ARBAMINCH UNIVERSITY WATER TECHNOLOGY INSTITUT

FACULTY OF WATER SUPPLY AND ENVIRONMENTAL ENGINEERING

Course title: CONSTRUCTION EQUIPMENT AND METHODS

Course code: WSEE-2112

Target Groups: 2nd Year Water Supply and Environmental Engineering Students

Instructor; Yohannis Awoke

February, 2020

Course Objectives & Outcomes

Objective;

- ✓ The major objective of this course is to introduce students with different type of construction equipment's which are very important in the site.

Outcome, at students are able to;

- ✓ Select suitable construction equipment's for earth work excavation like conveying and compacting etc.
- ✓ Have skills and knowledge on pile deriving, stone crusher, aggregate production and tunnel construction machinery

- **Course descriptions are given in each chapter**

Teaching & Learning Methods

- Lectures, home study and lab. Exercise

Assessment

- Continuous assessment= 50%
  - ✓ assignments,
  - ✓ laboratory report and
  - ✓ quiz
- Final exam 50%

CHAPTER-1
CONSTRUCTION EQUIPMENTS

CONTENTS

- ***Introduction***
  - *General*
  - *Classification of Equipments*
- ***Earth Work***
  - *Excavation, soil characteristics*
- ***Crane Shovel Family***
  - *Face Shovel, Dragline, Clam shells, Hoes*
- ***Heavy Earth moving Equipments***
  - *Excavators, Loaders, Dozers, Scrapers*
- ***Grading Equipment***
  - *Graders*

Construction Equipments

1. Introduction

- Today contractors undertake many types of construction activities that require different ***types***, ***sizes***, and ***groupings*** of equipment for purpose of ***earth moving***, ***excavating***, ***lifting, transporting,*** and ***compacting***.
- There is a piece of equipment for practically any work activity, large or small.
- ***Materials***, ***Money***, ***Manpower*** and ***Machineries*** (the ***4 M's***) are usual resources recognized in most situations.
- The dependency and need for heavy construction equipment have grown with the size and complexity of construction projects.
- The development of automated heavy construction equipment for earthmoving, excavating, and lifting occurred in the last two centuries.

Construction Equipments

1. Introduction

- The ***efficient*** and ***effective*** implementation of construction projects requires good management among ***resources***, ***activities*** and ***stakeholders***.
- Equipment types used in a construction project is largely dependent on their :
  - Direct input to unit prices(price per unit of input)
  - Type of work or trades
  - Scope/range of work(work involved in whole project)
  - Mobility
  - System of control and
  - Availability

Construction Equipments

1. Introduction

Classification of Construction Equipments

- construction equipments can classifying be based on whether the construction is a ***heavy*** or ***light*** construction works or services.

  I. ***Heavy***: Road and Hydro Power works, Large Irrigation schemes, Water Supply and Sewage plants and High Rise buildings and often called ***equipment intensive(demanding)***.

  II. ***Light***: Low rise buildings, water supply and sewerage lines, electric and telecommunication lines and small irrigation schemes and called ***labor intensive(demanding)*** services.

Construction Equipments

1. Introduction

Classification of Construction Equipments

- For the purpose of this course two major *classifications of equipments largely based on the type of works* involved are covered.

I. **Construction Equipments**

- ***Earth works equipments:*** Bulldozers, Shovels, Clamshells and Draglines, Loaders, Graders, Scrappers, Rollers, Drills, Grouting pumps, Pile driving and Hammers.
- ***Hauling and Hoisting equipments:*** Tractors, Normal and Dump trucks, Scrapers, Hoists, Conveyors and Cranes.
- ***Compaction and stabilization equipments***- Compactors
- ***Foundation Equipments*** - Pile Driving Equipments
- ***Pumping Equipments*** - Pumps, Hoses/tube, Pipes and Compressors.
- ***Concreting equipment:*** Mixers, Vibrators
- ***Tunnelling equipment***
- ***Drilling and blasting equipment***

Construction Equipments

1. Introduction

Classification of Construction Equipments

II. **Construction Plants Equipments**

- Aggregate production plants,
  - Crushers, Screens, Conveyors/device that transports/,and Feeders/part of machine that accepts or controls the input of material to be processed/.
- Asphalt mixing plant
  - Aggregate Batchers,

  Bitumen Emulsifier, and Mixers.
- Concrete Batching Plants and
  - Feeders, Mixers and Silos/tanks.

CONSTRUCTION EQUIPMENTS

2. Earth Work Equipments

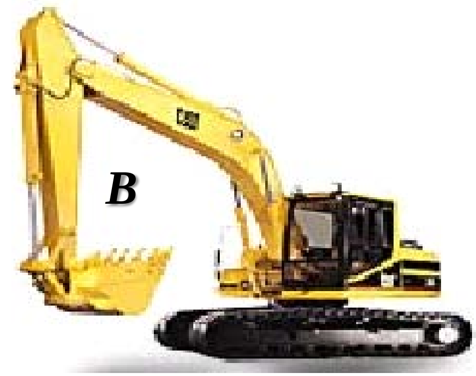
- ***Earth work*** includes:
  - Site preparation, excavation, loading, hauling
  - Embankment construction,
  - Backfilling, dredging
  - Preparing base course,
  - Sub-base and sub-grade,
  - Compaction, road surfacing
- All the above works involve the use of a large number of highly efficient and versatile equipment.
- The proper selection of these equipment and the length of time they will have to be used are an essential part of the estimator's work.
- Earth work equipments are broadly classified into ***earth moving, compaction, grading*** and ***hauling equipment***.

Construction Equipment

2. Earth Work Equipments

- ❑ Excavators
- ❑ Loaders
- ❑ Shovels
- ❑ Clamshells
- ❑ Draglines
- ❑ Scrapers
- ❑ Dumpers
- ❑ Dozers
- ❑ Graders
- ❑ Rollers

A



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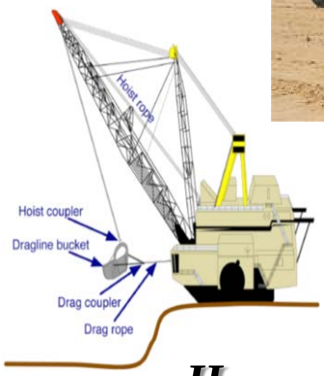

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Construction Equipments

2. Earth Work Equipments

Kinds of Work	Equipments
Clearing	Bulldozer, Rakedozer, Backhoe, Chipper
Excavating	Shovel (Backhoe, Dragline, Clamshell) Bulldozer, Ripper, Rock breaker
Loading	Wheel Loader, Track Loader Loading shovel (Front shovel)
Excavating / Loading	Power shovel (Backhoe, Dragline, Clamshell) BWE(Bucket Wheel Excavator)
Excavating / Hauling	Bulldozer, Scrapedozer, Scraper
Hauling	Dump truck (Rigid, Articulated), Wagon, Conveyer Clowler dump
Spreading / Grading	Bulldozer, Wheel dozer, Motor grader
Compacting.	Tire roller, Steel roller, Vibration roller, Tamping roller, Vibration compactor, Tamper, Bulldozer
Trenching	Trencher, Backhoe
Maintaining macadam road	Motor grader
Slant finishing	Backhoe, Motor grader
Rock Braking	Drill, Breaker, Spliter

Construction Equipments

2. Earth Work Equipments

Excavation Types

- ***Common Excavation***: refers to ordinary earth excavation.
- ***Rock Excavation:*** rock excavation cannot be done by ordinary earth handling equipment.
    - Rock materials must be removed by drilling and blasting or by some other methods.
    - This normally results in a considerably greater expense than earth excavation.
- ***Muck excavation***: includes materials that will decay or produce subsidence in embankments.
    - It is usually a soft organic material having a high water content.

CONSTRUCTION EQUIPMENTS

2. Earth Work Equipments

Excavation Types

- Typically, it would include such things as decaying stumps, roots, logs, and humus.
- These materials are hard to handle and can present special construction problems both at their point of excavation, and in transportation and disposal.

❑ ***Unclassified Excavation:*** refers to the materials that cannot be defined as soil or rock.

- The removal of common excavation will not require the use of explosives, although tractors equipped with rippers may be used to loosen consolidated formations.

Construction Equipments

2. Earth Work Equipments

General Soil Characteristics

- As earth moving equipments are mostly works related to soil, important aspects of soil shall be reviewed.
- From the characteristics of soils ***trafficability***, ***loadability*** and ***volume change*** are vital for earth works. Accordingly,
  - ***Trafficability*** - property that shows the ability of soil to support repeated traffic loading
  - ***Loadability*** - property that tells the ease or difficulty of excavating and loading
  - ***Soil Volume Change*** - property that is related with volumes of soil samples on different stress or compaction levels.

2. Earth Work Equipments

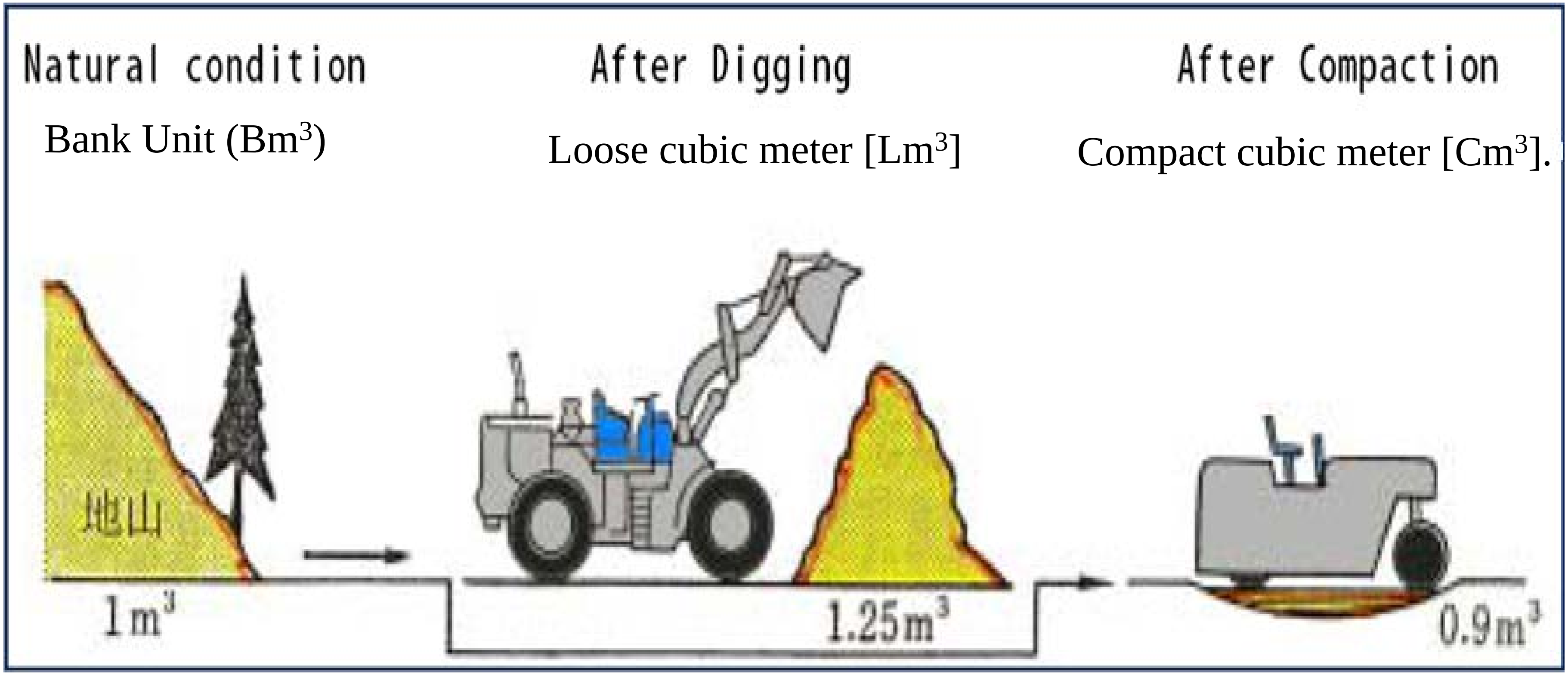
Soil Volume Change Characteristics

- There **are three principal conditions or states in which soil may exist**: ***bank***, ***loose***, and ***compacted***. The meanings of these terms are as follows:
  - ***Bank State*** - This is the state when the material is in its natural state i.e. before disturbance. Often referred to as "in – place'' or "in situ.''
    - Unit - Bank cubic meter [Bm^3]
  - ***Loose State*** - This is the state after the material is excavated or disturbed.
    - Unit - Loose cubic meter [Lm^3]
  - ***Compacted State*** - This is the state after the material is compacted.
    - Unit- Compact cubic meter [Cm^3].

Construction Equipments

2. Earth Work Equipments

Soil Volume Change Characteristics



2. Earth Work Equipments

Soil Volume Change Characteristics

Relationship between the three states

Swell: - an increase in volume of soil due to excavation

$$\text{Swell (\%)} = \frac{\text{Loose Volume} - \text{Bank Volume}}{\text{Bank Volume}} \times 100$$

$$= \frac{V_L - V_B}{V_B} \times 100 = [V_L/V_B - 1] \times 100$$

Since,

$$\gamma = W/V \Longrightarrow \gamma_L = W/V_L \text{ and } \gamma_B = W/V_B$$

$$\text{Swell (\%)} = [V_L/V_B - 1] \times 100$$

$$= \left[\frac{W/\gamma_L}{W/\gamma_B} - 1\right] \times 100 = [\gamma_B/\gamma_L - 1] \times 100$$

Shrinkage: - this is a decrease in volume of soil due to compaction

$$\text{Shrinkage (\%)} = \frac{\text{Bank Volume} - \text{Compacted Volume}}{\text{Bank Volume}} \times 100$$

$$= \frac{V_B - V_C}{V_B} \times 100 = [1 - V_C/V_B] \times 100$$

$$= [1 - \gamma_B/\gamma_C] \times 100$$

2. Earth Work Equipments

Soil Volume Change Characteristics

❑ Load and Shrinkage Factors:

- In performing earthmoving calculations, it is important to convert all material volumes' to common unit of measure.
- Bank cubic meter is most commonly used

Load factor: - is the ratio of bank volume to loose volume.

$$f_{L\ (load\ factor)} = V_B/V_L$$

$$f_L = \frac{1}{1 + swell}$$

Shrinkage factor: - is the ratio of compacted volume to bank volume.

$$f_{s\ (shrinkage\ factor)} = V_C/V_B$$

$$f_s = [\ 1 - shrinkage\ ]$$

Construction Equipments

2. Earth Work Equipments

Soil Volume Change Characteristics

❑ Swell values for different class of earth/soil

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

Construction Equipments

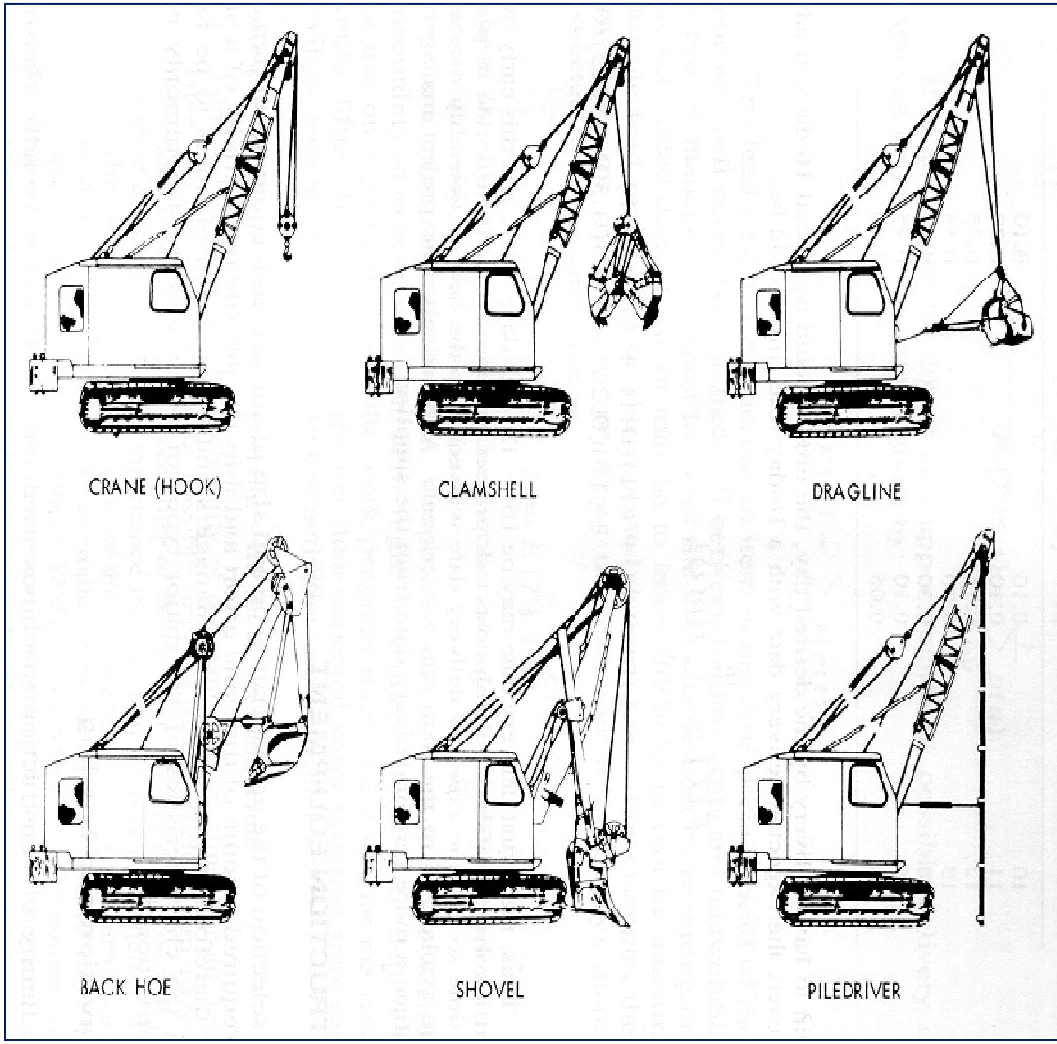
2. Earth Work Equipments

2.1 Crane Shovel Family

❑ Machine evolved a family of Cable-operated construction machines known as crane shovel.

❑ Common Features

- ***Mounting***
  - Crawlers/Tracks
  - Wheels
  - Tracks
- ***Superstructure or control room***
- ***Front end attachment***



2. Earth Work Equipments

2.1 Crane Shovel Family

A. Face Shovel

- Face shovel is equipment used mainly in quarries, pits and on construction sites to excavate and load blasted rock.
- These equipments are more effective for excavations ***above*** the ***wheel or grade level.***
- The basic parts of a power shovel include the mounting, cab, boom, dipper stick, dipper (bucket), and hoist line.
- ***Optimum depth of cut***: is that depth which produces the greatest output and at which the dipper comes up with full load without undue/excess crowding.
  - The depth varies with the class of soil and the size of the dipper.

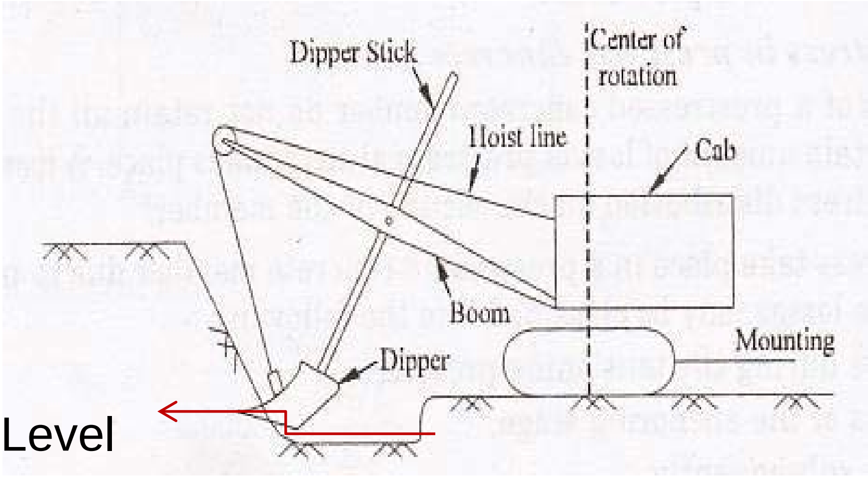
$$\%\ of\ optimum\ \ cut = \frac{Actual\ \ Depth}{Optimum\ \ Depth} \times 100$$

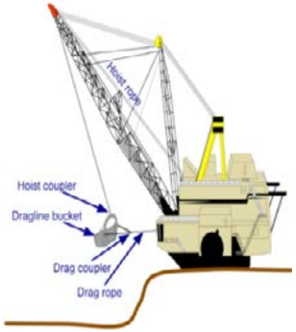
2. Earth Work Equipments

2.1 Crane Shovel Family

A. Face Shovel

- The output of a shovel is affected by numerous factors, including the following:
  - Class of material,
  - depth of cut,
  - angle of swing,
  - job conditions,
  - management conditions,
  - size of hauling units,
  - skill of operator and
  - physical condition of the shovel.



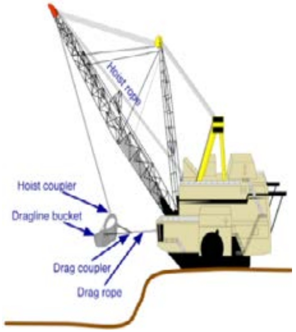


2. Earth Work Equipments

2.1 Crane Shovel Family

B. Dragline

- Draglines are used to *excavate earth and load* it into hauling units, such as trucks or tractors-pulled wagons, or deposit it into levees, dams and spoil banks near the pits from which it was excavated.
- These equipments are more efficient for excavation below the grade level(GL) and have the *longest reach* of all shovel equipments.
- A dragline can be used for dragging out sediments and is efficient for *underwater* construction.
- These equipments are weak while *excavating hard materials* and have a lesser productivity than a face shovels.

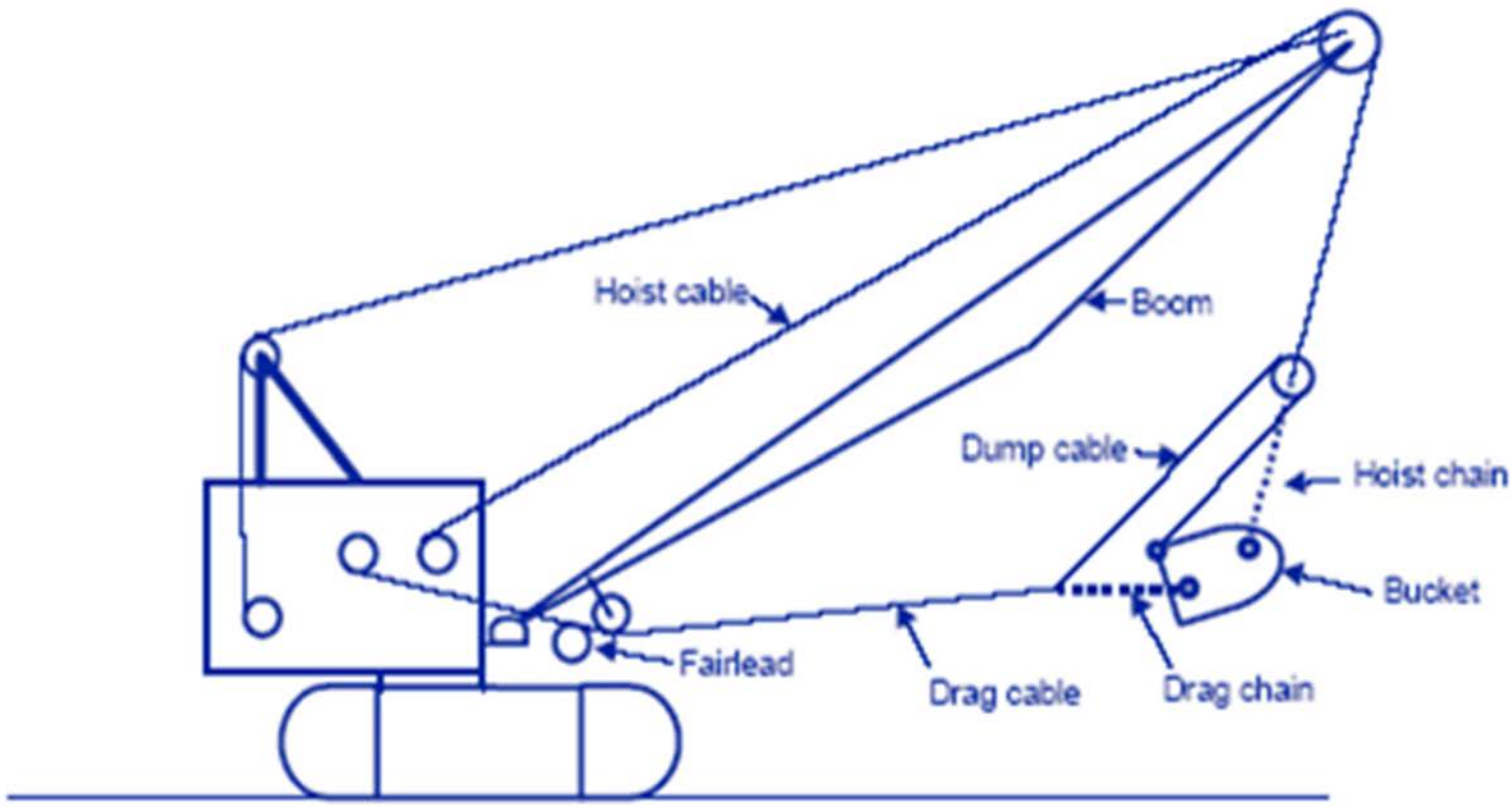


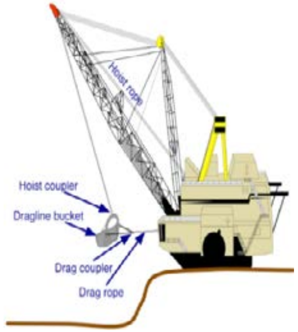
2. Earth Work Equipments

2.1 Crane Shovel Family

B. Dragline

- ❑ Basic Components of a Dragline





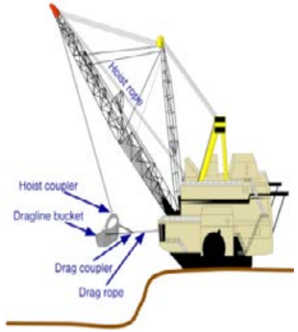
2. Earth Work Equipments

2.1 Crane Shovel Family

B. Dragline

- ***Types of Draglines***: Draglines may be divided into three types:
    - Crawler-mounted
    - Wheel-mounted, self-propelled
    - Truck-mounted
- ***Crawler-mounted draglines*** *can operate* over soft ground conditions that would not support wheel -or truck- mounted equipment.
    - The travel speed of a crawler machine is very slow, frequently less than 1 kmph,
    - It is necessary to use auxiliary, hauling equipment to transport the unit from one job to another.
- ***Wheel-and track-mounted*** units may have travel speeds in excess of 30 kmph.

Construction Equipments



2. Earth Work Equipments

2.1 Crane Shovel Family

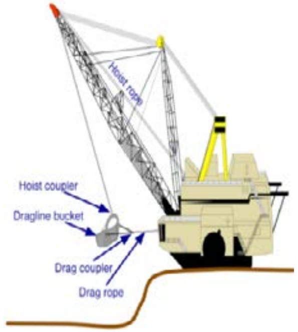
B. Dragline

Size of a Dragline

- The size of a dragline is indicated by the size of the bucket, expressed in cubic meter (cu m).
- Most draglines may handle more than one size bucket, depending on the length of the boom utilized and the class and weight of the material excavated.
- Since the maximum lifting capacity of a dragline is limited by the force which will tilt the machine over, it is necessary to reduce the size of the bucket when a long boom is used or when the excavated material has a high unit weight.

Dragline Bucket

Construction Equipments

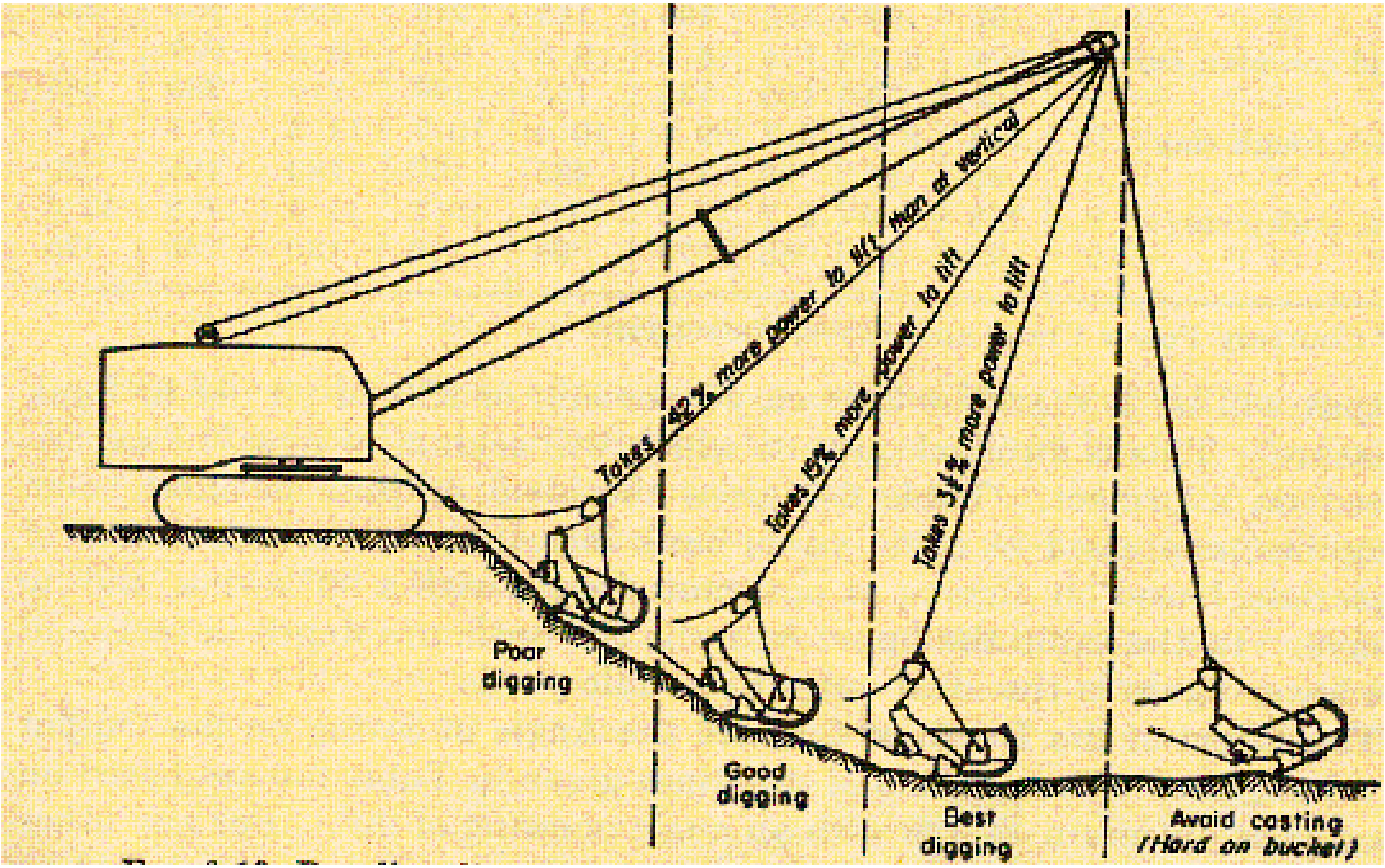


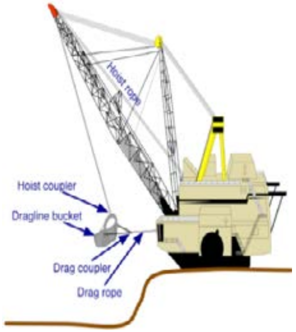
2. Earth Work Equipments

2.1 Crane Shovel Family

B. Dragline

Operation of a Dragline





2. Earth Work Equipments

2.1 Crane Shovel Family

B. Dragline

Output of drug lines

- The output of Draglines will vary with the following factors
  - Class of material
  - Depth of cut
  - Angle of swing
  - Size and type of bucket
  - Length of boom
  - Method of disposal, casting, or loading
  - Size of the hauling units, when used
  - Skill of the operator
  - Physical condition of the machine
  - Job conditions

2. Earth Work Equipments

2.1 Crane Shovel Family

C. Clamshells

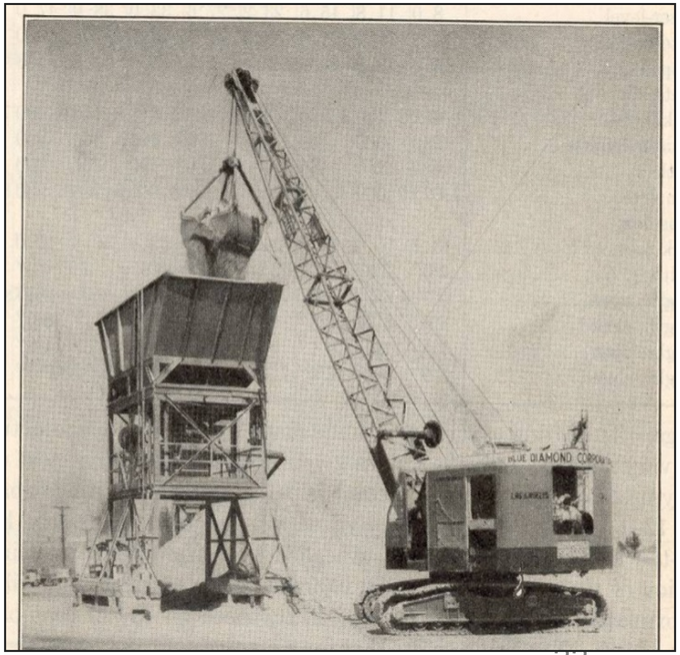
- Clamshells are used primarily for ***handling loose materials*** such as sand, gravel, crushed stone, coal, etc. and for removing materials from inside cofferdams, pier foundations, sewer manholes, sheet-lined trenches, etc.
- They are specially suited to ***vertically lifting materials*** from one location to another, as loading hoppers and overhead bins.
- The limits of vertical movements may be relatively large when they are used with long crane booms.
- Clamshell buckets are available in various sizes, and in ***heavy-duty types*** for digging, ***medium-weight types*** for general-purpose work and ***lightweight types*** for rehandling light materials.

2. Earth Work Equipments

2.1 Crane Shovel Family

C. Clamshells

- Manufacturers supply buckets either ***with removable teeth*** or ***without teeth***.
- Teeth are used in digging the harder types of materials but are not required when a bucket is used for re-handling purposes.



2. Earth Work Equipments

2.1 Crane Shovel Family

C. Clamshells

- The capacity of a clamshell bucket is usually given in cubic meter.
- The variable factors affecting operations include:
    - The difficulty of loading the bucket,
    - The size load obtainable,
    - The height of lift,
    - The angle of swing,
    - The method of disposing of the load, and
    - The experience of the operator.

2. Earth Work Equipments

2.1 Crane Shovel Family

D. Hoes

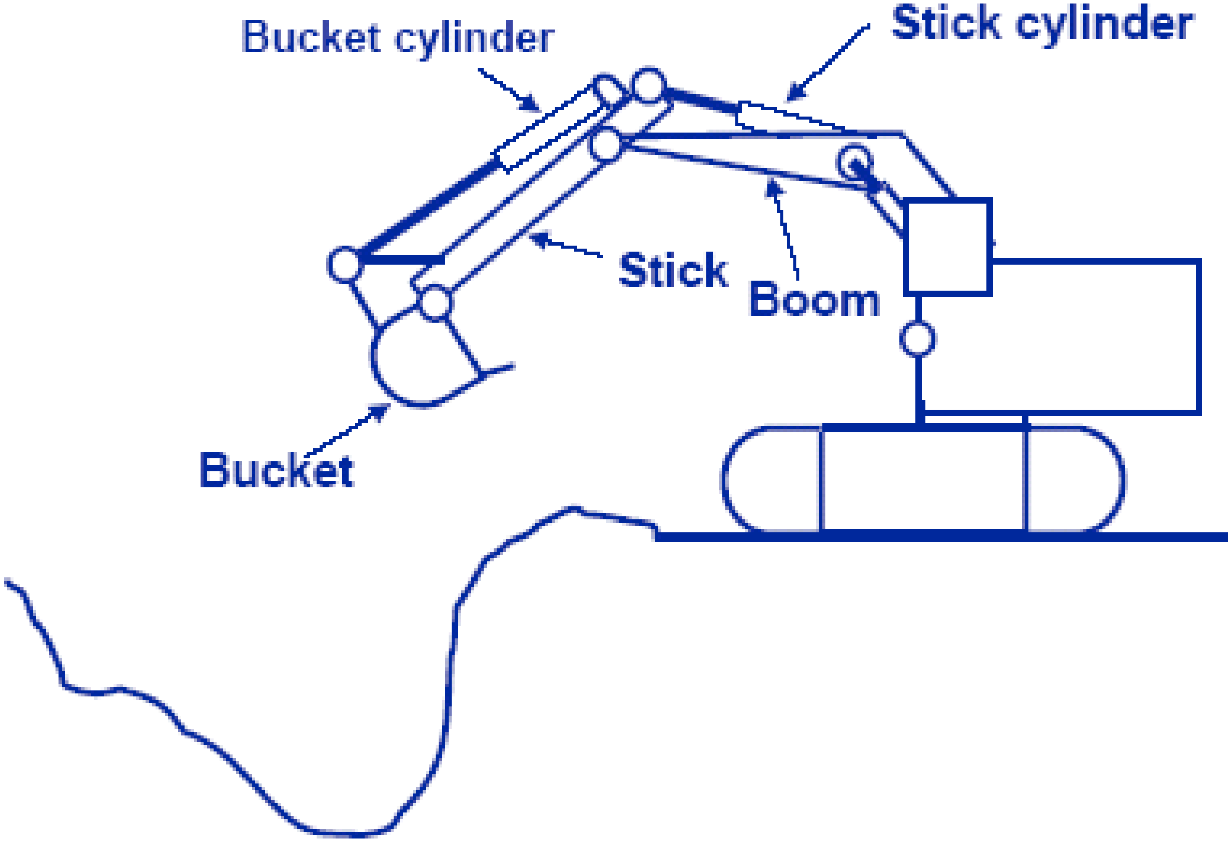
- Hoes are used primarily to excavate below the natural surface of the ground on which the machine rests.
- hoe is sometimes referred to by other names, such as ***backhoe*** or ***back shovel***.
- They are adapted to excavating trenches, pits for basements, and general grading work, which requires precise control of depths.
- Because of their rigidity they are superior to draglines in operating on close-range work and dumping into trucks.
- Because of the direct pull on the bucket, backhoes may exert greater tooth pressures than face shovels.
- In storm drain and utility work the hoe can perform the trench excavation and handle the pipe.

2. Earth Work Equipments

2.1 Crane Shovel Family

D. Hoes

Basic component of backhoes



2. Earth Work Equipments

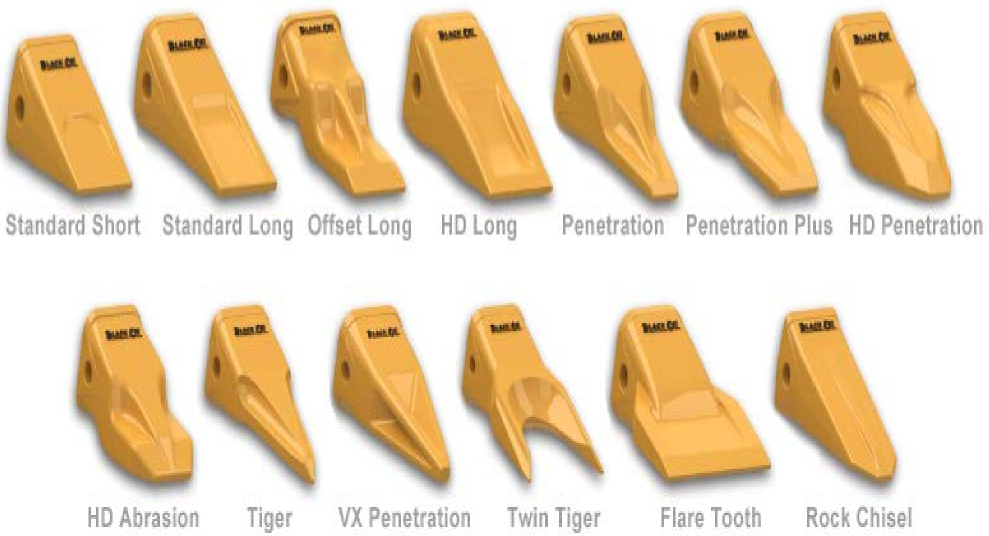
2.1 Crane Shovel Family

D. Hoes

Hoe Buckets

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

Teeth option



Bucket option

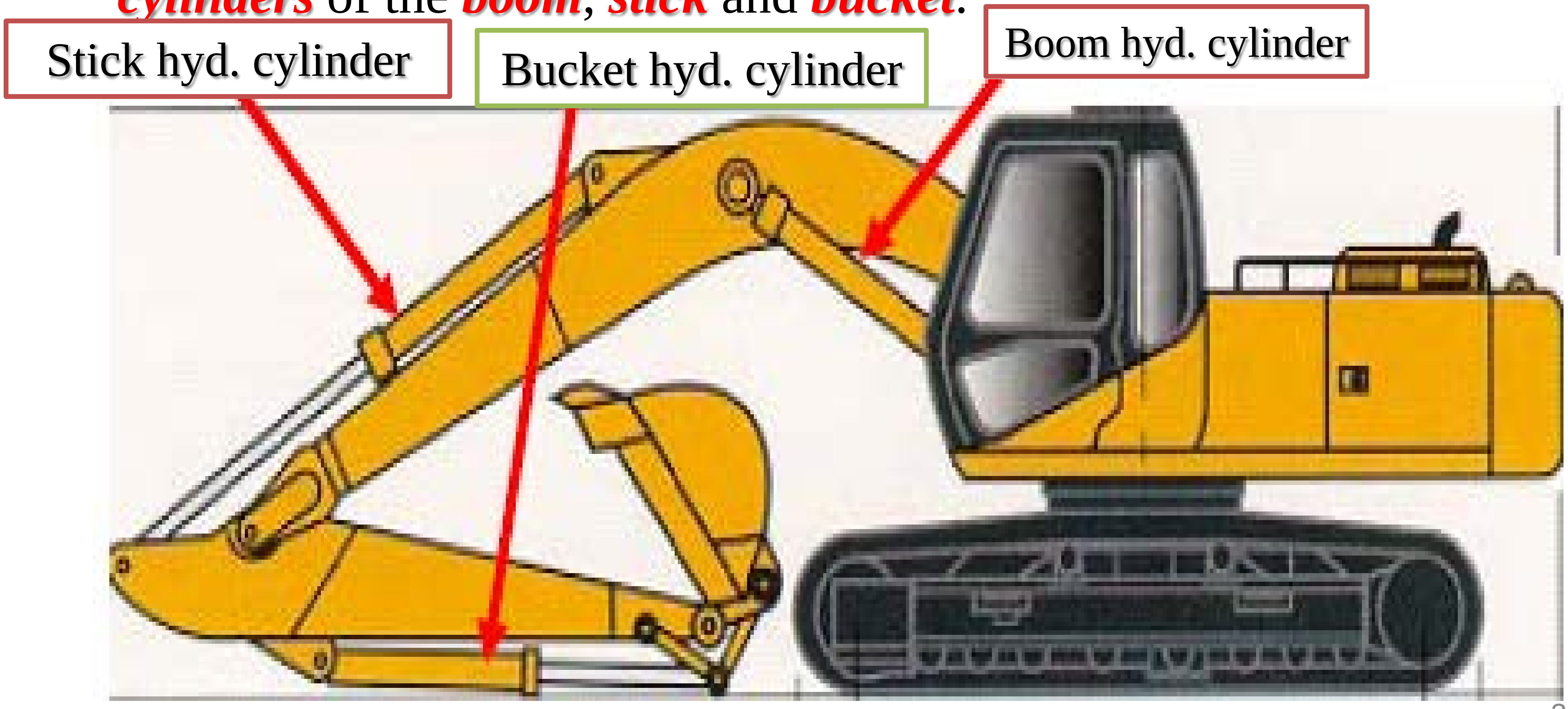
2. Earth Work Equipments

2.1 Crane Shovel Family

D. Hoes

Hydraulic Hoes

- Bucket penetration (break out force) is developed by the ***hydraulic cylinders*** of the ***boom***, ***stick*** and ***bucket***.



2. Earth Work Equipments

2.1 Crane Shovel Family

D. Hoes

Hydraulic Hoe Types

- The hoe can be track or wheel mounted

Construction Equipments

2. Earth Work Equipments

2.1 Crane Shovel Family

D. Hoes

2. Earth Work Equipments

2.1 Crane Shovel Family

Comparison between the shovel family

Comparison between the shovel family members:

No.	Parameters of comparison	Face shovel	Dragline	Backhoe	Clamshell
1	Operation in hard soil or rock	Good	Poor	Good	Good
2	Reach distance b/n machinery and digging point	Small	Longest	Small	Long
3	Loading efficiency on vehicles	Very good	Fair	Fair	Precise but slow
4	Digging Level	Mainly above grade level	Below its grade level	Below its grade level	At, above or below grade level

Construction Equipments

2. Earth Work Equipments

2.2 Heavy Earth moving Equipments

A. Excavators

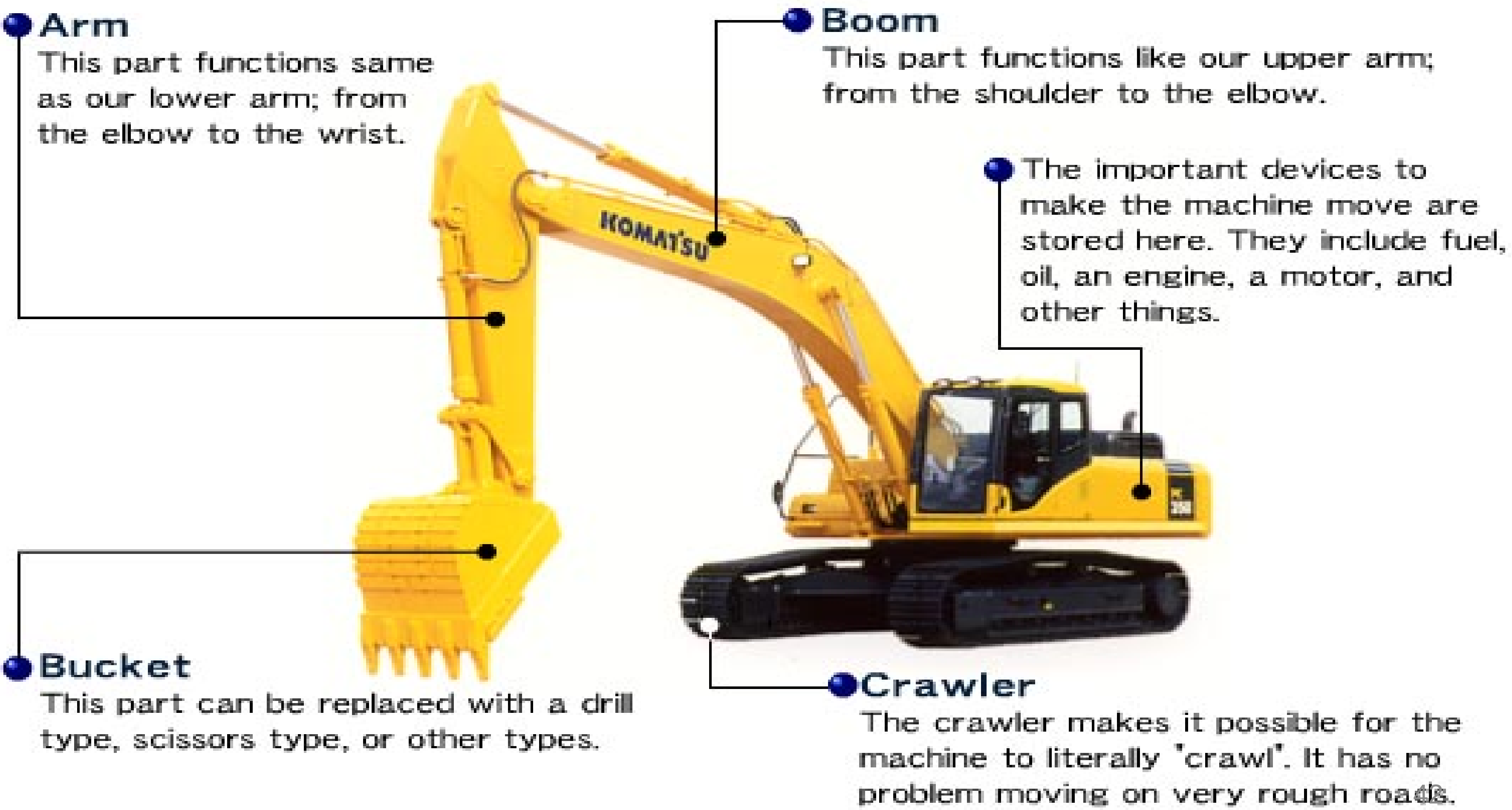
- Replaced the cable operated crane shove family
- Excavators are basically digging machines, having the following three main components
  - An ***undercarriage*** to give mobility. This may be crawler track mounted or wheel mounted.
  - A ***superstructure*** with operator's cabin mounted on either a slew ring/slider/ to traverse through 360° or on a rigid frame.
  - Hydraulically articulated *boom* and ***dipper arms with bucket***.
- Excavators are designed to excavate below the ground surface on which the machine rests.
- Good mobility and versatility and excellent for general-purpose work, such as excavating trenches and pits.

Construction Equipments

2.2 Heavy Earth moving Equipments

A. Excavators

Basic Parts of Excavator



2.2 Heavy Earth moving Equipments

A. Excavators

- Functions of excavators:
  - Excavating – Earthworks
  - Loading Excavated Material
  - Scarification/loosen the surface of soil/
  - Making of Drains
- Advantages of hydraulic excavators include:
  - Faster cycle time,
  - Higher bucket penetrating force,
  - More precise digging, and easier operator control.
  - Many attachments can be made to increase the versatility of the equipments.

2.2 Heavy Earth moving Equipments

A. Excavators

Types of excavators

- Excavators are of the following types based on the type of carriers on which they are mounted:
  - I. Crawler mounted excavator
  - II. Truck mounted excavator
  - III. Self propelled excavator
  - IV. Excavators mounted on barge or rail

I. Crawler mounted excavator:

- These excavators are mounted on the crawler system and are very suitable for carrying out large works in rough terrain.

Construction Equipments

2.2 Heavy Earth moving Equipments

A. Excavators

Types of excavators

I. Crawler mounted excavators:

- Crawler excavators have the following main characteristics;
  - Can be used for work on soft or wet grounds,sharp rocks or other adverse conditions.
  - These can climb steep grades
  - Requires very less turning space
  - Have very less speed for travelling
  - Can be shifted from one site to another only on trailors

2.2 Heavy Earth moving Equipments

A. Excavators

Types of excavators

II. Truck mounted excavators:

- These excavators are mounted on truck chassis/mounting/and has the following main characteristics:
  - High road speed and mobility is the main advantage.
  - Lower stability over sides and hence require counter-weight or outriggers.
  - Require more operating space.
  - Tyres or outriggers give high ground pressure and hence it requires firm and smooth operating locations.
  - Have two engines and two cabs, separately for truck chassis and excavator.

Truck mounted excavator

2.2 Heavy Earth moving Equipments

A. Excavators

Types of excavators

- ***III. Self propelled excavators/ ability of a machine to move by its own force/***

These excavators are self propelled. The main characteristics are:

- Medium travel speed generally between 10-30 Km per hour.
- Has one engine and one cab for control by one operator.

IV. Excavators on barge or rail:

- These excavators are mounted on barge or rail to carry out work of excavation in water or near railway line respectively.

Self propelled excavators

Excavator mounted on rail

2.2 Heavy Earth moving Equipments

A. Excavators

Common attachments

- Some common attachments include:
  - ***Augers***: Drills holes for poles, posts, soil sampling, and ground improvement
  - ***Jack Hammer***: vibratory hammer used to break up concrete and rock.
  - ***Bucket Ripper***: The bucket sides and bottom are lined with ripper teeth to break up hard soil or soft rock.
  - ***Thumb Bucket***: attached to bucket to provide a hook capacity.

Jack Hammer excavators


Thumb Bucket attachment

2.2 Heavy Earth moving Equipments

B. Loaders

- A bucket is attached to the arms and capable of being raised, lowered, and dumped through mechanical or hydraulic controls.
- The loaders having bucket in the front, known as "***front end loaders***" are very common.
- The loaders are versatile, self propelled equipment mounted either on crawler or wheel-type running gear.
- These are equipments used primarily:
  - To load excavated materials to a hauling unit,
  - Excavate soft to medium materials,
  - Loading hoppers,
  - Stockpiling/ accumulation materials,
  - Backfilling ditches, and
  - Moving concrete and other construction materials.

2.2 Heavy Earth moving Equipments

B. Loaders

Basic Parts of a loader

2.2 Heavy Earth moving Equipments

B. Loaders

Types of Loaders

- Loaders are of the following two types:
  - Crawler loaders
  - Wheel Loaders

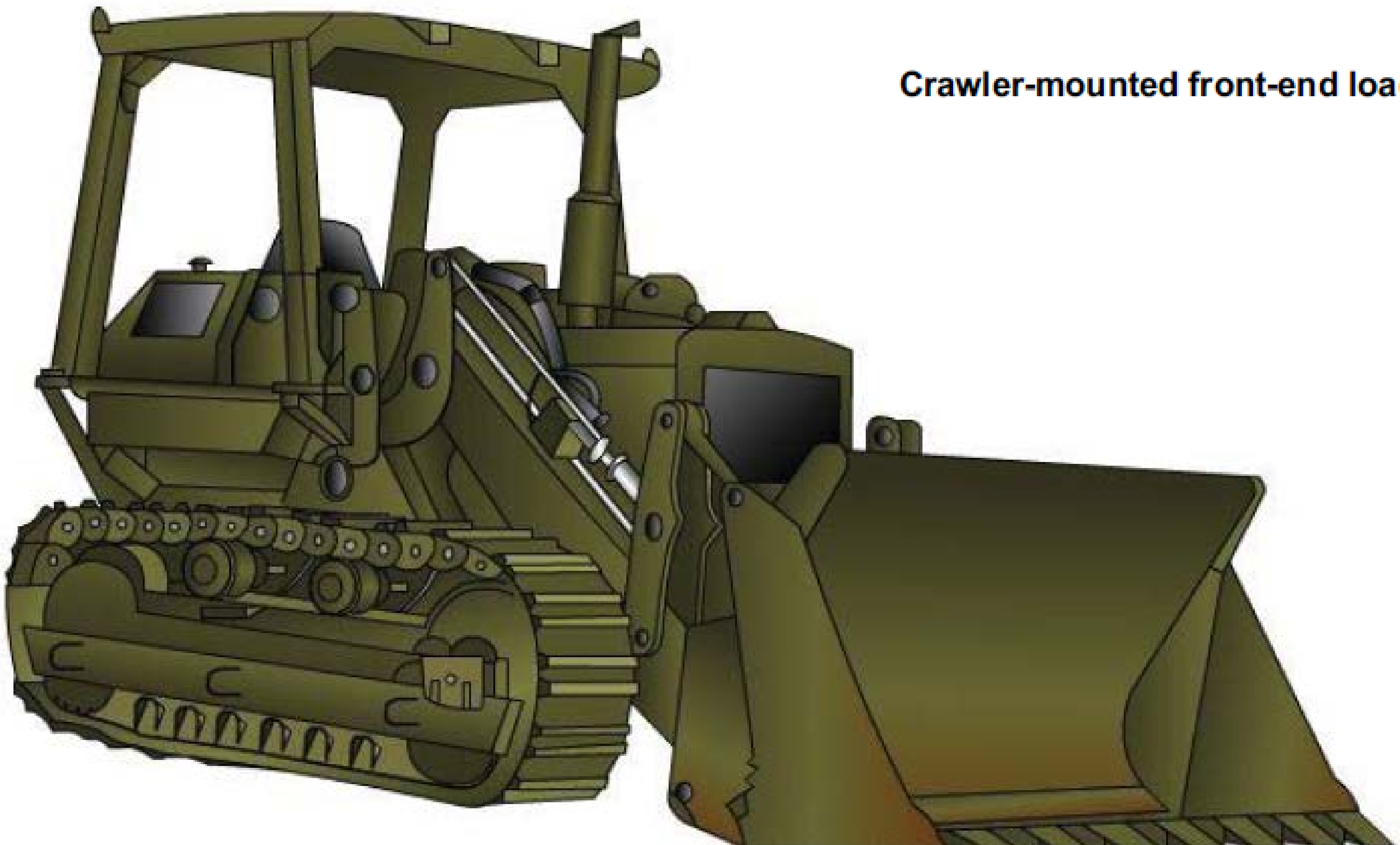
2.2 Heavy Earth moving Equipments

B. Loaders

Types of Loaders

I. Crawler loaders

- Crawler track types are generally preferred for digging and loading jobs where ground conditions are *poor and low pressure* characteristics are required.
- They are preferable for applications involving rock and sharp stony ground as there is possibility of tyre damage.
- These are best employed for short moves between loading and dumping points.
- They should be transported from one site to another after loading on the trailors.



Crawler-mounted front-end loader.

2.2 Heavy Earth moving Equipments

B. Loaders

Types of Loaders

II. Wheel loaders

- As a result of the development of more capable power trains, there was a steady trend towards wheel loaders at the expense of crawlers.
- Wheel loaders are also called bucket loaders or front-end loaders.
- A wheel loader use for building roads, preparing the job site, digging, carrying heavy loads, or moving materials.
- A wheel loader can handle a heavy-duty job easily.

2.2 Heavy Earth moving Equipments

B. Loaders

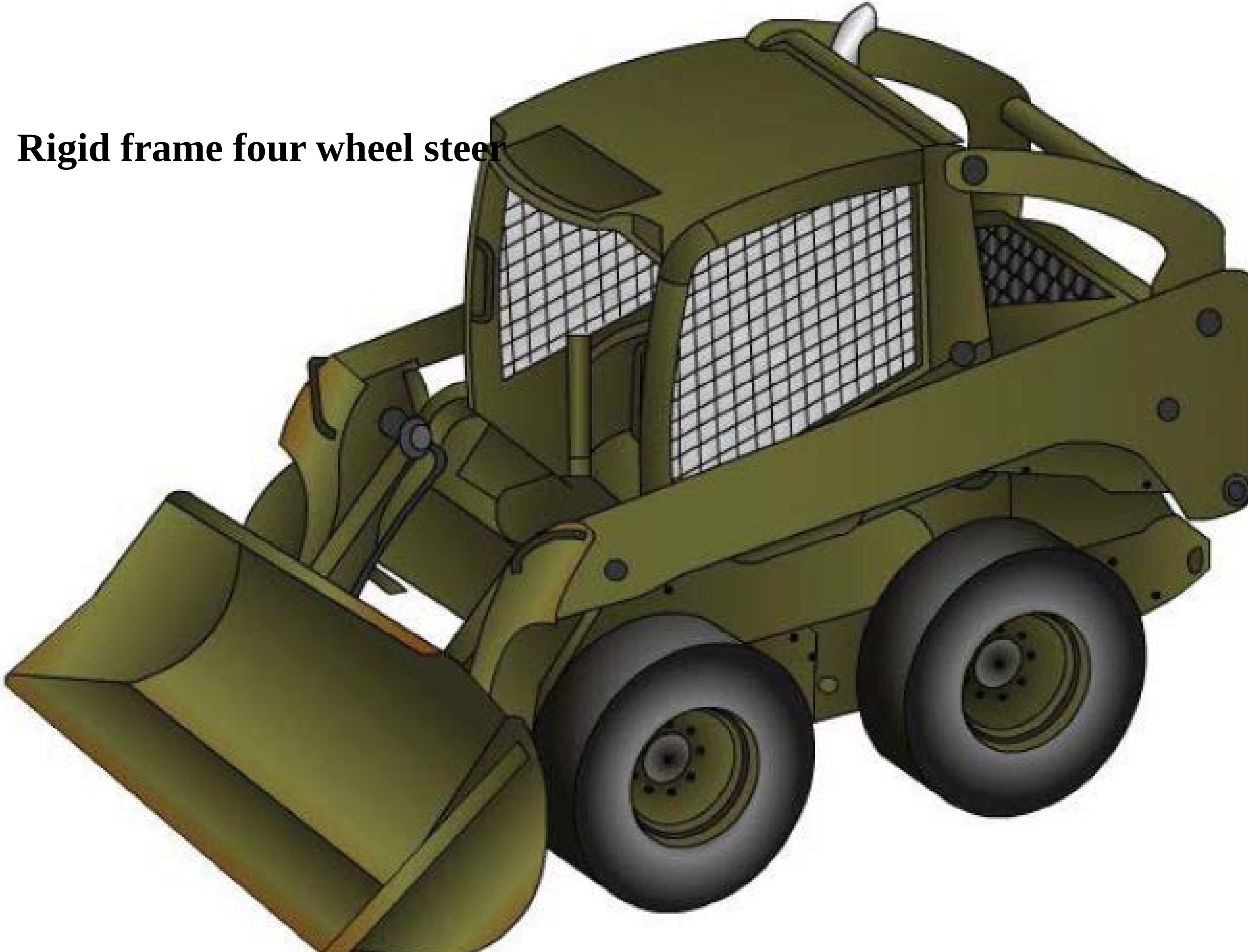
II. Wheel loaders

- From manoeuvrability/operation/point of view, wheel loaders are of
    A. Articulated type (Pivot steer)
    B. Rigid frame- two wheel steer or all wheel steer.

A. Articulated type of loaders

- They are hinged in the middle of the front and rear axels.
- Due to their ***operational characteristics*** and capability of ***working in limited space*** and ***short turning radius***, resulting higher speed of work, they have become popular.
- The articulation permits the loader to pivot 30-45 degree either side of the center.

Rigid frame four wheel steer



2.2 Heavy Earth moving Equipments

B. Loaders

II. Wheel loaders

Some advantage of articulated type of loaders are:

- Quick manoeuvring
- Less rolling resistance on turns
- Better mobility on soft surface
- Give better performance and high productivity.

B. Rigid frame type loaders

- These are comparatively cheaper than articulated frame type of loaders.
- Manoeuvring back and forth before dumping is required in most cases.
- Rigid frame loaders are of two types, namely two wheel steer and four wheel steer.

2.2 Heavy Earth moving Equipments

B. Loaders

II. Wheel loaders

- Some models of wheel loaders are designed as a combination of a backhoe and loader and often called ***backhoe loader***.

2.2 Heavy Earth moving Equipments

B. Loaders

Backhoe loader features

- Very common piece of equipment
- Many subcontractors own/lease
- Very versatile
- Easily transported
- “Low” maintenance costs
- Operator “friendly”
- Easily rented

2.2 Heavy Earth moving Equipments

B. Loaders

Operations

- Loaders are used to carry out the following main operations;

A. Loading

- Loading operation is the main operation performed by the loaders.
- Loading consists of scooping, lifting, turning and dumping materials such as sand, gravel, and crushed materials from stockpiles, bank or construction site into the hauling units.

B. Hauling

- Wheel loaders are excellent for moving loose materials over short distances to dump into hauling units, hoppers, conveyors, bins, or any other place of work in the construction site.

2.2 Heavy Earth moving Equipments

B. Loaders

Operations

C. Excavating

- Crawler loaders and heavy duty wheel loaders are excellent for many excavation jobs.
- These loaders can excavate as well as lift the excavated material and dump it into trucks or on the stockpiles

D. Clearing

- Loaders can scoop up and load the debris of demolished buildings into hauling units.
- Loaders are the first equipment to prepare the site for building and construction operations; and also the last equipment in order to backfill, spread, level and top with selected good soil.

2.2 Heavy Earth moving Equipments

B. Loaders

Attachments

- The following are main attachments which can be fitted to a wheel loader

a) ***Back filling attachment***

- Back filling can be done with the bucket of this attachment when used with the loader.

b) ***Forklift attachment***

- An industrial forklift when attached with the loader gives more stability, more tractive power and greater clearance than the normal.

c) ***Sweeping attachment***

- A sweeping attachment can be fitted to a wheel loader for general cleaning of roads and parking areas in the industries.

2.2 Heavy Earth moving Equipments

B. Loaders

Attachments

d) Multi purpose bucket

- A multi purpose or four-in-one bucket can be used as a dozer, scraper, clamshell and a general purpose loading.

e) Ripper-scarifier a attachment

- These are mounted on the rear of the loader to loosen hard surfaces.

f) Miscellaneous other attachments

- A large number of attachments for specialized jobs are also available for fitting to the loaders. Some of these are pipe laying attachments, pole handling attachments, boom for loader crane set up.

BACKHOE LOADER ATTACHMENTS

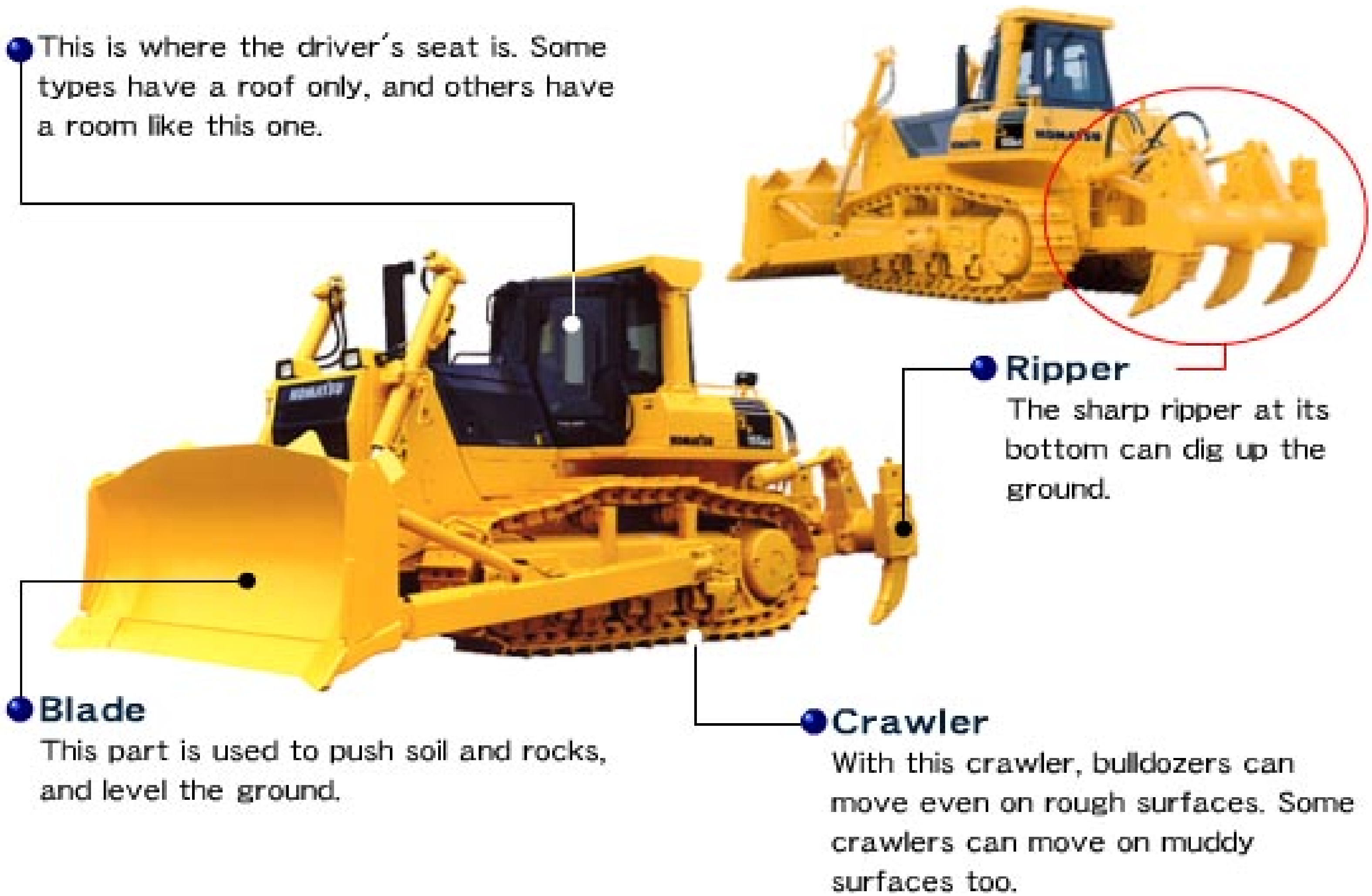
2.2 Heavy Earth moving Equipments

C. Dozers

- Dozers are machines designed primarily for ***cutting*** and ***pushing*** the material over relatively short distance.
- They consist of a tractor equipped with a ***front–mounted earthmoving blade*** controlled by ***hydraulic cylinders*** to vary the depth of cut.
- A dozer moves earth by lowering the blade and cutting until a full blade load of materials is obtained. It then pushes the material across the ground surface to the required location.
- Rear mounted hydraulic ***scarifiers*** and ***rippers*** can be fitted to loosen hard material prior to dozing.

2.2 Heavy Earth moving Equipments

C. Dozers



2.2 Heavy Earth moving Equipments

C. Dozers

Application of Dozers

- The following are the main dozer application
  - ***Clearing land*** of timber and stumps,
  - ***Opening up pilot roads*** through mountains and rocky terrain,
  - ***Moving earth*** for the haul distances up to approximately 100m,
  - ***Helping load*** tractor-pulled scrapers,
  - ***Spreading*** earth fills,
  - ***Backfilling*** trenches,
  - ***Side hill cuts***
  - ***Clearing*** construction sites of derbies, and
  - ***Maintaining*** haul roads.

2.2 Heavy Earth moving Equipments

C. Dozers

Application of Dozers

Moving earth

Helping scrappers

2.2 Heavy Earth moving Equipments

C. Dozers

Application of Dozers

2.2 Heavy Earth moving Equipments

C. Dozers

Dozer Blades

- A heavy blade of ***slightly concave profile*** is attached in the front of the tractor.
- The blades has a ***replaceable cutting edge***, which wears out with the use of the blade.
- The dozer blades are available in sizes from ***2m to 7.5m wide*** and ***0.8m to 1.5m height***.
- Dozer blades are of the following types:

A. ***U-Blade***: Used for moving ***big loads*** over ***longer distances***; curved shape and side and top extensions reduce the spillage of loose material; best suited for ***lighter materials***.

2.2 Heavy Earth moving Equipments

C. Dozers

Dozer Blades

B. ***Straight Blade***: Used primarily for ***shallow surface removal***, land clearing; designed to push dirt for short distances, versatile, lightweight and maneuverable, handles a wide range of materials.

C. ***Angle Blade***: It is designed to move material towards the sides of a cut, backfilling or cutting ditches, and sustainably reduces the amount of maneuvering.

D. ***C (cushion Blade)***: Used primarily with scrapers for "on the go" push loading; can be used for lighter excavation and other general tasks.

E. ***Land fill Blade***: These blades are specially designed to handle refuse and/or fill material.

2.2 Heavy Earth moving Equipments

2.2 Heavy Earth moving Equipments

C. Dozers

Blade adjustments

Tilting

Angle adjustment

2.2 Heavy Earth moving Equipments

C. Dozers

Dozer Blades and Material Evaluation

- Besides job requirement, several other consideration determine choice of attachment.
- ***Moisture content***, ***particle size***, and ***number of voids*** are the more important characteristics influencing dozing performance.

a) ***Moisture content***: If the moisture content increases above the optimum, material becomes heavy and will thus have a ***negative effect on dozing performance***.

b) ***Particle size***: Large particles resist penetration more than smaller ones, requiring more dozing power.

- Materials consisting of ***irregularly*** and ***sharp-edged*** particles are more difficult to doze than material composed of ***round-edged*** particles

2.2 Heavy Earth moving Equipments

C. Dozers

Dozer Blades and Material Evaluation

c) ***Voids***: Relatively dense materials with few voids contain large numbers of individual particles in close contact with each other . Because of this more force is required to break up this tightly bonded material.

2.2 Heavy Earth moving Equipments

C. Dozers

Rippers

- Crawler-tractor, mounted with ripper is finding increasing use in construction, mining and quarrying.
- ***Characteristic of material*** to be ripped influence the selection of ***ripper type***; ***number of shanks*** required, ***ripping speed*** and ***amount of ripper penetration***.

Types of Rippers

A. ***Fixed multiple-shank ripper***: used for comparatively simple ripping operations.

B. ***Variable multiple-shank ripper***: These are used where there are many boulders, or where the quality of rock is not consistent.


blade


crawler tractor


ripper

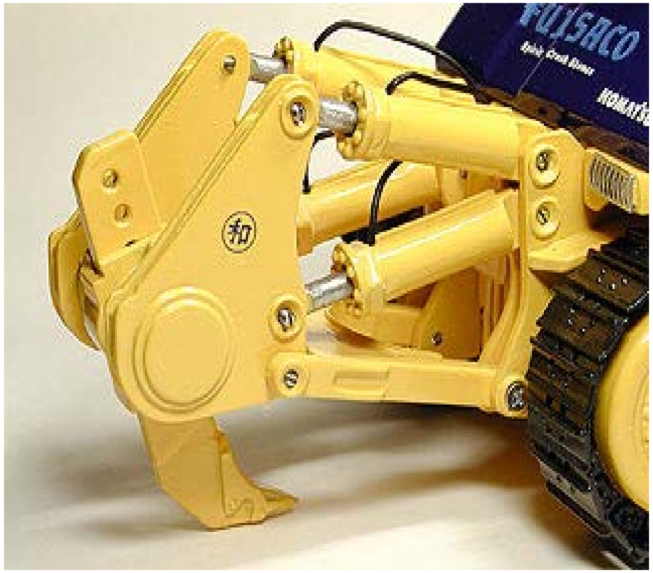
2.2 Heavy Earth moving Equipments

C. Dozers

Types of Rippers

c. ***Fixed giant ripper***: has only one single powerful shank, but is not common as compared to variable giant/great/ rippers.

d. ***Variable giant ripper***: has a single powerful shank . The angle of this ripper can be changed according to the ground requirements.



2.2 Heavy Earth moving Equipments

C. Dozers

Ripping Efficiency

- In order to achieve ***high ripping efficiency***, following suggestion should be considered.
  1) When material is not broken, loosen the surface in one direction, then cross-ripping should be adopted.
  2) If material is soft, use more than one shank ripper.
  3) Ripping should be done downhill.
  4) Avoid reversing/backward/ when shank is in the ground.
  5) When both dozing and ripping operations are required to be done, it should rip going out and doze on the way in.
  6) For hard material, use shorter tips, and for ordinary work use longest and sharpest point.

2.2 Heavy Earth moving Equipments

C. Dozers

Crawler Vs Tyre Tractors

A. Crawler Mounted tractors

B. Wheel Mounted tractors

2.2 Heavy Earth moving Equipments

C. Dozers

Crawler Vs Tyre Tractors

- Each type of tractor has certain advantages in certain conditions.
- ***Advantages of crawler mounted tractors:***
  1) More tractive effort, hence can also operate on loose or muddy soil.
  2) In absence of tyres, can easily operate in rocky conditions.
  3) Where maintenance of haul roads is difficult, it can easily travel, especially in rough terrain.
  4) Crawler tractors are more compact and powerful and hence can handle difficult jobs as well.

2.2 Heavy Earth moving Equipments

C. Dozers

Crawler Vs Tyre Tractors

- ***Advantages of wheel mounted tractors***:

1) Can travel at higher speeds during operations and also from one job to the other.
2) Ease in operation. Operator feels less fatigue.
3) Can travel on paved roads without damaging them.
4) Can travel long distances at its own power, whereas crawler mounted needs trailors.
5) When work is spread over long area, these are found to be producing more output.
6) Operation, maintenance and repair costs are less in wheeled tractor as compared to crawler tractors.

2.2 Heavy Earth moving Equipments

D. Scrapers

- Scrapers are capable of ***excavating***, ***hauling***, and ***dumping*** material ***over medium- to long-haul distances.***
- The scrapers are designed to ***dig***, ***load***, ***haul***, ***dump*** and ***spread*** and sometimes called as ***carry all***.

Types of scrapers

- The scrappers are of three types:

I. Towed scrapers:

- They are provided with either cable or hydraulic control.
- They are becoming obsolete/outdated.
- The scraper can be pulled in single or tandem configurations, or top loaded with an excavator.
- Travel at slower speed and can be used for short hauls only.

2.2 Heavy Earth moving Equipments

D. Scrapers

Types of scrapers

II. Self propelled or motorized or conventional scrapers:

- Generally manufactured in ranges from ***10-20*** cubic meters.
- Needs push loading by a crawler mounted or wheeled tractor.
- Have ***more hauling speed*** and hence are suitable for long distance hauling .

III. Self loading or elevating scrapers:

- The problem of loading by a pusher is overcome by these type of scrappers.
- These are twin engine scrappers and can work completely independently.
- Loads are restricted because of the additional weight of the loading elevator and its drive system.

2.2 Heavy Earth moving Equipments

D. Scrapers

Types of scrapers

- Another classification method of scrapers

I. ***Push-loaded (Conventional):***
   - Single powered axel
   - Tandem powered axels

II. ***Self loading:***
   - Push-pull, tandem powered axels
   - Elevating
   - Auger

Construction Equipments

2.2 Heavy Earth moving Equipments

D. Scrapers

Types of scrapers

Conventional (Push loaded)

Become uneconomical when

- Haul grades > 5%
- Return grades > 12%

Tandem powered Twin Engine

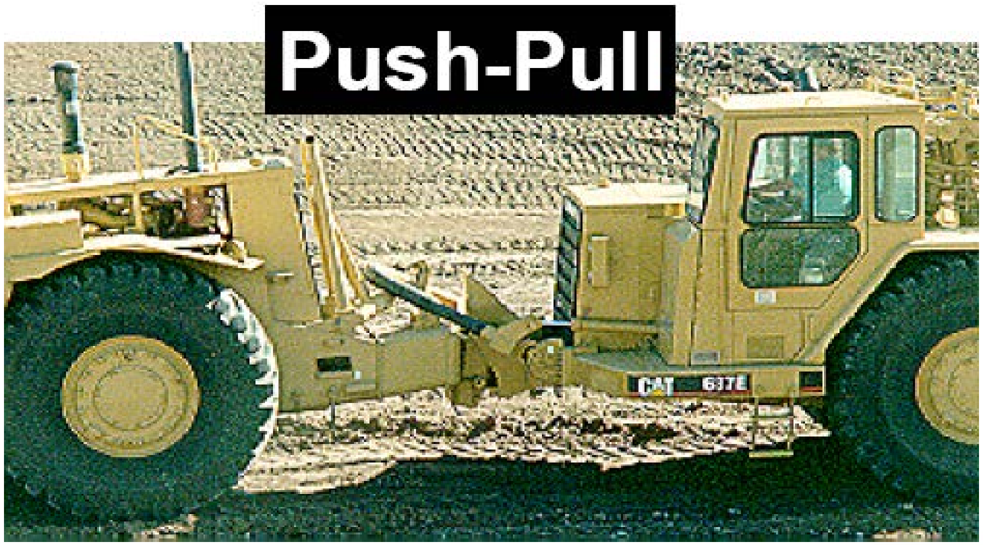
•Good for jobs having adverse grade

•Owning operating costs are about 25% higher

2.2 Heavy Earth moving Equipments

D. Scrapers

Types of scrapers



Push pull scrapers

- Can work as a team or operate individually with a pusher.
- Tire wear will increase in rock or abrasive materials.

Elevating scrapers

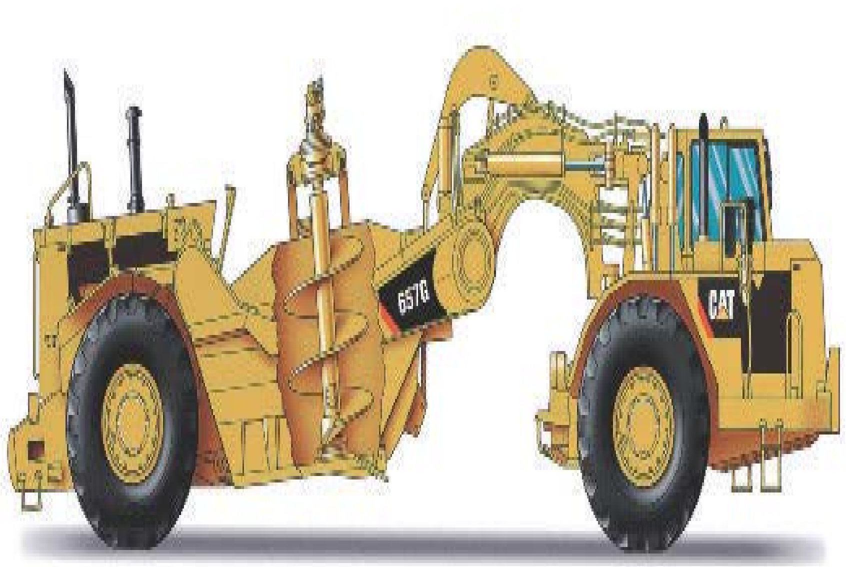
- Good for short hauls and in favourable materials.
- Can work alone in the cut.
- Cost more initially and to operate.

Construction Equipments

2.2 Heavy Earth moving Equipments

D. Scrapers

Types of scrapers



Auger Scrapers

- Can self load in difficult condition, laminated rock or granular material.
- The augers add weight to the scraper during travel and it is more costly to own and operate than the conventional.

2.2 Heavy Earth moving Equipments

D. Scrapers

Basic Parts of a scraper

- A scraper has the following main parts:

i. ***Bowl***

- The bowl is a pan to hold the scraped dirt
- It is hinged at the rear corners to the rear axle inside the wheels, and is capable of tilting down for digging or ejecting.

ii. ***Cutting edge***

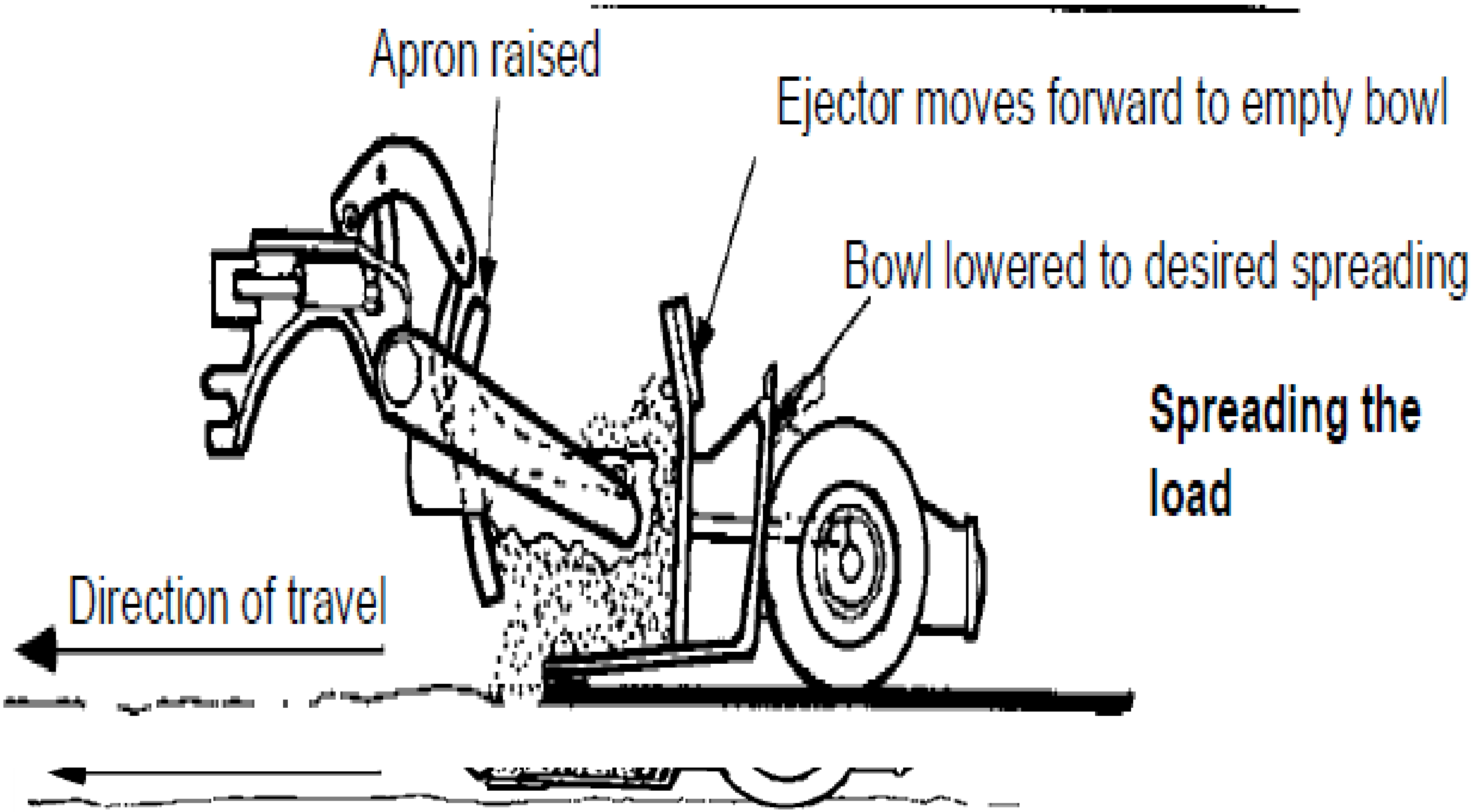
- The bowl has a cutting edge attached to the bottom.
- The cutting edge is lowered into the soil to make a shallow cut.

iii. ***Apron***

- This is a wall in front of the bowl, which opens and closes to regulate the flow of the earth in and out of the bowl.

2.2 Heavy Earth moving Equipments

Basic Parts of a scraper



2.2 Heavy Earth moving Equipments

D. Scrapers

Basic Parts of a scraper

iv. ***Tail gate or ejector***

- These are the rear of the pan which is capable of forward and backward movement inside the bowl

2.2 Heavy Earth moving Equipments

D. Scrapers

Operation

- Operation of a scraper is described here under for an earth work:

i. ***Loading or digging***

- The operator moves to the cut with the ejector at the rear and the apron raised approximately to 40 cm.
- The bowl is then lowered to the desired depth of cut, increase engine speed, move forward in first gear keeping optimum depth of cut.
- When the bowl is full, the apron is closed and the bowl is then raised.

ii. ***Transporting***

- The bowl is transported in high gear in raised position to provide sufficient clearance.
- During transporting, apron should be fully closed to prevent loss of material

2.2 Heavy Earth moving Equipments

D. Scrapers

Operation

❑ Operation of a scraper is described here under for an earth work:

iii. ***Unloading***

- The bowl should be positioned to spread the material to the desired depth during this operation.
- A partial opening of the apron during the initial unloading will help in even spreading.
- For wet and sticky material, the apron should be raised and lowered repeatedly until the material behind it is loosened and drops out of the bowl.
- Then the ejector is moved forward to push the remaining material out of the bowl at a uniform rate.
- When the dump is complete, the tail gate is fully retracted, the apron dropped and the ‘bowl’ raised to transporting position.

2.2 Heavy Earth moving Equipments

D. Scrapers

Operation

- Following are some of the suggestions for ***increasing scraper production***:
  - Construct and maintain smooth haul roads for faster travel.
  - Depth of cut should be according to the type of soil being cut.
  - Use ripper teeth in hard or abrasive materials for easy handling.
  - Where possible, loading be done in down grade
  - To increase the stability of the scraper during travel, carry the bowl as close to the ground as possible.
  - If necessary pre-wetting of the soil is done so that the soil is reasonably moist, as most soils load easily when they are moist.
  - Whenever possible, plan the work to eliminate all avoidable turns.

2.3 Grading Equipments

E. Graders

- Grading is the process of bringing earth work to the desired ***shape*** and ***elevation*** (grade).
- Motor graders are used for leveling and smoothening the earthwork, spreading and leveling the base course in the construction of roads and air fields.
- Motor graders can be used for the following types of works:
    - Gravel road repairing
    - Road shoulder reshaping, bank cutting and reshaping
    - Ditch filling or digging
    - Levelled or slopped ground finishing
    - Base course spreading and levelling
    - Material mixing, hard surface cutting, snow clearance,
    - Land clearance, frozen top soil and asphalt breaking

2.3 Grading Equipments

Graders

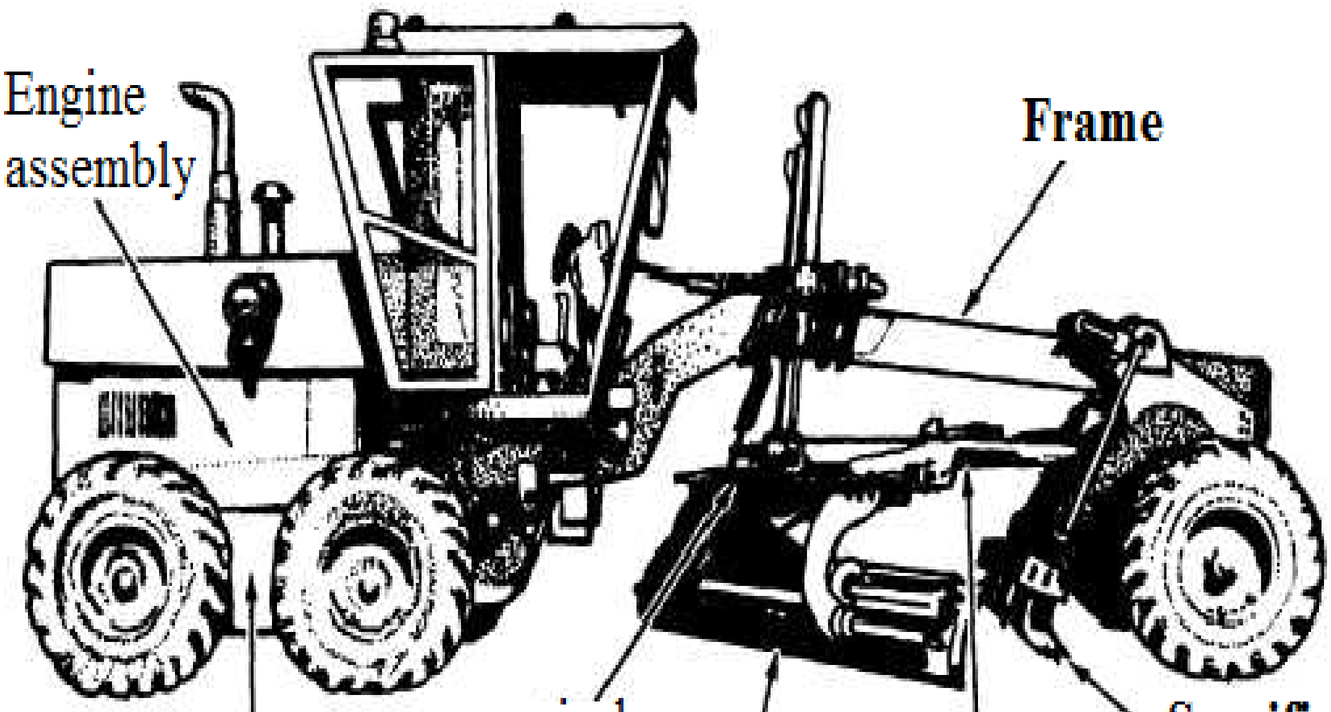
Comparison with dozers

- A grader is restricted to making shallow cuts in medium-hard materials.
- They should not be used for heavy excavations.
- A grader can move small amounts of material but cannot perform dozer-type work because of the structural strength and location of its moldboard.
- Graders can work on slopes as steep as 3:1.
- Grader are capable of progressively cutting ditches to a depth of 3 ft.

2.3 Grading Equipments

Basic parts of grader

- The components the grader that actually do the finishing are:
  - **Blade (Moldboard)**
  - **Scarifier**
  - **Rippers**



2.3 Grading Equipments

Graders

Blade

- The blade (Mould Board) is the ***main tool*** of the grader.
- It is carried by a ***rotating circle*** and is easily maneuverable to a wide range of cutting positions with the help of hydraulic controls.
- The blade and the circle are mounted on a frame and is supported at the front of the machine by a ball joint/similar to hip joint/.
- The blade can be adjusted to any position with help of levers as indicated below:
  - ***Side shift***: to provide sideways movement of blade.
  - ***Lifting the blade***: The blade can be lifted or lowered by levers operating the two rams.
  - ***Rotating the circle***: A hydraulic motor is provided to rotate the circle and blade. Blade can be rotated either in clockwise or counter clockwise direction.

2.3 Grading Equipments

Graders

Blade

- ***Adjusting blade cutting angle (Blade pitch)***: The vertical angle of the blade can be adjusted.

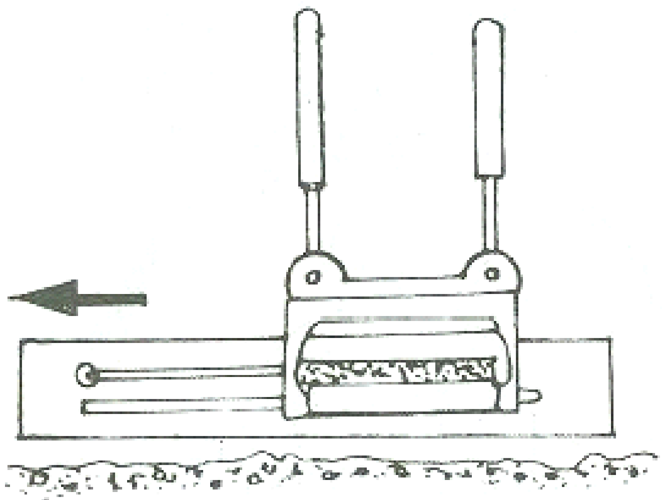


Fig. 4.2. Blade sideshift.

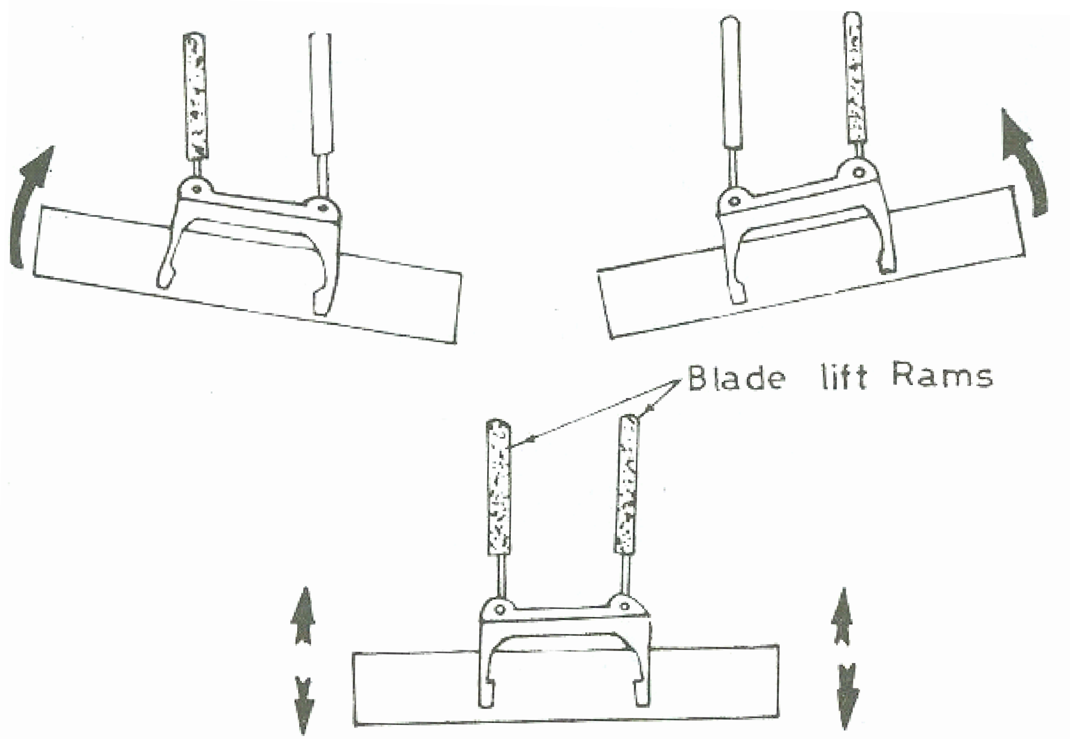


Fig. 4.3. Lifting the blade.

2.3 Grading Equipments

Graders

Blade

Adjusting blade cutting angle

2.3 Grading Equipments

Graders

Blade

Adjusting blade cutting angle

2.3 Grading Equipments

Graders

Scarifier

- Scarifier is a special tool attached with the motor grader for loosening the hard soil and has a set teeth mounted on adjustable shanks.
- This attachment digs up hard ground like asphalt, old pavement, frozen surface and hard soil with vegetation and brushes which can not be removed by the blade.
- The teeth are replaceable, and the number of teeth can be varied to suit the ground hardness.
- High strength alloy steel tips can be mounted on the teeth to prevent teeth wear and extend their service for economical performance.

2.3 Grading Equipments

Graders

Scarifier

2.3 Grading Equipments

Graders

Ripper

- The ripper is used to break up materials too hard to cut with moldboard blade.
- The depth of cut is controlled by hydraulically operated ripper control lever.
- Type of material to be ripped will determine position of the ripper shank.

2.3 Grading Equipments

Graders

Operations

A. *Grading:*

- Grading in road construction means flattening and smoothening the road surface and others by the scrapping action of the blade, includes working operation like, ***surface skimming***, ***light duty bulldozing***, ***leveling***, ***spreading*** and ***crowning****/making slope both side/*.
- A cutting depth of 2 to 3cm is considered to be the best for optimum efficiency.

B. *Spreading:*

- Gravel together with binding material is spread by the motor grader.
- For spreading the cutting angle is set at 60° nearly.
- Cutting edge of the blade is set above the ground at a distance equal to the depth to which the material is to be spread.

2.3 Grading Equipments

Graders

Operations

C. *Finishing and Leveling:*

- In final finishing and leveling, surface have to be finished to fine limits.
- In such cases make the finishing pass with the blade only slightly angled and set to skim the surface.

D. *Ditch Digging:*

- The front end of the blade is tilted down and the rear end is tilted up above the road surface. The front end cuts into the ground.
- This is used to dig drainage ditches and road side ditches.

E. *Cutting:*

- For the purpose of cutting in soft dirt, set the blade to an angle b/n 40-55 degree, while in hard dirt an angle of 30-45 degree is proper.

1- 6 group assignments(20%)

Presentation on

I. compaction equipment's (5 marks)

- Different types of rollers and other soil compaction equipments
- Methods of Compaction

II. Aggregate production equipment (5 marks)

- aggregate crushers ,types ,Processes and any others

III. Tunneling equipment (5 marks)

IV compressors (5 marks)

Chapter 2;
Productivity of the construction Equipment

CONTENTS

- ***Determination of Production of an Equipment***
- ***Productivity of Shovel Family and Excavator***
  - *General*
  - *Productivity of Face Shovel*
  - *Productivity of Dragline*
  - *Productivity of Clamshell*
  - *Productivity of Hoe/Excavator*

- ***Productivity of Heavy Earth Moving and Grading Equipments***
  - *Productivity of Loader*
  - *Productivity of Dozer*
  - *Productivity of Scraper*
  - *Productivity of Grader*

1. Determination of Production of an Equipment

Terminologies

- ***Peak Productivity***: is the ***theoretical productivity*** governed by design limitations only.

$$Q_p = V \times f_s \times f_f$$

Where: Q_p = *Peak Productivity*

V = *Volume carried/ bucket capacity*

f_s = *Bank Volume/loose volume*

f_f = *Bucket fill factor*

- ***Actual Productivity***: Productivity of an equipment after taking care of ***effective working hours*** and ***job management factor*** on the peak productivity.

PRODUCTIVITY OF THE CONSTRUCTION EQUIPMENT

1. Determination of Production of an Equipment

Terminologies

- ***Actual Productivity***:

$$Q_a = Q_p \times f_w \times f_j$$

Where: Q_a = *Actual Productivity*

Q_p = *Peak Productivity*

f_w = *Factor to take care of effective working hours*

f_j = *Factors to take care of the job management conditions*

PRODUCTIVITY OF THE CONSTRUCTION EQUIPMENT

1. Determination of Production of an Equipment

- Equipments can be broadly classified into two based on equipment productivity concepts:
  - ***Cyclic Operating*** or
  - ***Continuously Operating***.
- ***Cyclic operating equipments***: These are machines which are intentionally or unintentionally influenced by their operators. The actual productivity can be computed from:

$$Q_a = V_n x\, n_o x\, \eta$$

Where: Q_a *= Actual Productivity (Bm³/hr)*

V_n *= Volume per cycle (Bm³)*

η*= Efficiency of the equipment*

n_o *= number of cycle /Unit Time (usually Time in hours), if* T_o

is theoretical cycle time $n_o = \dfrac{60}{T_o}$

PRODUCTIVITY OF THE CONSTRUCTION EQUIPMENT

1. Determination of Production of an Equipment

- ***Continuously operating equipments***: These are machines that continuously operate, like pumps, conveyor belts, etc. For these kinds of machines:

$$Q_a = V_n \times a \times n_o \times 60 \times \eta$$

Where: Q_a = *Actual Productivity* (Bm^3/hr)

V_n = *Volume per bucket*

a = *Number of buckets*

η = *Efficiency of the equipment*

n_o = *number of cycle /Unit Time (usually Time in hours)*

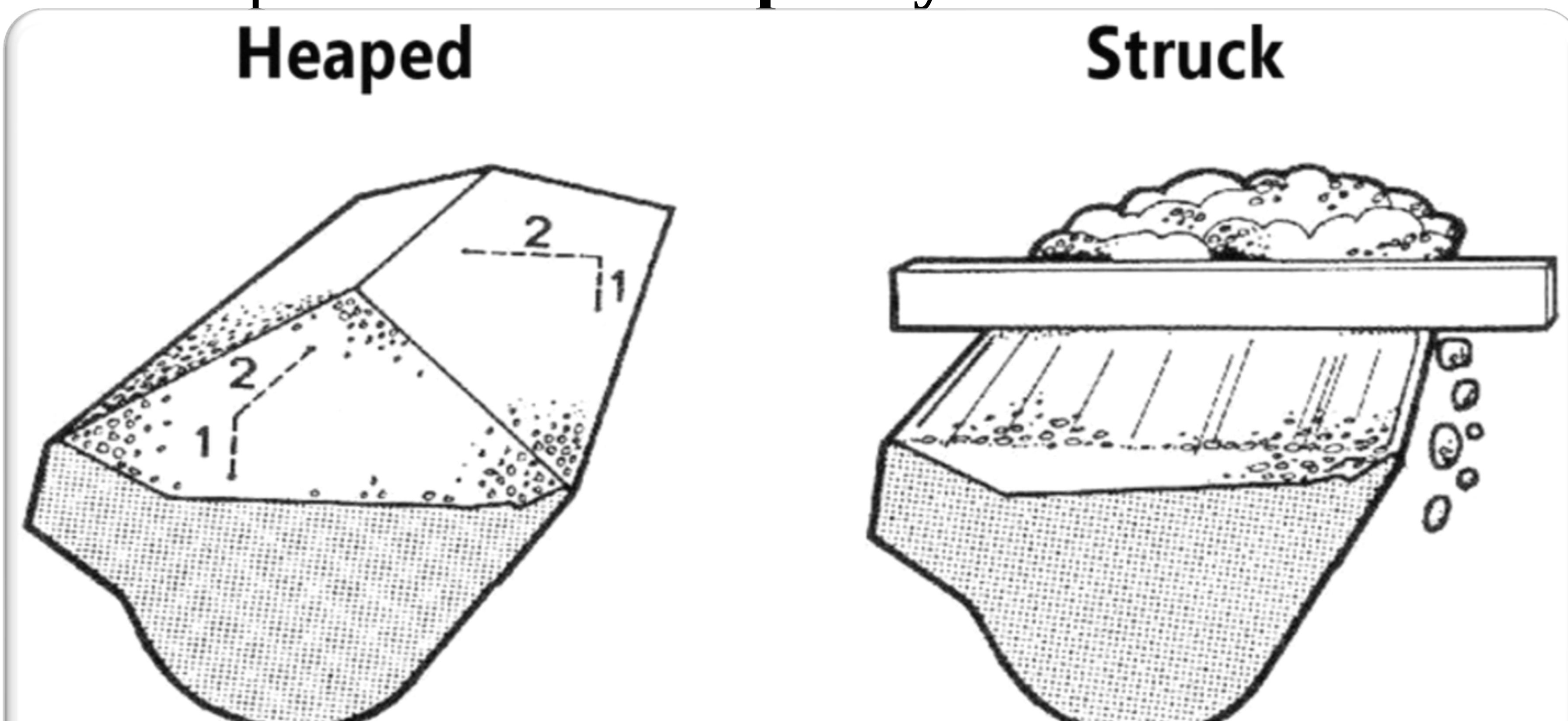
Productivity of the construction Equipment

Q_a - Shovel family is dependent on the actual ***volume per cycle*** and ***the cycle time***.

- V_n – Volume per bucket.
  - ***Plate line capacity*** is the bucket volume contained within the bucket when following ***the outline of the bucket sides***.
  - The ***Struck capacity*** is the volume below a straight line from the cutting edge to the bucket back sheet.
  - ***Water line capacity*** assumes a level of material even with the lowest edge of the bucket (i.e., the material level corresponds to the ***water level*** that would result if the bucket were filled with water).
  - ***Heaped volume*** is 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.

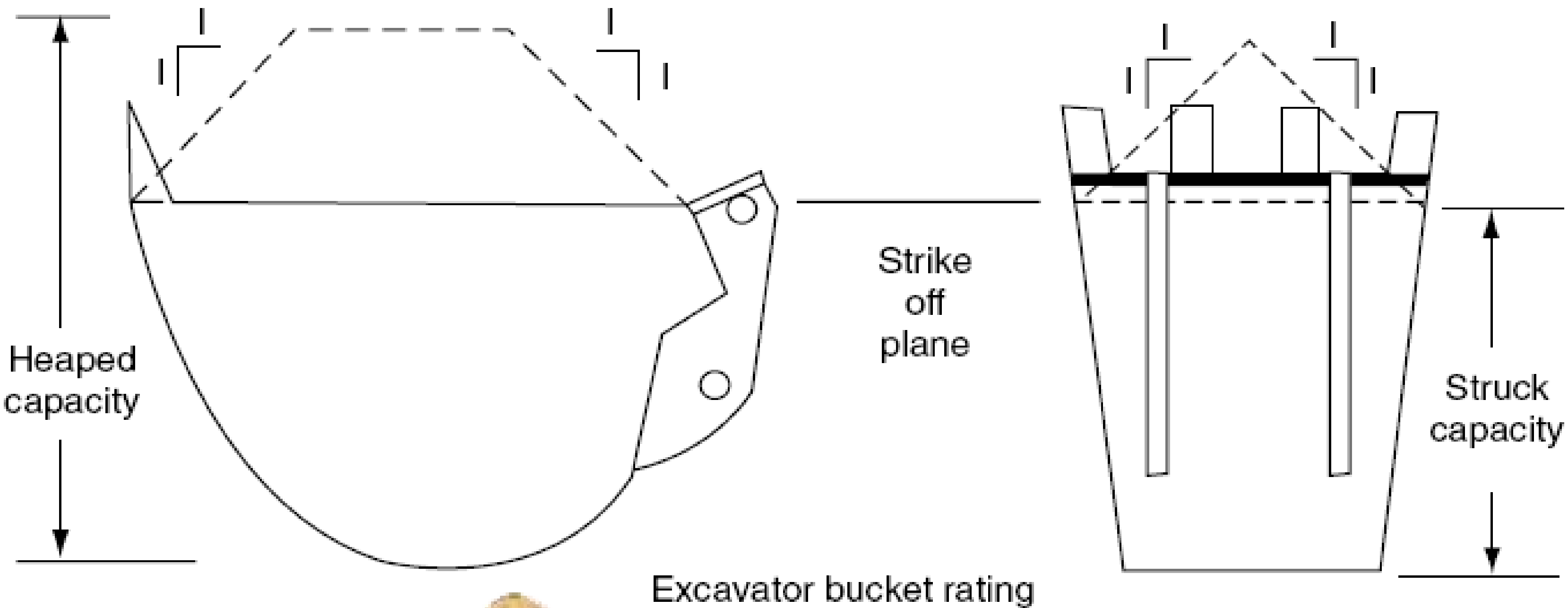
Productivity of the construction Equipment

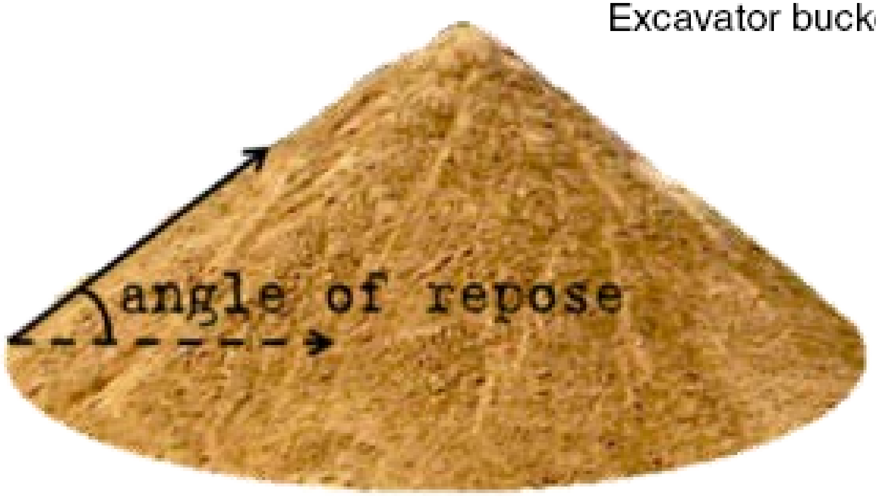
- The total amount of material carried by a bucket is the amount inside the bucket plus the amount piled on top of it. This is called the Heaped or **Rated Capacity**.



Productivity of the construction Equipment

- Figure – Struck and Heaped Bucket Capacity (Caterpillar Inc.)





Productivity of the construction Equipment

Machine	Rated Bucket Capacity
Backhoe and shovel	
Cable	Struck Volume
Hydraulic	Heaped Volume at 1:1 angle of repose
Clamshell	Plate line or water line volume
Dragline	90% of struck volume
Loader	Heaped volume at 2:1 angle of repose

Rated bucket capacity for different machine

PRODUCTIVITY OF THE CONSTRUCTION EQUIPMENT

- Commonly - ***Bucket ratings*** for the cable shovel, dragline, and cable backhoe are based on ***struck volume***:
  - Thus it is often assumed that the heaping of the buckets will compensate for the swell of the soil. That is, a ***5 m^3 bucket*** would be assumed to actually hold ***5 Bank m^3*** of material.
  - 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***.
  - If desired, the bucket load may be converted to ***bank volume by multiplying its loose volume by the soil's load factor.***

PRODUCTIVITY OF THE CONSTRUCTION EQUIPMENT

- ***CYCLE TIME*** ; is the time starting when an operation begins to the point of time when the operation ends.
  - Where T_c – cycle Time in minutes

    Cycle Time = Fixed Time + Variable Time

$$T_C = T_F + T_V$$

Where

- ***T_V* =*Variable Cycle Time*** - Variable time represents those components of cycle time related with ***travel time***.
  - ***Variable Cycle time*** is the time required to excavate and travel to load and travel to return to original position after loading.
- ***T_F*** = ***Fixed Cycle Time*** - Fixed time represents those components of cycle time ***other than travel time***.
  - ***Fixed Cycle time*** represents the time required to maneuver time, change gears time, loading time, spot time, and dump time.

2. PRODUCTIVITY OF SHOVEL FAMILY AND EXCAVATORS

A. Productivity of Face Shovel (Power Shovel)

- The production capacity or output of a shovel is expressed in cubic meter per hour.
- The output varies for various type of materials to be digged. The following are the main factors which affect the out put of face shovel:
  - Nature of the soil
  - Height or Depth of cut
  - Type of material
  - Angle of swing
  - Capacity of hauling unit and continuity of work
  - Mechanical condition of shovel
  - Efficiency of the operator
  - Relative positions of the shovel and hauling unit
  - Type of machine such as crawler or wheeled

A. Productivity of Face Shovel

STEP 1: HEAPED BUCKET LOAD VOLUME

- Shovels can usually be equipped with different size buckets. This would be a loose volume(lcy) value.

STEP 2: FILL FACTOR

- The Fill Factor adjusts Heaped Capacity in lcy based on the type of machine and class of material being excavated.
- Heaped bucket capacity × Fill factor

  = VOLUME (lcy)

A. Productivity of Face Shovel

Table 1. Fill Factors for Front Shovel Buckets

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

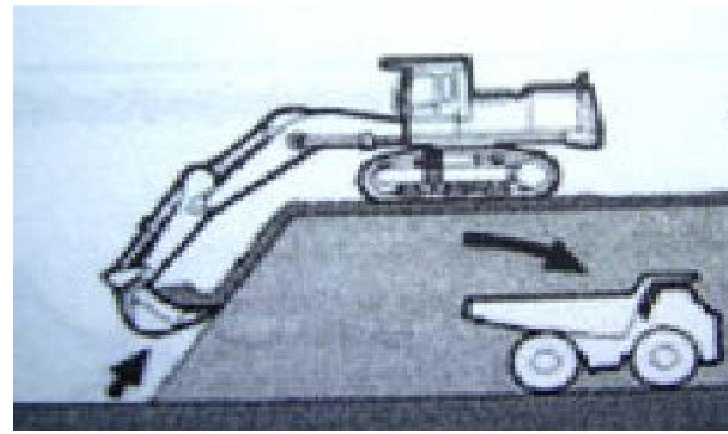
* Percent of heaped bucket capacity

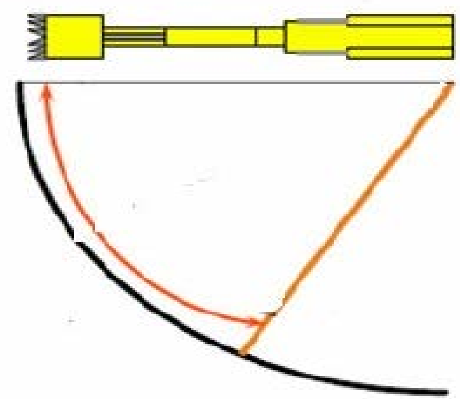
A. Productivity of Face Shovel

STEP 3: CYCLE TIME

- There are four elements in the production cycle of shovel:

1. Load bucket ….7-9sec
2. Swing with load ..4-6sec
3. Dump load ……..2-4 sec
4. Return swing …..4-5sec





A. Productivity of Face Shovel

STEP 3: CYCLE TIME

Typical excavation cycle times based on machine (bucket) size

The cycle times must be increased when loads are dumped into a smaller haul units. Small machine swing faster than large ones.

Excavation cycle times for hydraulic crawler hoes under average condition					
Bucket size (cu.m)	Load bucket (sec)	Swing loaded (sec)	Dump bucket (sec)	Swing empty (sec)	**Total cycle (sec)**
<0.75	5	4	2	3	**14**
0.75 - 1.2	6	4	2	3	**15**
1.5 - 2.0	6	4	3	4	**17**
2.25	7	5	4	4	**20**
2.6	7	6	4	5	**22**
3	7	6	4	5	**22**
3.8	7	7	4	6	**24**

A. Productivity of Face Shovel

STEP-3A DEPTH OF CUT

obtain maximum dig depth from manufacturer's data and check for optimum depth of cut within the range of 30% to 50%.

- The optimum height is 30% of max. digging height for material that is easy to excavate and load, such as loam, sand, or gravel.
- The optimum height is 40% of the max. digging height for Common earth.
- The optimum height is 50% of the max. digging height for tough materials, such as stick clay or blasted rock.

A. Productivity of Face Shovel

STEP 3B: Angle of Swing

- Angle of swing of a shovel is the horizontal angle, expressed in degrees, between the position of the bucket when it is excavating and the position where it discharges the load.
- The total cycle time includes digging, swing to the dumping position, dumping, and returning to the digging position.
- Increasing the swing angle will increase the cycle time and vice versa.

A. Productivity of Face Shovel

- STEP 3B: Angle of Swing
- The effect of height of cut and Angle of Swing on Shovel production published by PCSA from field study can be

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

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

A. Productivity of Face Shovel

STEP 4: EFFICIENCY FACTOR

- When selecting a minutes per hour efficiency factor visualize the work site and consider:
- Materials being handled, bank or broken
- Size of the shovels' dumping target,(large or small)

STEP 5: CLASS of MATERIAL

- Production will be in lcy, will need swell factor to adjust to bcy.

A. Productivity of Face Shovel

STEP 6: PRODUCTION

$$\boldsymbol{Production} = \frac{3600sec \times Q \times F \times (AS{:}D)}{t} \times \frac{E}{60min\ hr} \times \frac{1}{volume\ correction}$$

Where: Q=heaped capacity(lcy)

F=bucket fill factor

AS:D=angle of swing and depth(height) of cut correction

t= cycle time in second

E=efficiency (in min per hr)

A. Productivity of Face Shovel

Volume correction for loose volume to bank volume , $\frac{1}{1+swell}$

For loose volume to tons, $\frac{loose\ unit\ weight, lb}{2000 lb/ton}$

The above figures are for crawler type of tractor shovel, however for wheel shovels, bucket factor is about 10% lesser than those mentioned above.

Example

A 5-cu-yd shovel having a maximum digging height of 34 ft is being used to load poorly blasted rock. The face being worked is 12 ft high and the haul units can be positioned so that the swing angle is only 60^0. What is the adjusted ideal production if the ideal cycle time is 21 sec.

Solution

- **STEP1** : Size of the bucket 5cy
- **STEP2:**bucket fill factor for poor blasted rock:85%to 100% ;use 85% conservative.
- **STEP3:**cycle time given 21sec

Average height of excavation 12ft.

Optimum height for this machine and material(poorly blasted rock)=50%*34ft=17ft

Percentage optimum height=$\frac{12ft}{17ft} = 0.71$

Solution

- **STEP4:**Efficiency factor-ideal production,60 min hr.
- **STEP5:**Production will be in lcy
- **STEP6:**Ideal production per 60 min hour

$$\frac{3600\ \frac{\text{sec}}{\text{hr}} * 5cy * 0.85 * 1.08 *}{21\ \text{sec}/cycle} = 787\text{lcy/hr}$$

EXAMPLE 2

- A 3-cu-yd shovel, having a maximum digging height of 30 ft, will be used on a highway project to excavate well-blasted rock. The average face height is expected to be 22 ft. Most of the cut will require a 140^0 swing of the shovel in order to load the haul units. Determine the estimated production in cubic yards bank measure.

SOLUTION

- **STEP 1:** size of the bucket,3cy
- **STEP 2:** bucket fill factor for well blasted rock:100%to 110% ;use 100% estimate
- **STEP3:** cycle element time

Load	9sec (because of material ,rock)
swing loaded	4sec(small machine,3cy)
Dump	4sec(into haul units)
swing empty	4sec (small machine,3cy)
Total	=21sec

Average height of excavation 22ft

SOLUTION

- Optimum height for this machine and material(well blasted rock)=50%*30ft=15ft
- Percentage optimum height=$\frac{22ft}{15ft} * 100 = 147\%$
- height and swing for 147% from table 2 by interpolation;0.73
- **STEP4:**Efficiency factor: if the transportation research board (TRB)information were used, the efficiency would be 30 to 45 min per hour.assume

30 min for conservation estimates.

SOLUTION

- **STEP5:**Class of material, well blasted rock, swell 60%(table)
- **STEP6:** Production:

$$\frac{3600sec/hr \times 3cy \times 1 \times 0.73}{21sec/cycle} \times \frac{30min}{60min} \times \frac{1}{1+0.6} = \mathbf{117}\boldsymbol{bcy/hr}$$

Hydraulic Hoe : Production Estimating

- The same elements that affect shovel production are applicable to hoe excavation operation.
- Hoe cycle times are approximately 20% longer than similar size shovel and work.
- The optimum depth of cut for hoe is usually in the range of 30 to 60%.
- Standard data for "Cycle time" based on bucket size and average conditions (30-60^{0}swing angle, hauling unit at same level etc. is available.

Hydraulic Hoe : Production Estimating

- No standard data and factors based on angle of swing and depth of cut is available.
- **Step-1: Bucket size** (lcm)(From the manufacturer specification for the size of bucket to be used. Many different size buckets will fit the same machine. Interested in heaped capacity).
- **Step-2**: **Fill Factor**:(From the table for corresponding type of material. Heaped capacity is base on 1:1 material angle of repose. It must be adjusted based on the characteristics of material being handled).

Hydraulic Hoe : Production Estimating

- [Bucket volumetric capacity (lcm) = Heaped capacity *Fill Factor]

Bucket fill Factor	
Material	Bucket factor
Moist loam or sandy clay	1.0 - 1.1
Common soil	0.9 - 1.0
Sand and gravel	0.85 – 0.95
Hard tough clay	0.8 - 0.9
Rock –well blasted	0.6 - 0.75
Rock – poorly blasted	0.4 - 0.5

Hydraulic Hoe : Production Estimating

Step-3: Cycle time (sec)(Load + Swing with load + Dump + Swing empty).

Typical excavation cycle times based on machine (bucket) size

Excavation cycle times for hydraulic crawler hoes under average condition					
Bucket size (cu.m)	Load bucket (sec)	Swing loaded (sec)	Dump bucket (sec)	Swing empty (sec)	**Total cycle (sec)**
<0.75	5	4	2	3	**14**
0.75 - 1.2	6	4	2	3	**15**
1.5 - 2.0	6	4	3	4	**17**
2.25	7	5	4	4	**20**
2.6	7	6	4	5	**22**
3	7	6	4	5	**22**
3.8	7	7	4	6	**24**

Hydraulic Hoe : Production Estimating

- The cycle times must be increased when loads are dumped into a smaller haul units. Small machine swing faster than large ones.
- Depth of cut: 40 to 60%
- Swing angle = $30^0 – 60^0$
- **Step-4: Depth of cut** (Obtain maximum dig depth from manufacturer's data and check for optimum depth of cut within the range of 30% to 60%.)

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

Hydraulic Hoe : Production Estimating

Size Bucket (cu.m)	Stick length (m)	Maximum reach at ground level (m)	Maximum digging depth (m)	Maximum lading height (m)
0.3	1.5 – 2.1	5.8 – 6.7	3.7 – 4.6	4.3 – 4.9
0.6	1.8 – 2.7	7.3 – 8.2	4.9 – 5.5	5.2 – 5.8
0.8	1.5 – 4.0	7.9 – 10.1	4.9 – 7.0	5.2 – 7.6
1.1	1.8 – 4.0	8.2 – 10.7	5.2 – 6.4	5.5 – 7.0
1.5	2.1 – 4.3	8.8 – 11.6	5.5 – 8.2	5.8 – 7.3
1.9	2.1 – 4.9	9.8 – 12.2	6.1 – 8.8	6.1 – 7.9
2.3	3.0 – 3.4	11.6 – 12.8	7.6 – 9.1	7.3 – 7.9
2.7	2.4 – 3.7	11.0 – 11.9	7.0 – 8.2	6.4 – 6.7
3.1	3.4	13.4	8.8	8.2
3.8	2.4 – 4.6	12.2 – 14.0	7.9 – 9.8	7.6 – 7.9

Hydraulic Hoe : Production Estimating

- **Step-5: Efficiency Factor:**

–Bunching(In actual operation cycle time is never constant. When loading haul unit they will sometime bunch. The effect of bunching is a function of the no. of haul units.

–Operator efficiency: (Skill of operator)

–Equipment availability

Hydraulic Hoe : Production Estimating

- **Step-6: Compute production rate,** using following formula.

$$P\ (\text{lcm/hr}) = \left(\frac{3600 \times Q \times F}{t}\right) \times \left(\frac{E}{60}\right)$$

$$P\ (\text{bcm/hr}) = \left(\frac{3600 \times Q \times F}{t}\right) \times \left(\frac{E}{60}\right) \times \left(\frac{1}{1 + \text{S.F.}}\right)$$

Where;

P (lcm/hr) = Production in loose cubic meter (volume) per hour
P (bcm/hr) = Production in bank cubic meter (volume) per hour
P (ton/hr) = Production in tons (weight) per hour
Q = Heaped bucket capacity (lcm)
F = Bucket fill factor
t = Cycle time in seconds
E = Efficiency minutes per hour (take 30-45 if not given)
S.F. = Swell Factor
Luw = Loose unit weight (N)

Example-3

A crawler hoe having a 2.8 cu.m bucket is being considered for use on a project to excavate dry clay from a borrow pit. The clay will be loaded in trucks having a loading height of 3m. Soil-boring information indicates that below, 2.5 m, the material changes to an unacceptable silt material. What is the estimated production of the hoe in cubic meter bank measure, if the efficiency factor is equal to a 50-min hour?

Solution

Step-1: Size of Bucket (Q)= 2.8 cu.m

Step-2: Bucket fill factor (F)= 85%(taken average of 80-90 from the table,. for hard clay)

Step-3: Cycle times (t) = 22 sec (from the table, for nearest bucket size 3 cum)

Step-4: Optimum depth of cut to be within 30% to 60% .From the table maximum depth of cut 7 –8.2 m Depth of cut = 2.5 m

$$\frac{2.5}{7} * 100 = 35.7\%$$

$$\frac{2.5}{8.2} * 100 = 30.4\%$$

checking optimum depth of cut range b/n 30% and 60%.

Solution

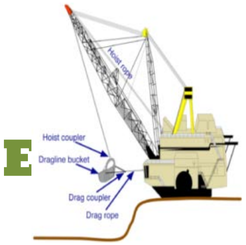
- **Step-5:** Efficiency factor (E)= 50 min per hour (given)
- **Step-6:** Production rate Calculation

$$P(bcm/hr) = \left(\frac{3600\,\text{sec} \times 2.8 \times 0.85}{22} \right) \times \left(\frac{50}{60} \right) \times \left(\frac{1}{1.35} \right)$$

$$= 240.4 bcm/hr$$

Material type vs swell

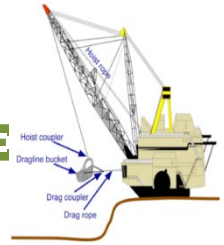
Material	Bank weight		Loose weight		Percent swell	Swell factor
	lb/cu yd	kg/m^3	lb/cu yd	kg/m^3		
Clay,dry	2,700	1,600	2,000	1,185	35	0.74
Clay, wet	3,000	1,780	2,200	1,305	35	0.74
Earth, dry	2,800	1,660	2,240	1,325	25	0.80
Earth, wet	3,200	1,895	2,580	1,528	25	0.80
Earth and gravel	3,200	1,895	2,600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



2. PRODUCTIVITY OF SHOVEL FAMILY AND EXCAVATORS

B. Productivity of Dragline

- Output or performance of dragline depends on the following factors:
  - Nature of the soil.
  - Depth of cut.
  - Angle of swing.
  - Capacity of hauling units, if employed.
  - Mechanical condition of the dragline.
  - Efficiency and skill of the operator.
  - Management conditions.
  - Size and type of bucket.
  - Working cycle



2. PRODUCTIVITY OF SHOVEL FAMILY AND EXCAVATORS

B. Productivity of Dragline

- Data are taken from "Liebher's Technical Hand Book Earth moving Product line".

Drag Line Production = Dragline Capacity (m³) x C x f

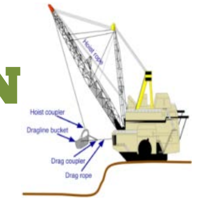
Where, C = Theoretical Cycles/hr = 120 Cycles/hr

f = Correcting factor

$= f_1 \times f_2 \times f_3 \times f_4 \times f_5 \times f_6 \times f_7$

f_2 – Digging factor				
Boom Length (m)	12	18	24	30
Digging factor, f_2	0.86	0.79	0.72	0.65

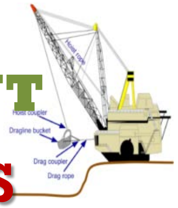
f_3 – Hoist factor				
Boom Length (m)	12	18	24	30
Hoist factor, f_3	0.95	0.92	0.90	0.87



2. PRODUCTIVITY OF SHOVEL FAMILY AND EXCAVATORS

B. Productivity of Dragline

f_1 - Fill factor		
	Class	Fill factor
1	Sand or fine gravel a) Dry b) Damp c) Wet	 1.1 to 1.2 1.0 to 1.1 0.9 to 0.8
2	Clay a) Sandy clay, dry b) Cohesive, dry c) Very cohesive, hard	 0.95 to 1.0 0.9 to 0.95 0.88 to 0.9
3	Earth with sand or gravel, dry	0.85 to 0.88
4	Top Soil a) Sandy clay b) Clay damp	 0.82 to 0.85 0.80 to 0.82
5	Clay with sand or gravel, damp	0.75 to 0.80
6	Slatelike rock, gravel	0.72 to 0.75
7	Gravel with clay, hard	0.70 to 0.72
8	Clay with large size gravel, damp	0.68 to 0.70



2. PRODUCTIVITY OF SHOVEL FAMILY AND EXCAVATORS

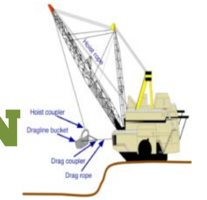
B. Productivity of Dragline

f_4 – Swing factor (Simultaneous swing and hoist)			
Angle of Swing (deg)	90°	120°	180°
Swing factor, f_4	0.98	0.95	0.91

f_5 – Loading factor			
Method of dumping	Truck	Hopper	Stock pile
Loading factor, f_5	0.96	0.95	1.0

f_6 – Job efficiency factor			
Actual working time	60 min/hr	50 min/hr	40 min/hr
Job efficiency factor, f_6	1.0	0.83	0.67

f_7 – Operator factor			
Operator	Experienced	Average	Beginner
Operator factor, f_7	1.0	0.95	0.85



2. PRODUCTIVITY OF SHOVEL FAMILY AND EXCAVATORS

B. Productivity of Dragline

Example 2.2

- **An experienced operator has to excavate 'wet gravel' with a dragline capacity of 2.3 m^3. The boom length is 18m and the swing angle will be 120 degrees. The material is dumped onto stockpile. Actual working time is 50 min per hour.**

  Solution

  Drag line production = Bucket capacity x C x f.

  where C = theoretical cycles/hr = 120 cycles/hr

  $$= 2.3 \times 120 \times f$$

  where $f = f_1 \times f_2 \times f_3 \times f_4 \times f_5 \times f_6 \times f_7 = 0.8 \times 0.79 \times 0.92 \times 0.95 \times 1.0 \times 0.83 \times 1.0$

  $$= 0.4588$$

  Therefore, Drag line production = 2.3x120x0.4588

  $$= 126.4\ m^3/hr$$

2. PRODUCTIVITY OF SHOVEL FAMILY AND EXCAVATORS

C. Productivity of Clamshell

- Data are taken from “Liebher’s Technical Hand Book Earth moving Product line”.

Clamshell Production (m^3/hr)= Clamshell Capacity (m^3) x C x f

Where, C = Theoretical Cycles/hr = 120 Cycles/hr

f = Correcting factor

$= f_1 \times f_2 \times f_3 \times f_4 \times f_5 \times f_6 \times f_7$

Correction factors

- f_1 – Fill factor
    - Same as those for dragline.

2. PRODUCTIVITY OF SHOVEL FAMILY AND EXCAVATORS

C. Productivity of Clamshell

f_2 – Digging factor					
Clamshell capacity (m^3)	1	2	3	4	5
Digging factor, f_2 =	0.98	0.97	0.96	0.96	0.95

f_3 – Hoist factor (considering average rope speed of 50m/min)				
Digging depth (m)	5	10	15	20
Hoist factor, f_3 =	0.88	0.76	0.64	0.52

f_4 – Swing factor				
Swing Angle (deg)	60	90	120	180
Swing factor, f_4=	1.2	1.0	0.98	0.90

f_5 – Dump factor			
Method of dumping	Truck	Hopper	Stock pile
Dump factor, f_5 =	0.90	0.95	1.0

2. PRODUCTIVITY OF SHOVEL FAMILY AND EXCAVATORS

C. Productivity of Clamshell

f_6 – Job efficiency factor			
Actual working time	60 min/hr	50 min/hr	40 min/hr
Job efficiency factor, f_6 =	1.0	0.83	0.67

f_7 – Operator factor			
Operator	Experienced	Average	Beginner
Operator factor, f_7 =	1.0	0.95	0.85

Example 2.3

- An average operator has to excavate ‘damp sand’ with a clamshell of 2.0 m^3. The digging depth is 10m and the swing angle will be 120 degrees. The sand is added into trucks and actual working time is 50 min/hr.

2. PRODUCTIVITY OF SHOVEL FAMILY AND EXCAVATORS

C. Productivity of Clamshell

Solution

Clamshell production = Clamshell capacity x C x f.

where C = theoretical cycles/hr

$= 2.0 \times 120 \times f$

where, $f = f_1 \times f_2 \times f_3 \times f_4 \times f_5 \times f_6 \times f_7$

$= 1.0 \times 0.97 \times 0.76 \times 0.98 \times 0.9 \times 0.83 \times 0.95$

$= 0.5127$

Therefore, Clamshell Production $= 2.0 \times 120 \times 0.5127$

$= 123.0\ m^3/hr$

3. PRODUCTIVITY OF EARTH MOVING EQUIPMENTS

A. Productivity of Loader

- The following example demonstrates the process for estimating loader production.

Example 3-1

- **A *4-cy wheel loader* will be used to load trucks from a quarry stock pile of *processed aggregate* having a maximum *aggregate size of 1¼ in*. The haul distance will be negligible. The aggregate has a *loose unit weight of 3,100*. Estimate the loader production in tons based on *50-min/hour efficiency factor*. Use a conservative fill factor.**

Solution

- **Step-1: *Size of bucket* = 4-cy**
- **Step-2: *Bucket fill factor* (*Table A-1*), aggregate over 1in., 85-90%, use 85% conservative estimate**

PRODUCTIVITY OF THE CONSTRUCTION EQUIPME

Material	Wheel loader fill factor (%)	Track loader fill factor (%)
Loose material		
Mixed moist aggregates	95–100	95–100
Uniform aggregates		
up to $\frac{1}{8}$ in.	95–100	95–110
$\frac{1}{8}-\frac{3}{8}$ in.	90–95	90–110
$\frac{1}{2}-\frac{3}{4}$ in.	85–90	90–110
1 in. and over	85–90	90–110
Blasted rock		
Well blasted	80–95	80–95
Average	75–90	75–90
Poor	60–75	60–75
Other		
Rock dirt mixtures	100–120	100–120
Moist loam	100–110	100–120
Soil	80–100	80–100
Cemented materials	85–95	85–100

3. PRODUCTIVITY OF EARTH MOVING EQUIPMENTS

A. Productivity of Loader

Solution cont.

- Step-2: Bucket fill factor

  Check tipping:

  Load weight: 4-cy x 0.85 = 3.4 lcy

  3.4 lcy x 3,100 lb/lcy (loose unit weight of material) = 10,540 lb.

  From ***Table A-2***, 4-cy machine static tipping load at full turn is 25,000 lb, for wheel loader operating load is limited to less than or equal to***50% of static tipping(***Max loaded bucket) at full turn. Therefore, operating load is

  0.5 x 25,000 lb = 12,500 lb

  10,540 lb actual load < 12,500 lb operating load; therefore okay!

- Step-3: ***Typical fixed time*** (***Table A-4***) 4-cy wheel loader, 30 to 33 sec; use 30 sec.

3. PRODUCTIVITY OF EARTH MOVING EQUIPMENTS

A. Productivity of Loader

Solution cont.

Table A-2 Representative specifications for wheel loader

Size, heaped bucket capacity (cy)	Bucket dump clearance (ft)	Static tipping load, @ full turn (lb)	Maximum forward speed				Maximum reverse speed				Raise/ dump/ lower cycle (sec)
			First (mph)	Second (mph)	Third (mph)	Fourth (mph)	First (mph)	Second (mph)	Third (mph)	Fourth (mph)	
1.25	8.4	9,600	4.1	7.7	13.9	21	4.1	7.7	13.9	—	9.8
2.00	8.7	12,700	4.2	8.1	15.4	—	4.2	8.3	15.5	—	10.7
2.25	9.0	13,000	4.1	7.5	13.3	21	4.4	8.1	14.3	23	11.3
3.00	9.3	17,000	5.0	9.0	15.7	26	5.6	10.0	17.4	29	11.6
3.75	9.3	21,000	4.6	8.3	14.4	24	5.0	9.0	15.8	26	11.8
4.00	9.6	25,000	4.3	7.7	13.3	21	4.9	8.6	14.9	24	11.6
4.75	9.7	27,000	4.4	7.8	13.6	23	5.0	8.9	15.4	26	11.5
5.50	10.7	37,000	4.0	7.1	12.4	21	4.6	8.1	14.2	24	12.7
7.00	10.4	50,000	4.0	7.1	12.7	22	4.6	8.2	14.5	25	16.9
14.00	13.6	98,000	4.3	7.6	13.0	—	4.7	8.3	14.2	—	18.5
23.00	19.1	222,000	4.3	7.9	13.8	—	4.8	8.7	15.2	—	20.1

3. PRODUCTIVITY OF EARTH MOVING EQUIPMENTS

A. Productivity of Loader

Table A-3 Representative specification for truck loaders

Size, heaped bucket capacity (cy)	Bucket dump clearance (ft)	Static tipping load (lb)	Maximum forward speed (mph)	Maximum reverse speed (mph)	Raise/ dump/ lower cycle (sec)
1.00	8.5	10,500	6.5	6.9	11.8
1.30	8.5	12,700	6.5	6.9	11.8
1.50	8.6	17,000	5.9*	5.9*	11.0
2.00	9.5	19,000	6.4*	6.4*	11.9
2.60	10.2	26,000	6.0*	6.0*	9.8
3.75	10.9	36,000	6.4*	6.4*	11.4

Table A-4 Fixed cycle time for loaders

Loader size, heaped bucket capacity (cy)	Wheel loader cycle time* (sec)	Track loader cycle time* (sec)
1.00–3.75	27–30	15–21
4.00–5.50	30–33	—
6.00–7.00	33–36	—
14.00–23.00	36–42	—

3. PRODUCTIVITY OF EARTH MOVING EQUIPMENTS

A. Productivity of Loader

Solution cont.

- Step-4: Efficiency factor, 50 min/hour
- Step-5: Class of material, aggregate 3,100 lb per lcy.
- Step-6: Probable production

$$p(lb/hr) = \frac{3600\,\mathrm{sec} \times Q \times F}{t} \times \frac{E}{60\,\mathrm{min}} \times \frac{unitwt, lb}{2000 lb/ton}$$

$$\frac{3{,}600\ \mathrm{sec/hr} \times 4\ \mathrm{cy} \times 0.85}{30\ \mathrm{sec/cycle}} \times \frac{50\ \mathrm{min}}{60\ \mathrm{min}} \times \frac{3{,}100\ \mathrm{lb/lcy}}{2{,}000\ \mathrm{lb/ton}} = 527\ \mathrm{ton/hr}$$

3. PRODUCTIVITY OF EARTH MOVING EQUIPMENTS

B. Productivity of a Dozer

- The production of dozer mainly depend upon the following factors:
    - i. Size and condition of the dozer
    - ii. Distance traveled by the dozer
    - iii. Speed of operation
    - iv. Characteristic of soil being handled
    - v. Surface on which dozer is operating
    - vi. Efficiency
- A dozer has no set volumetric capacity. There is no hopper or bowl to load; instead, the amount of material the dozer moves is dependant on the quantity that will remain in front of the blade during the push.

3. PRODUCTIVITY OF EARTH MOVING EQUIPMENTS

B. Productivity of a Dozer

- The major factors that control dozer production rate are:
  1. Condition of the material
  2. Blade type
  3. Cycle time

1. Condition of the material

- The type and condition of the material being handled affects the shape of the pushed mass in front of the blade.
  - Cohesive materials (clays)
  - Materials that exhibit a slippery quality or those that have high mica content will ride over the ground and swell out.
  - Cohesionless materials (sands) are known as “dead” materials because they do not exhibit heap or swell properties.

3. PRODUCTIVITY OF EARTH MOVING EQUIPMENTS

B. Productivity of a Dozer

1. Condition of the material

3. PRODUCTIVITY OF EARTH MOVING EQUIPMENTS

B. Productivity of a Dozer

2. Blade type

- Blade capacity is a function of a ***blade type*** and ***physical size***.

Blade volumetric load

- The load that a blade will carry can be estimated by several methods:
  1. Manufacturer's blade rating
  2. Previous experience (similar material, equipment, and work conditions)
  3. Field measurements

i. Manufacturers Blade rating

- Manufacturers may provide a blade rating based on SAE practice J1265.

3. PRODUCTIVITY OF EARTH MOVING EQUIPMENTS

B. Productivity of a Dozer

2. Blade type

i. Manufacturers Blade rating

$$V_s = 0.8\, W H^2$$
$$V_u = V_s + ZH(W - Z) \tan x^{\circ}$$

Where

V_s	=	capacity of straight or angle blade, in lcy
V_u	=	capacity of universal blade, in lcy
W	=	blade width, in yd, exclusive of end bits
H	=	effective blade height, in yd
Z	=	wing length measured parallel to the blade width, in yd
x	=	wing angle

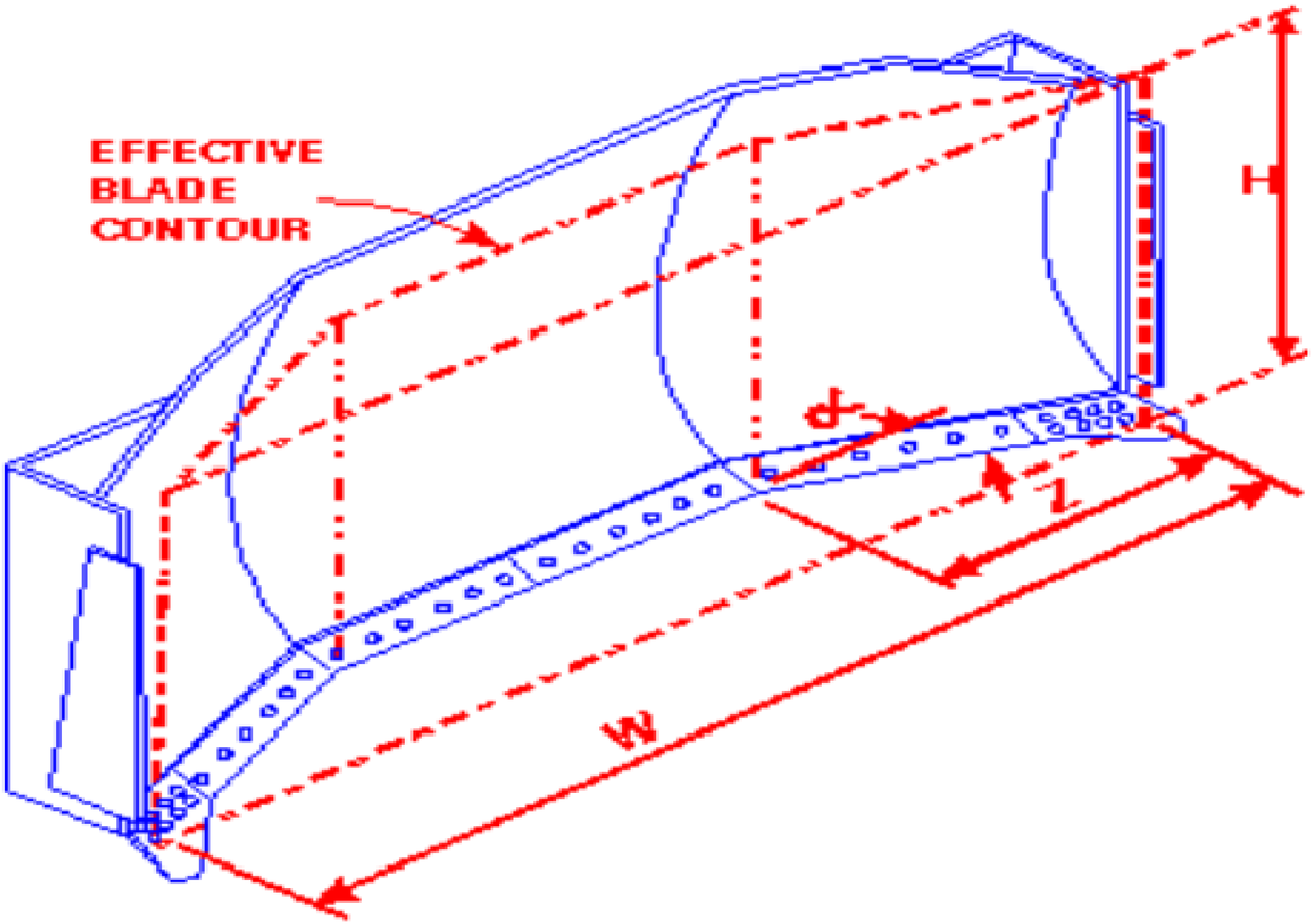


FIG. 4 - EFFECTIVE BLADE CONTOUR - SEMI-U & U-BLADES

3. PRODUCTIVITY OF EARTH MOVING EQUIPMENTS

B. Productivity of a Dozer

2. Blade type

Blade volumetric load

ii. Previous experience

- Properly documented past experience is an excellent blade load estimating method.

iii. Field measurement

- Measurement
  - Measure the height (*H*) *of the pile at the* inside edge of each rack.
  - Measure the width (*W*) *of the pile at the* inside edge of each rack.
  - Measure the greatest length (*L*) *of the* pile. This will not necessarily be at the middle.

3. PRODUCTIVITY OF EARTH MOVING EQUIPMENTS

B. Productivity of a Dozer

2. Blade type

Blade volumetric load

iii. Field measurement

- Computation
  - Average both the two-height and the two-width measurements. If the measurements are in feet, the blade load in loose cubic yards (lcy) is calculated by the formula

$$\text{Blade load (lcy)} = 0.0139\, H\, W\, L$$

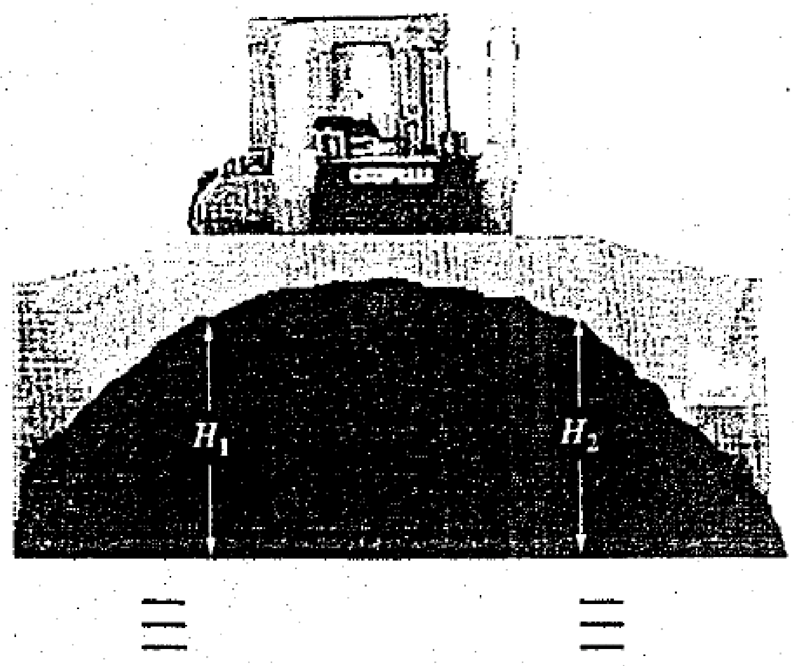
3. PRODUCTIVITY OF EARTH MOVING EQUIPMENTS

B. Productivity of a Dozer

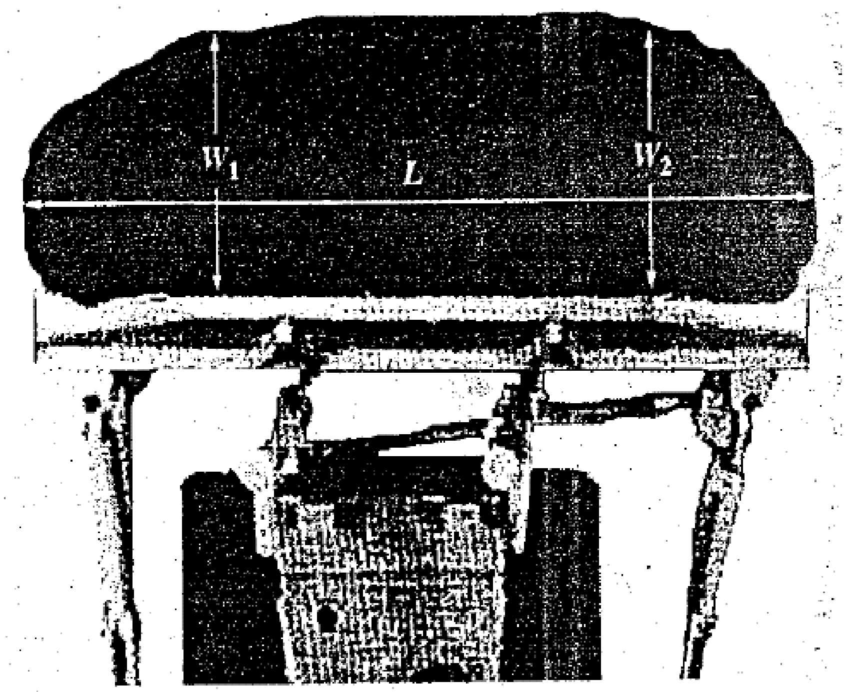
2. Blade type

Blade volumetric load

iii. Field measurement



Front view



Top view

3. PRODUCTIVITY OF EARTH MOVING EQUIPMENTS

B. Productivity of a Dozer

2. Blade type

Example 3.3

The measurement from a blade-load test were H_1 = 4.9 ft, H_2 = 5.2 ft, W_1 = 6.9 ft, W_2 = 7.0 ft,and L = 12.6 ft. What is the blade capacity in loose cubic yards for the tested material?

$$H = \frac{4.9 + 5.2}{2} = 5.05 \text{ ft}, \qquad W = \frac{6.9 + 7.0}{2} = 6.95$$

$$\text{Blade Load (lcy)} = 0.0139HWL = 0.0139(5.05)(6.95)(12.6) = 6.15 \text{ lcy}$$

3. PRODUCTIVITY OF EARTH MOVING EQUIPMENTS

Cycle time of a Dozer

- The sum of the time required to push, backtrack, and maneuver into position to push represents the complete dozer cycle.
- Dozing is generally performed at slow speed, 1.5 to 2 mph.
- Return Speed is usually the maximum that can be attained in the distance available.
- Dozer cycle time = fixed cycle time +variable cycle time

3. PRODUCTIVITY OF EARTH MOVING EQUIPMENTS

B. *Productivity of a Dozer*

- The following example demonstrates the process for estimating dozer production.

Example 3.4

- A ***power-shift crawler*** tractor has a rated ***blade capacity of 7.65Lm³***. The dozer is excavating ***loose common earth*** and pushing a ***distance of 200ft (61m)*** with speed of ***4km/hr***. Maximum ***reverse speed*** in third range is ***8 km/hr***. Estimate the production of the dozer, if job ***efficiency*** is ***50 min/hr***.

Solution

- Fixed time = 0.05 min (From ***Table B-1***)
- Dozing speed = 4.0 km/hr given but can be obtained from ***Table B-2***.

Table B-1 Typical dozer fixed cycle times	
Operating condition	**Time (min)**
Power-shift transmission	0.05
Direct-drive transmission	0.10
Hard digging	0.15

Table B-2 Typical dozer operating speeds	
Operating conditions	**Speeds**
Dozing	
Hard materials, haul 30m or less	2.4 Km/hr
Hard materials, haul over 30m	3.2 Km/hr
Loose materials, haul 30m or less	3.2 km/hr
Loose material haul over 30m	4.0 km/hr
Return	
30m or less	Max reverse speed in second range (power shift) or reverse speed in gear used for dozing (direct drive)
Over 30m	Max reverse speed in third range (power shift) or highest reverse speed

3. PRODUCTIVITY OF EARTH MOVING EQUIPMENTS

B. Productivity of a Dozer

Solution cont.

$$\text{Dozing time} = \frac{61\text{m}}{4\text{ km/hr x }16.7\text{ m/min}} = 0.91\text{min}$$

Note: 1km/hr = 16.7 m/min

$$\text{Return time} = \frac{61\text{m}}{8\text{ km/hr x }16.7\text{ m/min}} = 0.45\text{ min}$$

$$Cycletime = (0.05 + 0.91 + 0.45)\min = 1.14\min$$

$$P(lcm/hr) = \frac{Q(lcm) \times E(\min/hr)}{t(\min)}$$

$$production = \frac{7.65Lm^3 \times 50 \,{}^{\min}\!/_{hr}}{1.14\min} = 271 \,{}^{Lm^3}\!/_{hr}$$

3. PRODUCTIVITY OF EARTH MOVING EQUIPMENTS

B. Productivity of a Dozer

Use of graphs, charts and curves for estimating production

- Production curves for estimating the amount of material that Caterpillar bulldozers can push are usually available by the manufacturers.
- These curves are published in the Caterpillar Performance Handbook.
- The bulldozer production curves give ***maximum uncorrected production*** for universal, semi-universal, and straight blades and are based on the following conditions:
  - 100% efficiency (60 minute hour — level cycle).
  - Power shift machines with 0.05 min. fixed times.
  - Machine cuts for 15 m (50 feet), then drifts blade load to dump over a high wall. (Dump time — 0 sec.)
  - Soil density of 1370 kg/Lm^3 (2300 lb/LCY).

3. PRODUCTIVITY OF EARTH MOVING EQUIPMENTS

B. Productivity of a Dozer

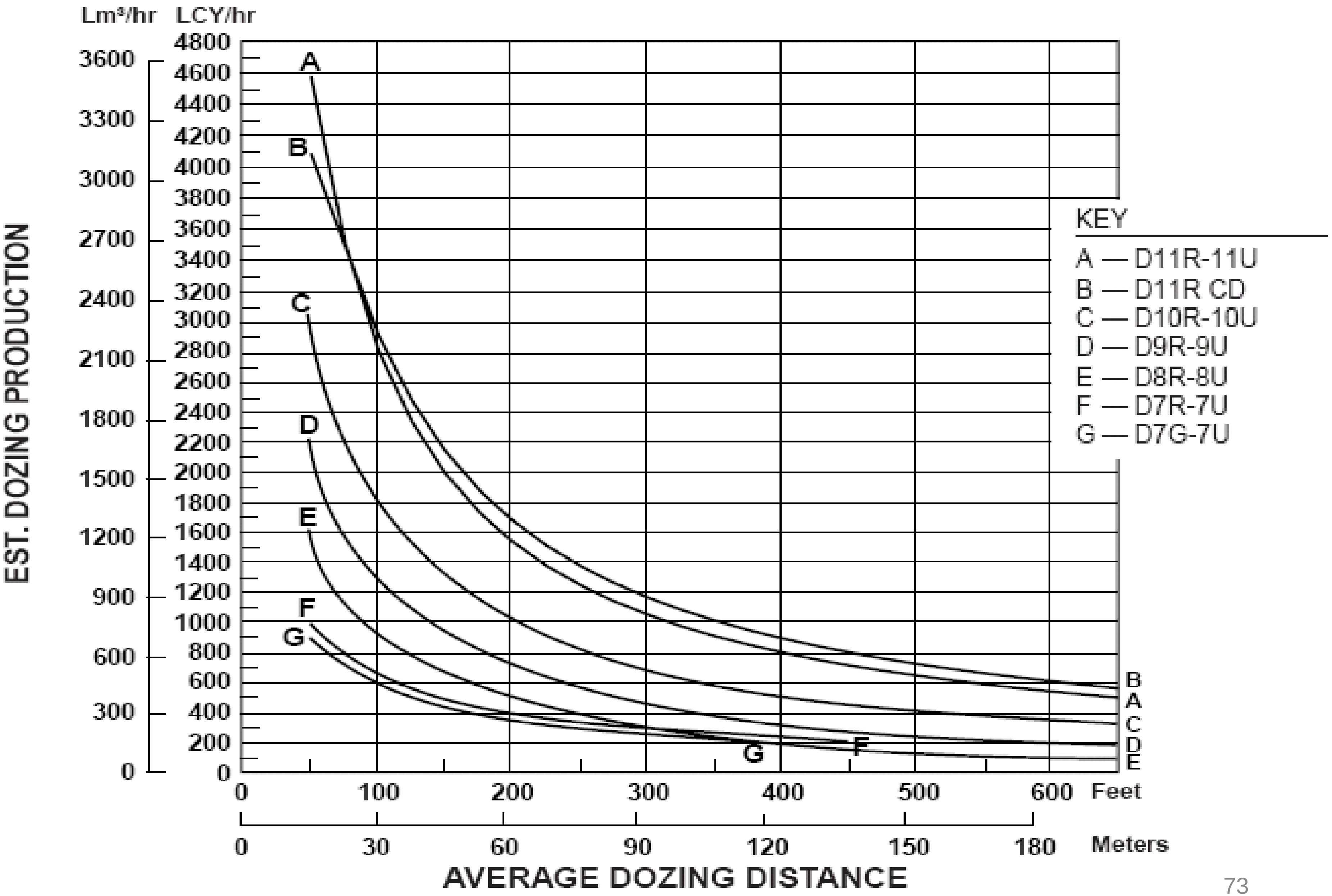
Use of graphs, charts and curves for estimating production

$$\begin{matrix}\text{Production (Lm}^3\text{/hr)} \\ \text{(LCY/hr)}\end{matrix} = \begin{matrix}\text{Maximum} \\ \text{production}\end{matrix} \times \begin{matrix}\text{Correction} \\ \text{factors}\end{matrix}$$

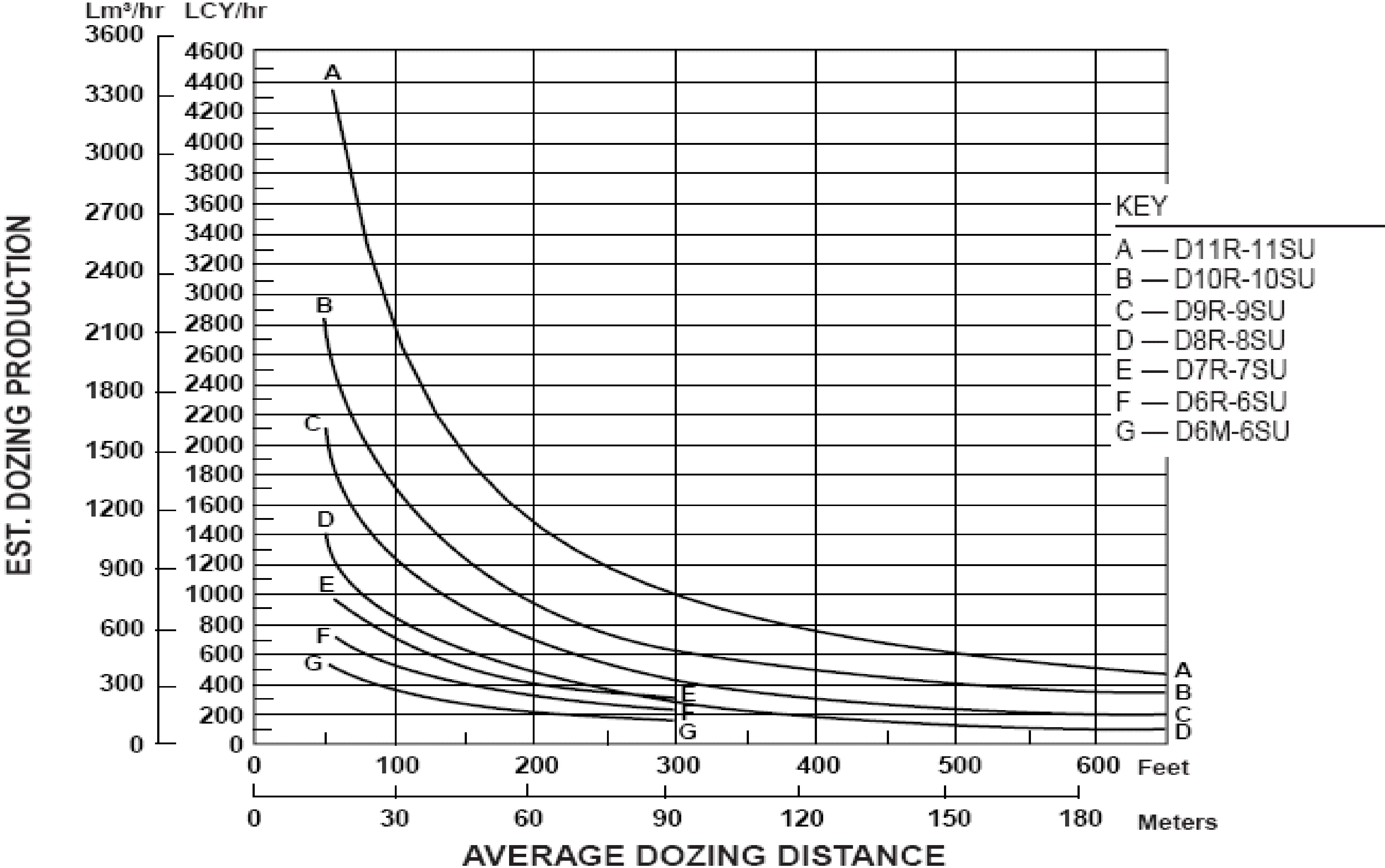
- To obtain estimated production in bank cubic meters or bank cubic yards, appropriate load factor from the Tables section should be applied to the corrected production as calculated above.

$$\begin{matrix}\text{Production Bm}^3\text{/hr} \\ \text{(BCY/h)}\end{matrix} = \begin{matrix}\text{Lm}^3\text{/hr} \times \text{LF} \\ \text{(LCY/h)} \times \text{LF}\end{matrix}$$

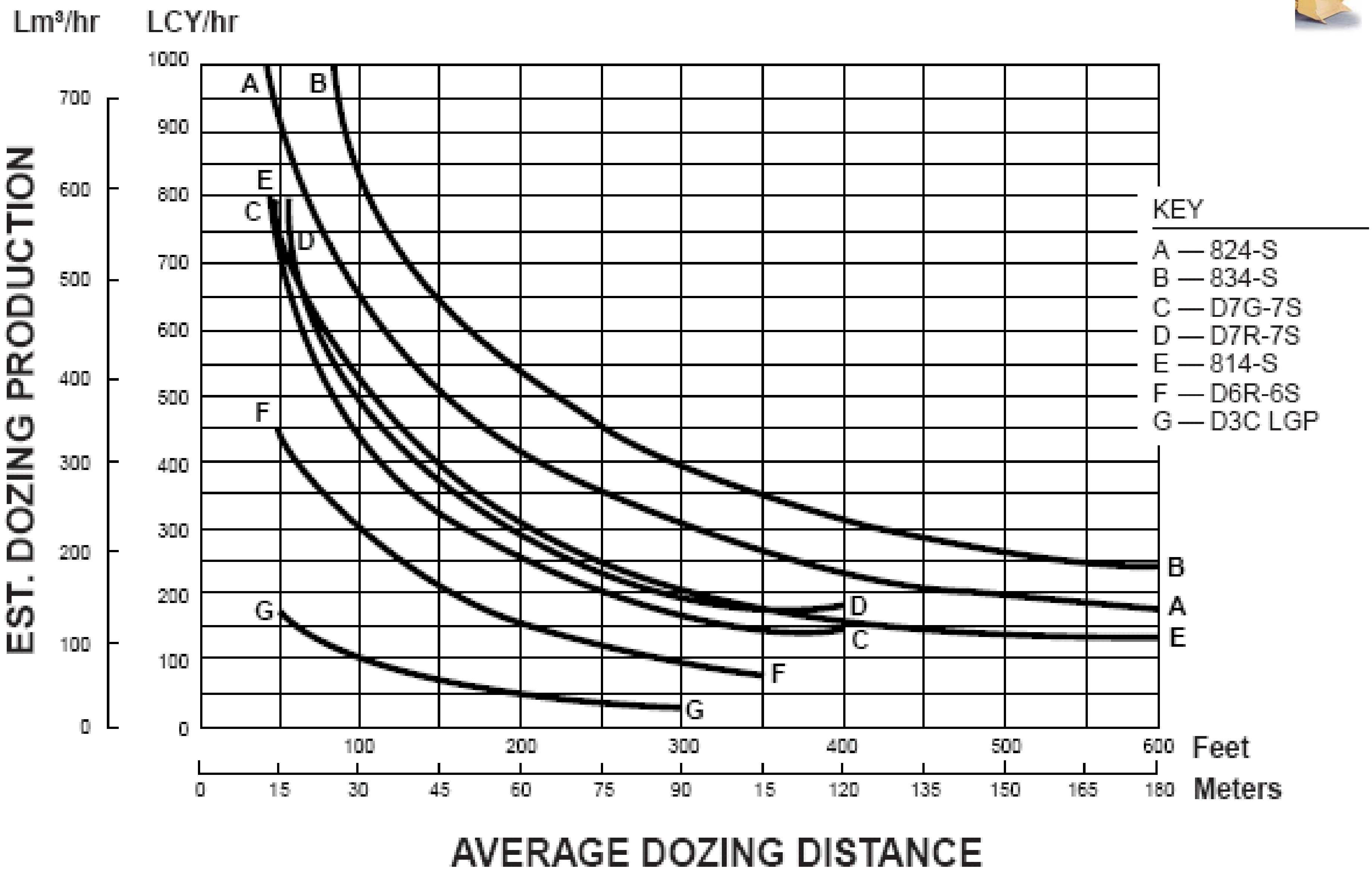
ESTIMATED DOZING PRODUCTION • Universal Blades • D7G through D11R



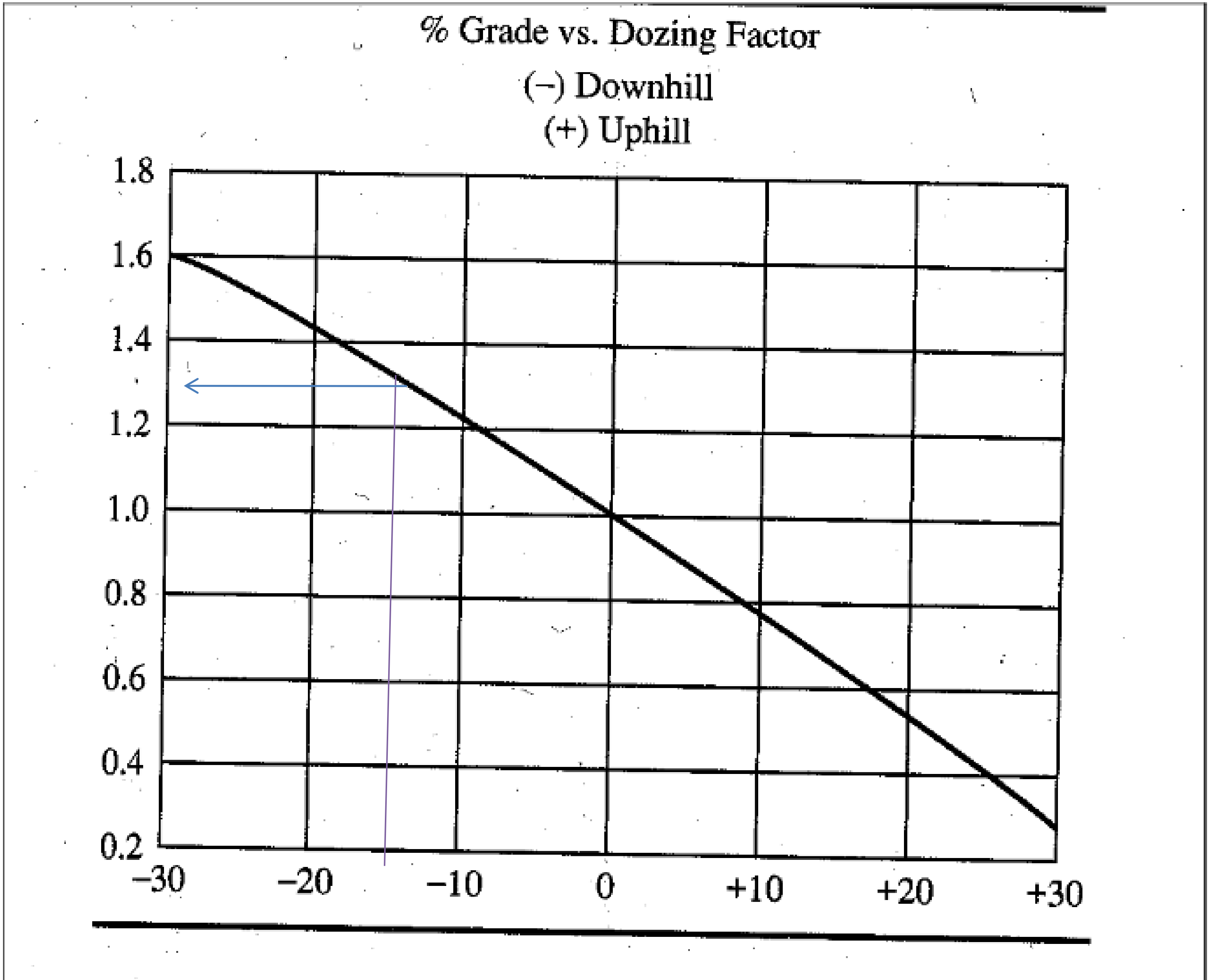
ESTIMATED DOZING PRODUCTION • Semi-Universal Blades • D6M through D11R



ESTIMATED DOZING PRODUCTION
Straight Blades ● D3, D6, D7, 814, 824, 834



	Track-type Tractor	Wheel-type Tractor
Operator		
Excellent	1.00	1.00
Average	0.75	0.75
Poor	0.60	0.50
Material		
Loose stockpile	1.20	1.20
Hard to cut; frozen		
with tilt cylinder	0.80	0.75
without tilt cylinder	0.70	-
cable controlled blade	0.60	-
Hard to drift; (dry, non-cohesive material) or very sticky material	0.80	0.80
Rock, ripped or blasted	0.60 to 0.80	-
Slot dozing	1.20	1.20
Side-by-side dozing	1.15 to 1.25	1.15 to 1.25
Visibility		
Dust, rain, snow, fog or darkness	0.80	0.80
Job efficiency		
50-min per hour	0.83	0.83
40-min per hour	0.67	0.67
Direct drive transmission (0.1-min fixed time)	0.80	-
Grades	See following graph	See following graph


% Grade vs. Dozing Factor
(−) Downhill
(+) Uphill
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
−30
−20
−10
0
+10
+20
+30

3. PRODUCTIVITY OF EARTH MOVING EQUIPMENTS

B. Productivity of a Dozer

Use of graphs, charts and curves for estimating production

Example 3.3

- **Determine average hourly production of a D8R/8SU (with tilt cylinder) moving hard-packed clay an average distance of 45m (150 feet) down a 15% grade, using a slot dozing technique.**

  Estimated material weight is 1600 kg/Lm3 (2650 lb/LCY). Operator is average. Job efficiency is estimated at 50 min/hr.

Solution

- **Uncorrected Maximum Production — 458 Lm^3/hr (600 LCY/hr) from Estimated dozer production graph for Semi universal blade.**

3. PRODUCTIVITY OF EARTH MOVING EQUIPMENTS

B. Productivity of a Dozer

Use of graphs, charts and curves for estimating production

Solution

Applicable Correction Factors:

Hard-packed clay is "hard to cut" material –0.80
Grade correction (from graph) . . . . –1.30
Slot dozing . . . . –1.20
Average operator . . . . –0.75
Job efficiency (50 min/hr) . . . . –0.83
Weight correction . . . .(2300/2650)–0.87

$$\begin{aligned}\text{Production} &= \text{Maximum Production} \times \text{Correction Factors}\\ &= (600\ \text{LCY/hr})\ (0.80)\ (1.30)\ (1.20)\ (0.75)\ (0.83)\ (0.87)\\ &= 405.5\ \text{LCY/hr}\end{aligned}$$

To obtain production in metric units, the same procedure is used substituting maximum uncorrected production in Lm^3.

$$\begin{aligned}&= 458\ Lm^3/h \times \text{Factors}\\ &= 309.6\ Lm^3/h\end{aligned}$$

3. PRODUCTIVITY OF EARTH MOVING EQUIPMENTS

B. Productivity of a Dozer

Productivity of Rippers

- Out put of rippers depend upon characteristic of soil, size of the dozer, speed of the machine, shape and size of the ripper tooth, number of shanks used, and depth and width of ripping pass.
- However, the following are the formulae used in general for calculating the out put of ripper.

Production per hour = (Bank volume ripped per pass) x (No. of passes per hour)

Where, Bank volume ripped per pass = (Length of pass)x(Width of ripping pass)x(Depth of penetration)x(Efficiency)

No. of passes per hour = 60/(Time for making one pass in min.)

Time taken in one pass = (Length of pass/Traveling speed) + Turn round

3. PRODUCTIVITY OF EARTH MOVING EQUIPMENTS

C. Productivity of Scraper

- Out put of scrapers depends on the following main factors:
  - i. Size and mechanical condition of the scraper
  - ii. Hauling distance
  - iii. Condition of the haul road
  - iv. Characteristics of soil and work area.
  - v. Efficiency
- Steps for determining production of scraper are summarised as follow:
  - ***Step-1***: Determination of weight (Empty vehicle weight, load weight and gross vehicle weight)
  - ***Step -2***: Rolling resistance
  - ***Step-3***: Grade resistance/assistance
  - ***Step-4***: Total resistance/assistance

READING ASSIGNMENT

3. PRODUCTIVITY OF EARTH MOVING EQUIPMENTS

C. Productivity of Scraper

- Steps for determining production of scraper are summarised as follow:
  - ***Step-5***: Travel speed
  - ***Step-6***: Travel time
  - ***Step-7***: Load time
  - ***Step-8***: Dump time
  - ***Step-9***: Turning time
  - ***Step-10***: Total cycle time
  - ***Step-11***: Pusher cycle time
  - ***Step-11***: Total resistance/assistance
  - ***Step-12***: Balance fleet time
  - ***Step-13***: Efficiency
  - ***Step-14***: Production

READING ASSIGNMENT

4. PRODUCTIVITY OF GRADING EQUIPMENTS

- Out put of a motor grader depends upon the following main factors:
  1. Size and mechanical condition of the motor grader
  2. Size of the blade
  3. Speed of travel
  4. Characteristics of soil being handled
  5. Efficiency of the operator
- In the majority of the cases, as the grader has multiple applications, the computation of its productivity is not always possible. It can, however, be estimated, case by case.

Method-1

- ***Average actual productivity*** for ***levelling and spreading*** can be computed as follow:

PRODUCTIVITY OF THE CONSTRUCTION EQUI

Method-1

$$Q_a = B \times L \times f_N \times f_Z \times 60/T \ [m^2/hr]$$

$$B = l \times \cos A$$

Where, B = width per strip with due consideration of over lapping

l = length of blade

A = Angle of blade width respect to the axis (refer Table 4.1)

L = lift thickness after compaction

f_N = factor to take care of *site conditions*, operator effectiveness (refer Table 4.2)

f_Z = time factor (refer Table 4.3)

T = Cycle time,

$$T = \frac{P \times D}{S \times E}$$

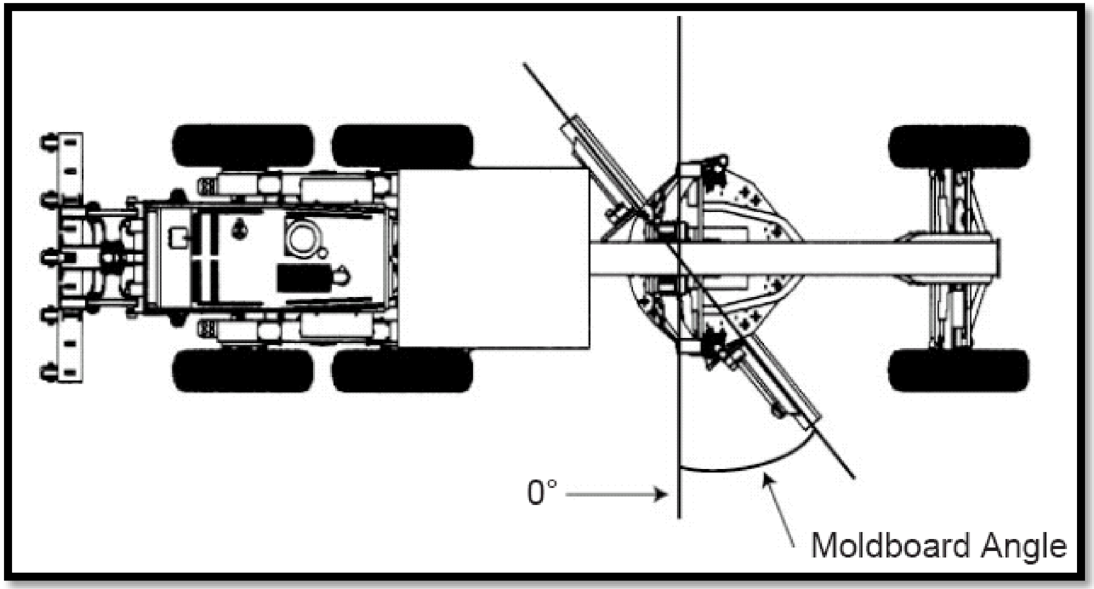
P = number of passes

D=Distance traveled in each pass

S=Speed of grade

E=Grader efficiency

Table 4.1 Blade angle for different operation	
Type of earth/operation	Angle A in degrees
Normal	30
Hard earth	45
Loose and light material	20
Scarify, mix and spreading across	30-50
Fine levelling and spreading along	0-30



Productivity of the construction Equi

Table 4.2 f_N- factor to take care of site conditions and operator effectiveness				
	Very good	good	Average	Poor
Site condition	0.95	0.9	0.8	0.6
Operator effectiveness	1.0	0.85	0.75	0.6

Table 4.3.A Average speed for different operation

Type of operation	Speed in Km/hr
Road maintenance	4-9
Mix	8
Spread	4-9
Sub base work	4-8
Fine levelling	9-22
Cutting slopes	7-9
Ditching	4-8
Back ward and idle non operational speed	10-Vmax as per manufacturers Spec.

Productivity of the construction Equi

Table 4.3.B Average speed for different operation	
Type of operation	**Speed in Km/hr**
Bank slopping	4.0
Ditching	4-6
Finishing	6.5-14.5
Grading and road maintenance	6.4-9.7
Mining	14.5-32.2
Snow removal	19.3-32.2
Spreading	9.7-14.5

4. PRODUCTIVITY OF GRADING EQUIPMENTS

Method-2

- Grader production is also calculated as area covered by motor grader per hour.

$$A(m^2/hr) = B \times V_{av} \times \eta$$

Where, B = width per strip (m)

$= 0.8 \times l \times \cos A$

l = *length of blade*

A = *Angle with respect to axis*

V_{av} = *Average speed (m/hr)*

η = *efficiency*

- Time required to complete a roadway project can be calculated by

$$T = \frac{\text{Number of passes x Distance (Km)}}{\text{Average speed (Km/hr) x Efficiency factor}}$$

4. PRODUCTIVITY OF GRADING EQUIPMENTS

Method-3 (CAT Performance handbook)

- One method expresses a motor grader's production in relation to the area covered by the moldboard.

$$A = S \times (L_e - L_o) \times 1000 \times E \text{ (Metric)}$$

$$A = S \times (L_e - L_o) \times 5280 \times E \text{ (English)}$$

where, A = *Hourly operating area* (m^2/h *or* ft^2/h)

S = *Operating speed (Km/h or mph)*

L_e = *Effective blade length (m or ft)*

L_o = *Width of overlap (m or ft)*

E = *Efficiency*

4. PRODUCTIVITY OF GRADING EQUIPMENTS

Method-3 (CAT Performance handbook)

- ***Operating speeds:*** typical operating speeds by operation are provided as follow:

Finish Grading:	0-4 km/h	(0-2.5 mph)
Heavy Blading:	0-9 km/h	(0-6 mph)
Ditch Repair:	0-5 km/h	(0-3 mph)
Ripping:	0-5 km/h	(0-3 mph)
Road Maintenance:	5-16 km/h	(3-9.5 mph)
Haul Road Maintenance:	5-16 km/h	(3-9.5 mph)
Snow Plowing:	7-21 km/h	(4-13 mph)
Snow Winging:	15-28 km/h	(9-17 mph)

- ***Effective blade length***: Since the moldboard is usually angled when moving material, an effective blade length must be computed to account for this angle. This is the actual width of material swept by the moldboard.

4. PRODUCTIVITY OF GRADING EQUIPMENTS

Method-3 (CAT Performance handbook)

- ***Effective blade length***:

Moldboard Length, m (ft)	Effective Length, m (ft) 30 degree blade angle	Effective Length, m (ft) 45 degree blade angle
3.658 (12)	3.17 (10.4)	2.59 (8.5)
3.962 (13)	3.43 (11.3)	2.80 (9.2)
4.267 (14)	3.70 (12.1)	3.02 (9.9)
4.877 (16)	4.22 (13.9)	3.45 (11.3)
7.315 (24)	6.33 (20.8)	5.17 (17.0)

- ***Width overlap***: The width of overlap is generally ***0.6 m*** (2.0 ft). This overlap accounts for the need to keep the tires out of the windrow on the return pass.

Method-3 (CAT Performance handbook)

- ***Job Efficiency***: **Job efficiencies vary based on job conditions, operator skill, etc.**
- **A good estimation for efficiency is approximately *0.70 to 0.85*, but actual operating conditions should be used to determine the best value.**

Example 4-1

- **A 140H motor grader with a 3.66 m (12 ft) moldboard is performing road maintenance on a township road. The machine is working at an average speed of 13 km/h (8 mph) with a moldboard carry angle of 30 degrees. What is the motor grader's production based on coverage area?**

  ***Note*: Due to the long passes involved in road maintenance- fewer turnarounds - a higher job efficiency of 0.90 is chosen.**

4. PRODUCTIVITY OF GRADING EQUIPMENTS

Method-3 (CAT Performance handbook)

Solution

- From the table, the effective blade length is 3.17 m (10.4 ft).

  Metric

- Production, $A = S \times (L_e - L_o) \times 1000 \times E$

  A = 13 km/h x (3.17 m - 0.6 m) x 1000 x 0.90

  A = 30,069 m^2/hr (3.07 hectars/hr)

  English

- Production, $A = S \times (L_e - L_o) \times 5280 \times E$

  A = 8 mph x (10.4 ft - 2 ft) x 5280 x 0.90

  A = 319,334 ft^2/hr (7.33 acres/hr)

THANK YOU!

Chapter 3;

Hauling and Compacting Equipment

CONTENTS

- **Hauling Equipment**
  - **General**
  - **Type of trucks**
  - **Selection of Dump Trucks**
  - **Capacities of trucks and hauling units**
  - **Small Vs. Large Dump Trucks**
  - **Truck production**
- **Compacting Equipment**
  - **General**
  - **Compaction Test**
  - **Types of Compacting Equipment**

CONSTRUCTION EQUIPMENTS

1. HAULING EQUIPMENT

1.1 General

- ***Hauling units*** transport the earth, aggregate, rock, ore, coal, and other material.
- Hauling units may be ***road vehicles*** or ***rail road locomotives***. Haulage mainly consists of trailers pulled by tractors or trucks.
- Trucks have ***high travel speeds*** when operating on suitable roads, provide relatively ***low hauling costs***.
- Trucks provide a ***high degree of flexibility*** permitting modifications in the total hauling capacity and adjustments for changing haul distances.
- Most trucks may be operated over any haul road for which the surface is ***sufficiently firm and smooth*** and on which the grades are ***not excessively steep***.

1. HAULING EQUIPMENT

- Some trucks now in use are designated as ***off-highway trucks*** because their size and total load are larger than that permitted on public highways. These trucks are used for hauling materials on ***large project sites***, where their ***size*** and ***costs*** are justified.
- ***Off-highway trucks*** are used for hauling materials in ***quarries*** and on ***large projects*** involving the movement of substantial amounts of earth and rock.

1.2 Types of Trucks

- Trucks may be classified according to a number of factors including:
    - *i.* ***The size*** and ***type of engine***: gasoline, diesel, butane, propane.
    - ***ii.*** ***The number of gears***.
    - ***iii.*** ***The kind of drive***: two-wheel, four-wheel, six-wheel, etc.
    - ***iv.*** ***The number of wheels*** and ***axles*** and arrangement of driving wheels.

1. HAULING EQUIPMENT

1.2 Types of Trucks

v. ***The method of dumping the load***: rear-dump, side-dump, bottom-dump.

vi. ***The class of material hauled***: earth, rock, coal, ore, etc.

vii. ***The capacity***: gravimetric (tons) or Volumetric (cubic yards or cubic meter).

viii. ***The type of frame***: rigid frame or articulated

A. Rear Dump trucks

- These are ***very common*** and ***heavy duty*** trucks and are capable of handling even quarry rocks.
- The body of these trucks is hinged at the back and fitted to with a hydraulic ram on the underside to lift the front of the body and tilt it to the dumping position.

1. HAULING EQUIPMENT

1.2 Types of Trucks

A. Rear Dump trucks

- Rear dump trucks are used when:
  - The material to be hauled is ***free-flowing*** or has ***bulky components***.
  - The hauling unit must dump into ***restricted locations*** or over the ***edge of a bank or fill***.
  - ***Maximum maneuverability*** in the loading or dumping area is required.
  - ***Maximum gradeability*** is required
  - ***Maximum flexibility*** is for hauling a variety of materials such as earth, required sand, and gravel and more bulky material such as blasted rock, ore, coal etc.

1. HAULING EQUIPMENT

1.2 Types of Trucks

A. Rear Dump trucks

Construction Equipments

1. HAULING EQUIPMENT

1.2 Types of Trucks

B. Bottom Dump trucks

- These are suitable for ***long hauls of easy flowing materials*** like sand, gravel, dry earth and which are ***to be spread in layers*** as on a fill or dam.
- The material is discharged through bottom ***while the vehicle is moving*** at a controlled rate by means of 2 longitudinal gates.
- This way of dumping ***will not the passage of other vehicles***
- These are ***unsuitable*** for ***big size material*** or ***wet or sticky materials*** due to limited openings.
- Due to low long bodies they have fast speeds on suitably maintained roads, but longer turning radius is required and maneuvering becomes more difficult in restricted spaces.

1. HAULING EQUIPMENT

1.2 Types of Trucks

B. Bottom Dump trucks

- Bottom dump trucks should be used, when:
  - The material to be handled is ***relatively free-flowing***.
  - The ***road is suitably maintained***, thus permitting high speed travel.
  - ***Long and steep grades*** are existing in the way.
  - The load is to be ***spread in wind rows***.

Construction Equipments

1. HAULING EQUIPMENT

1.2 Types of Trucks

B. Bottom Dump trucks

Bottom dump trailers deposits a windrow of material

1. HAULING EQUIPMENT

1.2 *Types of Trucks*

C. Side Dump trucks

- These dump trucks are most suitable when dumping is required to be done in a ***long narrow length*** or ***on one or both sides of a road*** (for dumping material on the ***road shoulders***).
- These ***requires a very less time to dump*** the material, whereas the rear dump truck must stop, reverse and then dump its load which needs a considerably more time.
- Side dump trucks are available in ***self-propelled*** that is truck type models or in a ***fully trailer type*** models (which is commonly known as side dump tractor-trailer).

Construction Equipments

1. HAULING EQUIPMENT

1.2 Types of Trucks

C. Side Dump trucks

1. HAULING EQUIPMENT

1.2 Types of Trucks

D. Articulated Dump trucks

- Articulated dump trucks are made on ***two or more separate machine*** elements joined together to permit maneuverability.
- It permits large machines to be separated into elements for transportation and ***increase operating efficiency***.
- Nowadays large dump tucks are ***gaining popularity*** because of their advantage in ***maneuverability through articulation***.

CONSTRUCTION EQUIPMENTS

1. HAULING EQUIPMENT

1.3 Selection of Dump Trucks

- Selection of ***type*** and ***size*** of dump truck is very important task and ***should be carefully decided*** considering various factors. Some of the important factors are:

A. Nature of work:

- For earth hauling purpose rear, side or bottom dump trucks are generally used.
- The rear and front side units are self-powered and are employed for loading by large shovels or draglines.
- The side dump units are used where space is restricted.
- For the transportation of rocks and other heavy materials under adverse road conditions, the rear dump trucks are most suitable.
- Bottom dump trucks are suitable only for free flowing materials and are used to spread the material on the fill.

1. HAULING EQUIPMENT

1.3 Selection of Dump Trucks

B. Nature of Haul:

- On ***steep grades***, the ***self-propelled rear dump trucks*** are selected as the uniform load distribution causes greater weight to be placed.
- Whereas, in the bottom dump units, which are semi-trailer type, while moving upgrade causes concentration of load towards the rear. Thus these dump units can be limited to the level ground.

C. Matching with other equipment:

- ***Capacities of the hauling*** should be decided after considering the size of excavator or loading unit.
- Generally, as a thumb rule size of the hauling unit is selected between ***4 to 6 times the bucket capacity*** of the loading unit.
- The ***number of hauling units*** is decided by ***time required in one cycle***, i.e. loading, hauling, unloading and returning back.

CONSTRUCTION EQUIPMENTS

1. HAULING EQUIPMENT

1.3 Selection of Dump Trucks

- Care should be taken that the ***waiting time for a truck*** by a loading unit or by a truck for its turn for loading is ***kept minimum***.

D. On-highway or off-highway:

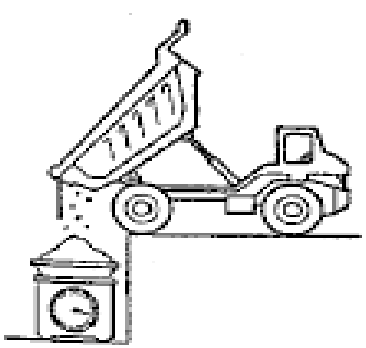
- If an on-highway type unit is applied to a rugged off-highway situation or vice versa, it will be too expensive and progress of work will be adversely affected.
- Generally, ***on-highway units*** are suitable for ***long***, ***high speed hauls*** over roads with ***low rolling resistance***.
- Whereas ***off-highway*** dump trucks also known as dumpers are used for ***short***, ***low speed hauls over rough roads***.
- ***Off-highway*** dump trucks are capable of moving on ***steep grades***, and has high power engines often fitted with turbochargers and torque converters.

1. HAULING EQUIPMENT

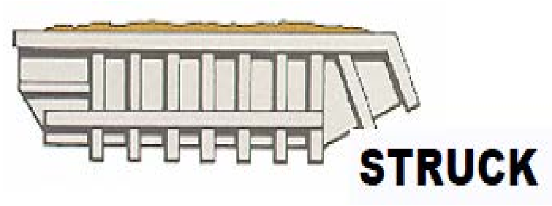
1.4 Capacities of Trucks and Hauling Equipment

- There are at least three methods of rating the capacities of trucks.

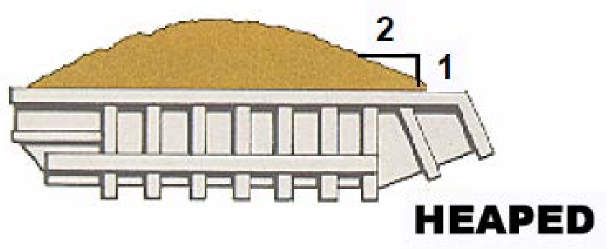
A. ***Gravimetric***: the load it will carry expressed as weight.



B. ***Struck volume***: the volumetric amount it will carry, if the load is water level (bowl or dump box).

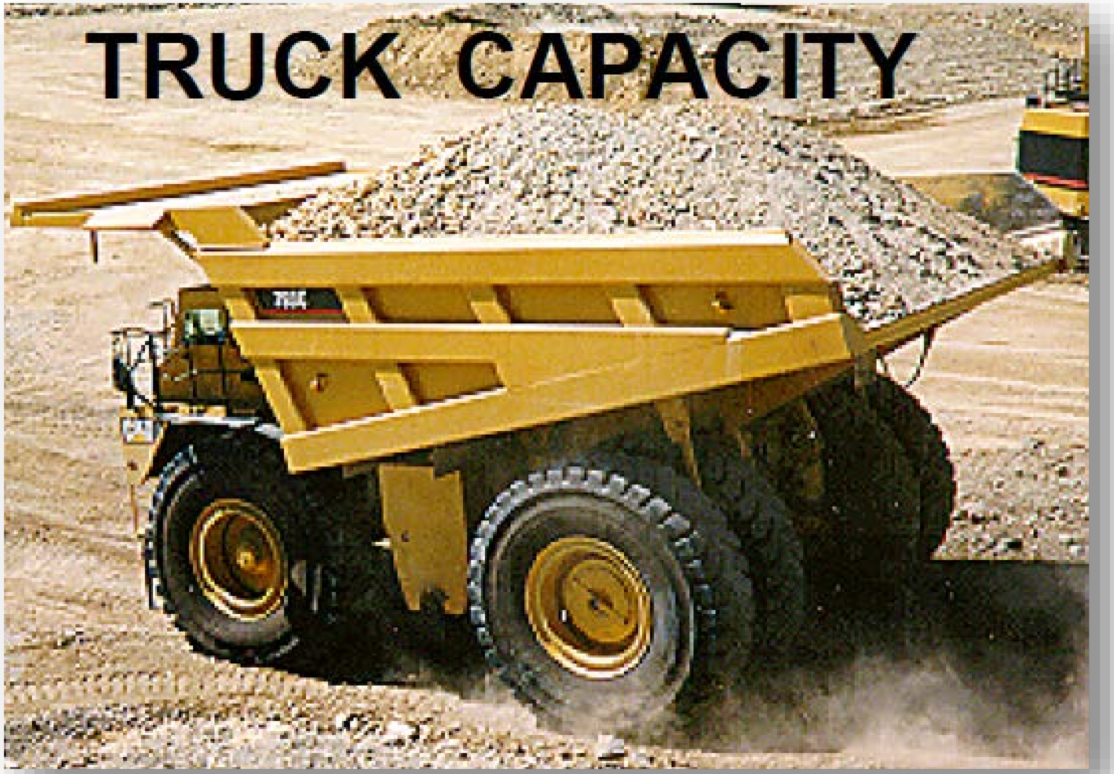


C. ***Heaped volume***: the volumetric amount it will carry, if the load is heaped on a 2:1 slope above the body (bowl or dump box).



1.4 Capacities of Trucks and Hauling Equipment

- The ***heaped capacity*** will vary with the height and angle at which the material may extend above the sides.
  - ***Wet earth*** or ***sandy clay*** may be hauled with a slope of about ***1: 1***.
  - ***Dry sand*** or ***gravel*** may not permit a slope greater than about ***3:1***.



1. HAULING EQUIPMENT

1.5 *Advantage and Disadvantages of Small and Large Trucks*

- The ***productive capacity*** of a truck or wagon depends on ***the size of its load*** and ***the number of trips*** it can make in an hour.
- The size of the load can be determined from the specifications furnished by the manufacturer.
- When loading with hoes, shovels. draglines, or belt loaders, it is desirable to use haul units whose capacities balance the output of the excavator.

Advantages of Small Trucks

- They are more ***flexible in maneuvering***, which may be an advantage on short hauls.
- ***Speed***, can achieve higher haul and return speed.
- ***Production***, there is less loss in production when one truck in a fleet breaks down.

1. HAULING EQUIPMENT

1.5 Advantage and Disadvantages of Small and Large Trucks

Advantages of Small Trucks

- ***Balance of fleet***: it is easier to balance the number of trucks with the output of the excavator, which will reduce the time.

Disadvantages of Small Trucks

- A small truck is ***more difficult for the excavator to load*** owing to the small target for depositing the bucket load.
- ***More total spotting time*** is lost in positioning the trucks because of the larger number required.
- ***More drivers are required*** to haul a given output of material.
- The greater number of trucks increases the ***danger of units bunching*** at the pit, along the haul road, or at the dump,
- The greater number of trucks required may ***increase the total investment in hauling equipment***, with more expensive maintenance and repairs, and more parts to stock.

1. HAULING EQUIPMENT

1.5 Advantage and Disadvantages of Small and Large Trucks

Advantages of Large Trucks

- ***Fewer trucks are required***, which may reduce the total investment in hauling units and the cost of maintenance and repair.
- ***Fewer drivers*** are required.
- The smaller number of trucks facilitates synchronizing the equipment and ***reduces the danger of bunching*** by the trucks. This is especially true for long hauls.
- There are ***fewer trucks to maintain and repair*** and fewer parts to stock.

Disadvantages of Large trucks

- The cost of ***truck time at loading is greater***, especially with small excavators.

1. HAULING EQUIPMENT

1.5 Advantage and Disadvantages of Small and Large Trucks

Disadvantages of Large trucks

- The heavier loads ***may cause more damage to the haul roads*** thus increasing the cost of mechanical maintenance to the trucks and requiring more support equipment for maintenance of the haul road.
- It is more difficult to balance the number of trucks with the output of the excavator.
- Repair parts may be more difficult to obtain.
- The largest sizes may not be permitted to haul on highways.

1. HAULING EQUIPMENT

1.6 Truck Production

- The most important consideration when matching excavator and truck is finding equipment having compatible capacities. ***Matched capacities yield maximum loading efficiency***.
- The following steps can be adopted in calculating truck production:

Step-1 Number of Bucket loads

- The first step in analyzing truck production is to determine the number of excavator bucket loads it takes to load the truck.

$$\text{Balanced number of bucket load} = \frac{\text{Truck capacity(lcy)}}{\text{Bucket capacity(lcy)}} \quad ..\text{eq1}$$

- No. of bucket loads must be an integer number.
- Check load weight against gravimetric capacity of the haul unit.

Construction Equipments

1. HAULING EQUIPMENT

1.6 Truck Production

Step-1 Bucket loads

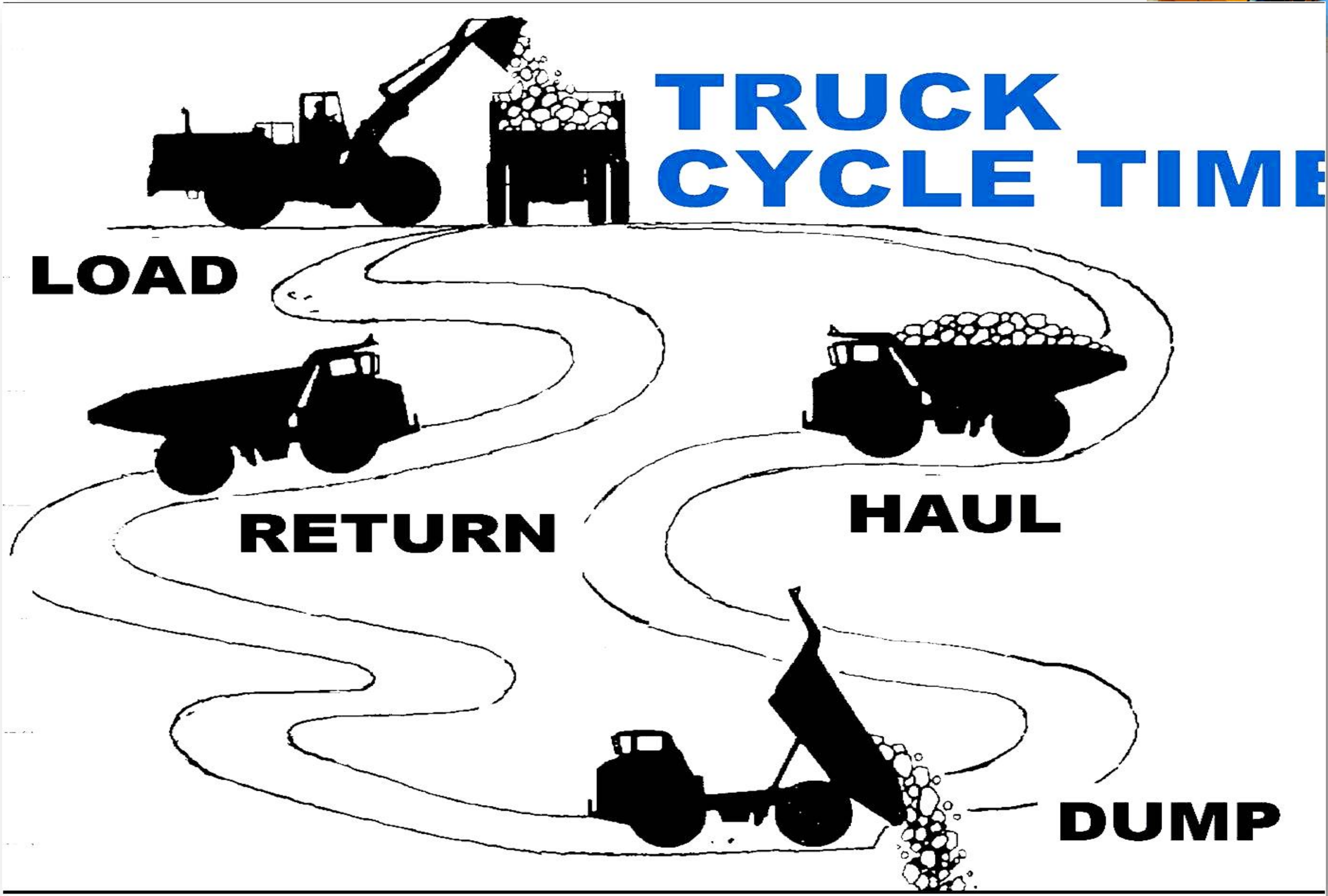
Matching the loader to the truck

1. HAULING EQUIPMENT

1.6 Truck Production

Step-2 Load 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.
- ***Fixed time***: spot time (moving the unit position to begin loading), load time, maneuver time, and dump time. Fixed time can usually be closely estimated for a particular type of operation.
- ***Variable time***: represents the travel time required for a unit to haul material to the unloading site and return.


TRUCK
CYCLE TIME
LOAD
RETURN
HAUL
DUMP

1. HAULING EQUIPMENT

1.6 Truck Production

Step-2 Load time

- ***Next lower integer***: for the case where the number of bucket loads is rounded down to an integer lower than the balance number of loads or reduced because of job conditions:

Load time = Number of bucket loads x Bucket cycle time Eqn. [2]

Truck load $_{LI}$ (Volumetric) = Number of bucket loads x Bucket Volume Eqn. [3]

- ***Next Higher integer***: If the division of truck cargo body volume by the bucket volume is rounded to the next higher integer that higher number of bucket is placed on the truck, excess material will spill of the truck. In such case:

Load time = Number of bucket loads x Bucket cycle time Eqn. [4]

Truck load $_{HI}$ (Volumetric) = Truck volumetric capacity Eqn. [5]

1. HAULING EQUIPMENT

1.6 Truck Production

Step-2 Load time and truck load volume

- always check the load weight against the gravimetric capacity of the truck.

Truck Load (Gravimetric) = Volumetric Load x Unit Weight Eqn. [6]

1.6 Truck Production

Step-3 Haul Time

- Hauling should be at highest safe speed and in the proper gear. To increase efficiency, see one way traffic patterns.

$$\text{Haul time(min)} = \frac{\text{Haul distance(ft)}}{88\ \text{fpm/mph} \times \text{Haul speed(mph)}}$$

1. HAULING EQUIPMENT

1.6 Truck Production

Step-4 Dump Time

- Dump time will depend on the ***type of hauling unit*** and ***congestion in the dump area***. Is the dump area crowded with support equipment?
  - Rear dumps must be spotted before dumping. Total dump time can exceed 2 minutes.
  - Bottom dump units dump while moving.

Turn and Dump Times (Min.)

Conditions	Bottom Dump	End Dump
Favorable	0.3	0.7
Average	0.6	1.0
Unfavorable	1.5	1.5

1. HAULING EQUIPMENT

1.6 Truck Production

Step-5 Return Time

- Based on the ***empty vehicle weight***, ***the rolling*** and ***grade resistance*** from the dump point to the loading area, return travel time can be estimated using the truck manufacturers

$$\text{Return time(hr)} = \frac{\text{Length of the Road Section (km)}}{\text{Average Speed (km/hr)}} = \frac{\text{L (km)}}{\text{V}_{\text{avg}}\text{ (km/hr)}}$$

Eqn. [15]

- OR $$\text{Return time(min)} = \frac{\text{Return distance (ft)}}{\text{88fpm/mph} \times \text{Return speed(mph)}}$$

Step-6 Truck cycle time

- The cycle time of a truck is the sum of the load time, haul time, dump time and the return time.

$$\textit{Truck time} = \textit{Load}_{\textit{Time}} + \textit{Haul}_{\textit{Time}} + \textit{Dump}_{\textit{Time}} + \textit{Return}_{\textit{Time}}$$

Eqn. [16]

1. HAUKING EQUIPMENT

1.6 Truck Production

Step-7 Number of Trucks Required

- The number of trucks required to keep the loading equipment working at capacity is:

$$\text{Balanced number of trucks} = \frac{\text{Truck cycle time (min)}}{\text{Excavator cycle time (min)}} \qquad \text{Eqn. [17]}$$

Step-8 Production

- The number of trucks must be an integer number.
- ***Integer lower than balance number***: If an integer number of trucks lower than the result of eqn. [17] is chosen, then ***the trucks will control the production***.

$$\underset{\text{(lcy/hr)}}{\text{Production}} = \underset{\text{load (lcy)}}{\text{Truck}} \times \underset{\text{of trucks}}{\text{Number}} \times \frac{60 \text{ min}}{\text{Truck cycle time (min)}} \qquad \text{Eqn. [18]}$$

1. HAULING EQUIPMENT

1.6 Truck Production

Step-8 Production

- ***Integer greater than balance number***: If an integer number of trucks greater than the result of the eqn. [17] is chosen, then ***production is controlled by the loading equipment***.

$$\frac{\text{Production}}{(\text{lcy/hr})} = \frac{\text{Truck}}{\text{load (lcy)}} \times \frac{60 \text{ min}}{\text{Excavator cycle time (min)}}$$ Eqn. [19]

- As a rule it is better to ***never keep the loading equipment waiting***. If there is not a sufficient number of haul trucks, there will be a loss in production.
- ***Truck bunching or queuing will reduce production 10 to 20%*** even when there is a perfect match between excavator capability and number of trucks.

1. HAULING EQUIPMENT

1.6 Truck Production

Step-9 Efficiency

- The production calculated with either Eqn. (18) or Eqn. (19) is based on a 60-min working hour. This production should be adjusted by an ***efficiency factor***.
- Longer haul distances usually result in better driver efficiency.
- Other critical ***elements affecting efficiency*** are ***bunching*** and ***equipment condition***.

$$\text{Adjusted production} = \text{Production} \times \frac{\text{Working time (min/hour)}}{60\text{ min}} \qquad \text{Eqn. [20]}$$

2. COMPACTING EQUIPMENT

2.1 General

- Compaction is the process whereby material particles are constrained to pack more closely together through a ***reduction of air void content***, generally ***by mechanical means***.
- Compaction can also be defined as the process of ***densifing*** or ***increasing the unit weight*** of a soil mass through application of ***static or dynamic force***, with the resulting ***expulsion of air*** and in some cases ***moisture***.
- Compaction is basically used to:
    - ***Increase bearing strength***
    - ***Reduce compressibility***
    - ***Improve volume change characteristics***
    - ***Reduce permeability***

2. COMPACTING EQUIPMENT

2.1 General

- Degree of compaction depends on:
  - ***Soil property***
  - ***Moisture content***: water lubricates the soil particles to slide into the densest position up to a certain limit, beyond which they create hydrostatic resisting forces.
  - ***Compaction method employed***
  - ***Amount of compactive effort***
  - ***Thickness of soil layer*** being compacted
  - ***Material gradation***: well graded materials compact better than poorly graded.

2.2 Types of Compacting Equipment

A) Smooth wheel rollers

- These rollers are most effective on ***granular materials***, with particle sizes ranging ***from large rocks to fine sand***.
- They are ***not suitable*** for producing high unit weights of compaction ***when used on relatively thick layers***.

2.2 Types of Compacting Equipment

B) Pneumatic Rubber-Tired Rollers

- Pneumatics are used on small- to medium-size soil compaction jobs, primarily on bladed ***granular base materials***.
- They are also used in compacting ***asphalt***, ***recycled pavement***, and ***base and sub base materials.***

2.2 Types of Compacting Equipment

C) Sheepsfoot Rollers

- The sheepsfoot roller is suitable compacting ***all fined-grained materials***, but is generally not suitable for use on ***cohesionless granular materials***.

2.2 Types of Compacting Equipment

D) Tamping Foot Compactor

- It is suitable for compacting ***all fined-grained soils***, but is generally ***not suitable*** for use ***on cohesionless granular soils***.
- This roller compacts the soil from the bottom of the lift to the top. Lift thickness is generally limited to 8 inches compacted depth.

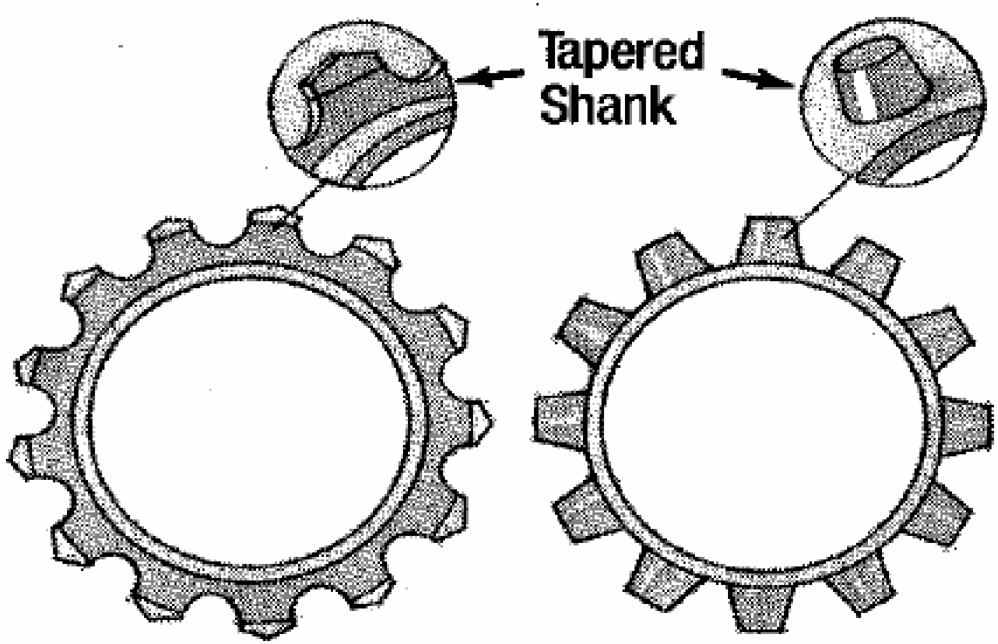
2. COMPACTING EQUIPMENT

2.2 Types of Compacting Equipment

D) Tamping Foot Compactor

Tamping foot

Pad foot



2.2 Types of Compacting Equipment

- The proper compaction equipment can not be selected until the soils are identified. The table below provides guidance for selecting compaction equipment based on the type of materials that must be compacted.

Material	Lift thickness (in.)	Number of passes	Compactor type	Comments
Gravel	8–12	3–5	Vib. padfoot	Foot psi 150–200
			Vib. smooth	—
			Pneumatic	Tire psi 35–130
			Sheepsfoot	Foot psi 150–200
Sand	8–10	3–5	Vib. padfoot	—
			Vib. smooth	—
			Pneumatic	Tire psi 35–65
			Smooth static	Tandem 10–15 ton
Silt	6–8	4–8	Vib. padfoot	Foot psi 200–400
			Tamping foot	—
			Pneumatic	Tire psi 35–50
			Sheepsfoot	Foot psi 200–400
Clay	4–6	4–6	Vib. padfoot	Foot psi 250–500
			Tamping foot	—
			Sheepsfoot	Foot psi 250–500

2.2 Types of Compacting Equipment

E) Vibrating compactors

i) Smooth drum vibratory compactors

Used for ***cohesion less materials***.

Construction Equipments

2.2 Types of Compacting Equipment

E) Vibrating compactors

ii) Dual drum vibratory compactors

- Use to compact ***cohesionless subgrade***, ***base courses***, ***wearing surfaces***, and ***asphalt***.

Dual drum

2.2 Types of Compacting Equipment

F) Vibratory plate compactor

- used for compacting ***granular soils***, ***crushed aggregate***, and ***asphalt concrete in locations where large compactors could not operate***.

2.2 Types of Compacting Equipment

G) Rammer (Back fill tamper)

- used for compacting ***cohesive or mixed soils in confined areas***.

Construction Equipments

2.2 Types of Compacting Equipment

H) Wheel Attachment Compaction

- often used to achieve compaction when backfilling utility trenches.

2.2 Types of Compacting Equipment

I) Trench Roller

2. COMPACTING EQUIPMENT

2.2 Types of Compacting Equipment

Rollers Production Estimating

- The compaction equipment used on a project must have a production capability matched to that of the excavation, hauling, and spreading equipment.
- Usually, excavation or hauling capability will set the expected maximum production for the job.
- The production formula for the compactor is:

$$\text{Compacted cubic yards per hour} = \frac{16.3 \times W \times S \times L \times \text{efficiency}}{n}$$

where

W = compacted width per roller pass in feet

S = average roller speed in miles per hour

L = compacted lift thickness in inches

n = number of roller passes required to achieve the required density

2. COMPACTING EQUIPMENT

2.2 Types of Compacting Equipment

Rollers Production Estimating

Example 2.1

A self propelled tamping foot compactor will be used to compact a fill being constructed of clay material. Field tests has shown that the required density can be achieved with ***four passes*** of the roller operating at an average ***speed of 3 mph***. The compacted fill will have a ***thickness of 6 in***. The compacting ***width of this machine is 7 ft***. ***1bcy equals 0.83ccy***. The ***scraper production***, estimated for the project is ***510bcy/hr***. How many rollers will be required to maintain this production? Assume a ***50-min/hour efficiency***.

CONSTRUCTION EQUIPMENTS

2. COMPACTING EQUIPMENT

2.2 Types of Compacting Equipment

Rollers Production Estimating

Example 2.1

Solution

$$\text{Compacted cubic yards per hour} = \frac{16.3 \times 7 \times 3 \times 6 \times 50/60}{4} = 428 \text{ ccy/hr}$$

$$\frac{428 \text{ ccy per hour}}{0.83} = 516 \text{ bcy/hr}$$

$$\frac{510 \text{ bcy/hr required}}{516 \text{ bcy/hr}} = 0.99$$

Therefore, only one roller will be required.

2. COMPACTING EQUIPMENT

2.2 Types of Compacting Equipment

Dynamic Compaction

- The densification technique of ***repeatedly dropping a heavy weight*** onto the ground surface is commonly referred to as "dynamic compaction."
- This process has also been described as ***heavy tamping***, ***impact densification***, ***dynamic consolidation***, ***pounding***, and ***dynamic pre-compression***.
- This process primarily consists of ***dropping a heavy weight repeatedly*** on the ground ***at regular intervals***.

THANK YOU!

CHAPTER-4

Economic analysis of construction Equipment

INTRODUCTION

- Construction equipments required for the execution of a certain construction project are either owned or rented from equipment leasing companies.
- These associated equipment costs are mainly classified into three categories as follows:
  - Equipment owning costs
  - Equipment operating costs
  - Operator’s salary and benefits

1) EQUIPMENT OWNING COSTS

- Equipment owning costs are all these costs in which the owner of the equipment expends(outflows) throughout the economic life of the equipment whether the equipment is working or not.
- These costs include mainly the ***depreciation cost*** of the equipment with the consideration of its ***salvage value***, ***Erection and installation costs***, ***major repairs*** and ***overhauling costs***, ***property taxes*** and ***insurance charges***.

1-A) DEPRECIATION COST

- Definition “Depreciation is a measure of the wearing out, consumption or other loss of value of depreciation asset arising from use, efflux ion of time or obsolescence through technology and market changes. Depreciation is allocated so as to charge a fair proportion of the depreciable amount in each accounting period during the expected useful life of the asset. Depreciation includes amortization of assets whose useful life is predetermined.”

- The depreciation cost can be calculated in many different ways such as the straight line, declining balance, sum of years-digits and unit production methods.
- In this case, it is better to use the unit production depreciation method to calculate the equipment depreciation cost which actually relates the depreciation cost with the real utilization of the equipment.

Examples

Example

Assume a contractor has purchased a new Caterpillar D8R Bulldozer with a delivered duty paid price of birr 9,750,000 ETB Calculate the hourly cost of the specified Bulldozer.

Assignment (5%)

The same contractor has purchased a new Caterpillar Wheel loader with a delivered price of birr 4,500,000 ETB. Moreover, the price of tires is birr 15,000 per tire, which is birr 60,000 for 4 tires.

Calculate the hourly cost of Wheel loader .

SOLUTION FOR THE DOZER

1-A) Depreciation Cost

A. Delivered price …………………… Birr 9,750,000

B. Cost of tires…………………Birr 0.00 (Crawler mounted)

C. Delivered price minus cost of tires (P)=9,750,000-0.0=9,750,00Birr

D. Assume the Bulldozer will be engaged partly in works such as borrow material production and common excavation with medium impact as well as in heavy rock ripping and dozing hard rock with high impact conditions.

Estimated economic life =Assume 10years

E. Estimated annual utilization (E)…….. 2000 Hrs

F. Estimated salvage value…….(S = 10% ***delivered price or case A***)

S = 0.1 * 9,750,000 = Birr 975,000

G. Estimated cost of capital……………………………………… (i = 8.5%)

H. Equivalent annual equipment cost of delivered price minus cost of tires

$$A_1 = P * \frac{[\,i\,(1+i)^n\,]}{[(1+i)^n - 1]}$$

n=Estimated economic life

A_1 = 9,750,000 * [0.085(1+0.085)^{10}] / [(1+0.085) ^{10} – 1]

A_1 = 1,485,979.18 Birr/Year

I. Equivalent annual salvage value

$$A_2 = S * \frac{i}{[(1+i)^n - 1]}$$

A_2 = 9,750,000 * 0.1*0.085 / [(1+0.085) ^{10} – 1]

A_2 = 65722.69 Birr/Year

J. Dozer Depreciation Cost per hour **(DDC)**

$$DDC = \frac{A_1 - A_2}{E}$$

DDC = (1,485,979.18 – 65,722.69)/2000

= 710.13 Birr/Hr

1-B) Insurance charges:

– Most local ***insurance*** companies charge between 0.75% to 1% of the equipment book value for ***heavy duty equipments*** and between 1 to 1.5% for ***light duty equipments*** such as small vehicles.

- A. Delivered price…….....…….....……Birr 9,750,000
- B. Annual insurance charges…..….1% of delivered price
- C. Estimated annual utilization……………...…2000Hrs
- D. Dozer Insurance Cost per hour **(DIC) = B/C**
- DIC= 0.01* 9,750,000 /2000
- **DIC = 48.75 Birr/Hrs**

1-C) Property Tax

- Different countries have different tax regulations whereby equipment owners pay annual property tax for their equipments.
- Currently there are no such tax regulations in Ethiopia but there is a registration fee for heavy duty construction equipments every two years.

A. Registration fee per two years………….Birr 2,000.00

B. Estimated annual utilization…………………2000 Hrs

C. Dozer Property Tax per hour **(DPT) = A/(2*B)**

DPT = 2000/(2*2000)

DPT = 0.5 Birr/Hr

1-D) Erection and Installation costs:

- The initial erection and installation costs shall be considered in calculating the equipment owning costs.
- These costs are usually applied to equipments which are transported in ***pieces*** from the supplier's place and need to be assembled at the contractor's place such as ***crushers, batching plants and so on.***
- For this particular case the cost of erection and installation will be zero since both equipments ***does not need to*** be erected or installed.
  - Dozer Erection and Installation Costs per hour **(DEIC)=**0.00 Birr/Hr

1-E) Summarized equipment owing cost

- Once the equipment depreciation cost, insurance charges, property tax, erection and installation costs **and cost of major repairs and overhauls a**re identified, all these costs will be summed to get the hourly owning cost of the equipment
- Hourly owning costs…………**DDC+DIC+DPT + DEIC**
- **Hourly owning costs = 710.13 + 48.75 + 0.50 + 0.00**

= 759.38 Birr/hr

2- EQUIPMENT OPERATING COSTS

- Equipment operating costs are costs in which the owner of the equipment expends throughout the economic life of the equipment when it is working.
- These costs include mainly the costs of ***fuel***, ***lube oils***, ***filters***, ***grease***, ***normal repairs***, ***tires***, ***undercarriage*** and ***special high wear items***.

2-A) Fuel

- Based on the estimated fuel consumption data provided by Caterpillar Performance Hand Book the fuel cost of the given dozer can be computed as follows
  - A Assumed Load factor ………………….Medium
  - B Estimated fuel consumption………….33 Ltr/Hr
  - C Fuel cost …………………………..… 11.90 Birr/Ltr
  - D Dozer Fuel Cost per hour **(DFC) = B*C**

DFC = 33Ltr/hr*11.9Br/Ltr

DFC = 392.70 Birr/Hr

2-B) Cost of lube oils, filters and grease:

- The cost of lubricants (lube oils), filters and grease will mainly depend on the maintenance practice of the equipment owner and conditions of the work location.
- Some equipment owners follow the equipment manufacturers' guideline concerning time periods between lube oils, filters and grease changes while others establish their own preventive maintenance guidelines.
- Therefore, depending on the equipment owner's preventive maintenance schedule or the equipment manufacturer's service guideline, the cost of lube oils, filters and grease will be calculated based on the number of changes over the economic life of the equipment.

2-B-1) Cost of lube oils

Lube oils include lubricants required for Crankcase/Engine, Transmission, Final drives and Hydraulic control systems.

A. Estimated consumption of Engine oil………0.129 Ltr/Hr

B.Price of Engine oil…………………………..68.79 Birr/Ltr

C.Estimated consumption of Transmission oil…..0.144 Ltr/Hr

D.Price of Transmission oil……………….……74.61 Birr/Ltr

E.Estimated consumption of Final drives oil……0.015 Ltr/Hr

F. Price of Final drives oil…………………….....70.36Birr/Ltr

G. Estimated consumption of Hydraulic oil…...0.038 Ltr/Hr

H. Price of Hydraulic oil…………………… 70.36 Birr/Ltr

I. Dozer Lube Oils Cost per hour **(DLOC) = A*B + C*D + E*F + G*H**

DLOC = 23.47 Birr/Hr

2-B-2) Cost of filters

Filter costs include the costs of ***Lube oil filters***, ***Fuel filters*** and ***Air filters***. The cost of filters depends entirely on the number of filter changes over a specified working time of the equipment.

A. **Scheduled Engine oil filter changes ……………..every 250 Hrs**

B. Price of Engine oil filter…………………………..807.93 Birr/Pc

C. Scheduled Transmission oil filter changes……..every 500 Hrs

D. Price of Transmission oil filter…………………..1529.63 Birr/Pc

E. Scheduled Hydraulic oil filter changes …………..every 500 Hrs

F. Price of Hydraulic oil filter………………………….1822 Birr/Pc

G. Scheduled Primary fuel filter change ………….every 2000 Hrs

H. Price of Primary fuel filter……………………..665.58 Birr/Pc

I. Scheduled Final fuel filter change ………..……..every 500 Hrs

J. Price of Final fuel filter…………………...…...1209.16 Birr/Pc

K. Scheduled Primary air filter change …………every 2000 Hrs

L. Price of Primary air filter……………………..3055.16 Birr/Pc

M. Scheduled Secondary air filter change ……every 1000 Hrs

N. Price of Secondary air filter………...………3050.00 Birr/Pc

O. Dozer Cost of Filter per hour (DCF) = B/A + D/C + F/E + H/G + J/I + L/K + N/M

DCF = 17.26 Birr/Hr

2-B-3) Cost of grease

- The total consumption of grease depends on the ***size of the equipment***, ***working environment of the equipment*** and the ***frequency of greasing by the equipment owner***.

  - A. Estimated grease consumption…..0.006 kg/Hr
  - B. Price of grease……………………..…..131 Birr/kg
  - **C.** Dozer Grease Cost per hour **(DGC) = A*B**
  - **DGC = 0.78 Birr/Hr**

2-C) Cost of tires:

- Cost of tires is one of the major operating costs for wheel mounted equipments. Tire costs include the cost of tire replacement and its repair.
- It is actually difficult to estimate tire economic life because of the tire wear variability depending on the ***site surface conditions, speed, wheel position, working load, maintenance conditions, road grades and curves as well as operator's skill.***
- The best way to estimate tire economic life is to use the equipment ***owner's tire utilization records*** for each type of equipment.

2-C) Cost of tires:

- In the absence of such accurate records, it is better to use tire economic life guide lines prepared both by the equipment and tire manufacturers.
- As provided in the Caterpillar Performance Hand Book , the economic life of tires is categorized into three zones.

A. Dozer Tire Cost per hour **(DTC) = 0.00 Birr/Hr (Crawler Mounted)**

2-D) Cost of normal repair

- Normal repairs are ***all the repair cost*** during the life time of the equipment excluding undercarriage as well as major repair and overall.
- Accurate estimated cost of normal repairs can be obtained from ***previous records*** of the equipment owner.
- However, in the absence of such accurate data, the equipment manufacturers' ***guideline*** can be used to estimate the hourly equipment cost of normal repairs.

2-D) Cost of normal repair

- In the Caterpillar Performance Hand Book, the hourly normal repair costs are calculated using the basic repair factor from charts provided based on the work application of the equipment which are rated as Zone A (moderate), Zone B (average) and Zone C (Severe).
- Moreover, extended-life multipliers will be used if the estimated economic life of the equipment is greater than 10,000 Hrs and these extended-life ***multipliers are given*** for each equipment depending on their economic life.

- The cost of normal repair cost provided in the caterpillar Hand book includes costs of parts and labors.

  A. Work application……..……………… Zone B (Average)

  B. Basic repair factor…………………….7.5 USD/Hr

  C. Estimated economic life…………….20,000 Hrs

  D. Extended life multiplier………………1.3

  E**. Hourly normal repair cost of *parts* = 0.7*B*D=6.825**

  F. Hourly normal repair cost of *labor* = 0.25*0.3*B*D=0.731

  G. Dozer Normal Repair Cost per hour (DNRC) = E + F

  DNRC = 7.55USD/Hr

Using the current selling rate of the commercial bank of Ethiopia, 1**USD =27.74 Birr**

DNRC = 27.74*7.55 = 209.437 Birr/Hr

2-E) Cost of high wear items(CHWI):

- High wear items are these items having very short economic life as compared to the basic equipment. Some of these items include ***cutting edges***, ***ripper tips***, ***bucket teeth***, ***body liners***, ***cables***, ***router bits*** and so on.
- Assume a dozer is ripping 30% of its working time and the estimated economic life of the ripper is 50 Hours. Moreover, the ripper is purchased for **Birr 1500**. Establish the hourly cost of the ripper
- Economic life of ripper as compared with the dozer operating time 50/0.3 = 167 Hr

Hourly cost of ripper

1500/167 = 8.982Birr/Hr

- As discussed earlier, the equipment operating cost includes the cost of fuel, lubricants, filters, grease, tires, undercarriage, normal repairs and high wear items and all these costs will be summed to get the operating cost of the equipment. Accordingly, the operating cost of the dozer can be summarized as follows
- **Hourly operating costs**

  = DFC + DLOC + DCF + DGC + DTC + DNRC +CHWI
- **Hourly operating costs**

  = **392.70** + **23.47** + **17.26** + **0.78** + **0.00** + **209.44+8.98** **Hourly operating costs = 652.63 Birr/Hr**

3. OPERATOR'S SALARY AND BENEFITS

- Based on the principles of direct labor hourly cost estimation, the annual operator's salary and benefits shall be summed up and divided by the annual utilization of the equipment to get the hourly cost of operators.

- In determining the annual operator's salary and benefits, the following costs, but not limited to, shall be assessed properly. Once, the annual salary and benefits are calculated for the equipment operators, the hourly cost of operators can be computed as follows:

  A. Total annual salary and benefits…………. 62,310.44 Birr

  B. Annual equipment utilization………………2000 Hrs

  C. Hourly operator's cost **= A/B = 31.16 Birr/Hr**

Table – Operator's annual salary and benefits cost breakdown

	SALARY AND BENEFITS	OPERATOR BY EQUIPMENT		CLARIFICATIONS AND REMARKS
		Dozer	**Wheel Loader**	
A	Basic salary	24,000.00	18,000.00	12 x Monthly salary
B	Overtime pay	7,500.00	5,625.00	313 x 2 = 626 hrs/yr
C	Project allowance	9,600.00	7,200.00	40% (A)
D	Hardship allowance	7,200.00	5,400.00	30% (A)
E	Food allowance	1,440.00	1,440.00	120 x Twelve months
F	Medical insurance	360.00	270.00	1.5% (A)
G	Bonus	4,000.00	3,000.00	2 x Monthly salary
H	Provident fund	2,400.00	1,800.00	10% (A)
I	Annual leave	3,143.77	2,357.83	20 + 21 = 41 working days
J	Severance pay	2,666.67	2,000.00	(1 + 1/3) months
Total annual salary and benefits (A+B+C+D+E+F+G+H+I+J)		**=62,310.44**	**47,092.83**	

Summary of all costs

The equipment hourly cost for owned equipments is then the sum of the equipment owning costs, equipment operating costs and the operator's salary and benefits.

A. Hourly owning costs…………………………**759.38** Birr

B. Hourly operating costs……………………..…**652.63** Birr

C. Hourly operator's costs……………………….**31.16** Birr

D. **Hourly Bulldozer costs = A + B + C**

Hourly Bulldozer costs = 1443.16Birr /Hr

Additional cost

- There are also cases where contractors may lease their equipments to other construction companies. Therefore, contractors and leasing companies are also interested to establish their equipment rental rates from time to time. In establishing these equipment rental rates, in addition to the equipment owning costs, equipment operating costs and operator's costs, contractors and equipment leasing companies need to understand the following cost components and include any additional costs to establish their equipment rental rates.
  - Overhead costs
  - Breakeven costs
  - Profit and income tax
  - Equipment rental rates

4) OVERHEAD COSTS

- In addition to the Equipment owning and operating costs as well as cost of operators, the equipment owner's overhead costs shall be included in determining the ***overall equipment hourly costs***. Overhead costs widely vary between equipment owners depending on organizational structure, number of staffs employed at head office and project sites, salary and benefit scales, office facilities and so on.

A. Hourly owning costs……………………….……. **759.38**Birr

B. Hourly operating costs…………………….….…**652.63** Birr

C. Hourly operator's costs…………………………**31.16** Birr

D. Hourly overhead costs **= 0.15*(A+B+C)**

Hourly overhead costs =216.47Birr

5) EQUIPMENT BREAKEVEN COST

- Equipment breakeven cost is the sum of equipment owning costs, operating costs, operator's costs and overhead costs. Accordingly, the hourly breakeven costs for the dozer is;

A. **Hourly owning costs……………………….. 759.38 Birr**

B. Hourly operating costs……………………..… 652.63 Birr

C. Hourly operator's costs…………………… 31.16 Birr

D.Hourly overhead costs …………………… 216.47Birr

E. Hourly breakeven costs = A + B + C + D

Hourly breakeven costs = 1659.64 Birr

6) PROFIT AND INCOME TAX

- Obviously equipment owners are investing their capital to get maximum possible profit from the contracts to be performed. The profit margin depends entirely on the market competitiveness and company strategies.
- Moreover, any equipment leasing company operating a profitable business in Ethiopia shall pay ***30% of its gross profit as income tax*** as per the Income tax proclamation No. 286/2002.

- For completeness of the exercise in establishing the equipment rental cost of the equipments in this example , **assume the net profit margin to be 10% of the equipment breakeven cost**. Accordingly, gross profit has to be calculated and added to the equipment breakeven cost to establish the rental rate of equipments.
  - Let **C be the equipment breakeven cost**
  - Gross Profit = X% * C
  - Net Profit = 10% * C
  - Income tax = 0.3 * Gross profit
  - Gross Profit = Net Profit + Income tax
  - X% * C = 10% * C + 0.3 * X% * C
  - X% = 10% + 0.3 * X%
  - **X% = 14.29%**

A. Hourly breakeven costs = **1659.64** Birr

B. Hourly gross profit = 0.1429*C= **237.16** Birr

7) EQUIPMENT RENTAL RATES

If the equipment owner wants to rent his equipment to others, equipment rental rates shall be calculated when the equipment is running and in its idle situation. ***Running equipment rental rate*** includes the ***breakeven costs plus the gross profit***. While ***idle equipment rental rate*** includes only the equipment ***owning costs, operator's costs and overhead costs.*** Therefore, contractors or equipment leasing companies can easily determine the rental rates of their equipments as far as the following hourly costs are properly calculated for each equipment.

- Equipment hourly owning costs
- Equipment hourly operating costs
- Operator's hourly costs
- Overhead hourly costs
- Hourly gross profit
- Hourly breakeven costs

- As an illustration, let's demonstrate to calculate the equipment idle rental rate and the equipment running rental rate the dozer;

Dozer Idle Rental Rate per hour

A**. Hourly owning costs……………………….….……. 759.38 Birr**

C. Hourly operator's costs……………………………..31.16 Birr

D. Hourly overhead costs ……………………….…….216.47 Birr

Hourly idle dozer rental rate = 1007.01 Birr

Dozer Running Rental Rate per hour

A. Hourly breakeven costs = 1659.64 Birr (including operating cost)

B. Hourly gross profit = 237.16 Birr

Hourly running dozer rental rate = 1896.803Birr

THANK YOU!