ADDIS ABABA UNIVERSITY

AAiT- SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

CENG 5213: CONSTRUCTION EQUIPMENT

CHAPTER-2

CONSTRUCTION EQUIPMENT AND PLANTS

PART-2 PRODUCTIVITY OF HAULING AND COMPACTION EQUIPMENT

CONTENTS

- ***Hauling Equipment***
  - *General*
  - *Type of trucks*
  - *Selection of Dump Trucks*
  - *Capacities of trucks and hauling units*
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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 of a fleet 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.

Construction Equipments

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 required for hauling a variety of materials such as earth, sand, and gravel and more bulky material such as blasted rock, ore, coal etc.

Construction Equipments

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 hamper the passage of other vehicles*** and also ***reduce the leveling efforts*** of the dumped material.
- 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.

Construction Equipments

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***.

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.

Construction Equipments

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

C. Matching with other equipment:

- 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.

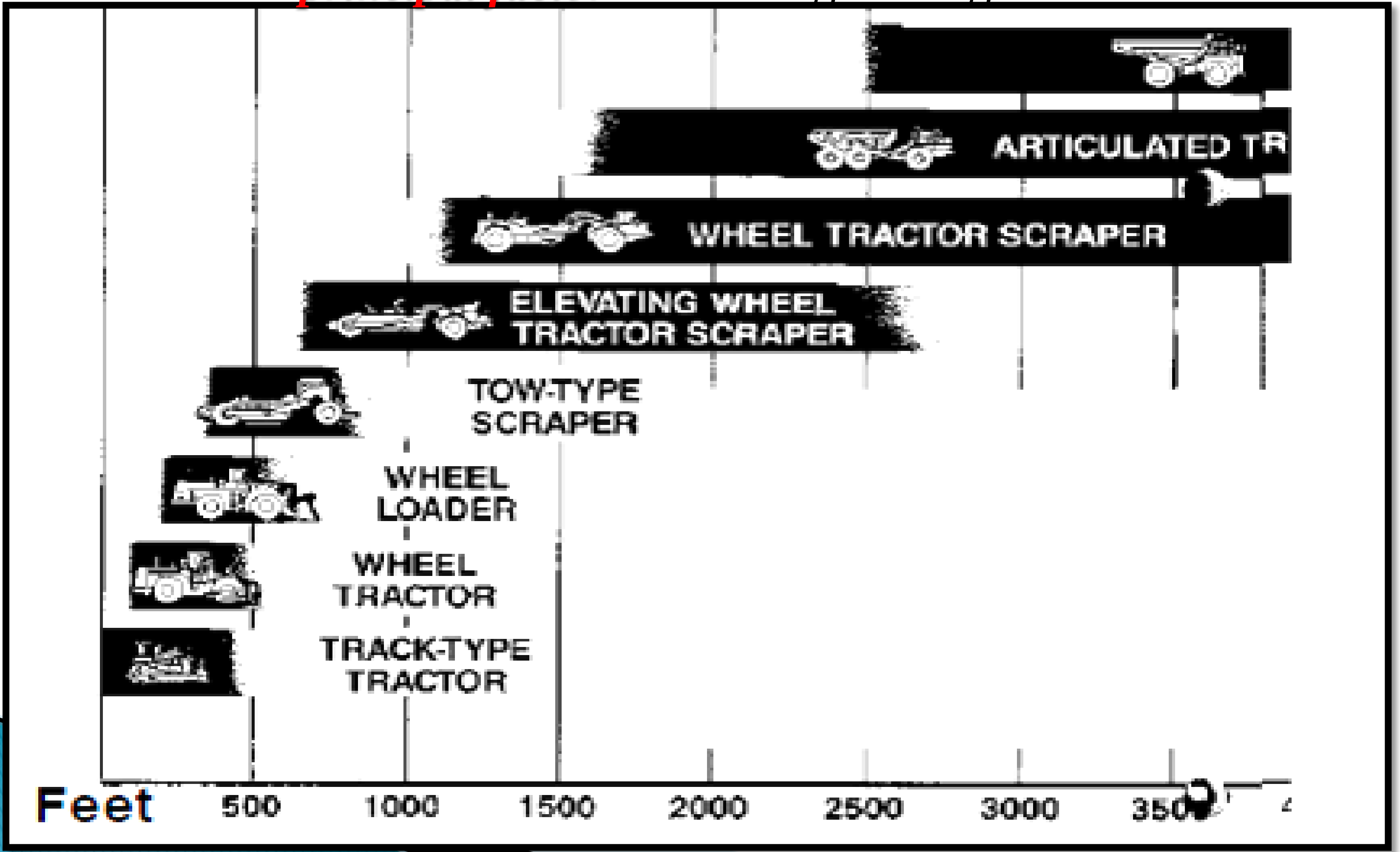
Construction Equipments

1. HAULING EQUIPMENT

1.3 Selection of Dump Trucks

E. Distance of travel:

- Distance is the ***principal factor*** in selecting hauling units.

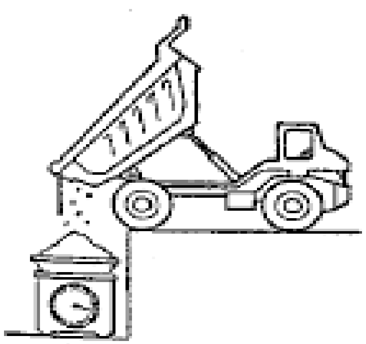


Construction Equipments

1. HAULING EQUIPMENT

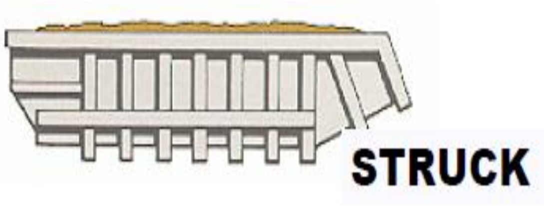
1.4 Capacities of Trucks and Hauling Equipment

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

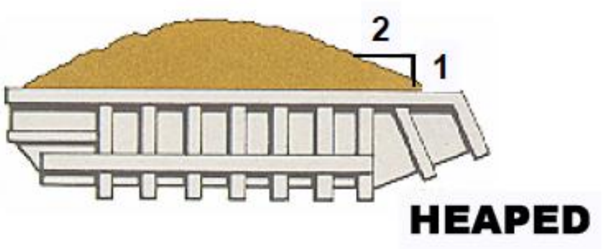


A. ***Gravimetric***: the load it will carry expressed as weight.

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).

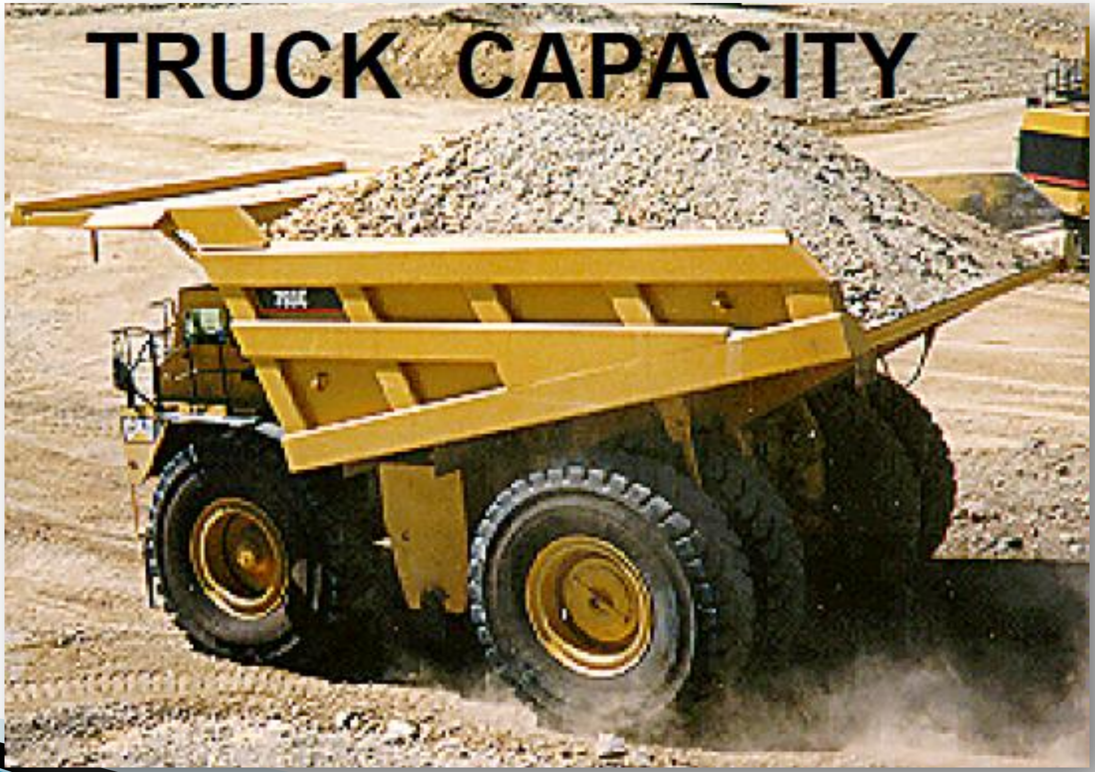


CONSTRUCTION EQUIPMENTS

1. HAULING EQUIPMENT

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

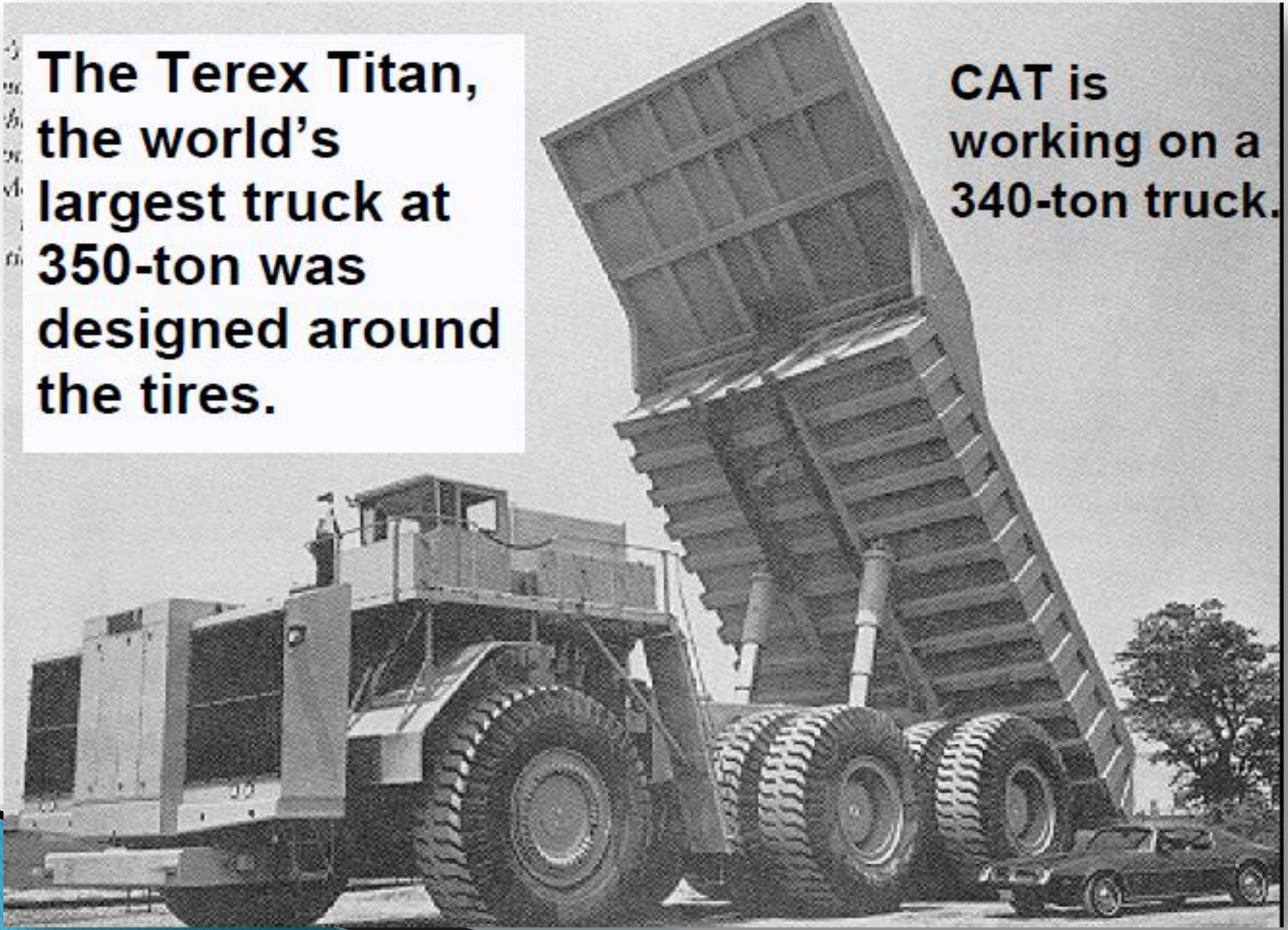
Disadvantages of Large trucks

- 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.

Construction Equipments

1. HAULING EQUIPMENT

1.5 Advantage and Disadvantages of Small and Large Trucks



Construction Equipments

1. HAULING EQUIPMENT

1.5 Advantage and Disadvantages of Small and Large Trucks

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 Bucket loads

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

$$\boxed{\text{Bucket loads} = \frac{\text{Truck capacity}}{\text{Loader Bucket capacity}}} \qquad \text{Eqn. [1]}$$

- 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 and truck load volume

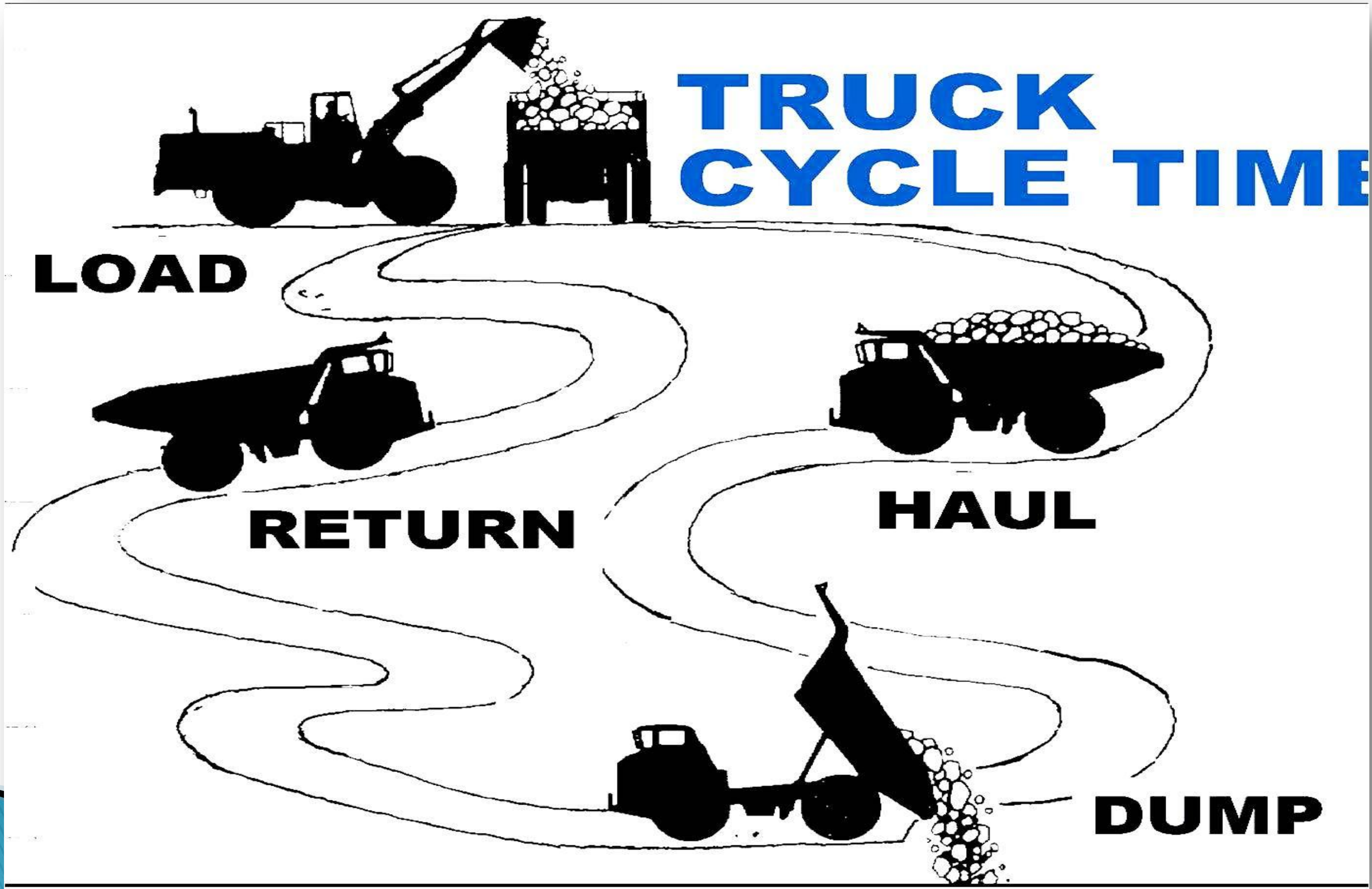
- In calculating the time required for a haul unit to make one complete cycle, it is customary to break the cycle down into ***fixed*** and ***variable*** components.
- ***Fixed time***: spot time (moving the unit position to begin loading), load time, maneuver time, and dump time. Fixed time can usually 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.

Construction Equipments

1. HAULING EQUIPMENT

1.6 Truck Production

Step-2 Load time and truck load volume



1. HAULING EQUIPMENT

1.6 Truck Production

Step-2 Load time and truck load volume

- ***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:

$$\boxed{\text{Load time} = \text{Number of bucket loads x Bucket cycle time}} \qquad \text{Eqn. [2]}$$

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

- ***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:

$$\boxed{\text{Load time} = \text{Number of bucket loads x Bucket cycle time}} \qquad \text{Eqn. [4]}$$

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

1. HAULING EQUIPMENT

1.6 Truck Production

Step-2 Load time and truck load volume

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

Truck Load (Gravimetric) = Volumetric Load x Unit Weight

Eqn. [6]

Truck load (Gravimetric) < Number of bucket loads x Bucket Volume

Eqn. [7]

1. HAULING EQUIPMENT

1.6 Truck Production

Step-3 Haul Time

- Hauling should be at highest safe speed and in the proper gear.
- Travel time will depend on
  - The ***vehicle's weight*** and ***power***,
  - The ***condition of the haul road***,
  - The ***grades*** encountered, and
  - The ***altitude*** above sea level.

A. Rolling Resistance

- The resistance that a vehicle encounters in traveling over a surface is made up of two components, ***rolling resistance*** and ***grade resistance***.

$$\boxed{\textit{Total Resistance} = \textit{Grade resistance} + \textit{Rolling resistance}} \qquad \text{Eqn. [8]}$$

Construction Equipments

1. HAULING EQUIPMENT

1.6 Truck Production

Step-3 Haul Time

A. Rolling Resistance

- Resistance may be expressed in either ***kilograms per metric ton*** or in ***kilograms [kg/t]*** .
- ***Rolling resistance*** is primarily due to ***tire flexing*** and ***penetration of the travel surface***.
  - The ***rolling resistance factor*** for a rubber-tired vehicle equipped with conventional tires moving over a hard, smooth, level surface has been found to be about ***20 kg/ton of vehicle weight***.
  - Tables can also be used or ***Customarily = 20 + 6 x Penetration(cm)***

1. HAULING EQUIPMENT

1.6 Truck Production

Step-3 Haul Time

B. Grade Resistance

- Grade resistance represents that component of vehicle weight which acts parallel to an inclined surface.
  - When the vehicle is traveling up a grade, grade resistance is positive.
  - When traveling downhill, grade resistance is negative.

$$\boxed{\text{Grade Resistance Factor (kg/t)} = 10 \text{ x Grade (\%)}} \qquad \text{Eqn. [9]}$$

C. Effective Grade

- The total resistance to movement of a vehicle (the sum of its rolling resistance and grade resistance) may be expressed in pounds or kilograms.

Construction Equipments

1. HAULING EQUIPMENT

1.6 Truck Production

Step-3 Haul Time

C. Effective Grade

- However, a somewhat simpler method for expressing total resistance is to state it as a grade (%), which would have ***a grade resistance equivalent to the total resistance actually encountered***.

$$\boxed{\text{Effective Grade (\%)} = \text{Grade (\%)} + \frac{\text{Rolling Resistance Factor (kg/t)}}{10}}$$ Eqn. [10]

D. Effect of Altitude

- All internal combustion engines ***lose power as their elevation above sea level increases*** because of the decreased density of air at higher elevations.

1. HAULING EQUIPMENT

1.6 Truck Production

Step-3 Haul Time

D. Effect of Altitude

- Engine power ***decreases*** approximately ***3%*** for ***each 305 m increase*** in altitude above the maximum altitude at which full rated power is delivered.
- ***Turbo-charged engines*** are more efficient at higher altitude than are naturally aspirated engines and may deliver full rated power up to an altitude of ***3,050 m or more***.
- Manufacturers use a ***de-rating factor*** to express percentage of reduction in rated vehicle power at various altitudes.

1. HAULING EQUIPMENT

1.6 Truck Production

Step-3 Haul Time

E. Effect of Traction

- The power available to move a vehicle and its load is expressed as ***rimpull for wheel vehicles*** and ***drawbar pull for crawler tractors***.
- Another factor limiting the usable power of a vehicle is the maximum traction that can be developed between the driving wheels or tracks and the road surface. Traction depends on the ***coefficient of traction*** and the ***weight on the drivers***:

Maximum usable pull = Coefficient of traction x Weight on drivers

- For crawler tractors and all-wheel-drive rubber-tired equipment, the weight on the drivers is the total vehicle weight. For other types of vehicles, consult the manufacturer's specifications to determine the weight on the drivers.

Construction Equipments

1. HAULING EQUIPMENT

1.6 Truck Production

Step-3 Haul Time

F. Estimating Travel Time

- The first method for estimating travel time over a haul route is to use Equations:

$$T_T = \frac{\text{Length of the Road Section (km)}}{\text{Average Speed (km/hr)}} = \frac{L\ (\text{km})}{V_{avg}\ (\text{km/hr})}$$

$$V_{max} = \frac{P_{mo}}{(G_P + G_E) \times \sum R} \times \eta$$

$$V_{avg} = V_{max} \times S_f$$

Where P_{mo} = *Power output of motor [KW]*

G_P = *Payload (KN)*

G_E = *Empty Weight of Hauler (KN)*

$\sum R$ = *Effective Grade*

η = *Efficiency*

S_f = *Average Speed Factor*

CONSTRUCTION EQUIPMENTS

1. HAULING EQUIPMENT

1.6 Truck Production

Step-3 Haul Time

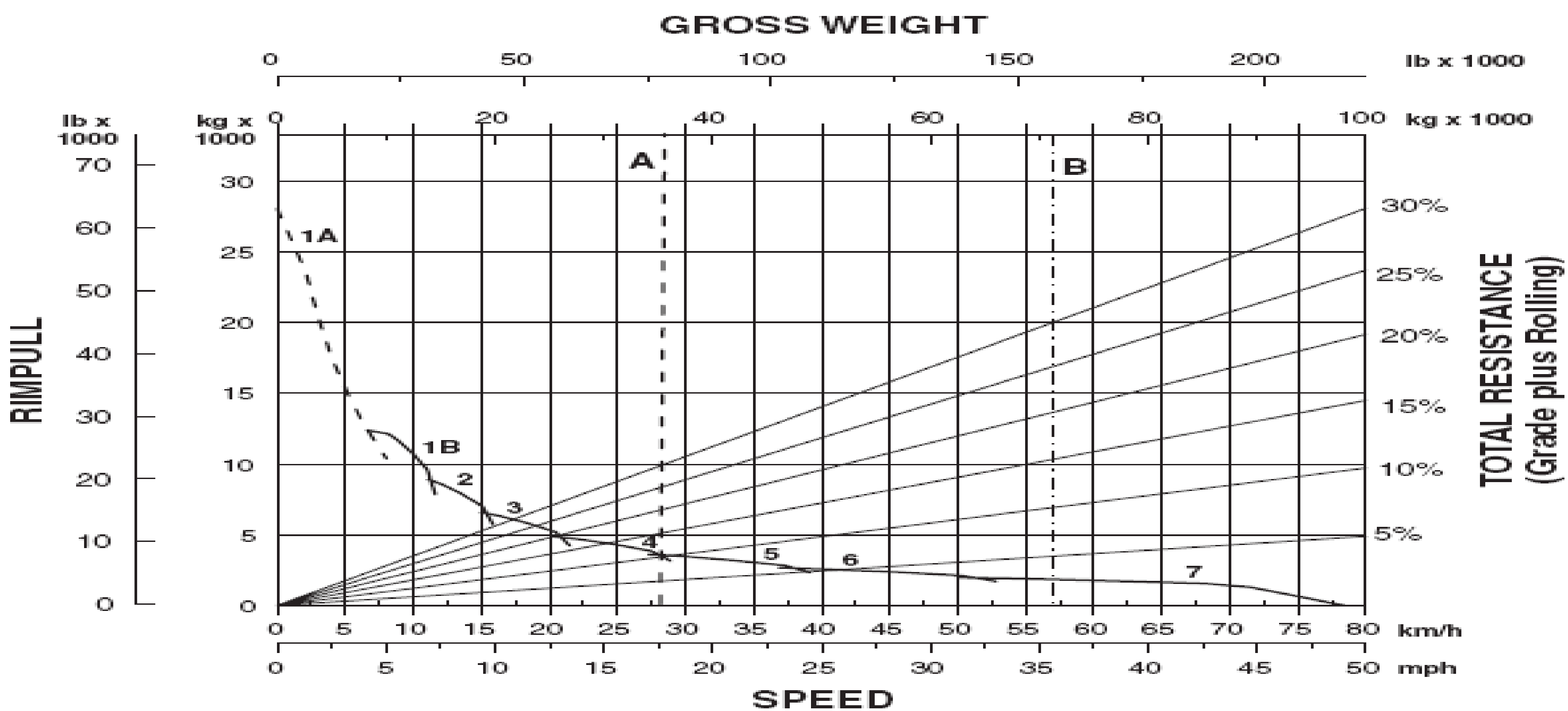
E. Estimating Travel Time

- Use of travel-time curves provided by some manufacturers.

Performance curve

769D Rimpull-Speed-Gradeability
● 18.00R33 Tires

Construction & Mining Trucks



Construction Equipments

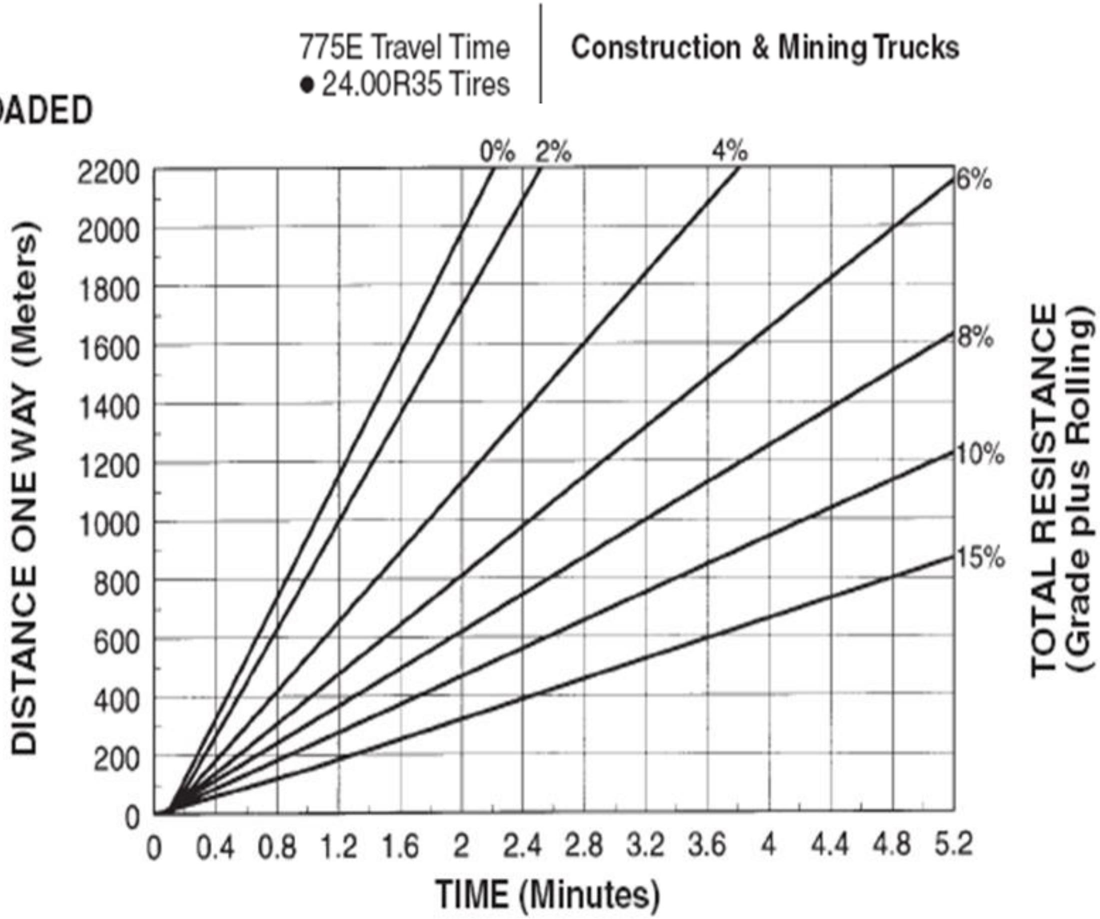
1. HAULING EQUIPMENT

1.6 Truck Production

Step-3 Haul Time

E. Estimating Travel Time

- To adjust for altitude duration when using travel-time curves, multiply the time obtained from the curve by the quantity “1 + de-rating factor” to obtain the adjusted travel time.



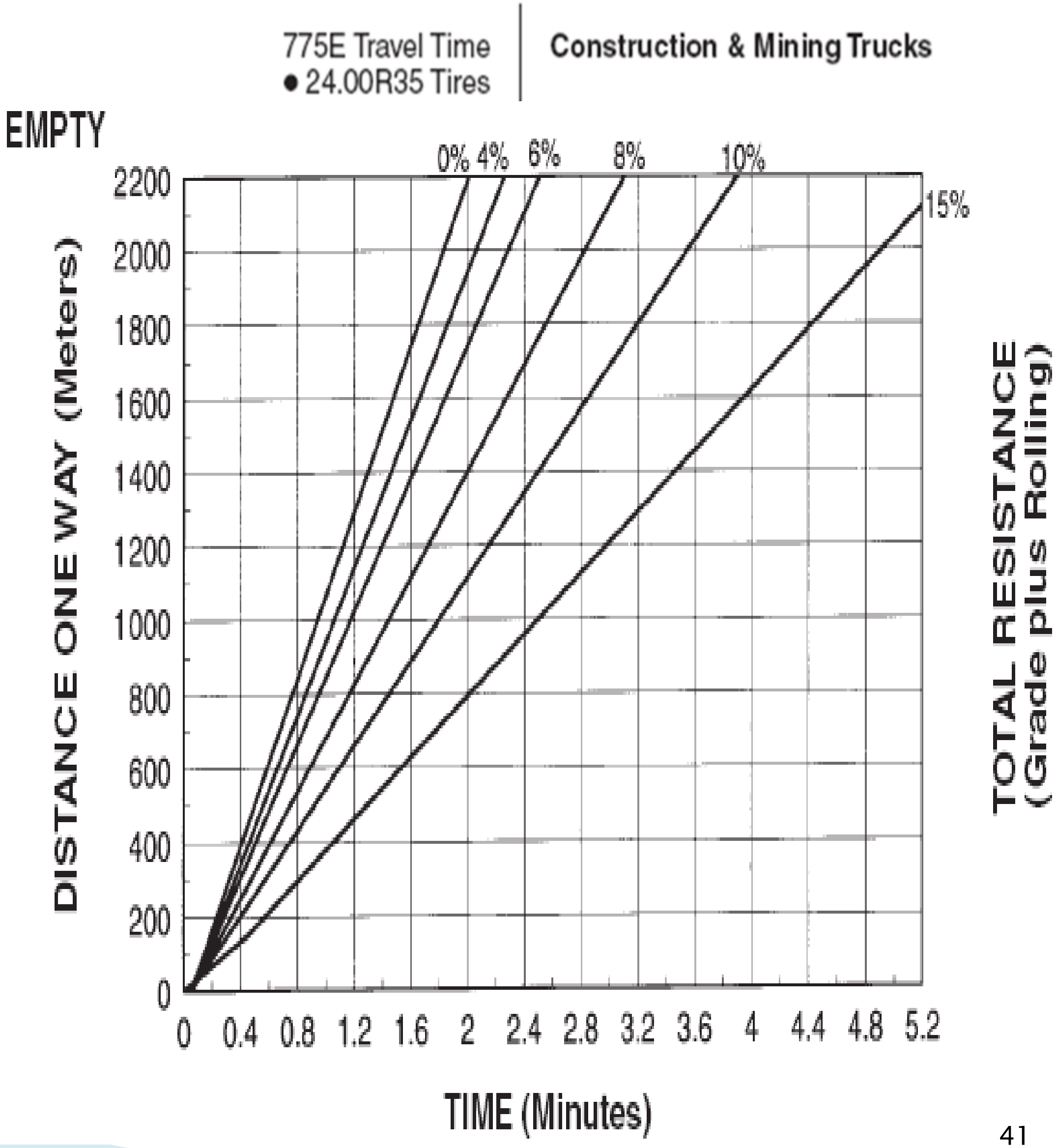
1. HAULING EQUIPMENT

1.6 Truck Production

Step-3 Haul Time

E. Estimating Travel Time

- However, travel-time curves cannot be used when the effective grade is negative.
- In this case, the average speed method must be used along with the vehicle retarder curve.



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 Dum Times (Min.)

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

CONSTRUCTION EQUIPMENTS

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 performance chart.

$$\boxed{T_R = \frac{\text{Length of the Road Section (km)}}{\text{Average Speed (km/hr)}} = \frac{\text{L (km)}}{V_{avg}\ \text{(km/hr)}}} \quad \text{Eqn. [15]}$$

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.

$$\boxed{\textit{Truck time} = \textit{Load}_{\textit{Time}} + \textit{Haul}_{\textit{Time}} + \textit{Dump}_{\textit{Time}} + \textit{Return}_{\textit{Time}}} \quad \text{Eqn. [16]}$$

1. HAULING 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***.

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

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***.

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

- 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***.

$$\boxed{\text{Adjusted production} = \text{Production} \times \frac{\text{Working time (min/hour)}}{60\text{ min}}}$$ 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.

Construction Equipments

2. COMPACTING EQUIPMENT

2.1 General

- Compaction is measured in terms of ***dry density***.
- The ***amount of compaction*** applied can be controlled by:
  - the ***choice of compaction equipment***,
  - the ***thickness*** being compacted,
  - the ***speed*** of the compaction equipment and
  - the ***number of passes*** of compaction equipment.

Influence of moisture on compaction

- Compaction depends mainly on the ***moisture content*** and on the amount of ***compacting force*** applied.
- For each soil there exists an ***optimal moisture content O.M.C***. at which the maximum compaction can be achieved.

Construction Equipments

2. COMPACTING EQUIPMENT

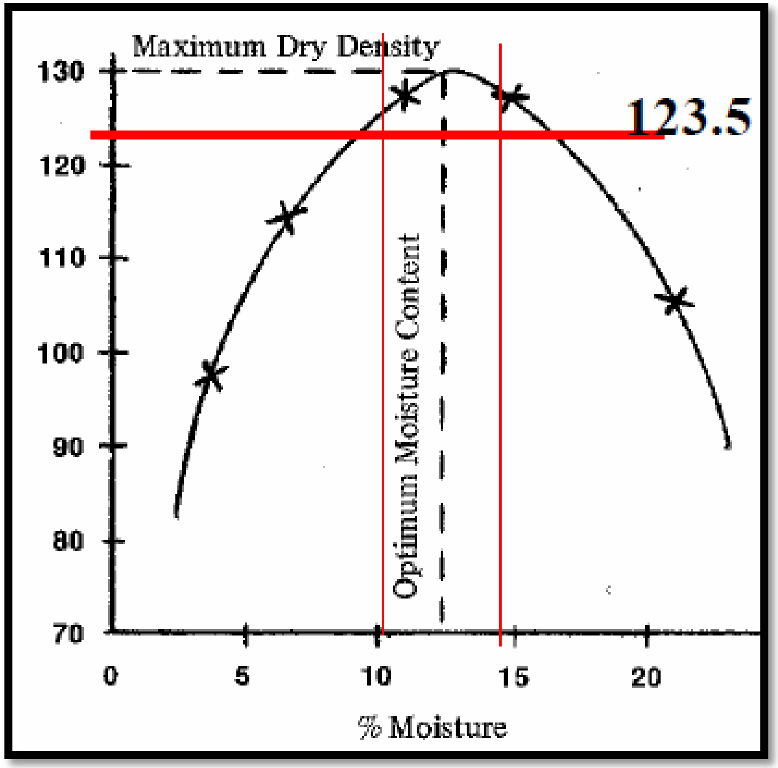
2.1 General

Influence of moisture on compaction

- Further addition of water after achieving optimum moisture keeps the particles apart there by reducing the density of the material.

The optimum water content (ω)

- ✓ Fine-grained soils – from 12 to 25%
- ✓ Well-graded granular – from 7 to 12%
- ✓ Normal Practice to work at ±2% of optimum or 95% of maximum dry unit weight.



2. COMPACTING EQUIPMENT

2.1 General

Adding water to the soil

- Water must be added prior to compaction if the water content (ω) is below the optimum moisture range.
- Water can be added to soil at the borrow pit or in-place (at the construction site).
- When it is necessary to add water, the following items are to be considered:
  - *Amount of water required*.
  - *Rate of water application*.
  - *Method of application*.
  - *Effects of the climate and weather*.

Construction Equipments

2. COMPACTING EQUIPMENT

2.1 General

Adding water to the soil

2. COMPACTING EQUIPMENT

2.2 Compaction Test

Laboratory Test

- The ***Proctor test*** is the standard laboratory test developed to evaluate a soil moisture density relationship under a specified compaction effort.
- There are two types of proctor test:
  - ***Standard Proctor test***
  - ***Modified Proctor test***, which is 4 times as great as the standard and mainly used where design loads such as airport run ways are involved.
- The compaction test are made over a range of soil moisture contents and the results are plotted as dry density versus moisture content.

2. COMPACTING EQUIPMENT

2.2 Compaction Test

Field Test

- Field verification tests of achieved compaction can be conducted by any of several accepted methods:
    - ***Sand cone***
    - ***Balloon***
    - ***Nuclear***
- The first two methods are ***destructive tests***. They involve:
    - ***excavating a hole*** in the compacted fill and weighing the excavated material.
    - ***determining the water content*** of the excavated material.
    - ***measuring the volume*** of the resulting hole.

2. COMPACTING EQUIPMENT

2.2 Compaction Test

Field Test

- ***Disadvantages*** of using sandcone and balloon methods:
  - ***time-consuming*** to conduct sufficient tests for statistical analysis.
  - problems with ***oversized particles***.
  - the determination of ***water content takes time***.

Nuclear Test

- Nuclear methods are used extensively to determine the water content and density of soils.
- The instrument required for this test can be easily transported to the fill, placed at the desired test location, and ***within a few minutes*** the results can be read directly from the digital display.

2. COMPACTING EQUIPMENT

2.2 Compaction Test

Field Test

Nuclear Test

- ***Advantages*** of the nuclear method when compared with other methods include the following:
  - ***Decreases the time required*** for a test from as much as a day to a few minutes, thereby eliminating potentially excessive construction delays.
  - It is ***nondestructive*** in that it does not require the removal of soil samples from the site of the tests.
  - Provides a means of performing density tests on soils containing ***large-sized aggregates*** and on ***frozen materials***.
  - Reduces or ***eliminates the effect of the personal element***, and ***possible errors***. Erratic results can be easily and quickly rechecked.

2. COMPACTING EQUIPMENT

2.2 Compaction Test

Field Test

Nuclear Test

- ***Disadvantages*** of the nuclear method when compared with other methods include the following:
  - Nuclear test instruments, if not used properly, present a ***potential source of radiation*** that can be harmful to humans.
  - These instruments usually ***require a skillful operator*** who exercise care to ensure that no harm can result from the use of the instruments.
  - A ***license is required to possess***, own, or use nuclear type instruments

2. COMPACTING EQUIPMENT

2.3 Types of Compacting Equipment

- Applying energy to a soil by one or more of the following methods will cause compaction:

a) Pressure (Static weight):

- Static compaction is achieved by ***pressing***.
- The static line load is calculated by dividing the axle load in Kg by the band width.
- To achieve good compaction, ***bigger weight is required***. Nowadays static compaction alone is not used.

B) Kneading (Manipulation or rearranging):

- This is a process of expelling air from the void space by continuously bringing the material, to be compacted, up and down.

2. COMPACTING EQUIPMENT

2.3 Types of Compacting Equipment

C) Vibration (Shaking):

- The vibration is done using a centrifugal force on a plate or roller. With each rotation the surface is lifted and is pressed back with an impact or vibration.
- In addition to the centrifugal force generated, creates kinetic energy on the vibrating plate or compactor.

D) Impact (Dynamic compaction or sharp blow):

- This involves impact and vibration. Impact and vibration have the same methods but differ in frequency only. Compaction above 50Hz is vibration and anything below that is impact.

2. COMPACTING EQUIPMENT

2.3 Types of Compacting Equipment

- The effectiveness of different compaction methods is dependent on the individual soil type being manipulated.
- Appropriate compaction methods based on soil type are identified in the table below.

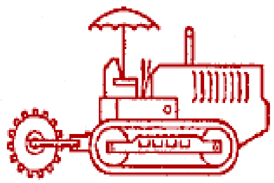
Material	Impact	Pressure	Vibration	Kneading
Gravel	Poor	No	Good	Very good
Sand	Poor	No	Excellent	Good
Silt	Good	Good	Poor	Excellent
Clay	Excellent with confinement	Very good	No	Good

- Equipment manufacturers have developed a variety of compactors that incorporate at least one of the compaction methods, and in some cases more than one, into their performance capabilities.

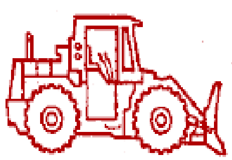
2. COMPACTING EQUIPMENT

2.3 Types of Compacting Equipment

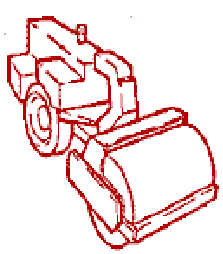
- Many types of compacting equipment are available including:



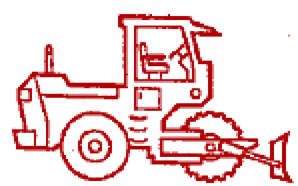
1. Sheepsfoot rollers



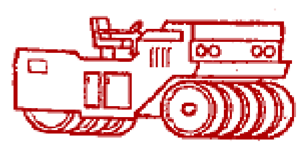
2. Tamping rollers



3. Smooth-drum vibratory soil compactors



4. Pad-drum vibratory soil compactors



5. Pneumatic-tired rollers

2. COMPACTING EQUIPMENT

2.3 Types of Compacting Equipment

- The table below summarizes the ***principal methods of compaction*** for the various types of compactors.

Compactor type	Impact	Pressure	Vibration	Kneading
Sheepsfoot		X		
Tamping foot	X	X		
Vibrating smooth	X		X	
Vibrating padfoot	X		X	
Pneumatic		X		X

A) Smooth wheel rollers

- The smooth-drum compactors, whether single- or dual-drum models, generate three compactive forces: (1) ***pressure***, (2) ***impact***, and (3) ***Vibration***.

2. COMPACTING EQUIPMENT

2.3 Types of Compacting Equipment

A) Smooth wheel rollers

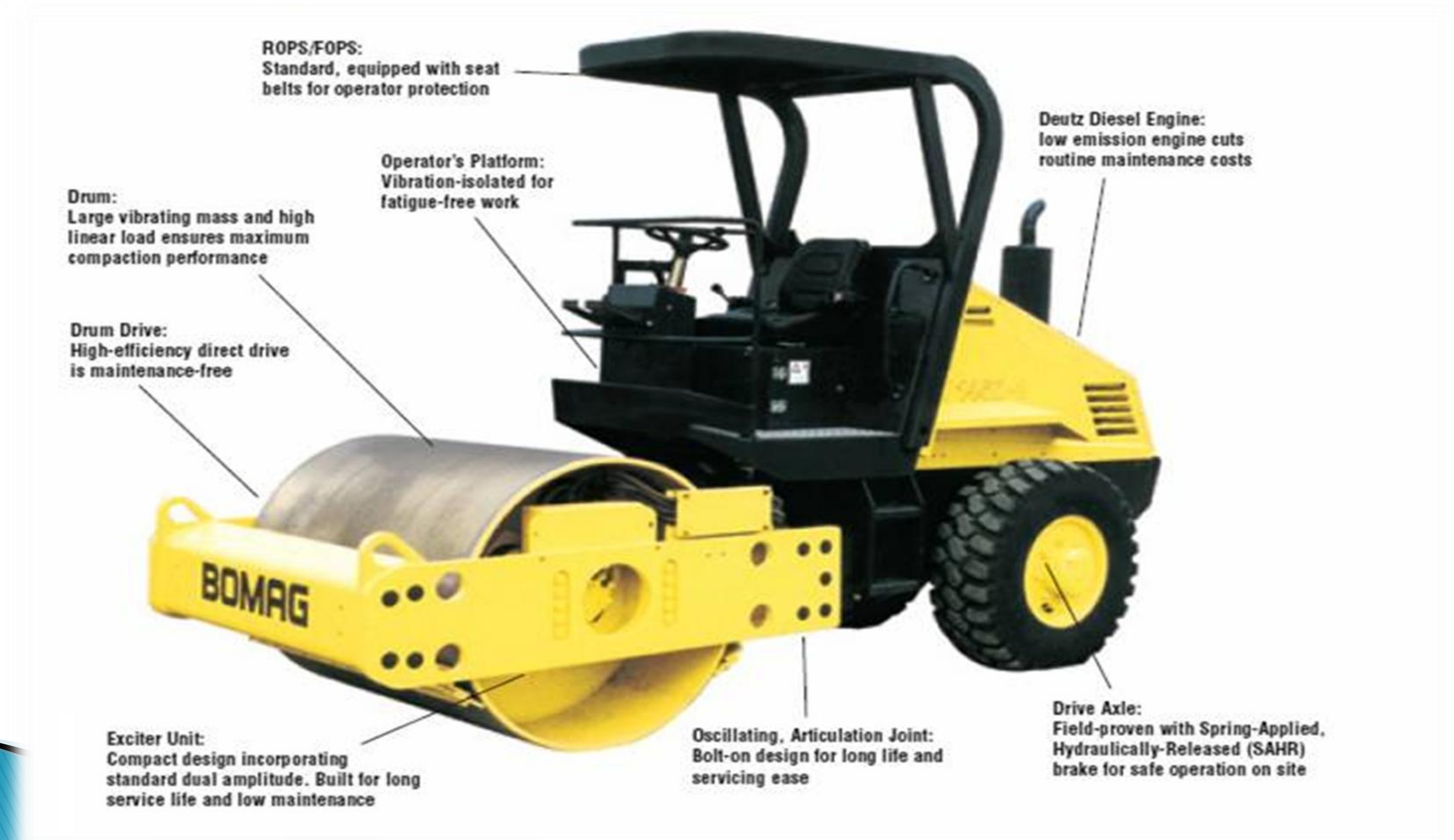
- These rollers are most effective on ***granular materials***, with particle sizes ranging ***from large rocks to fine sand***.
- They can be used on ***semi-cohesive soils*** with up to about 10% of the material having a PI of 5 or greater.
- They provide ***100% coverage*** under the wheels with ***ground contact pressures*** as high as ***45 to 55 lb./in^2***.
- They are ***not suitable*** for producing high unit weights of compaction ***when used on relatively thick layers***.

Construction Equipments

2. COMPACTING EQUIPMENT

2.3 Types of Compacting Equipment

A) Smooth wheel rollers



2. COMPACTING EQUIPMENT

2.3 Types of Compacting Equipment

B) Pneumatic Rubber-Tired Rollers

- These are surface rollers that apply the principle of ***kneading action*** to affect compaction below the surface. They may be self propelled or towed.
- They are heavily-loaded wagons with ***several rows of tires***. The tires are closely spaced, four to six in a row.
- They provide ***70% to 85% coverage*** under the wheels with ground contact pressures as high as ***85 to 100 lb./in***^{2}.
- 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.***

Construction Equipments

2. COMPACTING EQUIPMENT

2.3 Types of Compacting Equipment

B) Pneumatic Rubber-Tired Rollers

- Four parameters must be known to determine the ***compacting ability*** of pneumatic rollers: (1) ***Wheel load***, (2) ***Tire size***, (3) ***Tire ply*** and (4) ***Inflation pressure***.

Construction Equipments

2. COMPACTING EQUIPMENT

2.3 Types of Compacting Equipment

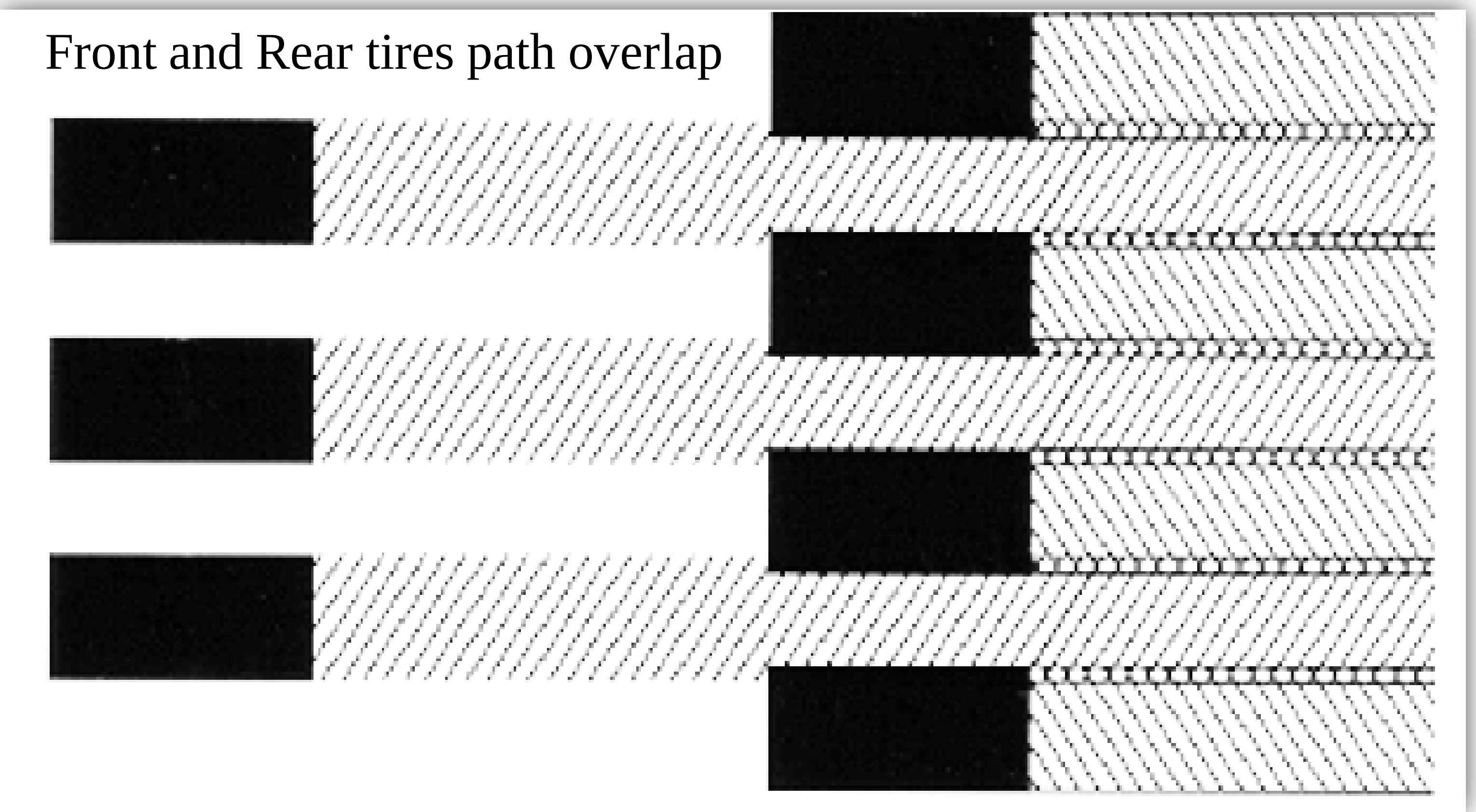
B) Pneumatic Rubber-Tired Rollers

Construction Equipments

2. COMPACTING EQUIPMENT

2.3 Types of Compacting Equipment

B) Pneumatic Rubber-Tired Rollers



2. COMPACTING EQUIPMENT

2.3 Types of Compacting Equipment

C) Sheepsfoot Rollers

- Sheepsfoot rollers are drums with a ***large number of projections***. The area of each of these projections may range from 4 to 13 in^2.
- The sheepsfoot roller is suitable compacting ***all fined-grained materials***, but is generally not suitable for use on ***cohesionless granular materials***.
- Since the sheepsfoot roller tends to ***aerate the soil*** as it compacts, it is ideally suited for working soils that have moisture contents above the acceptable moisture range.
- The ***contact pressure*** under the projections can range from ***200 to 1000 lb./in^2***.

2. COMPACTING EQUIPMENT

2.3 Types of Compacting Equipment

C) Sheepsfoot Rollers

- The sheepsfoot roller ***does not adequately compact the upper 2 to 3 in. of a lift***, and it should, therefore, be followed by a lighter pneumatic-tired or steel-wheeled roller if no succeeding lift is to be placed.

Construction Equipments

2. COMPACTING EQUIPMENT

2.3 Types of Compacting Equipment

C) Sheepsfoot Rollers

2. COMPACTING EQUIPMENT

2.3 Types of Compacting Equipment

D) Tamping Foot Compactor

- Tamping foot compactors are ***high speed***, ***self propelled***, ***non-vibratory*** rollers.
- These rollers usually have four steel-padded wheels and can be equipped with a small blade to help level the lift.
- 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.
- This type roller ***does not adequately compact the upper 2 or 3 inches of a lift***. Therefore, for the last lift it should be followed with a pneumatic or smooth-drum roller.

2. COMPACTING EQUIPMENT

2.3 Types of Compacting Equipment

D) Tamping Foot Compactor

Construction Equipments

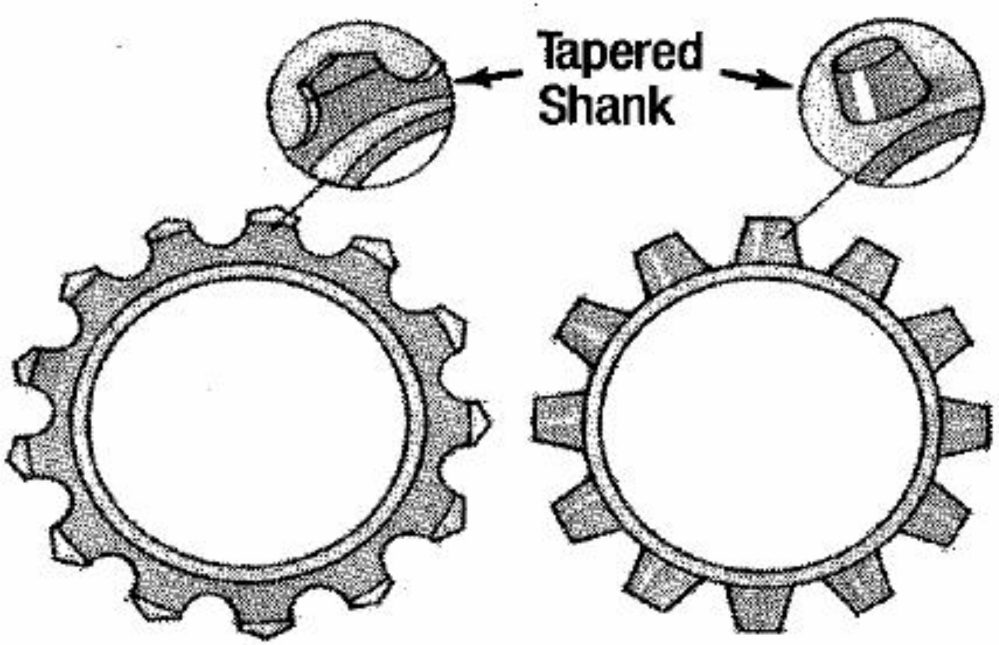
2. COMPACTING EQUIPMENT

2.3 Types of Compacting Equipment

D) Tamping Foot Compactor

Tamping foot

Pad foot



2. COMPACTING EQUIPMENT

2.3 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. COMPACTING EQUIPMENT

2.3 Types of Compacting Equipment

E) Vibrating compactors

- Vibration can be attached to the following type of rollers: (1) smooth wheel rollers, (2) Pneumatic rubber tired rollers, and (3) Sheepsfoot rollers.

i) Smooth drum vibratory compactors

- This roller uses vibratory action in conjunction with ballast weight of the drum to compact.
- One of the most effective means of attaining density for ***cohesionless materials***.
- It is a relatively light roller, therefore ***maximum loose-lift depth is 9 inches***.

Construction Equipments

2. COMPACTING EQUIPMENT

2.3 Types of Compacting Equipment

E) Vibrating compactors

Single drum

Padded drum

2. COMPACTING EQUIPMENT

2.3 Types of Compacting Equipment

E) Vibrating compactors

ii) Dual drum vibratory compactors

- Use this roller to compact ***cohesionless subgrade***, ***base courses***, ***wearing surfaces***, and ***asphalt***.
- Because it compacts from the top down, only relatively ***shallow lifts*** (***less than 4 inches***) can be worked.

Dual drum

2. COMPACTING EQUIPMENT

2.4 Types of Compacting Equipment

F) Vibratory plate compactor

- They are used for compacting ***granular soils***, ***crushed aggregate***, and ***asphalt concrete in locations where large compactors could not operate***.
- Many of these compactors can be operated either manually as a ***walk-behind unit*** or by ***remote control***.

2. COMPACTING EQUIPMENT

2.4 Types of Compacting Equipment

G) Rammer (Back fill tamper)

- Gasoline-engine-driven rammers are used for compacting ***cohesive or mixed soils in confined areas***.
- ***Performance*** criteria include ***pounds per blow***, ***area covered per hour***, and ***depth of compaction*** (lift) in inches.
- Rammers are self propelled in that each blow moves them slightly to contact a new area.

2. COMPACTING EQUIPMENT

2.4 Types of Compacting Equipment

H) Wheel Attachment Compaction

- ***To avoid hazards*** of having men work in ***excavations of limited dimensions***, a compaction wheel attached to an excavator boom is often used to achieve compaction when backfilling utility trenches.
- The feet on these wheels can be either the ***sheepsfoot*** or ***tamping shape***.
- The wheels are designed to compact ***all types of soil***.

2. COMPACTING EQUIPMENT

2.4 Types of Compacting Equipment

I) Trench Roller

- Small walk-behind and/or remotely controlled vibratory rollers having widths in the range of 24 to 38 in. are available.
- This units are ***designed specifically for trench work*** or for working in ***confined areas***.

2. COMPACTING EQUIPMENT

2.4 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

2.4 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***. ***1 bcy equals 0.83 ccy***. The ***scraper production***, estimated for the project is ***510 bcy/hr***. How many rollers will be required to maintain this production? Assume a ***50-min/hour efficiency***.

2. COMPACTING EQUIPMENT

2.4 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

2.4 Types of Compacting Equipment

Dynamic Compaction

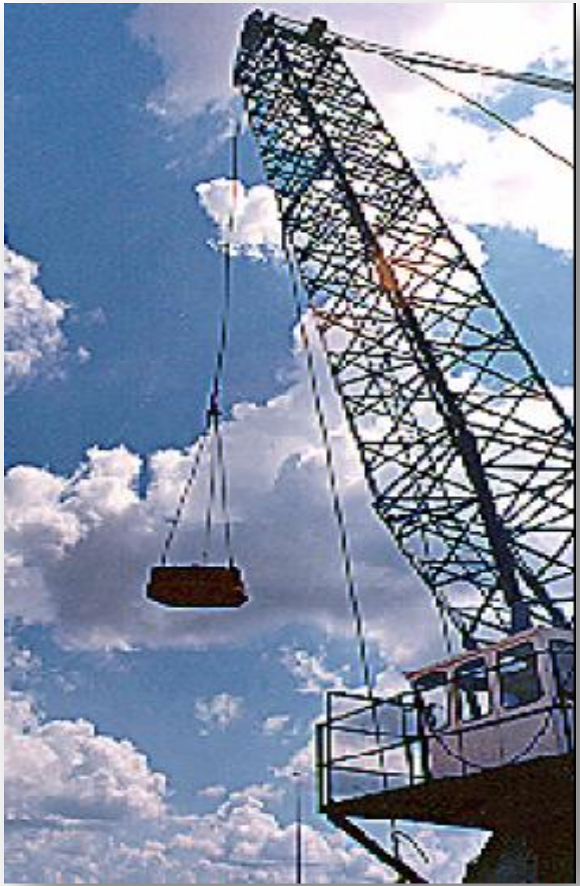
- The densification technique of ***repeatedly dropping a heavy weight*** onto the ground surface is commonly referred to as "dynamic compaction."
- This process has also been described as ***heavy tamping***, ***impact densification***, ***dynamic consolidation***, ***pounding***, and ***dynamic pre-compression***.
- This process primarily consists of ***dropping a heavy weight repeatedly*** on the ground ***at regular intervals***.
- The method can produce densification to ***depth greater than 35 ft***.
- The weight of the hammer varies over a range of ***18 to 80 kips***. The height of the hammer drop varies between ***25 to 100 ft***.
- ***Conventional cranes*** are used to drop the weights.

2. COMPACTING EQUIPMENT

2.4 Types of Compacting Equipment

Dynamic Compaction

- Can achieve densification to a ***depth*** of about ***30 ft.*** using ***30 ton weights*** and ***100 ft. drop heights***.



2. COMPACTING EQUIPMENT

2.4 Types of Compacting Equipment

Dynamic Compaction

- The ***degree of compaction*** achieved at a given site depends on the following factors:
  - ***Weight of the hammer***.
  - ***Height of the hammer drop***.
  - ***Spacing of the locations*** at which the hammer is dropped.
- The ***significance depth of influence*** for compaction can be given approximately by the following expression:

$$\boxed{D = n\sqrt{WH}}$$

Where, D = depth of improvement or significant depth (m)

n = an empirical coefficient (≈0.5)

W = dropping weight (metric ton)

H = height of drop (m)

THANK YOU!