plus limited manipulation



GRID ROLLER

5

- Most effective in compacting clean gravels and sands
- They can also be used to break up lumps of cohesive soil
- They are capable of both crushing and compacting soft rock



GRID ROLLER

6

Vibratory Compactors

- Available in a wide range of sizes and types:
  - In size they range from small hand-operated compactors through towed rollers to large self-propelled rollers
  - By type they include plate compactors, smooth drum rollers, and tamping foot rollers

7

- Small walk-behind vibratory plate compactors and vibratory rollers are used primarily for compacting around structures and in other confined areas
- Vibratory plate compactors are also available as attachments for hydraulic excavators
- The towed and self-propelled units are utilized in general earthwork
- Large self-propelled smooth drum vibratory rollers are often used for compacting bituminous bases and pavements

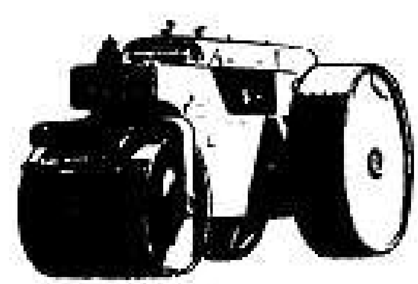
8

- Vibratory compactors are most effective in compacting noncohesive soils
- They may also be effective in compacting cohesive soils when operated at low frequency and high amplitude
- Many vibratory compactors can be adjusted to vary both the frequency and amplitude of vibration

9

Steel Wheel or Smooth Steel Drum Rollers

- Used for compacting granular bases, asphaltic bases, and asphalt pavements
- Types available include towed rollers and self-propelled rollers
- Self-propelled rollers include three-wheel (two-axle) and two- and three-axle tandem rollers
- The compactive force involved is primarily static weight

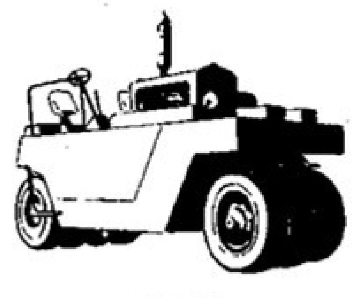


SMOOTH, STEEL WHEEL ROLLER

10

Rubber-Tired or Pneumatic Rollers

- Available as light- to medium-weight multitired rollers and heavy pneumatic rollers
- Heavy pneumatic rollers weighing up to 200 tons are used for dam construction, compaction of thick lifts, and proof rolling (test rolling before pavement layers are constructed)
- Effective on almost all types of soils but are least effective on clean sands and gravels

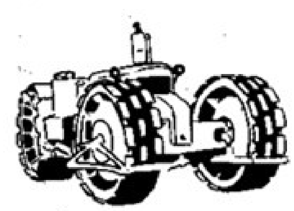


SMALL, MULTITIRED PNEUMATIC ROLLER

11

Segmented Pad Rollers

- Similar to tamping foot rollers except that they utilize pads shaped as segments of a circle instead of feet on the roller drum
- They produce less surface disturbance than do tamping foot rollers
- Effective on a wide range of soil types



SELF-PROPELLED SEGMENTED STEEL WHEEL ROLLER

12

Rammers or Tampers

- Small impact-type compactors
- Primarily used for compaction in confined areas
- Some rammers are classified as vibratory rammers because of their operating frequency

13

Compaction in Confined Areas

- The equipment available for compaction in confined areas such as trenches and around foundations includes:
  - Small vibratory plate compactors
  - Tampers or rammers
  - Walk-behind static and vibratory rollers
  - Attachments for backhoes and hydraulic excavators

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- Walk-behind vibratory roller with remote control

15

- Compactors which mount on the boom of backhoes and excavators include compaction wheels and vibratory plate compactors
- Such compactors are highly maneuverable
- Useful for compacting the material in deep excavations such as trenches
- Due to their long reach, these compactors often eliminate the safety hazard involved in having a compactor operator down in the trench

16

- Compaction wheels:
  - Small compactors similar in design to tamping foot rollers
  - Mounted on the boom of backhoes or hydraulic excavators

17

- Vibratory plate attachments:
  - Small vibratory plate compactors
  - Powered by the hydraulic system of the equipment to which they are attached

18

Selection of Compaction Equipment

- The proper selection of compaction equipment is an important factor in obtaining the required soil density with a minimum expenditure of time and effort

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

19

Compaction Operations

- After selecting compaction equipment, a compaction plan must be developed
- The major variables to be considered include:
  - Soil moisture content
  - Lift thickness (layer thickness)
  - Number of passes used
  - Ground contact pressure
  - Compactor weight
  - Compactor speed
  - Frequency and amplitude (for vibratory compactors)

20

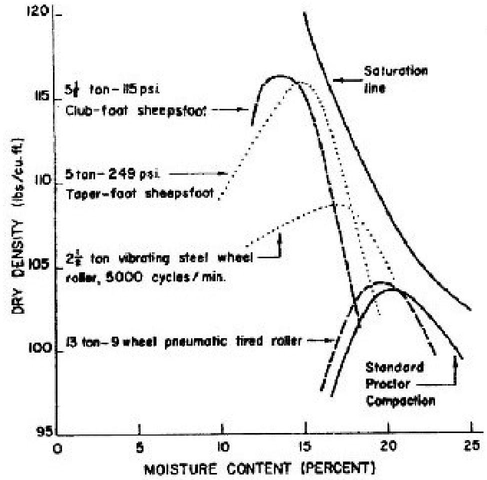
- The compactive effort delivered by a piece of compaction equipment will seldom be exactly the same as that of either the standard or modified compaction test
- As a result, the field optimum moisture content for a particular soil/compactor combination will seldom be the same as the laboratory optimum
- For plastic soils it has been observed that the field optimum moisture content is close to the laboratory Standard Proctor optimum for pneumatic rollers

21

- Field optimum is appreciably lower than laboratory optimum for tamping foot rollers
- For nonplastic soils, the field optimum for all nonvibratory equipment appears to run about 80% of the laboratory Standard Proctor optimum
- The vibratory compactor appears to be most effective in all types of soil when the field moisture is appreciably lower than laboratory optimum

22

• Only one of the four compactors has a field optimum moisture content close to the laboratory optimum



THE EFFECT OF MOISTURE CONTENT ON THE DRY DENSITY OF A SILTY CLAY (CL) SOIL IN 9 in. LOOSE LAYERS WHEN FULLY COMPACTED BY UP TO 64 PASSES BY DIFFERENT TYPES OF COMPACTING EQUIPMENT.

23

• Lifts should be kept thin for most effective compaction
• For all rollers, except vibratory rollers and heavy pneumatic rollers, a maximum lift thickness of 15 to 20 cm is suggested
• Lift thicknesses of 30 cm or more may be satisfactory using heavy pneumatic rollers
• The maximum lift thickness for effective vibratory compaction depends on the static weight of the compactor
• The compaction achieved by repeated passes of a compactor depends on the soil/compactor combination utilized

24

- For some combinations (such as a tamping foot roller compacting a clayey gravel), significant increases in density may continue to occur beyond 50 passes
- However, the increase in density is relatively small after about 10 passes for most soil/compactor combinations

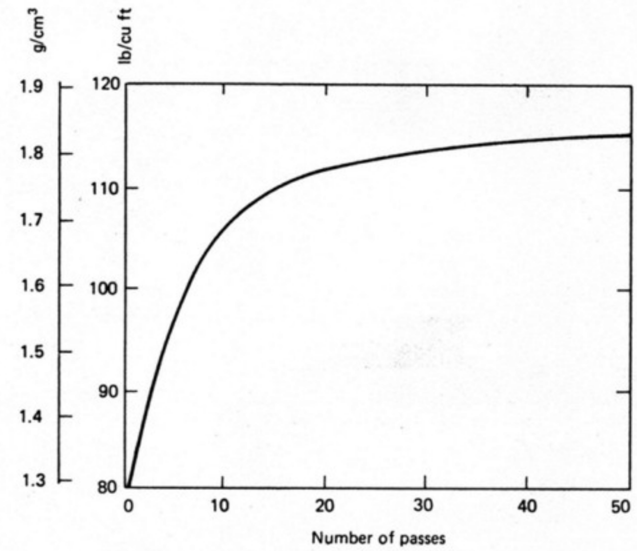


Figure 5-12 Typical effect of number of passes.

25

- If a tamping foot roller fails to "walk out" to within 2.5 cm of the surface after about five passes, it usually indicates that either the contact pressure or the soil moisture content is too high
- When using vibratory equipment, tests should be performed to determine the compactor speed that results in the highest compactor productivity

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Estimating Compactor Production

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

- Where:
  - P = Number of passes required
  - W = Width compacted per pass (m)
  - S = Compactor speed (km/h)
  - L = Compacted layer thickness (cm)
  - E = Job efficiency

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Example

- Estimate the production in compacted cubic meters per hour for a self-propelled tamping foot roller under the following conditions:
  - Average speed = 8 km/h
  - Compacted lift thickness = 15.2 cm
  - Effective roller width = 3.05 m
  - Job efficiency = 0.75
  - Number of passes = 8

28

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

= (10 x 3.05 x 8 x 15.2 x 0.75) /8

= 347.7 CCM/h

29

Job Management

- Trial operations are usually required to determine the exact values of soil moisture content, lift thickness, compactor weight, and vibrator frequency and amplitude that yield maximum productivity while achieving the specified soil density
- Traffic planning and control is an important factor in compaction operations
- Hauling equipment must be given the right-of-way without interfering with compaction operations
- The use of high-speed compaction equipment may be necessary to avoid conflicts between hauling and compacting equipment

30

Grading and Finishing

- Grading is the process of bringing earthwork to the desired shape and elevation (grade)
- Finish grading, or simply finishing, involves smoothing slopes, shaping ditches, and bringing the earthwork to the elevation required by the plans and specifications
- Finishing usually follows closely behind excavation, compaction, and grading
- Finishing, in turn, is usually followed closely by seeding or sodding to control soil erosion

31

- The piece of equipment most widely used for grading and finishing is the motor grader
- Used for stripping, grading, finishing, backfilling, mixing and spreading soil, and maintenance of haul roads

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- Grade trimmers and excavators are frequently used on large highway and airfield projects because their operating speed is greater than that of the motor grader

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Estimating Grader Production

- Grader production is usually calculated on
  - Linear basis for roadway projects (kilometers completed per hour)
  - Area basis for general construction projects (square meters per hour)
- The time required to complete a roadway project may be estimated as follows:

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

34

- Average speed will depend on operator skill, machine characteristics, and job conditions

Table 5–6 Typical grader operating speed

Operation	Speed mi/h	Speed 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

- 24.1 km of gravel road require reshaping and leveling. It is estimated that 6 passes of a motor grader will be required as follows:
- 2 passes at 6.4 km/h
- 2 passes at 8.0 km/h
- 2 passes at 9.7 km/h
- If job efficiency is estimated at 0.8. How many grader hours will be required for this job?

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

$$= \left[\left(\frac{2 \text{ x } 24.1}{6.4} + \frac{2 \text{ x } 24.1}{8} + \frac{2 \text{ x } 24.1}{9.7}\right)\right] \text{x} \frac{1}{0.8} = 23.16 \text{ h}$$

37

Job Management

- Careful job planning, the use of skilled operators, and competent supervision are required to maximize grader production efficiency
- Use the minimum possible number of grader passes to accomplish the work
- Eliminate as many turns as possible
- Use grading in reverse for distances less than 305 meters. May be used for longer distances when turning is difficult or impossible
- Several graders may work side by side if sufficient working room is available. Useful for grading large areas

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17. Project Session

Dr. Mohammad Almashaqbeh
Department of Civil Engineering
Hashemite University

Presentation Schedule

- Groups 1, 2, and 3 presenting on **May 20**
- Groups 4, 5, and 6 presenting on **May 23**
- Groups 7, 8, and 9 presenting on **May 27**
- Groups 10, 11, and 12 presenting on **May 30**

- **May 19** Report + presentation slides due for groups presenting on **May 20**
- **May 22** Report + presentation slides due for groups presenting on **May 23**
- **May 26** Report + presentation slides due for groups presenting on **May 27**
- **May 29** Report + presentation slides due for groups presenting on **May 30**

Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8	Group 9	Group 10	Group 11	Group 12
1730053	1837026	1738040	1834008	1836861	1633174	1732403	1635650	1837682	1736837	1631258	1731286
1732491	1836988	1732492	1836801	1831783	1635581	1737709	1632491	1737954	1539481	1732436	1831364
1838447	1833172	1732446	1833852	1636976	1639330	1732484	1636778	1630839	1737763	1737527	1732460
1732471	1538855	1732416	1837586	1834763	1632467	1732420	1632511	1631148	1732442	1732433	1837741
1732457	1537030	1737230	1837246	1632444	1631040	1732461	1631376	1737422	1536435	1732489	1736148
1732477	2038226	1736153	1834046	1632459	1731621	1732488	1632484	1636644	1732407	1737157	1739107
1836278						1737528	1636774		1738316	1730233	1732451

- Each group is required to conduct a productivity improvement study for a construction activity
- Each group is required to observe a construction activity, study the activity operation and suggest productivity improvements
- You are free to choose any construction project and activity, but the construction crew must have at least 5 workers in addition to equipment

- Avoid small-scale projects
- You can choose one of the following:
  - A local construction site that you visit in-person (follow health and safety regulations)
  - A remote project via web cams that provide live video feed of the construction site
  - A recorded video (e.g., YouTube)

- Your report should include the following:
- Description of the project and site conditions
- Description of the activity being investigated by your team (Crew size, equipment, and material, …)
- Analysis of the existing activity: How the activity is being performed by the crew (plans, images, and videos, …)
- Crew-balance chart, process chart, and flow diagrams for existing activity
- Problems in the existing activity based on your analysis

- Your report should include the following:
- Proposed improvements for the investigated activity (minimum 4 proposals)
- Crew-balance chart, process chart, and flow diagrams for proposed improvements
- Provide implementation plan (time and cost) for each of these proposals

- The results of the study include a technical report and a presentation
- Timing (18 min)
- Add pictures and/or videos to your presentation and report
- List all sources and references
- One submission per team
- Name the files: Group#_Project, Group#_PPT

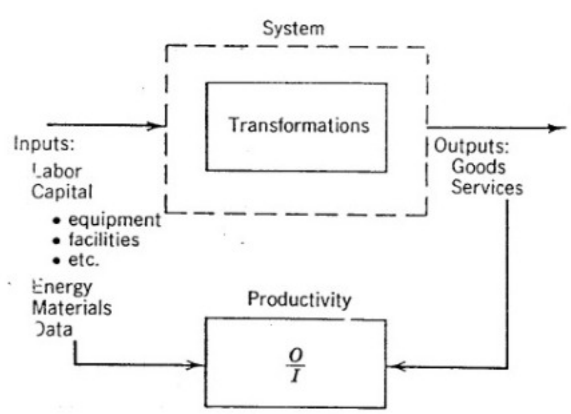
Construction Methods – 110401542

18. Improving Productivity and Performance

Dr. Mohammad Almashaqbeh
Department of Civil Engineering
Hashemite University

1

- Productivity: The output of construction goods and services per unit of labor input
- Productivity = Output (units of products) / Input (resources)



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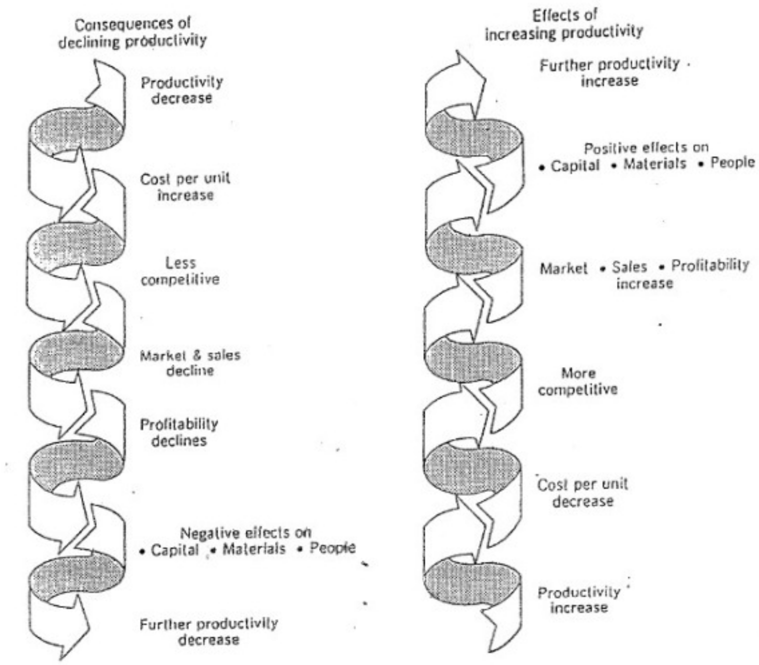

Spiral Effect of Productivity on Business

3

- The use of larger and more productive earthmoving equipment can increase productivity and lower unit production costs in the face of generally rising labor and materials costs
- Continued growth of technology such as robotics and industrialized building processes will have a significant impact on construction productivity in the future
- A better measure of construction industry performance is cost-effectiveness
- Construction industry productivity and cost effectiveness can be increased by improved management

4

- Most on-site delays and inefficiencies lie within the control of management
- Management is responsible for planning, organizing, and controlling the work
- If these management responsibilities were properly carried out, there would be few cases of workers standing idle waiting for job assignment, tools, or instructions
- The scope of management responsibility is great and the techniques for efficiently carrying out these responsibilities are varied and complex

5

A COMPARISON BETWEEN SOME OF THE IMPORTANT ORGANIZATIONAL AND BEHAVIORAL CHARACTERISTICS OF TRADITIONAL MANAGEMENT PRACTICES AND PRODUCTIVITY-IMPROVEMENT ACTIVITIES

Traditional Management approach	Productivity-Improvement approach
Organization characteristics	
Purpose is to get work done; emphasis is on output and practicability	Purpose is to find better solutions to organizational, technical, and people problems
Coordination and decision making follow chain of command	Position in hierarchy is unimportant; has no chain of command; does not make decisions
Power is based on position in hierarchy; leadership is at the top	Power and leadership are based not on position or rank but on knowledge and ability to pursuade
Functions are specialized; task assignments and division of labor are by skills	Functions may be specialized but may be diffuse, covering a spectrum of topics
Operations are task-oriented	Operations are change-oriented
Problems are solved by following precedent and explicit rules and procedures	Problem-finding and problem-solving techniques are employed to develop new approaches
Information and feedback limited to that made available through the system	Full access is given to all pertinent information and feedback
Human-behavior situation	
Rewards come through conformance and following the plan; penalties possible for those who do not follow the rules or who make waves	High rewards for innovation and for challenging usual practices; lower vulnerability; shielded from reprisals

6

- Work improvement:
  - The scientific study and optimization of work methods
  - One of the major tools for improving construction productivity
  - Such techniques are also known as work simplification, motion and time study, work study, and methods analysis
- Human factors:
  - Often not adequately considered
  - Play an important part in productivity
  - Workers' physical capacity, site working conditions, morale, and motivation are important elements in determining the most effective work methods and the resulting productivity for a particular task

7

Work Improvement

- Preplanning:
  - Detailed planning of work equipment and procedures prior to the start of work
  - An important but often overlooked component of work improvement
  - Physical models as well as traditional work improvement charts and diagrams may be used to advantage in the preplanning process
- Work improvement techniques include time studies, crew balance charts, process charts, and flow diagrams

8

Time Studies (Activity Sampling)

- Time studies are used to collect time data relating to a construction activity for the purpose of either statistical analysis or determining the level of work activity
- It is important that the data collected be statistically valid
- A random-number procedure is usually employed in selecting the time for making each observation
- The number of observations required for statistical validity depends on the type of study being made

9

- For time analysis, the number of observations required depends on sample size, the standard deviation of the sample, and the level of accuracy and confidence desired
- Techniques of activity sampling used to evaluate the efficiency of labor utilization:
  - Field ratings
  - Productivity ratings
  - Five-minute ratings

10

Field Ratings

- Used to measure the level of activity of a work force
- At the selected random times, each worker is observed and instantaneously classified as either working (engaged in a useful activity) or nonworking (not engaged in a useful activity)
- The number of working observations divided by the total number of observations yields the level of activity

11

- Basic operating rules for simple field ratings:

1. One counter records the active personnel; a second records the total number that have been observed
2. All those to be covered by the survey should be observed. At least 75% of the personnel must be in the sample to get dependable results. When greater detail is desired, counts should be made and reported by crafts, areas, or crews
3. The individual making the count should devote full time to the count (avoid distractions)

12

4. 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 the observation

5. The person doing the counting must understand the reasons for making the count

13

6. 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)

   This rule does not preclude taking special – purpose counts at the beginning and end of shifts to determine whether or not activities get underway quickly or if activity tends to slack off just before quitting time

7. No counts should be discarded

14

- To qualify as working, personnel should be engaged in such activities as:
  - Carrying material, holding, or supporting material
  - Participating in active physical work, including:
    - Measuring; laying out; reading blueprints; filling-in time cards; writing orders; or giving instructions
    - Holding a tagline or supporting a ladder
    - Operating a machine or piece of equipment, but only while actively engaged
  - Discussing the work, provided it can positively determined that such is the case

15

- Activities such as the following would be listed as not working:
  - Waiting for another to finish work, such as laborers waiting for their wheelbarrows to be loaded or waiting for a hoist
  - Talking while not actively working
  - Attending self-operating machines, unless engaged in a useful task
  - Walking about empty-handed
- Note that previous rules are not absolutes and that management should adjust them to provide the desired information

16

- 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
- 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

17

- 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

18

- Field ratings may be made with work forces of any size
- Where a large project is being observed, only a few trips around the project will be required to secure the necessary number of observations
- If a single crew is being rated, its members must be observed repeatedly

19

Example

- Calculate the percentage working and the adjusted field rating for the following sample report on a field rating:
- Number of workers on job site = 145
- Number of workers observed = 133
- Number of workers classified as working = 72

20

- Percentage working = 72/133 = 54.14%
- Adjusted field rating index = 64.14%

Productivity Ratings

- Define the individual activities that workers do and classify them into 3 categories:
  - Effective work
  - Contributory work
  - Not useful work or idle
- There is no right way to categorize the multitude of activities for productivity rating purposes
- It is necessary only to make clear the activities or conditions that are to be measured and how they are to be classified

- Effective work:
  - Activities directly involved in the actual process of putting together or adding to a unit being constructed
  - Work is effective only when it directly adds to the completed product
  - The definition of finished or end product is easily determined on most projects
  - Examples of finished/completed products: A cubic meter of excavation, a linear meter of pipe in place, or an electrical fixture installed in place

23

- Examples of effective work:
  - Building or stripping forms, placing concrete, finishing the concrete surface, painting a wall, placing bricks, attaching a valve to a pipe, nailing boards on a wall, or hauling material from an excavation
- Examples of effective work that is carried out away from the work station:
  - Mixing mortar for bricks or cutting boards before nailing them

24

- 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, or returning an empty truck to be filled

25

- Not useful or idle (ineffective work)
  - Doing something that is in no way necessary to complete the job
  - Examples: Walking empty-handed, taking a coffee break, waiting for a truck, correcting an error, or going back to the shop for a tool or a part

26

PRODUCTIVITY RATINGS FOR SEVERAL CONSTRUCTION TRADES*

Trade or craft	Effective	Percent of total time in category: Contributory	Not useful
Bricklayer	42	33	25
Carpenter	29	38	33
Cement finisher	37	41	22
Electrician	28	35	37
Instrument installer	30	30	40
Insulator	45	28	27
Ironworker	31	36	33
Laborer	44	26	30
Millwright	34	36	30
Equipment operator	38	22	40
Painter	46	26	28
Rigger	27	57	16
Sheetmetal	38	33	29
Pipefitter	27	36	37
Teamster	45	16	39
Average of above	36	33	31

*Data are from 2 years of ratings by a large construction firm which has used work sampling for many years. Ratings given represent good performance.

27

- The data clearly show the differences in ratings to be expected among craftsmen whose tasks are highly repetitive such as bricklayers or painters, and others, such as carpenters and pipe fitters

28

Construction Methods – 110401542

19. Improving Productivity and Performance

Dr. Mohammad Almashaqbeh
Department of Civil Engineering
Hashemite University

1

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Average of above	36	33	31

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2

Labor Utilization Factors

- The principal goal of any work improvement scheme is to increase the number of employees engaged in the effective work category
- But some essential contributory work is required in all jobs
- Making some allowance for essential contributory work when reporting overall performance is common
- The labor utilization factor takes into account this allowance based on that substantial credit for the contributory work is justified

3

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

Total observed = Effective + essential contributory + ineffective

4

- 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
- A painter does more effective work and less contributory work than does a plumber
- 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

5

- For example, a crew of laborers might have a factor in the range of 40% - 50%, electricians and pipe fitters: 30%- 40%, and painters: 45% - 55%
- For a particular kind of work or a mixed crew, the factor would be different
- 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

6

- 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

7

Example

- Calculate the labor utilization factor based on the following information:
- Number of workers observed = 20
- Number of effective workers = 12
- Number of contributory workers = 4

8

Labor utilization factor = $\frac{12+\frac{1}{4}\text{x}4}{20}$

= 65%

9

Five-Minute Ratings

- Quick method of activity sampling
- Less exact compared to field rating method
- Effective method for making a general work evaluation
- Purposes of 5-mintue rating:
    - Create awareness on the part of management of delays in a job
    - Measure the effectiveness of a crew
    - Indicate where more thorough, detailed observations or planning could result in savings

10

- Named because of the rule that no crew should be observed for less than 5 minutes
- A a rule of thumb is that the minimum observation time (in minutes) should be equal to the number of men in the crew
- 12 men should be observed for at least 12 minutes
- To increase the reliability of the results, multiples of 5-minute ratings are utilized

11

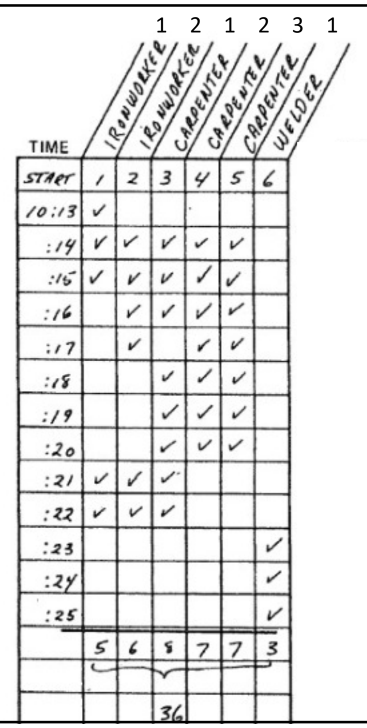
- For small crews working in close proximity to one another, all are observed at the same time
- Large crews can be mentally divided into subgroups for ease of observation
- Individuals in each group are then observed during consecutive blocks of time from 30 seconds to several minutes
- If the delay/nonwork in any clock of time exceeds 50% of the period of observation, then the rating for that individual is classified under delay/nonwork, otherwise classified as effective

12

- The sum of effective times for each individual and for the crew divided by the total time of observation will give an effectiveness ratio
- An adequate knowledge of the crew effectiveness is usually achieved by making four separate 5 minute ratings in a day, two during the first half of the shift and two during the last half
- Additional studies can increase the reliability of and confidence in the results

13

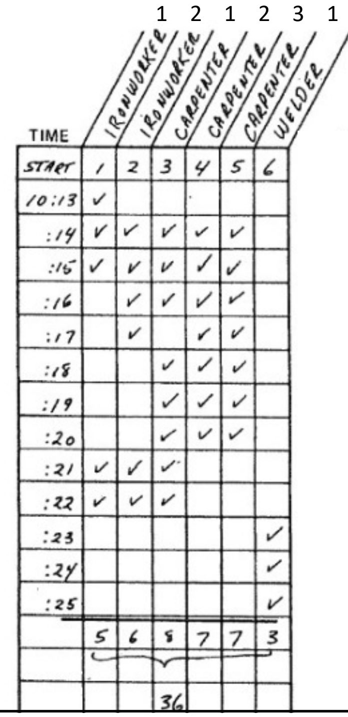
- Hoisting pre-cast concrete wall panels into place by a crane and having a crew that is landing and fastening them into place
- Data at the tops of the columns designate the individuals beings observed and their crafts
- In this case, with only six men in the crew, the complete group was being observed at the same time
- The observer divided the time into arbitrary 1-minute intervals



	1	2	1	2	3	1
TIME	IRONWORKER	IRONWORKER	CARPENTER	CARPENTER	CARPENTER	WELDER
START	1	2	3	4	5	6
10:13	✓					
:14	✓	✓	✓	✓	✓	
:15	✓	✓	✓	✓	✓	
:16		✓	✓	✓	✓	
:17		✓		✓	✓	
:18			✓	✓	✓	
:19			✓	✓	✓	
:20			✓	✓	✓	
:21	✓	✓	✓			
:22	✓	✓	✓			
:23						✓
:24						✓
:25						✓
	5	6	8	7	7	3
			36			

14

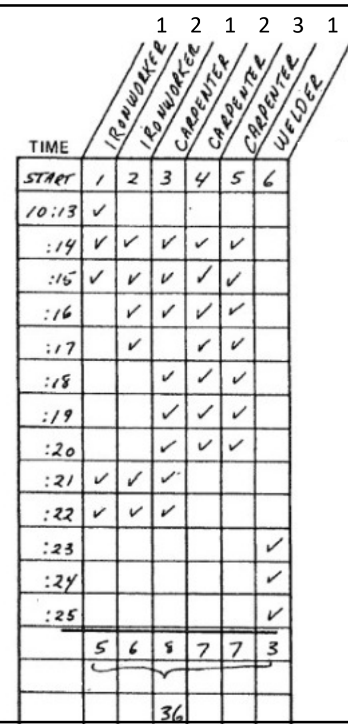
- Rather than work on a minute-by-minute basis, the observer can wait until a specific task is completed and then rate the workers as to whether the majority of their time was working or not
- After the study is completed, the ratio of effective to total time is computed on a man minute basis



TIME	1 IRONWORKER	2 IRONWORKER	1 CARPENTER	2 CARPENTER	3 CARPENTER	1 WELDER
START	1	2	3	4	5	6
10:13	✓					
:14	✓	✓	✓	✓	✓	
:15	✓	✓	✓	✓	✓	
:16		✓	✓	✓	✓	
:17		✓		✓	✓	
:18			✓	✓	✓	
:19			✓	✓	✓	
:20			✓	✓	✓	
:21	✓	✓	✓			
:22	✓	✓	✓			
:23						✓
:24						✓
:25						✓
	5	6	8	7	7	3
			36			

15

- Total man units = 78
- Effective = 36
- Effectiveness = 46.15%



TIME	1 IRONWORKER	2 IRONWORKER	1 CARPENTER	2 CARPENTER	3 CARPENTER	1 WELDER
START	1	2	3	4	5	6
10:13	✓					
:14	✓	✓	✓	✓	✓	
:15	✓	✓	✓	✓	✓	
:16		✓	✓	✓	✓	
:17		✓		✓	✓	
:18			✓	✓	✓	
:19			✓	✓	✓	
:20			✓	✓	✓	
:21	✓	✓	✓			
:22	✓	✓	✓			
:23						✓
:24						✓
:25						✓
	5	6	8	7	7	3
			36			

16

- More extensive studies can be undertaken using modifications of this techniques
- For studies lasting several hours, the time blocks can be 5 minutes in length
- Total man units = 46
- Effective = 19
- Effectiveness = 41.3%

TIME	CUTTER	WELDER
8:35	✓	
:40	✓	
:45	✓	
:50	✓	
:55		
9:00		
:05		
:10	✓	
:15	✓	
:20	✓	
:25	✓	
:30	✓	✓
:35		✓
:40		✓
:45		
:50		
:55		
10:00		
:05	✓	✓
:10	✓	✓
:15	✓	
:20	✓	
:25		✓
	13	6

17

Crew Balance Charts

- Offer an effective way to show the interrelationships among activities of individual members of crews along with the equipment they employ
- Before the chart can be made, the time devoted to each element of the activity by each person and machine must be observed and recorded
- The crew balance chart has vertical bars representing each person or machine element

18

- 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

19

- 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
- Be rearranging work assignments among various members of the crew, noneffective time can be reduced and productivity increased
- Analyses such as these often suggest that the crew size could be modified or to realign jobs so that work is equalized between crew members

20

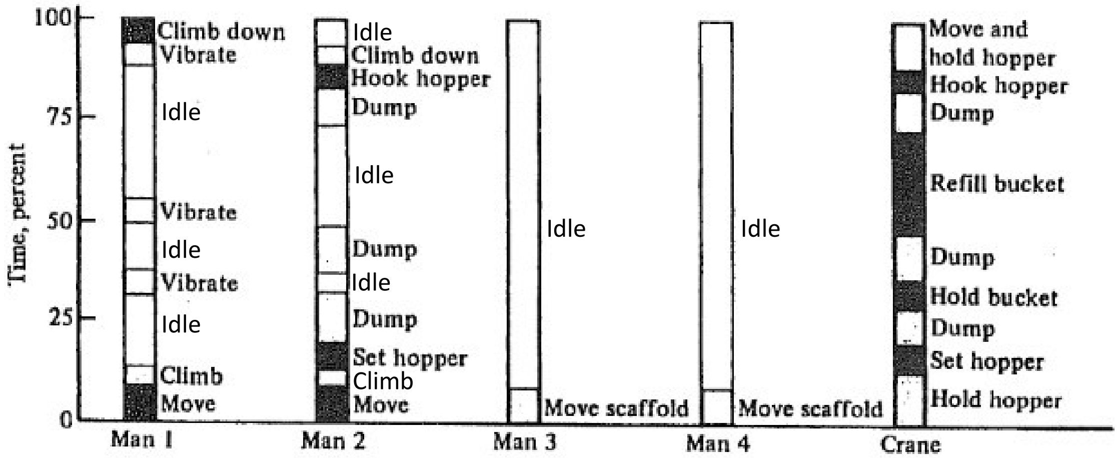
- It can be used for identifying potential rearrangement of the site or reassignment of tasks to improve the overall productivity of an entire crew
- It should be noted that crew balance chart does not necessarily demonstrate the effectiveness or efficiency of an operation, since being busy is not synonymous with using a good method
- However, it can reveal inefficiencies or greater or lesser levels of activity

21

Example

- Construction of a high-rise building
- 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

22



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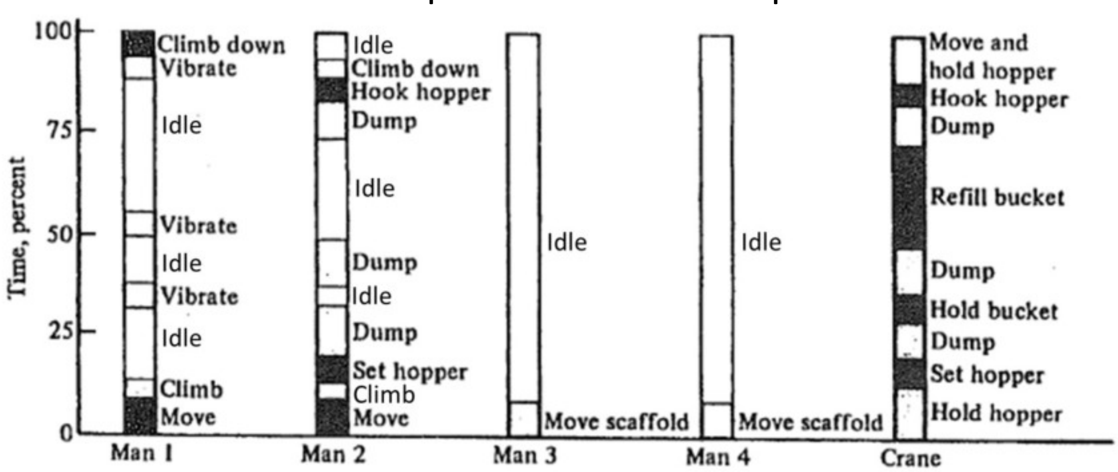
- Man 1 and Man 2 are doing the actual placing and vibrating of the concrete from a small portable scaffold
- Man 3 and Man 4 move the scaffold from one column to the next as each concrete placement was completed



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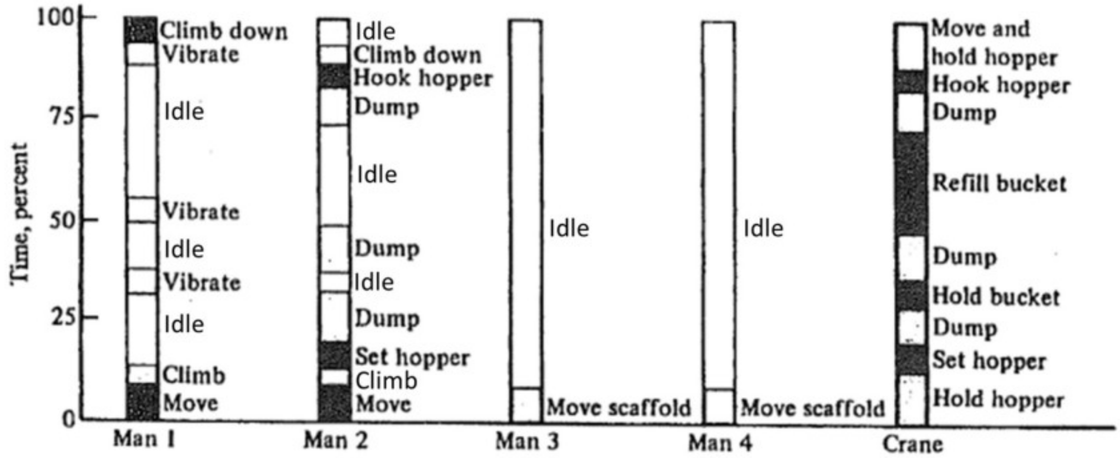
- Since the job-built wooden hopper is large and heavy and is not attached to the concrete bucket, it is moved by hooking it to the bucket and having the crane remove, transport, and place it



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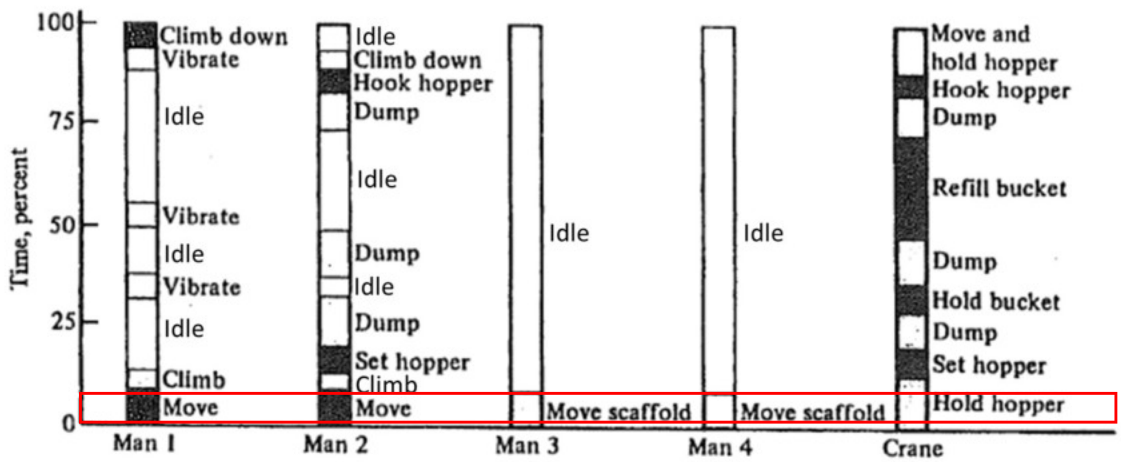

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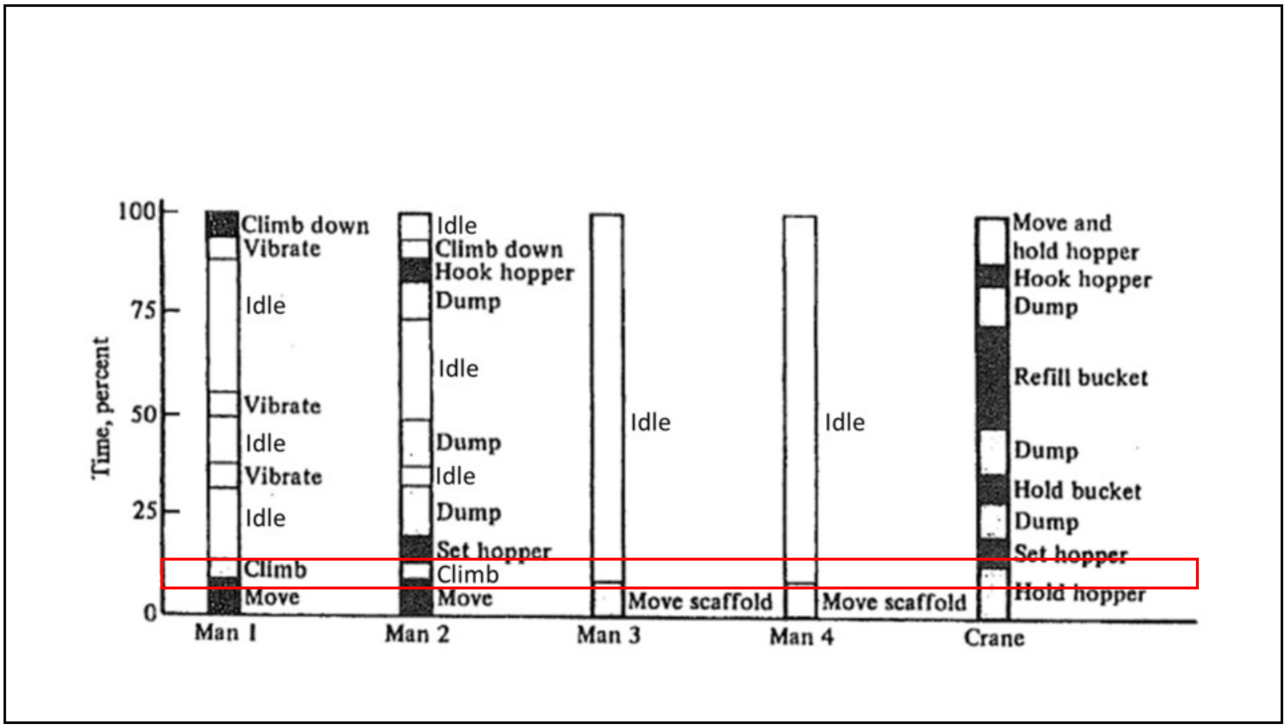
Time, percent
100
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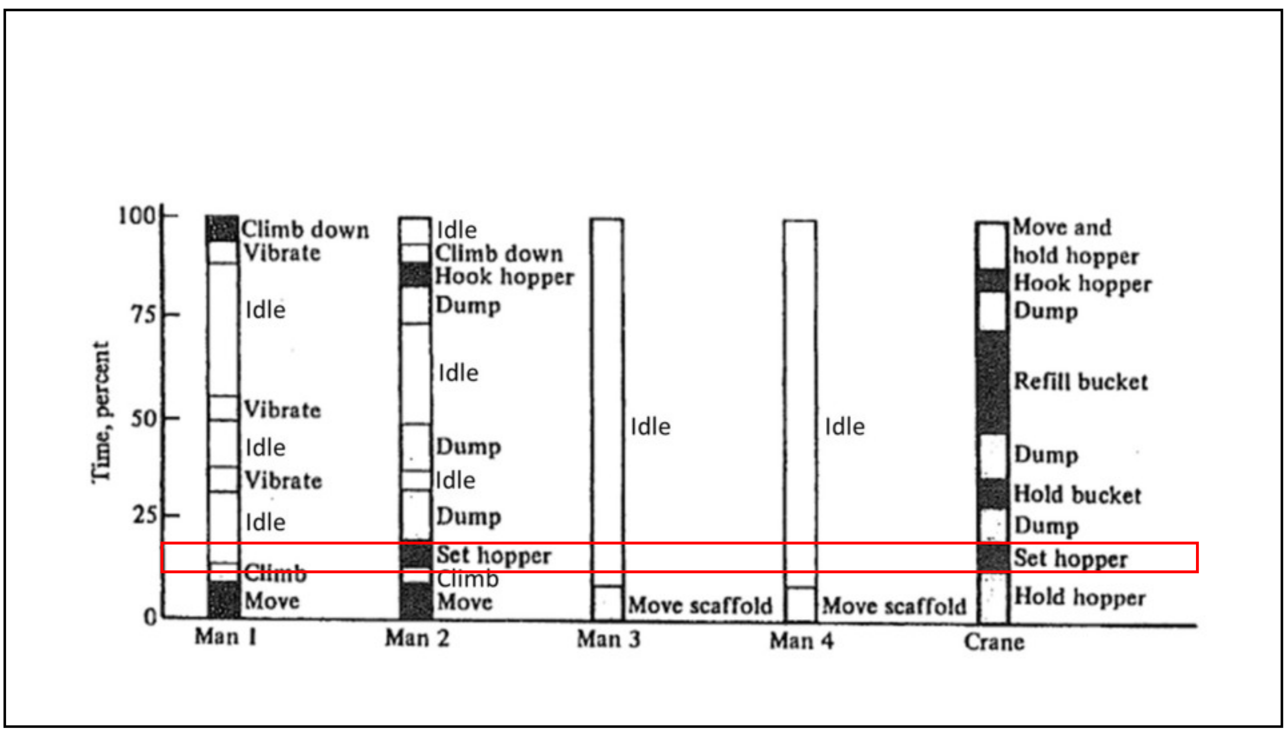
Man 1
Climb down
Vibrate
Idle
Vibrate
Idle
Vibrate
Idle
Climb
Move
Man 2
Idle
Climb down
Hook hopper
Dump
Idle
Dump
Idle
Dump
Set hopper
Climb
Move
Man 3
Idle
Move scaffold
Man 4
Idle
Move scaffold
Crane
Move and
hold hopper
Hook hopper
Dump
Refill bucket
Dump
Hold bucket
Dump
Set hopper
Hold hopper

27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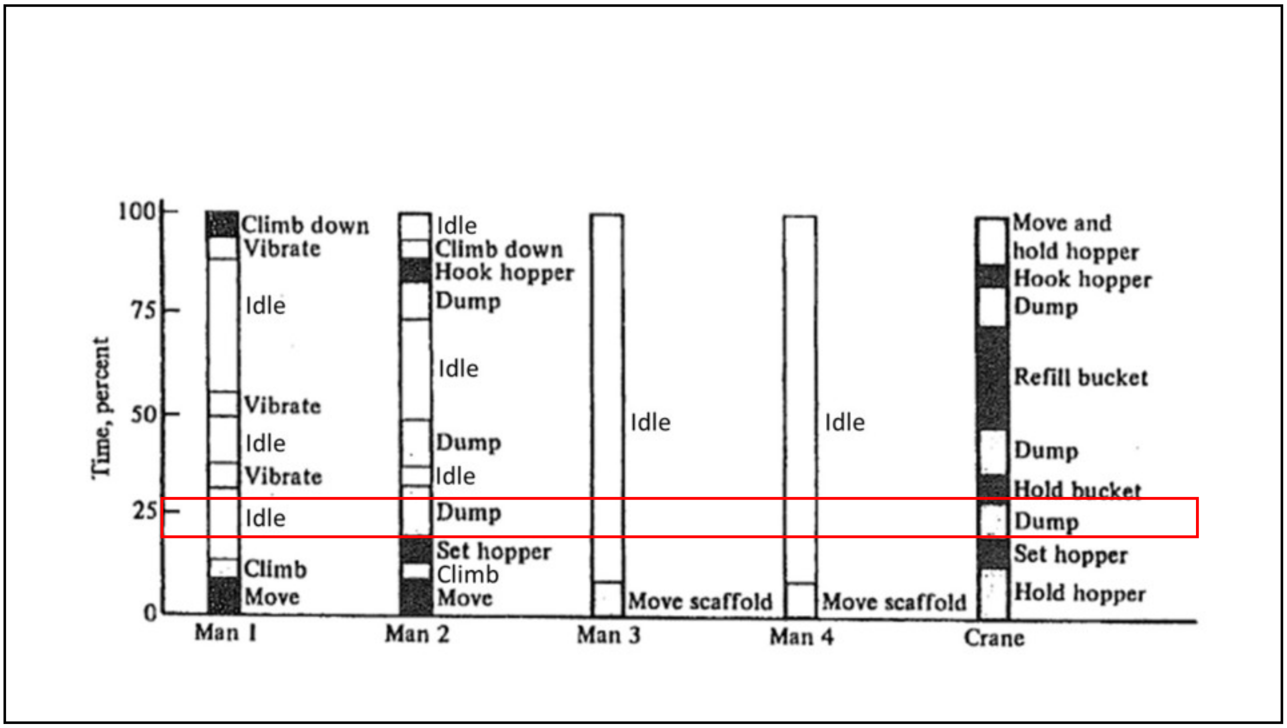
28



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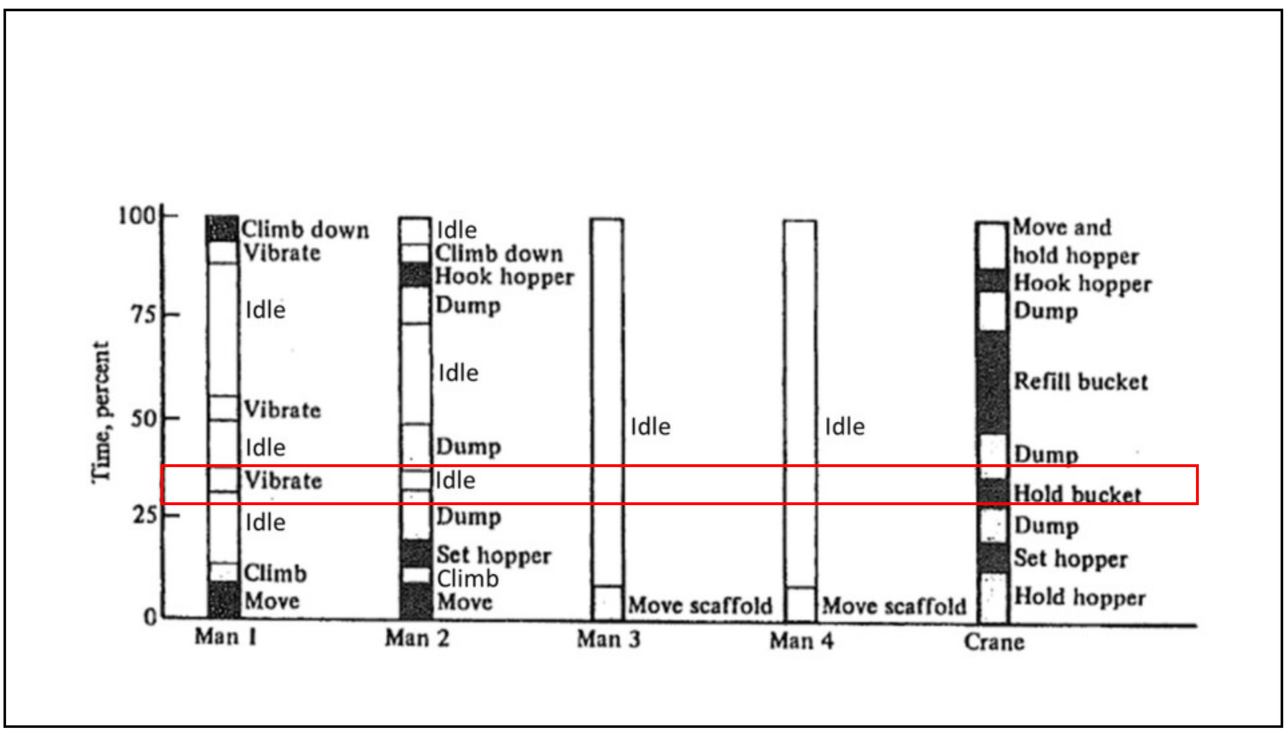
Man 1
Man 2
Man 3
Man 4
Crane

29



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Idle
Move scaffold
Idle
Move scaffold
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hold hopper
Hook hopper
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Refill bucket
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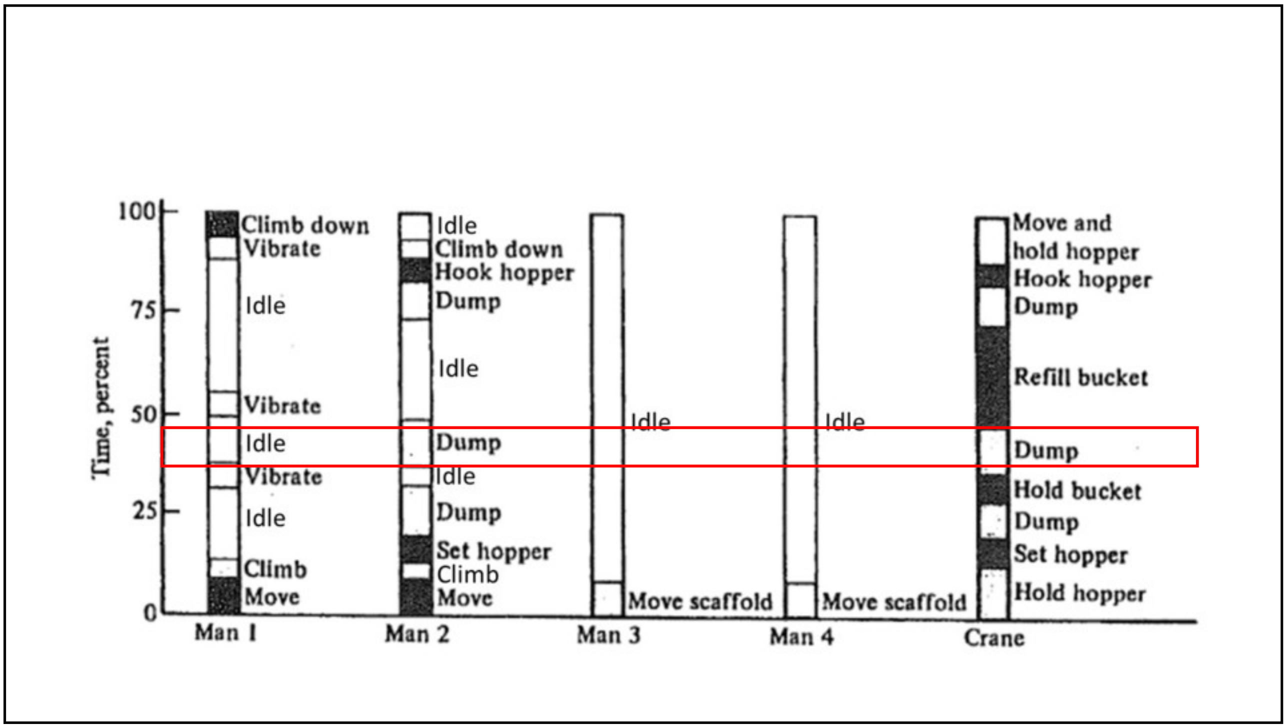
Man 1
Man 2
Man 3
Man 4
Crane

30



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Climb
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Dump
Idle
Dump
Set hopper
Climb
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Move scaffold
Idle
Move scaffold
Move and
hold hopper
Hook hopper
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Refill bucket
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Set hopper
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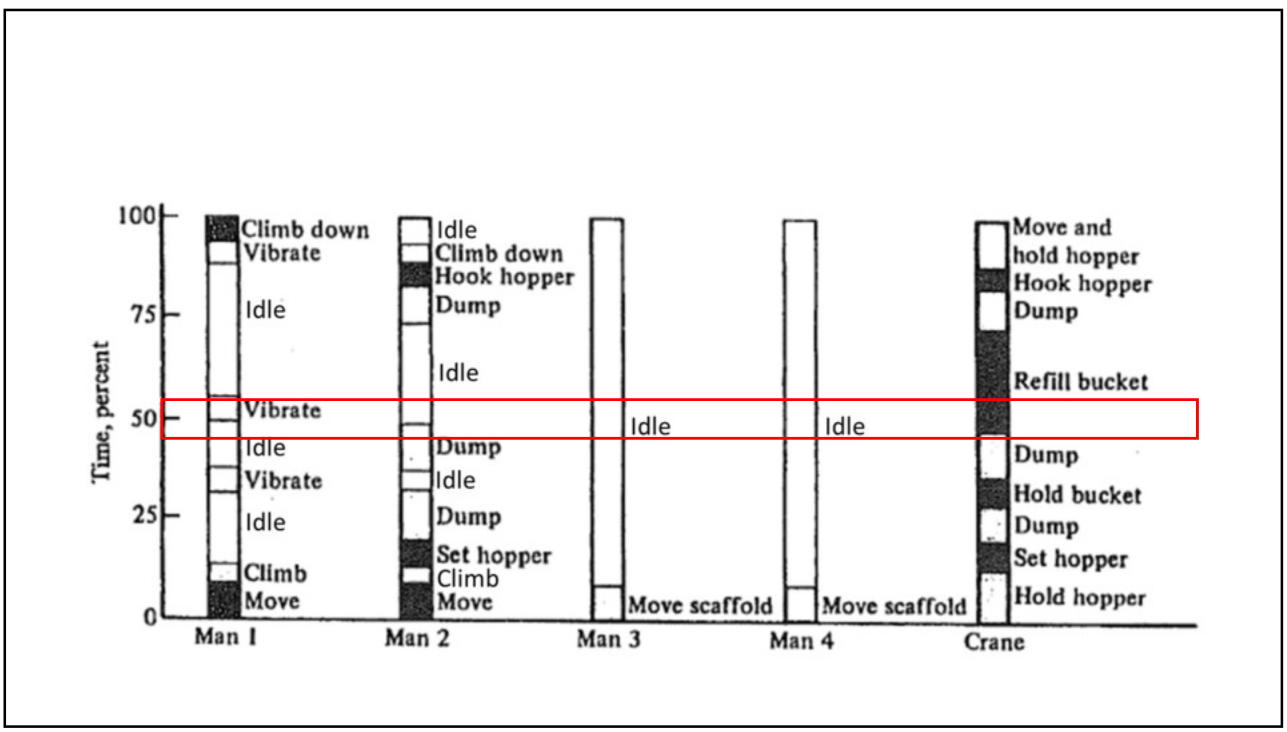
31



Time, percent
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50
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Dump
Idle
Dump
Set hopper
Climb
Move
Idle
Move scaffold
Idle
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Move and
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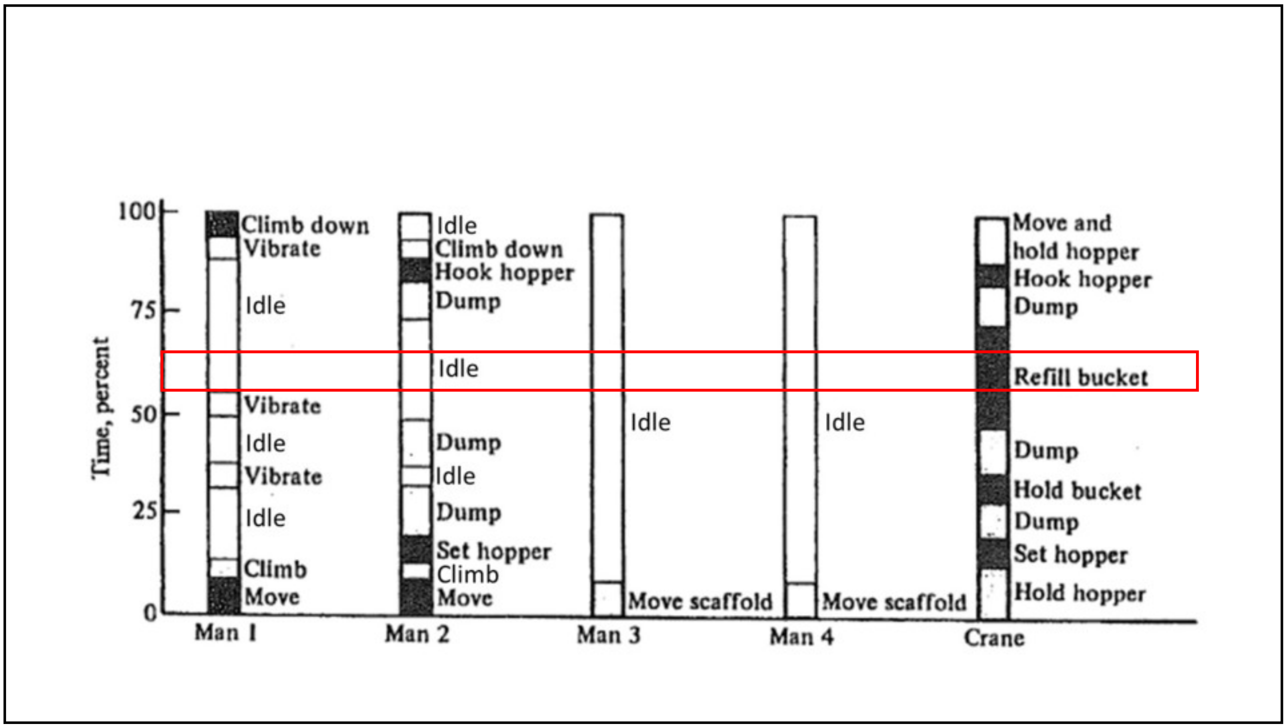
Hold bucket
Dump
Set hopper
Hold hopper

32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Time, percent
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hold hopper
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Refill bucket
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Hold bucket
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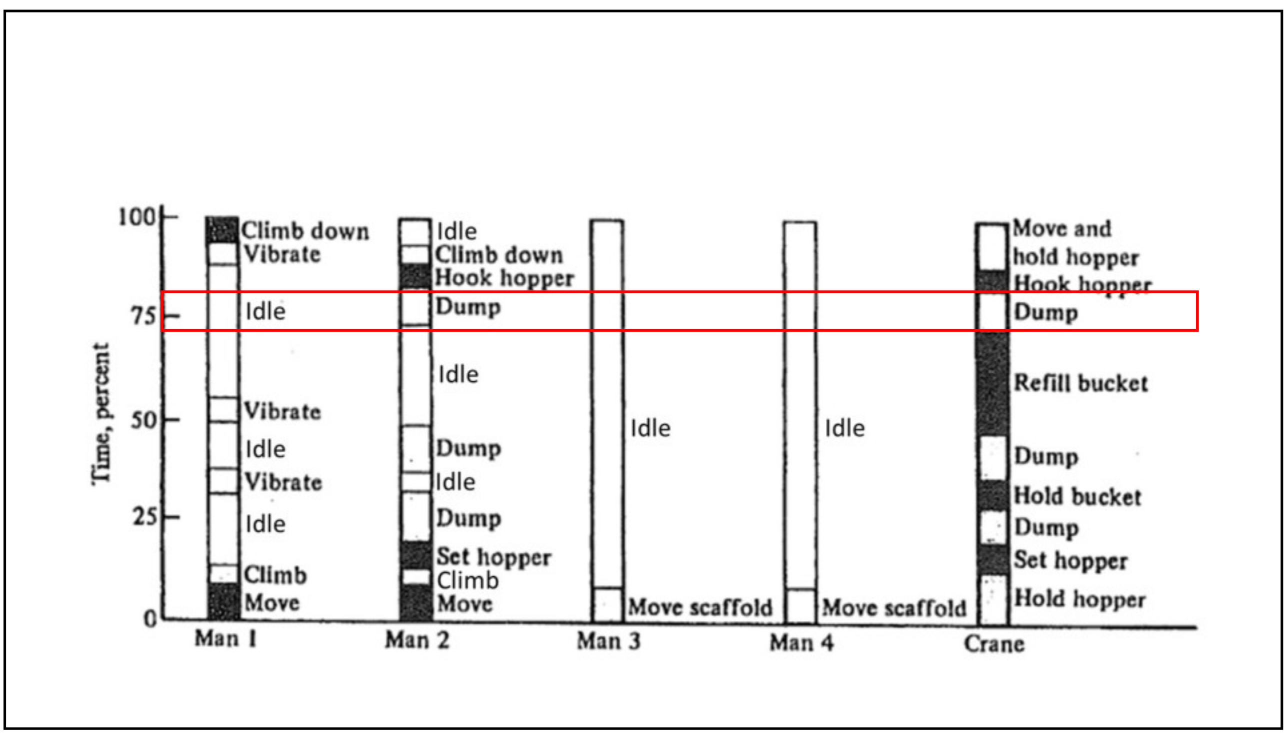
Set hopper
Hold hopper
Man 1
Man 2
Man 3
Man 4
Crane

33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Man 1
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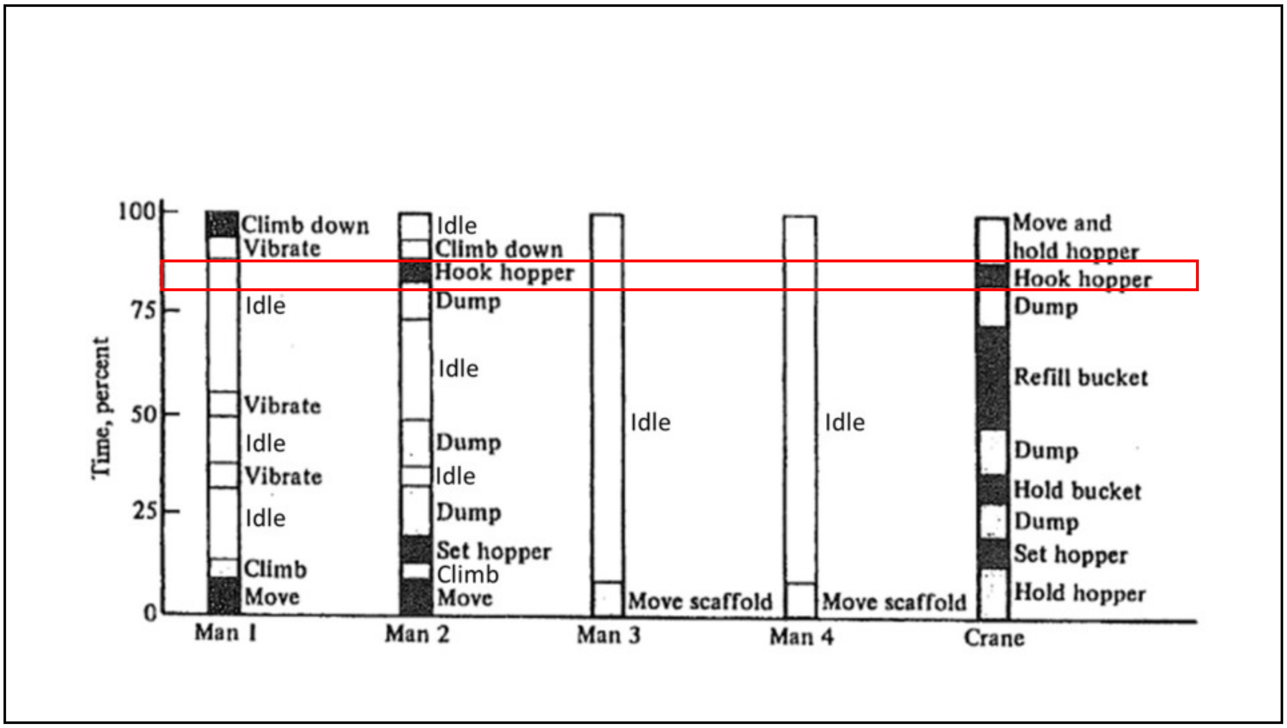
Man 3
Man 4
Crane

34



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Man 1
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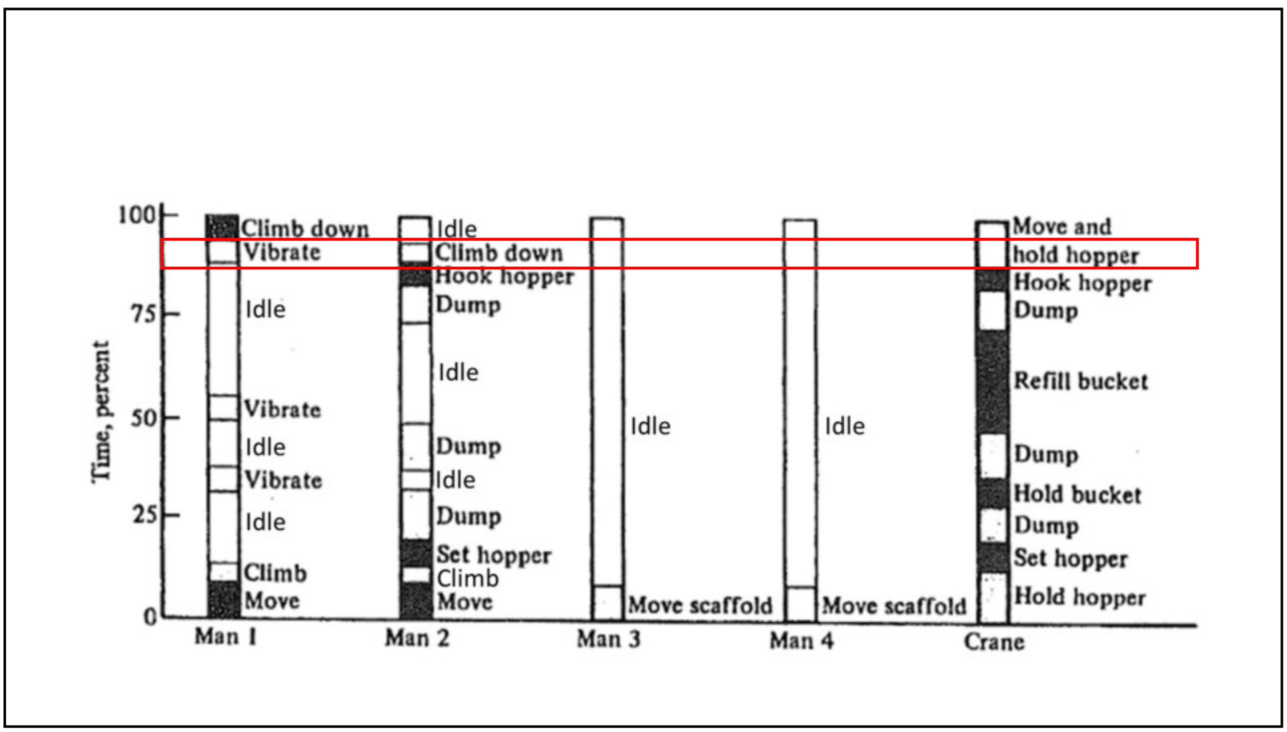
Man 3
Man 4
Crane

35



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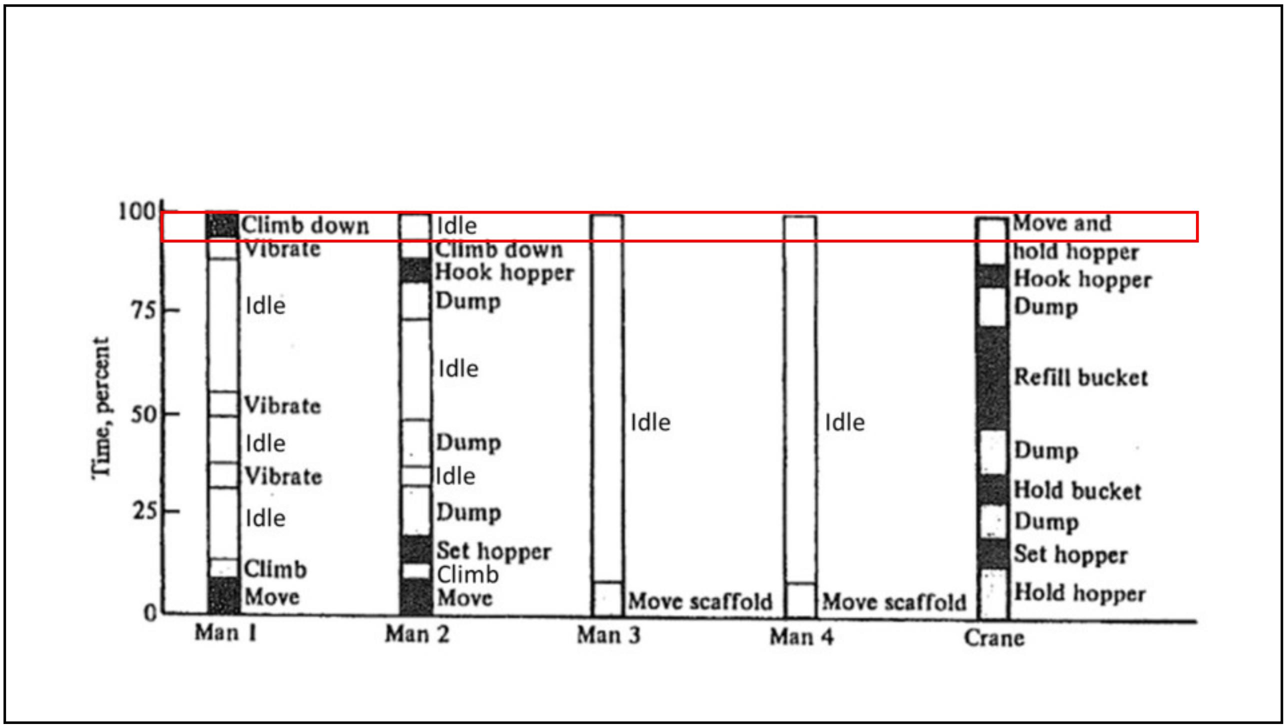
Man 1
Man 2
Man 3
Man 4
Crane

36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Man 1
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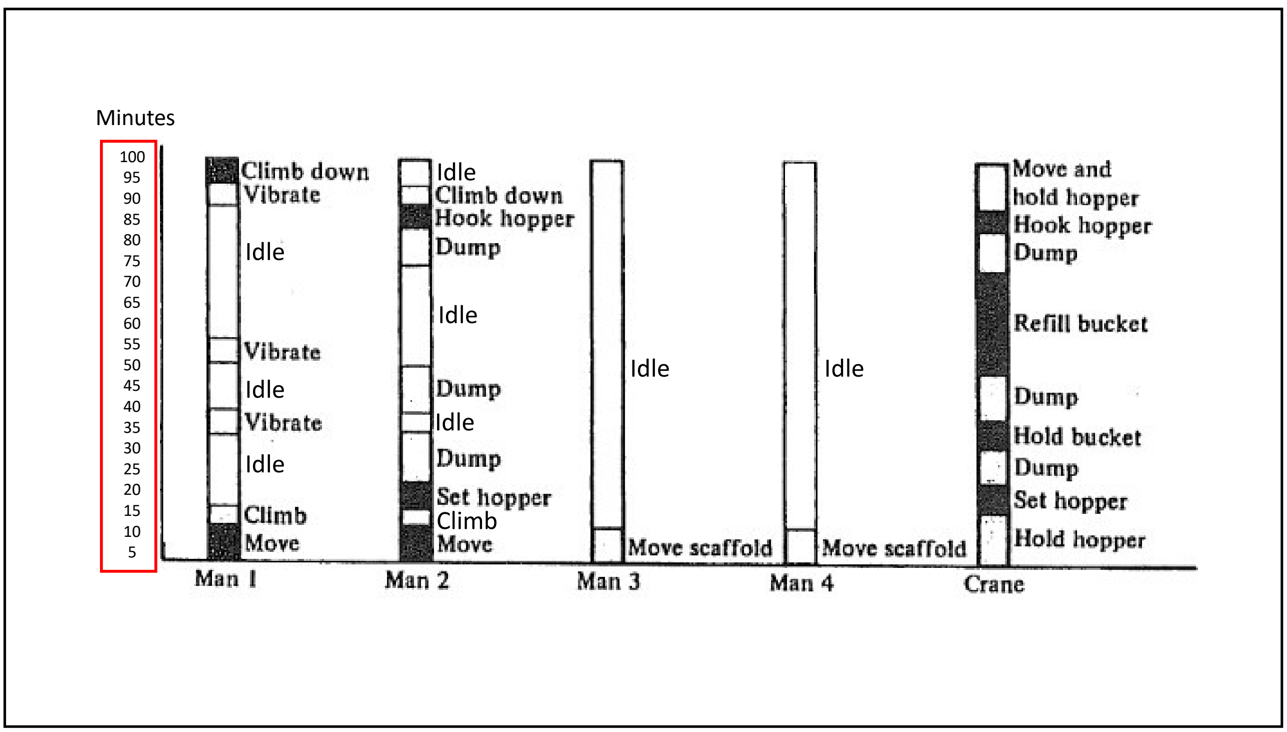
Man 3
Man 4
Crane

37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hold hopper
Hook hopper
Dump
Refill bucket
Dump
Hold bucket
Dump
Set hopper
Hold hopper
Man 1
Man 2
Man 3
Man 4
Crane

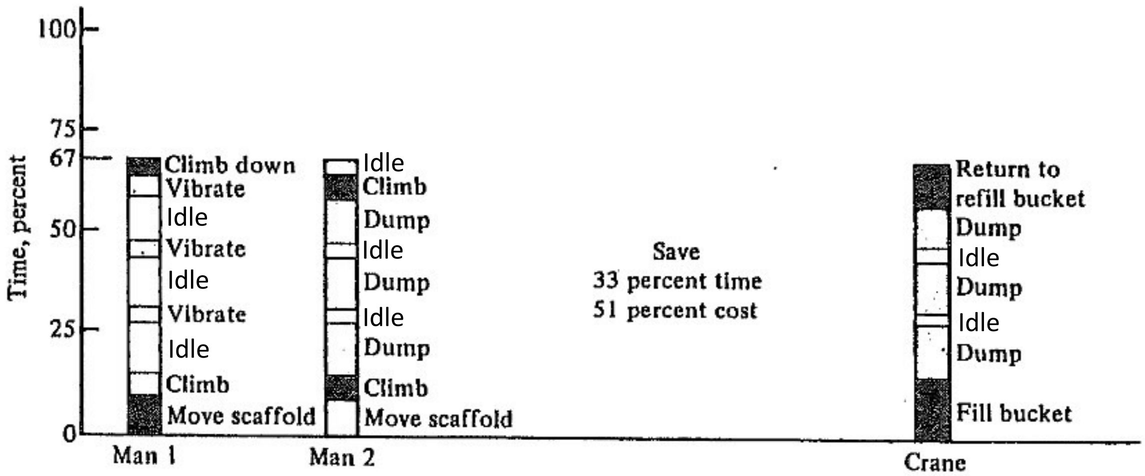
38

- The most obvious change would be to have the two men who place concrete (Man 1 and Man 2) move the scaffold and put Man 3 and Man 4 onto some other task
- This change could result in saving of labor cost but would not improve the effectiveness of the task as a whole, and it might tie up an expensive crane for a longer period of time
- Some might suggest that a ladder rather than a rolling scaffold might be used. This alternative should be ruled out for safety reasons

39

- Another alternative would be to eliminate the waiting period while the crane returns the bucket for refilling with concrete
- Since the crane must hold the bucket while the crew changes columns, the two operations of changing columns and refilling the bucket could be performed concurrently
- A solution to placing concrete from a bucket into a small area is to attach a rubber funnel to the bucket

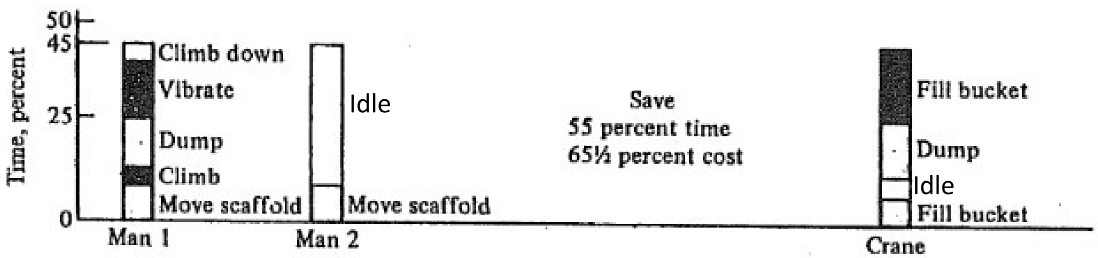
40



41

- A change might be considered relates to placing the concrete in lifts
- This procedure is usually desired to reduce the concrete pressure in the forms
- However, it costs very little more to design column forms to withstand the stresses of a full liquid head of concrete for their full height
- The sequence would then be to place vibrator in the bottom of the column form; completely fill it with concrete; and start the vibrator while slowly withdrawing it

42



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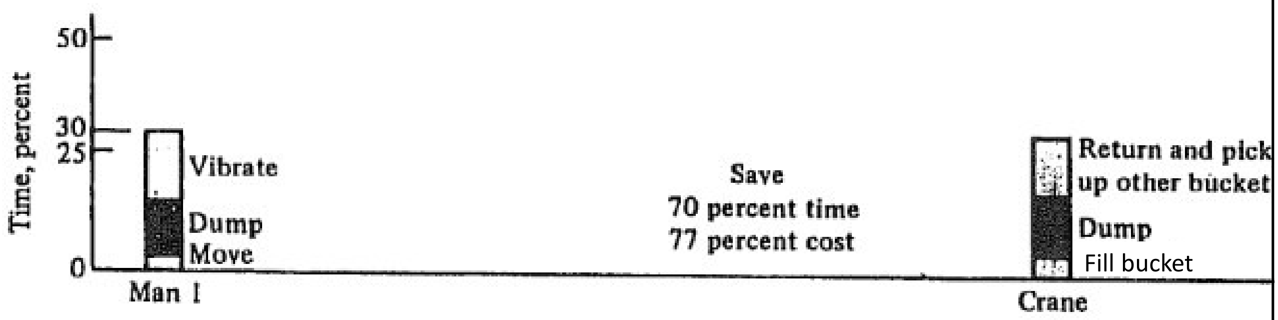
- If concrete placement in the column were to be deferred until after the forms for the floor above were in place, the scaffold would not be required at all
- This also would eliminate the need for the person who mounts, demounts, and moves the scaffold
- However, there are possibilities of concrete spills which would have to cleaned up, interferences with workers carrying out other tasks, and hazards associated with swinging concrete buckets over worker's heads

44



45

Flow Diagrams and Process Charts

- A commonly used graphical aid for the work improvement analyst is the combination of flow diagrams and process charts
- Flow diagrams and process charts help to eliminate excessive or duplicated transportation
- Rearranging the positions of the separate operations can often greatly reduce the need for ineffective movements

46

- The flow diagram is nothing more than a line sketch showing the movements of people or things
- The process chart which accompanies the flow diagram is chronologically arranged listing of the various steps in an operation
- Usually, each item carries a symbol which classifies it in terms of its general nature

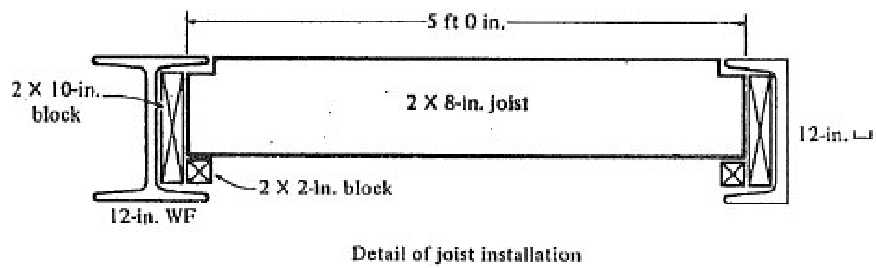
47

- A small circle: something is being done to the item, but only at a single location
- An arrow: the location of the item is being changed
- A square: the item is being checked or inspected
- Half a circle: the item is temporarily stopped, delayed, or otherwise held up
- A triangle: the item is in storage

Symbol	Name	Result
●	Operation	Produces, changes
➡	Transporation	Moves
■	Inspection	Verifies, checks
◗	Delay	Temporary storage, interference
▼	Storage	Keeps

48

• Installing short timber joists between steel floor beams in an industrial building



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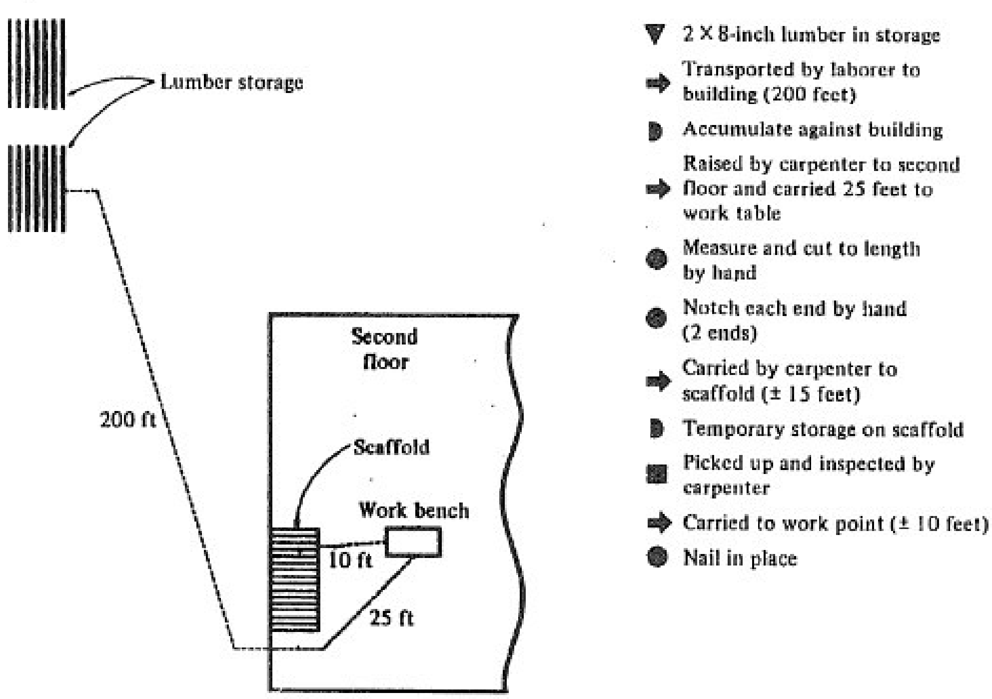

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Construction Methods – 110401542

20. Improving Productivity and Performance

Dr. Mohammad Almashaqbeh
Department of Civil Engineering
Hashemite University

1

Statistical Aspects of Work Sampling

- It is physically impossible to observe and record all the minute details of every repetition of any construction operation
- When gathering data for productivity improvement studies, the aim is rather to have the observations approximate the reality that has been observed – but within acceptable limits
- This is done by sampling
- If it is to be relied, sampling must adhere to certain statistical principles and rules

2

- Sampling, as used for productivity improvement applications, involves observing and classifying a small percentage of some whole to get a representation of that whole
- Sampling can be done by questionnaire, interview, or observation
- With a representative sample large enough to be statistically valid, a given characteristic involving the entire project or a single element of that project can be predicted

3

- This prediction is not exact, but if the sample is representative and large enough, the results are close enough to the real situation to serve as a basis for analysis and possible action
- Fundamental to any sampling effort is the fact that as the number of observations increases, the accuracy of the prediction improves
- However, sampling takes time and costs money
- The desire for accuracy must be balanced against the time and cost of more complete sampling

4

- Confidence interval used to express dependability of the result
- To say that the confidence limit is 95.5% is to say that purely as a matter of chance, the answer can be relied on 95.5% percent of the time
- Following a normal distribution:
  - 68.3% confidence interval = Avg. ± 1 × $\frac{\sigma}{\sqrt{n}}$
  - 95.5% confidence interval = Avg. ± 2 × $\frac{\sigma}{\sqrt{n}}$
  - 99.7% confidence interval = Avg. ± 3 × $\frac{\sigma}{\sqrt{n}}$

5

- $\frac{\sigma}{\sqrt{n}}$ = Standard Error
- σ = Standard Deviation
- n = Total number of observations
- $\sigma = \sqrt{\frac{\sum_{i=1}^{n}(X_i - \overline{X})^2}{n-1}}$
- X_i = Observation or sample
- $\overline{X}$ = Average

6

Example

1. Report the average field rating
2. Calculate the standard deviation and 95.5% confidence interval for this crew, given the following:

Observation	1	2	3
Number of workers on site	20	20	20
Number of workers observed	14	13	13
Number of workers classified as working	7	5	7

Add 10% for foreman and personal time

7

Construction Methods – 110401542

21. Improving Productivity and Performance

Dr. Mohammad Almashaqbeh
Department of Civil Engineering
Hashemite University

1

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Add 10% for foreman and personal time

4

Observation 1	
Number of workers on site	20
Number of workers observed	14
Number of workers classified as working	7
Percentage working	50%
Adjusted field rating index	60%

Observation 2	
Number of workers on site	20
Number of workers observed	13
Number of workers classified as working	5
Percentage working	38.46%
Adjusted field rating index	48.46%

5

Observation 3	
Number of workers on site	20
Number of workers observed	13
Number of workers classified as working	7
Percentage working	53.85%
Adjusted field rating index	63.85%

6

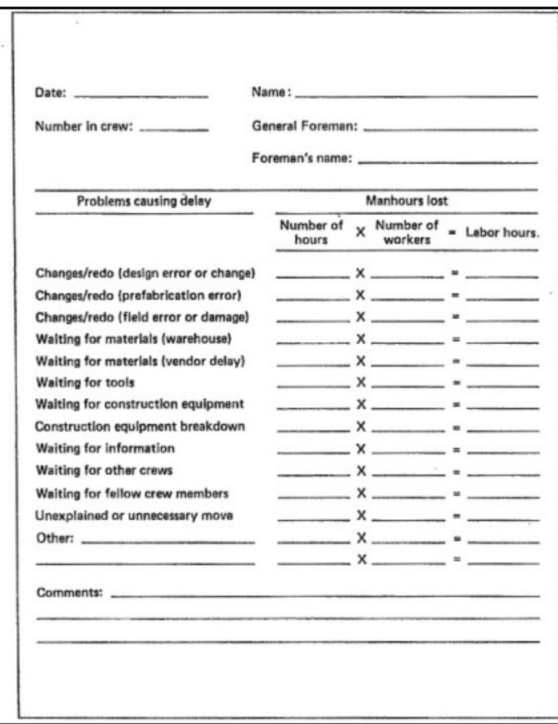
- Average field rating $= 57.44\%$
- $\sigma = \sqrt{\frac{(60\% - 57.44\%)^2 + (48.46\% - 57.44\%)^2 + (63.85\% - 57.44\%)^2}{3-1}}$

  $= 8\%$
- 95.5% confidence interval $= 57.44\% \pm 2 \times \frac{8\%}{\sqrt{3}}$

  $= [48.2\%, 66.68\%]$
- How to explain these results to a foreman?

7

- Foreman's delay survey questionnaire



Date: ______ Name: ______

Number in crew: ______ General Foreman: ______

Foreman's name: ______

Problems causing delay	Manhours lost: Number of hours	X	Number of workers	=	Labor hours
Changes/redo (design error or change)	______	X	______	=	______
Changes/redo (prefabrication error)	______	X	______	=	______
Changes/redo (field error or damage)	______	X	______	=	______
Waiting for materials (warehouse)	______	X	______	=	______
Waiting for materials (vendor delay)	______	X	______	=	______
Waiting for tools	______	X	______	=	______
Waiting for construction equipment	______	X	______	=	______
Construction equipment breakdown	______	X	______	=	______
Waiting for information	______	X	______	=	______
Waiting for other crews	______	X	______	=	______
Waiting for fellow crew members	______	X	______	=	______
Unexplained or unnecessary move	______	X	______	=	______
Other: ______	______	X	______	=	______
______	______	X	______	=	______

Comments: ______

8

Example

- Report the average productivity rating, given the percent of total time in each category for the following crew:

	Observation 1			Observation 2		
Trade	Effective	Contributory	Ineffective	Effective	Contributory	Ineffective
Concrete Laborer 1	60	22	18	50	30	20
Concrete Laborer 2	48	30	22	39	31	30
Crane Operator	70	20	10	38	32	30

9

	Observation 1			Observation 2		
Trade	Effective	Contributory	Ineffective	Effective	Contributory	Ineffective
Concrete Laborer 1	60	22	18	50	30	20
Concrete Laborer 2	48	30	22	39	31	30
Crane Operator	70	20	10	38	32	30
Average	59.33%	24.00%	16.67%	42.33%	31.00%	26.67%
Labor Utilization Factor	65.33%			50.08%		
Average Productivity Rating	57.71%					
Standard Deviation of Productivity Rating	10.78%					

10

Human Factors

- Workers who are fatigued, bored, or hostile will never perform at an optimum level of effectiveness
- Some major human factors to be considered include:
  - Environmental conditions
  - Safety conditions
  - Physical effort requirements
  - Work hours
  - Worker morale and motivation

11

- Worker productivity is seriously reduced by sustained periods of overtime work
- In general, a 40-h workweek appears to be the optimum
- When construction workers are put on a scheduled overtime basis:
  - Productivity usually drops sharply during the first week
  - Recovers somewhat during the following three weeks
  - Continues to decline until it finally levels off after about 9 weeks

12

- When first put on overtime:
  - Total worker production per week is initially higher than for a standard 40-h week
  - However, as productivity continues to decline, the total output for a 50-h or 60-h week falls to that of a 40-h week after about 8 weeks
- When the premium cost of overtime is considered, it is apparent that the labor cost per unit of production will always be higher for overtime work than for normal work

13

- As the length of the overtime period increases, the cost differential becomes sizable
- For example, if the hourly pay rate for overtime work (work beyond 40 h) is 150% of the standard rate, the labor cost per unit of production for a 60-h week after 8 weeks would be more than 80% higher than for a 40-h week

14

- Worker morale and motivation have also been found to be important factors in construction worker productivity
- The most productive projects tended to have the highest number of worker motivators and the lowest number of worker demotivators
- Demotivators:
  - Disrespectful treatment of workers
  - Lack of sense of accomplishment
  - Nonavailability of materials and tools
  - Necessity to redo work
  - Discontinuity in crew makeup

15

- Confusion on the project
- Lack of recognition for accomplishments
- Failure to utilize worker skills
- Incompetent personnel
- Lack of cooperation between crafts
- Overcrowded work areas
- Poor inspection programs
- Inadequate communication between project elements
- Unsafe working conditions
- Workers not involved in decision making

16

- Motivators:
  - Good relations between crafts
  - Good worker orientation programs
  - Good safety programs
  - Enjoyable work
  - Good pay
  - Recognition for accomplishments
  - Well-defined goals
  - Well-planned projects

17

Construction Methods – 110401542

22. Paving and Surface Treatments

Dr. Mohammad Almashaqbeh
Department of Civil Engineering
Hashemite University

1

- Paving and surface treatments are used to provide a roadway wearing surface and protect the underlying material from moisture
- Both concrete and asphalt mixes are used to construct pavements
- Because of their plastic nature, asphalt pavements are often referred to as flexible pavements
- Concrete pavements identified as rigid pavements

2

- Surface treatments:
  - Produced by applying liquid asphalt or some other bituminous material to a roadway surface
  - With or without the addition of aggregate

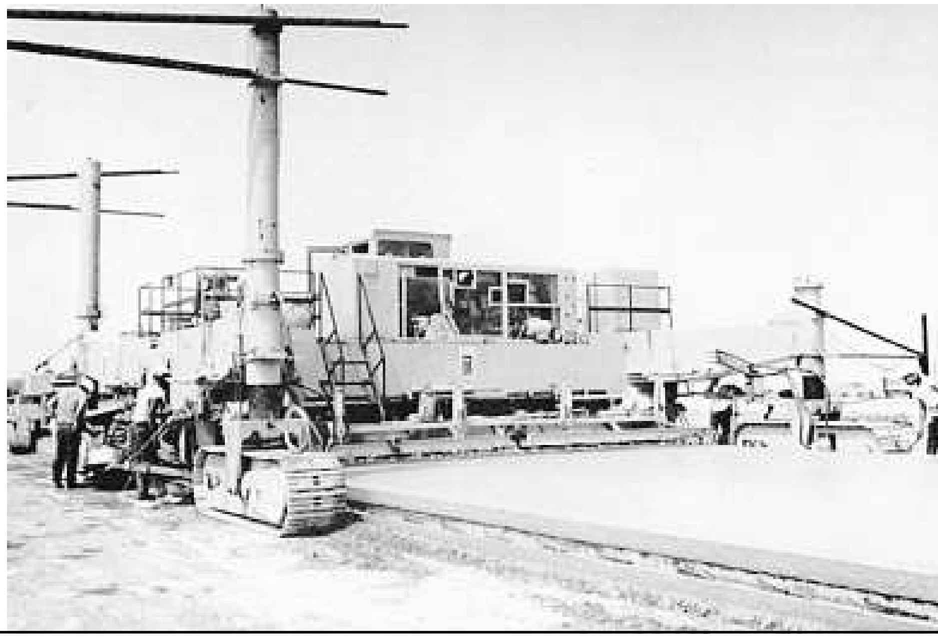
3

Concrete Paving

- Form-riding paver:
  - Paving can be accomplished using metal forms to retain the plastic concrete while it is placed and finished
  - This equipment is designed to ride on the concrete forms
- Slipform paver:
  - Capable of spreading, consolidating, and finishing a concrete slab without the use of conventional forms

4

Large slipform paver in operation



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- Since the paver’s tracks completely span the pavement slab, reinforcing steel may be placed ahead of the paver
- Typical slipform pavers are capable of placing slabs up to 25.4 cm thick and 7.3 m wide at speeds up to 6 m/min

6

- Small slipform pavers are used for pouring curbs and gutters

7

- Some machines are combination of grade trimmers and pavers:
  - Capable of both preparing the subgrade and placing the curb and gutter
- Slipform pavers typical production is about 0.8 km of curb and gutter per day and can reach up to 1.6 km/day

8

- Small slipform pavers are also capable of constructing sidewalks and highway median barriers

9

- Concrete saws equipped with diamond or abrasive blades are often used to cut joints in concrete slabs to control shrinkage cracking
- The depth of control joints should be about one-fourth of the slab thickness, but not less than the maximum size of the aggregate used
- Sawing should be done when the concrete is still green but has hardened sufficiently to produce a clean cut
- This is usually 6 to 30 h after the concrete has been placed

10

Roller Compacted Concrete (RCC)

- First used for the construction of concrete dams
- Its use has spread to pavements and other structures
- The process involves dumping and spreading zero-slump concrete onto a prepared base and then compacting the mixture with vibratory or rubber-tired rollers
- The construction technique has the advantages of speed, economy, and simplicity

11

- In pavement construction, modified asphalt pavers or concrete placer-spreader units can be used to place the RCC in the desired thickness
- Compaction of the RCC should take place as soon as possible but not more than 10 min after placing
- Vibratory rollers are commonly used for primary compaction
- This is often followed by a heavy pneumatic roller to help seal surface cracks and joints
- A light smooth-wheel static roller may be employed for final rolling to provide surface smoothing

12

- The rolling pattern commonly used for RCC is similar to that for asphalt pavements
- However, when an adjacent lane is to be placed before the first lane has hardened, it is suggested that an uncompacted strip about 300 mm wide be left on the adjoining side until the adjacent lane is placed
- After the adjacent lane is placed, the strip and joint between the lanes is compacted

13

Construction Methods – 110401542

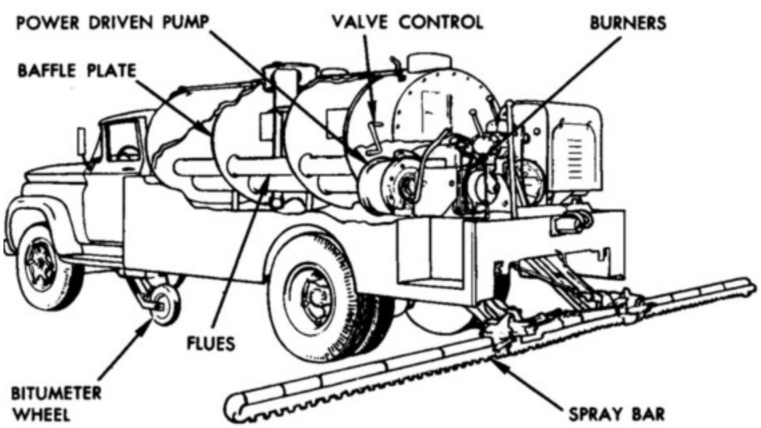
23. Paving and Surface Treatments

Dr. Mohammad Almashaqbeh
Department of Civil Engineering
Hashemite University

1

Asphalt Paving

- The bituminous distributor:
  - The bituminous or asphalt distributor is used to apply liquid bituminous materials
  - It is utilized in almost all types of bituminous construction



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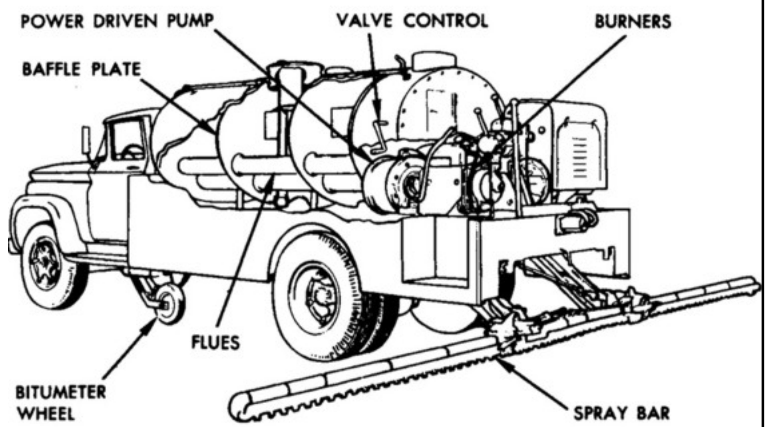
- The rate of liquid bituminous application is expressed in liters per square meter
- The rate at which the bituminous material is applied by a distributor depends on:
  - Spray bar length
  - Travel speed
  - Pump output



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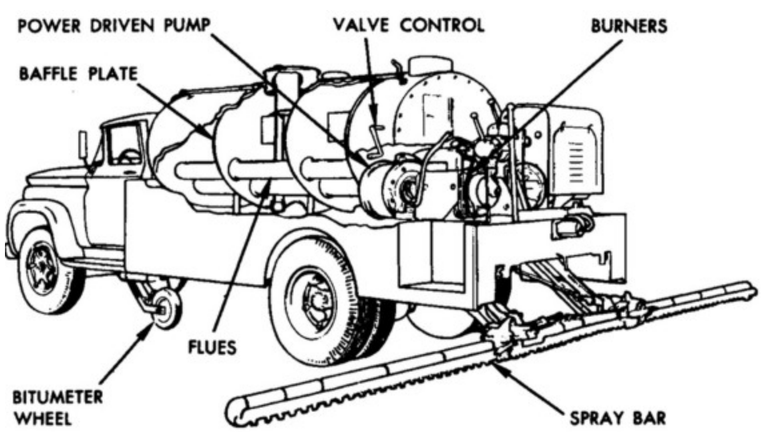
- Travel speed is measured by a bitumeter calibrated in meters per minute
- Pump output is measured by a pump tachometer calibrated in liter per minute



4

- Since standard asphalt volume is measured at a temperature of 15.5° C, a volumetric correction factor must be applied to convert asphalt volume at other temperatures to the standard volume

Table 8–1 Volumetric correction factor for asphalt*

Temperature °F	Temperature °C	To Obtain Standard Volume, Multiply Measured Volume by:
60	16	1.0000
80	27	0.9931
100	38	0.9862
120	49	0.9792
140	60	0.9724
160	71	0.9657
180	82	0.9590
200	93	0.9523
220	104	0.9458
240	116	0.9392
260	127	0.9328
280	138	0.9264
300	149	0.9201
320	160	0.9138
340	171	0.9076

*Specific gravity above 0.966. Applicable to all grades of asphalt cement and liquid asphalt grades 250, 800, and 3000.

5

- For a particular spray bar length, the road speed (bitumeter reading), and pump output (tachometer reading) needed to obtain a specified application rate can be found in the tachometer chart supplied by the distributor manufacturer
- If a tachometer chart is not available, the necessary road speed can be found by using the following equation

$$S = \frac{P}{W \times R} \text{ m/min}$$

6

$$S = \frac{P}{W \times R} \text{ m/min}$$

- Where:
  - S = road speed (m/min)
  - P = pump output (l /min)
  - W = spray bar width (m)
  - R = application rate (l/m^2)

Bituminous Surface Treatments

- Used to:
  - Bond old and new surfaces
  - Seal and restore old pavements
  - Provide a fresh waterproofing and wearing surface
- A wide variety of bituminous surface treatments are available, including prime coats, tack coats, dust palliatives, seal coats, single-pass surface treatments, and multiple-pass surface treatments

- Prime coat:
  - A coating of light bituminous material applied to a porous unpaved surface
  - The purpose of the prime coat is to seal the existing surface and to provide a bond between the existing surface and the new bituminous surface
  - The usual rate of bituminous application varies from 1.1 to 2.3 l/m^2
  - All liquid bituminous should be absorbed within 24 hours and it should cure in about 48 hours

9

- Tack coat:
  - A thin coating of light bituminous material applied to a previously paved surface to act as a bonding agent
  - The usual rate of application is 0.45 l/m^2 or less
  - The tack coat must be allowed to cure to a tacky condition before the new surfacing layer is placed

10

- Dust palliatives:
  - A substance applied to an unpaved surface to reduce the amount of dust produced by vehicular traffic and wind
  - Bituminous dust palliatives are designed to penetrate and bond particles in the unpaved surface and provide some waterproofing

11

- Dust palliatives:
  - Other agents used as dust palliatives include water, acrylic copolymer, pine resin, magnesium chloride, and petroleum resins
  - While water is effective in reducing dust, under very dry conditions it must be applied almost continuously
  - The other agents previously named are usually effective for 30 d or more

12

- Fog seal:
  - A light application of a slow-setting asphalt emulsion diluted by 1 to 3 parts of water
  - It is used to seal small cracks and voids and to restore old asphalt surfaces
  - The usual application rate is 0.4 to 0.9 l/m^2

13

- Emulsion slurry seal:
  - Composed of a mixture of slow-setting asphalt emulsion, fine aggregate, mineral filler, and water

14

- Emulsion slurry seal:
  - Usual mixtures contain by weight 20 to 25% asphalt emulsion, 50 to 65% fine aggregate, 3 to 10% mineral filler, and 10 to 15% water
  - The slurry is placed in a layer 0.6 cm or less in thickness using spreader boxes or slurry seal machines

15

- Sand seal:
  - Composed of a light application of a medium-viscosity liquid asphalt covered with fine aggregate
  - The rate of application varies from 0.45 to 0.68 l/m^2
  - Fine aggregate is applied at a rate of 5.4 to 8.1 kg/m^2

16

Single- and Multiple-Pass Surface Treatments

- Sometimes called aggregate surface treatments
- Made up of alternate applications of asphalt and aggregate
- Used to waterproof a roadway and to provide an improved wearing surface
- Widely used because they require a minimum of time, equipment, and material
- They also lend themselves to stage construction; that is, successive applications are repeated over a period of time to produce a higher level of roadway surface

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Single-pass Surface Treatments

- Constructed by spraying on a layer of asphalt and covering it with a layer of aggregate approximately one stone in depth
- The thickness of the finished surface is approximately equal to the maximum diameter of the aggregate used
- A typical single surface treatment consists of 13 to 16 kg/ m^2 of 1.3 cm or smaller aggregate covering 1.1 to 1.4 l/m^2 of binder
- The type and quantity of binder selected will depend on ambient temperature, aggregate absorbency, and aggregate size

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- The sequence of operations involved in placing a single surface treatment is as follows:
  1. Sweep the existing surface
  2. Apply prime coat and cure, if required
  3. Apply binder at the specified rate
  4. Apply aggregate at the specified rate
  5. Roll the surface
  6. Sweep again to remove loose stone

- Rotary power brooms are most often used for cleaning the existing surface, but blowers or water sprays may be used

- The prime coat and binder are applied with an asphalt distributor
- Spreading of aggregate must follow immediately after binder application
- Binder temperature has been found to drop to ambient surface temperature in about 2 minutes
- Every effort must be made to apply aggregate within 2 minutes after binder application

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- Major types of aggregate spreaders including whirl spreaders, vane spreaders, hopper spreaders, and self-propelled spreaders operate in conjunction with dump trucks
- Spreaders must apply aggregate uniformly and at the specified rate

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- After the application of aggregate, the surface is rolled to embed the aggregate in the binder and to interlock aggregate particles
- Pneumatic or steel wheel rollers may be used for compaction
- Pneumatic rollers are preferred because their contact pressure can be easily varied to prevent aggregate crushing
- After compaction, the surface is again swept to remove loose stone that might cause damage when thrown by fast vehicles

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Multiple-pass surface treatments

- Consist of two or more single surface treatments placed on top of each other
- The construction sequence is the same as single surface treatments except that steps 3 to 5 are repeated as required
- A double surface treatment consists of two binder/aggregate layers, a triple surface treatment consists of three binder/aggregate layers, and so on
- The maximum size of aggregate used in each layer should be about one half the size used in the underlying layer

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Construction Methods – 110401542

24. Paving and Surface Treatments

Dr. Mohammad Almashaqbeh
Department of Civil Engineering
Hashemite University

1

Asphalt Paving

- The principal types of asphalt pavements include:
  - Penetration macadam
  - Pavements constructed from road mixes and plant mixes
- Paving mixes may be either hot mixes or cold mixes
- Hot mixes are used in producing high-type pavements for major highways and airfields
- Cold mixes are employed primarily for roadway patching but may also be used for paving secondary roads

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Penetration Macadam

- Usually classified as a pavement
- Constructed using equipment and procedures very similar to those employed for constructing aggregate surface treatments
- May be used as a base as well as a pavement (wearing surface for a road or base course in the stage construction of a road or an airfield)
- Suitable for use in a remote or small paving area

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- To construct penetration macadam, a single layer of coarse aggregate, which may be 10 cm or more in thickness is placed
- This layer is then compacted and interlocked by rolling with a pneumatic or steel wheel roller
- Binder is then applied followed immediately by an application of an intermediate size aggregate ("key" aggregate)

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- The pavement is then rolled again to compact the key stone and force it into the binder
- Another application of binder and smaller key stone may follow
- The surface is swept after completion of rolling

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- Road mixes or mixed-in-place construction are produced by mixing binder with aggregate directly on the roadway
- This mix is then spread and compacted to form a pavement
- Road mixes may be produced by:
  - Motor graders
  - Rotary mixers
  - Travel plants

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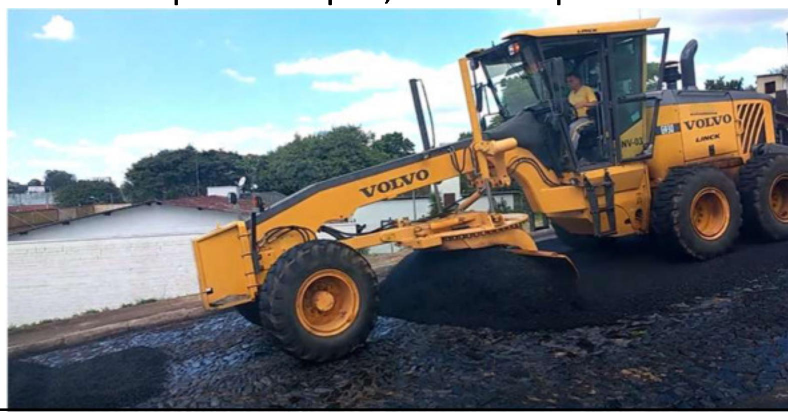
- To produce a road mix using the motor grader, aggregate is spread along the roadway and binder is applied by a distributor
- The materials are then mixed by moving them laterally, spread to the required depth, and compacted



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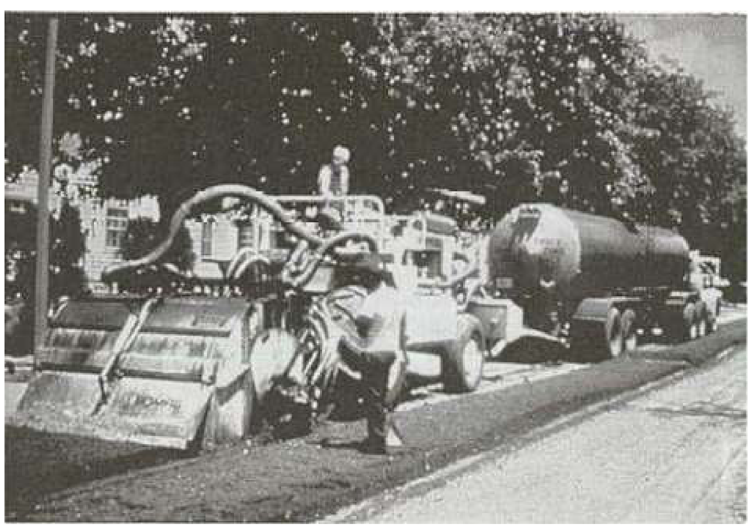
- Rotary mixers use a pulverizing rotor and a spray bar to mix aggregate and binder in one operation



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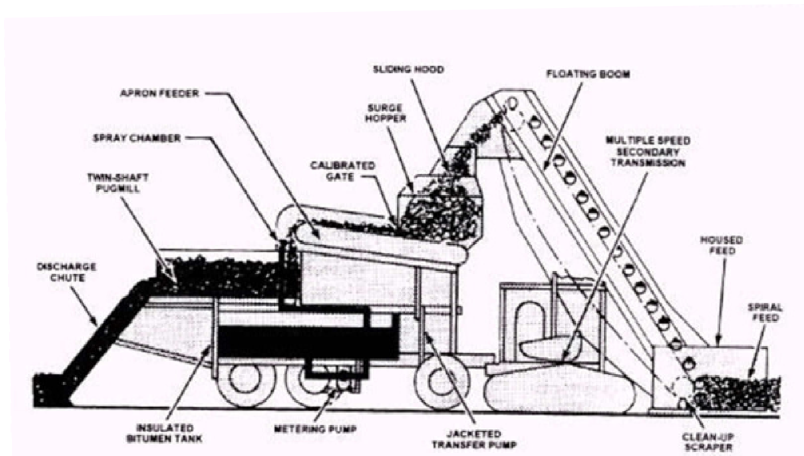
- Travel plants pick up aggregate from a windrow on the roadway, mix it with binder, and deposit the mix back on the roadway or into a finishing machine



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- Problems often encountered in mixed-in-place construction include:
  - Difficulty in obtaining aggregate moisture control
  - Lack of uniformity in the mix
  - Difficulty in obtaining uniform spreading of the mix
- As a result, the quality of road mixes is generally substantially inferior to that of plant mixes

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Hot- and Cold-Mix Asphalt Paving

- Hot-mix asphalt (HMA) pavement is considered the highest form of asphalt pavement
- It is suitable for use on airport runways, as well as highways and streets
- Since they require no curing, hot-mix asphalt pavements may be put in use as soon as the pavement has cooled to the ambient temperature
- After compaction and cooling, such pavements are very stable and resist damage caused by moisture or frost
- Hot mixes predominate in flexible pavement construction

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- Cold-mix pavements are constructed in generally the same way as are hot-mix pavements
- Cold mixes have certain advantages in that they can be transported long distances, stockpiled if necessary, and used only in the quantity needed
- However, they have the disadvantages of requiring curing, having low initial stability, and being difficult to compact adequately in cold weather

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- Hot-mix paving operations involve:
  - Delivery of the asphalt mix
  - Spreading of the mix
  - Compacting the mix
- Spreading and initial compaction of the mix is accomplished by the asphalt paver or finishing machine

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- In operation, the paver engages the material supply truck, couples the two units together, and pushes the truck as the mix is unloaded and the pavement placed

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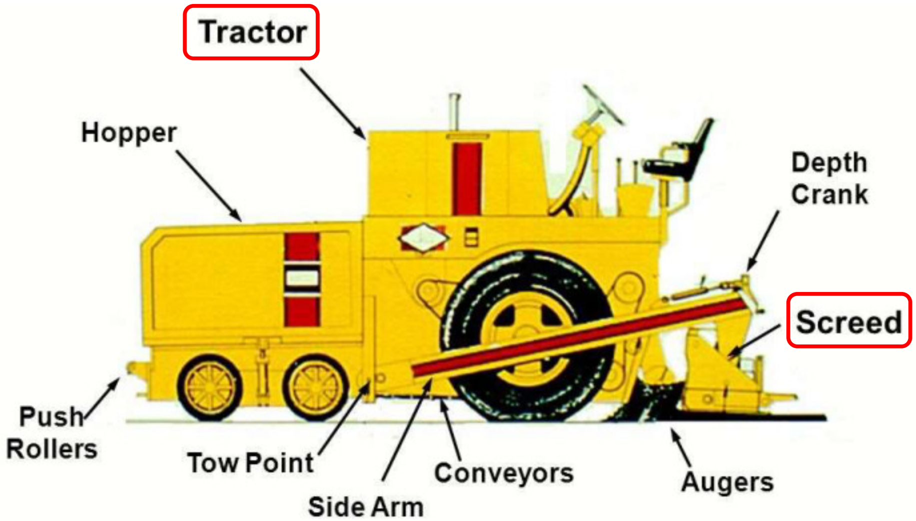
- The two principal parts of an asphalt paver are the tractor unit and the screed unit



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- The tractor unit:
  - Propels the paver
  - Pushes the dump truck delivering the mix
  - Pulls the screed unit
- The screed unit:
  - Strikes off the mix at the proper elevation
  - Provides initial compaction to the mix

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- Pavers can be fed by a material transfer vehicle
- The mobile transfer vehicle serves as a transfer bin, which separates the delivery truck from the paver
- The transfer vehicle permits continuous paving by providing an uninterrupted delivery of mix to the paver

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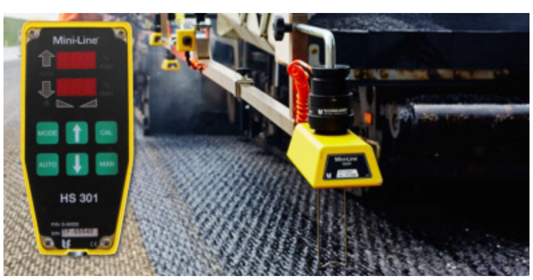
- Most pavers provide an automatic control system which uses a laser, fixed stringline, traveling stringline, or other methods as an elevation reference to automatically control the screed elevation



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- Another type of paver is the shoulder paver
- This is a small paver with a maximum paving width of about 3.1 m
- Used for paving highway shoulders or for widening existing pavements
- Available as attachments for motor graders or self-propelled machines

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- Items to be checked during paver operation include:
    - Grade and tolerance of the finished surface
    - Appearance and temperature of the mix
    - Weight of mix applied per square meter
    - Average thickness of mix actually obtained

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- Hot mix asphalt paving requires large quantities of asphalt mix per hour
- For example, an asphalt paver laying a 76-mm thick pavement 3.6 m wide at a speed of 15.2 m/min requires 544 t/h of hot mix
- Storage, handling, and hauling of the plant mix must be carefully planned and controlled

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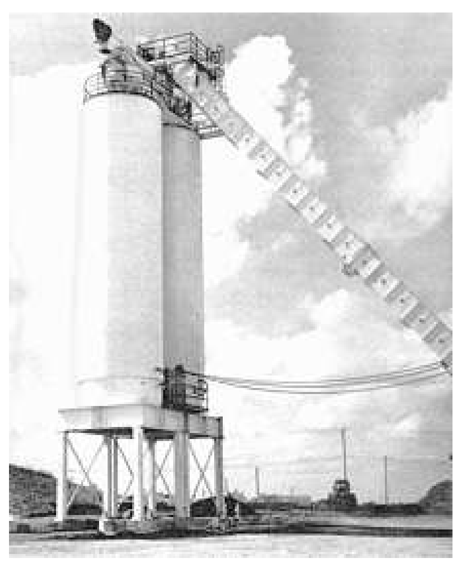
- The use of insulated tanks for storing the hot mix at the job site may be necessary when hauling capacity is limited or uncertain because of traffic conditions or other uncertainties
- Insulated and heated trucks are also available for hot-mix hauling



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- Compacting or rolling of the mix should begin immediately after it is placed by the paver
- The usual sequence of rolling involves:
  - Breakdown rolling
  - Intermediate rolling
  - Final or finish rolling
- Vibratory steel wheel rollers are frequently used for rolling asphalt pavements

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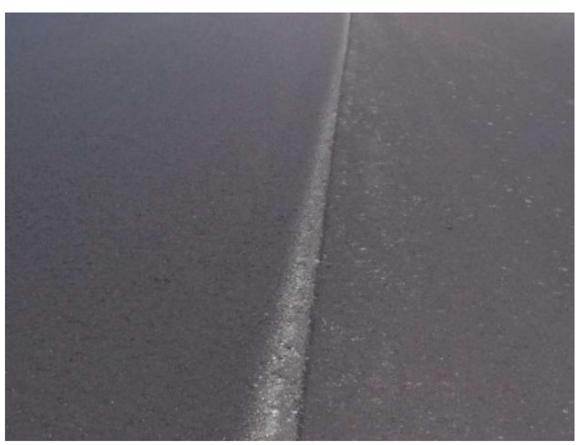
- Joints (transverse and longitudinal interface between two adjacent HMA mats) and the outside pavement edge should be rolled before the remainder of the pavement is rolled



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- Static steel wheel or vibratory rollers are commonly used for breakdown rolling
- Pneumatic-tired rollers are often used for intermediate rolling because they:
  - Provide a more uniform contact pressure than do steel wheel rollers
  - Improve the amount of surface sealing obtained during rolling

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- Two-axle or three-axle tandem steel wheel rollers are commonly used for finish rolling
- Two drum vibratory rollers are being employed for all phases of rolling

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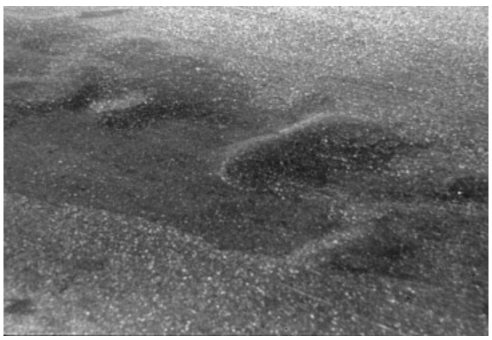
- The temperature of the asphalt mat can be critical with some asphalt mixes
- Rutting or shoving may result from rolling a mix that is too hot, whereas rolling a mix that is too cool may result in ineffective compaction



Shoving

Rutting

27

- It is important to determine whether the required density has been obtained in the compacted pavement
- Rapid measurement of pavement density can be made with a nuclear density device, nonnuclear density gauge, or an equipment-mounted measuring system
- Many of these devices also measure the temperature of the asphalt pavement to ensure that rolling is taking place at the optimum temperature

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- Before rolling operations are begun, carefully check the condition of the rollers
- Items to be checked during rolling include:
  - Adequacy of compaction
  - Surface smoothness
  - Use of proper rolling patterns and procedures
  - Condition of joints and edges

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Superpave

- Superpave is an asphalt pavement design and construction system
- Compared to conventional HMA pavement construction:
  - Employs stiffer asphalt mixes with lower asphalt content
  - Uses smaller and less rounded crushed aggregate
  - Utilizes asphalt optimized for local climatic conditions
- Contractors have experienced problems in achieving the specified compaction of Superpave mixes because of the stiffness of the mix, particularly when employing a polymer-modified binder

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25. Paving and Surface Treatments

Dr. Mohammad Almashaqbeh
Department of Civil Engineering
Hashemite University

1

Pavement Repair and Rehabilitation

- Expansion of the definition of highway construction includes **R**esurfacing, **R**estoration, **R**ehabilitation, and **R**econstruction (4R construction)
- Pavement management systems are used to maintain pavements in satisfactory condition at the lowest possible cost
- Such computer-based systems require continuing data collection and evaluation to permit a timely decision on the maintenance strategy to be employed

2

- Resurfacing involve surface treatments or overlays of asphalt or concrete

3

- Restoration and rehabilitation include any of the work required to return the highway to an acceptable condition
- One rehabilitation technique is the mechanical removal of the upper portion of the pavement by milling followed by a new pavement overlay

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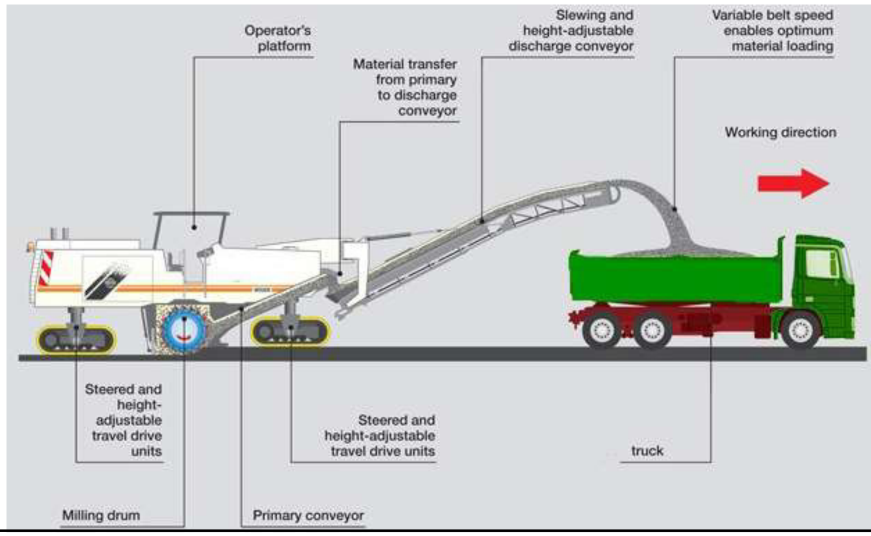
- The material removed is recycled and used as a portion of the aggregate for the new overlay



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- Restoration or rehabilitation may also require that subgrades or base courses be strengthened by soil stabilization or drainage improvements

6

- Reconstruction refers to complete removal of the old pavement structure and construction of a new pavement

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- Bridge management systems are developed to improve bridge life and lower costs by optimum bridge maintenance
- Bridge decks often require resurfacing or reconstruction as a result of the corrosion of the concrete reinforcing steel due to salt penetration into the concrete

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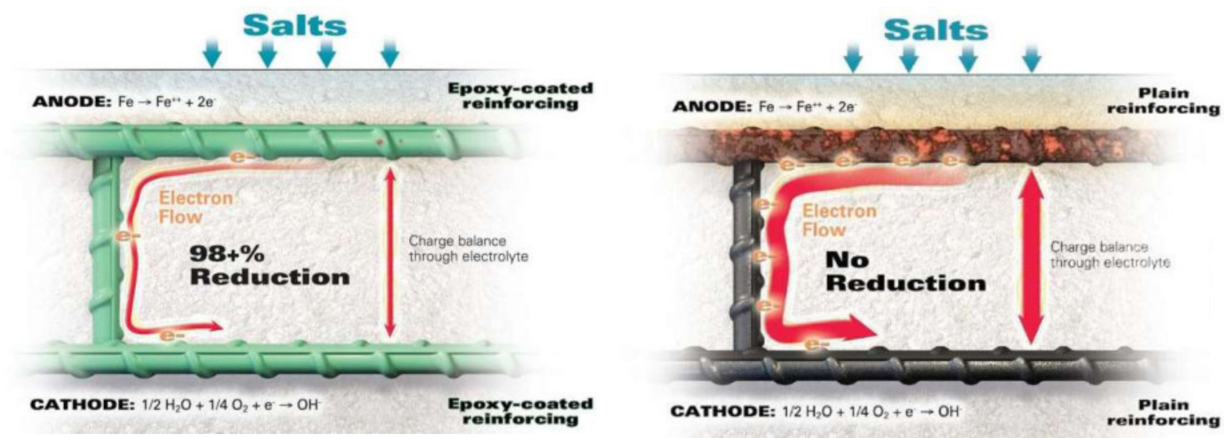
- Epoxy-coated reinforcing steel, chemical sealing of the pavement surface, and chemical additives in the concrete mix are used to reduce deterioration of bridge decks



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- The need to repair concrete highway pavements usually requires the closure of one or more traffic lanes
- The cost of traffic delays often exceeds the actual cost of repair
- Increased interest is being paid to the use of rapid-hardening materials (rapid hardening concrete) which permit the pavement to be reopened to traffic within a few hours instead of several days

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Recycling of Pavements

- Recycling consists of:
  - Demolition of old pavement
  - Recrushing of the pavement material
  - Reusing it in new asphalt or concrete mixes
- Recycling reduces cost, demand for new aggregate sources, problems associated with disposal of the old material

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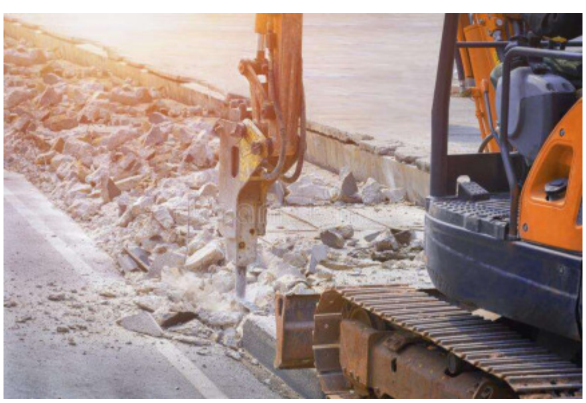
- Old concrete pavements are commonly broken up by hydraulic hammers and loaded into haul units for transporting to a recycling plant
- Reinforcing steel is removed and the concrete recrushed for reuse as aggregate



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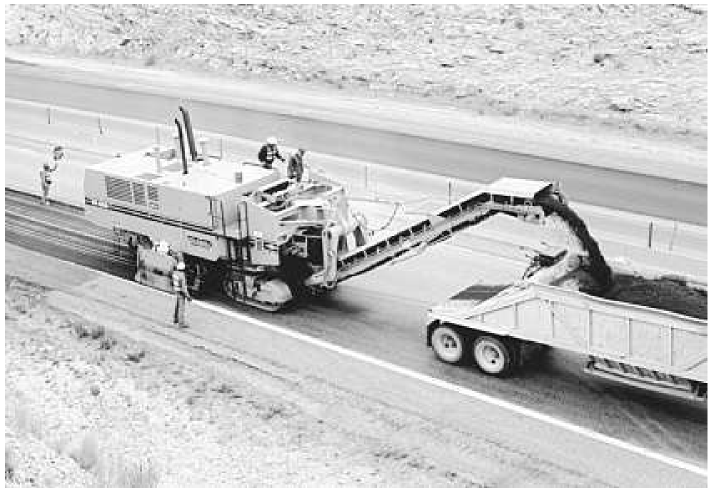
• Asphalt pavements are most often removed by milling and loaded into haul units for processing in a recycling plant



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• Also, a portable recycled asphalt crushing plant can be utilized

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